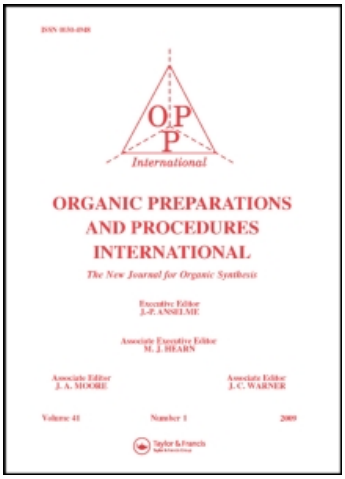

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INTRODUCTION

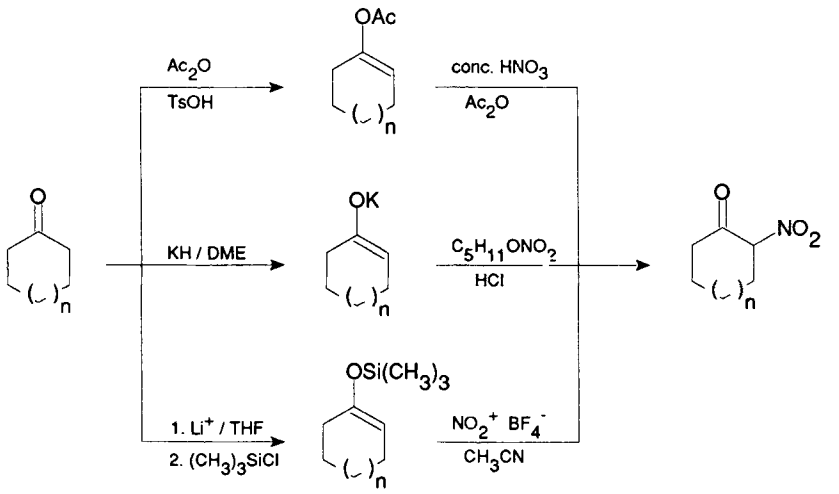
Among the many interesting developments in the field of synthetic methodology of the past years, the use of nitro compounds in organic synthesis is experiencing a burst of activity. It is now over a decade since the appearance of the bench mark review article by Seebach *et al.*[1] on the vast preparative potential of aliphatic nitro compounds and the efforts to develop efficient syntheses and utilizations of functionalized aliphatic nitro compounds have continued with increasing success. More recently, several excellent reviews appeared concerning the chemistry of nitroalkanes.[2-7] In 1988, we published a review devoted to the utilization of functionalized nitroalkanes as useful reagents for alkyl anion synthons and their applications in synthesis.[8] However, Seebach's review on nitroalkanes dates back to 1979 and in addition the article of Fisher and Weitz[9] deals with the preparations and reactions of cyclic ketones only. The principal aim of this report is to describe the recent progress in the preparation of nitroketones and in their utilization in interesting synthetic routes. We also would like to demonstrate the great versatility of nitroketones. They may provide viable, and occasionally superior, means of arriving at functionalized materials which could lead to increased use in organic synthesis.

I. PREPARATION OF NITROKETONES

The considerable versatility of nitroketones has increased their utilization in organic synthesis, so that many methods are appeared in the last years for their preparation, especially for the functionalized ones.

1. Cyclic α-Nitroketones

The preparation, chemical properties, and reactions of cyclic α-nitroketones have been reviewed.[9] The α-nitrocycloalkanones are prepared mainly from:

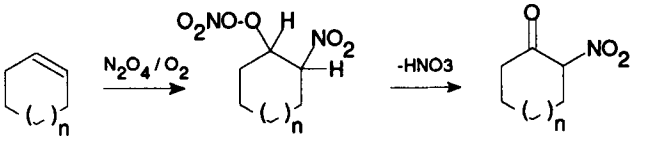


Scheme 1

(i) cycloalkanones (Scheme 1) by nitration of the corresponding enol acetate with nitric acid,[10-13] by nitration of the potassium enolate with pentyl nitrate,[14,15] or by nitration of the silyl enol ether with nitronium tetrafluoroborate;[12,16]

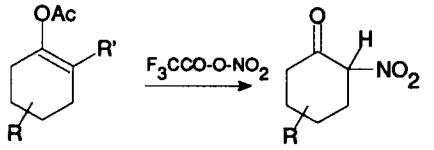
(ii) cycloalkenes by reaction with dinitrogen tetroxide[17-21] (Eq. 1).

In addition, a few examples of α-nitrocycloalkanones, obtained by intramolecular cyclization reactions, are known.[22-24]



(1)

Later Dampawan and Zajac[25] reported the synthesis of 2-alkyl-2-nitrocyclohexanones by nitration of the corresponding enol acetate under mild conditions, using trifluoroacetyl nitrate, generated from trifluoroacetic anhydride and ammonium nitrate (Eq.2).



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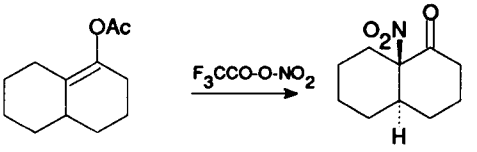
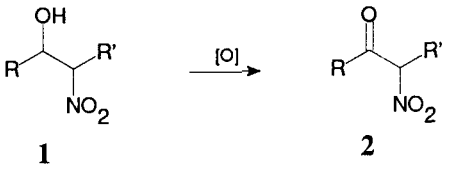


2. Non-Cyclic α-Nitroketones

The importance of non-cyclic α-nitroketones as synthetic intermediate has been demonstrated by the many efforts devoted, in the last few years, to improve their synthesis. The most widely employed methods to obtain these compounds are: (i) oxidation of 2-nitroalkanols (Eq.3) and, (ii) C-acylation of nitroalkanes (Eq.4).

In the past, these oxidations were normally carried out by treatment of the alcohols **1** with chromium trioxide[26,27] or sodium dichromate[27-29] in strong acid (Eq.3). However, these severe conditions frequently gave low yields, and acid-labile protecting groups present in the molecule did not survive. In the 1983, we reported a mild method for



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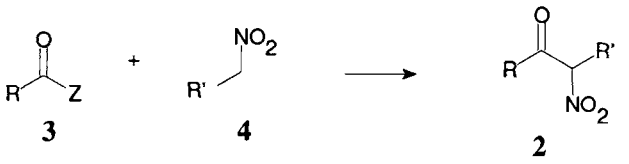
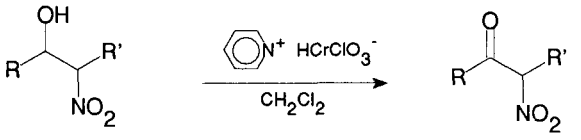


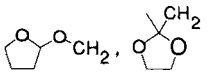
3 4 2 (4)

the oxidation of 2-nitroalkanols **1** to α-nitroketones **2** (Eq.5) using pyridinium chlorochromate (PCC),[30] in dichloromethane, as oxidant.

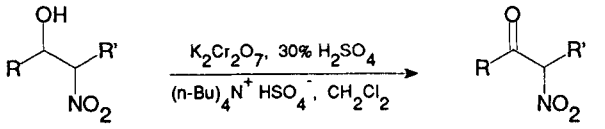


1 **2** (61-87%) (5)

R = CH_3, i-C_3H_7, $PhCH_2CH_2$, C_6H_{11}

R' = C_2H_5, CH_3, $CH_3OCOCH_2CH_2$, 

The oxidation proceeded smoothly even in the presence of acid-labile groups but long reaction times were necessary (34-36 hrs). This drawback was overcome by applying the phase-transfer technique.[31] The typical reaction was carried out by slow addition, at -10°, of potassium dichromate or potassium chromate and 30% sulfuric acid to a solution of 2-nitroalkanols and tetra-n-butylammonium hydrogen sulfate (0.1 mol per mol of nitro alcohol) in dichloromethane (Eq.6). In general, the reactions proceed to completion within 2 hrs. Under these conditions, acid-labile protecting groups are retained and good yields of α-nitroketones are obtained. Furthermore, a one-pot synthesis has been developed consisting of a solvent-free nitro-aldol reaction (Eq.7) on alumina followed by in situ oxidation under phase-transfer conditions.

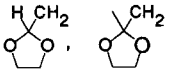


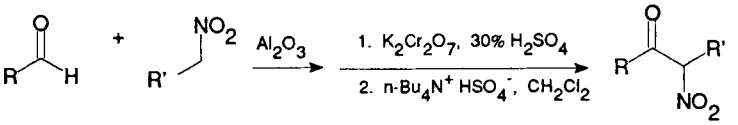
1 2

(68-95%) (6)

R = CH_3, i-C_3H_7, n-C_6H_{13}, CH_2=$CHCH_2CH_2$, $PhCH_2CH_2$

R' = C_2H_5, CH_3, $CH_3OCOCH_2CH_2$,

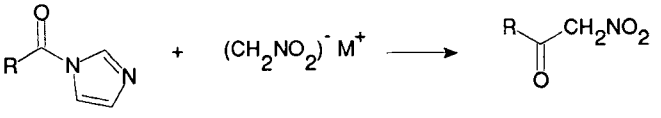




(82-93%) (7)

Historically, the C-acylation of nitroalkanes **4** to produce α-nitroketones **2** has been carried out with limited success. In 1903 Gabriel reported a poor yield of the α-nitroketone from the reaction of phthalic anhydride with sodium methanenitronate.[33] Other applications of this process using either acyl halides, anhydrides, or activated esters have proved the reaction to be of little synthetic value.[34] In the 1978 Seebach[35] devised the use of doubly metalated complex $[R\text{-}C{=}NO_2]^{2-}$ $2Li^+$ for the reaction with electrophiles. These dianions were generated at -90° and furnished α-nitroketones in fair to good yields when esters or acid chlorides were used as acceptors.

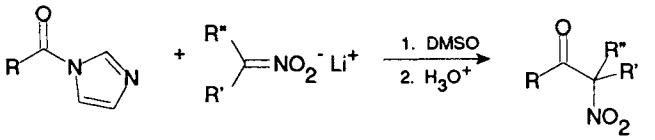
Later, the preparation of α-nitroketones via a direct acylation of sodium or potassium methanenitronate with the appropriate N-acylimidazole was reported[36] (Eq. 8). A more



(8)

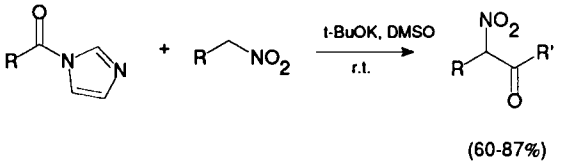
complete procedure was described by Mosher and coworkers[37] based on acylation of a dimethylsulfoxide solution of the lithium salt of nitroalkane, [previously prepared and

stored in the "dry form"] with acylimidazoles (Eq.9). Very recently Ono *et al.*[38] have developed a procedure by which it is possible to overcome the tedious and time con-



(9)

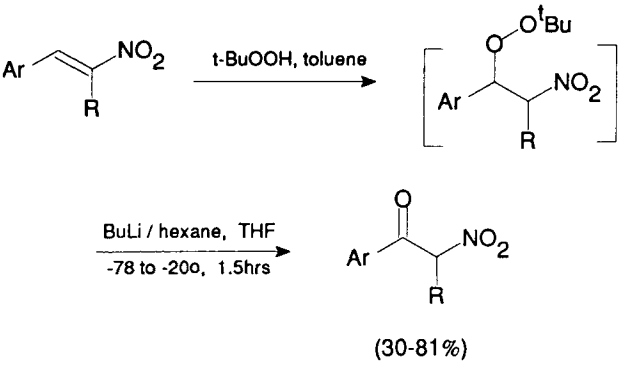
suming utilization of the "dry form" of lithium nitronate. In this method the potassium salt, prepared in situ (Eq.10) by treatment of nitro compounds with potassium t-butoxide



(10)

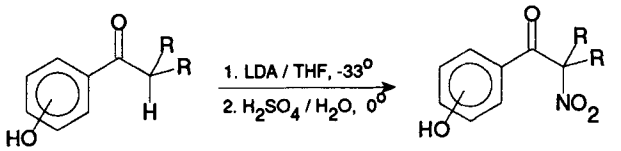
in dimethylsulfoxide, is sufficiently reactive to give the α-nitroketones in good yields with acylimidazoles.

The search for novel procedures to prepare α-nitroketones continues as these compounds gain in importance. Several methodologies have been devised recently: these include the preparation of aryl nitromethyl (and 1-nitroalkyl) ketones by the oxidation of β-nitrostyrene, using lithium tert-butyl hydroperoxide[39a] (Eq. 11) and the synthesis



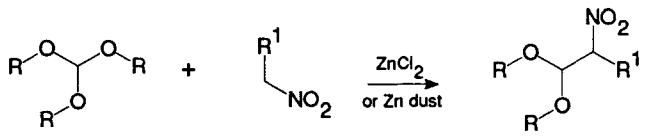
(11)

of 1-nitroalkyl hydroxyphenylketones from phenolic alkyl ketones[39b] (Eq.12). Rene and Royer[40] proposed a new way to obtain nitroacetaldehyde dialkylacetals, by reaction of



(12)

alkyl orthoformates with an excess of nitroalkanes in the presence of zinc chloride (Eq.13).

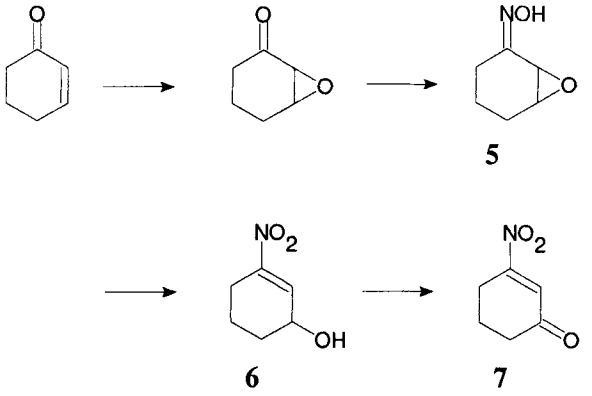


(13)

3. Synthesis of β-Nitroketones

Since nitroalkanes are versatile building blocks and intermediates and, functionalized aliphatic nitro compounds are often required, β-nitroketones play an important role in this context. Corey *et al.*[41a] reported a practical synthesis of 3-nitrocycloalkenones and their utilization as dienophiles in the Diels-Alder reaction. 3-Nitro-2-cyclohexenone (**7**) was prepared in 65% overall yield from 2-cyclohexenone (Eq.14). Oxidation of the epoxy oxime **5** with trifluoroperacetic acid afforded the nitro alcohol **6** in high yield which, upon oxidation either with pyridinium chlorochromate or chromic acid-sulfuric acid, gave the β-nitro enone **7**; a modified synthesis of **7** has been reported.[41b]

β-Nitro carbonyl compounds can be prepared by the Miyakoshi[42] procedure (Eq. 15) starting from alkyl vinyl ketones. The vinyl ketones were allowed to react in situ with sodium nitrite-acetic acid in THF for 18 hrs at room temperature. Good results were



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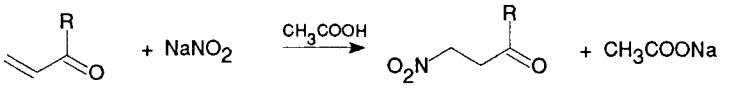
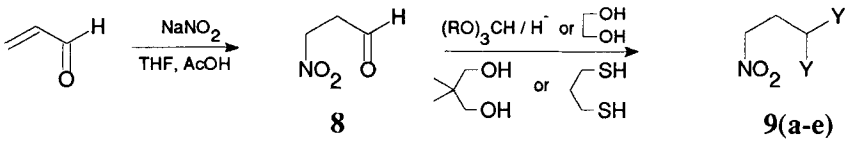


(42-82%)

(15)

R = CH_3, C_2H_5, $(CH_3)_2CH$, $CH_3(CH_2)_2$, $CH_3(CH_2)_3$, $CH_3(CH_2)_5$.

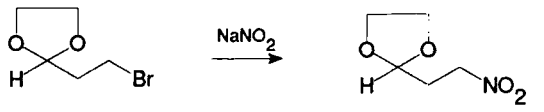


(62-100%)

9	Y	Y
a	OCH_3	OCH_3
b	OC_2H_5	OC_2H_5
c	$O(CH_2)_2O$	
d	$OCH_2C(CH_3)_2CH_2O$	
e	$S(CH_2)_3S$	

(16)

obtained generally using this approach. The preparation of 3-nitropropanal **8** and its acetal **9** has been described[43] (Eq. 16) using a 1.25:1.25:1 ratio of sodium nitrite-acetic acid-acrolein, at 0° for 3 hrs, with stirring. 3-Nitropropanal **8** was obtained pure in 70-80% yield. The derivatives **9a-e** were obtained using this standard procedure; the synthesis of acetal **9c** had been previously reported by nitration of 2-(2-bromoethyl)-1,3-dioxolane **10** with sodium nitrite in DMF (Eq.17)[44] or by reaction with nitrite anion

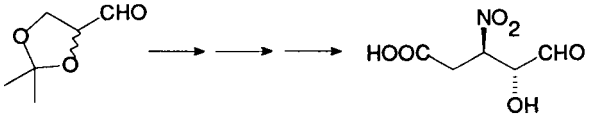


(17)

10 **9c**

bonded to a macroporous quaternary ammonium Amberlite resin.[45]

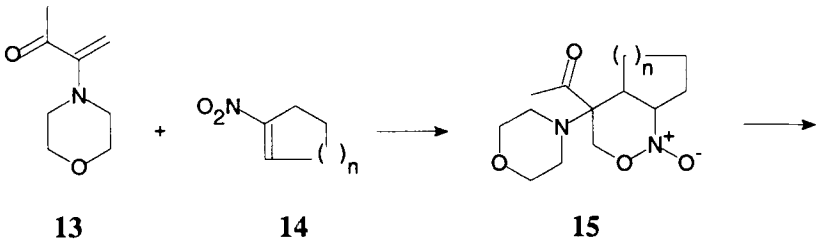
β-Nitroketones were prepared in several different additional ways: Mosher,[46] for instance, described the synthesis of chiral **12** (Eq.18) starting from 2,3-O-isopropylidene-



(18)

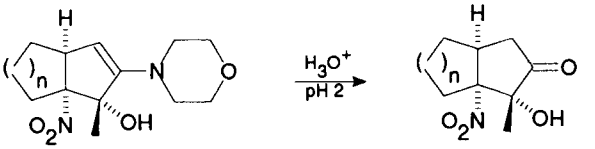
11 **12**

D-gliceraldehyde **11**. Pitacco and coworkers[47] reported the synthesis of β-nitroketones **17** by reaction of ketoenamin **13** (Eq.19) with 1-nitrocycloalkenes (**14**). The N-oxide system **15** was obtained as a labile intermediate that easily underwent rearrangement to the hexahydroindene derivative **16**. Successively, hydrolysis of **16** at pH 2 afforded the β-nitroketone **17**. Allylic nitroolefins constitute other source of β-nitroketones.[48] Eq.20 illustrates the sequence by which epoxynitro compounds were obtained from the corresponding allylic nitro compounds with m-CPBA and treatment of epoxynitro compounds with a catalytic amount of Et_3N, immediately led to the formation of γ-hydroxy-α-nitroolefins. Subsequent heating resulted in the isomerization of the double bond and, finally oxydation with PCC gave the α-(nitroalkyl)enones **18**.

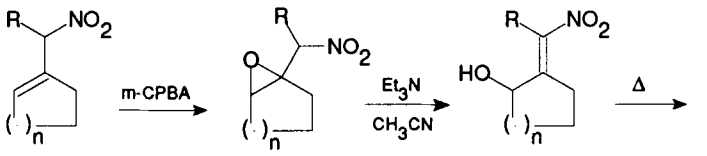


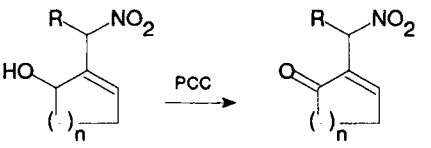
13 14 15

(19)



16 17





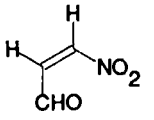
18

(20)

An enantioselective synthesis of cyclohexenyl nitroaldehydes **19-21** has been effected, via Diels-Alder reaction of 2,3-dimethylbutadiene with sugar nitroolefins as chiral dienophiles[49] followed by oxidative cleavage with sodium metaperiodate.

4. Synthesis of γ-Nitroketones

It is well known that nitroalkanes undergo base-catalyzed 1,4-addition to various α,β-unsaturated carbonyl compounds. These reactions are typically run as homogeneous



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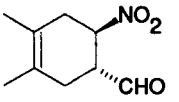

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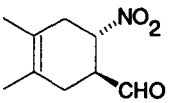

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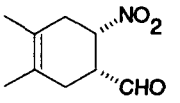

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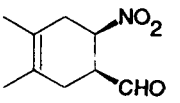
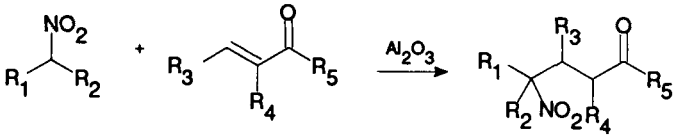


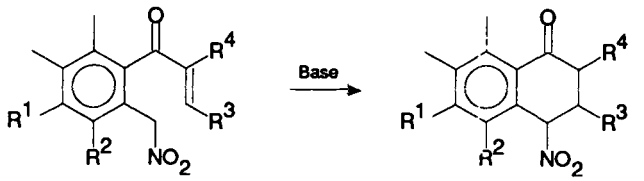
21b

solutions of the reactants in an organic solvent using soluble organic bases such as tetramethylguanidine,[50] potassium fluoride/18-crown-6,[51] sodium hydride / 18-crown-6,[52] diisopropylamine,[49b,52] tri-n-butylphosphine,[54] tetrabutylammonium fluoride.[52] We reported an efficient heterogeneous procedure for the preparation of 4-nitroketones and 4-nitroaldehydes from nitroalkanes and α,β-unsaturated carbonyl compounds (Eq.21).[57] The utilization of basic alumina as support for potassium fluoride, with THF



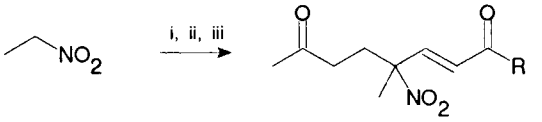
(52-73%) (21)

as solvent, gave the Michael addition products in good yields.[58a] An intramolecular Michael reaction in the presence of DBU in boiling ethanol or with KF/alumina in THF at room temperature[58b,c] has also been used to prepare 4-nitro-1-tetralones (Eq.22).



(22)

The synthesis of tertiary allylic nitrodicarbonyl compounds, by a double 1,4-addition of primary nitroalkanes to electron-deficient acetylenes and alkenes in the presence of potassium fluoride and tetrabutylammonium chloride in dimethylsulfoxide, has been described recently (Eq. 23).[59]



(23)

Reagents: i. KF, Bu_4NCl; ii. $HC{\equiv}CCOR$; iii. $H_2C{=}CHCOMe$

The combined use of n-Bu_4NF catalysis and high pressure led to successful Michael additions also in the case in which difficulties arise from the steric hindrance caused by substituents in the proximity of the Michael donor reaction center.[60a]

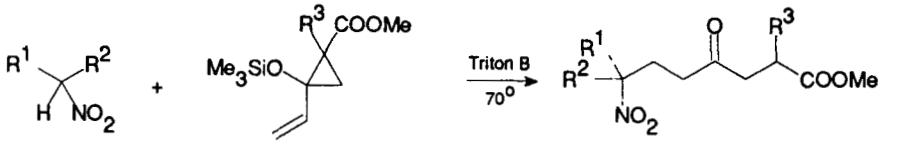
During the study of asymmetric Michael addition of nucleophiles to enones, the addition of nitromethane to chalcone was investigated under high-pressure conditions (Eq. 24).[60b] Although the reaction did not take place at atmospheric pressure it proceeded

$$MeNO_2 + PhCH{=}CHCOPh \xrightarrow{Base} PhCH(CH_2NO_2)CH_2COPh \qquad (24)$$

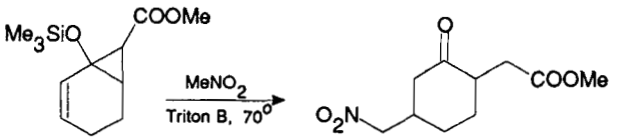
well by the action of quinine (QN) and quinidine (QD) under high-pressure, QD being more effective in asymmetric induction.

Another source of γ-nitroketones are the 2-alkenyl-substituted methyl 2-siloxycyclopropanecarboxylates, easily available from the corresponding silyl enol ethers, which act as masked vinyl ketones. In fact, the addition of nitroalkanes to vinyl silyloxycyclopropanes, catalyzed by Triton B, afforded γ-nitroketones in good yields[61] as shown in Eqs.25 and 26.

α,β-Unsaturated nitroalkenes themselves have been used as acceptors to prepare γ-nitroketones. Quantitative conjugate addition of 2-methyl-1,3-cyclalkanedione (**22**) to 2-methyl-2-nitropropene (**23**) in the presence of catalytic amounts of n-Bu_3P (ace-

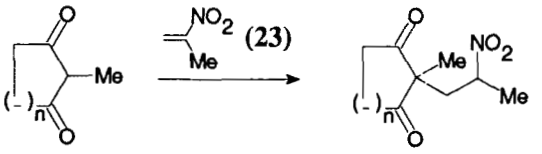


(67-91%) (25)



(26)

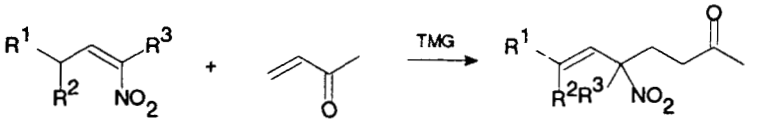
tonitrile, 10hrs) was reported (Eq. 27).[62] In the same way, γ-nitroketones have been



(27)

22 **24** (100%)

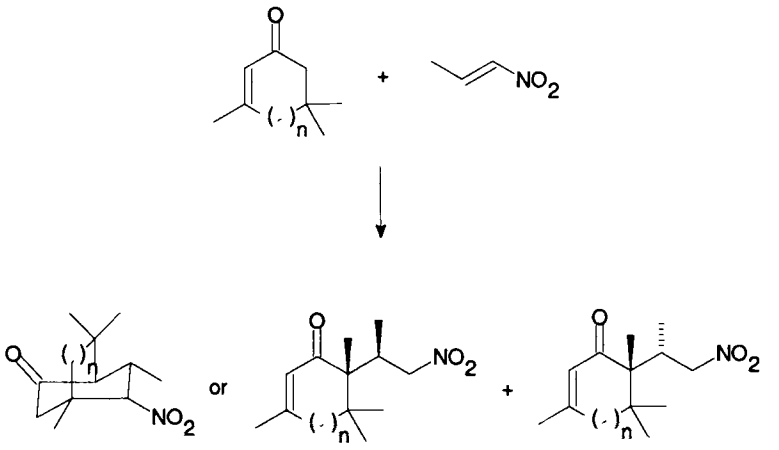
prepared from sugar nitro-olefins and 1,3-dienones.[63] The Michael addition of allylic nitro compounds to electron-deficient olefins, such as α,β-unsaturated ketones in CH_3CN and tetramethylguanidine (TMG) (0.1 eq.) has been described as an efficient method to prepare, δ,ε-unsaturated γ-nitroketones (Eq. 28).[64] The formation of three



(56-71%) (28)

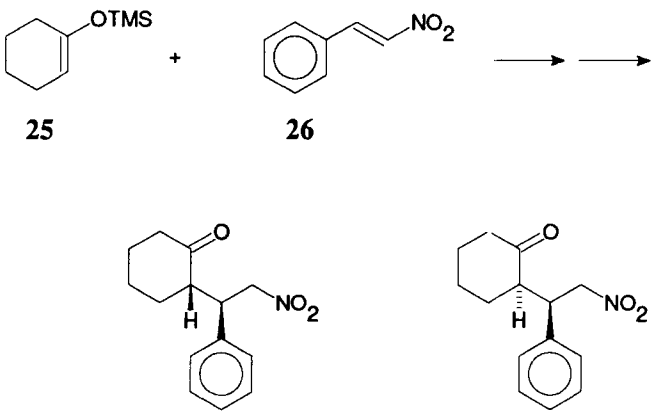
kinds of adducts was observed during the studies of Cory *et al.*[65] concerning the bicycloannulation of α-cyclohexenones and α-cyclopentenones with nitroalkenes in the presence of hexamethylphosphoramide (Eq.29).

Seebach and Brook[66] found that three equivalents of dichloro (diisopropoxy)titanium $(i\text{-}PrO)_2TiCl_2$, induced the stereoselective addition of 1-(trimethylsiloxy)cyclohexene



(29)

(**25**) to β-nitrostyrene (**26**) to give three cyclic nitronic esters which, after hydrolysis, led the nitroketones **27a** and its epimer **27b** (Eq.30).

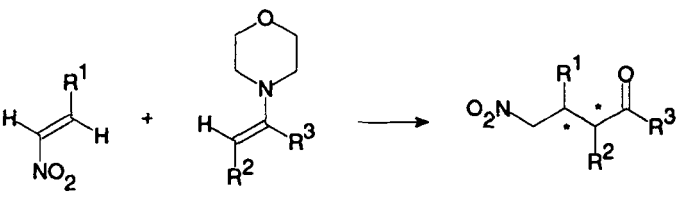


25 **26**

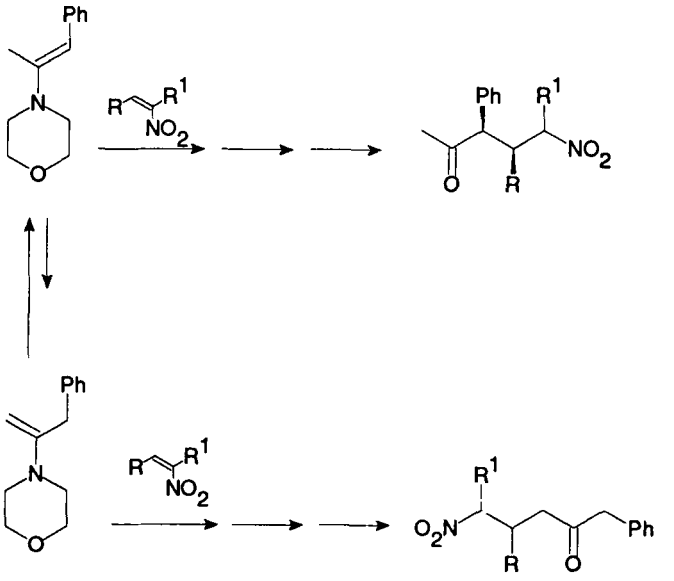
(30)

27a **27b**

The general reactivity of cycloenamines with conjugated nitroalkenes was studied by Valentin, Risaliti and coworkers.[67] In the 1981, Seebach and Golinski[68] reported the reaction of open-chain nitroolefins with open-chain enamines to give γ-nitroketones of 90-99% diastereomeric purity (Eq.31). More recently, carbo- and heterocyclization reactions of 2-(4-morpholinyl)-1-phenylpropene and α-nitroolefins have been studied by Valentin and coworkers.[69] These enamines (Eq.32) existing in two double bond isomers,

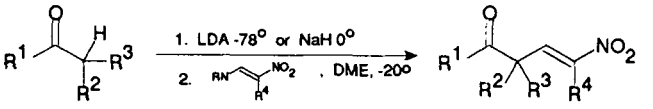


(31)



(32)

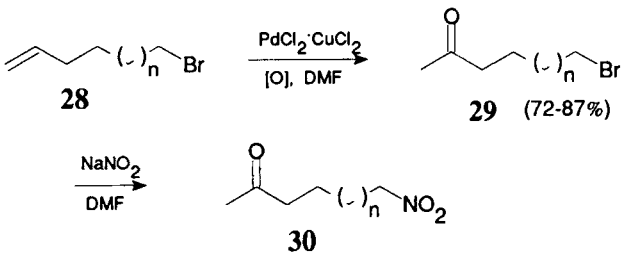
reacted with a series of nitroolefins under different conditions to afford, after hydrolysis, regioisomeric γ-nitroketones. Another route to γ-nitroketones utilizes the reaction of ketone enolates with nitro enamines[70] (Eq. 33). The geometry of the corresponding nitroolefins proved to be of the *E* type.



(33)

5. Synthesis of Other Nitroketones

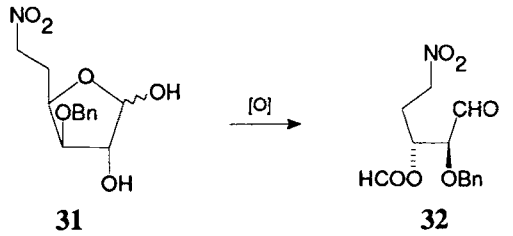
Nitroketones other than α-nitroketones are of less interest. However, functionalized aliphatic nitro compounds are sometimes required and some nitroalkanes with a carbonyl group in a remote position, have been synthetized for this purpose (Eq. 34).[70a] Conver-



(34)

n = 1, 3, 6.

sion of terminal alkenes **28** to carbonyl compounds **29** with palladium(II) chloride-copper(II)chloride/benzoquinone[71] followed by displacement of bromine with sodium nitrite in dimethylformamide (DMF), the nitroketones **30** in 63-75% yields.[72] During the synthesis of a chiral prostaglandin synthon,[70b] the interesting 5-nitroaldehyde **32** was prepared by oxidative cleavage at the C(1)-C(2) bond of 6-nitrofuranoside **31** (Eq.35).

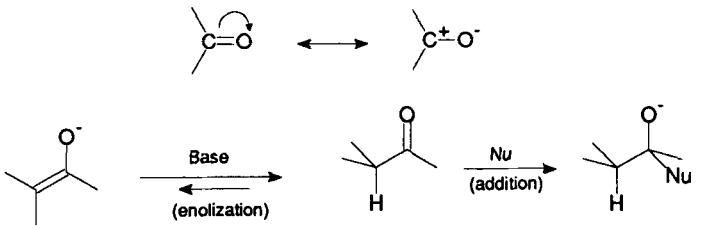


(35)

II. REACTIVITY OF NITROKETONES

1. The Reactivity of Isolated Nitro and Carbonyl Groups

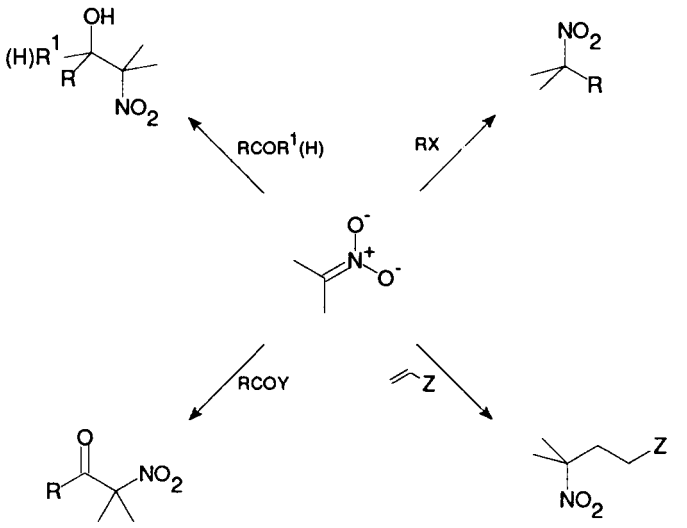
The nitroketones combine in the same molecule two important and very different functionalities. By far the most heavily exploited of the functional group is the carbonyl function. It serves as a model for the reactions of all functionalities with π bonds between dissimilar atoms. Furthermore, its modes of reaction are basically simple, but they are very versatile in terms of synthetic utility. Carbonyl reactivity is predicated on the electron imbalance in the π bond between carbon and the more electronegative oxygen, as illustrated below.



Scheme 2

The carbonyl dipole can do two things in the presence of a nucleophile/base: (i) it can enolize by removal of the α-hydrogen or (ii) be attacked directly by a nucleophile in a nucleophilic addition.

On the other hand, a nitro group acts as a strong electron-withdrawing group and activates a neighboring carbon-hydrogen bond for reaction with alkyl bromides or iodides, carbonyl compounds (Henry reaction), activated derivatives of carboxylic acids and with activated alkenes to afford, respectively, homologated nitroalkanes, 2-nitroalkanols, α-nitroketones and functionalized nitroalkanes (Scheme 3). The carbon atom bearing a nitro group can be considered as a potential nucleophile. Primary and secondary nitroalkanes are powerful synthetic tools because the carbon-carbon bond-forming processes[1] of such derived species as nitronate mono- and dianions,[35,73,74]



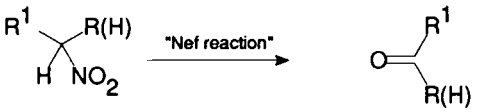
X = Halogens

Y = Imidazole

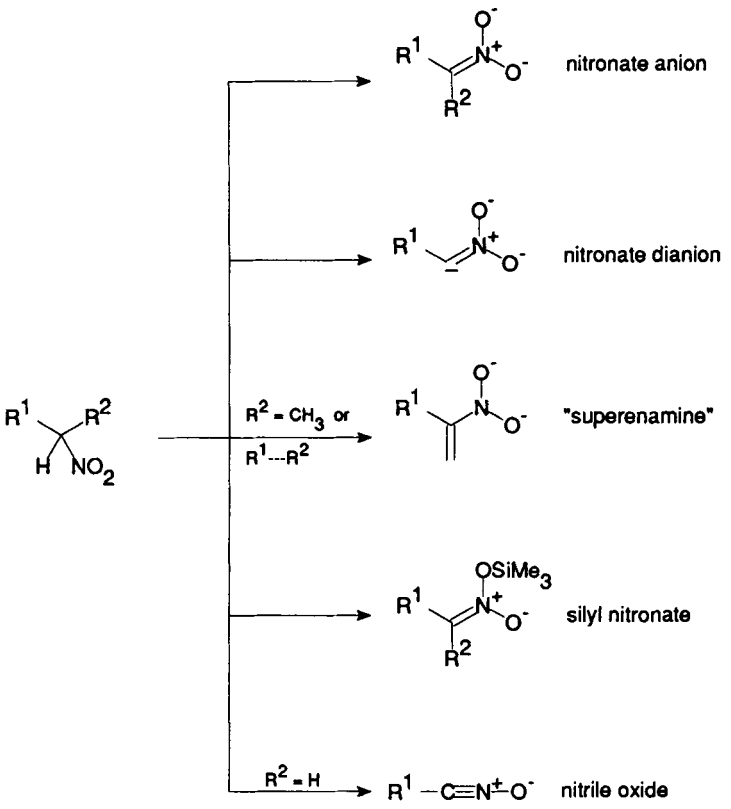
Z = COR, CHO, COOR, CN, SO, SO_2

Scheme 3

silylnitronates,[75,76] nitrile oxides,[77] and N,N-bis(lithioxy)enamines[78] (superenamines) are classical chain-lengthening reactions (Scheme 4, see next page). Moreover, aliphatic nitro compounds play an important role in the interconversion of organic functional groups; they can be converted to amines,[79] amides, hydroxylamines, nitrones, azido-sulfones[80] and sulfides.[81] One of the early transformations of the nitro group, was its conversion into a carbonyl group discovered by Nef in 1894. However, the classical Nef reaction is an acidic method, which is often incompatible with the presence of other functionalities, so several modifications have been devised (Eq.36).[82] Recent routes in-



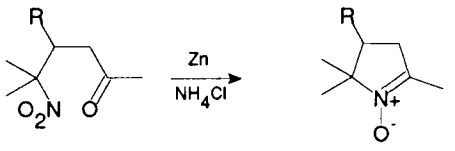
(36)



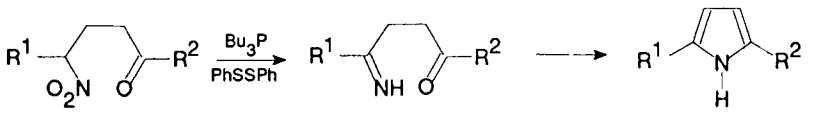
Scheme 4

clude oxidizing or reducing agents, ozonolysis of nitronates, neutral conditions or electrochemical systems.[8,82c]

Nitroketones contain two carbon atoms of different polarity: the electrophilic carbonyl carbon and the carbon bearing the nitro group which is available as a potential nucleophile (by removal of the proton). In addition, the nitro group itself can be converted into a nucleophile. These two groups when suitably located can undergo intramolecular reactions to give heterocyclic compounds. The synthesis of cyclic nitrones by reduction of γ-nitroketones[83] (Eq.37) and the preparation of pyrroles[86] (Eq. 38) exemplify the application of this concept. γ-Nitroketones also serve as precursors for the synthesis of 1,4-diketones, which are valuable intermediates for further elaboration into either furan

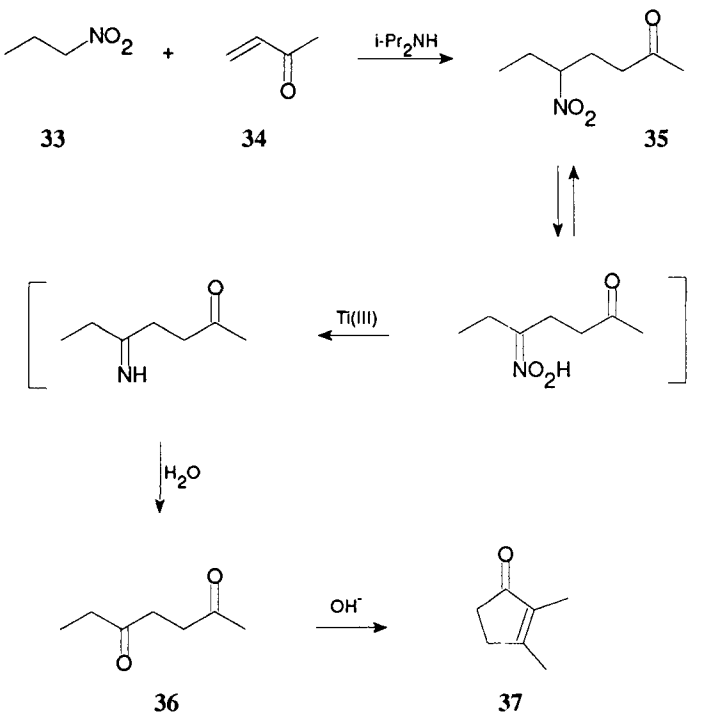


(37)



(38)

or cyclopentenone systems. For this purpose, Mc Murry and Melton[87] proposed the sequence reported in Eq.39.

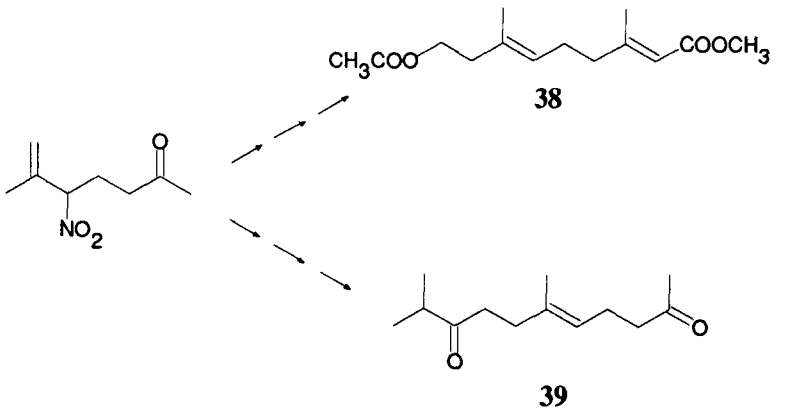


(39)

5-Nitroheptan-2-one (**35**) was prepared in 75% yield from 1-nitropropane (**33**) and methyl vinyl ketone (**34**) in the presence of diisopropylamine. The addition of an aqueous solution of four equiv. of fresh titanium trichloride in glyme at room temperature afforded 2,5-heptanedione (**36**) in 85% yield; base-catalyzed cyclization gave the

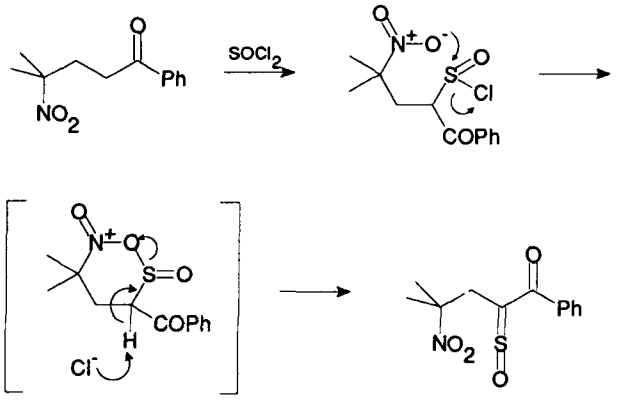
cyclopentenone **37**. A modification to this method has been reported by Clarck and Cork.[88]

Other utilizations of γ-nitroketones were reported by Ono[89] for the synthesis of terpenoids **38** and **39** via palladium-catalyzed allylilation of allylic γ-nitrocompounds (Eq.40).



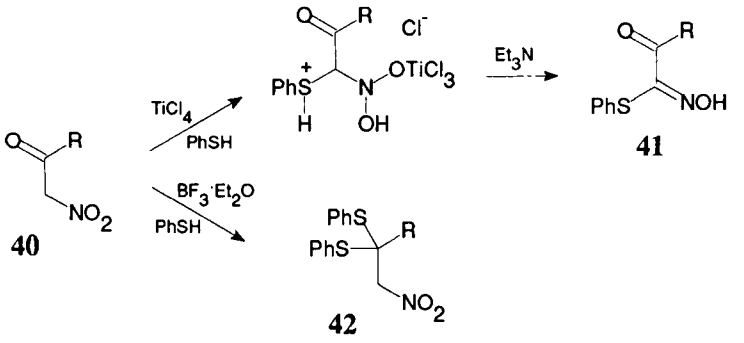
(40)

Interestingly, upon treatment of γ-nitroketones with thionyl chloride α-sulfinyl ketones[90] were obtained (Eq.41).



(41)

The dual reactivity of nitroketones was pointed out by Jung and coworkers[91] in the reaction of α-nitroketones with thiophenol (Eq.42). Treating α-nitroketones **40** with thiophenol and titanium tetrachloride in the presence of triethylamine, gave phenyl N-



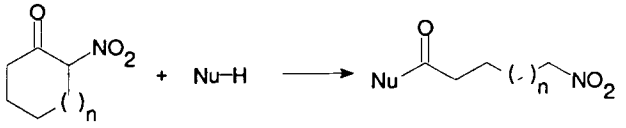
(42)

hydroxy-2-oxoalkanimido thioates **41**, while the same α-nitroketones in the presence of boron trifluoride gave thioketals **42** in excellent yields.

2. Reactivity of α-Nitroketones

Given the well known chemical differences of the carbonyl group and the carbon-nitro group moiety, their juxtaposition on two adjacent positions offers a new reactivity pattern, peculiar to α-nitroketones.In fact, α-nitrocycloalkanones and open-chain α-nitroketones have different reactivities and are utilized differently.

The synthetic utility of α-nitrocycloalkanones has been reviewed.[9] The C-C bond between the carbonyl group and the nitro substituted atom of cyclic α-nitroketones undergoes facile cleavage by nucleophilic agents under mild conditions. This retro-Claisen is useful for the synthesis of open-chain, α,ω-disubstituted compounds, which are difficult to prepare by other methods (Eq.43). Many of these reactions have carried

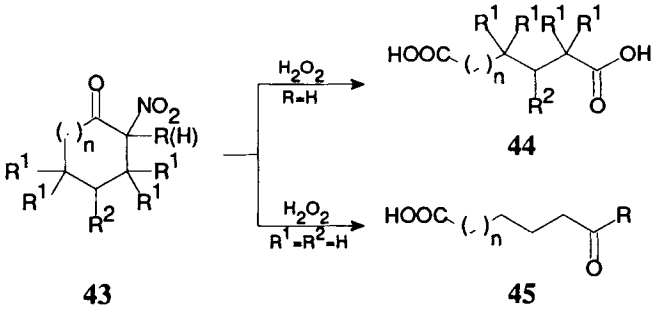


(43)

Nu = OH, OR, NH_2, RNH, RS.

out with water, alcohols, ammonia, thioalcohols, and amines under basic catalysis, to provide ω-nitrocarboxylic acids and its derivatives.[92-95] Cyclic α-nitroketones can also

be cleaved under acidic conditions.[96] Recently, we reported a new method for the oxidative ring-opening of these compounds under mild conditions. α-Nitrocycloalkanones **43**, treated for 8-10 hrs with 30% hydrogen peroxide and potassium carbonate in methanol, were smoothly converted into dicarboxylic acids **44** or ketoacids **45**, depending on whether the nitro group is secondary or tertiary (Eq. 44). The reaction proceeded

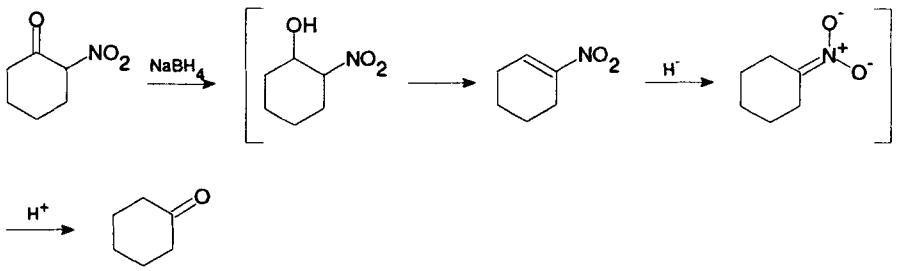


43 **44** **45** (44)

n = 0, 1, 2, 3, 7.

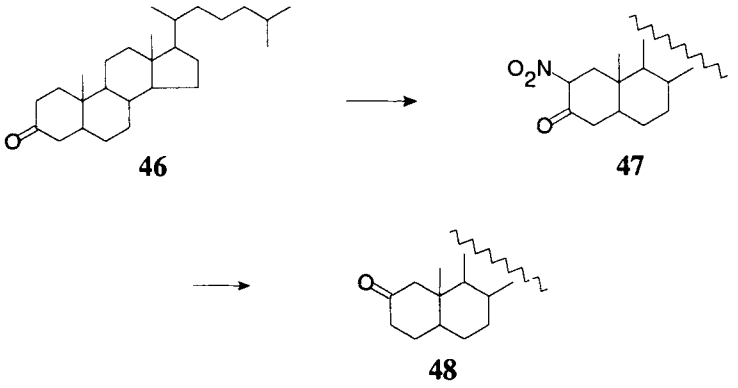
at room temperature, thus minimizing oxidative side-reactions. The products were obtained pure, requiring no additional purification.

In synthetic work, it is often desirable to shift the position of a carbonyl in cyclic systems by one carbon atom. 2-Nitrocycloalkanones, prepared by nitration of some cyclic ketones,[10-16] have been used for this purpose.[98] Reduction of these compounds with sodium borohydride leads to 2-nitroalcohols, nitroolefins, or nitroalkanes, which in turn can be converted to ketones by various methods (Eq.45). In this manner, cholestan-3-one



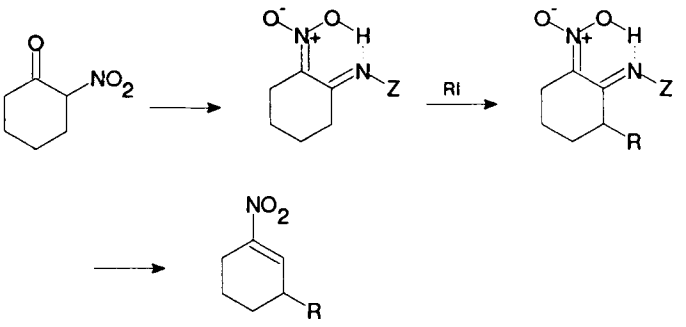
(45)

46 was converted into cholestan-2-one (**48**) via 2-nitrocholestan-3-one (**47**) (Eq.46). α-Nitrocycloalkanones are also, important precursors for the synthesis of 3-substituted



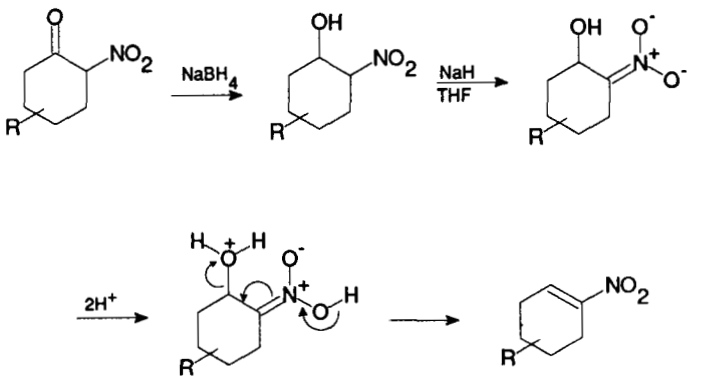
(46)

1-nitrocycloalkenes.[99] They were first converted into either α-nitro N,N-dimethylhydrazones or α-nitro cyclohexylimines, which exist exclusively in the *aci*-nitro form. Double deprotonation of these materials with sec-BuLi, produced highly reactive dianions which underwent alkylation by alkyl iodides in excellent yields (Eq.47).



(47)

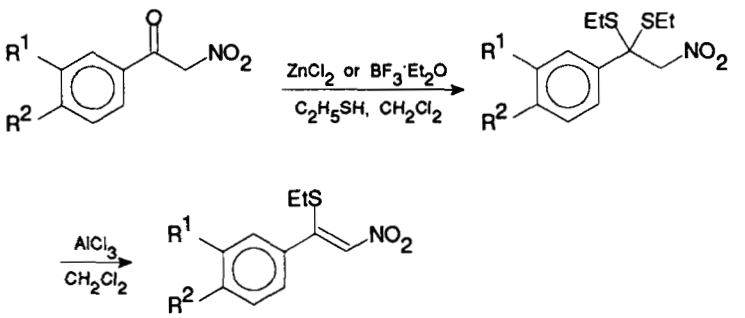
The reduction of α-nitrocyclohexanones to the 2-nitrocyclohexanols with sodium borohydride, followed by treatment of the β-nitroalcohols with sodium hydride and subsequent acidification of the salts was reported to give conjugate nitrohexenes regioselectively (Eq.48).[100] This sequence reaction is part of the overall process designed by Hassner *et al.*[98] for the transposition of a carbonyl group to an adjacent



(48)

position. However, by using excess BH_4^-, the isolation of the -nitroalcohol or nitroalkenes was precluded.

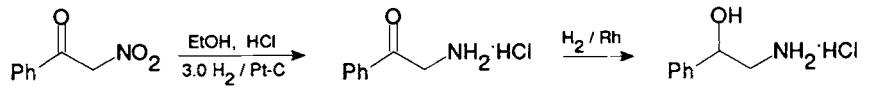
Aromatic nitromethyl ketones have been used as precursors of 1-ethylthio-2-nitroolefins[101] (Eq. 49). Lewis acids such as zinc chloride or boron trifluoride, in the presence



(49)

of ethanethiol converted these nitroketones into their S,S-diethyl thioacetals. Treatment of these compounds with aluminum chloride in dichloromethane, leads to the elimination of one molecule of ethanethiol to give the corresponding 1-ethylthio-2-nitro-1-arylethylene.

A new reductive method for selective conversion of α-nitroketones **49** to α-aminoketones hydrochlorides **50** has been reported[102] (Eq.50). Hydrogenation of **49** with 5% Pt-C afforded α-aminoketone hydrochloride **50** in 63% yield albeit with the formation of a small amount of β-amino alcohol hydrochloride **51**, the use of a Pt catalyst deac-

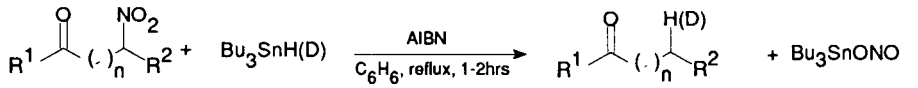


(50)

tivated by a sulfur compound (5% Pt-C) completely suppressed the formation of **51** and gave **50** chemoselectively and quantitatively. However, **50** can be converted into **51** by hydrogenation in the presence of a Rh complex.[103]

3. Denitration Reactions

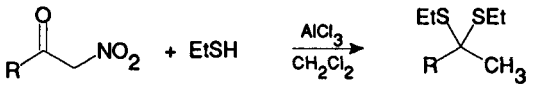
The nitro group of nitroketones may be converted into other functional groups. However, the full utilization of these compounds has, until recently, been limited because there was no method which led the replacement of the nitro group by hydrogen. In 1981 Ono *et al.*[104] discovered that tin hydrides are excellent reagents for denitrohydrogenation reactions (Eq.51). Thus, the nitro group in tertiary nitro compounds and some secondary nitro compounds, has been replaced by hydrogen or deuterium in good



(51)

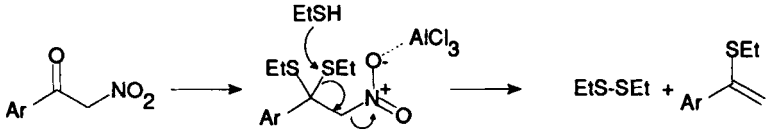
n = 0, 1, 2, ...

yields. Bu_3SnH selectively replaces the nitro group with hydrogen, without affecting other functionalities such as keto, ester, cyano, chloro, or organic sulfur groups. The reaction proceeds very slowly in the absence of azobisisobutyronitrile (AIBN) and it is inhibited by the addition of only small amounts of a strong electron acceptor like m-dinitrobenzene. Replacement of the nitro group by hydrogen, in primary α-nitroketones has been realized on treatment with ethanethiol in the presence of aluminum chloride (Eq.52).[105] This system seems to be specific to primary α-nitroketones. A possible mechanism involves an ionic process according to the Eq.53. Later we developed a new

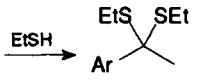


(52)

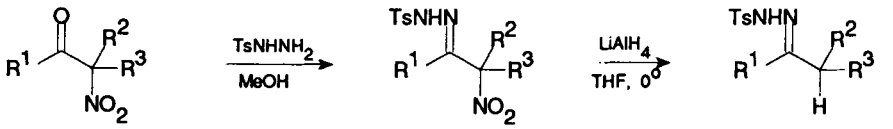
and efficient procedure for the hydrodenitration of α-nitroketones by treatment of their tosylhydrazones with lithium aluminum hydride in dry THF, at 0° (Eq.54).[106a] Our



(53)

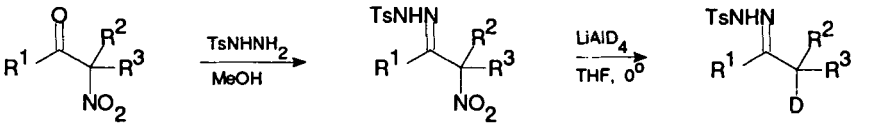


method gave a high yield of denitrated product and proved to be very efficient for secondary and tertiary nitro derivatives. The tosylhydrazones obtained are in general,

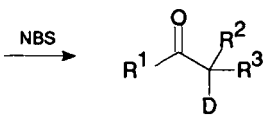


(54)

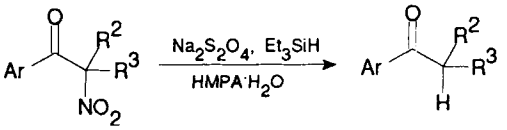
crystalline derivatives, so that it is possible to purify the product by simple crystallization. On the other hand, tosylhydrazones may be easily cleaved to afford the corresponding ketones.[107,108] These results led us to develop a new indirect method for the regiospecific C-deuteration of alkylketones[106b] (Eq.55) by using lithium aluminum deuteride.



(55)

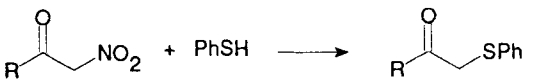


The Ono group has continued its studies on denitrohydrogenation methodologies and recently discovered a procedure effective for aromatic α-nitroketones[109] (Eq. 56). This



(56)

reductive removal of the nitro group has been performed by using $Na_2S_2O_4$-Et_3SiH in HMPA-H_2O; keto, ester, and cyano groups are not affected under these conditions. The nitro group in position to a carbonyl group, can indeed be replaced by the arylthio group under neutral conditions (Eq.57).[110] In a typical procedure, a mixture of nitro



(57)

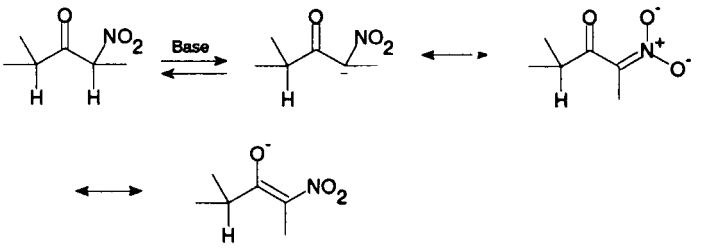
compound, benzenethiol and azoiisobutyronitrile in hexamethylphosphoramide afforded the thio substituted product in satisfactory yields at 90° for 1 hr. These results increase substantially the synthetic value of nitroketones.

Recently, we have shown[8] the sequence nitroaldol reaction, oxidation and successive denitrohydrogenation of the resulting α-nitroketones to be a useful chain-lenghtening procedure for the synthesis of many classes of natural products like jasmonoid, prostaglandin intermediates, and pheromones.

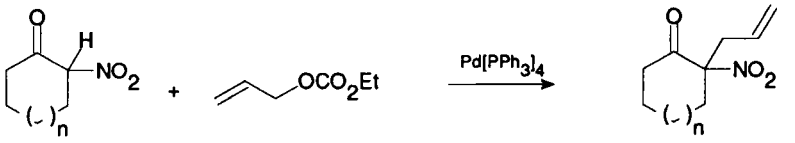
4. α-Nitroketones as Nucleophiles

As would be expected the α-hydrogen of primary or secondary α-nitroketones exhibits enhanced acidity with respect to that of nitroalkanes or carbonyl compounds. This is due to the converging electron-withdrawing action of the nitro and carbonyl groups on the same carbon atom which permits a better stabilization of the conjugate

anion. This effect combined with the possible replacement of the nitro group by hydrogen, allows the regioselective alkylation of ketones.



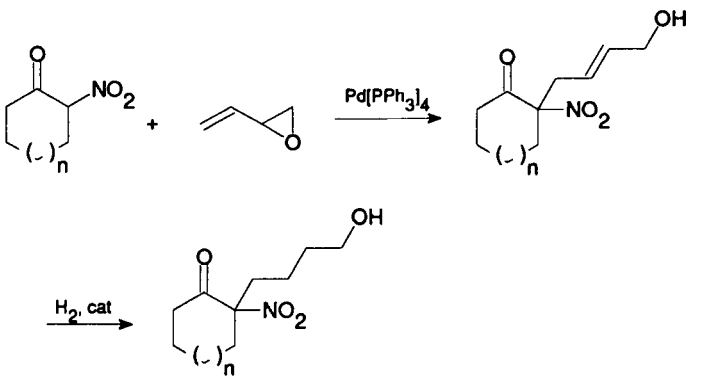
Ognyanov and Hesse [111] found that 2-nitrocycloalkanones smoothly reacted with allyl carbonate in the presence of 0.25 mol % tetrakis(triphenylphosphine)palladium to give the corresponding 2-alkyl substituted 2-nitrocycloalkanones in high yields (Eq. 58).



(58)

n = 1, 6.

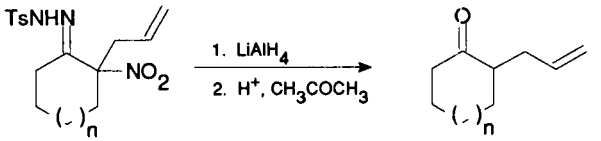
One year lather Hesse[112] reported the alkylation of 2-nitrocycloalkanones with vinyloxirane, catalyzed by $Pd[PPh_3]_4$ (Eq.59), followed by catalytic hydrogenation. In



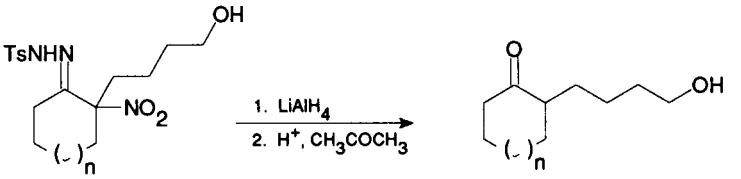
(59)

n = 1, 2, 3, 7.

both cases, the tosylhydrazones of the alkylated products could be reductively denitrated[113] with lithium aluminum hydride (Eqs.60-61).[106a] Ono[114] discovered a new

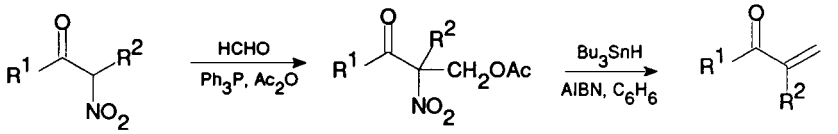


(85-94%) (60)



(83-96%) (61)

reaction of α-nitroketones with 37%-formaldehyde in the presence of catalytic amount of Ph_3P, for the regioselective synthesis of α-methylene carbonyl compounds (Eq. 62).

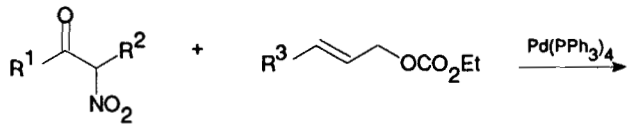


(62)

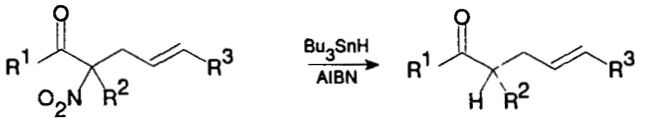
α-Nitroketones have been regioselectively allylated with allylic carbonate, in the presence of a palladium (0) catalyst, and subsequent denitration with Bu_3SnH[115] (Eq.63). Moreover, Michael addition of α-nitroketones to methyl vinyl ketone or acrylaldehyde, followed by hydrodenitration with Bu_3SnH, afforded 1,5-dicarbonyl compounds in good yield (Eq.64).[116]

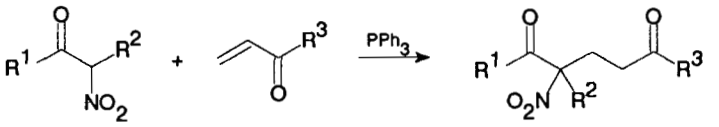
5. Ring Expansion of α-Nitroketones (The "Zip Reaction")

While cleavage of the C(1)-C(2) bond of α-nitroketones by an external nucleophiles has been extensively studied (see above, sec.2), the possibility of cyclic 2-nitroketones

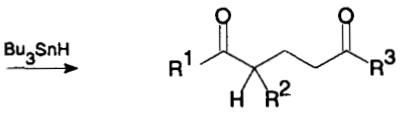


(63)

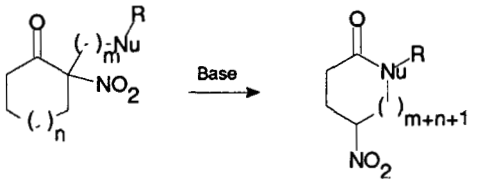




(64)

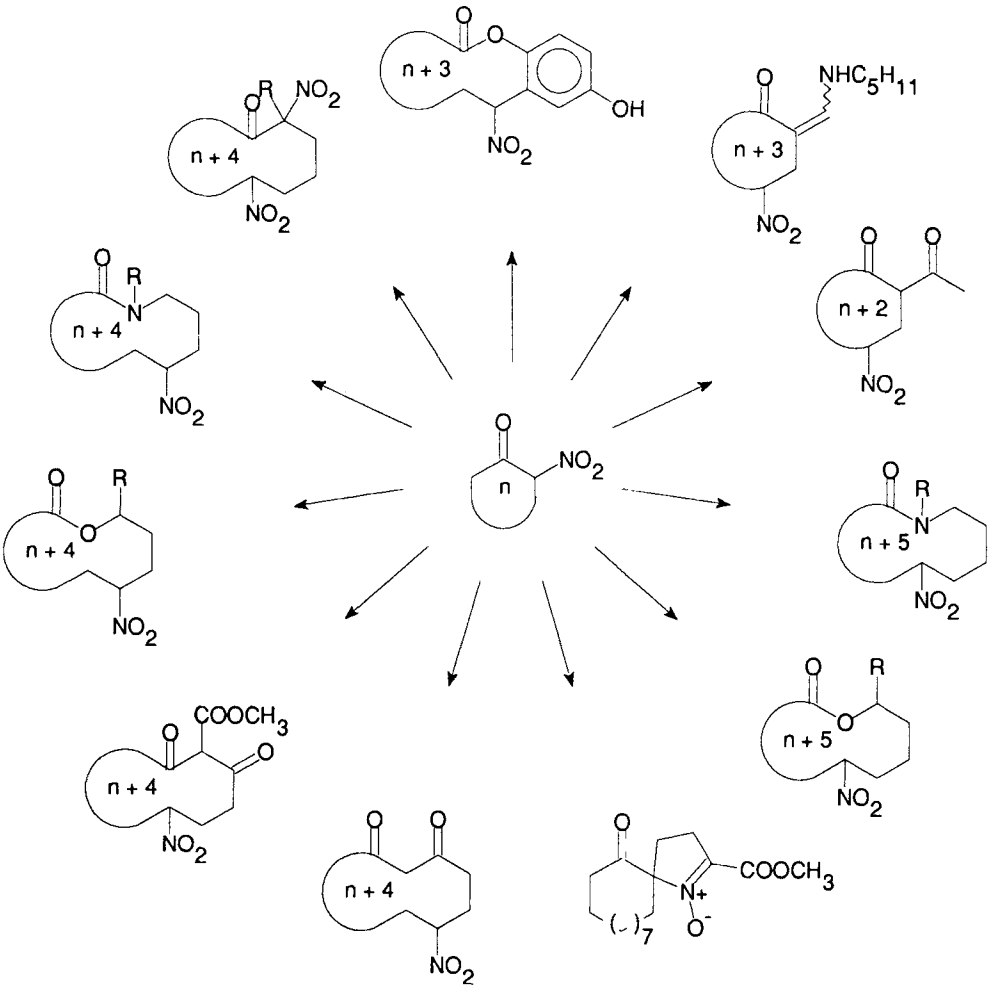


to react with internal nucleophile to give macrocyclic compounds by ring enlargement, has greatly improved the synthetic utility of this class of compounds (Eq.65). Many



(65)

internal nucleophiles, such as active methylene groups, alcohols, amines, and enamines have been utilized and the results obtained are reported in a recent review by Hesse and Stach who have devised an incisive name: "The Zip Reactions" for these processes.[117,118] Thus, by the zip reactions two, three, four or five carbon atoms, respectively, can be incorporated to the pre-existent cyclic system, and the principal macrocyclic synthetized compounds are listed in the Scheme 5.



CONCLUSIONS

Although nitroketones have been studied from some time, intense interest in these compounds has only arisen over the past 20 years. The aim of our review is to demonstrate how nitroketones can be obtained by several and simple ways and to illustrate the facile and useful transformations of nitroketones into various functionalized systems. We believe that the easily accessibility of nitroketones and their great versatility makes

this class of compounds quite modern and useful precursors and intermediates in the synthesis of complex molecules. It is hoped that our survey will trigger further work to broaden the utilization of these very important compounds.

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REFERENCES

1. D. Seebach, E. W. Colvin, F. Lehr and T. Weller, Chimia, 31, 1 (1979).
2. A. Yoshikoshi and M. Miyiashita, Acc. Chem. Res., 18, 384 (1985).
3. A. G. M. Barrett and G. G. Graboski, Chem. Rev., 86, 751 (1986).
4. R. S. Varma and G. W. Kabalka, Heterocycles, 24, 2645 (1986).
5. G. W. Kabalka and R. S. Varma, Org. Prep. Proc. Int., 19, 283 (1987).
6. N. Ono and A. Kaji, Synthesis, 693 (1986).
7. W. R. Bowman, Chem. Soc. Rev., 17, 283 (1988).
8. G. Rosini and R. Ballini, Synthesis, 833 (1988).
9. R. H. Fisher and H. M. Weitz, ibid., 261 (1981).
10. D. Sheehan and A. F. Vellturo, African Patent 6,705,789 (1968), C.A., 70, 57261 (1969).
11. H. Ozbal and W. W. Zajac Jr., J. Org. Chem., 46, 3082 (1981).
12. (a) P. Dampawan and W. Zajac jr., ibid., 47, 1176 (1982). (b) F. Elfehail, P. Dampawan and W. Zajac jr., Synth. Commun., 10, 929 (1984).
13. R. Ballini and P. Sorrenti, Org. Prep. Proc. Int., 16, 289 (1984).
14. H. Fever and P. M. Pivawer, J. Org. Chem., 31, 3152 (1966).

15. F. E. Elfehail and W. Zajac jr., ibid., 46, 5151 (1981).

16. I. S. Shvarts *et al.*, Izv. Akad. Nauk. SSSR, Ser. Kim. 1674 (1976); C.A., 85, 176926 (1976).

17. D. R. Lac Wicz, T. S. Simmons and K. L. Kreuz, U.S. Patent 3,466,326 (1969), Texaco Inc; C.A., 71, 101323 (1969).

18. H. Andrews, British Patent 1,240,836 (1971), Imperial Chemical Ind.; C.A., 75, 118039 (1971).

19. W. Voskuil, Dutch Patent 8275 (1970), Stamicarbon N.V.; C.A., 76, 85458 (1972).

20. S. Yamada, H. Sasak and T. Tanaka, German Auslegeschrift (DAS) 2,210,344 (1974), Toyo Soda Man. Co.; C.A., 78, 4737 (1973).

21. P. M. Pivawer, German Auslegeschrift (DAS) 1964964 (1972), Olin Corp.; C.A., 73, 98486 (1970).

22. H. H. Baer and S. R. Naik, J. Org. Chem., 35, 2927 (1970).

23. J. Skramstad, Tetrahedron Lett., 955 (1970).

24. J. Schneider, E. L. Evans and R. I. Fryer, J. Org. Chem., 37, 2604 (1972).

25. P. Dampawan and W. Zajac jr., Synthesis, 545 (1983).

26. K. Seler, Israel J. Chem., 4, 7 (1966); C.A., 66, 28479 (1967).

27. L. Canonica and C. Cardani, Gazz. Chim. Ital., 79, 262 (1949).

28. N. Levy and C.W. Scaife, J. Chem. Soc., 1103 (1946).

29. C.D. Hurd and M.E. Nilson, J. Org. Chem., 20, 927 (1955).

30. (a) G. Rosini and R. Ballini, Synthesis, 543 (1983). (b) During the preparation of this review a new oxidative method of 2-nitro alkanols by PCC has been reported: L. L. Adams and F. A. Luzzio, J. Org. Chem., 54, 5387 (1989).

31. G. Rosini, R. Ballini, P. Sorrenti and M. Petrini, Synthesis, 607 (1984).

32. J. M. Melot, F. Texier-Boullet and A. Foucaut, Tetrahedron Lett., 493 (1986).

33. S. Gabriel, Ber. Dtsch. Chem. Ges., 36, 570 (1903).

34. a) G. B. Bachman and T. Hokama, J. Am. Chem. Soc., 81, 4882 (1959). (b) Y. Hamada, K. Ando and T. Shioiri, Chem. Pharm. Bull., 29, 260 (1981).

35. D. Seebach and F. Leher, Angew. Chem. Int. Ed. Engl., 15, 505 (1976).

36. D. C. Baker and S. R. Putt, Synthesis, 478 (1978).

37. R. L. Crumbie, J. S. Nimitz and H. S. Mosher, J. Org. Chem., 47, 4040 (1982).

38. N. Ono, M. Fuji and A. Kaji, Synthesis, 532 (1987).

39. (a) M. A. Ashwell and R. F. W. Jackson, ibid., 229 (1988). (b) M. Cushman and J. Mathew, ibid., 397 (1982).

40. L. Rene and R. Royer, ibid., 878 (1981).

41. (a) E. J. Corey and H. Estreicher, Tetrahedron Lett., 603 (1981). (b) Y. D. Vankar and A. Bawa, Synth. Commun., 15, 1253 (1985).

42. T. Miyakoshi, S. Saito and J. Kumanotani, Chemistry Lett., 1677 (1981).

43. R. Ohrlein, W. Schwab, R. Ehrler and V. Jager, Synthesis, 535 (1986).

44. G. Rosini, R. Ballini, M. Petrini and P. Sorrenti, Tetrahedron, 40, 3809 (1984).

45. G. Gelbard and S. Colonna, Synthesis, 113 (1972).

46. T. W. Williams and H. S. Mosher, Tetrahedron Lett., 6269 (1985).

47. F. Felluya, G. Nardin, P. Pitti, G. Pitacco and E. Valentin, Tetrahedron 44, 6921 (1988).

48. R. Tamura, S. Tamai and H. Suzuki, Tetrahedron Lett. 2413 (1989).

49. M. C. Moreno, J. Plumet, E. Roman and J. A. Serrano, ibid. 3179 (1989).

50. (a) G. P. Pollini, A. Barco and G. DeGiuli, Synthesis, 44 (1972). (b) P. Bakuzis, M. L. Bakuzis and T.F. Weingartner, Tetrahedron Lett., 2371 (1978). (c) D. D. Miller, K. B. Moorthy and A. Hamada, ibid., 555 (1983). (d) R. V. Stevens and A. W. M. Lee, Chem. Commun., 102 (1982).

51. (a) J. H. Clark and D. G. Cork, Chemistry Lett., 1145 (1983). (b) J. H. Clark and D. G. Cork, Chem. Commun. 635 (1982).

52. Y. Nakashita and M. Hesse, Helv. Chim. Acta, 66, 845 (1983).

53. J. E. McMurry and I. Melton, J. Org. Chem., 38, 4367 (1973).

54. (a) T. Miyakoshi and S. Saito, Yakugaku, 31, 35 (1982); C.A., 96, 142217 (1982). (b) T. Miyakoshi and S. Saito, ibid., 31, 231 (1982); C.A., 97, 38526 (1982). (c) T. Miyakoshi and S. Saito, ibid., 31, 749 (1982); C.A., 97, 65361 (1982).

55. N. Ono, H. Miyake and A. Kaji, Chem. Commun., 875 (1983).

56. N. Ono, A. Kamimura and A. Kaji, Synthesis, 226 (1984).

57. (a) G. Rosini, E. Marotta, R. Ballini and M. Petrini, ibid., 237 (1986). (b) R. Ballini and M. Petrini, ibid., 1024 (1986), (c) G. Rosini, R. Ballini, M. Petrini and E. Marotta, Angew. Chem. Int. Ed. Engl., 98, 935 (1986).

58. (a) D. E. Bergbreiter and J. J. Lalonde, J. Org. Chem., 52, 1601 (1987). (b) T. Keumi, T. Inagaki, N. Nakayama, T. Morita and H. Kitajima, Chem. Commun., 1091 (1987). (c) Keumi, T. Inagaki, N. Nakayama, M. Taniguchi, T. Morita and H. Kitajima, J. Org. Chem., 54, 4034 (1989).

59. D. A. Anderson and J. R. Hwu, J. Chem. Soc. Perkin Trans. 1, 1594 (1989).

60. (a) K. Matsumoto, Angew. Chem. Int. Ed. Engl., 20, 770 (1981). (b) A. Seva, K. Takagi, H. Katayama, H. Yamada and K. Matsumoto, J. Org. Chem., 53, 1157 (1988).

61. E. L. Grimm, R. Zschiesche and H. V. Reissig, ibid., 50, 5543 (1985).

62. Y. Nakashita, T. Watanabe, E. Benkert, A. Lorenzi-Riatsch and M. Hesse, Helv. Chim. Acta, 67, 1204 (1984).

63. A. Gomez Sanchez, J. Gaban, M. Rico and J. Bellanato, J. Chem. Soc. Perkin Trans. 1, 2695 (1985).

64. N. Ono, I. Hamamoto, A. Kamimura, A. Kaji and R. Tamura, Synthesis, 258 (1986).

65. R. M. Cory, P. C. Anderson, M. D. Bailey, F. R. McLaren, R. D. Renneboog and B. R. Yamamoto, Canadian J. of Chem., 63, 2618 (1985).

66. D. Seebach and M. A. Brook, Helv. Chim. Acta, 68, 319 (1985).

67. (a) A. Risaliti, M. Forchiassin and E. Valentin, Tetrahedron Lett., 6331 (1966). (b) F. P. Colonna, E. Valentin, G. P. Pitacco and A. Risaliti, Tetrahedron, 29, 3011 (1973). (c) A. Risaliti, M. Forchiassin and E. Valentin, ibid., 24, 1889 (1968). (d) S. Daneo, G. Pitacco, A. Risaliti and E. Valentin, ibid., 38, 1499 (1982). (e) E. Valentin, G. Pitacco, F. P. Colonna and A. Risaliti, ibid., 30, 2741 (1974).

68. D. Seebach and J. Golinski, Helv. Chim. Acta, 64, 1413 (1981).

69. F. Felluga, P. Nitti, G. Pitacco and E. Valentin, Tetrahedron, 45, 5667 (1989).

70. (a) G. Rosini, R. Ballini and E. Marotta, ibid., 45, 5942 (1989) and unpublished results. (b) S. Torii, T. Inokuchi, R. Oi, K. Kondo and T. Kobayashi, J. Org. Chem., 51, 254 (1986).

71. J. Tsui, Synthesis, 369 (1984).

72. H. O. Larson in "Formation of the Nitro Group in Aliphatic and Alyciclic Systems". H. Feuer in S. Patai "The Chemistry of the Nitro and Nitroso Groups, Part I, Wiley-Interscience, New York, N.Y., 325-336 (1969).

73. D. Seebach, R. Henning, F. Leher and J. Gonnermann, Tetrahedron Lett., 1161 (1977).

74. M. Eyer and D. Seebach, J. Am. Chem. Soc., 107, 3601 (1985).

75. E. W. Colvin and D. Seebach, Chem. Commun., 689 (1978).

76. E. W. Colvin, A. K. Beck and D. Seebach, Helv. Chim. Acta, 64, 2264 (1981).

77. See for example: A.P. Kozikiwski, Acc. Chem. Res., 17, 410 (1984).

78. U. Brandli, M. Eyer and D. Seebach, Chem. Ber., 119, 573 (1986).

79. M. Petrini, R. Ballini and G. Rosini, Synthesis, 713 (1987) and references cited therein.

80. E. R. Koft, J. Org. Chem., 52, 3466 (1987).

81. N. Ono, T. Yanai and A. Kaji, Chem. Commun., 1040 (1986).

82. (a) A. Haines in "Methods of the Oxidation of Organic Compounds. Alcohols, Alcohols derivatives, Alkyl Alides, Nitroalkanes" Aca demic Press, 220-232 (1988) and ref. n. 51. (b) R. Ballini and M. Petrini, Tetrahedron Lett., 5329 (1989) and references cited therein; (c) H. W. Pinnick, "The Nef Reaction" in Organic Reactions, Vol. 38, p. 655, J. Whiley & Sons, Inc. New York, N.Y., 1990.

83. K. Hideg and L. Lex, J. Chem. Soc. Perkin Trans 1, 1431 (1986).

84. D. L. Haire, J. W. Hilborn and E. G. J. Janzen, J. Org. Chem., 51, 4298 (1986) and references cited therein.

85. See for example A. Brandi, F. Cordero and C. Querci, ibid., 54, 1748 (1989).

86. (a) D. H. R. Barton, W. B. Motherwell and S. Z. Zard, Tetrahedron Lett., 3707 (1984). (b) M. Miyashita, B. Z. Elshtaiwi and A. Yoshikoshi, Chem. Commun. 841 (1989).

87. J. E. McMurry and J. Melton, J. Am. Chem. Soc., 93, 5309 (1971).

88. J.H. Clark and D.G. Cork, J.Chem.Soc. Perkin Trans. 1, 2253 (1983).

89. (a) N. Ono, I. Hamamoto and A. Kaji, Synthesis, 950 (1985). (b) N. Ono, I. Hamamoto and A. Kaji, J. Chem. Soc. Perkin Trans. I, 1439 (1986).

90. D. C. Black, G. Fallon, B. M. Gatehouse and J. D. Wishart, Aust. J. Chem., 37, 777 (1984).

91. M. E. Jung, D. D. Grove and S. I. Kan, J. Org. Chem., 52, 4570 (1987).

92. R. Ballini and M. Petrini, Synth. Commun., 16, 1781 (1986).

93. A. S. Matlak and D. S. Breslow, J. Org. Chem., 32, 1995 (1967).

94. T. Aono, J. H. Bieri, M. Hesse, K. Kostova, A. Lorenzi-Riatsch, Y. Nakashita and R. Prewo, Helv. Chim. Acta, 68, 1033 (1985) and references cited therein.

95. P. L. Southwich, J. A. Fitzgerald, R. Madhav and D. A. Welsh, J. Org. Chem., 34, 3279 (1969).

96. (a) H. Fever and P. M. Pivawer, ibid., 34, 2917 (1969). (b) T. Simmons and K. L. Krevz, ibid., 33, 836 (1968). (c) R. H. Fisher and H. M. Weitz, Ann., 612 (1979).

97. R. Ballini, E. Marcantoni, M. Petrini and G. Rosini, Synthesis, 916 (1988).

98. A. Hassner, J. M. Larkin and J. E. Dowd, J. Org. Chem., 33, 1733 (1968) and references cited therein.

99. (a) S. E. Denmark, J. A. Sternberg and R. Lucoend, ibid., 53, 1251 (1988). (b) S. E. Denmark and J. J. Ares, J. Am. Chem. Soc., 110, 4432 (1988).

100. P. Dampawan and W. Zajac Jr., Tetrahedron Lett., 135 (1982).

101. M. Node, T. Kawabada, M. Fujimoto and K. Fuji, Synthesis, 234 (1984).

102. R. Tamura, D. Oda and H. Kurokawa, Tetrahedron Lett., 5759 (1986).

103. T. Hayashi, A. Katsumura, M. Konishi and M. Kumada, ibid., 425 (1979).

104. (a) N. Ono, H. Miyake, R. Tamura and A. Kaji, ibid., 1705 (1981). (b) N. Ono, H. Miyake and A. Kamimura, Tetrahedron, 41, 4013 (1985).

105. M. Node, T. Kawabata, M. Ueda and M. Fujimoto, Tetrahedron Lett., 4047 (1982)

106. (a) G. Rosini, R. Ballini and V. Zanotti, Synthesis, 137 (1983); (b) G. Rosini and R. Ballini, ibid., 228 (1983).

107. R. Ballini and M. Petrini, J. Chem. Soc. Perkin Trans. 1, 2563 (1988) and references cited therein.

109. A. Kamimura, K. Kurata and N. Ono, Tetrahedron Lett., 4819 (1989).

110. H. Miyake and K. Yamamura, Bull. Chem. Soc. Japan, 59, 89 (1986).

111. V. I. Ognyanov and M. Hesse, Synthesis, 645 (1985).

112. H. Stach and M. Hesse, Helv. Chim. Acta, 69, 1614 (1986).

113. G. Rosini and R. Ballini, unpublished results.

114. N. Ono, H. Miyake, M. Fuji and A. Kaji, Tetrahedron Lett., 3477 (1983).

115. N. Ono, I. Hamamoto and A. Kaji, J. Org. Chem., 51, 2832 (1986).

116. N. Ono, H. Miyake and A. Kaji, Chem. Commun., 875 (1983).

117. H. Stach and M. Hesse, Tetrahedron, 44, 1573 (1988).

118. For a brief account of how this name originated, see: A. Nikon and E. F. Silversmith, "Organic Chemistry: The Name Game. Modern Coined Terms and Their Origins". p. 257, Pergamon Press, New York, N.Y., 1987.

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