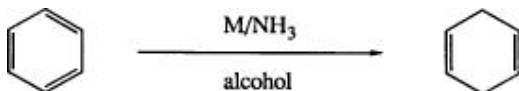


The Birch Reduction of Aromatic Compounds

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1. Introduction

The reduction of aromatic compounds by alkali metals in liquid ammonia represents an important method for the preparation of partially unsaturated six-membered rings. The reaction was discovered by Wooster and Godfrey, (1) but the major development resulted from the efforts of A. J. Birch, (2, 3) and the reaction has since come to bear his name. Although a variety of metals

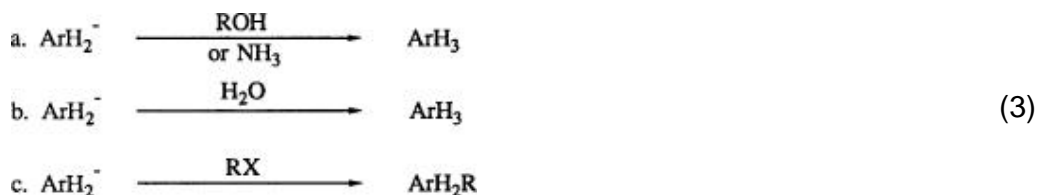
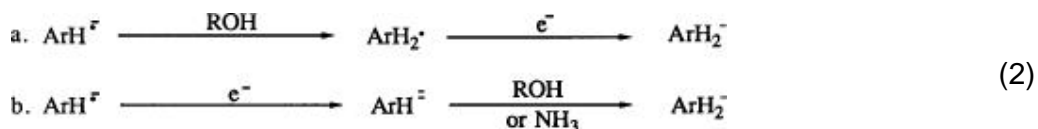


can be used, the most common are sodium and lithium, and, to a lesser extent, potassium. Cosolvents such as ether or tetrahydrofuran (THF) are often used to improve solubility, and weak acids such as alcohols may be employed during the reaction as proton sources. The latter are necessary for the reduction of benzene and its unactivated derivatives. Improvement in experimental procedures by Wilds and Nelson, (4) the application to polynuclear compounds by Hückel (5) and later by Harvey, (3f) and the development of methods for the alkylation of the anions generated in this process (i.e., reductive alkylation) have made this reaction an important approach to the synthesis of a wide variety of organic compounds. (6)

2. Mechanism, Regiochemistry, and Stereochemistry

2.1. Mechanism

Alkali metals dissolve in liquid ammonia to produce deep blue solutions that behave as if they contain metal cations and solvated electrons, and provide an excellent reducing medium. (7, 8) As shown in Eq. 1, the aromatic substrate accepts an electron to produce a radical anion in equilibrium with the reactant. In the presence of an alcohol, the radical anion may be protonated to furnish a radical which quickly adds an electron resulting in a monoanion (Eq. 2a). In the absence of an alcohol, the radical anion may simply persist in low concentration, (9, 10) and the addition of a stronger acid, like water or ammonium chloride, generally destroys metal faster than protonation of the radical anions can occur. Under these circumstances, little or no product is obtained since the equilibrium is shifted to the left. With substrates such as activated benzenes and polynuclear compounds, which have relatively high electron affinities, the radical anion can accept a second electron to afford a dianion (Eq. 2b). The dianion is then protonated by alcohol, if present, or more slowly by ammonia in the absence of alcohols, to provide the same monoanion as in Eq. 2a. This scheme suggests that with highly reactive substrates in the presence of an alcohol, both radical anions and dianions may be protonated during the rate-determining step. For example, both the radical

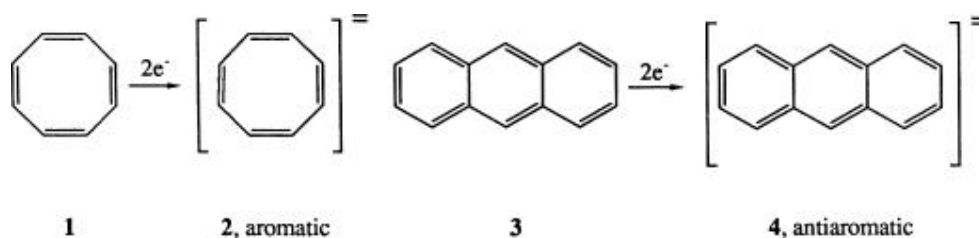


anion and the dianion are protonated in the rate-determining step when anthracene is reduced in the presence of *tert*-butyl alcohol (but not methanol, ethanol, isopropyl alcohol, or water). (8)

Depending on the basicity of the monoanion, it can be protonated by an

alcohol, if present, or by ammonia in the absence of an alcohol. Anions that are singly allylic or benzylic are protonated rapidly by ammonia. Examples include the reduction of styrene, stilbene, and phenanthrene. However, doubly benzylic anions, which are formed from anthracene, for example, appear to be persistent. Borderline basicity is provided by the dihydronaphthalene monoanion, formed as an intermediate in the reduction of naphthalene. The lithium salt is protonated in ammonia, especially at reflux temperature, whereas the sodium salt is considerably more resistant to protonation, especially at -78° . (11)

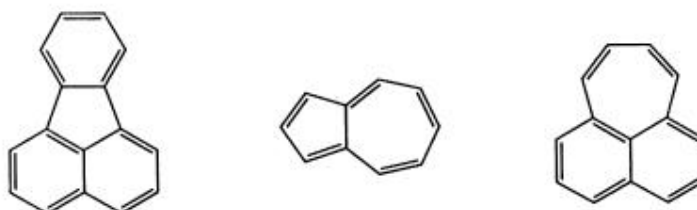
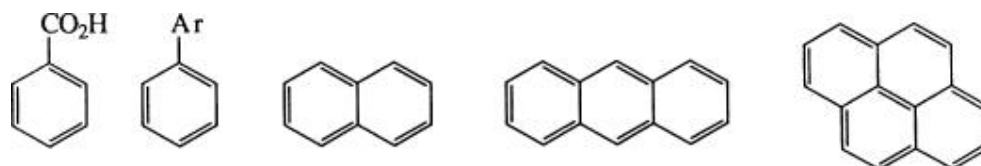
Aromatic compounds may be considered to fall into three classes with respect to their Birch reduction behavior. **Class 1:** Benzene and its unactivated derivatives, including alkylbenzenes, aryl ethers, and aminobenzenes, follow the pathway described by Eq. 2a. Alcohols are necessary for reduction to occur, and alkylation of anionic intermediates is not possible. **Class 2:** Activated benzenes such as benzoates and biphenyls, and many polynuclear aromatics with two, three, and four rings; these systems follow Eq. 2b. Alcohols are not necessary for the reduction of Class 2 systems, and, in fact, should generally be avoided since if present in amounts exceeding one equivalent, they usually cause overreduction. Alkylation of the final monoanions is possible in these cases, and unless an equivalent of an alcohol is added to prevent the amide formation which occurs when the dianion is protonated by ammonia, additional alkylation may take place. This result is due to a second deprotonation/alkylation step occurring after the initial alkylation. Complications may arise when the monoanion is itself protonated by ammonia; phenanthrene is an example. The dihydrophenanthrene monoanion is protonated by ammonia (Eq. 3a) and the resulting neutral compound, which is a biphenyl, is highly reactive under the reduction conditions. Compounds of this type are difficult to reduce without overreduction. **Class 3:** Systems which form dianions resistant to protonation by ammonia. This result is to be expected only for large polynuclear compounds or compounds that involve



Class 1 Systems



Class 2 Systems



Class 3 Systems

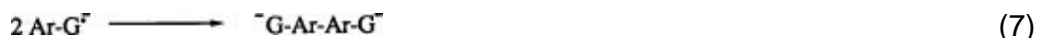


special stabilization such as an aromatic dianion. Cyclooctatetraene (**1**) represents a compound in which the original $4n \pi$ electron system is converted into a $4n + 2$ system **2** by the addition of two electrons. It is interesting to note that while conversion into an aromatic dianion assists reduction, the converse is not true. Anthracene (**3**) is converted into the (formally) antiaromatic dianion **4** by the acceptance of two electrons, yet the dianion is easily formed. (**12**) Solvation and ion triplet formation must play an important role, mitigating the electronic effects. (**13**)

Birch reduction may be accompanied by a number of side reactions. Among the most important are bond cleavage, dimerization, and substituent group reduction. Bond cleavage can result in the loss of a number of substituent groups (**3**) including benzylic oxygens in various forms; allyl, benzyl, and aryl ethers; and halogen and S-benzyl groups. Certain carbon-carbon bonds may also be cleaved during reduction, although this process is much more common in solvents other than ammonia. The mechanism of cleavage involves one of the three pathways shown in Eqs. **4–6**, depending on the nature of both the aromatic moiety and the substituent. (**14**)

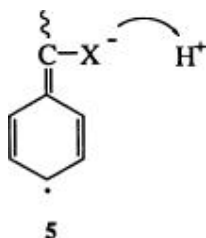


In principle, dimerization of the radical anions can also occur to provide the dianion illustrated in Eq. 7. However, this process is generally not observed under Birch reduction conditions with some exceptions. For example,



dimerization is the primary reaction pathway for pyridine radical anions in liquid ammonia when generated in the absence of alcohols. (15) Dimerization through the carbonyl carbon is also quite common with the reduction of ketones. 3k

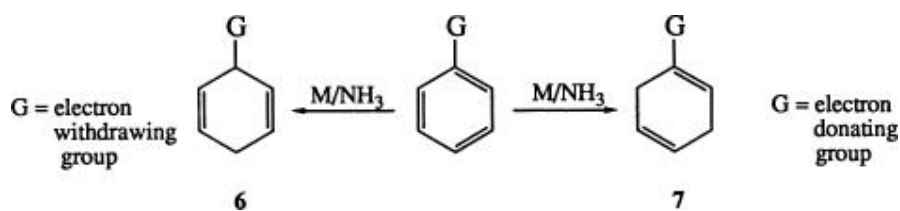
Finally, with certain substituents such as carbonyl groups, protonation of the radical anion or dianion may occur at the substituent group itself (i.e., 5) since this position may represent a site of relatively high negative charge.



This is especially true for otherwise unsubstituted benzenes or benzenes with additional substituents that are electron donors. In these cases, reduction may take place exclusively at the substituent, and the aromatic ring may not be reduced at all.

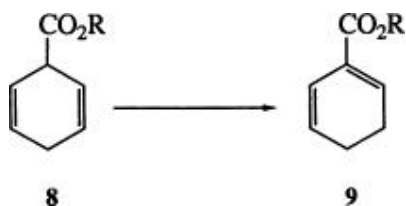
2.2. Regiochemistry

The Birch reduction of benzene derivatives generally gives nonconjugated cyclohexadienes with electron-withdrawing substituents enhancing reaction rates and occupying a saturated position in the product 6; electron-donating substituents decrease rates and occupy a vinyl position in product



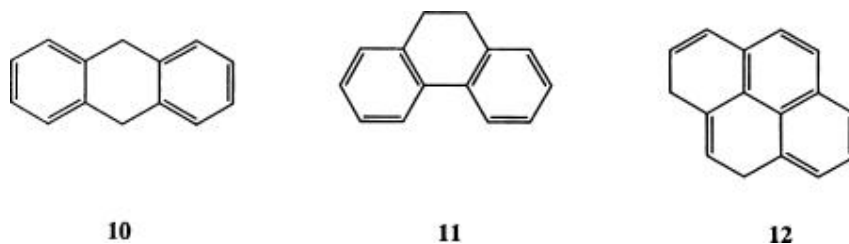
7. (3, 16-20) This behavior follows the “Birch rule:” electron-donating substituents direct reduction so that the major product has the maximum number of such groups attached to the residual double bonds, and a minimum of these groups are located at the allylic sites. 3a

The observation of conjugated products in some reactions is usually the result of isomerization of an initial nonconjugated product. This is most common with carbonyl or other substituent groups that may conjugate with a double bond, as shown for the conversion of 8 into 9.



Perhaps surprisingly, there is little difference in thermodynamic stability between 1,4-cyclohexadiene and 1,3-cyclohexadiene. With some substitution patterns, the nonconjugated isomer is actually more stable than its conjugated counterpart. (21) Apparently there is little stabilization in the conjugated isomer since the double bonds are not coplanar. (22)

With polynuclear compounds, reduction may occur 1,4 across an aromatic ring (10 from anthracene), 1,2 across an aromatic ring (11 from phenanthrene), or across more than one ring (12 from pyrene). Initial protonation is considered to take place at the position of highest electron density in the



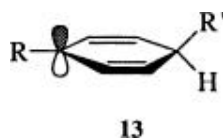
dianion. There is reasonable correlation between experimental results and predictions based on SCF MO theory (23-28) and electrostatic potential maps,

(17) although a number of exceptions exist. However, questions concerning protonation sites in dianions arise, (29) and the correct assignment is often provided by assuming that protonation of the dianion will take place to produce the most stable monoanion; *this appears to give a good prediction of regiochemistry whether or not the reaction is actually driven by monoanion stability.*

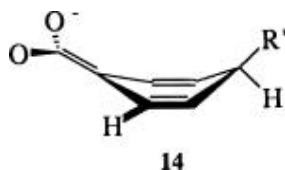
The effect of substituents on the regiochemistry of the reduction of polynuclear aromatic compounds is sometimes complex. In the simplest example, naphthalenes, electron donors in one ring often lead to reduction in the other ring, but this is not always true (see below). Similarly, electron-withdrawing substituents, especially at the β position, may not always lead to exclusive reduction in the substituted ring. Compounds for which the dianionic intermediates have substantial localization of negative charge at a specific site, for example the 9 and 10 positions in anthracene dianion, often are reduced with the same regiochemistry regardless of substitution pattern.

2.3. Stereochemistry

The stereochemistry of the reduction of nonrigid systems is determined by the stereochemistry of protonation of the final monoanion (Eq. 3). This is controlled by a number of factors, including the nature of R and R', and the hybridization at the anionic center. The simplest model is provided by the cyclohexadienyl anion 13. When R' is hydrogen, protonation occurs equally



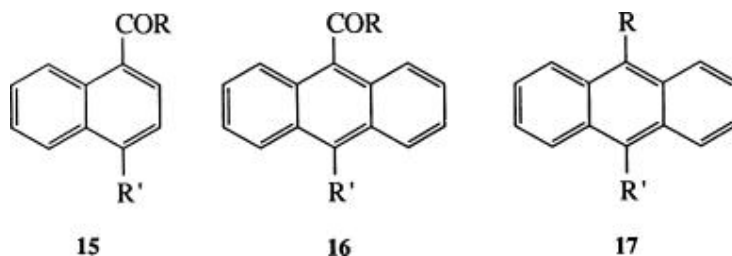
well from either side of the anion. Reduction of benzene- d_6 provides equal amounts of *cis* and *trans* (diprotio) products. (30) When R and R' are trimethylsilyl, a significant steric effect develops for protonation on the R' side, and consequently the *cis* isomer predominates by 4:1 with either metal/ammonia reduction (31) or electrochemical reduction in methylamine. (32) Predominance of the *cis* isomer is slightly less (3:1) for the electrochemical reduction of 4-trimethylsilyltoluene, as might be expected by the decrease in size of R' from trimethylsilyl to methyl. In the reduction of 4-isopropylbenzoic acid, however, the *trans* product is favored by 2:1, and with 4-*tert*-butylbenzoic acid, the *trans* isomer is formed exclusively. Clearly model 13 fails for these reactions. When R is a π substituent, the model 14, which takes the overlap of the π



substituent with the anionic center into account, becomes useful. In fact, this overlap demands a nonplanar structure because of the interference of the oxygens with the nearby vinyl hydrogens. These atoms cannot all be in the same plane, and the ring folds slightly with R' occupying the pseudoaxial position. (22) This causes the vinyl hydrogens to block the bottom lobe of the anion orbital. Hence protonation is preferable from the topside; this is the case even if protonation occurs through the enol or is metal-directed.

When the 1,4-cyclohexadiene ring generated during reduction is part of a larger polynuclear system, the ability of the six-membered ring and its anion to adopt variable folding angles leads to even more complex stereochemistry. These folding angles, defined by the angle between the two planes containing the vinyl carbons, may vary from 180° (planar) to 145° (highly puckered) in the neutral compounds, (22) with a correspondingly greater tendency toward planarity in the monoanion. 3h However, enolates in polynuclear systems should be considerably more folded than **14**, since the replacement of the vinyl double bond with an aromatic ring provides an even greater steric interaction due to the *peri* hydrogens.

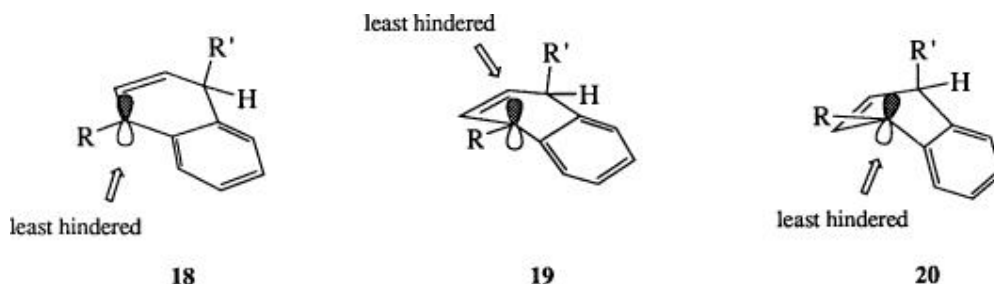
The reduction of esters **15** where R is *O-tert*-butyl and R' is either methyl or ethyl gives a slight excess of *trans* products (60:40). (33) However, when R is methyl, the methyl ketones show a predominance of the *cis* product that increases in the series Me < Et < *i*Pr for values of R', with relative yields of 60, 70, and 75% respectively. (33) Neither the ester nor the ketone products isomerize under the conditions used for the workup of the reaction. The



change from *trans* to *cis* products may result from greater enolate character in the intermediate monoanion derived from the ketones, producing a greater degree of ring folding. Even more ring folding is expected for the anions derived from **16** (34) because of increased *peri* interactions, and reduction produces exclusively *cis* products with either ketones or esters. (33) Interestingly, 9,10-dialkylanthracenes **17** afford greater amounts of *trans*

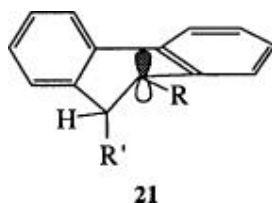
products when R and R' are primary, with a changeover to *cis* as the alkyl groups become larger. (35) Apparently the monoanion derived from 17 when R and R' are sterically small is relatively flat, in contrast to that from 16, as suggested by both experiment (36) and theory. (37)

The pattern that emerges can be rationalized, although the prediction of product ratios remains difficult. Planar anions such as 18 are expected to show little stereoselectivity, with *cis* products favored, because of a small steric effect from R'. Systems with modest folding such as 19 will be protonated



preferentially in the pseudoaxial position to give *trans* products. With more highly folded structures like 20, the bottom lobe of the anion orbital angles out to become more accessible, and at the same time Rφ is forced closer to the anionic center. Both of these effects promote protonation from the bottom to produce *cis* products. Hence even though the reasons for the observed stereochemical behavior may be understood, it remains difficult to predict product outcome when the geometry of the monoanion is not known.

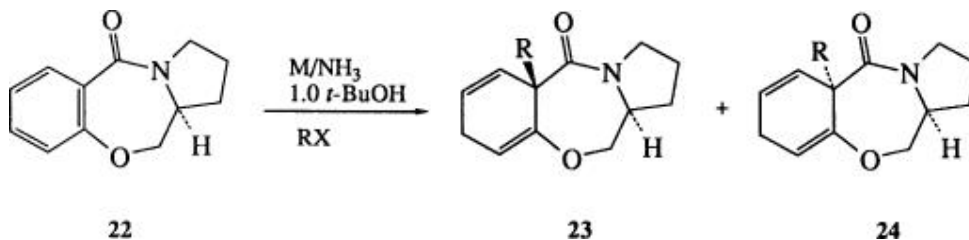
In systems for which reduction occurs in a 1,2 fashion, stereochemistry is more easily predicted since the geometry of 1,3-cyclohexadienes is better defined. (22) For example, substituents prefer the pseudoaxial position in 9,10-dihydrophenanthrenes, and the likely conformation of the monoanion can be



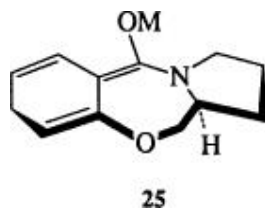
described as 21. Of course, there may be some pyramidalization at the anionic center, depending on the nature of R, but the anion will prefer to be pseudoaxial to maximize overlap with the adjacent aromatic ring. In either case, protonation will occur from the top resulting in *cis* products, as observed. (38)

The stereochemistry of reductive alkylation, where alkyl halides are added prior to the final quench, follows generally the same pattern as reduction. However, the larger size of the alkylating agents leads to more sensitivity to

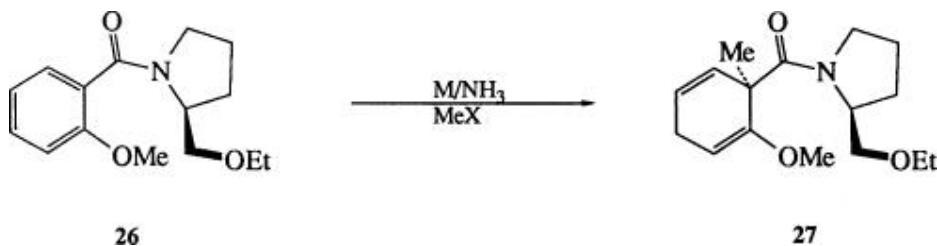
steric interference, and effects from possible prior coordination with the metal are absent. Stereoselectivity may be further increased by the use of chiral substrates, as demonstrated for the reductive alkylation of a number of chiral benzamides. (39) For example, the optically active benzoxazepinone **22** reacts



with potassium, sodium, or lithium in ammonia containing one equivalent of *tert*-butyl alcohol, followed by addition of alkyl halide, to give product ratios for **23/24** of 85:15 for R = methyl, and 98:2 to 99:1 for larger R groups.



This behavior may be understood by the enolate model **25**, in which the top face appears to be more accessible to the electrophile. Even greater diastereoselectivity is shown by **26**; **27** is produced with a 260:1 selectivity relative to methylation on the opposite side. (39)



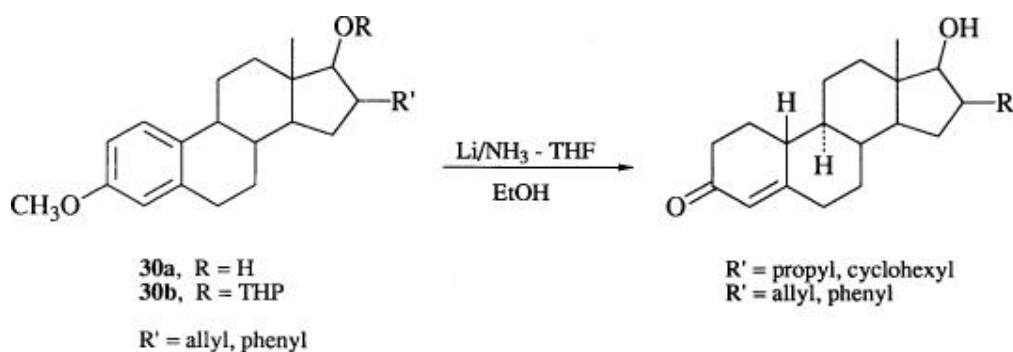
2.4. Regiochemistry and Stereochemistry—Intramolecular Effects

Although nonconjugated double bonds are generally not reduced under Birch conditions, norbornadiene and a number of related compounds are quite reactive. (40) For example, the reduction of **28** and **29** with sodium/ammonia in the presence of *tert*-butyl alcohol results in double bond reduction

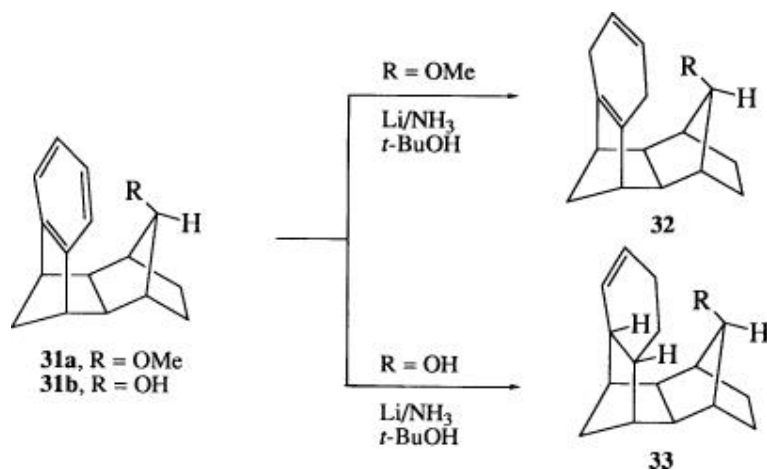


predominating over aromatic ring reduction in ratios of 2.1:1 and 10:1, respectively. This behavior is a consequence of orbital interactions through space, and orbital interactions through bonds. (41) Additional examples involve unsaturated sites separated by three, four, five, and six σ bonds. (40)

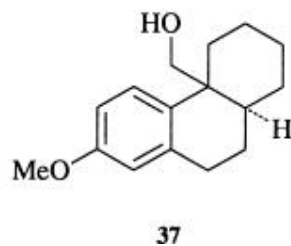
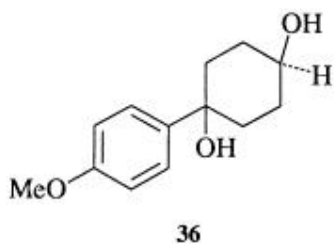
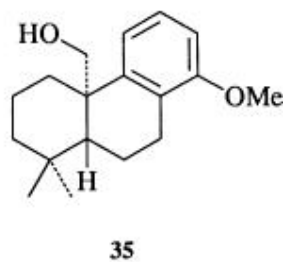
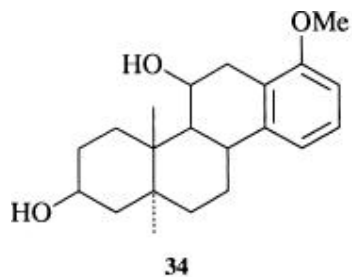
Reactivity, regiochemistry, and stereochemistry are also affected by the presence of hydroxy groups. When OR in **30** is hydroxy, an allyl or phenyl group at the 16 β position is reduced. However, when the hydroxy group is protected, as in **30b**, the 16 β substituents are left intact, suggesting the importance



of intramolecular protonation. (42) Ether **31a** reacts only slowly with lithium to produce the expected 1,4-cyclohexadiene **32**, but when R = OH,



the reaction is fast to produce **33**. Hence regiochemistry, and presumably stereochemistry, are controlled by internal protonation of the radical anion intermediate. (43) Similar rate and/or regiochemical effects are observed for the reductions of **34–37**. (44-48)

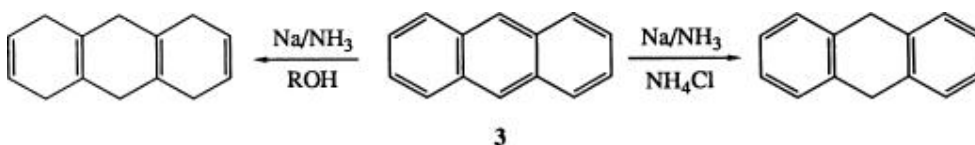


3. Scope and Limitations

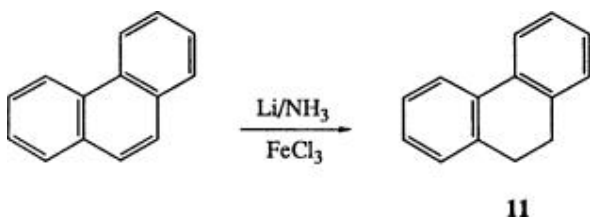
3.1. The Reduction of Polynuclear Aromatic Compounds

Polynuclear aromatic compounds are considerably more reactive than benzenes, [3f,h](#) and, as discussed under [Regiochemistry](#), the sites of reduction are controlled by the distribution of electron density in the anionic intermediates. With the exception of compounds like naphthalene, triphenylene, and perylene, where all of the rings are equivalent, this selectivity also controls which ring is reduced. Substituents may exert some control over ring selectivity. However, in a system like anthracene, where the electron density is highly localized at the 9,10 positions, reduction generally occurs at that position regardless of the nature of substituent groups.

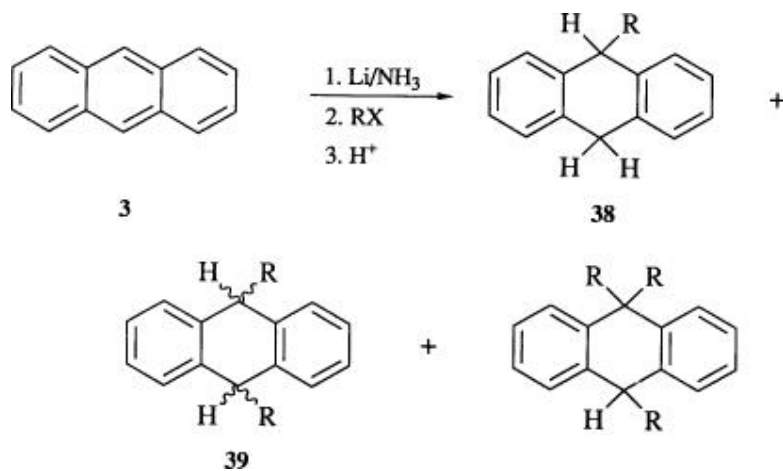
The application of classical Birch reduction procedures, including the Wilds and Nelson modification of adding the alcohol last, provides only marginal results with polynuclear aromatic compounds. [3f](#) The addition of alcohols to metal ammonia solutions of polynuclear aromatics invariably leads to reduction



beyond the stage of the addition of two hydrogens. Mixture of products at varying stages of reduction and/or isomerization products are also common. For example, anthracene (**3**) affords primarily the hexahydro isomer by reduction with sodium/ammonia in the presence of an alcohol. [\(49\)](#) Colloidal iron may be used in a number of instances to prevent overreduction, and its presence during the reduction of anthracene restricts reduction beyond the dihydro stage. [\(50, 51\)](#) However, the same results can be obtained in minutes rather than hours by avoiding the alcohol altogether and simply quenching with stronger acids like ammonium chloride. [3f,g](#) Nonetheless, iron salts are useful in systems like phenanthrene where reducible dihydro derivatives **11** are produced in situ via protonation with ammonia. [\(38\)](#)

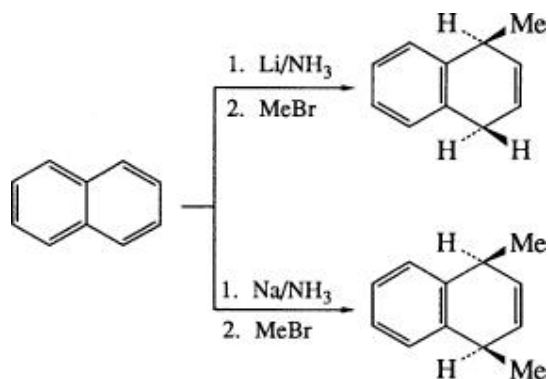


If alkyl halides are added to metal ammonia solutions of polynuclear aromatic compounds before the addition of a proton source, alkyl groups may be introduced into the reduced products. The number of alkyl groups introduced

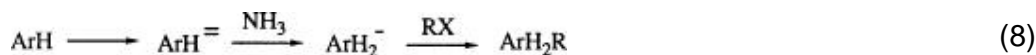


depends on reaction conditions. ³⁹ For example, anthracene provides mono-, di-, and trialkylated products under these conditions with *cis* and/or *trans*-³⁹ predominating when the alkyl halide is added to the metal/ammonia solution. However, if the metal/ammonia solution is added to the alkyl halide (inverse quench), ³⁸ is produced in 80–90% yield.

Naphthalene shows an unusual metal effect in that the use of sodium leads to >90% dialkylation whereas lithium provides >90% monoalkylation. (⁵²) Once again, however, inverse quench leads to almost exclusive formation of the monoalkylated product. These effects, metal and addition order, are both due to a secondary reaction. As discussed above, many polynuclear aromatics produce monoanions as the persistent intermediate, and alkylation affords



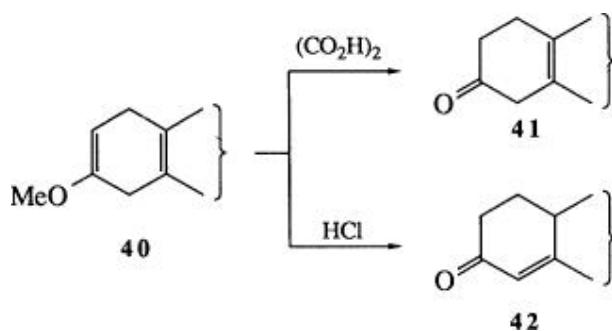
monoalkylated dihydroaromatics (Eq. 8). However, protonation of the dianion by ammonia generates amide ion and so the monoalkylated product may be deprotonated and subsequently alkylated again (Eq. 9). Since sodium



amide is more soluble than lithium amide, multiple alkylations are more common when sodium is used for the reduction. Inverse quenching into a large excess of alkyl halide consumes anions and amide so rapidly that secondary reactions are prevented. Alternatively, one equivalent of *tert*-butyl alcohol can be added to destroy the amide as it is formed.

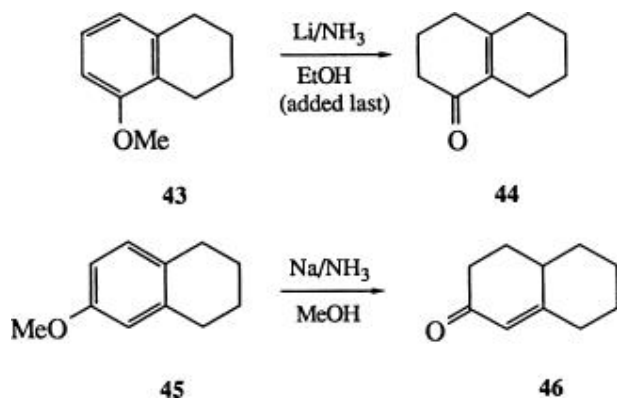
3.2. The Reduction of Aryl Ethers

In the absence of other activating substituents, anisoles are reduced to 1-methoxy-1,4-cyclohexadienes with the addition of hydrogen taking place at positions other than those occupied by the methoxy substituent (e.g., 40). The resulting enol ethers tend to undergo rearomatization on standing, so

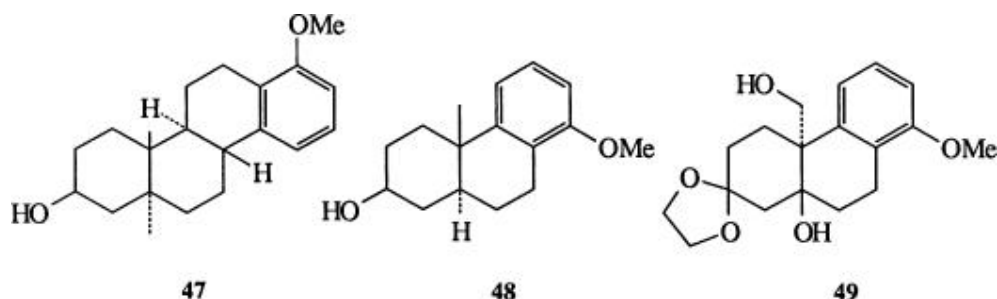


they are generally converted into the more stable ketones soon after preparation. This may be accomplished under mild conditions with oxalic acid in aqueous methanol, whereupon the double bond maintains its original position (41), or with hydrogen chloride to provide the conjugated ketone 42. This technique has wide application to the synthesis of steroids where the A ring is transformed into a Δ^2 -cyclohexenone. 3g,53–59

The reaction of 5-methoxytetralin (43) with sodium/ammonia in the presence of methanol gives only a trace of reduction products, while its isomer

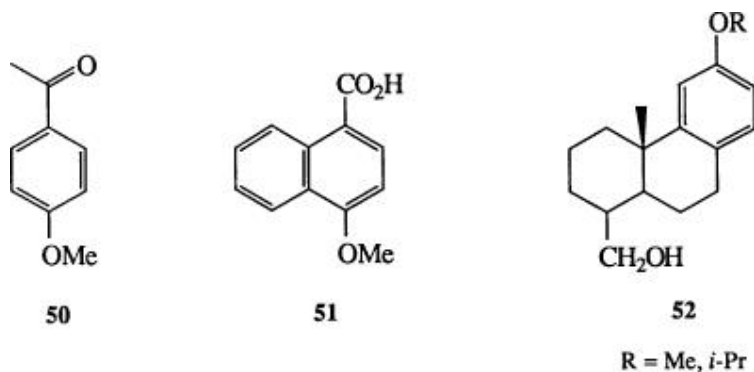


45 is successfully transformed into the enone **46** under similar conditions. (80) The diminished reactivity of **43** results from the fact that the normal course of reduction requires protonation to occur at a site bearing an alkyl substituent. However, by adding an alcohol last according to the Wilds and Nelson modification, (4) ketone **44** is isolated in 63% yield with lithium providing significantly better results than sodium. Compounds **47** (81) and **48** (82) containing the 5-methoxytetralin moiety provide poor yields of the desired enones even with

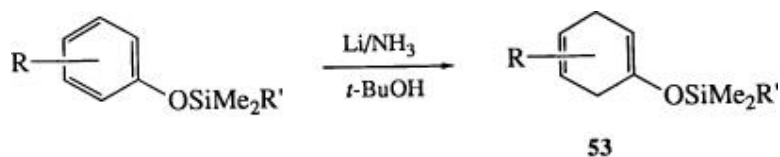


large excesses of lithium. In contrast, the unusually high reactivity of **49** is understandable in terms of an intramolecular protonation process (see above).

An important limitation in the reduction of aromatic ethers is the occasional partial or complete loss of the alkoxy group. This is especially true when the alkoxy group is *para* to an activating substituent. Both **50** (83) and **51** (84) are reduced exclusively 1,4 to the carbonyl substituent with complete loss of the methoxy group. The replacement of methoxy with larger groups (**85**) is only modestly successful in increasing oxygen retention as demonstrated with 12-methoxy and 12-isopropoxy-podocarpe-8,11,13-trien-19-ol (**52**). (86)

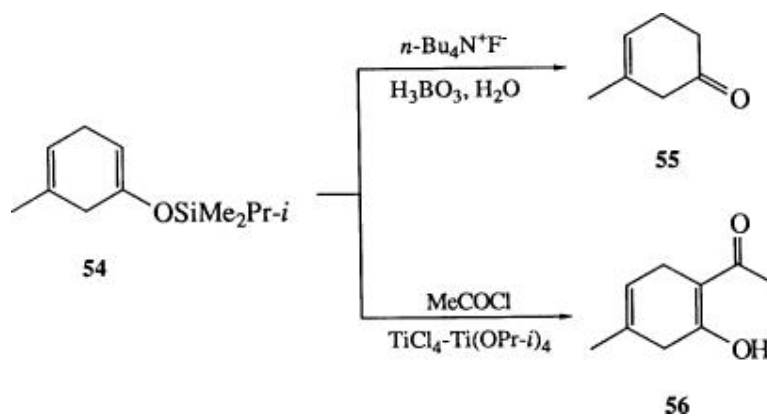


The Birch reduction of aryl silyl ethers has considerable synthetic utility. Although poor results are obtained with trimethylsilyl, *tert*-butyldimethylsilyl and isopropyldimethylsilyl phenyl ethers give good yields (80–97%) of 1,4-dihydroaryl silyl ethers **53**. (87) Further treatment of **54**, for example, with



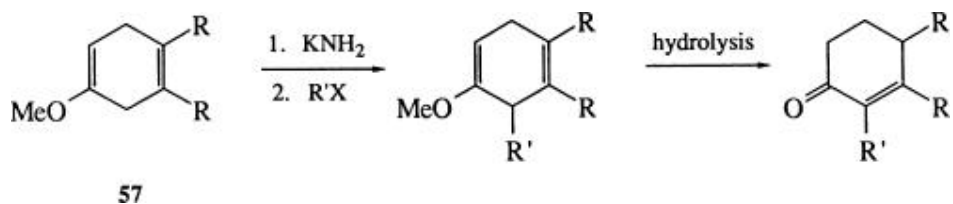
R = H, *o*-, *m*-, *p*-Me, *o*-, *m*-, *p*-OMe
 R' = *i*-Pr, *t*-Bu

tetrabutylammonium fluoride gives the relatively inaccessible β , γ -unsaturated ketone **55**, and titanium-mediated acylation provides cyclohexadiene **56**.

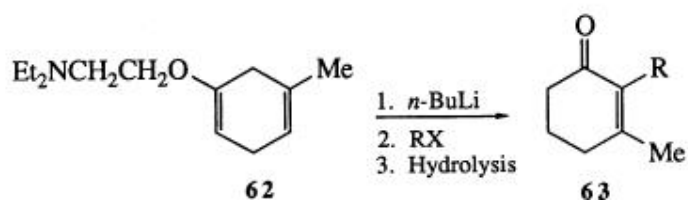
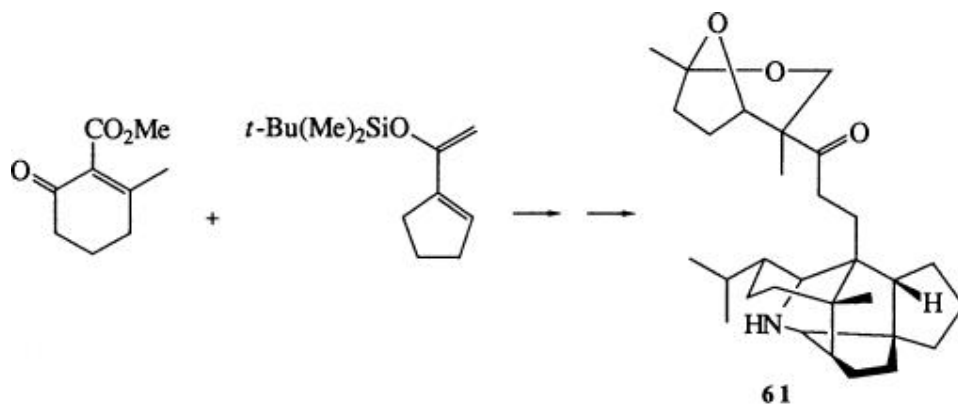
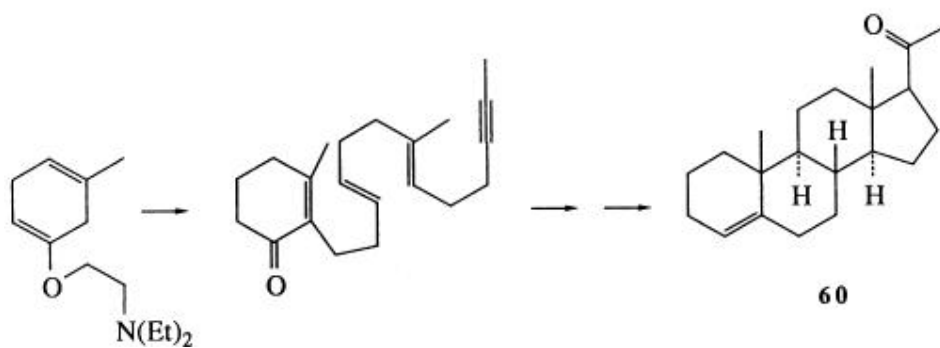
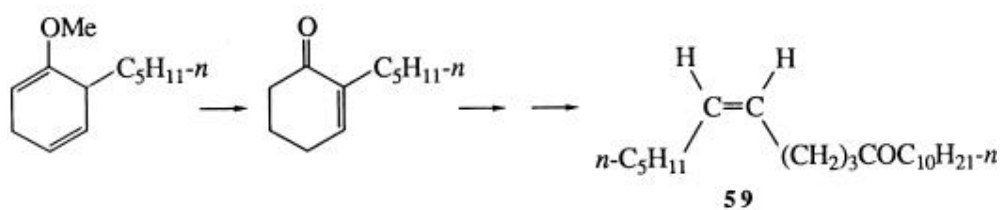
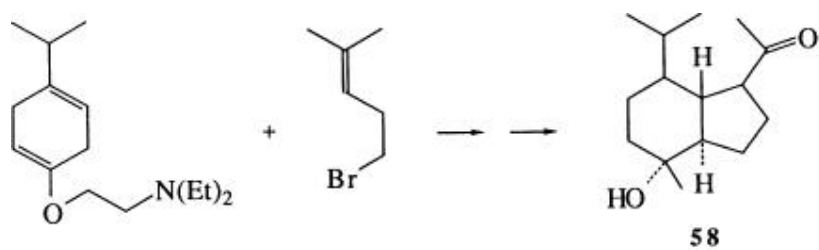


3.2.1.1. Alkylation of Dihydroaryl Alkyl Ethers

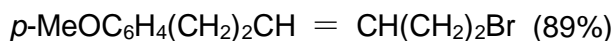
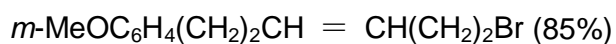
The reduction products of aryl ethers can serve as useful starting materials for synthesis. 1-Methoxy-1,4-cyclohexadienes **57** are deprotonated by potassium amide in ammonia at the allylic position next to the oxygen. (**88**, **89**) The resulting anion is alkylated in yields of 75–85% with butyl, pentyl, or hexyl bromides, or arylated in 50–60%



yield with bromobenzene. (**89**) This method provides a basis for the synthesis of olopanone (**58**), (**90**) (*Z*)-heneicosa-6-ene-11-one (**59**) (**89**) (the male sex attractant of the Douglas fir Tussock moth), and pregn-4-en-20-one (**60**). (**91**) A related process is used for the synthesis of the alkaloid secodaphrinphylline (**61**). (**92**) The protected ether derived from the Birch reduction of *m*-cresol is lithiated and then carboxylated followed by methylation of the acid and hydrolysis of the ether to produce 2-carbomethoxy-3-methylcyclohexenone. Subsequent Diels–Alder reaction with the *tert*-butyldimethylsilyl enol ether derived from 1-acetylcyclopentene leads to a tricyclic keto ester that provides the necessary carbocyclic skeleton for the synthesis of **61**. With **62**, where deprotonation of the methyl ether fails, the diethylaminoethyl ether reacts with *n*-butyllithium in hexamethylphosphoric triamide (HMPA), followed by addition of alkyl halide and hydrolysis, to produce 2-alkyl-3-methylcyclohex-2-en-1-ones **63**. (**93**, **94**)

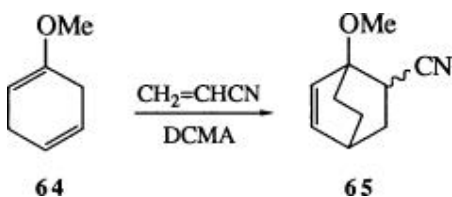


RX



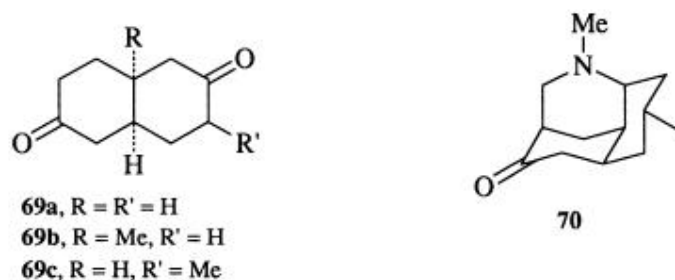
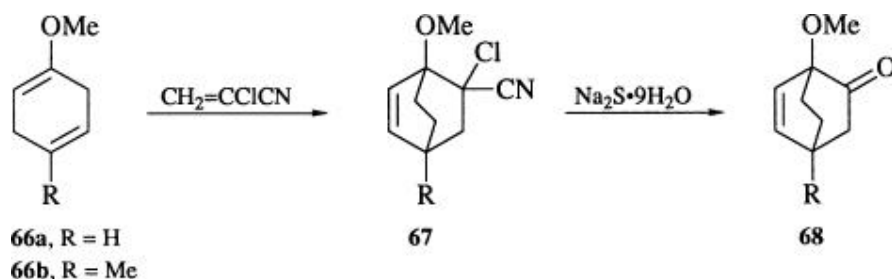
3.2.1.2. Cycloadditions

1-Methoxy-1,4-cyclohexadienes can be used as substrates in cycloadditions where prior isomerization to the conjugated isomer is accomplished in situ. This reaction is accelerated by catalysts, as illustrated by the reaction of 1-methoxy-1,4-cyclohexadiene (**64**) with acrylonitrile in the presence of dichloromaleic anhydride (DCMA) to afford adduct **65** in 75%

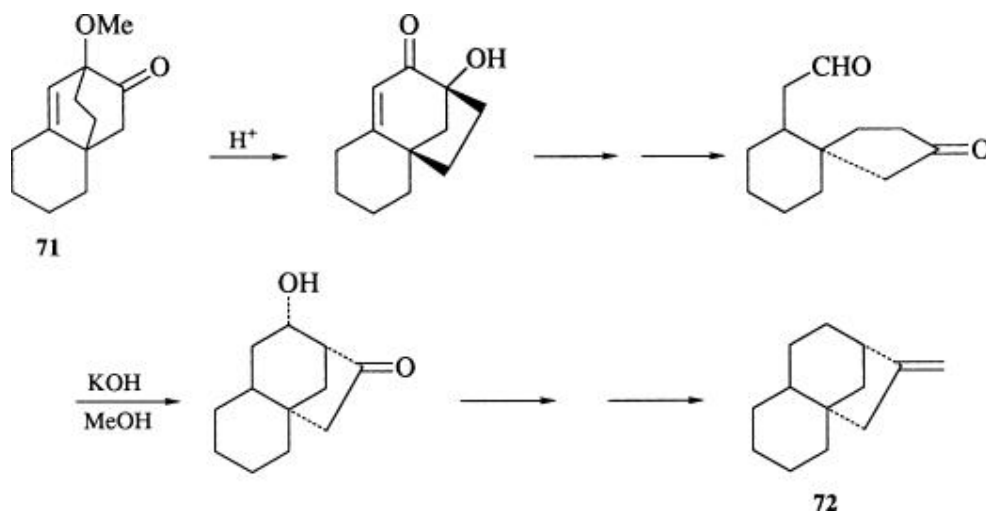


yield. (95) Under similar conditions, but in the absence of dichloromaleic anhydride, only unreacted **64** is recovered. Aluminum chloride and *p*-toluenesulfonic acid are also effective catalysts. (96)

α -Chloroacrylonitrile can also be used with complete (>99.9%) regioselectivity to produce adduct **67**, which can be converted into the bicyclic ketone



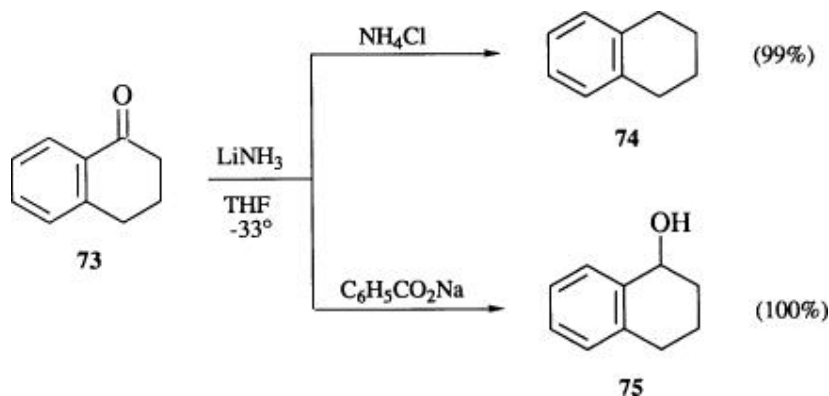
68 in over 80% yield. (97) Ketone **68** serves as a precursor to *cis*-decalin-2,6-diones **69**, (**98**) which can be used in the total synthesis of the lycopodium alkaloid luciduline (**70**). (99) Rearrangement of ketone **71**, available from 6-methoxy-1,2,3,4,7,8-hexahydronaphthalene and a ketene equivalent, ultimately furnishes **72**, a model of the veatchine group of diterpene alkaloids. (100)



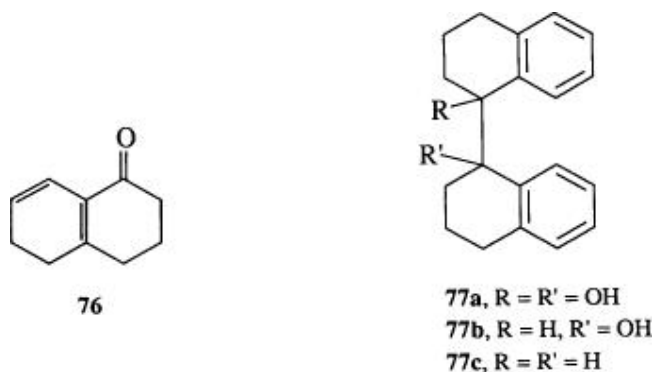
3.3. The Reduction and Reductive Alkylation of Aromatic Ketones

The Birch reduction of aromatic ketones is complicated by the fact that carbonyl reduction may take place in addition to, or in place of, aromatic ring reduction. Acetophenone reacts with potassium/ammonia in the presence of *tert*-butyl alcohol to give ethylbenzene. (101) Similarly, α -tetralone (**73**) affords

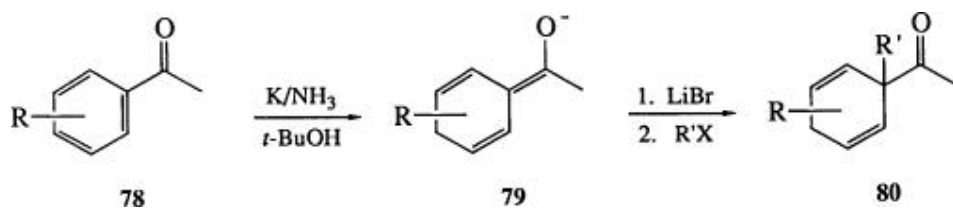
tetralin with lithium/ammonia reduction, but alcohol **75** is produced when sodium benzoate is used as a quenching agent. (102) Evidently additional reduction



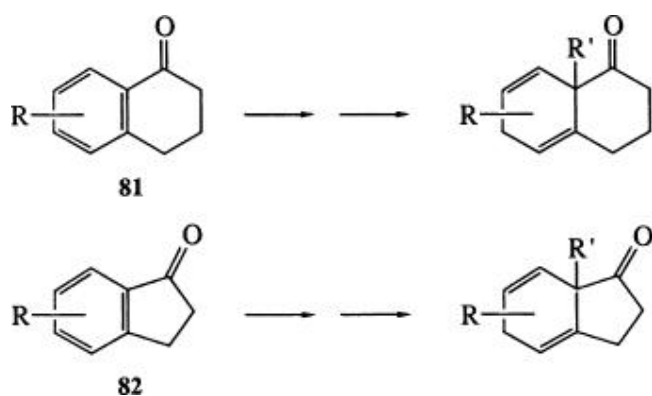
may occur during the quenching process even when relatively acidic agents like ammonium chloride are used. The reduction of α -tetralone is also quite sensitive to the order of addition of reagents, the metal employed, and the temperature. (103) With sodium added last, the nuclear reduction product **76** is produced in 30% yield together with **74** (12%) and **75** (49%). However, the use of lithium and lower temperatures (-78°) results in a considerable amount (54–84%) of dimerization (**77**), affording a mixture of **77a**, **77b**, and **77c**.



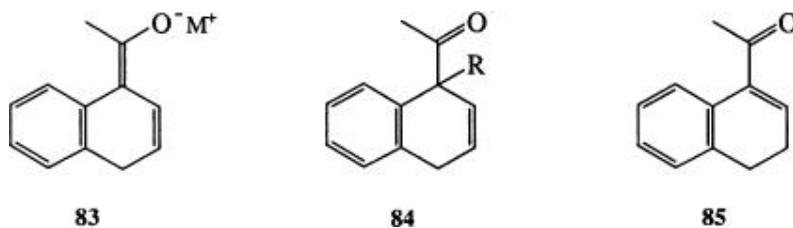
Overall reductive alkylation may be accomplished with acetophenones **78** by reduction to produce an enolate **79** which is subsequently alkylated. (83) This is best accomplished by initial reduction with potassium followed by exchange of the cation with lithium bromide prior to the alkylation step. Additional



improvements include adding the alkylating agent in aqueous tetrahydrofuran (1:1) at -78° to buffer the system and suppress dialkylation. (104) Similarly, 1-tetralones (81) (83, 104, 105) and 1-indanones (82), (106-108) including a number of methoxy derivatives, undergo reductive alkylation with $\text{R}' =$ methyl, ethyl, allyl, and benzyl halides.



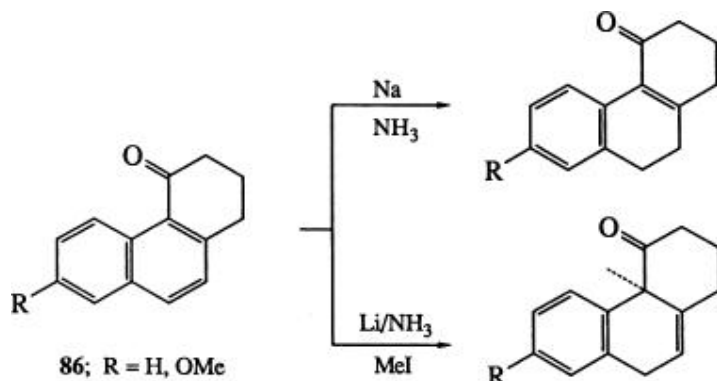
Reduction of 1-acetylnaphthalene (109-113) leads to the dienolate **83**, which can be alkylated with methyl or *n*-amyl iodide (109, 111) to produce **84**. On the other hand, protonation by ethanol affords the conjugated product **85**. (110, 111)



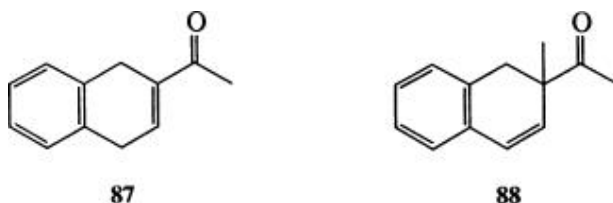
This is likely a rearrangement product since the reverse quench of **83** into aqueous ammonium chloride yields **84** ($\text{R} = \text{H}$). (113)

1-Keto-1,2,3,4-tetrahydrophenanthrenes **86**, (112, 114, 115) as well as A/B aromatic 11-keto steroids, (115, 116) react similarly to provide conjugated reduction products or nonconjugated, methylated reduction products.

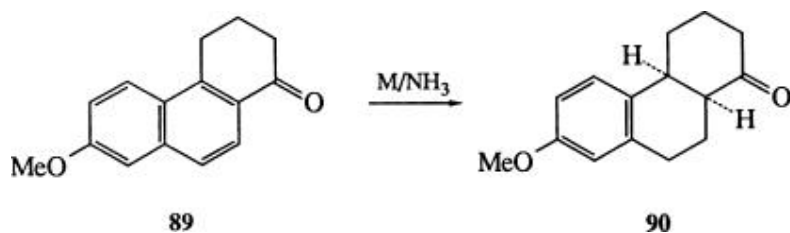
In contrast to the 1-isomer, the reduction of 2-acetylnaphthalene is more difficult to control. Both lithium and sodium reduction lead to tetrahydro



products with some reduction of the carbonyl group. However, the use of potassium for reduction, or lithium/ferric chloride for reductive methylation, affords the dihydro products **87** and **88** respectively. (111) Curiously neither the

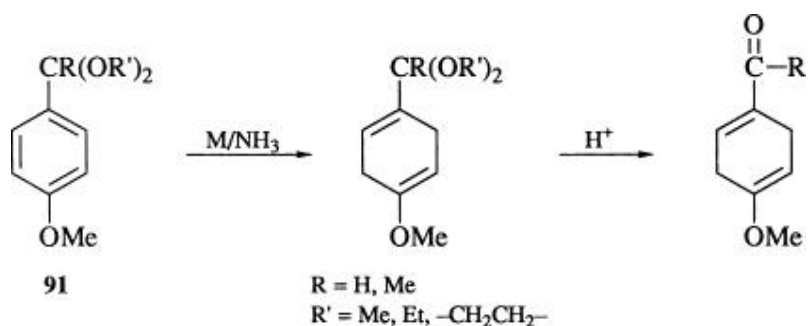


use of potassium nor ferric chloride limits the reduction of **89**, which yields the tetrahydro product **90**. (112) Preference for *cis*-fused B/C rings in the latter is presumably a consequence of protonation of the enolate from the sterically



less hindered equatorial side. Alkylation of the lithium enolate derived from **89** affords a mixture of *cis*- and *trans*-fused hexahydro isomers, and the use of sodium or potassium leads to a considerable amount of dialkylation.

Carbonyl groups may be protected during reduction by conversion into acetals, and a variety of *p*-anisaldehyde and *p*-methoxyacetophenone acetals and ketals **91** can be reduced to the 2,5-dihydro compounds in 30–80%

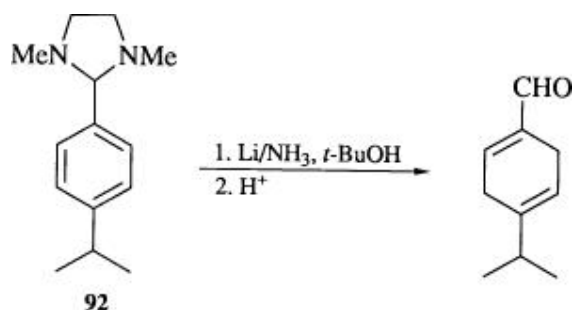


yields. (117) *p*-Isopropylbenzaldehyde can also be protected as the *N,N*-dimethylimidazoline (92) in an analogous transformation. (118)

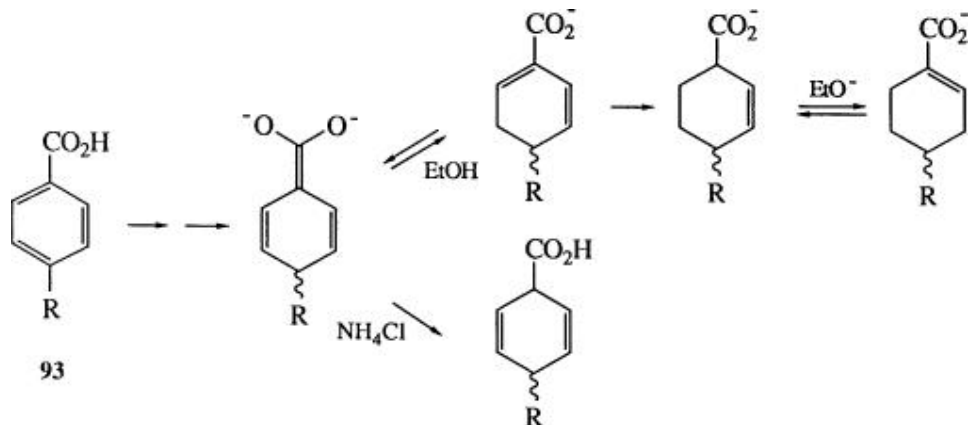
3.4. The Reduction of Aromatic Carboxylic Acids

3.4.1.1. Benzoic Acids

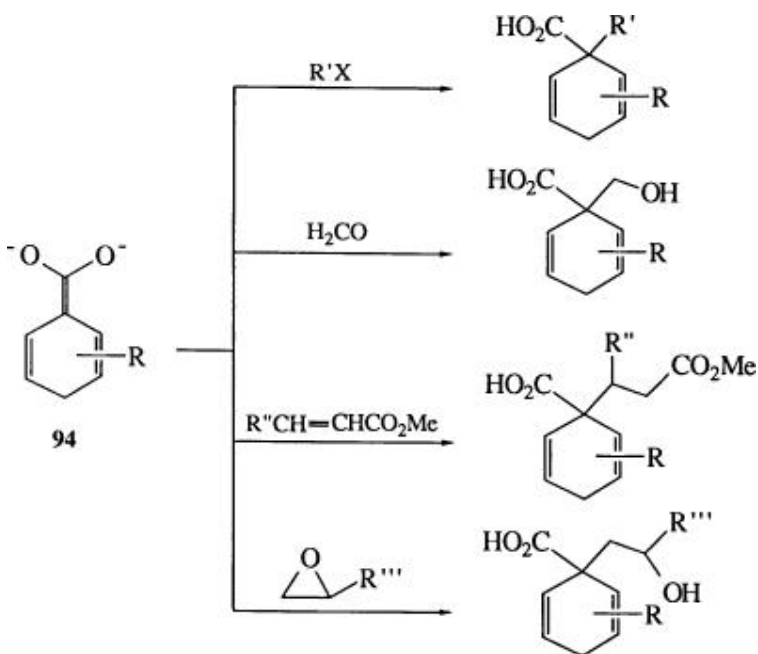
The carboxy group generally dominates regiochemistry, and is strongly activating in the Birch reduction. 3f,119 However, while classical reduction conditions produce good results with benzoic and *o*-toluic acids,



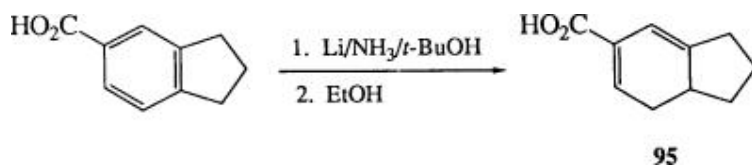
affording 1,4-dihydrobenzoic acids, (119-121) *p*-toluic acid (93, R = Me) gives mainly the tetrahydrotoluic acid under similar conditions. (120) With low levels of an alcohol, or in its absence together with short reaction periods followed by ammonium chloride quench, both 4-isopropyl and 4-*tert*-butylbenzoic acids



can be reduced efficiently to the 1,4-dihydro products. The former has a *cis/trans* ratio of 1:2 (122) while the latter gives only the *trans* isomer. (33) *m*-Alkylbenzoic

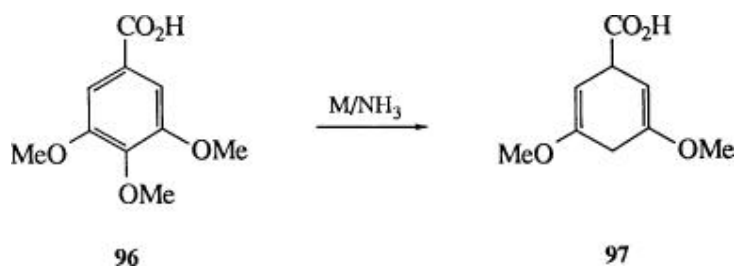


acids show similar behavior and are best reduced with water or ammonium chloride as the proton donor if 1,4-dihydro products are desired. (123) On the other hand, *o*-alkylbenzoic acids give mainly 1,4-dihydrobenzoates irrespective of the experimental procedure. In the absence of proton donors, the intermediate dianion **94** persists in solution and can be trapped with alkyl halides, (123) α , β -unsaturated esters, (124) epoxides, (125) or formaldehyde (126) to give a variety of synthetically useful products. The use of alcohols may serve as a



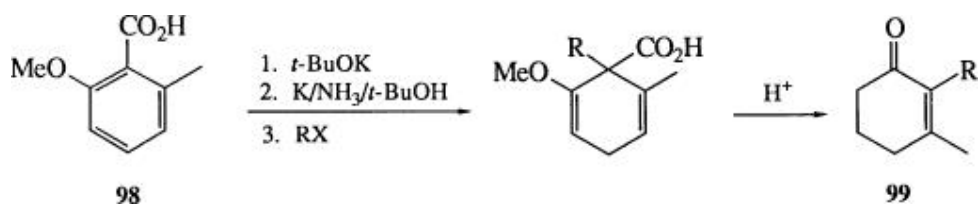
convenient method when conjugated products are desired, however, as illustrated in the synthesis of the tetrahydroindane carboxylic acid **95**. (127)

The loss of alkoxy and amino groups in benzoic acids by hydrogenolysis is common especially when they are in the *para* position. For example, the

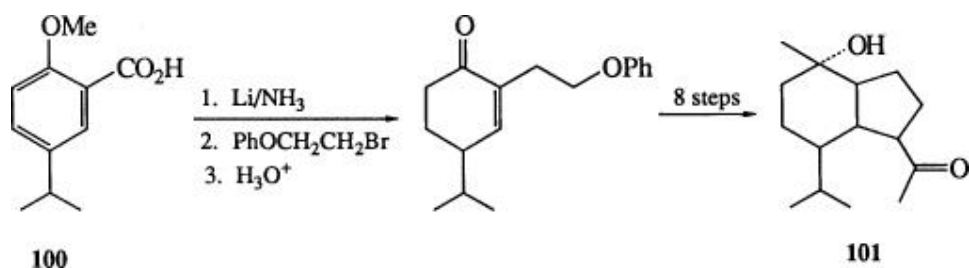


reduction of the trimethyl ether of gallic acid (**96**) leads to complete loss of the *p*-methoxy group but retention of those *meta* to the carboxy group. (**120**) *m*-Anisic acid is reduced smoothly with complete retention of the methoxy group. However, overreduction to the tetrahydro stage occurs with ethanol, and to a lesser extent with methanol, as the proton donor. This problem is corrected by reduction in the absence of an alcohol followed by the addition of ammonium chloride. (**120**, **128-130**)

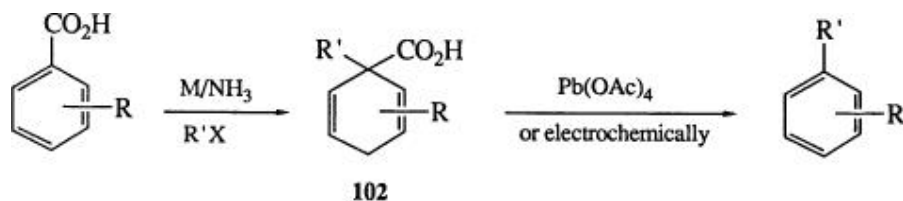
The loss of substituents can also be a problem with *o*-methoxybenzoic acids, especially when lithium is used in refluxing ammonia. (**131**) Some improvements involve the use of sodium instead of lithium, and the use of methanol as a proton donor. **132–133** A more general procedure, which also facilitates alkylation, involves the addition of potassium *tert*-butoxide prior to reduction by potassium metal in the presence of up to four equivalents of *tert*-butyl alcohol.



In this way 2-methoxy-6-methylbenzoic acid (**98**) can be reductively alkylated with methyl, benzyl, and 4-(1-butenyl) halides. Hydrolysis of the enol ethers leads to decarboxylation with production of cyclohexenones **99**. (**134**) In some



instances, it may be desirable to generate the lithium salt prior to alkylation, and such exchange is accomplished by the addition of lithium bromide. The reductive alkylation of 2-methoxybenzoic acids serves as the starting point for a number of total syntheses as illustrated for the sesquiterpenen **101**. (135) The reductive alkylation products of alkyl and alkoxybenzoic acids **102** can also undergo oxidative decarboxylation with lead tetraacetate, (136) or electrochemically, (137) to produce aromatic hydrocarbons and ethers in good yields.

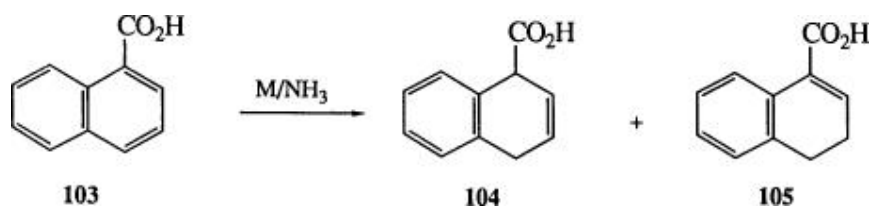


R = alkyl, alkoxy

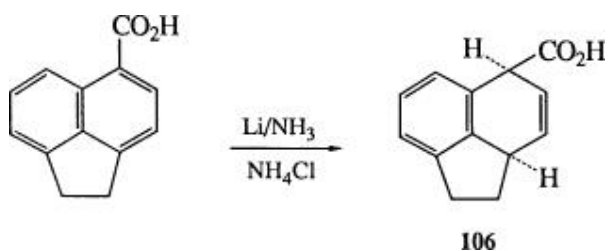
3.4.1.2. Polycyclic Aromatic Carboxylic Acids

The reduction of polycyclic aromatic carboxylic acids is especially easy when the carboxy group is located on a carbon that corresponds to a position of high electron density in the radical anion/dianion of the parent hydrocarbon. If the carboxy group is positioned at a site of low electron density relative to the parent hydrocarbon, however, reduction is often hard to control with respect to overreduction and/or isomerization.

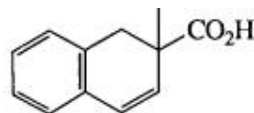
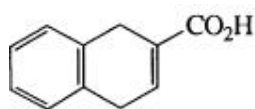
Conditions that give good results with benzoic acids, like the use of excess metal and the presence of an alcohol as a proton donor, often provide poor results with polycyclic aromatic carboxylic acids. For example, 1-naphthoic acid (**103**) provides substantial amounts of the 3,4-dihydro isomer **105** when reduced in the presence of an alcohol, 2a,138 but 1,4-dihydro-1-naphthoic acid



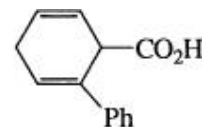
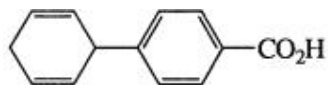
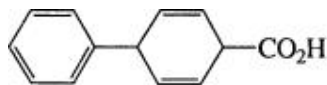
(**104**) becomes the exclusive product when ammonium chloride is used as the proton source. (84, 139) In contrast to the *trans* predominance observed for



4-substituted benzoic acids, 5-acenaphthoic acid gives the *cis* isomer **106**. (140) This result is presumably due to the added constraint provided by the five-membered ring. The reduction of 2-naphthoic acids is more difficult to control. (84, 141-144) However, the use of ferric chloride during the reduction leads to yields of ca. 75% for both reduction (**107**) and reductive methylation (**108**). (84) Interestingly, different regiochemistry is observed for these two processes.



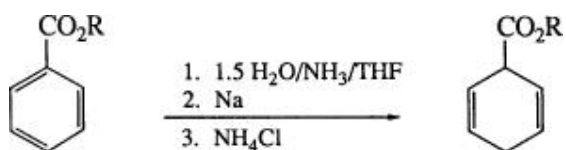
Reaction conditions are quite important in the reduction of biphenyl-4-carboxylic acid. (145, 146) However, with rapid quenching techniques, two products **109** (stereochemistry unknown) and **110** can be obtained in a ratio of 3:1



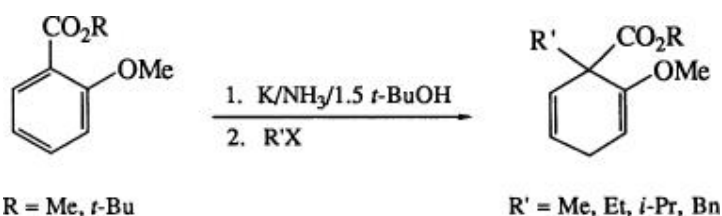
respectively. (146) In contrast, the *ortho* isomer provides a single product **111** with reduction being controlled by the carboxylic acid group. (145)

3.5. The Reduction of Aromatic Carboxylic Esters

The Birch reduction of aromatic esters is problematic in that carbonyl reduction is expected to be competitive with ring reduction (i.e., the Bouveault-Blanc procedure). However, if one or two equivalents of water, or *tert*-butyl alcohol, is added before metal addition, benzoate esters may be

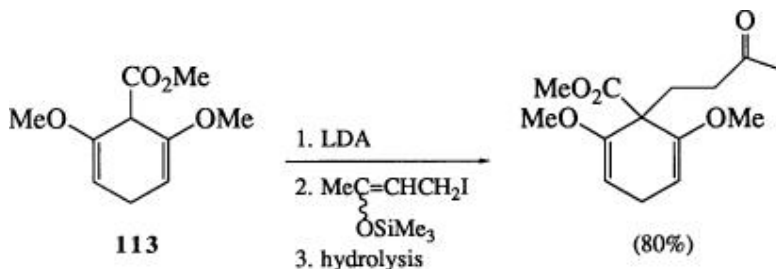


reduced in over 95% yield with sodium in ammonia, although yields are poor when 4-alkyl substituents are present or methyl esters are used. (147) However, if *tert*-butyl alcohol is used with lithium or potassium as the metal, good results are obtained with methyl benzoate. 3j This method, with potassium, also works well with reductive alkylation as illustrated for the *o*-methoxybenzoate ester

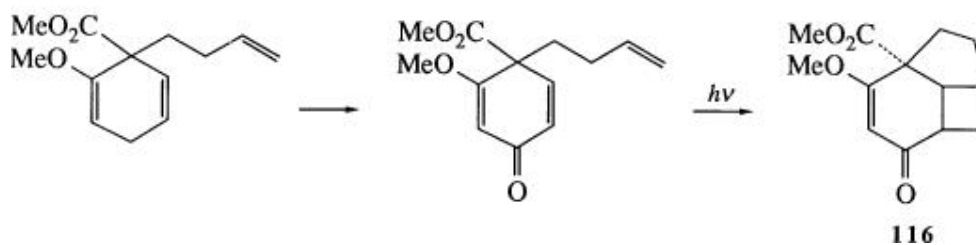
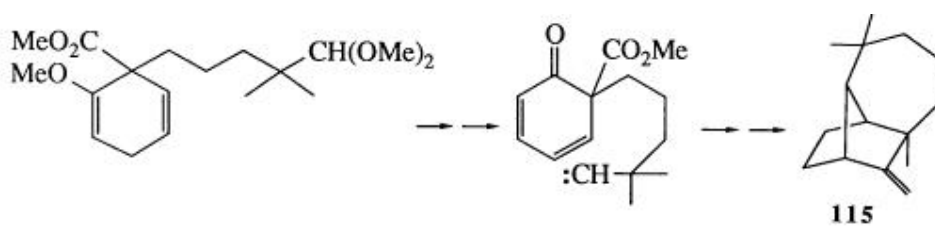
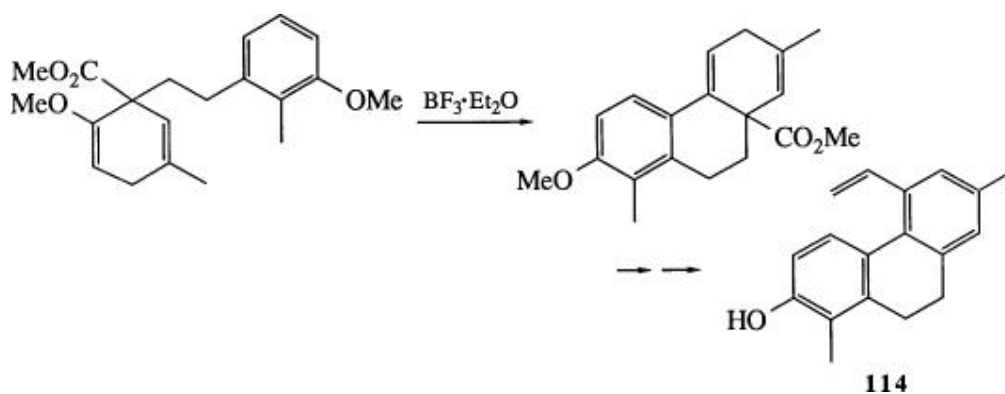


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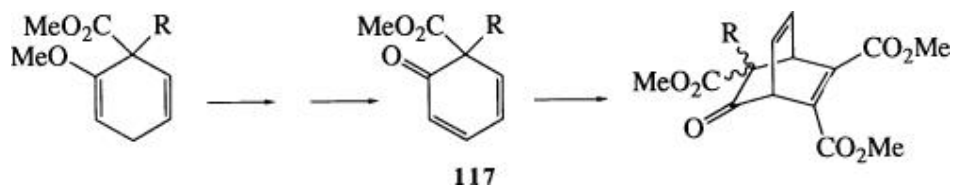
112. (134, 148) Yields are in the range 60–95% even in the presence of a 4-methyl substituent. However, in some cases it is necessary to convert the potassium enolate into the lithium enolate prior to the alkylation step, and with especially



active alkylating agents the ammonia must be removed first. 3j It is possible to carry out the alkylation step separately on the dihydrobenzoate (e.g., 113) by deprotonation with lithium *N,N*-diisopropylamide (LDA) followed by alkylation. (149) The reductive alkylation of *o*-methoxybenzoate esters provides



considerable opportunity for further synthetic elaboration as illustrated in the synthesis of juncunol (**114**), (**133**) (\pm)-longifolene (**115**), (**150**) and the tricyclic ketone **116**. (**151**) Similarly, conjugated dienes like **117** may be produced that serve as substrates for Diels–Alder reactions. (**152**)



In general, esters may serve as excellent alternatives to the parent carboxylic acids for Birch reduction, especially reductive alkylation. They are more

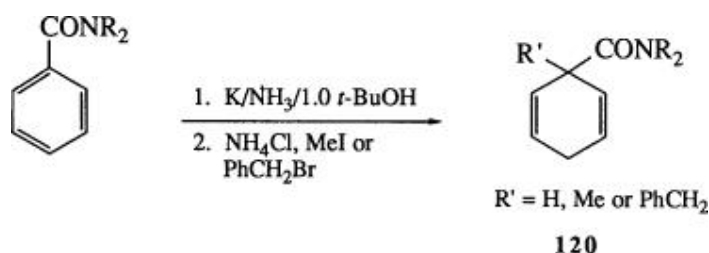
soluble; more resistant to isomerization, rearomatization, and decarboxylation; and are more easily isolated. They may also show improved regioselectivity,



as illustrated for reduction of ester **118**. The parent acid is reduced in both rings with the disubstituted ring favored by a 3:1 ratio whereas the ester gives **119** exclusively. (146)

3.6. The Reduction of Aromatic Amides

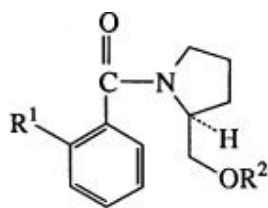
The reduction of aromatic amides is quite sensitive to conditions and can produce considerable amounts of benzaldehyde as well as dimeric products. (120, 152-157)



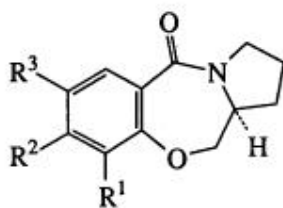
Best results are obtained when potassium is used in the presence of one equivalent of *tert*-butyl alcohol, and the resulting monoanion can be protonated or alkylated (**120**). (157)

3.6.1.1. Enantioselective Reductive Alkylation of Aromatic Amides

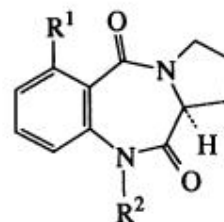
The incorporation of L-proline as a chiral auxiliary in **121–123** allows reductive alkylations with high diastereoselectivities (39, 158-164) although the sense of stereoselection in **121** is opposite to that in **122**. (159) Birch reduction of **121**, where



121, R¹ = OMe, Ph
R² = Me, CH₂OMe



122a, R¹, R², R³ = H
122b, R¹ or R² or R³ = Me

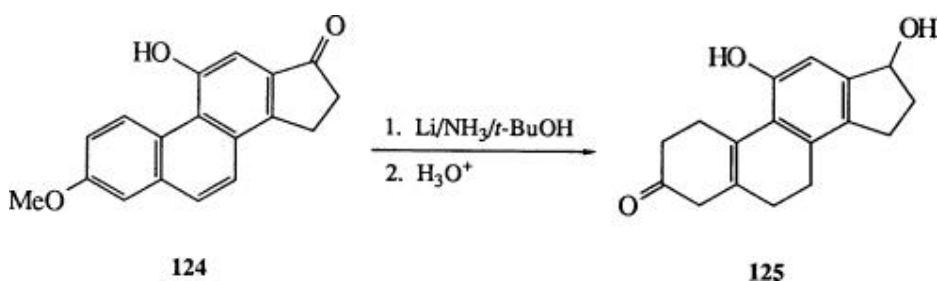


123, R¹ = H, Me
R² = H, Me

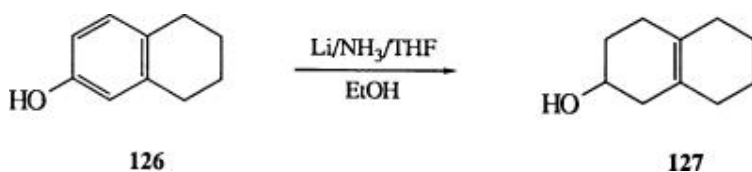
R¹ = OMe and R² = CH₂OMe, followed by alkylation with methyl iodide at -78° gives diastereomeric α -methylated dihydroaromatic products in a 260:1 ratio. (39) Amide **122**, where R¹ = R² = R³ = H, is less selective than **121** in methylation with a ratio of 85:15, but selectivity increases to 99:1 when ethyl iodide is used as the alkylating agent. This method can be used as a starting point for total synthesis as, for example, **122** in the enantiospecific preparation of (–)-longifolene (**115**). (150)

3.7. The Reduction of Phenols

Phenols are rather unreactive under Birch reduction conditions since the addition of an electron to a phenoxide produces a radical dianion. In polynuclear aromatics such as **124**, the aromatic ring bearing the hydroxy group is often not reduced. (165) The reduction of phenolic rings is best accomplished with high concentrations of lithium. The yield of **127** is increased from 46% to 76% by increasing the lithium concentration from 3.4 M to 4.3 M. (166) An exception to this lack of reactivity is 2-naphthol and its derivatives. 2a Increased

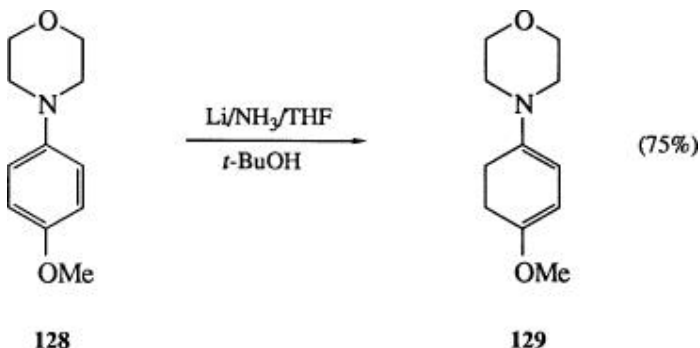


reactivity may be due to reduction occurring via the tautomeric α , β -unsaturated keto form.



3.8. The Reduction of Aromatic Amines

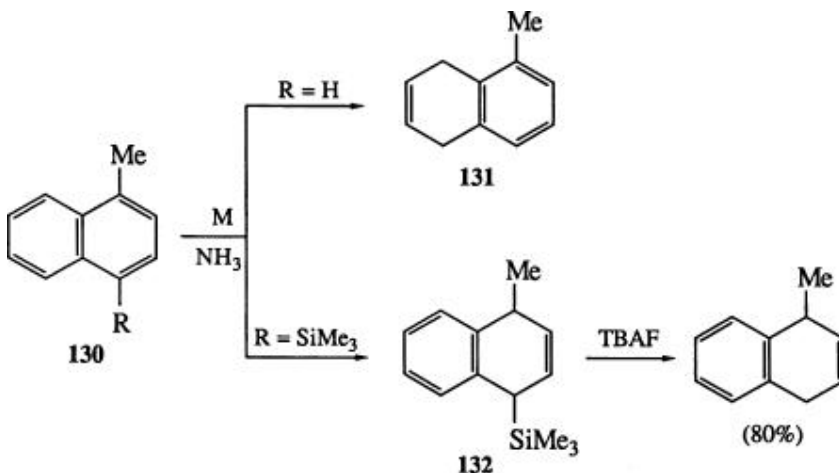
Aromatic amines undergo transformations analogous to anisoles in that the final products are ordinarily ketones and unsaturated ketones. (167, 168) In contrast to anisoles, however, the initial reduction products are usually not isolated with aryl amines, and overreduction is common. However, *N*-aryl-morpholine



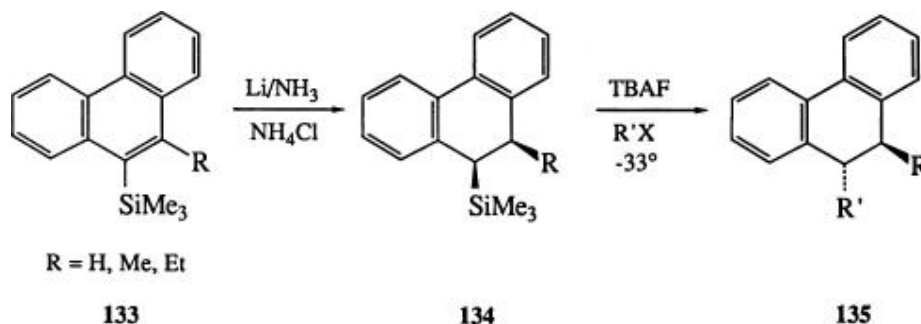
derivatives provide an important exception in that the primary reduction product is isolable. As illustrated for **128**, the products are generally conjugated cyclohexadienamines, although nonconjugated products are formed when there are substituents *ortho* to the nitrogen. (169)

3.9. The Reduction of Arylsilanes

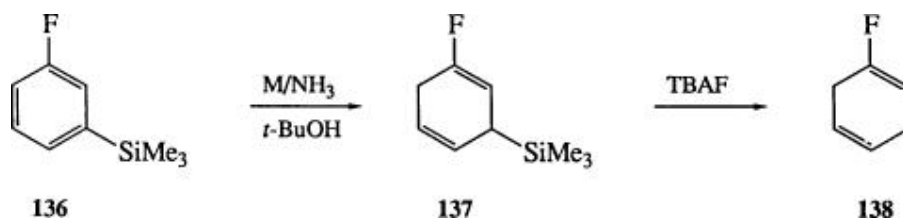
Carbanions are stabilized by an α -silyl substituent, (170) and consequently arylsilanes are reduced to provide allylic silanes in the absence of more strongly activating substituents. (171) Since allylic silyl groups are easily removed by fluoride ion, silyl substitution represents a way of controlling regiochemistry in the Birch reduction. (172-174) For example 1-methylnaphthalene (**130**,



R = H) is reduced in the unmethylated ring to produce 5-methyl-1,4-dihydronaphthalene (**131**). However with a 4-trimethylsilyl substituent at C-4 (**130**, R = SiMe₃), reduction occurs exclusively in the substituted ring to produce **132**. Subsequent removal of silicon by treatment with tetrabutylammonium fluoride (TBAF) affords 1-methyl-1,4-dihydronaphthalene in 80% overall yield. (**172**) The equivalent of overall reductive alkylation can also be accomplished by removal of the trimethylsilyl group in the presence of methyl or ethyl iodide. For example, the phenanthrene **133** is reduced to the benzylic silane **134**, which, in turn, can be treated with tetrabutylammonium fluoride in the presence of primary alkyl halides to produce the *trans*-9,10-dihydro derivative **135**. (**173**) This is especially significant since reduction of 9,10-dialkylphenanthrenes produces the *cis* isomers. Anthracenes and naphthalenes can also be alkylated in this way, and the products exhibit the same stereochemistry that they show during normal reductive alkylation in the absence of a silyl group. This result indicates that additional stereoselectivity by the replacement of silicon with RX is not possible and that the intermediate resulting from treatment with tetrabutylammonium fluoride is the carbanion and not a tight complex. (**174**) Silyl substitution can also be used to prevent cleavage of



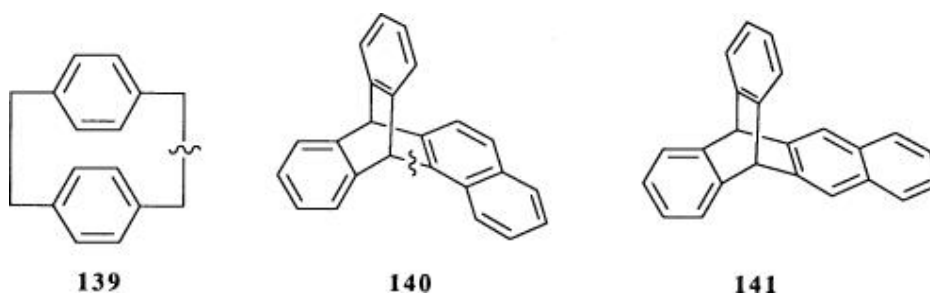
substituents that might otherwise be lost during reduction. For example, although fluorobenzene is rapidly converted into benzene and on to 1,4-cyclohexadiene under Birch reduction conditions, *m*-trimethylsilylfluorobenzene



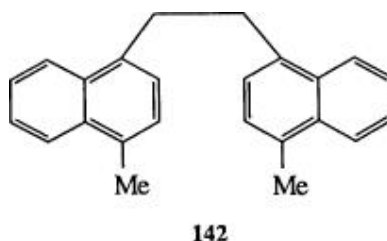
(136) is reduced with the fluorine retained. Subsequent removal of the silicon by tetrabutylammonium fluoride affords 1-fluoro-1,4-cyclohexadiene (138), which is not otherwise accessible by Birch reduction methods. (175)

3.10. Bond Cleavage and Dimerization

Dissolving metal reduction is sometimes accompanied by processes that alter the nature of the original ring system. Two such side reactions are bond cleavage and dimerization. As mentioned above, the cleavage of carbon–oxygen bonds is quite common in aryl ethers, and may become a major pathway. (176) This is especially true for alkali metal reduction in solvents other than ammonia. (177-185) Carbon–carbon bond cleavage is also possible with 1,2-diarylethanes



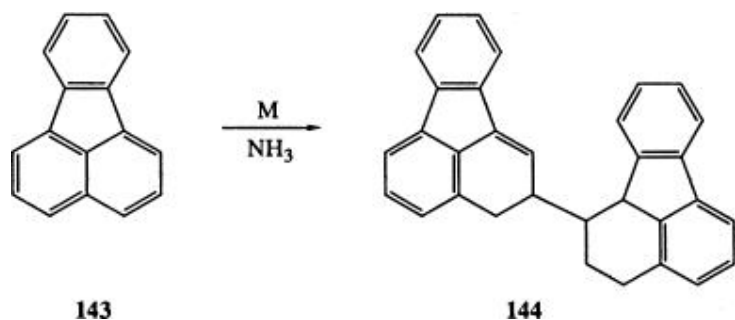
and diarylmethanes. [2.2]-Paracyclophane (139) undergoes cleavage of the ethane bond during lithium/ammonia reduction, (186) and the 1,2-benztritycene (140) ring opens to give 10-lithio-9-(2-naphthyl)-9,10-dihydroanthracene. (187) On the other hand, the isomeric 2,3-benztritycene (141) does not ring open under similar conditions. (187) The competition between Birch reduction and bond cleavage in 1,2-bis(4-methyl-1-naphthyl)ethane (142) is



quite sensitive to conditions, with cleavage increasing relative to reduction in the series $\text{Li} < \text{Na} < \text{K}$ and $\text{NH}_3 < \text{THF} < \text{HMPA}$. (188) It is quite significant, however, that reduction becomes the almost exclusive pathway at temperatures below -33° regardless of metal or solvent. Since this is the highest operating temperature for ammonia, effects that appear to be solvent related may in fact be more attributable to temperature.

Dimeric and oligomeric products may also result from the reduction reaction,

and in some cases this represents a major pathway. For example, fluoranthene (**143**) reacts with either sodium or lithium in ammonia to give

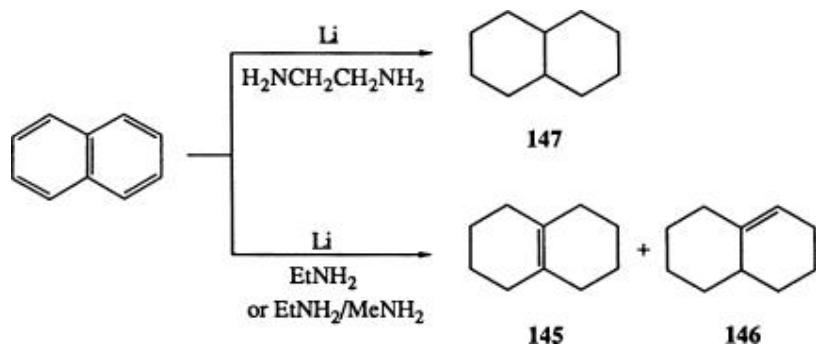


the dimer **144** in 30–52% yield together with polymeric material. (**189**) Similarly, the reduction of naphthalene can produce substantial amounts of dimer and trimer, especially with prolonged reaction times. (**190**) These processes do not involve dimerization of radical anions, as might be expected, but rather result from monoanion addition to neutral alkenyl aromatics. (**189**, **190**)

3.11. Comparison with Other Methods

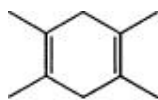
3.11.1.1. Benkeser Reduction

The use of lithium in primary amines, ethylenediamine, or mixtures of primary and secondary amines serves as an alternative to the classic Birch reduction procedure. Known as the Benkeser reduction, this system provides a more powerful reducing medium than metals in ammonia. (**191**) For example, whereas benzene gives 1,4-cyclohexadiene by Birch reduction, treatment with lithium in ethylamine provides mainly cyclohexene plus some cyclohexane. (**192**) Similarly, naphthalene, which under suitable metal ammonia reduction conditions affords 1,4-dihydronaphthalene almost quantitatively, (**11**) gives the octahydro products **145** and **146** in equal amounts by reduction with lithium in ethylamine. (**192**) When the solvent is changed to a mixture of ethylamine and methylamine, the selectivity (**193**) increases with **145** as the major product (80%). With ethylenediamine, reduction proceeds even further to produce decalin (**147**). (**194**) Polynuclear aromatic compounds normally

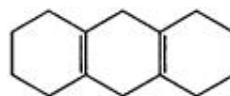


undergo reduction beyond the dihydro stage with lithium–amine systems and often yield a mixture of products. Reduction of these compounds beyond the addition of two hydrogens must result from protonation of the anionic intermediates by the amines. However, this need not suggest greater acidity in this medium as compared with ammonia, but probably results from the higher temperatures normally employed. The conjugation of dienes by the lithium salts of amines is well known. (195) In any event, Benkeser reduction does not serve as a substitute for the Birch reduction, but may be the method of choice when more highly reduced materials are desired or for the reduction of isolated double bonds.

The use of calcium in low-molecular-weight amines sometimes provides cleaner results than lithium. For example, the dienes **148** and **149** can be



148



149

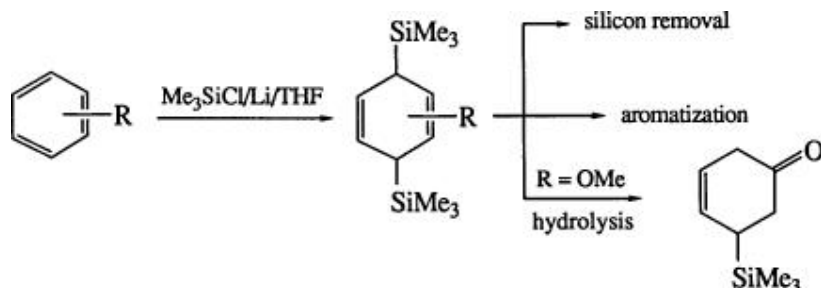
obtained by calcium–methylamine–ethylenediamine reduction of durene and anthracene respectively. (196) The addition of *tert*-butyl alcohol to such systems, however, gives products similar to those of the Birch reduction in a number of cases. For example, anisole and the isomeric xylenes are all reduced to the expected 1,4-cyclohexadienes with calcium/amines/*tert*-butyl alcohol with yields in the 75–90% range. (197)

3.11.1.2. Reduction in other Solvents

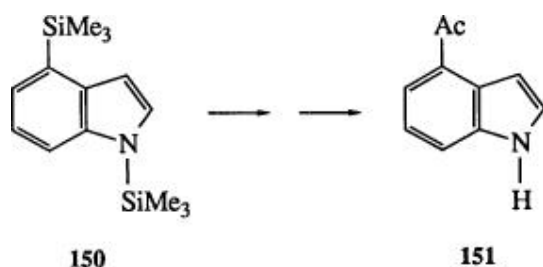
Electron addition to aromatics and other unsaturated cyclic compounds can also be accomplished by the use of alkali metals in solvents other than ammonia or amines, most notably tetrahydrofuran and HMPA. (198) This procedure seldom offers any advantage over metal/ammonia procedures, since reactions in these solvents are often quite slow. However, in the absence of ammonia or an alcohol as a proton source, the intermediates are radical anions or dianions, and alkylations may be possible that cannot be achieved in the presence of ammonia. Alloys such as Cs/K/Na in tetrahydrofuran reduce benzene, toluene, and xylene, generally producing tetrahydrobiphenyls as the major products. (199) Crown ethers enhance the solubility of alkali metals in tetrahydrofuran, (200) and the system sodium–potassium alloy/18-crown-6/tetrahydrofuran has been used for the reduction of benzoic acid and anthracene. (201, 202) The addition of sodium metal to polynuclear aromatics in a refluxing alcohol also represents a method for ring reduction, but it is not expected to have much general utility. (203)

3.11.1.3. Reductive Silylation

Benzene (204, 205) and its alkyl, (205) methoxy, (206, 207) and hydroxy derivatives (207) react with lithium in tetrahydrofuran in the presence of chlorotrimethylsilane to produce 3,6-bis(trimethylsilyl)-1,4-cyclohexadienes. This process, which may require extended reaction periods of a number

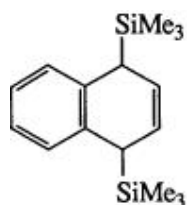


of days, can be accelerated by sonication as demonstrated for the reductive silylation of phenol. (207) 1,4-Cyclohexadiene, free of its conjugated isomer, can be prepared by the reductive silylation of benzene followed by silicon removal with aqueous potassium hydroxide in carbitol. (208) Rearomatization, affording an overall route to silylated aromatics, is also quite facile. For example, this

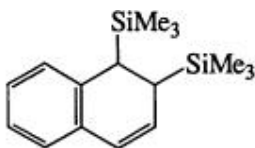


methodology can be used for the preparation of the silylated indole **150** with further conversion to the acyl derivative **151** by *ipso* Friedel–Crafts acylation. (209)

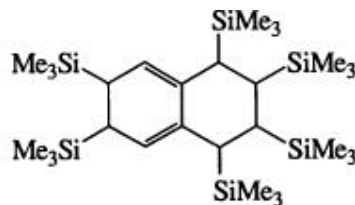
Naphthalene undergoes reductive silylation with sodium in tetrahydrofuran to provide both 1,2- and 1,4-dihydro isomers **152** and **153**, (210) whereas the use of potassium leads to a tetrasilylated compound. (211) With lithium/tetrahydrofuran (212)



152



153

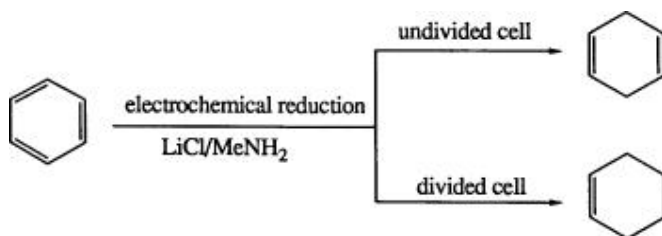


154

or magnesium/HMPA, (213) silylation proceeds further to give 154, which can be rearomatized with the loss of two silyl groups to provide 1,4,6,7-tetrakis(trimethylsilyl)-1,2,3,4-tetrahydronaphthalene, providing a source of tetrafunctional naphthalenes by subsequent electrophilic substitution on silicon.

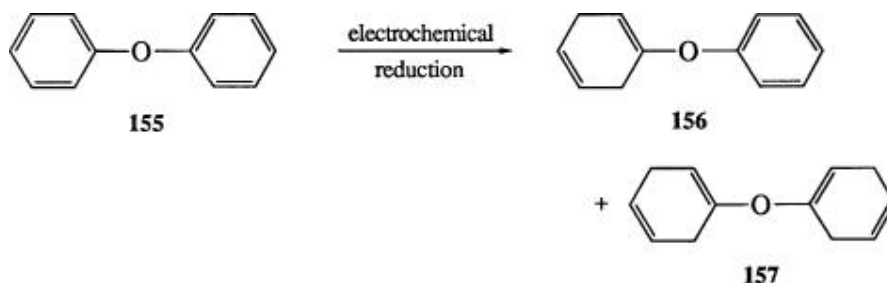
3.11.1.4. Electrochemical Reductions

Reactions similar to the Birch reduction can also be performed electrochemically. (214, 215) Benzene is reduced by electrochemical reduction using lithium chloride as the electrolyte to provide 1,4-cyclohexadiene in an undivided cell, but cyclohexene in a divided cell. (191, 216) The latter result is presumably due to the presence of lithium dimethylamide,



formed in the divided cell, that causes isomerization and further reduction of the initial product. Ethyl, isopropyl, and *tert*-butylbenzene can be similarly reduced producing 1-alkyl-1,4-cyclohexadienes in yields of 75–96% in the undivided cell.

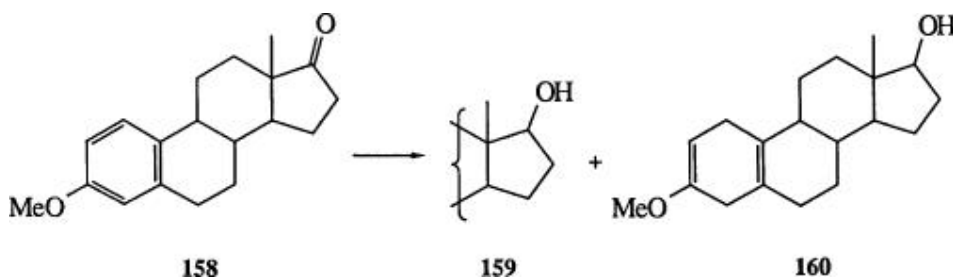
Efficient preparative electroreductions can be performed at mercury pool cathodes in solutions containing tetraalkylammonium electrolytes with a variety of solvents including acetonitrile, *N,N*-dimethylformamide (DMF), alcohols, ethers, sulfolane, and HMPA. (215) The use of aqueous solutions can



also produce interesting results. For example, diphenyl ether (**155**) is reduced to phenol and benzene by either Birch reduction or electrochemical reduction in dry *N-N*-dimethylformamide. However, with cathodic reduction in aqueous tetrahydrofuran, **156** and **157** are produced in combined yields of over 50%. (**217**)

Another interesting example is estrone 3-methyl ether (**158**) since it cannot be satisfactorily reduced by Birch reduction. By varying the current, the carbonyl and the aromatic ring can be selectively reduced producing either **159** or **160** in yields of over 80%. (**218**)

Polynuclear aromatic hydrocarbons can also be reduced electrochemically; in some instances results are quite comparable to Birch reduction and in others they are not. For example, preparative electrolysis of anthracene provides 9,10-dihydroanthracene in 90% yield. However, phenanthrene gives a mixture of dihydro, octahydro, and decahydro derivatives. (**215**)

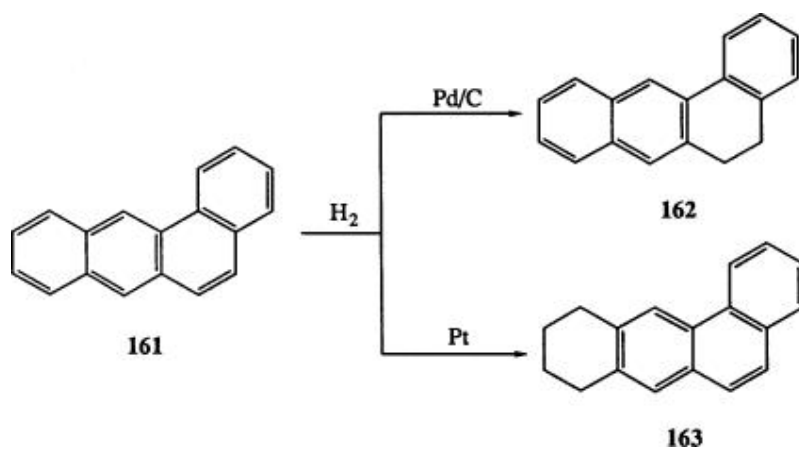


3.11.1.5. Catalytic Hydrogenation

Although aromatic rings can be reduced by catalytic hydrogenation, reduction normally proceeds far beyond the stage of dissolving metal reduction. (**219**) Thus while a useful procedure, catalytic hydrogenation



does not usually serve as an alternative to Birch reduction. Hydrogenation is often unpredictable and difficult to control. Either heterogeneous or homogeneous catalysts can be used, but in both cases the usual products from the hydrogenation of benzene derivatives are cyclohexanes. However, this method can be applied to polynuclear aromatics with exceptionally good results in some instances. For example, benz[*a*]anthracene (**161**) can be hydrogenated under mild conditions (20–50 psig, ambient temperature) to



provide **162** in 97% yield when palladium on charcoal is used as the catalyst, and **163** in 95% yield using a platinum catalyst at slightly higher hydrogen pressures. (220)

4. Experimental Conditions

4.1. Liquid Ammonia

Anhydrous ammonia is a toxic gas with a pungent odor, and all operations must be conducted in an efficient fume hood. Liquid anhydrous ammonia is available commercially in steel cylinders, and it can be removed in either liquid or gaseous form. However, ammonia from steel cylinders is often contaminated with iron, thereby providing a catalyst for the formation of alkali metal amides. This problem is especially important when sodium or potassium is employed, or when prolonged reaction times are necessary, and has led to the practice of double distillation – ammonia is removed as a gas and condensed into a preliminary vessel where it is dried with sodium until a blue color persists. It is then distilled into the reaction vessel. A simpler method is to pass the ammonia through a drying tube containing barium oxide (10–20 mesh).

Liquid ammonia has a boiling point of -33.4° , and an efficient condenser is required. A Dewar condenser containing a slurry of dry ice in isopropyl alcohol will normally suffice. A positive pressure of inert gas is also required, and argon or helium are preferred since nitrogen reacts with lithium metal.

4.2. Metals

The metals most frequently employed for Birch reduction are sodium, lithium, potassium, and, to a lesser extent, calcium and magnesium. Lithium is the most reactive, and also the most soluble in ammonia. Coupled with the fact that lithium is also less sensitive than sodium or potassium to iron-catalyzed reaction with ammonia, it is often the metal of choice. Lithium amide is also less soluble than either sodium or potassium amide, and this can reduce the amount of secondary isomerization products. With polynuclear compounds, however, the greater tendency for lithium salts to be protonated by ammonia can lead to overreduction, and sodium sometimes gives the best results.

Although alkali metals are quite soluble in ammonia ultimately producing so-called “metallic” or “bronz” phases, Birch reductions are most often done under dilute conditions. Ranges of 0.1–0.5 g metal per 100 mL of ammonia are common, and scaling up, when it includes more concentrated metal solutions, sometimes results in lower yields. Hence the ramifications of highly concentrated solutions of alkali metals in amine and ether solvents remain unclear. (221)

4.3. Cosolvents and Proton Donors

Cosolvents are often added to aid solubility. They are usually ethers, with diethyl ether, tetrahydrofuran, and glymes being the most common. However, since the anionic intermediates, as well as the products, are often more

soluble than the starting materials, only slight solubilization is necessary. Product outcome is occasionally affected by the nature of the cosolvent, but this may be more a function of ion pairing than solubilization. In any event, the routine use of diethyl ether or tetrahydrofuran in a ratio ranging from 1:3 to 1:2 relative to excess ammonia is probably prudent.

It is sometimes necessary to add acidic substances that may serve as proton sources. Generally, alcohols like ethanol and *tert*-butyl alcohol are employed for this purpose although occasionally stronger acids like water may be employed. The most serious problem normally comes about when a proton source is added where it is not required. This is true for almost all polynuclear aromatics as well as for a number of activated benzenes.

4.4. Reaction Procedures

The purity of starting materials remains a question. Carefully purified ammonia, cosolvents, proton donors, and aromatic substrates are sometimes critical. On the other hand, commercial anthracene can be reduced almost quantitatively without purification, and with "wet" ether as a cosolvent. As a general rule, the reduction of highly reactive substrates with short reaction times and rapid quenching (e.g., ammonium chloride) will not be overly sensitive to these considerations. Nonetheless, routine purification of materials is recommended. Commercial anhydrous tetrahydrofuran can be further dried by distillation from sodium benzophenone ketyl. Metals should be freshly cut under oil with their surfaces scraped clean, and then rinsed with petroleum ether. Additional details for the handling and purification of lithium, sodium, and potassium may be found in *Reagents for Organic Synthesis*. (222)

The order of addition can be quite important. There are several possibilities: the substance to be reduced dissolved in cosolvent containing an alcohol may be added to the ammonia already containing the metal, the alkali metal may be added last to the other reagents, or the alcohol may be added last. Of these methods, adding the metal last in small pieces is generally recommended.

The final quenching process is also important, and two general types of materials may be used: acidic materials like alcohols, water, or ammonium chloride, or electron-transfer agents like sodium benzoate or dienes followed by water. It is best to understand what is being accomplished in the final quench. This generally means one or more of the following possibilities: destroy excess metal, protonate anionic intermediates, and shift equilibria. If the quench is done slowly, as is the case with alcohols, metal is destroyed slowly and so excess metal during the quench can produce overreduction. A potential problem with electron-transfer reagents is that they can accept an electron from an anionic intermediate. This is not likely, however, except for dianions which are rare in ammonia. The addition of saturated ammonium chloride as fast as possible while keeping frothing under control is a good

general method. Where extreme sensitivity to overreduction during the quenching process exists, it is possible to pump the ammonia solution into dilute ammonium chloride (i.e., inverse quench).

Rapid workup is sometimes important, and allowing the quenched ammonia solution to stand for long periods to evaporate ammonia may be detrimental. When the amounts of ammonia are a few hundred mL or less, the quenched reaction mixture (no more violent frothing upon addition of water) may be poured into an excess of water (good hood) containing some ether, and then gently poured into a separatory funnel mounted on a ring stand (good hood, do not shake the funnel!). The water layer is then removed and more water is added to the separatory funnel *without shaking*. This water layer is drained off, and after two or three of these operations, the separatory funnel can be shaken without developing much pressure, and product isolation can proceed as usual.

For reductive alkylations, the alkylating agent in dry ether is added dropwise from a pressure equalizing dropping funnel. If reactive alkyl halides are added too quickly, violent evaporation of ammonia can result, and stoppers will be blown out.

4.5. Apparatus

Reactions are ordinarily conducted in a three-necked round-bottom flask with a sealed mechanical stirrer or equipped for magnetic stirring. In either case, glass or polyethylene stir blades or stir bars are preferred since Teflon darkens with repeated use in metal/ammonia solutions. The use of blackened stir bars does not seem to interfere with the reaction, however. The flask should be fitted with an inert gas inlet with a tee connection to a mercury bubbler and a Dewar condenser. If magnetic stirring is used, the third neck may be stoppered and used for the addition of reagents. With a flow of inert gas (stopper removed) the apparatus should be dried with a burner flame. After cooling, the Dewar condenser should be charged with dry ice/isopropyl alcohol, and the flask should also be cooled with a dry ice bath. Ammonia gas is then passed in through a drying tube containing 10–20 mesh barium oxide. Once the desired amount of ammonia is collected (usually estimated by premarking the flask), the bath can be removed if the reaction is to be run at reflux (ca. -33°), or otherwise remain if a lower temperature (ca. -78°) is desired. The aromatic substrate, dissolved in cosolvent, is then added via the stoppered neck. It may simply be poured in or added with a pressure equalizing addition funnel. The metal is added last in small pieces through the same inlet, and sometimes best results are obtained when this is done over a period of a few minutes.

5. Experimental Procedures

5.1.1.1. 1,2-Dimethyl-1,4-cyclohexadiene (Reduction of a Monocyclic Aromatic Hydrocarbon) (223)

To a flask containing 2.5 L of liquid ammonia were added slowly 450 g of anhydrous ether, 450 g (10 mol) of absolute ethanol, and 318.5 g (3.0 mol) of *o*-xylene in that order. Then 207 g (9.0 mol) of sodium was added in pieces over 5 hours. The ammonia was allowed to evaporate overnight, and 800 mL of ice water was slowly added with stirring. The organic layer was washed three times with 800-mL portions of water and dried over magnesium sulfate. Distillation through a 20-cm Vigreux column gave 250–300 g (77–92%) of a fraction boiling at 70–72° (48 mm).

5.1.1.2. 9,10-Dihydroanthracene (Reduction of a Polycyclic Aromatic Hydrocarbon) (224)

A solution of 0.36 g (2 mmol) of anthracene in 20 mL of tetrahydrofuran was added to 40 mL of anhydrous ammonia at –78° under an argon atmosphere. Lithium metal (35 mg, 5 mmol) was then added in pieces and the reaction mixture was stirred for 20 minutes. Saturated ammonium chloride solution was then added as quickly as possible to discharge the deep blue color. Ether (150 mL) was added, and washing, drying, and evaporation afforded pure 9,10-dihydroanthracene, mp 108°. The yield was essentially quantitative.

5.1.1.3. 7,12-Dihydrobenz[a]anthracene (The Use of Ferric Chloride to Control Reduction) (225)

A solution of benz[a]anthracene (1.14 g, 5 mmol) in 76 mL of dry tetrahydrofuran was added to 150 mL of anhydrous ammonia containing 40 mg of ferric chloride. Lithium wire (85 mg, 12 mmol) was added to the solution at reflux temperature, and after 2 hours the deep blue color was discharged by the addition of ethanol. After evaporation of the ammonia and dilution with water, the product was isolated by filtration. Dissolution in acetone, filtration, and removal of the solvent provided 7,12-dihydrobenz[a]anthracene (1.08 g, 70%, mp 111–112°).

5.1.1.4. 17 β -Hydroxy-16 β -methyl-estr-4-en-3-one (Conversion of an Anisole into a Cyclohexene-3-one) (42)

Anhydrous ammonia (300 mL) was added to 16 β -methyl-3-methoxyestra-1,3,5(10)-trien-17 β -ol (1.2 g, 4.2 mmol) in ethanol (5 mL) and tetrahydrofuran (50 mL) at –50°, followed by lithium ribbon (2.3 g) in ca. 0.3-g portions over 2 hours with stirring. After stirring an additional 1 hour, ammonia was evaporated in a slow stream of nitrogen, and the residue was extracted with ether. The extracts were washed with water, dried over Na₂SO₄, and the solvent was evaporated to give crude crystals (1.13 g). To a stirred solution of this enol ether in methanol (25 mL) was added 6 M HCl (3 mL).

After stirring at room temperature for 30 minutes, the reaction mixture was extracted with ether. The extracts were washed with water, dried over Na₂SO₄, and the solvent was evaporated to give crude crystals. Recrystallization from ether–hexane (1:1) gave 17 β -hydroxy-16 β -methylestr-4-en-3-one (0.98 g, 85%) as colorless needles, mp 228–229°.

5.1.1.5. *trans*-3 α , β

-Methyl-3-(1-methoxyethoxymethoxyethyl)-2,3,3a,4,5,6,9,9b-octahydro-1H-benz[e]inden-7(6H)-one (Conversion of an Anisole into a Cyclohexen-4-one) (226)

A solution of *trans*-7-methoxy-3 α , β

-methyl-3-(1-methoxyethoxymethoxyethyl)-2,3,3a,4,5,9a-hexahydro-1H-benz[e]indene (942 mg, 2.71 mmol) in 25 mL of dry tetrahydrofuran and 4 mL of ethanol was added to 65 mL of liquid ammonia at –78°. Lithium (128 mg, 18.3 mmol) was added and the mixture was stirred for 20 minutes. Ethanol (10 mL) was then added dropwise, and the solvent was evaporated. The residue was diluted with water (30 mL), extracted with ether, and then washed with saturated aqueous sodium chloride and evaporated. The residue was dissolved in ethanol (29 mL) and water (3 mL), and this solution was treated with oxalic acid (328 mg, 3.64 mmol) for 3 hours at room temperature. The mixture was neutralized with 10% aqueous sodium hydroxide and the solvent was evaporated. The residue was diluted with water (30 mL) and extracted with ether, and the extract was washed with saturated aqueous sodium chloride. The residue upon workup was chromatographed using hexane–ethyl acetate (4:1) to afford *trans*-3 α , β *-methyl-3-(1-methoxyethoxymethoxyethyl)-2,3,3a,4,5,6,9,9b-octahydro-1H-benz[e]inden-7(6H)-one* (838 mg, 92%) as an oil. ¹H NMR (CCl₄): δ 0.70 (s, 3H), 1.13 (d, 3H), 3.29 (s, 3H), 3.40–3.73 (m, 4H), 4.63 (d, 2H).

5.1.1.6. *2,4-Bis[(methoxycarbonyl)oxy]-17-(methoxycarbonyl)morphinan-6-one (Reduction of a 1-Benzylidihydroisoquinoline followed by Cyclization of the Resulting Enol Ether)* (227)

1-[3,5-Bis(benzyloxy)benzyl]-6-methoxy-3,4-dihydroisoquinoline hydrochloride (75 g, 0.15 mol), 850 mL of tetrahydrofuran, and 850 mL of *tert*-butyl alcohol were placed in a 5-L three-necked flask equipped with a dry ice condenser, a mechanical stirrer, and a stopper. Ammonia (2.2 L) was condensed in, and Li (11.5 g, 1.6 mol) was added in small pieces slowly until a blue color was obtained and maintained for 3 hours. Excess lithium was decomposed by addition of 75 mL of ethanol and ammonium chloride (200 g, large excess) and the ammonia was allowed to evaporate slowly overnight under a slight pressure of nitrogen. The residual solvents were evaporated and ether (1 L) and concentrated HCl (1 L) were added slowly with cooling. The reaction mixture was stirred initially at 25° and then in a bath at 50° for 24 hours. The reaction mixture was filtered, concentrated under reduced pressure to a volume of 1.5 L, and made just basic with KOH (initially solid and then 4 M

aqueous solution). A solution of ClCO_2CH_3 in CH_2Cl_2 was added slowly to the basic reaction mixture until the aqueous layer turned acidic. The mixture was extracted with methylene chloride (1 L). The aqueous layer was made alkaline with 2 M KOH, and it was again treated with $\text{ClCO}_2\text{CH}_3/\text{CH}_2\text{Cl}_2$ until it became acidic. The layers were separated, and the aqueous layer was extracted with CH_2Cl_2 . The combined CH_2Cl_2 layers were stirred with anhydrous K_2CO_3 and ClCO_2CH_3 at room temperature overnight. The reaction mixture was filtered, and the filtrate was extracted with saturated NaHCO_3 , dried over Na_2SO_4 , and concentrated to a brown oil (130 g). Purification by flash chromatography over silica gel [40–63 μm , 900 g, in $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{CN}$ (4:1)] gave 64.5 g (96%) of 2,4-bis[(methoxycarbonyloxy]-17-(methoxycarbonyl)morphinan-6-one as a pale yellow oil, which solidified on standing in the refrigerator. An analytical sample was obtained by recrystallization from *i*-PrOH: mp 133–135°.

5.1.1.7. 2-Methyl-2-cyclohexenone (Reduction of a 2-Alkylpyridine Followed by Hydrolysis and Aldol Condensation) (228)

2-Vinylpyridine (10.5 g, 0.1 mol) and absolute ethanol (36.8 g, 0.8 mol) in 300 mL of anhydrous ether was added quickly to a solution of lithium (3.45 g, 0.5 mol) in 1 L of ammonia. After disappearance of the blue color, the ammonia was evaporated in a stream of nitrogen, and the residue was dissolved in 480 mL of ethanol. A solution of sodium hydroxide (12.0 g) in 240 mL of water was then added, and the resulting system was stirred at room temperature under nitrogen for 2.5 hours. The solution was acidified by the addition of 10% HCl, and the resulting solution was extracted four times with 200-mL portions of ether. The combined ether layers were washed twice with saturated NaHCO_3 , once with saturated brine, and then dried over anhydrous sodium sulfate. Evaporation of the solvent followed by distillation of the residue afforded 6.97 g (63%) of 2-methyl-2-cyclohexenone, bp 61–62° (10 mm).

5.1.1.8. 2-(Phenoxyethyl)-4-isopropylcyclohexenone (Reductive Alkylation of an Anisic Acid Followed by Hydrolysis) (135)

Ammonia (400 mL) was distilled into a solution of 2-methoxy-5-isopropylbenzoic acid (19.5 g, 0.1 mol) in 100 mL of tetrahydrofuran at -78° . Lithium was added in pieces until a deep blue color persisted. β -Bromophenetole (110 mmol, 22.1 g) in 50 mL of tetrahydrofuran with 1 mL of dibromoethane was added immediately in one portion, and after stirring briefly, the cooling bath was removed allowing the ammonia to evaporate under a stream of nitrogen. 1,2-Dichloroethane (100 mL) and water (100 mL) were then added, and the two-phase mixture was refluxed for 2 hours. The organic layer was separated and the aqueous layer extracted twice with methylene chloride. The combined organic phase was dried over K_2CO_3 , concentrated in vacuo, and distilled through a short-path apparatus to give 14.2 g (55%) of 2-(phenoxyethyl)-4-isopropylcyclohexenone as a colorless oil, bp 155–170° (0.4 mm).

5.1.1.9. *1-Acetyl-1-methylcyclohexa-2,5-diene (Reductive Alkylation of a Monoaromatic Ketone. Exchange of the Potassium Counterion of the Enolate for Lithium Prior to Alkylation)* (83)

A solution of acetophenone (5.2 g, 43 mmol) and *tert*-butyl alcohol (52 mmol) in 20 mL of tetrahydrofuran was added to 140 mL of anhydrous ammonia at -78° . Potassium (3.7 g, 95 mmol) was added in pieces over 1–5 minutes, and stirring was continued for an additional 10 minutes. Anhydrous lithium bromide (95 mmol) was then added, and the mixture was stirred at -78° for 40 minutes. The ammonia was then evaporated over several hours and the resulting paste was methylated by the addition of methyl iodide (13.5 g, 95 mmol) with stirring at $0-10^{\circ}$ for 40 minutes. Salt solution was added followed by extraction with ether. Further washing followed by drying over sodium sulfate, evaporation, and distillation, gave pure 1-acetyl-1-methylcyclohexa-2,5-diene (4.8 g, 80%), bp 72.2° (18 mm).

5.1.1.10. *2-Methoxy-1-methylcyclohexa-2,5-diene-1-carboxylic Acid (Addition of Potassium *tert*-Butoxide prior to Reduction to Suppress Overreduction and Loss of a Methoxy Group)* (134)

Potassium *tert*-butoxide (5.6 g, 0.05 mol) was added to a stirred solution of 2-methoxybenzoic acid (7.6 g, 0.05 mol) in dry tetrahydrofuran (50 mL), followed by *tert*-butyl alcohol (4.0 mL, 0.05 mol) and liquid ammonia. The mixture was cooled to -70° , and potassium metal (4.89 g, 0.125 mol) was added in small pieces until a deep blue color persisted for more than 5 minutes. The color was discharged by the addition of a drop of 1,3-pentadiene, then a solution of methyl iodide (15.5 mL, 0.25 mol) in tetrahydrofuran (50 mL) was added. The ammonia was removed in a stream of N_2 , and 200 mL of sodium chloride solution was added. The product was extracted with methylene chloride while the pH of the mixture was progressively reduced to 4 by the addition of 1 M HCl. Drying (Na_2SO_4), evaporation of solvent, and distillation gave 2-methoxy-1-methylcyclohexa-2,5-diene-1-carboxylic acid (4.6 g, 84%) as a homogeneous colorless gum. 1H NMR: δ 1.24 (s, 3H), 2.80 (brs, 2H), 3.52 (s, 3H), 4.81 (t, 1H), 5.64–5.83 (m, 2H).

5.1.1.11. *Ethyl 1,4-Dihydrobenzoate (Reduction of an Aromatic Carboxylic Acid Ester Containing 1.25 Equivalent of Water)* (229)

Ethyl benzoate (7 g, 46 mmol) and water (1.2 mL, 69 mmol) were dissolved in 75 mL of tetrahydrofuran and added to 150 mL of anhydrous ammonia under inert gas at -78° . Sodium metal 2.67 g, 116 mmol) was then added in pieces and the reaction was stirred for 25 minutes. The mixture was then pumped through a glass tube into a large excess of NH_4Cl solution, and the product was separated by ether partition. Microdistillation afforded ethyl 1,4-dihydrobenzoate (64%) as a colorless oil: bp $54-56^{\circ}$ (0.35 mm).

5.1.1.12. (2'S,
6R)-1-Methoxy-6-methyl-6-([2 ϕ -(methoxymethyl)pyrrolidinyl]carbonyl)-1,4-cycl
ohexadiene (Reductive Alkylation of a Chiral Benzamide) (39)

A solution of 1-([2S)-methoxymethylpyrrolidinyl]carbonyl)-2-methoxybenzene (0.25 g, 1.0 mmol) in dry tetrahydrofuran (5 mL) and *tert*-butyl alcohol (74 mg, 1.0 mmol) was cooled to -78° , and anhydrous ammonia (60 mL) was added to the reaction mixture. Potassium (86 mg, 2.2 mmol) was added to the stirred solution in small pieces. Methyl iodide (0.28 g, 2 mmol) was added, and resulting yellow solution was stirred for 1 hour at -78° . After addition of NH_4Cl (~0.5 g), the mixture was warmed slowly while the ammonia was removed with a stream of nitrogen. Brine (~20 mL) was added, and the mixture was extracted with chloroform (3 \times 20 mL). The combined organic extracts were washed with 10% sodium thiosulfate (20 mL), water (20 mL), and brine (20 mL), and then dried over anhydrous magnesium sulfate. Evaporation of solvents provided the crude product as a 260:1 mixture of diastereomers (GC analysis). Flash chromatography (silica gel, ethyl acetate–hexane, 3:2) gave (2'S,

6R)-1-methoxy-6-methyl-6-([2'-(methoxymethyl)pyrrolidinyl]carbonyl)]-1,4-cycl
ohexadiene (0.23 g, 85%) as a colorless oil. ^1H NMR (CDCl_3): δ 1.42 (s, 3H), 1.68–2.00 (m, 4H), 2.73–3.01 (m, 2H), 3.22–3.38 (m, 5H), 3.53 (s, 3H), 3.60–3.68 (m, 2H), 4.32 (m, 1H), 4.67 (t, 1H), 5.53 (dt, 1H), 5.77 (m, 1H).

6. Tabular Survey

The computer search of *Chemical Abstracts* covers the literature to the end of 1988, although some later papers as well as those that appeared to mid-1989 have also been included. About 40 compounds reported in patents without indication of experimental condition are not included in the tables. Tables I to VII contain examples of reduction of aromatic compounds according to their functionality. A similar division is followed for Tables VIII to XII covering reductive alkylation reactions. All compounds which contain heteroatoms in a ring (not necessarily in the aromatic ring) are treated as aromatic heterocycles. Table XIII contains examples of reduction (or reductive alkylation) of aromatic amines, alcohols, acetals, phosphines, and nitriles which were sporadically reported in the literature. Within each table the compounds are listed according to increasing carbon atom numbers using the *Chemical Abstracts* convention. Carbon atom(s) and hydrogens of R in the ester group CO₂R as well as benzyl (OBn), methanesulfonyl (OMs), tetrahydropyranyl (OTHP), or acetyl (OAc) groups which undergo hydrolysis during reduction are not counted. The reaction condition columns include the type of metal (number given in parentheses represents molar equiv. of metal per 1 mol of aromatic reactant, if reported), solvent, reaction time, and temperature (°C) if provided in references. The reaction temperature is given only if it differs from the reflux temperature of ammonia (−33°). The notation M/ NH₃ indicates that the substrate was added to the metal–ammonia solution, while NH₃/M means that the metal was added last. In the quenching agent column, other reactants are also given that are required to convert the primary reduction product into the one actually isolated. Alkylating agents are listed according to increasing carbon atom numbers. Yields are given in parentheses and are based on either isolation or GC analyses (marked with asterisk). A dash (—) indicates that no yield information was reported. In some cases, yields have been calculated by the authors from the literature data. Numbers not in parentheses are the product ratios. When a reaction has been reported in more than one publication, the conditions producing the highest yields are given, and the reference to that paper is listed first.

The following abbreviations are used in the tables:

Ac	acetyl
Am	amyl
Bn	benzyl
Bu	butyl
DME	1,2-dimethoxyethane
DMF	<i>N,N</i> -dimethylformamide

DMSO	dimethyl sulfoxide
equiv	equivalent
Et	ethyl
HMPA	hexamethylphosphoric triamide
LDA	lithium diisopropylamide
M	metal
Me	methyl
MEM	methoxyethoxymethyl
Ms	methanesulfonyl
Ph	phenyl
Pr	propyl
THF	tetrahydrofuran
THP	tetrahydropyran-2-yl
TMEDA	<i>N,N,N',N'</i> -tetramethyl-ethylenediamine
Ts	<i>p</i> -toluenesulfonyl

Table I. Reduction of Aromatic Hydrocarbons

[View PDF](#)

Table II. Reduction of Aromatic Ethers

[View PDF](#)

Table III. Reduction of Aromatic Silanes

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Table IV. Reduction of Aromatic Ketones

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Table V. Reduction of Aromatic Carboxylic Acids and Derivatives

[View PDF](#)

Table VI. Reduction of Aromatic Heterocycles

[View PDF](#)

Table VII. Reduction of Bifunctional Aromatic Compounds

[View PDF](#)

Table VIII. Reductive Alkylation of Aromatic Hydrocarbons

[View PDF](#)

Table IX. Reductive Alkylation of Aromatic Ketones

[View PDF](#)

Table X. Reductive Alkylation of Aromatic Carboxylic Acids and Derivatives

[View PDF](#)

Table XI. Reductive Alkylation of Aromatic Heterocycles

[View PDF](#)

Table XII. Reductive Alkylation of Bifunctional Aromatic Compounds

[View PDF](#)

Table XIII. Miscellaneous Reductions and Reductive Alkylation of Aromatic Compounds

[View PDF](#)

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS

A. Monocyclic Aromatics




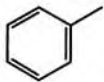
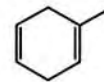
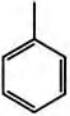
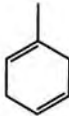
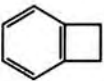
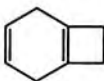
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C ₇ 	NH ₃ /Li(2.5), EtOH, Et ₂ O	—	 +  + (PhCH ₂) ₂ III I:II:III = 62:28:10	232
	NH ₃ /Li(2), Et ₂ O	<i>i</i> -PrOH	 (88*)	233, 234
C ₈ 	NH ₃ /Li (2.9), <i>i</i> -PrOH, THF, 2 h	NH ₄ Cl	 (98)	235

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

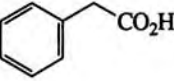
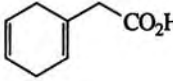
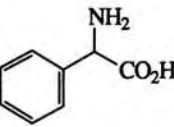
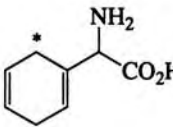


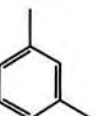
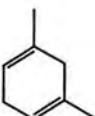
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	NH ₃ /Na, MeOH, 1.5 h	"	 (—)	236
	NH ₃ /Li (4.3), T ₂ O, EtOH, -50°, 15 min	MeOH	 (—) *Denotes position of T	237
	NH ₃ /Na (3), EtOH, Et ₂ O, 5 h, -78°	H ₂ O	 (77-92)	223, 233
	NH ₃ /Li (6), Et ₂ O	EtOH	 (91.7*)	233

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

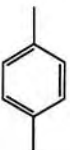
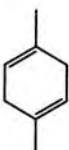
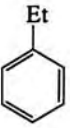
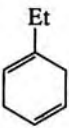
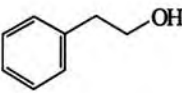
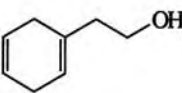
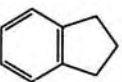
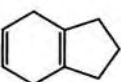
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	NH ₃ /Na (4), EtOH, Et ₂ O	H ₂ O	 (95*)	238, 233
	NH ₃ /Na (3), EtOH, Et ₂ O, 5 h, -78°	"	 (—)	239
C ₉ 	NH ₃ /Na, MeOH	—	 (—)	240

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

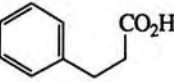
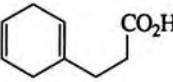
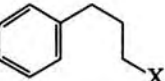
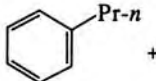
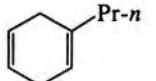
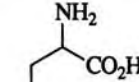
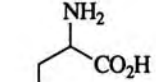
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, MeOH, -78°, 3 h	MeOH, NH ₄ Cl	 I + starting material II I:II = 6:4	241
 X = Cl, I	NH ₃ /Li (2.2), Et ₂ O, -78°, 2 h	EtOH	 I +  II I:II = 9:1	242
	NH ₃ /Na, MeOH, 1.5 h	NH ₄ Cl	 (—)	243

TABLE I. Reduction of Aromatic Hydrocarbons (*Continued*)

A. Monocyclic Aromatics

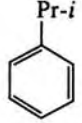
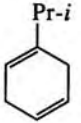
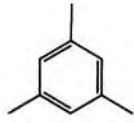
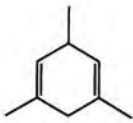
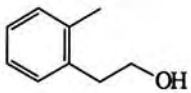
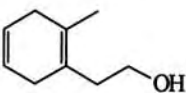
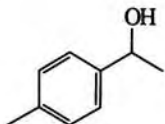
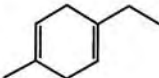
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), EtOH, Et ₂ O, 2.5 h	H ₂ O	 (92*)	238, 233
	NH ₃ /Li (2), Et ₂ O	EtOH	 (80.3*) + starting material (14.9*)	233
	NH ₃ /Li, <i>t</i> -BuOH, THF, -45°, 5 h	NH ₄ Cl	 (89)	244
	Na/NH ₃ , EtOH, Et ₂ O	"	 (80)	245

TABLE I. Reduction of Aromatic Hydrocarbons (*Continued*)

A. Monocyclic Aromatics

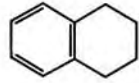
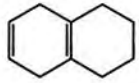
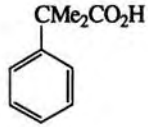
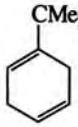
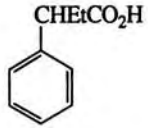
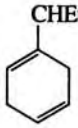
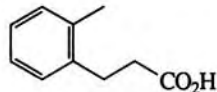
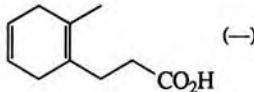
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na/NH ₃ , EtOH	H ₂ O	 (—)	2a, 246
	NH ₃ /Na, MeOH	NH ₄ Cl	 (—)	236
	"	"	 (—)	236
	NH ₃ /Li, EtOH	"	 (—)	247

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

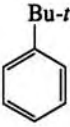
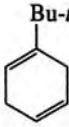
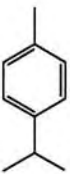
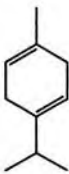
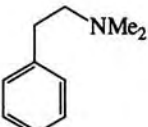
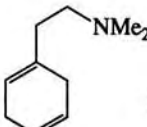
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), EtOH, Et ₂ O	H ₂ O	 (86*)	238, 233
	Na/NH ₃ , EtOH	"	 (—)	2a
	Na/NH ₃ , EtOH	—	 (—)	248

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

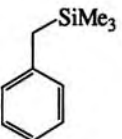
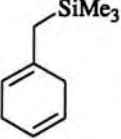
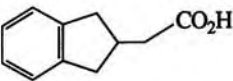
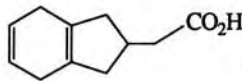
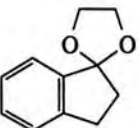
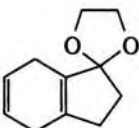
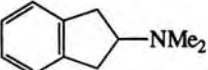
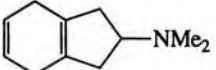
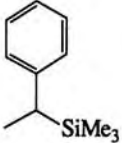
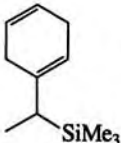
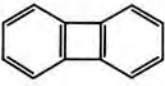
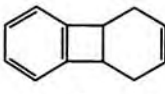
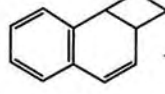
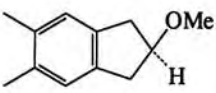
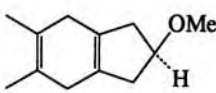
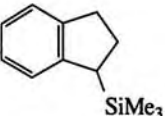
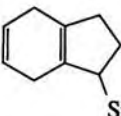
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3.3), EtOH	H ₂ O	 (68, 90*)	249
^{C11} 	NH ₃ /Li, 1 h	EtOH	 (ca 100)	250
	NH ₃ /Na (5.6), MeOH	H ₂ O	 (80)	251
	NH ₃ /Li, 1 h	EtOH	 (94*)	250

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

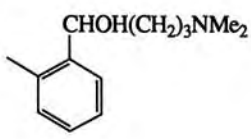
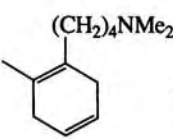
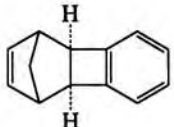
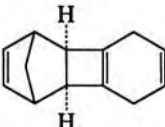
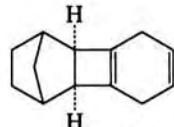
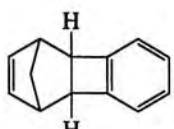
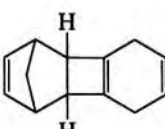
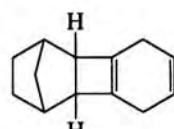
A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, Et ₂ O, 2 h	NH ₄ Cl	 (67)	252
C ₁₂ 	NH ₃ /Na (3), Et ₂ O, 15 min	EtOH	 +  + starting material III I:II:III = 4:1:11	253
	NH ₃ /Li, Et ₂ O	MeOH	 (88)	254
	NH ₃ /Li (7), <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl	 (70)	252

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₃ 	Na/NH ₃ , EtOH	—	 (87)	255
	Li (4.5)/NH ₃ , <i>t</i> -BuOH, THF, 4.5 h	NH ₄ Cl	 (53*) +  (47*)	256, 257
	"	"	 (71.4*) +  (28.6*)	256

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (2.5) NH ₃ , <i>t</i> -BuOH, THF	"	(-)	43
	NH ₃ /Li, Et ₂ O	MeOH	(87)	254, 251
	NH ₃ /Li, EtOH, THF	—	(80)	258

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

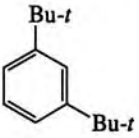
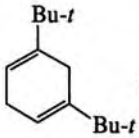
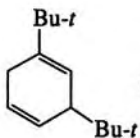
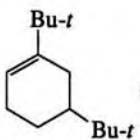
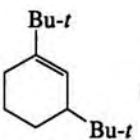
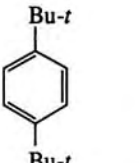
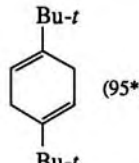
A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF, 2 h	NH ₄ Cl	(100)	252
	Li/NH ₃ , 15 min	EtOH, NH ₄ Cl	(95)	259
	NH ₃ /Li, <i>i</i> -PrOH, THF, 50 min	H ₂ O	 I:II = 9:2	260

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)



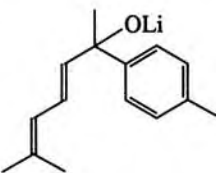
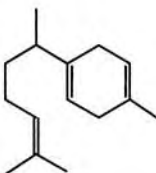
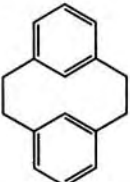
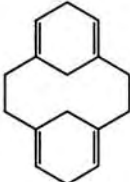
A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	MeOH	 (45*) +  (9*) +  (20*) +  (1*) + starting material (25*)	261
	"	"	 (95*)	262

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

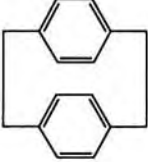
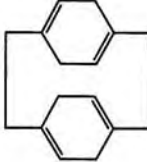
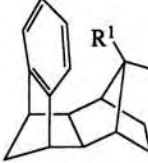

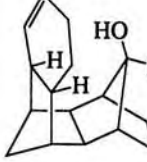
A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF, 3 h	NH ₄ Cl	 (83)	252
C15 	Li/NH ₃ , 15 min	EtOH, NH ₄ Cl	 (94)	259
C16 	NH ₃ /Na, EtOH, THF, -78°, 2 h	—	 (50)	263

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

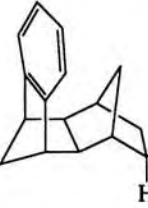
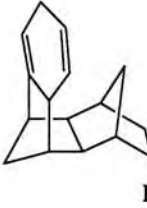
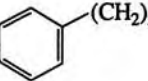
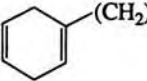
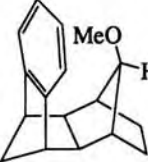
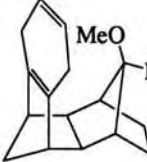
A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, EtOH, THF, 2 h	H ₂ O	 (93)	264, 265
 R ¹ , R ² = H	Li/NH ₃ , <i>t</i> -BuOH, THF, 7 h	NH ₄ Cl	 (—)	43, 266
R ¹ = OH, R ² = H	Li/NH ₃ , <i>t</i> -BuOH, THF, 10 min	"	 (ca 100)	43, 266
R ¹ = OAc, R ² = H	"	"	" (ca 100)	43, 266

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (ca 100)	43
^{C17} 	NH ₃ /Li (10), <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl	 (—)	267
	Li (2) NH ₃ , <i>t</i> -BuOH, THF, 5 h	"	 (4*)	43

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₈ 	Li (5)/NH ₃ , <i>t</i> -BuOH, THF, 3 h	NH ₄ Cl	 I + II	268
X-X = CH=CH	"	"	I:II = 20:1	
X-X = CH ₂ CH ₂	"	"	II (ca 100)	
	"	"	 I + II	268
X-X = CH=CH	"	"	I:II = 19.5:1	
X-X = CH ₂ CH ₂	"	"	II (ca 100)	

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₉ 	NH ₃ /Li (10), <i>t</i> -BuOH, THF, 2 h	"	 (-)	267
C ₂₀ 	NH ₃ /Li (3.5), THF, 20 min	ROH	 + (27*) (55*) (23*) (53*) (18*) (33*) (16*) (22*) (10*) (9*)	187
"	"	<i>t</i> -BuOH	(27*) (55*)	
"	"	<i>i</i> -PrOH	(23*) (53*)	
"	"	EtOH	(18*) (33*)	
"	"	CF ₃ CH ₂ OH	(16*) (22*)	
"	"	(CF ₃) ₂ CHOH	(10*) (9*)	

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

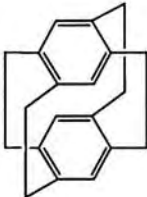
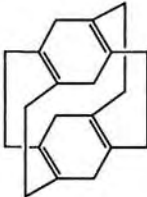
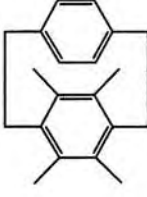
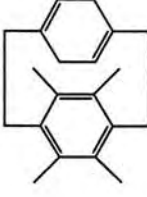
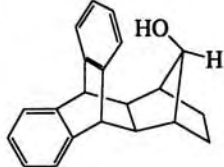
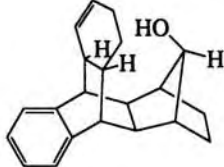
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, THF, 1 h	EtOH	 (ca 100)	269
	Na (3.25)/NH ₃ , <i>t</i> -BuOH, 20 min	H ₂ O	 (80)	270
C ₂₁ 	Li (4)/NH ₃ , <i>t</i> -BuOH, THF	NH ₄ Cl	 (ca 100)	43

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

A. Monocyclic Aromatics

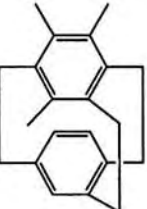
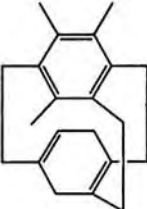
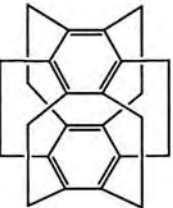
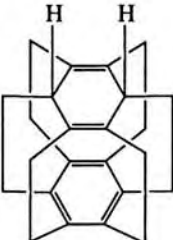
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na (3.58)/NH ₃ , <i>t</i> -BuOH, THF, 40 min	EtOH	 (85)	271
C ₂₄ 	Li/NH ₃ , MeOH THF, 4.5 h	H ₂ O	 (10)	272

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS

B. Polycyclic Hydrocarbons

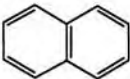
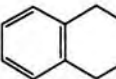
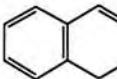
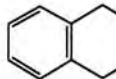
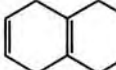
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₀ 	Na or Li (2)/NH ₃ , Et ₂ O, 3 h	NH ₄ Cl	 +  +  + oligomeric compounds (20-70*)	190, 273
	NH ₃ /Li (2.5), THF, -78°, 15 min	NH ₄ Cl ^a	I (94*) + III (3*)	274
	NH ₃ /Li (2.5), THF, 30 min; FeCl ₃ , 45 min ^b	"	II (98*) + III (1*)	274
	NH ₃ /Li (5), THF, 30 min	"	II (1*) + III (98*)	274
	NH ₃ /Na, EtOH, Et ₂ O	H ₂ O	 (62)	275

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

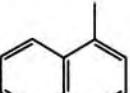
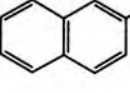
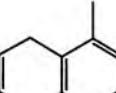
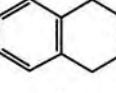
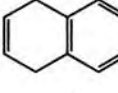
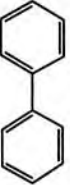




Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₁  	Li/NH ₃ , Et ₂ O, 3 h	H ₂ O	 (96*)	276, 277
	NH ₃ /Li (3), THF, -78°, 30 min	NH ₄ Cl ^a	 +  I:II = 3:1	29, 278
C ₁₂ 	NH ₃ /Li (2.2), THF, 15 min		 +  +  + 	279, 280
	"	MeOH	I (57*) + II (22*) + III (5*) + IV (13*)	
	"	NH ₄ Cl	I (100*)	
	NH ₃ /Li (2.2), <i>t</i> -BuOH, 15 min	H ₂ O	I (30.5*) + II (15*) + III (18*) + IV (16.5)	

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

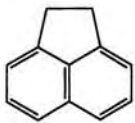
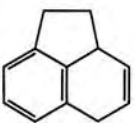
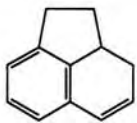
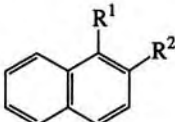
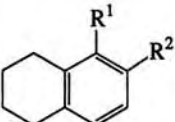
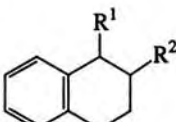
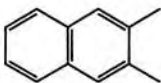
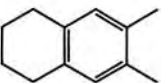
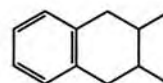
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na (2.35)/NH ₃ , Et ₂ O, -70°, 3 h	NH ₄ Cl	 (–) +  (–)	281
	Li/NH ₃ , Et ₂ O, 3 h	H ₂ O	 I +  II	276
R ¹ = Et; R ² = H	"	"	I (95*) + II (5*)	
R ¹ = H; R ² = Et	"	H ₂ O, H ₂ , 10% Pd/C	I (51*) + II (49*)	
	"	"	 (30*) +  (70*)	276

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

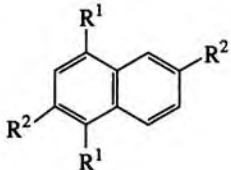
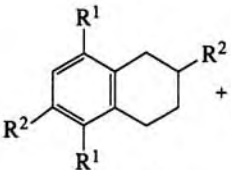
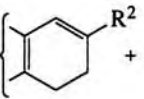
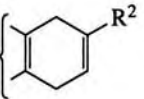
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
			 I +  II +  III	274
R ¹ = Me; R ² = H	NH ₃ /Li (7.6), THF, 2.5 h	NH ₄ Cl ^a	I (95*) + II (1*) + III (4*)	
	NH ₃ /Li (2.5), THF, -78°, 20 min	"	I (2*) + II (1*) + III (93*)	
	" ; FeCl ₃ , 2.5 h ^b	"	I (4*) + II (82*) + III (11*)	
R ¹ = H; R ² = Me	NH ₃ /Li (10), THF, 2.5 h	"	I (94*) + III (5*)	
	NH ₃ /Li (2.5), THF, -78°, 20 min	"	I (8*) + III (91*)	
	" ; FeCl ₃ , 2.5 h ^b	"	I (8*) + II (86*) + III (2*)	

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

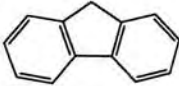
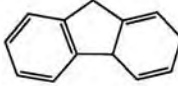
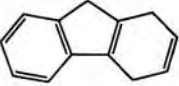
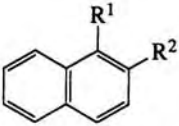
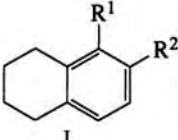
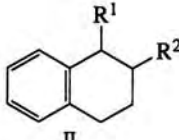
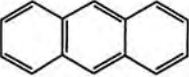
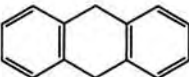
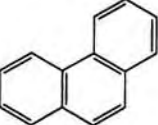
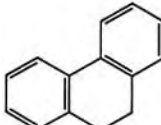
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₃ 	NH ₃ /Li (2.2), Et ₂ O, -78°, 5 min	NH ₄ Cl	 (39*) +  (37*) + starting material (11*)	282
 R ¹ = <i>i</i> -Pr; R ² = H R ¹ = H; R ² = <i>i</i> -Pr	Li/NH ₃ , Et ₂ O, 3 h " "	H ₂ O " H ₂ O; H ₂ , 10% Pd/C	 I +  II I (95*) + II (5*) I (54*) + II (45*)	276
C ₁₄ 	NH ₃ /Li (2.5), THF, FeCl ₃ , 2 h	EtOH	 (100)	51
	NH ₃ /Li (3.5), THF, FeCl ₃ , 1 h	H ₂ O	 (80*)	38, 5

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

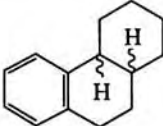
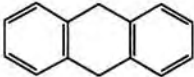
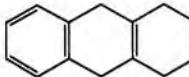
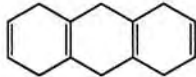
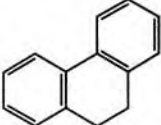
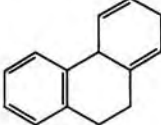
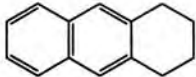
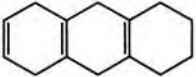
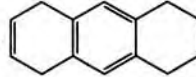
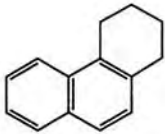
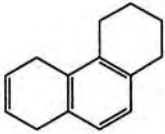
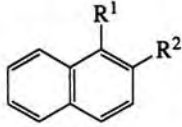
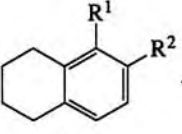
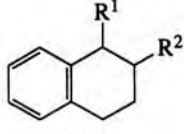
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
"	NH ₃ /Na, EtOH, THF	NH ₄ Cl	 (78.2) ^c	283
	NH ₃ /Li (2.5), THF, 2 h NH ₃ /Li (6), EtOH, THF, -70°	EtOH H ₂ O	 I +  II I (76*) + II (9*) I (8*) + II (80*)	50
	NH ₃ /Li (2.5), THF, FeCl ₃ , 2 h	H ₂ O	 (62*) + starting material (23*)	38

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

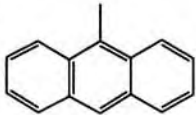
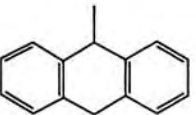
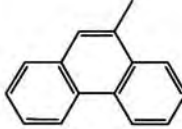
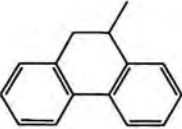
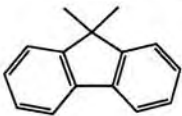
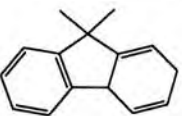
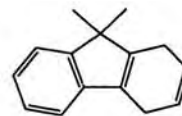
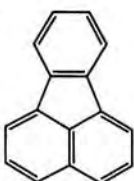
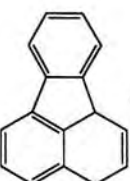
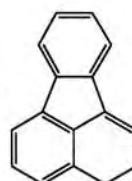
B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, <i>t</i> -BuOH, THF, -70°	NH ₄ Cl	 (34) +  (—)	284
	NH ₃ /Na (5), EtOH, THF	"	 (62)	285
	Li/NH ₃ , Et ₂ O, 2 h	H ₂ O	 I +  II	276
R ¹ = <i>t</i> -Bu; R ² = H	"	"	I (84*) + II (16*)	
R ¹ = H; R ² = <i>t</i> -Bu	"	H ₂ O; H ₂ , 10% Pd/C	I (68*) + II (32*)	

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₅ 	Li (2.5)/NH ₃ , THF, 1 h	EtOH, H ₂ O	 (78)	286
	NH ₃ /Li (5), THF, FeCl ₃ , 3 h	"	 (82)	38
	NH ₃ /Li (2.5), THF	NH ₄ Cl	 (60*) +  (25*) + starting material (4*)	282
C ₁₆ 	NH ₃ /Li (2.2), Et ₂ O, 10 min	"	 (84*) +  (12*)	287

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na (2)/NH ₃ , DME, 1 h	MeOH	(30-52)	189
	NH ₃ /Li (2), THF, 10 min	NH ₄ Cl	(94*)	288
	NH ₃ /Na (3.5), THF, -78°, 30 min	"	(37)	289

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

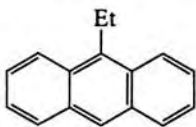
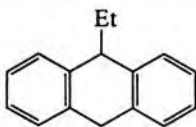
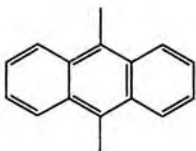
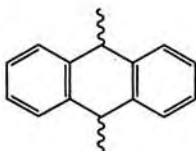
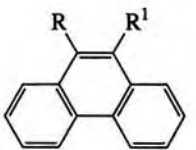

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), THF, -78°	NH ₄ Cl ^a	I + II + III	31, 290
	NH ₃ /Li (2.5), THF, -78°	"	I (31*) + III (69*)	
	NH ₃ /Li (2.5), THF, -78°	"	I (34*) + II (58*) + III (17*)	
	NH ₃ /Li (10), THF	"	I + II	31, 290
	NH ₃ /Li (10), THF, -78°	"	I (2*) + II (98*)	
	NH ₃ /Li (10), THF, -78°	"	I (31*) + II (66*)	
	NH ₃ /Na, THF, 45 min	NH ₄ Cl	(33)	291, 289

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

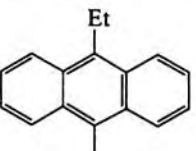
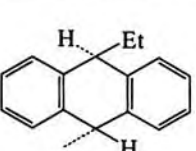
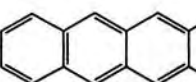
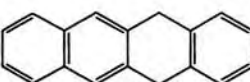
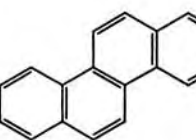
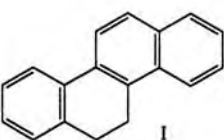
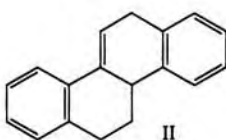
B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (2.5)/NH ₃ , THF, 1 h	EtOH, H ₂ O	 (87)	286
	"	"	 (→) <i>cis/trans</i> = 52/48	286
 R, R ¹ = Me R = H; R ¹ = Et	NH ₃ /Li (3.5), THF, FeCl ₃ , 3 h	H ₂ O	 I I (72*) I (86*)	38

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C17 	Li (1.5)/NH ₃ , THF, 1 h	EtOH, H ₂ O	 (→)	286
C18 	NH ₃ /Li (2.5), THF, FeCl ₃ , 2 h	EtOH, H ₂ O	 (80)	286
	NH ₃ /Na (2.5), THF, 20 min NH ₃ /Na (8), THF, FeCl ₃ , 20 min	NH ₄ Cl "	 I +  II 292 I (82*) + II (9*) I (15*) + II (80*)	

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons






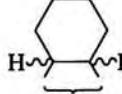
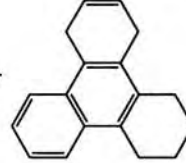
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, -78°, 30 min	NH ₄ Cl ^a	 (67)	293
	NH ₃ /Li (5), THF, -78°, 30 min	"	I (47) +  (13) +  (3)	293
			+  (2) +  (14) +  (9)	

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

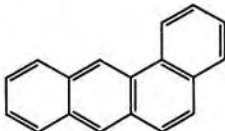
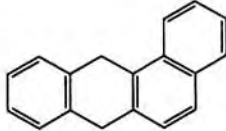
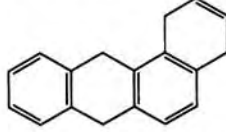
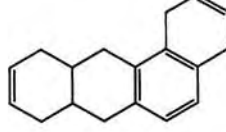
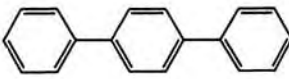
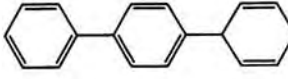
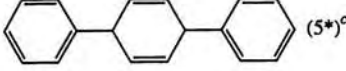


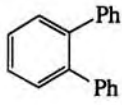
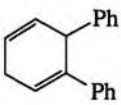
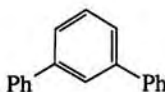
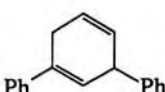
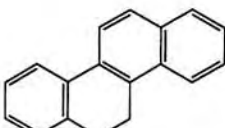
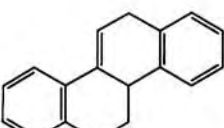
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, FeCl ₃ , 2 h	EtOH	 (94)	225
	NH ₃ /Li (5), THF, 2 h	"	 (66)	225, 294
	NH ₃ /Li (7-10), THF, 2 h	"	 (82)	225
	NH ₃ /Li (2.2), 30 min	H ₂ O ^d	 (87*) +  (5*) ^c	295

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

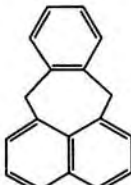
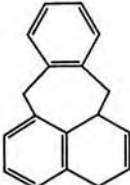
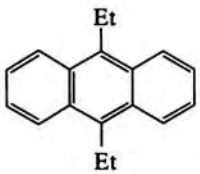
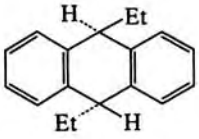
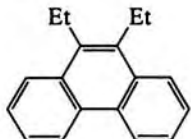
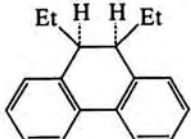
B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (7.5), 30 min	H ₂ O	 (30-40*)	295
	NH ₃ /Li (2.2), THF, 30 min	"	 (98*)	295
	"	"	 (ca 100)	295
	NH ₃ /Li (3.5), THF, FeCl ₃ , 1 h	H ₂ O	 (ca 100)	292

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), THF, -78°, 20 min	NH ₄ Cl ^a	 (80)	296
	Li (2.5)/NH ₃ , THF, 1 h	EtOH, H ₂ O	 (100)	286
	NH ₃ /Li (3.5), THF, FeCl ₃ , 3 h	H ₂ O	 (61*) + starting material (21*)	38

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

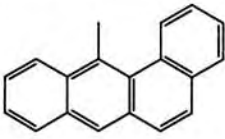
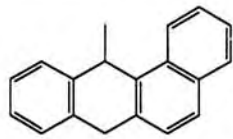
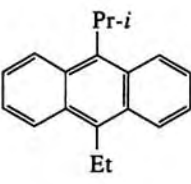
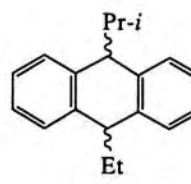
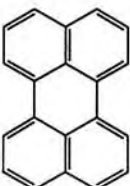
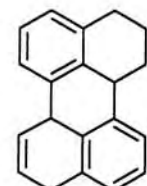


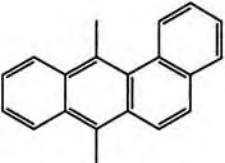
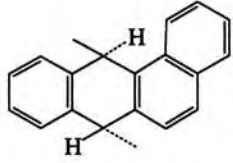
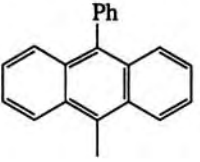
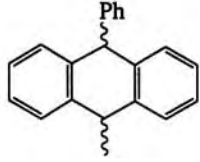
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₉ 	NH ₃ /Li (2.5), THF, FeCl ₃ , 2 h	EtOH, H ₂ O	 (80*) + starting material (20*)	286
	NH ₃ /Li (2.2), THF, 30 min	NH ₄ Cl	 (97*) <i>cis/trans</i> = 74/26	35
C ₂₀ 	NH ₃ /Li (10), THF, 30 min	NH ₄ Cl ^a	 (85*)	31

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (10), <i>t</i> -BuOH, 30 min	"	 (90*)	31, 297
	NH ₃ /Li (4), THF, 2 h	EtOH, H ₂ O	 (61)	286
C ₂₁ 	NH ₃ /Na (2.5), THF, -78°, 30 min	NH ₄ Cl	 (-) <i>cis/trans</i> = 20/80	28

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TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

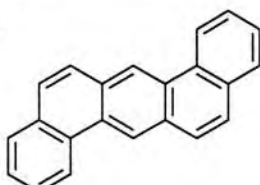
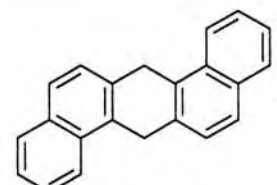
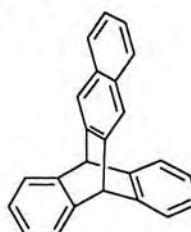
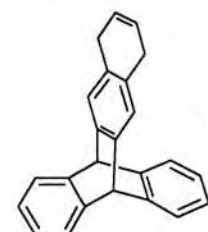
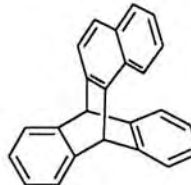
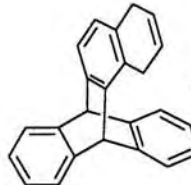
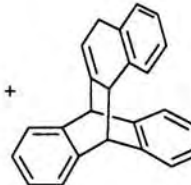
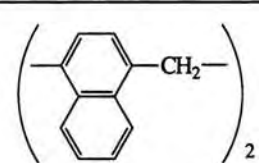
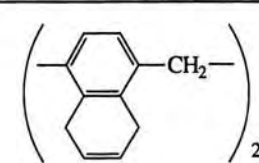
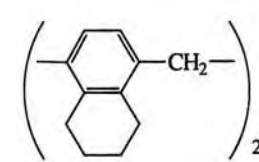
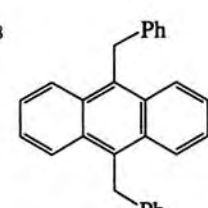
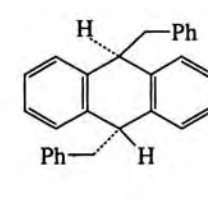
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₂₂ 	NH ₃ /Li, THF, FeCl ₃ , 2 h	EtOH, H ₂ O	 (92)	286
C ₂₄ 	NH ₃ /Li (2.2), THF, 20 min	<i>t</i> -BuOH	 (—)	187
	NH ₃ /Na, THF, -78°, 20 min	"	 (40) +  (—)	187

TABLE I. REDUCTION OF AROMATIC HYDROCARBONS (Continued)

B. Polycyclic Hydrocarbons

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), THF, -78°, 30 min	NH ₄ Cl ^a	 (85)	298
	NH ₃ /Na (10), THF, 30 min	"	 (80*)	188
C ₂₈ 	Li (2.5)/NH ₃ , THF, 1 h	EtOH, H ₂ O	 (ca 100)	286

^a The reaction mixture was pumped (with argon pressure) through a glass tube into a large excess of saturated ammonium chloride solution.

^b After stirring the reaction mixture for 20-30 min a trace of FeCl₃ was added and the temperature allowed to increase from -78° to reflux (ca -33°) for the time indicated.

^c The yield represents a mixture of *cis* and *trans* isomers.

^d A solution of water (6 mmol) in THF (76 mL) was added over 10 min (half quench) to the product of lithium-*p*-terphenyl interaction (without cosolvent), followed by addition of excess of solid NH₄Cl.

TABLE II. REDUCTION OF AROMATIC ETHERS

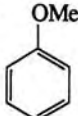
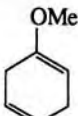
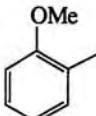
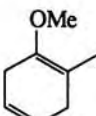
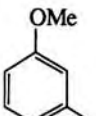
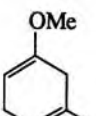
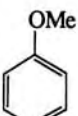
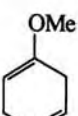
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C7 	NH ₃ /Li (3.6), <i>t</i> -BuOH, THF, 1 h	MeOH	 (75)	299, 4
C8 	Li (4)/NH ₃ , <i>t</i> -BuOH, THF, 25 min	<i>t</i> -BuOH, H ₂ O	 (65)	300, 301
	NH ₃ /Li (4), <i>t</i> -BuOH, THF	MeOH	 (80)	302, 303
	NH ₃ /Li (4), EtOH, 30 min	NH ₄ Cl	 (91)	304, 305

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

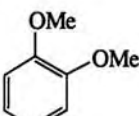
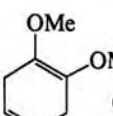
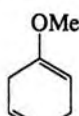
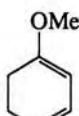
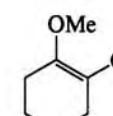
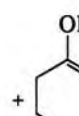
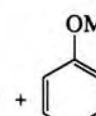
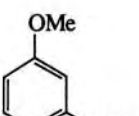
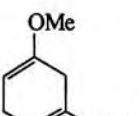
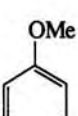
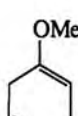
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, EtOH, 4 h	MeOH	 (19*) +  (37*) +  (3*) +  (24*) +  (9*) +  (7*)	306
	NH ₃ /Li, Et ₂ O	EtOH	 (55-76)	303, 307
	"	"	 (55-76)	303, 307

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

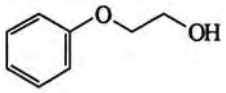
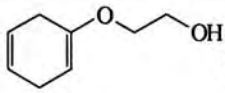
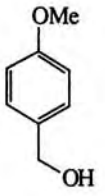
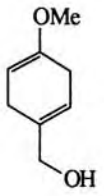
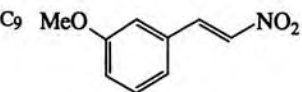
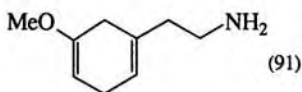
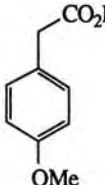
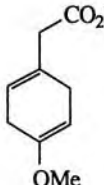
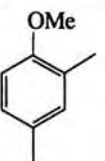
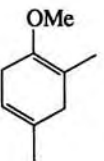
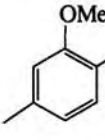
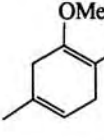
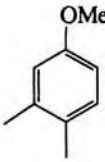
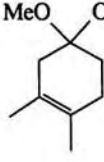
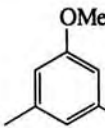
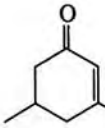
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (73)	308
	NH ₃ /Na (4.4), EtOH, THF	NH ₄ Cl	 (81)	309, 310
^{C9} 	Li/NH ₃ , <i>t</i> -BuOH, THF, -63°	MeOH	 (91)	311
	NH ₃ /Li, <i>t</i> -BuOH, 10 h	"	 (80)	312

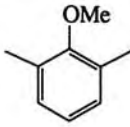
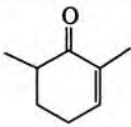


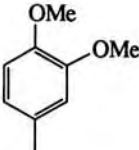
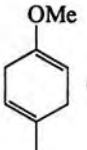
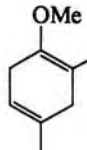
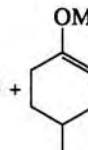
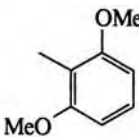
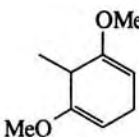
TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, 2 h	NH ₄ Cl	 (69)	313
	Li (6.5)/NH ₃ , <i>t</i> -BuOH, NH ₃ , 20 min	<i>t</i> -BuOH	 (83)	300
	NH ₃ /Li, EtOH, Et ₂ O, 45 min	NH ₄ Cl, MeOH- TsOH (reflux 8 h)	 (87)	314, 315
	Na/NH ₃ , MeOH	H ₂ O, H ₃ O ⁺	 (16)	2a, 316

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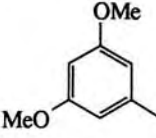
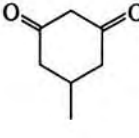
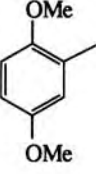
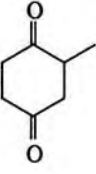
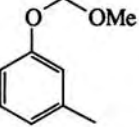
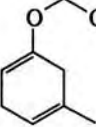
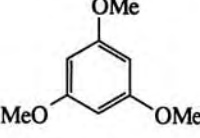
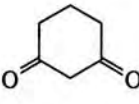
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (10)	2a
	NH ₃ /Na (3), EtOH, THF	NH ₄ Cl	 (ca 100)	317, 318
	NH ₃ /Na, EtOH, 4 h	MeOH	 (25*) +  (57*) +  (6.6*)	306
	NH ₃ /Li, <i>t</i> -BuOH, THF, 15 h	"	 (86)	319, 320

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, 2.5 h	MeOH, H ₃ O ⁺	 (73)	321, 322
	NH ₃ /Na (6), EtOH	NH ₄ Cl, H ₃ O ⁺	 (60)	323, 324
	NH ₃ /Li, THF, <i>t</i> -BuOH	—	 (—)	92
	NH ₃ /Na, EtOH	NH ₄ Cl, H ₃ O ⁺	 (—)	128

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

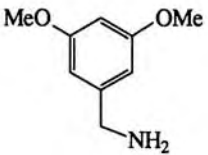
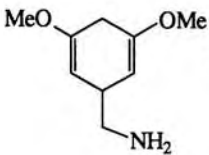
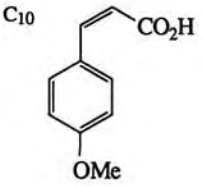
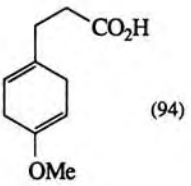
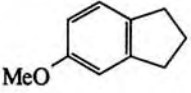
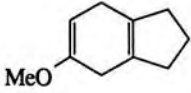
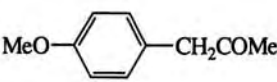
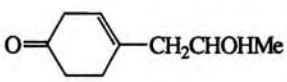
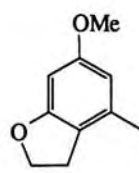
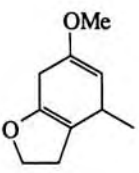
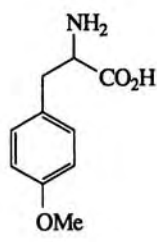
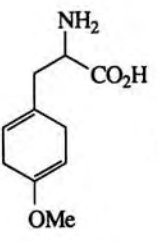
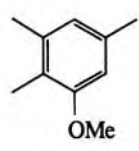
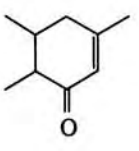
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, 2 h	NH ₄ Cl	 (78, 95*)	156
	NH ₃ /Li, <i>t</i> -BuOH, 5 h	NH ₄ Cl	 (94)	325, 326
	NH ₃ /Li (5), DME, 20 min	EtOH	 (93)	327, 328
	NH ₃ /Li, <i>t</i> -BuOH, THF, 2.5 h	MeOH, H ₃ O ⁺	 (70)	48

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , H ₂ O	—	 (—)	329
	NH ₃ /Na, <i>t</i> -BuOH	NH ₄ Cl	 (90)	330
	Na/NH ₃ , EtOH	EtOH, H ₃ O ⁺	 (60)	331

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

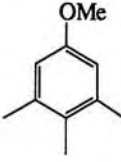
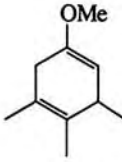
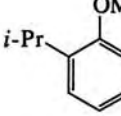
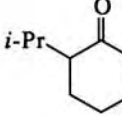
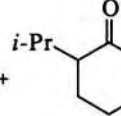
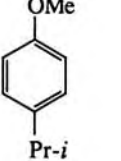
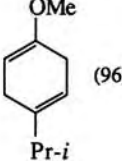
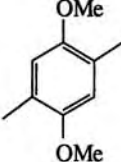
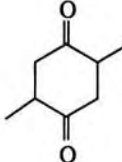
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, 6 h	MeOH	 (90)	332
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (13) +  (13)	168, 307
	NH ₃ /Li, Et ₂ O	EtOH	 (96)	333
	NH ₃ /Na (6), EtOH	NH ₄ Cl, H ₃ O ⁺	 (60)	324

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

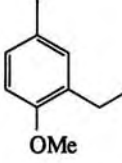
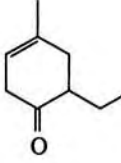
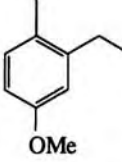
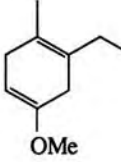
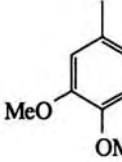
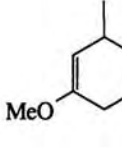
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (6), EtOH, Et ₂ O, 6 h	H ₂ O, (CO ₂ H) ₂	 (52)	334
	NH ₃ /Na, <i>t</i> -BuOH, THF, 5 h	NH ₄ Cl	 (—)	335
	NH ₃ /Na (5), EtOH, 4 h	MeOH	 (80)	306

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (46*) + (41*) + (3.7*)	306
	NH ₃ /Na, MeOH, Et ₂ O	H ₂ O	 (80)	336
	Li/NH ₃ , EtOH	NH ₄ Cl	 (77)	337
	NH ₃ /Li, <i>t</i> -BuOH, 1 h	"	 I	156
R = H; R ¹ = Me			I (—)	
R = Me; R ¹ = H			I (—)	

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, Et ₂ O	NH ₄ Cl	 I + II I:II = 1:2	338
	"	"	 (57) + (7)	338
	Na/NH ₃ , EtOH	H ₂ O	 (81)	339
	Li/NH ₃ , <i>t</i> -BuOH, THF, -63°	MeOH	 (96)	311

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

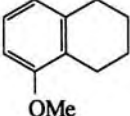
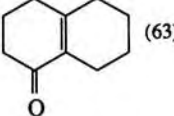
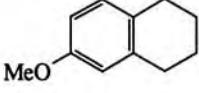
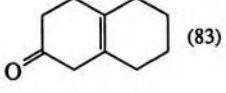
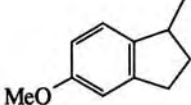
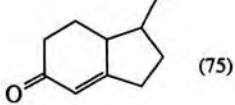
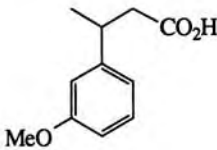
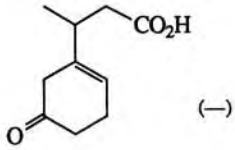
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, Et ₂ O, 6.5 h	MeOH, H ₃ O ⁺	 (63)	340, 4
	NH ₃ /Li (5), DME, 20 min	EtOH, AcOH, H ₂ O	 (83)	327, 328
	Li/NH ₃ , Et ₂ O	EtOH, H ₃ O ⁺	 (75)	341
	Li/NH ₃ , <i>t</i> -BuOH, 2 h	NH ₄ Cl, H ₃ O ⁺	 (—)	342

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

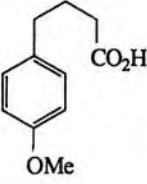
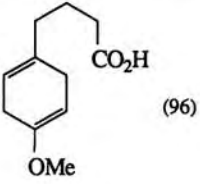
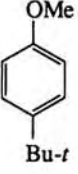
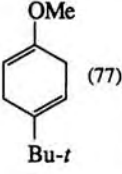
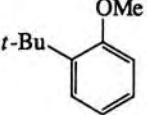
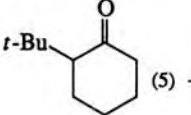
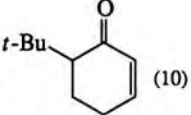
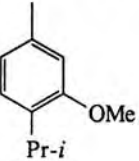
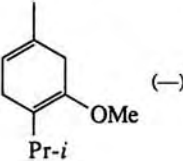
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, 5 h	NH ₄ Cl	 (96)	325
	NH ₃ /Li (5), Et ₂ O	EtOH	 (77)	343
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (5) +  (10)	168
	NH ₃ /Na, MeOH	H ₂ O	 (—)	2a, 344

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

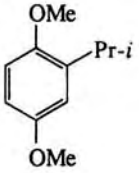
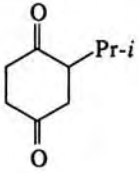
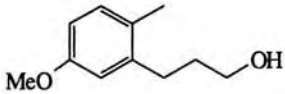
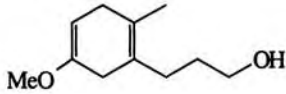
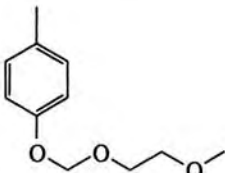
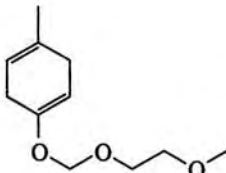
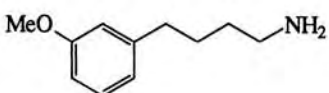
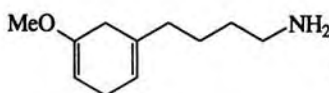
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (6), EtOH	NH ₄ Cl, H ₃ O ⁺	 (60)	324
	NH ₃ /Li, EtOH	NH ₄ Cl	 (90)	247, 345
	Li (8)/NH ₃ , EtOH, THF, 2 h	NH ₄ Cl	 (91)	346
	NH ₃ /Li, EtOH		 (75)	347

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

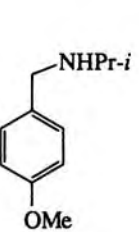
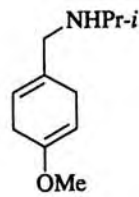
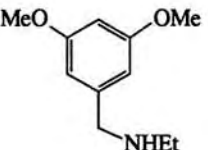
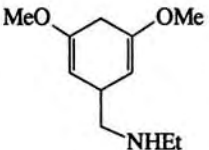
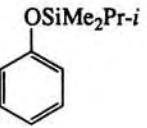
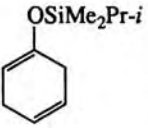
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, 45 min	C ₆ H ₅ CO ₂ H	 (97)	348
	NH ₃ /Li, <i>t</i> -BuOH, 2 h	NH ₄ Cl	 (—)	156
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	"	 (90)	349

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

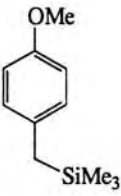
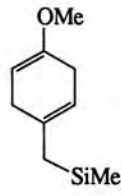
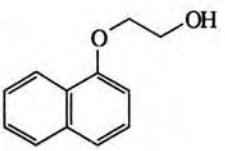
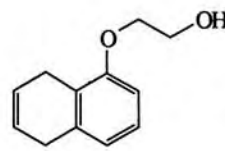
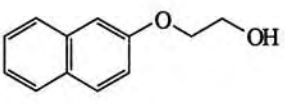
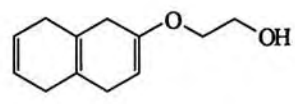
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
0.94 	NH ₃ /Li (4.3), EtOH, THF, 2 h	"	 (84)	252
C ₁₂ 	NH ₃ /Na, MeOH, Et ₂ O	H ₂ O	 (85)	339
	"	"	 (62)	339

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

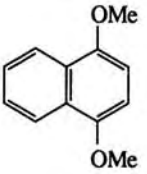
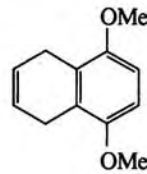
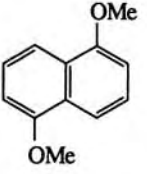
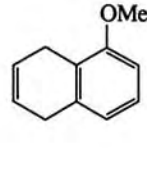
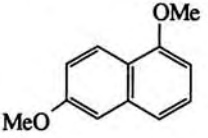
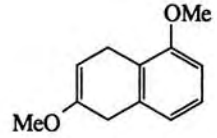
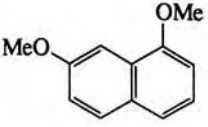
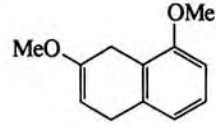
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (6), 30 min	EtOH	 (40)	350, 331
	NH ₃ /Na, EtOH, THF	"	 (63)	351
	"	"	 (85)	352
	"	"	 (89)	352

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

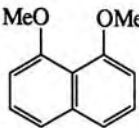
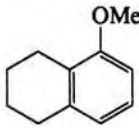
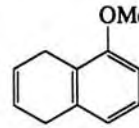
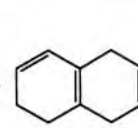
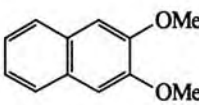
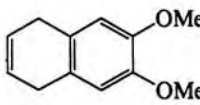
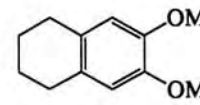
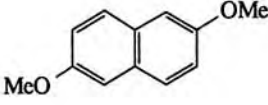
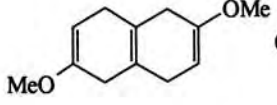
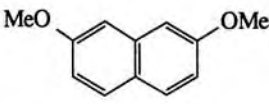
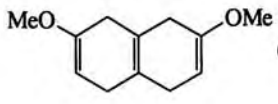
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na/NH ₃ , EtOH, THF, 5 min	"	 +  + 	353
	Na/NH ₃ , EtOH, THF	EtOH	 I +  II	354
	Na (4)/NH ₃ , EtOH, THF	"	I (45*) + II (40*)	
	Na (20)/NH ₃ , EtOH, THF	"	I (21*) + II (55*)	
	NH ₃ /Na, EtOH, THF	"	 (74)	351
	NH ₃ /Na (5.4), THF, -78°, 1 h	"	 (96)	355, 356

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

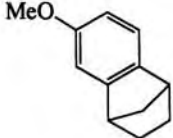
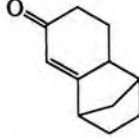
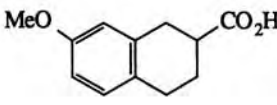
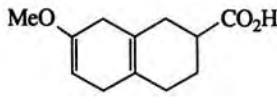
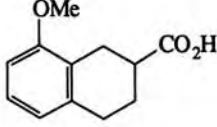
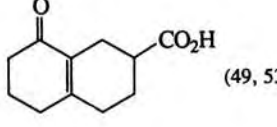
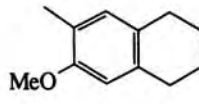
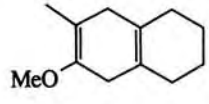
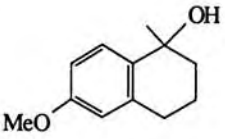
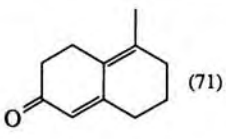
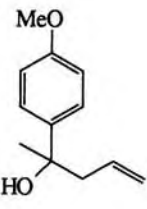
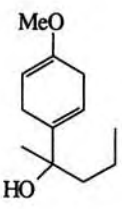
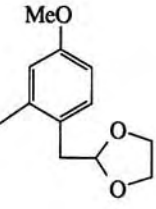
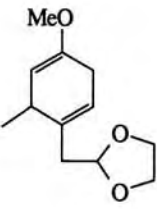
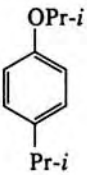
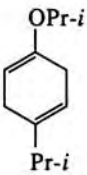
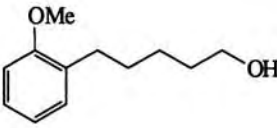
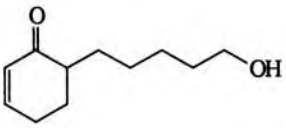
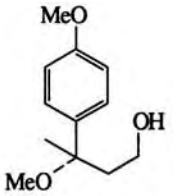
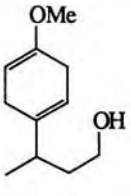
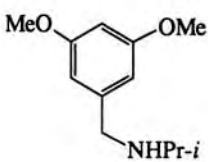
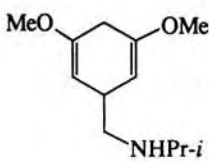
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, THF	H ₂ O, H ₃ O ⁺	 (77)	357
	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 3 h	MeOH	 (85)	2a
	NH ₃ /Na, EtOH, 8 h	NH ₄ Cl, H ₃ O ⁺	 (49, 53*)	358
	NH ₃ /Li, Et ₂ O, 30 min	EtOH	 (95)	328

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, EtOH	H ₂ O, H ₃ O ⁺	 (71)	359
	NH ₃ /Na (5.8), EtOH, THF	NH ₄ Cl	 (91)	360
	NH ₃ /Li, THF, 2.5 h	EtOH	 (85)	361

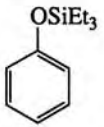
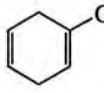
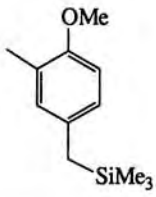
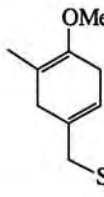
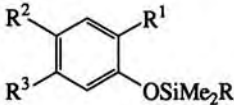
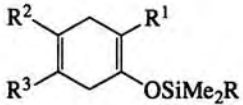
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5.8), EtOH, THF	NH ₄ Cl	 (80)	360
	NH ₃ /Li, <i>i</i> -PrOH, THF, -78°, 2 h	H ₂ O, H ₃ O ⁺	 (50)	362
	NH ₃ /Na, EtOH, THF, 5 h	NH ₄ Cl	 (85)	360
	NH ₃ /Li, <i>t</i> -BuOH, 2 h	"	 (—)	156

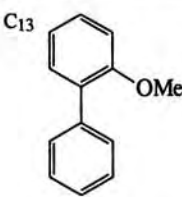
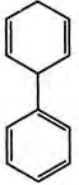
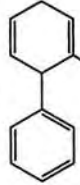
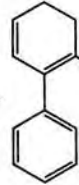
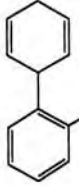
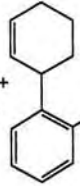
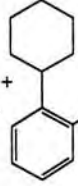
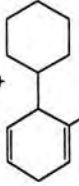
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																																			
	NH ₃ /Li (6.25), <i>t</i> -BuOH, THF, 45 min	"	 (87)	363																																			
	NH ₃ /Li, EtOH, Et ₂ O, 2 h	"	 (88)	364, 252																																			
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	NH ₄ Cl	 I	349																																			
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R</th> <th></th> </tr> </thead> <tbody> <tr> <td>H</td> <td>H</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (95)</td> </tr> <tr> <td>Me</td> <td>H</td> <td>H</td> <td><i>i</i>-Pr</td> <td>I (89)</td> </tr> <tr> <td>H</td> <td>Me</td> <td>H</td> <td><i>i</i>-Pr</td> <td>I (89)</td> </tr> <tr> <td>H</td> <td>H</td> <td>Me</td> <td><i>i</i>-Pr</td> <td>I (90)</td> </tr> <tr> <td>H</td> <td>OMe</td> <td>H</td> <td><i>i</i>-Pr</td> <td>I (80)</td> </tr> <tr> <td>H</td> <td>H</td> <td>OMe</td> <td><i>i</i>-Pr</td> <td>I (90)</td> </tr> </tbody> </table>	R ¹	R ²	R ³	R		H	H	H	<i>t</i> -Bu	I (95)	Me	H	H	<i>i</i> -Pr	I (89)	H	Me	H	<i>i</i> -Pr	I (89)	H	H	Me	<i>i</i> -Pr	I (90)	H	OMe	H	<i>i</i> -Pr	I (80)	H	H	OMe	<i>i</i> -Pr	I (90)	
R ¹	R ²	R ³	R																																				
H	H	H	<i>t</i> -Bu	I (95)																																			
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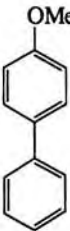
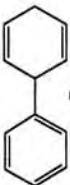
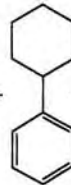
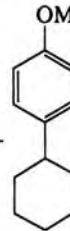
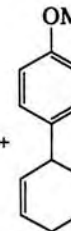
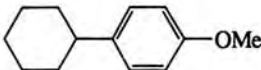
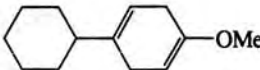
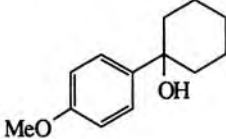
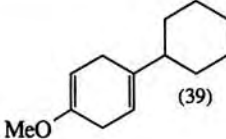
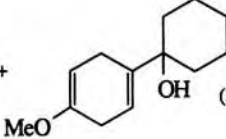
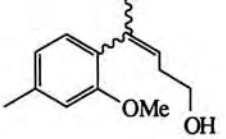
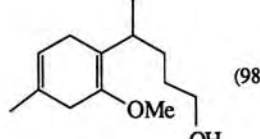
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, 10-20 min	"	 +  + 	279
	"	NH ₄ Cl	(7*) (81.5*) (5*)	
	"	MeOH	(4*) (55*) (26*)	
	NH ₃ /Ca (1.59), THF, 10-20 min	"	(44*) (34*) (2.5*)	
	NH ₃ /M, proton source, THF	H ₂ O	 I +  II +  III +  IV	279
	Li (2.63), <i>t</i> -BuOH	"	I (27*) + II (12.5*) + III (9.1*) + IV (37*)	
	Li (2.6), MeOH	"	I (33*) + II (8*) + III (11*) + IV (32*)	
	Li (2.57), NH ₄ OAc	"	I (36*) + IV (53*)	
	K (2.59), <i>t</i> -BuOH	"	I (13*) + II (43*) + III (16*) + IV (13*)	
	K (2.64), MeOH	"	I (25*) + II (11*) + III (12*) + IV (33*)	
	Ca (1.33), <i>t</i> -BuOH	MeOH	I (12*) + II (7*) + III (22*) + IV (23.5*)	

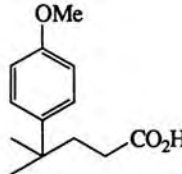
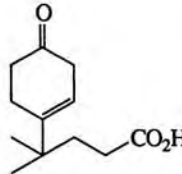
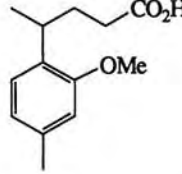
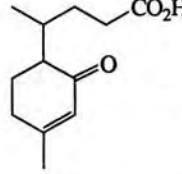
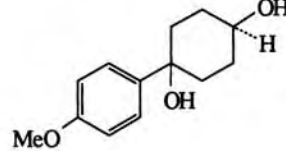
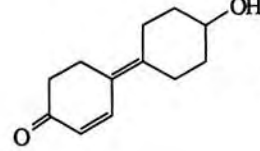
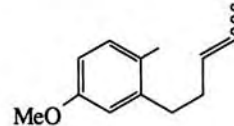
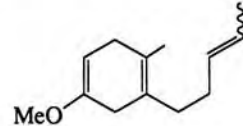
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.38), THF, <i>t</i> -BuOH	H ₂ O	 (9*) +  (7.5*) +  (13*) +  (13*) + starting material (45*)	279
	NH ₃ /Li, Et ₂ O, 10 min	EtOH	 (84-88)	4
	Li/NH ₃ , EtOH, THF, 25 min	"	 (39) +  (26)	48
	NH ₃ /Na, EtOH, 10 h	"	 (98)	365

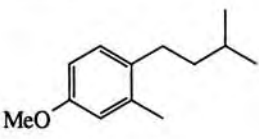
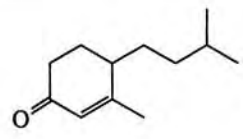
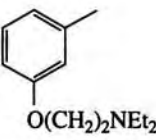
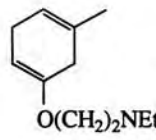
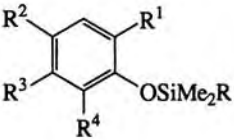
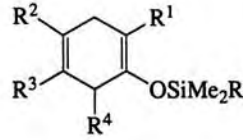
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5.6), <i>t</i> -BuOH, THF, 3 h	NH ₄ Cl, H ₃ O ⁺	 (94)	366
	NH ₃ /Li, <i>t</i> -BuOH, THF, -78°, 5 h	EtOH, H ₃ O ⁺	 (90-94)	367
	Li/NH ₃ , EtOH, THF, 25 min	"	 (92)	48
	NH ₃ /Li (7), EtOH, Et ₂ O, 40 min	NH ₄ Cl	 (ca 100)	368

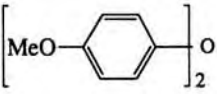
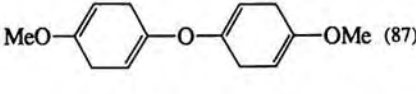
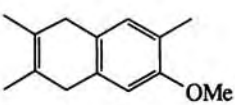
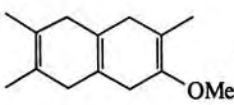
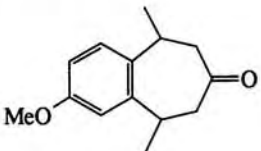
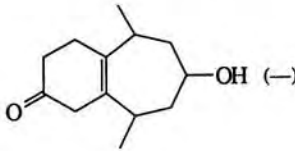
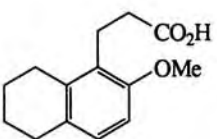
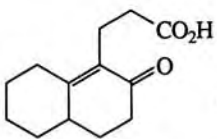
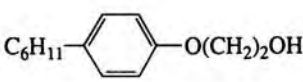
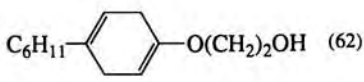
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																																																
	NH ₃ /Li (4.6), Et ₂ O, 20 min	EtOH, H ₃ O ⁺	 (63)	369																																																
	NH ₃ /Na, EtOH, Et ₂ O, 40 min	EtOH, H ₂ O	 (88)	94																																																
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	NH ₄ Cl	 I	349																																																
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th>R</th> <th></th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>H</td> <td>H</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (96)</td> </tr> <tr> <td>H</td> <td>Me</td> <td>H</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (95)</td> </tr> <tr> <td>H</td> <td>H</td> <td>Me</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (92)</td> </tr> <tr> <td>Me</td> <td>H</td> <td>Me</td> <td>H</td> <td><i>i</i>-Pr</td> <td>I (93)</td> </tr> <tr> <td>Me</td> <td>H</td> <td>H</td> <td>Me</td> <td><i>i</i>-Pr</td> <td>I (54)</td> </tr> <tr> <td>H</td> <td>OMe</td> <td>H</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (85)</td> </tr> <tr> <td>H</td> <td>H</td> <td>OMe</td> <td>H</td> <td><i>t</i>-Bu</td> <td>I (95)</td> </tr> </tbody> </table>	R ¹	R ²	R ³	R ⁴	R		Me	H	H	H	<i>t</i> -Bu	I (96)	H	Me	H	H	<i>t</i> -Bu	I (95)	H	H	Me	H	<i>t</i> -Bu	I (92)	Me	H	Me	H	<i>i</i> -Pr	I (93)	Me	H	H	Me	<i>i</i> -Pr	I (54)	H	OMe	H	H	<i>t</i> -Bu	I (85)	H	H	OMe	H	<i>t</i> -Bu	I (95)	
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H	H	OMe	H	<i>t</i> -Bu	I (95)																																															

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C_{14} 	NH ₃ /Na, EtOH, dioxane, 4 h	MeOH	 (87)	306
	NH ₃ /Li, THF, 30 min	MeOH, NH ₄ Cl	 (74)	370
	NH ₃ /Li, Et ₂ O, 25 min	EtOH, H ₃ O ⁺	 (—)	371
	NH ₃ /Li, EtOH	H ₂ O, H ₃ O ⁺	 (—)	372
	NH ₃ /Li, Et ₂ O	EtOH	 (62)	4

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>i</i> -PrOH, THF, -78°, 3 h	H ₂ O, H ₃ O ⁺	(70)	362
	NH ₃ /Na, EtOH, 3.5 h	H ₂ O	(60-65)	373
	NH ₃ /Li, <i>t</i> -BuOH, THF	H ₂ O, (CO ₂ H) ₂	(90)	374
	Li/NH ₃ , ^a EtOH, THF, 10 min	EtOH, H ₃ O ⁺	(60)	48

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																				
	NH ₃ /Li, <i>t</i> -BuOH, THF, -78°, 5 h	EtOH, (CO ₂ H) ₂	(48)	375																				
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	NH ₄ Cl	I	349																				
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th></th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>H</td> <td>Me</td> <td>H</td> <td>I (95)</td> </tr> <tr> <td>Me</td> <td>Me</td> <td>H</td> <td>H</td> <td>I (97)</td> </tr> <tr> <td>Me</td> <td>H</td> <td>H</td> <td>Me</td> <td>I (60)</td> </tr> </tbody> </table>	R ¹	R ²	R ³	R ⁴		Me	H	Me	H	I (95)	Me	Me	H	H	I (97)	Me	H	H	Me	I (60)	
R ¹	R ²	R ³	R ⁴																					
Me	H	Me	H	I (95)																				
Me	Me	H	H	I (97)																				
Me	H	H	Me	I (60)																				
	NH ₃ /Na (4), THF	MeOH	R = H (33) R = OH (64)	376																				

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C15

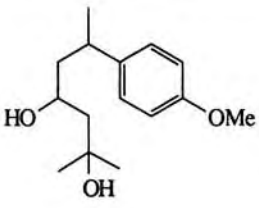
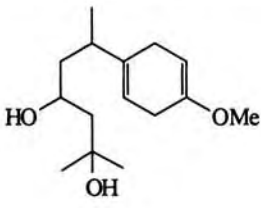
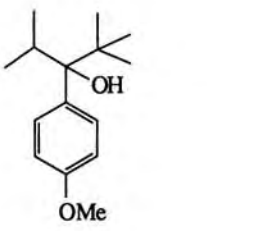
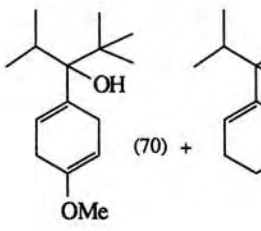
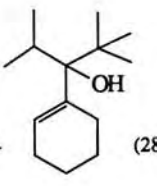
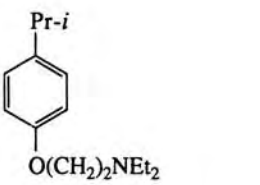
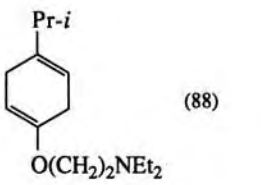
TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, THF, 10 min	EtOH	(86)	370
	NH ₃ /Na (2.5), EtOH, THF-Et ₂ O	H ₂ O, H ₃ O ⁺	(67)	377
	Na/NH ₃ , THF, 30 min	MeOH, H ₃ O ⁺	(34) + (12)	378
	Li/NH ₃ , 15 min	EtOH, NH ₄ Cl	(85)	259

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

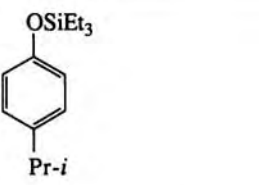
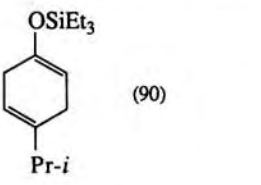
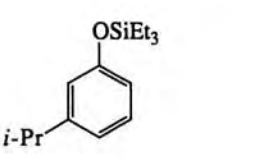
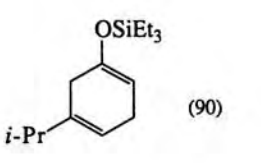
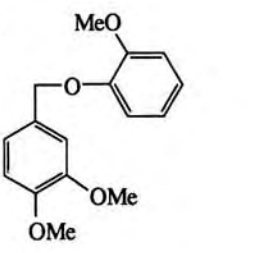
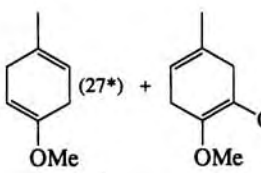
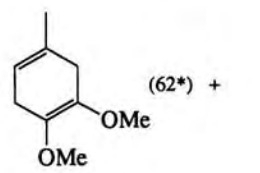
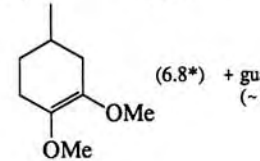
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	NH ₄ Cl	(95)	349
	NH ₃ /Li, <i>t</i> -BuOH, Et ₂ O, 5 h	MeOH	(66.5)	379, 380
	NH ₃ /Li (6), <i>t</i> -BuOH, THF, -60°, 2 h	1. EtOH, NH ₄ Cl 2. H ₃ O ⁺ 3. H ₂ , 5% Pd/C	(63)	381
	Li/NH ₃ , EtOH, THF, 25 min	H ₂ O, H ₃ O ⁺	(70)	48

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, -78°, 5 h	EtOH	 (91)	382
	NH ₃ /Li, EtOH, THF, 2.5 h	NH ₄ Cl	 (70) +  (28)	383
	NH ₃ /Li, <i>t</i> -BuOH, Et ₂ O	—	 (88)	90

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (7)/NH ₃ , <i>t</i> -BuOH, THF, 35 min	NH ₄ Cl	 (90)	87
	"	"	 (90)	87
	NH ₃ /Na (5), EtOH, dioxane, 4 h	MeOH	 (27*) +  (62*) +  (6.8*) + guaiacol (~100)	306

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

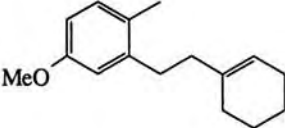
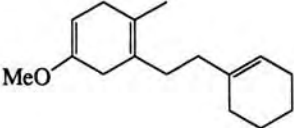
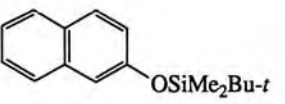
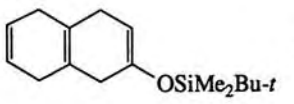
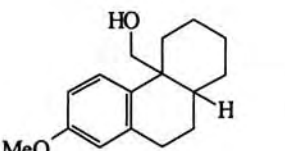
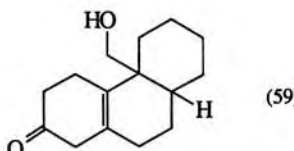
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, <i>t</i> -BuOH, THF, 5 h	NH ₄ Cl	 (92)	335
	Li (6)/NH ₃ , <i>t</i> -BuOH, THF, 45 min	"	 (91)	349
	NH ₃ /Na, <i>t</i> -BuOH, THF, -78°, 3 h	MeOH, H ₃ O ⁺	 (59)	44

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

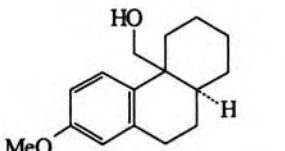
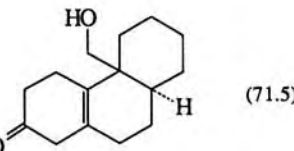
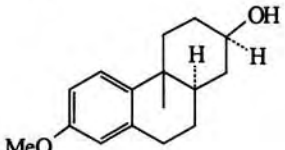
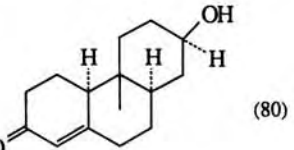
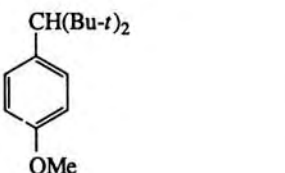
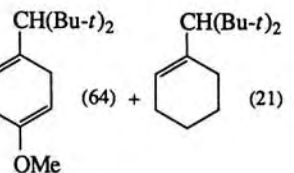
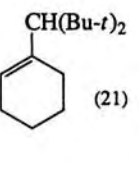
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (71.5)	44
	Li/NH ₃ , THF, 15 min	<i>t</i> -BuOH, H ₃ O ⁺	 (80)	384
	NH ₃ /Li (5.6), EtOH, THF, 5 h	Cl(CH ₂) ₂ Cl	 (64) +  (21)	383

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

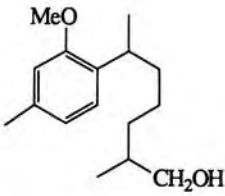
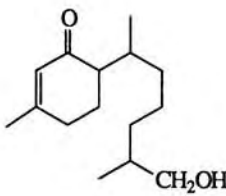
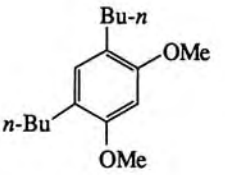
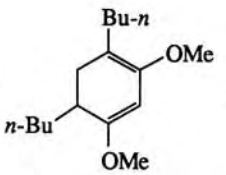
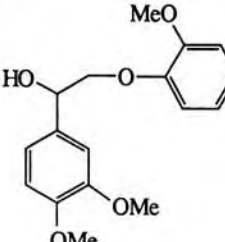
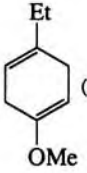
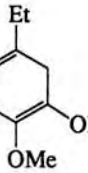
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, Et ₂ O, 15 min	EtOH, H ₃ O ⁺	 (45)	385
	NH ₃ /Li, <i>t</i> -BuOH, 3 h	EtOH, <i>t</i> -BuOK in DMSO	 (90)	386
C17 	NH ₃ /Na, EtOH, dioxane, 4 h	MeOH	 (50*) +  (47*) + guaiacol (50*)	306

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

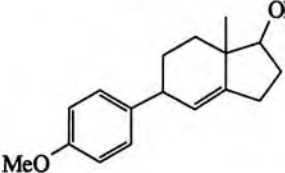
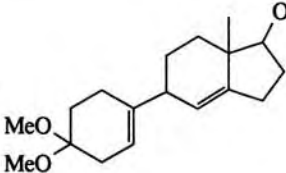
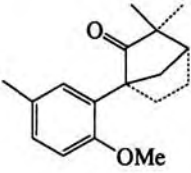
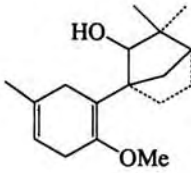
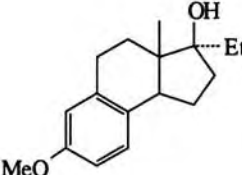
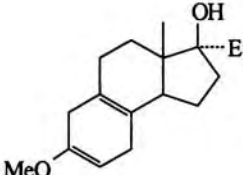
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, THF, 1 h	EtOH, MeOH-H ⁺	 (54)	48
	NH ₃ /Li, <i>i</i> -PrOH, Et ₂ O, -70°	H ₂ O	 (ca 100)	46
	NH ₃ /Li, <i>t</i> -BuOH, THF, 3.5 h	MeOH	 (72)	387

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

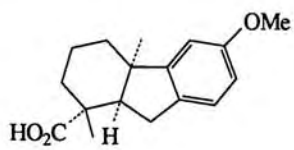
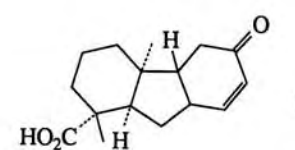
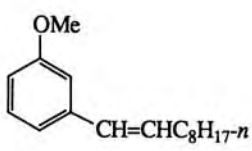
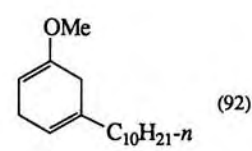
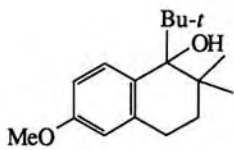
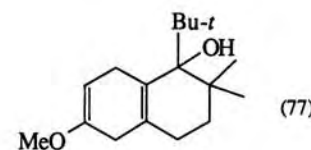
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, THF	H ₂ O, H ₃ O ⁺	 (48)	388
	NH ₃ /Li, <i>t</i> -BuOH, THF, 14 h	MeOH	 (92)	89
	NH ₃ /Li, EtOH, THF, 3.5 h	NH ₄ Cl	 (77)	383

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

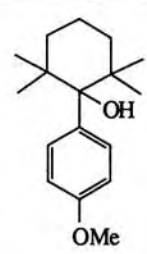
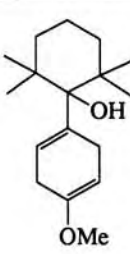
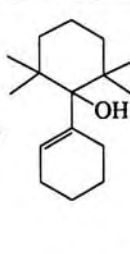
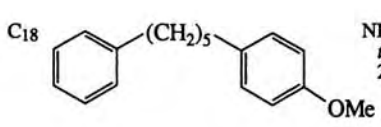
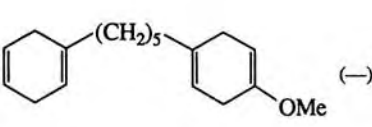
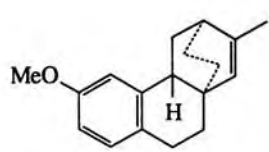
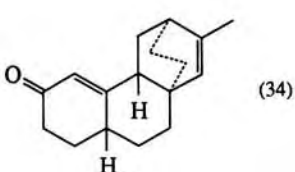
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF, 2 h	"	 (I) +  (II) I:II = 4:1	383
	NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl	 (—)	267
	Li/NH ₃ , EtOH, THF, -78°, 2 h	EtOH, H ₃ O ⁺	 (34)	389

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

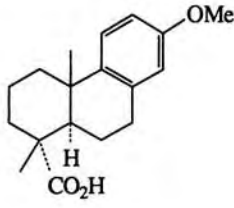
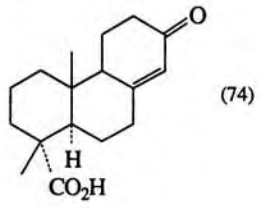
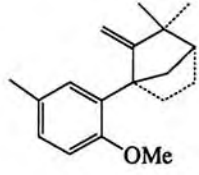
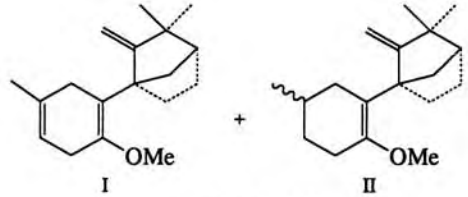
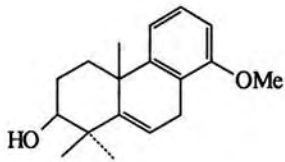
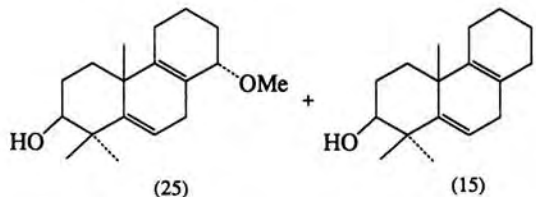
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , Et ₂ O, 20 min	EtOH, H ₃ O ⁺	 (74)	390
	Li/NH ₃ , THF, 1 h, <i>t</i> -BuOH	NH ₄ Cl	 I + II (-) I:II = 1:1	46
	NH ₃ /Li, <i>t</i> -BuOH, dioxane	H ₂ O	 (25) + (15)	391

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

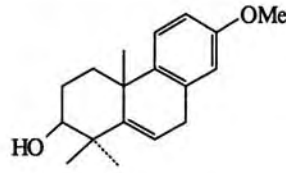
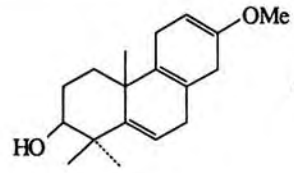
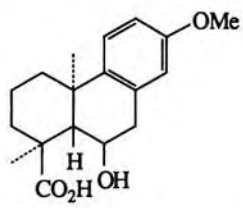
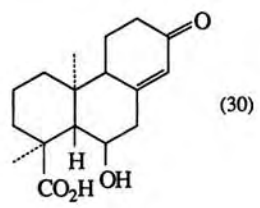
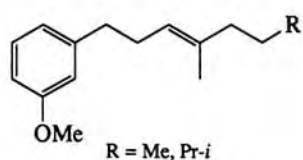
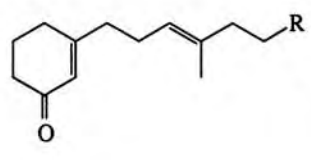
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, Et ₂ O, 75 min	"	 (87)	392
	Li (6.5)/NH ₃ , Et ₂ O, 30 min	EtOH, H ₃ O ⁺	 (30)	393
 R = Me, Pr- <i>i</i>	NH ₃ /Na, EtOH	H ₂ O, H ₃ O ⁺	 (-)	394

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , Et ₂ O, 20 min	EtOH, H ₃ O ⁺	 (79)	395
	NH ₃ /Li, EtOH, 2 h	H ₂ O, H ₃ O ⁺ , Ac ₂ O- pyridine	 (11) + (9)	82
			 I	
R ¹ = OH; R ² = H	NH ₃ /Li, EtOH, Et ₂ O, 75 min	H ₂ O	I (81)	392
R ¹ , R ² = C = O	NH ₃ /Li, Et ₂ O, 30 min	EtOH	I (48)	396

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, Et ₂ O, 45 min	H ₂ O, Ac ₂ O- pyridine	 (77)	314
	NH ₃ /Li, THF, 40 min	EtOH	 (80)	397, 340
	Li/NH ₃ , <i>t</i> -BuOH, THF, -70°, 6 h	NH ₄ Cl, H ₃ O ⁺	 (62)	47

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

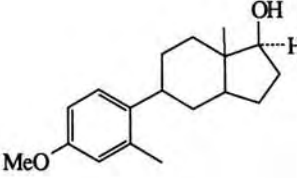
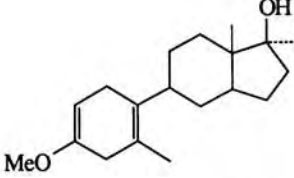
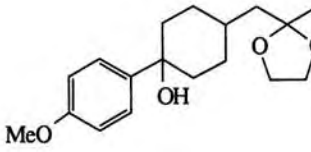
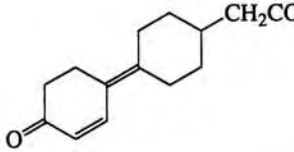
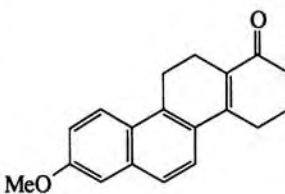
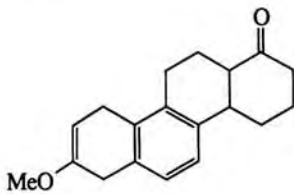
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na(3)/NH ₃ , t-BuOH, THF, 2 h	NH ₄ Cl	 (90*)	398
	Li/NH ₃ , ^a EtOH, THF, 10 min	EtOH, AcOH- MeOH	 (67)	48
C ₁₉ 	K/NH ₃ , MeOH	—	 (—)	399

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

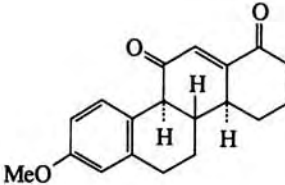
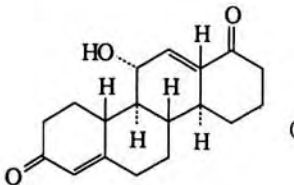
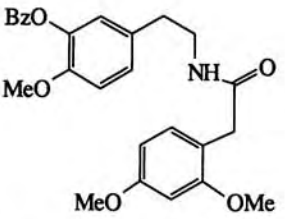
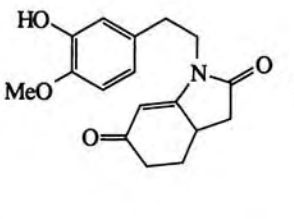
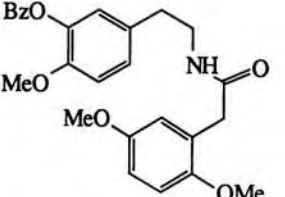
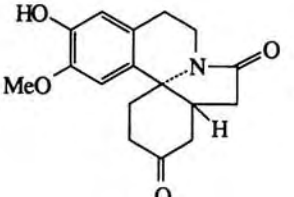
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Na/NH ₃ , EtOH	MeOH, H ₃ O ⁺	 (—)	400
	NH ₃ /Na, MeOH	H ₂ O, 10% H ₂ SO ₄ in DMF	 (85)	401
	"	"	 (90)	402

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

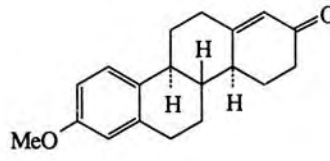
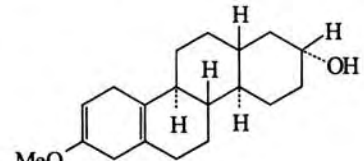
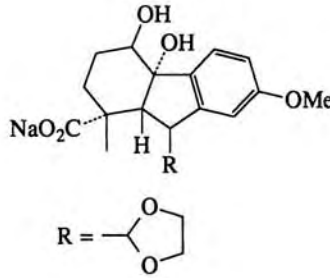
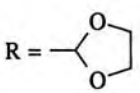
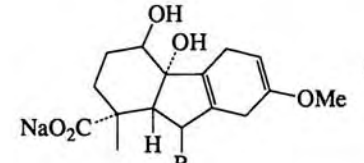
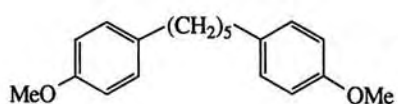
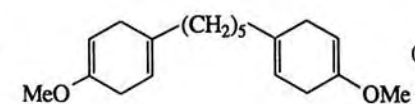
No. of Carbon Atoms	Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
		NH ₃ /Li, <i>t</i> -BuOH, THF, 4 h	H ₂ O	 (61)	403
	 R = 	NH ₃ /Na, EtOH, THF	EtOH	 (—)	404
		NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl	 (—)	267

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

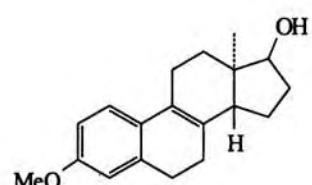
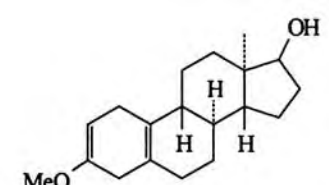
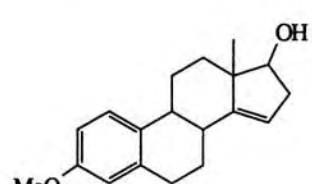
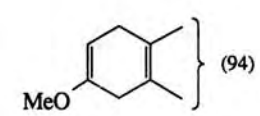
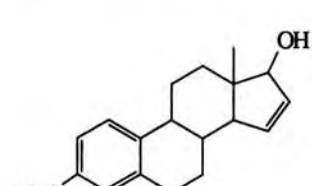
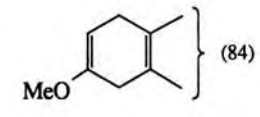
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, THF, 10 min	EtOH	 (96)	55
	NH ₃ /Li, EtOH, THF, -40°, 30 min	NH ₄ Cl	 (94)	56
	NH ₃ /Li, EtOH, THF, -78°, 30 min	"	 (84)	57

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

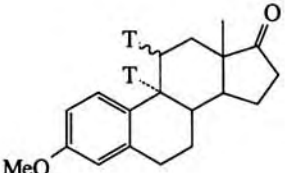
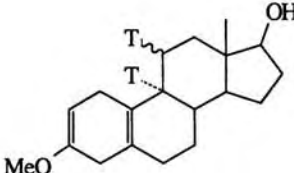
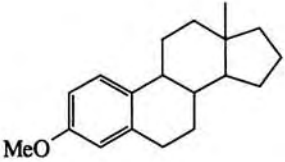
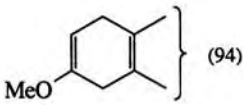
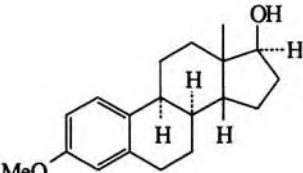
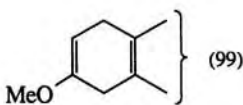
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, <i>i</i> -PrOH, THF	MeOH	 (—)	405
	NH ₃ /Li, EtOH, Et ₂ O, 2 h	EtOH, H ₂ O	 (94)	58
	NH ₃ /Na, <i>i</i> -PrOH, THF, 1 h	"	 (99)	59, 340

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

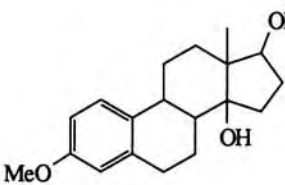
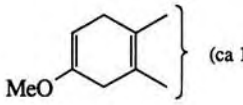
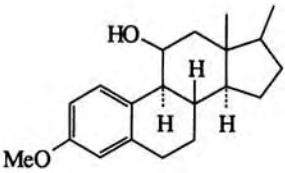
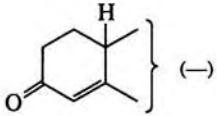
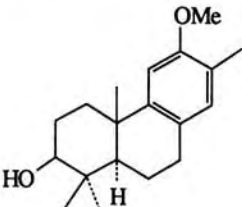
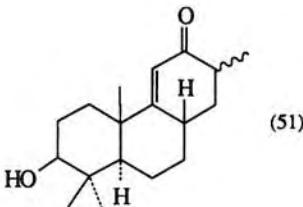
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), <i>i</i> -PrOH, THF, 2 h	NH ₄ Cl	 (ca 100)	406
	NH ₃ /Na, EtOH	H ₂ O, H ₃ O ⁺	 (—)	407
	NH ₃ /Li, EtOH, THF	H ₂ O, H ₃ O ⁺	 (51)	408

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

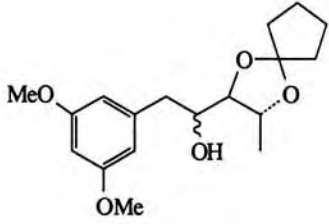
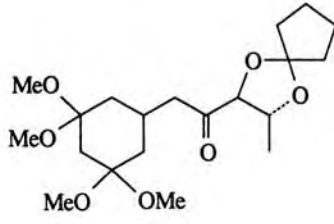
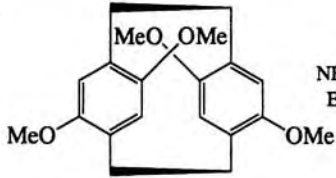
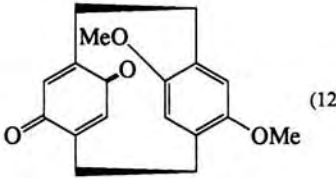
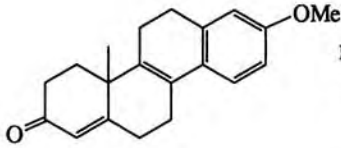
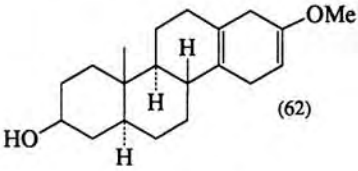
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, 1 h	1. H ₃ O ⁺ 2. TsOH-MeOH 3. Pyridine/CrO ₃	 (37)	409
C ₂₀ 	NH ₃ /Li, EtOH, Et ₂ O, -78°	H ₂ O, H ₃ O ⁺	 (12)	410
	Li/NH ₃ , EtOH, Et ₂ O-dioxane, 2 h	EtOH	 (62) + 8 α isomer (20)	411

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

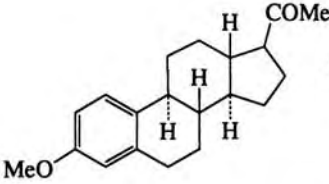
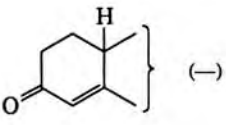
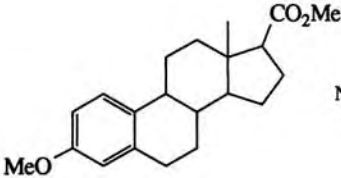
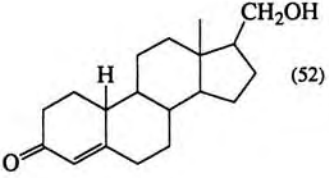
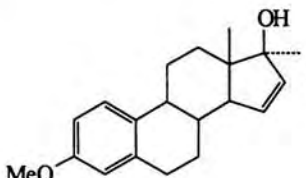
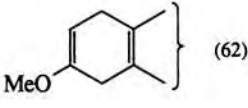
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , EtOH, Et ₂ O	H ₃ O ⁺ , CrO ₃	 (—)	412
	NH ₃ /Li, Et ₂ O, 30 min	EtOH, H ₃ O ⁺	 (52)	78, 413
	NH ₃ /Li, EtOH, THF, -78°	NH ₄ Cl	 (62)	57

Table II. Reduction of Aromatic Ethers (Continued)

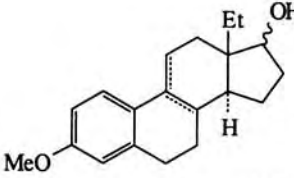
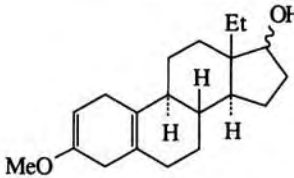
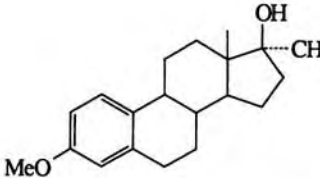
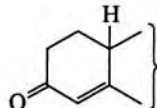
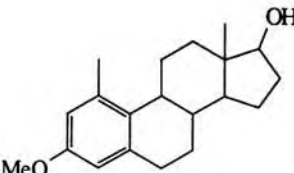
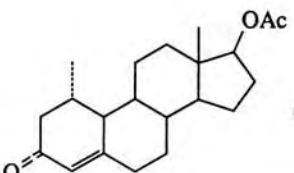
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 mixture of $\Delta^{9,10} + \Delta^{10,11}$	NH_3/Li , EtOH	—	 (78)	60
	NH_3/Li , THF, 1 h	EtOH, H_3O^+	 (40)	61
	Li/NH_3 , THF, 3.5 h	MeOH, H_3O^+ , Ac ₂ O, pyridine	 (—)	62

Table II. Reduction of Aromatic Ethers (Continued)

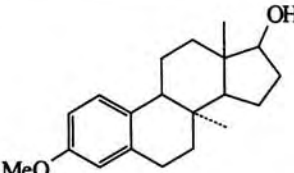
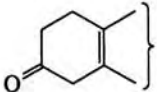
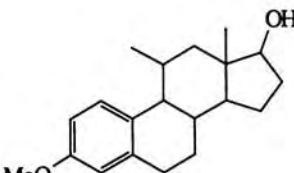
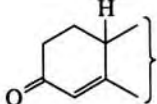
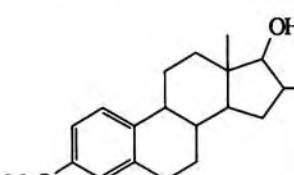
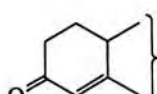
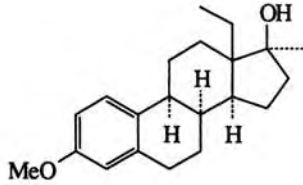
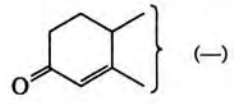
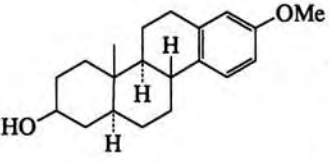
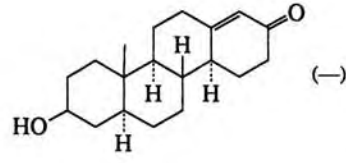
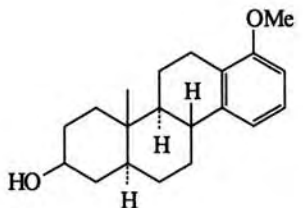
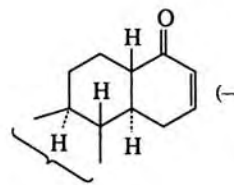
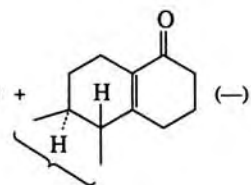
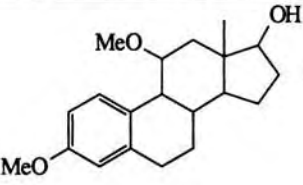
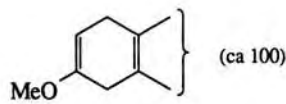
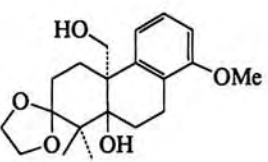
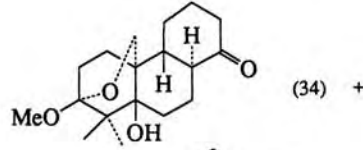
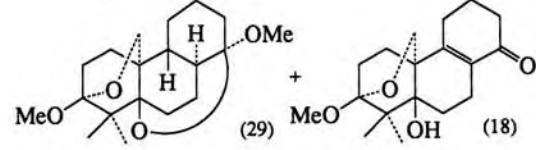
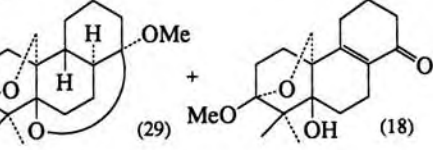
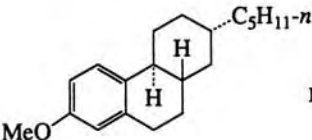
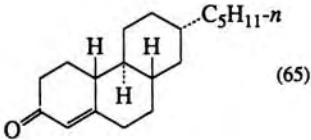
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH_3/Li , EtOH, THF	EtOH, H_3O^+	 (86)	63
	NH_3/Na , EtOH	H_2O , H_3O^+	 (—)	414
	NH_3/Li , EtOH, THF, -50° , 3 h	H_2O , H_3O^+	 (82)	42

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, 15 min	EtOH, H ₃ O ⁺	 (—)	65
	NH ₃ /Li, <i>t</i> -BuOH, THF, 5 h	NH ₄ Cl, H ₃ O ⁺	 (—)	66
	NH ₃ /Li, EtOH	H ₂ O, H ₃ O ⁺	 (—) +  (—)	81

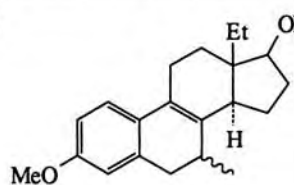
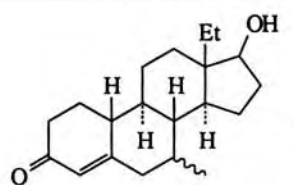
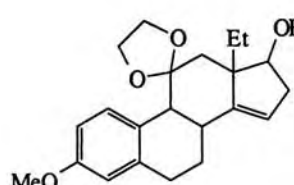
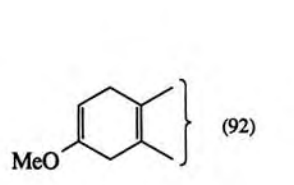
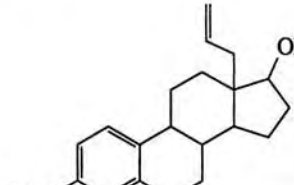
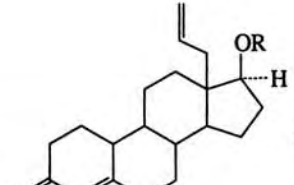
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF	—	 (ca 100)	415
	NH ₃ /Li, EtOH, -70°	H ₃ O ⁺ , MeOH-TsOH	 (34) +  (29) +  (18)	416
	Li/NH ₃ , THF	<i>t</i> -BuOH, H ₃ O ⁺	 (65)	417

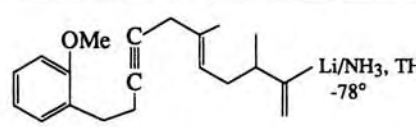
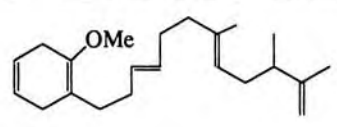
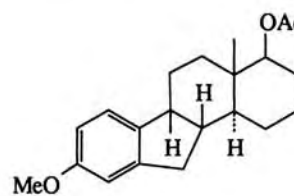
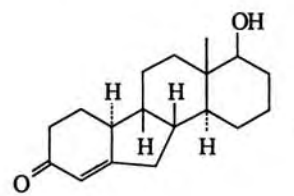
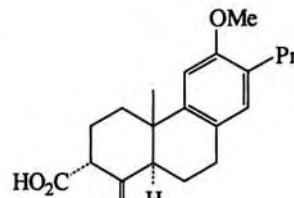
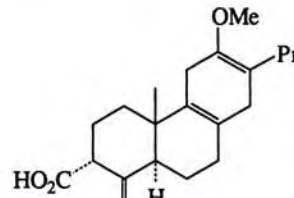
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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH_3/Li , THF, aniline, -50° , 5 h	MeOH , H_3O^+	 (43)	67
	NH_3/Li , <i>t</i> -BuOH, THF, 4 h	NH_4Cl	 (92)	68
 <p>R = THP</p>	NH_3/Li , EtOH, THF, -50° , 30 min	H_2O , H_3O^+	 (85)	418

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH_3 , THF, -78°	EtOH	 (ca 100)	419
	NH_3/Li , THF, -40° , 2 h	MeOH , H_3O^+	 (36)	420
	NH_3/Li , <i>t</i> -BuOH, Et ₂ O, 2 h	H_2O	 (—)	421

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Table II. Reduction of Aromatic Ethers (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF	NH ₄ Cl, (CO ₂ H) ₂	(82)	69
	NH ₃ /Li, <i>i</i> -PrOH	H ₂ O, H ₃ O ⁺	(84)	422, 423
	NH ₃ /Na, <i>i</i> -PrOH, THF	NH ₄ Cl, H ₃ O ⁺ , Al(OPr- <i>i</i>) ₃	(86)	70

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Table II. Reduction of Aromatic Ethers (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, EtOH, THF, -50°, 1 h	H ₂ O, H ₃ O ⁺	I (75-85)	71, 42
17β-OH, 16β-Et 17α-OH, 16α-Et 17β-OH, 16α-Et 17α-OH, 16β-Et			I I I I	
	NH ₃ /Na, <i>t</i> -BuOH, THF, 5 h	MeOH	(87)	340
	NH ₃ /Li (5), <i>t</i> -BuOH, THF	THF	(89)	424

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (6.7), EtOH, THF, -78°, 20 min	EtOH, (CO ₂ H) ₂		226
	NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl		267
	NH ₃ /Li, <i>t</i> -BuOH, THF, -50°	1. NH ₄ Cl, 2. LiAlH ₄ , 3. H ₃ O ⁺		72

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , Et ₂ O, 1 h	1. MeOH, 2. H ₃ O ⁺ , 3. CrO ₃		425
	NH ₃ /Li, EtOH, THF	H ₂ O, (CO ₂ H) ₂		73
	NH ₃ /Li, THF, 2 h	EtOH, H ₃ O ⁺		61

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, THF	—	(—)	426
	NH ₃ /Li, EtOH, THF, -50°, 3 h	H ₂ O, H ₃ O ⁺	I	42
<p>R ————— R¹</p> <p>H <i>n</i>-Pr</p> <p>H <i>i</i>-Pr</p> <p>THP CH₂</p>			<p>I } (75-85)</p> <p>I }</p> <p>I (50)</p>	
	Li/NH ₃ , THF, 2 h	EtOH, H ₃ O ⁺	(75)	417

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₂₃	NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	NH ₄ Cl	(80)	74
	NH ₃ /Na, <i>t</i> -BuOH, THF, 3 h	NH ₄ Cl, H ₃ O ⁺	(82)	427
R = C ₂ H ₄ O ₂ ketal				
	NH ₃ /Na, <i>t</i> -BuOH, THF, 4 h	NH ₄ Cl	(93)	427
R = C ₂ H ₄ O ₂ ketal				

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TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

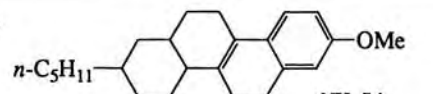
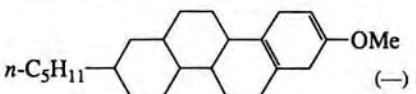
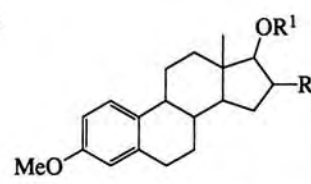
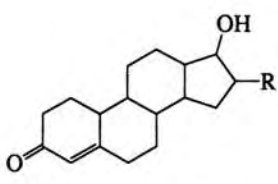
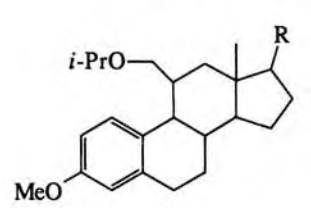
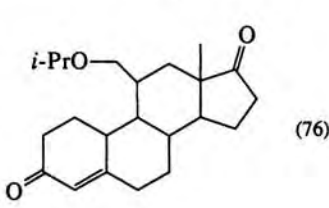
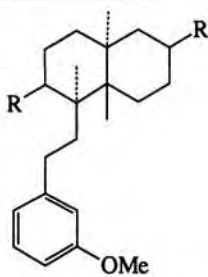
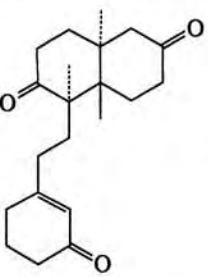
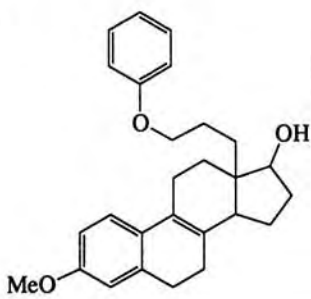
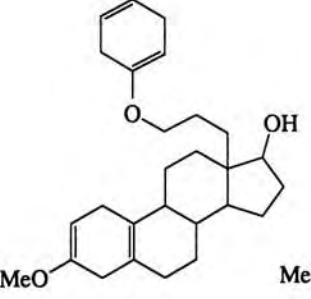
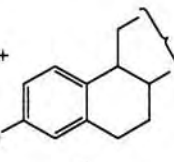
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C24 	NH ₃ /Li, EtOH	—	 (—)	428
C25 	NH ₃ /Li, EtOH, THF, -50°, 3 h	H ₂ O, H ₃ O ⁺		42
	R ¹ = THP; R = C ₆ H ₅	"	R = C ₆ H ₅ (56)	
	R ¹ = H; R = C ₆ H ₁₁	"	R = C ₆ H ₁₁ (—)	
	Li/NH ₃ , THF, 4 h	EtOH, H ₃ O ⁺	 (76)	75
	R = C ₂ H ₄ O ₂ ketal			

TABLE II. REDUCTION OF AROMATIC ETHERS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C26 	NH ₃ /Li, <i>t</i> -BuOH, THF, 8 h	MeOH, H ₃ O ⁺	 (—)	429
	R = C ₂ H ₄ O ₂ ketal			
C27 	NH ₃ /Li, THF, <i>t</i> -BuOH, 10 min	NH ₄ Cl	 I +  II	74
			I:II = 1:1 (—)	

^a The alcohol (10 mmol) in THF (45 mL) was treated with ethereal methyllithium (10 mmol for each hydroxy group), then liquid ammonia, and ethanol and lithium were added successively to the reaction flask.

TABLE III. REDUCTION OF AROMATIC SILANES

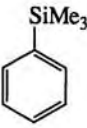
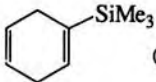
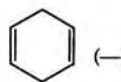
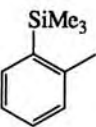

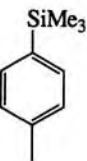
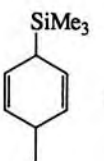
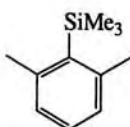
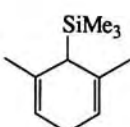
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₉ 	NH ₃ /Li (2.5), EtOH, -70°	H ₂ O	 (5) +  (—)	249
C ₁₀ 	NH ₃ /Li (2.7), EtOH, -70°	"	 (60, 90*)	249
	NH ₃ /Li (2.3), EtOH, -70°	"	 (58, 95*)	249
C ₁₁ 	NH ₃ /Li (3.1), EtOH, -70°	"	 (70)	249

TABLE III. REDUCTION OF AROMATIC SILANES (Continued)

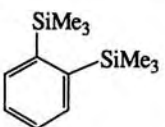
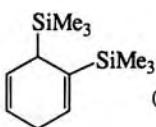
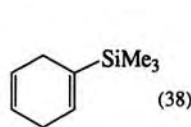
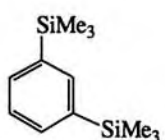
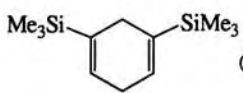
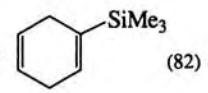
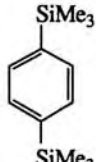
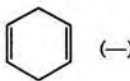
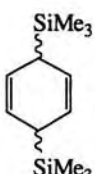
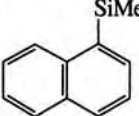
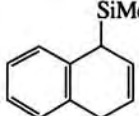
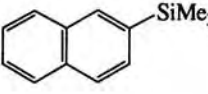
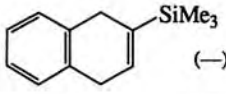
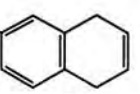
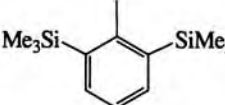
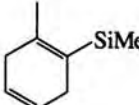
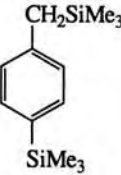
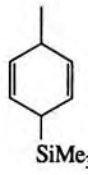
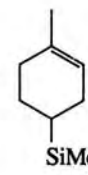
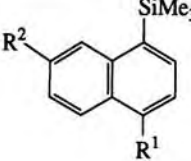
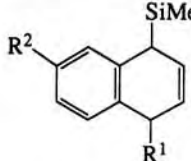
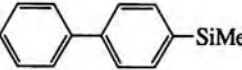
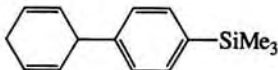
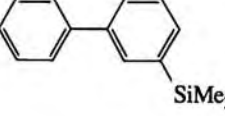
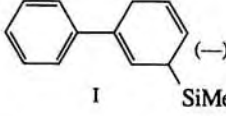
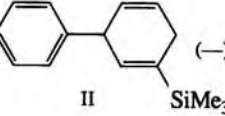
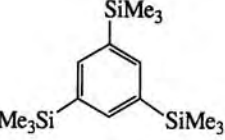
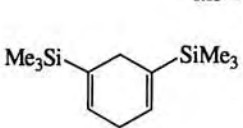
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₂ 	NH ₃ /Li (2.8), EtOH, -70°	H ₂ O	 (46) +  (38)	249
	NH ₃ /Li (4.0), EtOH, -70°	"	 (3) +  (82)	249
	NH ₃ /Li (7.5), EtOH, -30°	"	 (—)	249
	NH ₃ /Li (6.0), THF, <i>t</i> -BuOH, -78°	NH ₄ Cl	 <i>cis/trans</i> = 87/13 (86*)	31

TABLE III. REDUCTION OF AROMATIC SILANES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₃ 	NH ₃ /Li (2.2), THF, -78°, 20 min	NH ₄ Cl ^a	 (89)	172
	Na/NH ₃	NH ₄ Cl	 (—) +  (—) I:II = 80:20	430
	NH ₃ /Li (6), EtOH, -70°	H ₂ O	 (55)	249
	NH ₃ /Li (6.6), EtOH, -30°	"	 +  I + II (65)	249

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TABLE III. REDUCTION OF AROMATIC SILANES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₄ 	NH ₃ /Li (2.5), THF, -78°, 20 min	NH ₄ Cl ^a	 I R ¹ R ² Me H I (78*) H Me I (85*)	172
C ₁₅ 	NH ₃ /Li (2.5), THF, -78°, 20 min	NH ₄ Cl ^a	 (92*)	174
	"	"	 (—) +  (—) I:II = 1:1	31
	NH ₃ /Li (5.7), EtOH, -70°	H ₂ O	 (85)	249

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TABLE III. REDUCTION OF AROMATIC SILANES (Continued)

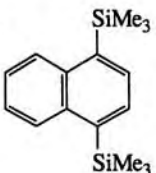
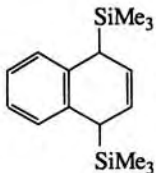
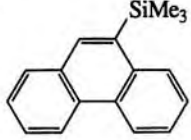
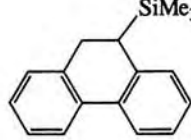
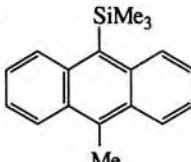
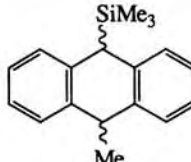
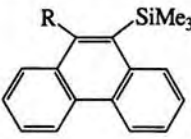
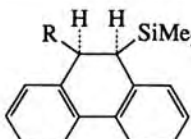
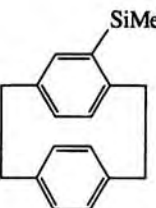
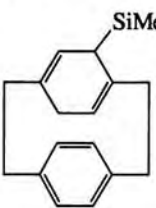
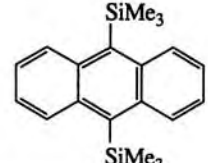
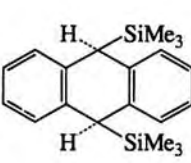
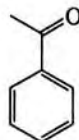
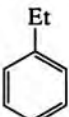
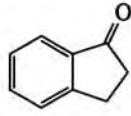
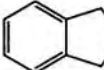
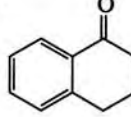
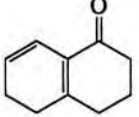
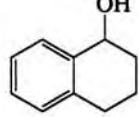
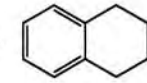
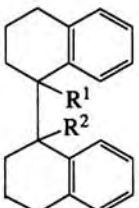
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C16 	Na/NH ₃	NH ₄ Cl	 (ca 100)	430
C17 	NH ₃ /Li (2.5), THF, -78°, 20 min	NH ₄ Cl ^a	 (96*)	174, 173
C18 	NH ₃ /Li (2.5), THF, -78°, 20 min	NH ₄ Cl ^a	 (96) <i>cis/trans</i> = 78/22	31

TABLE III. REDUCTION OF AROMATIC SILANES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 I R = Me I (98*) R = Et I (96*)	174, 173
C19 	NH ₃ /Li (3.2), EtOH, THF, -78°, 30 min	NH ₄ Cl	 (55, 80*)	31
	NH ₃ /Li (4), THF, -78°, 20 min	"	 (100)	31

^a The reaction mixture was pumped (with argon pressure) through a glass tube into a large excess of saturated ammonium chloride solution.

TABLE IV. REDUCTION OF AROMATIC KETONES

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₈ 	K (6)/NH ₃ , <i>t</i> -BuOH, Et ₂ O	H ₂ O	 (78) + starting material (14)	101
C ₉ 	Li (5)/NH ₃ , THF, 20 min, Co ^d	NH ₄ Cl	 (91, 93*)	102 a
C ₁₀ 			 I +  II +  III  + IVa R ¹ , R ² = OH IVb R ¹ = H; R ² = OH IVc R ¹ , R ² = H	

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TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)						Refs.
			% composition ^c						
			I	II	III	IVa	IVb	IVc	
	NH ₃ /Li, THF, 1h	C ₆ H ₅ CO ₂ Na	—	100	—	—	—	—	102b
	Li (5)/NH ₃ , THF, 1 h	NH ₄ Cl	—	—	99	—	—	—	102a
	"	NH ₄ Cl ^b	1	70	13	1	—	—	103
	NH ₃ /Li (5), THF, 1 h	NH ₄ Cl	11	5	70	—	—	—	103
	"	NH ₄ Cl ^b	22	26	48	2	—	—	103
	NH ₃ /Na (2.5), THF, 30 min	"	31	49	12	1	—	—	103
	" , -78°, 30 min	"	30	56	4	2	—	—	103
	Li (5)/NH ₃ , THF, -78°, 1 h	"	7	8	1	57	13	9	103
	"	NH ₄ Cl	—	—	13	5	2	71	103
	NH ₃ /Li (5), THF, -78°, 1 h	NH ₄ Cl ^b	21	11	9	21	24	9	103

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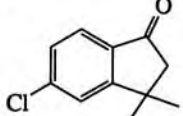
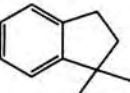
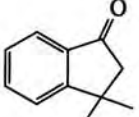
C ₁₁ 	Li (5)/NH ₃ , THF, 2 h, Al ^a	NH ₄ Cl	 (79, 90*)	102a
	Li (5)/NH ₃ , THF, 1 h, Al ^a	"	" (73, 92*)	102a

TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

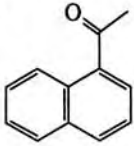
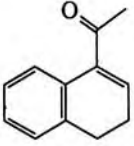
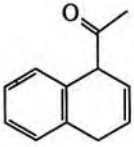
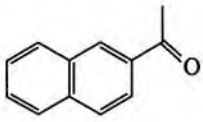
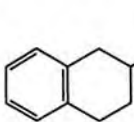
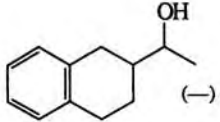
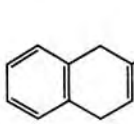
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C12 	Na (5)/ NH ₃ , THF, 1 h	EtOH, NH ₄ Cl	 (81*)	110, 111
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, 30 min	NH ₄ Cl ^b	 (68, 95*)	113
	NH ₃ /Li (4 or 8), THF, 30 min	NH ₄ Cl	 (–) +  (–) I II I:II = 1:1	111
	NH ₃ /Li (4 or 8), THF, 30 min, FeCl ₃	"	 (75)	111
	NH ₃ /K (4 or 8), THF, 30 min	"	" (80)	111

TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

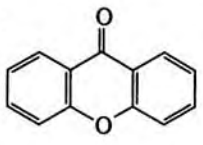
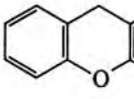
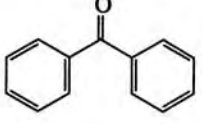
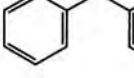
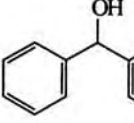
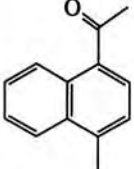
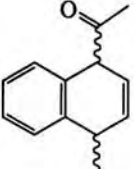
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C13 	Li (5)/NH ₃ , THF, 1 h, Co ^d	NH ₄ Cl	 (77, 98*)	102a
	"	"	 (87, 97*)	102a
	Na/NH ₃	H ₂ O	 (ca 100)	431
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 30 min	NH ₄ Cl ^b	 (86 ^d) <i>cis/trans</i> = 60/40	33, 113

TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (5)/NH ₃ , THF, 4 h, Al ^a	NH ₄ Cl	(95*)	102a
C ₁₄ 	NH ₃ /Na (3), THF, EtOH	NH ₄ Cl	(ca 100)	114
	"	"	(34)	114
	Li (5)/NH ₃ , THF, 1 h	EtOH, NH ₄ Cl	(48*) + (30*)	110

TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 30 min	NH ₄ Cl ^b	(88 ^d) <i>cis/trans</i> = 70/30	33, 113
<i>t</i> -Bu-	Li (5)/NH ₃ , THF, 2 h, Co ^a	NH ₄ Cl	<i>t</i> -Bu- (92, 95*)	102a
C ₁₅ 	Li (5)/NH ₃ , THF, 1 h	EtOH, NH ₄ Cl	(77, 88*)	110
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 20 min	NH ₄ Cl ^b	(79 ^d) <i>cis/trans</i> = 75/25	33

TABLE IV. REDUCTION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (5)/NH ₃ , THF, 1 h, Al ^a	NH ₄ Cl	(75, 96*)	102a
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, 20 min	NH ₄ Cl ^b	I	33
C ₁₇ R = Me			I (62)	
C ₁₈ R = Et			I (66)	
C ₁₉ 	NH ₃ /Na, EtOH, THF	NH ₄ Cl	(74)	432

^a The reduction was carried out in the presence of catalytic amounts of metal.

^b The reaction mixture was pumped (with argon pressure) through a glass tube into a large excess of saturated ammonium chloride.

^c Yields were measured by peak area on GC; the difference from 100% represents unreacted starting material.

^d The yield represents a mixture of *cis* and *trans* isomers.

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES

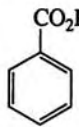
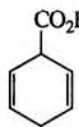
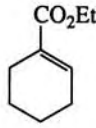
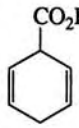
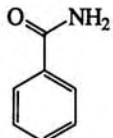
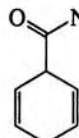
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C7  R = H R = Et	NH ₃ /Na (3.3), EtOH	NH ₄ Cl	 (89-95)	433, 121
	Mg (2)/NH ₃ , EtOH, Et ₂ O	"	 (—)	434
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, 25 min, -78°	NH ₄ Cl ^a	 R = Et (64) R = <i>t</i> -Bu (40)	229
 R = <i>t</i> -Bu	NH ₃ /Na (4.5), <i>t</i> -BuOH	NH ₄ Cl	 (82)	120, 155

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

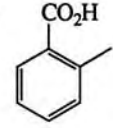
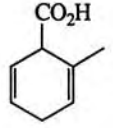
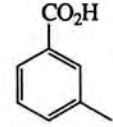
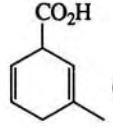
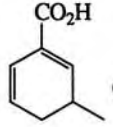
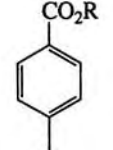
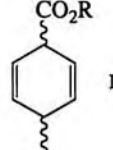
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C_8 	NH_3/Li (5), EtOH, 3 min	NH_4Cl	 (100*)	123
	"	"	 (85*) +  (11*)	123, 435
			 I	
R = H	NH_3/Li (5), H_2O	—	I (95) ^b	123

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

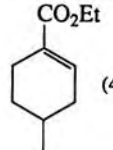
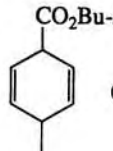
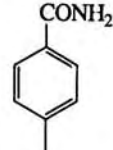
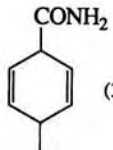
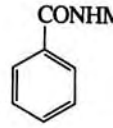
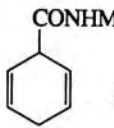
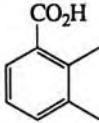
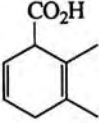
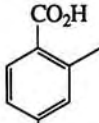
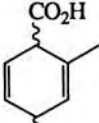
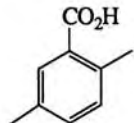
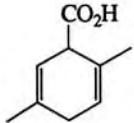
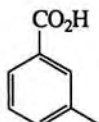
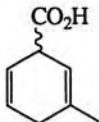
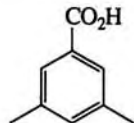
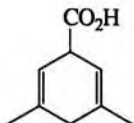
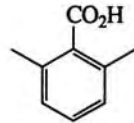
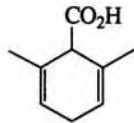
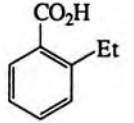
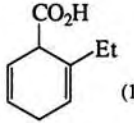
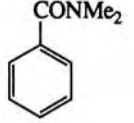
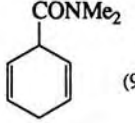
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R = Et	Mg (2)/ NH_3 , EtOH, Et_2O	NH_4Cl	 (40)	434
R = <i>t</i> -Bu	NH_3/Na (2.5), H_2O (1.5), THF, -78°, 30 min	NH_4Cl^a	 (37)	229
	Mg (2)/ NH_3 , EtOH	NH_4Cl	 (32)	434
	NH_3/Na (2.3)	EtOH	 (—)	155

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₉ 	NH ₃ /Li (5), EtOH, 3 min	NH ₄ Cl	 (95*)	123, 435
	"	"	 (100*) ^b	123
	"	"	 (100*)	123, 435
	NH ₃ /Li (4), 20 min	"	 (99*) ^b	123

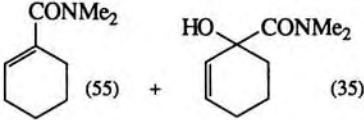
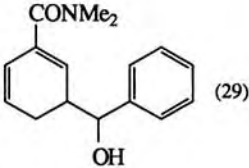
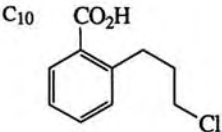
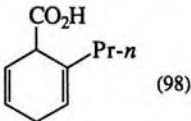
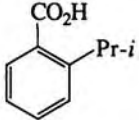
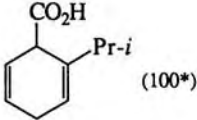
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), EtOH, 3 min	"	 (95*)	123
	"	"	 (100*)	123
	"	"	 (100*)	123
	NH ₃ /K (2.2), <i>t</i> -BuOH, THF, -78°	NH ₄ Cl	 (92)	157, 155

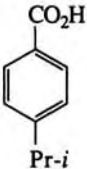
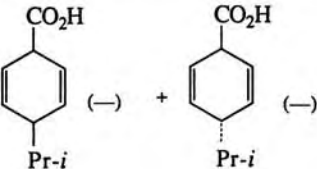
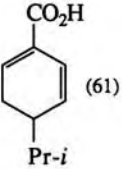
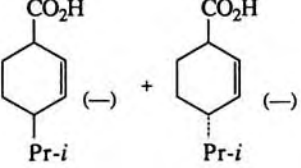
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (3.3)	EtOH	 (55) + (35)	157
	NH ₃ /Na (3.3)	NH ₄ Cl	 (29)	157
	NH ₃ /Na (4), Et ₂ O, 3 h	NH ₄ Cl	 (98)	242
	NH ₃ /Li (5), EtOH	"	 (100*)	123

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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), Et ₂ O, -70°, 20 min	EtOH, ^c NH ₄ Cl	 (—) + (—)	122
	"	EtOH	 (61)	122
	NH ₃ /Li (7), Et ₂ O, -70°, 20 min	EtOH, ^c NH ₄ Cl	 (—) + (—)	122

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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

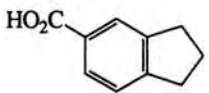
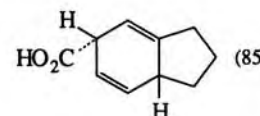
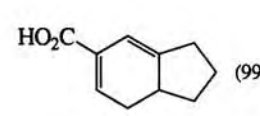
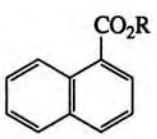
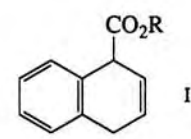
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), Et ₂ O, 4 h	NH ₄ Cl	 (85)	242
	NH ₃ /Li (3), <i>t</i> -BuOH, THF, 10 min	EtOH	 (99)	127
C ₁₁ 			 I	
R = H	NH ₃ /Na (3.5), Et ₂ O, -78°, 10 min	NH ₄ Cl ^a	I (ca 100)	139, 84
R = <i>t</i> -Bu	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 25 min	"	I (42)	229

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

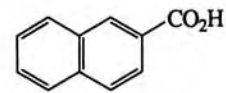
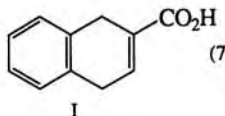
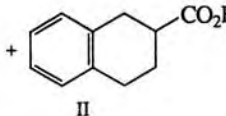
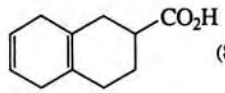
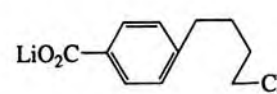
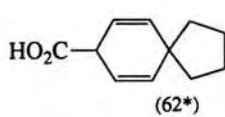
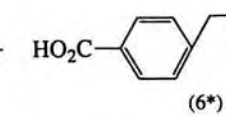
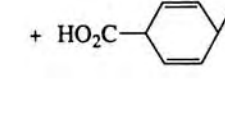
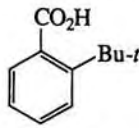
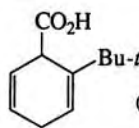
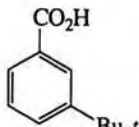
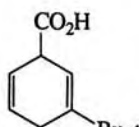
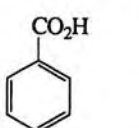
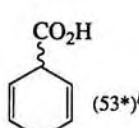
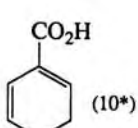
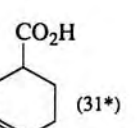
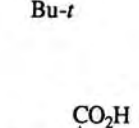
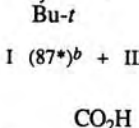
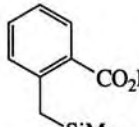
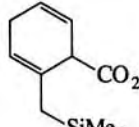
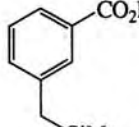
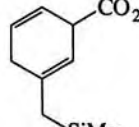
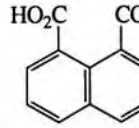
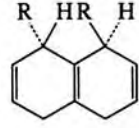
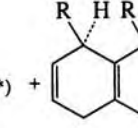
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), THF, 30 min	NH ₄ Cl	 (75) +  (20)	84, 142
	NH ₃ /Li (5), THF, 30 min	"	II (90)	84
	NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	EtOH	 (86)	436, 437
	NH ₃ /Li (3), 20 min	NH ₄ Cl	 (62*) +  (6*) +  (32*)	438

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), EtOH, 3 min	NH ₄ Cl	 (100*)	123
	"	"	 (99*)	123
	"	"	 (53*) ^b +  (10*) +  (31*)	123
	NH ₃ /Li (5), H ₂ O	—	I (87*) ^b + III (8*)	123
	NH ₃ /Li (5), EtOH, 3 min	NH ₄ Cl	 (100*)	123

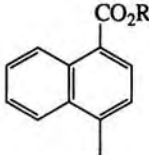
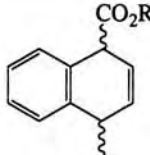
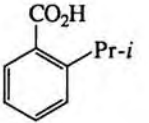
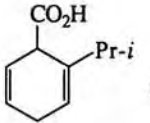
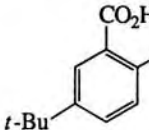
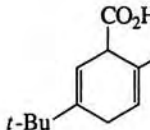
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), <i>t</i> -BuOH, Et ₂ O, 2 h	NH ₄ Cl, CH ₂ N ₂	 (87, 93*)	252
	"	"	 (95*)	252
	NH ₃ /Li, H ₂ O, 1 h	H ₂ O, CH ₂ N ₂	 (90*) +  (10*) R = CO ₂ Me	132

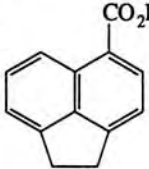
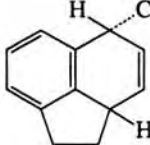
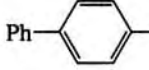
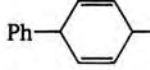
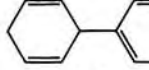
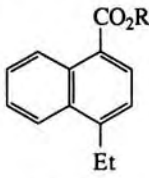
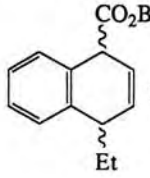
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
			 I	
R = H	NH ₃ /Li (4), Et ₂ O	NH ₄ Cl	I, (90) ^b	140
R = <i>t</i> -Bu	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 20 min	NH ₄ Cl ^a	I, (82) ^b ; <i>cis/trans</i> = 40/60	33
	NH ₃ /Li (5), EtOH	NH ₄ Cl	 (100*)	123
	"	"	 (100*)	123

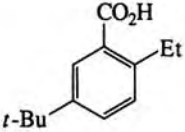
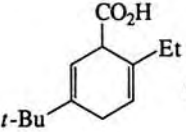
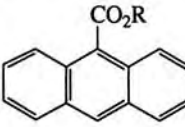
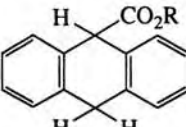
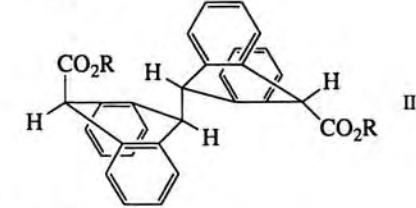
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), Et ₂ O, 10 min	NH ₄ Cl	 (85)	140
			 I +  II	
R = H	NH ₃ /Na (2.5), H ₂ O (1.5), THF, -78°, 15 min	NH ₄ Cl ^a	(-) I:II = 3:1	147, 145
R = Et	"	"	I (ca 100)	147
R = <i>t</i> -Bu	"	"	I (ca 100)	146
	"	"	 (80) ^b <i>cis/trans</i> = 40/60	33
R = <i>t</i> -Bu				

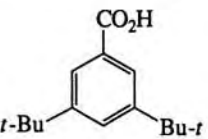
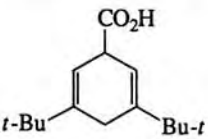
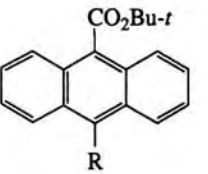
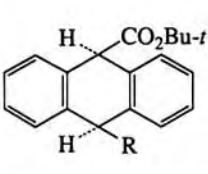
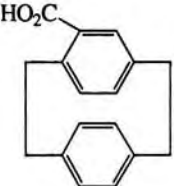
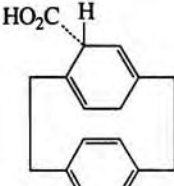
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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), EtOH, 3 min	NH ₄ Cl	 (100*)	123
C ₁₅ 	NH ₃ /Na (2.5), proton source, THF, 30 min	NH ₄ Cl ^a	 I +  II	229
R = Et	H ₂ O (1.5)	"	I (66, 92*)	
	—	"	I (25*) + II (44, 75*)	
R = <i>t</i> -Bu	H ₂ O (1.5)	"	I (65)	
	—	"	I (44*) + II (36, 56*)	

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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), EtOH	NH ₄ Cl	 (99*)	123
	NH ₃ /Na (2.5), H ₂ O (1.5), THF, 20 min	NH ₄ Cl ^a	 I	33
C ₁₆ R = Me			I (80)	
C ₁₇ R = Et			I (79)	
	NH ₃ /Na (2), EtOH, ^d THF, 1 h	NH ₄ Cl	 (86)	439

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TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

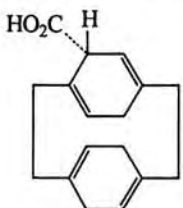
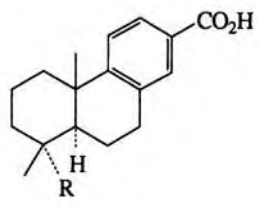
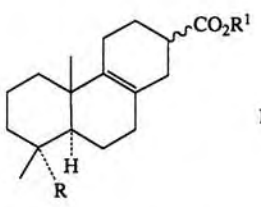
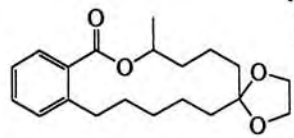
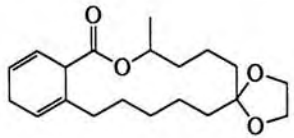
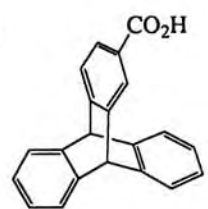
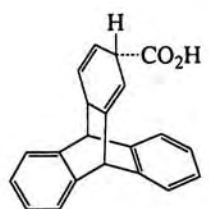
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (20), EtOH, ^d THF, 1 h	"	 (95.6*)	440
			 I	441
C ₁₈ R = CO ₂ H	NH ₃ /Li, EtOH, -78°, 20 min	H ₂ O, CH ₂ N ₂	I, R = CO ₂ Me; R ¹ = Me (18.3) ^b	
R = Me	NH ₃ /Li, THF, -78°, 3 h	EtOH	I, R = Me; R ¹ = H (95) ^b	

TABLE V. REDUCTION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₂₀ 	NH ₃ /Na, <i>t</i> -BuOH, THF, 30 min	"	 (89)	442
C ₂₁ 	NH ₃ /Na (3.5), EtOH, -78°, 25 min	NH ₄ Cl	 (40)	443

- ^a The reaction mixture was pumped (with argon pressure) through a glass tube into a large excess of saturated ammonium chloride.
- ^b The yield represents a mixture of *cis* and *trans* isomers.
- ^c Dry ethanol was added to the reaction mixture within 5 min; after an additional 5 min, before the blue color was discharged, excess solid ammonium chloride was added.
- ^d Metal and alcohol were added to the reaction mixture over a period of 1 h.

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES
A. Nitrogen Heterocycles


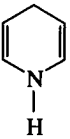
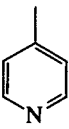


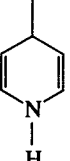

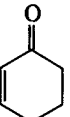
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C5 	NH ₃ /Li (3), EtOH	NH ₄ Cl	 (90)	444
C6 	NH ₃ /Li (2.5), -78°, 30 min	"	 (92)	444
	NH ₃ /Li (3), EtOH	"	 (80)	444
	NH ₃ /Na (2), EtOH	H ₂ O, 30% H ₂ SO ₄ , 100°, 6 h	 (12)	445

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

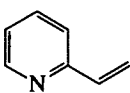
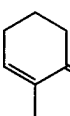
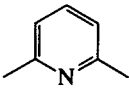
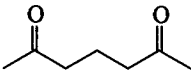
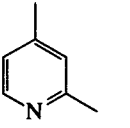
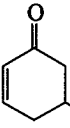
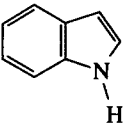
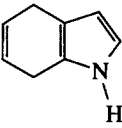
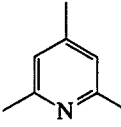
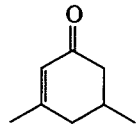
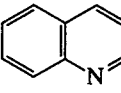
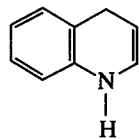
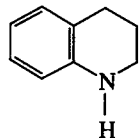
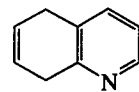
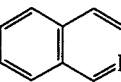
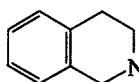
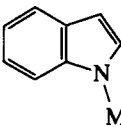
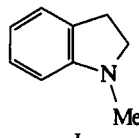
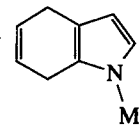
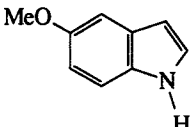
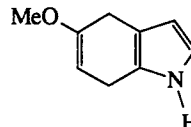
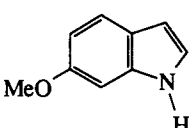
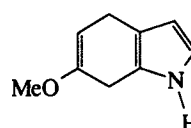
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C7 	Li (9.9)/NH ₃ , EtOH, Et ₂ O	1. EtOH, NaOH _{aq} (2.5 h, rt) 2. H ₃ O ⁺	 (63)	228
	NH ₃ /Na, EtOH	H ₂ O	 (72)	446
	NH ₃ /Na (2), EtOH	H ₂ O, 30% H ₂ SO ₄ , 100°, 6 h	 (17)	445
C8 	NH ₃ /Li (4), -78°	MeOH ^a	 (51)	447, 448

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ Na (2), EtOH	H ₂ O, 30% H ₂ SO ₄ , 100°, 6 h	 (30)	445
C ₉ 	NH ₃ /Li (4)	NH ₄ Cl	 (ca 100)	449
	NH ₃ /Li (5), 1 h	MeOH ^b	 (36) +  (8) + starting material (26)	448
	NH ₃ /Li (5), MeOH	H ₂ O	I (5) + II (24) + III (9)	
	NH ₃ /Na, EtOH	"	 (92)	450, 451

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, Et ₂ O	MeOH	 (—)	448, 452
	NH ₃ /Li, MeOH	H ₂ O	I (32) +  (37)	448, 452
	NH ₃ /Li (4)	MeOH ^b	 (82)	453
	NH ₃ /Li, MeOH, THF	H ₂ O	 (65)	448

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

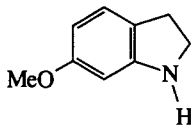
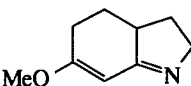
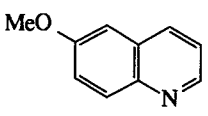
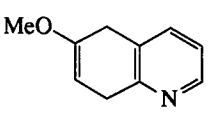
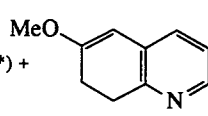
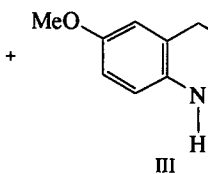
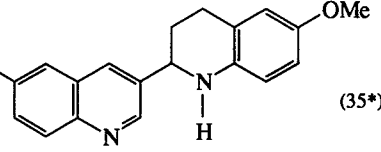
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, THF, 10 min	MeOH ^b	 (92)	454, 455
C ₁₀ 	NH ₃ /Li (5), MeOH (excess)	H ₂ O	 (32*) +  (16*) +  (5*) + starting material (8*)	448, 453
	NH ₃ /Li (2), 1 h	MeOH ^b	I (15*) +  (35*) + starting material (14*)	448
	NH ₃ /Li (5), 1 h	"	III (32*) + starting material (9*)	

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

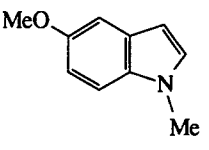
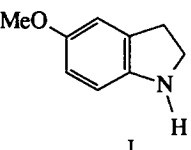
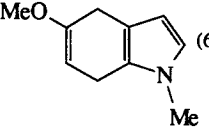
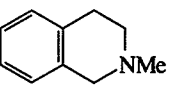
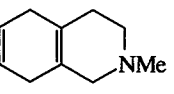
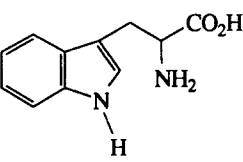
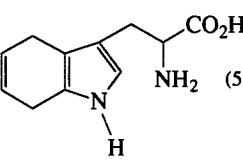
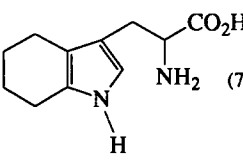
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (8), THF, 4 h	FeCl ₃ , MeOH	 (70*)	448, 453
	NH ₃ /Li (4), MeOH (excess)	H ₂ O	 (60*) + I (5*) starting material (8*)	448
	NH ₃ /Li, Et ₂ O, 15 min	EtOH ^c	 (89)	456
C ₁₁ 	NH ₃ /Li, -78°, 40 min	MeOH, ^b NH ₄ OAc	 (55*) +  (7)	457

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.												
	NH ₃ /Na, MeOH, Et ₂ O	H ₂ O	 <table border="0"> <tr> <td>R¹</td> <td>R²</td> <td></td> </tr> <tr> <td colspan="3"><hr/></td> </tr> <tr> <td>H</td> <td>OMe</td> <td>I (98)</td> </tr> <tr> <td>OMe</td> <td>H</td> <td>I (97)</td> </tr> </table>	R ¹	R ²		<hr/>			H	OMe	I (98)	OMe	H	I (97)	456, 336
R ¹	R ²															
<hr/>																
H	OMe	I (98)														
OMe	H	I (97)														
	Li/NH ₃ , THF, -75°, 1 h	EtOH ^b	 <table border="0"> <tr> <td>R¹</td> <td>R²</td> <td></td> </tr> <tr> <td colspan="3"><hr/></td> </tr> <tr> <td>H</td> <td>OMe</td> <td>I (77*)</td> </tr> <tr> <td>OMe</td> <td>H</td> <td>I (50*)</td> </tr> </table>	R ¹	R ²		<hr/>			H	OMe	I (77*)	OMe	H	I (50*)	458
R ¹	R ²															
<hr/>																
H	OMe	I (77*)														
OMe	H	I (50*)														
	NH ₃ /Li (3.4), -78°	<i>i</i> -PrOH ^a		447, 452												

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
"	NH ₃ /Na, EtOH, THF	H ₂ O		452
	Li (6)/NH ₃ , EtOH, Et ₂ O	1. EtOH, NaOH _{aq} (2.5 h, rt) 2. H ₃ O ⁺		228
	NH ₃ /K (4.4), <i>t</i> -BuOH (2), THF, -78°, 45 min	NH ₄ Cl		162
	NH ₃ /K (8), <i>t</i> -BuOH (2), THF, -78°, 45 min	"		162

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

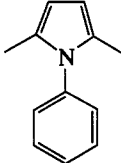
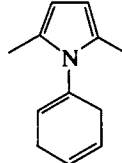
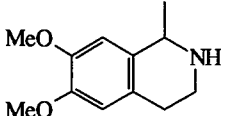
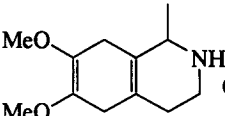
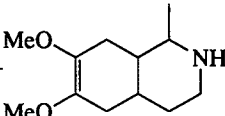
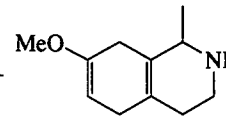
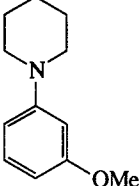
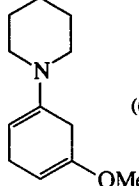
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5.6), MeOH	H ₂ O	 (—)	459
	Li/NH ₃ , THF, -75°, 1 h	EtOH ^b	 (50*) +  (16*) +  (34*)	458
	NH ₃ /Li (10), <i>t</i> -BuOH, THF, -70°, 2 h	EtOH	 (63)	460

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

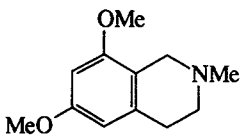
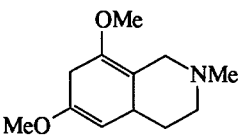
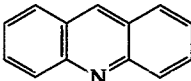
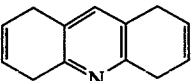

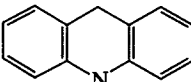
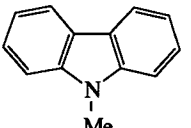
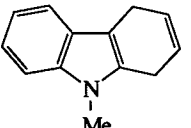
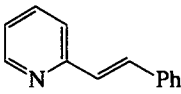
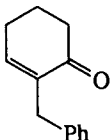
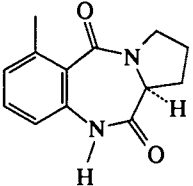
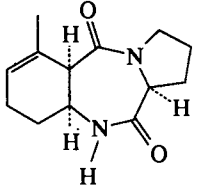
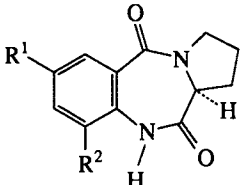
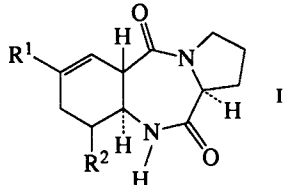
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (10), <i>t</i> -BuOH, Et ₂ O	NH ₄ Cl	 (45)	461
	NH ₃ /Li, EtOH, THF	H ₂ O	 (62)	462
	NH ₃ /Li, NH ₄ OAc, THF	"	 (—)	462
	NH ₃ /Na, THF, 30 min	NH ₄ Cl	 (—)	452

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)


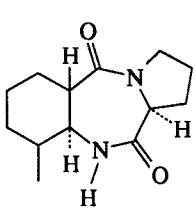
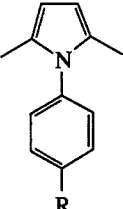
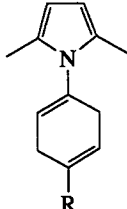
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.									
	Na (6)/NH ₃ , EtOH, Et ₂ O	1. EtOH NaOH _{aq} (2.5 h, rt) 2. H ₃ O ⁺	 (52)	228									
	NH ₃ /K (4.4), <i>t</i> -BuOH (2), THF, -78°, 45 min	NH ₄ Cl	 (49*)	162									
	"	"	 I	162									
			<table border="0"> <tr> <td>R¹</td> <td>R²</td> <td></td> </tr> <tr> <td>Me</td> <td>H</td> <td>I (84)</td> </tr> <tr> <td>H</td> <td>Me</td> <td>I (49)</td> </tr> </table>	R ¹	R ²		Me	H	I (84)	H	Me	I (49)	
R ¹	R ²												
Me	H	I (84)											
H	Me	I (49)											

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.				
	NH ₃ /K (8), <i>t</i> -BuOH (2), THF, -78°, 45 min	NH ₄ Cl	 (86)	162				
	NH ₃ /Na (5.6), EtOH	H ₂ O	 I	459				
			<table border="0"> <tr> <td>R = Me</td> <td>I (—)</td> </tr> <tr> <td>R = OMe</td> <td>I (—)</td> </tr> </table>	R = Me	I (—)	R = OMe	I (—)	
R = Me	I (—)							
R = OMe	I (—)							

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

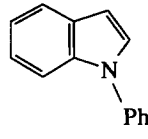
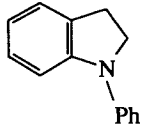
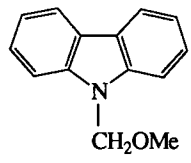
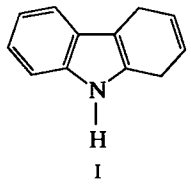
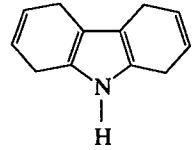
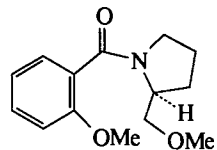
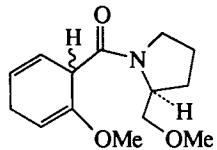
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₄ 	NH ₃ /Na (2.2), THF, 15 min	NH ₄ Cl	 (87)	463
	NH ₃ /Na, THF, 30 min	NH ₄ Cl, H ₃ O ⁺	 (70)	452
	NH ₃ /Na, EtOH, THF	H ₂ O, H ₃ O ⁺	I (8) +  (42)	452
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°	NH ₄ Cl	 (92)	39

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

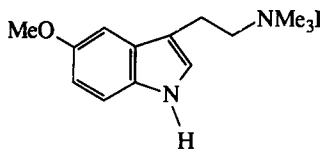
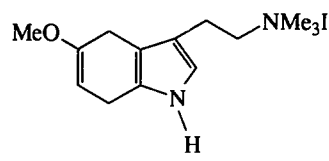
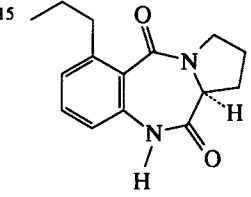
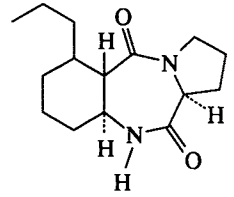
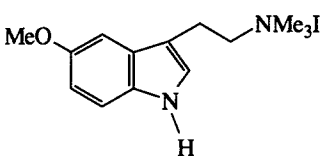
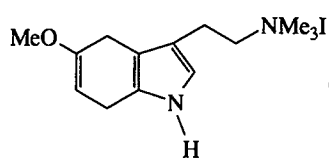
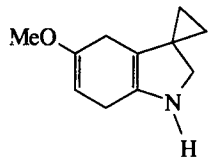
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, MeOH (excess)	H ₂ O	 (43)	464
C ₁₅ 	NH ₃ /K (8), <i>t</i> -BuOH (5), THF, -78°	NH ₄ Cl	 (83)	163
	NH ₃ /Li, MeOH (excess)	H ₂ O	 (46)	464
	NH ₃ /Li (4)	"	 (83)	464

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

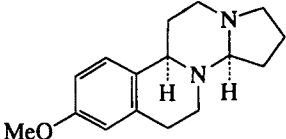
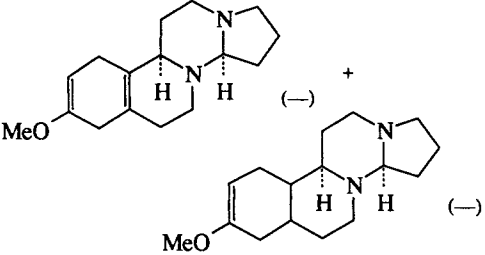
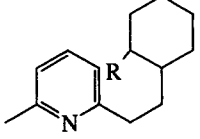
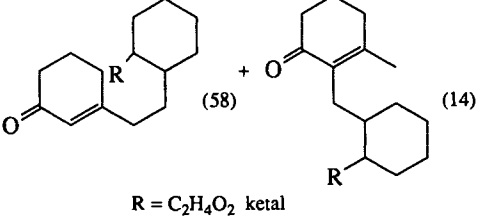
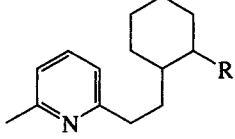
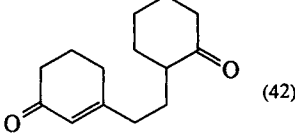
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
<p>C16</p> 	Li/NH ₃ , THF	EtOH ^b		458
 <p>R = C₂H₄O₂ ketal</p>	NH ₃ /Li (2.2), EtOH, Et ₂ O, 15 min	EtOH, NaOH _{aq} (2.5 h, rt)		465
 <p>R = C₂H₄O₂ ketal</p>	NH ₃ /Na, EtOH, Et ₂ O, 15 min	1. EtOH, NaOH _{aq} (2.5 h, rt) 2. H ₃ O ⁺		466

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

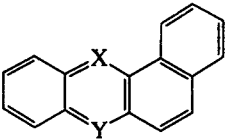
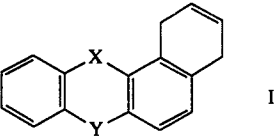
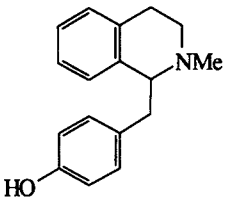
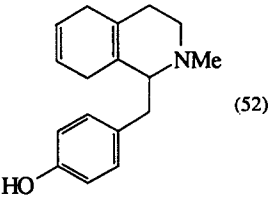
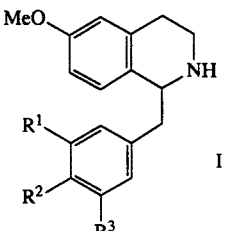
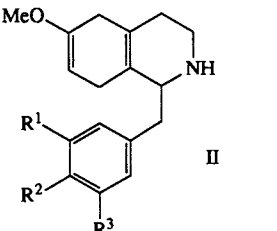
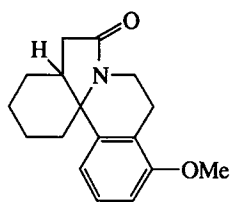
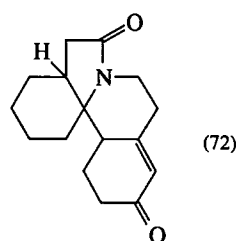
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
<p>C17</p>  <p>X = CH; Y = NH X = NH; Y = CH</p>	NH ₃ /Li (2), THF, 20 min	MeOH ^b	 <p>I, X = CH₂; Y = NH (42) I, X = NH; Y = CH₂ (50)</p>	467
	NH ₃ /Li, EtOH, 2 h	NH ₄ Cl		468
 <p>I</p>	Li/NH ₃ , <i>t</i> -BuOH, Et ₂ O, -70°, 1 h		 <p>II</p>	

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

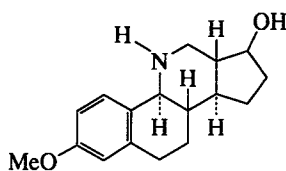
Reactant			Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)			Refs.			
R ¹	R ²	R ³			R ¹	R ²	R ³				
(+)-I	H	H	OH	"	MeOH	(+)-II	H	H	OH	(96)	469, 470
I	H	OBn	H	"	"	II	H	OH	H	(90)	311
I	OH	H	OH	"	NH ₄ Cl	II	OH	H	OH	(95)	471
I	OBn	H	OBn	"	"	II	"	"	"	(92)	472, 471



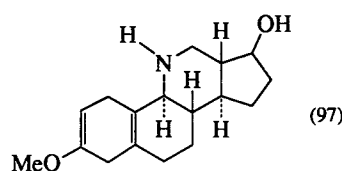
NH₃/Li, EtOH, 15 min
NH₄Cl, H₃O⁺



473



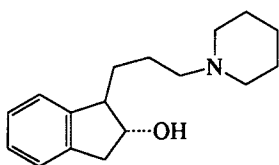
NH₃/Li, *t*-BuOH, THF, 5 h
H₂O



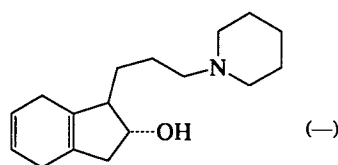
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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

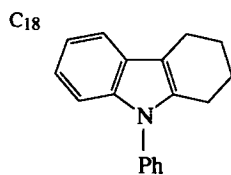
Reactant			Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)			Refs.
R ¹	R ²	R ³			R ¹	R ²	R ³	



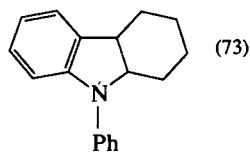
NH₃/Li, Et₂O, 2 h
EtOH



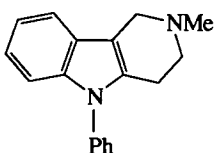
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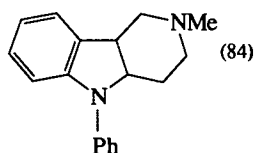
NH₃/Na (2.2), THF, 15 min
NH₄Cl



463

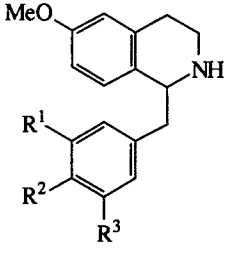
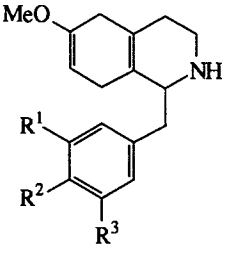
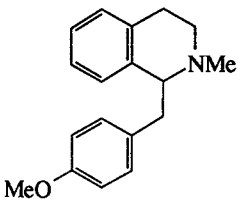
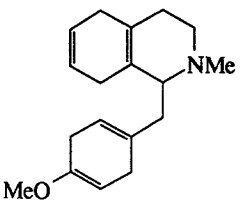


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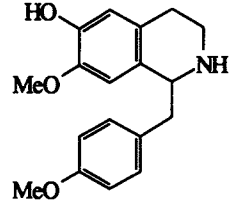
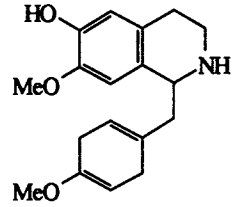
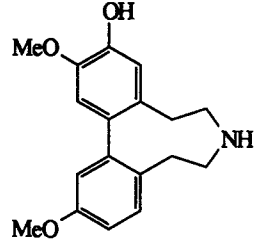
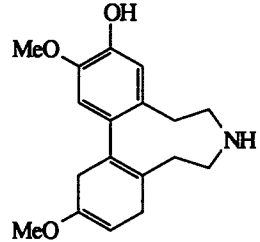
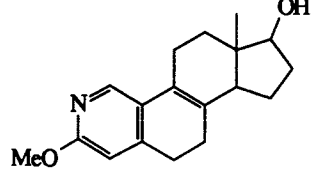
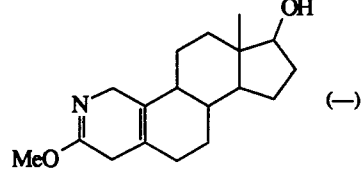
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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , <i>t</i> -BuOH, Et ₂ O, -70°, 1 h			
R ¹ R ² R ³			R ¹ R ² R ³	
OMe H OH	"	MeOH	OMe H OH (78)	472
H OMe OH	"	NH ₄ Cl	H OMe OH (90)	476
OBn OMe H	"	"	OH OMe H (75)	311, 477
OH OMe OH	"	MeOH	OH OMe OH (95)	478
OBn OMe OBn	"	"	" " " (90)	311
	NH ₃ /Li, EtOH, 2 h	NH ₄ Cl	 (36)	468

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (10), <i>t</i> -BuOH, ^a THF	H ₂ O	 (71)	479
	NH ₃ /Na, MeOH, THF, Et ₂ O, -70°	NH ₄ Cl	 (96)	480, 481
	NH ₃ /Na, THF, -70°, 2 h	"	 (—)	482

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.															
	Li/NH ₃ , <i>t</i> -BuOH, THF, -70°, 2 h	MeOH																	
<table border="0"> <tr> <td>R¹</td> <td>R²</td> </tr> <tr> <td>H</td> <td>H</td> </tr> <tr> <td>Ms</td> <td>OH</td> </tr> </table>	R ¹	R ²	H	H	Ms	OH			<table border="0"> <tr> <td>R¹</td> <td>R²</td> <td></td> </tr> <tr> <td>H</td> <td>H</td> <td>(83)</td> </tr> <tr> <td>H</td> <td>OH</td> <td>(ca 100)</td> </tr> </table>	R ¹	R ²		H	H	(83)	H	OH	(ca 100)	483 484
R ¹	R ²																		
H	H																		
Ms	OH																		
R ¹	R ²																		
H	H	(83)																	
H	OH	(ca 100)																	
	NH ₃ /Li, <i>t</i> -BuOH, THF, 1 h	NH ₄ Cl		485															

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																			
	NH ₃ /Na, <i>t</i> -BuOH, 6 h	MeOH		486																			
<table border="0"> <tr> <td>R¹</td> <td>R²</td> </tr> <tr> <td>H</td> <td>OMe</td> </tr> <tr> <td>S (-)</td> <td>OMe</td> </tr> <tr> <td></td> <td>H</td> </tr> </table>	R ¹	R ²	H	OMe	S (-)	OMe		H	NH ₃ /Na, <i>t</i> -BuOH ^a	"	I (95)	487, 488											
R ¹	R ²																						
H	OMe																						
S (-)	OMe																						
	H																						
	Li/NH ₃ , <i>t</i> -BuOH, THF, -60°, 30 min	MeOH		489																			
<table border="0"> <tr> <td>R¹</td> <td>R²</td> </tr> <tr> <td>(-)</td> <td>OH</td> </tr> <tr> <td></td> <td>OMe</td> </tr> <tr> <td></td> <td>OBn</td> </tr> <tr> <td></td> <td>OMe</td> </tr> </table>	R ¹	R ²	(-)	OH		OMe		OBn		OMe			<table border="0"> <tr> <td>R¹</td> <td>R²</td> <td></td> </tr> <tr> <td>(+)</td> <td>OH</td> <td>OMe (72)</td> </tr> <tr> <td></td> <td>OH</td> <td>OMe (85)</td> </tr> </table>	R ¹	R ²		(+)	OH	OMe (72)		OH	OMe (85)	489 311
R ¹	R ²																						
(-)	OH																						
	OMe																						
	OBn																						
	OMe																						
R ¹	R ²																						
(+)	OH	OMe (72)																					
	OH	OMe (85)																					

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF	H ₂ O	 (—)	490
	NH ₃ /Li, <i>t</i> -BuOH, THF, 30 min	<i>t</i> -BuOH, EtOH ^b	 (96)	491
	NH ₃ /K (5), proton source, -78°, 10 min	NH ₄ Cl	 I + II	164

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	<i>t</i> -BuOH (1)	"	I (70) + II (1)	
	<i>t</i> -BuOH (5)	"	I (50) + II (31)	
	<i>t</i> -BuOH (10), 45 min	"	I (26) + II (59)	
	Li/NH ₃ , EtOH, -60°	NH ₄ Cl	 (—)	477
	Na/NH ₃ , THF, -70°, 30 min	"	 (ca 100)	482

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, 6 h	"	(78)	485
	NH ₃ /Li, <i>i</i> -PrOH, THF, 2 h	"	(83)	492
	NH ₃ /Li, <i>t</i> -BuOH, THF, 1 h	"	(76)	485

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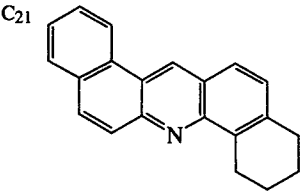
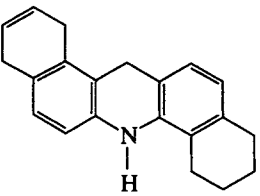
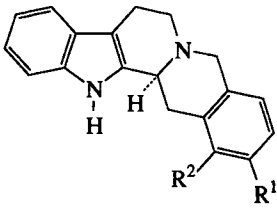
TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>i</i> -BuOH, THF	"	(68)	490
	Na/NH ₃ , <i>i</i> -BuOH	"	(—)	493
	NH ₃ /Li, MeOH, THF	H ₂ O, H ₃ O ⁺	(59)	76

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

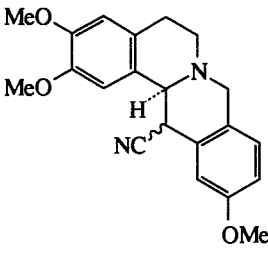
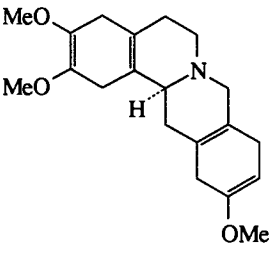
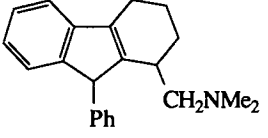
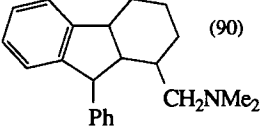
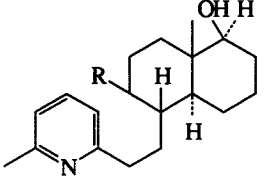
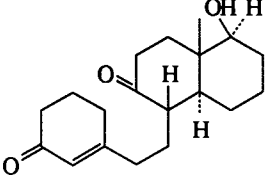
A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, THF, 20 min	EtOH ^b	 (ca 100)	494
	NH ₃ /Li, <i>i</i> -PrOH, HMPA	H ₂ O, CH ₂ N ₂	I, R ¹ = OMe; R ² = CO ₂ H (35)	495
R ¹ = OMe; R ² = CO ₂ H	NH ₃ /Li, <i>i</i> -PrOH, THF, -78°, 5 h	NH ₄ Cl	I, R ¹ = OMe; R ² = CH ₂ OH (32)	496

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH, THF, 6 h	NH ₄ Cl	 (74)	485
	NH ₃ /Na (2.2), THF, 15 min	"	 (90)	463
	NH ₃ /Na (2.2), EtOH, Et ₂ O, 15 min	1. EtOH, NaOH _{aq} (2.5 h, rt) 2. H ₃ O ⁺	 (93)	465, 497
R = C ₂ H ₄ O ₂ ketal				

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TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

A. Nitrogen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 C ₂₂	NH ₃ /Na, <i>i</i> -PrOH	—	 (—)	498
 R = C ₂ H ₄ O ₂ ketal	NH ₃ /Na (3), EtOH, Et ₂ O, -70°, 1 h	H ₂ O, NaOH	 (65)	499

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)

B. Oxygen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 C ₅	Li (2.5)/NH ₃ , -78°, 3 min	NH ₄ Cl	 (80)	500
	NH ₃ /Na, G ^c	H ₂ O, CH ₂ N ₂	 (—)	501
	NH ₃ /Na (3), MeOH, 1 h	NH ₄ Cl, H ₃ O ⁺ , CH ₂ N ₂	 (87)	502, 503
	NH ₃ /Na (5), EtOH, 1 h	"	 (92)	502
	NH ₃ /Na (3), <i>i</i> -PrOH, 1 h	"	 (85)	502

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
B. Oxygen Heterocycles

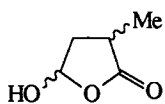
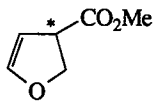
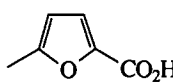
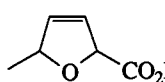
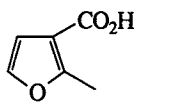
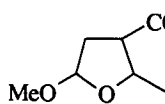
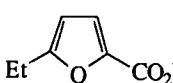
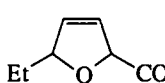
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), 35 min	NH ₄ Cl, H ₃ O ⁺	 (28)	504
	NH ₃ /Na, G ^c	H ₂ O, CH ₂ N ₂	 (—)	501
C ₆ 	NH ₃ /Li (3), MeOH, 30 min	MeOH, HCl ^e	 (83,90*)	505, 506
	NH ₃ /Na, MeOH, 1 h	NH ₄ Cl, H ₃ O ⁺ , CH ₂ N ₂	 (95)	507
C ₇ 	NH ₃ /Li (3), MeOH, 30 min	MeOH, HCl ^d	 (85,90*)	505

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
B. Oxygen Heterocycles

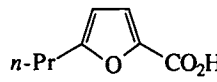
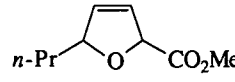
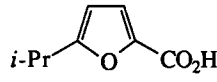
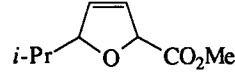
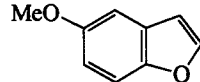
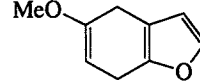
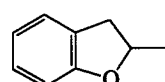
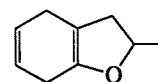
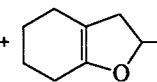
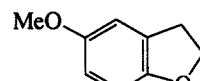
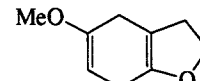
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₈ 	"	"	 (75,93*)	505
	"	"	 (70,85*)	505
C ₉ 	NH ₃ /Li (5), EtOH	NH ₄ Cl	 (88)	508
	NH ₃ /Li, <i>t</i> -BuOH, Et ₂ O, 6.5 h	MeOH ^a	 (—) +  (—) main product	509
	NH ₃ /Li (5), EtOH	NH ₄ Cl	 (—)	508

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
B. Oxygen Heterocycles

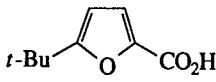
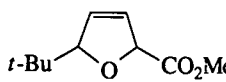
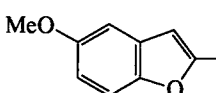
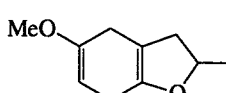
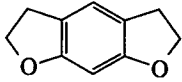
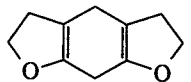
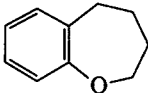
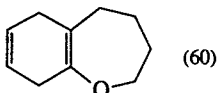
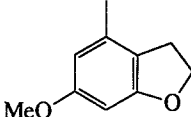
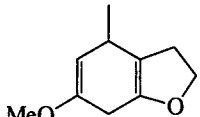
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), MeOH, 30 min	MeOH, HCl ^d	 (71,87*)	505
C ₁₀ 	NH ₃ /Li, EtOH	NH ₄ Cl	 (70)	508
	NH ₃ /Na (4), EtOH, THF, -70°	"	 (—)	510
	NH ₃ /Na (4), EtOH, THF, -70°	NH ₄ Cl	 (60)	510
	NH ₃ /Li, Et ₂ O, 2 h	EtOH ^b	 (81)	511

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
B. Oxygen Heterocycles

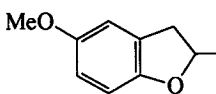
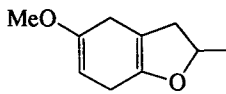
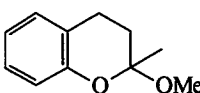
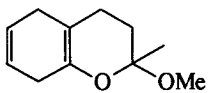
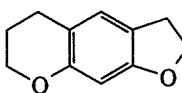
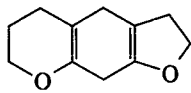
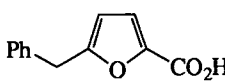
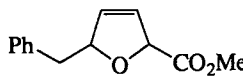
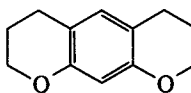
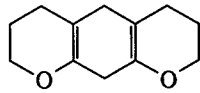
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3.8), EtOH	NH ₄ Cl	 (80)	508
C ₁₁ 	NH ₃ /Li, <i>t</i> -BuOH, THF	"	 (82)	512
	NH ₃ /Na (4), EtOH, THF, -70°	"	 (—)	510
C ₁₂ 	NH ₃ /Li (3), MeOH, 30 min	MeOH, HCl ^d	 (40,55*)	505
	NH ₃ /Na (4), EtOH, THF, -70°	NH ₄ Cl	 (—)	510

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
B. Oxygen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	(—)	510
	NH ₃ /Li, <i>t</i> -BuOH, THF	"	(—)	512
C13 	NH ₃ /Li (3), MeOH, 30 min	MeOH, HCl ^d	(40,50*)	505
	NH ₃ /Na (4), EtOH, THF, -70°	NH ₄ Cl	(67)	510
C15 	NH ₃ /Li (5), <i>t</i> -BuOH, THF	—	(—)	512

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (*Continued*)
B. Oxygen Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (8), <i>t</i> -BuOH, Et ₂ O, 2 h	MeOH	(—)	513
	"	"	(—)	513
C19 	NH ₃ /Li, Et ₂ O	EtOH ^b	(ca 100)	514

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
B. Oxygen Heterocycles

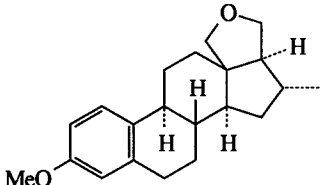
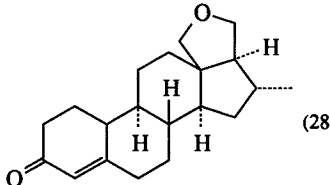
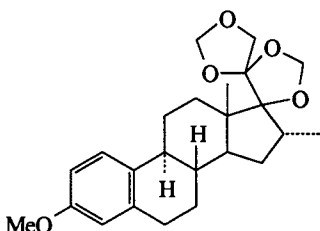
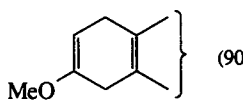
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C21 	NH ₃ /Li, <i>t</i> -BuOH, Et ₂ O, 3.5 h	MeOH, H ₃ O ⁺	 (28)	515
C24 	NH ₃ /Li, EtOH, -78°	NH ₄ Cl	 (90)	516

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
C. Sulfur Heterocycles




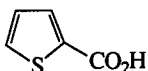
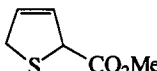
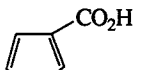
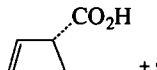






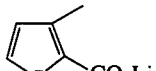
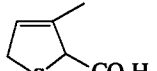
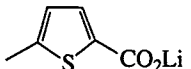
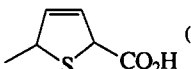
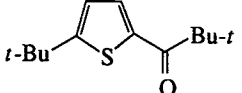
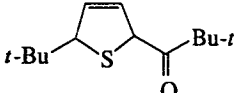
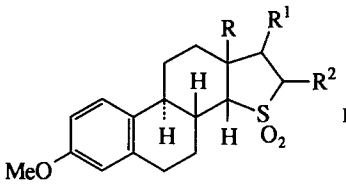
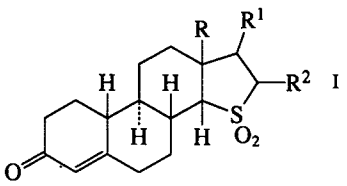
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C4 	NH ₃ /Li (2.2), MeOH, -40°, 8 h	H ₂ O	 (12) +  (26) + starting material (30) + cleaved product (17)	517
C5 	NH ₃ /Li (3), 5 min	NH ₄ Cl, CH ₂ N ₂	 (78*)	518, 519
	NH ₃ /Na (2.5), <i>i</i> -PrOH, 1 h	H ₃ O ⁺	 + starting material (→) 3:2	520
	NH ₃ /Li (2.2), MeOH, -40°, 8 h	H ₂ O	 (7) +  (32) + starting material (27) + cleaved product (10)	521
	"	"	 +  + starting material + cleaved product (→)	521
C6 	NH ₃ /Li (2), 30 min	NH ₄ Cl	 (75)	522

TABLE VI. REDUCTION OF AROMATIC HETEROCYCLES (Continued)
C. Sulfur Heterocycles

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (50)	522
	NH ₃ /Li, <i>t</i> -BuOH, -78°, 10, min	—	 (88)	523
C ₁₈ 	Li/NH ₃ , THF, -78°	EtOH, H ₃ O ⁺	 I	524
<u>R</u> <u>R¹</u> <u>R²</u>			<u>R</u> <u>R¹</u> <u>R²</u>	
H OAc H			I H OH H (73)	
H H OAc			I H H OH (62)	
C ₁₉ Me OAc H			I Me OH H (58)	

^a Metal and alcohol were added slowly in alternating proportions to the reaction mixture.

^b Alcohol was added slowly to the reaction mixture until the color disappeared.

^c The use of 1,2:5,6-di-*O*-isopropylidene- α -D-glycopyranose (G) as the proton source caused asymmetric reduction.

^d The mixture, after removal of the ammonia, was mixed with dry methanol. Hydrogen chloride gas was passed into the solution until the pH became 1.

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS

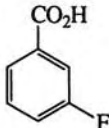
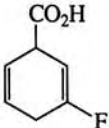


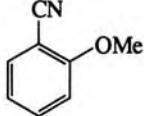
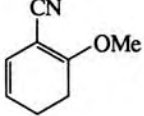
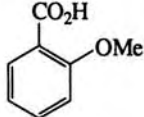
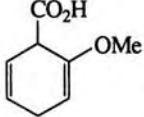
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₇ 	NH ₃ /Na (3), EtOH	NH ₄ Cl	 (50)	525
	Li, NH ₃ , Et ₂ O, -78°, 45 min	EtOH	 (ca 100)	526
C ₈ 	NH ₃ /Li, <i>t</i> -BuOH, THF, -78°	NH ₄ Cl	 (76)	157
	NH ₃ /Li (2.5), MeOH, ^a 35 min	"	 (—)	131, 435

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

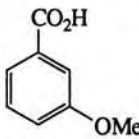
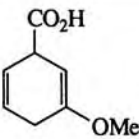
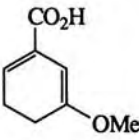
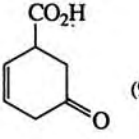
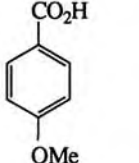
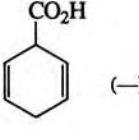
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₈ 	NH ₃ /Li (2.5)	"	 (ca 100)	131, 129
	NH ₃ /Na, EtOH, 45 min	"	 (96)	130, 527
	NH ₃ /Li (3), H ₂ O, 30 min	H ₃ O ⁺	 (94)	528
	NH ₃ /Li (2.5)	NH ₄ Cl	 (—)	131, 128

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

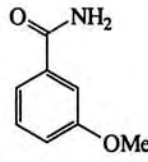
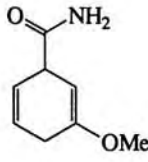
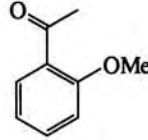
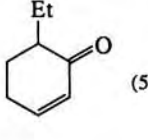
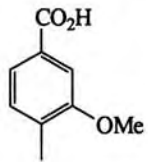
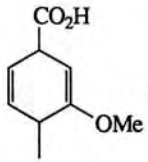
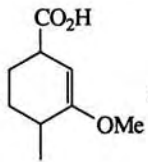
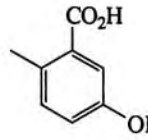
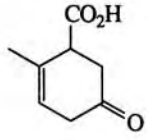
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (7.6), EtOH	"	 (31)	120, 155
C ₉ 	NH ₃ /Na, MeOH, Et ₂ O	H ₂ O, H ₃ O ⁺	 (50)	101
	NH ₃ /Li (3), <i>t</i> -BuOH	NH ₄ Cl	 (—) +  (—) main product	529
	NH ₃ /Li, 2 h	EtOH, NH ₄ Cl, H ₃ O ⁺	 (76)	530, 531

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

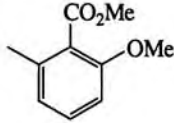
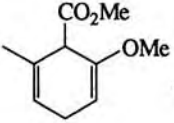
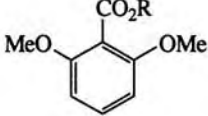
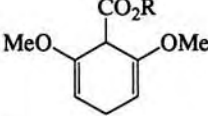
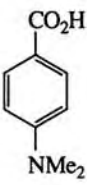
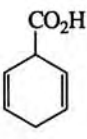
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K, <i>t</i> -BuOH, THF	NH ₄ Cl	 (—)	92
	NH ₃ /Na, Et ₂ O	NH ₄ Cl	 I	532
	NH ₃ /K (2.5), <i>t</i> -BuOH (1.5), THF, -78°, 35 min	"	R = H I (80) R = Me I (91)	149
	NH ₃ /Li (4)	NH ₄ Cl	 (—)	131

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

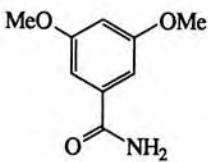
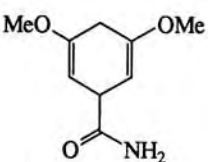
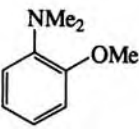
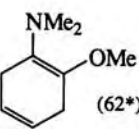
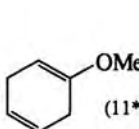
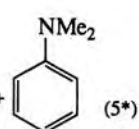
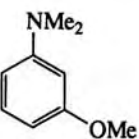
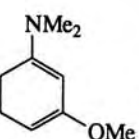
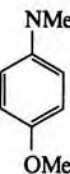
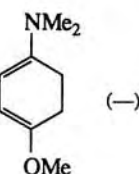
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (5), EtOH	"	 (68)	156
	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 80 min	EtOH	 (62*) +  (11*) +  (5*)	169
	"	"	 (92)	169
	"	"	 (—)	169

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
<p>C₁₀</p>	NH ₃ /Na, EtOH, dioxane, 4 h	MeOH	<p>I + II (50*)</p> <p>(16*)</p>	306
	NH ₃ /Na (5.2), EtOH	NH ₄ Cl	<p>(87)</p>	120, 533
	"	"	<p>(—)</p>	534

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	<p>(73)</p>	120, 156
<p>C₁₁</p> <p>R = Me</p>	NH ₃ /Na, MeOH, 2 h	NH ₄ Cl, H ₃ O ⁺	<p>(68)</p>	535
	NH ₃ /Na (2.3), <i>t</i> -BuOH	H ₂ O	<p>(—)</p>	536
	NH ₃ /Na, EtOH, Et ₂ O, 3 h ^b	"	<p>(67)</p>	537

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

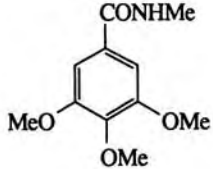
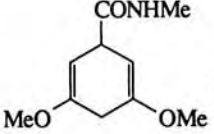
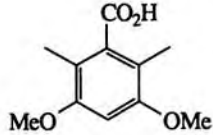
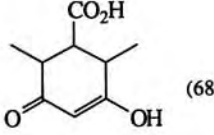
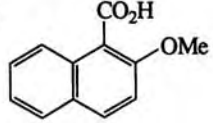
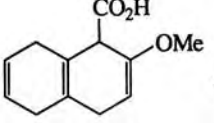
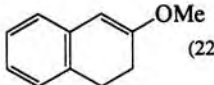
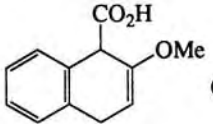
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₁ 	NH ₃ /Na (5), EtOH	NH ₄ Cl	 (90)	154, 120
	NH ₃ /Na, EtOH, THF	NH ₄ Cl, H ₃ O ⁺	 (68.5)	538
C ₁₂ 	NH ₃ /Li (10), Et ₂ O, 30 min	EtOH	 (52)	437
	NH ₃ /Na (2.5), EtOH, THF	H ₂ O, CH ₂ N ₂	 (22) +  (66)	539

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

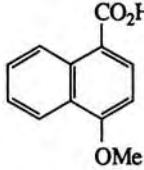
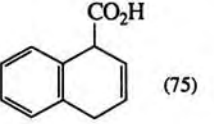
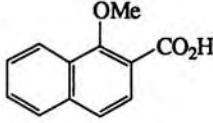
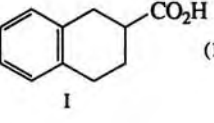
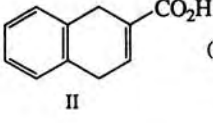
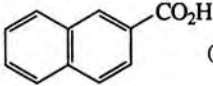
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), 30 min	NH ₄ Cl	 (75)	84
	NH ₃ /Li (3), 30 min	NH ₄ Cl	 I (10) +  II (60)	84
	NH ₃ /Li (5), 30 min	"	I (75)	84
	NH ₃ /Li (5), 30 min, FeCl ₃	"	I (15) + II (40) +  (10)	84, 142

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

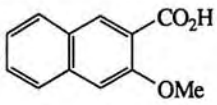
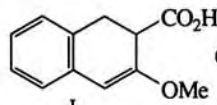
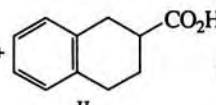
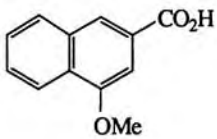
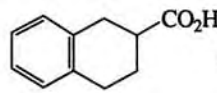
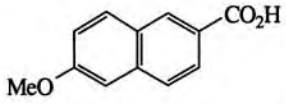
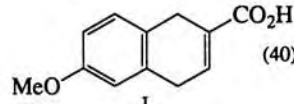
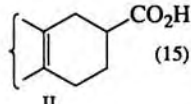
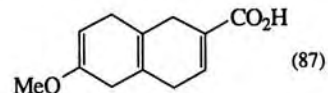
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), 30 min	"	 (65) +  (25)	84
	NH ₃ /Li (3), 30 min	"	II (85)	
	" + FeCl ₃	"	I (80)	
	NH ₃ /Li (5), 30 min	"	 (80)	84, 142
	NH ₃ /Li (3), 30 min	"	 (40) +  (15)	84
	NH ₃ /Li (3), 30 min	"	II (95)	
	" + FeCl ₃	"	I (80)	
	NH ₃ /Li, <i>t</i> -BuOH, THF, 4 h	MeOH	 (87)	144

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

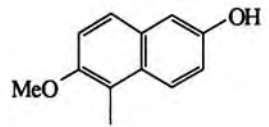
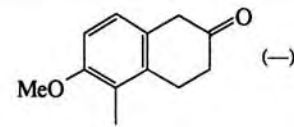
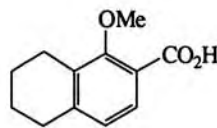
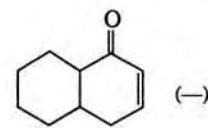
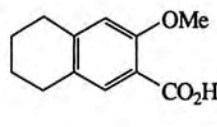
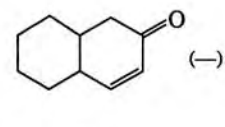
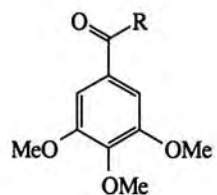
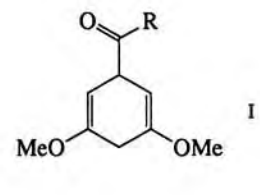
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, EtOH	H ₂ O	 (—)	540
	NH ₃ /Na, EtOH	H ₂ O, H ₃ O ⁺	 (—)	339
	NH ₃ /Na, <i>t</i> -BuOH, THF	NH ₄ Cl, H ₃ O ⁺	 (—)	541
	NH ₃ /Na (4-6), EtOH	NH ₄ Cl	 I	120

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

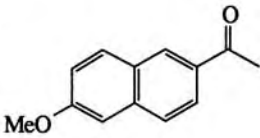
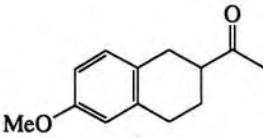
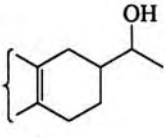
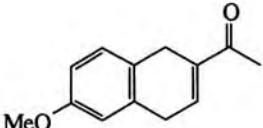
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
			I R = NHCH ₂ CO ₂ H (40) I R = NHCH ₂ CONH ₂ (10) I R = NMe ₂ (6) I R = NHEt (64) I R = NHCH ₂ CH ₂ OH (—)	
C ₁₃ 	NH ₃ /Li (2, 4 or 8), THF, 30 min	NH ₄ Cl	 +  I + II (90) I : II = 1 : 1	111, 542
	NH ₃ /K (4 or 6), " THF, 30 min		 (70)	111

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

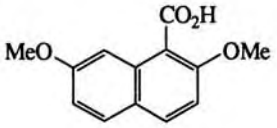
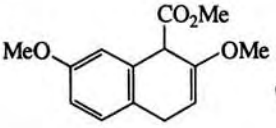
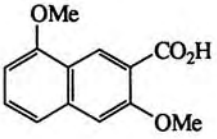
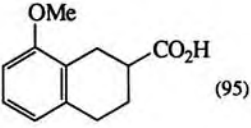
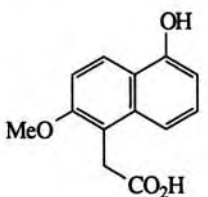
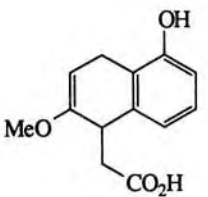
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (2.5), EtOH, THF	H ₂ O, CH ₂ N ₂	 (75)	539, 543
	NH ₃ /Li (8), t-BuOH, THF, 5 min	NH ₄ Cl	 (95)	143
	NH ₃ /Li	EtOH	 (61)	544

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

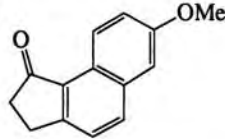
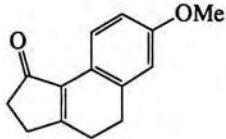
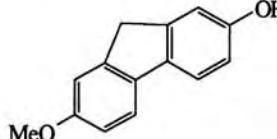
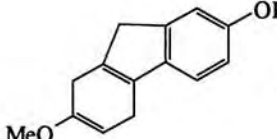
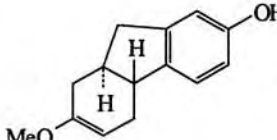
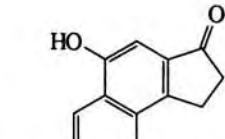
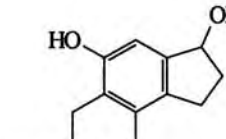
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₄ 	NH ₃ /Na, EtOH, THF, 3 min	NH ₄ Cl	 (86)	545
	NH ₃ /Li (6), <i>t</i> -BuOH	"	 (73)	546
	NH ₃ /Li (90), EtOH	"	 (50)	546
	NH ₃ /Li, THF, 2 h	"	 (80-85)	547, 548

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

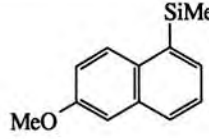
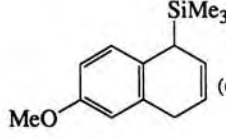
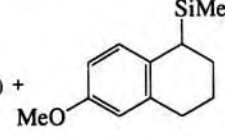
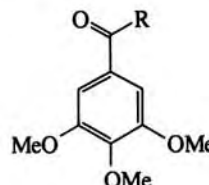
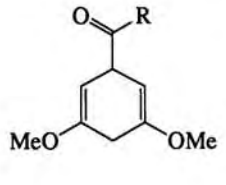
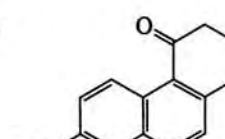
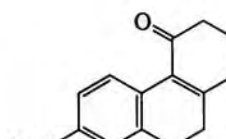
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, -78°, 20 min	NH ₄ Cl	 (67*) +  (18*)	172
	NH ₃ /Na (5), EtOH	NH ₄ Cl	 I	120
R = NEt ₂			I (82)	
R = NHBu- <i>t</i>			I (2)	
C ₁₅ 	NH ₃ /M (2, 4 or 6), THF, 30 min M = Na, Li, K	NH ₄ Cl	 (70-80)	112, 545

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

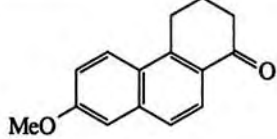
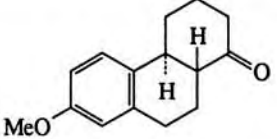
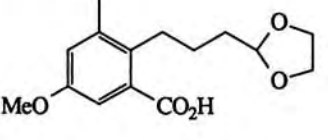
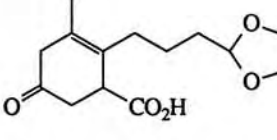
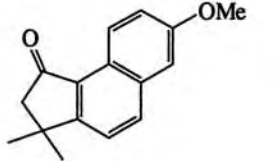
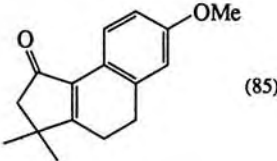
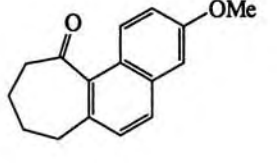
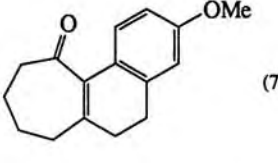
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /M (4), THF, FeCl ₃ , 30 min M = Na, Li	"	 (80-90)	112
	NH ₃ /Li, <i>t</i> -BuOH, THF	NH ₄ Cl, H ₃ O ⁺	 (80)	374
^{C16} 	NH ₃ /Na, EtOH, THF	NH ₄ Cl	 (85)	545
	"	"	 (78)	545

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

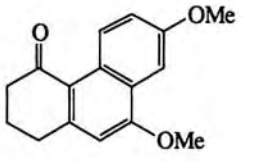
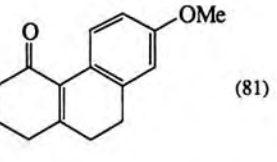
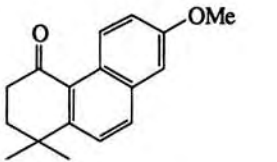
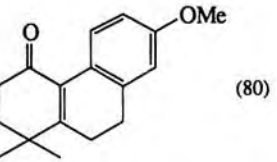
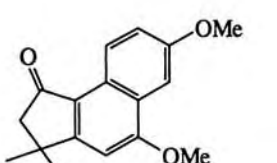
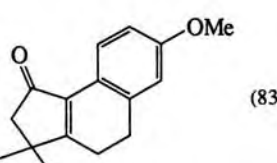
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (81)	549
^{C17} 	NH ₃ /Na, EtOH, THF	NH ₄ Cl	 (80)	550
	"	"	 (83.5)	549

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₈ 	NH ₃ /Li, <i>t</i> -BuOH	NH ₄ Cl, H ₃ O ⁺	(—)	166
	NH ₃ /Li, <i>t</i> -BuOH	1. MeI- K ₂ CO ₃ 2. H ₃ O ⁺	(—)	551
	NH ₃ /Li, EtOH	NH ₄ Cl	(75)	552

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₉ 	NH ₃ /Li, EtOH, THF, 30 min	H ₂ O	(—)	116
	NH ₃ /Li, <i>t</i> -BuOH, THF, 3 h	MeOH, H ₃ O ⁺	(27)	397
	NH ₃ /Li, Et ₂ O, 1 h	EtOH, Ac ₂ O in pyridine, 20°, 10 h	(5) + (10)	397

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

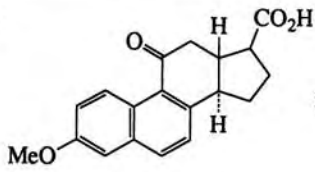
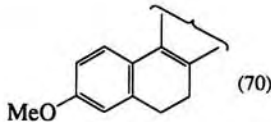
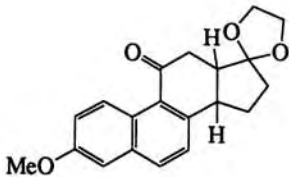
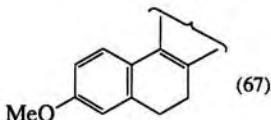
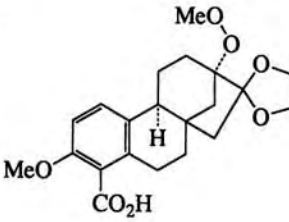
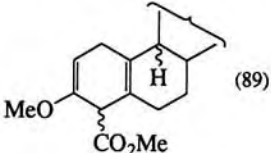
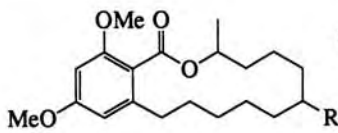
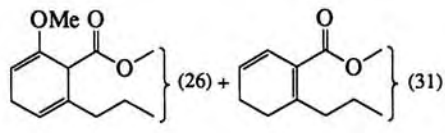
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
<p>C₂₀</p> 	NH ₃ /Na, EtOH, THF	NH ₄ Cl	 (70)	553
	"	"	 (67)	432
<p>C₂₂</p> 	NH ₃ /Na (2.5), <i>t</i> -BuOK (1) ^c , THF, -78°, 15 min	H ₂ O, CH ₂ N ₂	 (89)	554

TABLE VII. REDUCTION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 <p>R = C₂H₄O₂ ketal</p>	NH ₃ /Na, <i>t</i> -BuOH, THF	NH ₄ Cl	 (26) + (31)	442

^a 2-Methoxybenzoic acid with Li (3)/NH₃ showed (NMR) about 70% loss of OMe. The presence of MeOH produces 2-methoxy-1,4-dihydrobenzoic acid with little loss of OMe.

^b Sodium metal was added to the reaction mixture over 3 h.

^c An ammonia-THF solution of this compound was treated with 1 equiv. of *t*-BuOK before normal Birch reduction.

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS

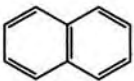
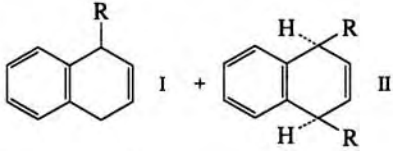
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																					
C ₁₀ 	NH ₃ /M, THF, 20 min	RX	 I + II																						
			<table border="1"> <thead> <tr> <th>R</th> <th>I</th> <th>II</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>—</td> <td>(85*)</td> </tr> <tr> <td>"</td> <td>(95*)</td> <td>(2*)</td> </tr> <tr> <td>"</td> <td>(20*)</td> <td>(80*)</td> </tr> <tr> <td>"</td> <td>(90*)</td> <td>—</td> </tr> <tr> <td>Et</td> <td>(25*)</td> <td>(75*)^b</td> </tr> <tr> <td>"</td> <td>(90*)</td> <td>(9*)^b</td> </tr> </tbody> </table>	R	I	II	Me	—	(85*)	"	(95*)	(2*)	"	(20*)	(80*)	"	(90*)	—	Et	(25*)	(75*) ^b	"	(90*)	(9*) ^b	
R	I	II																							
Me	—	(85*)																							
"	(95*)	(2*)																							
"	(20*)	(80*)																							
"	(90*)	—																							
Et	(25*)	(75*) ^b																							
"	(90*)	(9*) ^b																							
	Na (2.5)	MeBr (gas)		52																					
	Li (3.5)	"		52																					
	Na (2.5)	MeBr (liq)		11																					
	"	MeBr (liq) ^a		11																					
	"	EtBr		11																					
	"	EtBr ^a		11																					

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

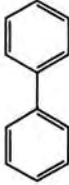
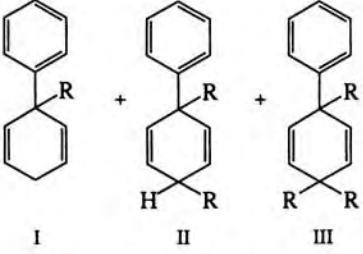
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																																																												
C ₁₂ 	NH ₃ /M (2.5), 20 min, cosolvent	RX	 I + II + III																																																													
			<table border="1"> <thead> <tr> <th colspan="3">% composition^c</th> </tr> <tr> <th>I (R = Me)</th> <th>II (R = Me)</th> <th>III (R = Me)</th> </tr> </thead> <tbody> <tr> <td>Li</td> <td>MeBr</td> <td>99</td> <td>1</td> <td>—</td> <td>280</td> </tr> <tr> <td>Ca</td> <td>"</td> <td>100</td> <td>—</td> <td>—</td> <td>280</td> </tr> <tr> <td>Na</td> <td>"</td> <td>50</td> <td>40</td> <td>10</td> <td>280</td> </tr> <tr> <td>Na, toluene</td> <td>"</td> <td>68</td> <td>32</td> <td>—</td> <td>280</td> </tr> <tr> <td>Na, TMEDA</td> <td>"</td> <td>51</td> <td>43</td> <td>3</td> <td>280</td> </tr> <tr> <td>Na, THF</td> <td>"</td> <td>38</td> <td>54</td> <td>7</td> <td>280</td> </tr> <tr> <td>Na, DME</td> <td>"</td> <td>45</td> <td>46</td> <td>9</td> <td>280</td> </tr> <tr> <td>NH₃/Li (2.4), Et₂O, -70°, 1 h</td> <td>ClCH₂CO₂Me</td> <td>R = CH₂CO₂Me</td> <td colspan="2">I (65)</td> <td>555</td> </tr> <tr> <td>"</td> <td>Cl(CH₂)₂NMe₂</td> <td>R = (CH₂)₂NMe₂</td> <td colspan="2">I (20-30)</td> <td>556</td> </tr> </tbody> </table>	% composition ^c			I (R = Me)	II (R = Me)	III (R = Me)	Li	MeBr	99	1	—	280	Ca	"	100	—	—	280	Na	"	50	40	10	280	Na, toluene	"	68	32	—	280	Na, TMEDA	"	51	43	3	280	Na, THF	"	38	54	7	280	Na, DME	"	45	46	9	280	NH ₃ /Li (2.4), Et ₂ O, -70°, 1 h	ClCH ₂ CO ₂ Me	R = CH ₂ CO ₂ Me	I (65)		555	"	Cl(CH ₂) ₂ NMe ₂	R = (CH ₂) ₂ NMe ₂	I (20-30)		556	
% composition ^c																																																																
I (R = Me)	II (R = Me)	III (R = Me)																																																														
Li	MeBr	99	1	—	280																																																											
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Na, DME	"	45	46	9	280																																																											
NH ₃ /Li (2.4), Et ₂ O, -70°, 1 h	ClCH ₂ CO ₂ Me	R = CH ₂ CO ₂ Me	I (65)		555																																																											
"	Cl(CH ₂) ₂ NMe ₂	R = (CH ₂) ₂ NMe ₂	I (20-30)		556																																																											

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

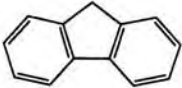
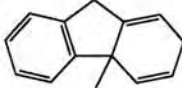
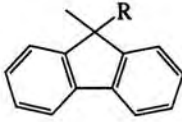
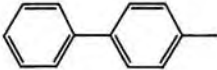
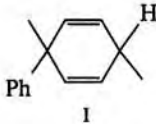
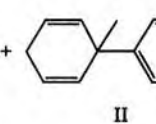
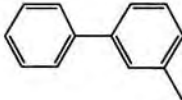
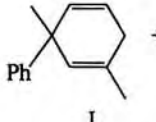
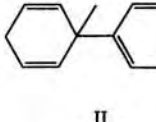
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₃ 	Li (2.2)/NH ₃ , Et ₂ O, -78°, 5 min	MeBr (gas)	 (45*) +  R = H (26*) R = Me (13*)	282
	NH ₃ /Li (3.8), THF, 30 min	"	 I +  II I:II = 45:55 (—)	29
	"	"	 I +  II I:II = 80:20 (—)	29

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

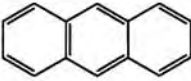
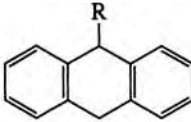
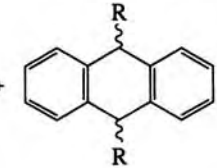
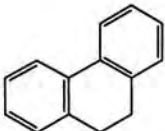
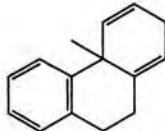
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₄ 		RX	 I* +  II R I* cis-II* trans II*	
	Li (2.5)/NH ₃ , THF, 1 h	MeBr (gas)	Me — 78 22	557
	NH ₃ /Na (2.5), Et ₂ O, 15 min	MeI ^a	Me 95 5 ^b	11
	Li (2.5)/NH ₃ , THF, 1 h	EtBr	Et — 84 16	557
	"	EtBr ^a	Et 97 3 —	11
	"	<i>i</i> -PrCl	<i>i</i> -Pr — 70 18	557
	"	<i>t</i> -BuBr	<i>t</i> -Bu 14 2 —	557
	NH ₃ /Li (5), THF, 5 min	MeBr	 (53, 93*)	38

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

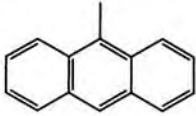
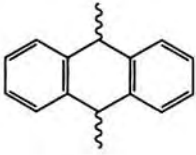

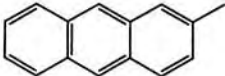
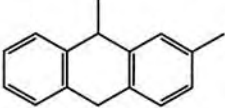
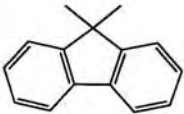

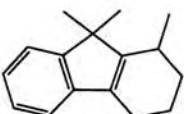
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₅ 	NH ₃ /Na (2.5), THF, 20 min	MeI ^a	 +  I:II = 30:70 (—)	28
	"	"	 (80*)	29
	NH ₃ /Li (2.5), THF, 2.5 h	MeBr (gas)	 (80*) +  (9*)	282

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

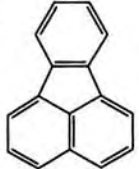
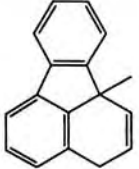
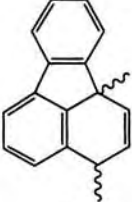
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₆ 	NH ₃ /Li (2.2), Et ₂ O, 10 min	"	 (88*)	287
	"	H ₂ O-MeBr ^d (gas)	I (96*)	
	NH ₃ /K (2.2), Et ₂ O, -78°, 5 min	MeBr (gas)	I (20*) +  cis-II (50*) trans-II (22*)	287

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

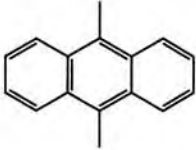
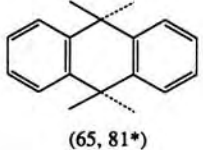
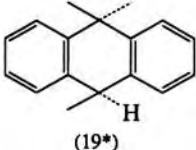
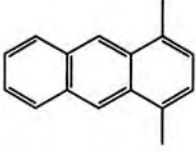
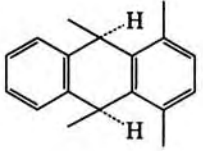
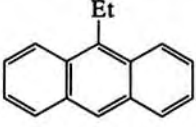
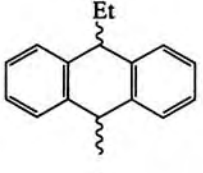
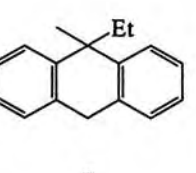
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (2.5)/NH ₃ , THF, 1 h	"	 + 	557
	"	"	 (80*)	557
	NH ₃ /Na (2.5), THF, 30 min	MeI ^a	 +  I:II = 27:73	28

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

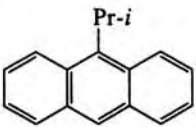
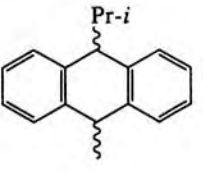
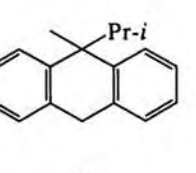
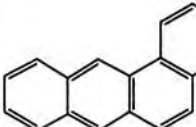
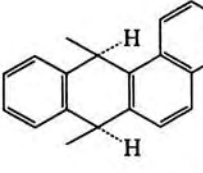
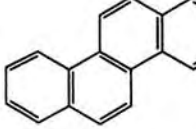
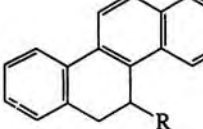
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C17 	"	"	 +  I:II = 10:90	28
C18 	Li (2.5)/NH ₃ , THF, 1 h	MeBr (gas)	 (46)	557
	NH ₃ /Na (2.5), THF, 20 min	"	 R = H (23*) + R = Me (65*)	292

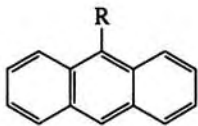
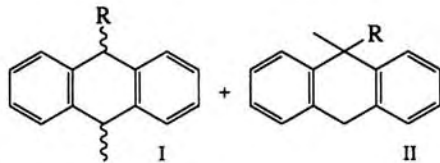
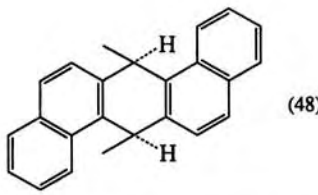
TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (8), THF, FeCl ₃ , 20 min	"	 (48*) + (21*)	292
			 (15*)	
	NH ₃ /Li (2.2), THF, 30 min	H ₂ O-MeBr ^d (gas)	 (91*)	295
	NH ₃ /Li (2.2), THF, -78°, 10 min	MeCl	 I <i>cis</i> -I (51*) <i>trans</i> -I (32*)	295

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.2), THF, 30 min	MeBr (gas)	 (90*)	295
	"	"	 (45*) + (24*) + (10*)	295
	NH ₃ /Na (2.5), THF, 30 min	MeI ^a	 I + II I:II = 9:91	28

TABLE VIII. REDUCTIVE ALKYLATION OF AROMATIC HYDROCARBONS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (2.5), THF, 30 min	MeI ^a		28
C ₂₀ R = Ph			(—) I:II = 0:100	
C ₂₁ R = PhCH ₂			(—) I:II = 43:57	
C ₂₂	Li (2.5)/NH ₃ , THF, 1 h	MeBr (gas)		557

^a The reaction mixture was pumped (argon pressure) through a glass tube into a large excess of alkyl halide in THF (inverse quench).

^b The yield represents a mixture of *cis* and *trans* isomers.

^c The yields were based on biphenyl converted and measured by peak area on GLC.

^d A solution of water in THF (half quench) was added to the reaction mixture over 10 min, then a stream of methyl bromide was passed through a column of 50% silica gel-sand into the reaction vessel until the color of the solution was discharged.

TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES

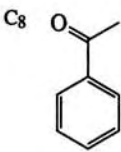
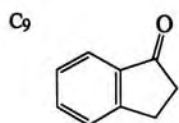
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.																								
	NH ₃ /M (2.2-2.5), proton source, THF, -78°, 10 min	RX ^b		83																								
			% composition ^c																									
			<table border="1"> <thead> <tr> <th>I</th> <th>II</th> <th>III</th> <th>IV</th> <th>V</th> <th>VI</th> </tr> </thead> <tbody> <tr> <td>21</td> <td>—</td> <td>1</td> <td>47</td> <td>11</td> <td>3</td> </tr> <tr> <td>41</td> <td>1</td> <td>2</td> <td>18</td> <td>19</td> <td>3</td> </tr> <tr> <td>26</td> <td>5</td> <td>6</td> <td>19</td> <td>8</td> <td>8</td> </tr> </tbody> </table>	I	II	III	IV	V	VI	21	—	1	47	11	3	41	1	2	18	19	3	26	5	6	19	8	8	
I	II	III	IV	V	VI																							
21	—	1	47	11	3																							
41	1	2	18	19	3																							
26	5	6	19	8	8																							
	Li, H ₂ O (1.1)	MeI																										
	Li, AcOH (1)	"																										
	Li, <i>t</i> -BuOH (1.2)	"																										

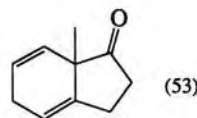
TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)						Refs.
			L	II	III	IV	V	VI	
	Li, <i>t</i> -BuOH (6)	"	36	2	3	23	3	4	
	Na, <i>t</i> -BuOH (1.2)	"	12	25	23	8	3	3	
	Na, <i>t</i> -BuOH (1.2), LiBr ^a	"	53	—	1	14	3	9	
	Na, <i>t</i> -BuOH (1.2), LiBr ^a	"	61	—	1	21	3	—	
	K, <i>t</i> -BuOH (1.2), LiBr ^a	"	84	—	1	2	3	7	
	"	EtI	59	—	—	—	—	—	
	"	ClCH ₂ CN	26	—	—	—	—	—	
	"	CH ₂ Br	85	—	—	—	—	—	
	"	BrCH ₂ CO ₂ Et	62	—	—	—	—	—	



NH₃/K (2.5), *t*-BuOH (2), THF, -78°, LiBr^a

MeI^d



106, 558

TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (2.5), <i>t</i> -BuOH (2), THF, -78°, LiBr ^c	MeI ^a	(55*) ^e + (26*)	83
C ₁₀	"	"	(60)	83
C ₁₂	Li (2.5)/NH ₃ , THF, 10 min	RX	I	109, 111
	"	MeI	I, R = Me (65, 96*)	
	"	<i>n</i> -C ₅ H ₁₁ I	I, R = <i>n</i> -C ₅ H ₁₁ (59, 72*)	

TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES (Continued)

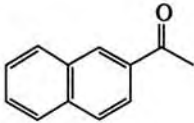
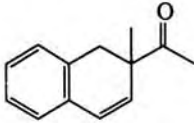
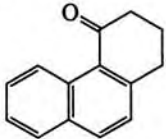
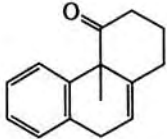
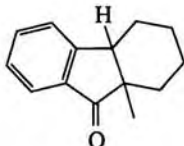
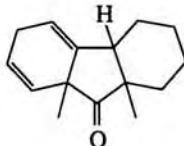
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), THF, 30 min, FeCl ₃	MeI	 (80)	111
C ₁₄ 	Li (3.5)/NH ₃ , THF, 10 min	MeI	 (51, 55*)	115
	NH ₃ /Li, <i>t</i> -BuOH (3), THF, -78°, 10 min	"	 (53)	164

TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES (Continued)

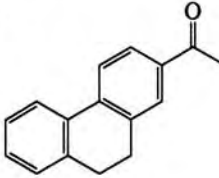
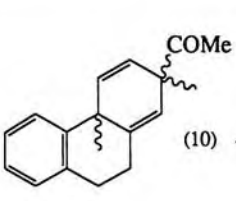
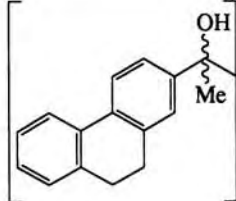
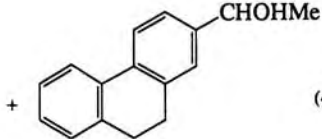
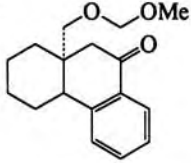
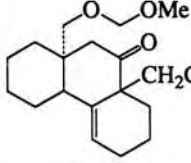
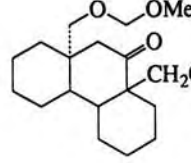
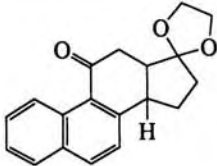
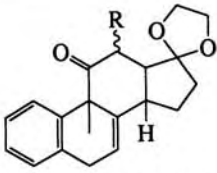
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₆ 	Li (3.5)/NH ₃ , THF, 10 min	"	 (10) +  (9) +  (48)	559
C ₁₇ 	NH ₃ /Li, <i>t</i> -BuOH (3), THF, -78°, 10 min	1. BrCH ₂ CO ₂ Me 2. H ₂ , Rh/Al	 I +  II (→ I + II (45))	164

TABLE IX. REDUCTIVE ALKYLATION OF AROMATIC KETONES (*Continued*)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₉ 	Li (3.5)/NH ₃ , THF, 10 min	MeI	 R = H (58*) + R = Me (25*)	115

^a The ammonia was evaporated during 1-4 h, and the resulting pasty mixture was alkylated by adding alkyl halide and stirring the mixture at 0-10° for 40 min.

^b Yields were measured by peak area on GC; the difference from 100% represents starting material, propio- and isobutyrophenone.

^c The resulting blue solution was mixed with anhydrous lithium halide (2.2 equiv) and stirred at -78° for 40 min.

^d After 20 min, alkyl halide and aqueous THF (1:1) were added simultaneously to the reaction mixture.

^e The yield represents a mixture of both isomers.

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES

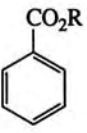
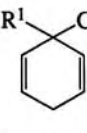
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₇  R = H	NH ₃ /Li (4), -78°	R ¹ X	 I	
	"	MeI	I (96*)	123
	"	EtBr	I (99*)	123
	"	MeOCH ₂ Br	I (—)	560
	"	BrCH ₂ CO ₂ H	I (79)	561
	"	<i>n</i> -PrBr	I (98*)	123
	"	<i>i</i> -PrBr	I (98*)	123
	"	<i>t</i> -BuBr	I (12)	561
	"	PhCH ₂ Br	I (62)	561
	"	C ₆ H ₁₁ CH ₂ Br	I (54)	561
	"	<i>n</i> -C ₇ H ₁₅ I	I (—)	125
	"	3,5-(MeO) ₂ C ₆ H ₃ CH ₂ Br	I (—)	562
	"	CH ₂ = CHCO ₂ Me, CH ₂ N ₂	I R = Me; R ¹ = (CH ₂) ₂ CO ₂ Me (65)	124

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

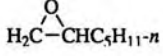
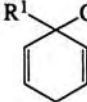
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R = H	"	MeCH=CHCO ₂ Me, CH ₂ N ₂	I, R = Me; R ¹ = MeO ₂ CCH ₂ CH Me (70)	124
	"		I, R = H; R ¹ = n-C ₅ H ₁₁ CHOHCH ₂ (—)	125
R = Me	"	R ¹ X	 I	563
	"	BrCH=CHCH ₂ Br	I (—)	
	"	Br(CH ₂) ₃ Br	I (—)	
	"	2-IC ₆ H ₄ CH ₂ Br	I (—)	

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

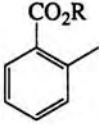
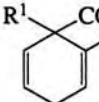
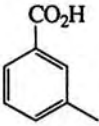
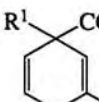
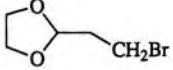
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4), 20 min	R ¹ X	 I	
R = H	"	MeI	I (98*)	123
	"	EtBr	I (66)	564
	"	<i>i</i> -PrBr	I (98*)	123
	"	PhCH ₂ Br	I (51)	564
R = Me	"	Br(CH ₂) ₃ Br	I (—)	563
	NH ₃ /Li (4), 20 min	R ¹ X	 I	
	"	MeI	I (99*)	123, 565
	"	<i>i</i> -PrBr	I (—)	137
	"		I (94)	566

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

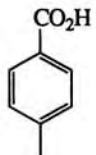
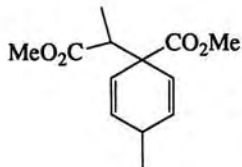
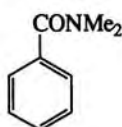
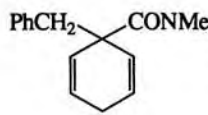
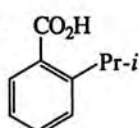
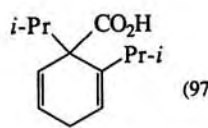
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	CH ₂ = CHCH ₂ CH ₂ Br	I (91)	566
	"	PhO(CH ₂) ₄ Br, ^a NH ₄ Cl, H ₃ O ⁺	I, R ¹ = HO(CH ₂) ₄ (75)	567
	"	MeCH=CHCO ₂ Me, CH ₂ N ₂	 (—)	124
C ₉ 	NH ₃ /Li, <i>t</i> -BuOH (1), THF, -78°	PhCH ₂ Br, NH ₄ Cl ^b	 (76)	157
C ₁₀ 	NH ₃ /Li (4), 20 min	<i>i</i> -PrBr	 (97*)	123

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

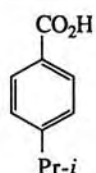
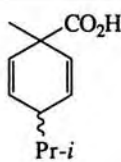
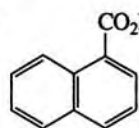
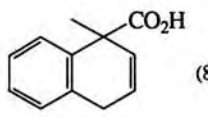
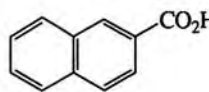
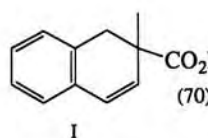
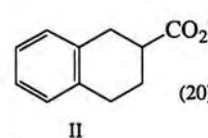
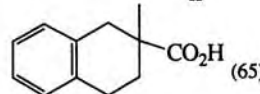
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), Et ₂ O, 45 min	MeI, ^d NH ₄ Cl	 (92) ^f	568
C ₁₁ 	NH ₃ /Li (3), 30 min	MeI	 (85)	84
	"	"	 (70) +  (20)	84
	NH ₃ /Li (5), 30 min	"	II (25) +  (65)	84
	NH ₃ /Li (5), FeCl ₃ , 30 min	"	I (75)	84

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

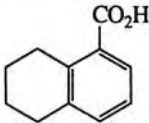
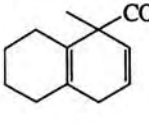
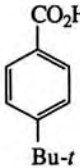
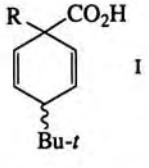
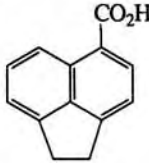
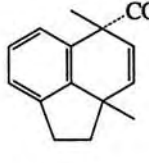
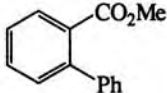
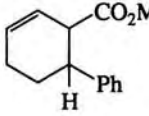
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, Et ₂ O	"	 (74)	569
	NH ₃ /Li (4), 20 min	RX	 I	123
		MeI	I (99*) ^c	
		EtBr	I (94*) ^c	
		<i>i</i> -PrBr	I (93*) ^c	
C ₁₃ 	NH ₃ /Li (2.5), Et ₂ O, 10 min	MeI	 (83)	140

TABLE X. REDUCTIVE ALKYLATION OF AROMATIC CARBOXYLIC ACIDS AND DERIVATIVES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li, <i>t</i> -BuOH (3), THF, -78°, 10 min	"	 (90)	164

^a After stirring for 1 h the solution was treated with *tert*-butyl alcohol. Lithium wire was again added to maintain the blue color, and after 20 min ammonium chloride was added.

^b After addition of alkyl halide the resulting solution was stirred for 1 h at -78°. It is essential to quench the alkylation reaction mixture with excess ammonium chloride before evaporation of ammonia.

^c The yield represents a mixture of *cis* and *trans* isomers.

^d The solution was cooled to -70° and dry methyl iodide was added dropwise. After 15 min the colorless solution was treated with solid ammonium chloride.

TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES

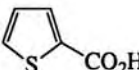
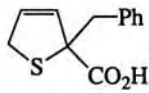

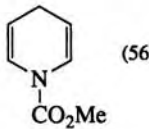
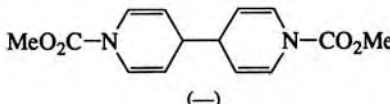
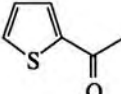
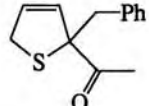
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₅ 	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br	 (68)	570
	NH ₃ /Li (3), EtOH, -78°, 1 h	(MeO) ₂ CO	 (56)	571
	NH ₃ /Li (3), -78°, 1 h	"	 (57)	571
C ₆ 	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br	 (73)	570

TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

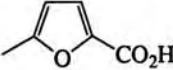
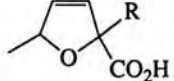

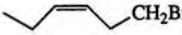
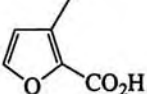
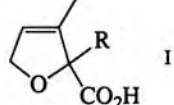
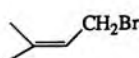
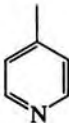
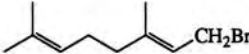
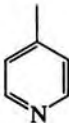
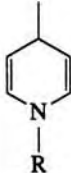
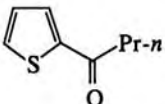
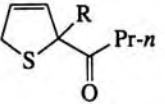

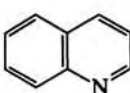
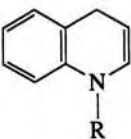
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (2.5)/NH ₃ , -78°	RX	 I	
		MeI	I (75)	572
		EtI	I (75)	572
		<i>i</i> -PrBr	I (95)	572
		 CH ₂ Br	I (68)	572
		PhCH ₂ Cl	I (75)	572
		<i>n</i> -C ₆ H ₁₃ Br	I (85)	136
		 CH ₂ Br	I (65)	136
	Li (2.5)/NH ₃ , -78°	RX	 I	136
		 CH ₂ Br	I (75)	

TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.	
	Li (2.5)/NH ₃ , -78°		I (60)		
	NH ₃ /Li (2.5), -78°, 30 min	MeI	I, R = Me (93)	444	
		<i>n</i> -PrBr	I, R = <i>n</i> -Pr (96)		
(MeO) ₂ CO		I, R = CO ₂ Me (ca 100)			
	NH ₃ /Li (3), EtOH, -78°		(80-93) I	444	
			MeI		I, R = Me
			<i>n</i> -PrBr		I, R = <i>n</i> -Pr
			(MeO) ₂ CO		I, R = CO ₂ Me

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TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.	
C ₈ 	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a RX	 I	570	
		MeI	I (72)		
			I (68)		
		<i>n</i> -C ₄ H ₉ Br	I (55)		
		PhCH ₂ Br	I (82)		
C ₉ 	NH ₃ /Li (2.5), 30 min		I	573	
			(MeO) ₂ SO ₂ ^b		I, R = Me (88)
			EtBr ^b		I, R = Et (80)
			<i>n</i> -PrBr ^b		I, R = <i>n</i> -Pr (89)
			<i>i</i> -PrBr ^b		I, R = <i>i</i> -Pr (78)

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TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

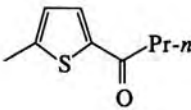
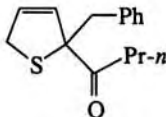
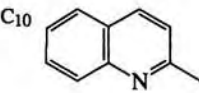
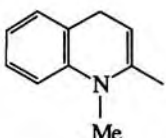
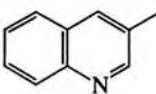
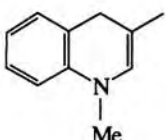
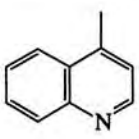
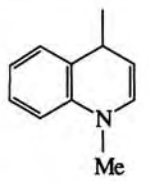
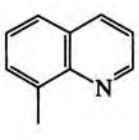
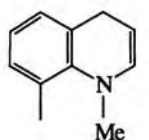
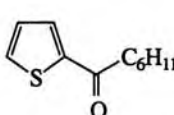
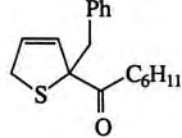
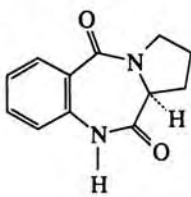
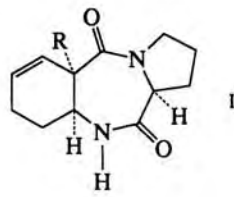
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
		<i>n</i> -BuBr ^b	I, R = <i>n</i> -Bu (84)	
		PhCH ₂ Br ^b	I, R = PhCH ₂ (45)	
		MeOCH ₂ Cl ^b	I, R = MeOCH ₂ (79)	
		(MeO) ₂ CO ^b	I, R = CO ₂ Me (78)	
	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br	 (67)	570
	NH ₃ /Li (2.5), 30 min	(MeO) ₂ SO ₂ ^b	 (70)	573
	"	"	 (87)	573

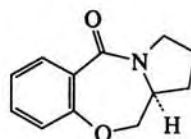
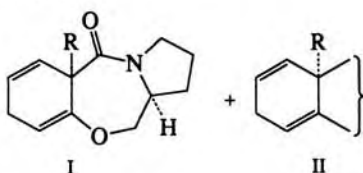
TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (93)	573
	"	"	 (87)	573
	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br		570
	NH ₃ /K (4.4), <i>t</i> -BuOH (2), THF, -78°, 45 min	RX ^c	 I	160, 162

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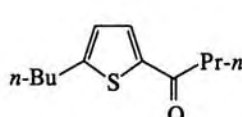
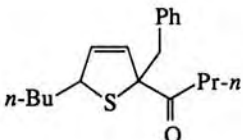
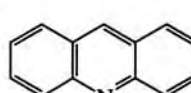
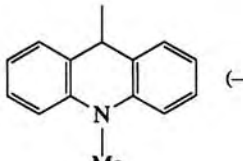
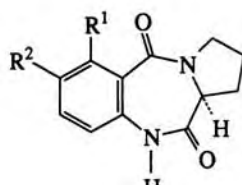
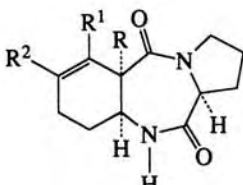
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TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K, <i>t</i> -BuOH, THF, -78°	MeI	I (54)	
		EtI	I (68)	
		CH ₂ = CHCH ₂ Br	I (62)	
		ClCH ₂ CH ₂ CH ₂ Br	I (44)	
		CH ₂ = CHCH ₂ CH ₂ Br	I (25)	
		PhCH ₂ Br	I (68)	
		RX		
MeI	I (67) + II (—) I:II = 85:15	158, 39		
EtI	I (82) + II (—) I:II = 99:1	158, 39		
CH ₂ = CHCH ₂ Br	I (75) + II (—) I:II = 98:2	158, 39		
CH ₂ = CHCH ₂ CH ₂ Br	I (89) + II (—) I:II = 98:2	158, 39		
ClCH ₂ CH ₂ CH ₂ Br	I (91) + II (—) I:II = —	161		
PhCH ₂ Br	I (73) + II (—) I:II = —	39		
(MeO) ₂ CHC(Me) ₂ (CH ₂) ₃ I	I (96) + II (—) I:II = —	150		

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TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br	 (76)	570
C ₁₃ 	NH ₃ /Li, THF	MeI	 (—)	462
	NH ₃ /K (4.4), <i>t</i> -BuOH (2), THF, 45 min, -78°	RX	 I	162

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TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R ¹ — R ²				
Me H		MeI ^c	I (53)	
H Me		"	I (78)	
" "		EtI ^c	I (87)	
" "		CH ₂ = CHCH ₂ Br ^c	I (68)	
" "		PhCH ₂ Br ^c	I (78)	
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°	MeI	(85)	159
	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a MeI	(44)	570

TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₄				
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°	MeI	I	
R = Me			I (90)	159
R = OMe			I (85)	39
	NH ₃ /Na (2.3), EtOH, Et ₂ O, 1 h	NH ₄ Cl, ^a PhCH ₂ Br	(61)	570
C ₁₅				
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°	RX	I	39
		MeI	I (70) ^d	
		PhCH ₂ Br	I (75) ^d	

TABLE XI. REDUCTIVE ALKYLATION OF AROMATIC HETEROCYCLES (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°	RX	 I	159
		MeI	I (85)	
	NH ₃ /K (2.2), <i>t</i> -BuOH (1), THF, -78°, LiBr	ClCH ₂ CH ₂ CH ₂ Br	I (78)	
C ₁₉ 	NH ₃ /K (4.5), <i>t</i> -BuOH (1), THF, -78°, 10 min	RX	 I	164
		MeI	I (86)	
		EtI	I (40)	
		CH ₂ = CHCH ₂ Br	I (66)	
		PhCH ₂ Br	I (46)	

^a After stirring for 1 h, solid ammonium chloride (1.2 equiv) was added and then the mixture was stirred for an additional 30 min. Then excess alkylating agent was added slowly into the reaction mixture and it was stirred for an additional 1 h.

^b The deep blue-green solution was cooled to ca -70° and the appropriate alkylating agent was introduced from a syringe.

^c Before alkylation 1,3-pentadiene (2-3 drops) was added to the reaction mixture to destroy the excess metal.

^d The yield represents a mixture of *cis* and *trans* isomers.

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS

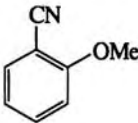
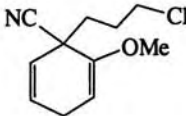
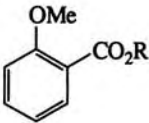
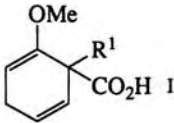
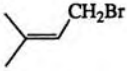
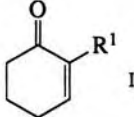
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₈ 	NH ₃ /Li, <i>t</i> -BuOH (1), THF, -78°	Br(CH ₂) ₃ Cl, NH ₄ Cl ^a	 (85)	157
 R = H	NH ₃ /K (2.5), <i>t</i> -BuOH (1), <i>t</i> -BuOK (1), ^b THF, -70°, 10 min ^c	R ¹ X	 I	
	"	MeI	I (84)	134, 132
	NH ₃ /Li, -78°, THF		I (—)	574
	"	CH ₂ = CHCH ₂ CH ₂ Br ^d	I (—)	575
	"	MeCH = CHCH ₂ Br ^d	I (—)	575
	"	CH ₂ = CH(CH ₂) ₃ Br ^d	I (—)	575
	"	R ¹ X ^d , H ₃ O ⁺	 I	

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

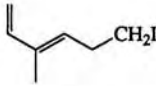
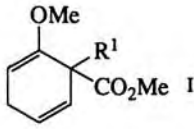
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R = Me	"	<i>n</i> -PrI	I (30)	576
	"	<i>i</i> -PrI	I (26)	576
	"	CH ₂ = CHCH ₂ Cl	I (27)	576
	"	<i>n</i> -C ₅ H ₁₁ Br	I (27)	576
	"		I (34)	577
	NH ₃ /Na, THF	<i>n</i> -C ₇ H ₁₅ Br	I (46-59)	578
	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -70°, 10-30 min ^c	R ¹ X		I
	"	MeI	I (95)	134, 579
	"	EtI	I (96)	134, 579
	"	<i>n</i> -PrCl	I (67)	579
	"	<i>i</i> -PrI	I (90)	152
	"	CH ₂ = CHCH ₂ Br	I (79)	580, 581
	"	CH ₂ = CBrCH ₂ Br ^e	I (76)	580

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

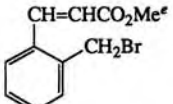
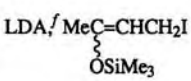
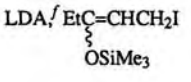
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
"	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, 70°, 10-30 min ^c , LiBr ^g	ClCH ₂ CH ₂ CH ₂ Br	I (65)	152, 563
"	"	AcOCH ₂ CH ₂ Br	I (85)	581
"	"	CH ₂ = CHCH ₂ CH ₂ Br	I (76)	580, 151
"	"	CH ₂ = CHCH ₂ CH ₂ CH ₂ Br ^e	I (67)	580
"	"	PhCH ₂ Br	I (78)	581, 152
"	"	(MeO) ₂ CHCMe ₂ (CH ₂) ₃ I	I (98)	150
"	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, 70°, 10-30 min ^c , LiI ^h		I (56)	580
"	"	LDA, 	I R ¹ = MeCOCH ₂ CH ₂ (82)	149
"	"	LDA, 	I R ¹ = EtCOCH ₂ CH ₂ (82)	149

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

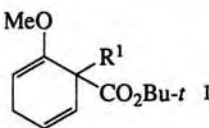
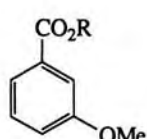
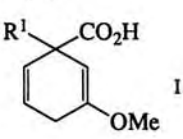
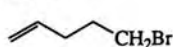
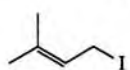
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R = <i>t</i> -Bu	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -70°, 10-20 min ^c	R ¹ X	 I	
	"	MeI	I (96)	134
	"	<i>i</i> -PrI	I (94)	134
	"	CH ₂ = CHCH ₂ CH ₂ Br	I (nil)	134
	" + LiBr ^g	CH ₂ = CHCH ₂ CH ₂ Br	I (60)	134
	NH ₃ /M (2.5), THF, -78°	R ¹ X	 I	
R = H	M = Li	MeI	I (90*)	582, 131
	M = Li	<i>i</i> -PrBr	I (—)	137
	M = Li		I (—)	575
	M = Na		I (90)	583

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

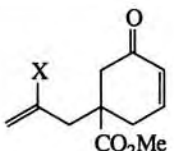
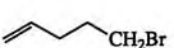
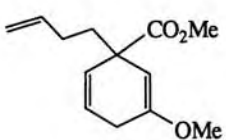
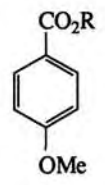
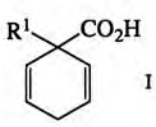
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	M = Li	CH ₂ = CXCH ₂ X, H ₃ O ⁺ , CH ₂ N ₂	 X = Cl (77) X = Br (86)	105
R = Me	Li, <i>t</i> -BuOH (1)		 (66)	151
	NH ₃ /Li (2.5), THF	R ¹ X	 I	
R = H	"	MeI	I, R ¹ = Me (—)	137
	"	MeCH = CHCO ₂ Me	I, R ¹ = MeO ₂ CCH ₂ CH Me (—)	124

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

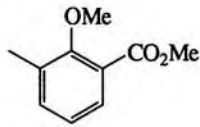
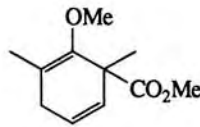
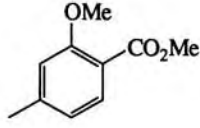
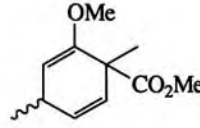
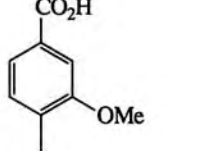
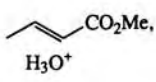
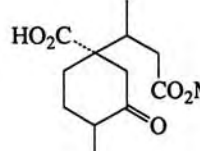
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 <chem>COC(=O)c1cc(C)cc(OC)c1</chem>	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -78°, 10 min ^c	MeI	 (69)	152
 <chem>COC(=O)c1cc(C)cc(OC)c1</chem>	"	"	 (80)	152
 <chem>OC(=O)c1cc(C)cc(OC)c1</chem>	NH ₃ /Li (6)	 <chem>C=CC(=O)OC</chem> , H ₃ O ⁺	 (60)	584

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

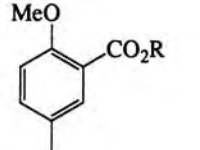
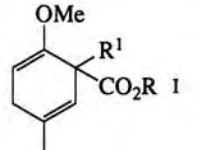
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 <chem>COC(=O)c1cc(C)cc(OC)c1</chem>	NH ₃ /Li, THF	R ¹ X	 I	
R = H	"	CH ₂ =CHCH ₂ Br ^d	I (50)	575
	"	CH ₂ =CHCH ₂ CH ₂ Br ^d	I (—)	575
	"	MeOCH ₂ CH=CHCH ₂ Br	I (—)	575
	NH ₃ /Na (2.5), <i>t</i> -BuOH (2), -70°	LDA ^f , 2-Me-3-MeOC ₆ H ₃ (CH ₂) ₂ I	I' (—)	133
R = Me	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -70°, 10 min ^c	MeI	I (74)	152
	+ LiBr ^g	CH ₂ =CHCH ₂ CH ₂ Br	I (85)	151
	+ HMPA	2-Me-3-MeOC ₆ H ₃ (CH ₂) ₂ I ^e	I (60)	134

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

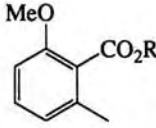
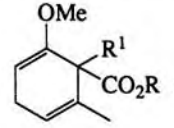
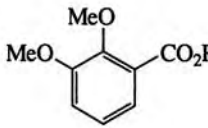
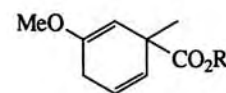
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -70°, 10 min ^c	R ¹ X		
R = H	" + <i>t</i> -BuOK (1) ^b	MeI	I (90)	134
	" + <i>t</i> -BuOK (1) ^b	PhCH ₂ Br	I (91)	134
	" + <i>t</i> -BuOK (1) ^b	CH ₂ = CHCH ₂ CH ₂ Br ^c	I (87)	134
R = Me	" + LiBr	CH ₂ = CHCH ₂ CH ₂ Br	I (57)	151
R = <i>t</i> -Bu	"	MeI	I (96)	134
	"	MeI	 (70)	134
R = Me				

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

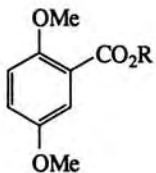
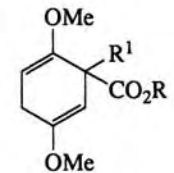
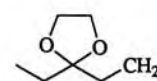
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, -78°, 15 min ^c	R ¹ X		
R = H	"	$\text{MeC}(\text{OSiMe}_3)=\text{CHCH}_2\text{I}$	I, R ¹ = MeCOCH ₂ CH ₂ (82.5)	149
	"	$\text{EtC}(\text{OSiMe}_3)=\text{CHCH}_2\text{I}$	I, R ¹ = EtCOCH ₂ CH ₂ (93)	149
	"		I, R ¹ = EtCOCH ₂ CH ₂ (67)	148
	"	PhCH ₂ Br	I, R ¹ = EtCOCH ₂ CH ₂ (74)	585
	"	2-MeC ₆ H ₄ CH ₂ Br	I, R ¹ = EtCOCH ₂ CH ₂ (74)	585
	"	3-MeOC ₆ H ₄ CH ₂ Br	I, R ¹ = EtCOCH ₂ CH ₂ (75)	585

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
"	"	4-MeOC ₆ H ₄ CH ₂ Br	I, R ¹ = EtCOCH ₂ CH ₂ (77)	585
"	"	3,5-(MeO) ₂ C ₆ H ₃ CH ₂ Br	I, R ¹ = EtCOCH ₂ CH ₂ (68)	585
"	"	2-CO ₂ Me, 3-MeO-C ₆ H ₃ CH ₂ Br ^e	I, R ¹ = EtCOCH ₂ CH ₂ (88)	586, 587
"	"	PhCH ₂ CH ₂ I	I, R ¹ = EtCOCH ₂ CH ₂ (70)	588
"	"	3,5(MeO) ₂ C ₆ H ₃ (CH ₂) ₂ I	I, R ¹ = EtCOCH ₂ CH ₂ (82)	589, 590
"	"	3-MeOC ₆ H ₄ (CH ₂) ₂ I	I, R ¹ = EtCOCH ₂ CH ₂ (63)	588
"	"	2-CO ₂ Me, 3-MeO-C ₆ H ₃ (CH ₂) ₂ I	I, R ¹ = EtCOCH ₂ CH ₂ (50)	588
R = Me	NH ₃ /Li (2.2), <i>t</i> -BuOH (1), THF, -78°, 20 min ^c	CH ₂ =CHCH ₂ CH ₂ Br ^e	I, R ¹ = EtCOCH ₂ CH ₂ (96)	151
"	"	$\begin{array}{c} \text{MeC}=\text{CHCH}_2\text{I} \\ \\ \text{OSiMe}_3 \end{array}$	I, R ¹ = MeCOCH ₂ CH ₂ (79)	149
"	"	$\begin{array}{c} \text{EtC}=\text{CHCH}_2\text{I} \\ \\ \text{OSiMe}_3 \end{array}$	I, R ¹ = EtCOCH ₂ CH ₂ (83)	149

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

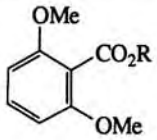
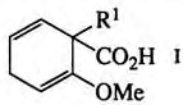
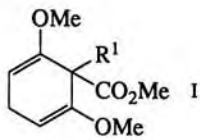
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na (2.4), THF, -78°, 15 min ^c	R ¹ X		
R = H	"	$\begin{array}{c} \text{MeC}=\text{CHCH}_2\text{I} \\ \\ \text{OSiMe}_3 \end{array}$	I, R ¹ = MeCOCH ₂ CH ₂ (74)	149
"	"	$\begin{array}{c} \text{EtC}=\text{CHCH}_2\text{I} \\ \\ \text{OSiMe}_3 \end{array}$	I, R ¹ = EtCOCH ₂ CH ₂ (74)	149
R = Me	NH ₃ /M (2.2 - 2.5), <i>t</i> -BuOH (1), THF, -78°, 15-30 min ^c	R ¹ X		
"	M = K	MeI	I (96)	134, 152
"	M = Li	CH ₂ = CHCH ₂ CH ₂ Br	I (61)	151

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)


Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	M = K	$\text{MeCHCH}_2\text{CH}_2\text{I}$ OSiMe_3	I (97)	149
	M = K	LDA, $\text{MeC}=\text{CHCH}_2\text{I}$ OSiMe_3	I, R ¹ = MeCOCH ₂ CH ₂ (80)	149
	M = K	LDA, $\text{EtC}=\text{CHCH}_2\text{I}$ OSiMe_3	I, R ¹ = EtCOCH ₂ CH ₂ (82)	149
	M = K, + LiBr ^g	$\text{MeCHCH}_2\text{CH}_2\text{I}$ OSiMe_3	" (ca 100)	591
	M = K, + LiBr ^g	$\text{EtCHCH}_2\text{CH}_2\text{I}$ OSiMe_3	" (ca 100)	591
	M = K	MeO_2C  CH_2Br^e	" (67)	152

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

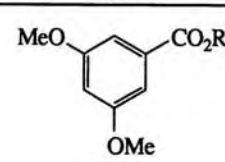
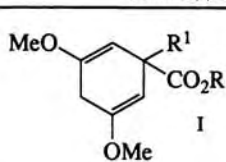
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (2.5), THF, -78°, 20 min ^c	R ¹ X	 I	
R = H	"	MeI	I (87)	592, 593
	"	EtBr	I (50)	594
	"	n-C ₅ H ₁₁ Br	I (ca 100)	136
	"	Me ₂ C = CHCH ₂ I	I (87)	583
	"	2-CO ₂ Me-3-MeO-C ₆ H ₃ CH ₂ I ^e	I (87)	586
	"	$\text{MeC}=\text{CHCH}_2\text{I}$ OSiMe_3	I, R ¹ = MeCOCH ₂ CH ₂ (79)	149
	"	$\text{EtC}=\text{CHCH}_2\text{I}$ OSiMe_3	I, R ¹ = EtCOCH ₂ CH ₂ (79)	149

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)




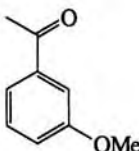
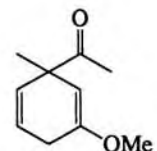
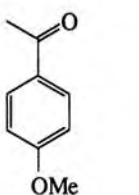
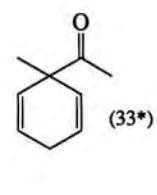
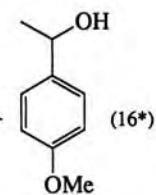
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
R = Me	NH ₃ /Li (2.2), <i>t</i> -BuOH (1), -78°, THF, 20 min ^c	$\text{MeC}=\text{CHCH}_2\text{I}$ 	I, R ¹ = MeCOCH ₂ CH ₂ (84)	149
	"	$\text{EtC}=\text{CHCH}_2\text{I}$ 	I, R ¹ = EtCOCH ₂ CH ₂ (87)	149
	"	$\text{MeOC}=\text{CHCH}_2\text{I}$ 	I, R ¹ = MeOCOCH ₂ CH ₂ (87)	149
	NH ₃ /K (2.2), <i>t</i> -BuOH (1.2), THF, -78°, 10 min, LiBr ^g	MeI ^h	 (89*)	83
	"	"	 (33*) +  (16*) + starting material (37*)	83

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

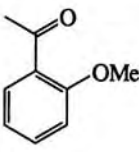
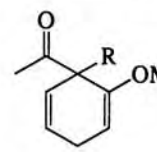
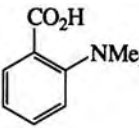
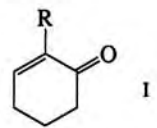
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	R ⁱ	 I	
	"	MeI	I (92)	595, 83
	"	CH ₂ = CHCH ₂ I	I (95)	595
	"	<i>i</i> -PrI	I (76)	595
	NH ₃ /Li (2.5)	RX, H ₃ O ⁺ , heat	 I	
	"	MeI	I (45*)	131
	"	EtI	I (70*)	131
	"	<i>i</i> -PrBr	I (55*)	131
	"	CH ₂ = CHCH ₂ Br	I (65*)	131
	"	PhCH ₂ Br	I (80*)	131

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH_3/K (2.5), <i>t</i> -BuOH (2), THF, -78° , LiBr, 20 min	RX^i		
R^1 R^2 R^3 OMe H H " H H OMe " H OMe H "		MeI " " EtI $\text{CH}_2 = \text{CHCH}_2\text{I}$ $\text{EtO}_2\text{CCH}_2\text{Br}$ $\text{EtC} \equiv \text{CCH}_2\text{Br}$ $\text{Me}(\text{CH}_2)_4\text{C} \equiv \text{CCH}_2\text{Br}$ PhCH_2Br	I (—) I (75) I (78) I (—) I (—) I (—) I (—) I (—) I (83)	596 107, 597 107, 597 108 108 108 108 108 598

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
		R^1X		
$\text{R} = \text{H}$ $\text{R} = \text{Me}$	NH_3/Li , THF, -78° NH_3/K (2.5), <i>t</i> -BuOH (1), THF, -78°	$2\text{-Me-3-MeOC}_6\text{H}_3(\text{CH}_2)_2\text{I}$ $2\text{-CO}_2\text{Me-3-MeO-}$ $\text{C}_6\text{H}_3\text{CH}_2\text{I}^e$	I (94) I (93)	133 134
	NH_3/Li , THF, -78°	$\text{MeCH} = \text{CHCO}_2\text{Me}$, H_3O^+ , CH_2N_2		124
	"	$\text{CH}_2 = \text{CXCH}_2\text{X}$, H_3O^+ , CH_2N_2 , AcOCl, CHCl_3	 $\text{X} = \text{Br}$ (87) $\text{Y} = \text{I}$ (73)	105

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

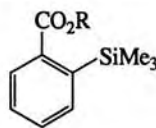
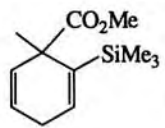
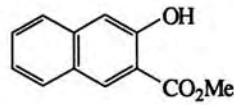
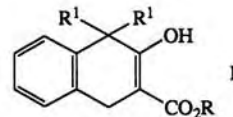
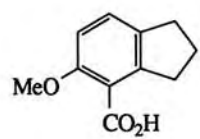
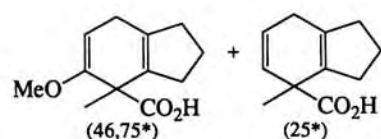
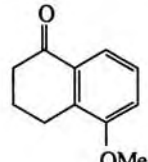
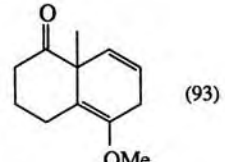
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 CO_2R SiMe_3 $\text{R} = \text{Me}$	NH_3/Na , $t\text{-BuOH}$ (1), -78°	MeI , NH_4Cl	 (76)	3j
C_{11}  OH CO_2Me	NH_3/Na , MeOH , Et_2O , 30 min	R^1X MeI PhCH_2Cl	 I I , $\text{R} = \text{H}$ (25) I , $\text{R} = \text{Me}$ (22)	599
 MeO CO_2H	Na (3)/ NH_3 , THF , 15 min	MeI	 (46,75*) + (25*)	600
 OMe	NH_3/K (2.5), $t\text{-BuOH}$ (2), THF , -78° , LiBr , 10 min	MeI^t	 (93)	104

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

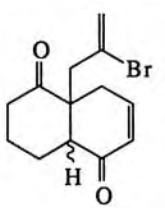
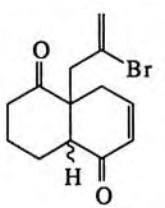
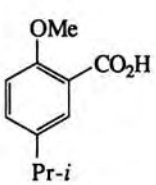
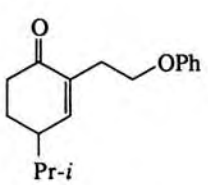
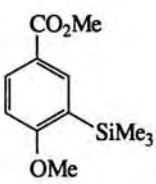
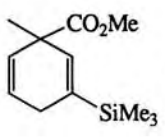
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 Br H	"	$\text{CH}_2=\text{CBrCH}_2\text{Br}$, H_3O^+	 (68)	105
 OMe CO_2H Pr-i	NH_3/Li , THF , -78°	$\text{PhOCH}_2\text{CH}_2\text{Br}$, ^d H_3O^+	 (55)	135
 CO_2Me SiMe_3 OMe	NH_3/Na , $t\text{-BuOH}$, -78°	MeI , NH_4Cl	 (67)	3j

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

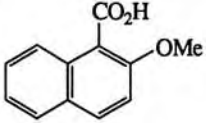
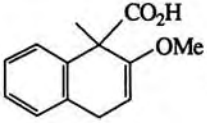
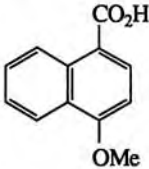
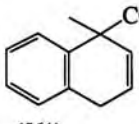
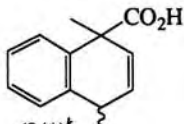
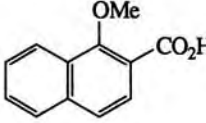
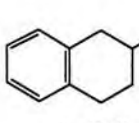
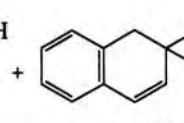
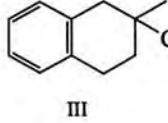
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₂ 	NH ₃ /Na, Et ₂ O	MeI	 (ca 100)	569
	NH ₃ /Li (3), 30 min	"	 (56*) +  (24*) ^k	84
	"	"	 I (15*) +  II (40*) + 2-naphthoic acid (10*)	84
	NH ₃ /Li (5), 30 min	"	I (25*) +  III (50*)	84

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

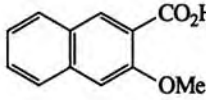
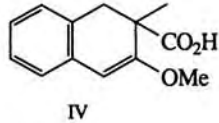
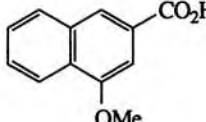
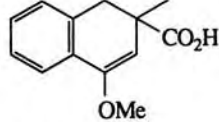
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	" + FeCl ₃	"	II (60*) + 2-naphthoic acid (10*)	84
	NH ₃ /Li (3), 30 min	"	I (25*) +  IV (65*)	84
	NH ₃ /Li (5), 30 min	"	I (25*) + III (55*)	84
	" + FeCl ₃	"	IV (75*)	84
	NH ₃ /Li (3), 30 min	"	I (22*) +  V (65*)	84
	NH ₃ /Li (5) 30 min	"	I (24*) + III (60*)	84
	" + FeCl ₃	"	V (78*)	84

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

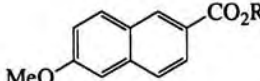
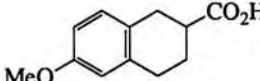
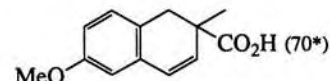
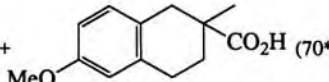
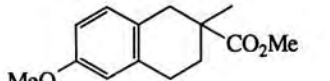
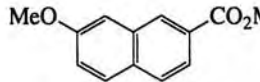
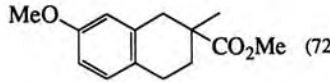
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
 R = H	NH ₃ /Li (3), 30 min	"	 (25*) +  (70*)	84
	NH ₃ /Li (5), 30 min	"	VI (25*) +  (70*)	84
	" , FeCl ₃	"	VII (80*)	84
R = Me	NH ₃ /Na (2.5), THF, 3 min	1. MeI 2. H ₂ - 10% Pd/C	 (70)	601
	"	"	 (72)	601

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

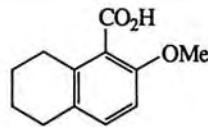
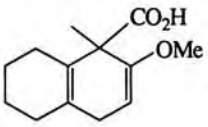
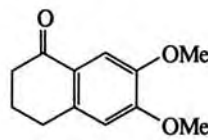
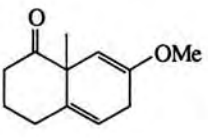
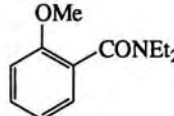
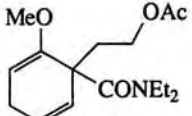
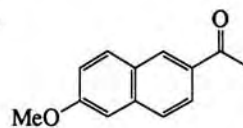
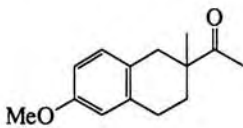
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Na, Et ₂ O	MeI	 (92)	569
	NH ₃ /K (2.5), <i>t</i> -BuOH (3), THF, -78°, LiBr, 10 min	MeI ²	 (93)	104
	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -78°	AcOCH ₂ CH ₂ Br	 (95)	152
C13 	NH ₃ /Li (4 or 8), THF, 30 min	MeI	 (60)	111

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

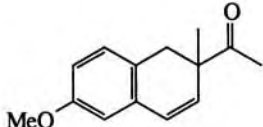
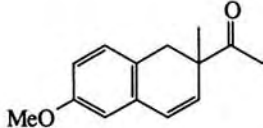
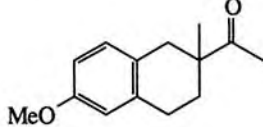
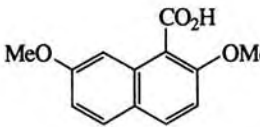
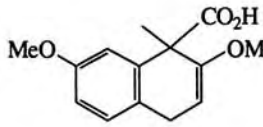
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (4 or 8), THF, 30 min, FeCl ₃	"	 (50-60)	111
	NH ₃ /Na (4), THF, 30 min	"	 (80)	111
	NH ₃ /Na (6), THF, FeCl ₃	"	 (60)	111
	NH ₃ /Na (2.5), Et ₂ O	"	 (ca 100)	569

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

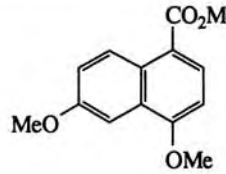
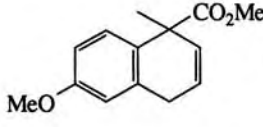
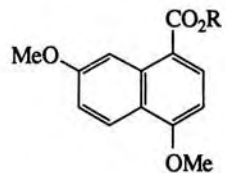
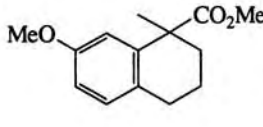
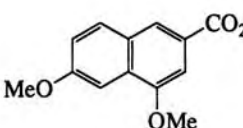
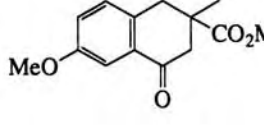
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li/NH ₃ , THF, 5 min	"	 (78)	548
	NH ₃ /Na (5), THF	1. MeI 2. H ₂ - 10% Pd/C	 (69)	601
	"	"	 (70)	601

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

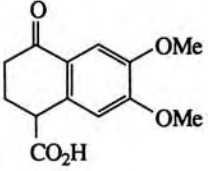
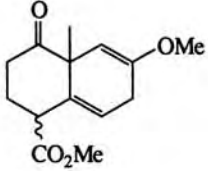
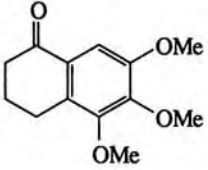
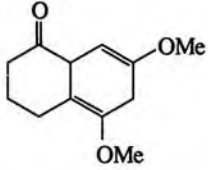
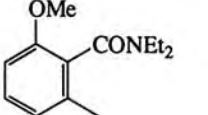
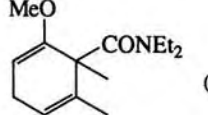
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /K (4.5), <i>t</i> -BuOH (3), THF, -78°, 10 min, LiBr ^s	1. MeI 2. CH ₂ NH ₂	 4 α (64) 4 β (19)	104
	"	MeI	 (93)	104
	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -78°	MeI	 (98)	152

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

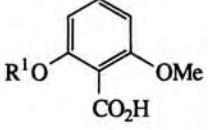
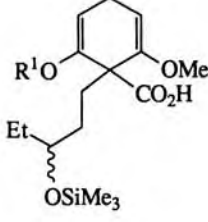
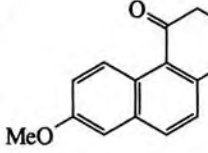
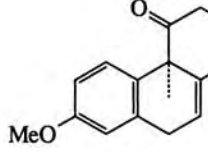
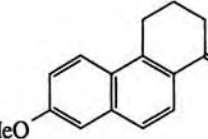
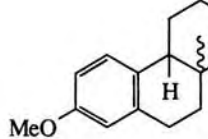
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C14  R ¹ = Si(Me ₂)Bu- <i>t</i>	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -78°, LiBr ^s	EtCHCH ₂ CH ₂ I OSiMe ₃	 (88)	149, 591
C15 	NH ₃ /M (4), THF, 30 min, M = Li, Na or K	MeI	 (70-75)	112
	NH ₃ /Li (6), THF, 30 min	"	 (80) ^t	112

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

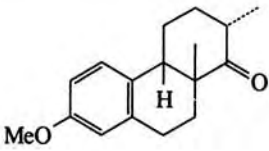
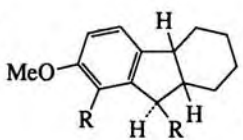
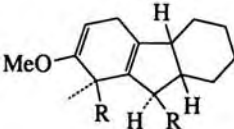
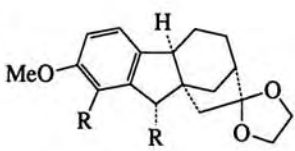
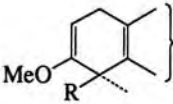
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	K(6), THF, 30 min	"	 (85)	112
C ₁₆  R = CO ₂ H	Li/NH ₃ , THF, 25 min	"	 (50)	132
C ₂₀ 		MeI		
	R = CO ₂ H Na/NH ₃	"	(-)	602
	R = CO ₂ Me NH ₃ /Na, -70°	"	(61)	603

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

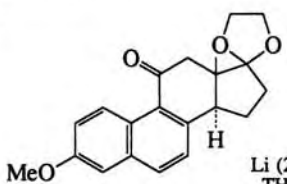
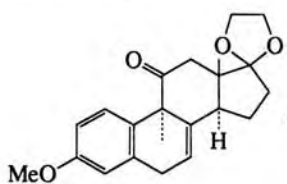
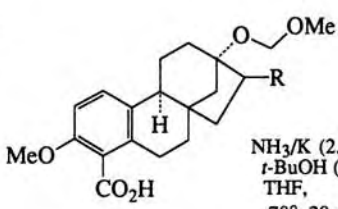
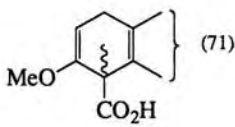
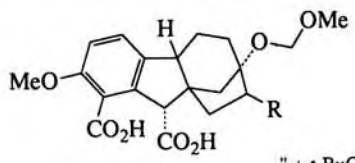
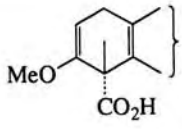
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₂₁ 	Li (2.5)/NH ₃ , THF, 10 min	"	 (59, 70*)	115
C ₂₂  R = C ₂ H ₄ O ₂ ketal	NH ₃ /K (2.5), <i>t</i> -BuOH (1), THF, -78°, 20 min	"	 (71)	554

TABLE XII. REDUCTIVE ALKYLATION OF BIFUNCTIONAL AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	" + <i>t</i> -BuOK (1) ^b	"	 (84)	604, 587
R = C ₂ H ₄ O ₂ ketal				

^a After addition of alkyl halide, the resulting yellow solution was stirred for 1 h at -78°. It is essential to quench the alkylation reaction mixture with excess NH₄Cl before evaporation of ammonia.

^b An ammonia-THF solution of this compound was treated with 1 equiv of *t*-BuOK before normal Birch reduction. Pretreatment with one equiv of base completely prevents hydrogenolysis in most cases.

^c Before alkylation 1,3-pentadiene (2-3 drops) was added to the reaction mixture to destroy excess metal.

^d Alkyl halide and 1,2-dibromoethane were added in one portion to the reaction mixture.

^e The ammonia was removed before alkylation.

^f The resulting 1,4-dihydro derivative was subsequently alkylated by treatment with lithium diisopropylamide (LDA) at -78° (0.5 h, THF) followed by alkyl halide.

^g The resulting blue solution was mixed with anhydrous lithium halide and stirred at -78° for 40 min.

^h The ammonia was evaporated during 1-4 h and the resulting pasty mixture was alkylated by adding alkyl halide and stirring the mixture at 0-10° for 40 min.

ⁱ After 20 min alkyl halide and aqueous THF (1:1) were added simultaneously to the reaction mixture.

^j Metal was added to the reaction mixture in small portions over 2 h.

^k The yield represents a mixture of *cis* and *trans* isomers.

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS

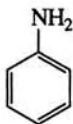
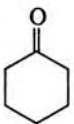
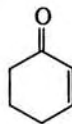
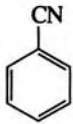
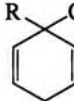
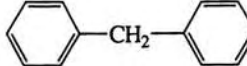
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C6 	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (27) +  (42)	168
C7 	NH ₃ /Li, <i>t</i> -BuOH (1), THF, -78°	RX, NH ₄ Cl ^a	 I	157
		Cl(CH ₂) ₃ Br	I (83)	
		PhCH ₂ Br	I (73)	
		2-MeOC ₆ H ₄ CH ₂ Br	I (67)	
		H ₂ O	 (90)	

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

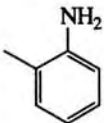
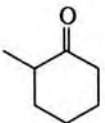
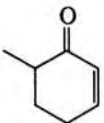
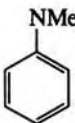
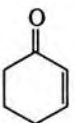
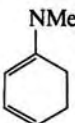
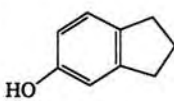
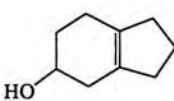
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (18) +  (50)	168
C ₈ 	NH ₃ /Na, EtOH	"	 (57)	167
	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 80 min	EtOH	 (87*)	169
C ₉ 	Li ^b /NH ₃ , THF, -40 to -50°	EtOH ^c	 (70*)	166

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

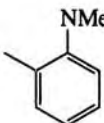
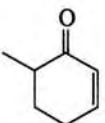
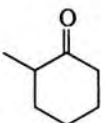
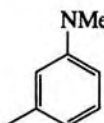
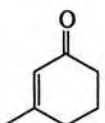
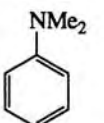
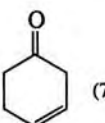
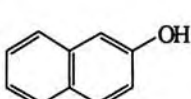
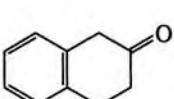
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	"	 (43) +  (22)	168, 167
	NH ₃ /Na, EtOH	"	 (54)	167
	"	"	 (72)	167
C ₁₀ 	NH ₃ /Na (2), <i>t</i> -AmOH	"	 (65)	2a

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

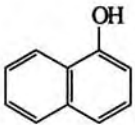
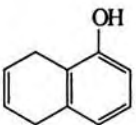
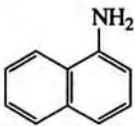
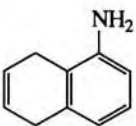
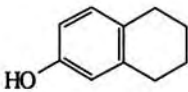
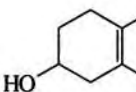
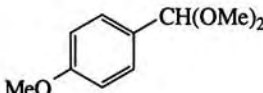
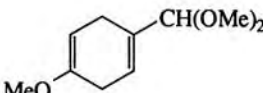
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (3), 1 h	EtOH, H ₃ O ⁺	 (97-99)	605, 606
	Na/NH ₃	NH ₄ Br	 (—)	607
	Li ^b /NH ₃ , THF, -40 to -50°	EtOH ^c	 (76*)	166
	NH ₃ /Na, EtOH	H ₂ O	 (30)	117

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

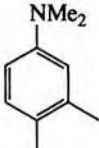
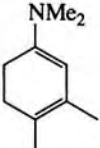
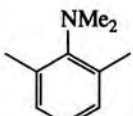
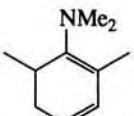
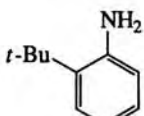
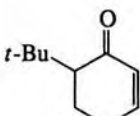
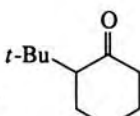
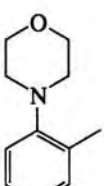
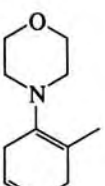
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 80 min	EtOH	 (—)	169
	"	"	 (—)	169
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (25) +  (23)	168
^{C11} 	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 80 min	EtOH	 (95)	169

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

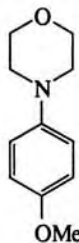
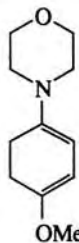

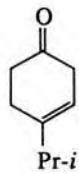
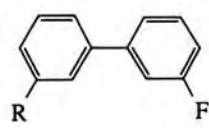
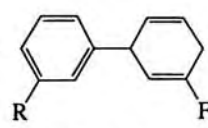
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (75)	169
	NH ₃ /Na, EtOH	H ₂ O, H ₃ O ⁺	 (59)	167
^{C12} 	NH ₃ /Na (2), Et ₂ O, 20 min	NH ₄ Cl	 I I R = F (50) I R = H (—)	175

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

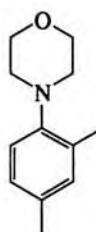
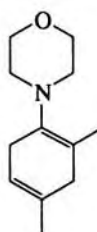
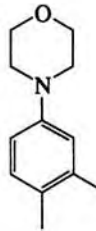
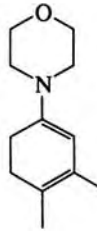
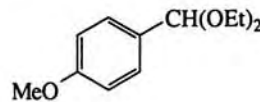
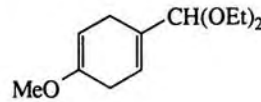
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	NH ₃ /Li (5), <i>t</i> -BuOH, THF, 80 min	EtOH	 (95)	169
	"	"	 (78)	169
	NH ₃ /Na, EtOH	H ₂ O	 (—)	117

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

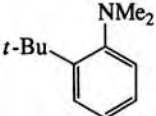
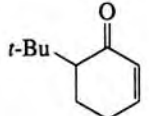
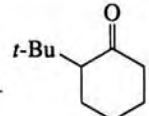
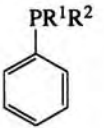
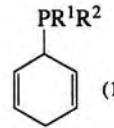
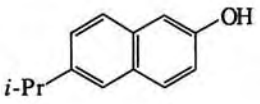
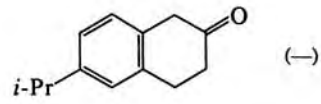
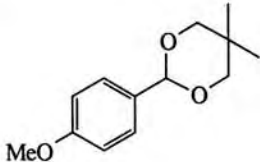
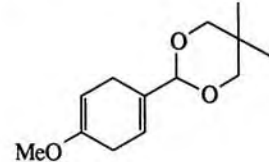
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	Li (4)/NH ₃ , <i>t</i> -BuOH, 1 h	H ₂ O, H ₃ O ⁺	 (24) +  (20)	168
 R ¹ , R ² = <i>i</i> -Pr	NH ₃ /Na (2), -78°, 4 h	H ₂ O	 (13*) + starting material (81*)	608
C13 	Na/NH ₃ , MeOH	H ₂ O, H ₃ O ⁺	 (—)	609
	NH ₃ /Na, EtOH	H ₂ O	 (75)	117

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

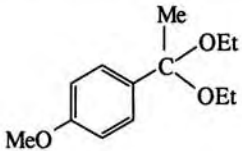
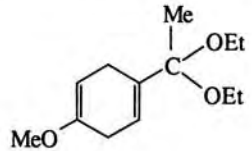
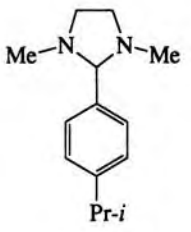
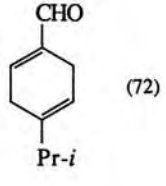
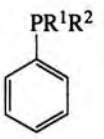
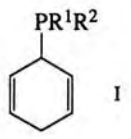
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
	"	"	 (—)	117
C14 	NH ₃ /Li, <i>t</i> -BuOH, THF, 2 h	MeOH, H ₃ O ⁺	 (72)	118
 R ¹ Ph R ² <i>i</i> -Pr	NH ₃ /Na (2), -78°, 4 h	H ₂ O	 I	608
C15 R ¹ Ph R ² <i>i</i> -Pr			I (73*) + starting material (15*) + R ¹ R ² P (12*)	
C16 R ¹ Ph R ² <i>n</i> -Bu			I (21*) + starting material (22*) + R ¹ R ² P (5*)	

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

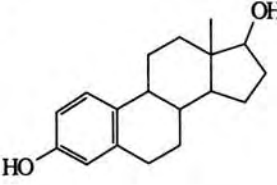
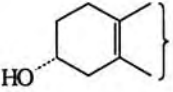
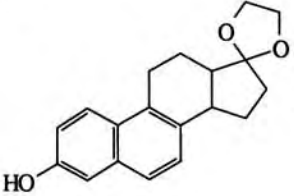
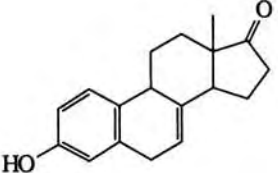
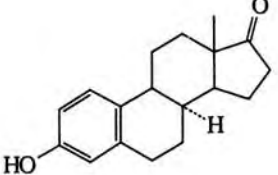
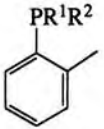
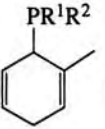
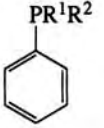
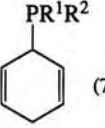
Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₁₈ 	Li ^b /NH ₃ , THF, -40° to -50°	EtOH ^c	 (77*)	160
C ₂₀ 	Li/NH ₃ , THF, -70°, 2.5 h	H ₂ O, H ₃ O ⁺	 (55, 76*) ^d	610
	K/NH ₃ , THF, 3 h	EtOH, H ₃ O ⁺	 (45)	610

TABLE XIII. MISCELLANEOUS REDUCTION AND REDUCTIVE ALKYLATION OF AROMATIC COMPOUNDS (Continued)

Reactant	Reduction Conditions	Quenching Agent	Product(s) and Yield(s) (%)	Refs.
C ₂₁  R ¹ , R ² = <i>o</i> -MeC ₆ H ₄	NH ₃ /Na (2), -78°, 4 h	H ₂ O	 (40*) + starting material (51*)	608
C ₂₂  R ¹ , R ² = <i>p</i> -Me ₂ NC ₆ H ₄	NH ₃ /Na (2), THF, -78°, 2 h	"	 (75, 92*)	608

^a After addition of alkyl halide the yellow solution was stirred for 1 h at -78°. It is essential to quench the alkylation reaction mixture with excess NH₄Cl before evaporation of ammonia.

^b The reaction was performed with a high concentration of lithium in ammonia (ca 4 M).

^c Ethanol was added to the reaction mixture at 30-min intervals until the solution was decolorized (ca. 1.75 h).

^d Slightly better yields were obtained if the naphthoxide anion was formed by reaction of the substrate with sodium hydride before addition to a solution of the metal in ammonia.

7. Acknowledgments

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References

1. C. B. Wooster and K. L. Godfrey, *J. Am. Chem. Soc.*, 1937, **59**, 596.
2. (a) A. J. Birch, *J. Chem. Soc.*, 1944, 430. (b) For a complete list of Birch's contributions, see *Tetrahedron*, **44**, No. 10, pp. V–XVIII (1988).
3. A number of reviews have appeared. For example, see (a) A. J. Birch, *Quart. Rev., Chem. Soc.*, 1950, **4**, 69. (b) A. J. Birch and H. Smith, *ibid.*, 1958, **7**, 17. (c) H. Smith, *Organic Reactions in Liquid Ammonia*, Vol. **1**, Part 2, Wiley-Interscience, New York, 1963. (d) W. Hückel, *Fortschr. Chem. Forsch*, 1966, **6**, 197. (e) M. Smith, in *Reduction: Techniques and Applications in Organic Synthesis*, R. L. Augustine, Ed., Marcel Dekker, New York, 1968. (f) R. G. Harvey, *Synthesis*, 1970, 161. (g) A. J. Birch and G. S. R. Subba Rao, in *Advances in Organic Chemistry, Methods and Results*, E. C. Taylor, Ed., Wiley-Interscience, New York, 1972, pp. 1–65. (h) P. W. Rabideau, *Tetrahedron*, 1989, **45**, 1579. (i) D. Caine, *Org. React.*, 1976, **23**, 1. (j) For applications to natural product synthesis, see J. M. Hook and L. N. Mander, *Natural Prod. Rep.*, 1986, **3**, 35. (k) For application to carbonyl compounds see J. W. Huffman, *Acc. Chem. Res.*, 1983, **16**, 399; S. K. Pradhan, *Tetrahedron*, 1986, **42**, 6351.
4. A. L. Wilds and N. A. Nelson, *J. Am. Chem. Soc.*, 1953, **75**, 5360.
5. W. Hückel and H. Bretschneider, *Justus Liebigs Ann. Chem.*, 1939, **540**, 157.
6. See reference [3j](#) for a number of synthetic applications.
7. For a more detailed description of metal–ammonia solutions, see, for example, *The Chemistry of Nonaqueous Solvents*, J. L. Lagowski, Ed., Vol. **2**, Academic Press, New York, 1967, pp. 265–317.
8. See reference [3h](#) for a recent review of the mechanistic aspects of this reaction.
9. *The protonation of radical anions by ammonia is not considered likely because of their relatively low basicity.* ([10](#))
10. M. Szwarc, Ed., *Ions and Ion Pairs in Organic Chemistry*, Vol. **2**, Wiley-Interscience, New York, 1974.
11. P. W. Rabideau and E. G. Burkholder, *J. Org. Chem.*, 1978, **43**, 4283.
12. A. Streitwieser, Jr., C. M. Berke, and K. Robbers, *J. Am. Chem. Soc.*, 1978, **100**, 8271.
13. A. Streitwieser, Jr., *Acc. Chem. Res.*, 1984, **17**, 353.
14. T. D. Walsh, *J. Am. Chem. Soc.*, 1987, **109**, 1511.
15. O. R. Brown, R. J. Butterfield, and J. P. Millington, *Electrochim. Acta*, 1982, **27**, 1655.
16. *A series of papers providing an excellent discussion of the regiochemistry in the Birch reduction of benzenes, including 1,3 vs. 1,4 products as well*

as the effect of substituent groups, has appeared. (17-20)

17. A. J. Birch, A. L. Hinde, and L. Radom, *J. Am. Chem. Soc.*, 1980, **102**, 3370.
18. A. J. Birch, A. L. Hinde, and L. Radom, *J. Am. Chem. Soc.*, 1980, **102**, 4074.
19. A. J. Birch, A. L. Hinde, and L. Radom, *J. Am. Chem. Soc.*, 1980, **102**, 6430.
20. A. J. Birch, A. L. Hinde, and L. Radom, *J. Am. Chem. Soc.*, 1981, **103**, 284.
21. For a more detailed discussion, see reference 3h, and also P. W. Rabideau and D. L. Huser, *J. Org. Chem.*, 1983, **48**, 4266.
22. P. W. Rabideau and A. Sygula, in *The Conformational Analysis of Cyclohexenes, Cyclohexadienes and Related Hydroaromatics*, P. W. Rabideau, Ed., VCH, New York, 1989, Ch. 3.
23. A. Streitwieser, Jr., *Molecular Orbital Theory for Organic Chemists*, Wiley, New York, 1961.
24. H. E. Zimmerman, *Tetrahedron*, 1961, **16**, 169.
25. M. J. S. Dewar, J. A. Hashmall, and N. Trinajstić, *J. Am. Chem. Soc.*, 1970, **92**, 5555.
26. V. Parker, *J. Am. Chem. Soc.*, 1976, **98**, 98.
27. K. Müllen, W. Huber, G. Neumann, C. Scheiders, and H. Unterberg, *J. Am. Chem. Soc.*, 1985, **107**, 801.
28. P. W. Rabideau, A. J. Maxwell, and A. Sygula, *J. Org. Chem.*, 1986, **51**, 3181.
29. P. W. Rabideau, N. K. Peters, and D. L. Huser, *J. Org. Chem.*, 1981, **46**, 1593.
30. E. W. Garbisch, Jr. and M. G. Griffith, *J. Am. Chem. Soc.*, 1968, **90**, 117.
31. Z. Marcinow and P. W. Rabideau, Louisiana State University, unpublished results.
32. C. Eaborn, R. A. Jackson, and R. Pearce, *J. Chem. Soc., Perkin Trans. 1*, 1974, 2055.
33. P. W. Rabideau, L. M. Day, C. A. Husted, J. L. Mooney, and D. M. Wetzel, *J. Org. Chem.*, 1986, **51**, 1681.
34. *This has been demonstrated by variable temperature NMR.* (33)
35. P. P. Fu, R. G. Harry, J. W. Paschal, and P. W. Rabideau, *J. Am. Chem. Soc.*, 1975, **97**, 1145. See also P. W. Rabideau and E. G. Burkholder, *J. Org. Chem.*, 1979, **44**, 2354.
36. P. W. Rabideau, D. M. Wetzel, C. A. Husted, and J. R. Lawrence, *Tetrahedron Lett.*, 1984, **25**, 31.
37. A. Sygula and P. W. Rabideau, *J. Org. Chem.*, 1987, **52**, 3521.

38. P. W. Rabideau and R. G. Harvey, *J. Org. Chem.*, 1970, **35**, 25.
39. A. G. Schultz, M. Macielag, P. Sundararaman, A. Taveras, and M. Welch, *J. Am. Chem. Soc.*, 1988, **110**, 7828.
40. M. N. Paddon-Row, *Acc. Chem. Res.*, 1982, **15**, 245 and references cited therein.
41. R. Hoffman, *Acc. Chem. Res.*, 1971, **4**, 1.
42. G. Goto, K. Yoshioka, K. Hiraga, M. Masuoka, R. Nakayama, and T. Miki, *Chem. Pharm. Bull.*, 1978, **26**, 1718.
43. E. Cotsaris and M. N. Paddon-Row, *J. Chem. Soc., Perkin Trans. 2*, 1984, 1487.
44. T. Kametani, T. Toya, M. Tsubuki, K. Kawai, and T. Honda, *Chem. Pharm. Bull.*, 1986, **34**, 3169.
45. W. S. Johnson, R. Pappo, and W. F. Johns, *J. Am. Chem. Soc.*, 1956, **78**, 6339.
46. D. W. MacSweeney and R. Ramage, *Tetrahedron*, 1971, **27**, 1481.
47. E. Fujita and M. Ochiai, *Chem. Pharm. Bull.*, 1978, **26**, 264.
48. D. J. Humphreys, P. M. Lawrence, C. E. Newall, G. H. Phillips, and P. A. Wall, *J. Chem. Soc., Perkin Trans. 1*, 1978, 24.
49. J. Runge, *Z. Chem.*, 1962, **2**, 374; *J. Prakt. Chem.*, [4] 1966, **31**, 280.
50. R. G. Harvey, *J. Org. Chem.*, 1967, **32**, 238.
51. R. G. Harvey and K. Urberg, *J. Org. Chem.*, 1968, **33**, 2570.
52. P. W. Rabideau and R. G. Harvey, *Tetrahedron Lett.*, 1970, 4139.
53. A. A. Akhrem and Y. A. Titov, *Total Steroid Synthesis*, Plenum, New York, 170.
54. F. J. Kakis, in *Steroid Reactions*, C. Djerassi, Ed., Holden Day, San Francisco, 1963, pp. 267–298.
55. E. Ottow, S. Beier, W. Elger, D. Henderson, G. Neef, and R. Wiechert, *Steroids*, 1984, **44**, 519.
56. G. Schubert, K. Ponsold, and U. Eibisch, *Pharmazie*, 1984, **39**, 92.
57. D. K. Phillips, P. P. Wickam, G. O. Potts, and A. Arnold, *J. Med. Chem.*, 1968, **11**, 924.
58. K. J. Sax, R. H. Blank, R. H. Evands, L. I. Feldman and C. E. Holmland, *J. Org. Chem.*, 1964, **29**, 2351.
59. H. L. Holland and G. J. Taylor, *Can. J. Chem.*, 1981, **59**, 2809.
60. H. Baier, G. Duerner, and G. Quinkert, *Helv. Chim. Acta*, 1985, **68**, 1054.
61. S. J. Brandes and J. A. Katzenellenbogen, *Mol. Pharmacol.*, 1987, **32**, 391.
62. C. C. Bolt and F. J. Zeelen, *Recl. Trav. Chim. Pays-Bas*, 1973, **92**, 1267.
63. G. Amiard, R. Heymes, and T. Von Thoung, *Bull. Soc. Chim. Fr.*, 1972,

272.

64. See reference [42](#).
65. G. S. R. Subba Rao and N. S. Sundar, *Indian J. Chem., Sect. B*, 1977, **15B**, 585.
66. T. Kametani, K. Suzuki, and H. Nemoto, *Tetrahedron Lett.*, 1980, **21**, 1469.
67. Z. P. Zhuang and W. S. Zhou, *Tetrahedron*, 1985, **41**, 3633.
68. B. Aweryn and A. R. Daniewski, *Pol. J. Chem.*, 1980, **54**, 251.
69. F. E. Ziegler and T. F. Wang, *J. Am. Chem. Soc.*, 1984, **106**, 718.
70. R. B. Garland, J. R. Palmer, and R. Pappo, *J. Org. Chem.*, 1976, **41**, 531.
71. G. Goto, K. Yoshioka, K. Hiraga, and T. Miki, *Chem. Pharm. Bull.*, 1977, 1295.
72. G. Neef, U. Eder, G. Haffer, G. Sauer, and R. Wiechert, *Chem. Ber.*, 1980, **113**, 1106.
73. R. Joly, J. Warnant, J. Jolly, and A. Farcilli, *Bull. Soc. Chim. Fr.*, 1973, 2694.
74. C. G. Pitt, D. H. Rector, C. E. Cook, and M. C. Wani, *J. Med. Chem.*, 1979, **22**, 966.
75. H. J. J. Loozen and M. S. DeWinter, *Recl. Trav. Chim. Pays-Bas*, 1980, **99**, 311.
76. R. J. Marshall, I. McIndewar, J. A. M. Peters, N. P. van Vliet, and F. J. Zeelen, *Eur. J. Med. Chem. Chim. Ther.*, 1984, **19**, 43.
77. D. K. Banerjee and P. R. Srinivasan, *Indian J. Chem.*, 1972, **10**, 891.
78. A. Sandoval, G. H. Thomas, C. Djerassi, G. Rosenkranz, and F. Sondheimer, *J. Am. Chem. Soc.*, 1955, **77**, 148.
79. H. Nemoto, M. Nagai, F. Fukumoto, and T. Kametani, *Tetrahedron Lett.*, 1985, **26**, 4613.
80. See reference [2a](#).
81. W. S. Johnson, B. Bannister, and R. Rappo, *J. Am. Chem. Soc.*, 1956, **78**, 6331.
82. R. B. Turner, K. H. Gänshirt, P. E. Shaw, and J. D. Tauber, *J. Am. Chem. Soc.*, 1966, **88**, 1776.
83. M. Narisada and F. Watanabe, *J. Org. Chem.*, 1973, **38**, 3887.
84. A. R. Murthy, N. S. Sundar, and G. S. R. Subba Rao, *Tetrahedron*, 1982, **38**, 2831.
85. A. J. Birch and G. S. R. Subba Rao, *Aust. J. Chem.*, 1970, **23**, 1641.
86. R. C. Cambie and A. W. Missen, *Aust. J. Chem.*, 1972, **25**, 973.
87. T. L. Macdonald, *J. Org. Chem.*, 1978, **43**, 3621.
88. A. J. Birch, *J. Chem. Soc.*, 1950, 1551.

89. K. Pramod, H. Ramanathan, and G. S. R. Subba Rao, *J. Chem. Soc., Perkin Trans. 1*, 1983, 7.
90. F.-H. Koster and H. Wolf, *Tetrahedron Lett.*, 1981, **22**, 3937.
91. P. M. Bishop, J. R. Pearson, and J. K. Sutherland, *J. Chem. Soc., Chem. Commun.*, 1983, 123.
92. J. Orban and J. V. Turner, *Tetrahedron Lett.*, 1983, **24**, 2697.
93. J. Amupitan and J. K. Sutherland, *J. Chem. Soc., Chem. Commun.*, 1978, 852.
94. J. Amupitan, E. Hug, M. Mellor, E. G. Scovell, and J. K. Sutherland, *J. Chem. Soc., Perkin Trans. 1*, 1983, 747.
95. A. J. Birch and K. P. Dastur, *Tetrahedron Lett.*, 1972, **41**, 4195.
96. A. J. Birch and K. P. Dastur, *J. Chem. Soc., Perkin Trans. 1*, 1973, 1650.
97. D. A. Evans, W. L. Scott, and L. K. Truesdale, *Tetrahedron Lett.*, 1972, 121.
98. D. A. Evans, W. L. Scott, and L. K. Truesdale, *Tetrahedron Lett.*, 1972, 137.
99. W. L. Scott and D. A. Evans, *J. Am. Chem. Soc.*, 1972, **94**, 4779.
100. M. A. Qassem, N. A. J. Rogers, and A. A. Othman, *Tetrahedron*, 1968, **24**, 4535.
101. A. R. Pinder and H. Smith, *J. Chem. Soc.*, 1954, 113.
102. (a) S. S. Hall, S. D. Lipsky, F. J. McEnroe, and A. P. Bartels, *J. Org. Chem.*, 1971, **36**, 2588. (b) S. S. Hall, S. D. Lipsky, and G. H. Small, *Tetrahedron Lett.*, 1971, 1853.
103. Z. Marcinow and P. W. Rabideau, *J. Org. Chem.*, 1988, **53**, 2117.
104. J. M. Brown, T. M. Cresp, and L. N. Mander, *J. Org. Chem.*, 1977, **42**, 3984.
105. N. N. Marinovic and H. R. Ramanathan, *Tetrahedron Lett.*, 1983, **24**, 1871.
106. R. McCaquee, C. J. Moody, and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1983, 2399.
107. Z. Lidert, R. McCaquee, C. J. Moody, and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1985, 383.
108. C. J. Moody and J. Toczec, *Tetrahedron Lett.*, 1986, **27**, 5253.
109. S. Mejer and Z. Marcinow, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1976, **24**, 175 [C. A., **85**, 94121v (1976)].
110. S. Mejer and R. Pacut, *Pol. J. Chem.*, 1978, **52**, 529.
111. G. S. R. Subba Rao and N. S. Sundar, *J. Chem. Soc., Perkin Trans. 1*, 1982, 875.
112. N. S. Sundar and G. S. R. Subba Rao, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1381.

113. P. W. Rabideau, C. H. Husted, and D. M. Young, *J. Org. Chem.*, 1983, **48**, 4149.
114. S. Mejer, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1962, **10**, 469 [C. A., **59**, 1554 (1963)].
115. S. Mejer, Z. Marcinow, and S. Respondek, *Pol. J. Chem.*, 1980, **54**, 2247.
116. A. J. Birch and G. S. R. Subba Rao, *Aust. J. Chem.*, 1970, **23**, 547.
117. K. S. J. Stapleford, *Synth. Commun.*, 1982, **23**, 651.
118. A. J. Birch and K. P. Dastur, *Aust. J. Chem.*, 1973, **26**, 1363.
119. See reference [3a](#).
120. M. E. Kuehne and B. F. Lambert, *J. Am. Chem. Soc.*, 1959, **81**, 4278.
121. H. Plieninger and G. Ege, *Angew. Chem.*, 1958, **70**, 505.
122. F. Camps, J. Coll, and J. Pascual, *J. Org. Chem.*, 1967, **32**, 2563.
123. H. van Bekkum, C. B. van den Bosch, G. van Minnen-Pathuis, J. C. de Mos, and A. M. van Vijk, *Recl. Trav. Chim. Pays-Bas*, 1971, **90**, 137.
124. G. S. R. Subba Rao, K. Raj, and H. Ramanathan, *J. Chem. Soc., Chem. Commun.*, 1980, 315.
125. W. J. Sipio, *Tetrahedron Lett.*, 1985, **26**, 2039.
126. G. W. Holbert and B. Ganem, *J. Am. Chem. Soc.*, 1978, **100**, 352.
127. J. V. Turner, B. F. Anderson, and L. N. Mander, *Aust. J. Chem.*, 1980, **33**, 1061.
128. A. J. Birch, P. Hextall, and S. Sternhell, *Aust. J. Chem.*, 1954, **7**, 256.
129. O. L. Chapman and P. Fitton, *J. Am. Chem. Soc.*, 1963, **85**, 41.
130. M. E. C. Biffin, A. G. Mortiz, and D. B. Paul, *Aust. J. Chem.*, 1972, **25**, 1329.
131. A. J. Birch, J. Slobbe, *Aust. J. Chem.*, 1977, **30**, 1045.
132. H. O. House, R. C. Strickland, and E. J. Zaiko, *J. Org. Chem.*, 1976, **41**, 2401.
133. A. L. Cossey, M. J. Gunter, and L. N. Mander, *Tetrahedron Lett.*, 1980, **21**, 3309.
134. J. M. Hook, L. N. Mander, and M. Woolias, *Tetrahedron Lett.*, 1982, **23**, 1095.
135. D. F. Taber and R. W. Korsmeyer, *J. Org. Chem.*, 1978, **43**, 4925.
136. A. J. Birch and J. Slobbe, *Tetrahedron Lett.*, 1976, 2079.
137. J. Slobbe, *J. Chem. Soc., Chem. Commun.*, 1977, 82.
138. J. L. Marshall and T. K. Folsom, *J. Org. Chem.*, 1971, **36**, 2011.
139. P. W. Rabideau, E. G. Burkholder, and M. J. Yates, *Synth. Commun.*, 1980, **10**, 627.
140. M. C. Gossel and R. C. Hayward, *J. Chem. Soc., Perkin Trans. 2*, 1976, 851.

141. J. Slobbe, *Aust. J. Chem.*, 1978, **31**, 1157.
142. G. S. R. Subba Rao, A. R. K. Murthy, and N. S. Sundar, *Indian J. Chem.*, 1978, **16B**, 1027.
143. L. N. Mander and S. G. Pyne, *Aust. J. Chem.*, 1981, **34**, 1899.
144. D. J. Beames, J. A. Halleday, and L. N. Mander, *Aust. J. Chem.*, 1972, **25**, 137.
145. D. Franks, M. C. Grossel, R. Hayward, and L. J. S. Knutsen, *J. Chem. Soc., Chem. Commun.*, 1978, 941.
146. P. W. Rabideau, S. J. Nyikos, D. L. Huser, and E. G. Burkholder, *J. Chem. Soc., Chem. Commun.*, 1980, 210.
147. P. W. Rabideau, D. L. Huser, and S. J. Nyikos, *Tetrahedron Lett.*, 1980, **21**, 1401.
148. A. L. Cossey, L. N. Mander, and S. G. Pyne, *Aust. J. Chem.*, 1979, **32**, 817.
149. R. J. Hamilton, L. N. Mander, and S. P. Sethi, *Tetrahedron*, 1981, **42**, 2881.
150. A. G. Schultz and S. Puig, *J. Org. Chem.*, 1985, **50**, 915.
151. A. G. Schultz, M. Plummer, A. G. Taveras, and R. K. Kullnig, *J. Am. Chem. Soc.*, 1988, **110**, 5547.
152. A. G. Schultz, J. P. Dittami, F. P. Lavieri, C. Salowey, P. Sundararaman, and M. B. Szymula, *J. Org. Chem.*, 1984, **49**, 4429.
153. A. J. Birch, J. Cymerman-Craig, and M. Slaytor, *Aust. J. Chem.*, 1955, **8**, 512.
154. R. Furstoss, G. Esposito, P. Teissier, and B. Waegell, *Bull. Soc. Chim. Fr.*, 1974, 2485.
155. L. Dickson, C. A. Matuszak, and A. H. Qazi, *J. Org. Chem.*, 1978, **43**, 1007.
156. A. Mann, C. Humblet, J. P. Chambon, R. Schlichter, M. Desarmenien, P. Feltz, and C. G. Wermuth, *J. Med. Chem.*, 1985, **28**, 1440.
157. A. G. Schultz and M. Macielag, *J. Org. Chem.*, 1986, **51**, 4983.
158. A. G. Schultz and P. Sundararaman, *Tetrahedron Lett.*, 1984, **25**, 4591.
159. A. G. Schultz, P. Sundararaman, M. Macielag, F. P. Lavieri, and M. Welch, *Tetrahedron Lett.*, 1985, **26**, 4575.
160. A. G. Schultz, P. J. McCloskey, P. Sundararaman, and J. P. Springer, *Tetrahedron Lett.*, 1985, **26**, 1619.
161. P. J. McCloskey and A. G. Schultz, *Heterocycles*, 1987, **25**, 437.
162. A. G. Schultz, P. J. McCloskey, and J. J. Court, *J. Am. Chem. Soc.*, 1987, **109**, 6493.
163. P. J. McCloskey and A. G. Schultz, *J. Org. Chem.*, 1988, **53**, 1380.
164. A. G. Schultz, M. Macielag, D. E. Podhorez, J. C. Suhadolnik, and R. K.

- Kullnig, J. Org. Chem., 1988, **53**, 2456.
165. A. J. Birch and G. S. R. Subba Rao, Tetrahedron Lett., 1967, 857.
166. J. Fried, N. A. Abraham, and T. S. Santhanakrishnan, J. Am. Chem. Soc., 1967, **89**, 1044.
167. A. J. Birch, J. Chem. Soc., 1946, 593.
168. G. Stork and W. N. White, J. Am. Chem. Soc., 1956, **78**, 4604.
169. A. J. Birch, E. G. Hutchinson, and G. Subba Rao, J. Chem. Soc. C, 1971, 637.
170. For a recent discussion of this effect, see J. P. Gilday, J. C. Gallucci, and L. A. Paquette, J. Org. Chem., 1989, **54**, 1399.
171. C. Eaborn, D. R. M. Walton, and G. Seconi, J. Chem. Soc., Perkin Trans. 2, 1976, 1857.
172. P. W. Rabideau and G. L. Karrick, Tetrahedron Lett., 1987, **28**, 2481.
173. P. W. Rabideau and Z. Marcinow, Tetrahedron Lett., 1988, **29**, 3761.
174. Z. Marcinow, D. K. Clawson, and P. W. Rabideau, Tetrahedron, 1989, **45**, 5441.
175. D. W. Jessup, J. W. Paschal, and P. W. Rabideau, J. Org. Chem., 1977, **42**, 2620.
176. (a) For a review, see: L. M. Stock, in *Coal Science*, Vol. 1, M. L. Gorbaty, J. W. Larson, and I. Wender, Eds., Academic Press, New York, 1982. (b) R. H. Fish and J. W. Dupon, J. Org. Chem., 1988, **53**, 5230.
177. E. Grovenstein, Jr., A. M. Bhatti, D. E. Quest, D. Sengupta, and D. van Derveer, J. Am. Chem. Soc., 1983, **105**, 6290.
178. W. E. Bachmann, J. Am. Chem. Soc., 1933, **55**, 3005.
179. K. Ziegler and F. Thielmann, Chem. Ber., 1953, **56**, 1740.
180. J. B. Conant and B. S. Garvey, Jr., J. Am. Chem. Soc., 1927, **49**, 2599.
181. J. J. Eisch, J. Org. Chem., 1963, **28**, 707.
182. C. J. Collins, H.-P. Hombach, B. Maxwell, M. C. Woody, and B. M. Benjamin, J. Am. Chem. Soc., 1980, **102**, 851. C. J. Collins, H.-P. Hombach, B. E. Maxwell, B. M. Benjamin, and D. McKamey, J. Am. Chem. Soc., 1981, **103**, 1213.
183. A. Lagendijk and M. Szwarc, J. Am. Chem. Soc., 1971, **93**, 5359.
184. R. R. Chambers, Jr., C. J. Collins, and B. E. Maxwell, J. Org. Chem., 1985, **50**, 4960. See also reference [181](#).
185. T. D. Walsh and T. L. Megremis, J. Am. Chem. Soc., 1981, **103**, 3897. T. D. Walsh, J. Am. Chem. Soc., 1987, **109**, 1511.
186. C. B. Wooster, J. Am. Chem. Soc., 1934, **56**, 2436.
187. P. W. Rabideau, D. W. Jessup, J. W. Ponder, and G. F. Buckman, J. Org. Chem., 1979, **44**, 4594.

188. Z. Marcinow, C. E. Hull, and P. W. Rabideau, *J. Org. Chem.*, 1989, **54**, 3602.
189. A. Streitwieser, Jr. and S. Suzuki, *Tetrahedron*, 1961, **16**, 153.
190. J. J. deVlieger, A. P. G. Kieboom, and H. van Bekkum, *J. Org. Chem.*, 1986, **51**, 1389.
191. For a review, see E. M. Kaiser, *Synthesis*, 1972, 391.
192. R. A. Benkeser, R. E. Robinson, D. M. Sauve, and O. H. Thomas, *J. Am. Chem. Soc.*, 1955, **77**, 3230.
193. R. A. Benkeser and E. M. Kaiser, *J. Org. Chem.*, 1964, **29**, 955.
194. J. D. Brooks, R. A. Durie, and H. Silberman, *Aust. J. Chem.*, 1964, **17**, 55.
195. L. Reggel, S. Friedman, and L. Wender, *J. Org. Chem.*, 1958, **23**, 1136.
196. R. A. Benkeser, F. G. Belmonte, and M.-H. Yang, *Synth. Commun.*, 1983, **13**, 1103.
197. R. A. Benkeser, J. A. Laugal, and A. Rappa, *Tetrahedron Lett.*, 1984, **25**, 2089.
198. For some examples, see K. Müllen, *Angew. Chem., Int. Ed. Engl.*, 1987, **26**, 204.
199. E. Grovenstein, Jr., T. H. Longfield, and D. E. Quest, *J. Am. Chem. Soc.*, 1977, **99**, 2800.
200. J. L. Dye, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 587.
201. D. J. Mathre and W. C. Guida, *Tetrahedron Lett.*, 1980, **21**, 4773.
202. See reference [176b](#).
203. K. C. Bass, *Org. Synth., Coll. Vol.* **5**, 1973, 398.
204. D. R. Weyenberg and L. H. Toporcer, *J. Am. Chem. Soc.*, 1962, **84**, 2843.
205. M. Laguerne, J. Dunogués, R. Calas, and N. Duffaut, *J. Organomet. Chem.*, 1976, **112**, 49.
206. M. Laguerne, J. Dunogués, R. Calas, and N. Duffaut, *J. Organomet. Chem.*, 1975, **93**, C17.
207. A. G. Barnett, *J. Org. Chem.*, 1988, **53**, 1815.
208. (a) J. Dunogués, R. Calas, and N. Ardoin, *J. Organomet. Chem.*, 1972, **43**, 127. (b) M. Keil and F. Effenberger, *Chem. Ber.*, 1982, **115**, 1103.
209. A. G. Barnett, *J. Org. Chem.*, 1984, **49**, 4409.
210. D. R. Weyenberg and L. H. Toporcer, *J. Org. Chem.*, 1965, **30**, 943.
211. L. Birkofer and N. Ramadan, *Chem. Ber.*, 1971, **104**, 138.
212. M. Laguerne, J. Dunogués, and R. Calas, *Tetrahedron Lett.*, 1981, **22**, 1227.
213. J. Dunogués, R. Calas, C. Brian, and N. Duffaut, *J. Organomet. Chem.*, 1970, **23**, C50.
214. (a) C. K. Mann and K. K. Barnes, *Electrochemical Reactions in*

- Nonaqueous Systems*, Marcel Dekker, Inc., NY, 1970, Ch. "2". (b) H. Lund, in *Organic Electrochemistry*, M. M. Baizer and H. Lund, Eds., Marcel Dekker, NY, 1983.
215. For a recent review, see E. Kariv-Miller, R. I. Pacut, and G. K. Lehman, *Topics Curr. Chem.*, 1988, **148**, 97.
216. R. A. Benkeser, E. M. Kaiser, and R. F. Lambert, *J. Am. Chem. Soc.*, 1964, **86**, 5272.
217. R. I. Pacut and E. Kariv-Miller, *J. Org. Chem.*, 1986, **51**, 3468.
218. E. Kariv-Miller, K. E. Swenson, G. K. Lehman, and R. Andruzzi, *J. Org. Chem.*, 1985, **50**, 556.
219. For reviews, see (a) M. Smith in Augustine, *Reduction Techniques and Applications in Organic Synthesis*, Marcel Dekker, NY, 1968, pp. 309–395. (b) E. L. Muetterties and J. R. Bleeke, *Acc. Chem. Res.*, 1979, **12**, 324. (c) M. Bennett, *CHEMTECH*, 1980, **10**, 444.
220. P. P. Fu, H. M. Lee, and R. G. Harvey, *J. Org. Chem.*, 1980, **45**, 2797.
221. M. K. Faber, O. Fussa-Rydel, J. B. Skowrya, L. E. H. McMills, and J. L. Dye, *J. Am. Chem. Soc.*, 1989, **111**, 5957.
222. M. Fieser and L. F. Fieser, *Reagents for Organic Synthesis*, Vol. **1**, New York, 1967.
223. L. A. Paquette and J. H. Barnett, *Org. Synth.*, Coll. Vol. **5**, 1973, 467.
224. *This reaction has been performed numerous times by the authors. See reference 11 for general procedures.*
225. R. G. Harvey and K. Urberg, *J. Org. Chem.*, 1968, **33**, 2206.
226. H. Nemoto, M. Nagai, K. Fukumoto, and T. Kametani, *J. Chem. Soc., Perkin Trans. 1*, 1986, 1621.
227. A. Manmade, J. L. Marshall, R. A. Minns, H. Dalzell, and R. K. Razdan, *J. Org. Chem.*, 1982, **47**, 1717.
228. S. Danishefsky and P. Cain, *J. Org. Chem.*, 1975, **40**, 3606.
229. P. W. Rabideau, D. M. Wetzel, and D. M. Young, *J. Org. Chem.*, 1984, **49**, 1544.
230. W. Hückel and U. Wörfall, *Chem. Ber.*, 1955, **88**, 338.
231. J. P. Wibaut and F. A. Haak, *Recl. Trav. Chim. Pays Bas*, 1948, **67**, 85.
232. P. Radlick and H. T. Crawford, *J. Chem. Soc., Chem. Commun.*, 1974, 127.
233. A. P. Krapcho and A. A. Bothner-By, *J. Am. Chem. Soc.*, 1959, **81**, 3658.
234. M. Demuth and K. Schaffner, *Angew. Chem., Int. Ed. Engl.*, 1982, **21**, 820.
235. P. Radlick and L. R. Brown, *J. Org. Chem.*, 1973, **38**, 3412.
236. H. F. Alburn and W. Dvonch, *W. Brit. Patent GB 1295950 (1972) [C.A., 78, 71562f (1973)]*.

237. P. Egli, J. Labelled Comp. Radiopharm., 1981, **18**, 1677.
238. R. A. Benkeser, M. L. Burrous, J. J. Hazdra, and E. M. Kaiser, J. Org. Chem., 1963, **28**, 1094.
239. T. Watabe, A. Hiratsuka, T. Aizawa, and T. Sawahata, Tetrahedron Lett., 1982, **23**, 1185.
240. E. Giovannini and H. Wegmüller, Helv. Chim. Acta, 1958, **41**, 933.
241. B. B. Sinder and T. C. Kirk, J. Am. Chem. Soc., 1983, **105**, 2364.
242. S. G. Davies and G. H. Whitham, J. Chem. Soc., Perkin Trans. 1, 1978, 1479.
243. M. L. Snow, C. Lauinger, and C. Ressler, J. Org. Chem., 1968, **33**, 1774.
244. A. K. Singh, R. K. Bakshi, and E. J. Corey, J. Am. Chem. Soc., 1987, **109**, 6187.
245. P. Weyerstahl, H. Marschall-Weyerstahl, and S. Scholz, Justus Liebigs Ann. Chem., 1986, 1248.
246. W. Hüchel and U. Wörfall, Chem. Ber., 1956, **89**, 2098.
247. D. Johnson, J. W. Smart, and J. K. Sutherland, J. Chem. Soc., Chem. Commun., 1977, 497.
248. J. E. Sundeen and F. P. Hauck, U.S. Patent US 4131744 (1988) [C.A., **90**, 151684k (1979)].
249. C. Eaborn, R. A. Jackson, and R. Pearce, J. Chem. Soc., Perkin Trans. 1, 1975, 470.
250. J. E. Sundeen, J. A. Reid, J. A. Osband, and F. P. Hauck, J. Med. Chem., 1977, **20**, 1478.
251. A. J. Birch, P. Fitton, D. C. C. Smith, D. E. Steere, and A. R. Stelfox, J. Chem. Soc., 1963, 2209.
252. D. J. Coughlin and R. G. Salomon, J. Org. Chem., 1979, **44**, 3784.
253. C. A. Matuszak and L. Dickson, J. Org. Chem., 1972, **37**, 3345.
254. G. Bringmann, Justus Liebigs Ann. Chem., 1985, 2105.
255. F. P. Hauck and J. E. Sundeen, Ger. Offen. DE 2435898 (1975) [C.A., **83**, 113761f (1975)].
256. M. N. Paddon-Row and R. Hartcher, J. Am. Chem. Soc., 1980, **102**, 662.
257. M. N. Paddon-Row, R. Hartcher, and R. N. Warrener, J. Chem. Soc., Chem. Commun., 1976, 305.
258. R. F. Travares and E. Katten, Tetrahedron Lett., 1977, 1713.
259. J. S. R. Zilenovski and S. S. Hall, J. Org. Chem., 1981, **46**, 4139.
260. A. W. Burgstahler, P. L. Chien, and M. O. Abdel-Rahman, J. Am. Chem. Soc., 1964, **86**, 5281.
261. J. R. Cozort, J. F. Outlaw, Jr., A. Hawkins, and S. Siegel, J. Org. Chem., 1983, **48**, 4190.

262. J. F. Outlaw, Jr., J. R. Cozort, N. Garti, and S. Siegel, *J. Org. Chem.*, 1983, **48**, 4186.
263. J. Reiner and W. Jenny, *Helv. Chim. Acta*, 1969, **52**, 1624.
264. J. L. Marshall and B.-H. Song, *J. Org. Chem.*, 1974, **39**, 1342.
265. J. L. Marshall and T. K. Folsom, *Tetrahedron Lett.*, 1971, 757.
266. E. Cotsaris and M. N. Paddon-Row, *J. Chem. Soc., Chem. Commun.*, 1982, 1206.
267. D. N. Butler and R. Milburn, *Can. J. Chem.*, 1972, **50**, 1249.
268. M. N. Paddon-Row and R. Hartcher, *J. Am. Chem. Soc.*, 1980, **102**, 671.
269. R. Gray and V. Boekelheide, *J. Am. Chem. Soc.*, 1979, **101**, 2128.
270. W. D. Rohrbach and V. Boekelheide, *J. Org. Chem.*, 1983, **48**, 3673.
271. W. D. Rohrbach, R. Sheley, and V. Boekelheide, *Tetrahedron*, 1984, **40**, 4823.
272. Y. Sekine and V. Boekelheide, *J. Am. Chem. Soc.*, 1981, **103**, 1777.
273. E. J. Eisenbraun, D. V. Hertzler, R. C. Bansal, P. W. K. Flanagan, and M. C. Hamming, *Prepr. Pap.—Am. Chem. Soc., Div. Petrol. Chem.*, 1986, **13**, 55.
274. P. W. Rabideau and D. L. Huser, *J. Org. Chem.*, 1983, **48**, 4266.
275. A. J. Birch, A. R. Murray, and H. Smith, *J. Chem. Soc.*, 1951, 1945.
276. Th. J. Nieuwstad and H. van Bekkum, *Recl. Trav. Chim. Pays-Bas*, 1972, **91**, 1069.
277. W. Hückel and C. M. Jennewein, *Chem. Ber.*, 1962, **95**, 350.
278. W. Hückel and M. Wartini, *Justus Liebigs Ann. Chem.*, 1965, **689**, 40.
279. A. J. Birch and G. Nadamuni, *J. Chem. Soc., Perkin Trans. 1*, 1972, 545.
280. D. F. Lindow, C. N. Cortez, and R. G. Harvey, *J. Am. Chem. Soc.*, 1972, **94**, 5406.
281. K. Sakane, S. Oda, E. Haruki, Y. Otsuji, and E. Imoto, *Bull. Chem. Soc. Jpn.*, 1974, **47**, 2515.
282. R. G. Harvey, P. P. Fu, and P. W. Rabideau, *J. Org. Chem.*, 1976, **41**, 2706.
283. S. Mejer, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1961, **9**, 773.
284. J. Runge, *Justus Liebigs Ann. Chem.*, 1967, **707**, 75.
285. S. Mejer, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1962, **10**, 463 [C.A., **59**, 1553 (1963)].
286. R. G. Harvey, L. Arzadon, J. Grant, and K. Urberg, *J. Am. Chem. Soc.*, 1969, **91**, 4535.
287. R. G. Harvey, D. F. Lindow, and P. W. Rabideau, *Tetrahedron*, 1972, **28**, 2909.
288. R. G. Harvey and P. W. Rabideau, *Tetrahedron Lett.*, 1970, 3695.

289. P. W. Rabideau, J. L. Mooney, W. K. Smith, and A. Sygula, *J. Org. Chem.*, 1988, **53**, 589.
290. E. J. Eisenbraun, R. G. Melton, P. W. Flanagan, M. C. Hamming, and G. W. Keen, *Prepr. Pap.—Am. Chem. Soc., Div. Petrol. Chem.*, 1961, **16**, B43.
291. P. W. Rabideau, J. L. Mooney, and K. B. Lipkowitz, *J. Am. Chem. Soc.*, 1986, **108**, 8130.
292. R. G. Harvey, *J. Org. Chem.*, 1971, **36**, 3306.
293. Z. Marcinow, A. Sygula, and P. W. Rabideau, *J. Org. Chem.*, 1988, **53**, 3603.
294. P. P. Fu, C. Cortez, K. B. Sukumaran, and R. G. Harvey, *J. Org. Chem.*, 1973, **44**, 4265.
295. R. G. Harvey, P. P. Fu, and P. W. Rabideau, *J. Org. Chem.*, 1976, **41**, 2706.
296. P. W. Rabideau, J. L. Mooney, and J. N. Hardin, *J. Org. Chem.*, 1985, **50**, 5737.
297. D. H. Paskovich and N. C. Das, *J. Chem. Soc., Chem. Commun.*, 1967, **39**.
298. P. W. Rabideau and Z. Marcinow, *Fuel*, 1985, **64**, 872.
299. A. J. Birch and K. B. Chamberlain, *Org. Synth. Coll. Vol.* **6**, 1988, 936.
300. P. F. Schuda, S. J. Potlock, H. Ziffer, *Tetrahedron*, 1987, **43**, 463.
301. P. Yates and G. E. Langford, *Can. J. Chem.*, 1981, **59**, 34.
302. S. A. Monti, S.-C. Chen, Y.-L. Yang, S.-S. Yuan, and O. P. Bourgeois, *J. Org. Chem.*, 1978, **43**, 4062.
303. P. A. Harland and P. Hodge, *Synthesis*, 1982, 223.
304. G. L. Burge, D. J. Collins, and J. D. Reitze, *Aust. J. Chem.*, 1982, **35**, 1913.
305. H. Nishimura, T. Takabatake, K. Kaku, A. Seo, and J. Mizutani, *Agric. Biol. Chem.*, 1981, **45**, 1861.
306. P. A. Pernemalm and C. W. Dence, *Acta Chem. Scand., Ser B*, 1974, **28**, 453.
307. D. J. Goldsmith and J. J. Soria, *Tetrahedron Lett.*, 1986, **27**, 4701.
308. A. T. Bottini, F. P. Corson, and K. A. Frost, *Tetrahedron*, 1972, **28**, 4701.
309. W. F. Berkowitz, A. S. Amarasekara, and J. Perumattam, *J. Org. Chem.*, 1987, **52**, 1119.
310. H. Iio, M. Isobe, T. Kawai, and T. Goto, *Tetrahedron*, 1979, **25**, 941.
311. H. C. Beyerman, F. F. van Leeuwen, T. S. Lie, L. Maat, and C. Olieman, *Recl. Trav. Chim. Pays-Bas*, 1976, **95**, 238.
312. A. J. Pearson and M. Chandler, *J. Chem. Soc., Perkin Trans. 1*, 1980, 2238.

313. G. A. Schiehser and J. D. White, *J. Org. Chem.*, 1980, **45**, 1864.
314. R. D. Stipanovic and R. B. Turner, *J. Org. Chem.*, 1968, **33**, 3261.
315. J. B. Lambert and D. E. Marko, *J. Am. Chem. Soc.*, 1985, **107**, 7878.
316. A. J. Birch and K. P. Dastur, *Tetrahedron Lett.*, 1974, 1009.
317. A. J. Pearson, P. Ham, C. W. Ong, T. R. Perrior, and D. C. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1527.
318. A. J. Pearson, *Tetrahedron Lett.*, 1981, **22**, 4033.
319. G. R. Stephenson, *J. Chem. Soc., Perkin Trans. 1*, 1982, 2449.
320. A. J. Birch and R. A. Russell, *Aust. J. Chem.*, 1971, **24**, 1975.
321. F. J. Sardina, A. D. Johnston, A. Mourino, and W. H. Okamura, *J. Org. Chem.*, 1982, **47**, 1576.
322. K. Mori and K. Sato, *Tetrahedron*, 1982, **38**, 1221.
323. J. R. Andersen and O. Joergensen, *J. Chem. Soc., Perkin Trans. 1*, 1979, 3095.
324. V. S. Russkikh and G. G. Abashev, *Zh. Org. Khim. (Russ.)*, 1983, **19**, 837 [C. A., **99**, 104832h (1983)].
325. A. J. Pearson, *J. Chem. Soc., Perkin Trans. 1*, 1979, 1255.
326. A. J. Pearson, P. Ham, and D. C. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1982, 489.
327. H. O. House and C. J. Blankleu, *J. Org. Chem.*, 1968, **33**, 53.
328. B. R. Davis, G. F. Burkinshaw, E. G. Hutchinson, P. D. Woodgate, and R. Hodges, *J. Chem. Soc. C*, 1971, 3002.
329. M. Murai, S. Sato, and T. Masamune, *J. Chem. Soc., Chem. Commun.*, 1982, 511.
330. K. Kaminski and T. Sokotowska, *Rocz. Chemii*, 1973, **47**, 1091 [C. A., **79**, 137461b (1973)].
331. M. Kocor, O. P. Kaltenberg, W. Kotlarek, and A. J. Sadlej, *Rocz. Chemii*, 1974, **48**, 1951 [C.A., **82**, 124492z (1975)].
332. K. P. Dastur, *J. Am. Chem. Soc.*, 1974, **96**, 2605.
333. M. D. Soffer and M. A. Jevnick, *J. Am. Chem. Soc.*, 1955, **77**, 1003.
334. O. P. Vig, A. K. Vig, O. P. Chugh, and K. C. Gupta, *Indian J. Chem.*, 1975, **13**, 1126.
335. P. Marsham, D. A. Widdowson, and J. K. Sutherland, *J. Chem. Soc., Perkin Trans. 1*, 1974, 238.
336. C. B. Clarke and A. R. Pinder, *J. Chem. Soc.*, 1958, 1967.
337. T. Momose, S. Uchida, N. Yamaashi, and T. Imanishi, *Heterocycles*, 1975, **3**, 713.
338. W. Hüchel and E. Vevera, *Chem. Ber.*, 1956, **89**, 2105.
339. See reference [275](#).

340. H. L. Dryden, G. M. Webber, R. R. Burtner, and J. A. Cella, *J. Org. Chem.*, 1961, **26**, 3237.
341. T. K. Das, A. Das Gupta, P. K. Ghosal, and P. C. Dutta, *Indian J. Chem.*, 1976, **14B**, 238.
342. A. J. Birch, J. E. T. Corrie, P. L. Macdonald, and G. Subba Rao, *J. Chem. Soc., Perkin Trans. 1*, 1972, 1186.
343. D. P. Hamon and N. J. Shirley, *Aust. J. Chem.*, 1987, **40**, 1321.
344. A. F. Thomas, B. Wilhalm, and J. H. Bowie, *J. Chem. Soc. B*, 1967, 392.
345. D. Johnson, J. W. Smart, and J. K. Sutherland, *J. Chem. Soc., Chem. Commun.*, 1977, 497.
346. V. Bhushan, M. M. Rajopadhye, and S. Chandrasekaran, *Indian J. Chem.*, 1985, **24B**, 424.
347. J. J. Venit and P. Magnus, *Tetrahedron Lett.*, 1980, **21**, 4815.
348. G. Stork and D. Livingston, *Chem. Lett.*, 1987, 105.
349. R. E. Donaldson and P. L. Fuchs, *J. Org. Chem.* 1977, **42**, 2032.
350. A. V. R. Rao, V. H. Deshpande, K. M. Sathaye, and S. W. Jaweed, *Indian J. Chem., Sect. B*, 1987, **24B**, 697.
351. M. Kocor and W. Kotlarek, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1961, **9**, 507.
352. M. Kocor and W. Kotlarek, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1971, **19**, 219 [C.A., **75**, 48741t (1971)].
353. M. Kocor and O. P. Kaltenberg, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1972, **20**, 25 [C.A., **76**, 153411d (1972)].
354. M. Kocor and W. Kotlarek, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, 1972, **20**, 15 [C.A., **76**, 153412e (1972)].
355. P. Radlick, *J. Org. Chem.*, 1965, **30**, 3208.
356. B. Weinstein and A. H. Fenselan, *J. Org. Chem.*, 1965, **30**, 3209.
357. K. Wiesmer, P.-T. Ho, W.-C. Liu, and M. N. Shanbhag, *Can. J. Chem.*, 1975, **53**, 2140.
358. J. W. Huffman and M. L. Mole, *J. Org. Chem.*, 1972, **37**, 13.
359. J. Marshall and R. E. Conrow, *J. Am. Chem. Soc.*, 1983, **105**, 5679.
360. A. J. Pearson and T. R. Perrior, *J. Organomet Chem.*, 1985, **285**, 253.
361. A. Murai, S. Sato, and T. Masamune, *Bull. Chem. Soc. Jpn.*, 1984, **57**, 2276.
362. M. Ihara, M. Toyota, M. Abe, Y. Ishida, K. Fukumoto, and T. Kametani, *J. Chem. Soc., Perkin Trans. 1*, 1986, 1543.
363. T. L. Macdonald, *J. Org. Chem.*, 1978, **43**, 4241.
364. R. G. Salomon, M. F. Salomon, M. G. Zagorski, J. M. Reuter, and D. J. Coughlin, *J. Am. Chem. Soc.*, 1982, **104**, 1008.

365. D. G. Leppard, P. W. Reynolds, C. B. Chapleo, and A. S. Dreiding, *Helv. Chim. Acta*, 1976, **59**, 695.
366. J. D. White, J. F. Ruppert, M. A. Avery, S. Torii, and J. Nokami, *J. Am. Chem. Soc.*, 1981, **103**, 1813.
367. E. L. Michelotti and E. L. Sanchez, *Z. Naturforsch.*, 1983, **38B**, 497.
368. A. B. Kazi and J. K. Sutherland, *Indian J. Chem.*, 1987, **26B**, 511.
369. B. A. McAndrew, *J. Chem. Soc., Perkin Trans. 1*, 1979, 1837.
370. C. L. Kirkemo and J. D. White, *J. Org. Chem.*, 1985, **50**, 1316.
371. P. C. Mukharji, D. Bhattacharjee, and T. K. Das Gupta, *Indian J. Chem.*, 1970, **8**, 318.
372. G. Subrahmanyam, *Indian J. Chem.*, 1970, **8**, 210.
373. M. V. R. Koteswara Rao, G. S. Krishna Rao, and S. Dev, *Tetrahedron*, 1966, **22**, 1977.
374. K. Yamada, H. Nagase, Y. Hayakawa, K. Akoi, and Y. Hirata, *Tetrahedron Lett.*, 1973, 4963.
375. K. Mori, T. Miyake, I. Yoshimura, and M. Matsui, *Agr. Biol. Chem.*, 1969, **33**, 1745.
376. K. K. Chakravarti, B. G. Hazra, and Y. Gopichandol, *Indian J. Chem.*, 1974, **12**, 275.
377. P. K. Oommen, *Bull. Chem. Soc. Jpn.*, 1976, **49**, 1985.
378. S. B. Maiti, A. P. Kundu, A. Chatterjee, and S. R. Raychuduri, *Indian J. Chem.*, 1986, **25B**, 15.
379. L. J. Chinn and H. L. Dryden, Jr., *J. Org. Chem.*, 1961, **26**, 3904.
380. T. Kametani, H. Matsumoto, T. Honda, and K. Fukumoto, *Tetrahedron Lett.*, 1980, **21**, 4847.
381. L. N. Mander and L. T. Palmer, *Aust. J. Chem.*, 1979, **32**, 823.
382. K. Mori, M. Matsui, and I. Yoshimura, *Agric. Biol. Chem.*, 1970, **34**, 1204.
383. A. R. K. Murthy and G. S. R. Subba Rao, *Indian J. Chem.*, 1981, **20B**, 569.
384. R. E. Ireland and L. N. Mander, *J. Org. Chem.*, 1967, **32**, 689.
385. O. P. Vig, S. D. Sharma, S. D. Kumar, and V. K. Handa, *Indian J. Chem.*, 1979, **17B**, 295.
386. A. J. Birch, D. N. Butler, R. Effenberber, R. W. Rikards, and T. J. Simpson, *J. Chem. Soc., Perkin Trans. 1*, 1979, 807.
387. L. J. Chinn, H. L. Dryden, Jr., and R. R. Burtner, *J. Org. Chem.*, 1961, **26**, 3910.
388. P. C. Chakraborti, S. Ghosh, P. R. Kanjilal, G. O. S. V. Satyanarayana, and V. R. Ghatak, *Indian J. Chem.*, 1979, **18B**, 183.
389. H. Nemoto, M. Hashimoto, H. Kurobe, K. Fukumoto, and T. Kametani, *J.*

- Chem. Soc., Perkin Trans. 1, 1985, 927.
390. R. C. Cambie and R. A. Franich, *Aust. J. Chem.*, 1971, **24**, 117.
391. N. Hamanaka, T. Okuno, T. Nakajima, A. Furusaki, and T. Matsumoto, *Chem. Lett.*, 1972, 1037.
392. R. B. Turner, O. Buchardt, E. Herzog, R. B. Morin, A. Riebel, and J. M. Sanders, *J. Am. Chem. Soc.*, 1966, **88**, 1766.
393. A. K. Banerjee, C. D. Ceballo, M. N. Vallejo, and E. H. Bolivar, *Bull. Chem. Soc. Jpn.*, 1978, **52**, 608.
394. J. F. Grove, R. C. Jennings, A. W. Johnson, and A. F. White, *Chem. Ind. (London)*, 1974, 346.
395. R. F. Church, R. E. Ireland, and J. A. Marshall, *J. Org. Chem.*, 1966, **31**, 2526.
396. G. Stork, A. Meisels, and J. E. Davies, *J. Am. Chem. Soc.*, 1963, **85**, 3419.
397. R. C. Cambie, W. A. Denny, T. R. Close, and L. N. Mander, *Aust. J. Chem.*, 1971, **24**, 99.
398. F. M. Hauser and K.-W. Park, *J. Org. Chem.*, 1978, **43**, 113.
399. A. J. Birch and H. Smith, *J. Chem. Soc.*, 1951, 1882.
400. A. J. Birch and J. A. K. Quartey, *Chem. Ind. (London)*, 1953, 489.
401. K. Ito, M. Haruna, and H. Furukawa, *J. Chem. Soc., Chem. Commun.*, 1975, 681.
402. M. Haruna and K. Ito, *J. Chem. Soc., Chem. Commun.*, 1976, 345.
403. W. F. Johns, *J. Org. Chem.*, 1963, **28**, 1856.
404. Y. Yamada and H. Nagaoka, *Synthesis*, 1977, 577.
405. J. Romer and H. Wagner, *Radiochem. Radioanal. Lett.*, 1976, **25**, 255.
406. G. Teichmuller, K. Barnikol-Oettler, G. Streibhardt, M. Wentzke, and H. Henkel, *Ger. (East) DD 208157 A1 (1984) [C.A., 101, 211553z (1984)]*.
407. R. P. Stein, G. C. Buzby, Jr., G. H. Douglas, and H. Smith, *Tetrahedron Lett.*, 1967, 3603.
408. E. E. van Tamelen, J. G. Carlson, R. K. Russel, and S. R. Zawacky, *J. Am. Chem. Soc.*, 1981, **103**, 4615.
409. J. H. Dodd, J. E. Starret, and S. M. Weinreb, *J. Am. Chem. Soc.*, 1984, **106**, 1811.
410. H. A. Staab, C. P. Herz, and H. E. Henke, *Tetrahedron Lett.*, 1974, 4393.
411. W. Nagata, T. Terasawa, S. Hirai, and K. Takeda, *Tetrahedron Lett.*, 1960, 27; *Chem. Pharm. Bull.*, 1961, **9**, 769.
412. W. F. Johns, *J. Am. Chem. Soc.*, 1958, **80**, 6456.
413. S. Hayakawa, T. Takata, T. Fujiwara, and S. Hashimoto, *Biochem. J.*, 1977, **164**, 709.

414. J. A. J. Leemhuis, Ger. Offen. DE 2459706 (1975) [C.A., **83**, 179400u (1975)].
415. R. Bucourt, A. Pierdet, and J. Salmon, Ger. Offen. DE 2158260 (1972) [C.A., **77**, 102026v (1972)].
416. E. Fujita, M. Shibuya, S. Nakamura, Y. Okada, and T. Fujita, J. Chem. Soc., Perkin Trans. 1, 1974, 165.
417. D. Varech, L. Lacombe, and J. Jacques, Nouv. J. Chim., 1984, **8**, 445.
418. K. Yoshioka, T. Asako, G. Goto, K. Hiraga, and T. Miki, Chem. Pharm. Bull., 1973, **21**, 2195.
419. R. L. Carney and W. S. Johnson, J. Am. Chem. Soc., 1974, **96**, 2549.
420. O. F. Katsapova, E. B. Krylova, V. F. Martynov, and A. G. Shavva, Zh. Obshch. Khim. (Russ.), 1981, **51**, 2797 [C.A., **96**, 123084v (1982)].
421. E. E. van Tamelen and E. G. Taylor, J. Am. Chem. Soc., 1980, **102**, 1202.
422. M. Ihara, M. Toyota, K. Fukumoto, T. Kametani, and T. Honda, J. Chem. Res. Synop., 1984, 252.
423. T. Kametani and T. Honda, Heterocycles, 1981, **16**, 1673.
424. K. M. R. Pillai, W. V. Murray, I. Shooshani, D. L. Williams, D. Gordon, S. Y. Wang, and F. Johnson, J. Med. Chem., 1984, **27**, 1131.
425. D. Burn and V. J. Petrov, J. Chem. Soc., 1962, 364.
426. R. V. Coombs and E. E. Galanty, Ger. Offen. DE 2035879 (1971) [C.A., **74**, 100301 v (1971)].
427. A. R. Daniewski, M. Guzewska, and M. Kocor, J. Org. Chem., 1975, **40**, 3131.
428. W. Sucrow, P. Geschwinder, and H. Minas, Ger. Offen. DE 3522023 (1986) [C.A., **105**, 133415x (1986)].
429. R. E. Ireland, P. B. Beslin, R. Giger, U. Hengartner, H. A. Kirst, and H. Maag, J. Org. Chem., 1977, **42**, 1267.
430. H. Alt, E. R. Franke, and H. Bock, Angew Chem., Int. Ed. Engl., 1969, **8**, 525.
431. C. B. Wooster, J. Am. Chem. Soc., 1928, **50**, 1388.
432. S. Mejer and S. Respondek, Bull. Acad. Pol. Sci., Ser. Sci. Chim., 1966, **14**, 611 [C.A., **66**, 105088a (1967)].
433. M. E. Kuehne and B. F. Lambert, Org. Synth., Coll. Vol. **5**, 1973, 400.
434. P. Markov and C. Ivanoff, Tetrahedron Lett., 1962, 1139.
435. W. E. Barnett and L. L. Needham, J. Org. Chem., 1975, **40**, 2843.
436. L. N. Mander, R. H. Prager, and J. V. Turner, Aust. J. Chem., 1974, **27**, 2645.
437. E. L. Eliel and T. H. Hoover, J. Org. Chem., 1959, **24**, 938.
438. M. Julia and B. Malassine, Tetrahedron Lett., 1972, 2495.

439. J. L. Marshall and B.-H. Song, *J. Org. Chem.*, 1975, **40**, 1942.
440. J. L. Marshall and L. Hall, *Tetrahedron*, 1981, **37**, 1271.
441. A. Tahara, M. Shimagaki, S. Ohara, T. Tanaka, and T. Nakata, *Chem. Pharm. Bull.*, 1975, **23**, 2329.
442. T. B. Windholz and D. R. Brown, *J. Org. Chem.*, 1972, **37**, 1647.
443. P. W. Rabideau, J. W. Paschal, and L. A. Patterson, *J. Am. Chem. Soc.*, 1975, **97**, 5700.
444. A. J. Birch and E. A. Karakhanov, *J. Chem. Soc., Chem. Commun.*, 1975, 480.
445. A. J. Birch, *J. Chem. Soc.*, 1947, 1270.
446. C. Harris, *Ber.*, 1914, **47**, 784.
447. J. W. Ashmore and G. K. Helmkamp, *Org. Prep. Proced. Int.*, 1976, **8**, 223.
448. W. A. Remers, G. J. Gibbs, C. Pidacks, and M. J. Weiss, *J. Org. Chem.*, 1971, **36**, 279.
449. A. J. Birch and P. G. Lehman, *Tetrahedron Lett.*, 1974, 2395.
450. A. J. Birch and D. Nasipuri, *Tetrahedron*, 1959, **6**, 148.
451. W. Hüchel, S. Gupté, and M. Wartini, *Chem. Ber.*, 1966, **99**, 1388.
452. S. O'Brien and D. C. C. Smith, *J. Chem. Soc.*, 1960, 4609.
453. W. A. Remers, G. J. Gibbs, C. Pidacks, and M. J. Weiss, *J. Am. Chem. Soc.*, 1967, **89**, 5513.
454. H. Iida, S. Aoyagi, and C. Kibayashi, *J. Chem. Soc., Perkin Trans. 1*, 1975, 2502.
455. H. Iida, S. Aoyagi, Y. Yuasa, and C. Kibayashi, *Heterocycles*, 1977, **6**, 1747.
456. T. A. Crabb and J. R. Wilkinson, *J. Chem. Soc., Perkin Trans. 1*, 1975, 58.
457. O. Yonemitsu, P. Ceruti, and B. Witkop, *J. Am. Chem. Soc.*, 1966, **88**, 3941.
458. C. Verchere and C. Viel, *Heterocycl. Chem.*, 1980, **17**, 49.
459. A. J. Birch, R. W. Rickards, and K. J. Stapleford, *Aust. J. Chem.*, 1969, **22**, 1321.
460. Yu. L. Slominski, A. R. Smirnowa, S. V. Popow, and A. I. Tolmaczev, *Zh. Org. Khim. (Russ.)*, 1983, **19**, 2389 [C.A., **100**, 53184c (1984)].
461. G. L. Olson, H.-C. Cheung, K. D. Morgan, J. F. Blount, L. Todaro, L. Berger, A. B. Davidson, and E. Boff, *J. Med. Chem.*, 1981, **24**, 1026.
462. A. J. Birch and H. H. Mantsch, *Aust. J. Chem.*, 1969, **22**, 1103.
463. B. Heath-Brown, *Chem. Ind.* 1969, 1595.
464. W. A. Remers and M. J. Weiss, *Tetrahedron Lett.*, 1968, 81.

465. S. Danishefsky, P. Cain, and A. Nagel, *J. Am. Chem. Soc.*, 1975, **97**, 380.
466. S. Danishefsky and R. Cavanaugh, *J. Am. Chem. Soc.*, 1968, **90**, 520.
467. M. Schaefer-Ridder and U. Engelhardt, *J. Org. Chem.*, 1981, **46**, 2895.
468. T. Kametani, T. Uryu, and K. Fukumoto, *J. Chem. Soc., Perkin Trans. 1*, 1977, 383.
469. H. Schmidhammer and A. Brossi, *Can. J. Chem.*, 1982, **60**, 3055.
470. See reference [227](#).
471. F. L. Hsu, K. C. Rice, and A. Brossi, *Helv. Chim. Acta*, 1980, **63**, 2042.
472. F. L. Hsu, K. C. Rice, and A. Brossi, *Helv. Chim. Acta*, 1982, **65**, 1576.
473. T. Kitahara and M. Matsui, *Agric. Biol. Chem.*, 1974, **38**, 171.
474. K. K. Pivnitski and Yu. P. Badanova, *Zh. Obshch. Khim. (Russ.)*, 1978, **48**, 1669 [C. A., **90**, 6601b (1979)].
475. J. E. Sundeen, J. A. Reid, J. A. Osband, and F. P. Hauck, *J. Med. Chem.*, 1977, **20**, 1478.
476. K. C. Rice, *J. Org. Chem.*, 1980, **45**, 3135.
477. R. Grewe, H. Fischer, and W. Friedrichsen, *Chem. Ber.*, 1967, **100**, 1.
478. H. C. Beyerman, J. van Berkel, T. S. Lie, L. Maat, J. C. M. Wessels, H. H. Bosman, E. Buurman, E. J. M. Bijsterveld, and H. J. M. Sinnige, *Recl. Trav. Chim. Pays-Bas*, 1978, **97**, 127.
479. G. C. Morrison, R. O. Waite, and J. Shavel, Jr., *J. Heterocycl. Chem.*, 1972, **9**, 683.
480. H. Tanaka, M. Shibata, and K. Ito, *Chem. Pharm. Bull.*, 1984, **32**, 3271.
481. H. Tanaka, Y. Takamura, M. Shibata, and K. Ito, *Chem. Pharm. Bull.*, 1986, **34**, 24.
482. R. J. Chorvat, J. R. Palmer, and R. Pappo, *J. Org. Chem.*, 1978, **43**, 966.
483. W. Nagata, T. Sugawara, M. Narisada, T. Wakabayashi, and Y. Hayase, *J. Am. Chem. Soc.*, 1967, **89**, 1484.
484. W. Nagata, T. Wakabayashi, M. Narisada, Y. Hayase, and S. Kakamate, *J. Am. Chem. Soc.*, 1971, **93**, 5741.
485. S. Takano, M. Sasaki, H. Kanno, K. Shishido, and K. Ogasawara, *J. Org. Chem.*, 1978, **43**, 4169.
486. J. D. Wilcock and E. Winterfeldt, *Chem. Ber.*, 1974, **107**, 975.
487. A. I. Meyers, D. B. Miller, and F. H. White, *J. Am. Chem. Soc.*, 1988, **110**, 4778.
488. H. Rischke and J. D. Wilcock, *Chem. Ber.*, 1973, **106**, 3106.
489. H. C. Beyerman, E. Buurman, L. Maat, and C. Olieman, *Recl. Trav. Chim. Pays-Bas*, 1976, **95**, 184.
490. W. V. Curran, *J. Chem. Soc. D*, 1971, 478.
491. L. Mandell, C. A. Wilson, S. Sinclair, and F. J. Heldrich, *Heterocycles*,

- 1987, **26**, 713.
492. T. Kametani, M. Kajiwara, T. Takahashi, and K. Fukumoto, *J. Chem. Soc., Perkin Trans. 1*, 1975, 737.
493. G. C. Morrison, R. O. Waite, and J. Shavel, Jr., *Tetrahedron Lett.*, 1967, 4055.
494. S. Kumar and N. Agarwal, *J. Org. Chem.*, 1986, **51**, 2445.
495. T. Kametani, Y. Hirai, and K. Fukumoto, *Heterocycles*, 1976, **4**, 29.
496. T. Kametani, Y. Hirai, and K. Fukumoto, *Chem. Pharm. Bull.*, 1976, **24**, 2500.
497. S. Danishefsky and A. Nagel, *J. Chem. Soc., Chem. Commun.*, 1972, 373.
498. F. L. Weisenborn and H. E. Applegate, *J. Am. Chem. Soc.*, 1956, **78**, 2021.
499. J. P. Kutney, P. Grice, K. Piotrowska, S. J. Rettig, J. Szykula, J. Trotter, and L. V. Chu, *Helv. Chim. Acta*, 1983, **66**, 1820.
500. I. M. Coggiola, *Nature*, 1963, **200**, 954.
501. T. Kinoshita and T. Miwa, *J. Chem. Soc., Chem. Commun.*, 1974, 181.
502. T. Kinoshita, K. Miyano, and T. Miwa, *Bull. Chem. Soc. Jpn.*, 1975, **48**, 1865.
503. T. Kinoshita and T. Miwa, *Carbohydr. Res.*, 1973, **28**, 175.
504. J. Slobbe, *Aust. J. Chem.*, 1976, **29**, 2553.
505. T. Masamune, M. Ono, and H. Matsue, *Bull. Chem. Soc. Jpn.*, 1975, **48**, 491.
506. J. E. Semple, P. C. Wang, Z. Lysenko, and M. M. Joullie, *J. Am. Chem. Soc.*, 1980, **102**, 7505.
507. T. Kinoshita and T. Miwa, *Bull. Chem. Soc. Jpn.*, 1978, **51**, 225.
508. S. D. Darling and K. D. Wills, *J. Org. Chem.*, 1967, **32**, 2794.
509. D. P. Brust and D. S. Tarbell, *J. Org. Chem.*, 1966, **31**, 1251.
510. B. Graffe, M. C. Sacquet, and P. Maitte, *Bull. Soc. Chim. Fr. (7-8)*, 1979, 350.
511. A. Murai, S. Sato, and T. Masamune, *Bull. Chem. Soc. Jpn.*, 1984, **57**, 2286.
512. L. J. Dolby and E. Adler, *Tetrahedron Lett.*, 1971, 3803.
513. L. H. Brannigan and D. S. Tarbell, *J. Org. Chem.*, 1966, **31**, 1251.
514. J. M. Ferland and Y. Lefebvre, *Can. J. Chem.*, 1984, **62**, 315.
515. D. K. Banerjee and P. R. Srinivasan, *Indian J. Chem.*, 1972, **10**, 891.
516. D. F. Crowe, P. H. Christie, J. I. DeGraw, A. N. Fujiwara, E. Grange, P. Lim, M. Tanabe, T. Cairns, and G. Skelly, *Tetrahedron*, 1983, **39**, 3083.
517. S. F. Birch and D. T. McAllan, *J. Chem. Soc.*, 1951, 2556.

518. W. G. Blenderman, M. M. Joullie, and G. Preti, *Tetrahedron Lett.*, 1979, 4985.
519. Ya. L. Gol'dfarb, A. V. Semenovskii, E. P. Zaharov, G. V. Davydova, and F. M. Stoyanovich, *Bull. Acad. Sci. USSR, Chem. Ser. (Engl. Trans.)*, 1979, 448 [C. A., **90**, 168011m (1979)].
520. G. Lange, M. E. Savard, T. Viswanatha, and G. I. Dimitrenko, *Tetrahedron Lett.*, 1985, **26**, 1791.
521. S. F. Birch and D. T. McAllan, *J. Chem. Soc.*, 1951, 3411.
522. W. G. Blenderman and M. M. Joullie, *Synth. Commun.*, 1981, **11**, 881.
523. K. Nishino, S. Yano, Y. Kohashi, K. Yamamoto, and I. Murata, *J. Am. Chem. Soc.*, 1979, **101**, 5059.
524. G. A. Tolstikov, E. E. Shul'ts, Yu. T. Struchkov, D. S. Yufit, and S. Lindeman, *Zh. Org. Khim. (Russ.)*, 1986, **22**, 121 [C. A., **106**, 102607c (1987)].
525. P. W. Rabideau, J. W. Paschal, and L. E. Patterson, *J. Am. Chem. Soc.*, 1975, **97**, 5700.
526. J. A. Marshall and G. A. Flynn, *Synth. Commun.*, 1979, **9**, 123.
527. W. M. Grootaert, R. Mijngheer, and P. J. DeClercq, *Tetrahedron Lett.*, 1982, **23**, 3287.
528. F. X. Webster and R. M. Silverstein, *Synthesis*, 1987, 922.
529. G. S. R. Subba Rao and H. Ramanathan, *Indian J. Chem., Sect. B*, 1981, **20B**, 1089.
530. J. Dixon, B. Lythgoe, I. A. Siddiqui, and J. Tideswell, *J. Chem. Soc. C*, 1971, 1301.
531. P. R. Bruck, R. D. Clark, R. S. Davidson, W. H. H. Günther, P. S. Littlewood, and B. Lythgoe, *J. Chem. Soc. C*, 1967, 2529.
532. M. C. Grossel and M. J. Perkins, *J. Chem. Soc., Perkin Trans. 2*, 1975, 1544.
533. O. L. Chapman and P. Fitton, *J. Am. Chem. Soc.*, 1961, **83**, 1005.
534. D. H. R. Barton, L. Bould, D. L. J. Clive, P. D. Magnus, and T. Hase, *J. Chem. Soc. C*, 1971, 2204.
535. N. M. Przhialgovskaya and S. R. Gaevskaya, *Zh. Org. Khim. (Russ.)*, 1970, **6**, 2310 [C. A., **74**, 53313p (1971)].
536. N. A. Nelson, R. S. P. Hsi, J. M. Schuck, and L. D. Khan, *J. Am. Chem. Soc.*, 1960, **82**, 2573.
537. L. A. Paquette, T. J. Nitz, R. J. Ross, and P. James, *J. Am. Chem. Soc.*, 1984, **106**, 1446.
538. J. B. Hendrickson and P. M. DeCapite, *J. Org. Chem.*, 1985, **50**, 2112.
539. P. K. Oommen, *Aust. J. Chem.*, 1975, **28**, 2095.
540. J. W. Cornforth and R. Robinson, *J. Chem. Soc.*, 1946, 676.

541. I. Alfaro, W. Ashton, L. D. McManus, R. C. Newstead, K. L. Rabone, N. A. J. Rogers, and W. Kernick, *Tetrahedron*, 1970, **26**, 201.
542. V. M. Kapoor and A. M. Mehta, *Synthesis*, 1975, 471.
543. P. K. Oommen, *Aust. J. Chem.*, 1976, **29**, 2087.
544. T. Matsumoto and A. Suzuki, *Bull. Chem. Soc. Jpn.*, 1959, **32**, 128.
545. B. Basu, S. Bhattacharya, and D. Mukherjee, *Tetrahedron Lett.*, 1984, **25**, 1195.
546. J. Fried and N. A. Abraham, *Tetrahedron Lett.*, 1965, 3505.
547. D. N. Patil and A. N. Mehta, *J. Chem. Soc., Perkin Trans. 1*, 1982, 201.
548. S. P. Khanapure, B. G. Hazra, and K. G. Das, *J. Chem. Soc., Perkin Trans. 1*, 1981, 1360.
549. S. Bhattacharyya, B. Basu, and D. Mukherjee, *Tetrahedron*, 1983, **39**, 4221.
550. S. Bhattacharyya and D. Mukherjee, *Tetrahedron Lett.*, 1982, **23**, 4175.
551. A. M. Mehta and D. N. Patil, *J. Chem. Res. (S)*, 1982, 4.
552. S. Bhattacharyya, M. Ghosal, and D. Mukherjee, *Tetrahedron Lett.*, 1987, **28**, 2431.
553. D. K. Banerjee, E. J. Jacob, and N. Mahishi, *Steroids*, 1970, **16**, 733.
554. L. N. Mander and R. Urech, *Aust. J. Chem.*, 1983, **36**, 1177.
555. P. M. Müller and R. Pfister, *Helv. Chim. Acta*, 1983, **66**, 771.
556. P. M. Müller, R. Pfister, and R. Urban, *European Patent 12801 [C. A., 93, 1858395 (1980)]*.
557. R. G. Harvey and L. Arzadon, *Tetrahedron*, 1969, **25**, 4887.
558. T. L. Gilchrist, C. W. Rees, and D. Tuddenham, *J. Chem. Soc., Perkin Trans. 1*, 1981, 3214.
559. S. Mejer and Z. Marcinow, *Rocz. Chemii*, 1977, **51**, 1281 [C.A., **88**, 73856k (1978)].
560. F. Zutterman, P. DeClercq, and M. Vandewalle, *Tetrahedron Lett.*, 1971, 3191.
561. I. K. Zhurkovich and D. V. Ioffe, *Zh. Org. Khim. (Russ.)*, 1974, **10**, 212 [C.A., **80**, 120365w (1974)].
562. B. M. Bandara, A. J. Birch, and W. D. Raverty, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1755.
563. A. L. J. Beckwith, D. M. O'Shea, and D. H. Roberts, *J. Chem. Soc., Chem. Commun.*, 1983, 1445.
564. R. M. Acheson and R. F. Flowerday, *J. Chem. Soc., Perkin Trans. 1*, 1974, 2339.
565. J. A. Marshall and P. G. M. Wuts, *Synth. Commun.*, 1977, **7**, 233.
566. C. P. Chuang and D. J. Hart, *J. Org. Chem.*, 1983, **48**, 1782.

567. J. A. Marshall and P. G. M. Wuts, *J. Org. Chem.*, 1977, **42**, 1794.
568. L. N. Mander, J. V. Turner, and B. G. Coombe, *Aust. J. Chem.*, 1974, **27**, 1985.
569. M. D. Bachi, J. W. Epstein, Y. Herzberg-Minzly, and H. J. E. Loewenthal, *J. Org. Chem.*, 1969, **34**, 126.
570. K. Kosugi, A. V. Anisimov, H. Yamamoto, R. Yamashiro, K. Shirai, and T. Kumamoto, *Chem. Lett.*, 1981, 1341.
571. G. A. Olah and R. J. Hunadi, *J. Org. Chem.*, 1981, **46**, 715.
572. A. J. Birch and J. Slobbe, *Tetrahedron Lett.*, 1978, 627.
573. A. J. Birch and P. C. Lehman, *J. Chem. Soc., Perkin Trans. 1*, 1973, 2754.
574. S. Chandrasekaran and J. V. Turner, *Tetrahedron Lett.*, 1982, **23**, 3799.
575. A. S. Kende, R. A. Battista, and S. B. Sandoval, *Tetrahedron Lett.*, 1984, **25**, 1341.
576. D. F. Taber, *J. Org. Chem.*, 1976, **41**, 2649.
577. D. F. Taber and S. A. Saleh, *J. Am. Chem. Soc.*, 1980, **102**, 5085.
578. D. F. Taber, B. P. Gunn, and I. Ching Chiu, *Org. Synth.*, 1983, **61**, 59.
579. A. G. Schultz and J. P. Dittami, *Tetrahedron Lett.*, 1983, **24**, 1369.
580. A. G. Schultz, F. P. Lavieri, and T. E. Snead, *J. Org. Chem.*, 1985, **50**, 3086.
581. A. G. Schultz, F. P. Lavieri, M. Macielag, and M. Plummer, *J. Am. Chem. Soc.*, 1987, **109**, 3991.
582. A. B. Smith and R. E. Richmond, *J. Am. Chem. Soc.*, 1983, **105**, 575.
583. R. Castanedo, C. B. Zetina, and L. A. Maldonado, *Heterocycles*, 1987, **25**, 175.
584. G. S. R. Subba Rao and H. Ramanathan, *Indian J. Chem., Sect. B*, 1981, **20B**, 1089.
585. J. M. Hook and L. N. Mander, *J. Org. Chem.*, 1980, **45**, 1722.
586. L. N. Mander and M. Woolias, *Aust. J. Chem.*, 1981, **34**, 2249.
587. J. M. Hook, L. N. Mander, and R. Urech, *J. Org. Chem.*, 1984, **49**, 3250.
588. J. M. Hook, L. N. Mander, R. Urech, *Synthesis*, 1979, 374.
589. M. J. Gunter and L. N. Mander, *Aust. J. Chem.*, 1981, **34**, 675.
590. K. D. Krautwurst and W. Tochtermann, *Chem. Ber.*, 1981, **114**, 214.
591. L. N. Mander and R. J. Hamilton, *Tetrahedron Lett.*, 1981, **22**, 4115.
592. A. Goplan and P. Magnus, *J. Am. Chem. Soc.*, 1980, **102**, 1756.
593. A. Goplan and P. Magnus, *J. Org. Chem.*, 1984, **49**, 2317.
594. A. Casares, J. M. L. Cardoso, and L. A. Maldonado, *Synth. Commun.*, 1981, **11**, 223.
595. L. N. Mander and M. Woolias, *Synthesis*, 1979, 185.

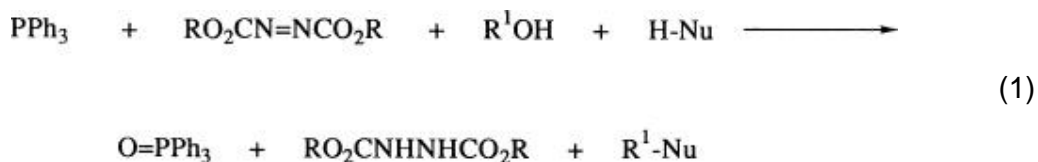
596. Z. Lidert and C. W. Rees, *J. Chem. Soc., Chem. Commun.*, 1982, 499.
597. Z. Lidert and C. W. Rees, *J. Chem. Soc., Chem. Commun.*, 1983, 317.
598. H. C. Hibbard, C. J. Moody, and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1985, 735.
599. N. M. Prziyalgovskaya, E. N. Sidorenko, and A. T. Prudchenko, *Zh. Org. Khim. (Russ.)*, 1975, **11**, 1679 [C.A., **83**, 192895d (1975)].
600. H. O. House and E. J. Zaiko, *J. Org. Chem.*, 1977, **42**, 3780.
601. B. Basu and D. Mukherjee, *J. Chem. Soc., Chem. Commun.*, 1984, 105.
602. A. J. Baker and A. C. Goudie, *J. Chem. Soc., Chem. Commun.*, 1972, 951.
603. H. J. E. Loewenthal, *Guide for the Perplexed Organic Experimentalist*, Hyden, London, 1978, pp. 133–138.
604. J. M. Hook, L. N. Mander, and R. Urech, *J. Am. Chem. Soc.*, 1980, **102**, 6628.
605. C. D. Gutsche and H. H. Peter, *Org. Synth., Coll. Vol.* **4**, 1963, 887.
606. J. F. Eastham and D. R. Larkin, *J. Am. Chem. Soc.*, 1959, **81**, 3652.
607. G. M. Watt, C. M. Knowles, and L. O. Morgan, *J. Am. Chem. Soc.*, 1947, **69**, 1657.
608. J. A. van Doorn and N. Meijboom, *J. Chem. Soc., Chem. Commun.*, 1987, 1700.
609. G. Stork and J. W. Schulenberg, *J. Am. Chem. Soc.*, 1956, **78**, 250.
610. D. J. Marshall and R. Deghenghi, *Can. J. Chem.*, 1969, **47**, 3127.

The Mitsunobu Reaction

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1. Introduction

Alkyl and aryl phosphites and phosphines react with compounds having weak heteroatom–heteroatom bonds, such as S–S, O – O, etc., and with azo compounds to form reactive phosphonium salts. These phosphonium salts in turn promote “redox” condensation reactions with compounds having active hydrogens. The condensation reaction of alcohols using the redox couple of a triaryl- or trialkylphosphine and a dialkyl azodicarboxylate has become known as the Mitsunobu reaction, based on his pioneering work in the late 1960s. (1-3) The overall reaction is summarized in Eq. 1, wherein the alcohol (R^1OH) and acidic compound ($H-Nu$) are condensed to form product (R^1-Nu), while triphenylphosphine is oxidized to triphenylphosphine oxide and the azodicarboxylate is reduced to the hydrazine.



Although the typical redox combination is diethyl azodicarboxylate (DEAD) and triphenylphosphine, many other combinations have found selected use. The reaction is generally limited to primary and secondary alcohols, although tertiary alcohols react in a few intramolecular 4a and intermolecular 4b–d reactions. For secondary alcohols the reaction usually proceeds with clean inversion of stereochemistry. The acidic component of the reaction (denoted as $H-Nu$ in Eq. 1) generally has an aqueous $pK_a < 15$, with intramolecular reactions providing the exceptions. Example of $H-Nu$ include oxygen nucleophiles such as carboxylic acids and phenols; nitrogen nucleophiles such as imides, hydroxamates, and heterocycles; sulfur nucleophiles such as thiols and thioamides; and carbon nucleophiles such as β -ketoesters.

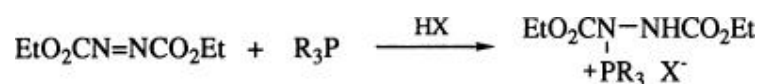
Major reviews of the Mitsunobu reaction were published in 1981 by Mitsunobu (5) and in 1983 by Castro. 6a The former review concentrated on reactions using DEAD/triphenylphosphine, while the latter review focused on reactions in which halogens replaced the hydroxy group using reagents such as triphenylphosphine/carbon tetrachloride, triphenyl phosphite/iodomethane, and triphenylphosphine/*N*-halosuccinimide. Reactions involving the DEAD/triphenylphosphine redox system are the principal subject of this review,

with emphasis on the literature between 1981 and 1988.

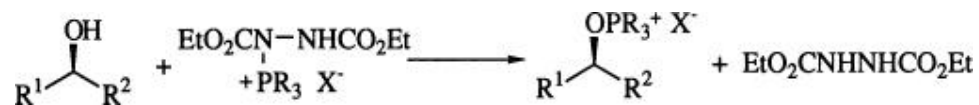
2. Mechanism

In his 1981 review Mitsunobu proposed that the dehydration reactions of alcohols using DEAD and R_3P proceed in three steps: (1) reaction of R_3P with DEAD in the presence of the acid component to form a salt wherein a phosphorus–nitrogen bond is formed; (2) reaction of the DEAD– R_3P adduct with the alcohol to form an activated oxyphosphonium ion intermediate; and (3) displacement via an S_N2 process to form the inverted product and the phosphine oxide. (5) The mechanistic details of each step are discussed below.

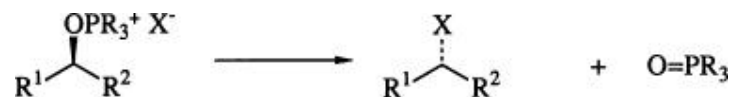
STEP 1: ADDUCT FORMATION



STEP 2: ALCOHOL ACTIVATION

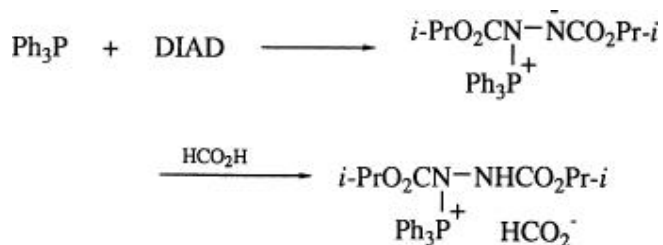


STEP 3: S_N2 REACTION



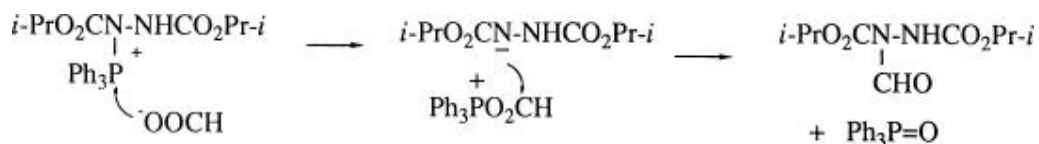
2.1.1. Step 1: Adduct Formation

The reaction of triphenylphosphine and DEAD or diisopropyl azodicarboxylate (DIAD) in methylene chloride or tetrahydrofuran proceeds rapidly to form a colorless zwitterionic adduct, which in the presence of formic acid yields the aphosphonium formate. The reaction is irreversible since treatment

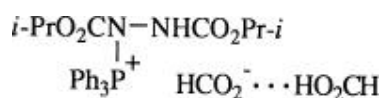


of the adduct with tri-*n*-butylphosphine does not lead to phosphine exchange. [6b](#)

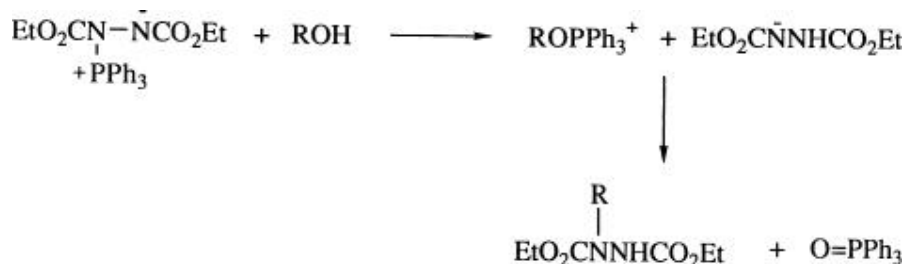
The azaphosphonium formate is unstable with respect to formation of the *N*-formyl hydrazide (10 minutes at 25°) and triphenylphosphine oxide. Acetic acid behaves similarly. [\(7\)](#) This mode of adduct decomposition could be a major



reason for poor yields in Mitsunobu reactions run with sterically small acids having nucleophilic carboxylates when the reagent ratios are 1:1:1. The Mitsunobu reagent can be stabilized by employing triphenylphosphine:DIAD:formic acid in a ratio of 1:1:2, wherein the extra mole of acid hydrogen bonds to the formate ion to reduce its nucleophilicity and afford a reagent having a $t_{1/2}$ of 15 hours at 25°. [\(7\)](#) When the Mitsunobu reagent is formed in the presence



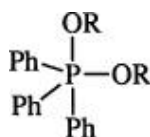
of a sterically unhindered alcohol and no carboxylic acid, *N*-alkylated products arise. [\(7\)](#)



The Mitsunobu reagent has been shown to have a P — N bond, as opposed to a P — O bond or heterocyclic structure, by IR C = O stretching frequencies and ³¹P NMR isotope shifts induced by ¹⁵N-DIAD. (8, 9)

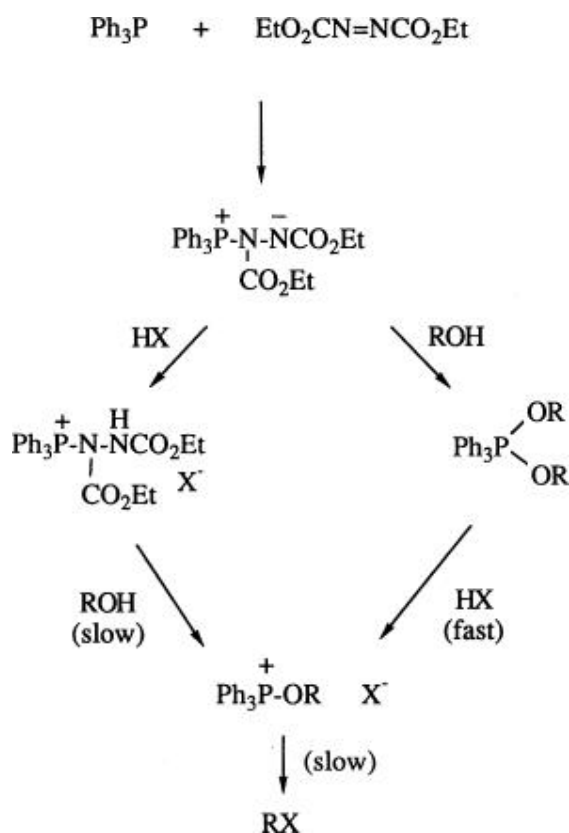
2.1.2. Step 2: Alcohol Activation

The structure of the activated alcohol species in the Mitsunobu reaction is still under debate, and is dependent on the nature of the substrate and reaction conditions. In his 1981 review Mitsunobu proposed that the activated species was an oxyphosphonium salt. (5) As support for this mechanism, stable oxyphosphonium salts were subsequently isolated and characterized from Mitsunobu reactions involving hindered carbohydrate alcohols, (10) and they have been generated electrochemically. (11) However, the existence of the oxyphosphonium salt intermediate has been questioned. NMR studies of the reaction of triphenylphosphine, DEAD, and alcohols indicate that the key intermediate is the pentavalent dialkoxyphosphorane. (12-14) Using 3,4-dichlorophenol



as the alcoholic component, a diaryloxyphosphorane can be isolated as a crystalline compound. (15) Treatment with an acid affords an ester and triphenylphosphine oxide, leading to the claim that the activated species in the Mitsunobu reaction must be the phosphorane, which on reaction with an acid affords the ester, an alcohol for recycle, and phosphine oxide.

Since the phosphorane was generated in the absence of the acid component of the system, a revised mechanism for the reaction was proposed. 16a In the presence of the acidic component the reaction proceeds as postulated by Mitsunobu via the oxyphosphonium ion intermediate, with formation of that intermediate and its subsequent S_N2 reaction being the slow steps. However, in the absence of acid, the dialkoxyphosphorane is formed. Addition of acid results in the rapid formation and subsequent reaction of the oxyphosphonium salt, and regeneration of a mole of the alcohol. This is recycled via the original

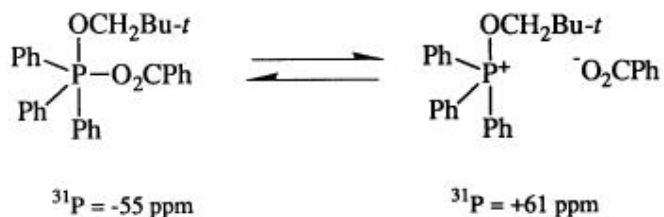


mechanism since acid is present. Thus under these conditions part of the reaction proceeds via the phosphorane and part via the oxyphosphonium salt.

Two subsequent studies have shown that even in the presence of acid, phosphoranes can be formed. [16b,c](#) When one equivalent each of benzoic acid, triphenylphosphine, and DEAD, and two equivalents of ethanol are mixed at -78° in tetrahydrofuran, peaks corresponding to both the phosphorane and the oxyphosphonium salt are observed by ^{31}P NMR. [16b](#) In a similar experiment with isopropyl alcohol, the oxyphosphonium salt is the major species, with only a trace of the phosphorane observable. [16b](#) Similarly, with the hindered neopentyl alcohol and diacetone glucose, both phosphorane and oxyphosphonium salt were observed at 0° in the presence of benzoic acid. [16c](#) These data suggest that an equilibrium mixture of phosphorane and oxyphosphonium salt exists, with the nature of the alcohol, solvent, and acid determining the equilibrium concentrations.

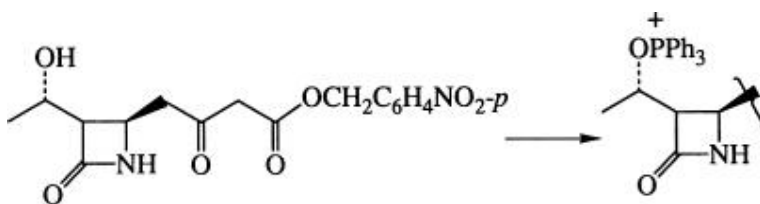
In addition, a third species, an (acyloxy)alkoxyphosphorane, has been suggested, based on NMR data. [16d](#) When neopentyl alcohol is treated at 0° in tetrahydrofuran with one equivalent of triphenylphosphine and one equivalent of DIAD, followed by 0.5 equivalent of benzoic acid, a ^{31}P NMR peak is observed at -11 ppm. This peak is roughly midway between that expected for an oxyphosphonium salt ($+60$ ppm) and that expected for a

phosphorane (−50 to −60 ppm). As the temperature is lowered, the peak becomes broader and coalescence occurs at −90°. At −100° two peaks appear, a downfield peak at +61 ppm ascribed to the oxyphosphonium salt, and an upfield peak at −55 ppm ascribed to the (acyloxy)alkoxyphosphorane. The equilibrium



constant between the two species was found to be highly sensitive to solvent and proton sources. Polar solvents such as acetonitrile favor the ion pair. The ion pair is also favored by addition of protic sources such as excess alcohol, benzoic acid, or diisopropyl hydrazine-1,2-dicarboxylate. [16d](#)

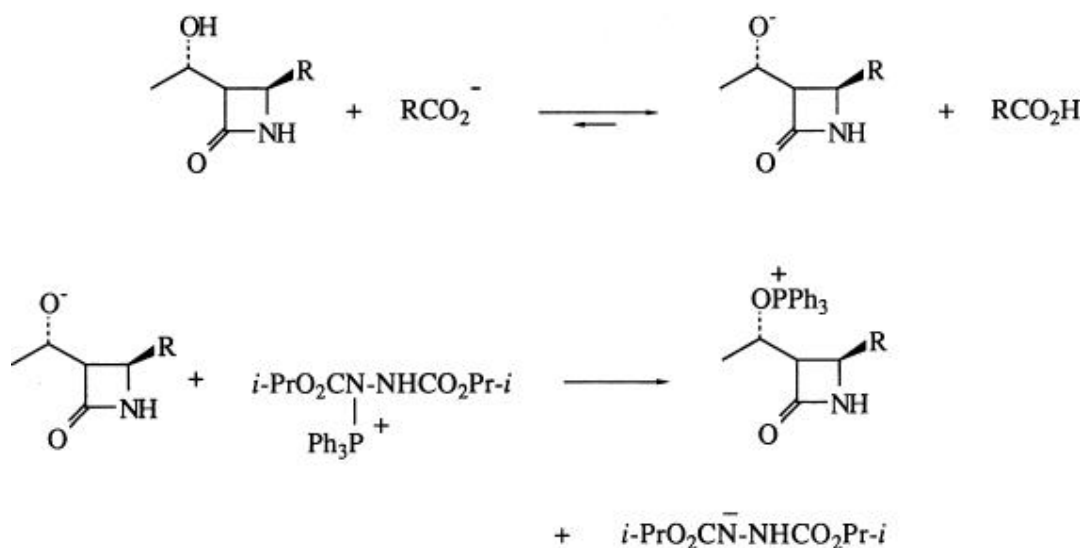
Although three activated alcohol species may be involved as intermediates in the Mitsunobu reaction, the oxyphosphonium salt is most likely the key intermediate involved in the displacement of triphenylphosphine oxide leading to product. In a study of the Mitsunobu reaction used to invert the hydroxy center in a thienamycin total-synthesis intermediate, the oxyphosphonium intermediate is the only activated alcohol species observable by NMR. [\(7\)](#) The parameters controlling its formation were clarified.



Three factors control the rate of alcohol activation via the oxyphosphonium salt: (1) the basicity of the carboxylate generated in the formation of the Mitsunobu reagent; (2) the extent of hydrogen bonding to the carboxylate; and (3) substituent effects in the triarylphosphine. [\(7\)](#)

The carboxylate functions as a base to deprotonate the alcohol before $-\text{Ph}_3\text{P}$ transfer takes place. Examination of the rate of oxyphosphonium ion

intermediate formation as a function of pK_a of the acid component affords a linear plot of pK_a vs. \log rate with a slope of 1.25, indicating a high degree of sensitivity of the activation to carboxylate basicity. Using very strong acids with weakly basic carboxylates, such as trifluoroacetic acid, results in very slow formation of intermediate. Use of formic acid in the azetidinone intermediate

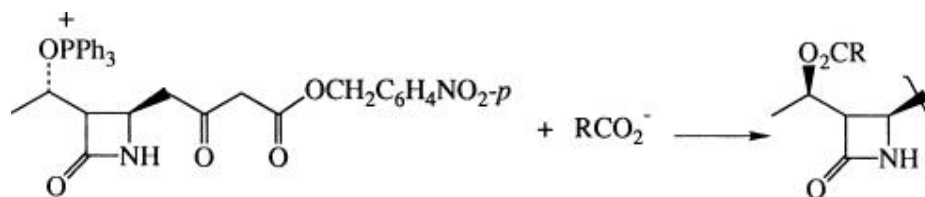


inversion and increasing the $\text{HCOOH}/\text{HCOO}^-$ ratio from 0.54 to 2 affords a 170-fold decrease in the rate of oxyphosphonium ion formation. The principal cause of this effect is the solvation of the formate on by formic acid, thereby reducing the effective basicity of the formate ion. This is the same effect that is used to stabilize the Mitsunobu reagent. The two effects must be properly balanced for a successful Mitsunobu reaction.

With substituted triarylphosphines, a classical Hammett effect is noted for the rate of activated species formation, with a rho of 1.5. (7)

2.1.3. Step 3: S_N2 Reaction

With the azetidinone intermediate as a substrate and formate as the nucleophile, the Mitsunobu reaction proceeds with at least 200:1 stereochemical inversion. The reaction of the oxyphosphonium intermediate with various carboxylates shows only a small effect of carboxylate basicity on the S_N2 reaction rate ($\beta_{\text{Nu}} = 0.1\text{--}0.15$). This indicates that the transition state for the displacement has considerable S_N1 character with much bond breaking and little bond formation. Thus, although formate is excellent for formation of the oxyphosphonium ion intermediate and trifluoroacetate is poor, they behave similarly in the S_N2 step. (7) An unusual salt effect occurs in the S_N2



reaction. The reaction appears to be zero in formate as the rate of S_N2 reaction remains relatively constant when the concentration of formate ion is increased. However, in the presence of a swamping salt, the reaction displays normal second-order kinetics. Since the ionic intermediates in the S_N2 reaction afford neutral products, addition of excess formate to this step stabilizes the intermediates, and fortuitously, the rate enhancement expected by addition of formate is balanced by the retardation caused by the increase in ionic strength.

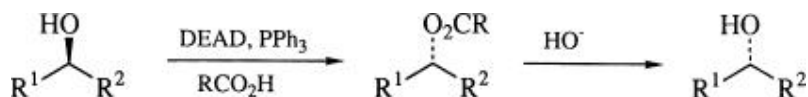
In summary, the effectiveness of the Mitsunobu reaction is quite surprising given the complexity of its mechanism. The poor yields obtained in many of the reactions reported in the literature can be traced to the failure to successfully execute one of the three key steps in the reaction.

3. Scope and Limitations

3.1. Carbon–Oxygen Bond Formation

3.1.1.1. Ester Formation

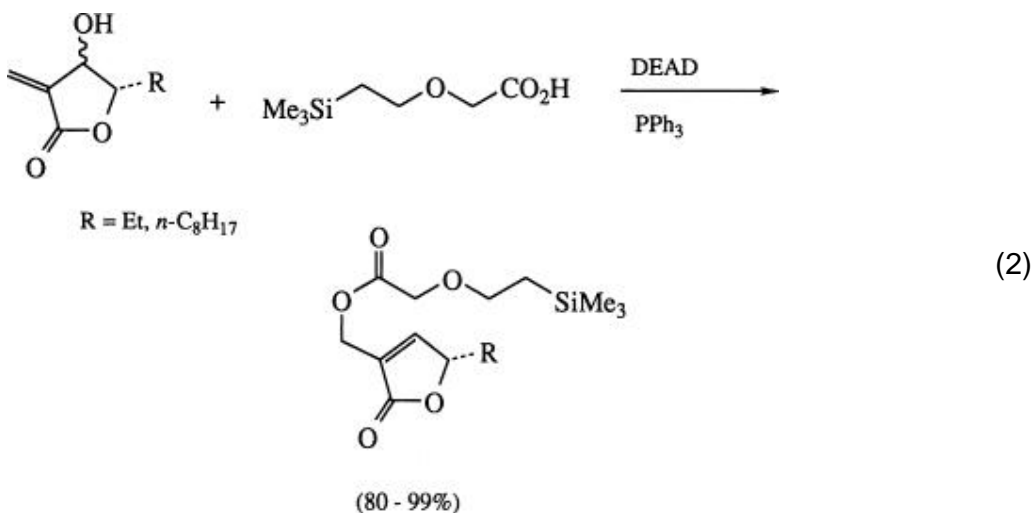
The major use of the Mitsunobu reaction is to invert optically pure secondary alcohols via formation of inverted esters. The reaction is compatible with a wide range of functional and protecting groups,



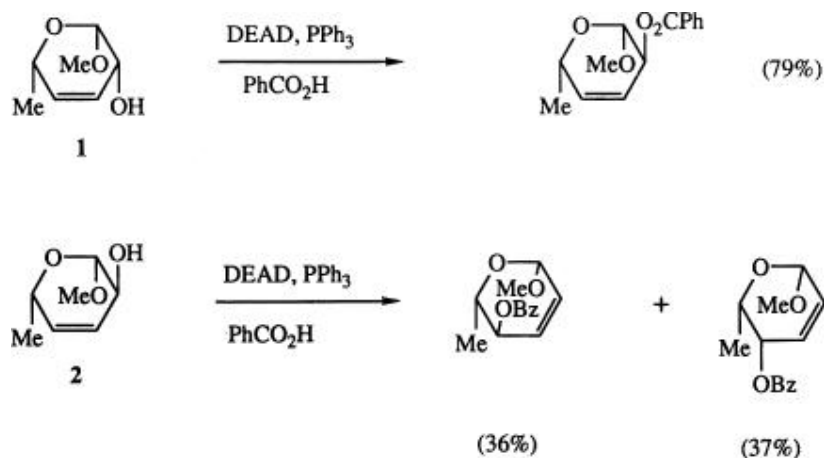
including β -lactams, (17-32) acetals; (33-42) azides; (43) thioethers; (20, 26, 31, 44-47) trimethylsilyl (TMS), (48, 49) triethylsilyl (TES), (50, 51) and *tert*-butyldimethylsilyl (TBS) ethers, (52-58) chlorides; (55, 59) iodides; (59-61) acetylenes; (62-65) C – Si bonds; (66-69) carbobenzyloxy (Cbz); (70, 71) *tert*-butoxycarbonyl (*t*-Boc); (72-74) tetrahydropyranyl (THP), (75-78) sulfones; (28, 57, 58, 79) *O*-alkyl oximes; (80) dithianes; (76, 81-83) allenes; (84) trichloroethyl; (85) cyclopropenes; (86) C – Hg bonds; (87) trityl; (88, 89) dichlorocyclopropanes; (90) nitriles; (91-93) methoxyethoxymethyl (MEM) and methoxymethyl (MOM) ethers; (48, 49, 94, 95) 1,2-dioxetanes; (96) diazo; (22) nitro; (22-24, 31, 97-99) and tosyl. (100, 101)

3.1.1.2.1. Esters of Allyl Alcohols

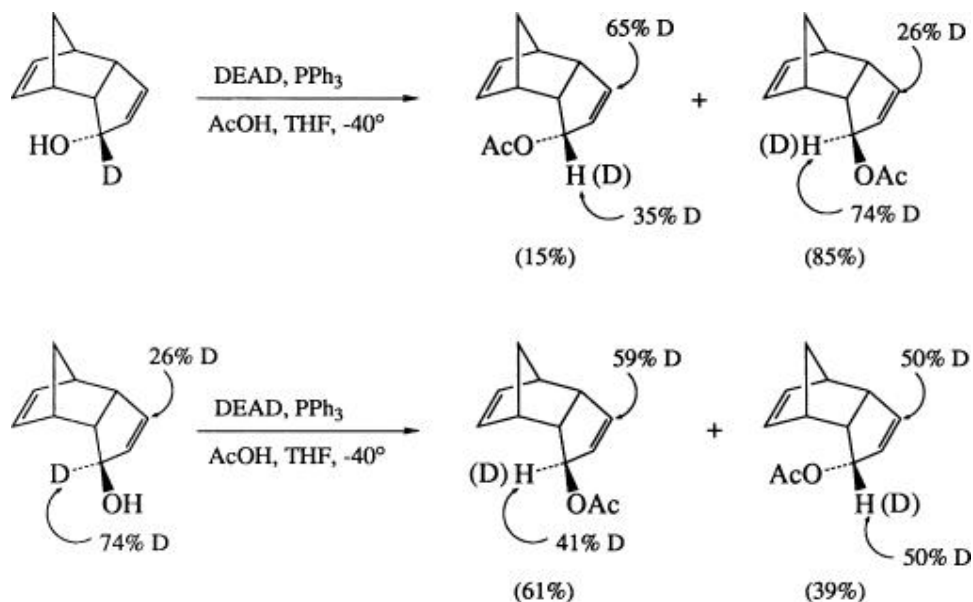
Mitsunobu reaction of allyl alcohols generally provides the inverted S_N2 product. (35, 38, 40, 44, 48, 49, 54, 55, 76, 77, 80, 83, 84, 91, 102-120) However, in a few cases, S_N2 (Eq. 2) (69, 91, 121-124) or S_N1 products (124) are observed.



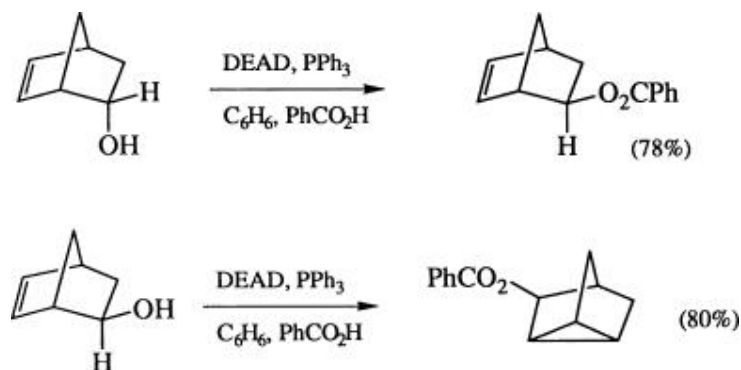
The 1,2-*cis*-pyranoside **1** forms the S_N2 product in 79% yield, but the 1,2-*trans* pyranoside **2** forms the epimeric S_N1' product in equal amounts. (123) The latter reaction apparently proceeds through the allyl carbocation owing to steric hindrance to the incoming nucleophile and to ionization assistance from the anomeric effect of the *trans* methoxy group. Similar results are observed with phthalimide as nucleophile on a similar pyranoside.



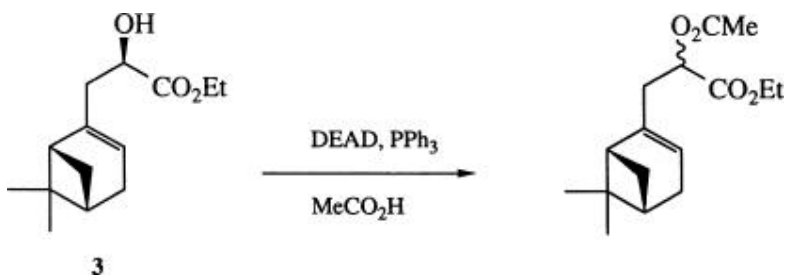
Reaction of dicyclopentadienols results in mixtures of inversion and retention products. 124b Deuterium labelling experiments show that extensive scrambling occurs during the reaction, indicating that competing direct and allylic substitution are occurring. The lack of concentration effects on the ratio of inversion to retention rules out the possibility that retention occurs by an S_N1 mechanism (unimolecular) and inversion by an S_N2 mechanism (bimolecular). The reaction probably proceeds through an allylic cation with steric effects determining the location of nucleophile capture. 124b



2-*endo*-Norbornenol reacts with benzoic acid under typical Mitsunobu conditions to provide the *exo* benzoate in 78% yield. [124c](#) In contrast, the *exo* alcohol furnished only the nortricyclic benzoate in 80% yield, presumably by π participation.

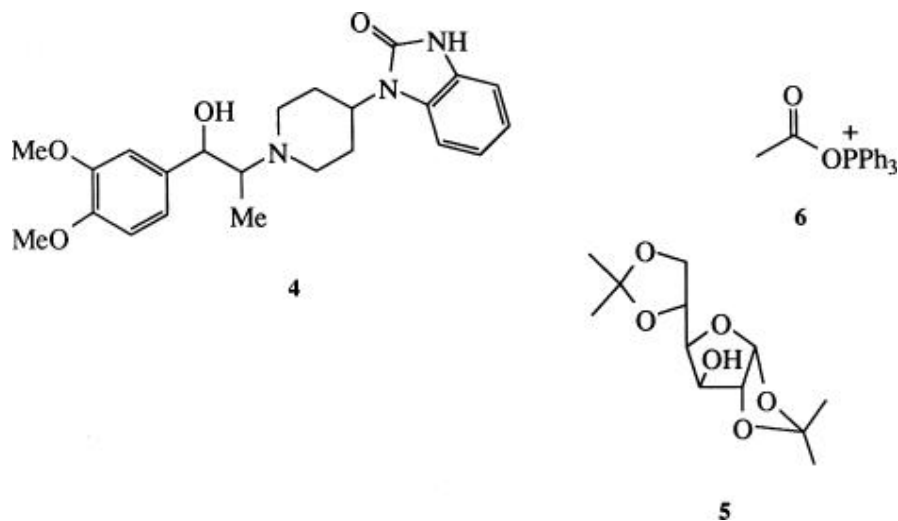


3.1.1.2.2. Esterification of Secondary Alcohols—Retention or Epimerization
 In a few cases secondary alcohols do not proceed with inversion because of an acidic epimerizable center or steric hindrance. The α -hydroxy ester [3](#) esterifies with complete epimerization. ([125](#)) Preparation of the α -methoxy- α -trifluoromethylphenylacetate (MTPA) ester of 2-hydroxy-3-butanone gives 9% racemization, ([126](#))

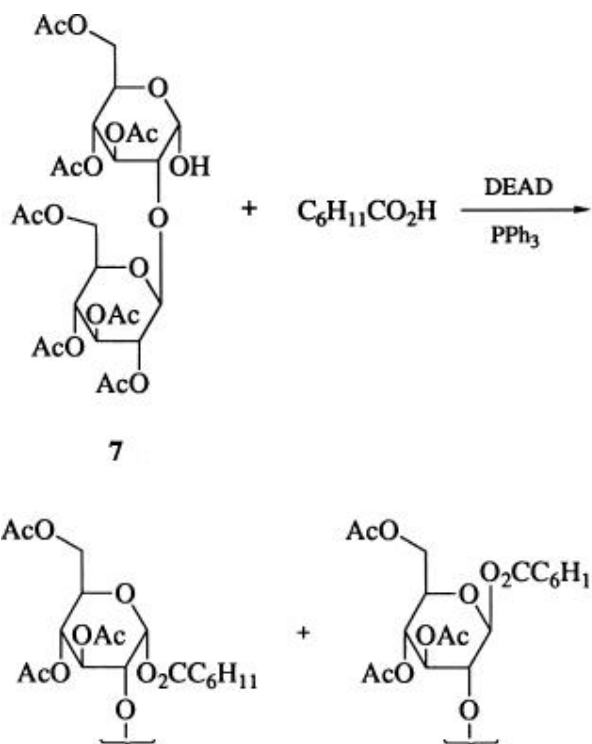


but no racemization occurs in the preparation of these esters with α -hydroxyesters. [127–128](#)

Steric hindrance results in retention of configuration in the reactions of **4** [129–130](#) and **5**. ([131](#)) It is postulated that the carboxylic acid is activated to form **6**, which then acylates the alcohol. With hemiacetal **7** complete epimerization



occurs at room temperature, whereas complete inversion occurs at -50° when cyclohexanecarboxylic acid is used to form the ester. ([50](#))

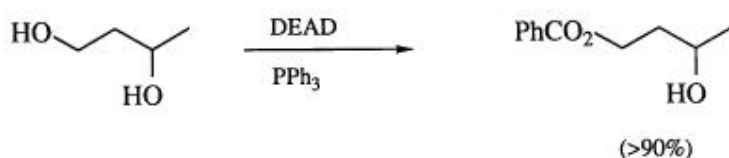
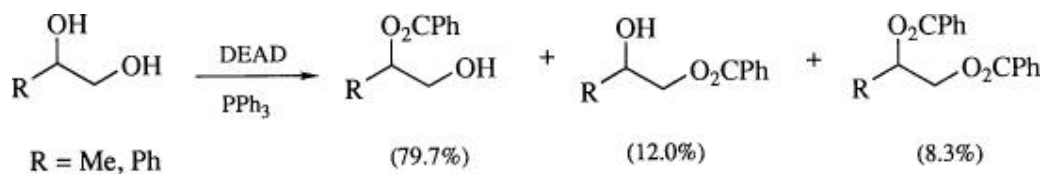


3.1.1.2.3. Aryl Esters

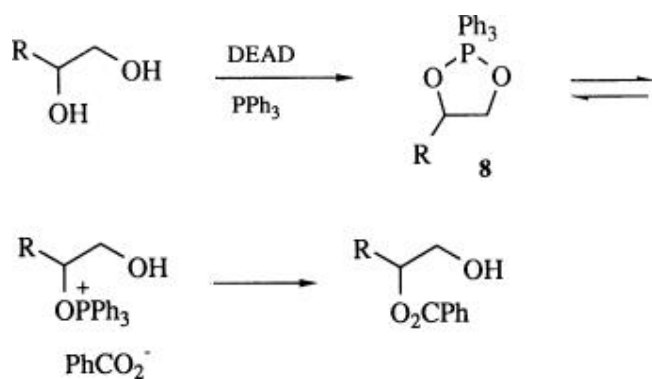
Phenols and carboxylic acids in the presence of triphenylphosphine/ DEAD react to form aryl esters in 67–96% yields. Phenols having both electron-withdrawing and electron-donating groups form esters with acetic acid and benzoic acid in high yields, but do not react with trifluoro- and trichloroacetic acids. (132)

3.1.1.2.4. Polyhydroxylic Compounds

Selective reaction can sometimes be obtained with compounds containing several hydroxy groups. Unexpectedly, 1,2-propanediol and styrene glycol undergo predominant reaction at the secondary center instead of the primary center. (133) 1,3-Diols are esterified predominantly at the primary center. (133) The 1,2-diols form the phosphorane **8**

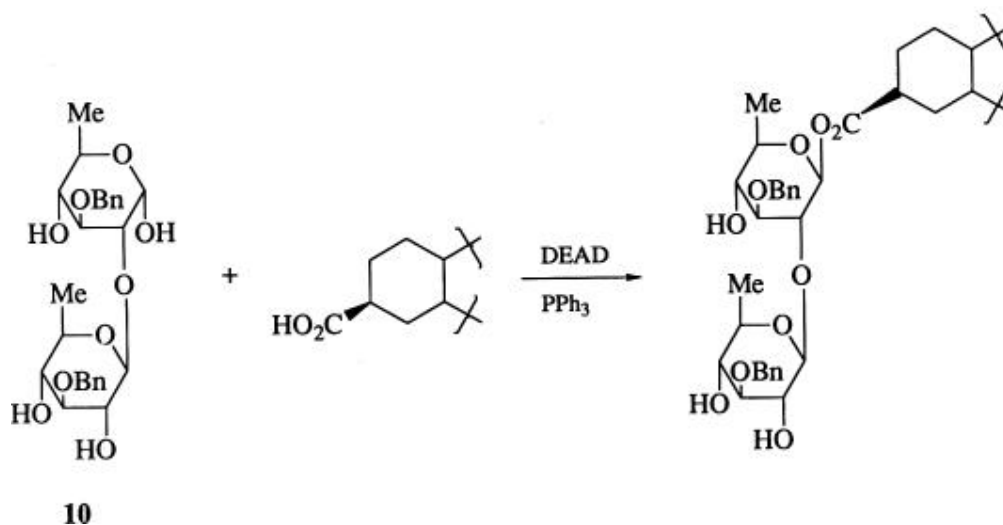
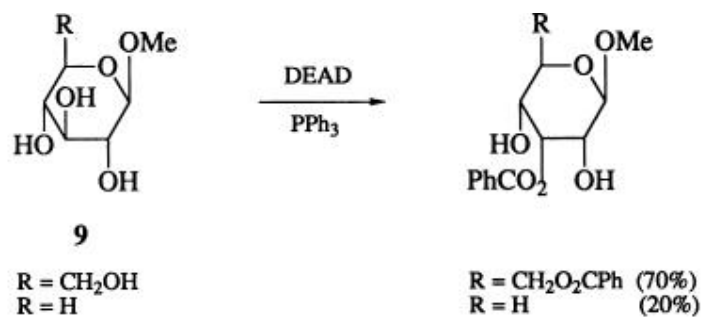


which opens via protonation of the least hindered oxygen to produce the oxyphosphonium salt and leads to esterification of the secondary center. 1,3-Diols form no phosphorane. Instead, the oxyphosphonium salt from the primary alcohol is formed preferentially, leading to ester formation at the primary center. (133)

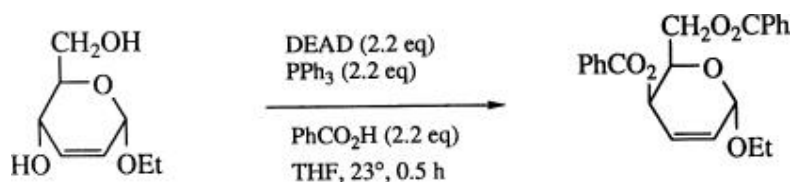


In steroids containing secondary hydroxy groups at the 3 position and at the 7 and/or 12 positions, selective esterification with inversion occurs only at the 3 position. (134-136)

The 3 position of pyranoside **9** is selectively esterified, presumably because of steric effects. (137) The hemiacetal **10** reacts selectively at the more reactive

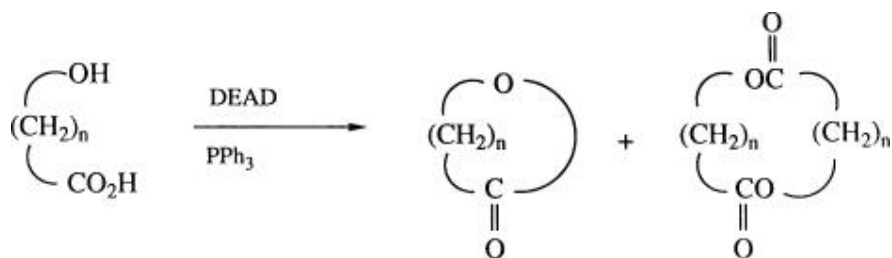


anomeric position to give the inverted ester in 40% yield. (50) Compounds that contain two primary hydroxy groups, 138–139 two secondary hydroxy groups, (37, 43, 78) or a primary and a secondary hydroxy group, (33, 55, 140, 141) are esterified at both centers, given sufficient reagent and reaction time.

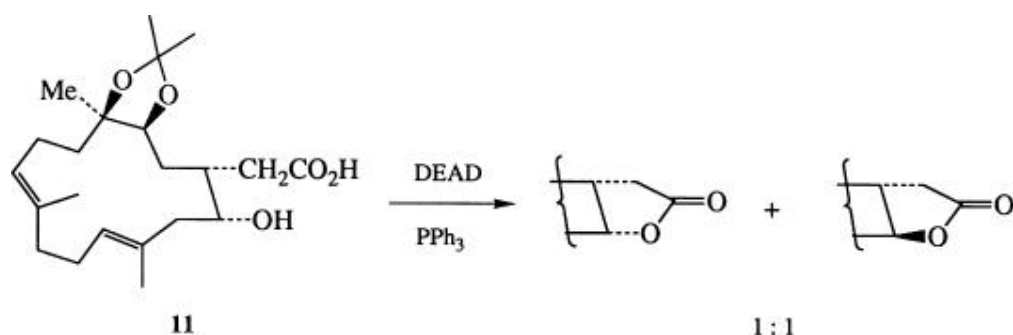


3.1.1.2.5. Lactones

Lactones are prepared by intra- or intermolecular reactions of compounds containing both an alcohol and a carboxylic acid. High dilution favors the intramolecular reaction. As with esterification, inversion at the



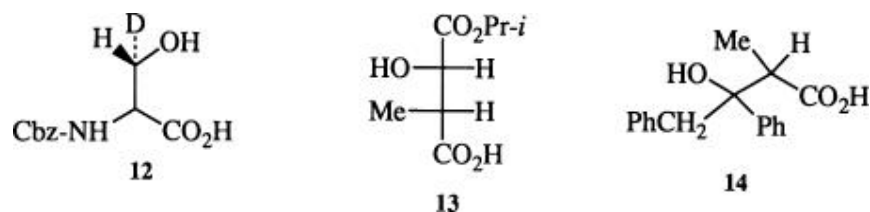
hydroxy center usually occurs, indicating that the hydroxy group is activated and displaced in an intramolecular $\text{S}_{\text{N}}2$ reaction. An exception to this is hydroxy acid **11**, which undergoes complete epimerization. (142) In this case,



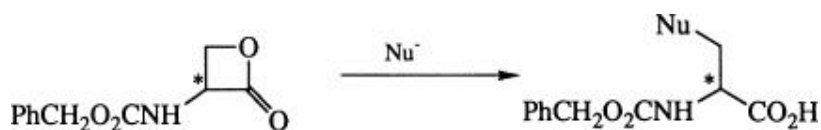
competing carboxy group and hydroxy group activation may be occurring.

Either alkenes or β -lactones result from reaction of β -hydroxy acids, depending on substrate structure and solvent polarity.

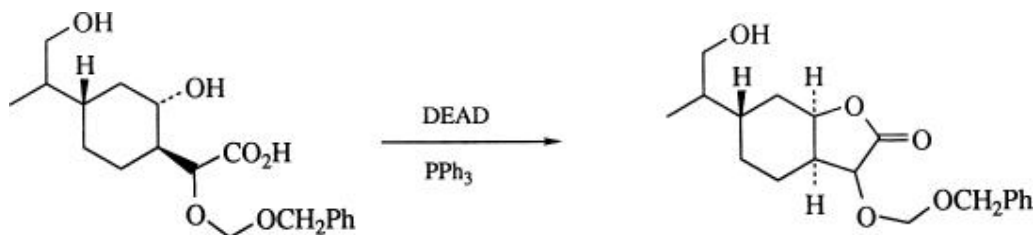
β -Lactones are prepared in good yields at -78° . Stereochemical studies indicate that lactonization of primary (**12**) and secondary (**13**) alcohols proceed by hydroxy group activation (inversion), while tertiary alcohols (**14**) proceed via carboxy group activation (retention). (143-146) β -Lactones prepared from D-



or L-serine derivatives **12** are useful chiral intermediates for formation of a wide variety of α -amino acids. (147-149)



Lactonization of a secondary alcohol is possible in the presence of a primary alcohol under high dilution conditions. (150) Mitsunobu conditions have been



used in the preparation of the natural product macrolactones gleosporone, (151) milbemycin β_3 , (152, 153) colletodiol, (154) vermiculin, (155) and griseoviridin. (156, 157)

3.1.1.2.6. Polymers

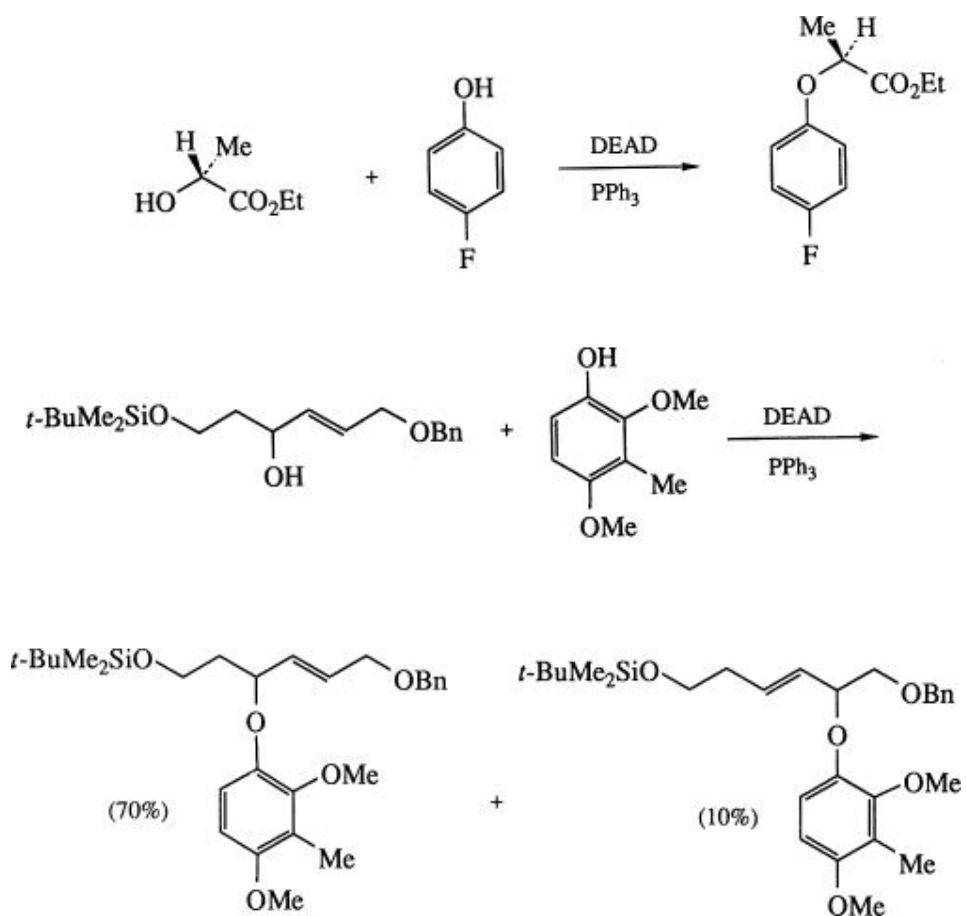
N-Protected amino acids react with *p*-alkoxybenzyl and diphenylmethanol resins to form polymeric esters. (158, 159)

3.1.1.3. Ether Formation

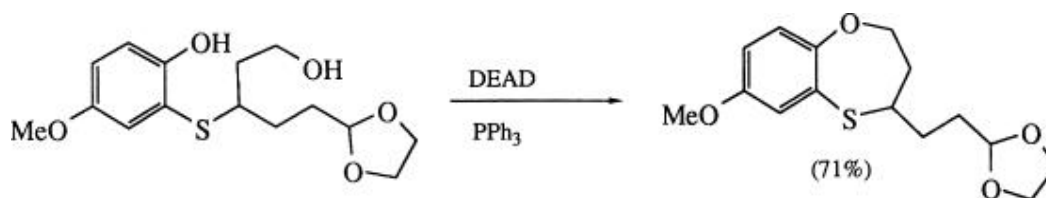
Alkyl aryl ethers, enol ethers, and cyclic dialkyl ethers can be prepared using the Mitsunobu reaction.

3.1.1.3.1. Alkyl Aryl Ethers

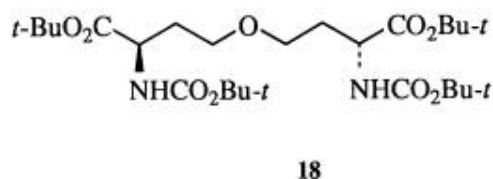
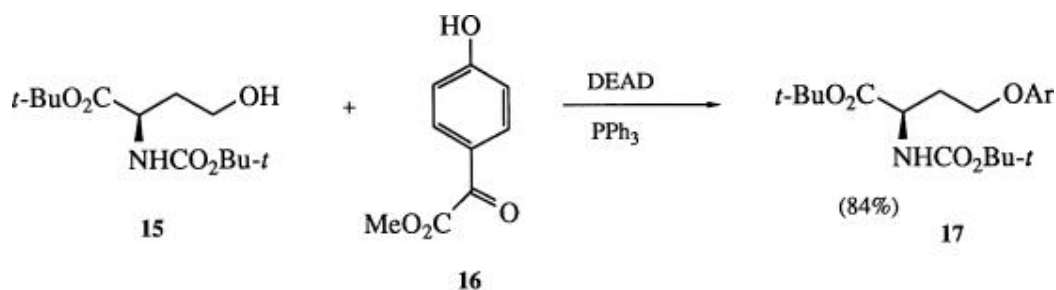
Reaction of a phenol with primary or secondary alcohols in the presence of DEAD/triphenylphosphine produces an alkyl aryl ether. (160, 161) For reaction of secondary alcohols, there is inversion at the hydroxy carbon, (162) indicating that the reaction occurs by activation of the alcohol followed by S_N2 displacement by the phenol. In the reactions of allyl alcohols the S_N2' reaction sometimes competes with the S_N2 reaction. (163)



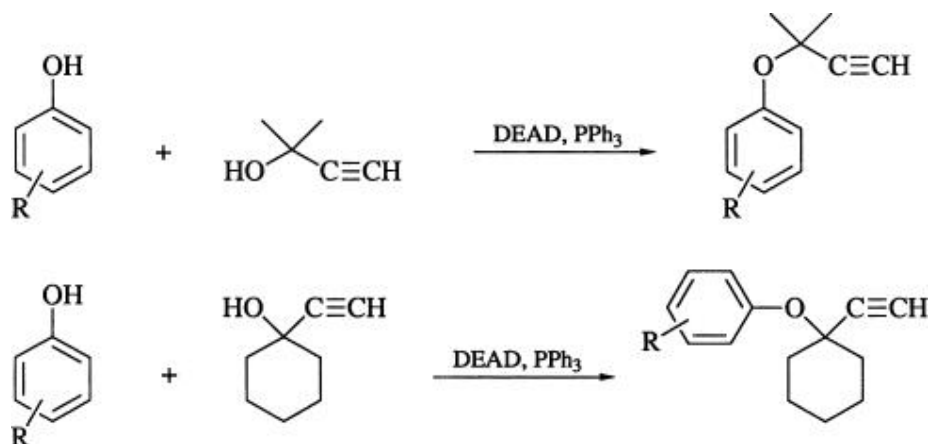
Intramolecular reactions are used to form 6- and 7-membered cyclic ethers.
(164-167)



Reaction of alcohol **15** with phenol **16** gives the coupling product **17** in good yield only when the concentrations of the alcohol and the DEAD/triphenylphosphine adduct are kept low during the reaction. (168) This prevents coupling of the alcohol with itself to form alkyl ether **18**, which otherwise forms in 30–35% yield.

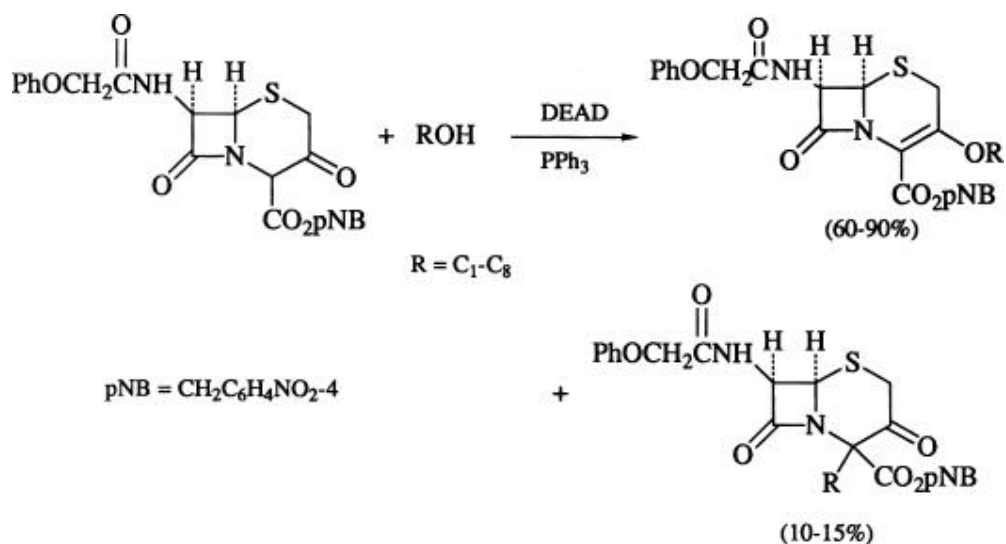


Generally, the Mitsunobu reaction is not successful when tertiary alcohols are used. However, coupling of phenols with several acetylenic tertiary alcohols proceeds in 35–55% yields. [4b,c](#) Since the stereochemistry of the reactions was not determined, the coupling mechanism is not known.



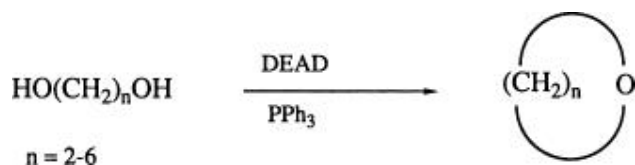
3.1.1.3.2. Enol Ethers

Enol ethers are prepared by reaction of β -ketoesters with alcohols. ([169-171](#)) Further discussion of the factors affecting C-vs. O-alkylation of these compounds is found in the section on ambident alkylations.

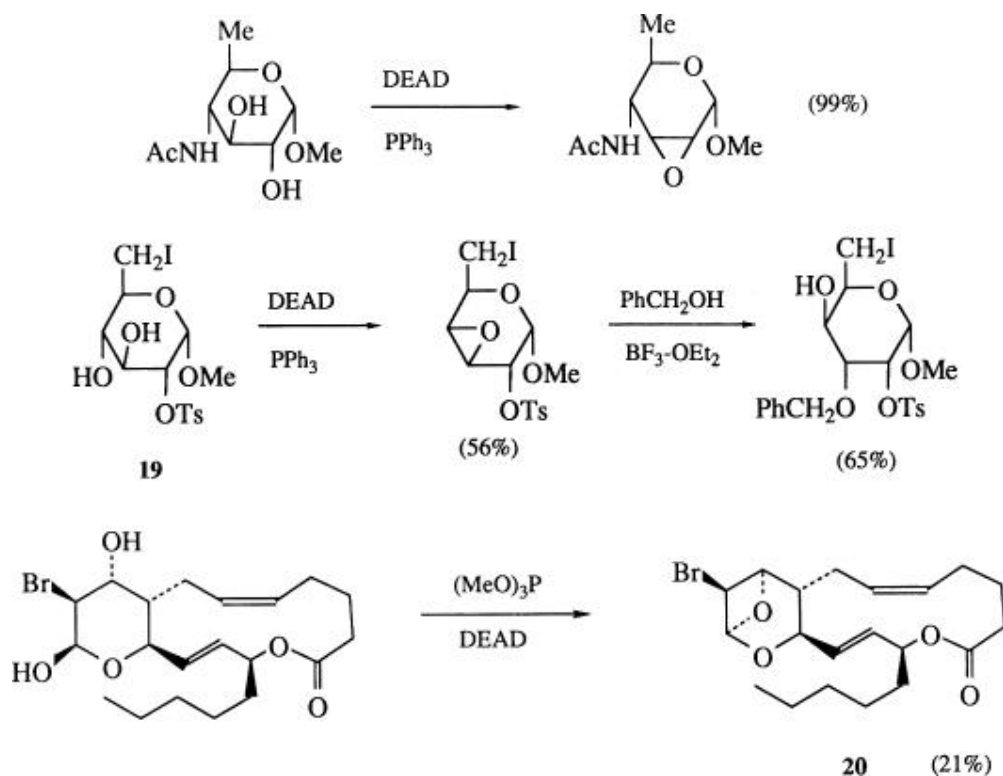


3.1.1.3.3. Dialkyl Ethers

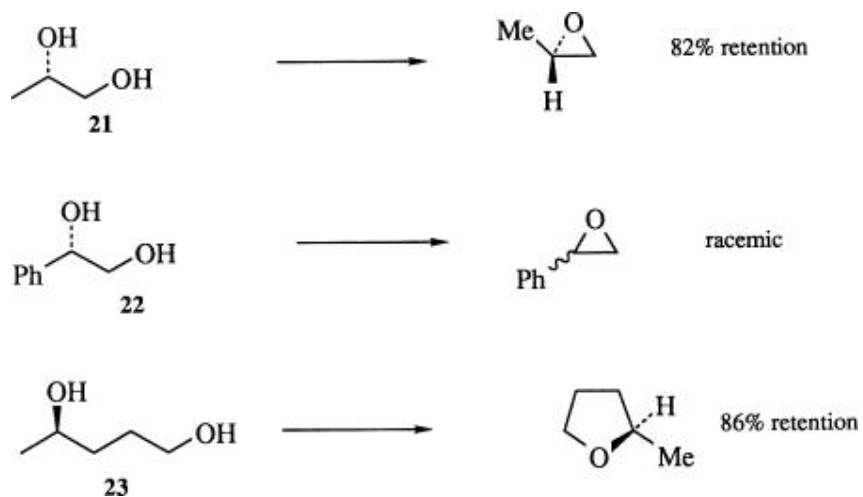
Intermolecular coupling of alcohols with DEAD/triphenylphosphine usually does not occur. Exceptions include the formation of **18** and the use of mercuric bromide to catalyze ether formation between sugars and cyclohexanol. (172, 173) However, intramolecular coupling to make 3-to 7-membered cyclic ethers is a common and high-yield reaction. (174) Formation



of epoxides from *trans* 1,2-diols in sugars often occurs stereoselectively, with only one of the two hydroxy groups being activated and replaced because of steric effects. (175-178) Formation of epoxide can be used to invert both hydroxy groups of pyranoside **19**. (179) Formation of oxetane **20** is a key



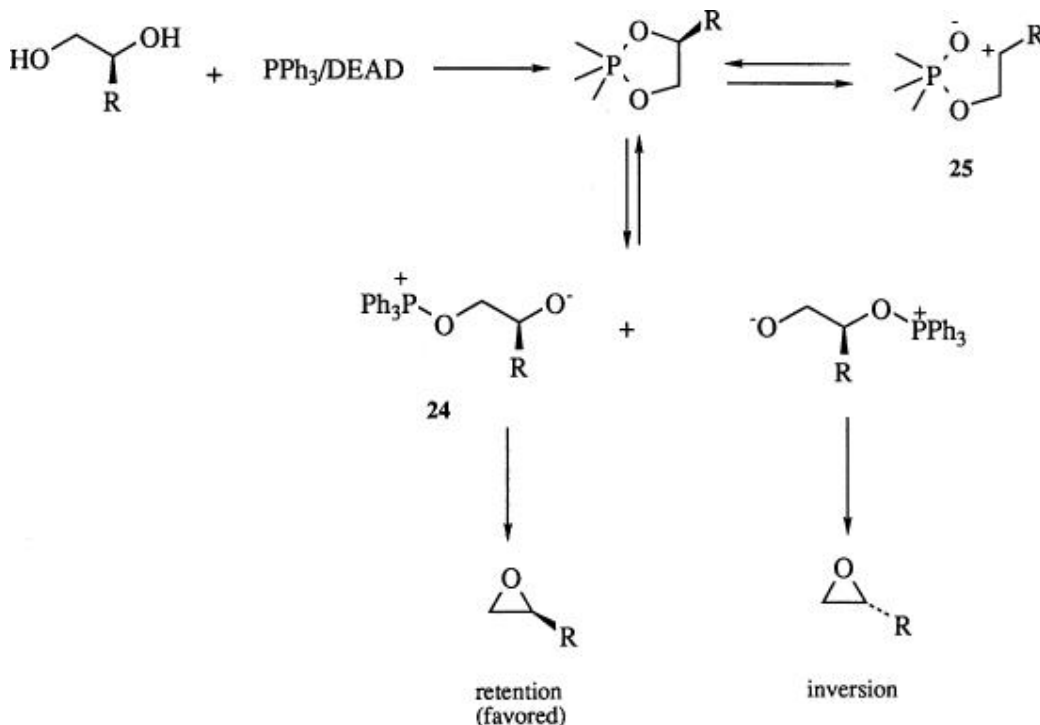
step in the synthesis of thromboxane A₂. (180) Epoxidation of chiral diols **21–23** using triphenylphosphine/DEAD, triphenylphosphine/tetrachloride, or diethoxytriphenylphosphine results primarily in retention of configuration in **21** and **23** and racemization in **22**. (181) An explanation of these results is



shown in Scheme 1. It is postulated that the phosphorane and betaines are in equilibrium. For steric reasons, epoxide formation from collapse of betaine **24** is favored, resulting in retention of configuration. Racemized product may be

due to racemization of the phosphorane via the stabilized carbocation **25**.
(181)

Scheme 1.



The regioselectivity for epoxide formation of 1,2-diols is opposite to that for ester formation (p. 343). Identical phosphorane intermediates are postulated in both cases. For esterification in the presence of a carboxylic acid, the phosphorane must open to give the secondary oxyphosphonium salt to account for the observed findings. In the absence of acid the phosphorane opens to give the primary oxyphosphonium zwitterion, which leads to epoxide formation with retention of configuration.

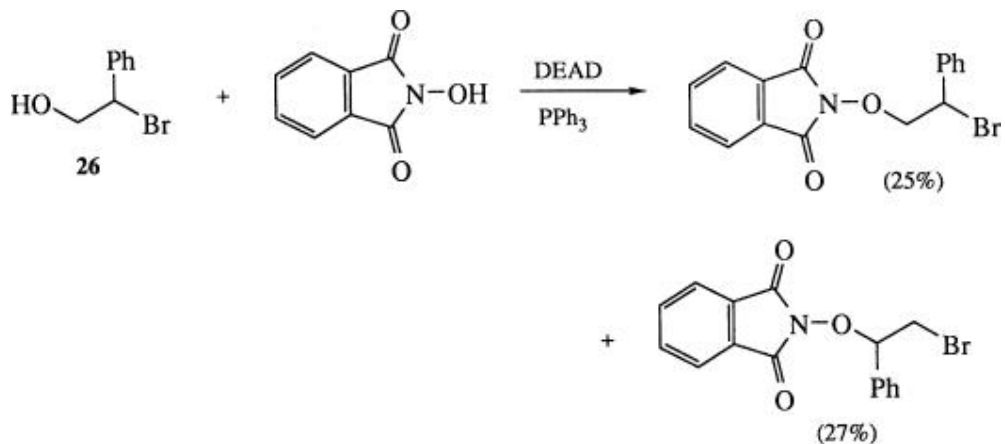
3.1.1.4. Other Oxygen Nucleophiles

Alcohols are converted to tosylates of inverted configuration using lithium tosylate or zinc tosylate and triphenylphosphine/DEAD in yields up to 94%.

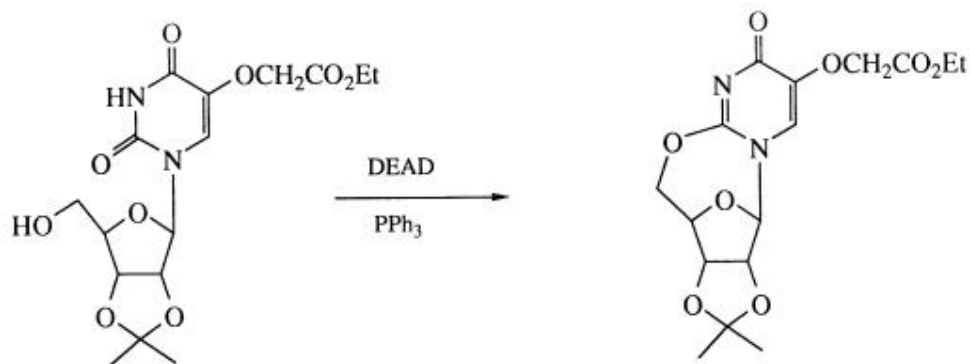
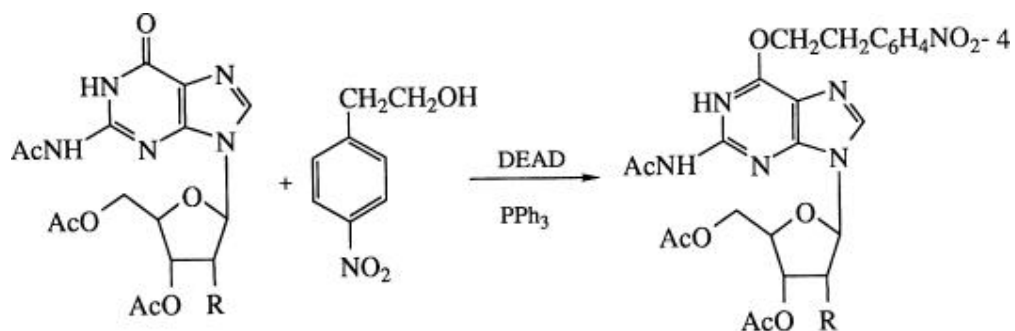
(140, 182) *N*-Hydroxyphthalimide reacts with alcohols and

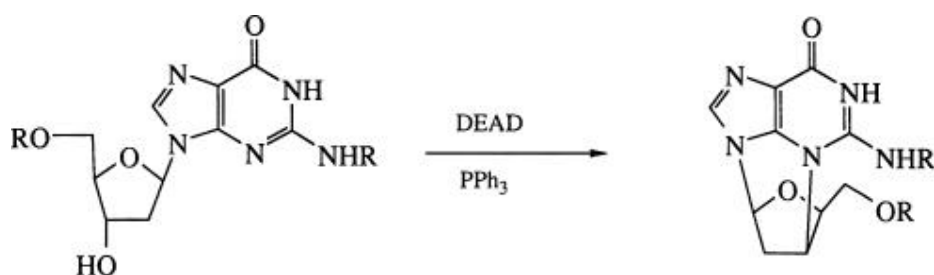
DEAD/triphenylphosphine to form phthalimidooxy derivatives. (183, 184)

Bromohydrin **26** forms equal amounts of the expected $\text{S}_{\text{N}}2$ product and that arising from a phenonium ion ($\text{S}_{\text{N}}1$) rearrangement. (185)

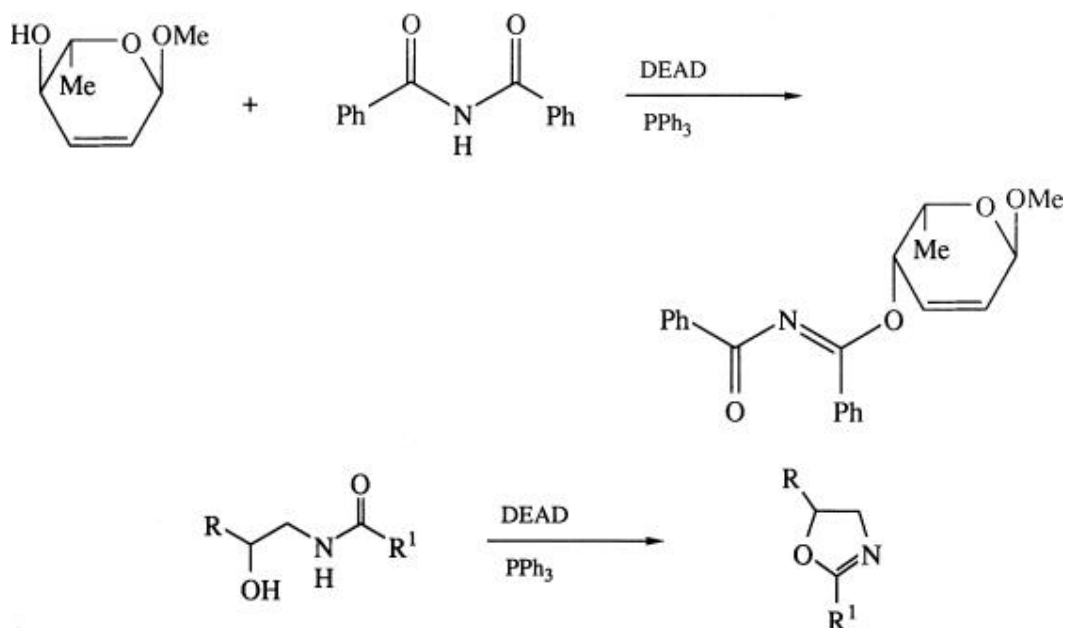


Ethanol, (186) 4-nitrophenethanol, (187-189) and 3,4-dimethoxybenzyl alcohol (190) react at oxygen of the amide functionality in guanosine nucleotides. In contrast, thymidine and uridine nucleotides alkylate on nitrogen with 4-nitrophenethanol, (191) while inosine gives a 2:1 mixture of O- vs. N-alkylation. (192) If the nucleotides have unprotected hydroxy groups, then intramolecular reactions

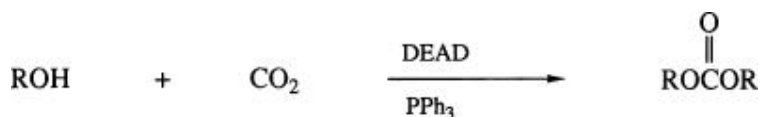




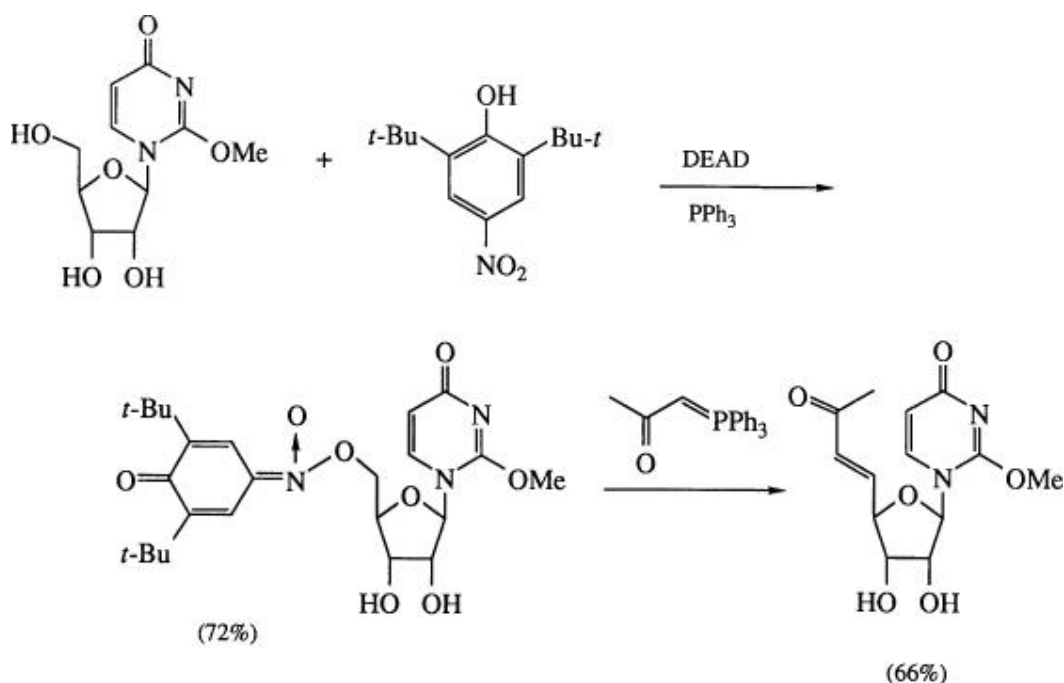
occur. (193, 194) While cyclic imides such as succinimide and phthalimide react at nitrogen, acyclic imides react at oxygen. (195) Hydroxyamides react intramolecularly to form 2-oxazolines. (196) Phosphinic acids (197) and phosphonates (198) form esters with alcohols using DEAD/triphenylphosphine.



Carbonates are prepared from alcohols and CO₂ using DEAD/triphenylphosphine. (199) 2,6-Di-*tert*-butyl-4-nitrophenol reacts with the primary hydroxy



group of nucleosides to form aci-nitro esters using triphenylphosphine/DEAD. The aci-nitro esters react with Wittig reagents to form olefins, serving as masked aldehydes. (200) Aryl and alkyl carboxylic acids are converted to

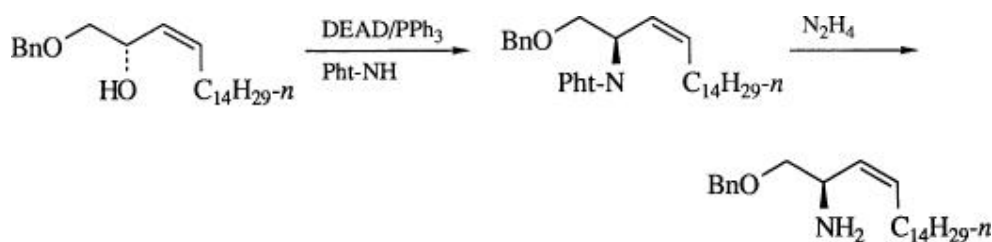


anhydrides in 60–96% yields using triphenylphosphine/DEAD in tetrahydrofuran. (201)

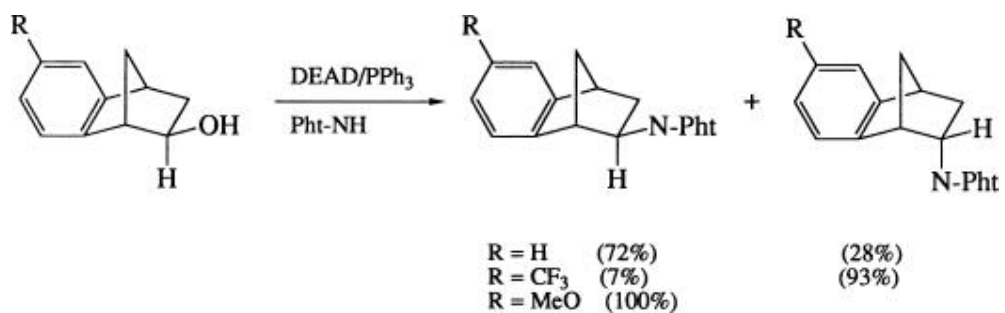
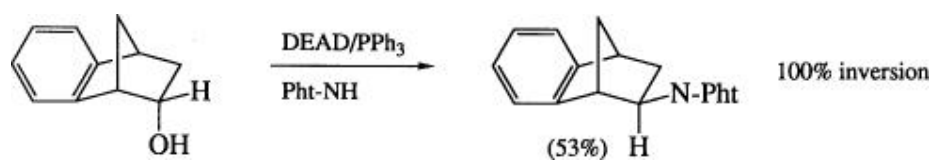
3.2. Carbon–Nitrogen Bond Formation

3.2.1.1. Cyclic Imides

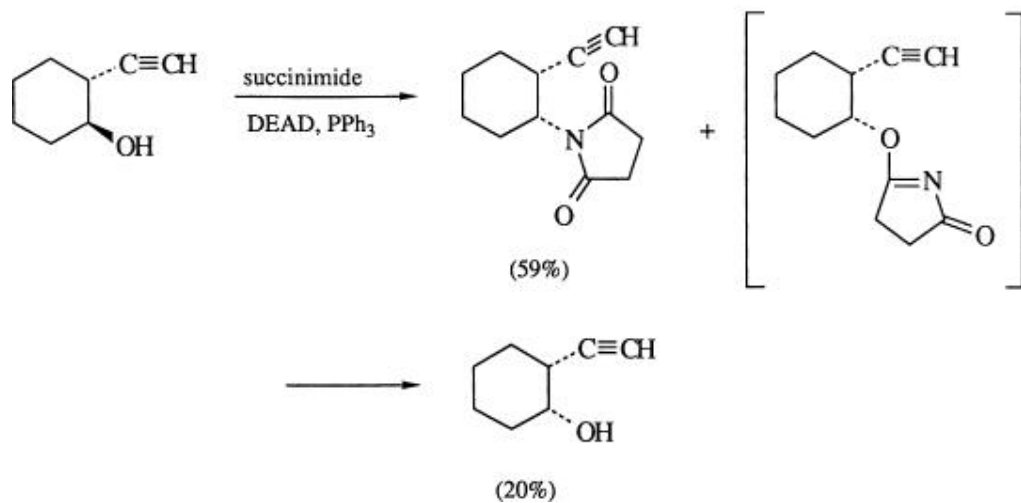
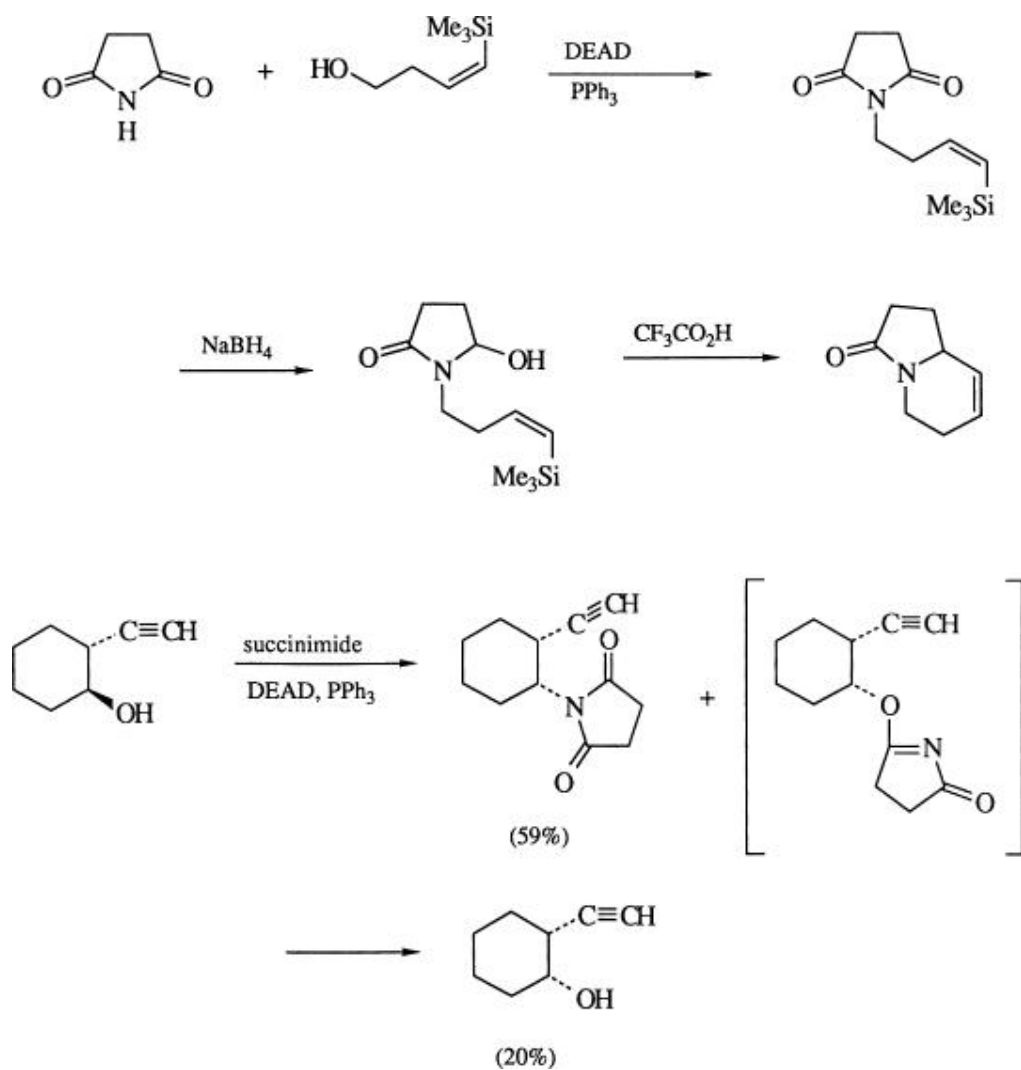
Conversion of alcohols into inverted amines is accomplished by coupling a secondary alcohol with phthalimide using DEAD/triphenylphosphine followed by hydrazinolysis of the phthalimido product to the amine. (202) *endo*-Benzonorbornen-2-yl alcohols react to form *exo* phthalimido



derivatives, but *exo* alcohols give mixtures of *endo* and *exo* products by a phenyl-assisted S_N1 process. Substitution of a trifluoromethyl group into the phenyl ring reduces the amount of S_N1 character, (203) while a 4-methoxy group results in complete retention. (204) Coupling of alcohols with other cyclic

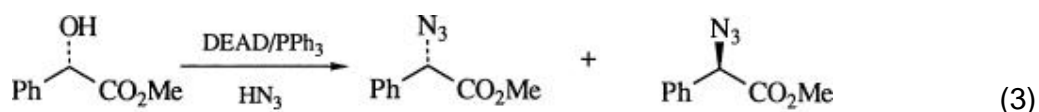


imides, including glutarimide, succinimide, hydantoin, and oxazolidinedione, is used to make substrates for *N*-acyliminium cyclizations. (205) There is one example of competitive *O*-alkylation, leading to an inverted alcohol. (206)

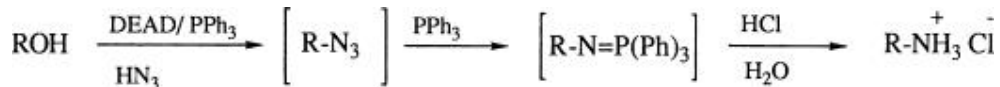


3.2.1.2. Azides

Alcohols are converted into azides using hydrazoic acid, zinc azide, or diphenylphosphoryl azide as nucleophile, generally in benzene or toluene solvent. Secondary alcohols are inverted except when steric hindrance leads to retention (207) or when the presence of an acidic hydrogen leads to racemization (Eq. 3). (208) A convenient one-pot preparation of amines from

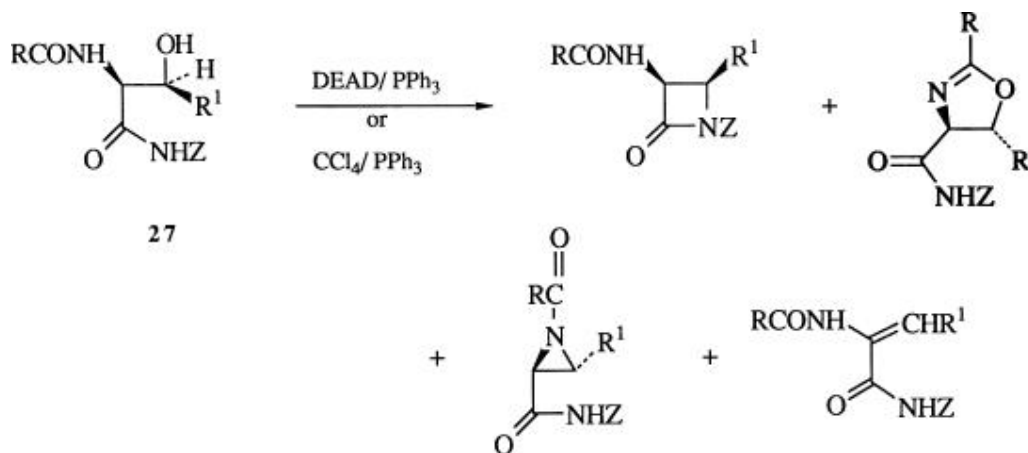


alcohols employs the Mitsunobu reaction to make the azide followed by an in situ Staudinger reaction with triphenylphosphine to produce an imino-phosphorane, which is hydrolyzed to the amine during aqueous workup. (208) Overall isolated yields range from 35 to 85%.

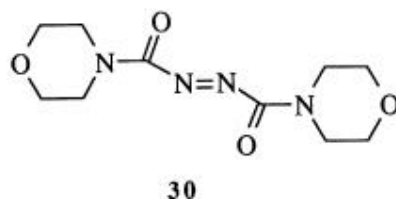
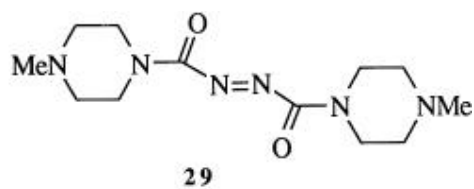
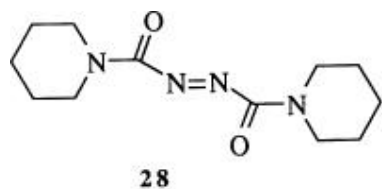


3.2.1.3. Lactam Formation

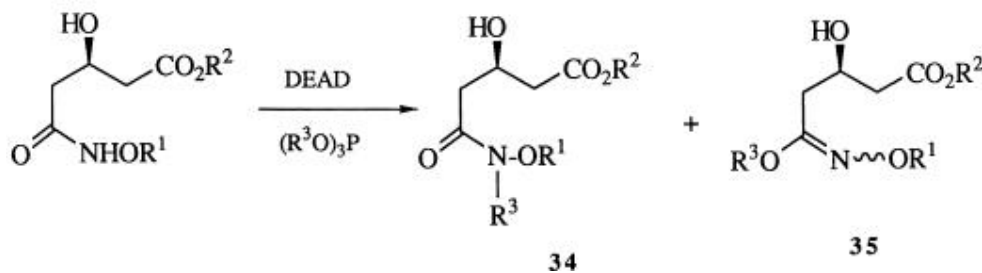
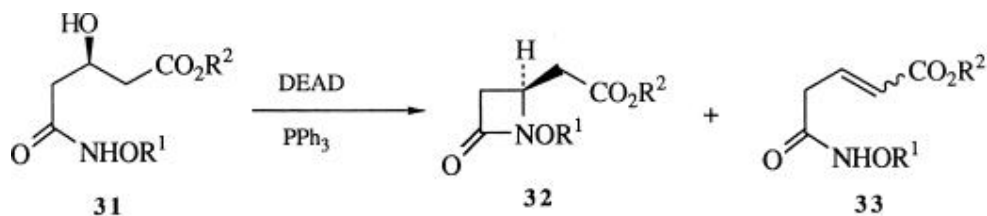
β -Lactams are formed by intramolecular dehydration of β -hydroxycarboxamide derivatives. (209-211) Side reactions include elimination and formation of oxazolines and aziridines. Oxazoline and aziridine formation can be prevented by using carbonate, (209-211) oxazolin-2-oyl, (212, 213) or phthalimide (212, 214, 215) protecting groups for the side-chain amino group. Yields of β -lactams are 80–90% for hydroxamate precursors (Z = benzyloxy) (209-211) and 70–80% for anilide precursors (Z = 4-tolyl). (214, 215) Cyclization of **27** (Z = 4-tolyl, R = H, R' = benzyloxy)



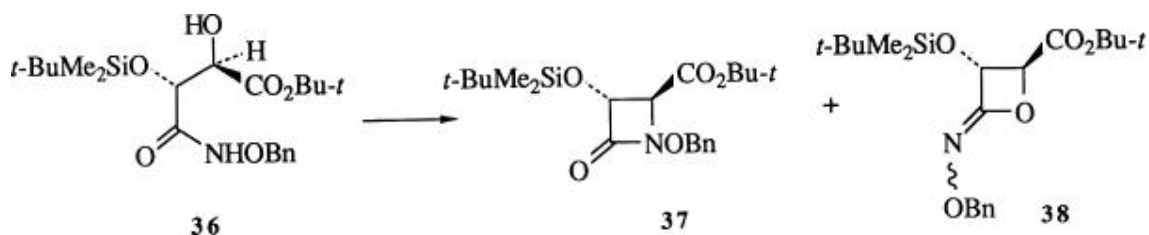
using DEAD and a variety of phosphines gives only small changes in yield of β -lactam: triphenylphosphine (74%), tri-*n*-butylphosphine (68%), triethyl phosphite (79%), and tris(dimethyl-amino)phosphine (67%). (215) Replacing DEAD with azo reagents **28–30** gives no β -lactam formation with triphenylphosphine, but 47–57% yields with tri-*n*-butylphosphine. (215) Cyclization of **31** with DEAD/triphenylphosphine gives 22% β -lactam **32** and 78% elimination product **33**. (216) The olefin



is also the major product with triphenylphosphine/carbon tetrachloride/triethylamine, triphenylphosphine dibromide, and triphenylphosphine dichloride. β -Lactam yields of 50–70% are achievable when triphenyl phosphite, phenoxydiphenylphosphine, or diphenoxyphenylphosphine are used along with DEAD. Use of trimethyl phosphite and triisopropyl phosphite with DEAD results in mixtures of *N*- and *O*-alkylation (**34** and **35**). (216) Cyclization

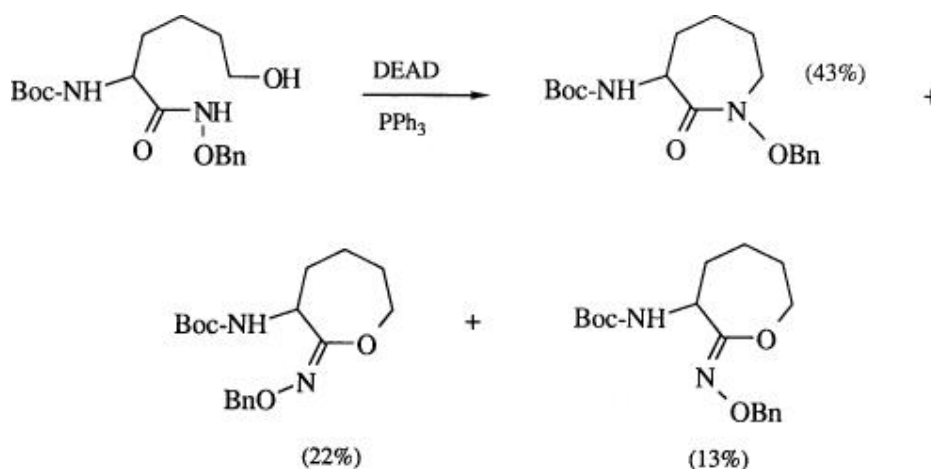


of amide **36** results in some competitive *O*-alkylation, depending on the azodicarboxylate. (217) With diisopropyl azodicarboxylate, 40% of **37** and no **38** are obtained. Diethyl azodicarboxylate gives 22% **37** and 5.5% **38**, while dimethyl azodicarboxylate gives 14% each of **37** and **38**.

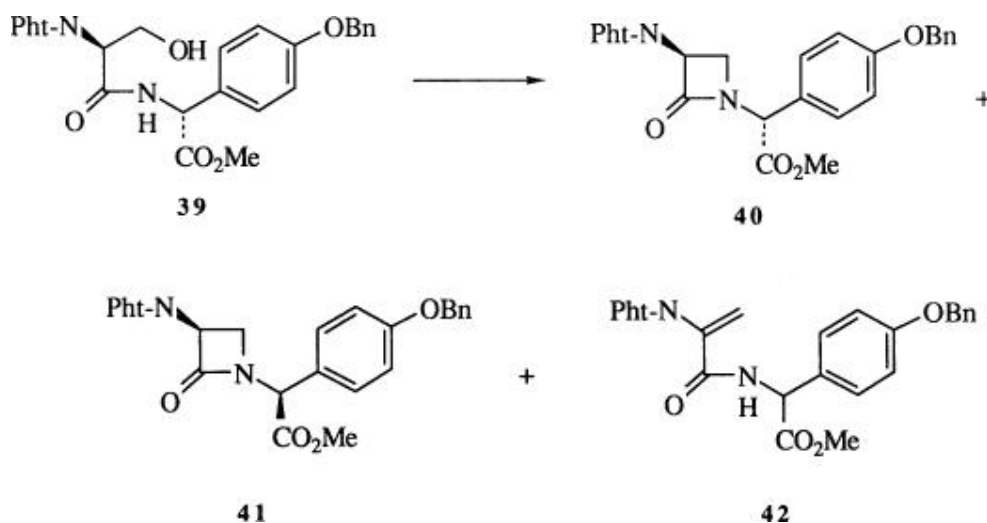


Competitive *N*- and *O*-alkylation also occurs in the cyclization to the 7-membered lactam. (218)

Cyclization of amide **39** using 5.0 equivalents of triphenylphosphine/DEAD in tetrahydrofuran affords a thermodynamic mixture of diastereomers **40** and **41** (2:1 ratio) along with 2% elimination product **42**. (219) Unreacted **39** isolated from a reaction mixture is not epimerized, indicating that epimerization occurs in the intermediate oxyphosphonium salt or in the product β -lactam. Treating pure **40** with 2.5 equivalents of DEAD/triphenylphosphine

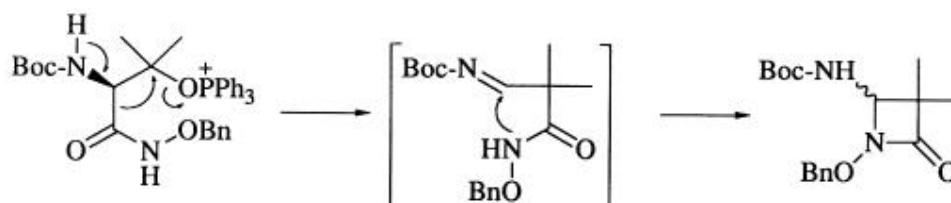
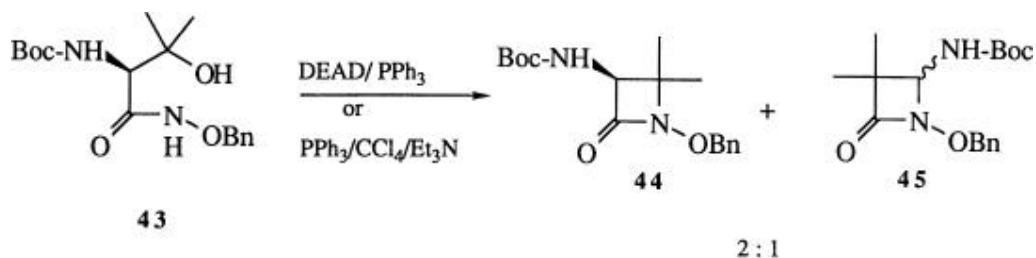


in tetrahydrofuran results in a reestablishment of the 2:1 diastereomeric mixture in 15 minutes, indicating that the DEAD-triphenylphosphine adduct is a sufficiently strong base to epimerize the product β -lactam. Decreasing the amounts of DEAD and triphenylphosphine has no effect on the diastereomeric ratio of **40** to **41**, which are at thermodynamic equilibrium, but increases the elimination product **42**: 7% at 2.5 equivalents, 12% at 1.8 equivalents, 16% at 1.5 equivalents, and 23% at 1.0 equivalent. When triphenylphosphine is



replaced with triethyl phosphite, the reaction is slower and less epimerization takes place. With 2.5 equivalents of DEAD/triethyl phosphite, the ratio of **40:41** is 6.8:1, while with 1.0 equivalent the ratio is >50:1. ¹H NMR analysis indicates that epimerization is taking place in the oxyphosphonium ion intermediate. (168, 219)

β -Lactam formation occurs with tertiary alcohol **43** but gives a mixture of isomeric products **44** and **45**. **4a** Labeling experiments suggest that **45** arises via an intramolecular 1,2-acyl migration–cyclization process. (220)

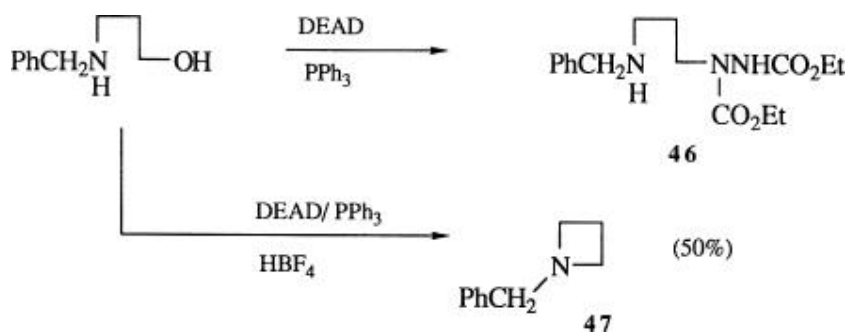


3.2.1.4. Other Carbon–Nitrogen Bond-Forming Intramolecular Cyclizations
 Aziridines, (221) azetidines, (222, 223) pyrrolidines, (224, 225) and piperidines (222) are formed by intramolecular reactions of ω -aminoalcohols with

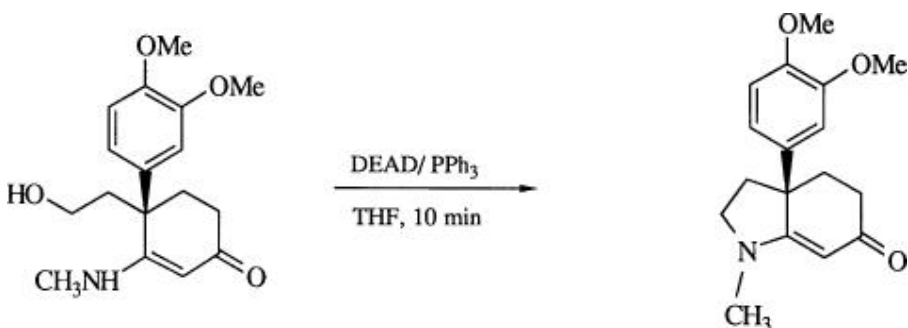
DEAD/triphenylphosphine.

High yields of aziridines are obtained from 2-aminoethanol derivatives provided that the amine is secondary and one of the carbon atoms is substituted. (221)

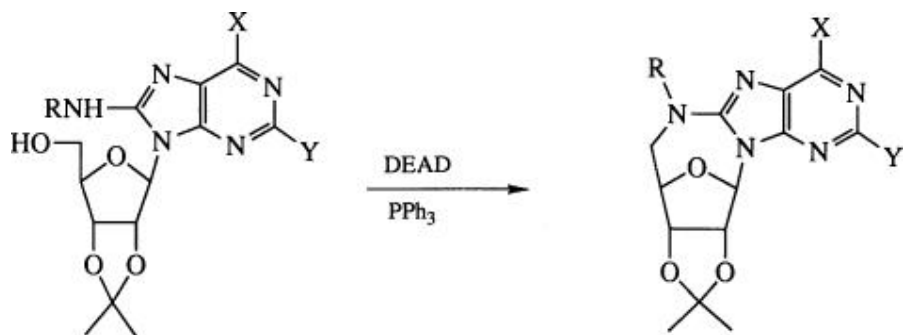
Reaction of 3-(*N*-benzylamino)-1-propanol with DEAD/triphenylphosphine results in formation of the DEAD adduct **46**. (222) The desired azetidine **47** is obtained by using an acid to protonate the hydrazide anion, preventing



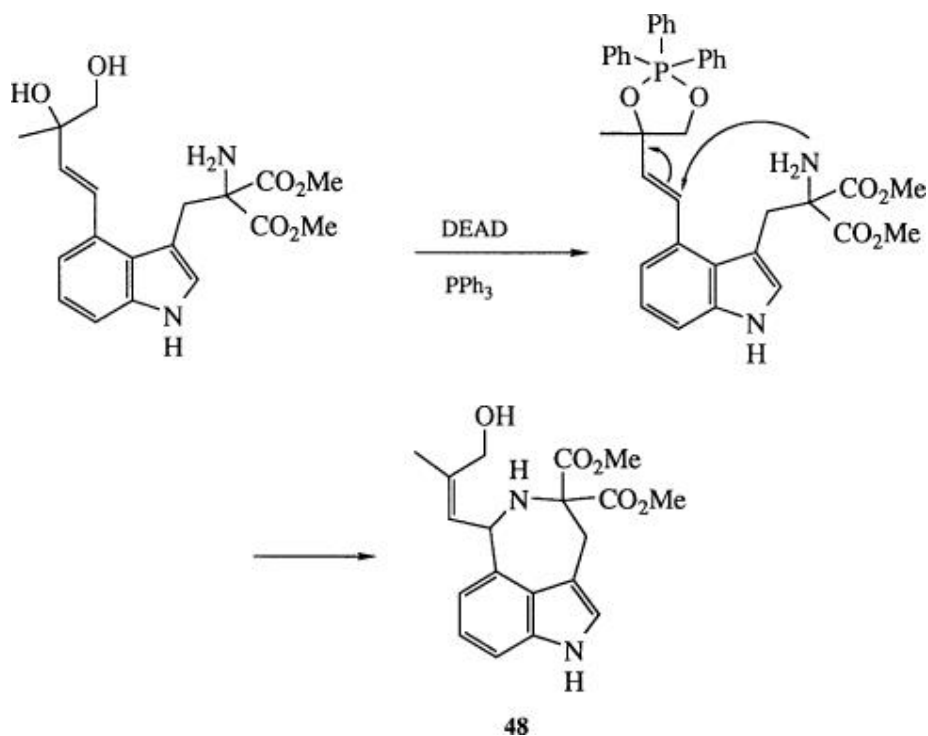
its reaction. The pyrrolidine moiety of mesembrine is constructed by an intramolecular Mitsunobu reaction. (224) Nitrogen-bridged cyclonucleosides with



a 7-membered ring are prepared in high yields with DEAD/triphenylphosphine. (226) An intramolecular S_N2' reaction provides the 7-membered heterocycle

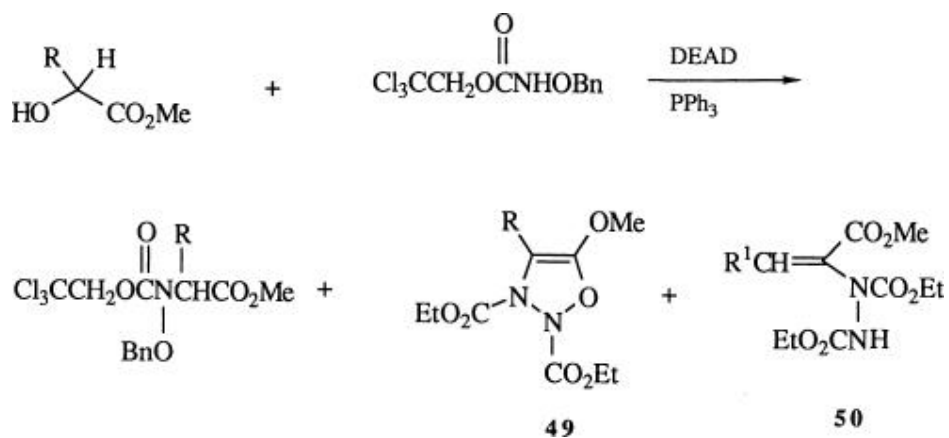


48. (227) Activation of the tertiary alcohol is made possible by initial activation of the primary hydroxy group followed by ring closure to the phosphorane, which is observed by ^{31}P NMR.

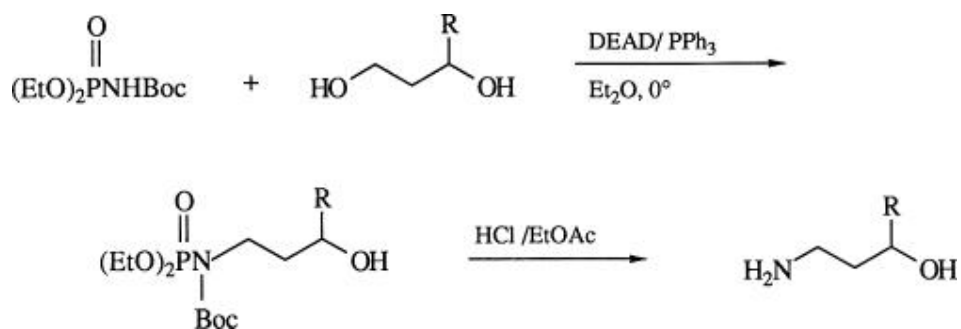


3.2.1.5. Other Intermolecular Carbon–Nitrogen Bond-Forming Reactions

Protected hydroxylamines react with α -hydroxycarbonyl compounds to form protected aminoacid esters in 20–82% yields, plus adducts **49** and **50** in 10–50% yields arising from reaction of the α -hydroxycarbonyl compound with

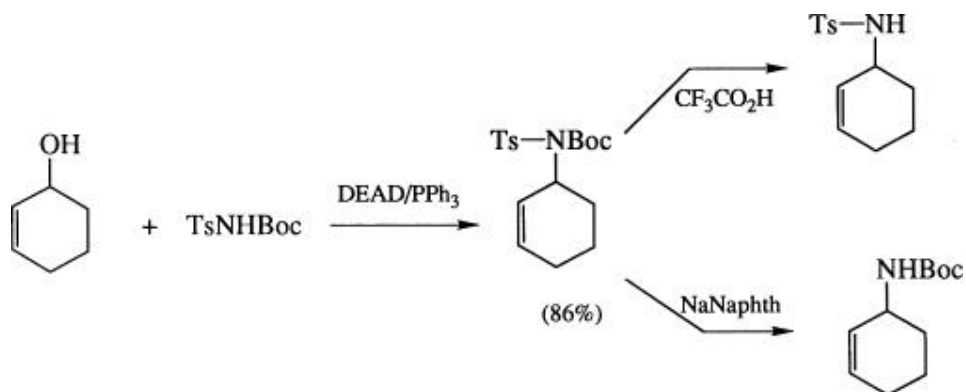


DEAD. (228) Phosphoramidates condense with alcohols, and the resulting *N*-alkylated products can be cleaved to form amines. 229,230a



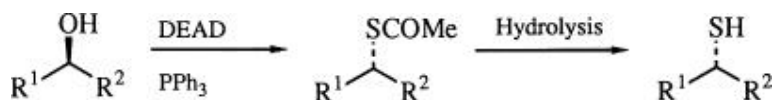
N-Alkyl- and *N*-acylsulfonamides react with alcohols in the presence of DEAD/triphenylphosphine to give alkylated sulfonamide products. The Boc or tosyl groups can be selectively removed to give the monoselectively protected amines. 230b



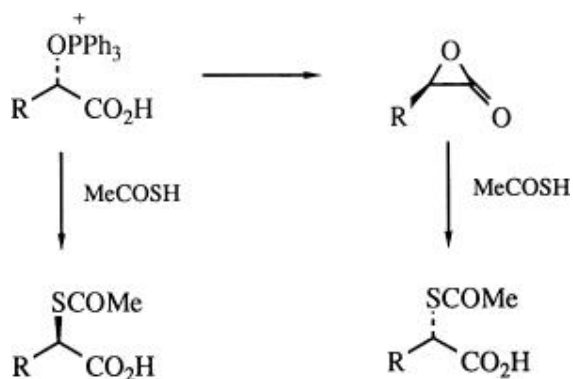


3.3. Carbon–Sulfur Bond Formation

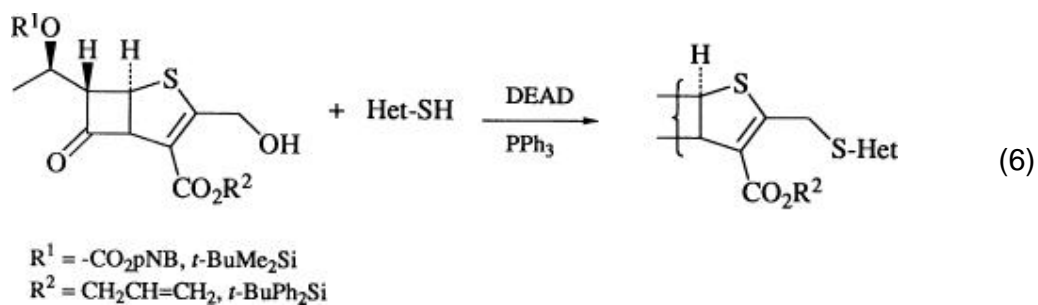
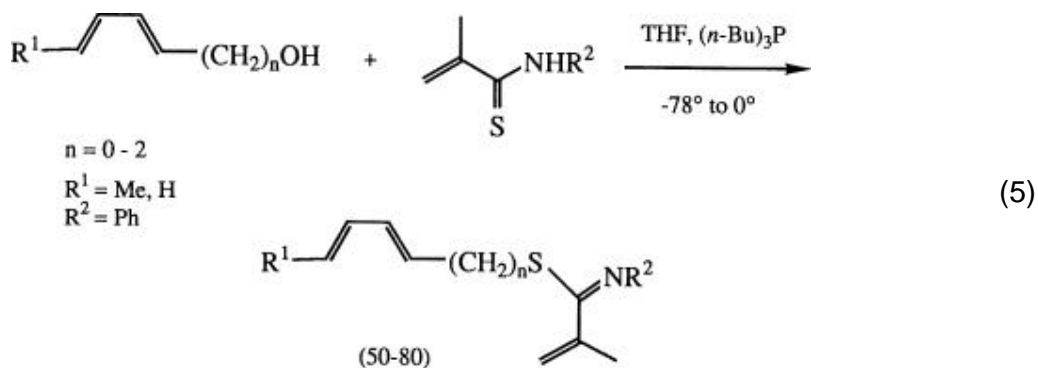
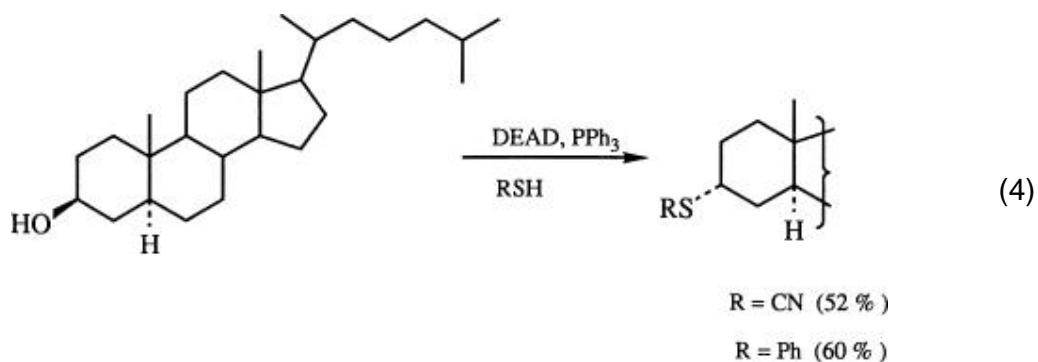
Alcohols can be converted into thiols by reaction of the alcohol with triphenylphosphine, DEAD, and thiolacetic acid to form a thiol ester, followed by saponification or reduction of the thiol ester to the thiol. (231-244) Important to the success of this reaction is preformation of the DEAD–triphenylphosphine

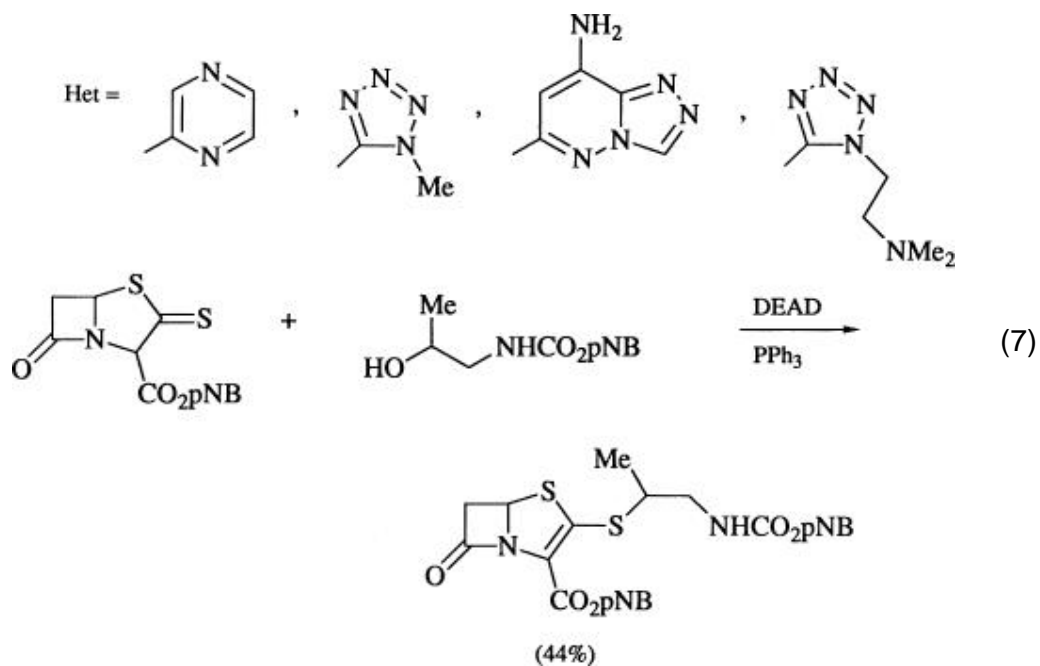


adduct at 0° before addition of the thiolacetic acid and the alcohol, which prevents nucleophilic addition of the thioacid to DEAD. (231) While complete inversion occurs with optically pure 2-octanol, (231) 3-β-cholestanol, (231) ethyllactate, (232) methyl phenylacetate, (232) and diethyl malate, (232) significant racemization occurs with ethyl mandelate (69% ee), (232) mandelic acid (85% ee), (233) lactic acid (68% ee), (233) and 2-hydroxy-3-phenylpropionic acid (52% ee). (233) In the last three, involvement of an α-lactone intermediate appears to be the cause of racemization. (233) Other nucleophiles used to form carbon–sulfur bonds



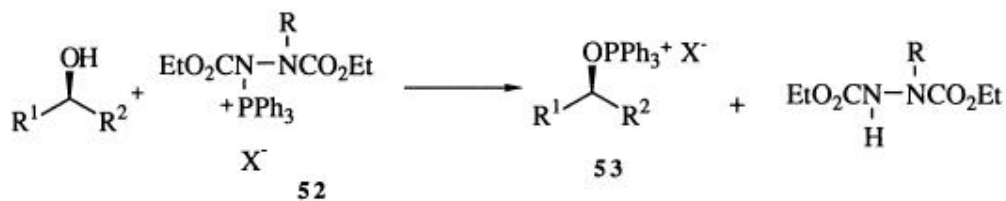
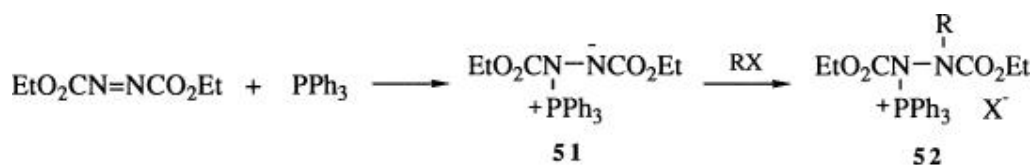
include thiocyanate (Eq. 4), (245) thiophenol (Eq. 4), (244-247) thioamides (Eq. 5), (248, 249) thioureas, (250) zinc *N,N*-dimethyldithiocarbamate, (251) alkyl thiols, (252) heterocyclic thiols (Eq. 6), (253, 254) and dithioesters (Eq. 7). (255)



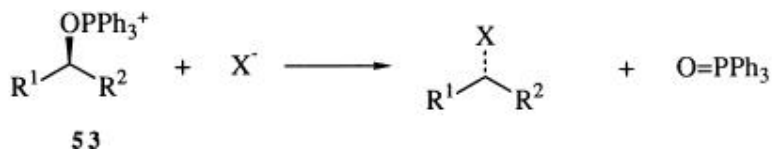
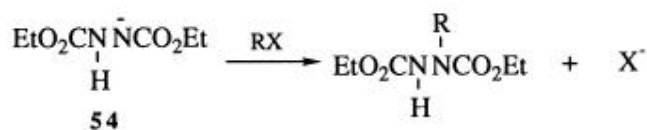
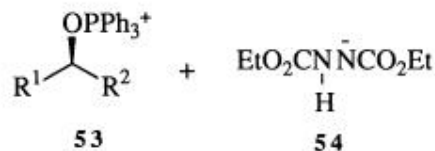
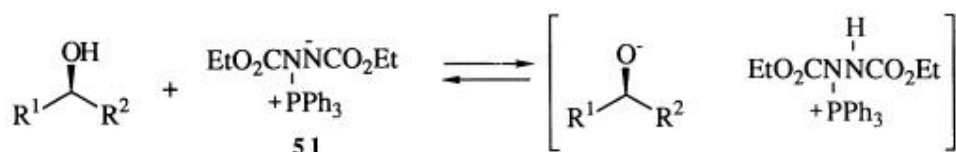


3.4. Carbon–Halogen Bond Formation

Alcohols are converted into halides using DEAD/triphenylphosphine along with an alkyl or acyl halide. (245) Two possible reaction pathways are shown. In

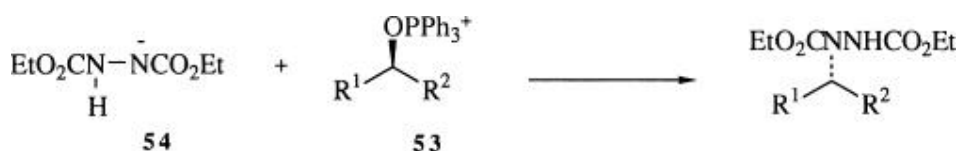


MECHANISM II



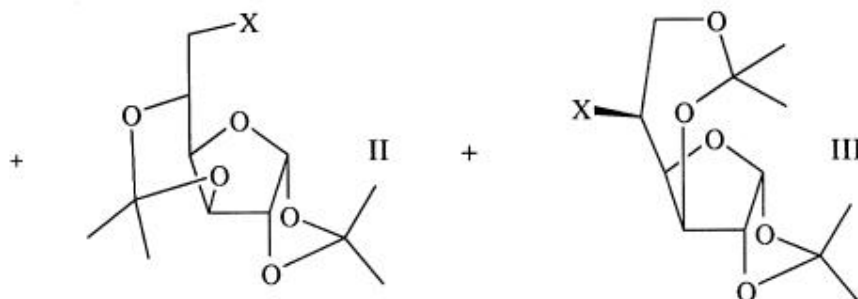
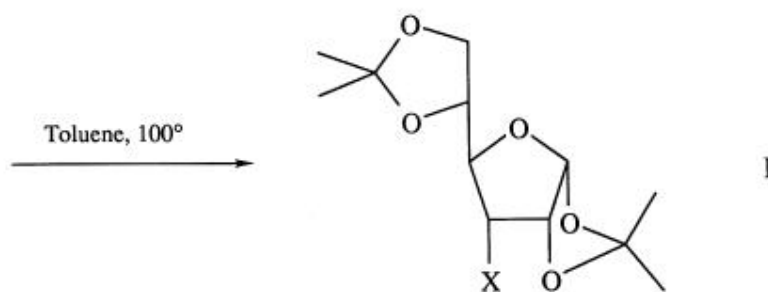
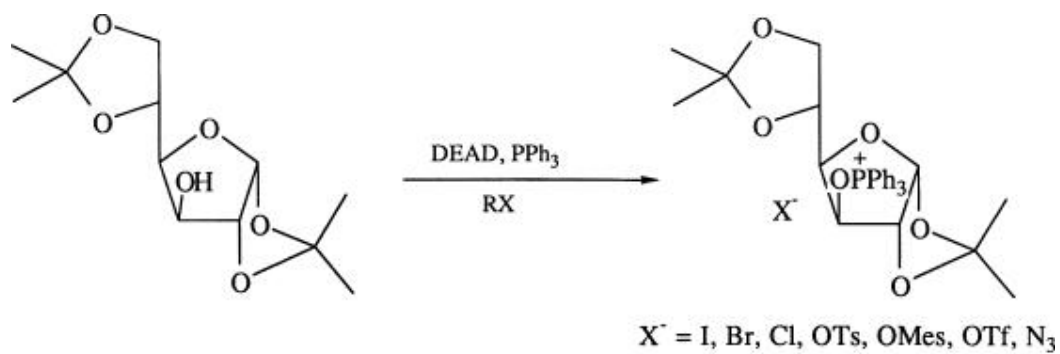
the first pathway the zwitterionic intermediate **51** is alkylated to form the azaphosphonium intermediate **52** with the halide counterion. The transfer of phosphorus occurs from **52** to the alcohol to form the oxyphosphonium

intermediate **53**, with X^- perhaps serving as a basic catalyst. S_N2 reaction of **53** with X^- produces the inverted halide. The second pathway differs in that phosphorus transfer occurs from the zwitterionic intermediate **51** to form the oxyphosphonium intermediate **53** and hydrazine anion **54**. The hydrazine anion is then alkylated with RX to generate X^- , which reacts with oxyphosphonium intermediate **53** to produce the inverted halide. In the latter mechanism an expected competing side reaction would be reaction of **53** and **54**, a commonly observed reaction when no acid or alkylating agent is present. (256)



The lack of this as a competing side reaction in the absence of acid is one piece of evidence to disfavor the second mechanism. Intermediate phosphoranes, which have been shown to form with hindered alcohols in the absence of acid, may also play a role. (12-16)

The intermediate oxyphosphonium salts from several hindered carbohydrates have been isolated and characterized. (10, 257) Heating the oxyphosphonium salt in toluene results in S_N2 displacement for $X^- = \text{I}$, but rearrangements

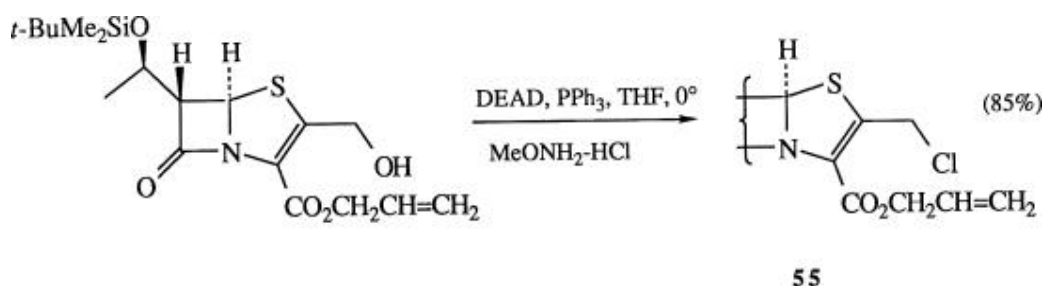


X	I	II	III
I	70%	0%	0%
Br	7%	35%	11%
Cl	5%	55%	27%

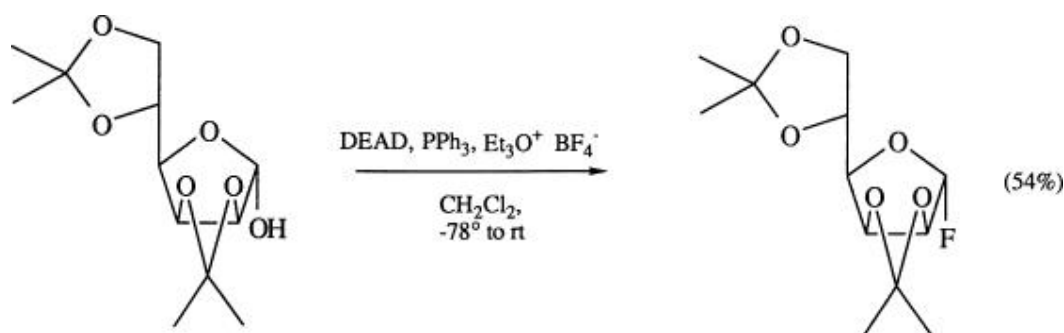
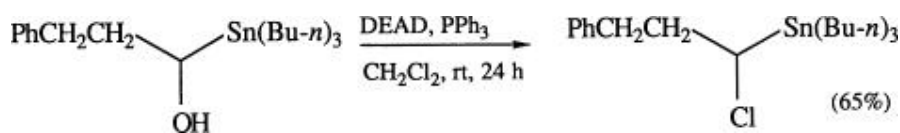
when $X^- = \text{Br}, \text{Cl}$ because of attack of X^- on the isopropylidene protecting group.

Besides alkylating or acylating agents, several other sources of halide ion can be used in conjunction with DEAD/triphenylphosphine. The halide may be

supplied by an ammonium salt such as pyridinium hydrochloride or hydrobromide, methoxyamine hydrochloride, or 2-amino-5-bromothiazole hydrobromide. (258) In these cases the zwitterionic intermediate **51** is protonated by HX to liberate X⁻ for the reaction. The mildness of this procedure is demonstrated by formation of the penam **55** in 85% yield when no other method was successful. (258) The source of halide may also be methylene chloride



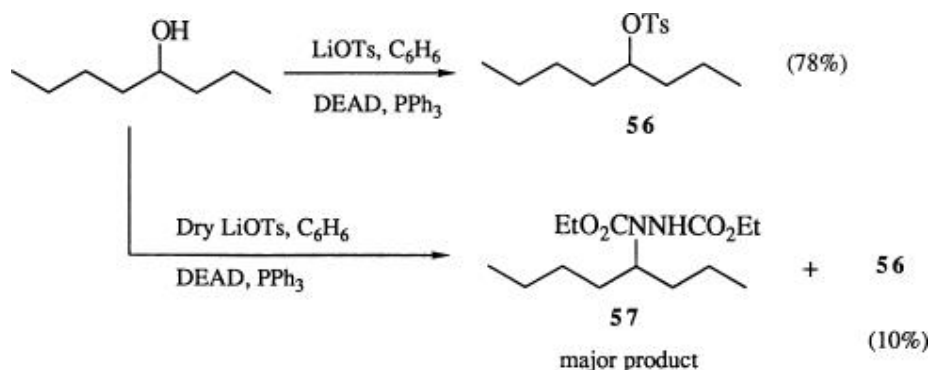
as solvent (259) or methylene bromide in benzene solution. (260) Triethyloxonium tetrafluoroborate is used as a source of fluoride. In the one example reported,



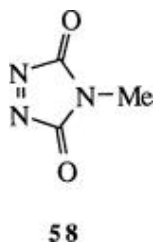
retention of configuration occurred. (261)

Primary and secondary alcohols react with triphenylphosphine, DEAD, and zinc halides to produce alkyl halides in 66–90% yields. (251, 262) Formation of 2-phenethyl chloride from the corresponding alcohol with no elimination indicates the mildness of the procedure. (262) Lithium halides, including F, Cl, Br, and I, or also lithium cyanide, react with alcohols in the presence of triphenylphosphine/DEAD to give the corresponding halides or nitrile in

50–96% yields. (263) Water (or HX) may play a role in these reactions. In the reaction of 4-octanol with lithium tosylate, triphenylphosphine, and DEAD, a 78% yield of the expected tosylate **56** was formed. However, when the lithium tosylate was rigorously dried, only 10% of **56** was formed, and the major product was the DEAD addition product **57**. (182) Optically active secondary



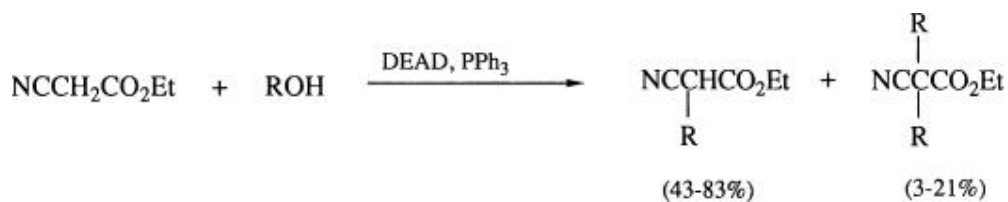
alcohols are converted to inverted iodides and bromides in 65–91% yields using MeX , triphenylphosphine, or tri-*n*-butylphosphine, with the DEAD substitute 4-methyl-1,2,4-triazolidine-3,5-dione (**58**). (264)



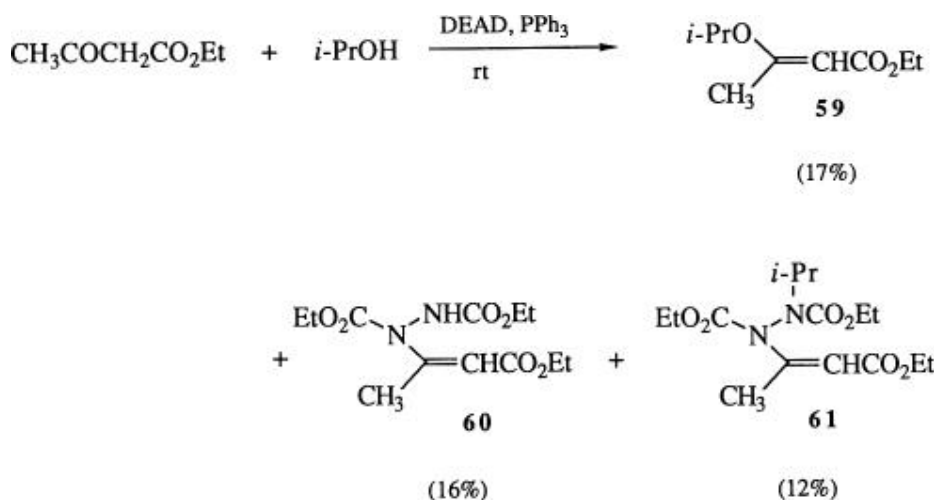
3.5. Carbon–Carbon Bond Formation

Use of the Mitsunobu reaction to form carbon–carbon bonds is limited to compounds having highly acidic C – H bonds, such as β -diketones, (265) β -ketoesters, (265) α -cyanothioesters, (266) and α -cyanoesters. (265) β -Diesters are not acidic enough to undergo reaction. (265)

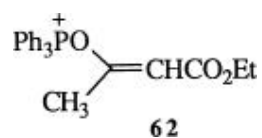
Alkylation of ethyl cyanoacetate occurs in 43–83% yields with primary and secondary alcohols provided the DEAD–triphenylphosphine adduct is preformed. Dialkylation occurs to the extent of 3–21%. (265) Reaction of ethyl acetoacetate



with 2-propanol and the preformed DEAD-triphenylphosphine adduct at room temperature gives 17% *O*-alkylated product **59** plus the DEAD addition products **60** and **61**. No *C*-alkylation occurs. Reducing the temperature to -10° to -20° increases the yield of **59** to 35%. (265) Compounds **60**

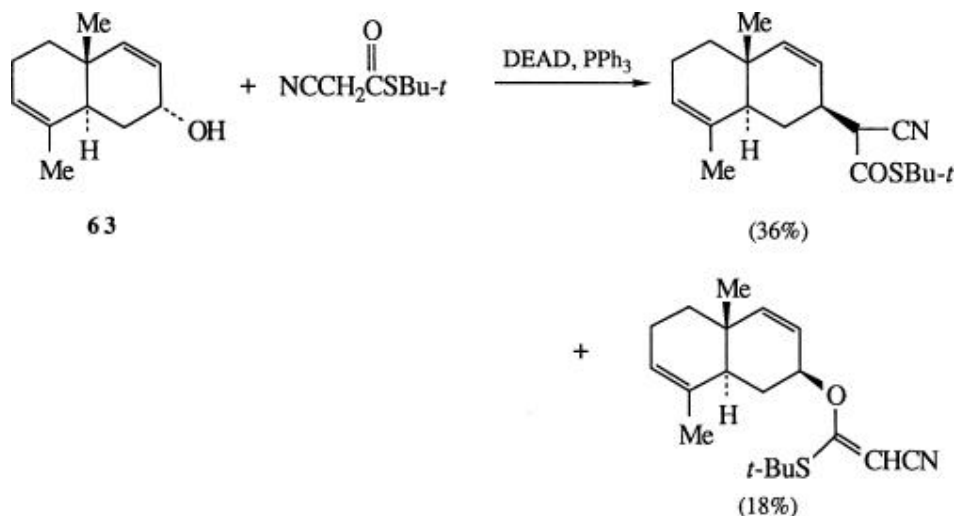


and **61** may be formed from the oxyphosphonium ion **62**. In the absence of an alcohol, **60** is formed in 68% yield. (265) Methyl acetoacetate undergoes

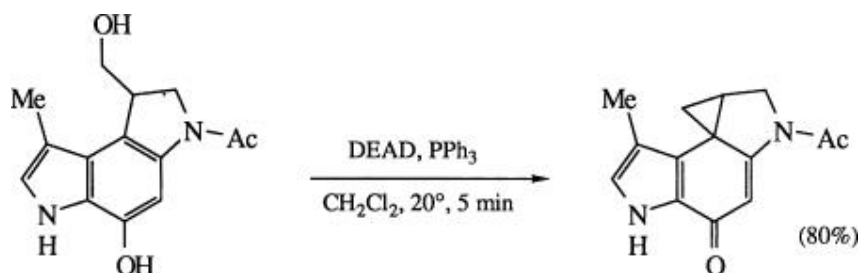


reaction with optically active 2-octanol at -30° giving an *O/C* alkylation ratio of 90/10 with 15% racemization. (267) Alkylation with 1-phenyl-1-ethanol gives a 55/45 *C/O* ratio with 5% racemization. (267) The *C/O* ratio is 40/60 with 1-(4-nitrophenyl)-1-ethanol with <10% racemization; the overall yield of alkylated products is 24%. (268, 269)

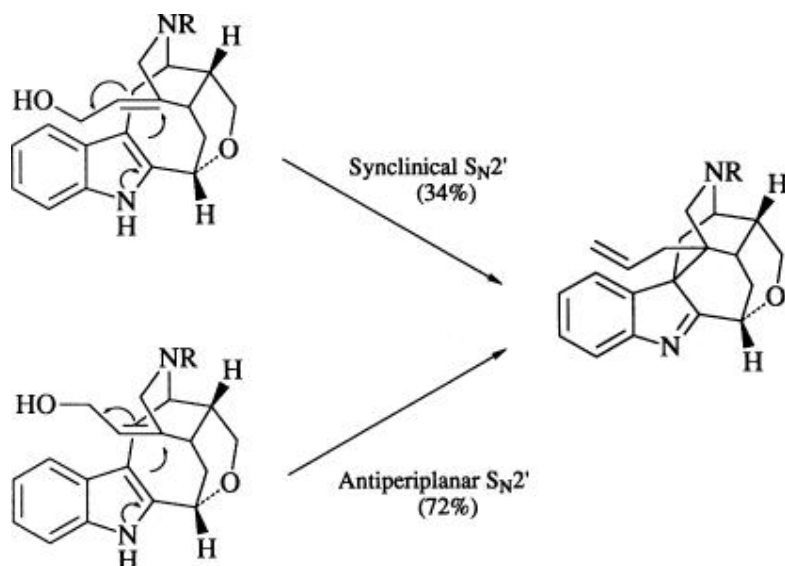
Alkylation of 1,3-cyclohexanedione with 2-propanol in the presence of DEAD/triphenylphosphine gives exclusively *O*-alkylation in 81% yield. (265) Alcohol **63** undergoes reaction with (*S*)-*tert*-butyl cyanothiolacetate to provide a 2:1 mixture of *C/O* products in overall 54% yield. (266) Intramolecular formation



of a fused cyclopropane ring via a Mitsunobu reaction is a key step in the syntheses of the antitumor antibiotic CC-1065 and related compounds. [270–273a](#)



Carbon–carbon bond formation at the 3 position of the tricyclic indole shown below can be accomplished via an intramolecular S_N2' reaction by treatment with DEAD/triphenylphosphine/ NaH in THF. The *Z* isomer reacts faster than the *E* isomer and gives a better yield (72% vs. 34%), which is probably due to the antiperiplanar relationship between the 2,3-indole double bond and the developing vinyl group. [273b](#)

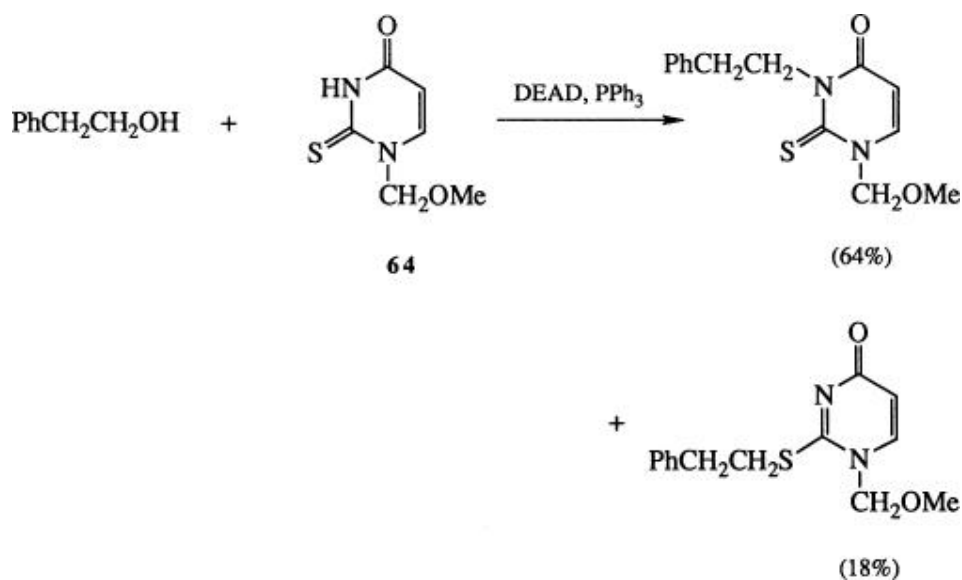


Nitriles are formed via reaction of alcohols with DEAD/triphenylphosphine and hydrogen cyanide. (245) Oleyl alcohol reacts with lithium cyanide/DEAD/triphenylphosphine to give the corresponding nitrile in 58% yield. (263)

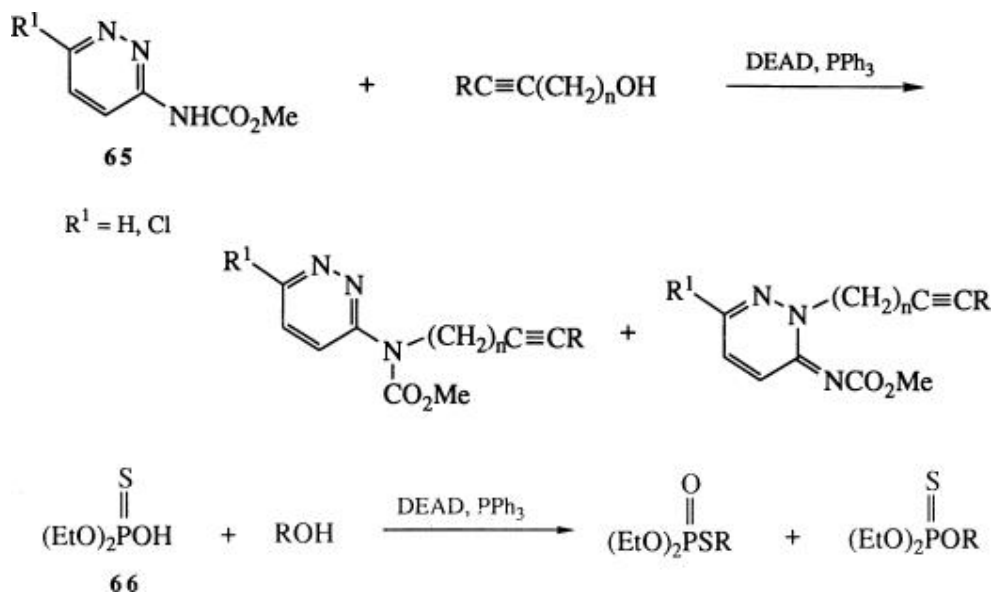
3.6. Ambident Nucleophiles

Ambident alkylations have been briefly discussed in previous sections, including *N*- vs. *O*-alkylation of hydroxamic acids, carboxamides, and nucleotide imides, and *C*- vs. *O*-alkylation of β -diketones and β -ketoesters. Further examples of ambident reactivity are described below.

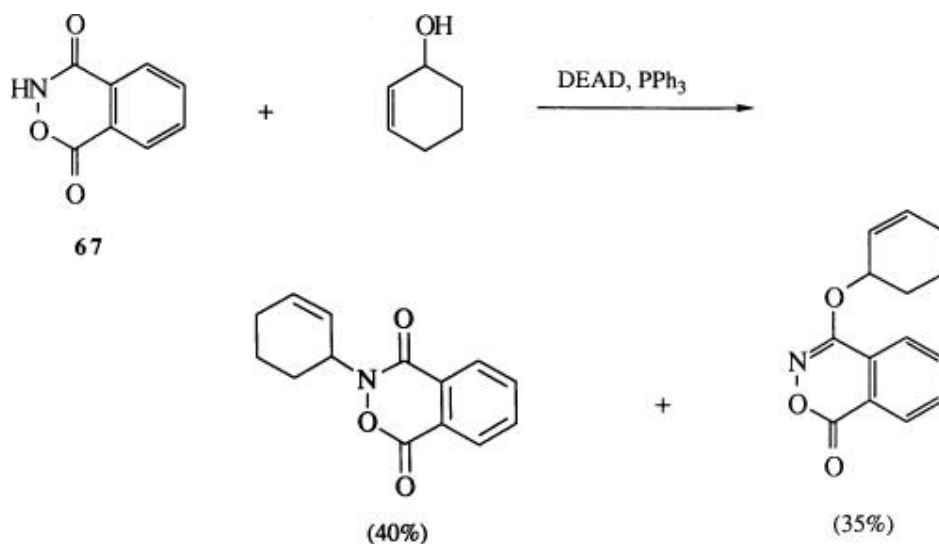
N-Alkylation predominates over *S*-alkylation in the reaction of thiouracil **64** with 2-phenylethanol. (250) Competitive *N*-alkylation of the diazenes **65** occurs



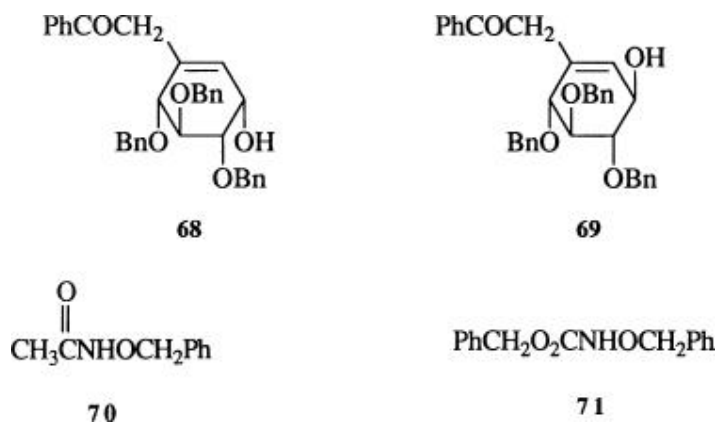
with product ratios ranging from 2:1 to 1:2 depending on the alcohol. (274) Both *O*- and *S*-alkylation occur in the Mitsunobu reaction of alcohols with phosphorothioic acid **66**. With primary alcohols the *S*-alkylated product is formed nearly exclusively, but with secondary alcohols nearly equal amounts of products are formed. (275) *N,O*-Phthaloylhydroxylamine (**67**) undergoes reaction with



2-cyclohexenol to give 40% *N*-alkylated product and 35% *O*-alkylated product. (89) Reaction of **68** with **67** gives 28% β *C*-*N* product and 33% β *C*-*O*

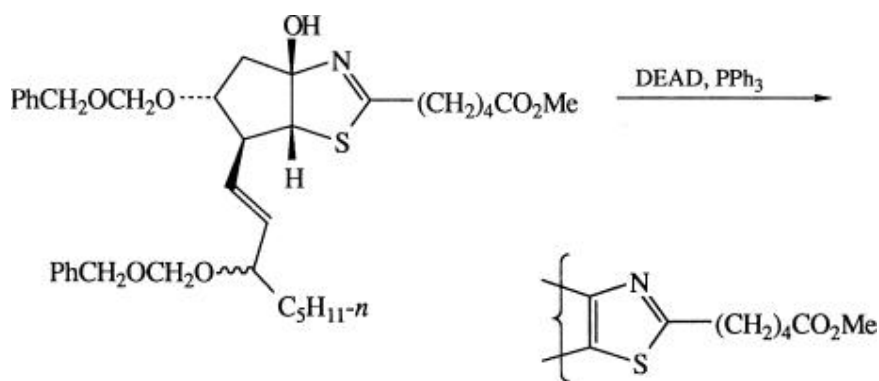


product. The anomer **69** undergoes reaction to give only α C–O product in 58% yield. (89) Hydroxamate **70** reacts with a primary alcohol almost exclusively on oxygen, while hydroxamate **71** reacts primarily on nitrogen. (276)



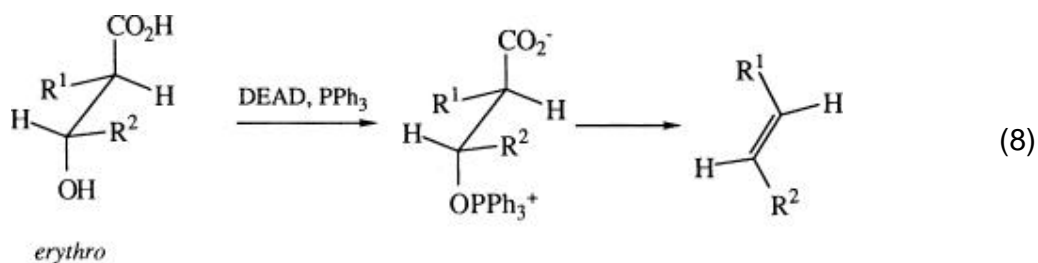
3.7. Dehydration to Form Alkenes

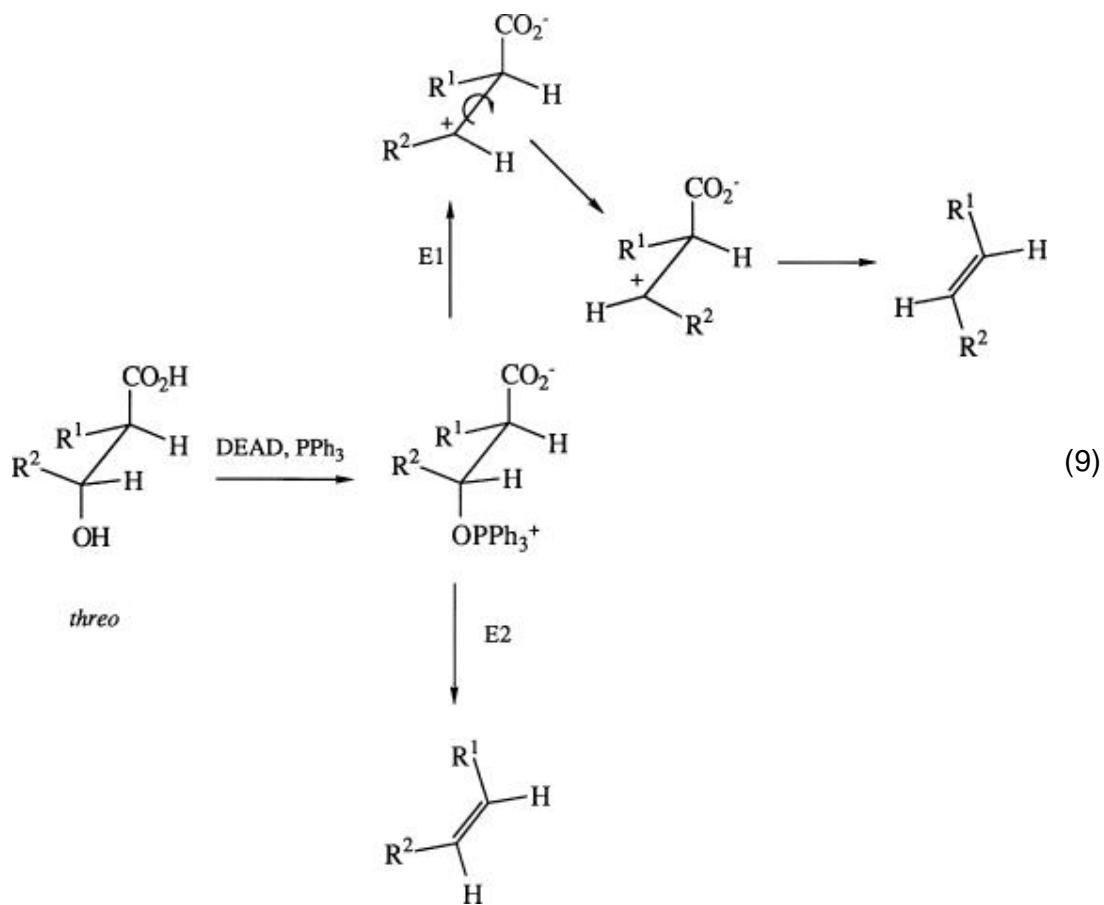
Addition of triphenylphosphine/DEAD to an alcohol in the absence of a nucleophile leads to formation of alkenes. (277-282) Alkenes can be major side



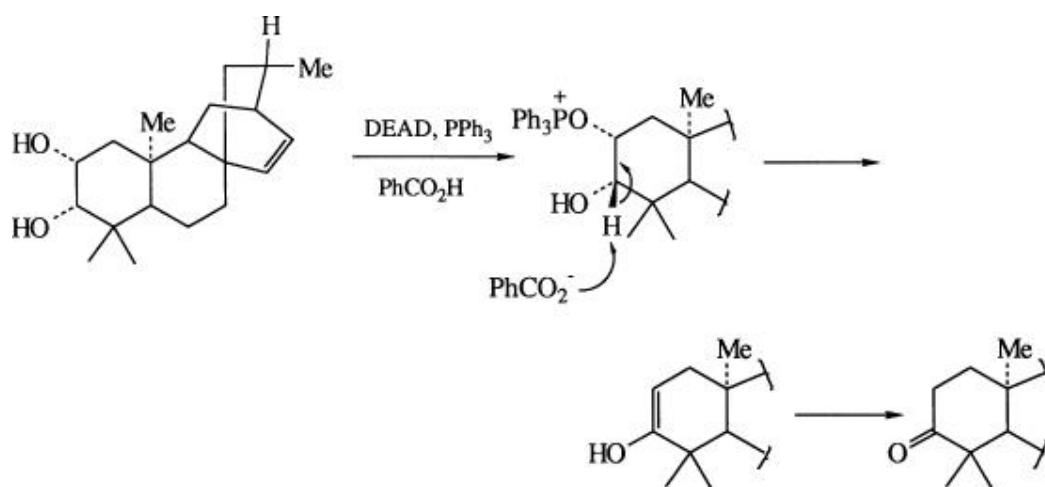
products in esterification reactions. Use of more acidic carboxylic acids (i.e., less basic carboxylic anions as nucleophiles) such as trifluoro- and dichloroacetic acids reduces the amount of elimination product. (7)

erythro-3-Hydroxycarboxylic acids undergo *anti* elimination to form *E* alkenes in 80–95% yields (Eq. 8). Under the same conditions, *threo*-3-hydroxycarboxylic acids form *Z* alkenes when R² is an alkyl group, but form *E* alkenes when R² is an electron-donating group such as 4-anisyl (Eq. 9). The latter is rationalized by invoking competitive E1 and E2 mechanisms, with



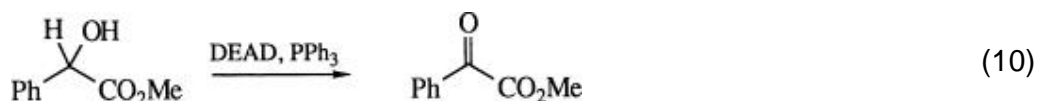


the E1 mechanism predominating when R² is electron donating. (283, 284)
 Hindered *cis*-1,2-diols eliminate to form enols which tautomerize to ketones. (285, 286)

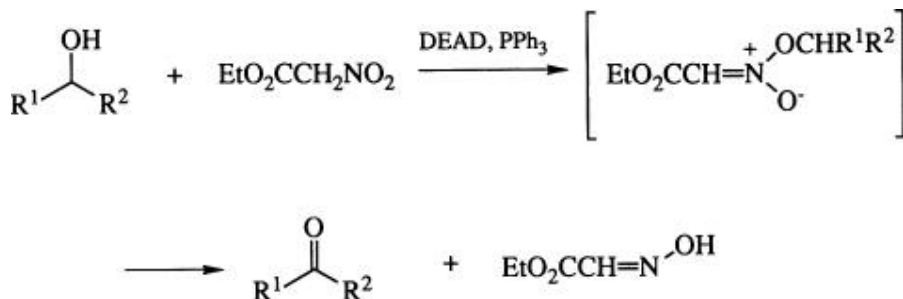


3.8. Other Reactions

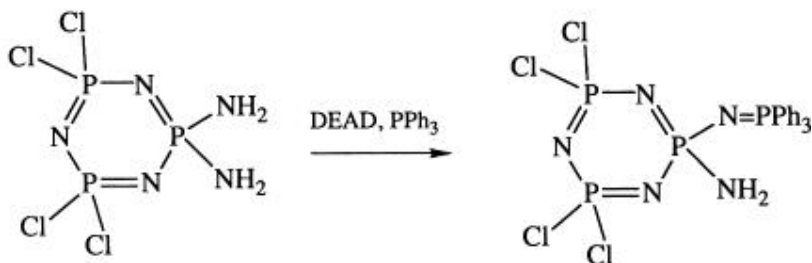
In isolated instances the outcome of the Mitsunobu reaction is alcohol oxidation rather than substitution. (228, 287, 288) With aromatic α -hydroxycarbonyl compounds, oxidation is the predominant reaction. (228) The highest yield of oxidation product occurs with a DEAD/triphenylphosphine ratio of 2:1 and with compounds of increasing α -H acidity (Eq. 10). Attempted condensation



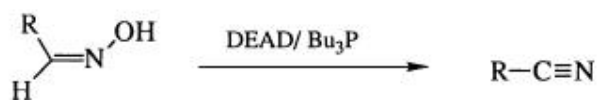
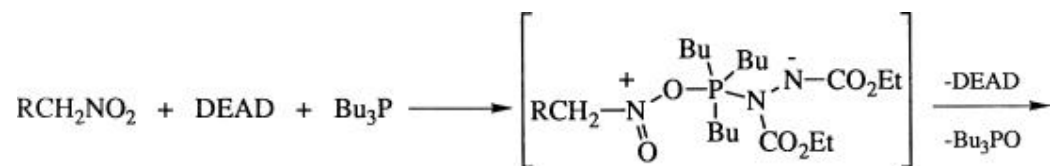
of ethyl nitroacetate with alcohols leads instead to oxidation of the alcohols to ketones or aldehydes, presumably arising from O-alkylation of the nitroacetate. (288)



Phosphazenes are prepared from reaction of DEAD/triphenylphosphine with carboxamides, sulfonamides, and phosphinamides. 289–292a



Treatment of primary nitro groups in dichloromethane with $\text{Sn}(\text{SPh})_4$, tributylphosphine, and DEAD affords the corresponding nitriles in a combined process of deoxygenation and dehydration. The same result can be obtained in a slower reaction using only tributylphosphine (2 equiv) and DEAD (1 equiv), the proposed mechanism of which is shown. [292b](#)



4. Comparison with Other Methods

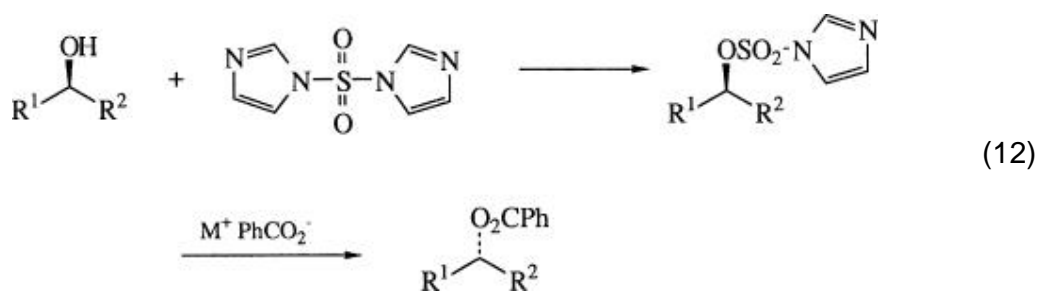
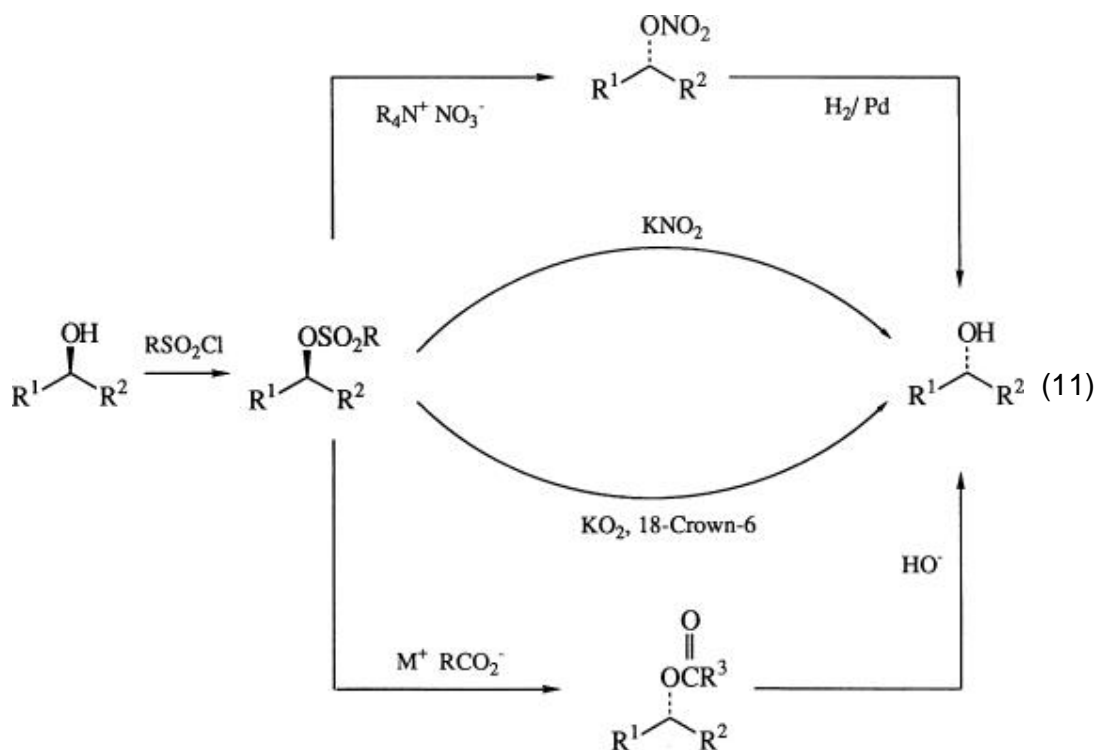
The manipulation of the alcohol functional group is a synthetic goal which has been approached by a wide variety of methods. Most of these methods rely on activation of the hydroxy group followed by displacement with an appropriate nucleophile. In the Mitsunobu reaction the alcohol activation is accomplished via an oxyphosphonium salt. In this section alternatives to the Mitsunobu reaction are discussed and compared in terms of yield, stereoselectivity, and ease of operation.

In general terms the advantages of the Mitsunobu method include the following: (1) generally good yields with high stereoselectivity (inversion); (2) experimental ease since the alcohol activation and displacement reactions take place in one pot, often at room temperature; (3) compatibility with a wide range of functional groups, as outlined in the Scope and Limitations section.

One of the major drawbacks of the Mitsunobu reaction is the difficulty of removing the redox byproducts triphenylphosphine oxide and di(ethoxycarbonyl)hydrazine. This becomes a major concern in large-scale applications where product purification by chromatography is not feasible.

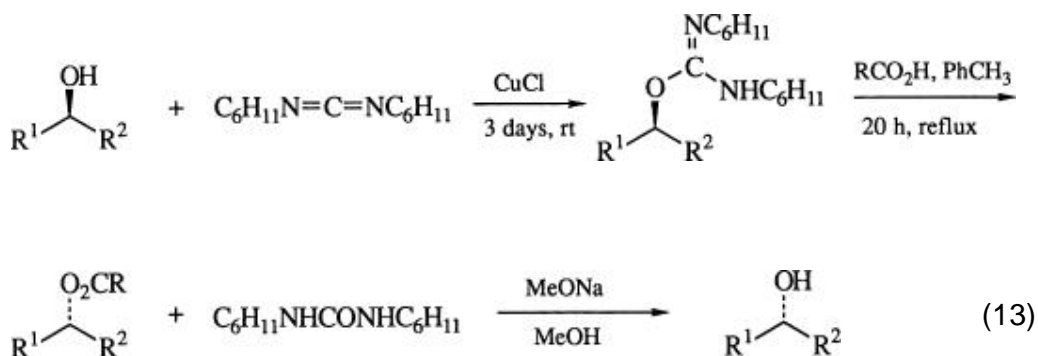
4.1. Inversion of Alcohols

Other than the Mitsunobu reaction, there are several methods for inverting alcohols. Four procedures involve formation of a sulfonate ester followed by: (1) displacement with a cesium, (293-297) potassium, (298, 299) or tetraalkylammonium carboxylate (300) followed by hydrolysis; (2) displacement with potassium superoxide; (301-303) (3) displacement with potassium nitrite; (304, 305) or (4) displacement with nitrate ion followed by reduction (306, 307) (Eq. 11). Similarly, imidazolyl sulfonates, prepared by reaction of the alcohol with *N,N'*-sulfuryldiimidazole, are displaced with inversion of configuration by benzoate (Eq. 12). (308-310) Some documented cases where the alternative methods give better results than the Mitsunobu reaction are described below. For inversion of the homoallylic alcohol (*R*)-ricinealaidic acid (72) the Mitsunobu reaction gives racemization, whereas mesylate formation, substitution with cesium propionate, and hydrolysis with lithium hydroxide give 51% inverted alcohol



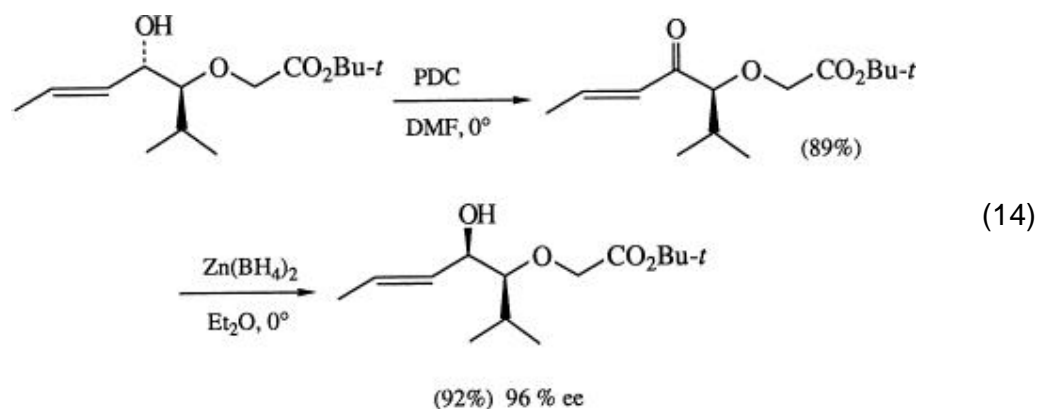
and 30% elimination product. (293) Mitsunobu reaction with **73** gives predominant formation of elimination product and cyclic ether, while mesylate formation followed by cesium acetate/18-crown-6 ether gives a 70% yield of inverted ester with only 5% elimination product. (295) Other examples include inversion of capnellene-8 α , 10 β -diol via the mesylate and potassium superoxide displacement, (303) inversion of 3 α -hydroxygibberellins using reaction of cesium acetate/18-crown-6 ether on the mesylate, (297) inversion

of a crinine precursor using mesylate formation followed by cesium acetate, (296) and inversion of a swainsonine precursor by making the trifluorosulfonate followed by reaction with potassium acetate/18-crown-6 ether. (299) Conversion of alcohols to isourea ethers followed by esterification and hydrolysis is a mild and simple Mitsunobu alternative (Eq. 13). (311) Overall yields range from 45 to

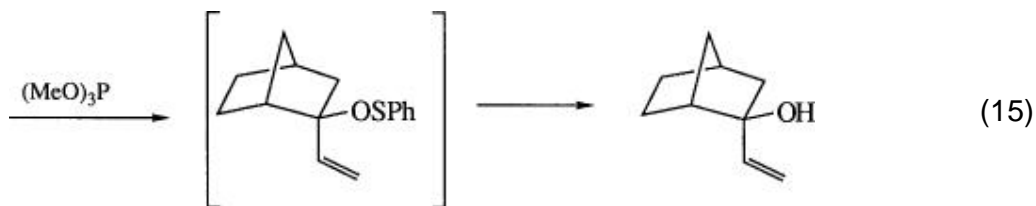


75%. The method is applicable to imide alkylations. (312) An attractive feature of this method is that the dicyclohexylurea byproduct is insoluble and easily removable by filtration.

When alcohol activation/displacement methods do not work, inversion by means of oxidation to a ketone and selective reduction is sometimes a viable alternative (Eq. 14). (313-316) Tertiary alcohols cannot be inverted using the

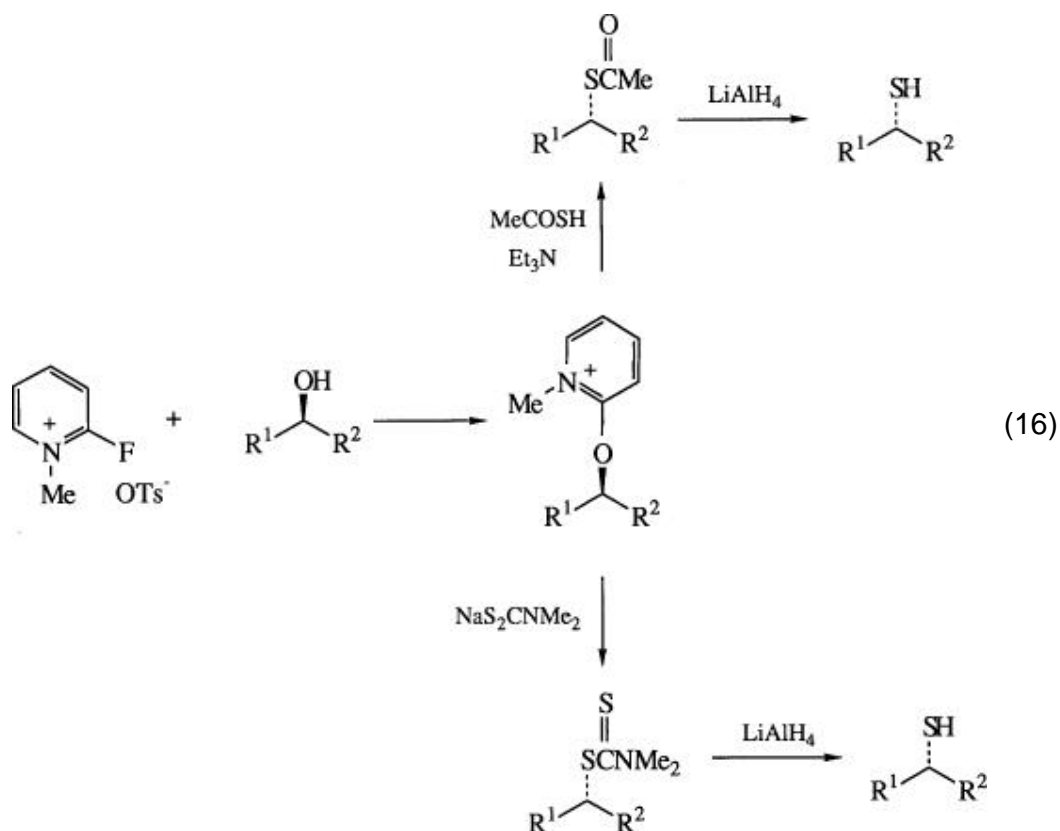


Mitsunobu method or other alcohol activation/displacement methods. As an alternative, tertiary vinyl alcohols are inverted by a [2,3] sulfoxide sigmatropic rearrangement (Eq. 15). (317, 318)



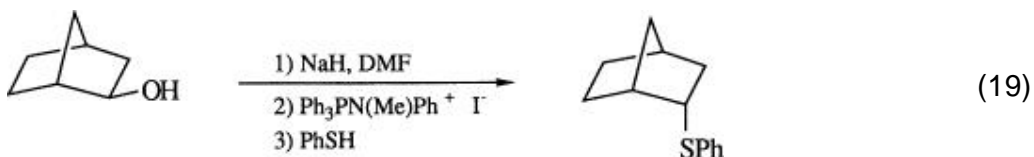
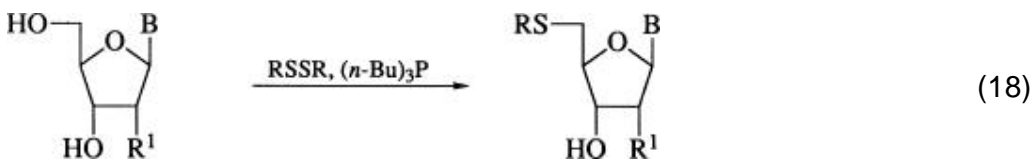
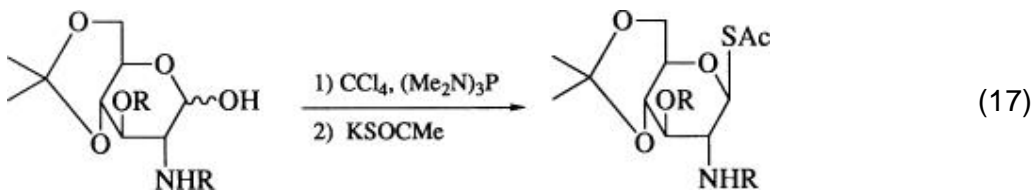
4.2. Carbon–Sulfur Bond Formation from Alcohols

Alternatives to the Mitsunobu reaction for preparing inverted thiols from alcohols include: (1) formation of a sulfonate ester, displacement with a cesium thiocarboxylate, followed by reduction or hydrolysis; (232) (2) formation of 2-alkoxypyridinium salts using 2-fluoro-1-methylpyridinium tosylate, displacement with thiolacetate (319) or sodium *N,N*-dimethylthiocarbamate, (320) and reduction (Eq. 16); (3) preparation of alkoxytris(dimethylamino)phosphonium hexafluorophosphate



salts followed by reaction with thiolate, thiocyanate, or thiolacetate (Eq. 17); (321-324) the byproducts are easy to remove since they are water soluble; (4) reaction of the alcohol with a disulfide and tri-*n*-butylphosphine (Eq. 18); (325) (5) reaction of the alcohol with tri-*n*-butylphosphine and an *N*-alkyl- or

N-aryltiosuccinimide; (326) clean inversion of configuration is demonstrated by formation of 3 α -(phenylthio)cholest-5-ene in 81% yield from cholesterol; and (6) activation of an alcohol using aminotriphenylphosphonium

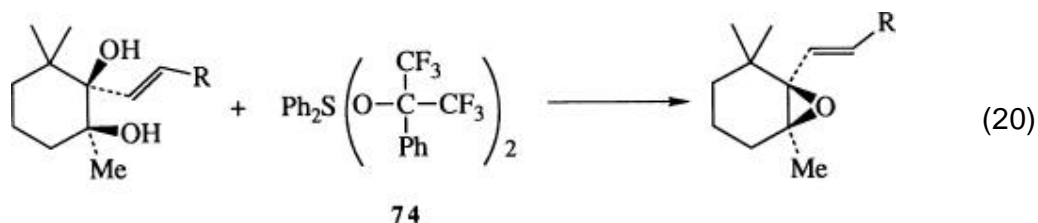


salts followed by displacement with a thiol (Eq. 19). (327) For carbon–sulfur bond formation from alcohols, the Mitsunobu reaction has found the most use in formation of inverted thioacetates which are usually hydrolyzed or reduced to free thiols. The Mitsunobu and mesylate/cesium carboxylate procedures gave similar yields and enantioselectivities in a side-by-side comparison. (232) In the preparation of phenylthio compounds from primary or secondary alcohols the procedures using tri-*n*-butylphosphine with diaryl disulfides or *N*-(aryltio)succinimide have found the widest use. (328)

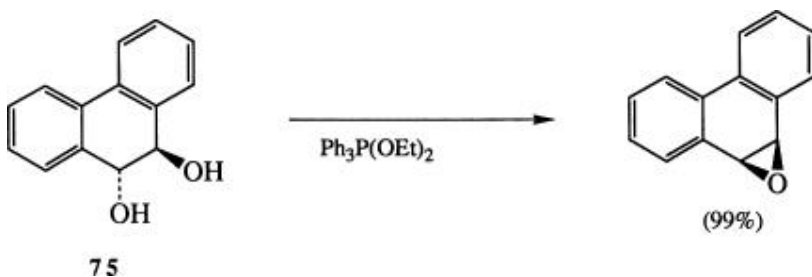
4.3. Carbon–Oxygen Bond Formation

As alternatives to the Mitsunobu reaction, cyclic ethers are prepared from diols by use of diethoxytriphenylphosphorane, (329, 330) pentaethoxyphosphorane, (330, 331) diaryldialkoxysulfuranes, (332, 333) and the reagent systems triphenylphosphine/carbon tetrachloride (334, 335) and tris(dimethylamino)phosphine/carbon tetrachloride. (336, 337) A comparative study of the cyclodehydration of chiral diols using triphenylphosphine/carbon tetrachloride/potassium carbonate, diethoxytriphenylphosphine, and triphenylphosphine/DEAD revealed that (*S*)-propane-1,2-diol and (*R*)-pentane-1,4-diol cyclize with retention of configuration while (*S*)-phenylethane-1,2-diol gives primarily racemic styrene oxide with all three reagent systems. (181)

Two noteworthy reactions are the following: The sulfurane **74** promotes the epoxidation of the highly hindered bis(tertiary) alcohol (Eq. 20). (333)
Diethoxytriphenylphosphine



converts the acidic and thermally sensitive diol **75** to the arene oxide in 99% yield, demonstrating the mildness of the reaction conditions. (329)



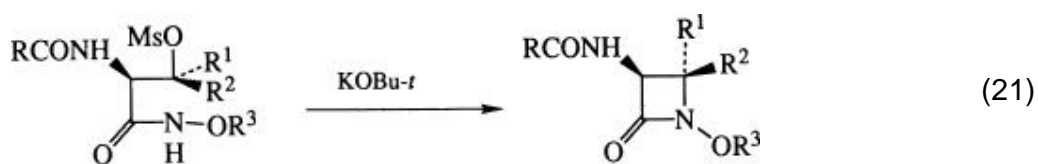
Aryl alkyl ethers are prepared from reaction of the alcohol with tris(dimethylamino) phosphine/carbon tetrachloride followed by reaction with phenols. (322)

4.4. Carbon–Nitrogen Bond Formation

Formation of azides from alcohols is accomplished using triphenylphosphine/carbon tetrachloride/lithium azide (338, 339) or tris(dimethylamino)phosphine/carbon tetrabromide/sodium azide. (321, 340) A comparison of reagents used in the preparation of 5'-azido-5'-deoxythymidine from thymidine indicates that triphenyl phosphine/carbon tetrabromide/lithium azide produces better yields (90%) than triphenyl phosphite/iodomethane/lithium azide (50% yield) or triphenylphosphine/DEAD/lithium azide (36–46% yields). (339)

Aziridines, azetidines, and pyrrolidines are prepared by action of triphenylphosphine dibromide (341–343) or triphenylphosphine/carbon tetrachloride/triethylamine (344, 345) on the appropriate aminoalkanols.

For large-scale preparation of β -lactams, cyclization of a β -mesylate is a viable alternative to the Mitsunobu cyclization since chromatographic separation of the redox byproducts is not required (Eq. 21). (346, 347)

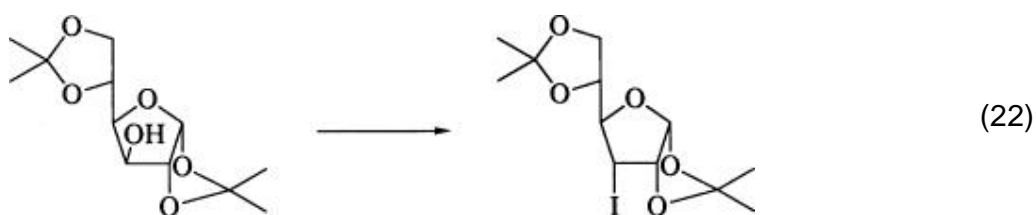


4.5. Formation of Carbon–Halogen Bonds

Other than the Mitsunobu reaction, alcohols are converted to halides by several methods. Many of these methods involve mechanisms similar to the Mitsunobu reaction in that an oxyphosphonium salt formed from the alcohol is then converted to the halide by an S_N2 displacement. These methods include the reagents triphenyl phosphite/iodomethane, triphenylphosphine/halogen adducts, triphenylphosphine/carbon tetrahalide, triphenylphosphine/2,4,5-triiodoimidazole, triphenylphosphine/*N*-halosuccinimide, and tris(dimethylamino) phosphine/carbon tetrachloride. A comprehensive review of these reagents was published in 1983. [6a](#)

Activation of the alcohol is also accomplished by formation of imidazolyl sulfonate, (308-310) trifluoromethanesulfonates, 348–349 imino esters, (350) chlorosulfates, (351) 2-alkoxybenzoxazolium salts, (352) and 2-alkoxybenzothiazolium salts, (353) followed by S_N2 displacement with halide.

Diacetone-D-glucose, having a hindered secondary hydroxy group, serves as a good example to compare the various reagents. The inverted iodide (Eq. 22) is prepared in moderate to good yields by nearly all the reagents, as shown



in Table A. By contrast, none of the methods give the inverted chlorides or bromides in a appreciable yields. With the phosphonium reagents, rearrangement of the 5,6-isopropylidene groups or elimination are the major reaction pathways.

Table A. Conversion of Diacetone-D-Glucose to the Inverted Halides (Eq. 22)

Reagent	Yield (%)	Refs
<i>Iodide</i>		
PPh ₃ /MeI	—	354
DEAD/PPh ₃ /MeI	70	10
PPh ₃ /imidazole/ I ₂	60	355
PPh ₃ /triiodoimidazole/ I ₂	78	355
CIPPh ₂ /imidazole/ I ₂	67	356
(4-Me ₂ NC ₆ H ₄)PPh ₂ /imidazole/I ₂	62	356
Polymeric PPh ₃ /imidazole/ I ₂	45	356
(TfO) ₂ O/ <i>n</i> -Bu ₄ NI	87	348
<i>N,N'</i> /Sulfuryldiimidazole	71	308
(Me ₂ N) ₂ PCI/MeI	62	357
<i>Bromide</i>		
PPh ₃ /tribromoimidazole/imidazole	30	358
DEAD/PPh ₃ /PhCH ₂ Br	7 ^a	10
(TfO) ₂ O/ <i>n</i> -Bu ₄ NBr	42 ^b	349
PPh ₃ / Br ₂	0 ^a	359
PPh ₃ / <i>N</i> -bromosuccinimide	0 ^a	360
<i>Chloride</i>		
DEAD/PPh ₃ /PhCH ₂ Cl	5 ^a	10
PPh ₃ / CCl ₄	0 ^b	361
(Chloromethylene)dimethyliminium chloride	0	350
(TfO) ₂ O/ <i>n</i> -Bu ₄ NCl	22 ^b	349

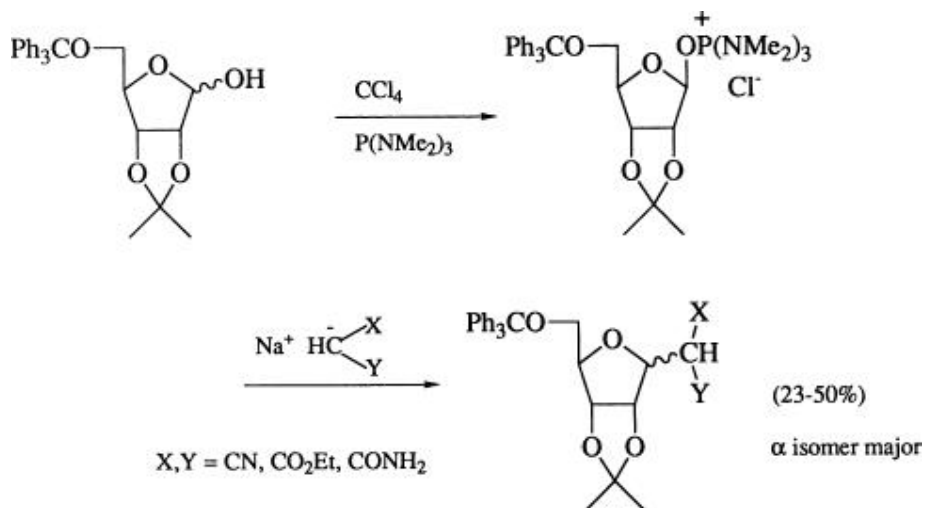
^aThe major reaction is rearrangement to 6-halide.

^bThe major side reaction is elimination.

4.6. Carbon–Carbon Bond Formation

C-Glycosides are synthesized by reaction of malonate anions with sugar hydroxy groups that have been activated as alkoxytris (dimethylamino)

phosphonium salts. (362) Alcohols are converted to nitriles using tris(dimethylamino)phosphine



/carbon tetrachloride/potassium cyanide (321, 363) or triphenylphosphine/carbon tetrachloride/potassium cyanide. (364, 365)

Alcohols activated as 1-ethyl-2-alkoxy-pyridinium salts react with Grignard reagents to form carbon-carbon bonds. (366)

5. Experimental Considerations

Although optimal conditions for the Mitsunobu reaction depend on the substrate alcohol and the nucleophile, a few generalities are outlined below.

5.1.1.1.1. Solvent

The majority of Mitsunobu reactions are carried out in tetrahydrofuran solution. However, several other solvents have been used with good results, including dioxane, (62, 178, 367) dichloromethane, (368-370) chloroform, 175–176 diethyl ether, (52, 54, 86, 96, 99, 371-373) dimethylformamide, (139, 176, 177, 374) toluene, (34, 35, 375, 376) benzene, (48, 49, 53, 90, 106, 111, 123, 128, 377-383) and hexamethylphosphoramide. (138, 384) The dipolar aprotic solvents have found use with carbohydrates that are insoluble in the typical nonpolar solvents.

5.1.1.1.2. Phosphine

Triphenylphosphine has been used in more than 90% of the reported Mitsunobu reactions. Tri-*n*-butylphosphine, (215, 248, 385, 386) substituted triarylphosphines, (7) tris(dimethylamino)phosphine, (215) trialkyl phosphites, (170, 180, 215, 219) triphenyl phosphite, (216) phenoxydiphenylphosphine, (216) and diphenoxyphenylphosphine (216) have found limited use. Use of diphenyl(2-pyridyl)phosphine (387) and (4-dimethylamino)diphenylphosphine (197) facilitate product isolation since the resulting phosphine oxide is removed by aqueous acid washing. Use of polymeric triphenylphosphine eliminates the problem of phosphine oxide removal from the product. 388a

5.1.1.1.3. Azodicarboxylate

Diethyl and diisopropyl azodicarboxylates are used in most Mitsunobu applications and generally can be used interchangeably. Dimethyl azodicarboxylate is used less often, but has the advantage that the byproduct hydrazine can be removed by aqueous extraction. (170) Polymer-supported alkyl azodicarboxylates can be used, and have the advantages of facilitating product purification and of being reusable. 388b Oxidants other than azodicarboxylates successfully employed in Mitsunobu reactions include 4-methyl-1,2,4-triazolidine-3,5-dione (58), (264) dibenzoyl peroxide, (133) dimethyl ketomalonate, (389) and 3-methylbenzothiazole-2-selone. (390)

5.1.1.1.4. Nucleophile

For inversions, typical carboxylic acid nucleophiles include benzoic acid, acetic acid, formic acid, 4-nitrobenzoic acid, and 3,5-dinitrobenzoic acid. The latter two are often used since the corresponding esters are generally crystalline compounds which can be readily purified. For compounds with acidic or basic labile functionalities such as β -lactams, formic acid or phenoxyacetic acid (28) are used since the corresponding esters are readily hydrolyzed. Mosher esters

are prepared using α -methoxy- α -(trifluoromethyl)phenylacetic acid. (126, 127, 391, 392)

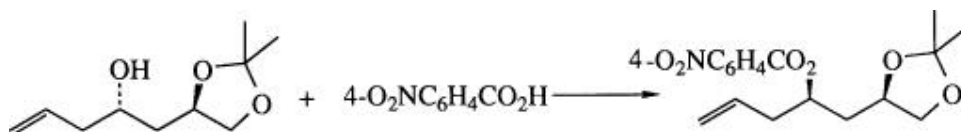
5.1.1.1.5. Temperature

Most Mitsunobu reactions are carried out between 0° and room temperature. More hindered secondary alcohols, such as those found in carbohydrates, often require temperatures of 70–100°. An initial temperature of –50° gives increased selectivity in the esterification of an anomeric center in carbohydrates. (50)

5.1.1.1.6. Order of Addition of Reagents

Typically, triphenylphosphine, the alcohol, and the nucleophile are dissolved in the solvent and DEAD is added dropwise to the solution. (5) Alternatively, DEAD and triphenylphosphine are reacted first to form the DEAD-triphenylphosphine adduct, followed by addition of the alcohol and the nucleophile. (50, 231) Since DEAD is a strong oxidant, Michael acceptor, and dienophile, it is important that no excess DEAD be present in the reaction. This is accomplished either by preforming the DEAD–triphenylphosphine adduct or by adding DEAD slowly to the reaction mixture so that the DEAD–triphenylphosphine adduct forms while keeping the DEAD concentration low. In tetrahydrofuran and dichloromethane solution, formation of the DEAD–triphenylphosphine adduct is fast, completing within minutes at –20°. (7)

6. Experimental Procedures

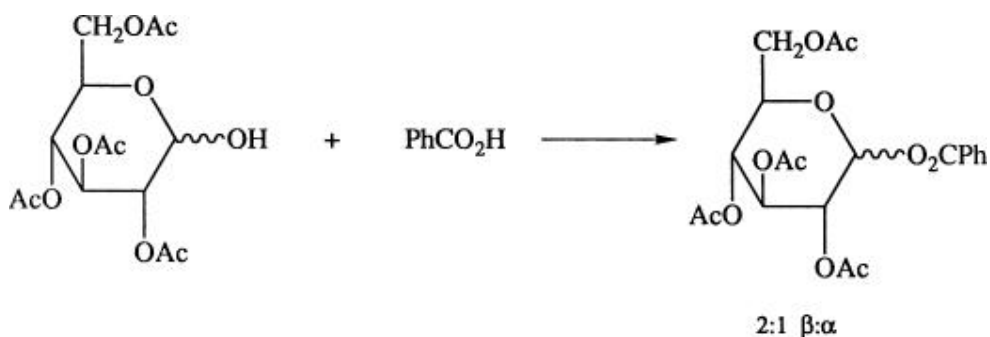


6.1.1.1. (4S)-2,2-Dimethyl-4-[(2R)-2-(4-nitrobenzoyloxy)pent-4-enyl]-1,3-dioxolane (Esterification with Inversion) (34)

To a stirred suspension of triphenylphosphine (5.41 g, 0.0206 mol) and 4-nitrobenzoic acid (3.45 g, 0.0206 mol) in toluene (60 mL) cooled to -30° was added a solution of (4S)-2,2-dimethyl-4-[(2S)-pent-4-enyl-2-ol]-1,3-dioxolane (3.2 g, 0.0172 mol) in toluene (10 mL). A solution of diethyl azodicarboxylate (3.3 mL, 0.0206 mol) in toluene (30 mL) was added dropwise over 15 minutes to the vigorously stirred mixture while the temperature was maintained at -30° . When the addition was complete the mixture was allowed to warm gradually to 0° over 1 hour whereupon saturated aqueous sodium bicarbonate (75 mL) was added. The aqueous phase was separated and extracted with ether (2×75 mL). The organic extracts were combined, dried, and concentrated. To the residue was added ether (25 mL) and hexane (75 mL) whereupon the bulk of the triphenylphosphine oxide was filtered off. Concentration of the residue gave a viscous oil which was purified by chromatography (ether–hexane 1:4) to give the 4-nitrobenzoate ester (5.23 g, 90%) as colorless needles from cold

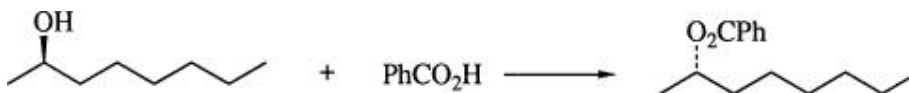
hexane, mp $28-30^{\circ}$; $[\alpha]_D^{21} = -44.8^{\circ}$ (c 2.5, CHCl₃); ν_{\max} (CHCl₃) 1725, 1608,

1530, 1352, 1275, 920, 874, 840 cm^{-1} ; $^1\text{H NMR}$ δ 8.1–8.4 (4H, m), 5.5–6.1 (1H, m), 5.35 (1H, m), 5.18 (1H, m), 5.05 (1H, m), 3.9–4.35 (1H, m), 4.0 (1H, dd, $J = 6, 6$ Hz), 3.55 (1H, dd, $J = 5, 7.7$ Hz), 2.05 (2H, m), and 1.32 and 1.38 (3H each, s); Anal. Calcd. for C₁₇H₂₁O₆N: C, 60.88; H, 6.31; N, 4.17. Found: C, 60; 75; H, 6.35; N, 4.2



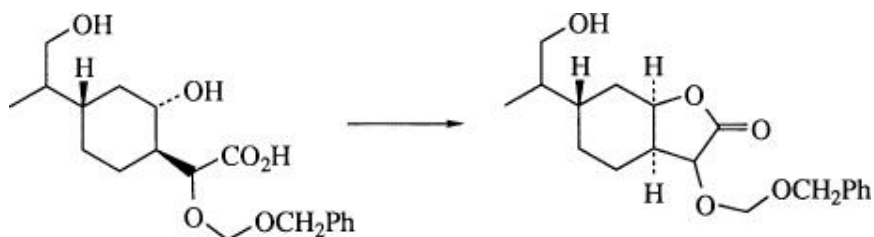
6.1.1.2. 2,3,4,6-Tetra-O-acetyl-1-O-benzoyl-D-glucose (Selective Esterification of an Anomeric Center) [50](#)

To a solution of triphenylphosphine (0.98 g, 3.7 mmol) in dry tetrahydrofuran (6 mL) at -50° , under an argon atmosphere, was added DIAD (0.74 mL, 3.7 mmol). The mixture was stirred at this temperature for 10 minutes, whereupon a thick yellow precipitate formed. The hemiacetal 2,3,4,6-tetra-O-acetyl-D-glucose (1.0 g, 2.9 mmol) was added and the stirring continued at -50° for a further 10 minutes before benzoic acid (0.46 g, 3.8 mmol) was added. The mixture was allowed to warm slowly to room temperature over a period of 2 hours, the solvent removed in vacuo, and the residue purified by flash chromatography (ethyl acetate/hexane 1:4) to furnish the title compound (1.04 g, 80%) as a 2:1 mixture of anomers. Crystallization from ether gave the pure β -anomer (mp $143\text{--}144^{\circ}$); $[\alpha]_{\text{D}} - 27.6^{\circ}$ (c 1.0, CHCl_3).



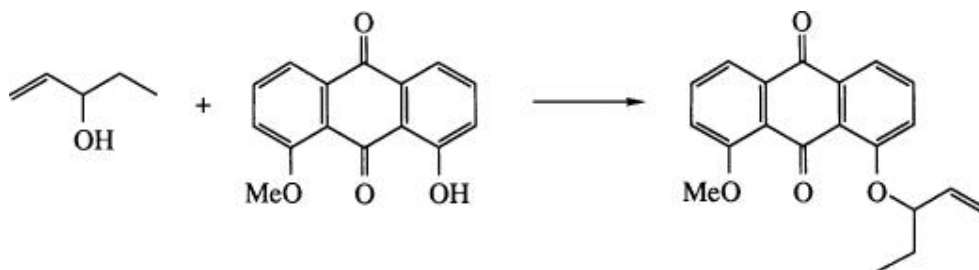
6.1.1.3. 2-(+)-Benzoyloxyoctane (Esterification using Polymer-Supported Triphenylphosphine) [388a](#)

Benzoic acid (3.05 g, 2.5 mmol) and polymer-supported triphenylphosphine (1.5 g, 4.4 mmol contained P) were weighed into an oven-dried 50-mL flask. Dry tetrahydrofuran (10 mL) was then added under a nitrogen atmosphere, followed by 2-(-)-octanol (3.25 g, 2.5 mmol) diluted with tetrahydrofuran (5 mL). The flask was cooled on a 25° water bath while DEAD (6.09 g, 3.5 mmol) was added by syringe over 2–3 minutes. The polymer darkened in appearance, but little yellow color from the DEAD reagent remained in solution. TLC indicated complete reaction within 10 minutes. The mixture was stirred 4 hours at ambient temperature and then filtered. The polymer was thoroughly washed with ether. Evaporation of the solvent afforded an oily white solid containing the ester and the *sym*-dicarbethoxyhydrazine. The mixture was transferred to and eluted from a shortpath silica column using 5–10% ether in hexane (the majority of the hydrazine product is insoluble in this solvent). Removal of solvent after chromatography gave the title compound in 65% yield.



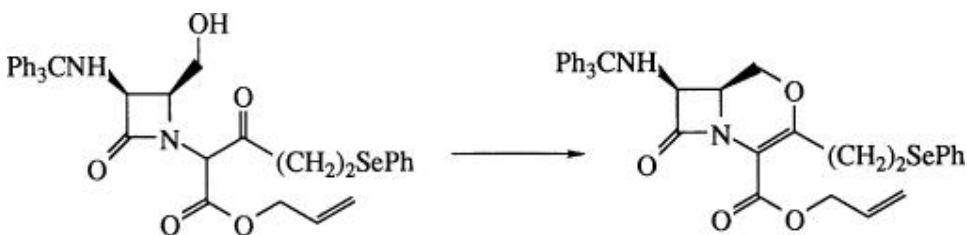
6.1.1.4. (3*a*S,6*S*,7*a*R)-3-[Benzyloxy]methoxy]hexahydro-6-(2-hydroxy-1-methylethyl)-2(3*H*)-benzofuranone (Lactonization of a Secondary Alcohol in the Presence of a Primary Alcohol) (150)

A magnetically stirred solution of tetrahydrofuran (310 mL) and triphenylphosphine (5.2 g, 19.8 mmol) at -20° under nitrogen was treated with diethyl azodicarboxylate (2.3 mL, 14.8 mmol) in tetrahydrofuran (10 mL). After 30 minutes at -20° , diastereomeric diols (1*S*,2*S*,4*S*)-7-[(benzyloxy)methoxy]-2,9-dihydroxy-*p*-menthane-7-carboxylic acid (2.6 g, 7.39 mmol) in tetrahydrofuran (50 mL) were added via syringe pump over 4.5 hours while carefully maintaining the reaction temperature at -20° . The reaction mixture was quenched at -20° with saturated aqueous sodium chloride (100 mL) and 30% hydrogen peroxide. After dilution with ether (500 mL) the layers were separated and the aqueous layer was extracted with additional ether (3 \times 200 mL). The combined organic layers were dried with magnesium sulfate and filtered, and the solvents were removed in vacuo. Flash chromatography (70/30 ethyl acetate/hexanes) afforded a mixture of epimeric lactones contaminated with diethyl hydrazodicarboxylate. Analytical samples were obtained by medium pressure liquid chromatography (75/25 ethyl acetate/hexanes) α -isomer: white crystals, mp 83–84 $^{\circ}$; IR (thin crystalline film) 3500, 2900, 1780, 1500, 1450, 1380, 1340, 1275, 1200, 1160, 1060, 1025, 960, 900, 855, 740, 695 cm^{-1} ; ^1H NMR (CDCl_3) δ 7.30 (s, 5H), 4.85 (AB_q, $J_{\text{AB}} = 8.0$ Hz, 2H), 4.85 (br m, 1H), 4.6 (s, 2H), 3.90 (br s, 1H), 3.55 (m, 2H), 2.20 (br d, 2H), 1.90–1.00 (m, 7H), 0.95 (d, $J = 6.6$ Hz, 3H); MS, m/e 335 (M + H, isobutane).



6.1.1.5. 1-Methoxy-8-O-(1-penten-3-yl)anthraquinone (Preparation of an Alkyl Aryl Ether) (393)

To a stirred solution of 1-hydroxy-8-methoxyanthraquinone (20 g, 78.7 mmol), triphenylphosphine (26 g, 95.9 mmol), and 1-penten-3-ol (12 mL, 10.1 g, 0.117 mol) in dry tetrahydrofuran (300 mL) at 0° was added dropwise from an addition funnel diethyl azodicarboxylate (20 mL, 20.12 g, 0.127 mol) dissolved in dry tetrahydrofuran (50 mL). After addition, the mixture was stirred at room temperature for 1 hour. Tetrahydrofuran was removed under reduced pressure to give a dark red syrup which was filtered through neutral alumina with dichloromethane and then chromatographed on silica gel (3:1 hexane/ethyl acetate) to provide the yellow ether (22.1 g, 87%); mp 97–98.5°; ¹H NMR (CDCl₃) δ 1.10 (t, 3H, J = 7.4 Hz), 1.98 (m, 2H), 4.01 (s, 3H), 4.68 (m, 1H), 7.28 (m, 2H), 7.59 (m, 2H), 7.81 (m, 2H). High resolution mass spectrum: Calcd. for C₂₀H₁₈O₄: 322.1204. Found: 322.1201.



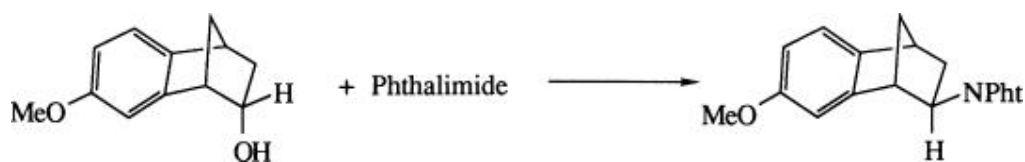
6.1.1.6. Allyl(6S,7S)-8-Oxo-3-[2-(phenylseleno)ethyl]-7-(tritylamino)-1-aza-4-oxa-bicyclo[4.2.0]oct-2-ene-2-carboxylate (Formation of a Cyclic Enol Ether) (394)

To a solution of allyl 2-[(3S,4S)-4-hydroxymethyl-2-oxo-3-tritylamino-1-azetidiny]-3-oxo-5-phenylselenopentanoate (6.49 g, 9.73 mmol) and triphenylphosphine (2.68 g, 1.05 equiv) in dry tetrahydrofuran (270 mL) under argon was added diisopropyl azodicarboxylate (2.07 mL, 1.05 equiv). After 15 minutes the solvent was removed, and the residual oil was chromatographed to afford the O-2-isocephem (5.30 g, 73%) as white crystals (from ethyl acetate/hexane): mp 128–129°; IR (KBr) 1770, 1710, 1610 cm⁻¹; ¹H NMR (CDCl₃) δ 2.71–3.35 (m, 8H), 4.56–4.97 (m, 3H), 5.20–5.42 (m, 2H), 5.83–6.00 (m, 1H), 7.19–7.49 (m, 20H).



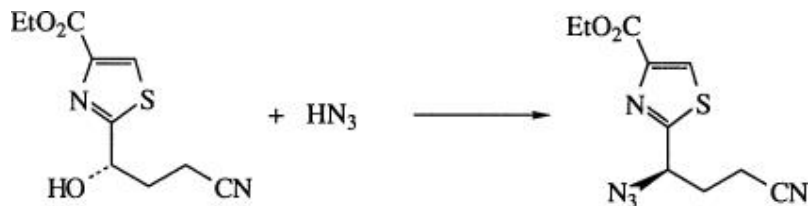
6.1.1.7. Methyl 4-Acetamido-2,3-anhydro-4,6-dideoxy- α -D-allopyranoside (Formation of an Epoxide) (175)

Triphenylphosphine (2.0 g) was added to a solution of methyl 4-acetamido-4,6-dideoxy- α -D-glucopyranoside (630 mg, 2.9 mmol) in ethanol-free chloroform (50 mL). After stirring 15 minutes, diethyl azodicarboxylate (1.3 g) was added dropwise. The mixture was stirred 4 hours at room temperature and then allowed to stand overnight. The solvent was removed and the residue subjected to column chromatography on silica gel (60 g). Balast compounds were eluted with benzene–ethanol (100:2); product was isolated in 99% yield (570 mg); mp 185–186° (from ethyl acetate); $[\alpha]_D^{25} + 205^\circ$ (CHCl₃). ¹H NMR (CDCl₃) δ 1.15 (3H, d, $J_{56} = 6.1$ Hz, H-6), 2.00 (3H, s, MeCON), 3.35 (dd, $J_{23} = 4.0$ Hz, H-3), 3.40 (3H, s, MeO), 3.50 (dd, $J_{12} = 3.2$ Hz, H-2), 3.59 (dq, $J_{45} = 9.5$ Hz, H-5), 4.15 (dt, $J_{34} = 1.8$ Hz, H-4), 4.86 (d, H-1), 6.24 (d, $J_{4-NH} = 9.0$ Hz, NH).



6.1.1.8. *exo*-2-Phthalimido-7-methoxybenzonorbornene (Phthalimide as a Nucleophile) (205)

A solution of *endo*-2-hydroxy-7-methoxybenzonorbornene (600 mg, 3.15 mmol), phthalimide (640 mg, 4.3 mmol), and triphenylphosphine (1.1 g, 4.2 mmol) in tetrahydrofuran (25 mL) was treated with diethyl azodicarboxylate (0.65 mL, 4.12 mmol). The reaction was stirred at room temperature under argon for 72 hours. Brine (30 mL) was added and the layers separated. The aqueous layer was washed with ether (4 \times 20 mL). The combined organic pool was dried over sodium sulfate, filtered, and evaporated in vacuo to give 2.55 g of a viscous oil, which was purified by flash chromatography with dichloromethane as the eluant to give 850 mg (84%) of product as a white solid: mp 133–134°; ¹H NMR (CDCl₃) δ 7.85–7.55 (m, 4H, phthalimide ArH), 7.08 (d, 1H, $J = 8.0$ Hz, H-5), 6.88 (d, 1H, $J = 2.3$ Hz, H-8), 6.66 (dd, 1H, $J = 8.0$ and 2.3 Hz, H-6), 4.33–3.97 (m, 1H, CHN), 3.77 (s, 3H, OMe), 3.55–3.40 (m, 2H, bridgeheads), 2.88–2.45 (m, 2H, methylene), 2.10–1.45 (m, 2H, methylene); IR (KBr) 2970, 1709, 1612, 1478, 1466, 1370, 1354, 1331, 1289, 1246, 1233, 1128, 1089, 1030, 719, 662 cm⁻¹; EIMS, m/e (rel. intensity) 319 (3.8, M⁺), 146 (100), 131 (20.4), 115, (7.0), 103 (16.5), 77 (8.6).



6.1.1.9. 4-Ethoxycarbonyl-2-(3'-cyano-1'-(R)-azidoprop-1'-yl)thiazole
(Formation of an Azide) (395)

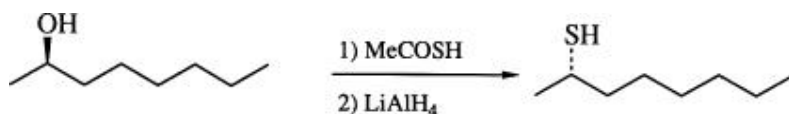
To a stirred solution of 4-ethoxycarbonyl-2-(3'-cyano-1'-(S)-hydroxyprop-1'-yl)thiazole (13.2 g, 55 mmol) and triphenylphosphine (15.9 g, 60.5 mmol) in toluene (225 mL) at room temperature were successively added a solution of hydrazoic acid in absolute toluene (110 mL, 60.5 mmol) and diethyl azodicarboxylate (10.5 g, 60.5 mmol) in absolute toluene (110 mL). The reaction was stirred at room temperature overnight and the solvent was removed in vacuo. The residue was treated with ethyl acetate/petroleum ether (1:1) to remove triphenylphosphine oxide. The filtrate was evaporated and the residue was first filtered on silica gel (ethyl acetate/petroleum ether, 1:1) followed by basic aluminum oxide (ethyl acetate/petroleum ether, 3:7) to give the product azide (13.1 g, 90%); mp 49–50°; $R_f = 0.57$ (ethyl acetate); $[\alpha]_D^{20} + 64.1^\circ$ (c 1.2, CH₂Cl₂); ee > 98%; ¹H NMR (CDCl₃) δ 1.43 (t, 3H, $J = 7$ Hz), 2.10–2.87 (m, 4H), 4.48 (q, 2H, $J = 7$ Hz), 5.15 (m, 1H), 8.35 (s, 1H); Anal. Calcd: for C₁₀H₁₁N₅O₂S : C, 45.27; H, 4.18; N, 26.40; S, 12.09. Found: C, 45.34; H, 4.24, N, 26.25; S, 11.90.



6.1.1.10. [(4S)-(Benzyloxycarbonyl)]-N-benzyloxy-2-azetidione (Formation of a β-Lactam) (396)

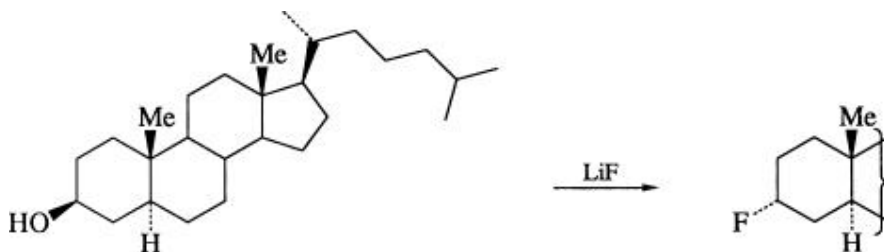
The monobenzyl hydroxamate of D-malic acid (2.64 g, 8.02 mmol) was dissolved in dry tetrahydrofuran (50 mL). Triphenylphosphine (2.0 g, 8 mmol) was added, followed by diethyl azodicarboxylate (1.26 mL). The solution was stirred at room temperature under a drying tube for 11 hours. The solution was then concentrated to 10 mL and chromatographed on a medium-pressure

apparatus with ethyl acetate-hexanes (1:4 then 1:1) on silica gel. Evaporation of the rich cut gave the product as an oil (2.4 g, 96%); $[\alpha]_{\text{D}}^{20} - 12.6^{\circ}$ (*c* 3.6, MeOH); IR (neat) 1745, 1780 cm^{-1} ; ^1H NMR δ 2.8 (m, 2H), 4.1 (m, 1H), 4.95 (s, 2H), 5.2 (s, 2H), 7.32 (s, 5H), 7.5 (s, 5H).



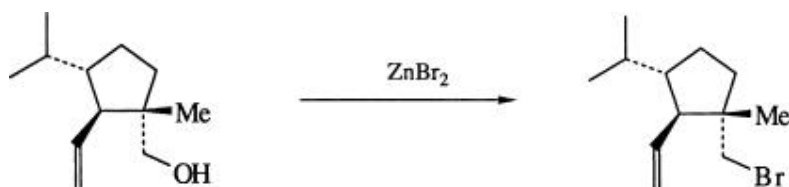
6.1.1.11. (2S)-(+)-Octanethiol (Formation of a Thiol) (231)

Diisopropyl azodicarboxylate (8.33 g, 40 mmol) was added to an efficiently stirred solution of triphenylphosphine (10.50 g, 40 mmol) in tetrahydrofuran (100 mL) at 0°. The mixture was stirred at 0° for 30 minutes, resulting in a white precipitate. (2*R*)-(-)-Octanol (2.60 g, 20 mmol) and thiolacetic acid (3.04 g, 40 mmol) in tetrahydrofuran (50 mL) were added dropwise over 10 minutes and the mixture was stirred for 1 hour at 0° and 1 hour at 22–25°. A clear yellow solution resulted. The solution was concentrated and then purified by column chromatography over silica gel (elution with hexanes–dichloromethane, 1:1) to give the desired octane thiolacetate (3.70 g, 98%). The thiolacetate (3.00 g, 15.95 mmol) was dissolved in anhydrous ether (25 mL) and added dropwise to a suspension of lithium aluminum hydride (0.61 g, 4.0 equiv) in ether (15 mL) under a nitrogen atmosphere. The reaction mixture was stirred at 22–25° for 0.5 hour and the excess lithium aluminum hydride was destroyed by the careful addition of 1 N hydrochloric acid solution (10 mL). The ether layer was separated and dried over sodium sulfate to give the thiol (2.37 g, 100%) as a clear oil. A purified sample was prepared by distillation (2.05 g, 88.6%), bp 65–70° (15 torr).



6.1.1.12. 3- α -Cholestanyl Fluoride (Formation of a Carbon–Fluorine Bond) (263)

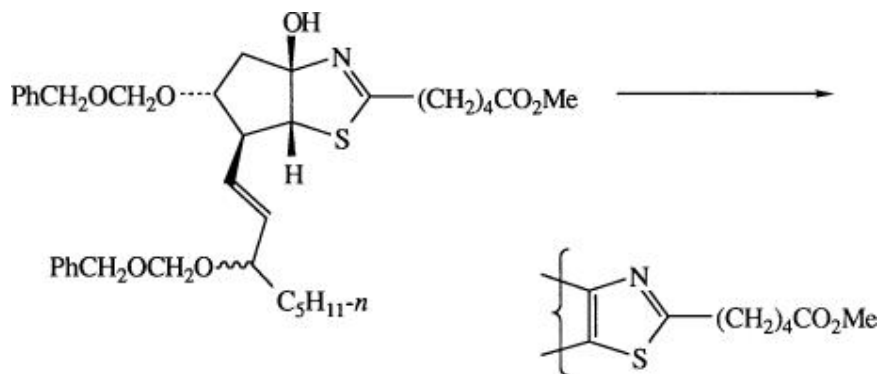
Diethyl azodicarboxylate (1.70 g, 9.8 mmol) was added dropwise with stirring to a 0° solution of triphenylphosphine (2.62 g, 10 mmol) in dry tetrahydrofuran under argon. After 20 minutes lithium fluoride (0.52 g, 20 mmol) was added to the nearly colorless solution followed by 3-β-cholestanol (0.388 g, 1.0 mmol) dissolved in a minimum volume of tetrahydrofuran. The mixture was aged at room temperature until the alcohol was consumed. Upon evaporation of solvent, the residue was poured into water and extracted with ether. The ether extracts were washed with brine, dried over sodium sulfate, and evaporated. Flash chromatography on silica afforded the fluoride in 51% yield.



6.1.1.13. (-)-1(S)-(Bromomethyl)-1-methyl-2 β -vinyl-3 α -isopropylcyclopentane (Formation of a Carbon-Bromine Bond using Zinc Bromide) (397)

A solution of 1(S)-(hydroxymethyl)-1-methyl-2 β -vinyl-3 α -isopropylcyclopentane (0.80 g, 4.4 mmol) and freshly recrystallized triphenylphosphine (3.45 g, 13.2 mmol) in anhydrous tetrahydrofuran (25 mL) was treated with a solution of zinc bromide (0.99 g, 4.4 mmol) in tetrahydrofuran (15 mL) followed by a solution of diethyl azodicarboxylate (2.1 mL, 13.3 mmol) in tetrahydrofuran (15 mL). After 15 minutes, the transparent orange solution became a slurry. The mixture was stirred at room temperature for 16 hours and filtered. Concentration of the filtrate in vacuo gave an orange residue that was purified by chromatography on silica gel (hexane elution) to give the product (0.98 g, 91%) as a colorless oil:

$[\alpha]_D^{23} = -13.98^\circ$ (c 2.9, CHCl₃); ¹H NMR (300 MHz, CDCl₃) δ 5.61 (ddd, *J* = 17.1, 10.3, 9.4 Hz, 1H), 5.05 (dd, *J* = 10.3, 2.1 Hz, 1H), 5.00 (dd, *J* = 17.2, 2.1 Hz, 1H), 3.38 (d, *J* = 9.9 Hz, 1H), 3.34 (d, *J* = 9.9 Hz, 1H), 2.13 (dd, *J* = 9.6, 9.7 Hz, 1H), 1.89–1.27 (series of m, 6H), 0.96 (s, 3H), 0.90 (d, *J* = 6.8 Hz, 3H), 0.83 (d, *J* = 6.7 Hz, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 139.4, 116.6, 54.9, 48.8, 46.5, 45.8, 37.0, 30.0, 24.2, 21.9, 20.7, 18.0; MS, *m/z* (*M*⁺ – Br) Calcd. 165.1643, Obsd 165.1685.



6.1.1.14. Methyl

[(5a,6b)(1E,3R)]-5,6-Dihydro-5-[(phenylmethoxy)methoxy]-6-(3-[(phenylmethoxy)methoxy]-1-octenyl)-4H-cyclopentathiazole-2-pentanoate (Dehydration to Form an Alkene) (278) Methyl(3a*R*-(3a α ,5 β ,6a,(1*E*,3*R*), 6a α))3a,5,6,6a-tetrahydro-3a-hydroxy-5-[(phenylmethoxy)methoxy]-6-(3-[(phenylmethoxy)methoxy]-1-octenyl)-4*H*-cyclopentathiazole-2-pentanoate (0.60 g) was dissolved in dry tetrahydrofuran (10 mL). Diethyl azodicarboxylate (1.04 g, 6.0 mmol) was added and the solution was cooled to 0°, followed by addition of triphenylphosphine (1.60 g, 6.10 mmol). The reaction was aged for 20 hours, then the solvent was removed, and the residue was partitioned between ether (30 mL) and water (30 mL). The organic layer was separated, washed with brine, and dried. Evaporation gave a gum (3.1 g) which was purified by column chromatography (100 g of silica gel, 33% ethyl acetate/hexane) to give the thiazole (0.38 g, 67%) as a clear oil: IR (CHCl₃) 1730 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 0.88 (3H, t), 1.20–1.88 (12H, m), 2.37 (2H, t), 2.84 (1H, dd, *J* = 16.0, 4.8 Hz), 2.98 (2H, t), 3.15 (1H, dd, *J* = 16.0, 6.9 Hz), 3.68 (3H, s), 3.86 (1H, m), 4.07 (1H, m), 4.58 (1H, m), 4.50–4.88 (8H, m), 5.48 (1H, m), 5.76 (1H, m), 7.33 (10H, m); MS (CI) *m/e* 622 (MH⁺), 484, 408, 364.

7. Tabular Survey

Mitsunobu reactions of alcohols to form carbon–oxygen, carbon–nitrogen, carbon–sulfur, and carbon–halogen bonds are grouped in Tables I–XX and follow the order of the discussion in the Scope and Limitations section. Because of the large number of examples of ester formation, this category has been further broken down into six subcategories that relate to the general nature of the alcohol component: general secondary alcohols, general primary alcohols, alcohols contained in β -lactams, alcohols contained in steroids, alcohols contained in carbohydrates, and allylic alcohols.

Within each table, the compounds are listed according to increasing carbon number, and increasing hydrogen number within a given carbon number. Yields are given in parentheses; numbers not in parentheses are product ratios. A dash indicates that no yields or experimental conditions are given in the reference. Unless otherwise noted, triphenylphosphine and diethyl or diisopropyl azodicarboxylate were used in the reactions.

Some entries involve esterification of a structurally large alcohol with a comparably large acid to give a product that, even using a partial structure, is too large for the printed page. In such entries, the notation [RH] appears under the acid structure, and the product structure contains R in place of the acid. Likewise, when very large ethers are products, the notation [ROH] appears under the hydroxy compound, and the product contains RO in place of the hydroxy compound.

The literature has been reviewed from 1981 through June 1990. Examples of reactions prior to 1981 are found in the previous reviews of Castro [6a](#) and Mitsunobu. ([5](#))

The following abbreviations are used in the tables:

Ac	acetyl
Bn	benzyl
Boc	<i>tert</i> -butoxycarbonyl
Bz	benzoyl
C ₅ H ₉	cyclopentyl
C ₆ H ₁₁	cyclohexyl
Cbz	carbobenzyloxy
ClAc	chloroacetyl
DEAD	diethyl azodicarboxylate

DIAD	diisopropyl azodicarboxylate
DMAD	dimethyl azodicarboxylate
DMF	<i>N,N</i> -dimethylformamide
DMtr	4,4 ϕ -dimethoxytriphenylmethyl
Ether	diethyl ether
HMPA	hexamethylphosphoric triamide
MEM	methoxyethoxymethyl
Mes	mesityl
MOM	methoxymethyl
MTD	4-methyl-1,2,4-triazoline-2,5-dione
MTFPA	2-methoxy-2-(trifluoromethyl)phenylacetic acid
Pht	<i>o</i> -phthalyl, <i>o</i> -C ₆ H ₄ (CO) ₂
pNB	<i>p</i> -nitrobenzyl
rt	room temperature
SEM	(2-trimethylsilylethoxy)methyl
TES	triethylsilyl
THF	tetrahydrofuran
THP	tetrahydropyranyl
Ts	<i>p</i> -toluenesulfonyl

Table I. Ester Formation from Secondary Alcohols, General

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Table II. Ester Formation from Primary Alcohols

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Table III. Ester Formation from Secondary Alcohols, β -Lactams

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Table IV. Ester Formation from Secondary Alcohols, Steroids

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Table V. Ester Formation from Secondary Alcohols, Carbohydrates

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Table VI. Ester Formation from Secondary Alcohols, Allylic

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Table VII. Lactone Formation

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Table VIII. Formation of Alkyl Aryl Ethers

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Table IX. Dialkyl Ether Formation, Epoxides

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Table X. Carbon–Oxygen Bond Formation, Four- to Six-Membered Cyclic Ethers

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Table XI. Enol Ether Formation

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Table XII. Carbon–Oxygen Bond Formation with *N*-Hydroxyimides and Amides

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Table XIII. Carbon–Oxygen Bond Formation, Tosylates

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Table XIV. Carbon–Oxygen Bond Formation, Formation of Imidates from Amides and Imides

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Table XV. Carbon–Nitrogen Bond Formation, Imides

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Table XVI. Carbon–Nitrogen Bond Formation, Azides

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Table XVII. Carbon–Nitrogen Bond Formation, β -Lactams

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Table XVIII. Carbon–Nitrogen Bond Formation, General

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Table XIX. Formation of Carbon–Sulfur Bonds

[View PDF](#)

Table XX. Carbon–Halogen Bond Formation

[View PDF](#)

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL

	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃		PhCO ₂ H	rt	 (79.7) (12) (8.3)	133
C ₄	 R = BnO, <i>n</i> -C ₅ H ₁₁ , Ph, 	PhCO ₂ H	CH ₂ Cl ₂ , 0°, 2 h	 (—)	369
	 88% ee	(-)-(S)-MTFPA	THF, 4 h, rt	 70% ee (—)	126
C ₅	 R ¹ R ² R ³ H H H Me H H <i>i</i> -Pr H H H H Ph H Ph H Me H Ph	PhCO ₂ H	—	 (—)	60, 61
C ₆		PhCO ₂ H	THF, 0°	 (87)	348
		PhCO ₂ H	C ₆ H ₆	 (—)	90
		PhCO ₂ H	C ₆ H ₆	 (—)	90
		"	"	 (—)	90
		"	Toluene, 12 h, 22°	 (80)	375
		"	THF, rt, overnight	 (46)	64
		—	—	 (—)	399
		4-O ₂ NC ₆ H ₄ CO ₂ H	THF	 (—)	66

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

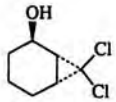
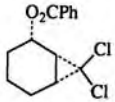
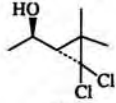
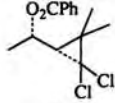
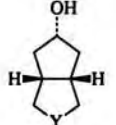
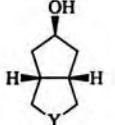
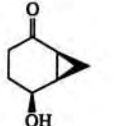
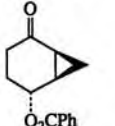
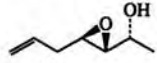

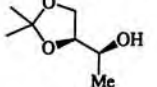
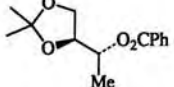
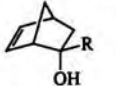
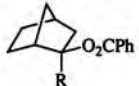
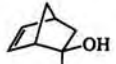
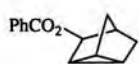
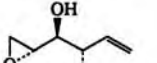
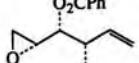
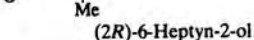
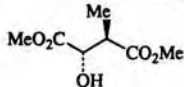
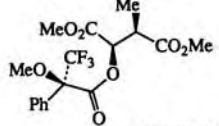
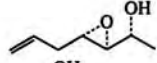
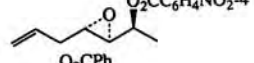
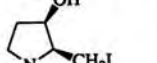
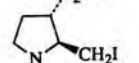
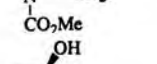
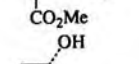
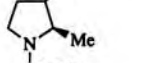
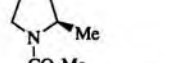
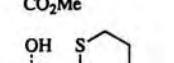
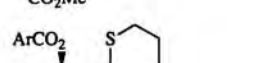
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	C ₆ H ₆		(—) 90
	"	C ₆ H ₆		(—) 90
	PhCO ₂ H	1) Ether, 20°, 14 h 2) KOH, MeOH/H ₂ O		400
			Y = S Y = O	(80) (78)
	PhCO ₂ H	C ₆ H ₆ , 2 h, rt		(80) 316
	PhCO ₂ H	CH ₂ Cl ₂		(86) 401
	PhCO ₂ H	THF, rt, 12 h		(—) 402
	PhCO ₂ H	C ₆ H ₆		(78) 124c
R = H, D				
	PhCO ₂ H	C ₆ H ₆		(80) 124c
	PhCO ₂ H	THF, 14 h, 22°		(64) 88
	AcOH	THF, 18 h, rt, DMAD	(2S)-Acetoxy-6-heptyne	(83) 65
	(+)-(R)-MTFPA	C ₆ H ₆ , rt, 120 h		(20) 128
	4-O ₂ NC ₆ H ₄ CO ₂ H	Toluene, rt		(90) 376
	PhCO ₂ H	THF, 0°, 5 h		(—) 403
	—	—		(—) 404
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, rt, 35 h		(51) 405
	4-O ₂ NC ₆ H ₄ CO ₂ H	-8° to rt, 1 h, toluene		(73) 34

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

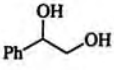
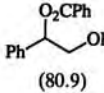
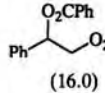
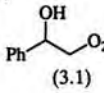
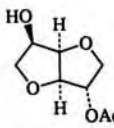
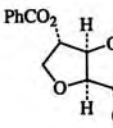
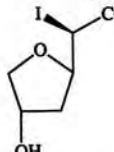
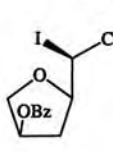
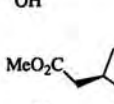
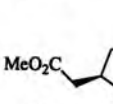
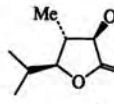
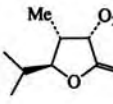
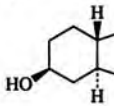
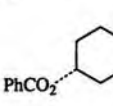
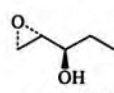
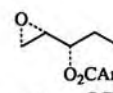
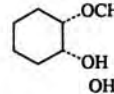
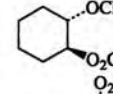
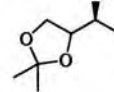
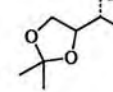
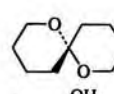
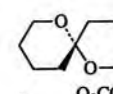
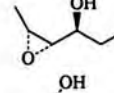
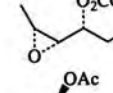
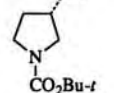
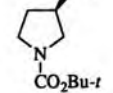
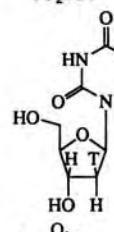
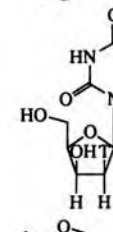
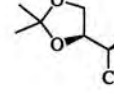
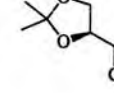
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
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	PhCO ₂ H	THF, rt, 15 h	 (85)	406
	PhCO ₂ H	THF, -15° to rt, 2 h	 (58)	407
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, rt, overnight	 (95)	408
	PhCO ₂ H	THF	 (70)	409
	"	THF, rt, 14 h	 (83)	47
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, rt, 15 h	 (87.7)	410
	PhCO ₂ H	THF	 (40)	411
	4-O ₂ NC ₆ H ₄ CO ₂ H	THF, 15 h, 20°	 (75)	412
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, rt, overnight	 (87)	413, 414
	4-O ₂ NC ₆ H ₄ CO ₂ H	THF, 18 h, rt	 (55)	415
	AcOH	—	 (66)	72, 73
	PhCO ₂ H	(1) HMPA, 7 h, 60° (2) NaOMe/MeOH	 (72)	402
	PhCO ₂ H	THF, rt, 12 h	 (72)	402

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	HOAc	Et ₂ O, rt, 4 h		(65) 416
	PhCO ₂ H	THF		(72) 417
	PhCO ₂ H	—		(—) 418
	4-O ₂ NC ₆ H ₄ CO ₂ H	Toluene, 1 h, -35° to ambient		(71) 33
	PhCO ₂ H	THF, 4 h, 20°		(98) 419, 420
	"	—		(—) 85
	4-O ₂ NC ₆ H ₄ CO ₂ H	C ₆ H ₆		(80) 421
	HOAc	—		(—) 422
	4-O ₂ NC ₆ H ₄ CO ₂ H	Toluene, 1 h, -30 to 0°		(90) 34, 35
	HCO ₂ H	THF		(—) 423
	PhCO ₂ H	THF		(25) 129, 130
	"	25°, 18 h		424
	PhCO ₂ H	THF, rt, 15 h		(80) 425
	HCO ₂ H	1) THF, rt, 2 h 2) HO ⁻		(75) 426
	PhCO ₂ H	THF, 22°, 40 h		100% <i>syn</i> (69) 427
	Zn(O ₂ CR) ₂	Toluene		R = Me (80) 251
	<i>n</i> -Bu ₄ N ⁺ O ₂ CPh	THF		R = Ph (84) 428
	<i>n</i> -Bu ₄ N ⁺ O ₂ CPh	THF		R = Ph (60) 428

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	(+)- <i>R</i> -2-MTFPA	C ₆ H ₆ , 65 h		(19) 127
	PhCO ₂ H	THF		(73) 429
	AcOH	C ₆ H ₆ , 12 h, rt		(47) 382
	HOAc	THF		(—) 430
	HCO ₂ H	C ₆ H ₆ , rt, 48 h		(59) 431
	PhCO ₂ H	—		(83) 432
	PhCO ₂ H	—		(—) 433
			100% retention	
	—	1) THF, rt 2) NaOH		(52) 434
	PhCO ₂ H	THF, 20°, 12 h		(90) 435, 436
	PhS-CH(Cl)-CO ₂ H	—		(—) 68
	PhCO ₂ H	—		(82) 437
				(11)
	—	—		(—) 438
	PhCO ₂ H	THF, rt, 2 h		(73) 97
	(+)- <i>R</i> -MTFPA	C ₆ H ₆ , rt, 137 h		(33) 392

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	—	—		(—) 439
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, 20 h, rt		(85) 440
	PhCO ₂ H	—		(—) 441
	PhCO ₂ H	THF		(63) 442
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	THF, rt, overnight		(94) 443
	PhCO ₂ H	THF, rt, 16 h		(76) 36
	PhCO ₂ H	THF, rt, 1 h		(86) 81
	PhCO ₂ H	Et ₂ O, rt, overnight		(37) 82
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	1) THF, 24 h, 25° 2) KOH, MeOH		(72) 444
	PhCO ₂ H	THF, rt, 48 h		(68) 445
	HO ₂ CCH ₂ P(O)(OEt) ₂	C ₆ H ₆		(80) 446
			R = CH ₂ P(O)(OEt) ₂	
	PhCO ₂ H	1) C ₆ H ₆ , rt, 24 h 2) NaOH, MeOH, H ₂ O		(70) 447
	PhCO ₂ H	Et ₂ O, rt, 48 h		(86) 448
	4-O ₂ NC ₆ H ₄ CO ₂ H	Toluene, rt, 45 min		(78) 376
	PhCO ₂ H	THF, reflux, overnight		(52) 70

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

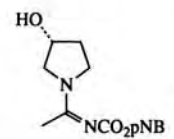
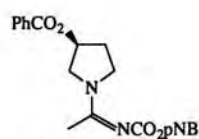
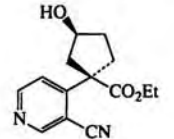
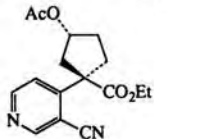
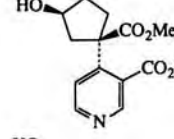
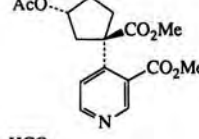
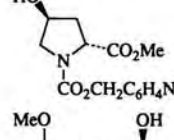
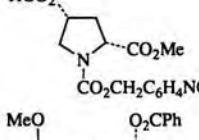
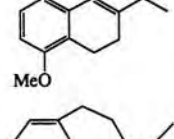
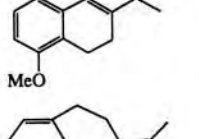
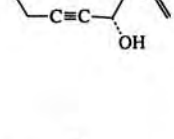
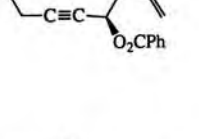
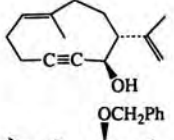
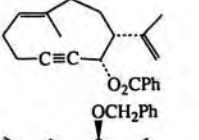
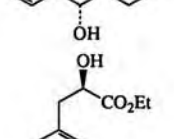
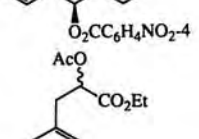
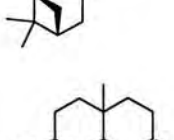
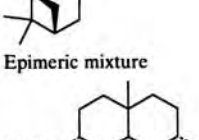
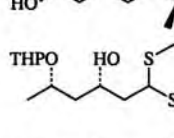
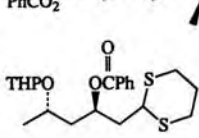
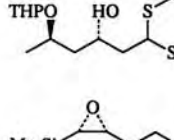
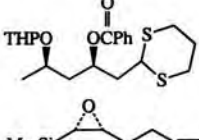
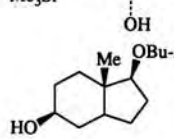
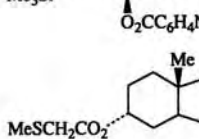




Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, rt, 2 h		(86) 97
	AcOH	THF, rt, 20 h		(91) 449
	AcOH	CH ₂ Cl ₂		(85) 450
	HCO ₂ H	-10° to rt, 3 h		(57) 98
	PhCO ₂ H	THF, 2 h		(70) 451
	PhCO ₂ H	C ₆ H ₆ , 14 h, rt		(90) 379
	"	"		(90) 379
	4-O ₂ NC ₆ H ₄ CO ₂ H	THF, 20°, 15 h		(75) 406
	AcOH	—		(—) 125
	AcOH	—		(—) 125
	AcOH	—		(—) 125
	AcOH	—		(—) 125
	AcOH	—		(—) 125
	AcOH	—		(—) 125

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

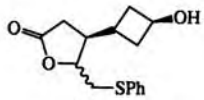
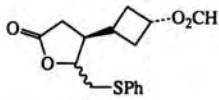
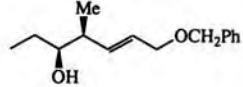
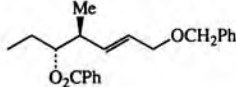
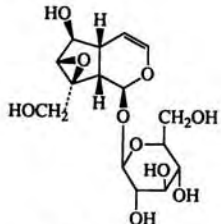
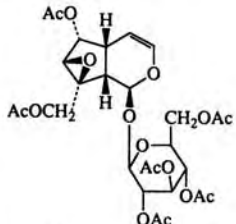
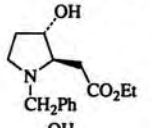
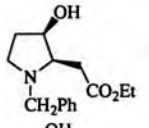
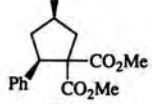
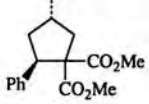
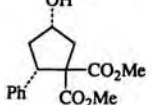
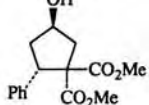
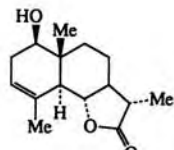
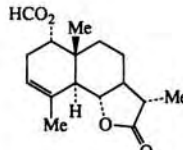
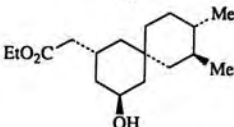
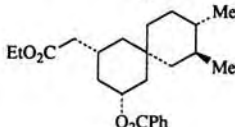
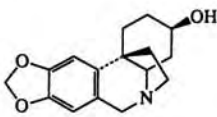
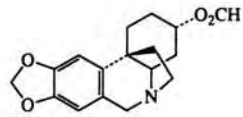
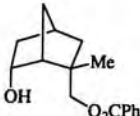
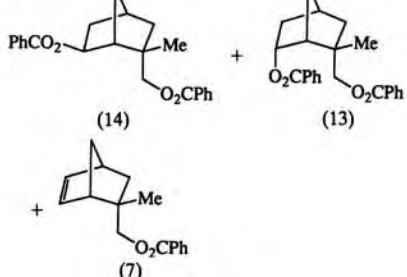
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₅ 	HCO ₂ H	—		(—) 46
	PhCO ₂ H	—		(65) 453
	PhCO ₂ H	1) THF, reflux, 3 h 2) NaOMe/MeOH 3) Ac ₂ O/pyridine		(73) 141
	—	—		(—) 442
	HOAc	—		(—) 454
	HOAc	—		(—) 454
	HCO ₂ H	THF, reflux, 6 h		(85) 455
	PhCO ₂ H	Et ₂ O, rt, 2 h		(52) 373
C ₁₆ 	HCO ₂ H	THF, 3 days, rt		(50) 456
	PhCO ₂ H	C ₆ H ₆ , 60–65°, 3 h		383

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		THF, rt, 7 h		(57) 94, 95
	PhCO ₂ H	THF, rt, 2.5 h		(93) 94, 95
	AcOH	C ₆ H ₆ /toluene, 16 h, rt		(64) 39, 42
	4-O ₂ NC ₆ H ₄ CO ₂ H	1) THF 2) NaOH		(67) 457
	PhOCH ₂ CO ₂ H	THF, rt, overnight		(94) 458
	4-PhC ₆ H ₄ CO ₂ H	—		(40) 37
	AcOH	—		(—) 71
		THF, rt, 2 h		(50) 459
	PhCO ₂ H	THF, 0°		(88) 460
	PhCO ₂ H	CH ₂ Cl ₂ , rt, 2 days		(74) 368
	PhCO ₂ H	THF, 22°, 40 h		(67) 427
	PhCO ₂ H	Et ₂ O, 23°, 5 h		(—) 461

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		THF, -13°, 1 h, 3°, 0.5 h		(80) 462
	PhCO ₂ H	THF, 5°, overnight		(70) 463
	PhCO ₂ H	THF, 5°, overnight		(—) 463
	AcOH	THF, rt, 18 h		59
			X = Cl X = I	(80) (85)
	PhCO ₂ H	C ₆ H ₆ , rt, 3 days		(64) 377
	PhCO ₂ H	—		(57) 464
C₁₈				
	Zn(OAc) ₂	CH ₂ Cl ₂ /toluene (1:3), 90–100°, 23 h		(41) 465
				(11)
	AcOH	THF, 0°		(—) 466
	PhCO ₂ H	THF, 5°		(—) 57, 58
C₂₀				
	PhCO ₂ H	THF, reflux, 48 h		(55) 467
	PhCO ₂ H	—		(—) 468
	PhCO ₂ H	C ₆ H ₆ , rt, 3 days		(37) 377

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	AcOH	—		(—) 56
	HCO2H	THF, rt, 0.5 h		(82) 469
	PhCO2H	—		(—) 470
	PhCO2H	—		(90) 471
	PhCO2H	THF, rt, 14 h		(72) 472
	PhCO2H	1) THF, 0°, 2 h 2) NaOMe, MeOH, 23°, 6 h		(91) 473
	HCO2H	C6H6:DMF (19:1), 2 h, rt		(89) 92
	PhCO2H	THF		(75) 474
	4-O2NC6H4CO2H	Toluene, 0°		(—) 475, 476
		THF, 2 h, rt		(80) 477
		"		(38) 477
	AcOH	THF, rt		(63) 129, 130
	PhCO2H	THF, 20°, 20 h		(81) 79

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		AcOH	THF, -50°		(70) 87
		—	—		(—) 478
C ₂₄		PhCO ₂ H	—		(78) 479
C ₂₅		PhCO ₂ H	THF, 1 h, 20°		(92) 480
C ₂₆		PhCO ₂ H	THF, 45 min, 0°		(57) 78
		PhCO ₂ H	—		(70) 481
		PhCO ₂ H	THF, rt, 15 min		(41) 482
					(41)
C ₂₇		4-O ₂ NC ₆ H ₄ CO ₂ H	THF, 22°, 120 h		(50) 88
		"	"		(45) 88
		NaO ₂ CH	THF, rt, overnight		(92) 483
		PhCO ₂ H	THF, 3.5 h		(77) 484
		AcOH	THF, 24 h		(60) 45

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		PhCO ₂ H	Et ₂ O, rt, overnight		(97) 99
		"	"		(93) 99
		PhCO ₂ H	THF		(54) 485
C ₂₈		PhCO ₂ H	1:1 Toluene: pentane, 0°, 1.5 h		(75) 486
		PhCO ₂ H	Et ₂ O, 2 h, 0°		(95) 371
C ₂₉		HCO ₂ H	THF, 0°, 2 h		(45) 487
C ₃₀		PhCO ₂ H	1) THF, rt, 20 h 2) K ₂ CO ₃ , MeOH, rt, 15 h		(47) 488
C ₃₁		PhCO ₂ H	THF, rt		(—) 489
		PhCO ₂ H	THF, -40 to -20°, 19 h		(57) 490
C ₃₃		PhCO ₂ H	—		(—) 491
C ₃₄		HCO ₂ H	C ₆ H ₆		(70) 53
C ₃₈		PhCO ₂ H	C ₆ H ₆		(97) 492

TABLE I. ESTER FORMATION FROM SECONDARY ALCOHOLS, GENERAL (Continued)

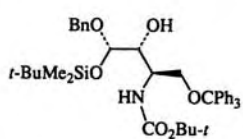
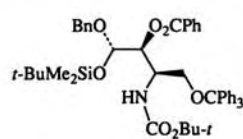
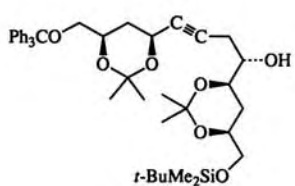
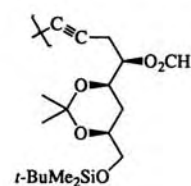
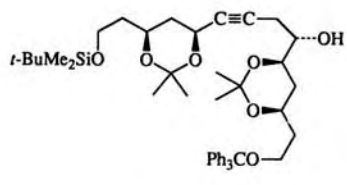
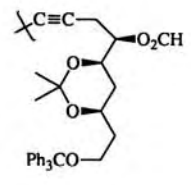
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₄₁		PhCO ₂ H	THF, rt, 14 h		(60) 472
C ₄₃		HCO ₂ H	ether		(84) 52
C ₄₇		HCO ₂ H	ether		(84) 52

TABLE II. ESTER FORMATION FROM PRIMARY ALCOHOLS

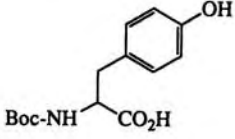
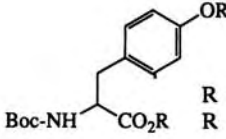
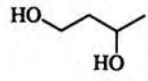
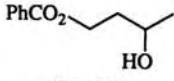
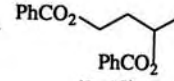
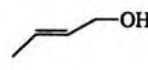
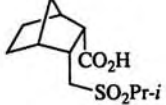
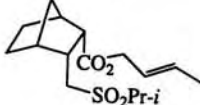
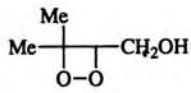
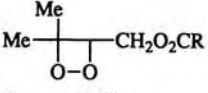

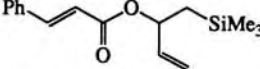
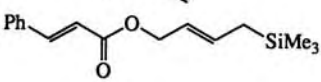
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁	MeOH		THF, 0°, 12 h		74
C ₂	EtOH				
C ₄		PhCO ₂ H	rt	 +  (70-90) (0-10)	133
			THF, rt, 17 h		(68) 493
C ₅		RCO ₂ H	Ether, 0-10°, 2-12 h		96
				R = <i>n</i> -C ₁₇ H ₃₅ (98) R = <i>p</i> -O ₂ NC ₆ H ₄ (97)	
C ₇		Ph-CH=CH-CO ₂ H	—	 (19)  (37)	69

TABLE II. ESTER FORMATION FROM PRIMARY ALCOHOLS (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		—		(61) 100
PhCH ₂ CH ₂ OH	<i>n</i> -Bu ₄ N ⁺ O ₂ CPh	THF	Me ₃ Si(CH ₂) ₂ CO ₂ Ph	(—) 428
		—		68
<i>n</i> = 2–5			(—)	
PhCH=CHCH ₂ OH		Ether, rt, 12 h		86
	PhCO ₂ H	—		(—) 494
	4-O ₂ NC ₆ H ₄ CO ₂ H	DMF, rt, 24 h		(80) 495
	PhCO ₂ H	—		(80) 496
	PhCO ₂ H	THF, 35°, 12 h		(57) 497
	"	"		(55) 497
	MeO ₂ CCH ₂ CO ₂ H	—		498
			(80)	
		THF, rt		(77) 499

TABLE II. ESTER FORMATION FROM PRIMARY ALCOHOLS (*Continued*)

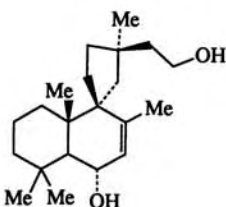
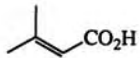
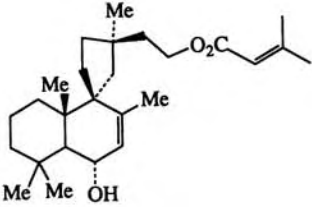
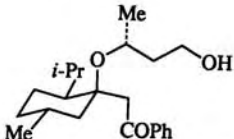
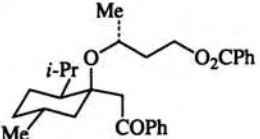
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₀			Et ₂ O, rt, 20 h		(43) 372
C ₂₂		PhCO ₂ H	THF		(75) 474

TABLE III. ESTER FORMATION FROM SECONDARY ALCOHOLS, β -LACTAMS

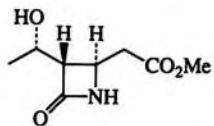
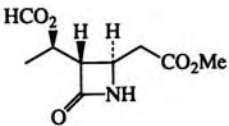
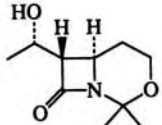
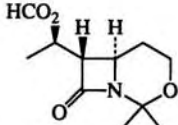
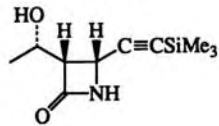
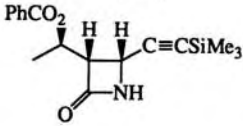
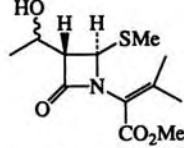
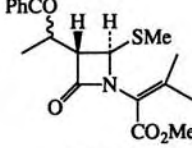
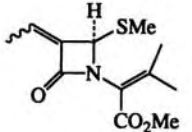
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₆		HCO ₂ H	THF		(—) 17
C ₁₀		"			(68) 18
		PhCO ₂ H	—		(—) 19
C ₁₂	 3:1 8S:8R	PhCO ₂ H	THF, 1.5 h 20°	 1:3 8S:8R	(71) 20
				 3:2 E:Z	(15)

TABLE III. ESTER FORMATION FROM SECONDARY ALCOHOLS, β -LACTAMS (Continued)

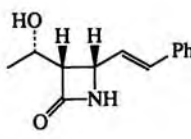
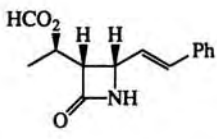
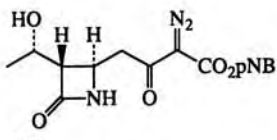
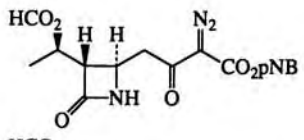
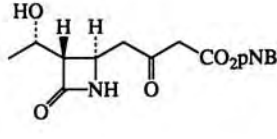
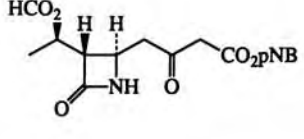
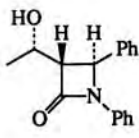
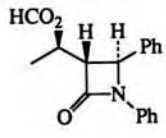
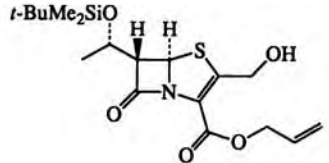
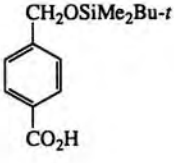
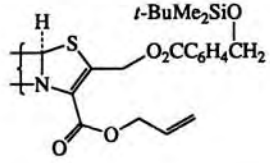
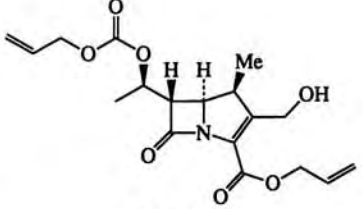
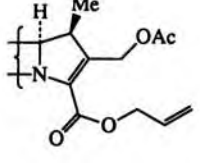
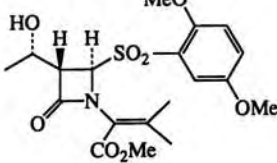
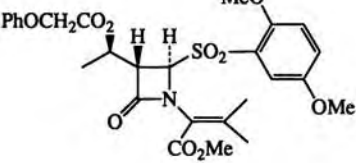
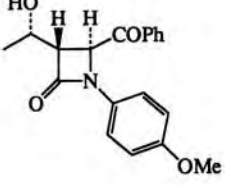
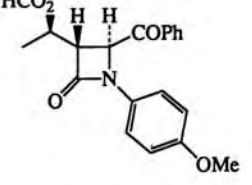
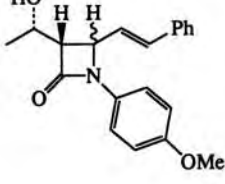
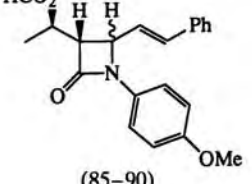
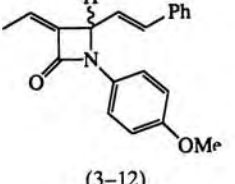
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.	
C ₁₃		HCO ₂ H	—		(79) 21	
C ₁₆		HCO ₂ H	—		(95) 22	
		HCO ₂ H	—		(—) 23,24	
C ₁₇		HCO ₂ H	0–25°, 1.5 h		(95) 25	
C ₁₈			—		(—) 26	
		AcOH	Et ₂ O, rt, 5 min		(75) 27	
		PhOCH ₂ CO ₂ H	THF, rt, overnight		(—) 28	
C ₁₉		HCO ₂ H	—		(74) 29	
C ₂₀		HCO ₂ H	0–25°, 1.5 h	 (85–90)	 (3–12)	25

TABLE III. ESTER FORMATION FROM SECONDARY ALCOHOLS, β -LACTAMS (Continued)

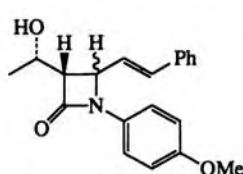
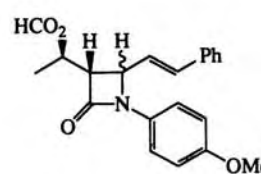
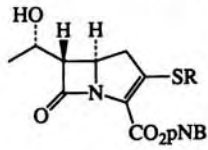
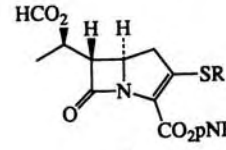
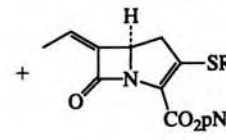
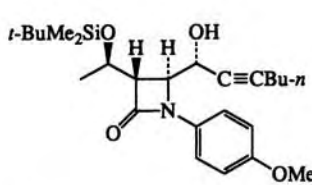
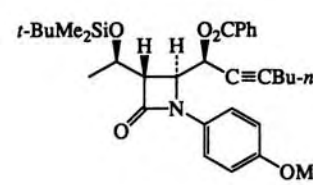
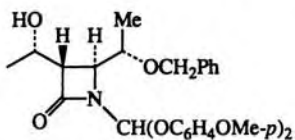
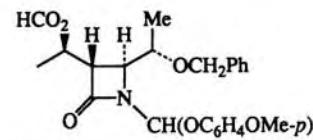
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₀		HCO ₂ H	THF, rt, 1.5 h		(84) 30
		"	THF, rt, 0.5 h		(32-39) 31
	R = CH=CHNHAc R = CH ₂ CH ₂ NHAc			+ 	(37-54)
C ₂₅		PhCO ₂ H	—		(—) 32
C ₂₈		HCO ₂ H	THF, rt, 2 h		(91) 500

TABLE IV. ESTER FORMATION FROM SECONDARY ALCOHOLS, STEROIDS

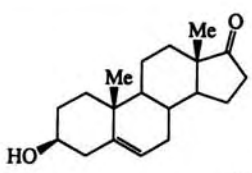
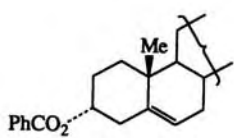
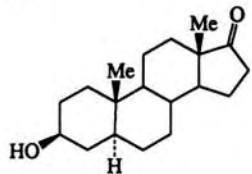
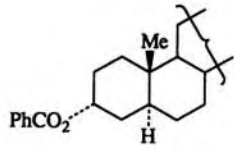
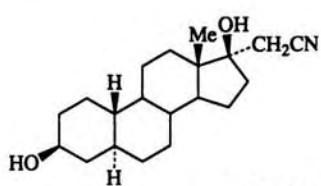
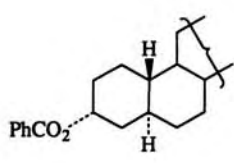
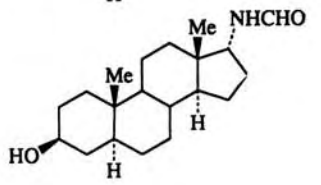
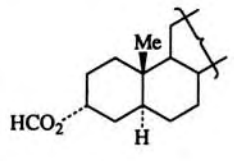
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₉ 	PhCO ₂ H	—	 (—)	501
	PhCO ₂ H	THF, 2 h, rt	 (83)	502
C ₂₀ 	PhCO ₂ H	C ₆ H ₆ , 5 h, rt	 (33)	93
	HCO ₂ H	THF, 20°, 8 h	 (85)	503

TABLE IV. ESTER FORMATION FROM SECONDARY ALCOHOLS, STEROIDS (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₁ 	PhCO ₂ H	C ₆ H ₆ : THF (4:1) 5 h, reflux	 (—)	504
	HCO ₂ H	THF	 (20)	505
	PhCO ₂ H	—	 (—)	501
	CF ₃ CO ₂ H	—	 (74)	506
C ₂₂ 	AcOH	THF, rt, 70 h	 (73)	135, 136
	HCO ₂ H	C ₆ H ₆ , 48 h, rt	 (88)	380
	PhCO ₂ H	THF, 25–60°	 (—)	507
C ₂₆ 	PhCO ₂ H	rt, 3 h	 (—)	75

TABLE IV. ESTER FORMATION FROM SECONDARY ALCOHOLS, STEROIDS (Continued)

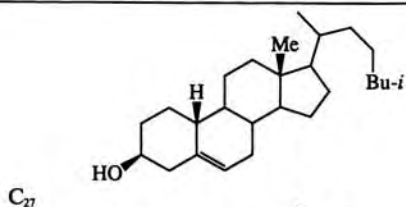
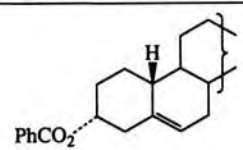
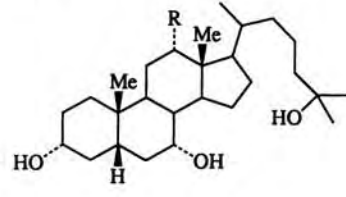
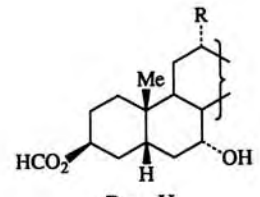
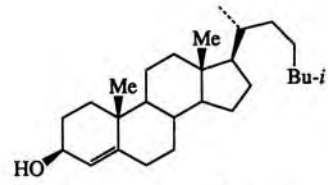
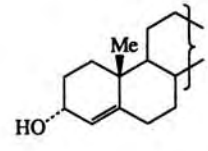
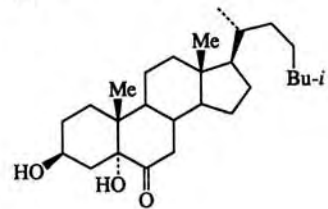
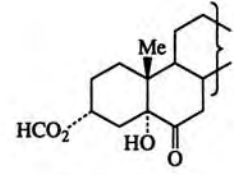
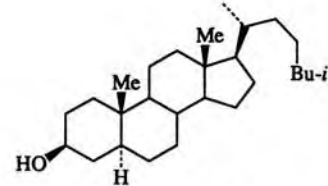
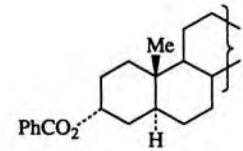
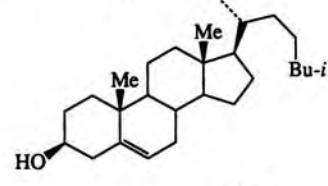
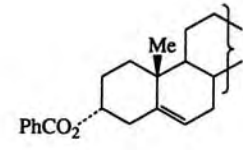
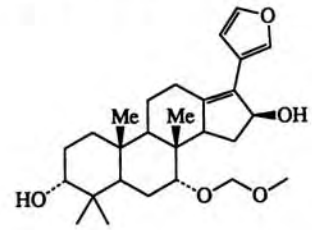
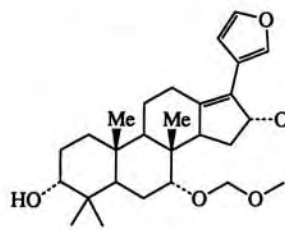
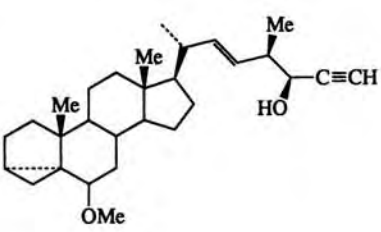
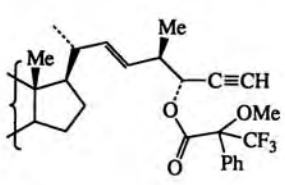
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	—	 (—)	501
	HCO ₂ H	C ₆ H ₆ , 48 h, reflux	 R = H (55) R = OH (40)	134
	—	—	 (—)	508
	HCO ₂ H	THF, rt	 (98)	509
	PhCO ₂ H	—	 (—)	501
	PhCO ₂ H	—	 (—)	501
	PhCO ₂ H	1) THF, 23°, 3 h 2) NaOH, EtOH	 (50)	510
	MTFPA	—	 (—)	391

TABLE IV. ESTER FORMATION FROM SECONDARY ALCOHOLS, STEROIDS (Continued)

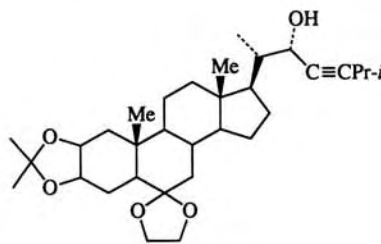
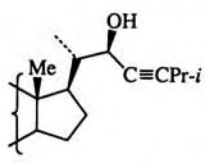
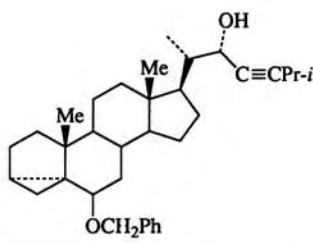
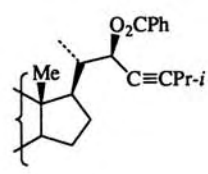
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₂		—	—		(75) 63
C ₃₃		PhCO ₂ H	THF, 10–15°, 0.5 h		(75) 511

TABLE V. ESTER FORMATION FROM SECONDARY ALCOHOLS, CARBOHYDRATES

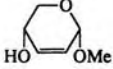
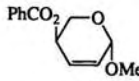
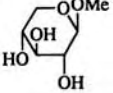
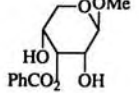
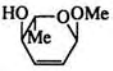
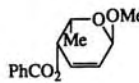
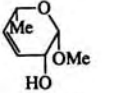
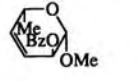
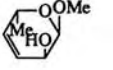
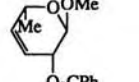
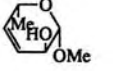
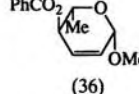
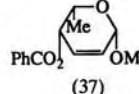
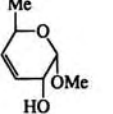
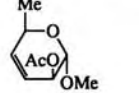
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₆		PhCO ₂ H	—		(—) 512
		PhCO ₂ H	THF, 1 h		(20) 137
C ₇		PhCO ₂ H	THF, 0°-rt, 2 h		(96) 513, 514
		PhCO ₂ H	C ₆ H ₆ , rt		(80) 123
		PhCO ₂ H	C ₆ H ₆ , rt		(80) 123
		PhCO ₂ H	C ₆ H ₆ , rt	 + 	123
		AcOH	C ₆ H ₆ , rt, 2 h		(73) 515

TABLE V. ESTER FORMATION FROM SECONDARY ALCOHOLS, CARBOHYDRATES (Continued)

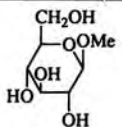
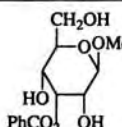
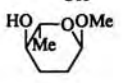
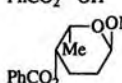
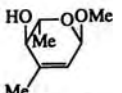
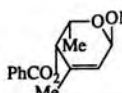
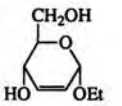
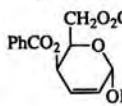
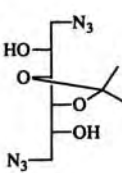
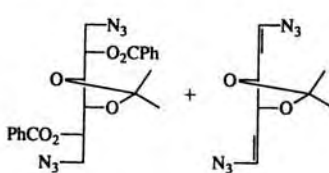
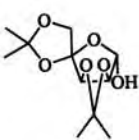
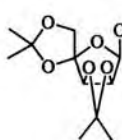
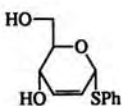
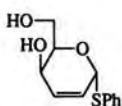
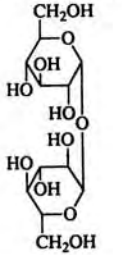
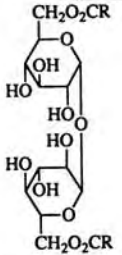

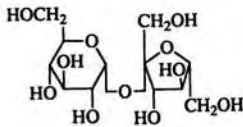
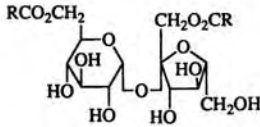
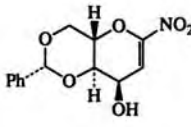
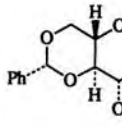
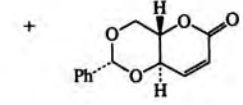
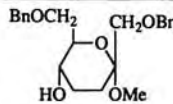
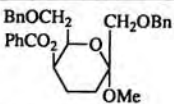
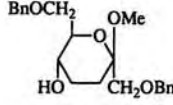
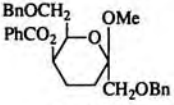
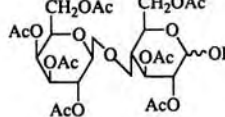
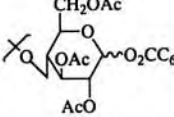
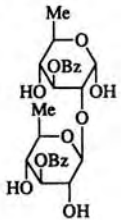
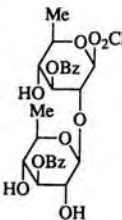
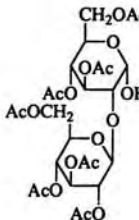
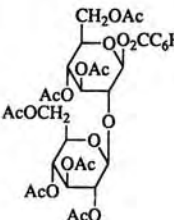
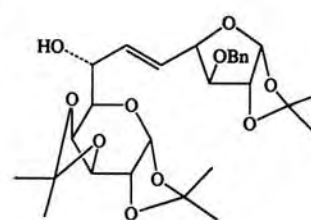
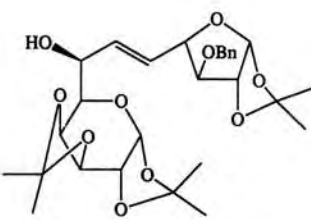
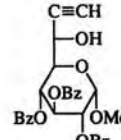
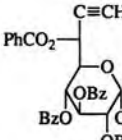
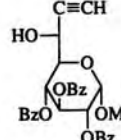
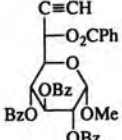
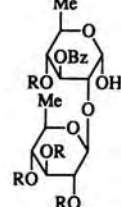
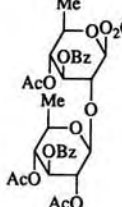
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
		PhCO ₂ H	THF, 1 h		(70) 137
		PhCO ₂ H	THF		(89) 516
C ₈		PhCO ₂ H	C ₆ H ₆ , rt, 2 days		(64) 381
		PhCO ₂ H	THF, 23°, 0.5 h		(85) 140
C ₉		PhCO ₂ H	—		(8) 43
C ₁₁		<i>n</i> -Bu ₄ N ⁺ ⁻ O ₂ CPh	THF		(60) 428
C ₁₂		PhCO ₂ H	1) THF, 24 h, rt 2) K ₂ CO ₃ , MeOH		(86) 517
		<i>n</i> -C ₅₉ H ₁₁₇ OTHP C ₂₂ H ₄₅ - <i>n</i> CO ₂ H	HMPA:CH ₂ Cl ₂ (1:1), rt, overnight		(61) 138
		<i>n</i> -C ₁₅ H ₃₁ CO ₂ H	DMF, rt, 14 h	"	(59) 139
		<i>n</i> -C ₁₅ H ₃₁ CO ₂ H	DMF, rt, 14 h		(59) 139
C ₁₃		HCO ₂ H	THF, 48 h, 5°		(56) 518
					(27)

TABLE V. ESTER FORMATION FROM SECONDARY ALCOHOLS, CARBOHYDRATES (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, 1 h, rt	+ 41	41
	PhCO ₂ H	THF, 1 h, rt	(92) 41	41
C ₁₄ 	PhCO ₂ H	THF, 1 h, rt	(86) 519	519
	4-O ₂ NC ₆ H ₄ CO ₂ H	Dioxane, reflux, 1 h	(90) 62	62
	PhCO ₂ H	THF, -50°	(62) 50	50
	PhCO ₂ H	THF, -50°	(80) 50	50
	PhCO ₂ H	—	(24) 101	101
C ₁₅ 	PhCO ₂ H	THF, 1 h	(73) 137	137
C ₁₈ 	4-O ₂ NC ₆ H ₄ CO ₂ H	THF, 12 h, rt	(70) 62	62
C ₁₉ 	PhCO ₂ H	1) Et ₂ O, 25°, 3 h 2) K ₂ CO ₃ , MeOH	(81) 517	517
C ₂₂ 	C ₆ H ₁₁ CO ₂ H	THF, -50° to rt	(64) 50	50

TABLE V. ESTER FORMATION FROM SECONDARY ALCOHOLS, CARBOHYDRATES (CONTINUED)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, rt, 1 h		(82) 520
	PhCO ₂ H	THF, rt, 1 h		(72) 520
	<i>c</i> -C ₆ H ₁₁ CO ₂ H	THF, -50° to rt	 β:α 4.5:1	(63) 50
	[RCO ₂ H]	THF, rt, 20 min		(40) 50
	<i>c</i> -C ₆ H ₁₁ CO ₂ H	THF, -50° to rt		(85) 50
	4-O ₂ NC ₆ H ₄ CO ₂ H	1) Dioxane, 3 h, reflux 2) Na ₂ CO ₃ , MeOH		(70) 521
	PhCO ₂ H	THF, 12 h, rt		(76) 62
	PhCO ₂ H	THF, 12 h, rt		(69) 62
	[RCO ₂ H]	THF, rt, 20 min		(90) 50

442

443

TABLE V. ESTER FORMATION FROM SECONDARY ALCOHOLS, CARBOHYDRATES (Continued)

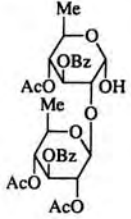
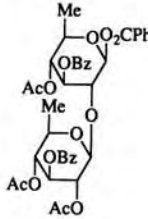
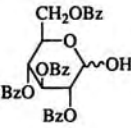
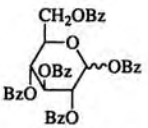
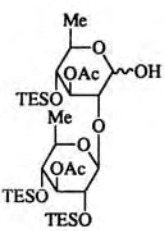
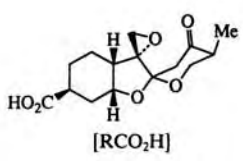
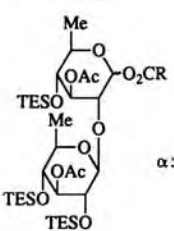
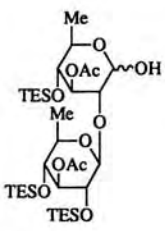
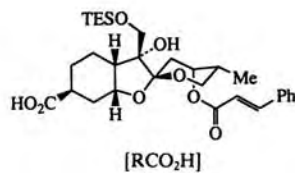
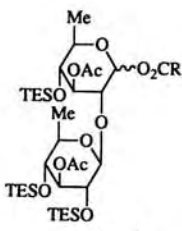
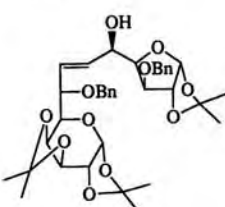
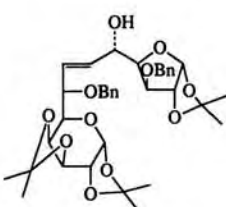
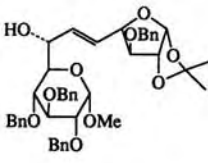
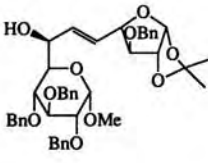
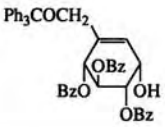
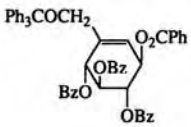
	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
444	C ₁₂ 	PhCO ₂ H	THF, rt, 20 min	 (95) 50	
	C ₁₄ 	PhCO ₂ H	THF, -50° to rt	 4:1 α:β (54) 50	
		 [RCO ₂ H]	THF, rt, 20 min	 α:β 1:2 (55) 50,51	
		 [RCO ₂ H]	THF	 α:β 1:3 (55) 522	
	C ₃₆ 	4-O ₂ NC ₆ H ₄ CO ₂ H	1) Dioxane, 3 h, reflux 2) Na ₂ CO ₃ , MeOH	 (—) 521	
	C ₄₁ 	4-O ₂ NC ₆ H ₄ CO ₂ H	1) Dioxane, 3 h, reflux 2) Na ₂ CO ₃ , MeOH	 (70) 521	
	C ₄₇ 	PhCO ₂ H	THF, 3-Å sieves, 0.5 h at -10°, 1 h at rt	 (70) 37	

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₅ 	Me ₃ Si-CH ₂ -CH ₂ -O-CH ₂ -CO ₂ H	THF, 0–25°, 1 h		121, 122 (80) (99) R = Et R = <i>n</i> -C ₈ H ₁₇
	PhCO ₂ H	THF, rt, 20 h		55 (38) (66) (91) R = Cl R = H R = (CH ₂) ₆ CO ₂ Et
	PhCO ₂ H	THF, rt, 20 h		(82) 55
	<i>n</i> -C ₁₇ H ₃₃ CO ₂ H	THF, 0°, 90 min		(11) 91
				(16)
C ₆ 	PhCO ₂ H	—		(92) 523
	3,5-(O ₂ N) ₂ C ₆ H ₃ CO ₂ H	0°, 2.5 h		(91) 80
C ₇ 	AcOH	THF, sieves, rt, 1 h		(90) 105
		THF, –5 to 0°, 3 h		(70) 107
C ₈ 	AcOH	THF, 36 h		(92) 108
	AcOH	THF, rt, 0.5 h		(—) 110
	4-BrC ₆ H ₄ CO ₂ H	THF		(—) 525
	HCO ₂ H	1) THF 2) KHCO ₃ , MeOH		(85) 526

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	HOAc	THF, 20 h, rt	 	524
			I II + III	
			I (%) II (%) III (%) Yield (%)	
			1 1.0 1.4 2.8 100 0 0 70	
			2 2.5 2.5 4.0 0 20 80 —	
			3 2.6 2.6 21 0 12 88 58	
			4 2.6 2.6 100 100 0 0 —	
	Zn(OAc) ₂	THF, rt	 	(12) 527 (65)
	PhCO ₂ H	(—)		(—) 528
	PhCO ₂ H	THF, 15 min, rt		(89) 103, 104
			R = Ph ₃ C, <i>t</i> -BuMe ₂ Si	
	PhCO ₂ H	THF, 1 h, 25°		(—) 114
	PhCO ₂ H	—		(—) 83
	PhCO ₂ H	C ₆ H ₆ , 12 h, rt		(28) 529
	AcOH	THF	 70:30 at rt 61:39 at -40°	(90) 124b
	AcOH	THF, -40°	 65% D 26% D 35% D 74% D 85:15	(90) 124b

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)


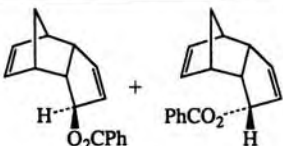
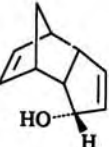
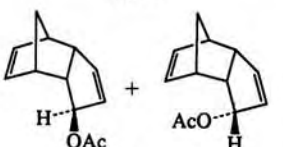
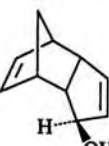
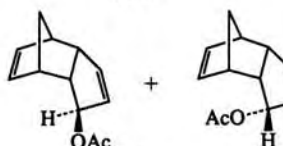
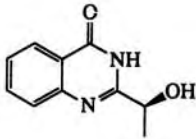
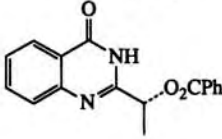
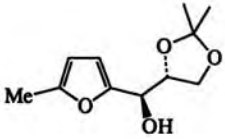
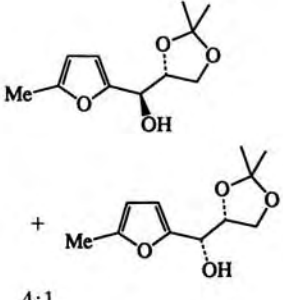
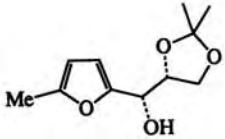
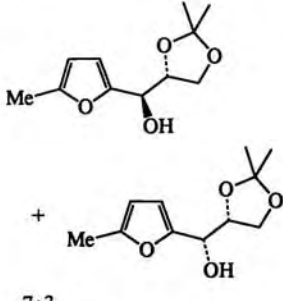
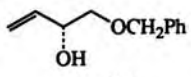
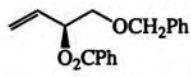
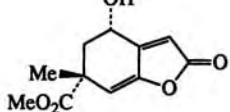
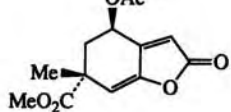
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, -40°	 90:10	(90) 124b
	AcOH	THF, -40°	 98:2	(90) 124b
	AcOH	THF, -40°	 85:15	(90) 124b
	PhCO ₂ H	THF, rt, 18 h		(59) 530
	PhCO ₂ H	1) THF, rt, 24 h 2) NaOMe, MeOH	 4:1	(76) 531
	PhCO ₂ H	1) THF, rt, 24 h 2) NaOMe, MeOH	 7:3	(65) 531
	PhCO ₂ H	—		(—) 532
	AcOH	THF, rt, 15 h		(83) 120

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

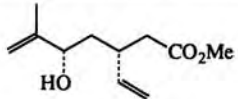
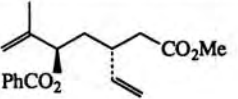
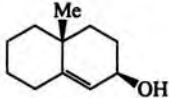
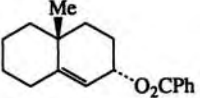
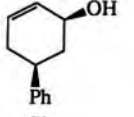
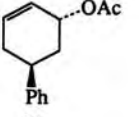
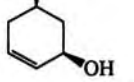
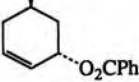
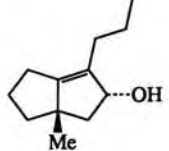
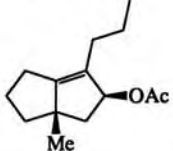
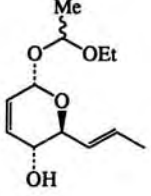
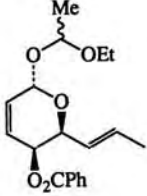
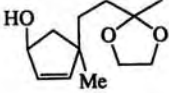
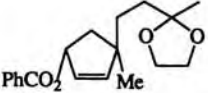
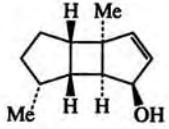
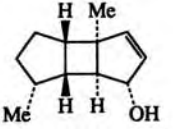
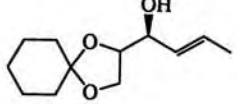
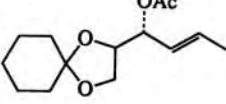
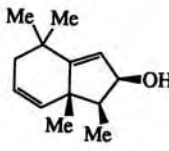
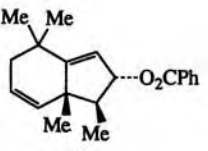
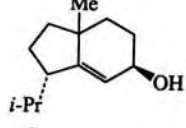
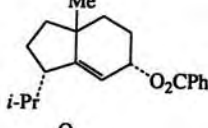
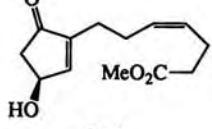
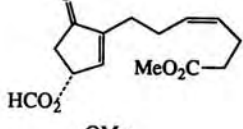
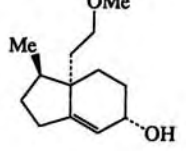
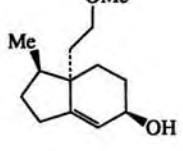
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, 25°, 3 h	 (61) 113	
	PhCO ₂ H	—	 (—) 116	
	AcOH	—	 (—) 115	
	PhCO ₂ H	Ether, 15 h, rt	 (85) 533	
	AcOH	C ₆ H ₆ , rt	 (82) 111	
	PhCO ₂ H	THF, rt, 3.5 h	 (85) 534	
	PhCO ₂ H	THF, rt, 1.5 h	 (85) 535	
	—	—	 (—) 109	
	AcOH	THF, -15 to 10°, 4 h	 (30) 35	
	PhCO ₂ H	THF, rt, 9 h	 (91) 117	
	PhCO ₂ H	—	 (89) 112	
	HCO ₂ H	THF, rt, overnight	 (91-94) 536	
	PhCO ₂ H	1) C ₆ H ₆ , rt, 1 h 2) K ₂ CO ₃ , MeOH	 (73) 537	

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

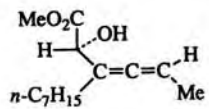
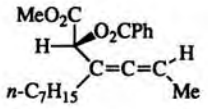
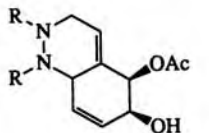
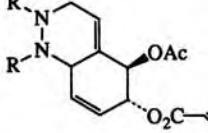
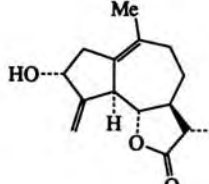
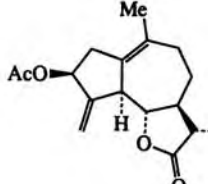
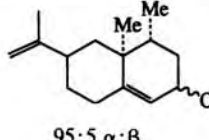
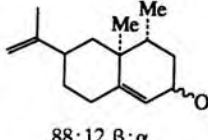
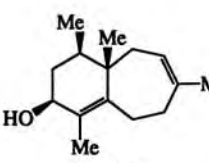
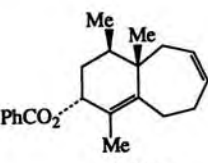
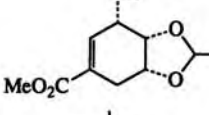
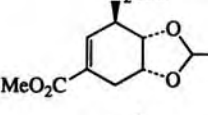
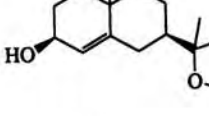
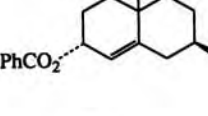
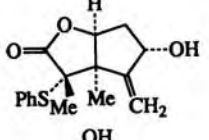
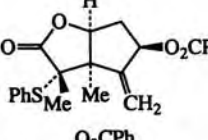
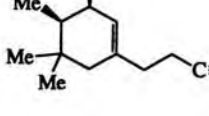
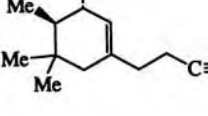
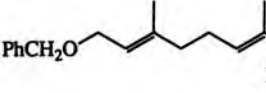
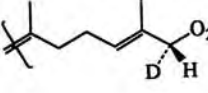
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₄ 	PhCO ₂ H	—		(90) 538
	Ph-CH=CH-CO ₂ H	THF, rt, overnight		(55-70) 539
			R = CO ₂ Et CO ₂ CH ₂ CCl ₃ CO ₂ CH ₂ CH ₂ SiMe ₃	
C ₁₅ 	AcOH	THF		(44) 119
 95:5 α:β	PhCO ₂ H	THF, rt, 24 h	 88:12 β:α	(—) 540
	PhCO ₂ H	THF, 5 h, rt		(66) 102
	PhCO ₂ H	THF, 3 h, rt		(91) 38
	PhCO ₂ H	THF, 17 h, rt		(98) 40
C ₁₆ 	PhCO ₂ H	THF, 20°, 12 h		(91) 541
	PhCO ₂ H	—		(65) 542
C ₁₇ 	PhCO ₂ H	THF, rt, 20 min		(95) 543

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	HCO ₂ H	C ₆ H ₆ , rt, 15 min		(—) 106
	PhCO ₂ H	C ₆ H ₆ , 3 h, rt		(19) 378
	—	—		55
			R = CH ₂ OSiMe ₂ Bu- <i>t</i> R = CO ₂ Et	(91) (93)
C₁₉				
	PhCO ₂ H	C ₆ H ₆ , 3 h, rt		(62) 28
	PhCO ₂ H	—		(73) 544
C₂₀				
	PhCO ₂ H	THF, 3 h, rt		(87) 545
	PhCO ₂ H	THF, rt, overnight		(88) 546
	PhCO ₂ H	THF, rt, 5 min		(73) 547
C₂₁				
	AcOH	THF, 53 h, 17°		(75) 548
	PhCO ₂ H	THF, 15 min		(93) 118

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

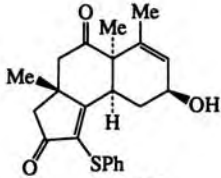
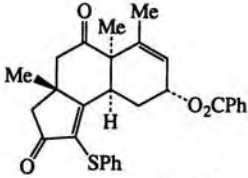
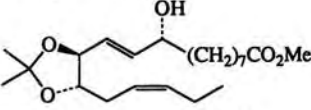
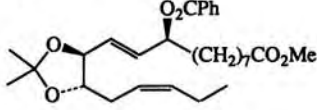
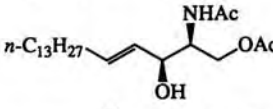
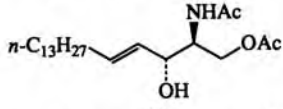
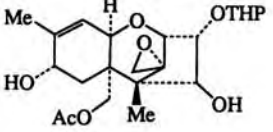
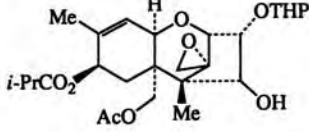
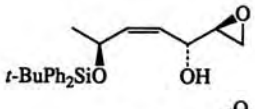
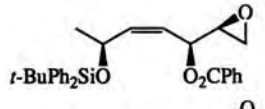
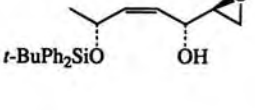
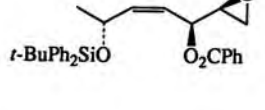
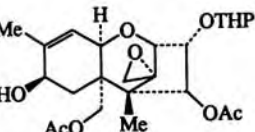
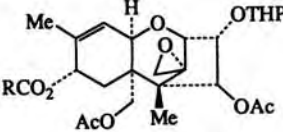
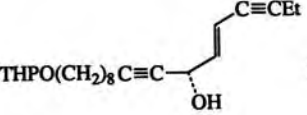
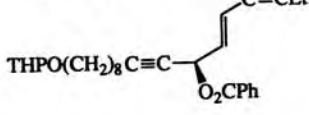
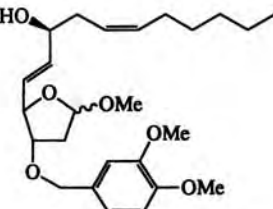
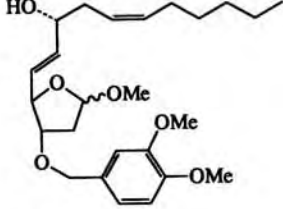
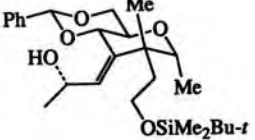
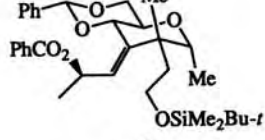
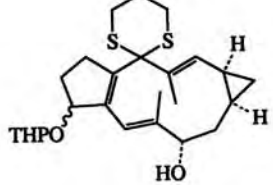
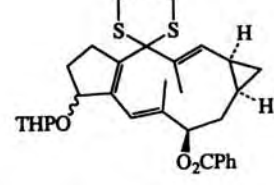
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCO ₂ H	THF, 1 h, 15°		(—) 44
	PhCO ₂ H	THF, 20°, 3 h		(83) 549
	PhCO ₂ H	1) THF 2) KOH/EtOH		(61) 550
	<i>i</i> -PrCO ₂ H	rt, 3 h		(35) 77
	PhCO ₂ H	—		(—) 551
	PhCO ₂ H	—		(—) 551
	RCO ₂ H	rt, 3 h	 R = HO(Me) ₂ CCH ₂ R = H	77 (21) (60)
	PhCO ₂ H	—		(—) 552
	PhCO ₂ H	—		(—) 491
	PhCO ₂ H	THF, rt, 5 min		(78) 553
	PhCO ₂ H	THF		(—) 76

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

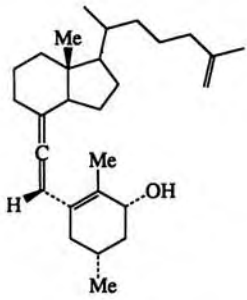
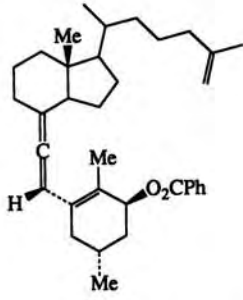
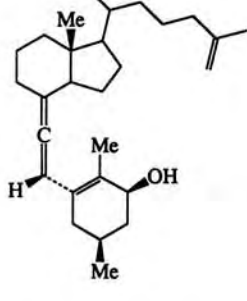
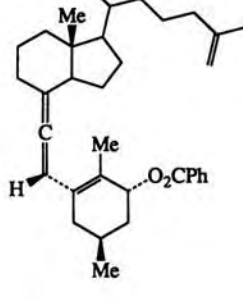
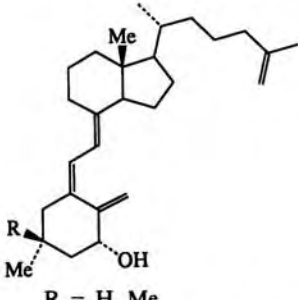
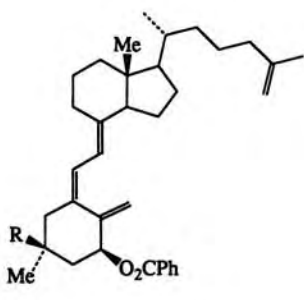
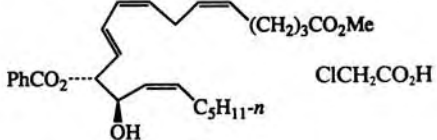
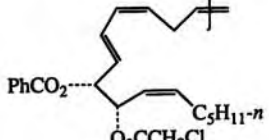
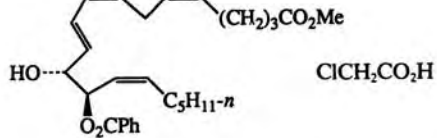
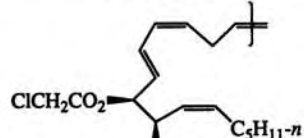
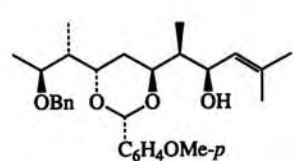
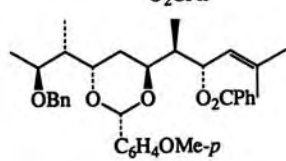
Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C_{28} 	PhCO ₂ H	C ₆ H ₆ , rt, 0.5 h		(32) 84
	PhCO ₂ H	C ₆ H ₆ , rt, 0.5 h		(32) 84
 R = H, Me	PhCO ₂ H	C ₆ H ₆ , rt, 0.5 h		(31-37) 84
	PhCO ₂ H	THF, rt, 10 min		(76) 554
	PhCO ₂ H	THF, rt, 10 min		(—) 554
C_{29} 	PhCO ₂ H	THF, 20°, 2 h		(85) 555

TABLE VI. ESTER FORMATION FROM SECONDARY ALCOHOLS, ALLYLIC (Continued)

	Alcohol	Carboxylic Acid	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₄		4-BrC ₆ H ₄ CO ₂ H	Et ₂ O, rt, overnight		(87) 54
C ₃₆		PhCO ₂ H	THF, 0°	 R = 3,4-(MeO) ₂ C ₆ H ₃ CH ₂	(—) 491
C ₃₉	 R = 3,4-(MeO) ₂ C ₆ H ₃ CH ₂	PhCO ₂ H	THF, 0°	 +	556
C ₄₂		HCO ₂ H	C ₆ H ₆ , rt, 1 h		124a
C ₅₁		PhCO ₂ H	C ₆ H ₆ , rt		(—) 557

TABLE VII. LACTONE FORMATION

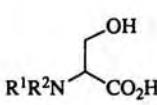
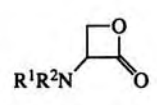
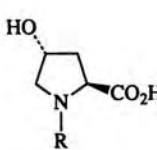
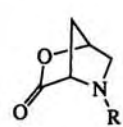
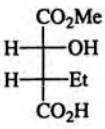
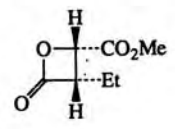
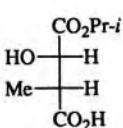
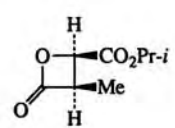
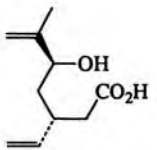
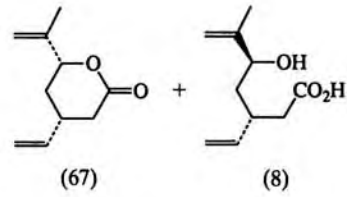
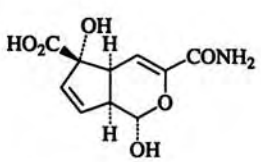
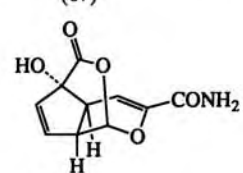
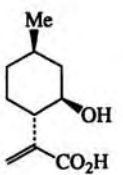
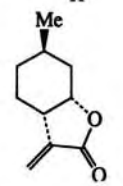
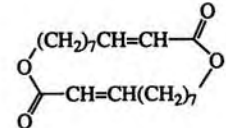
Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.												
C ₃ 	DMAD, THF, -78° to rt or CH ₃ CN, -55° to rt	 <table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>PhCH₂O₂C</td> <td>H</td> <td>(60)</td> </tr> <tr> <td>PhCH₂O₂C</td> <td>PhCH₂</td> <td>(76)</td> </tr> <tr> <td><i>t</i>-BuO₂C</td> <td>H</td> <td>(72)</td> </tr> </tbody> </table>	R ¹	R ²	Yield (%)	PhCH ₂ O ₂ C	H	(60)	PhCH ₂ O ₂ C	PhCH ₂	(76)	<i>t</i> -BuO ₂ C	H	(72)	147-149
R ¹	R ²	Yield (%)													
PhCH ₂ O ₂ C	H	(60)													
PhCH ₂ O ₂ C	PhCH ₂	(76)													
<i>t</i> -BuO ₂ C	H	(72)													
C ₅ 	THF, 0° to rt, several hours	 <table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>PhCO</td> <td>(93)</td> </tr> <tr> <td>MeCO</td> <td>(70)</td> </tr> <tr> <td><i>p</i>-Tosyl</td> <td>(86)</td> </tr> <tr> <td>PhCH₂O₂C</td> <td>(56)</td> </tr> <tr> <td><i>t</i>-BuO₂C</td> <td>(72)</td> </tr> </tbody> </table>	R	Yield (%)	PhCO	(93)	MeCO	(70)	<i>p</i> -Tosyl	(86)	PhCH ₂ O ₂ C	(56)	<i>t</i> -BuO ₂ C	(72)	558, 559
R	Yield (%)														
PhCO	(93)														
MeCO	(70)														
<i>p</i> -Tosyl	(86)														
PhCH ₂ O ₂ C	(56)														
<i>t</i> -BuO ₂ C	(72)														
C ₆ 	THF, rt, 16 h		(61) 396												
C ₈ 	THF, 0° to rt, 12 h		(62) 144												
C ₁₀ 	THF, -40°, 3 h		113												
	(<i>n</i> -Bu) ₃ P, THF, 4-Å sieves, -15° to rt		(28-31) 430												
	C ₆ H ₆ , rt, 36 h		(43) 560												
HO(CH ₂) ₇ CH=CHCO ₂ H	C ₆ H ₆ , 72 h, 20°, 4-Å sieves		(24) 561												

TABLE VII. LACTONE FORMATION (Continued)

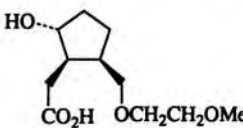
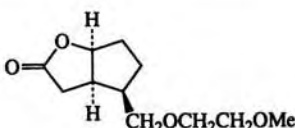
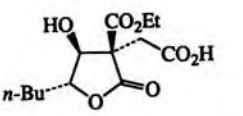
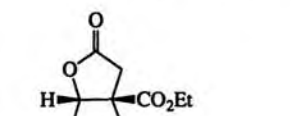
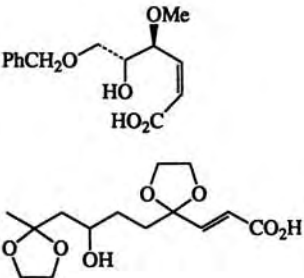
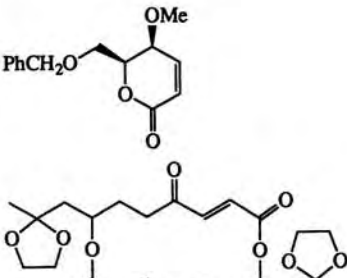
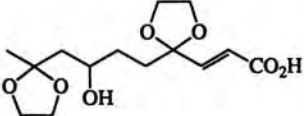
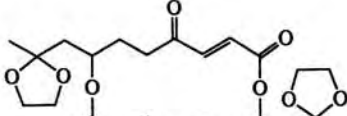
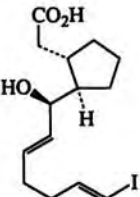
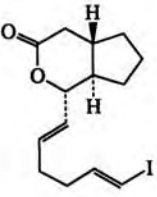
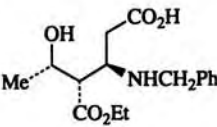
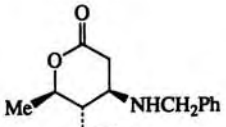
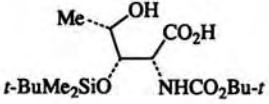
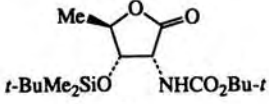
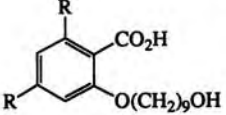
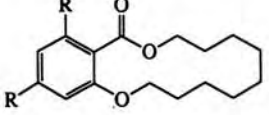
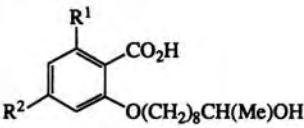
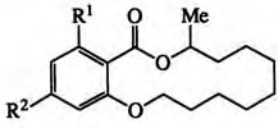
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₁		C ₆ H ₆ , 3 h, 5–10°		(—) 562
C ₁₃		THF, rt, overnight		(57) 563
C ₁₄		—		(69) 564
		Toluene, –20° for 20 h, 15° for 15 h		(38) 155
		Toluene, –30°		(63) 565
C ₁₆		THF		(53) 566
		THF, rt, 18 h		(54) 567
		THF, 25°		568
			R = H R = PhCH ₂ O	(66) (40)
C ₁₇		THF, 25°		568
			R ¹ = R ² = H R ¹ = OH R ² = PhCH ₂	(20) —

TABLE VII. LACTONE FORMATION (Continued)

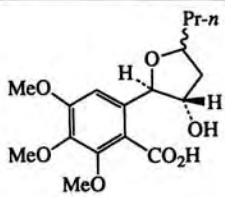
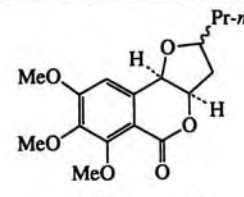
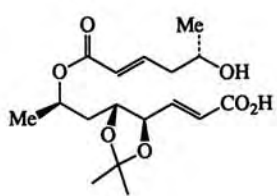
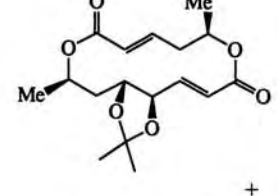
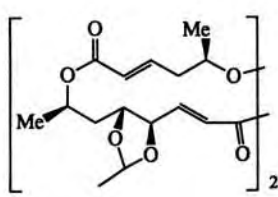
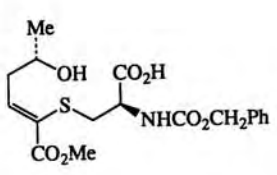
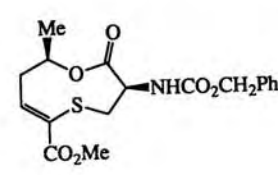
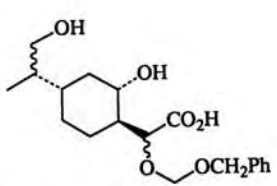
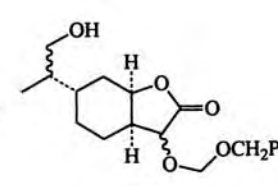
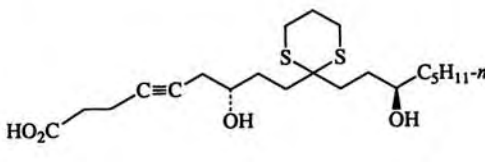
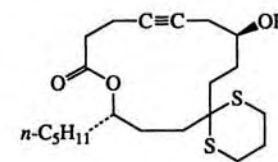
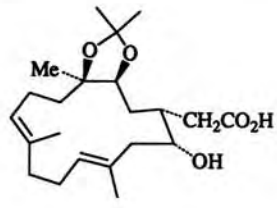
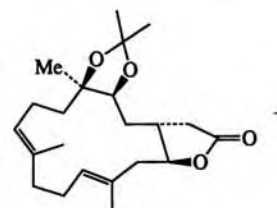
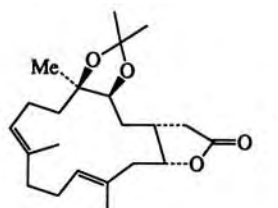
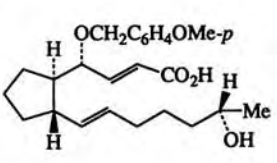
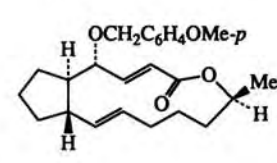
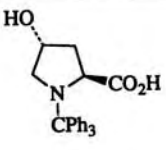
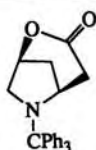
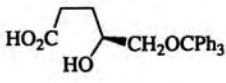
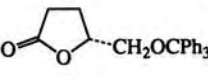
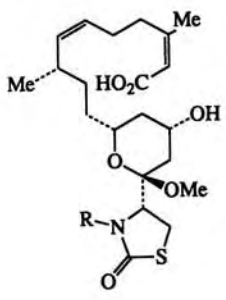
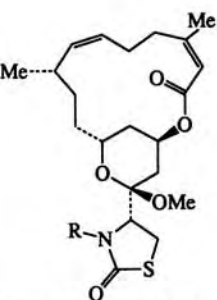
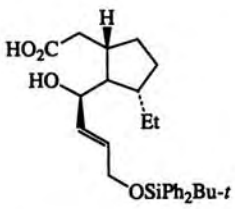
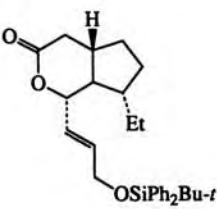
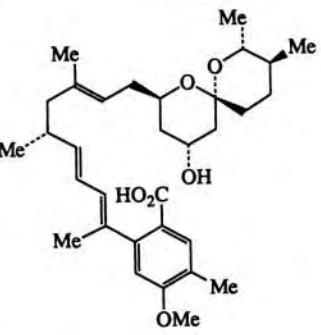
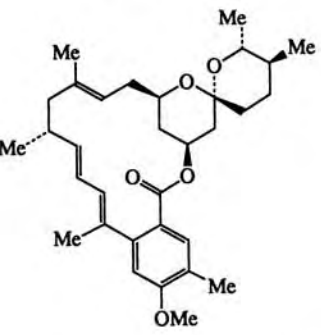
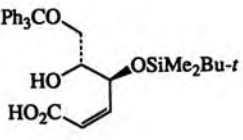
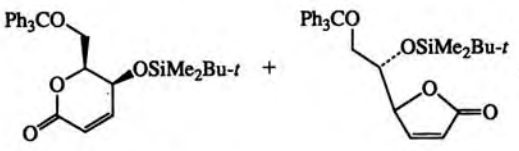
Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
	THF, rt, 3 h		(69) 569
	Toluene, -10 to 0°, 115 h	 + 	(45) 154 (21)
C_{18} 	C_6H_6 , rt, 2 days		(39) 156, 157
C_{19} 	THF, 4.5 h, -20°, high dilution		(—) 150
C_{21} 	C_6H_6 , 10 min		(59) 151
C_{22} 	—	 + 	142 (50) (50)
C_{24} 	Toluene, 2.5 mM reaction conc.		(85) 570

TABLE VII. LACTONE FORMATION (Continued)

Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
	THF, 0°, 5 min		(60) 571
	C ₆ H ₆ /THF, rt, 24 h		(80) 572
<p>C₂₈</p> 	C ₆ H ₆	 <p>R = 4-MeOC₆H₄CH₂ R = Me₃SiCH₂CH₂O₂C</p>	(68) 573, 574 (68) (25)
<p>C₂₉</p> 	Toluene, -20°		(67) 575
<p>C₃₁</p> 	C ₆ H ₆ , 8°		(77) 152, 153
<p>C₃₄</p> 	—	 <p>(62) + (38)</p>	564

470

471

TABLE VII. LACTONE FORMATION (Continued)

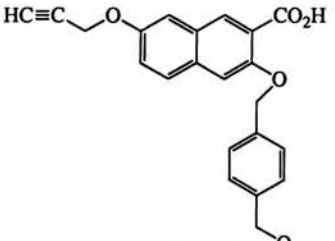
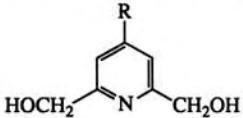
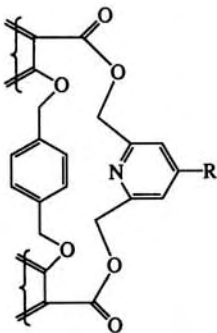
Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C_{36}  	THF, rt, 2-3 days	 R = H R = NMe ₂	576 (58) (54)

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS

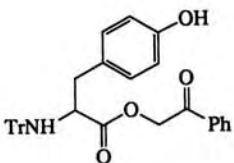
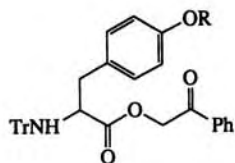
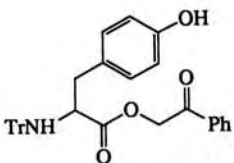
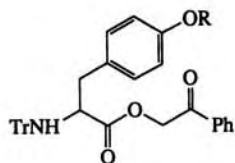
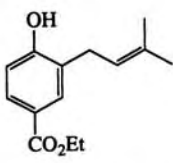
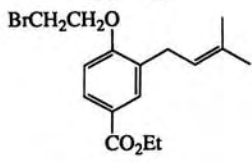
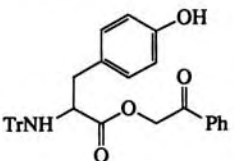
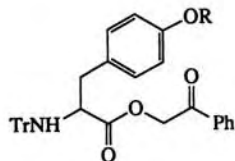
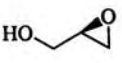
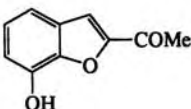
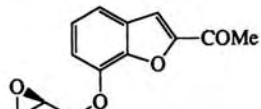
Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁ MeOH		THF		74
C ₂ EtOH				74
			R = Me R = Et	(70) (75)
BrCH ₂ CH ₂ OH		THF, rt, 20 h		(70) 577
C ₃ <i>i</i> -PrOH HC≡CCH ₂ OH		THF		74
			R = <i>i</i> -Pr R = propargyl	(66) (60)
		THF, 0°, 3 h		(80) 578

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

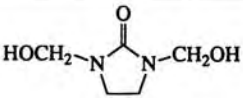
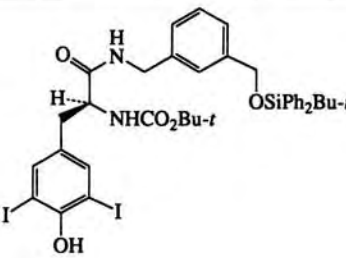
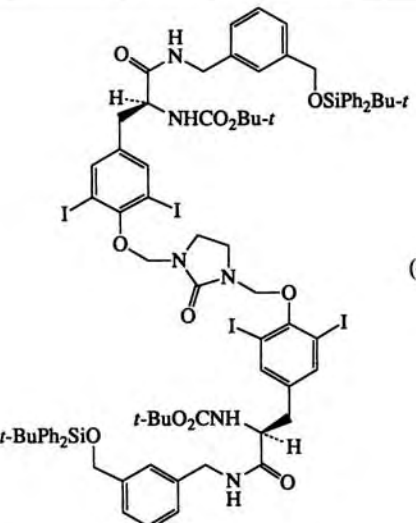
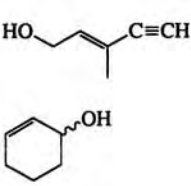
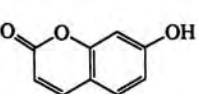
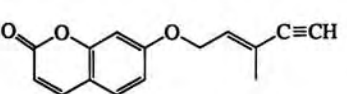
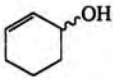
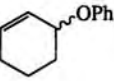
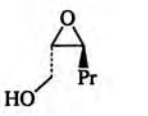
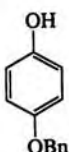
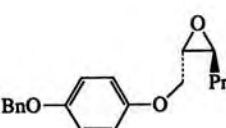
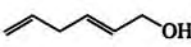
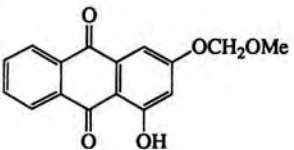
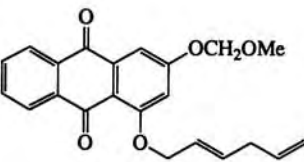
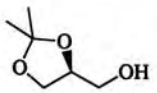
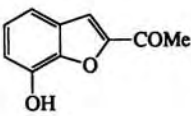
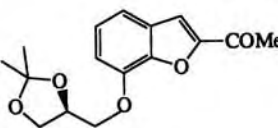
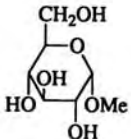
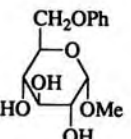


Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
		—		(—) 585
<p>C₆</p> 		THF, rt, 16 h		(83) 586
	PhOH	—		(—) 587
		THF		(78) 588
		THF, rt, 3 h		(82) 589
		THF, 2 h, 40°		(79) 590
<p>C₇</p> 	PhOH	Pyridine		(30) 591
	4-RC ₆ H ₄ OH	THF, rt, 4 days		592
			R = H	(72)
			R = CN	(39)

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

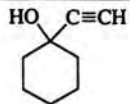
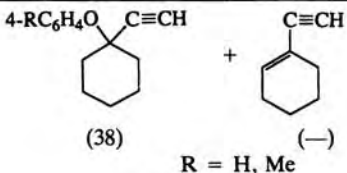
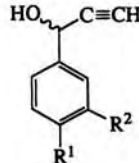
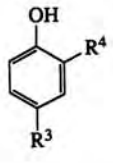
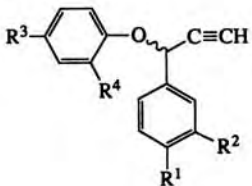

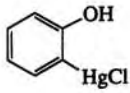
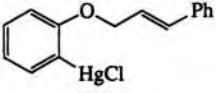
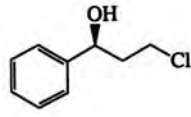
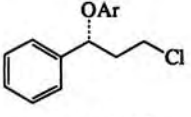
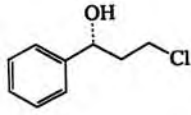
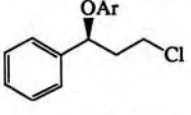
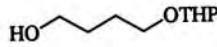
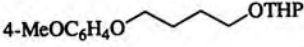
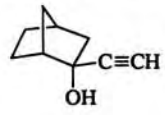
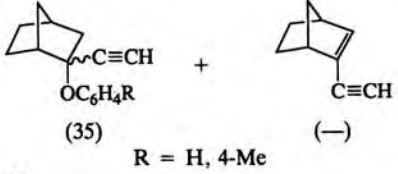
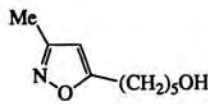
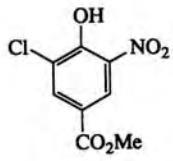
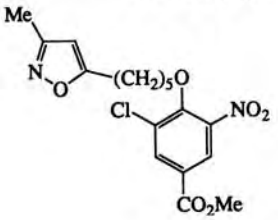
Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.																																																												
	4-RC ₆ H ₄ OH	—		593																																																												
<p>C₉</p> 		—		594																																																												
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr><td>H</td><td>H</td><td>H</td><td>H</td><td>52</td></tr> <tr><td>H</td><td>H</td><td>Me</td><td>H</td><td>51</td></tr> <tr><td>H</td><td>H</td><td>Cl</td><td>H</td><td>50</td></tr> <tr><td>H</td><td>H</td><td>MeO</td><td>H</td><td>46</td></tr> <tr><td>H</td><td>H</td><td>H</td><td>Me</td><td>51</td></tr> <tr><td>MeO</td><td>H</td><td>H</td><td>H</td><td>51</td></tr> <tr><td>MeO</td><td>H</td><td>Me</td><td>H</td><td>55</td></tr> <tr><td>MeO</td><td>H</td><td>Cl</td><td>H</td><td>45</td></tr> <tr><td>MeO</td><td>H</td><td>MeO</td><td>H</td><td>45</td></tr> <tr><td>MeO</td><td>MeO</td><td>Me</td><td>H</td><td>50</td></tr> <tr><td>H</td><td>H</td><td>NO₂</td><td>H</td><td>40</td></tr> </tbody> </table>					R ¹	R ²	R ³	R ⁴	Yield (%)	H	H	H	H	52	H	H	Me	H	51	H	H	Cl	H	50	H	H	MeO	H	46	H	H	H	Me	51	MeO	H	H	H	51	MeO	H	Me	H	55	MeO	H	Cl	H	45	MeO	H	MeO	H	45	MeO	MeO	Me	H	50	H	H	NO ₂	H	40
R ¹	R ²	R ³	R ⁴	Yield (%)																																																												
H	H	H	H	52																																																												
H	H	Me	H	51																																																												
H	H	Cl	H	50																																																												
H	H	MeO	H	46																																																												
H	H	H	Me	51																																																												
MeO	H	H	H	51																																																												
MeO	H	Me	H	55																																																												
MeO	H	Cl	H	45																																																												
MeO	H	MeO	H	45																																																												
MeO	MeO	Me	H	50																																																												
H	H	NO ₂	H	40																																																												
		—		(—) 579																																																												
	ArOH	THF, rt, overnight		(70) (65) 595 (62)																																																												
	ArOH	THF, rt, overnight		(68) (—) 595 (—)																																																												
	4-MeOC ₆ H ₄ OH	CH ₂ Cl ₂ , rt, 0.5 h		(99) 370																																																												
	RC ₆ H ₄ OH	rt		593																																																												
		CH ₂ Cl ₂ , rt, overnight		(78) 596																																																												

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

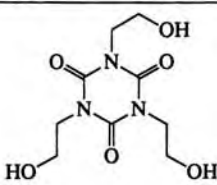
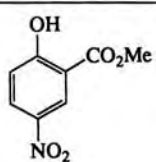
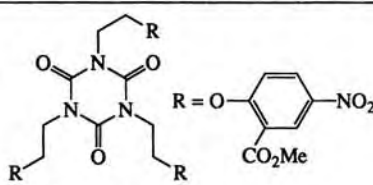
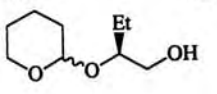
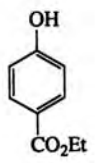
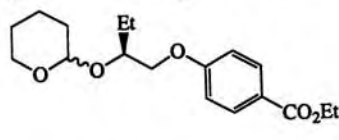
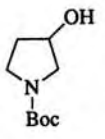

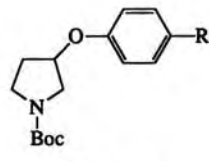
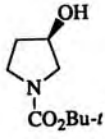
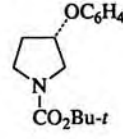
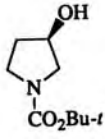
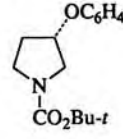
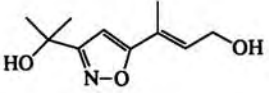
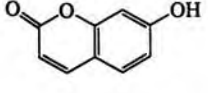
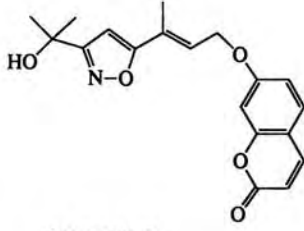
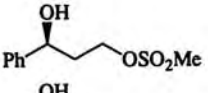
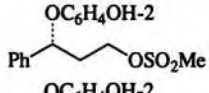
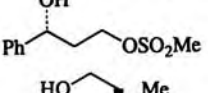
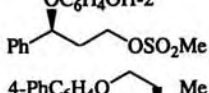
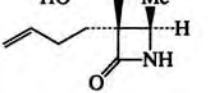
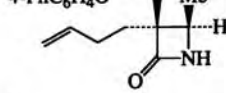

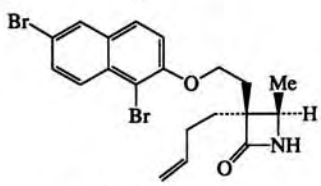
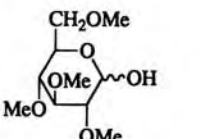
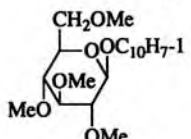
Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
		Dioxane	 R = O-C ₆ H ₄ -NO ₂ CO ₂ Me	(95) 597
		THF, rt, 24 h		(22) 598
		—		599
	4-NCC ₆ H ₄ OH	THF, rt, overnight	 R = H R = CH ₂ CH ₂ NPh	(82) (75)
	4-NCC ₆ H ₄ OH	THF, rt, overnight	 OC ₆ H ₄ CN-4	(85) 600
		—		(61) 601
	2-HOC ₆ H ₄ OH	Ether, -10°, 4 h	 OC ₆ H ₄ OH-2	(71) 602
	2-HOC ₆ H ₄ OH	Ether, -10°, 4 h	 OC ₆ H ₄ OH-2	(83) 602
	4-PhC ₆ H ₄ OH	—	 4-PhC ₆ H ₄ O	(50) 426
	1,6-Dibromo-2-naphthol	—		(70) 426
	1-Naphthol	THF, rt, 15 h	 CH ₂ OMe OOC ₁₀ H ₇ -1	(66) 603

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

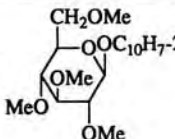
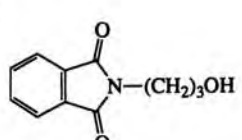
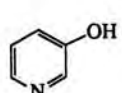
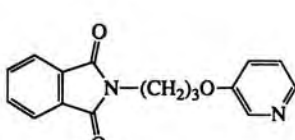
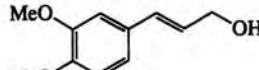
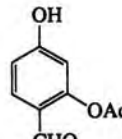
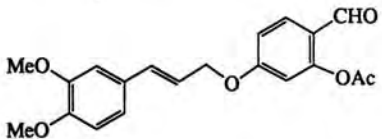
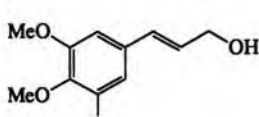
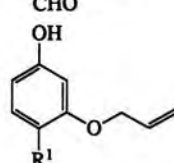
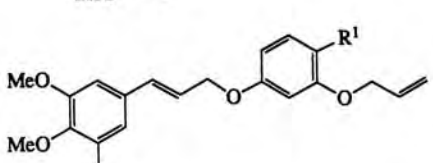
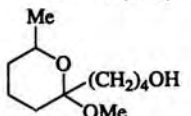
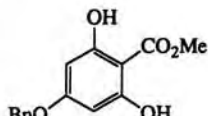
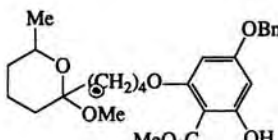
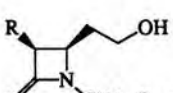
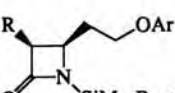
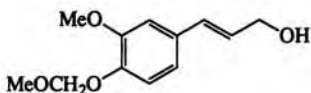
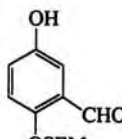
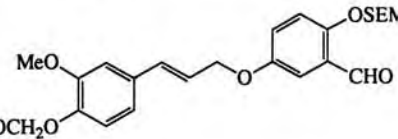
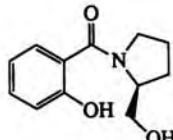
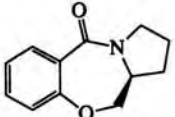
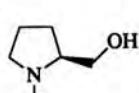
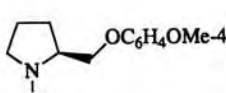
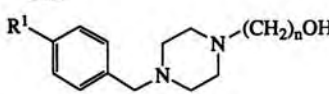
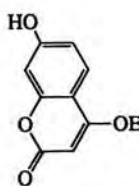
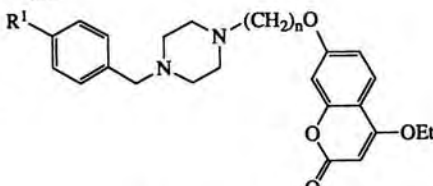
Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
	2-Naphthol	THF, rt, 15 h		(72) 603
C ₁₁ 		DMF, rt, overnight		(43) 604
		THF, rt, 22 h		(30) 605
		—		(20–25) 606, 607
R = H, MeO R' = H, Bn, MeO				
		THF, rt, 48 h		(65) 568
	PhOH 4-O ₂ NC ₆ H ₄ OH 2,4-(O ₂ N) ₂ C ₆ H ₃ OH	THF, 0–5°, 1 h		608
R = PhNt, PhCH ₂ O ₂ CNH			H 4-O ₂ N 2,4-(O ₂ N) ₂	(54) (67) (45)
C ₁₂ 		THF, rt, 24 h		(55) 605
		—		(80) 166
C ₁₃ 	4-MeOC ₆ H ₄ OH	THF, 80°, 15 min		370
		THF, rt, 0.5 h		609
			R ¹ = Cl, n = 2 R ¹ = H, n = 3	(58) (59)

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

	Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
			THF, rt		(84) 168
C ₁₅			Toluene, 2 h, rt		(71) 164
		2-MeOC ₆ H ₄ OH	-25° to rt, ether (n-Bu) ₃ P		(34) 610
		PhOH 4-ClC ₆ H ₄ OH 2-MeOC ₆ H ₄ OH	THF, rt, overnight		(84) 611
C ₁₆		2-MeOC ₆ H ₄ OH	THF, rt, 2 h		(—) 612
C ₁₇		4-PhCH ₂ OC ₆ H ₄ OH	CH ₂ Cl ₂ , rt, 16 h		(73) 613
					(3-5)
C ₁₉			—		(70) 167
					(10)

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

	Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
			—		(73) 224
C ₂₁		PhOH	THF, rt, overnight		(73) 614
			THF, rt, 3 h		(77) 615
	$\alpha:\beta = 2:1$			$\alpha:\beta = 4:5$	
C ₂₁			<i>n</i> -(Bu) ₃ P, THF, 0.75 h, 4–25°		(80) 385, 386
					(50) 165
			THF, 20°, 2 h		(50) 165
C ₂₂		4-AcC ₆ H ₄ OH	THF, 0.5 h		(71) 616
		4-MeOC ₆ H ₄ OH	THF, 80°, 1 h		(82) 617
		4-MeOC ₆ H ₄ OH	CH ₂ Cl ₂		(84) 618
			THF, 15 min, 25°		(95) 385

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
<p>C₂₆</p>		<p><i>n</i>-(Bu)₃P, THF, 0.75 h, 4–25°</p>	<p>R = Ph R = <i>t</i>-Bu</p>	<p>385 (87) (55)</p>
<p>C₂₈</p>		<p>THF, rt</p>		<p>(88) 167</p>
		<p>THF, 20°, 1 h</p>		<p>(—) 165</p>
<p>C₃₅</p>	(—)	<p>Dioxane, rt</p>	<p>n = 3 n = 0</p>	<p>367 (94) (87)</p>
	ArOH	<p>THF, 1 h</p>	<p>(18–25)</p>	<p>247</p>
<p>Ar = Ph, 4-MeOC₆H₄, 2,3-(MeO)₂C₆H₃, 3,4,5-(MeO)₃C₆H₂, 4-PhOC₆H₄, 4-O₂NC₆H₄, 3-Me₂NC₆H₄, 4-PhCOC₆H₄, 4-OHCC₆H₄</p>				
<p>C₄₁</p>		<p>THF, rt, 45 min</p>		<p>(—) 619</p>
		<p>"</p>		<p>619</p>
<p>R = <i>n</i>-C₁₆H₃₃ R = <i>n</i>-C₁₈H₃₇</p>				
<p>(87) (91)</p>				

TABLE VIII. FORMATION OF ALKYL ARYL ETHERS (Continued)

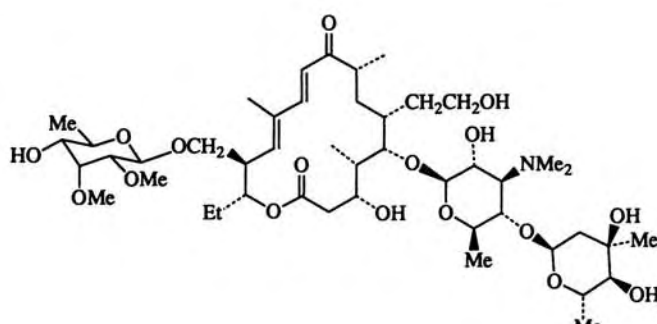
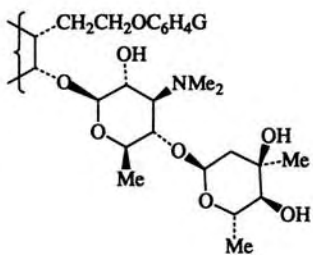
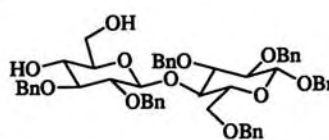
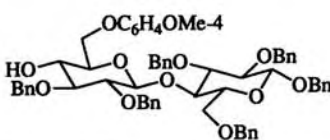
Alcohol	Phenol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₇				
		GC ₆ H ₄ OH	Toluene:CH ₂ Cl ₂ :THF 1.6:2:4, 0.5 h, rt	244
<p>G = H (52), 4-O₂N, 4-MeO, 4-OHC, 4-HOCH₂, 3,5-Cl₂, 3-Me₂N, 4-EtO₂C, 4-Ph, 3-PhO, 4-PhO, 4-PhCO</p>				
C ₆₀				
	4-MeOC ₆ H ₄ OH	CH ₂ Cl ₂		(75) 620

TABLE IX. DIALKYL ETHER FORMATION, EPOXIDES

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃		C ₆ H ₆ , reflux		447, 621
			R = CH ₂ CH=CH ₂ (59) R = CH ₂ Ph (72) R = <i>n</i> -C ₁₆ H ₃₃ (72)	
		C ₆ H ₆ , 25°		(—) 181
			82% retention	
C ₆		THF, 0°		(87) 622
		DMF, 2 h, rt		(65) 374
C ₇		Dioxane, 70°, 10 min		(100) 178
		C ₆ H ₆ , 125–130°, 1.5 h		(—) 402

TABLE IX. DIALKYL ETHER FORMATION, EPOXIDES (Continued)

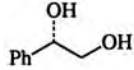

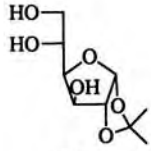
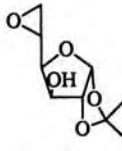
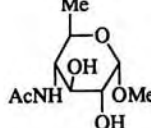
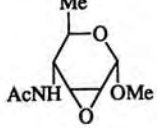
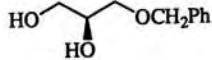
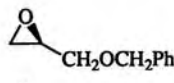
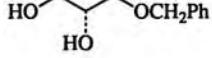
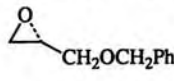
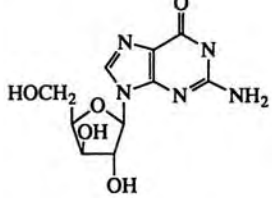
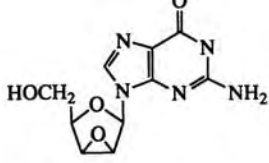
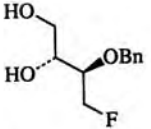
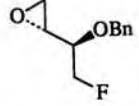
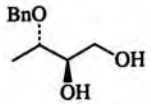
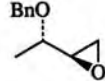
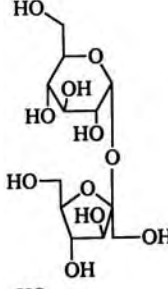
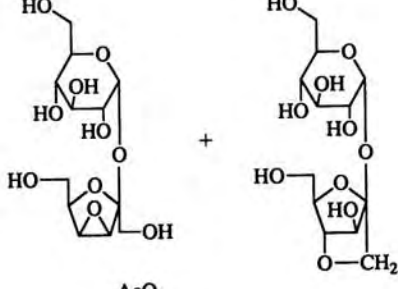
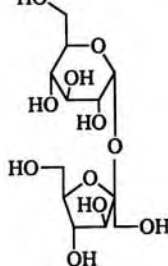
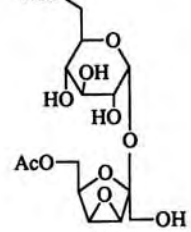
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₈		C ₆ H ₆ , 25°	 racemic (68)	181
C ₉		C ₆ H ₆ , reflux, 2.5 h 3-Å sieves	 (85)	83, 623
		CHCl ₃ , 18 h, rt	 (99)	175
C ₁₀		C ₆ H ₆ , reflux, 20 h	 (61)	624
		C ₆ H ₆ , reflux, 20 h	 (76)	624
		—	 (—)	625
		C ₆ H ₆ , rt	 (78)	626
C ₁₁		110°, neat	 (88)	627
C ₁₂		DMF, rt, 16 h	 (24)	176, 628
		DMF, AcOH, 16 h, rt	 (42)	176, 628

TABLE IX. DIALKYL ETHER FORMATION, EPOXIDES (Continued)

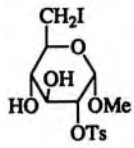
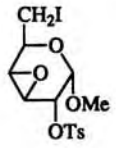
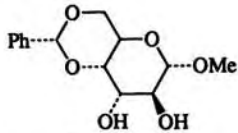
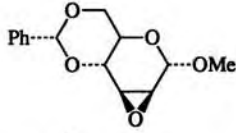
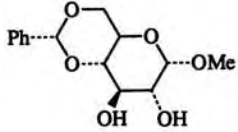
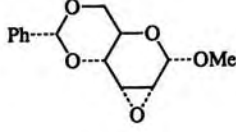
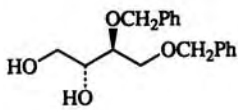
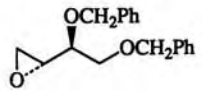
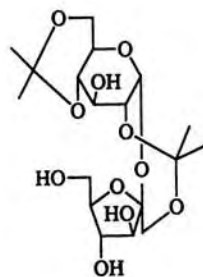
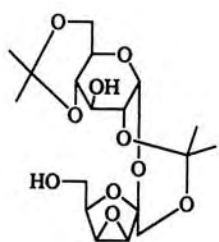
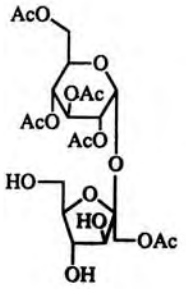
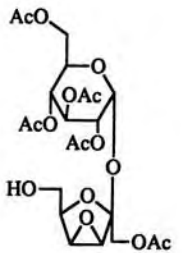
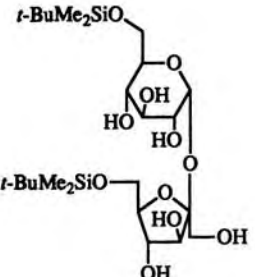
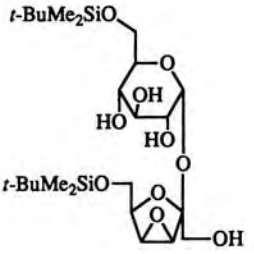
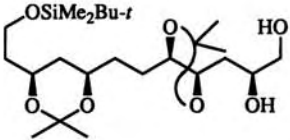
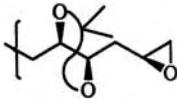
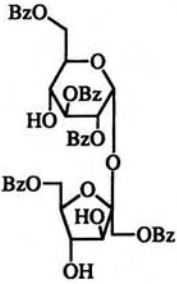
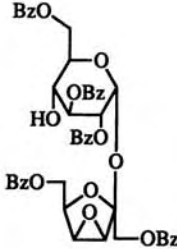
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₄		Toluene, 2 h, 90°	 (56)	179
C ₁₅		THF, reflux, 30 min	 (70)	177
		DMF, 7 days, 80°	 (81)	177
C ₁₈		C ₆ H ₆ , 125–130°, 1.5 h	 (83)	402
		C ₆ H ₆ , reflux, 1.5 h	 (60)	176, 628
C ₂₂		DMF, 60°	 (54)	629
C ₂₄		—	 (—)	176

TABLE IX. DIALKYL ETHER FORMATION, EPOXIDES (Continued)

Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
	C_6H_6 , 85°, 4 days, 3-Å sieves	 (70)	630
	$CHCl_3$, 3 h	 (80)	176, 628

C₁₇

TABLE X. CARBON-OXYGEN BOND FORMATION, FOUR- TO SIX-MEMBERED CYCLIC ETHERS

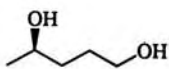
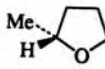
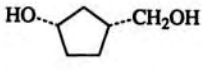

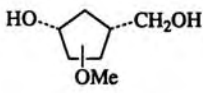
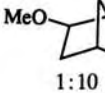
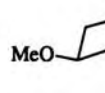
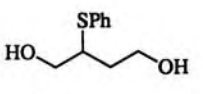
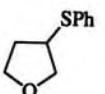
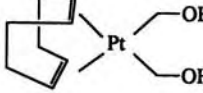
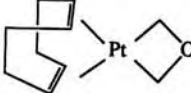
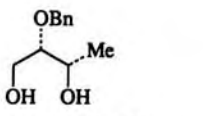
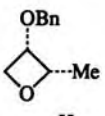
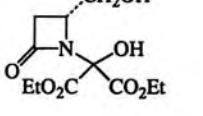
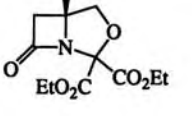
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₅		C ₆ H ₆ , 25°	 86% retention	181
C ₆		CH ₂ Cl ₂ or CHCl ₃ , rt	 (—)	631
C ₇		CH ₂ Cl ₂ or CHCl ₃ , rt	 +  (81)	631
C ₁₀		THF, 10 h, rt	 (74)	632
		THF, -35°	 (71)	633
C ₁₁		(MeO) ₃ P, CH ₂ Cl ₂ , rt, 5 min	 (52)	634
		THF, 1 h, rt	 (80)	635

TABLE X. CARBON-OXYGEN BOND FORMATION, FOUR- TO SIX-MEMBERED CYCLIC ETHERS (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₂		THF, rt, 1 h		(65) 635
		(MeO) ₃ P, THF, 25°, 2 h		(32) 180
C ₁₄		—		(—) 636
		C ₆ H ₆ , 48 h, rt		637
			R = H R = Mc	(53) (48)
		C ₆ H ₆ , 1 h		(80) 638, 639
C ₁₇		—		(—) 640
C ₁₉		THF, HCO ₂ H, 17 h, rt		(70) 641
C ₂₁		(MeO) ₃ P, CH ₂ Cl ₂ , 0.5 h		(20) 180
		(MeO) ₃ P, CH ₂ Cl ₂ , 0.5 h		(21) 180

TABLE XI. ENOL ETHER FORMATION

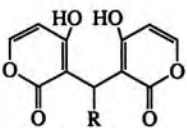
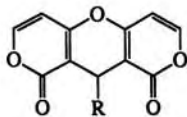
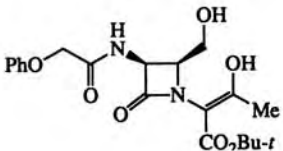
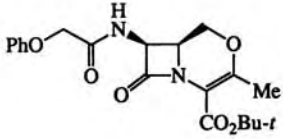
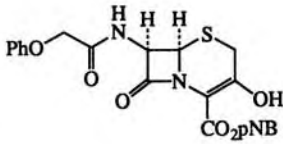
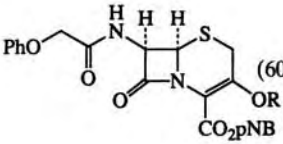
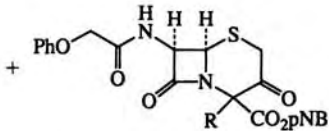
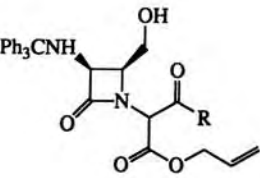
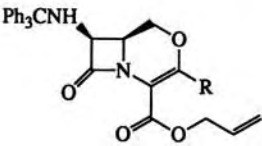
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																
C ₁₁		C ₆ H ₆ , rt, 17 h	 <table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>(73)</td> </tr> <tr> <td>Et</td> <td>(88)</td> </tr> <tr> <td><i>n</i>-Pr</td> <td>(62)</td> </tr> <tr> <td>Ph</td> <td>(80)</td> </tr> <tr> <td>4-ClC₆H₄</td> <td>(60)</td> </tr> <tr> <td>4-MeOC₆H₄</td> <td>(77)</td> </tr> </tbody> </table>	R	Yield (%)	H	(73)	Et	(88)	<i>n</i> -Pr	(62)	Ph	(80)	4-ClC ₆ H ₄	(60)	4-MeOC ₆ H ₄	(77)	171		
R	Yield (%)																			
H	(73)																			
Et	(88)																			
<i>n</i> -Pr	(62)																			
Ph	(80)																			
4-ClC ₆ H ₄	(60)																			
4-MeOC ₆ H ₄	(77)																			
C ₂₀		THF, rt, 0.5 h	 (57)	169																
C ₂₂		THF or CH ₂ Cl ₂ , rt, 20 min, DMAD; ROH, R = CH ₃ to <i>n</i> -C ₈ H ₁₇	 (60-90)  (10)	170																
C ₂₉		THF, rt, 15 min	 <table border="1"> <thead> <tr> <th>R</th> <th>(% yield)</th> </tr> </thead> <tbody> <tr> <td>CH₂CH₂SePh</td> <td>(73)</td> </tr> <tr> <td>CH₂Cl</td> <td>(82)</td> </tr> <tr> <td>(CH₂)₃SePh</td> <td>(91)</td> </tr> <tr> <td>H</td> <td>(39)</td> </tr> <tr> <td>Me</td> <td>(95)</td> </tr> <tr> <td><i>n</i>-Pr</td> <td>(81)</td> </tr> <tr> <td><i>c</i>-C₄H₉</td> <td>(95)</td> </tr> </tbody> </table>	R	(% yield)	CH ₂ CH ₂ SePh	(73)	CH ₂ Cl	(82)	(CH ₂) ₃ SePh	(91)	H	(39)	Me	(95)	<i>n</i> -Pr	(81)	<i>c</i> -C ₄ H ₉	(95)	394
R	(% yield)																			
CH ₂ CH ₂ SePh	(73)																			
CH ₂ Cl	(82)																			
(CH ₂) ₃ SePh	(91)																			
H	(39)																			
Me	(95)																			
<i>n</i> -Pr	(81)																			
<i>c</i> -C ₄ H ₉	(95)																			

TABLE XII. CARBON-OXYGEN BOND FORMATION WITH *N*-HYDROXYIMIDES AND AMIDES

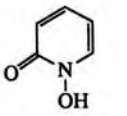
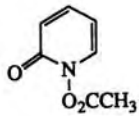
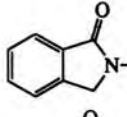
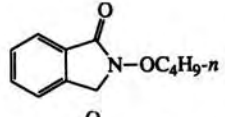
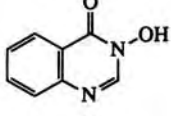
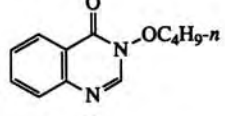
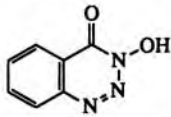
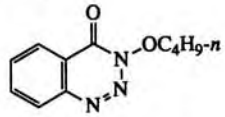
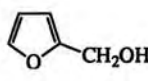
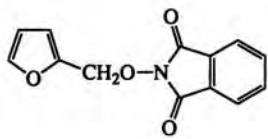
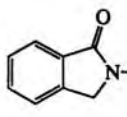
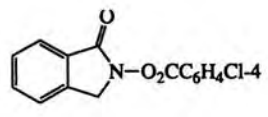
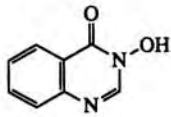
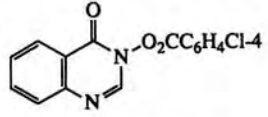
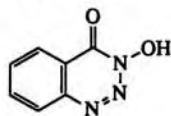
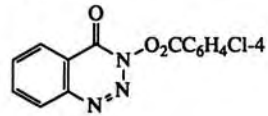
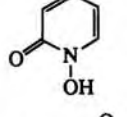
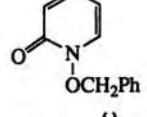
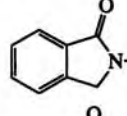
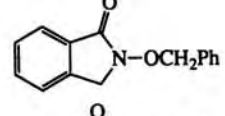
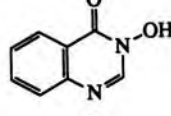
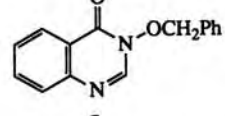
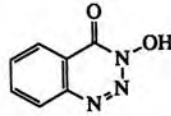
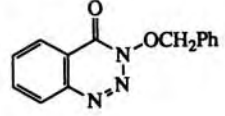
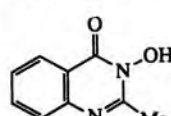
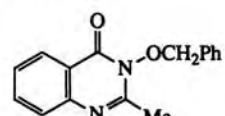
	Alcohol	<i>N</i> -Hydroxy Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂	CH ₃ CO ₂ H		THF, rt, 24 h	 (82)	183
C ₄	<i>n</i> -C ₄ H ₉ OH		"	 (75)	183
			"	 (82)	183
			"	 (73)	183
C ₅		<i>N</i> -Hydroxyphthalimide	THF, rt, 1 h	 (—)	642
C ₇	4-ClC ₆ H ₄ CO ₂ H		THF, rt, 24 h	 (71)	183
			"	 (50)	183
			"	 (66)	183
	PhCH ₂ OH		THF, rt, 24 h	 (94)	183
			"	 (94)	183
			"	 (63)	183
			"	 (83)	183
			"	 (80)	183

TABLE XII. CARBON-OXYGEN BOND FORMATION WITH *N*-HYDROXYIMIDES AND AMIDES (Continued)

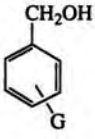
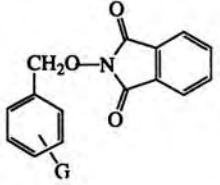
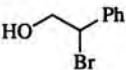
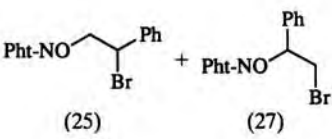
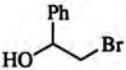
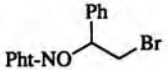
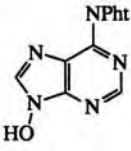
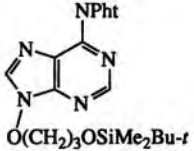
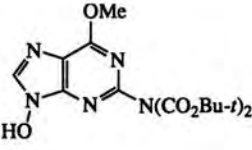
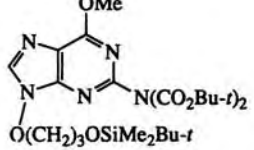
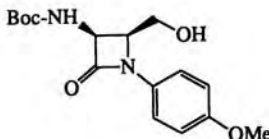
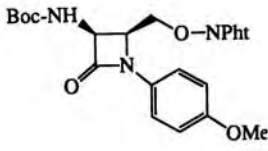
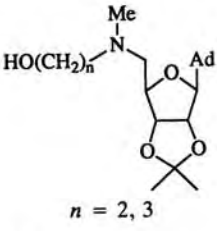
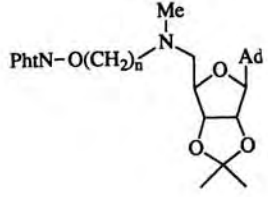
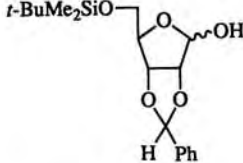
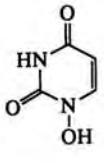
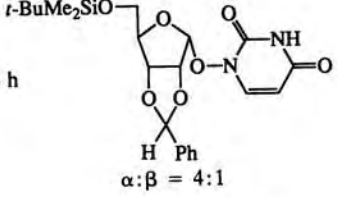
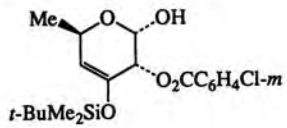
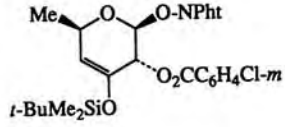
	Alcohol	<i>N</i> -Hydroxy Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
	 G = H, 4-F, 4-OH, 2-OH, 3-OH, 4-NHCOMe	Pht-NOH	THF, rt, 1 h	 (15-65)	642
C ₈		Pht-NOH	THF, rt, 18 h	 (25) + (27)	185
C ₉		Pht-NOH	THF, rt, 18 h	 (69)	185
	<i>t</i> -BuMe ₂ SiO(CH ₂) ₃ OH		THF	 (70)	643
			THF	 (89)	643
C ₁₅		Pht-NOH	THF, rt, 0.5 h	 (81)	644
C ₁₆	 n = 2, 3	Pht-NOH	—	 (—)	645
C ₁₈			THF, rt, 24 h	 (31)	646
C ₁₉		Pht-NOH	THF, rt, 0.5 h	 (53)	647

TABLE XII. CARBON-OXYGEN BOND FORMATION WITH *N*-HYDROXYIMIDES AND AMIDES (Continued)

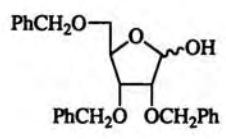
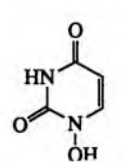
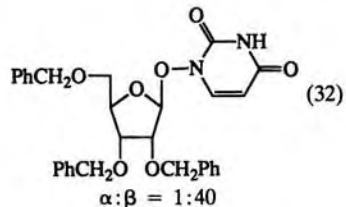
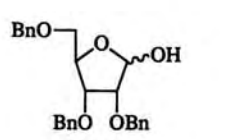
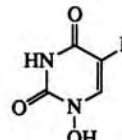
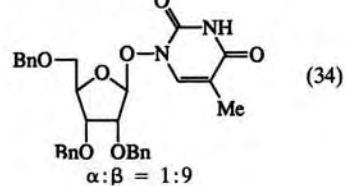
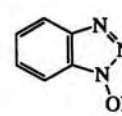
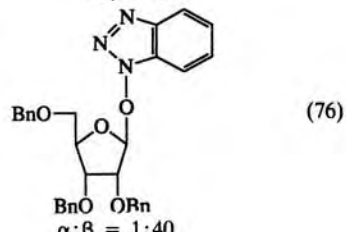
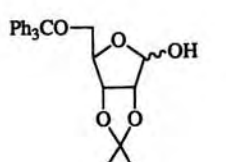
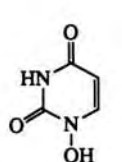
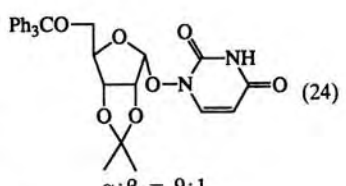
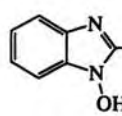
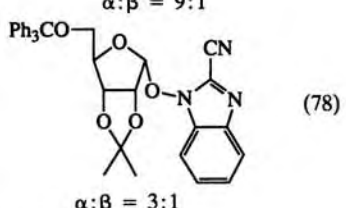
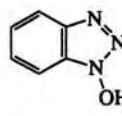
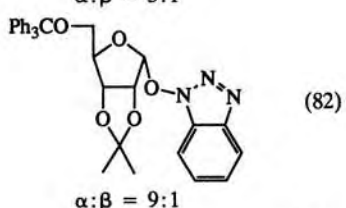
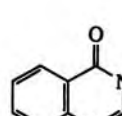
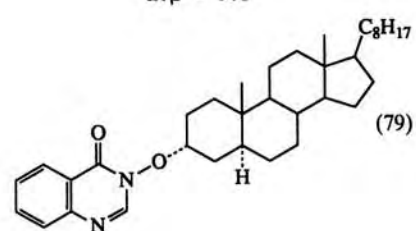
Alcohol	<i>N</i> -Hydroxy Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₆ 		THF, rt, 24 h	 (32) 64%	646
		THF, rt, 24 h	 (34) 64%	646
		THF, rt, 24 h	 (76) 64%	646
C ₂₇ 		THF, rt, 24 h	 (24) 64%	646
		"	 (78) 64%	646
		"	 (82) 64%	646
Cholestan-3β-ol		"	 (79) 18%	183

TABLE XII. CARBON-OXYGEN BOND FORMATION WITH *N*-HYDROXYIMIDES AND AMIDES (Continued)

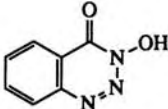
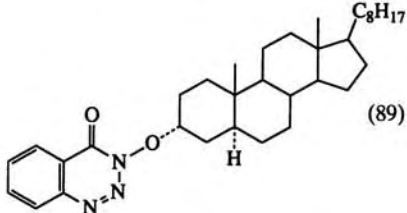
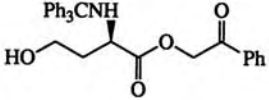
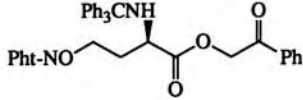
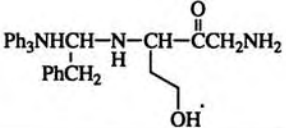
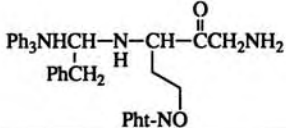
	Alcohol	<i>N</i> -Hydroxy Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
			"	 (89)	183
C ₃₀		Pht-NOH	THF, rt, 1.5 h	 (65)	648
C ₃₁		Pht-NOH	—	 (40)	649

TABLE XIII. CARBON-OXYGEN BOND FORMATION, TOSYLATES

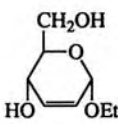
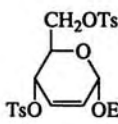
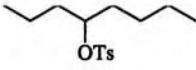
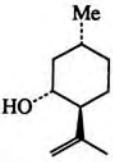
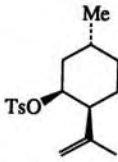
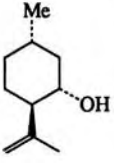
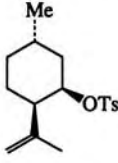
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.	
C ₄	2-Butanol	TsOLi or (TsO) ₂ Zn, C ₆ H ₆ , rt, 24 h	CH ₃ CH(OTs)CH ₂ CH ₃ (82)	182	
C ₅	C ₅ H ₉ OH	"	C ₅ H ₉ OTs (48–86)	182	
C ₆	C ₆ H ₁₁ OH	"	C ₆ H ₁₁ OTs (15–80)	182	
C ₈		(TsO) ₂ Zn		(—)	140
	4-Octanol	TsOLi or (TsO) ₂ Zn, C ₆ H ₆ , rt, 24 h		(78–84)	182
C ₁₀		LiOTs or (TsO) ₂ Zn, C ₆ H ₆ , rt, 48 h		(67–94)	182
		"		(68–90)	182

TABLE XIII. CARBON-OXYGEN BOND FORMATION, TOSYLATES (Continued)

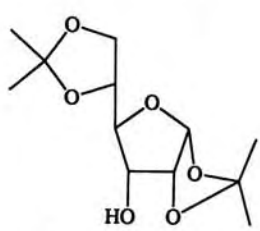
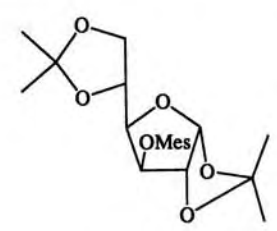
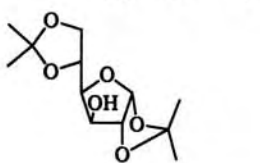
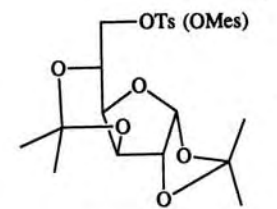
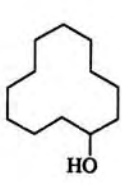
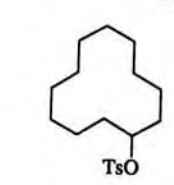
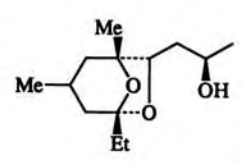
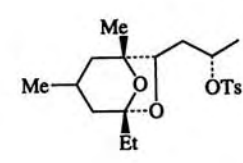
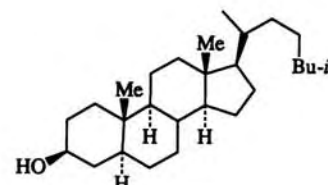
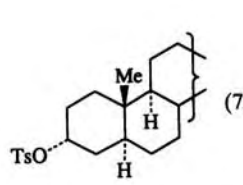
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₂		MeOMes, 24 h, toluene, 100°	 (83)	16
		MeOMes or TsOMe, toluene, 100°, 24 h	 (OMes) -OTs (67) -OMes (40)	16
		(TsO) ₂ Zn, C ₆ H ₆ , rt, 48 h	 (62)	182
C ₁₃		LiOTs, C ₆ H ₆ , rt	 (52)	182
C ₂₇		(TsO) ₂ Zn or LiOTs, C ₆ H ₆ , rt, 3 h	 (75-88)	182

TABLE XIV. CARBON-OXYGEN BOND FORMATION, FORMATION OF IMIDATES FROM AMIDES AND IMIDES

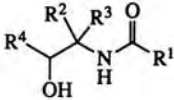
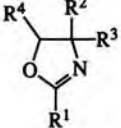
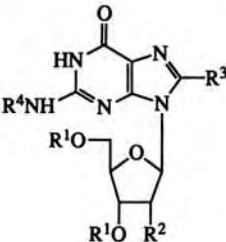
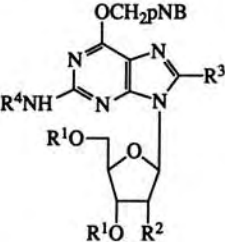
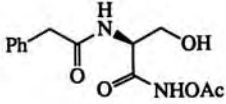
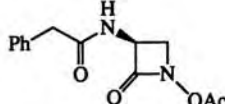
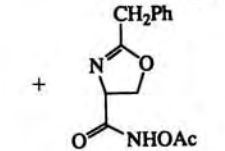
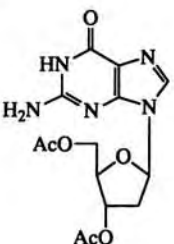
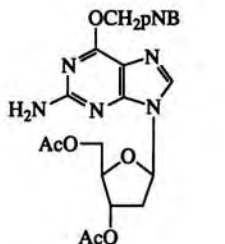
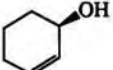
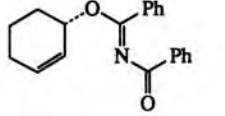
Amide/Imide	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																																																							
C ₃ 	—	THF, rt, 4 h	 <table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R₄</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr><td>Ph</td><td>H</td><td>H</td><td>Ph</td><td>63</td></tr> <tr><td>CF₃</td><td>H</td><td>H</td><td>Ph</td><td>31</td></tr> <tr><td>CCl₃</td><td>H</td><td>H</td><td>Ph</td><td>26</td></tr> <tr><td>CF₃</td><td>Me</td><td>Me</td><td>H</td><td>67</td></tr> <tr><td>CCl₃</td><td>Me</td><td>Me</td><td>H</td><td>56</td></tr> <tr><td>Ph</td><td>H</td><td>H</td><td>H</td><td>68</td></tr> <tr><td>4-O₂NC₆H₄</td><td>H</td><td>H</td><td>H</td><td>68</td></tr> <tr><td>4-O₂NC₆H₄</td><td>H</td><td>H</td><td>Et</td><td>63</td></tr> <tr><td>4-O₂NC₆H₄</td><td>Me</td><td>Me</td><td>H</td><td>60</td></tr> <tr><td>4-O₂NC₆H₄</td><td>H</td><td>H</td><td>Ph</td><td>58</td></tr> </tbody> </table>	R ¹	R ²	R ³	R ₄	Yield (%)	Ph	H	H	Ph	63	CF ₃	H	H	Ph	31	CCl ₃	H	H	Ph	26	CF ₃	Me	Me	H	67	CCl ₃	Me	Me	H	56	Ph	H	H	H	68	4-O ₂ NC ₆ H ₄	H	H	H	68	4-O ₂ NC ₆ H ₄	H	H	Et	63	4-O ₂ NC ₆ H ₄	Me	Me	H	60	4-O ₂ NC ₆ H ₄	H	H	Ph	58	196
R ¹	R ²	R ³	R ₄	Yield (%)																																																							
Ph	H	H	Ph	63																																																							
CF ₃	H	H	Ph	31																																																							
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4-O ₂ NC ₆ H ₄	H	H	H	68																																																							
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4-O ₂ NC ₆ H ₄	Me	Me	H	60																																																							
4-O ₂ NC ₆ H ₄	H	H	Ph	58																																																							
C ₁₀ 	4-O ₂ NC ₆ H ₄ CH ₂ CH ₂ OH	Dioxane, rt, 24 h	 <table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th>Yield (%)</th> <th>Ref.</th> </tr> </thead> <tbody> <tr><td><i>i</i>-PrCO</td><td>H</td><td>H</td><td><i>i</i>-PrCO</td><td>85</td><td>188</td></tr> <tr><td><i>i</i>-PrCO</td><td>O₂CPr-<i>i</i></td><td>H</td><td><i>i</i>-PrCO</td><td>72</td><td>187</td></tr> <tr><td>PhCO</td><td>O₂CPh</td><td>H</td><td>PhCO</td><td>—</td><td>187, 188</td></tr> <tr><td>MeCO</td><td>OAc</td><td>Br</td><td>MeCO</td><td>84</td><td>189</td></tr> <tr><td>MeCO</td><td>H</td><td>H</td><td>H</td><td>—</td><td>650</td></tr> <tr><td><i>i</i>-PrCO</td><td>H</td><td>H</td><td>H</td><td>—</td><td>651</td></tr> <tr><td>TMS</td><td>H</td><td>H</td><td><i>i</i>-PrCO</td><td>—</td><td>194</td></tr> </tbody> </table>	R ¹	R ²	R ³	R ⁴	Yield (%)	Ref.	<i>i</i> -PrCO	H	H	<i>i</i> -PrCO	85	188	<i>i</i> -PrCO	O ₂ CPr- <i>i</i>	H	<i>i</i> -PrCO	72	187	PhCO	O ₂ CPh	H	PhCO	—	187, 188	MeCO	OAc	Br	MeCO	84	189	MeCO	H	H	H	—	650	<i>i</i> -PrCO	H	H	H	—	651	TMS	H	H	<i>i</i> -PrCO	—	194								
R ¹	R ²	R ³	R ⁴	Yield (%)	Ref.																																																						
<i>i</i> -PrCO	H	H	<i>i</i> -PrCO	85	188																																																						
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TMS	H	H	<i>i</i> -PrCO	—	194																																																						
C ₁₃ 	—	—	 (11) 652 +  (55)																																																								
C ₁₄ 	pNBCH ₂ OH	Dioxane, rt, 10 min	 (68) 653																																																								
(PhCO) ₂ NH		rt	 (—) 195																																																								

TABLE XIV. CARBON-OXYGEN BOND FORMATION, FORMATION OF IMIDATES FROM AMIDES AND IMIDES (Continued)

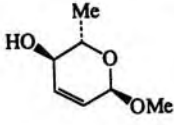
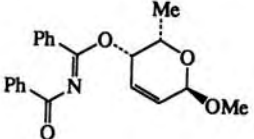
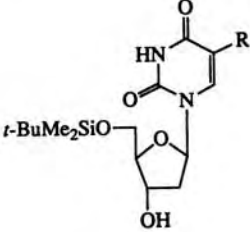
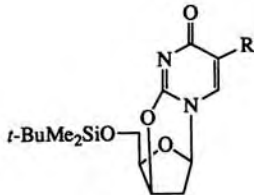
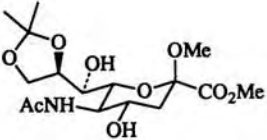
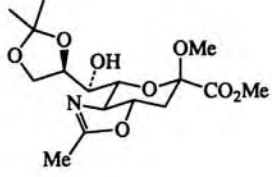
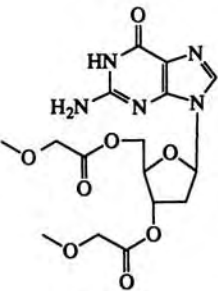
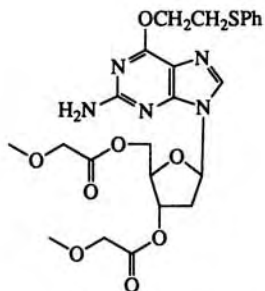
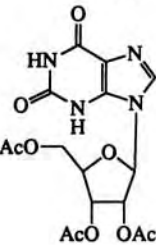
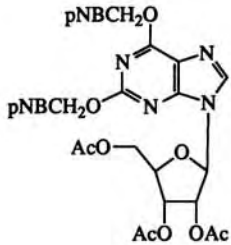
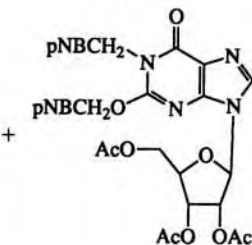
Amide/Imide	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
(PhCO) ₂ NH		THF, rt, 2 h		(93) 195
C ₁₅ 	—	5:1 Toluene:THF, 30 min, 80°	 R = H (88) R = Me (91)	654
C ₁₆ 	—	C ₆ H ₆ , 3-Å sieves, rt, 30 min		(87) 655
	HOCH ₂ CH ₂ SPh	Dioxane		(—) 656
	pNBCH ₂ OH	Dioxane, rt	 (47) 657	
			 + (18)	

TABLE XIV. CARBON-OXYGEN BOND FORMATION, FORMATION OF IMIDATES FROM AMIDES AND IMIDES (Continued)

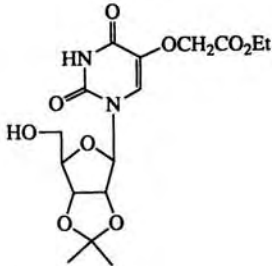
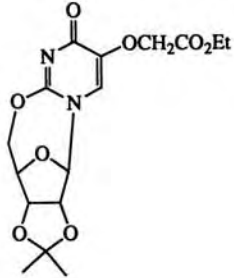
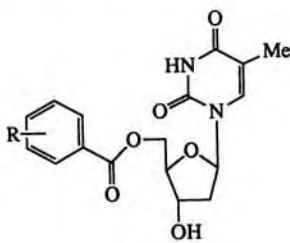
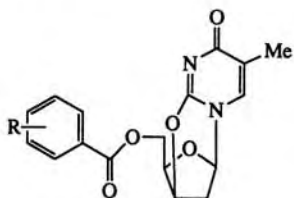
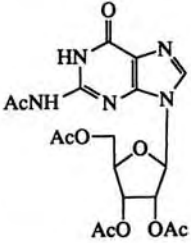
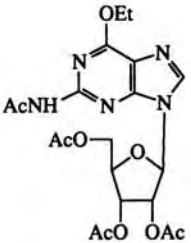
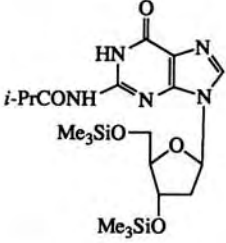
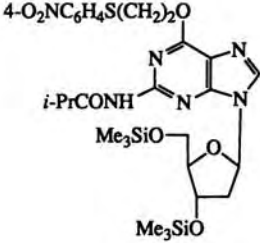
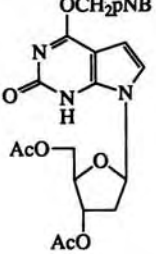
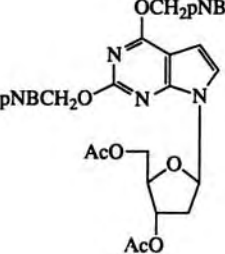
Amide/Imide	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																
	—	Dioxane, rt, 3 h		(70) 193																
<p>C₁₇</p> 	—	DMF, 1 h		658																
			<table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>86</td> </tr> <tr> <td>4-MeO</td> <td>80</td> </tr> <tr> <td>4-O₂N</td> <td>66</td> </tr> <tr> <td>3,5-(O₂N)₂</td> <td>90</td> </tr> <tr> <td>3,4-(MeO)₂</td> <td>84</td> </tr> <tr> <td>2-Br</td> <td>65</td> </tr> <tr> <td>2,6-Cl₂</td> <td>76</td> </tr> </tbody> </table>	R	Yield (%)	H	86	4-MeO	80	4-O ₂ N	66	3,5-(O ₂ N) ₂	90	3,4-(MeO) ₂	84	2-Br	65	2,6-Cl ₂	76	
R	Yield (%)																			
H	86																			
4-MeO	80																			
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3,5-(O ₂ N) ₂	90																			
3,4-(MeO) ₂	84																			
2-Br	65																			
2,6-Cl ₂	76																			
<p>C₁₈</p> 	EtOH	Dioxane, rt		(82) 186																
<p>C₁₉</p> 	4-O ₂ NC ₆ H ₄ S(CH ₂) ₂ OH	Dioxane, rt, 1 h		(50) 659																
<p>C₂₂</p> 	pNBCH ₂ OH	—		(—) 660																

TABLE XIV. CARBON-OXYGEN BOND FORMATION, FORMATION OF IMIDATES FROM AMIDES AND IMIDES (Continued)

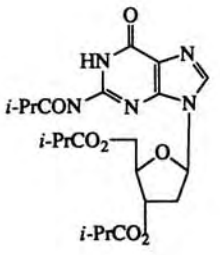
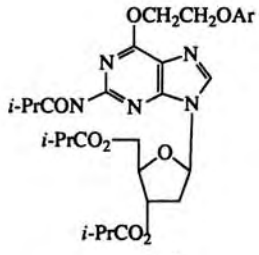
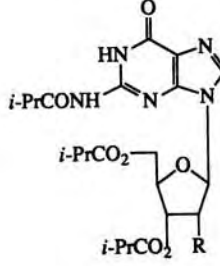
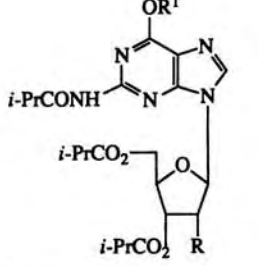
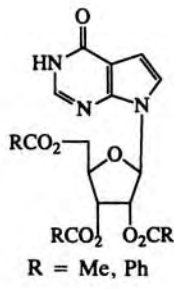
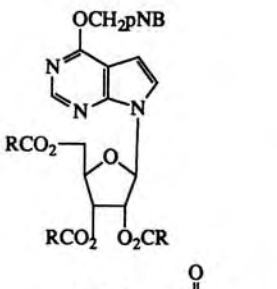
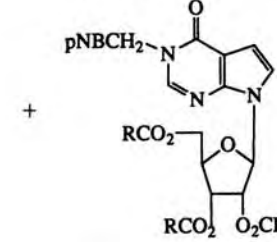
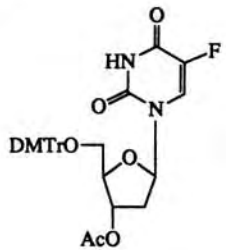
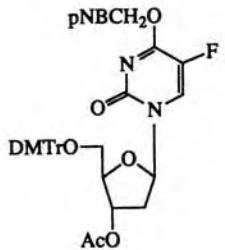
Amide/Imide	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																														
	3,4-(MeO) ₂ C ₆ H ₄ (CH ₂) ₂ OH	THF, rt, 20 h	 (78)	661																														
	R'OH	Dioxane, 2 h, rt		662																														
			<table border="1"> <thead> <tr> <th>R</th> <th>R'</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>Et</td> <td>71</td> </tr> <tr> <td>H</td> <td><i>i</i>-Pr</td> <td>81</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>Me</td> <td>40</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>Et</td> <td>64</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>PhCH₂</td> <td>62</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>allyl</td> <td>42</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>propargyl</td> <td>35</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td><i>i</i>-Pr</td> <td>82</td> </tr> <tr> <td><i>i</i>-PrCO₂</td> <td>PhCH₂CH₂</td> <td>73</td> </tr> </tbody> </table>	R	R'	Yield (%)	H	Et	71	H	<i>i</i> -Pr	81	<i>i</i> -PrCO ₂	Me	40	<i>i</i> -PrCO ₂	Et	64	<i>i</i> -PrCO ₂	PhCH ₂	62	<i>i</i> -PrCO ₂	allyl	42	<i>i</i> -PrCO ₂	propargyl	35	<i>i</i> -PrCO ₂	<i>i</i> -Pr	82	<i>i</i> -PrCO ₂	PhCH ₂ CH ₂	73	
R	R'	Yield (%)																																
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<i>i</i> -PrCO ₂	<i>i</i> -Pr	82																																
<i>i</i> -PrCO ₂	PhCH ₂ CH ₂	73																																
<p>C₃₁</p>  R = Me, Ph	pNBCH ₂ OH	Dioxane, rt, 10 min	 (55)	653, 660																														
			 (24)																															
<p>C₃₂</p> 	pNBCH ₂ OH	Dioxane, 3 d, 40°	 (30)	663																														

TABLE XIV. CARBON-OXYGEN BOND FORMATION, FORMATION OF IMIDATES FROM AMIDES AND IMIDES (Continued)

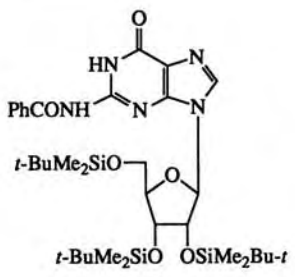
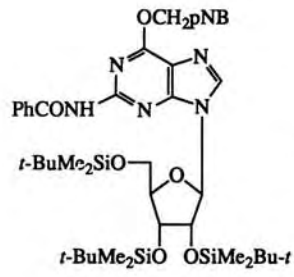
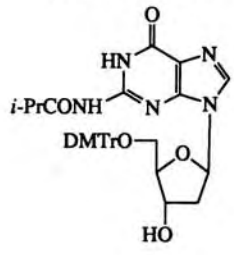
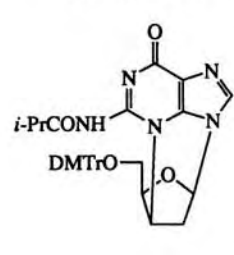
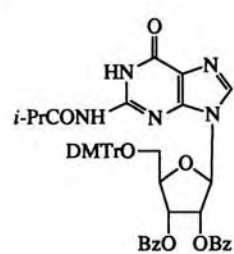
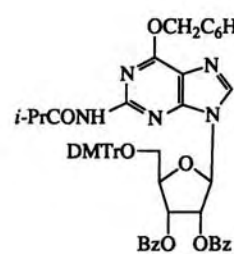
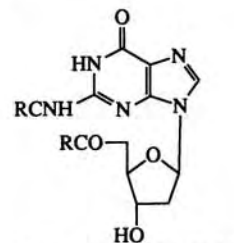
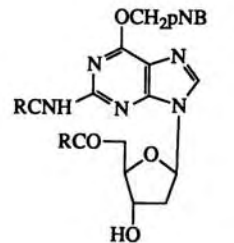
	Amide/Imide	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₅		pNBCH ₂ OH	Dioxane, 1 h, rt		(87) 664
		—	Dioxane, rt, 1 h		(82) 194
C ₄₉		3,4-(MeO) ₂ C ₆ H ₃ CH ₂ OH	THF		(—) 190
C ₅₀		pNBCH ₂ OH	CH ₂ Cl ₂ , rt, 5 h		(61) 665
	R = <i>p</i> -MeOC ₆ H ₄ C(Ph) ₂				

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES

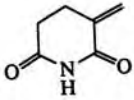
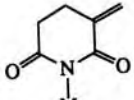
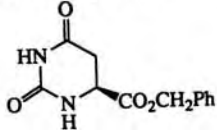
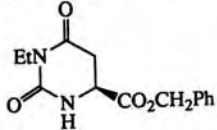
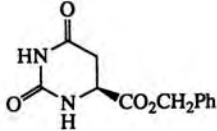
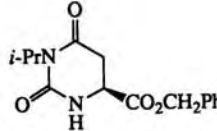

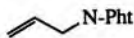
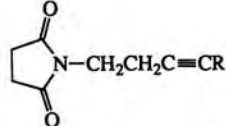
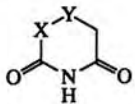
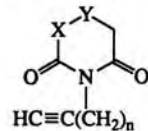
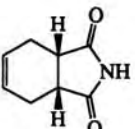
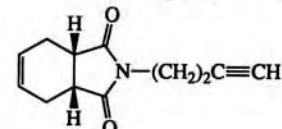
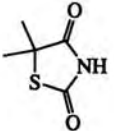
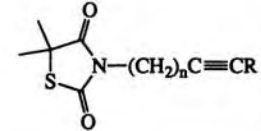
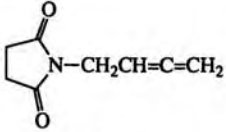
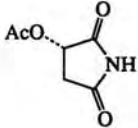
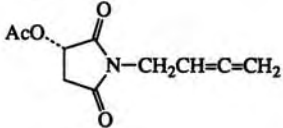
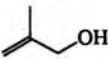
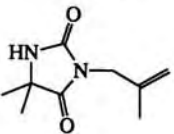

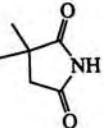
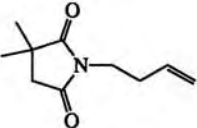
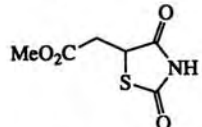
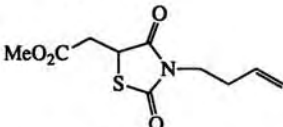
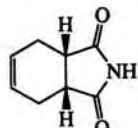
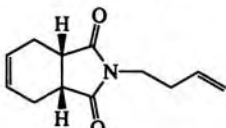

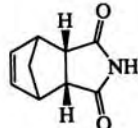
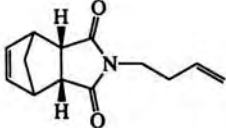
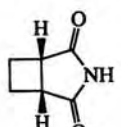
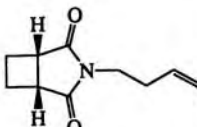
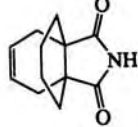
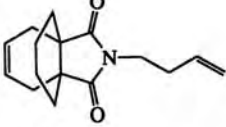
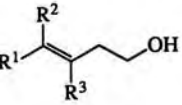
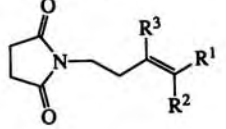
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																								
C ₁ MeOH		THF, rt	 (78)	666																								
C ₂ EtOH	(<i>t</i> -BuO ₂ C) ₂ NH	CH ₂ CN, rt, 20 h	(<i>t</i> -BuO ₂ C) ₂ NEt (86)	667																								
		Dioxane, reflux, 4 h	 (59)	668																								
C ₃ <i>i</i> -PrOH		Dioxane, reflux, 4 h	 (61)	668																								
C ₄ 	Phthalimide	THF, rt, 17 h	 (68)	669																								
RC≡CCH ₂ CH ₂ OH	Succinimide	—	 (84–91)	670																								
			R = H, Me, Me ₃ Si, <i>t</i> -Bu, C(Me) ₂ OMe, <i>i</i> -Pr, <i>n</i> -Pr																									
	Phthalimide	THF	PhN-CH ₂ CH ₂ C≡CR	671																								
HC≡C(CH ₂) _n OH		THF, rt, overnight	 (672)																									
			<table border="1"> <thead> <tr> <th>n</th> <th>X</th> <th>Y</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>2</td> <td>CH₂</td> <td>S</td> <td>34</td> </tr> <tr> <td>4</td> <td>CH₂</td> <td>S</td> <td>28</td> </tr> <tr> <td>4</td> <td>CH₂</td> <td>O</td> <td>69</td> </tr> <tr> <td>2</td> <td>S</td> <td>CHPh</td> <td>66</td> </tr> <tr> <td>2</td> <td>S</td> <td>CMe₂</td> <td>63</td> </tr> </tbody> </table>	n	X	Y	Yield (%)	2	CH ₂	S	34	4	CH ₂	S	28	4	CH ₂	O	69	2	S	CHPh	66	2	S	CMe ₂	63	
n	X	Y	Yield (%)																									
2	CH ₂	S	34																									
4	CH ₂	S	28																									
4	CH ₂	O	69																									
2	S	CHPh	66																									
2	S	CMe ₂	63																									
HC≡C(CH ₂) ₂ OH		THF, rt, overnight	 (78)	673																								
RC≡C(CH ₂) _n OH		—	 (674)																									
			<table border="1"> <thead> <tr> <th>n</th> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>2</td> <td>H</td> <td>79</td> </tr> <tr> <td>4</td> <td>H</td> <td>53</td> </tr> <tr> <td>2</td> <td>PhCH₂CH₂</td> <td>99</td> </tr> </tbody> </table>	n	R	Yield (%)	2	H	79	4	H	53	2	PhCH ₂ CH ₂	99													
n	R	Yield (%)																										
2	H	79																										
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2	PhCH ₂ CH ₂	99																										

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
$\text{HOCH}_2\text{CH}=\text{C}=\text{CH}_2$	Succinimide	THF, 0°-rt, 2.4 h		(99) 675
$\text{CH}_2=\text{C}=\text{CHCH}_2\text{OH}$		THF, 1 h, rt		(87) 676
	5,5-Dimethylhydantoin	THF, rt, 2 days		(64) 677
		—		(58) 678
		—		(43) 672
		THF, rt, overnight		(43) 673
		THF, rt, overnight		(100) 673
		"		(89) 673
		"		(91) 673
	Succinimide	THF, 3 h, rt		(85-96) 675

R ¹	R ²	R ³
H	H	H
Me	H	H
H	Me	H
Me	Me	H
H	Me	Me

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																																																	
		—		672																																																	
<table border="1"> <thead> <tr> <th>X</th> <th>Y</th> <th>R¹</th> <th>R²</th> <th>R³</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>CH₂</td> <td>S</td> <td>H</td> <td>H</td> <td>Me</td> <td>33</td> </tr> <tr> <td>CH₂</td> <td>O</td> <td>H</td> <td>Et</td> <td>H</td> <td>75</td> </tr> <tr> <td>S</td> <td>CHPh</td> <td>H</td> <td>H</td> <td>H</td> <td>33</td> </tr> <tr> <td>S</td> <td>CHPh</td> <td>H</td> <td>Et</td> <td>H</td> <td>60</td> </tr> <tr> <td>S</td> <td>CH₂</td> <td>Me</td> <td>H</td> <td>H</td> <td>30</td> </tr> <tr> <td>S</td> <td>CHMe</td> <td>H</td> <td>H</td> <td>H</td> <td>70</td> </tr> <tr> <td>S</td> <td>CHMe</td> <td>H</td> <td>Et</td> <td>H</td> <td>74</td> </tr> </tbody> </table>						X	Y	R ¹	R ²	R ³	Yield (%)	CH ₂	S	H	H	Me	33	CH ₂	O	H	Et	H	75	S	CHPh	H	H	H	33	S	CHPh	H	Et	H	60	S	CH ₂	Me	H	H	30	S	CHMe	H	H	H	70	S	CHMe	H	Et	H	74
X	Y	R ¹	R ²	R ³	Yield (%)																																																
CH ₂	S	H	H	Me	33																																																
CH ₂	O	H	Et	H	75																																																
S	CHPh	H	H	H	33																																																
S	CHPh	H	Et	H	60																																																
S	CH ₂	Me	H	H	30																																																
S	CHMe	H	H	H	70																																																
S	CHMe	H	Et	H	74																																																
HO(CH ₂) _n OH	Phthalimide	—	PhN(CH ₂) _n OH	(—) 679																																																	
<i>n</i> -BuOH		Dioxane, reflux, 4 h		(69) 668																																																	
		THF, rt, overnight		674																																																	
<table border="1"> <thead> <tr> <th>n</th> <th>R¹</th> <th>R²</th> <th>R³</th> <th>Y</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>2</td> <td>Me</td> <td>H</td> <td>H</td> <td>S</td> <td>62</td> </tr> <tr> <td>2</td> <td>H</td> <td>H</td> <td>H</td> <td>S</td> <td>87</td> </tr> <tr> <td>2</td> <td>H</td> <td>H</td> <td>Me</td> <td>S</td> <td>80</td> </tr> <tr> <td>3</td> <td>Me</td> <td>H</td> <td>H</td> <td>S</td> <td>78</td> </tr> <tr> <td>2</td> <td>Me</td> <td>Et</td> <td>H</td> <td>S</td> <td>81</td> </tr> <tr> <td>3</td> <td>Me</td> <td>H</td> <td>H</td> <td>CH₂</td> <td>65</td> </tr> </tbody> </table>						n	R ¹	R ²	R ³	Y	Yield (%)	2	Me	H	H	S	62	2	H	H	H	S	87	2	H	H	Me	S	80	3	Me	H	H	S	78	2	Me	Et	H	S	81	3	Me	H	H	CH ₂	65						
n	R ¹	R ²	R ³	Y	Yield (%)																																																
2	Me	H	H	S	62																																																
2	H	H	H	S	87																																																
2	H	H	Me	S	80																																																
3	Me	H	H	S	78																																																
2	Me	Et	H	S	81																																																
3	Me	H	H	CH ₂	65																																																
C ₅ 	Phthalimide	rt, overnight		(69) 680																																																	
HC≡C(CH ₂) ₃ OH	5,5-Dimethylhydantoin	THF, rt, 2 days		(72) 677																																																	
	Succinimide	—		(—) 681																																																	
<p>R = R¹ = H R = R¹ = Me R = H, R¹ = Me R = Me, R¹ = H</p>																																																					

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.												
$\text{CH}_2=\text{C}=\text{C}-\text{CH}_2-\text{CH}_2-\text{OH}$		—	 <table border="1"> <thead> <tr> <th>R</th> <th>Y</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>S</td> <td>77</td> </tr> <tr> <td>Me</td> <td>CH₂</td> <td>86</td> </tr> <tr> <td>H</td> <td>S</td> <td>71</td> </tr> </tbody> </table>	R	Y	Yield (%)	Me	S	77	Me	CH ₂	86	H	S	71	674
R	Y	Yield (%)														
Me	S	77														
Me	CH ₂	86														
H	S	71														
$\text{RC}\equiv\text{C}(\text{CH}_2)_3\text{OH}$		THF, rt, 3.5–8 h	 R = H, Me ₃ Si, Ph	(86) 299												
	5,5-Dimethylhydantoin	THF, rt, 2 days		(71) 677												
		THF, rt, overnight		(81) 673												
		THF, rt, overnight		(100) 673												
		THF, rt, overnight		(100) 673												
	Succinimide	THF, rt, overnight		(12) 682												
	Phthalimide	THF, rt, 2 days	 <table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>55</td> </tr> <tr> <td>Me</td> <td>72</td> </tr> <tr> <td>n-Pr</td> <td>75</td> </tr> <tr> <td>n-C₆H₁₃</td> <td>78</td> </tr> <tr> <td>n-C₇H₁₅</td> <td>75</td> </tr> </tbody> </table>	R	Yield (%)	H	55	Me	72	n-Pr	75	n-C ₆ H ₁₃	78	n-C ₇ H ₁₅	75	683
R	Yield (%)															
H	55															
Me	72															
n-Pr	75															
n-C ₆ H ₁₃	78															
n-C ₇ H ₁₅	75															
$n\text{-C}_5\text{H}_{11}\text{OH}$		Dioxane, reflux, 4 h		(53) 668												

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

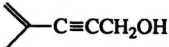
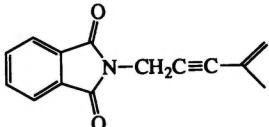
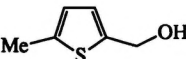
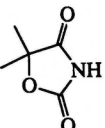
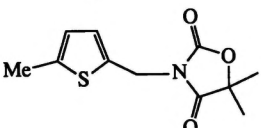
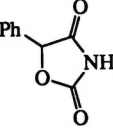
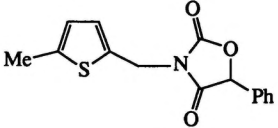
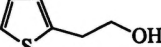
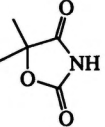
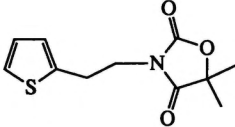
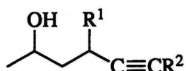
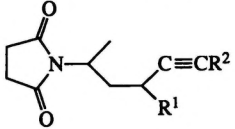
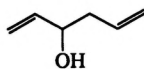
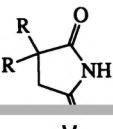
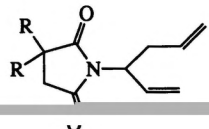
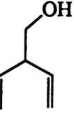
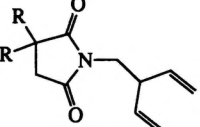
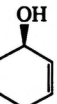
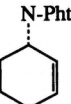
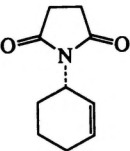
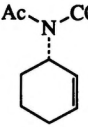
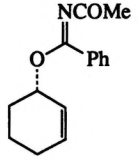
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
	Phthalimide	—		(60) 684
		THF, rt, 14 h		(—) 685, 686
		"		(78) 685, 686
		"		(68) 685, 686
	Succinimide	THF	 $R^1 = R^2 = H$ $R^1 = Me, R^2 = H$ $R^1 = H, R^2 = Me$	687 (45) (—) (—)
		"		(72) 688
	"	"	 $R = H, Ph$	
	Phthalimide	THF, 15 min, 0–25°		(57) 689
	Succinimide	"		(53) 689
	PhCONHCOMe	THF, rt, 0.5 h	 (34) +  (35)	689

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

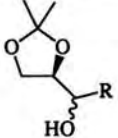
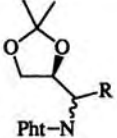

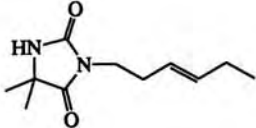

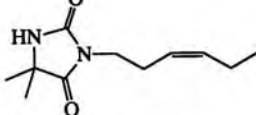

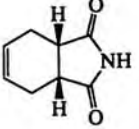
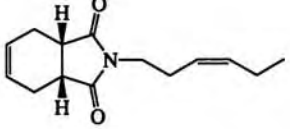
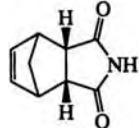
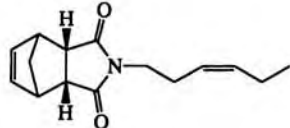
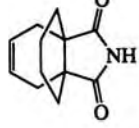
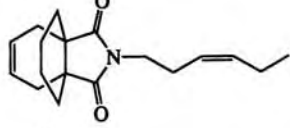

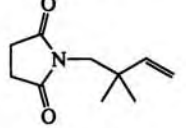

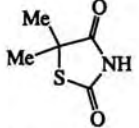
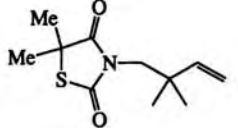

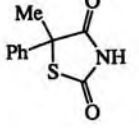
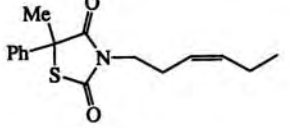
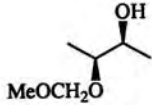
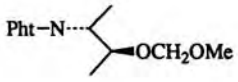
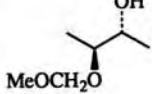
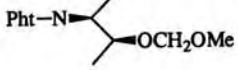
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.												
	Phthalimide	THF, 15 h, rt	 <table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>63</td> </tr> <tr> <td>Et</td> <td>71</td> </tr> <tr> <td>Allyl</td> <td>43</td> </tr> <tr> <td>n-Pr</td> <td>76</td> </tr> <tr> <td>Vinyl</td> <td>41</td> </tr> </tbody> </table>	R	Yield (%)	Me	63	Et	71	Allyl	43	n-Pr	76	Vinyl	41	690
R	Yield (%)															
Me	63															
Et	71															
Allyl	43															
n-Pr	76															
Vinyl	41															
	5,5-Dimethylhydantoin	THF, rt, 2 days		(81) 677												
	"	"		(64) 677												
		THF, rt, overnight		(90) 673												
		THF, rt, overnight		(70) 673												
		THF, rt, overnight		(30) 673												
	Succinimide	—		(—) 691												
		—		(71) 682												
		—		(47) 674												
	Phthalimide	0° to rt		(—) 692												
	Phthalimide	0° to rt		(—) 692												

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
HOCH ₂ CO ₂ Bu- <i>n</i>		THF		(26) 693
		THF	+ (-) 4:1	693
		THF		(-) 693
HOCH ₂ CO ₂ Bu- <i>n</i>		THF	+	693
			+	(-)
			+	(-)
HO(CH ₂) ₃ SiMe ₃	Phthalimide	—	Pht-N(CH ₂) ₃ SiMe ₃	(-) 694
C ₇ 		THF, 14 h, rt		(62) 695, 696
		THF, overnight		697, 698

n	m	Yield (%)
2	2	51
2	3	62
3	2	37
3	3	60
2	4	65

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																		
PhCH ₂ OH		CH ₃ CN, rt, 20 h		(77) 667																		
		THF, rt		(85) 666																		
	Phthalimide	THF, rt, overnight		(91) 699																		
		THF, rt, overnight		(70) 700																		
	Phthalimide	THF, 3 d, 25°		(44) 701																		
	Succinimide	THF, 0° for 40 min, rt for 2 min		702																		
			R = Me R = H	(84) (61)																		
		—		672																		
			X = S X = O	(68) (54)																		
		—		674																		
			<table border="1"> <thead> <tr> <th>R</th> <th>Y</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>S</td> <td>82</td> </tr> <tr> <td>Me</td> <td>CH₂</td> <td>72</td> </tr> <tr> <td>H</td> <td>S</td> <td>65</td> </tr> </tbody> </table>	R	Y	Yield (%)	Me	S	82	Me	CH ₂	72	H	S	65							
R	Y	Yield (%)																				
Me	S	82																				
Me	CH ₂	72																				
H	S	65																				
		—		(—) 703																		
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>H</td> <td>H</td> </tr> <tr> <td>Et</td> <td>H</td> <td>H</td> </tr> <tr> <td>Ph</td> <td>H</td> <td>H</td> </tr> <tr> <td>Me</td> <td>Me</td> <td>H</td> </tr> <tr> <td>H</td> <td>H</td> <td>Me</td> </tr> </tbody> </table>	R ¹	R ²	R ³	Me	H	H	Et	H	H	Ph	H	H	Me	Me	H	H	H	Me	
R ¹	R ²	R ³																				
Me	H	H																				
Et	H	H																				
Ph	H	H																				
Me	Me	H																				
H	H	Me																				

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

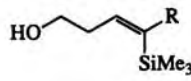
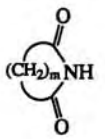
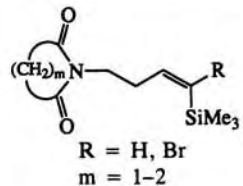
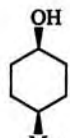
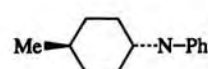
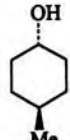
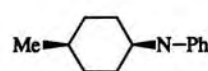
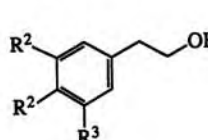
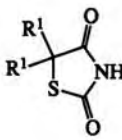
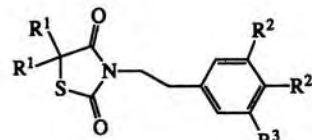
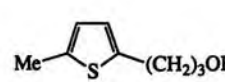
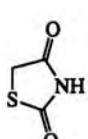
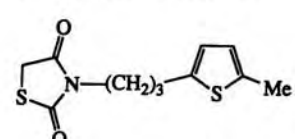
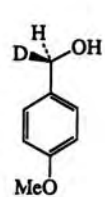
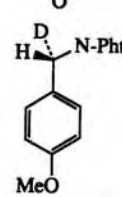
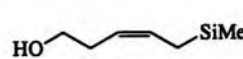
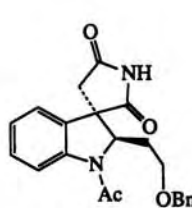
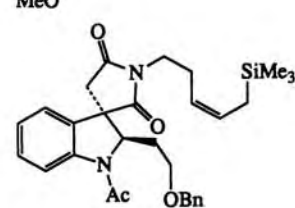
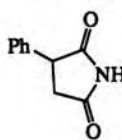
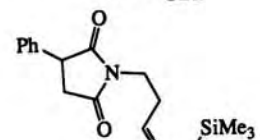
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																												
		THF, 12 h, rt	 R = H, Br m = 1-2	(56-76) 704, 705																												
	Phthalimide	—		(—) 706																												
	Phthalimide	—		(—) 706																												
		—		674																												
<table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>H</td> <td>H</td> <td>84</td> </tr> <tr> <td>H</td> <td>H</td> <td>H</td> <td>17</td> </tr> <tr> <td>Me</td> <td>MeO</td> <td>H</td> <td>81</td> </tr> <tr> <td>H</td> <td>MeO</td> <td>H</td> <td>40</td> </tr> <tr> <td>Me</td> <td>MeO</td> <td>MeO</td> <td>73</td> </tr> <tr> <td>H</td> <td>MeO</td> <td>MeO</td> <td>47</td> </tr> </tbody> </table>					R ¹	R ²	R ³	Yield (%)	Me	H	H	84	H	H	H	17	Me	MeO	H	81	H	MeO	H	40	Me	MeO	MeO	73	H	MeO	MeO	47
R ¹	R ²	R ³	Yield (%)																													
Me	H	H	84																													
H	H	H	17																													
Me	MeO	H	81																													
H	MeO	H	40																													
Me	MeO	MeO	73																													
H	MeO	MeO	47																													
		THF, 14 h, rt		(58) 695, 696																												
	Phthalimide	THF, 0-25°, 22 h		(73) 707																												
		THF, rt, overnight		(98) 708																												
		"		(—) 708																												

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

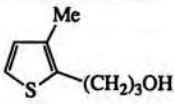
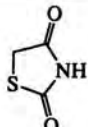
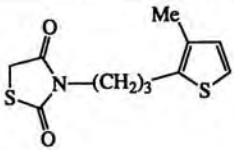
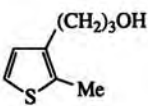
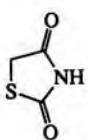
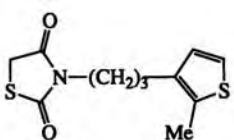
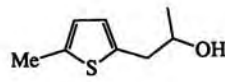
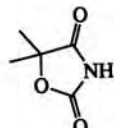
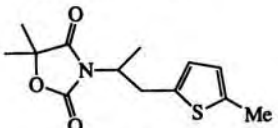
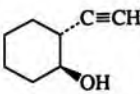
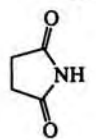
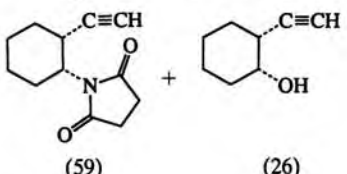
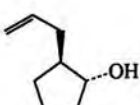
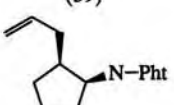
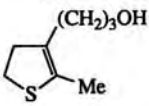
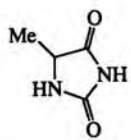
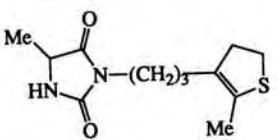

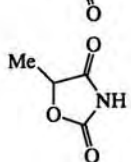
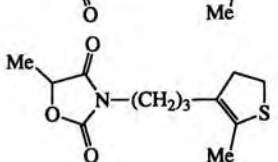
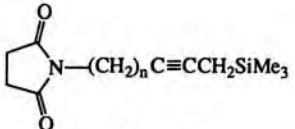
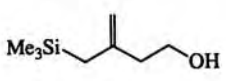
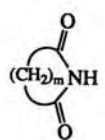
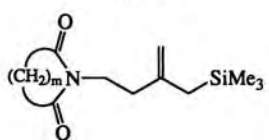


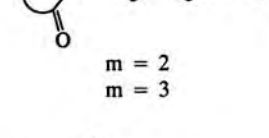
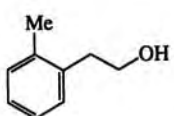
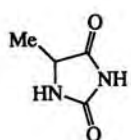
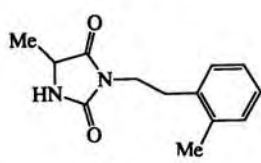
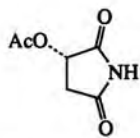
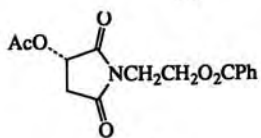
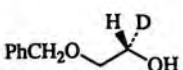
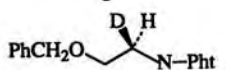
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
		THF, 14 h, rt		(60) 695, 696
		THF, 14 h, rt		(74) 695, 696
		THF, 14 h, rt		(65) 685, 686
		THF, 36 h, rt		206
	Phthalimide	THF, 3 days, 25°		(76) 701
		THF, 14 h, rt		(57) 695, 696
		THF, 14 h, rt		(68) 695, 696
$\text{HO}(\text{CH}_2)_n\text{C}\equiv\text{CCH}_2\text{SiMe}_3$	Succinimide	THF		709
		THF		710
		THF		(71) (61)
		THF, 2 d, rt		(53) 711
$\text{PhCO}_2\text{CH}_2\text{CH}_2\text{OH}$		—		(95) 712
	Phthalimide	THF, 2 h, rt		(90) 494

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.												
PhCH ₂ OCH ₂ CD ₂ OH	Phthalimide	—	PhCH ₂ OCD ₂ N—Pht	(96) 713												
	Phthalimide	THF, overnight, rt		(85) 714, 715												
	Phthalimide	THF, 3 days, 25°		(29) 701												
	Succinimide	—		(—) 716												
	Phthalimide	THF, 48 h		(—) 717												
HO—CH ₂ —CH ₂ —OCH ₂ Ph		THF, rt, 4 h		(95) 718												
	Phthalimide	THF, 0° to rt		(100) 719, 720												
		—		(80–83) 721												
			<table border="1"> <thead> <tr> <th>X</th> <th>R</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>Me</td> </tr> <tr> <td>H</td> <td>CH₂CH=CH₂</td> </tr> <tr> <td>H</td> <td>CH₂CH₂CH=CH₂</td> </tr> <tr> <td>OMe</td> <td>CH₂CH₂CH=CH₂</td> </tr> </tbody> </table>	X	R	H	Me	H	CH ₂ CH=CH ₂	H	CH ₂ CH ₂ CH=CH ₂	OMe	CH ₂ CH ₂ CH=CH ₂			
X	R															
H	Me															
H	CH ₂ CH=CH ₂															
H	CH ₂ CH ₂ CH=CH ₂															
OMe	CH ₂ CH ₂ CH=CH ₂															
	Succinimide	THF, rt, overnight		(—) 722, 723												
			<table border="1"> <thead> <tr> <th>R</th> <th>R'</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>H</td> </tr> <tr> <td>Cl</td> <td>H</td> </tr> <tr> <td>MeO</td> <td>H</td> </tr> <tr> <td>H</td> <td>MeO</td> </tr> <tr> <td>MeO</td> <td>MeO</td> </tr> </tbody> </table>	R	R'	H	H	Cl	H	MeO	H	H	MeO	MeO	MeO	
R	R'															
H	H															
Cl	H															
MeO	H															
H	MeO															
MeO	MeO															

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

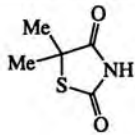
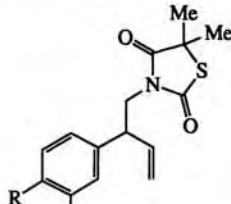
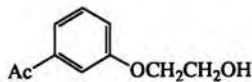
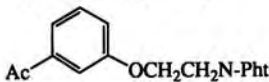
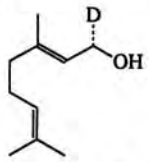
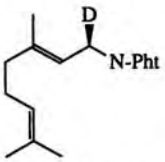
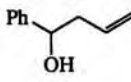
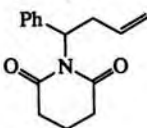
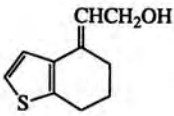
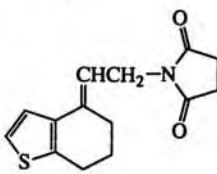
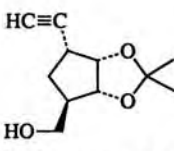
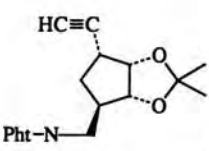
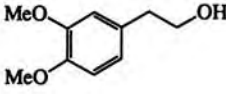
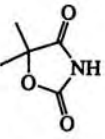
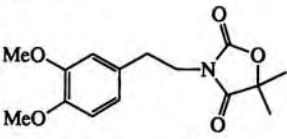
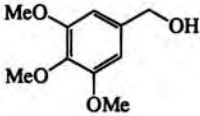
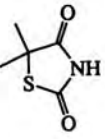
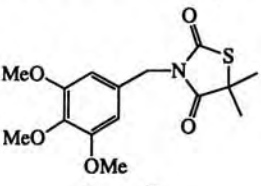
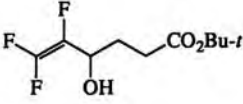
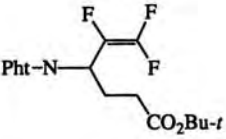
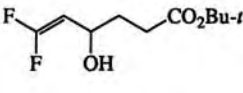
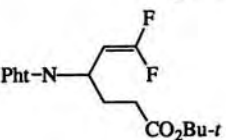
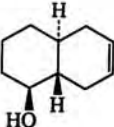
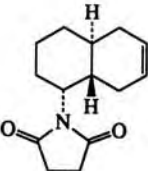
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
		—	 R = R' = H R = MeO, R' = H	682 (72) (57)
	Phthalimide	Toluene, rt, 2 h		(87) 724
	Phthalimide	THF, 25°, 12 h		(89) 725
	Glutarimide	THF, rt, 17 h		(55) 726
	Succinimide	THF, rt, 18 h		(25) 727
	Phthalimide	THF, rt, 1 h		(70) 728
		THF, rt, 14 h		(70) 685, 686
		THF, rt, overnight		(87) 682
	Phthalimide	THF		(—) 729
	Phthalimide	THF		(—) 729
	Succinimide	THF, 0° to rt, 1.25 h		(62) 730, 731

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																				
	Phthalimide	THF, rt, 48 h		(40) 732, 733																				
	Succinimide	"		(50) 732, 733																				
	Phthalimide	THF, 22°, 15 h		(66) 734																				
	Phthalimide	THF, 3 days, 25°		(50) 701																				
	Phthalimide	THF, 48 h, rt		(37) 732, 733																				
		THF, rt, 14 h		(55) 695, 696																				
	Phthalimide	THF, rt, overnight		(60) 241																				
	Phthalimide	THF, rt, overnight		735																				
			<table border="1"> <thead> <tr> <th>R</th> <th>Yield (%)</th> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>78</td> <td><i>n</i>-Bu</td> <td>79</td> </tr> <tr> <td>Me</td> <td>87</td> <td><i>n</i>-C₆H₁₃</td> <td>85</td> </tr> <tr> <td>Et</td> <td>84</td> <td><i>n</i>-C₈H₁₇</td> <td>54</td> </tr> <tr> <td><i>i</i>-Pr</td> <td>90</td> <td>PhCH₂</td> <td>63</td> </tr> </tbody> </table>	R	Yield (%)	R	Yield (%)	H	78	<i>n</i> -Bu	79	Me	87	<i>n</i> -C ₆ H ₁₃	85	Et	84	<i>n</i> -C ₈ H ₁₇	54	<i>i</i> -Pr	90	PhCH ₂	63	
R	Yield (%)	R	Yield (%)																					
H	78	<i>n</i> -Bu	79																					
Me	87	<i>n</i> -C ₆ H ₁₃	85																					
Et	84	<i>n</i> -C ₈ H ₁₇	54																					
<i>i</i> -Pr	90	PhCH ₂	63																					
	Phthalimide	THF, rt, 5 h		(79) 532																				
	Phthalimide	rt, overnight		(78) 736																				
	Phthalimide	THF, rt, 12 h		(—) 737																				

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

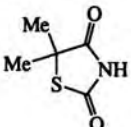
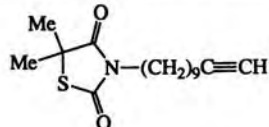
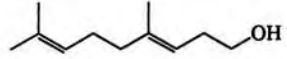
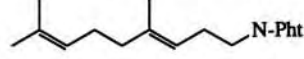
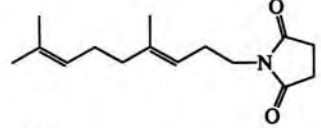
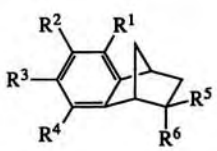
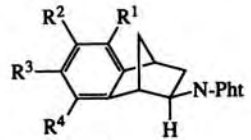
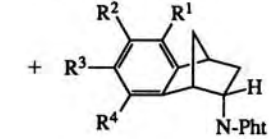
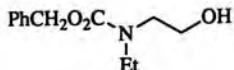
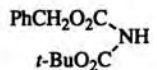
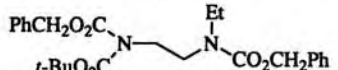
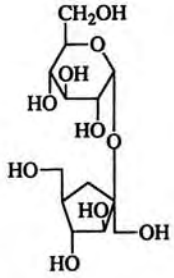
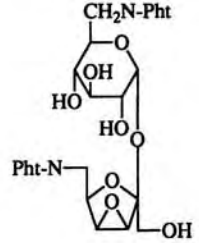
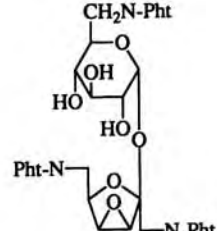
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.																																																																																								
$\text{HC}\equiv\text{C}(\text{CH}_2)_9\text{OH}$		THF, rt, overnight	 (82)	682																																																																																								
	Phthalimide	THF, rt, 48 h	 (38)	732, 733																																																																																								
	Succinimide	"	 (48)	732, 733																																																																																								
$\text{CH}_2=\text{CH}(\text{CH}_2)_9\text{OH}$	Phthalimide	THF, rt, 48 h	$\text{CH}_2=\text{CH}(\text{CH}_2)_9\text{N-Pht}$ (38)	732, 733																																																																																								
C_{12} 	Phthalimide	THF, rt, 20–60 h	 (204) + 	204																																																																																								
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th>R⁵</th> <th>R⁶</th> <th>Yield (%)</th> <th><i>exo/endo</i></th> </tr> </thead> <tbody> <tr><td>CF₃</td><td>H</td><td>H</td><td>H</td><td>OH</td><td>H</td><td>33</td><td>11/89</td></tr> <tr><td>H</td><td>CF₃</td><td>H</td><td>H</td><td>OH</td><td>H</td><td>34</td><td>7/93</td></tr> <tr><td>H</td><td>H</td><td>CF₃</td><td>H</td><td>OH</td><td>H</td><td>34</td><td>7/93</td></tr> <tr><td>H</td><td>H</td><td>H</td><td>CF₃</td><td>OH</td><td>H</td><td>13</td><td>33/67</td></tr> <tr><td>H</td><td>H</td><td>H</td><td>H</td><td>OH</td><td>H</td><td>24</td><td>72/28</td></tr> <tr><td>CF₃</td><td>H</td><td>H</td><td>H</td><td>H</td><td>OH</td><td>62</td><td>100/0</td></tr> <tr><td>H</td><td>CF₃</td><td>H</td><td>H</td><td>H</td><td>OH</td><td>64</td><td>100/0</td></tr> <tr><td>H</td><td>H</td><td>CF₃</td><td>H</td><td>H</td><td>OH</td><td>63</td><td>100/0</td></tr> <tr><td>H</td><td>H</td><td>H</td><td>CF₃</td><td>H</td><td>OH</td><td>36</td><td>100/0</td></tr> <tr><td>H</td><td>H</td><td>H</td><td>H</td><td>H</td><td>OH</td><td>53</td><td>100/0</td></tr> </tbody> </table>	R ¹	R ²	R ³	R ⁴	R ⁵	R ⁶	Yield (%)	<i>exo/endo</i>	CF ₃	H	H	H	OH	H	33	11/89	H	CF ₃	H	H	OH	H	34	7/93	H	H	CF ₃	H	OH	H	34	7/93	H	H	H	CF ₃	OH	H	13	33/67	H	H	H	H	OH	H	24	72/28	CF ₃	H	H	H	H	OH	62	100/0	H	CF ₃	H	H	H	OH	64	100/0	H	H	CF ₃	H	H	OH	63	100/0	H	H	H	CF ₃	H	OH	36	100/0	H	H	H	H	H	OH	53	100/0	
R ¹	R ²	R ³	R ⁴	R ⁵	R ⁶	Yield (%)	<i>exo/endo</i>																																																																																					
CF ₃	H	H	H	OH	H	33	11/89																																																																																					
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CF ₃	H	H	H	H	OH	62	100/0																																																																																					
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H	H	H	CF ₃	H	OH	36	100/0																																																																																					
H	H	H	H	H	OH	53	100/0																																																																																					
		CH ₃ CN, rt, 20 h	 (79)	667																																																																																								
	Phthalimide	Pyridine, 0° to 25°, 2.5 h	 (62)	738																																																																																								
	Phthalimide	Pyridine, rt, 48 h	 (68)	738																																																																																								

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

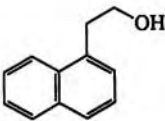
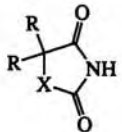
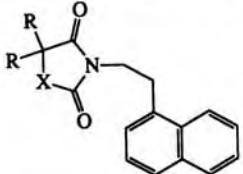
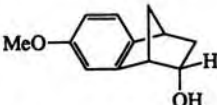
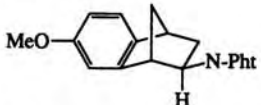
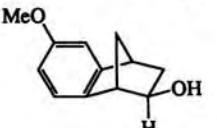
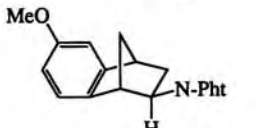
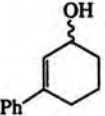
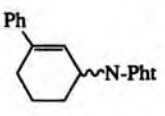
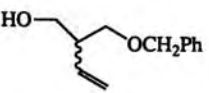
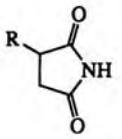
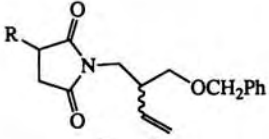
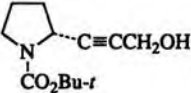
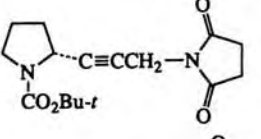
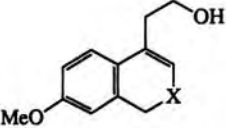
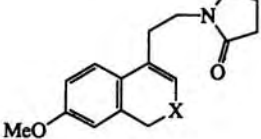
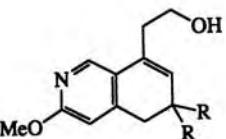
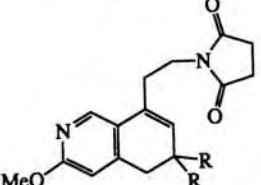
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.												
		—	 <table border="1"> <thead> <tr> <th>X</th> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>O</td> <td>Me</td> <td>65</td> </tr> <tr> <td>S</td> <td>H</td> <td>75</td> </tr> <tr> <td>NH</td> <td>Me</td> <td>72</td> </tr> </tbody> </table>	X	R	Yield (%)	O	Me	65	S	H	75	NH	Me	72	739
X	R	Yield (%)														
O	Me	65														
S	H	75														
NH	Me	72														
	Phthalimide	THF, 72 h, rt		(84) 205												
	Phthalimide	"		(87) 205												
	Phthalimide	THF, 2.5 h, rt		(58) 740												
		THF, rt, overnight	 R = Me = H = Ph	741 (68) (80) (—)												
	Succinimide	—		(91) 742												
	Succinimide	THF, rt, 18 h	 X = O X = S	743 (30) (35)												
	Succinimide	THF, rt, 18 h	 R = H R = Me	744 (30) (53)												

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

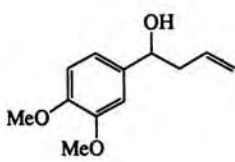
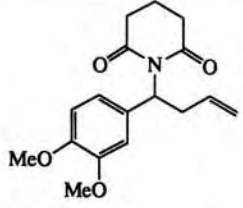
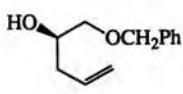
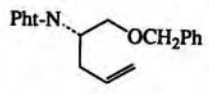
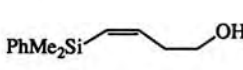
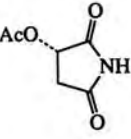
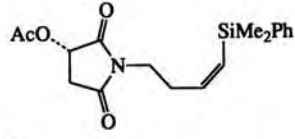
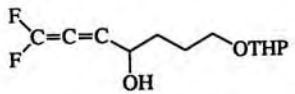
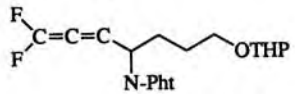
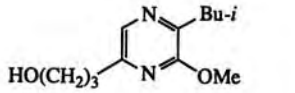
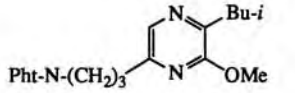
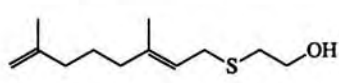
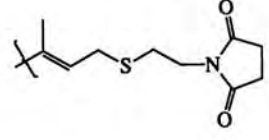
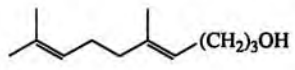
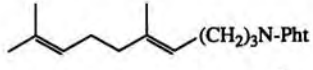
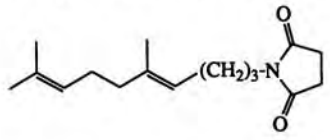
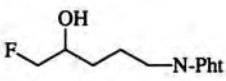
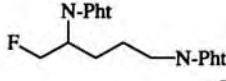
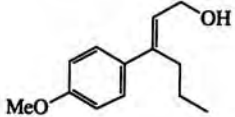
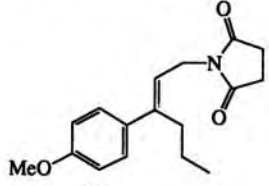
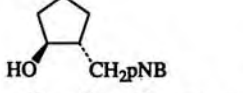
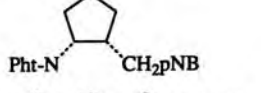
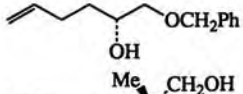
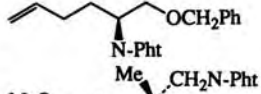
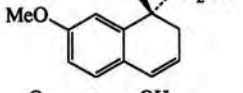
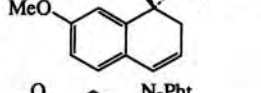
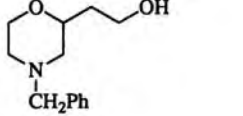
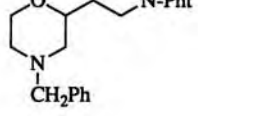
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
	Glutarimide	THF, rt, 3 days		(47) 745
	Phthalimide	THF, 12 h, -20°		(70) 746
		THF, 4 h, rt		(96) 676
	Phthalimide	—		(—) 747
	Phthalimide	THF, rt, overnight		(93) 714, 715
	Succinimide	THF, rt, 48 h		(52) 732, 733
	Phthalimide	THF, rt, 48 h		(39) 732, 733
	Succinimide	"		(50) 732, 733
C_{13}				
	Phthalimide	—		(60) 748
	Succinimide	THF, rt, 18 h		(40) 749
	Phthalimide	THF, rt, 72 h		(42) 717
	Phthalimide	THF		(—) 750
	Phthalimide	THF, rt, 12 h		(—) 751
	Phthalimide	THF, rt, 20 h		(—) 752

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

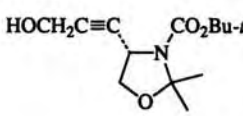
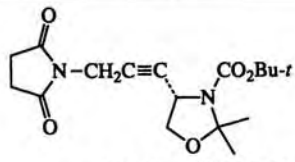
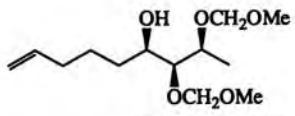
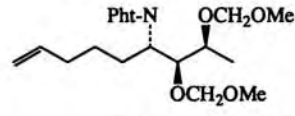
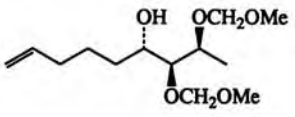
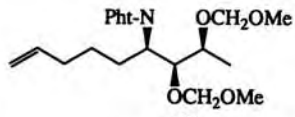
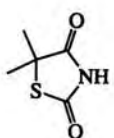
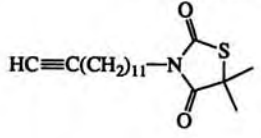
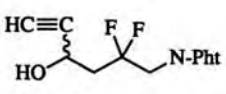
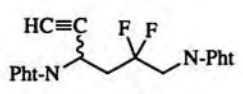
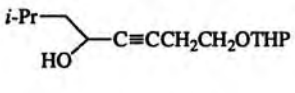
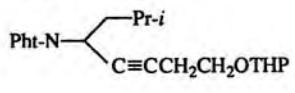
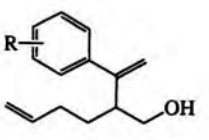
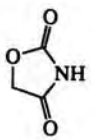
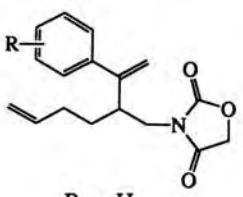
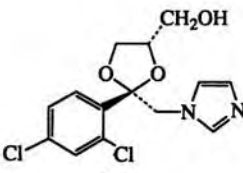
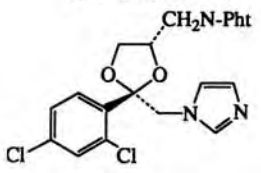
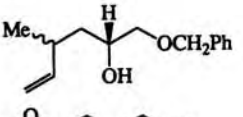
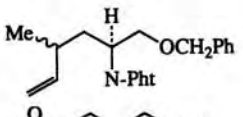
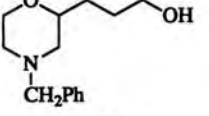
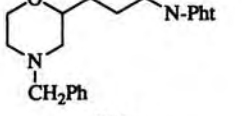
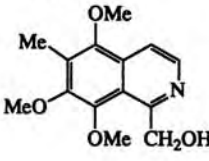
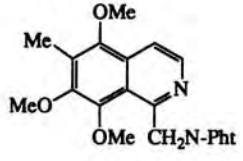
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
	Succinimide	—		(72) 742
	Phthalimide	THF, 14 h, rt		(60) 753
	Phthalimide	THF, 14 h, rt		(57) 753
$\text{HC}\equiv\text{C}(\text{CH}_2)_{11}\text{OH}$		THF, rt, overnight		(81) 682
C_{14} 	Phthalimide	THF, rt, 65 h		(36) 754
	Phthalimide	THF, 16 h, reflux		(60) 755
		THF, rt, 14 h		756
			R = H (73) R = 3-MeO (70) R = 4-MeO (73)	
	Phthalimide	THF, 0–25°, 1 h		(87) 757
	Phthalimide	—		(—) 758
	Phthalimide	THF, rt, 20 h		(86) 752
	Phthalimide	THF, rt, 2 h		(50) 759

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

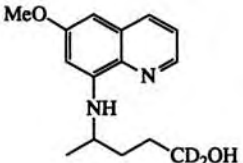
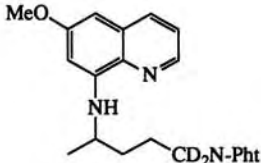
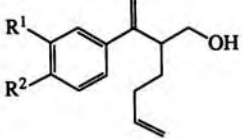
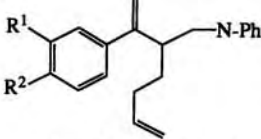
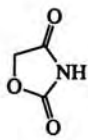
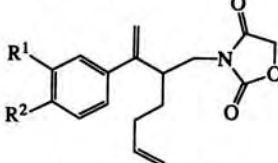
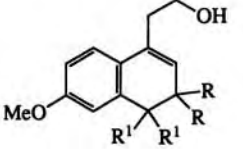
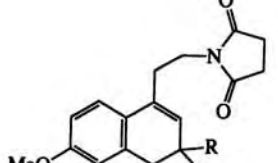
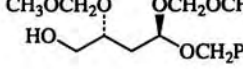
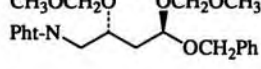
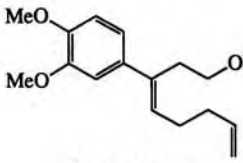
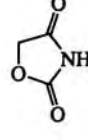
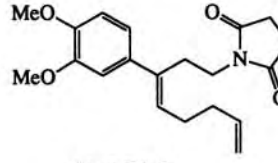
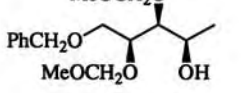
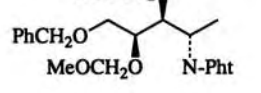

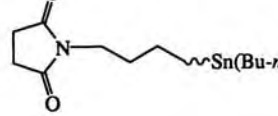
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₅ 	Phthalimide	C ₆ H ₆ , reflux, 3 h		(30-40) 760
	Phthalimide	THF, 14 h		761, 762
			R ¹ = H, R ² = MeO (82) R ¹ = R ² = MeO (73)	
		—		763
			R ¹ = MeO, R ² = H (92)	
	Succinimide	THF, 18 h, rt		764
			R = H, R ¹ = Me (33) R = Me, R ¹ = H (35)	
	Phthalimide	THF, 0° to rt		(92) 719, 720
C ₁₆ 		—		(99) 765
	Phthalimide	0° to rt		(—) 692
	Succinimide	THF, 23°		(95) 766

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

	Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
		Phthalimide	THF, 22°, 15 h		(58) 734
C ₁₇		Phthalimide	THF		(65-80) 767
		Phthalimide	—		(82) 768
		Succinimide	THF, rt, 20 min		(73) 769
C ₁₈		Phthalimide	1 h, rt		(88) 770
			THF, rt		771
				X = CH ₂ , O, S X = NH	(81-98) (48)
			THF, rt		(81-98) 771
			THF, rt		771
				X = CO (81-98), X = SO ₂ (57)	
			THF, rt		(—) 771
				R ¹ = H, R ² = NHCO ₂ CH ₂ CH=CH ₂ R ² = H, R ¹ = NHCO ₂ CH ₂ CH=CH ₂	

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

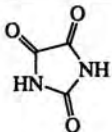
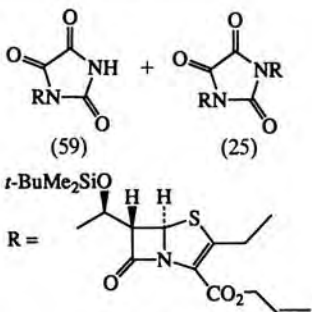
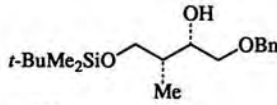
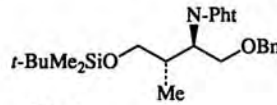
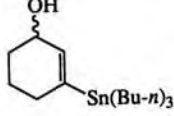
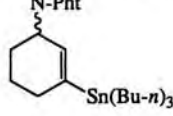
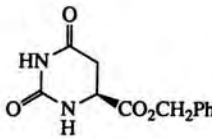
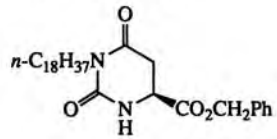
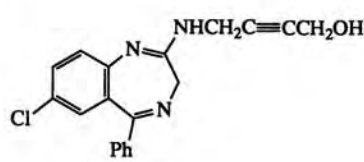
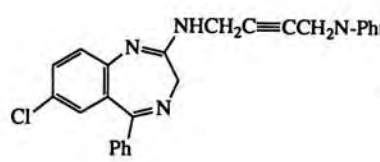
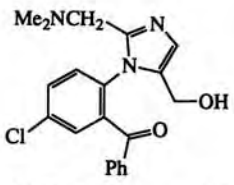
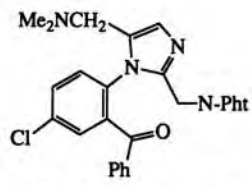
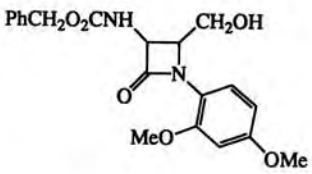
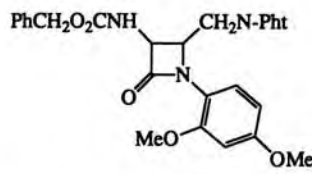
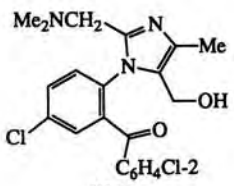
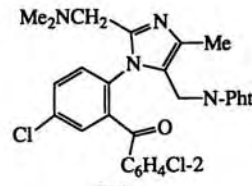
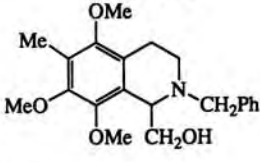
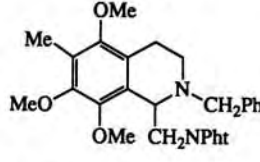
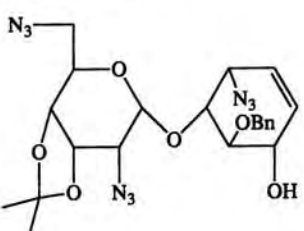
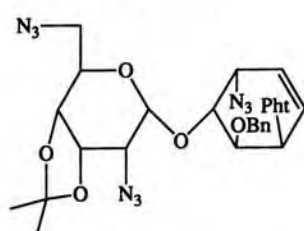
Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
		THF, rt	 (59) + (25)	771
	Phthalimide	THF, rt, 12 h		(72) 772
	Phthalimide	THF		(65-80) 767
$n\text{-C}_{18}\text{H}_{37}\text{OH}$		Dioxane, reflux, 4 h		(39) 668
C_{20} 	Phthalimide	—		(89) 770
	Phthalimide	1 h, rt		(—) 770
	Phthalimide	THF, 1 h, rt		(88) 773
C_{21} 	Phthalimide	—		(44) 770
	Phthalimide	—		(86) 759
C_{22} 	Phthalimide	THF, rt, overnight		(59) 774

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

	Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
		Phthalimide	THF, overnight, rt		(60) 775
		Phthalimide	THF, rt, 14 h		(64) 776
		Phthalimide	DMF		(100) 777
C ₂₅		Phthalimide	THF, 20°, 20 h		(77) 202
		Phthalimide	THF, rt, 18 h		(79) 778
C ₂₆		Phthalimide	THF, rt, 18 h		(64) 779
C ₂₇		Phthalimide	THF, rt, 18 h		(46) 778
C ₂₈		Phthalimide	1) THF, rt, overnight 2) Hydrazine, EtOH		(81) 780
C ₂₉		Phthalimide	THF, 0°, 3 h		(83) 612
		Phthalimide	THF, rt, 3 h		(100) 781, 782

TABLE XV. CARBON-NITROGEN BOND FORMATION, IMIDES (Continued)

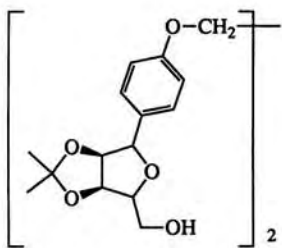
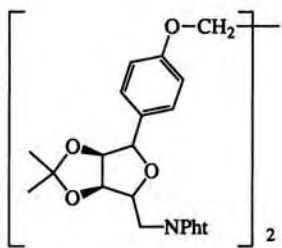
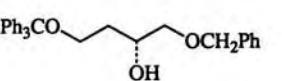
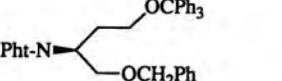
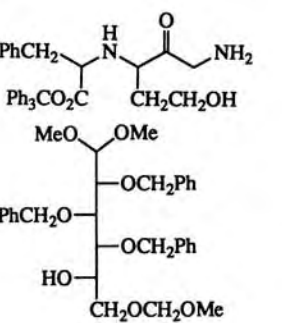
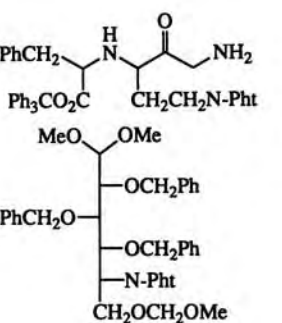
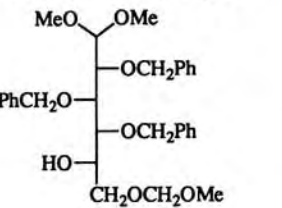
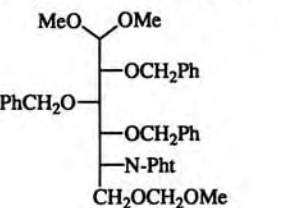
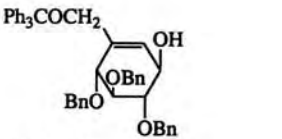
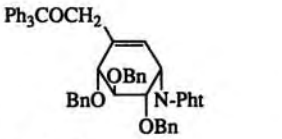
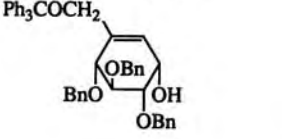
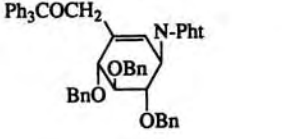
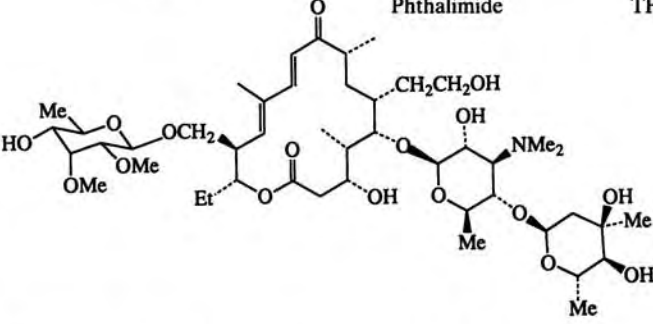
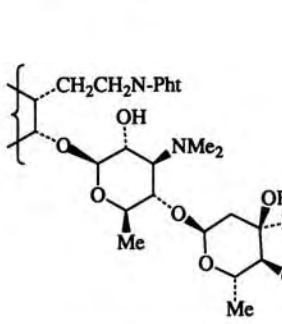
	Alcohol	Imide	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₀		Phthalimide	THF, reflux, 3.5 h		(71) 783
		Phthalimide	—		(78) 784
C ₃₁		Phthalimide	—		(58) 649
		Phthalimide	THF, rt		(75) 785
C ₁₇		Phthalimide	THF, rt, 1 h		(41) 89
		Phthalimide	THF, rt, 1 h		(48) 89
		Phthalimide	THF, 1 h, rt		244
C ₃₆₂	HO(CH ₂ CH ₂ O) ₁₈₀ CH ₂ CH ₂ OH	Phthalimide	CH ₂ Cl ₂ , 3 h, rt	Pht-N(CH ₂ CH ₂ O) ₁₈₀ CH ₂ CH ₂ N-Pht	(—) 786

TABLE XVI. CARBON-NITROGEN BOND FORMATION, AZIDES

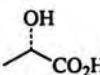
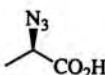
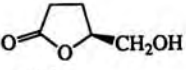
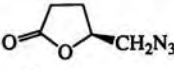
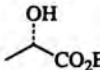
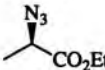
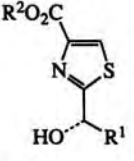
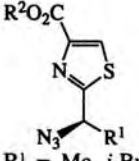
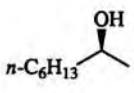
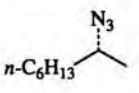
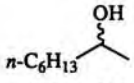
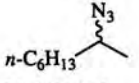
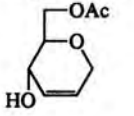
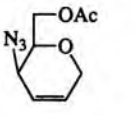
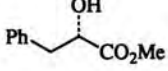
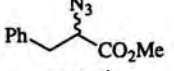
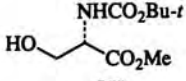
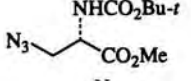
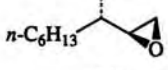
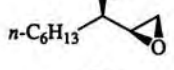
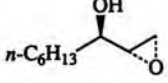
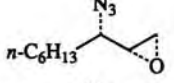
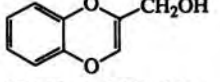
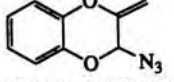
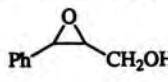
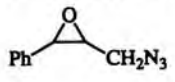
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃		C ₆ H ₆ , HN ₃ , 4–24 h, rt		(—) 208
	HOCH(CH ₂ OH) ₂	C ₆ H ₆ , HN ₃ , 3 h, 50°	HOCH(CH ₂ N ₃) ₂	(—) 208
C ₄	HOCH ₂ C≡CCH ₂ OH	"	N ₃ CH ₂ C≡CCH ₂ N ₃	(—) 208
	HOCH ₂ CH=CHCH ₂ OH	C ₆ H ₆ , HN ₃ , 4–24 h, rt	N ₃ CH ₂ CH=CHCH ₂ N ₃	(—) 208
C ₅		C ₆ H ₆ , HN ₃ , 4–24 h, rt		(—) 208
		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(83) 787
C ₆	C ₂ H ₅ O(CH ₂) ₂ O(CH ₂) ₂ OH	C ₆ H ₆ , HN ₃ , 3 h, 50°	C ₂ H ₅ O(CH ₂) ₂ O(CH ₂) ₂ N ₃	(—) 208
C ₇	PhCH ₂ OH	"	PhCH ₂ N ₃	(—) 208
		Toluene, HN ₃ , rt		(83–90) 788
	<i>t</i> -BuO ₂ CNHCH ₂ CH ₂ OH	HN ₃ , THF, toluene	<i>t</i> -BuO ₂ CNHCH ₂ CH ₂ N ₃	(—) 717
C ₈		C ₆ H ₆ , HN ₃ , 3 h, 50°		(—) 208
		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(81) 787
	Ph(CH ₂) ₂ OH	Zn(N ₃) ₂ , toluene, rt, 0.5–2 h	Ph(CH ₂) ₂ N ₃	(83) 787
		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(80) 787
C ₉		C ₆ H ₆ , HN ₃ , 4–24 h, rt		(—) 208
		THF/C ₆ H ₆ , HN ₃ , overnight, rt		(73) 790
		—		(100) 791
		—		(—) 791
		Zn(N ₃) ₂ , THF, rt		(75) 527
	PhCH=CHCH ₂ OH	Zn(N ₃) ₂ , toluene, rt, 0.5–2 h	PhCH=CHCH ₂ N ₃	(85) 787
		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(78) 787

TABLE XVI. CARBON-NITROGEN BOND FORMATION, AZIDES (Continued)

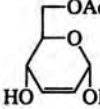
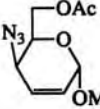
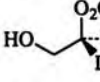
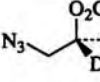
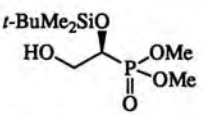
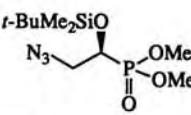
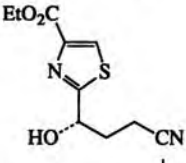
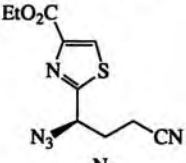


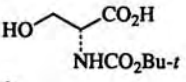
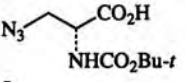
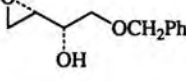
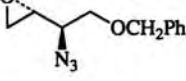
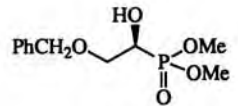
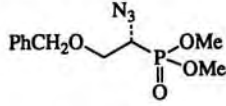
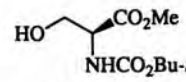
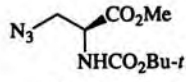


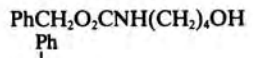
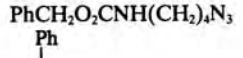
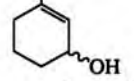
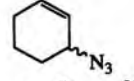
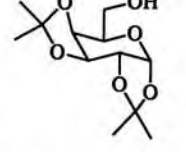
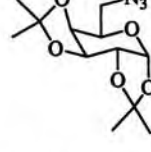
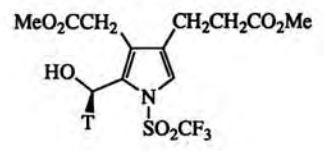
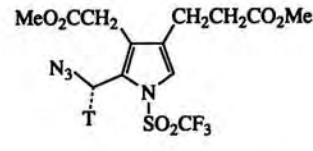
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₀		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(85) 787
		HN ₃ , THF/toluene, 2 h, rt		(85) 792
		THF/C ₆ H ₆ , HN ₃ , –35°, 1 h		(90) 793
C ₁₁		Toluene, HN ₃ , rt, overnight		(90) 395
		Zn(N ₃) ₂ :(pyridine) ₂ , toluene		(76) 251
		C ₆ H ₆ , HN ₃ , 3 h, 50°		(—) 208
		(PhO) ₂ PON ₃ , THF, 1.5 h, rt		(61) 794
C ₁₂		C ₆ H ₆ , HN ₃ , 1.5 h, rt		(70) 793
		HN ₃ , C ₆ H ₆		(—) 795
		HN ₃ , C ₆ H ₆ , 0.5 h, 60°		(73) 796
C ₁₃		CH ₂ Cl ₂ /C ₆ H ₆ , HN ₃ , rt, 20 h		(95) 797
		HN ₃ , C ₆ H ₆ , rt, 24 h		(52) 798
		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h		(82) 787
		—		(—) 799

TABLE XVI. CARBON-NITROGEN BOND FORMATION, AZIDES (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₅		HN ₃ , toluene	(83)	800
C ₁₆		HN ₃ , THF, 15 min	(80)	801
		HN ₃ , C ₆ H ₆	(85)	802
		HN ₃ , C ₆ H ₆ , 25°, 3 h	(—)	625
C ₁₈		HN ₃	(95)	771
C ₁₉		(PhO) ₂ PON ₃ , THF, rt, 24 h	(83)	803
C ₂₀		HN ₃ , toluene/THF, rt, 20–30 min	(61) R = CH=CHNHAc (48) R = CH ₂ CH ₂ NHAc	31
C ₂₁		HN ₃ , CH ₂ Cl ₂ , rt	(77)	804
		HN ₃ , toluene, rt, 15 h	(30) R = C ₆ H ₁₁ , R' = H (35) R = Ph, R' = H (60) R = 4-MeOC ₆ H ₄ , R' = H (50) R = 4-MeOC ₆ H ₄ , R' = MeO	800
		HN ₃ , C ₆ H ₆ , 18 h, 80°	(18)	207

TABLE XVI. CARBON-NITROGEN BOND FORMATION, AZIDES (Continued)

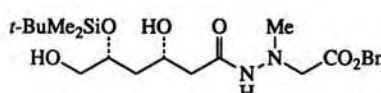
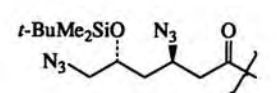
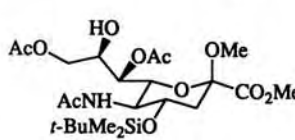
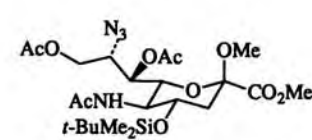
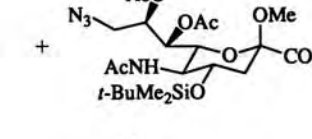
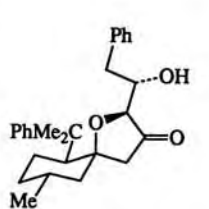
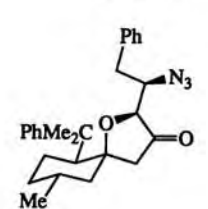
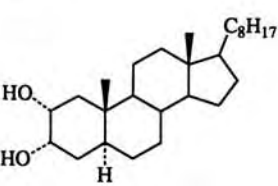
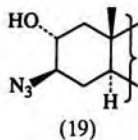
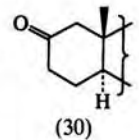
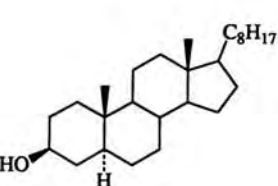
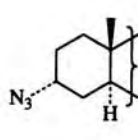
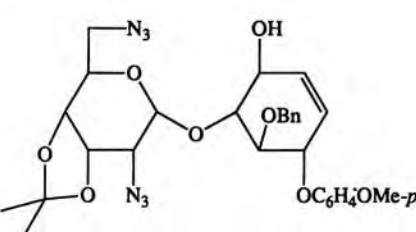
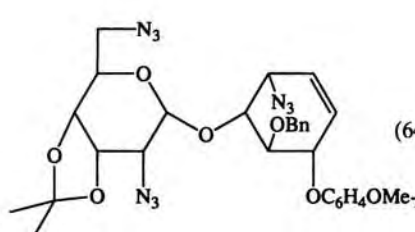
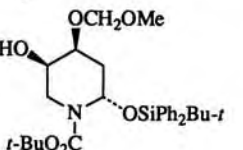
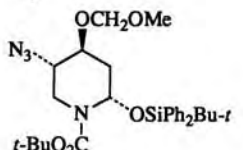
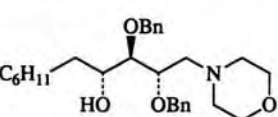
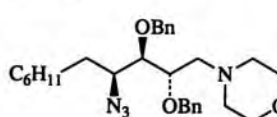
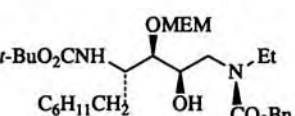
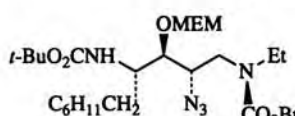
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₂₂		HN ₃ , C ₆ H ₆ /CH ₃ CN	 (70)	805
C ₂₃		HN ₃ , C ₆ H ₆	 (21) +  (28)	806
C ₂₆		(PhO) ₂ PON ₃ , THF, rt, 48 h	 (79)	807
C ₂₇		HN ₃ , C ₆ H ₆ , 9 h, 80°	 (19) +  (30)	285
C ₂₈		Zn(N ₃) ₂ , toluene, rt, 0.5–2 h	 (81)	787
C ₂₈		HN ₃ , toluene, -15°	 (64)	774
C ₂₉		HN ₃ , C ₆ H ₆ , 1 h, rt	 (95)	808
C ₂₉		(PhO) ₂ PON ₃	 (43)	809
C ₃₀		HN ₃ , THF, rt, 16 h	 (82)	810

TABLE XVI. CARBON-NITROGEN BOND FORMATION, AZIDES (Continued)

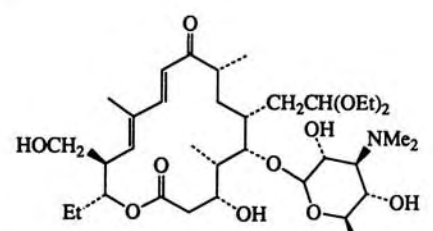
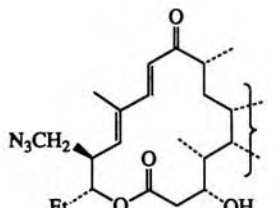
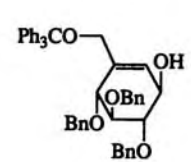
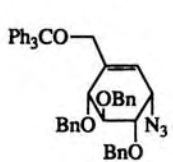
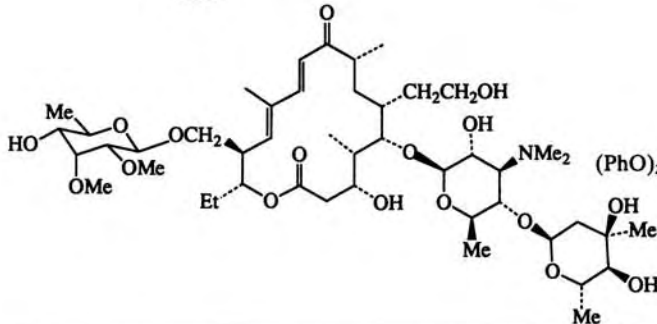
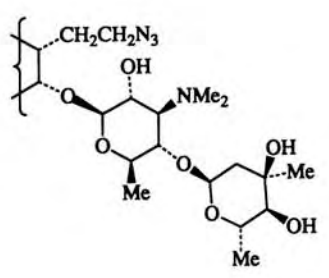
	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₅		(PhO) ₂ PON ₃ , THF, 0°-rt, 1.5 h		(—) 247
C ₄₇		HN ₃ , -10°		(72) 89
		(PhO) ₂ PON ₃ , THF, 0°, 40 min		(55) 244

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																				
C ₃		—	<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>% Yield</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>Me</td> <td>Boc</td> <td>70</td> </tr> <tr> <td>NHCbz</td> <td>H</td> <td>Boc</td> <td>71</td> </tr> <tr> <td>NHCbz</td> <td>H</td> <td><i>t</i>-Bu</td> <td>63</td> </tr> <tr> <td>NHCbz</td> <td>H</td> <td>CPh₃</td> <td>56</td> </tr> </tbody> </table>	R ¹	R ²	R ³	% Yield	Me	Me	Boc	70	NHCbz	H	Boc	71	NHCbz	H	<i>t</i> -Bu	63	NHCbz	H	CPh ₃	56	811
R ¹	R ²	R ³	% Yield																					
Me	Me	Boc	70																					
NHCbz	H	Boc	71																					
NHCbz	H	<i>t</i> -Bu	63																					
NHCbz	H	CPh ₃	56																					
C ₅		(PhO) ₃ P, 12 h, 60–70°	<p>R = Me R¹ = CH₂Ph (50) R = R¹ = CH₂Ph (35) R = CH₂Ph R¹ = Boc (70)</p>	216																				
C ₆		—	<p>R¹ = <i>t</i>-BuO, PhCH₂O R² = H, Me R³ = H, Me, Et, <i>n</i>-Pr R⁴ = H, Me R⁵ = H, Me R⁶ = PhCH₂, <i>t</i>-Bu, Ph₂CH</p>	(—) 812																				

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.																												
C ₉		THF, 25°		(75) 423																												
		THF, 25°, 1 h		(75) 426																												
C ₁₁		THF, rt, 11 h		(78-96) 396																												
		THF, 3 h, rt		(21-51) 813																												
C ₁₂		THF, rt, 1-3 h	<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>% I</th> <th>% II</th> </tr> </thead> <tbody> <tr> <td>CO₂Me</td> <td>4-BnOC₆H₄</td> <td>93</td> <td>0</td> </tr> <tr> <td>CO₂Me</td> <td>Ph</td> <td>81</td> <td>0</td> </tr> <tr> <td>CO₂Me</td> <td>H</td> <td>50</td> <td>30</td> </tr> <tr> <td>4-MeOC₆H₄</td> <td>H</td> <td>9</td> <td>38</td> </tr> <tr> <td>PhCH₂</td> <td>H</td> <td>26</td> <td>26</td> </tr> <tr> <td>CO₂Et</td> <td>CO₂Et</td> <td>82</td> <td>18</td> </tr> </tbody> </table>	R ¹	R ²	% I	% II	CO ₂ Me	4-BnOC ₆ H ₄	93	0	CO ₂ Me	Ph	81	0	CO ₂ Me	H	50	30	4-MeOC ₆ H ₄	H	9	38	PhCH ₂	H	26	26	CO ₂ Et	CO ₂ Et	82	18	211
R ¹	R ²	% I	% II																													
CO ₂ Me	4-BnOC ₆ H ₄	93	0																													
CO ₂ Me	Ph	81	0																													
CO ₂ Me	H	50	30																													
4-MeOC ₆ H ₄	H	9	38																													
PhCH ₂	H	26	26																													
CO ₂ Et	CO ₂ Et	82	18																													
		THF, 0°, 0.5 h		(68) 814																												
C ₁₃		THF, 12 h, rt		(63-70) 813																												
		THF, 4 h, rt		(58) 815																												
		THF		(77) 816																												

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
		THF, 25–50°, 1 h	 R = OBn R = 4-MeOC ₆ H ₄	817 (54) (100)
C ₁₄		—		(40–70) 818
		—		(75) 396
		—		(75) 396
		THF, 1.5 h, rt	 R = Me, PhCH ₂	(80) 819
C ₁₅		THF, 30 min, rt		(70) 820
		THF, rt, 7 h		(80) 819
		THF, DMAD, rt		(75) 821
		THF, rt, 10 h		(—) 822
C ₁₆		THF, 4 h	 R = Me R = Et	823 (58) (78)
		THF, 3 h		(67) 823
		—		(—) 824

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₇		CH ₂ Cl ₂ , rt, overnight	(50)	825
		THF	(20-25) + (50)	4a
C ₁₈		THF	(34)	826, 827
		—	(—)	215
		—	(—)	215
		THF	(59)	828
		THF	(57)	828
		THF, 2 h, rt	(43) + (22) + (13)	218
C ₁₉		THF, rt, 1 h	(55) + (3)	211
		THF, rt, 16 h	(75-85)	635

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
	THF, rt	 R = CONH ₂ ,	(—) 829
	—		(67) 830
	CH ₂ Cl ₂ , overnight	 R = Ph R = CH ₂ Ph	831 (65) (79)
	—	 I II	217
		DMAD DEAD DIAD	I (40) I (22) + II (5.5) I (14) + II (14)
	CH ₂ Cl ₂ , overnight, rt		(70) 831
	THF, 55°, 6 h	 R = H R = Me	832 (66) (68)
	—		(66) 833
	THF, 12 h		(62) 826, 827

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

	Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.	
C ₂₃		CCl ₄ , PPh ₃ , Et ₃ N, CH ₂ CN, rt, overnight		(77) 834	
C ₂₄		THF, 15 h, rt		835	
			Ar = 2-PhCH ₂ OC ₆ H ₄ (63) Ar = 3-PhCH ₂ OC ₆ H ₄ (83) Ar = 4-PhCH ₂ OC ₆ H ₄ (62) Ar = 2-PhCH ₂ O-5-CF ₃ C ₆ H ₃ (60)		
C ₂₅		CH ₂ Cl ₂ , 4 h, rt		(74) 825	
		THF, 1 h, rt		(96) 211	
C ₂₆		THF, 3 h, rt		(70) 813	
C ₂₇		THF, rt, 15 min		219	
			2:1 ratio of diastereomers		
			Eq. DEAD/PPh ₃	% Lactam	% elim
			1.0	77	23
			1.5	84	16
			1.8	88	12
			2.5	93	7
			4.0	97	3
			5.0	>98	<2
C ₃₀		—		(69) 213	

TABLE XVII. CARBON-NITROGEN BOND FORMATION, β -LACTAMS (Continued)

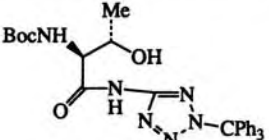
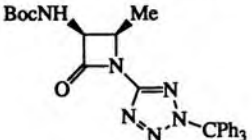
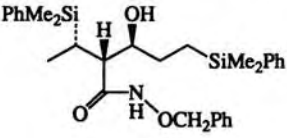
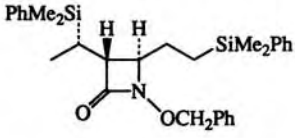
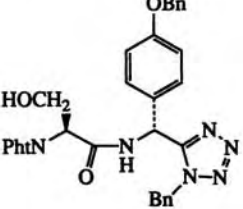
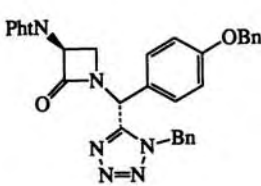
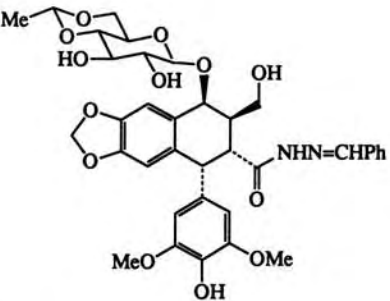
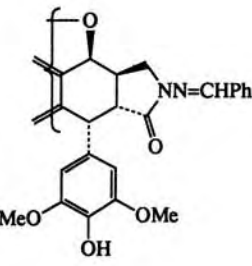
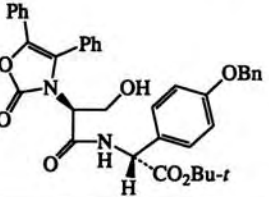
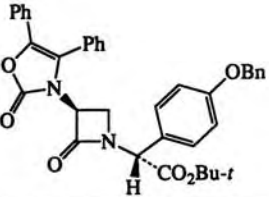
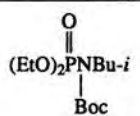
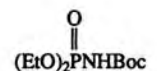
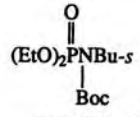
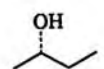
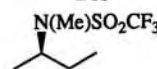
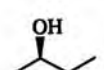
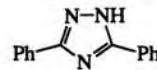
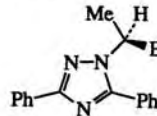
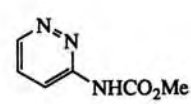
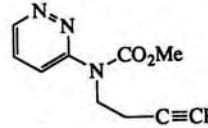
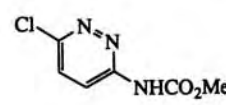
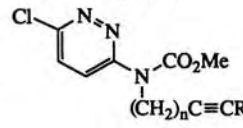
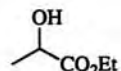
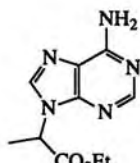
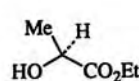
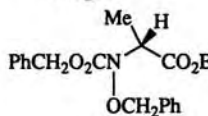
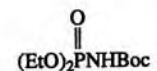
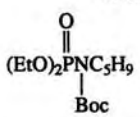
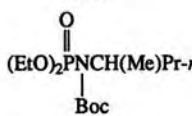
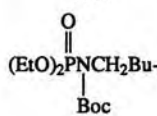
Alcohol	Conditions	Product(s) and Yield(s) (%)	Refs.
	THF		(43) 836
	—		(—) 18
	—		(67) 837
<p>C₃₆</p> 	THF, 25°, 20 min		(90) 838
<p>C₃₇</p> 	THF, P(OEt) ₃ , rt, 4 h		(83) 168

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL

Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.																																																		
C ₁ MeOH		THF, rt, 20 h		(39) 839																																																		
		THF		(—) 840																																																		
C ₂ 	—	Ether/THF, 2–18 h, rt		221																																																		
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>R³</th> <th>R⁴</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr><td>H</td><td>H</td><td>H</td><td>Ph</td><td>0</td></tr> <tr><td>PhCH₂</td><td>H</td><td>H</td><td>H</td><td>18</td></tr> <tr><td>PhCH₂</td><td>Me</td><td>H</td><td>H</td><td>59</td></tr> <tr><td>PhCH₂</td><td>H</td><td>H</td><td>Me</td><td>90</td></tr> <tr><td>PhCH₂</td><td>Me</td><td>Me</td><td>H</td><td>89</td></tr> <tr><td>PhCH₂</td><td>H</td><td>H</td><td>Ph</td><td>65</td></tr> <tr><td><i>n</i>-C₆H₁₁</td><td>H</td><td>H</td><td>Ph</td><td>86</td></tr> <tr><td><i>t</i>-Bu</td><td>H</td><td>H</td><td>Ph</td><td>77</td></tr> <tr><td>Me</td><td>Me</td><td>H</td><td>Ph</td><td>84</td></tr> </tbody> </table>	R ¹	R ²	R ³	R ⁴	Yield (%)	H	H	H	Ph	0	PhCH ₂	H	H	H	18	PhCH ₂	Me	H	H	59	PhCH ₂	H	H	Me	90	PhCH ₂	Me	Me	H	89	PhCH ₂	H	H	Ph	65	<i>n</i> -C ₆ H ₁₁	H	H	Ph	86	<i>t</i> -Bu	H	H	Ph	77	Me	Me	H	Ph	84	
R ¹	R ²	R ³	R ⁴	Yield (%)																																																		
H	H	H	Ph	0																																																		
PhCH ₂	H	H	H	18																																																		
PhCH ₂	Me	H	H	59																																																		
PhCH ₂	H	H	Me	90																																																		
PhCH ₂	Me	Me	H	89																																																		
PhCH ₂	H	H	Ph	65																																																		
<i>n</i> -C ₆ H ₁₁	H	H	Ph	86																																																		
<i>t</i> -Bu	H	H	Ph	77																																																		
Me	Me	H	Ph	84																																																		
C ₃ <i>i</i> -PrOH		C ₆ H ₆ , rt		(73) 230a																																																		
	TsNHMe	THF	<i>i</i> -PrNMeTs	(53) 840																																																		
	CF ₃ SO ₂ NHMe	THF	CF ₃ SO ₂ N(Me)Pr- <i>i</i>	(82) 840																																																		
	CF ₃ SO ₂ NHPh	THF	CF ₃ SO ₂ N(Ph)Pr- <i>i</i>	(26) 840																																																		
	TsNHPh	THF	TsN(Ph)Pr- <i>i</i>	(66) 840																																																		
		Et ₂ O, rt		(58–72) 229																																																		
			R = H, Me, Et, <i>n</i> -Pr, CH ₂ Ph																																																			
		THF, rt, overnight, DIAD		228																																																		
			<table border="1"> <thead> <tr> <th>R</th> <th>R¹</th> <th>% I</th> <th>% II</th> <th>% III</th> </tr> </thead> <tbody> <tr><td>H</td><td>—</td><td>30</td><td>—</td><td>—</td></tr> <tr><td>Me</td><td>—</td><td>82</td><td>9</td><td>—</td></tr> <tr><td>Et</td><td>—</td><td>59</td><td>9</td><td>—</td></tr> <tr><td><i>i</i>-Pr</td><td>—</td><td>20</td><td>48</td><td>—</td></tr> <tr><td><i>i</i>-Bu</td><td><i>i</i>-Pr</td><td>50</td><td>14</td><td>10</td></tr> <tr><td>PhCH₂</td><td>Ph</td><td>43</td><td>20</td><td>11</td></tr> </tbody> </table>	R	R ¹	% I	% II	% III	H	—	30	—	—	Me	—	82	9	—	Et	—	59	9	—	<i>i</i> -Pr	—	20	48	—	<i>i</i> -Bu	<i>i</i> -Pr	50	14	10	PhCH ₂	Ph	43	20	11																
R	R ¹	% I	% II	% III																																																		
H	—	30	—	—																																																		
Me	—	82	9	—																																																		
Et	—	59	9	—																																																		
<i>i</i> -Pr	—	20	48	—																																																		
<i>i</i> -Bu	<i>i</i> -Pr	50	14	10																																																		
PhCH ₂	Ph	43	20	11																																																		
C ₄ <i>n</i> -BuOH		C ₆ H ₆ , rt		(85) 230a																																																		

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.																					
<i>i</i> -BuOH	"	"		(77) 230a																					
<i>s</i> -BuOH		C ₆ H ₆ , rt		(66) 230a																					
	CF ₃ SO ₂ NHMe	THF		(84) 840																					
		THF, 4 h, rt		(34) 841																					
RC≡CCH ₂ CH ₂ OH		—	 R = H R = Me R = CH ₂ OTHP	274, 842 (19) (22) (13)																					
RC≡C(CH ₂) _n OH		THF, 25°, 8 h		274, 842																					
			<table border="1"> <thead> <tr> <th>R</th> <th>n</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>Me</td> <td>2</td> <td>43</td> </tr> <tr> <td>H</td> <td>2</td> <td>47</td> </tr> <tr> <td>CH₂OTHP</td> <td>2</td> <td>37</td> </tr> <tr> <td>CH₂OTBDMS</td> <td>2</td> <td>45</td> </tr> <tr> <td>H</td> <td>3</td> <td>53</td> </tr> <tr> <td>H</td> <td>4</td> <td>48</td> </tr> </tbody> </table>	R	n	Yield (%)	Me	2	43	H	2	47	CH ₂ OTHP	2	37	CH ₂ OTBDMS	2	45	H	3	53	H	4	48	
R	n	Yield (%)																							
Me	2	43																							
H	2	47																							
CH ₂ OTHP	2	37																							
CH ₂ OTBDMS	2	45																							
H	3	53																							
H	4	48																							
	Adenine	—		(—) 843																					
	PhCH ₂ O ₂ CNHOCH ₂ Ph	—		(37) 844																					
C ₅ H ₉ OH		C ₆ H ₆ , rt		230a																					
<i>n</i> -PrCH(CH ₃)OH	"	"		230a																					
<i>t</i> -BuCH ₂ OH	"	"		230a																					

590

C₅

591

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

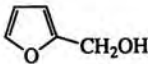
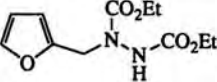
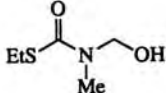
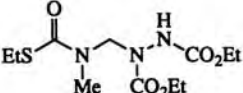
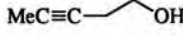
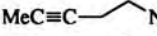
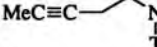
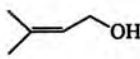
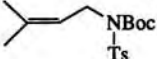
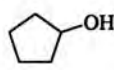
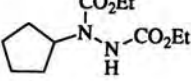

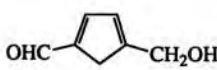
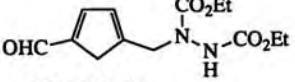
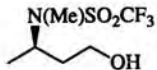
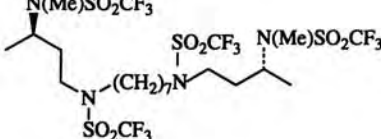
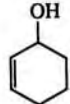
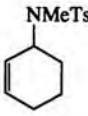
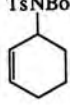


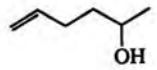
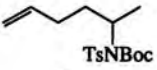
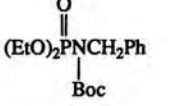

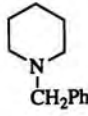
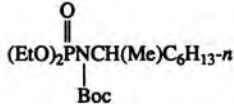
Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
	DEAD	THF, 1 h, rt		(60) 256
	"	"		(90) 256
	TsNHMe	THF, rt, 3 h		(51) 230b
	TsNHBoc	THF, rt, 3 h		(96) 230b
	TsNHBoc	THF, rt, 3 h		(85) 230b
	DEAD	THF, rt, 1 h		(78) 256
$\text{H}_2\text{N}(\text{CH}_2)_5\text{OH}$	—	HCl, DMF		(23) 222
C_6				
	DEAD	THF, rt, 1 h		(12) 256
	$\text{CF}_3\text{SO}_2\text{NH}(\text{CH}_2)_7\text{NHSO}_2\text{CF}_3$	THF		(80) 840
	TsNHMe	THF, rt, 3 h		(62) 230b
	TsNHBoc	THF, rt, 3 h		(86) 230b
	TsNHBoc	THF, rt, 3 h		(88) 230b
	TsNHBoc	THF, rt, 3 h		(75) 230b
C_7				
PhCH_2OH	$(\text{EtO})_2\text{PNHBoc}$	C_6H_6 , rt		(80) 230a
PhCH_2OH	TsNHMe	THF, rt, 3 h	$\text{PhCH}_2\text{NMeTs}$	(50) 230b
	$\text{CF}_3\text{SO}_2\text{NHMe}$	THF	$\text{CF}_3\text{SO}_2\text{N}(\text{Me})\text{CH}_2\text{Ph}$	(70) 840
	$\text{CF}_3\text{SO}_2\text{NHPh}$	THF	$\text{CF}_3\text{SO}_2\text{N}(\text{Ph})\text{CH}_2\text{Ph}$	(41) 840
	TsNHPh	THF	$\text{TsN}(\text{Ph})\text{CH}_2\text{Ph}$	(68) 840
PhCH_2OH	PhNH_2	HCl, DMF/THF	PhNHCH_2Ph	(10) 222
		"		(43) 222
C_8				
$n\text{-C}_6\text{H}_{13}\text{CH}(\text{Me})\text{OH}$	$(\text{EtO})_2\text{PNHBoc}$	C_6H_6 , rt		(71) 230a

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

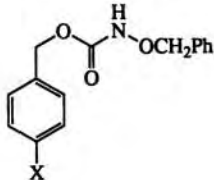
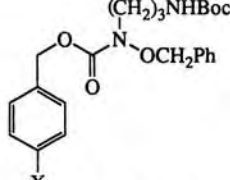
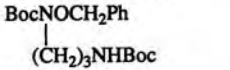
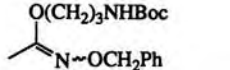
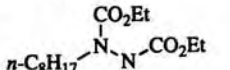
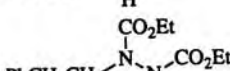
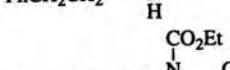
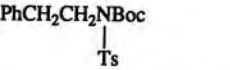
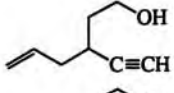
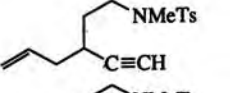
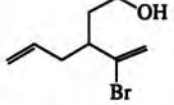
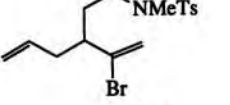
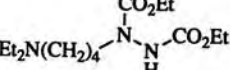
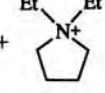
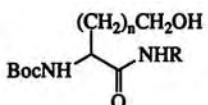
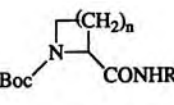
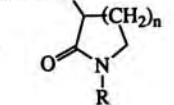
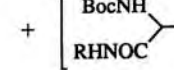
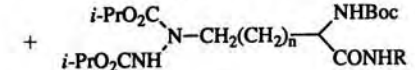
Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
BocNH(CH ₂) ₃ OH		THF, rt	 X = H, NO ₂	(70-90) 845
BocNH(CH ₂) ₃ OH	BocNHCH ₂ Ph	THF, rt		(41) 845
BocNH(CH ₂) ₃ OH	AcNHCH ₂ Ph	THF, rt		(—) 845
<i>n</i> -C ₈ H ₁₇ OH	DEAD	THF, 1 h, rt		(44) 256
PhCH ₂ CH ₂ OH	"	"		(37) 256
4-MeOC ₆ H ₄ CH ₂ OH	"	"		(80) 256
C _x PhCH ₂ CH ₂ OH	TsNHMe	THF, rt, 3 h	PhCH ₂ CH ₂ NMeTs	(58) 230b
PhCH ₂ CH ₂ OH	TsNHBoc	THF, rt, 3 h		(97) 230b
	TsNHMe	THF, rt, 3 h		(80) 230b
	TsNHMe	THF, rt, 3 h		(58) 230b
Et ₂ N(CH ₂) ₄ OH	DEAD	THF, rt, 1 h	 (20) + 	(—) 256
C ₃ 	DIAD	—	 +  +  + 	846

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

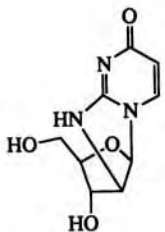
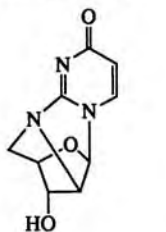
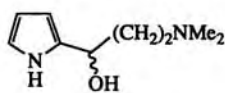
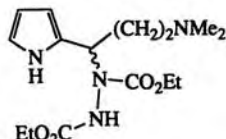
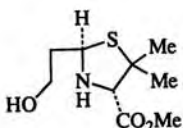
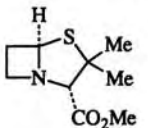
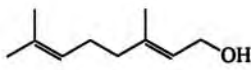
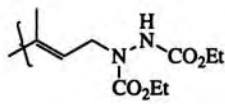
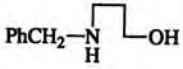
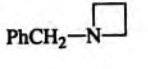
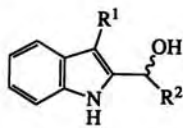
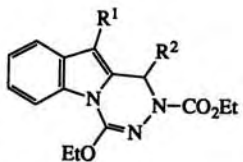
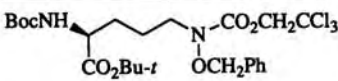
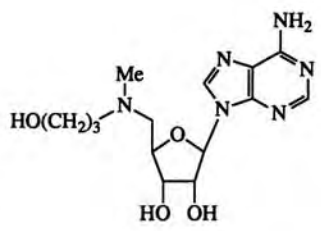
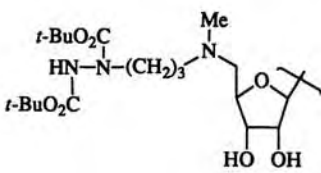
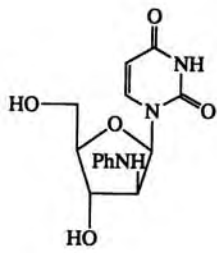
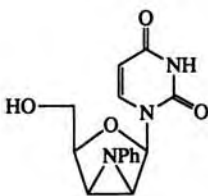
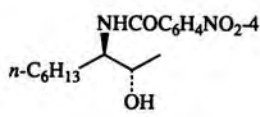
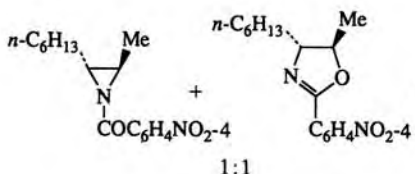
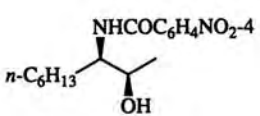
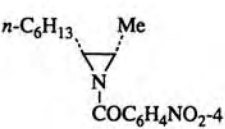
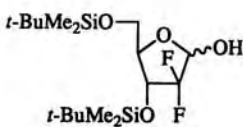
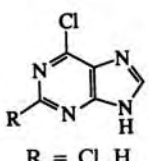
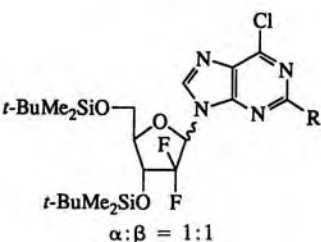
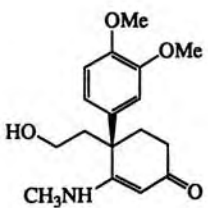
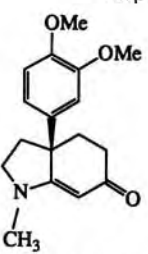
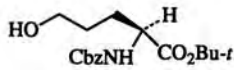
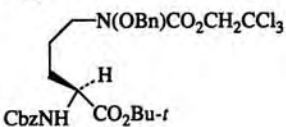
Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)					Refs.	
			R	n	% I	% II	% III		% IV
			H	1	0	34.2	7.2	25.2	
			Me	1	0	38.3	10.0	14.9	
			<i>n</i> -Bu	1	0	47.6	15.6	0	
			PhCH ₂	1	23.1	36.4	0	12.7	
			EtO ₂ C(Me)CH	1	0	60.8	1.4	5.7	
			H	2	20.9	56.3	0	0	
			Me	2	43.2	0	0	33.1	
			<i>n</i> -Bu	2	10.5	0	22.9	25.5	
			PhCH ₂	2	37.6	0	8.1	29.4	
			EtO ₂ C(Me)CH	2	50.5	0	3.1	32.8	
			H	3	0	0	30.6	21.8	
			Me	3	0	0	25.9	28.3	
			<i>n</i> -Bu	3	0	0	22.0	38.0	
			PhCH ₂	3	0	0	15.5	41.4	
			EtO ₂ C(Me)CH	3	0	0	24.8	32.3	
		—							
		Dioxane, 38 h, rt							(33) 847
		DEAD							(46) 848
									(5)
		—							(24) 223
C ₁₀		THF, 4 days, rt, BF ₃ ⁻ , Et ₂ O							
		DEAD							(69) 256
		—							(40-50) 222
C ₁₁									
		DEAD							848
									(28)
									(34)
									(—)
									(—)

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.																																
		THF		(60) 849																																
	TsNHMe	THF		(48) 840																																
	CF ₃ SO ₂ NHMe	THF		(86) 840																																
	CF ₃ SO ₂ NHPh	THF		(86) 840																																
	TsNHPh	THF		(65) 840																																
		THF, 22°, 18–24 h		(61) 850, 851																																
				(35)																																
	DEAD	THF, 1 h rt		(86) 256																																
		—		(—) 852																																
	—	THF, rt, 10 h		226																																
			<table border="1"> <thead> <tr> <th>X</th> <th>Y</th> <th>R</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>NH₂</td> <td>H</td> <td>Me</td> <td>64</td> </tr> <tr> <td>NH₂</td> <td>H</td> <td>PhCH₂</td> <td>55</td> </tr> <tr> <td>OH</td> <td>H</td> <td>PhCH₂</td> <td>48</td> </tr> <tr> <td>NH₂</td> <td>H</td> <td>allyl</td> <td>37</td> </tr> <tr> <td>OH</td> <td>H</td> <td>allyl</td> <td>29</td> </tr> <tr> <td>OH</td> <td>Me₂NCH₂NH</td> <td>PhCH₂</td> <td>55</td> </tr> <tr> <td>OH</td> <td>Me₂NCH₂NH</td> <td>allyl</td> <td>52</td> </tr> </tbody> </table>	X	Y	R	Yield (%)	NH ₂	H	Me	64	NH ₂	H	PhCH ₂	55	OH	H	PhCH ₂	48	NH ₂	H	allyl	37	OH	H	allyl	29	OH	Me ₂ NCH ₂ NH	PhCH ₂	55	OH	Me ₂ NCH ₂ NH	allyl	52	
X	Y	R	Yield (%)																																	
NH ₂	H	Me	64																																	
NH ₂	H	PhCH ₂	55																																	
OH	H	PhCH ₂	48																																	
NH ₂	H	allyl	37																																	
OH	H	allyl	29																																	
OH	Me ₂ NCH ₂ NH	PhCH ₂	55																																	
OH	Me ₂ NCH ₂ NH	allyl	52																																	
	CbzNHCHO ₂ Ph	THF, rt, 5 h		(75–80) 853																																

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
	$\text{Cl}_3\text{CCH}_2\text{O}_2\text{C}$ PhCH_2ONH	THF, rt, 16 h		(75-80) 853
	$(t\text{-BuO}_2\text{CN}=\text{N})_2$	—		(—) 645
	—	Dioxane, 38 h, rt		(37) 847
	—	—		(—) 854
	—	THF, 0°-rt, 2 h		(73) 854
	 R = Cl, H	—	 $\alpha:\beta = 1:1$	(50) 855
	—	THF, rt, 10 min		(85) 225
	$\text{Cl}_3\text{CCH}_2\text{O}_2\text{CNHOBn}$	CH ₃ CN		(—) 856

 C₁₅

 C₁₆

 C₁₇

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

	Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₁₈		—	—		(—) 211
				+	
C ₁₉		—	THF, 1 h, -78°		(85) 227
				+	(3)
		BnO ₂ CNHOBn	THF, rt		(62-70) 276
C ₂₁		—	—		(—) 211
				+	
C ₂₁		AcNHOBn	THF, 1.5 h, rt		(—) 276
				+	
				+	
				+	

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

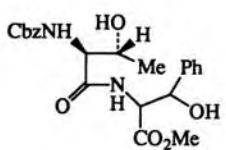
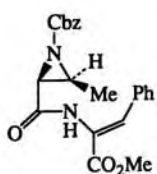
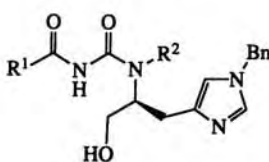
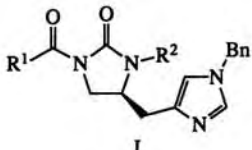
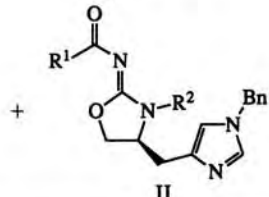
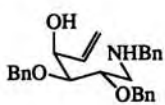
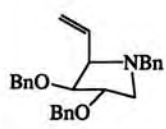
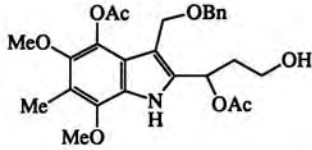
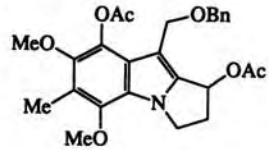
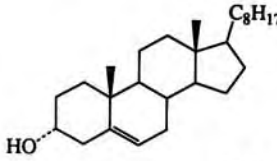
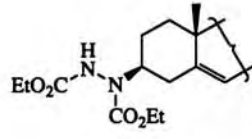
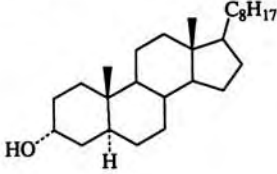
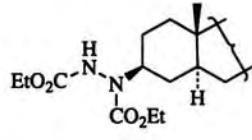
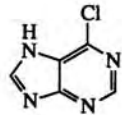
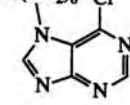
Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.																												
C ₂₂ 		THF		(—) 818																												
C ₂₃ 		THF, rt, 2 h	 I  II	857																												
			<table border="1"> <thead> <tr> <th>R¹</th> <th>R²</th> <th>I</th> <th>II</th> </tr> </thead> <tbody> <tr> <td>C₆H₅</td> <td>Et</td> <td>56</td> <td>44</td> </tr> <tr> <td>C₆H₅</td> <td><i>i</i>-Bu</td> <td>59</td> <td>41</td> </tr> <tr> <td>4-ClC₆H₄</td> <td>Et</td> <td>57</td> <td>43</td> </tr> <tr> <td>2,4-Cl₂C₆H₃</td> <td>Et</td> <td>80</td> <td>20</td> </tr> <tr> <td>2,4-Cl₂C₆H₃</td> <td><i>i</i>-Bu</td> <td>81</td> <td>19</td> </tr> <tr> <td>2-Cl-4-O₂NC₆H₃</td> <td><i>i</i>-Bu</td> <td>83</td> <td>17</td> </tr> </tbody> </table>	R ¹	R ²	I	II	C ₆ H ₅	Et	56	44	C ₆ H ₅	<i>i</i> -Bu	59	41	4-ClC ₆ H ₄	Et	57	43	2,4-Cl ₂ C ₆ H ₃	Et	80	20	2,4-Cl ₂ C ₆ H ₃	<i>i</i> -Bu	81	19	2-Cl-4-O ₂ NC ₆ H ₃	<i>i</i> -Bu	83	17	
R ¹	R ²	I	II																													
C ₆ H ₅	Et	56	44																													
C ₆ H ₅	<i>i</i> -Bu	59	41																													
4-ClC ₆ H ₄	Et	57	43																													
2,4-Cl ₂ C ₆ H ₃	Et	80	20																													
2,4-Cl ₂ C ₆ H ₃	<i>i</i> -Bu	81	19																													
2-Cl-4-O ₂ NC ₆ H ₃	<i>i</i> -Bu	83	17																													
C ₂₄ 	—	THF, rt		(95) 858																												
C ₂₆ 	—	—		(61) 224																												
C ₂₇ 	DEAD	THF, 1 h, rt		(15) 256																												
	DEAD	THF, 1 h, rt		(20) 256																												
C ₃₀ (4-MeOC ₆ H ₄) ₃ CNH(CH ₂) ₈ OH		THF, 48 h	(4-MeOC ₆ H ₄) ₃ CNH(CH ₂) ₈ Cl 	(65) 859																												

TABLE XVIII. CARBON-NITROGEN BOND FORMATION, GENERAL (Continued)

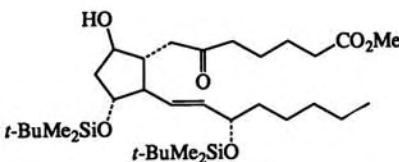
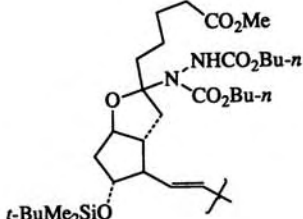
Alcohol	Nitrogen Compound	Conditions	Product(s) and Yield(s) (%)	Refs.
	Di- <i>n</i> -butyl azodicarboxylate	THF, 1 h, rt		(100) 256

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS

	Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃		Zn(S ₂ CNMe ₂) ₂	Toluene, 0°		(85) 860
		MeCOSH	THF, 0°, 15 min	 (40%) 68% ee	233
C ₄		EtCS ₂ H	THF, 0°, 0.5 h		(61) 861
			THF, (<i>n</i> -Bu) ₃ P, -78° to 0°		(50-80) 248, 249
C ₅			—		(—) 250
		EtCS ₂ H	THF, 0°, 0.5 h		(98) 861
		EtCS ₂ H	THF, 0°, 2 h		(29) 861
C ₅		EtCS ₂ H	THF, 0°, 2 h		(94) 861

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

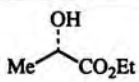
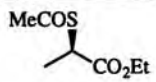
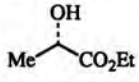
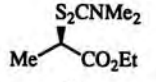
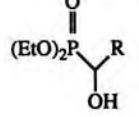
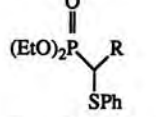
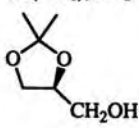
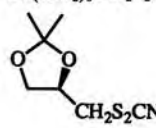
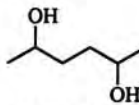
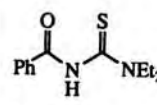
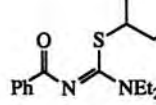
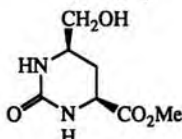
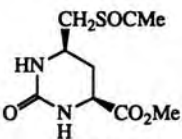
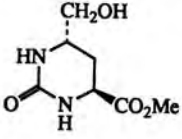
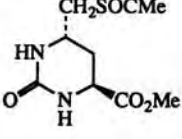
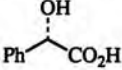
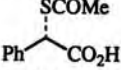
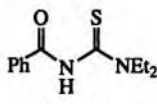
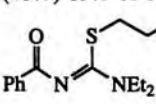
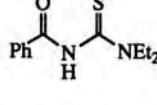
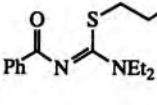
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
	MeCOSH	—	 (—) 232	
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	 (80) 860	
	PhSH	C ₆ H ₆ , rt, 48 h	 (50–55) 246 R = H, Me, Et, <i>n</i> -Pr, <i>n</i> -C ₃ H ₁₁	
C ₅ H ₉ OH	EtCS ₂ H	THF, 0°, 1.5 h	C ₅ H ₉ S ₂ CEt (62) 861	
<i>n</i> -C ₅ H ₁₁ OH	EtCS ₂ H	THF, 0°, 2 h	<i>n</i> -C ₅ H ₁₁ S ₂ CEt (95) 861	
Br(CH ₂) ₅ CH ₂ OH	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	Br(CH ₂) ₅ CH ₂ S ₂ CNMe ₂ (89) 860	
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	 (87) 860	
		—	 (—) 250	
C ₆ H ₁₁ OH	EtCS ₂ H	THF, 0°, 1.5 h	C ₆ H ₁₁ S ₂ CEt (14) 861	
C ₇	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	PhCH ₂ S ₂ CNMe ₂ (92) 860	
PhCH ₂ OH	MeCOSH	—	PhCH ₂ SCOMe (—) 231	
PhCH ₂ OH	EtCS ₂ H	THF, 0°, 0.5 h	PhCH ₂ S ₂ CEt (82) 861	
PhCH ₂ OH	MeCS ₂ H	THF, 0°, 0.5 h	PhCH ₂ S ₂ CMe (48) 861	
<i>t</i> -BuO ₂ CNH(CH ₂) _n OH	<i>i</i> -BuCS ₂ H	THF, 0°, 0.5 h	PhCH ₂ S ₂ CBu- <i>i</i> (92) 861	
<i>n</i> = 2–8	PhCOSH	—	<i>t</i> -BuO ₂ CNH(CH ₂) _n SCOPh (50–70) 236	
	MeCOSH	THF/DMF, 4 h, 20°	 (74) 862	
	MeCOSH	THF/DMF, 4 h, 20°	 (83) 862	
C ₈	MeCOSH	THF, rt, overnight	4-O ₂ NC ₆ H ₄ CH ₂ CH ₂ SOCMe (—) 863	
	MeCOSH	THF, 0°, 15 min	 233 (48%) 85% ee retention	
PhCH ₂ CH ₂ OH		—	 (—) 250	
PhOCH ₂ CH ₂ OH		—	 (—) 250	

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

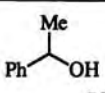
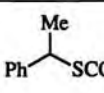
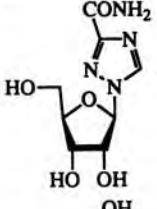
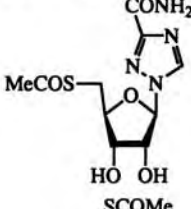
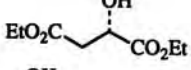
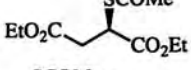
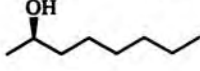
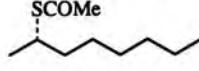
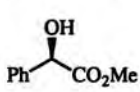
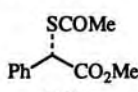
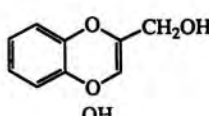
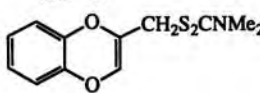
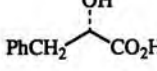
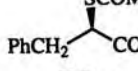
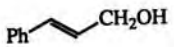
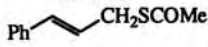
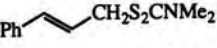
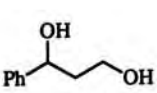
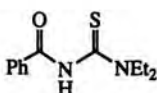
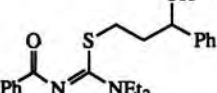
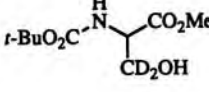
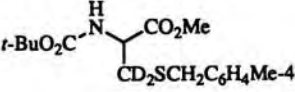
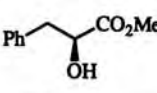
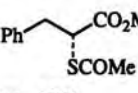
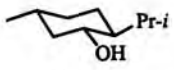
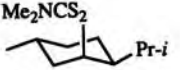
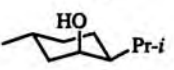

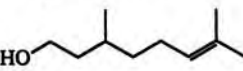
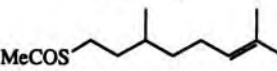
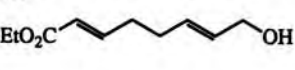
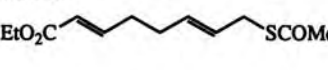
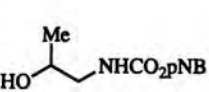
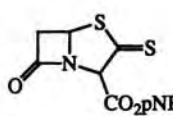
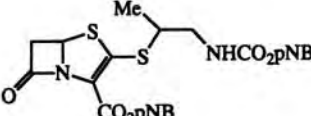
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
	MeCOSH	—		(—) 237
	MeCOSH	Dioxane, rt, 15 h		(64) 241
	MeCOSH	—		(92) 232
	MeCOSH	—		(98) 231
	MeCOSH	THF, 0°	 69% ee	(78) 232
	Zn(S ₂ CNMe ₂) ₂	THF, rt		(77) 527
	MeCOSH	THF	 52% ee	(45) 233
	"	"		(89) 231
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°		(95) 860
		—		(—) 250
	4-MeC ₆ H ₄ CH ₂ SH	Toluene, rt		(66) 864
	MeCOSH	—		(—) 233
	Zn(S ₂ CNMe ₂) ₂	Toluene, rt		(86) 251
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°		(86) 860
	MeCOSH	THF, rt, 2 h		(83) 238
	MeCOSH	—		(—) 865
		—		(44) 255

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.												
	MeCOSH	THF, rt, 2 h		(91) 241												
	MeCOSH	—		(73) 240												
		THF, 0°, 1 h		(95) 254												
	MeCOSH	THF, 2 h		(—) 238												
	"	"		(54) 238												
C_{12} 	$Zn(S_2CNMe_2)_2$	Toluene, 0°		(92) 860												
	MeCOSH	THF, 1 h, rt		(85) 98												
<table border="0"> <tr> <td>R^1</td> <td>R^2</td> </tr> <tr> <td>H</td> <td>$CO_2CH_2CH=CH_2$</td> </tr> <tr> <td>$CO_2CH_2CH=CH_2$</td> <td>H</td> </tr> <tr> <td>H</td> <td>CO_2Me</td> </tr> <tr> <td>CO_2Me</td> <td>H</td> </tr> <tr> <td>H</td> <td>CH_2SMe</td> </tr> </table>	R^1	R^2	H	$CO_2CH_2CH=CH_2$	$CO_2CH_2CH=CH_2$	H	H	CO_2Me	CO_2Me	H	H	CH_2SMe				
R^1	R^2															
H	$CO_2CH_2CH=CH_2$															
$CO_2CH_2CH=CH_2$	H															
H	CO_2Me															
CO_2Me	H															
H	CH_2SMe															
	MeCOSH	THF		(84) 241												
	MeCOSH	DMF, rt		(43) 866												

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

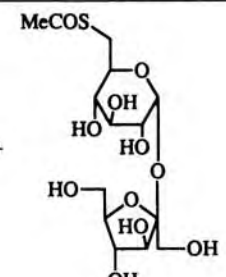
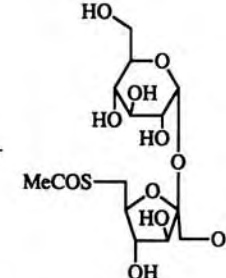
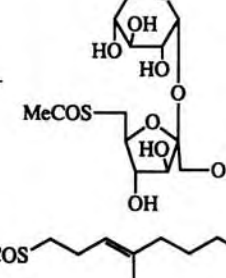
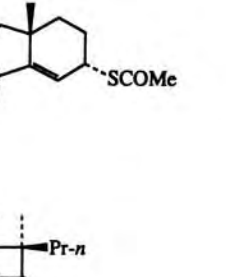
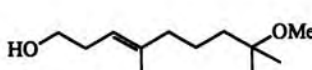
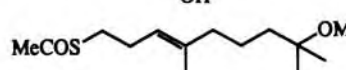
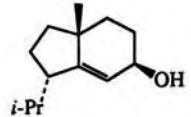
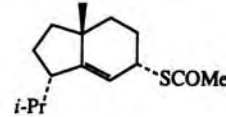
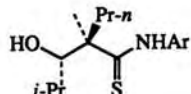
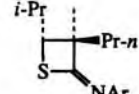
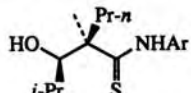
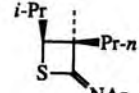
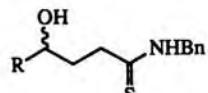
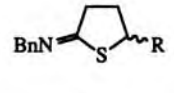
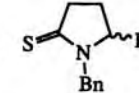
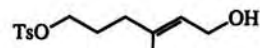
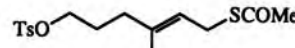

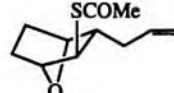
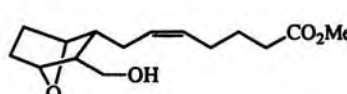
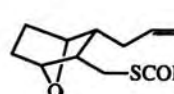
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.															
			 + 	(21)															
			 + 	(21)															
	MeCOSH	THF, 2 h		(64) 238															
	MeCOSH	DME, 0°		(82) 112															
	—	—		(100) 249															
	—	—		(100) 249															
	—	THF, rt, 3.5–10 h	 + 	867															
			<table border="1"> <thead> <tr> <th colspan="3">I</th> </tr> <tr> <th>R</th> <th>% I</th> <th>% II</th> </tr> </thead> <tbody> <tr> <td>Ph</td> <td>47</td> <td>23</td> </tr> <tr> <td>Me</td> <td>42</td> <td>32</td> </tr> <tr> <td>Et</td> <td>40</td> <td>23</td> </tr> </tbody> </table>	I			R	% I	% II	Ph	47	23	Me	42	32	Et	40	23	
I																			
R	% I	% II																	
Ph	47	23																	
Me	42	32																	
Et	40	23																	
$n\text{-C}_{12}\text{H}_{25}\text{OH}$	EtCS ₂ H	THF, 0°, 1.5 h	$n\text{-C}_{12}\text{H}_{25}\text{S}_2\text{CEt}$	(88) 861															
	MeCOSH	—		(—) 865															
	MeCOSH	THF, 12 h, 0–23°		(33) 868															
	MeCOSH	THF, 12 h, 0–23°		(90) 868															

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

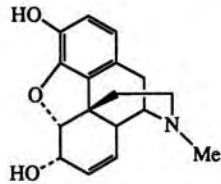
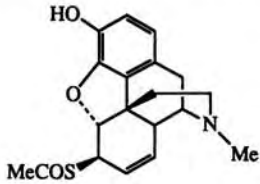
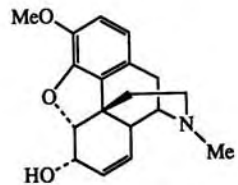
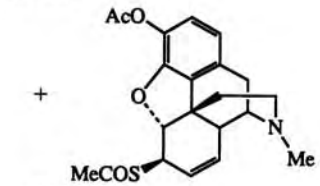
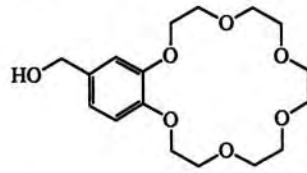
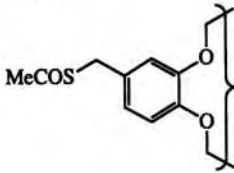
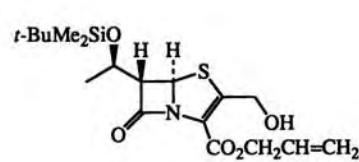
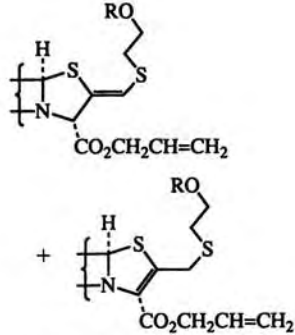
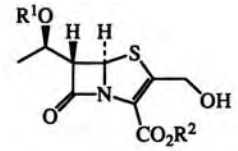
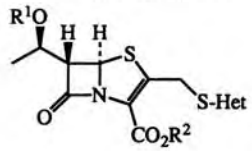
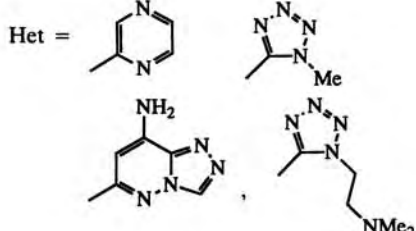
	Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
616		MeCOSH	THF, 0°		(73) 234
		"	"		(22)
		MeCOSH	rt		(100) 234
617		HSCH ₂ CH ₂ OR	CH ₂ Cl ₂ , reflux	 <p>R = <i>t</i>-BuMe₂Si, <i>t</i>-BuPh₂Si (73–81%) 1:1</p>	252
	 <p>R¹ = -CO₂pNB, <i>t</i>-BuMe₂Si- R² = -CH₂CH=CH₂, <i>t</i>-BuPh₂Si-</p>	Het-SH	—	 <p>Het = </p>	253

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

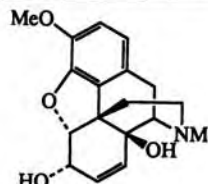
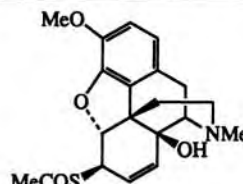
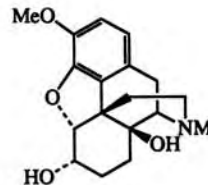
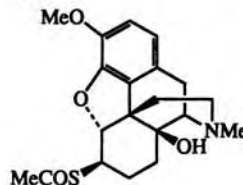
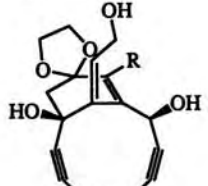
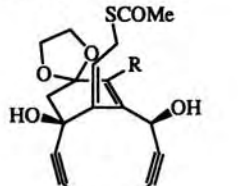
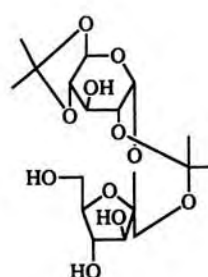
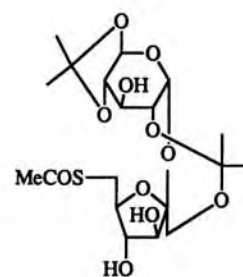
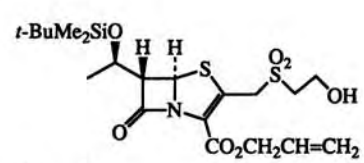
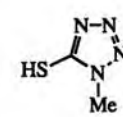
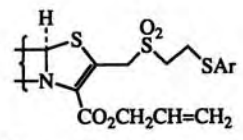
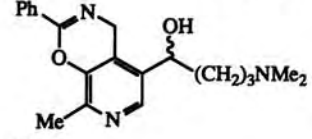
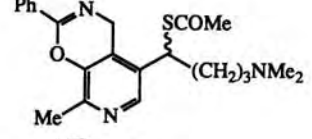
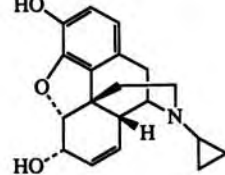
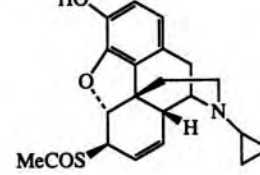
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
	MeCOSH	THF, 0°		(89) 870
	MeCOSH	THF, 0°		(—) 870
 <p>R = H, NHCO₂Me</p>	MeCOSH	—		(45–60) 871, 872
	MeCOSH	DMF, rt		(54) 866
<p>C₂₀</p> 		THF, 1 min		(90) 252
	MeCOSH	THF, 2 h, 0°		(81) 873
	MeCOSH	THF, 0°		(—) 870

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

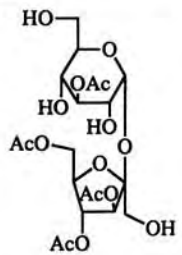
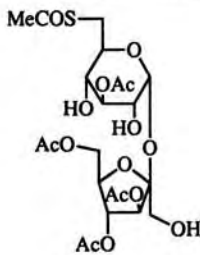
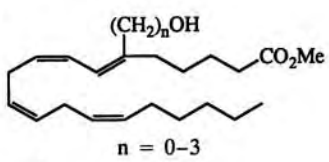
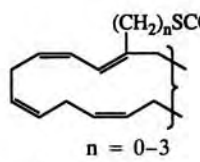
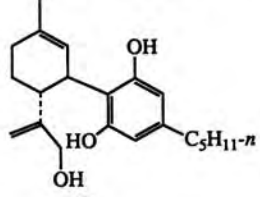
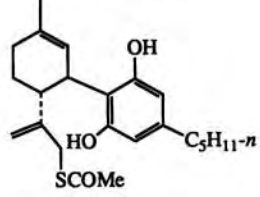
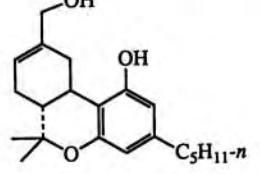
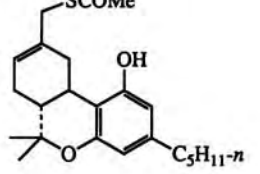
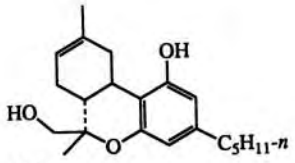
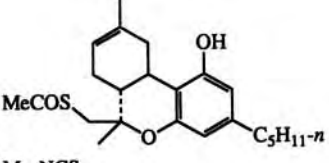
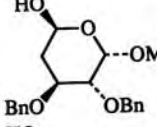
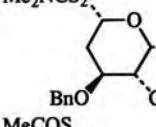
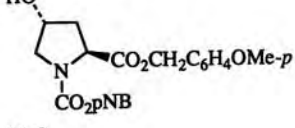
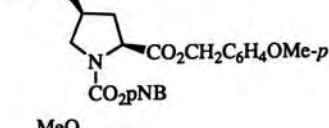
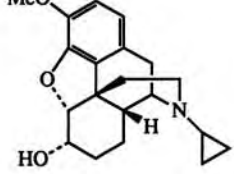
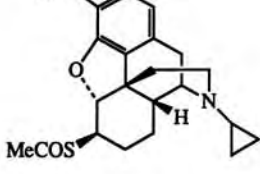
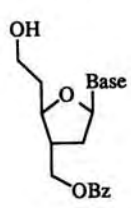
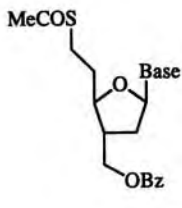
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
	MeCOSH	DMF, rt		(48) 866
C_{21}  $n = 0-3$	MeCOSH	rt, 2 h	 $n = 0-3$	(80-84) 239
	MeCOSH	THF, 0°-rt, 1.5 h		(57) 874
	MeCOSH	THF, 0°-rt, 1.5 h		(69) 874
	MeCOSH	THF, 0°-rt, 1.5 h		(23) 874
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°		(91) 860
	MeCOSH	THF, rt, 4 h		(99) 469
	MeCOSH	THF, 0°		(—) 870
C_{24} 	MeCOSH	THF, 0°		417

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

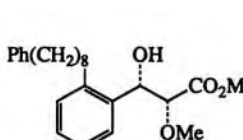
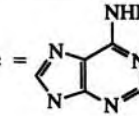
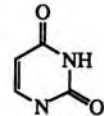
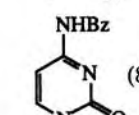
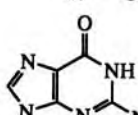
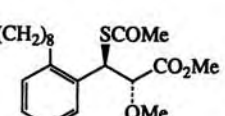
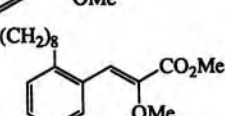
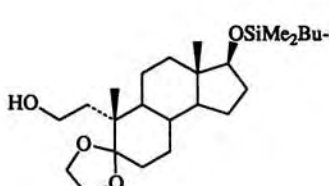
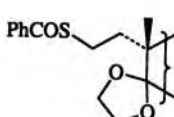
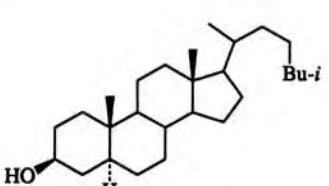
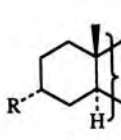
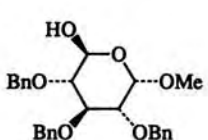
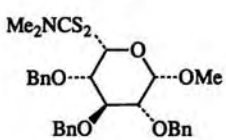
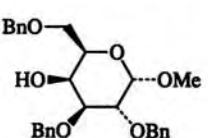
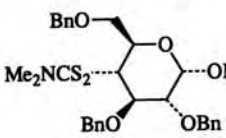
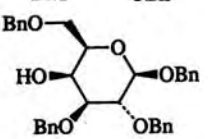
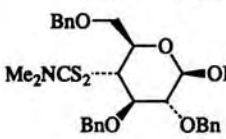
Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
<p>622</p> <p>C₂₅</p> 	MeCOSH	Toluene, (n-Bu) ₃ P, rt, 18 h	<p>Base =  (69)  (78)</p> <p> (87)  (73)</p> <p> (15) 875</p> <p>+  (65)</p>	
	PhCOSH	—	 (56) 876	
<p>623</p> <p>C₂₇</p> 	RSH	—	<p>I</p>  <p>I R = NCS (52) 245 I R = PhS (60) 245 I R = MeCOS (94) 231 I R = Me₂NCS₂ (87) 860 I R = EtCS₂ (33) 861</p>	
<p>C₂₈</p> 	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	 (90) 860	
<p>C₂₉</p> 	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	 (78) 860	
	Zn(S ₂ CNMe ₂) ₂	Toluene, 0°	 (81) 860	

TABLE XIX. FORMATION OF CARBON-SULFUR BONDS (Continued)

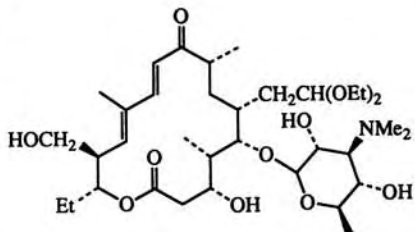
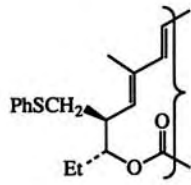
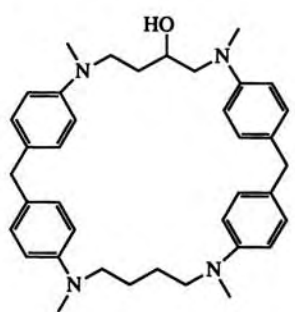

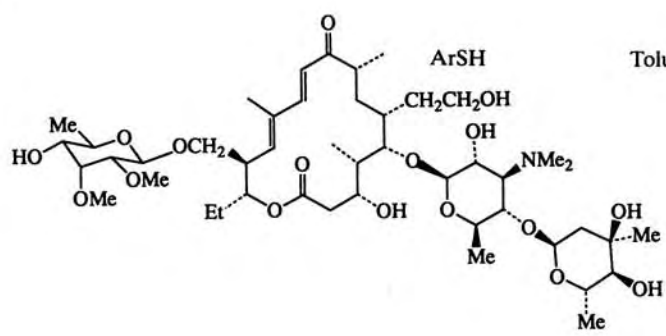
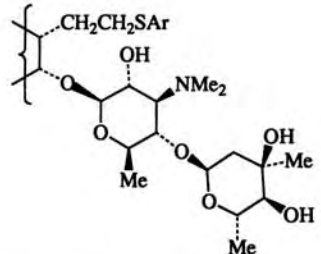
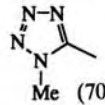
	Alcohol	Sulfur Nucleophile	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₃₅		PhSH	THF, rt, 0.5 h		247
C ₃₈		MeCOSH			235
C ₄₇		ArSH	Toluene, rt, 1 h or THF	 <p>Ar = Ph (56),  (70)</p>	244

TABLE XX. CARBON-HALOGEN BOND FORMATION

	Alcohol	Halide Source	Conditions	Product(s) and Yield(s) (%)	Refs.
C ₅		ZnX ₂	THF, rt, 30 min	 X = Cl X = Br X = I	262 (85%) (76%) (72%)
C ₆		 Cl ⁻	THF, 0°, 5 min		(55) 258
	C ₆ H ₁₁ OH	MeI	MTD, THF, 6 h, rt	C ₆ H ₁₁ I	(74) 264
		MeBr	"	C ₆ H ₁₁ Br	(71) 264
		ZnCl ₂	THF, rt, 2 h	C ₆ H ₁₁ Cl	(90) 262
C ₇		EtBr	THF, 20°, 2 h		(77) 877
	4-O ₂ NC ₆ H ₄ CH ₂ OH	Pyridinium hydrochloride or MeONH ₂ -HCl	THF, 0°, 5 min	4-O ₂ NC ₆ H ₄ CH ₂ Cl	(95) 258
	PhCH ₂ OH	Pyridinium hydrobromide	"	4-O ₂ NC ₆ H ₄ CH ₂ Br	(84) 258
		MeI	MTD, THF, 6 h, rt	PhCH ₂ I	(92) 264
		MeBr	"	PhCH ₂ Br	(91) 264
		LiBr	THF, 0°	"	(60) 263
		ZnBr ₂	—		(65) 878
		MeI	—		(64) 879
C ₈	4-ClC ₆ H ₄ CH ₂ CH ₂ OH	Pyridinium hydrochloride	THF, 0°, 5 min	4-ClC ₆ H ₄ CH ₂ CH ₂ Cl	(96) 258
	PhCH ₂ CH ₂ OH	ZnCl ₂	THF, 0.5 h, rt	PhCH ₂ CH ₂ Cl	(80) 262
	"	LiBr	THF, 0°	PhCH ₂ CH ₂ Br	(95) 263
		LiBr	THF, 0°		(93) 263
		LiBr	THF, rt		(80) 263
		MeI	MTD, THF, 6 h, rt		(65) 264
C ₉		ZnI ₂	THF, rt		(88) 527
		PhCH ₂ Br	—	 (69) + (14)	10

TABLE XX. CARBON-HALOGEN BOND FORMATION (Continued)

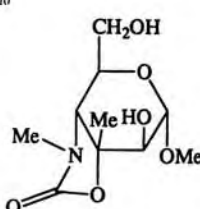
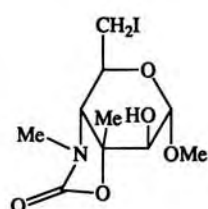
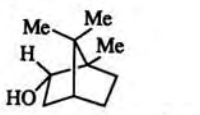
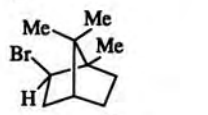

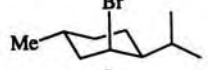
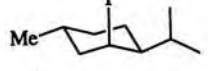
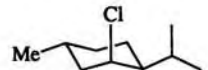
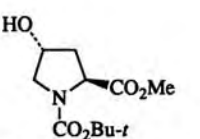
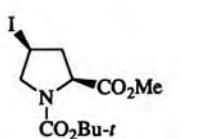
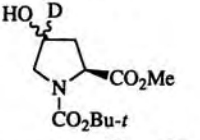
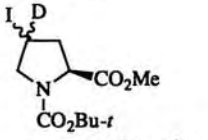
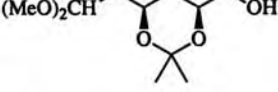
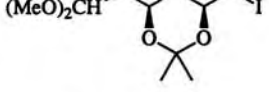
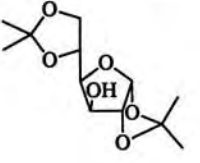
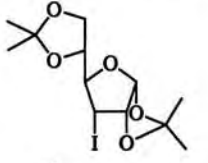
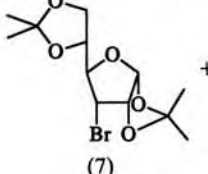
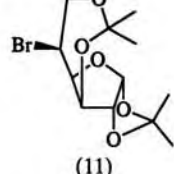
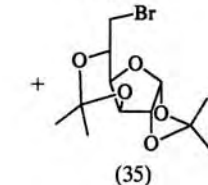
Alcohol	Halide Source	Conditions	Product(s) and Yield(s) (%)	Refs.
C_{10} 	MeI	C_6H_6 , rt, 1 h		(53) 880
	MeBr	MTD, THF, 6 h, rt		(75) 264
	MeBr	MTD, THF, 6 h, rt		(88) 264
	MeI	"		(88) 264
	ZnI ₂	Toluene	"	(77) 251
	ZnCl ₂	"		(73) 251
C_{11} HO(CH ₂) ₃ CO ₂ CH ₂ C ₆ H ₄ NO ₂ -4	Pyridinium hydrochloride	THF, 0°, 5 min	Cl(CH ₂) ₃ CO ₂ CH ₂ C ₆ H ₄ NO ₂ -4	(82) 258
	Pyridinium hydrobromide	"	Br(CH ₂) ₃ CO ₂ CH ₂ C ₆ H ₄ NO ₂ -4	(76) 258
	MeI	THF, 0° to rt		(90) 254
	MeI	THF, rt, 2.5 h		(61) 881
	MeI	—		(—) 630
C_{12} 	MeI	Toluene, reflux		(70) 10
	PhCH ₂ Br	Toluene, reflux	 (7) +  (11)	10
			+  (35)	

TABLE XX. CARBON-HALOGEN BOND FORMATION (Continued)

Alcohol	Halide Source	Conditions	Product(s) and Yield(s) (%)	Refs.
	PhCOCl	Toluene, reflux	 (5) + (55) + (27)	10
	PhCOCl or MeI or PhCH ₂ Br	Toluene, reflux	 X = I (78) X = Br (50) X = Cl (75)	10
	Et ₃ O ⁺ BF ₄ ⁻	CH ₂ Cl ₂ , -78° to rt		(54) 261
	ZnBr ₂	THF, rt, 16 h		(91) 397
C ₁₅ 	ZnX ₂	THF, rt, 20 min	 X = Cl (66) X = Br (72)	262
	MeI	THF, 4 h, reflux	 (21) (9)	882
	MeI	Toluene, 5 h, 50°		(50) 883

TABLE XX. CARBON-HALOGEN BOND FORMATION (Continued)

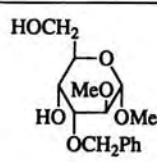
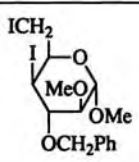
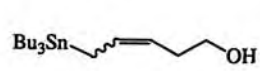

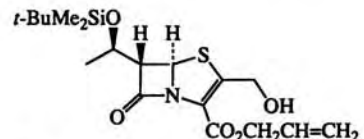
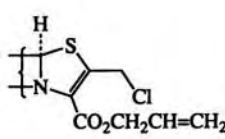
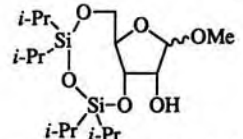
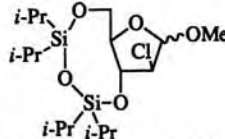
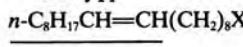
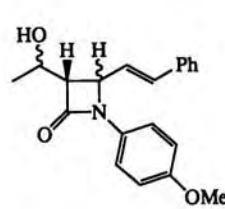
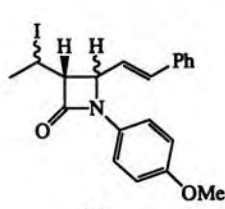
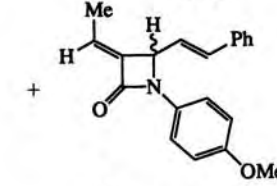
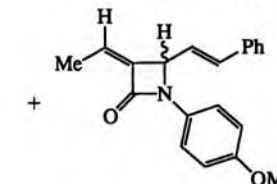
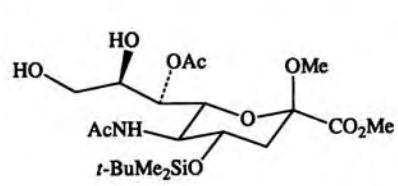
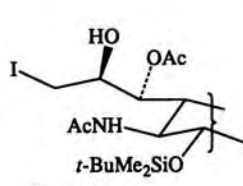
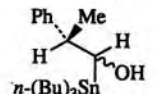
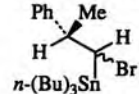
Alcohol	Halide Source	Conditions	Product(s) and Yield(s) (%)	Refs.										
	MeI	Toluene, 5 h, 50°		(23) 883										
C ₁₇ 	MeI	—		(—) 879										
C ₁₈ 	Pyridinium hydrochloride or MeONH ₃ ⁺ Cl ⁻	THF, 0°, 5 min		(62-85) 258										
	PhCH ₂ Cl	Toluene, 24 h, reflux		(46) 884										
<i>n</i> -C ₈ H ₁₇ CH=CH(CH ₂) ₈ OH	LiX	THF, 0°		263										
			<table border="1"> <thead> <tr> <th>X</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>F</td> <td>50</td> </tr> <tr> <td>Cl</td> <td>97</td> </tr> <tr> <td>Br</td> <td>97</td> </tr> <tr> <td>I</td> <td>91</td> </tr> </tbody> </table>	X	Yield (%)	F	50	Cl	97	Br	97	I	91	
X	Yield (%)													
F	50													
Cl	97													
Br	97													
I	91													
C ₂₀ 	MeI	THF		(30) 885										
				(20)										
				(20)										
C ₂₁ 	MeI	Toluene, 80°, 3-Å sieves		(83) 886										
	CH ₂ Br ₂	C ₆ H ₆ , reflux		(—) 260										

TABLE XX. CARBON-HALOGEN BOND FORMATION (Continued)

Alcohol	Halide Source	Conditions	Product(s) and Yield(s) (%)	Refs.										
	MeI	THF, rt, 19 h		(74) 615										
	CH2Cl2	CH2Cl2, rt, 24 h		(65) 259										
	MeI	C6H6, rt, 48 h		(60) 259										
	MeI	C6H6, rt, 48 h		(50) 259										
	MeI	—		(—) 630										
	ZnI2	30°		(—) 887										
	LiX	THF, rt	 <table border="1"> <thead> <tr> <th>X</th> <th>Yield (%)</th> </tr> </thead> <tbody> <tr> <td>F</td> <td>51</td> </tr> <tr> <td>Cl</td> <td>84</td> </tr> <tr> <td>Br</td> <td>96</td> </tr> <tr> <td>I</td> <td>62–78</td> </tr> </tbody> </table>	X	Yield (%)	F	51	Cl	84	Br	96	I	62–78	263
X	Yield (%)													
F	51													
Cl	84													
Br	96													
I	62–78													
	ZnCl2	THF, rt, 2 h		(92) 262										
	ZnCl2	THF, rt, 20 min		(90) 262										
	MeBr	THF/C6H6		(57) 616										

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References

1. O. Mitsunobu, M. Yamada, and T. Mukaiyama, *Bull. Chem. Soc. Jpn.*, 1967, **40**, 935.
2. O. Mitsunobu and M. Yamada, *Bull. Chem. Soc. Jpn.*, 1967, **40**, 2380.
3. O. Mitsunobu and M. Eguchi, *Bull. Chem. Soc. Jpn.*, 1971, **44**, 3427.
4. (a) W. A. Slusarchyk, T. Dejneka, J. Gougoutas, W. H. Koster, D. R. Kronenthal, M. Malley, M. G. Perri, F. L. Routh, J. E. Sundeen, E. R. Weaver, and R. Zahler, *Tetrahedron Lett.*, 1986, **27**, 2789. (b) R. S. Subramanian and K. K. Balasubramanian, *Synth. Commun.*, 1989, **19**, 1255. (c) R. S. Subramanian and K. K. Balasubramanian, *Tetrahedron Lett.*, 1989, **30**, 2297. (d) H. Brunner, P. Hankofer, and B. Treitinger, *Chem. Ber.*, 1990, 1029.
5. O. Mitsunobu, *Synthesis*, 1981, 1.
6. (a) B. R. Castro, *Org. Reactions*, 1983, **29**, 1. (b) D. Crich, H. Dyker, and R. J. Harris, *J. Org. Chem.*, 1989, **54**, 257.
7. D. L. Hughes, R. A. Reamer, J. J. Bergan, and E. J. J. Grabowski, *J. Am. Chem. Soc.*, 1988, **110**, 6487.
8. E. Brunn and R. Huisgen, *Angew. Chem. Int. Ed. Engl.*, 1981, **8**, 513.
9. R. A. Reamer, private communication.
10. H. Kunz and P. Schmidt, *Justus Liebigs Ann. Chem.*, 1982, 1245.
11. H. Ohmori, S. Naki, H. Miyasaka, and M. Masui, *Chem. Pharm. Bull.*, 1982, **30**, 4192.
12. R. D. Guthrie and I. D. Jenkins, *Aust. J. Chem.*, 1982, **35**, 767.
13. M. von Itzstein and I. D. Jenkins, *Aust. J. Chem.*, 1983, **36**, 557.
14. M. von Itzstein and I. D. Jenkins, *J. Chem. Soc., Perkin Trans. 1*, 1986, 437.
15. E. Grochowski, B. D. Hilton, R. J. Kupper, and C. J. Michejda, *J. Am. Chem. Soc.*, 1982, **104**, 6876.
16. (a) M. Varasi, K. A. M. Walker, and M. L. Maddox, *J. Org. Chem.*, 1987, **52**, 4235. (b) A. Pautard-Cooper and S. A. Evans, Jr., *J. Org. Chem.*, 1989, **54**, 2485. (c) D. Camp and I. D. Jenkins, *J. Org. Chem.*, 1989, **54**, 3045. (d) D. Camp and I. D. Jenkins, *J. Org. Chem.*, 1989, **54**, 3049.
17. D. H. Shih, F. Baker, L. Cama, and B. G. Christensen, *Heterocycles*, 1984, **21**, 29.
18. I. Fleming and J. D. Kilburn, *J. Chem. Soc., Chem. Commun.*, 1986, 1198.
19. T. Chiba, M. Nagatsuma, and T. Nakai, *Chem. Lett.*, 1985, 1343.
20. A. Yoshida, T. Hayashi, N. Takeda, S. Oida, and E. Ohki, *Chem. Pharm. Bull.*, 1981, **29**, 2899.

21. G. Cainelli, M. Contento, D. Giacomini, and M. Panunzio, *Tetrahedron Lett.*, 1985, **26**, 937.
22. D. J. Hart, and D.-C. Ha, *Tetrahedron Lett.*, 1985, **26**, 5493.
23. D. G. Melillo, I. Shinkai, T. Liu, K. Ryan, and M. Sletzinger, *Tetrahedron Lett.*, 1980, **21**, 2783.
24. I. Shinkai, T. Liu, R. A. Reamer, and M. Sletzinger, *Tetrahedron Lett.*, 1982, **23**, 4899.
25. G. I. Georg, J. Kant, and H. S. Gill, *J. Am. Chem. Soc.*, 1987, **109**, 1129.
26. E. Perrone, M. Alpegiani, A. Bedeschi, F. Giudici, F. Zarini, G. Franceschi, C. Della Bruna, D. Jabes, and G. Meinardi, *J. Antibiotics*, 1987, **40**, 1636.
27. S. M. Schmitt, T. N. Salzmann, D. H. Shih, and B. G. Christensen, *J. Antibiotics*, 1988, **41**, 780.
28. H. Maruyama and T. Hiraoka, *J. Org. Chem.*, 1986, **51**, 399.
29. D. M. Tschaen, L. M. Fuentes, J. E. Lynch, W. L. Laswell, R. P. Volante, and I. Shinkai, *Tetrahedron Lett.*, 1988, **29**, 2779.
30. G. I. Georg and H. S. Gill, *J. Chem. Soc., Chem. Commun.*, 1985, 1433.
31. D. F. Corbett, S. Coulton, and R. Southgate, *J. Chem. Soc., Perkin Trans. 1*, 1982, 3011.
32. J. S. Prasad and L. S. Liebeskind, *Tetrahedron Lett.*, 1988, **29**, 4253.
33. P. J. Kocienski, S. D. A. Street, C. Yeates, and S. F. Campbell, *J. Chem. Soc., Perkin Trans. 1*, 1987, 2171.
34. P. J. Kocienski, S. D. A. Street, C. Yeates, and S. F. Campbell, *J. Chem. Soc., Perkin Trans. 1*, 1987, 2183.
35. M. Suzuki, T. Sugiyama, M. Watanabe, T. Murayama, and K. Yamashita, *Agric. Biol. Chem.*, 1987, **51**, 1121.
36. M. Vandewalle, J. Van der Eycken, W. Oppolzer, and C. Vullioud, *Tetrahedron*, 1986, **42**, 4035.
37. M. L. Swain and R. W. Turner, *J. Chem. Soc., Chem. Commun.*, 1981, 840.
38. D. Lesuisse and G. A. Berchtold, *J. Org. Chem.*, 1985, **50**, 888.
39. P. Schnurrenberger, E. Hungerbuhler, and D. Seebach, *Justus Liebig Ann. Chem.*, 1987, 733.
40. M. Ando, S. Sayama, and K. Takase, *J. Org. Chem.*, 1985, **50**, 251.
41. R. D. Guthrie, R. W. Irvine, B. E. Davison, K. Henrick, and J. Trotter, *J. Chem. Soc., Perkin Trans. 2*, 1981, 468.
42. P. Schnurrenberger, E. Hungerbuhler, and D. Seebach, *Tetrahedron Lett.*, 1984, **25**, 2209.
43. A. Dereault, I. Tranchepain, and J. C. Depezay, *Synthesis*, 1987, 491.
44. D. E. Ward, *Can. J. Chem.*, 1987, **65**, 2380.

45. J. W. Morzycki, *Can. J. Chem.*, 1986, **64**, 1536.
46. S. Kosuge, M. Hayashi, and N. Hamanaka, *Tetrahedron Lett.*, 1982, **23**, 4027.
47. L. K. P. Lam, I. A. Gair, and J. B. Jones, *J. Org. Chem.*, 1988, **53**, 1611.
48. T. Sugimura and L. A. Paquette, *J. Am. Chem. Soc.*, 1987, **109**, 3017.
49. T. Sugimura, and L. A. Paquette, *J. Am. Chem. Soc.*, 1986, **108**, 3841.
50. A. B. Smith, K. J. Hale, and R. A. Rivero, *Tetrahedron Lett.*, 1986, **27**, 5813.
51. A. B. Smith and R. A. Rivero, *J. Am. Chem. Soc.*, 1987, **109**, 1272.
52. S. Hanessian, S. P. Sahoo, and M. Botta, *Tetrahedron Lett.*, 1987, **28**, 1143.
53. W. C. Still, C. Gennari, J. A. Noguez, and D. A. Pearson, *J. Am. Chem. Soc.*, 1984, **106**, 260.
54. E. M. Oltz, K. Nakanishi, B. Yagen, D. G. Corley, G. E. Rottinghaus, and M. S. Tempesta, *Tetrahedron*, 1986, **42**, 2615.
55. M. Gill and R. W. Rickards, *Aust. J. Chem.*, 1981, **34**, 2587.
56. C. Le Drian and A. E. Greene, *J. Am. Chem. Soc.*, 1982, **104**, 5473.
57. M. Isobe, Y. Ichikawa, D. Bai, and T. Goto, *Tetrahedron Lett.*, 1985, **26**, 5203.
58. M. Isobe, Y. Ichikawa, D. Bai, and T. Goto, *Tetrahedron*, 1986, **42**, 2863.
59. Y. Koxsal, P. Raddatz, and E. Winterfeldt, *Justus Liebig Ann. Chem.*, 1984, 450.
60. Y. Tamaru, S. Kawamura, and Z. Yoshida, *Tetrahedron Lett.*, 1985, **26**, 2885.
61. Y. Tamaru, S. Kawamura, and Z. Yoshida, *Tetrahedron Lett.*, 1984, **25**, 1063.
62. S. Jarosz, J. Glodek, and A. Zamojski, *Carbohydr. Res.*, 1987, **163**, 289.
63. M. Aburatani, T. Takeuchi, and K. Mori, *Agric. Biol. Chem.*, 1985, **49**, 3557.
64. B. L. Roy and P. Deslongchamps, *Can. J. Chem.*, 1985, **63**, 651.
65. K.-H. Marx, P. Raddatz, and E. Winterfeldt, *Justus Liebig Ann. Chem.*, 1984, 474.
66. S. Okamoto, T. Shimazaki, Y. Kobayashi, and F. Sato, *Tetrahedron Lett.*, 1987, **28**, 2033.
67. S. Okamoto, T. Shimazaki, Y. Kobayashi, and F. Sato, *Tetrahedron Lett.*, 1987, **28**, 5849.
68. M. Wada, T. Shigehisa, and K. Akiba, *Tetrahedron Lett.*, 1985, **26**, 5191.
69. H. Masterlerz, *J. Org. Chem.*, 1984, **49**, 4092.
70. M. Kori, K. Itoh, and H. Sugihara, *Chem. Pharm. Bull.*, 1987, **35**, 2319.

71. M. Yamada, K. Tachibana, and T. Kuroda, *Carbohydr. Res.*, 1983, **112**, 189.
72. D. M. Flanagan and M. M. Joullie, *Heterocycles*, 1987, **26**, 2247.
73. K. L. Bhat, D. M. Flanagan, and M. M. Joullie, *Synth. Commun.*, 1985, **15**, 587.
74. K. Barlos, M. Lampropoulou, V. Marmaras, D. Papaioannou, and S. Patrianakou, *Justus Liebigs Ann. Chem.*, 1986, 1407.
75. M. Koreeda and I. A. George, *J. Am. Chem. Soc.*, 1986, **108**, 8098.
76. A. B. Smith, B. D. Dorsey, M. Visnick, T. Maeda, and M. S. Malamas, *J. Am. Chem. Soc.*, 1986, **108**, 3110.
77. M. C. Wani, D. H. Rector, and C. E. Cook, *J. Org. Chem.*, 1987, **52**, 3468.
78. G. L. Bundy, D. R. Morton, D. C. Peterson, E. E. Nishizawa, and W. L. Miller, *J. Med. Chem.*, 1983, **26**, 790.
79. Y. Masaki, K. Nagata, and K. Kaji, *Chem. Lett.*, 1983, 1835.
80. E. J. Corey, K. Nimura, Y. Konishi, S. Hashimoto, and Y. Hamada, *Tetrahedron Lett.*, 1986, **27**, 2199.
81. H. Redlich, B. Schneider, R. W. Hoffmann, and K. J. Geueke, *Justus Liebigs Ann. Chem.*, 1983, 393.
82. M. Mori, T. Chuman, K. Kato, and K. Mori, *Tetrahedron Lett.*, 1982, **23**, 4593.
83. S. Achab and B. C. Das, *J. Chem. Soc., Chem. Commun.*, 1983, 391.
84. G. A. Leyes and W. H. Okamura, *J. Am. Chem. Soc.*, 1982, **104**, 6099.
85. S. Takano, C. Kasahara, and K. Ogasawara, *Heterocycles*, 1982, **19**, 1443.
86. A. Padwa, G. D. Kennedy, and M. W. Wannamaker, *J. Org. Chem.*, 1985, **50**, 5334.
87. C. Sato, S. Ikeda, H. Shirahama, and T. Matsumoto, *Tetrahedron Lett.*, 1982, **23**, 2099.
88. J. Mulzer, L. Autenrieth-Ansorge, H. Kirstein, T. Matsuoka, and W. Munch, *J. Org. Chem.*, 1987, **52**, 3784.
89. M. Hayashida, N. Sakairi, and H. Kuzuhara, *Carbohydr. Res.*, 1986, **154**, 115.
90. F. Mohamadi and W. C. Still, *Tetrahedron Lett.*, 1986, **27**, 893.
91. M. Nishizawa, K. Adachi, and Y. Hayashi, *J. Chem. Soc., Chem. Commun.*, 1984, 1637.
92. G. Palmisano, B. Danieli, G. Lesma, and R. Riva, *J. Chem. Soc., Perkin Trans. 1*, 1985, 923.
93. M. Hubner, I. Fussel, and K. Ponsold, *Pharmazie*, 1984, **39**, 462.
94. S. Takano and K. Shishido, *Heterocycles*, 1982, **19**, 1439.

95. S. Takano and K. Shishido, *Chem. Pharm. Bull.*, 1984, **32**, 3892.
96. W. Adam, C. Babatsikos, and G. Cilento, *Z. Naturforsch.*, 1984, **39B**, 679.
97. T. Shibata, K. Iino, and Y. Sugimara, *Heterocycles*, 1986, **24**, 1331.
98. G. Emmer, P. Kneussel, J. Hildebrant, F. Turnowsky, A. Haselberger, A. Wenzel, and P. Stutz, *J. Antibiotics*, 1985, **38**, 1371.
99. T. Sugiyama, A. Sato, and K. Yamashita, *Agric. Biol. Chem.*, 1982, **46**, 481.
100. W. R. Roush and T. A. Blizzard, *J. Org. Chem.*, 1984, **49**, 4332.
101. O. Mitsunobu, M. Ebina, and T. Ogihara, *Chem. Lett.*, 1982, 373.
102. G. Majetich, J. Defauw, and C. Ringold, *J. Org. Chem.*, 1988, **53**, 50.
103. Y. Guindon, D. Delorme, C. K. Lau, and R. Zamboni, *J. Org. Chem.*, 1988, **53**, 267.
104. Y. Guindon and D. Delorme, *Can. J. Chem.*, 1987, **65**, 1438.
105. T. Sugai and K. Mori, *Synthesis*, 1988, 19.
106. R. Ramage and A. M. MacLeod, *Tetrahedron*, 1986, **42**, 3251; *J. Chem. Soc., Chem. Commun.*, 1984, 1008.
107. H. Suzuki, A. Tanaka, and K. Yamashita, *Agric. Biol. Chem.*, 1987, **51**, 3369.
108. J. L. Pawlak and G. A. Berchtold, *J. Org. Chem.*, 1987, **52**, 1765.
109. M. Tanaka, K. Tomioka, and K. Koga, *Tetrahedron Lett.*, 1985, **26**, 3035.
110. H. Hiraoka, K. Furuta, N. Ikeda, and H. Yamamoto, *Bull. Chem. Soc., Jpn.*, 1984, **57**, 2777.
111. M. Dorsch, V. Jager, and W. Sponlein, *Angew. Chem., Int. Ed. Engl.* 1984, **23**, 798.
112. E. J. Corey and T. A. Engler, *Tetrahedron Lett.*, 1984, **25**, 149.
113. J. A. Marshall, M. J. Coghlan, and M. Watanabe, *J. Org. Chem.*, 1984, **49**, 747.
114. J. K. Whitesell, M. Fisher, and P. Jardine, *J. Org. Chem.*, 1983, **48**, 1556.
115. J. C. Fiaud and L. Aribi-Zouioveche, *Tetrahedron Lett.*, 1982, **23**, 5279.
116. J. A. Marshall and K. E. Flynn, *J. Am. Chem. Soc.*, 1982, **104**, 7430.
117. M. Ishihara, T. Tsuneya, H. Shiota, and M. Shiga, *J. Org. Chem.*, 1986, **51**, 491.
118. P. A. Grieco, R. E. Zelle, R. Lis, and J. Finn, *J. Am. Chem. Soc.*, 1983, **105**, 1403; 1986, **108**, 5908.
119. M. Ando, H. Yamaoka, and K. Takase, *Chem. Lett.*, 1982, 501.
120. F. Kido, Y. Noda, and A. Yoshikoshi, *J. Chem. Soc., Chem. Commun.*, 1982, 1209; *Tetrahedron*, 1987, **43**, 5467.
121. S. D. Burke and G. J. Pacofsky, *Tetrahedron Lett.*, 1986, **27**, 3345.
122. S. D. Burke, G. J. Pacofsky, and A. D. Piscopio, *Tetrahedron Lett.*, 1986,

- 27**, 445.
123. I. Dyong, J. Weigand, and J. Thiem, *Justus Liebigs Ann. Chem.*, 1986, 577.
124. (a) S. Sakamoto, T. Tsuchiya, S. Umezawa, and H. Umezawa, *Bull. Chem. Soc., Jpn.*, 1987, **60**, 1481. (b) V. Farina, *Tetrahedron Lett.*, 1989, **30**, 6645. (c) R. S. Subramanian and K. K. Balasubramanian, *Tetrahedron Lett.*, 1990, **31**, 2201.
125. R. Pellegata, I. Dosi, M. Villa, G. Lesma, and G. Palmisano, *Tetrahedron*, 1985, **41**, 5607.
126. L. G. Lee and G. M. Whitesides, *J. Org. Chem.*, 1986, **51**, 25.
127. H. Akita, A. Furuichi, H. Koshiji, K. Horikoshi, and T. Oishi, *Chem. Pharm. Bull.*, 1984, **32**, 1342.
128. H. Akita, A. Furuichi, H. Koshiji, K. Horikoshi, and T. Oishi, *Chem. Pharm. Bull.*, 1983, **31**, 4384.
129. T. Oritani, M. Ichimura, Y. Hanyu, and K. Yamashita, *Agric. Biol. Chem.*, 1983, **47**, 2613.
130. T. Oritani, K. Yamashita, and C. Kabuto, *J. Org. Chem.*, 1984, **49**, 3689.
131. G. Gryniewicz, *Rocz. Chem.*, 1976, **50**, 1449.
132. I. Grochowski, *Bull. Acad. Pol. Sci.*, 1980, **28**, 489.
133. A. M. Pautard and S. A. Evans, *J. Org. Chem.*, 1988, **53**, 2300.
134. B. Dayal, D. N. Greeley, T. H. Williams, G. S. Tint, and G. Salen, *J. Lipid Res.*, 1984, **25**, 646.
135. P. Welzel, H. Stein, and T. Milkova, *Justus Liebigs Ann. Chem.*, 1982, 2119.
136. P. Welzel and H. Stein, *Tetrahedron Lett.*, 1981, **22**, 3385.
137. K. Weinges, S. Haresma, and W. Maurer, *Carbohydr. Res.*, 1987, **164**, 453.
138. I. D. Jenkins and M. B. Goren, *Chem. Phys. Lipids*, 1986, **41**, 225.
139. S. Bottle and I. D. Jenkins, *Chem. Soc., Chem. Commun.*, 1984, 385.
140. M. Georges, D. Mackay, and B. Fraser-Reid, *Can. J. Chem.*, 1984, **62**, 1539.
141. K. Weinges and D. Brunner, *Justus Liebigs Ann. Chem.*, 1986, 54.
142. J. A. Marshall, R. C. Andrews, and L. Lebioda, *J. Org. Chem.*, 1987, **52**, 2381.
143. S. E. Ramer, R. N. Moore, and J. C. Vederas, *Can. J. Chem.*, 1986, **64**, 706.
144. J. S. Bajwa and M. J. Miller, *J. Org. Chem.*, 1983, **48**, 1114.
145. J. Mulzer, G. Bruntrup, and A. Chucholowski, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 622.

146. W. Adam, N. Narita, and Y. Nishizawa, *J. Am. Chem. Soc.*, 1984, **106**, 1843.
147. L. D. Arnold, T. H. Kalantar, and J. C. Vederas, *J. Am. Chem. Soc.*, 1985, **107**, 7105.
148. L. D. Arnold, J. C. G. Drover, and J. C. Vederas, *J. Am. Chem. Soc.*, 1987, **109**, 4649.
149. L. D. Arnold, R. G. May, and J. C. Vederas, *J. Am. Chem. Soc.*, 1988, **110**, 2237.
150. P. R. McGuirk and D. B. Collum, *J. Am. Chem. Soc.*, 1982, **104**, 4496; *J. Org. Chem.*, 1984, **49**, 843.
151. G. Adam, R. Zibuck, and D. Seebach, *J. Am. Chem. Soc.*, 1987, **109**, 6176.
152. S. V. Attwood, A. G. M. Barrett, R. A. E. Carr, and G. Richardson, *J. Chem. Soc., Chem. Commun.*, 1986, 479.
153. A. G. M. Barrett, R. A. E. Carr, S. V. Attwood, G. Richardson, and N. D. A. Walshe, *J. Org. Chem.*, 1986, **51**, 4840.
154. H. Tsutsui and O. Mitsunobu, *Tetrahedron Lett.*, 1984, **25**, 2163.
155. G. Traverso, D. Pirillo, and A. Gazzaniga, *Gazz. Chim. Ital.*, 1983, **113**, 461.
156. L. Liu, R. S. Tanke, and M. J. Miller, *J. Org. Chem.*, 1986, **51**, 5332.
157. J. Butera, J. Rini, and P. Helquist, *J. Org. Chem.*, 1985, **50**, 3676.
158. K. Barlos, D. Gatos, J. Kallitsis, D. Papaioannou, P. Sotiariou, and W. Schafer, *Justus Liebigs Ann. Chem.*, 1987, 1031.
159. K. Barlos, D. Gatos, J. Kallitsis, D. Papaioannou, and P. Sotiriou, *Justus Liebigs Ann. Chem.*, 1988, 1079.
160. S. Bittner and Y. Assaf, *Chem. Ind. (London)*, 1975, 281.
161. M. S. Manhas, W. H. Hoffman, B. Lal, and A. K. Bose, *J. Chem. Soc., Perkin Trans. 1*, 1975, 461.
162. N. L. Dirlam, B. S. Moore, and F. J. Urban, *J. Org. Chem.*, 1987, **52**, 3587.
163. S. Danishefsky, E. M. Berman, M. Ciufolini, S. J. Etheredge, and B. E. Segmuller, *J. Am. Chem. Soc.*, 1985, **107**, 3891.
164. H. Sugihara, H. Mabuchi, M. Hirate, T. Inamoto, and Y. Kawamatsu, *Chem. Pharm. Bull.*, 1987, **35**, 1930.
165. T. L. Shih, M. J. Wyratt, and H. Mrozik, *J. Org. Chem.*, 1987, **52**, 2029.
166. A. G. Schultz and P. Sundararaman, *Tetrahedron Lett.*, 1984, **25**, 4591.
167. B. M. Trost, M. G. Saulnier, *Tetrahedron Lett.*, 1985, **26**, 123.
168. C. A. Townsend, G. M. Salituro, L. T. Nguyen, and M. J. Di Novi, *Tetrahedron Lett.*, 1986, **27**, 3819.
169. M. Hrytsak and T. Durst, *Heterocycles*, 1987, **26**, 2393.

170. D. O. Spry and A. R. Bhala, *Heterocycles*, 1986, **24**, 1653.
171. M. Moreno-Manas, J. Ribas, and A. Virgili, *Synthesis*, 1985, 699.
172. G. Gryniewicz and A. Zamojski, *Syn. Comm.*, 1978, **8**, 491.
173. W. A. Szarek, H. C. Jarrell, and J. K. N. Jones, *Carbohydr. Res.*, 1977, **57**, C13.
174. J. T. Carlock and M. P. Mack, *Tetrahedron Lett.*, 1978, 5153.
175. K. Capek, J. Capkova, J. Jary, Y. A. Knirel, and A. S. Shashkov, *Coll. Czech. Chem. Comm.*, 1987, **52**, 2248.
176. R. D. Guthrie, I. D. Jenkins, S. Thang, and R. Yamasaki, *Carbohydr. Res.*, 1983, **121**, 109.
177. R. D. Guthrie and I. D. Jenkins, *Aust. J. Chem.*, 1981, **34**, 1997.
178. R. J. Ferrier, P. Prasit, and G. J. Gainsford, *J. Chem. Soc., Perkin Trans. 1*, 1983, 1629.
179. R. J. Ferrier, P. Schmidt, and P. C. Tyler, *J. Chem. Soc., Perkin Trans. 1*, 1985, 301.
180. (a) S. S. Bhagwat, P. R. Hamann, and W. C. Still, *J. Am. Chem. Soc.*, 1985, **107**, 6372. (b) S. S. Bhagwat, P. R. Hamann, W. C. Still, S. Bunting, and F. A. Fitzpatrick, *Nature*, 1985, **315**, 511. (c) S. S. Bhagwat, P. R. Hamann, and W. C. Still, *Tetrahedron Lett.*, 1985, **26**, 1955.
181. P. L. Robinson, C. N. Barry, S. W. Bass, S. E. Jarvis, and S. A. Evans, *J. Org. Chem.*, 1983, **48**, 5396.
182. I. Galynker and W. C. Still, *Tetrahedron Lett.*, 1982, **23**, 4461; *J. Am. Chem. Soc.*, 1982, **104**, 1774.
183. E. Grochowski and T. Boleslawska, *Pol. J. Chem.*, 1981, **55**, 615.
184. E. Grochowski and J. Jurczak, *Carbohydr. Res.*, 1976, C15; *Synthesis*, 1976, **10**, 682.
185. D. W. Dixon and R. H. Weiss, *J. Org. Chem.*, 1984, **49**, 4487.
186. H. Usui, A. Matsuda, and T. Veda, *Chem. Pharm. Bull.*, 1986, **34**, 1961.
187. T. Trichtinger, R. Charubala, and W. Pfeleiderer, *Tetrahedron Lett.*, 1983, **24**, 711.
188. F. Himmelsbach, B. S. Schulz, T. Trichtinger, R. Charubala, and W. Pfeleiderer, *Tetrahedron*, 1984, **40**, 59–72.
189. B. S. Schulz and W. Pfeleiderer, *Helv. Chim. Acta*, 1987, **70**, 210.
190. H. Takaku, T. Ito, and K. Imai, *Chem. Lett.*, 1986, 1005.
191. B. S. Schulz and W. Pfeleiderer, *Tetrahedron Lett.*, 1983, **24**, 3587.
192. A. van Aerschot, B. Peeters, and H. Vanderhaeghe, *Nucleotides, Nucleosides*, 1987, **6**, 437.
193. A. J. Malkiewicz, B. Nawrot, and E. Sochacka, *Z. Naturforsch.*, 1987, **42B**, 360.

194. X. Gao, B. L. Gaffney, S. Hadden, and R. A. Jones, *J. Org. Chem.*, 1986, **51**, 755.
195. P. G. Sammes and D. Thetford, *J. Chem. Soc., Chem. Commun.*, 1985, 352; *J. Chem. Soc., Perkin Trans. 1*, 1988, 111; *Tetrahedron Lett.*, 1986, **27**, 2275.
196. D. M. Roush and M. M. Patel, *Synth. Commun.*, 1985, **15**, 675.
197. P. B. Kay and S. Trippett, *J. Chem. Soc., Perkin Trans. 1*, 1987, 1813.
198. D. W. Norbeck, J. B. Kramer, and P. A. Lartey, *J. Org. Chem.*, 1987, **52**, 2174.
199. W. A. Hoffman, *J. Org. Chem.*, 1982, **47**, 5209.
200. J. Kimura, H. Kobayashi, O. Miyahara, and O. Mitsunobu, *Bull. Chem. Soc. Jpn.*, 1986, **59**, 869.
201. E. Grochowski, H. Stepowska, and C. J. Michejda, *Bull. Pol. Acad. Sci.* 1984, **32**, 129.
202. J. Mulzer and C. Brand, *Tetrahedron*, 1986, **42**, 5961.
203. G. L. Grunewald, V. M. Paradkar, B. Pazhenchevsky, M. A. Pleiss, D. J. Sall, W. L. Seibel, and T. J. Reitz, *J. Org. Chem.*, 1983, **48**, 2321.
204. G. L. Grunewald, H. S. Arrington, W. J. Bartlett, T. J. Reitz, and D. J. Sall, *J. Med. Chem.*, 1986, **29**, 1972.
205. Review: W. N. Speckamp and H. Hiemstra, *Tetrahedron*, 1985, **41**, 4367.
206. D. J. Hart, *J. Org. Chem.*, 1981, **46**, 367.
207. H. Knotz and E. Zbiral, *Lieb Ann. Chem.*, 1986, 1736.
208. E. Fabiano, B. T. Golding and M. M. Sadeghi, *Synthesis*, 1987, 190.
209. P. G. Mattingly, J. F. Kerwin, and M. J. Miller, *J. Am. Chem. Soc.*, 1979, **101**, 3983.
210. M. J. Miller, P. G. Mattingly, M. A. Morrison, and J. F. Kerwin, *J. Am. Chem. Soc.*, 1980, **102**, 7026.
211. M. J. Miller, *Acc. Chem. Res.*, 1986, **19**, 49.
212. M. J. Miller and P. G. Mattingly, *Tetrahedron*, 1983, **39**, 2563.
213. M. Jung and M. J. Miller, *Tetrahedron Lett.*, 1985, **26**, 977.
214. A. K. Bose, D. P. Sahu, and M. S. Manhas, *J. Org. Chem.*, 1981, **46**, 1229.
215. A. K. Bose, M. S. Manhas, D. P. Sahu, and V. R. Hegde, *Can. J. Chem.*, 1984, **62**, 2498.
216. M. A. Morrison and M. J. Miller, *J. Org. Chem.*, 1983, **48**, 4421.
217. T. Kolasa and M. J. Miller, *Tetrahedron Lett.*, 1987, **28**, 1861.
218. P. J. Maurer and M. J. Miller, *J. Org. Chem.*, 1981, **46**, 2835; *J. Am. Chem. Soc.*, 1983, **105**, 240.
219. (a) C. A. Townsend and L. T. Nguyen, *J. Am. Chem. Soc.*, 1981, **103**,

- 4582; (b) *Tetrahedron Lett.*, 1982, **23**, 4859.
220. J. D. Godfrey, R. H. Mueller, and D. J. Von Langen, *Tetrahedron Lett.*, 1986, **27**, 2793.
221. J. R. Pfister, *Synthesis*, 1984, 969.
222. P. G. Sammes and S. Smith, *J. Chem. Soc., Chem. Commun.*, 1983, 682; *J. Chem. Soc., Perkin Trans. 1*, 1984, 2415.
223. P. G. Sammes, S. Smith, and G. T. Woolley, *J. Chem. Soc., Perkin Trans. 1*, 1984, 2603.
224. S. Danishefsky and J. Regan, *Tetrahedron Lett.*, 1981, **22**, 3919.
225. S. Takano, Y. Imamura, and K. Ogasawara, *Chem. Lett.*, 1981, 1385; *Tetrahedron Lett.*, 1981, **22**, 4479.
226. K. Minamoto, Y. Fujiki, N. Shiomi, Y. Uda, and T. Sasaki, *J. Chem. Soc., Perkin Trans. 1*, 1985, 2337.
227. A. P. Kozikowski and M. Okita, *Tetrahedron Lett.*, 1985, **26**, 4043.
228. T. Kolasa and M. J. Miller, *J. Org. Chem.*, 1987, **52**, 4978.
229. T. Gajda, *Synthesis*, 1987, 1108.
230. (a) E. Slusarska and A. Zwierzak, *Lieb. Ann. Chem.*, 1986, 402. (b) J. R. Henry, L. R. Marcin, M. C. McIntosh, P. M. Scola, G. D. Harris, and S. M. Weinreb, *Tetrahedron Lett.*, 1989, **30**, 5709.
231. R. P. Volante, *Tetrahedron Lett.*, 1981, **22**, 3119.
232. B. Strijtveen and R. M. Kellogg, *J. Org. Chem.*, 1986, **51**, 3664.
233. B. Strijtveen and R. M. Kellogg, *Rec. Trav. Chim. Pays-Bas*, 1987, **106**, 539.
234. I. Fujii, H. Togame, M. Yamamoto, K. Kanematsu, I. Takayanagi, and F. Konno, *Chem. Pharm. Bull.*, 1988, **36**, 2282.
235. (a) R. Breslow, A. W. Czarnik, M. Lauer, R. Leppkes, J. Winkler, and S. Zimmerman, *J. Am. Chem. Soc.*, 1986, **108**, 1969. (b) J. Winkler, E. Coutouli-Argyropoulou, R. Leppkes, and R. Breslow, *J. Am. Chem. Soc.*, 1983, **105**, 7198.
236. T. Kunieda, T. Ishizuka, and M. Hirobe, *Chem. Pharm. Bull.*, 1983, **31**, 3360.
237. P. L. Polavarapu and H. E. Smith, *J. Phys. Chem.*, 1988, **92**, 1774.
238. G. D. Prestwich, W.-S. Eng, R. M. Roe, and B. D. Hammock, *Arch. Biochem. Biophys.*, 1984, **228**, 639.
239. F. A. J. Kerdesky, S. P. Schmidt, J. H. Holms, R. D. Dyer, G. W. Carter, and D. W. Brooks, *J. Med. Chem.*, 1987, **30**, 1177.
240. C.-P. Mak and G. Schulz, *Heterocycles*, 1988, **27**, 331.
241. N. B. Hanna, K. G. Upadhya, C. R. Petrie, R. K. Robins, and G. N. Revankar, *Nucleosides and Nucleotides*, 1986, **5**, 343.
242. I. D. Jenkins and S. Thang, *Aust. J. Chem.*, 1984, **37**, 1925.

243. G. A. Flynn, *J. Org. Chem.*, 1983, **48**, 4125.
244. H. A. Kirst, J. E. Toth, M. Debono, K. E. Willard, B. A. Truedell, J. L. Oh, F. T. Counter, A. M. Felty-Duckworth, and R. S. Pekarek, *J. Med. Chem.*, 1988, **31**, 1631.
245. H. Loibner and E. Zbiral, *Helv. Chim. Acta*, 1976, **59**, 2100.
246. T. Gajda, *Synthesis*, 1988, 327.
247. H. A. Kirst, J. E. Toth, J. A. Wind, M. Debono, K. E. Willard, R. M. Molloy, J. W. Paschal, J. L. Ott, A. M. Felty-Duckworth, and F. T. Counter, *J. Antibiotics*, 1987, **40**, 823.
248. Y. Tamaru, O. Ishige, S. Kawamura, and Z. Yoshida, *Tetrahedron Lett.*, 1984, **25**, 3583.
249. Y. Tamaru, T. Hioki, S. Kawamura, H. Satomi, and Z. Yoshida, *J. Am. Chem. Soc.*, 1984, **106**, 3876.
250. H. Nagasawa and O. Mitsunobu, *Bull. Chem. Soc. Jpn.*, 1981, **54**, 2223.
251. P. Rollin, *Synth. Commun.*, 1986, **16**, 611.
252. M. Alpegiani, E. Perrone, and G. Franceschi, *Heterocycles*, 1988, **27**, 49.
253. M. Alpegiani, A. Bedeschi, E. Perrone, F. Zarini, and G. Franceschi, *Heterocycles*, 1985, **23**, 2255.
254. J. R. Dormoy, *Synthesis*, 1982, 753.
255. T. Tanaka, T. Hashimoto, K. Iino, Y. Sugimura, and T. Miyadera, *J. Chem. Soc., Chem. Commun.*, 1982, 713.
256. R. L. Dow, R. C. Kelly, I. Schletter, and W. Wierenga, *Synth. Commun.*, 1981, **11**, 43.
257. H. Kunz and P. Schmidt, *Tetrahedron Lett.*, 1979, 2123.
258. M. Alpegiani, A. Bedeschi, and E. Perrone, *Gazz. Chim. Ital.*, 1985, **115**, 393.
259. Y. Torisawa, M. Shibasaki, and S. Ikegami, *Tetrahedron Lett.*, 1981, **22**, 2397.
260. M. Shibasaki, Y. Torisawa, and S. Ikegami, *Tetrahedron Lett.*, 1982, **23**, 4607.
261. H. Kunz and W. Sager, *Helv. Chim. Acta*, 1985, **68**, 283.
262. P.-T. Ho and N. Davies, *J. Org. Chem.*, 1984, **49**, 3027.
263. S. Manna, J. R. Falck, and C. Mioskowski, *Synth. Commun.*, 1985, **15**, 663.
264. T. Oshikawa and M. Yamashita, *Bull. Chem. Soc. Jpn.*, 1984, **57**, 2675.
265. T. Kurihara, M. Sugizaki, I. Kime, M. Wada, and O. Mitsunobu, *Bull. Chem. Soc. Jpn.*, 1981, **54**, 2107.
266. H.-J. Liu and H. Wynn, *Can. J. Chem.*, 1986, **64**, 658.
267. D. Cabaret, N. Maigrot, and Z. Welvart, *Tetrahedron Lett.*, 1981, **22**,

- 5279.
268. D. Cabaret, N. Maigrot, and Z. Welvart, *Tetrahedron Lett.*, 1984, **25**, 547.
269. D. Cabaret, N. Maigrot, and Z. Welvart, *Tetrahedron*, 1985, **41**, 5357.
270. P. Magnus and T. Gallagher, *J. Chem. Soc., Chem. Commun.*, 1984, 389.
271. P. Magnus, T. Gallagher, J. Schultz, Y.-S. Or, and T. P. Ananthanarayan, *J. Am. Chem. Soc.*, 1987, **109**, 2706.
272. D. L. Boger and R. S. Coleman, *J. Am. Chem. Soc.*, 1988, **110**, 4796.
273. (a) M. A. Warpehoski, I. Gebhard, R. C. Kelly, W. C. Krueger, L. H. Li, J. P. McGovern, M. D. Prairie, N. Wicnienski, and W. Wierenga, *J. Med. Chem.*, 1988, **31**, 590. (b) P. Magnus, B. Mugrage, M. R. DeLuca, and G. A. Cain, *J. Am. Chem. Soc.*, 1990, **112**, 5220.
274. D. L. Boger and R. S. Coleman, *J. Org. Chem.*, 1984, **49**, 2240.
275. B. Mlotkowska, and M. Wartalowska-Graczyk, *J. Prakt. Chem.*, 1987, **329**, 735.
276. P. J. Maurer and M. J. Miller, *J. Am. Chem. Soc.*, 1982, **104**, 3096.
277. R. H. Bradbury and K. A. M. Walker, *Tetrahedron Lett.*, 1982, **23**, 1335.
278. R. H. Bradbury and K. A. M. Walker, *J. Org. Chem.*, 1983, **48**, 1741.
279. M. A. Tius, A. Thurkauf, *Tetrahedron Lett.*, 1986, **27**, 4541.
280. B. Schonecker, H. Eibisch, G. Schubert, M. Wunderwald, and K. Ponsold, *Pharmazie*, 1986, **41**, 320.
281. L. A. Paquette, J. L. Romine, and H.-S. Lin, *Tetrahedron Lett.*, 1987, **28**, 31.
282. D. R. St. Laurent and L. A. Paquette, *J. Org. Chem.*, 1986, **51**, 3861.
283. J. Mulzer, A. Pointner, A. Chucholowski, and G. Bruntrup, *J. Chem. Soc., Chem. Commun.*, 1979, 52.
284. J. Mulzer and O. Lammer, *Angew. Chem. Suppl.*, 1983, 887.
285. G. Penz and E. Zbiral, *Monatsh. Chem.*, 1981, **112**, 1045.
286. L. P. L. Piacenza, K. Pegel, M. Laing, E. S. Waight, C. M. Weeks, and C. P. Gorst-Allman, *J. Chem. Soc., Perkin Trans. 1*, 1985, 703.
287. R. F. C. Brown, K. B. Caldwell, B. M. Gatehouse, and P. Y. T. Teo, *Aust. J. Chem.*, 1985, **38**, 1339.
288. O. Mitsunobu and N. Yoshida, *Tetrahedron Lett.*, 1981, **22**, 2295.
289. S. Bittner, Y. Assaf, P. Krief, M. Pomerantz, B. T. Ziemnicka, and C. G. Smith, *J. Org. Chem.*, 1985, **50**, 1712.
290. S. Bittner, Y. Assaf, and M. Pomerantz, *J. Org. Chem.*, 1982, **47**, 99.
291. M. Pomerantz, W.-N. Chou, M. K. Witczak, and C. G. Smith, *J. Org. Chem.*, 1987, **52**, 159.
292. (a) C. Lensink, B. DeRuiter, and J. C. van de Grampel, *J. Chem. Soc.*,

- Dalton Trans., 1984, 1521. (b) F. Urf and J. Vilarrasa, Tetrahedron Lett., 1990, **31**, 7497.
293. W. H. Kruizinga, B. Strijtveen, and R. M. Kellogg, J. Org. Chem., 1981, **46**, 4321.
294. J. W. Huffman and R. C. Desai, Synth. Commun., 1983, **13**, 553.
295. Y. Torisawa, H. Okabe, and S. Ikegami, Chem. Lett., 1984, 1555.
296. S. F. Martin and C. L. Campbell, J. Org. Chem., 1988, **53**, 3184.
297. C. L. Willis, Tetrahedron Lett., 1987, **28**, 6705.
298. U. Burkard and F. Effenberger, Chem. Ber., 1986, **119**, 1594.
299. J. M. Dener, D. J. Hart, and S. Ramesh, J. Org. Chem., 1988, **53**, 6022.
300. D. M. Floyd, G. A. Crosby and N. M. Weinshenker, Tetrahedron Lett., 1972, 3265, 3269.
301. E. J. Corey, K. C. Nicolaou, M. Shibasaki, Y. Machida, and C. S. Shiner, Tetrahedron Lett., 1975, 3183.
302. J. San Filippo, C.-I. Chern, J. S. Valentine, J. Org. Chem., 1975, **40**, 1678.
303. M. Ladlow, G. Pattenden, and S. J. Teague, Tetrahedron Lett., 1986, **27**, 3279.
304. R. Latrell and G. Lohaus, Justus Liebigs Ann. Chem., 1974, 901.
305. B. Raduchel, Synthesis, 1980, 292.
306. G. Cainelli, F. Maneschalchi, G. Martelli, M. Panunzio, and L. Plessi, Tetrahedron Lett., 1985, **26**, 3369.
307. G. Cainelli, M. Panunzio, T. Basile, A. Bongini, D. Giacomini, and G. Martelli, J. Chem. Soc., Perkin Trans. 1, 1987, 2637.
308. S. Hanessian and J.-M. Vatele, Tetrahedron Lett., 1981, **22**, 3579.
309. S. Hanessian, S. P. Sahoo, C. Couture, and H. Wyss, Bull. Soc. Chim. Belg., 1984, **93**, 571.
310. S. Hanessian, C. Couture, and H. Wyss, Can. J. Chem., 1985, **63**, 3613.
311. J. Kaulen, Angew. Chem. Int. Ed. Engl., 1987, **26**, 773.
312. Y. Inoue, M. Taguchi, and H. Hashimoto, Synthesis, 1986, 332.
313. S. D. Burke, D. M. Armistead, F. J. Schoenen, and J. M. Fevig, Tetrahedron, 1986, **42**, 2787.
314. S. Labidalle, Z. Y. Min, A. Reynet, H. Moskowitz, J.-M. Vierfond, and M. Miocque, Tetrahedron, 1988, **44**, 1171.
315. R. A. Bell and J. V. Turner, Tetrahedron Lett., 1981, **22**, 4871.
316. T. Kitahara, H. Kurata, and K. Mori, Tetrahedron, 1988, **44**, 4339.
317. E. Morera and G. Ortar, J. Org. Chem., 1983, **48**, 119.
318. W. L. Brown and A. G. Fallis, Tetrahedron Lett., 1985, **26**, 607; Can. J. Chem., 1987, **65**, 1828.

319. K. Hojo, H. Yoshino, and T. Mukaiyama, *Chem. Lett.*, 1977, 133.
320. K. Hojo, H. Yoshino, and T. Mukaiyama, *Chem. Lett.*, 1977, 437.
321. B. Castro and C. Selve, *Bull. Soc. Chim. Fr.*, 1971, 2296.
322. I. M. Downie, H. Heaney, and G. Kemp. *Angew. Chem. Int. Ed. Engl.*, 1975, **14**, 370.
323. F. Chretien, Y. Chapleur, B. Castro, and B. Gross, *J. Chem. Soc., Perkin Trans. 1*, 1980, 381.
324. A. Hasegawa, E. Seki, Y. Hioki, and M. Kiso, *Carbohydr. Res.*, 1984, **131**, 61.
325. I. Nakagawa and T. Hata, *Tetrahedron Lett.*, 1975, 1409.
326. K. A. M. Walker, *Tetrahedron Lett.*, 1977, 4475.
327. Y. Tanigawa, H. Kanamaru, and S. Murahashi, *Tetrahedron Lett.*, 1975, 4655.
328. The popularity of these reagents is shown by the 84 citations of references [325](#) and [326](#) through 1988.
329. P. L. Robinson, C. N. Barry, J. W. Kelly, and S. A. Evans, Jr., *J. Am. Chem. Soc.*, 1985, **107**, 5210.
330. B. C. Chang, W. E. Conrad, D. B. Denney, D. Z. Denney, R. Edelman, R. L. Powell, and D. W. White, *J. Am. Chem. Soc.*, 1971, **93**, 4004.
331. D. B. Denney, D. Z. Denney, and J. J. Gigantino, *J. Org. Chem.*, 1984, **49**, 2831.
332. J. C. Martin, J. A. Franz, and R. J. Arhart, *J. Am. Chem. Soc.*, 1974, **96**, 4604.
333. W. Eschenmoser and C. H. Eugster, *Helv. Chim. Acta*, 1978, **61**, 822.
334. C. N. Barry and S. A. Evans, Jr., *J. Org. Chem.*, 1981, **46**, 3361.
335. C. N. Barry and S. A. Evans, Jr., *Tetrahedron Lett.*, 1983, **24**, 661.
336. B. Castro and C. Selve, *Tetrahedron Lett.*, 1973, 4459.
337. P. Kocienski and M. Todd, *J. Chem. Soc., Perkin Trans. 1*, 1983, 1783.
338. T. Hata, I. Yamamoto, and M. Sekine, *Chem. Lett.*, 1975, 977.
339. I. Yamamoto, M. Sekine, and T. Hata, *J. Chem. Soc., Perkin Trans. 1*, 1980, 306.
340. Y. Chapleur, B. Castro, and B. Gross, *Synth. Commun.*, 1977, **7**, 143.
341. V. N. Gogte, S. B. Kulkarni, and B. D. Tilak, *Tetrahedron Lett.*, 1973, 1867.
342. J. P. Freeman and P. J. Mondron, *Synthesis*, 1974, 894.
343. J. Okada, K. Ishimura, and R. Sudo, *Bull. Chem. Soc. Jpn.*, 1970, **43**, 1185.
344. V. Stoilova, L. S. Trifonov, and A. S. Orahovats, *Synthesis*, 1979, 105.
345. R. Appel and R. Kleinstuck, *Chem. Ber.*, 1974, **107**, 5.

346. D. M. Floyd, A. W. Fritz, J. Pluscec, E. R. Weaver, and C. M. Cimarusti, *J. Org. Chem.*, 1982, **47**, 5160.
347. D. M. Floyd, A. W. Fritz, and C. M. Cimarusti, *J. Org. Chem.*, 1982, **47**, 176.
348. R. W. Binkley and D. G. Hehemann, *J. Org. Chem.*, 1978, **43**, 3244.
349. R. W. Binkley, M. G. Ambrose, and D. G. Hehemann, *J. Org. Chem.*, 1980, **45**, 4387.
350. S. Hanessian and N. R. Plessas, *J. Org. Chem.*, 1969, **34**, 2163.
351. H. J. Jennings and J. K. N. Jones, *Can. J. Chem.*, 1965, **43**, 2372.
352. T. Mukaiyama, S. Shoda, and Y. Watanabe, *Chem. Lett.*, 1977, 383.
353. K. Hojo and T. Mukaiyama, *Chem. Lett.*, 1976, 619.
354. J. B. Lee and M. M. El Sawi, *Chem. Ind. (London)*, 1960, 839.
355. P. J. Garegg, *Pure Appl. Chem.*, 1984, **56**, 845.
356. B. Classon, Z. Liu, and B. Samuelsson, *J. Org. Chem.*, 1988, **53**, 6126.
357. S. A. Lysenko, M. P. Koroteev, S. A. Ermishkina, A. S. Shashkov, E. E. Nifant'ev, and N. K. Kochetkov, *Izv. Akad. Nauk SSSR Ser Khim (Eng. Trans.)*, 1979, 2215.
358. B. Classon, P. J. Garegg, and B. Samuelsson, *Can. J. Chem.*, 1981, **59**, 339.
359. N. K. Kochetkov and A. I. Usov, *Tetrahedron*, 1963, **19**, 973.
360. S. Hanessian, M. M. Ponpipom, and P. Lavalley, *Carbohydr. Res.*, 1972, **24**, 45.
361. C. R. Haylock, L. D. Melton, K. N. Slessor, and A. S. Tracey, *Carbohydr. Res.*, 1971, **16**, 375.
362. F. Germain, Y. Chapleur, and B. Castro, *Tetrahedron*, 1982, **38**, 3593.
363. R. Boigegrain, B. Castro, and C. Selve, *Tetrahedron Lett.*, 1975, 2529.
364. D. Brett, I. M. Downie, and J. B. Lee, *J. Org. Chem.*, 1967, **32**, 855.
365. A. Mizumo, Y. Hamada, and T. Shioiri, *Synthesis*, 1980, 1007.
366. T. Mukaiyama, M. Imaoka, and T. Izawa, *Chem. Lett.*, 1977, 1257.
367. P. A. Aristoff, A. W. Harrison, and A. M. Huber, *Tetrahedron Lett.*, 1984, **25**, 3955.
368. R. W. Hoffmann and A. Endesfelder, *Justus Liebigs Ann. Chem.*, 1986, 1823.
369. J. M. Palazon, B. Anorbe, and V. S. Martin, *Tetrahedron Lett.*, 1986, **27**, 4987.
370. T. Fukuyama, A. A. Laird, and L. M. Hotchkiss, *Tetrahedron Lett.*, 1985, **26**, 6291.
371. H. Suemune, Y. Mizuhara, H. Akita, T. Oishi, and K. Sakai, *Chem. Pharm. Bull.*, 1987, **35**, 3112.

372. C. Somoza, M. I. Colombo, A. C. Olivieri, M. Gonzalez-Sierra, and E. A. Ruveda, *Synth. Commun.*, 1987, **17**, 1727.
373. A. G. M. Barrett, R. A. E. Carr, M. A. W. Finch, J. C. Florent, G. Richardson, and N. D. A. Walshe, *J. Org. Chem.*, 1986, **51**, 4254.
374. D. A. Otero and R. Simpson, *Carbohydr. Res.*, 1984, **128**, 79.
375. J. Mulzer and N. Salimi, *Justus Liebigs Ann. Chem.*, 1986, 1172.
376. W. R. Roush, R. J. Brown, and M. Di Mare, *J. Org. Chem.*, 1983, **48**, 5083.
377. T. Kinoshita, M. Miyata, S. M. Ismail, Y. Fujimoto, K. Kakinuma, N. Ikegawa, and M. Morisaki, *Chem. Pharm. Bull.*, 1988, **36**, 144.
378. C. A. Hoeger, A. D. Johnston, and W. H. Okamura, *J. Am. Chem. Soc.*, 1987, **109**, 4690.
379. J. A. Marshall, J. Lebreton, B. S. De Hoff, and T. M. Jenson, *J. Org. Chem.*, 1987, **52**, 3883; *Tetrahedron Lett.*, 1987, **28**, 723.
380. T. Iida, T. Momose, T. Tamura, T. Matsumoto, F. C. Chang, J. Goto, and T. Nambara, *J. Lipid Res.*, 1988, **29**, 165.
381. I. Dyong, H. Merten, and J. Thiem, *Justus Liebigs Ann. Chem.*, 1986, 600.
382. F.-H. Koster, H. Wolf, and H. Kluge, *Justus Liebigs Ann. Chem.*, 1986, 78.
383. B. M. Trost and P. G. McDougal, *J. Org. Chem.*, 1984, **49**, 458.
384. G. W. Ashley, G. Harris, and J. Stubbe, *Biochemistry*, 1988, **27**, 7841.
385. J. E. Toth, P. R. Hamann, and P. L. Fuchs, *J. Org. Chem.*, 1988, **53**, 4694.
386. J. E. Toth and P. L. Fuchs, *J. Org. Chem.*, 1987, **52**, 473.
387. D. Camp and I. D. Jenkins, *Aust. J. Chem.*, 1988, **41**, 1835.
388. (a) R. A. Amos, R. W. Emblidge, and N. Havens, *J. Org. Chem.*, 1983, **48**, 3598. (b) L. D. Arnold, H. I. Assil, and J. C. Vederas, *J. Am. Chem. Soc.*, 1989, **111**, 3973.
389. O. Achmatowicz and G. Gryniewicz, *Tetrahedron Lett.*, 1977, 3179.
390. O. Mitsunobu, A. Takemasa, and R. Endo, *Chem. Lett.*, 1984, 855.
391. Y. Fujimoto, M. Ohhana, T. Terasawa, and N. Ikekawa, *Tetrahedron Lett.*, 1985, **26**, 3239.
392. H. Akita, A. Furuichi, H. Koshiji, K. Horikoshi, and T. Oishi, *Chem. Pharm. Bull.*, 1983, **31**, 4376.
393. M. P. Cava, Z. Ahmed, N. Benfaremo, R. A. Murphy, and G. J. O'Malley, *Tetrahedron*, 1984, **40**, 4767.
394. H. Mastalerz, M. Menard, V. Vinet, J. Desiderio, J. Fung-Tomc, R. Kessler, and Y. Tsai, *J. Med. Chem.*, 1988, **31**, 1190.
395. U. Schmidt, R. Utz, A. Lieberknecht, H. Griesser, B. Potzolli, J. Bahr, K. Wagner, and P. Fischer, *Synthesis*, 1987, 233.

396. M. J. Miller, J. S. Bajwa, P. G. Mattingly, and K. Peterson, *J. Org. Chem.*, 1982, **47**, 4928.
397. J. Wright, G. J. Drtina, R. A. Roberts, and L. A. Paquette, *J. Am. Chem. Soc.*, 1988, **110**, 506.
398. S. Kosuge, N. Hamanaka, and M. Hayashi, *Tetrahedron Lett.*, 1981, **22**, 1345.
399. T. Kitahara, K. Koseki, and K. Mori, *Agric. Biol. Chem.*, 1983, **47**, 389.
400. A. Berkessel, *J. Org. Chem.*, 1989, **54**, 1685.
401. L. Dai, B. Lou, and Y. Zhang, *J. Am. Chem. Soc.*, 1988, **110**, 5195.
402. E. Abushanab, P. Vemishetti, R. W. Leiby, H. K. Singh, A. B. Mikkilineni, D. C. Wu, R. Saibaba, and R. P. Panzica, *J. Org. Chem.*, 1988, **53**, 2598.
403. Y. Tamaru, S. Kawamura, T. Bando, K. Tanaka, M. Hojo, and Z. Yoshida, *J. Org. Chem.*, 1988, **53**, 5491.
404. Y. Tamaru, M. Hojo, and Z. Yoshida, *J. Org. Chem.*, 1988, **53**, 5731.
405. P. F. Deschenaux, T. Kallimopoulous, and A. Jacot-Guillarmad, *Helv. Chim. Acta*, 1989, **72**, 1259.
406. J. Thiem and H. Luders, *Makromol. Chem.*, 1986, **187**, 2275; *Polymer Bull.*, 1984, **11**, 365.
407. M. Labelle, H. E. Morton, Y. Guindon, and J. P. Springer, *J. Am. Chem. Soc.*, 1988, **110**, 4533.
408. G. Brussani, S. V. Ley, J. L. Wright, and D. J. Williams, *J. Chem. Soc., Perkin Trans. 1*, 1986, 303.
409. G. Stork and S. D. Rychnovsky, *J. Am. Chem. Soc.*, 1987, **109**, 1564; *Pure Appl. Chem.*, 1987, **59**, 345.
410. K. Mori and T. Otsuka, *Tetrahedron*, 1985, **41**, 553.
411. T. Harada, I. Wada, and A. Oku, *J. Org. Chem.*, 1989, **54**, 2599.
412. J. Mulzer, A. Angermann, and W. Munch, *Justus Liebigs Ann. Chem.*, 1986, 825.
413. K. Mori, H. Watanabe, K. Yanagi, and M. Minobe, *Tetrahedron*, 1985, **41**, 3663.
414. K. Mori, H. Watanabe, K. Yanagi, and M. Minobe, *Tetrahedron Lett.*, 1984, **25**, 6025.
415. P. C. B. Page, C. M. Rayner, and I. O. Sutherland, *Tetrahedron Lett.*, 1986, **27**, 3535.
416. H.-J. Gais, G. Bulow, A. Zatorski, M. Jentsch, P. Maidonis, and H. Hemmerle, *J. Org. Chem.*, 1989, **54**, 5115.
417. K. C. Schneider and S. A. Benner, *Tetrahedron Lett.*, 1990, **31**, 335.
418. F. Kido, S. C. Sinha, T. Abiko, M. Watanabe, and A. Yoshikoshi, *J. Chem. Soc., Chem. Commun.*, 1990, 418.
419. F. Sugawara, H. Nakayama, G. A. Strobel, and T. Ogawa, *Agric. Biol.*

- Chem., 1986, **50**, 2261.
420. F. Sugawara, H. Nakayama, and T. Ogawa, *Carbohydr. Res.*, 1983, **123**, C25.
421. P. E. Eaton, P. G. Jobe, and I. D. Reingold, *J. Am. Chem. Soc.*, 1984, **106**, 6437.
422. T. Antonsson, C. Moberg, L. Tottie, and A. Heumann, *J. Org. Chem.*, 1989, **54**, 4914.
423. R. M. Williams and B. H. Lee, *J. Am. Chem. Soc.*, 1986, **108**, 6431.
424. D. R. Dodds and J. B. Jones, *J. Am. Chem. Soc.*, 1988, **110**, 577.
425. T. Harada, K. Sakamoto, Y. Ikemura, and A. Oku, *Tetrahedron Lett.*, 1988, **29**, 3097.
426. R. M. Williams, B. H. Lee, M. M. Miller, and O. P. Anderson, *J. Am. Chem. Soc.*, 1989, **111**, 1073.
427. J. Mulzer, T. Schulze, A. Strecker, and W. Denzer, *J. Org. Chem.*, 1988, **53**, 4098.
428. G. Grynkiewicz, *Pol. J. Chem.*, 1981, **55**, 2047.
429. K. Mori and K. Tanida, *Heterocycles*, 1981, **15**, 1171.
430. A. B. Smith, III, G. A. Sulikowski, and K. Fujimoto, *J. Am. Chem. Soc.*, 1989, **111**, 8039.
431. A. Baumeler, W. Brade, A. Haag, and C. H. Eugster, *Helv. Chim. Acta*, 1990, **73**, 700.
432. P. De Witt, D. Misiti, and G. Zappia, *Tetrahedron Lett.*, 1989, **30**, 5505.
433. P. G. Sammes, *Gazz. Chim. Ital.*, 1986, **116**, 109.
434. K. Kakiuchi, S. Kumanoya, M. Ue, Y. Tobe, and Y. Odaira, *Chem. Lett.*, 1985, 989.
435. A. Warm and P. Vogel, *Helv. Chim. Acta*, 1987, **70**, 690.
436. A. Warm and P. Vogel, *Tetrahedron Lett.*, 1986, **27**, 5615.
437. H. Sefoi, H. Takeno, and M. Hashimoto, *Heterocycles*, 1986, **24**, 1261.
438. Y. Naoshima and H. Hasegawa, *Chem. Lett.*, 1987, 2379.
439. I. Murata, Y. Sugihara, T. Sugimura, and S. Wakabayashi, *Tetrahedron*, 1986, **42**, 1745.
440. K. Mori and T. Ebata, *Tetrahedron*, 1986, **42**, 4413.
441. J.-C. Zwick, P. Vogel, V. Mange, and G. Chapuis, *Helv. Chim. Acta*, 1987, **70**, 1231.
442. N. Ikota and A. Hanaki, *Heterocycles*, 1988, **27**, 2535.
443. K. Mori and M. Ikunaka, *Tetrahedron*, 1984, **40**, 3471.
444. T. Hamatani, S. Matsubara, H. Matsuda, and M. Schlosser, *Tetrahedron*, 1988, **44**, 2875.
445. P. Yates, R. S. Grewal, P. C. Hayes, and J. F. Sawyer, *Can. J. Chem.*,

- 1988, **66**, 2805.
446. G. E. Keck, E. P. Boden, and M. R. Wiley, *J. Org. Chem.*, 1989, **54**, 896.
447. A. B. Mikkilineni, P. Kumar, and E. Abushanab, *J. Org. Chem.*, 1988, **53**, 6005.
448. J. M. Chong and E. K. Mar, *Tetrahedron*, 1989, **45**, 7709.
449. K. Tomioka and K. Koga, *Tetrahedron*, 1988, **44**, 4351.
450. M. Iwao and T. Kuraishi, *Tetrahedron Lett.*, 1983, **24**, 2649.
451. A. V. R. Rao, J. S. Yadav, K. B. Reddy, and A. R. Mehendale, *J. Chem. Soc., Chem. Commun.*, 1984, 453; *Tetrahedron*, 1984, **40**, 4643.
452. S. K. Richardson, M. R. Sabol, and D. S. Watt, *Synth. Commun.*, 1989, **19**, 359.
453. S. Takano, Y. Sekiguchi, and K. Ogasawara, *J. Chem. Soc., Chem. Commun.*, 1987, 555.
454. B. M. Trost, B. Yang, and M. L. Miller, *J. Am. Chem. Soc.*, 1989, **111**, 6482.
455. R. S. Harapanhalli, *J. Chem. Soc., Perkin Trans. 1*, 1988, 2633.
456. I. H. Sanchez, F. J. Lopez, J. J. Soria, M. I. Larraza, and H. J. Flores, *J. Am. Chem. Soc.*, 1983, **105**, 7640.
457. Y. Kobayashi, N. Kato, T. Shimazaki, and F. Sato, *Tetrahedron Lett.*, 1988, **29**, 6297.
458. S. Shibahara, T. Okonogi, T. Yoshida, Y. Murai, T. Kudo, S. Inouye, and S. Kondo, *J. Antibiotics*, 1990, **43**, 62.
459. P. J. Maurer and M. J. Miller, *J. Am. Chem. Soc.*, 1983, **105**, 240.
460. S. Takano and Y. Shimazaki, *Chem. Lett.*, 1988, 2041.
461. R. L. Halterman and H. L. Nimmons, *Organometallics*, 1990, **9**, 273.
462. N. Ishizuka, M. Shiro, and Y. Makisumi, *J. Chem. Soc., Perkin Trans. 1*, 1990, 827.
463. H.-E. Hogberg, E. Hedenstrom, A.-B. Wassgren, M. Hjalmarsson, G. Bergstrom, J. Lofqvist, and T. Norin, *Tetrahedron*, 1990, **46**, 3007.
464. A. S. Amarasekara and A. Hassner, *Tetrahedron Lett.*, 1987, **28**, 3151.
465. N. Jeker and C. Tamm, *Helv. Chim. Acta*, 1988, **71**, 1904.
466. H.-J. Gais and T. Lied, *Angew. Chem., Int. Ed. Engl.*, 1984, **23**, 145.
467. K. H. Bell, *Aust. J. Chem.*, 1987, **40**, 399.
468. M. Zeches, T. Ravao, B. Richard, G. Massiot, and L. Le Men-Olivier, *Tetrahedron Lett.*, 1984, **25**, 659.
469. M. Sunagawa, H. Matsumura, T. Inoue, M. Fukasawa, and M. Kato, *J. Antibiotics*, 1990, **43**, 519.
470. C. E. Tonn, J. M. Palazon, C. Ruiz-Perez, M. L. Rodriguez, and V. S. Martin, *Tetrahedron Lett.*, 1988, **29**, 3097.

471. J. A. Marshall and W. Y. Gung, *Tetrahedron Lett.*, 1989, **30**, 309.
472. N. Ikota, *Chem. Pharm. Bull.*, 1989, **37**, 3399.
473. D.-S. Shin, P. Yadagiri, and J. R. Falck, *Tetrahedron Lett.*, 1989, **30**, 3923.
474. T. Harada, H. Kurokawa, and A. Oku, *Tetrahedron Lett.*, 1987, **28**, 4847.
475. C. Yeates, S. D. A. Street, P. Kocienski, and S. F. Campbell, *J. Chem. Soc., Chem. Commun.*, 1985, 1388.
476. P. Kocienski, S. D. A. Street, C. Yeates, and S. F. Campbell, *J. Chem. Soc., Perkin Trans. 1*, 1987, 2189.
477. P. Barbier and F. Schneider, *J. Org. Chem.*, 1988, **53**, 1218.
478. M. Harre, P. Raddatz, R. Walenta, and E. Winterfeldt, *Angew. Chem., Int. Ed. Engl.*, 1982, **21**, 480.
479. K.-Y. Ko and E. L. Eliel, *J. Org. Chem.*, 1986, **51**, 5353.
480. K. Koike, M. Sugimoto, Y. Nakahara, and T. Ogawa, *Carbohydr. Res.*, 1987, **162**, 237.
481. S. Nimkar, D. Menaldino, A. H. Merrill, and D. Liotta, *Tetrahedron Lett.*, 1988, **29**, 3037.
482. S. Kamata, N. Haga, T. Tsuru, K. Uchida, H. Kakushi, H. Arita, and K. Hanasaki, *J. Med. Chem.*, 1990, **33**, 229.
483. D. R. Williams, P. A. Jass, H.-L. A. Tse, and R. D. Gaston, *J. Am. Chem. Soc.*, 1990, **112**, 4552.
484. K. Shisido, K. Tanaka, K. Fukumoto, and T. Kametani, *Chem. Pharm. Bull.*, 1985, **33**, 532; *Tetrahedron Lett.*, 1983, **24**, 2783.
485. H. Saito, Y. Nishimura, S. Kondo, and T. Takeuchi, *Chem. Lett.*, 1988, 1235.
486. P. Yadagiri, S. Lumin, J. R. Falck, A. Karara, and J. Capdevila, *Tetrahedron Lett.*, 1989, **30**, 429.
487. S. Ohuchida, N. Hamanaka, S. Hashimoto and M. Hayashi, *Tetrahedron Lett.*, 1982, **23**, 2883.
488. S. Nishiyama, S. Yamamura, K. Kato, and T. Takita, *Tetrahedron Lett.*, 1988, **29**, 4743.
489. J. Prandi and J.-M. Beau, *Tetrahedron Lett.*, 1989, **30**, 4517.
490. H. Takahata, T. Takamatsu, and T. Yamazaki, *J. Org. Chem.*, 1989, **54**, 4812.
491. P. Yadagiri, D.-S. Shin, and J. R. Falck, *Tetrahedron Lett.*, 1988, **29**, 5497.
492. Y. Ichikawa, A. Narita, A. Shiozawa, Y. Hayashi, and K. Narasaka, *J. Chem. Soc., Chem. Commun.*, 1989, 1919.
493. P. Metz, *Tetrahedron*, 1989, **45**, 7311.
494. F. Hammerschmidt, *Justus Liebigs Ann. Chem.*, 1988, 961.

495. M. Mag and J. W. Engels, *Nucleosides, Nucleotides*, 1988, **7**, 725.
496. C. A. Townsend, A. S. Neese, and A. B. Theis, *J. Chem. Soc., Chem. Commun.*, 1982, 116.
497. R. Croteau, N. M. Felton, and C. J. Wheeler, *J. Biol. Chem.*, 1985, **260**, 5956.
498. T. Takahashi, M. Miyazawa, H. Ueno, and J. Tsuji, *Tetrahedron Lett.*, 1986, **27**, 3881.
499. S. D. Pastor, P. A. Odorisio, and R. Ravichandran, *Phosphorous Sulfur*, 1986, **29**, 67.
500. Y. Ito, Y. Kobayashi, T. Kawabata, M. Takase, and S. Terashima, *Tetrahedron*, 1989, **45**, 5767.
501. P. Tecon, Y. Hirano, and C. Djerassi, *Org. Mass. Spec.*, 1982, **17**, 277.
502. S. N. Newaz and R. K. Tcholakian, *Steroids*, 1984, **43**, 445.
503. N. S. Nadaraia, V. I. Sladkov, and N. N. Survivorov, *J. Org. Chem. USSR (Eng. Trans.)*, 1988, **24**, 682.
504. D. C. Swinney, D. E. Ryan, P. E. Thomas, and W. Levin, *Biochemistry*, 1987, **26**, 7073.
505. M. E. Deluca, A. M. Seldes, and E. G. Gros, *Helv. Chim. Acta*, 1986, **69**, 1844.
506. R. H. Purdy, A. L. Morrow, J. R. Blinn, and S. M. Paul, *J. Med. Chem.*, 1990, **33**, 1572.
507. R. B. Gabbard and A. Segaloff, *Steroids*, 1983, **42**, 555.
508. G. Stork and M. Sofia, *J. Am. Chem. Soc.*, 1986, **108**, 6826.
509. J. Valisolalao, B. Luu, and G. Ourisson, *Tetrahedron*, 1983, **39**, 2779.
510. E. J. Corey and R. W. Hahl, *Tetrahedron Lett.*, 1989, **30**, 3023.
511. M. Aburitani, T. Takeuchi, and K. Mori, *Agric. Biol. Chem.*, 1986, **50**, 3043.
512. M. M. Campbell, A. J. Floyd, T. Lewis, M. F. Mahon, and R. J. Oglivie, *Tetrahedron Lett.*, 1989, **30**, 1993.
513. P. G. Sammes and D. Thetford, *J. Chem. Soc., Perkin Trans. 1*, 1988, 111.
514. H. W. Pauls and B. Fraser-Reid, *J. Carbohydr. Chem.*, 1985, **4**, 1.
515. G. Schulte, W. Meyer, A. Starkloff, and I. Dyong, *Chem. Ber.*, 1981, 1809.
516. H. W. Pauls and B. Fraser-Reid, *Carbohydr. Res.*, 1986, **150**, 111.
517. S. Valverde and S. Garcia-Ochoa, *J. Carbohydr. Chem.*, 1989, **8**, 553.
518. F. Baumberger, A. Vasella, and R. Schauer, *Helv. Chim. Acta*, 1988, **71**, 429.
519. O. Achmatowicz and M. H. Burzynska, *Tetrahedron*, 1982, **38**, 3507.
520. O. Achmatowicz and M. H. Burzynska, *Carbohydr. Res.*, 1985, **141**, 67.

521. S. Jarosz, *Carbohydr. Res.*, 1988, **183**, 201.
522. H. A. Vaccaro, R. A. Rivero, and A. B. Smith, III, *Tetrahedron Lett.*, 1989, **30**, 1465.
523. F. M. Hauser, S. R. Ellenberger, and W. P. Ellenberger, *Tetrahedron Lett.*, 1988, **29**, 4939.
524. J. L. Pawlak, R. E. Padykula, J. D. Kronis, R. A. Aleksejczyk and G. A. Berchtold, *J. Am. Chem. Soc.*, 1989, **111**, 3374.
525. A. Balan and H. Ziffer, *J. Chem. Soc., Chem. Commun.*, 1990, 175.
526. B. M. Trost and E. D. Edstrom, *Angew. Chem., Int. Ed. Engl.*, 1990, **29**, 520.
527. N. Ruiz and P. Rollin, *Tetrahedron Lett.*, 1989, **30**, 1637.
528. A. J. Pearson, Y.-S. Lai, W. Lu, and A. A. Pinkerton, *J. Org. Chem.*, 1989, **54**, 3882.
529. J. A. Marshall and J. Lebreton, *J. Org. Chem.*, 1988, **53**, 4108.
530. J. Bergman and A. Brynolf, *Tetrahedron*, 1990, **46**, 1295.
531. J. Jurczak, S. Pikul, and J. Raczko, *Pol. J. Chem.*, 1987, **61**, 645.
532. A. V. R. Rao, D. S. Bose, M. K. Gurjar, and T. Ravindranathan, *Tetrahedron*, 1989, **45**, 7031.
533. F. Gauchet, M. Julia, H. Mestdagh, and C. Rolando, *Bull. Chim. Soc. Fr.*, 1987, 1036.
534. T. Honda, T. Kametani, K. Kanai, Y. Tatsuzaki, and M. Tsubuki, *J. Chem. Soc., Perkin Trans. 1*, 1990, 1733.
535. A. I. Meyers and S. Bienz, *J. Org. Chem.*, 1990, **55**, 791.
536. K. A. Babiak, J. S. Ng, J. H. Dygos, C. L. Weyker, Y.-F. Wang, and C. H. Wong, *J. Org. Chem.*, 1990, **55**, 3377.
537. K. Sakurai, T. Kitahara, and K. Mori, *Tetrahedron*, 1990, **46**, 761.
538. J. A. Marshall and X.-J. Wang, *J. Org. Chem.*, 1990, **55**, 2995.
539. T. Hudlicky, G. Seone, and T. Pettus, *J. Org. Chem.*, 1989, **54**, 4239.
540. A. G. Davies and I. G. E. Davison, *J. Chem. Soc., Perkin Trans. 2*, 1989, 825.
541. M. Koreeda, D. J. Ricca, and J. I. Luengo, *J. Org. Chem.*, 1988, **53**, 5588.
542. J. D. Harling and W. B. Motherwell, *J. Chem. Soc., Chem. Commun.*, 1988, 1380.
543. H. Fretz, W.-D. Woggon, and R. Voges, *Helv. Chim. Acta*, 1989, **72**, 391.
544. R. V. Bonnert, M. J. Davies, J. Howarth, and P. R. Jenkins, *J. Chem. Soc., Chem. Commun.*, 1990, 148.
545. C. Le Drain, E. Vieira, and P. Vogel, *Helv. Chem. Acta*, 1989, **72**, 338.
546. A. J. Briggs and K. A. M. Walker, *J. Org. Chem.*, 1990, **55**, 2962.
547. S. J. Danishefsky, M. P. Cabal, and K. Chow, *J. Am. Chem. Soc.*, 1989,

- 111**, 3456.
548. M. Ando, H. Kusaka, H. Ohara, K. Takase, H. Yamaoka, and Y. Yanagi, *J. Org. Chem.*, 1989, **54**, 1952.
549. B. Gosse-Kobo, P. Mosset, and R. Gree, *Tetrahedron Lett.*, 1989, **30**, 4235.
550. Y. Ito, M. Sawamura, and T. Hayashi, *Tetrahedron Lett.*, 1988, **29**, 239.
551. M. T. Nunez, M. L. Rodriguez, and V. S. Martin, *Tetrahedron Lett.*, 1988, **29**, 1979.
552. A. V. R. Rao, P. R. Krishna, and J. S. Yadav, *Tetrahedron Lett.*, 1989, **30**, 1669.
553. H. Pak, J. K. Dickson, and B. Fraser-Reid, *J. Org. Chem.*, 1989, **54**, 5357.
554. S. Lumin and J. R. Falck, *Tetrahedron Lett.*, 1990, **31**, 2971.
555. N. K. Kochetkov, D. V. Yashunsky, A. F. Sviridov, and M. S. Ermolenko, *Carbohydr. Res.*, 1990, **200**, 209.
556. S. Lumin, P. Yadagiri, and J. R. Falck, *Tetrahedron Lett.*, 1988, **29**, 4237.
557. U. C. Dyer and Y. Kishi, *J. Org. Chem.*, 1988, **53**, 3383.
558. M. M. Bowers-Nemia and M. M. Joullie, *Heterocycles*, 1983, **20**, 817.
559. M. Thaning and L.-G. Wistrand, *Helv. Chim. Acta*, 1986, **69**, 1711.
560. B. S. Bal and H. W. Pinnick, *Heterocycles*, 1981, **16**, 2091.
561. M. Barbier, *Helv. Chim. Acta*, 1981, **64**, 1407.
562. H. Suemune, H. Maruoka, S. Saeki, and K. Sakai, *Chem. Pharm. Bull.*, 1986, **34**, 4629.
563. T. Sakai, M. Yoshida, S. Kohmoto, M. Utaka, and A. Takeda, *Tetrahedron Lett.*, 1982, **23**, 5185.
564. S. Valverde, A. Garcia-Ochoa, and M. Martin-Lomas, *J. Chem. Soc., Chem. Comm.*, 1987, 1714.
565. S. D. Burke, A. D. Piscopio, and J. L. Buchanan, *Tetrahedron Lett.*, 1988, **29**, 2757.
566. D. G. Melillo, T. Liu, K. M. Ryan, M. Sletzing, and I. Shinkai, *Tetrahedron Lett.*, 1981, **22**, 913.
567. Y. Hamada, A. Kawai, and T. Shioiri, *Chem. Pharm. Bull.*, 1985, **33**, 5601.
568. R. J. Bass, B. J. Banks, M. R. G. Leeming, and M. Snarey, *J. Chem. Soc., Perkin Trans. 1*, 1981, 124.
569. K. Mori and H. Takaishi, *Tetrahedron*, 1989, **45**, 1639.
570. S. Hatakeyama, K. Osanai, H. Numata, and S. Takano, *Tetrahedron Lett.*, 1989, **30**, 4845.
571. D. Papaioannou, G. Stavropoulos, K. Karagiannis, G. S. Francis, T. Brekke, and D. W. Aksnes, *Acta Chem. Scand.*, 1990, **44**, 243.
572. S. Takano, M. Yonaga, and K. Ogasawara, *Synthesis*, 1981, 265.

573. R. Zibuck, N. J. Liverton, and A. B. Smith, *J. Am. Chem. Soc.*, 1986, **108**, 2451.
574. A. B. Smith, III, I. Noda, S. W. Remiszewski, N. J. Liverton, and R. Zibuck, *J. Org. Chem.*, 1990, **55**, 3977.
575. S. D. Burke, D. M. Armistead, and K. Shankaran, *Tetrahedron Lett.*, 1986, **27**, 6295.
576. B. J. Whitlock and H. W. Whitlock, *J. Am. Chem. Soc.*, 1990, **112**, 3910.
577. Y. Ueda, J. M. Chuang, L. B. Crast, Jr., and R. A. Partyka, *J. Antibiotics*, 1989, **42**, 1379.
578. J. Nakano, M. Mimura, M. Hayashida, K. Kimura, and T. Nakanishi, *Heterocycles*, 1983, **20**, 1975.
579. R. C. Larock and D. E. Stinn, *Tetrahedron Lett.*, 1988, **29**, 4687.
580. R. Schlecker and P. C. Thieme, *Tetrahedron*, 1988, **44**, 3289.
581. S. Takano, Y. Iwabuchi, and K. Ogasawara, *J. Chem. Soc., Chem. Commun.*, 1988, 1204.
582. K. Maruyama, N. Nagai, and Y. Naruta, *J. Org. Chem.*, 1986, **51**, 5083.
583. R. A. Murphy and M. P. Cava, *Tetrahedron Lett.*, 1984, **25**, 803.
584. F. Cottet, L. Cottier, G. Descotes, and R. M. Srivastava, *J. Heterocyclic Chem.*, 1988, **25**, 1481.
585. P. E. J. Sanderson, J. D. Kilburn, and W. C. Still, *J. Am. Chem. Soc.*, 1989, **111**, 8314.
586. R. F. W. Jackson and R. A. Raphael, *J. Chem. Soc., Perkin Trans. 1*, 1984, 535.
587. G. Consiglio, O. Piccolo, L. Roncetti, and F. Morandini, *Tetrahedron*, 1986, **42**, 2043.
588. D. M. Walba, R. T. Vohra, N. A. Clark, M. A. Handschy, J. Xue, D. S. Parmar, S. T. Lagerwall, and K. Skarp, *J. Am. Chem. Soc.*, 1986, **108**, 7424.
589. J. A. Rao and M. P. Cava, *J. Org. Chem.*, 1989, **54**, 2751.
590. J. Nakano, M. Mimura, M. Hayashida, M. Fujii, K. Kimura, and T. Nakanishi, *Chem. Pharm. Bull.*, 1988, **36**, 1399.
591. P. Beraud, A. Bourhim, S. Czernicki, and P. Krausz, *Tetrahedron Lett.*, 1989, **30**, 325.
592. A. P. Marchand and P. R. Dave, *J. Org. Chem.*, 1989, **54**, 2775.
593. R. S. Subramanian and K. K. Balasubramanian, *Tetrahedron Lett.*, 1989, **30**, 2297.
594. R. S. Subramanian and K. K. Balasubramanian, *Tetrahedron Lett.*, 1988, **29**, 6797.
595. M. Srebnik, P. V. Ramachandran, and H. C. Brown, *J. Org. Chem.*, 1988, **53**, 2916.

596. G. D. Diana, D. Cutcliffe, R. C. Oglesby, M. J. Otto, J. P. Mallamo, V. Akullian, and M. A. McKinlay, *J. Med. Chem.*, 1989, **32**, 450.
597. B. C. Askew, *Tetrahedron Lett.*, 1990, **31**, 4245.
598. D. H. S. Horn, R. H. Nearn, J. B. Siddall, G. B. Staal, and D. C. Cerf, *Aust. J. Chem.*, 1983, **36**, 1409.
599. R. F. Nutt and M. M. Joullie, *J. Am. Chem. Soc.*, 1982, **104**, 5852.
600. M. M. Bowers, P. Carroll, and M. M. Joullie, *J. Chem. Soc., Perkin Trans. 1*, 1989, 857.
601. P. G. Baraldi, A. Barco, S. Benetti, A. Casolari, S. Manfredini, G. P. Pollini, and D. Simoni, *Tetrahedron*, 1988, **44**, 1267.
602. Y. Gao and K. B. Sharpless, *J. Org. Chem.* 1988, **53**, 4081.
603. T. Kometani, H. Kondo, and Y. Fujimori, *Synthesis*, 1988, 1005.
604. R. W. Guthrie, G. L. Kaplan, F. A. Mennona, J. W. Tilley, R. W. Kierstead, J. G. Mullin, R. A. Le Mahieu, S. Zawoiski, M. O'Donnell, H. Crowley, B. Yaremko, and A. F. Welton, *J. Med. Chem.*, 1989, **32**, 1820.
605. Y. Shizuri, H. Shigemori, Y. Okuno, and S. Yamamura, *Chem. Lett.*, 1986, 2097.
606. M. M. Ponpipom, B. Z. Yue, R. L. Bugianesi, D. R. Brooker, M. N. Chang, and T. Y. Shen, *Tetrahedron Lett.*, 1986, **27**, 309.
607. M. M. Ponpipom, R. L. Bugianesi, D. R. Brooker, B. Z. Yue, S. B. Hwang, and T. Y. Shen, *J. Med. Chem.*, 1987, **30**, 136.
608. H. Yamashita, N. Minami, K. Sakakibara, S. Kobayashi, and M. Ohno, *J. Antibiotics*, 1987, **40**, 1716.
609. D. R. Buckle, D. J. Outred, H. Smith, and B. A. Spicer, *J. Med. Chem.*, 1984, **27**, 1452.
610. S. Takano, M. Akiyama, and K. Ogasawara, *Chem. Lett.*, 1985, 505.
611. K. A. M. Walker, M. B. Wallach, D. R. Hirschfeld, *J. Med. Chem.*, 1981, **24**, 67.
612. S. Takano, M. Akiyama, and K. Ogasawara, *J. Chem. Soc., Perkin Trans. 1*, 1985, 2447.
613. D. M. Walba, K. F. Eidman, R. C. Haltiwanger, *J. Org. Chem.*, 1989, **54**, 4939.
614. J. Krapcho, C. Turk, D. W. Cushman, J. R. Powell, J. M. De Forrest, E. R. Spitzmiller, D. S. Karanewsky, M. Duggan, G. Rovnvak, J. Schwartz, S. Natarajan, J. D. Godfrey, D. E. Ryano, R. Neubeck, K. S. Atwal, and E. W. Petrillo, *J. Med. Chem.*, 1988, **31**, 1148.
615. N. Chida, M. Ohtsuka, and S. Ogawa, *Chem. Lett.*, 1988, 969.
616. H. P. Isenring and W. Hofheinz, *Tetrahedron* 1983, **39**, 2591.
617. M. Petitou, P. Duchaussoy, and J. Choay, *Tetrahedron Lett.*, 1988, **29**, 1389.

618. F. Yamazaki, T. Nukada, Y. Ito, S. Sato, and T. Ogawa, *Tetrahedron Lett.*, 1989, **30**, 4417.
619. N. Nakamura, H. Miyazaki, N. Ohkawa, T. Oshima, and H. Koike, *Tetrahedron Lett.*, 1990, **31**, 699.
620. K. Sakai, Y. Nakahara, and T. Ogawa, *Tetrahedron Lett.*, 1990, **31**, 3035.
621. I. Abushanab and M. S. P. Sarma, *J. Med. Chem.*, 1989, **32**, 76.
622. G. W. J. Fleet and T. K. M. Shing, *Tetrahedron Lett.*, 1983, **24**, 3657.
623. S. Achab and B. C. Das, *Synth. Commun.*, 1982, **12**, 931.
624. S. Takano, K. Seya, E. Goto, M. Hirama, and K. Ogasawara, *Synthesis*, 1983, 116.
625. C. Jiang, R. J. Suhadolnik, and D. C. Baker, *Nucleosides, Nucleotides*, 1988, **7**, 271.
626. P. Vemishetti, R. Saibaba, R. P. Panzica, and E. Abushanab, *J. Med. Chem.*, 1990, **33**, 681.
627. E. Abushanab, M. Bessodes, and K. Antonakis, *Tetrahedron Lett.*, 1984, **25**, 3841.
628. R. D. Guthrie, I. D. Jenkins, S. Thang, and R. Yamasaki, *Carbohydr. Res.*, 1988, **176**, 306.
629. K. Capek, T. Vydra, M. Ranny, and P. Sedmera, *Coll. Czech. Chem. Commun.*, 1985, **50**, 2191.
630. M. Kinoshita, M. Morioka, M. Taniguchi, and J. Shimizu, *Bull. Chem. Soc., Jpn.*, 1987, **60**, 4005.
631. W. Kirmse and U. Mrotzeck, *Chem. Ber.*, 1988, **121**, 485.
632. Abd El Samii, A. Ashmaway, and J. M. Mellor, *J. Chem. Soc., Perkin Trans. 1*, 1988, 2509.
633. J. F. Hoover and J. M. Stryker, *J. Am. Chem. Soc.*, 1989, **111**, 6466.
634. M. M. Francl, G. Hansell, B. P. Patel, and C. S. Swindell, *J. Am. Chem. Soc.*, 1990, **112**, 3535.
635. B. H. Lee, A. Biswas, and M. J. Miller, *J. Org. Chem.*, 1986, **51**, 106.
636. T. R. Kelly, C. T. Jagoe, and Q. Li, *J. Am. Chem. Soc.*, 1989, **111**, 4522.
637. J. W. Huffman and R. C. Desai, *J. Org. Chem.*, 1982, **47**, 3254.
638. L. A. Paquette and T. Sugimara, *J. Am. Chem. Soc.*, 1986, **108**, 3841.
639. L. A. Paquette and T. Sugimara, *J. Am. Chem. Soc.*, 1987, **109**, 3017.
640. A. F. Cichy, P. Vemishetti, and E. Abushanab, *Nucleosides, Nucleotides*, 1989, **8**, 957.
641. V. C. O. Njar, G. Spiteller, J. Wicha, and E. Caspi, *Heterocycles*, 1989, **28**, 1051.
642. C. Yoshida, K. Tanaka, Y. Todo, R. Hattori, Y. Fukukoka, M. Komatsu, and I. Saikawa, *J. Antibiotics*, 1986, **39**, 90.

643. M. R. Harnden and P. G. Wyatt, *Tetrahedron Lett.*, 1990, **31**, 2185.
644. R. E. Mewshaw and T. J. Commons, *J. Antibiotics*, 1987, **40**, 1563.
645. J. A. Secrist, *Nucleosides, Nucleotides*, 1987, **6**, 73.
646. E. Grochowski and H. Stepowska, *Synthesis*, 1988, 795.
647. K. C. Nicolaou and R. D. Groneberg, *J. Am. Chem. Soc.*, 1990, **112**, 4085.
648. K. Barlos, D. Papaioannou, and C. Sanida, *Justus Liebigs Ann. Chem.*, 1986, 287.
649. K. Barlos, P. Mamos, D. Papaioannou, C. Sanida, and C. Antonopoulos, *J. Chem. Soc., Chem. Commun.*, 1986, 1258.
650. W. Pfeleiderer, M. Schwarz, and H. Schirmeister, *Chemica Scr.*, 1986, **26**, 147.
651. B. S. Schulz and W. Pfeleiderer, *Tetrahedron Lett.*, 1985, **26**, 5421.
652. M. J. Miller, A. Biswas, and M. A. Krook, *Tetrahedron*, 1983, **39**, 2571.
653. A. van Aerschot, P. Herjewijn, G. Janssen, and H. Vanderhaeghe, *Nucleosides, Nucleotides*, 1988, **7**, 519.
654. J. Hiebl, E. Zbiral, J. Balzarini, and E. De Clercq, *J. Med. Chem.*, 1990, **33**, 845.
655. H. H. Brandstetter and E. Zbiral, *Justus Liebigs Ann. Chem.*, 1983, 2055.
656. I. Kieper, T. Schmidt, B. Fera, and H. Ruterjans, *Nucleosides, Nucleotides*, 1988, **7**, 821.
657. A. van Aerschot, M. Mag, P. Herdewijn, and H. Vanderhaeghe, *Nucleosides, Nucleosides*, 1989, **8**, 159.
658. S. Czernecki and J.-M. Valery, *J. Chem. Soc., Chem. Commun.*, 1990, 801.
659. M. Mag and J. W. Engels, *Nucl. Acid Res.*, 1988, **16**, 3525.
660. A. van Aerschot, B. Peeters, and H. Vanderhaeghe, *Nucleosides, Nucleotides*, 1987, **6**, 437.
661. H. Takaku, S. Ueda, and Y. Tomita, *Chem. Pharm. Bull.*, 1984, **32**, 2882.
662. B. S. Schulz and W. Pfeleiderer, *Nucleosides, Nucleotides*, 1987, **6**, 529.
663. J. F. Habener, C. D. Vo, G. P. Gryan, L. Ercolani, and A. H. Wang, *Proc. Natl. Acad. Sci. USA*, 1988, **85**, 1735.
664. M. J. Dahma and K. K. Ogilvie, *J. Org. Chem.*, 1988, **53**, 3710.
665. P. Herdewijn, J. Balzarini, M. Baba, R. Pauwels, A. van Aerschot, G. Janssen, and E. De Clercq, *J. Med. Chem.*, 1988, **31**, 2040.
666. M. J. Wanner and G. J. Koomen, *Tetrahedron Lett.*, 1989, **30**, 2301.
667. L. Grehn and U. Ragnarsson, *Coll. Czech. Chem. Commun.*, 1988, **53**, 2778.
668. M. Suzuki, H. Maeda, K. Kondo, H. Sugano, and K. Matsumoto, *Chem.*

- Pharm. Bull., 1989, **37**, 1764.
669. G. J. Hitchings, M. Helliwell, and J. M. Vernon, J. Chem. Soc., Perkin Trans. 1, 1990, 83.
670. J.-W. Choi and D. J. Hart, Tetrahedron, 1985, **41**, 3959.
671. D. L. Boger and S. M. Sakya, J. Org. Chem., 1988, **53**, 1415.
672. P. N. W. van der Vliet, J. A. M. Hamersma, and W. N. Speckamp, Tetrahedron, 1985, **41**, 2007.
673. B. P. Wijnberg, W. N. Speckamp, and A. R. C. Oostveen, Tetrahedron, 1982, **38**, 209.
674. J. A. M. Hamersma and W. N. Speckamp, Tetrahedron, 1982, **38**, 3255.
675. D. A. Burnett, J.-K. Choi, D. J. Hart, and Y.-M. Tsai, J. Am. Chem. Soc., 1984, **106**, 8201.
676. J. M. Dener and D. J. Hart, Tetrahedron, 1988, **44**, 7037.
677. Z.-K. Liao and H. Kohn, J. Org. Chem., 1984, **49**, 3812.
678. L. F. Cannizzo and R. H. Grubs, J. Org. Chem., 1985, **50**, 2316.
679. R. K. Saiki, P. S. Walsh, C. H. Levenson, and H. A. Erlich, Proc. Natl. Acad. Sci. USA, 1989, **86**, 6230.
680. H. Yamada, K. Kurumaya, T. Eguchi, and M. Kajiwara, J. Lab. Comp. Radiopharm., 1987, **24**, 561.
681. P. M. M. Nossin and W. N. Speckamp, Tetrahedron Lett., 1981, **22**, 3289.
682. J. A. M. Hamersma, P. M. M. Nossin, and W. N. Speckamp, Tetrahedron, 1985, **41**, 1999.
683. P. G. Baraldi, M. Guarneri, F. Moroder, G. P. Pollini, and D. Simoni, Synthesis, 1982, 653.
684. A. Doutheau, A. Saba, and J. Gore, Tetrahedron Lett., 1982, **23**, 2461.
685. S. Kano, Y. Yuasa, T. Yokomatsu, and S. Shibuya, J. Org. Chem., 1983, **48**, 3835.
686. S. Kano, Y. Yuasa, T. Yokomatsu, and S. Shibuya, Heterocycles, 1984, **22**, 1411.
687. A. L. Castelhana and A. Krantz, J. Am. Chem. Soc., 1984, **106**, 1877.
688. H. Ent, H. de Konig, and W. N. Speckamp, Tetrahedron Lett., 1985, **26**, 5105.
689. P. G. Sammes and D. Thetford, J. Chem. Soc., Perkin Trans. 1, 1989, 655.
690. J. Mulzer, A. Angermann, B. Schubert and C. Seilz, J. Org. Chem., 1986, **51**, 5294.
691. P. M. M. Nossin, J. A. M. Hamersma, and W. N. Speckamp, Tetrahedron Lett., 1982, **23**, 3807.
692. H. Iida, N. Yamazaki, and C. Kibayashi, J. Chem. Soc., Chem. Commun.,

- 1987, 746.
693. H.-G. Capraro, M. Lang, and P. Schneider, *Heterocycles*, 1989, **28**, 643.
694. R. B. Silverman and G. M. Banik, *J. Am. Chem. Soc.*, 1987, **109**, 2219.
695. S. Kano, Y. Yuasa, T. Yokomatsu, and S. Shibuya, *Synthesis*, 1983, 585.
696. S. Kano, Y. Yuasa, T. Yokomatsu, and S. Shibuya, *Heterocycles*, 1983, **20**, 2411.
697. A. R. Chamberlin, H. D. Nguyen, and J. Y. L. Chung, *J. Org. Chem.*, 1984, **49**, 1682.
698. A. R. Chamberlin and J. Y. L. Chung, *Tetrahedron Lett.*, 1982, **23**, 2619.
699. R. P. Polniaszek, S. E. Belmont, and R. Alvarez, *J. Org. Chem.*, 1990, **55**, 215.
700. A. R. Chamberlin and J. Y. L. Chung, *J. Am. Chem. Soc.*, 1983, **105**, 3653.
701. L. S. Hegedus and J. M. McKearin, *J. Am. Chem. Soc.*, 1982, **104**, 2444.
702. D. J. Hart and Y.-M. Tsai, *J. Am. Chem. Soc.*, 1984, **106**, 8209.
703. S. Kano, Y. Yuasa, K. Asami, and S. Shibuya, *Chem. Lett.*, 1986, 735.
704. C. Flann, T. C. Malone, and L. E. Overman, *J. Am. Chem. Soc.*, 1987, **109**, 6097.
705. L. E. Overman, T. C. Malone, and G. P. Meier, *J. Am. Chem. Soc.*, 1983, **105**, 6993.
706. A. Shirahata, T. Morohoshi, and K. Samejima, *Chem. Pharm. Bull.*, 1988, **36**, 3220.
707. K. Ramalingam, P. Nanjappan, D. M. Kalvin, and R. W. Woodard, *Tetrahedron*, 1988, **44**, 5597.
708. J. Mittendorf, H. Hiemstra, and W. N. Speckamp, *Tetrahedron*, 1990, **46**, 4049.
709. H. Hiemstra and W. N. Speckamp, *Tetrahedron Lett.*, 1983, **24**, 1407.
710. J.-C. Gramain and R. Remuson, *Tetrahedron Lett.*, 1985, **26**, 327.
711. Z.-K. Liao and H. Kohn, *J. Org. Chem.*, 1985, **50**, 1884.
712. T. Kametani, H. Yukawa, and T. Honda, *J. Chem. Soc., Chem. Commun.*, 1988, 685.
713. F. Hammerschmidt, *Justus Liebigs Ann. Chem.*, 1988, 537.
714. A. Ohta, Y. Aoyagi, Y. Kurihara, K. Huasa, and M. Shimazaki, *Heterocycles*, 1987, **26**, 3181.
715. A. Ohta, Y. Aoyagi, Y. Kurihara, K. Yuasa, and M. Shimazaki, *Heterocycles*, 1988, **27**, 437.
716. B. P. Wijnberg and W. N. Speckamp, *Tetrahedron Lett.*, 1981, **22**, 5079.
717. R. J. Miller, A. Kulipulos, and J. K. Coward, *J. Org. Chem.*, 1989, **54**, 3436.

718. T. Kametani, H. Yukawa, and T. Honda, *J. Chem. Soc., Perkin Trans. 1*, 1990, 571.
719. K. Shishido, Y. Sukegawa, K. Fukumoto, and T. Kametani, *Heterocycles*, 1985, **23**, 1629.
720. K. Shishido, Y. Sukegawa, K. Fukumoto, and T. Kametani, *J. Chem. Soc., Perkin Trans. 1*, 1987, 993.
721. S. Kano, Y. Yuasa, T. Yokomatsu, K. Asami, and S. Shibuya, *J. Chem. Soc., Chem. Commun.*, 1986, 1717.
722. H. Ent, H. de Konig, and W. N. Speckamp, *J. Org. Chem.*, 1986, **51**, 1687.
723. H. Ent, H. de Konig, and W. N. Speckamp, *Tetrahedron Lett.*, 1983, **24**, 2109.
724. G. Riggio, A. J. Raeber and W. H. Hopff, *Helv. Chim. Acta*, 1989, **72**, 1216.
725. S. Inoue, H. Takaya, K. Tani, S. Otsuka, T. Sato, and R. Noyori, *J. Am. Chem. Soc.*, 1990, **112**, 4897.
726. D. J. Hart and K. Kanai, *J. Org. Chem.*, 1982, **47**, 1555.
727. I. R. Trehan, G. L. Kad, S. Rani, and R. Bala, *Ind. J. Chem.*, 1985, **24B**, 659.
728. R. R. Bukownik and C. S. Wilcox, *J. Org. Chem.*, 1988, **53**, 463.
729. M. Kolb, J. Barth, J. G. Heydt, and M. J. Jung, *J. Med. Chem.*, 1987, **30**, 267.
730. D. J. Hart, *J. Org. Chem.*, 1981, **46**, 3576.
731. D. J. Hart and K. Kanai, *J. Am. Chem. Soc.*, 1983, **105**, 1255.
732. O. P. Vig, I. R. Trehan, G. L. Kad, and J. Ghose, *Ind. J. Chem.*, 1983, **22B**, 516.
733. O. P. Vig, I. R. Trehan, G. L. Kad, S. Kumari, and A. L. Bedi, *J. Ind. Chem. Soc.*, 1985, **62**, 238.
734. J. Mulzer, B. Buttelman, and W. Munch, *Justus Liebigs Ann. Chem.*, 1988, 445.
735. A. Morikawa, T. Sone, and T. Asano, *J. Med. Chem.*, 1989, **32**, 46.
736. P. Casara, C. Danzin, B. Metcalf, and M. Jung, *J. Chem. Soc., Perkin Trans. 1*, 1985, 2201.
737. P. Casara, C. Danzin, B. Metcalf, and M. Jung, *J. Chem. Soc., Chem. Commun.*, 1982, 1190.
738. L. Amariutet, G. Descotes, C. Kugel, J.-P. Maitre, and J. Mentech, *J. Carbohydr. Chem.*, 1988, **7**, 21.
739. S. Kano and Y. Yuasa, *Heterocycles*, 1983, **20**, 857.
740. C. K. Hiebert and R. B. Silverman, *J. Med. Chem.*, 1988, **31**, 1566.
741. J. N. Zonjee, H. de Konig, and W. N. Speckamp, *Tetrahedron*, 1989, **45**,

- 7553.
742. J. Y. L. Chung and J. T. Wasicak, *Tetrahedron Lett.*, 1990, **31**, 3957.
743. I. R. Trehan, R. L. Kaul, R. K. Sharma, and J. Singh, *Ind. J. Chem.*, 1982, **21B**, 197.
744. I. R. Trehan, R. Bala, D. K. Trikha, and J. Singh, *Ind. J. Chem.*, 1981, **20B**, 1022.
745. H. Ent, H. De Konig, and W. N. Speckamp, *Heterocycles*, 1988, **27**, 237.
746. S. Takano, Y. Iwabuchi, and K. Ogasawa, *J. Chem. Soc., Chem. Comm.*, 1988, 1527.
747. A. L. Castelhana and A. Krantz, *J. Am. Chem. Soc.*, 1987, **109**, 3491.
748. C. Danzin, P. Bey, D. Schirlin, and N. Claverie, *Biochem. Pharm.*, 1982, **31**, 3871.
749. I. R. Trehan, M. Vig, and K. Bala, *Ind. J. Chem.*, 1982, **21B**, 200.
750. S. Takano, M. Moriya, Y. Iwabuchi, and K. Ogasawara, *Tetrahedron Lett.*, 1989, **30**, 3805.
751. S. Takano, K. Inomata, T. Sato, M. Takahashi, and K. Ogasawara, *J. Chem. Soc., Chem. Commun.*, 1990, 290.
752. S. Kato, T. Morie, K. Hino, T. Kon, S. Naruto, N. Yoshida, T. Karasawa, and J. Matsumoto, *J. Med. Chem.*, 1990, **33**, 1406.
753. N. Yamazaki and C. Kibayashi, *J. Am. Chem. Soc.*, 1989, **111**, 1396.
754. D. A. Kendrick, C. Danzin, and M. Kolb, *J. Med. Chem.*, 1989, **32**, 170.
755. M. van Marsenille, C. Gysen, D. Tourwe, and G. van Binst, *Bull. Soc. Chim., Belg.*, 1986, **95**, 127.
756. S. Kano, Y. Yuasa, T. Yokomatsu, K. Asami, and S. Shibuya, *Chem. Pharm. Bull.*, 1988, **36**, 2934.
757. B. De, J. J. Plattner, E. N. Bush, H. S. Jae, G. Diaz, E. S. Johnson, and T. J. Perun, *J. Med. Chem.*, 1989, **32**, 2036.
758. S. Takano, M. Moriya, Y. Iwabuchi, and K. Ogasawara, *Chem. Lett.*, 1990, 109.
759. N. Saito, N. Kawakami, E. Yamada, and A. Kubo, *Chem. Pharm. Bull.*, 1989, **37**, 1493.
760. J. D. McChesney and S. Sarangan, *J. Label. Comp. Radiopharm.*, 1984, **21**, 293.
761. S. Kano, T. Yokomatsu, H. Nemoto, and S. Shibuya, *J. Org. Chem.*, 1986, **51**, 561.
762. S. Kano, T. Yokomatsu, H. Nemoto, and S. Shibuya, *Tetrahedron Lett.*, 1985, **26**, 1531.
763. S. Kano, T. Yokomatsu, H. Nemoto, and S. Shibuya, *Chem. Lett.*, 1986, 143.
764. I. R. Trehan, J. Singh, and K. Bala, *Ind. J. Chem.*, 1982, **21B**, 514.

765. S. Kano, T. Yokomatsu, H. Nemoto, and S. Shibuya, *J. Am. Chem. Soc.*, 1986, **108**, 6746.
766. G. E. Keck, E. J. Enholm, *Tetrahedron Lett.*, 1985, **26**, 3311.
767. E. Laborde, L. E. Lesheski, and J. S. Kiely, *Tetrahedron Lett.*, 1990, **31**, 1837.
768. S. Takano, S. Otaki, and K. Ogasawara, *J. Chem. Soc., Chem. Commun.*, 1983, 1172.
769. G. E. Keck, E. N. K. Cressman, and E. J. Enholm, *J. Org. Chem.*, 1989, **54**, 4335.
770. M. Gall and B. V. Kamdar, *J. Org. Chem.*, 1981, **46**, 1575.
771. M. Alpegiani, A. Bedeschi, E. Perrone, F. Zarini, and G. Franceschi, *Heterocycles*, 1988, **27**, 1329.
772. T. K. Chakraborty and S. P. Joshi, *Tetrahedron Lett.*, 1990, **31**, 2043.
773. M. Sendai, S. Hashiguchi, M. Tomimoto, S. Kishimoto, T. Matsuo, M. Kondo, and M. Ochiai, *J. Antibiotics*, 1985, **38**, 346.
774. N. Sakairi, M. Hayashida, A. Amano, and H. Kuzuhara, *J. Chem. Soc., Perkin Trans. 1*, 1990, 1301.
775. M. F. Farnum and J. P. Klinman, *Biochemistry*, 1986, **25**, 6028.
776. H. Iida, N. Yamazaki, and C. Kibayashi, *Tetrahedron Lett.*, 1985, **26**, 3255.
777. Y. Nishimura, W. Wang, S. Kondo, T. Aoyagi, and H. Umezawa, *J. Am. Chem. Soc.*, 1988, **110**, 7249.
778. A. B. Tabor, A. B. Holmes, and R. Baker, *J. Chem. Soc., Chem. Commun.*, 1989, 1025.
779. K.-H. Ongania and M. Wallnofer, *Arch. Pharm.*, 1985, **318**, 2.
780. A. B. Reitz, R. W. Tuman, C. S. Marchione, A. D. Jordan, Jr., C. R. Bowden, and B. E. Maryanoff, *J. Med. Chem.*, 1989, **32**, 2110.
781. A. Kubo, N. Saito, R. Yamauchi, and S. Sakai, *Chem. Pharm. Bull.*, 1987, **35**, 2158.
782. A. Kubo, N. Saito, H. Yamato, K. Masubuchi, and M. Nakamura, *J. Org. Chem.*, 1988, **53**, 4295.
783. C. S. Wilcox and M. D. Cowart, *Carbohydr. Res.*, 1987, **171**, 141.
784. S. Takano, S. Otaki, and K. Ogasawara, *Chem. Lett.*, 1983, 175.
785. N. Chida, Y. Furuno, and S. Ogawa, *J. Chem. Soc., Chem. Commun.*, 1989, 1230.
786. J. D. Rozzell, *Methods in Enzymology*, 1987, **136**, 479.
787. M. C. Viaud and P. Rollin, *Synthesis*, 1990, 130.
788. U. Schmidt, P. Gleich, H. Greisser, and R. Utz, *Synthesis*, 1986, 992.
789. J. F. Callahan, D. Ashton-Shue, H. G. Bryan, W. M. Bryan, G. D.

- Heckman, L. B. Kinter, J. E. McDonald, M. L. Moore, D. B. Schmidt, J. S. Silvestri, F. L. Stassen, L. Sulat, N. C. F. Yim, and W. F. Huffman, *J. Med. Chem.*, 1989, **32**, 391.
790. M. Otsuka, A. Kittaka, T. Iimori, H. Yamashita, S. Kobayashi, and M. Ohno, *Chem. Pharm. Bull.*, 1985, **33**, 509.
791. M. Bessodes, I. Abushanab, and K. Antonakis, *Tetrahedron Lett.*, 1984, **25**, 5899.
792. F. Hammerschmidt, *Justus Liebigs Ann. Chem.*, 1988, 955.
793. F. Hammerschmidt and H. Vollenkle, *Justus Liebigs Ann. Chem.*, 1989, 577.
794. S. Takano, T. Sugihara, S. Satoh, and K. Ogasawara, *J. Am. Chem. Soc.*, 1988, **110**, 6467.
795. B. T. Golding and C. Howes, *J. Chem. Res. (S)*, 1984, 1.
796. W. Schmid and E. Zbiral, *Monatsh. Chem.*, 1983, **114**, 1253.
797. B. T. Golding, M. C. O'Sullivan, and L. L. Smith, *Tetrahedron Lett.*, 1988, **29**, 6651.
798. A. Hassner and W. Dehaen, *J. Org. Chem.*, 1990, **55**, 2243.
799. J.-R. Schauder, S. Jendrzejewski, A. Abell, G. J. Hart, and A. R. Battersby, *J. Chem. Soc., Chem. Commun.*, 1987, 436.
800. H. Brunner, P. Hankofer, and B. Treitinger, *Chem. Ber.*, 1990, 1029.
801. S. Oida, A. Yoshida, T. Hayashi, N. Takeda, and E. Ohki, *Chem. Pharm. Bull.*, 1980, **28**, 3258.
802. Y. Masaki, Y. Serizawa, K. Nagata, H. Oda, H. Nagashima, and K. Kaji, *Tetrahedron Lett.*, 1986, **27**, 231.
803. D. F. Taber, P. B. Decker, H. M. Fales, T. H. Jones, and H. A. Lloyd, *J. Org. Chem.*, 1988, **53**, 2968.
804. A. P. Kozikowski and W. Tuckmantel, *Tetrahedron Lett.*, 1989, **30**, 4613.
805. S. De Bernardo, J. P. Tengji, G. Sasso, and M. Weigele, *Tetrahedron Lett.*, 1988, **29**, 4077.
806. H. H. Brandstetter, E. Zbiral, and G. Schulz, *Justus Liebigs Ann. Chem.*, 1982, 1.
807. W. H. Pearson and J. V. Hines, *J. Org. Chem.*, 1989, **54**, 4235.
808. K. Clinch, A. Vasella, and R. Schauer, *Tetrahedron Lett.*, 1987, **28**, 6425.
809. M. Nakano, S. Atsuumi, Y. Koike, S. Tanaka, H. Funabashi, J. Hashimoto, and H. Morishima, *Tetrahedron Lett.*, 1990, **31**, 1569.
810. S. H. Rosenberg, J. F. Dellaria, D. J. Dempf, C. W. Hutchins, K. W. Woods, R. B. Maki, E. de Lara, K. P. Spina, H. H. Stein, J. Cohen, W. R. Baker, J. J. Plattner, H. D. Kleinert, and T. J. Perun, *J. Med. Chem.*, 1990, **33**, 1582.
811. P. G. Mattingly and M. J. Miller, *J. Org. Chem.*, 1981, **46**, 1557.

812. H. Breuer, H. Straub, U. D. Treuner, J.-M. Drossand, H. Hohn, and K. R. Lindner, *J. Antibiotics*, 1985, **38**, 813.
813. C. Yoshida, K. Tanaka, J. Nakano, Y. Todo, T. Yamafuji, R. Hattori, Y. Fukuoka, and I. Saikawa, *J. Antibiotics*, 1986, **39**, 76.
814. G. Costerousse and G. Teutsch, *Tetrahedron*, 1986, **42**, 2685.
815. M. Shibuya, Y. Jinbo, and S. Kubota, *Chem. Pharm. Bull.*, 1984, **32**, 1303.
816. H. Yamada, H. Sugiyama, and M. Kajiwara, *Heterocycles*, 1987, **26**, 2841.
817. S. Thaisrivongs, H. J. Schostarez, D. T. Pals, and S. R. Turner, *J. Med. Chem.*, 1987, **30**, 1837.
818. D. P. Sahu, P. Mashava, M. S. Manhas, and A. K. Bose, *J. Org. Chem.*, 1983, **48**, 1142.
819. C. Gennari, G. Schimperna, and I. Venturini, *Tetrahedron*, 1988, **44**, 4221.
820. H. J. Schostarez, *J. Org. Chem.*, 1988, **53**, 3628.
821. C. K. Zercher and M. J. Miller, *Tetrahedron Lett.*, 1989, **30**, 7009.
822. B. M. Kim and K. B. Sharpless, *Tetrahedron Lett.*, 1990, **31**, 4317.
823. P. G. Mattingly and M. J. Miller, *J. Org. Chem.*, 1983, **48**, 3556.
824. A. Biswas, C. Eigenbrot, and M. J. Miller, *Tetrahedron*, 1986, **42**, 6421.
825. F. R. Atherton and R. W. Lambert, *Tetrahedron*, 1983, **39**, 2599.
826. W. A. Slusarchyk, J. Dejneka, E. M. Gordon, E. R. Weaver, and W. H. Koster, *Heterocycles*, 1984, **21**, 191.
827. E. M. Gordon, M. A. Ondetti, J. Pluscec, C. M. Cimarusti, D. P. Bonner, and R. B. Sykes, *J. Am. Chem. Soc.*, 1982, **104**, 6053.
828. A. Andrus, B. Partridge, J. V. Heck, B. G. Christensen, and J. P. Springer, *Heterocycles*, 1984, **22**, 1713.
829. C. Yoshida, K. Tanaka, R. Hattori, Y. Fukuoka, M. Komatsu, S. Kishimoto, and I. Saikawa, *J. Antibiotics*, 1986, **39**, 215.
830. C.-N. Hsiao, S. P. Ashburn, and M. J. Miller, *Tetrahedron Lett.*, 1985, **26**, 4855.
831. F. R. Atherton and R. W. Lambert, *Tetrahedron*, 1984, **40**, 1039.
832. W. V. Curran, A. A. Ross, and V. J. Lee, *J. Antibiotics*, 1988, **41**, 1418.
833. M. A. Williams and M. J. Miller, *Tetrahedron Lett.*, 1990, **31**, 1807.
834. C. C. Wei, S. De Bernardo, J. P. Teng, J. Borgese, and M. Weigele, *J. Org. Chem.*, 1985, **50**, 3462.
835. G. Costerousse, A. Cagniant, and G. Teutsch, *Bull. Chim. Soc., Fr.*, 1988, 151.
836. A. Andrus, B. Partridge, J. V. Heck, and B. G. Christensen, *Tetrahedron*

- Lett., 1984, **25**, 911.
837. D. W. Anderson, M. M. Campbell, and M. Malik, *Tetrahedron Lett.*, 1990, **31**, 1755.
838. J. F. Kadow, D. M. Vyas, and T. W. Doyle, *Tetrahedron Lett.*, 1989, **30**, 3299.
839. K. Ramasamy, R. K. Olsen, and T. Emery, *J. Org. Chem.*, 1981, **46**, 5438.
840. M. L. Edwards, D. M. Stemerick, and J. R. McCarthy, *Tetrahedron Lett.*, 1990, **31**, 3417.
841. P. H. J. Carlsen and O. R. Gautun, *Acta Chem. Scand.*, 1990, **44**, 485.
842. D. L. Boger, R. S. Coleman, and B. J. Invergo, *J. Org. Chem.*, 1987, **52**, 1521.
843. C. G. Overberger and J. Y. Chang, *Tetrahedron Lett.*, 1989, **30**, 51.
844. R. W. Feenstra, E. H. M. Stokkingreef, R. J. F. Nivard, and H. C. J. Ottenheijm, *Tetrahedron*, 1988, **44**, 5583.
845. B. H. Lee and M. J. Miller, *J. Org. Chem.*, 1983, **48**, 24.
846. K. Nakajima, M. Morishita, and K. Okawa, "Peptide Chem. 1983," (Ed. E. Munkata), Protein Research Foundation, Osaka, 1984, pp. 77–80.
847. K. Minamoto, K. Azuma, T. Tanaka, H. Iwasaki, S. Eguchi, S. Kadoya, and R. Moroi, *J. Chem. Soc., Perkin Trans. 1*, 1988, 2955.
848. H. Bottcher and B. Arzt, *Angew. Chem., Int. Ed. Engl.*, 1984, **23**, 518.
849. H. J. Bestman and D. Roth, *Angew. Chem., Int. Ed. Engl.*, 1990, **29**, 99.
850. D. L. Boger and R. S. Coleman, *J. Org. Chem.*, 1986, **51**, 3250.
851. D. L. Boger and R. S. Coleman, *J. Am. Chem. Soc.*, 1987, **109**, 2717.
852. V. E. Marquez, C. K. H. Tseng, S. P. Treanor, and J. S. Driscoll, *Nucleosides, Nucleotides*, 1987, **6**, 239.
853. B. H. Lee, G. J. Gerfen, and M. J. Miller, *J. Org. Chem.*, 1984, **49**, 2418.
854. D. H. Boschelli, *Synth. Commun.*, 1988, **18**, 1391.
855. J. W. Hertel, C. S. Grossman, J. S. Kroin, S. Mineishib, S. Chubb, B. Nowak, and W. Plunkett, *Nucleosides, Nucleotides*, 1989, **8**, 951.
856. E. K. Dolence, A. A. Minnick, and M. J. Miller, *J. Med. Chem.*, 1990, **33**, 461.
857. T. H. Kim and H. Rapoport, *J. Org. Chem.*, 1990, **55**, 3699.
858. R. C. Bernotas, *Tetrahedron Lett.*, 1990, **31**, 469.
859. R. A. Bell and H. N. Hunter, *Tetrahedron Lett.*, 1987, **28**, 147.
860. P. Rollin, *Tetrahedron Lett.*, 1986, **27**, 4169.
861. K. Kpegba and P. Metzner, *Synthesis*, 1989, 137.
862. J. L. Adams, T. D. Meek, S.-M. Mong, R. K. Johnson, and B. W. Metcalf, *J. Med. Chem.*, 1988, **31**, 1355.

863. S. J. Gee, T. Miyamoto, M. H. Goodrow, D. Buster, and B. D. Hammock, *J. Agric. Food Chem.*, 1988, **36**, 863.
864. Y. Hidaka and Y. Shimonishi, *Bull. Chem. Soc., Jpn.*, 1989, **62**, 1986.
865. R. E. Dolle, C.-S. Li, and A. N. Shaw, *Tetrahedron Lett.*, 1989, **30**, 4723.
866. I. D. Jenkins and S. Thang, *Aust. J. Chem.*, 1984, **37**, 1925.
867. H. Takahata, E. Ohkura, K. Ikuro, and T. Yamazaki, *Synth. Commun.*, 1990, **20**, 285.
868. S. E. Hall, W.-C. Han, D. N. Harris, A. Hedberg, and M. L. Ogletree, *J. Med. Chem.*, 1989, **32**, 974.
869. I. Fuji, R. Kiyama, K. Kanematsu, *Biorg. Chem.*, 1989, **17**, 240.
870. K. Kanematsu, T. Yoshiyasu, and M. Yoshida, *Chem. Pharm. Bull.*, 1990, **38**, 1441.
871. M. F. Cabal, R. S. Coleman, and S. J. Danishefsky, *J. Am. Chem. Soc.*, 1990, **112**, 3253.
872. J. N. Haseltine and S. J. Danishefsky, *J. Org. Chem.*, 1990, **55**, 2576.
873. R. Breslow, J. Chmielewski, D. Foley, B. Johnson, N. Kumabe, M. Varney, and R. Mehra, *Tetrahedron*, 1988, **44**, 5515.
874. D. R. Compton, P. J. Little, B. R. Martin, J. K. Saha, J. Gilman, H. Sard, and R. K. Razdan, *Eur. J. Med. Chem.*, 1989, **24**, 293.
875. T. W. Ku, K. H. Kondrad, and J. C. Gleason, *J. Org. Chem.*, 1989, **54**, 3487.
876. G. A. Flynn, *J. Org. Chem.*, 1983, **48**, 4125.
877. M. Nakata, M. Arai, K. Tomooka, N. Ohsawa, and M. Kinoshita, *Bull. Chem. Soc., Jpn.*, 1989, **62**, 2618.
878. P. A. Wender and N. C. Ihle, *J. Am. Chem. Soc.*, 1986, **108**, 4678.
879. D. P. Curran and P. A. van Elburg, *Tetrahedron Lett.*, 1989, **30**, 2501.
880. M. Georges, D. MacKay, and B. Fraser-Reid, *Carbohydr. Res.*, 1984, **130**, 115.
881. J. R. Dormoy and B. Castro, *Synthesis*, 1986, 81.
882. Y. Chapleur, F. Germain, A. Aubry, and D. Bayeul, *J. Carbohydr. Chem.*, 1984, **3**, 443.
883. H. Kunz and J. Weissmuller, *Justus Liebigs Ann. Chem.*, 1984, 66.
884. J. P. Schaumberg, G. C. Hokanson, J. C. French, E. Smal, and D. C. Baker, *J. Org. Chem.*, 1985, **50**, 1651.
885. G. I. Georg and J. Kant, *J. Org. Chem.*, 1988, **53**, 692.
886. I. Zbiral, H. H. Brandstetter, and E. P. Schreiner, *Monatsh. Chem.*, 1988, **119**, 127.
887. F. Freeman and K. D. Robarge, *Carbohydr. Res.*, 1987, **171**, 1; 1988, **29**, 6797.