proved to be a convenient source of material from which the *meso* isomers could be isolated. The physical properties of the isolated dimers are summarized in Table II and the composition of the reduction products formed in the aluminum amalgam reductions are shown in Table III.

Preparation of the Cross Dimer, 1-(*o*-Methylphenyl)-*N*,*N'*-,2-triphenylethylenediamine (6).—A solution containing 1.81 g (0.01 mol) of 1 (X = H) and 1.95 g (0.01 mol) of 1 (X = *o*-Me) in 200 ml of THF was treated with 0.92 g (0.04 g-atom) of sodium and shaken for 24 hr. The orange solution was drained from the excess sodium, treated with methanol, diluted with water, and extracted with ether. After removal of the solvent, the residue was analyzed by nmr by using the methyl resonances to determine the relative amounts of cross dimer 6, *dl* "homo dimer" 5 (X = o-Me), and the small amount of monomeric reduction product *N*-(*o*-methylphenyl)aniline. The contribution made by 5 (X = *o*-Me) and 6 to the area of the benzylic resonances was then calculated and subtracted from the total area to give the amount of *dl*-5 (X = H) (see Table IV).

TABLE IV

FORMATION OF THE CROSS DIMER

	Product anal, %				
		Homo dimers			
Reaction conditions[a]	Cross dimer 6	*dl*-5 (X = *o*-Me)	*dl*-5 (X = H)	*meso*-5 (X = H)	Monomer[b]
Mixed Schiff bases, 1 (X = H and *o*-Me)	51	19	27	<1	3
Mixed dimeric dianions, 3 (X = H and *o*-Me)	51	19	25	<1	5
Mixed diamines, *meso*-5 (X = H) and *meso*-5 (X = *o*-Me) + DSS[c]	54	18	22	<1	6
Cross dimer 6 + DSS[c]	47	17	34	2	<1
Dianion 3 (X = *o*-Me) treated with 2 equiv of 1 (X = H)	22	15	19	<1	5[d]
meso-5 (X = H) + DSS,[c] then treated with 1 equiv of 1 (X = *o*-Me)	27	10	40	<1	e

[a] 24-hr reaction time. [b] *N*-(*o*-Methylphenyl)aniline. [c] Disodium-stilbene. [d] Product contained 21% of 1 (X = H) and 19% of 1 (X = *o*-Me). [e] Product contained 13% of 1 (X = H) and 10% of 1 (X = *o*-Me).

Isolation of the cross dimer 6 was effected by recrystallization from methanol to remove the more soluble *dl*-5 (X = *o*-Me). The solid so obtained was recrystallized from DMF when the DMF complex of *dl*-5 (X = H) separated. The filtrate from this was acidified with 6 *N* HCl and the white precipitate was filtered, washed with water, dried, and recrystallized from absolute ethanol to give 6: mp 125–128°; nmr ($CDCl_3$, D_2O washed) δ 6.4–7.3 (m, 19 aromatic H), 4.81 (d, 1 H, CHCH, J = 8.0 cps), 4.54 (d, 1 H, CHCH, J = 8.0 cps), 2.03 (s, 3 H, CH_3).

Anal. Calcd for $C_{27}H_{26}N_2$: C, 85.67; H, 6.93; N, 7.40. Found: C, 85.68; H, 7.05; N, 7.32.

In an alternative procedure, each Schiff base in THF was treated with sodium in separate Schlenk tubes. After a 24-hr reaction time, the solutions were drained from the excess metal into the same nitrogen-filled flask and stirred for a further 24 hr. The isolated product was analyzed as described with the result shown in Table IV.

A similar cross product was prepared from 1 (X = H) and 1 (X = *m*-Me) and isolated by recrystallization from methanol: mp 120–121.5°; nmr ($CDCl_3$, D_2O washed) δ 6.4–7.4 (m, 19 aromatic H), 4.53 (broad s, 2 benzylic H), 2.33 (s, 3 H, CH_3).

Anal. Calcd for $C_{27}H_{26}N_2$: C, 85.67; H, 6.93; N, 7.40. Found: C, 85.89; H, 6.90; N, 7.58.

Isomerization with the Disodium-Stilbene Complex.—A solution of 0.005 mol of the selected diamine in 25 ml of THF was treated at room temperature under N_2 with a solution (THF) of 0.005 mol of the disodium-stilbene complex.[25] The color changed from the deep red of the stilbene complex to orange within 10–15 min. The solution was stirred 24 hr and quenched by the addition of methanol, and the product was isolated by diluting with water and extracting with ether.

Both *meso*- and *dl*-*N*,*N'*,1,2-tetraphenylethylenediamine (5, X = H) so treated produced the equilibrium composition of 93% *dl* and 7% *meso*.

A mixture of 0.911 g (0.0025 mol) of *meso*-5 (X = H) and 0.981 g (0.0025 mol) of *meso*-5 (X = *o*-Me) was isomerized under these conditions (see Table IV). Similarly treated was a solution of 1.41 g (0.004 mol) of the cross dimer, 1-(*o*-methylphenyl)-*N*,*N'*-2-triphenylethylenediamine, in 25 ml of THF. Product composition is shown in Table IV.

Registry No.—6, 33021-01-1.

Acknowledgment.—The authors wish to acknowledge helpful discussions with Dr. D. Mackay of this department. This research was financially supported by the National Research Council of Canada.

Reactivity Differences in Competitive Metal Hydride Reductions of α,β-Unsaturated and Saturated Ketones

H. HAUBENSTOCK

Richmond College of the City University of New York, Staten Island, New York 10301

Received July 30, 1971

Competitive reduction experiments involving mixtures of saturated and α,β-unsaturated six-membered ring ketones and lithium aluminum hydride or lithium tri-*tert*-butoxyaluminohydride have shown a large reactivity difference between the two types of ketones. Both hindered and unhindered ketone systems were employed as substrates. The unsaturated ketones were consistently less reactive than the saturated ketones. This reactivity difference is enhanced with the more selective tri-*tert*-butoxyaluminohydride reagent.

Competition experiments in which α,β-unsaturated and saturated six-membered ring ketones are made to compete for limited amounts of lithium aluminum hydride ($LiAlH_4$) or lithium tri-*tert*-butoxyaluminohydride (LTAH) reveal remarkable reactivity differences between the two types of ketones. The experiments described involve the inverse addition of standardized[1] solutions of $LiAlH_4$ in ether, or weighed amounts of LTAH in tetrahydrofuran (or ether), to stirred mixtures of two ketones. These experiments were the outgrowth of observations of the low reactivity of several cyclic enones toward $LiAlH_4$ reductions. The reactions carried out, together with the major products obtained, are listed in eq 1–3.

Analyses of the products were carried out by gas chromatography directly on the concentrated reaction products and also after catalytic hydrogenation with palladium on charcoal (except for the isophorone–dihydroisophorone competitive reduction, eq 1). Catalytic

[1] H. Felkin, *Bull. Soc. Chim. Fr.*, 347 (1950).

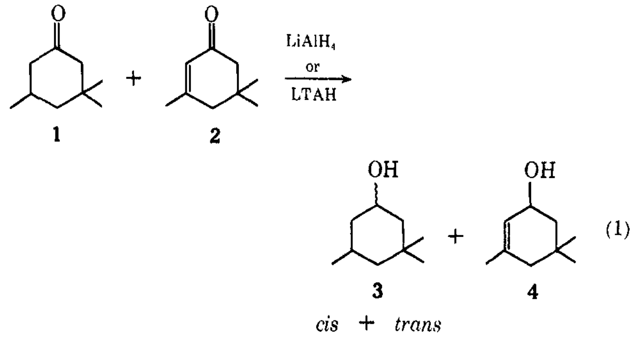
TABLE I

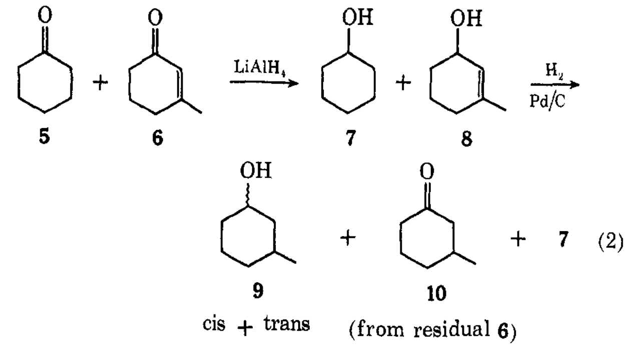
DIHYDROISOPHORONE (**1**)–ISOPHORONE (**2**) REDUCTIONS

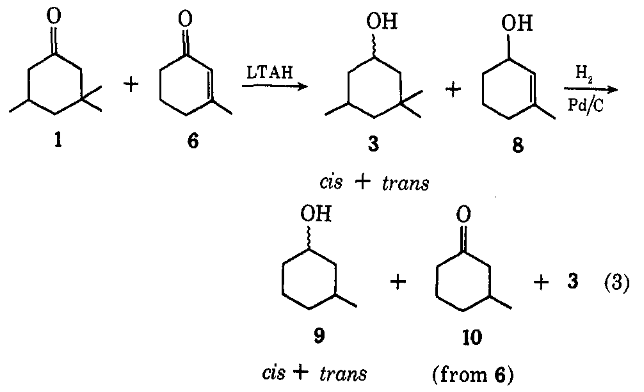
Ketone mixture	Metal hydride	Product analysis,[a] % **1**	 **3**[b]	 **2**[c]	 **4**[c]
1, **2** (0.030 mol each)[d]	$LiAlH_4$ (0.015 equiv)[e]	69.9[b]	30.1[b]	88	12
1, **2** (0.030 mol each)[d]	LTAH (~0.015 mol)[f]	61.9[g]	38.1[g]		0
		39.4[h]		60.6[h]	
1, **2** (0.030 mol each)[d]	LTAH (0.015 mol)[i]	59.5[j]	40.5[j]		0
		38.2[h]		61.8[h]	

[a] Analysis by glc on a 10 ft, 10% Carbowax 20M column at 150°, silanized, acid-washed. [b] **1** and **3** normalized to 100%. **3** was 57% *trans*, 43% *cis*. [c] **2** and **4** normalized to 100%. [d] In 100 ml of ether. [e] 0.73 *M* in ether added inversely. [f] In ether. [g] **1** and **3** normalized to 100%. **3** was 77% *trans*, 23% *cis*. [h] **1** and **2** normalized to 100%. [i] In 75 ml of tetrahydrofuran. [j] **1** and **3** normalized to 100%. **3** was 89% *trans*, 11% *cis*.

hydrogenation was necessary since the unsaturated alcohol **8** decomposed to a large extent during gas chromatographic analysis. Hydrogenation converted **8** to **9** which could be readily analyzed (see the Experimental Section).







Results and Discussion

The results of the competition between dihydroisophorone (**1**) and isophorone (**2**) are listed in Table I. Hydrogenation of the product was of course unfeasible in this case, and although some decomposition of the unsaturated alcohol **4** did occur during glpc analysis, satisfactory results were obtained by using selectivity factors derived from standard mixtures (*e.g.*, **2** and **4**) under carefully controlled analytical conditions.

Reductions of **1** to the epimeric *cis*- and *trans*-**3** occurred to the extent of 30% with $LiAlH_4$, while only 12% reduction of **2** occurred (first entry in Table I). The *unreacted* ketone composition for this experiment was found to be 46% **1** and 54% **2**, in very good agreement with that calculated (44% and 56%, respectively) on the basis of the relative extents of reduction for **1** and **2**. On the basis of the extent of total reduction, 86% of hydride was used. The second and third entries in Table I show that LTAH is much more selective than $LiAlH_4$, since reduction of **1** occurred, but no reduction of **2** was observed, In the second entry, the unreacted ketone composition was 39% **1** and 61% **2** (calculated values 38% **1** and 62% **2**), while for the third entry the observed ketone composition was 38% **1**, 62% **2** (calculated values 38% **1**, 62% **2**). These unreacted ketone ratios serve as additional analytical checks. The solubility of LTAH in ether is low, and its use in tetrahydrofuran is much more satisfactory. Separate experiments showed that reduction of the C=C double bond in **2** with $LiAlH_4$ was negligibly small as expected from previous studies.[2] The reduction of **1** with LTAH is a much more stereoselective process than with $LiAlH_4$, leading to a greater *trans*/*cis*-**3** ratio (*cf.* footnotes *b*, *g*, and *j*, Table I, and also footnotes *h*, *i*, Table II). Reductions in tetrahydrofuran are also more stereoselective than corresponding reductions in diethyl ether. These observations are in accord with previous reduction studies of **1** with $LiAlH_4$ and lithium alkoxyaluminohydrides.[3]

Steric and torsional factors[4] which have been used to explain relative reactivity in hydride attack on opposite faces of a carbonyl group in a given cyclohexanone do not appear to explain the reduced reactivity of **2** relative to **1**. In **1**, the almost equal amounts of *cis*- and *trans*-**3** obtained in reduction with $LiAlH_4$ is presumably due to opposing steric factors (axial methyl on C-3) and torsional effects (partial eclipsing of equatorial hydrogens on C-2 and C-6 with entering hydride). Inspection of Dreiding models[5] reveals that in **2** the steric factor is still present, while the torsional factor is reduced by elimination of one flanking CH_2 group by the presence of the C=C double bond. Therefore it appears that the reduced reactivity of **2** is inherent in the enone system, possibly arising from reduced conjugation of the two double bonds in going from the ground state to the transition state. However, the exact mechanism for

---

[2] M. R. Johnson and B. Rickborn, *J. Org. Chem.*, **35**, 1041 (1970).

[3] H. Haubenstock and E. L. Eliel, *J. Amer. Chem. Soc.*, **84**, 2363 (1962).

[4] M. Chérest, H. Felkin, and N. Prudent, *Tetrahedron Lett.*, 2199 (1968); M. Chérest and H. Felkin, *ibid.*, 2205 (1968).

[5] In structure **2** carbons 1, 2, 3, 4, and 6 are taken as coplanar, with carbon 5 below (or above) the plane.

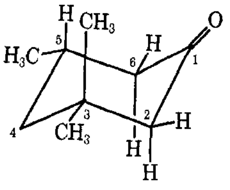
TABLE II

RESULTS OF OTHER COMPETITION REDUCTIONS

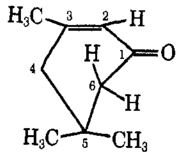
Ketone mixture	Metal hydride	Product analysis, %				
		5	**7**	**6**	**10**	**9**
5, **6** (0.020 mol each)[a]	$LiAlH_4$ (0.0116 equiv)[b]	66,[c] 65[d]	34,[c] 35[d]			
					82[d]	18[d,e]
		46[c]		54[c]		
		48[d]			52[d]	
		1	**3**	**6**	**10**	**9**
1, **6** (0.030 mol each)[f]	LTAH (0.0149 equiv)[g]	77,[c] 79[d]	23,[c,h] 21[d,i]			
					98[d]	2[d,e]
		44[c]		56[c]		
		45[d]			55[d]	

[a] In 60 ml of ether. Analyzed on 10 ft, 10% Carbowax 20M column at 135 and 120°. [b] 0.585 *M* in ether, added inversely. [c] Before hydrogenation. Normalized to 100%. [d] After hydrogenation. Normalized to 100%. [e] Mixture of cis and trans isomers. [f] In 100 ml of tetrahydrofuran. Analyzed on Carbowax 20M at 125°. [g] In 55 ml of tetrahydrofuran, added inversely. [h] **3** was 87% *trans*, 13% *cis*. [i] **3** was 92% *trans*, 8% *cis*.

reduction of enones is not yet established. Further competitive studies with conjugated and nonconjugated enone systems may be useful, and we intend to explore this further.



1



2

The first entry in Table II compares two unhindered ketones, **5** and **6** competing for $LiAlH_4$. The methyl group in **6** lies in the plane of the enone system and does not exert any significant steric hindrance in the reduction. Once again, considering possible steric and torsional factors, the enone **6** does not appear to be at a disadvantage relative to the saturated ketone **5**. As in the hindered ketone cases (*vide supra*), the enone is again less reactive, undergoing only 18% reduction compared with 35% reduction of **5**. As can be seen from Table II, the observed extent of reduction of **5**, and the relative ketone ratios both before and after hydrogenation, agree very well with each other. Also, the calculated remaining ketone composition is 45% **5**, 55% **6**, in good agreement with the observed 46–48% **5**, 52–54% **6** (or **10**).

The last entry in Table II compares the unhindered enone **6** with the relatively hindered ketone **1**. The reagent used was the more selective LTAH. Again, the saturated ketone **1**, even though more highly hindered, suffered more reduction (~22%), while the enone **6** was only 2% reduced. The observed unreacted ketone composition was 55–56% **6** (or **10**), 44–45% **1** (calculated 55% **6**, 45% **1**).

The fact that LTAH is more selective than $LiAlH_4$ might at first be ascribed to its greater "bulk." However, the nature of the active species in reductions with this reagent is uncertain,[6,7] and it is not always as stereoselective as its apparent size would suggest.[3,6] LTAH is less reactive than $LiAlH_4$[3] and kinetic studies of reductions with this reagent have been carried out.[8] The lower reactivity and higher selectivity of LTAH should prove useful in reductions of saturated ketones in the presence of conjugated enones.

Since the proportions of *cis*- and *trans*-**3**, obtained from reductions of ketone **1** (Tables I and II), agree well with previous values obtained in the reduction of **1** alone,[3] the present results are due to kinetic control, not to equilibrations.[9]

Experimental Section

Isophorone (**2**) and **10** were obtained from Matheson, and fractionally distilled. Dihydroisophorone (**1**) was prepared by oxidation[10] of the commercial alcohol mixture. 3-Methylcyclohex-2-en-1-one (**6**) was obtained from Aldrich. Samples of the known unsaturated alcohols **4**[11] and **8**[2] were prepared by $LiAlH_4$ reduction of the corresponding ketones, and the saturated alcohols **3** and **9** were similarly prepared by reduction of the corresponding ketones. LTAH was obtained from Ventron. Gas chromatographic analyses were carried out with a Hewlett-Packard 5750 chromatograph. Sensitivity factors derived from standard mixtures were determined for the various components. For example, in the analysis of two components **1** and **2**, $K_2 = (A_2/A_1)(X_1/X_2)$; $K_1 = 1.0$, where K_1 and K_2 are relative sensitivity factors, A_1 and A_2 are experimentally determined areas (by the peak height–width at half-height methods), and X_1 and X_2 are the moles (or weights) of the components.

Reduction of Dihydroisophorone and Isophorone (1 and 2) with $LiAlH_4$.—A solution of **1** (4.23 g, 0.030 mol) and **2** (4.16 g, 0.030 mol) in 100 ml of anhydrous ether was added to a reactor equipped with a stirrer, reflux condenser, and addition funnel; 5 ml of 0.73 *M* $LiAlH_4$ in ether was transferred by pipet to the addition funnel and added dropwise to the well-stirred ketone solution. The reaction mixture was kept at room temperature overnight, and hydrolyzed (water and 10% sulfuric acid). The ether solution was washed (NaCl, $NaHCO_3$) and dried ($MgSO_4$) and the product was concentrated for glpc analysis by distillation of solvent (an oil bath was used, maximum temperature 85°).

Reduction of 1 and 2 with LTAH.—A solution of LTAH (3.8 g) was dissolved in 75 ml of tetrahydrofuran (distilled from $LiAlH_4$ through a helix-packed column) and added dropwise to a well-stirred solution of **1** (4.20 g, 0.030 mol) and **2** (4.18 g, 0.030 mol) in 100 ml of absolute ether. The work-up was carried out in the same manner as described above.

Reduction of 5 and 6 with $LiAlH_4$.—Ketones **5** (2.02 g, 0.021 mol) and **6** (2.21 g, 0.020 mol) in 60 ml of anhydrous ether were reduced by the dropwise inverse addition of 5 ml of 0.585 *M* $LiAlH_4$ in ether (0.0029 mol). After 3.5 hr of stirring, the reaction mixture was hydrolyzed with water and 10% sulfuric acid and worked up and concentrated in the usual manner, giving

---

[6] H. C. Brown and H. R. Deck, *J. Amer. Chem. Soc.*, **87**, 5620 (1965).

[7] D. C. Ayres, D. N. Kirk, and R. Sawdaye, *J. Chem. Soc. B*, 1133 (1970).

[8] J. Klein, E. Dunkelblum, E. L. Eliel, and Y. Senda, *Tetrahedron Lett.*, 6127 (1968).

[9] T. Toromanoff in "Topics in Stereochemistry," Vol. 2, N. L. Allinger and E. L. Eliel, Ed., Interscience, New York, N. Y., 1967, p 157. This review contains a discussion of the stereochemistry of hydride reductions of cyclohexenones.

[10] E. L. Eliel and H. Haubenstock, *J. Org. Chem.*, **26**, 3504 (1961).

[11] J. Klein and E. Dunkelblum, *Tetrahedron*, **24**, 5701 (1968).

22 g of concentrated product. A portion of the product (3.0 g) was retained for glpc analysis and the remainder was hydrogenated in 50 ml of anhydrous ethanol over 0.2 g of 5% palladium on charcoal using a Parr apparatus (initial pressure 43 psig). The solution of hydrogenated product was filtered and concentrated by distillation through a 12 in. helix-packed fractionating column (oil bath). The concentrated product was directly analyzed by glpc.

Reduction of 1 and 6 with LTAH.—Ketones **1** (4.22 g, 0.030 mol) and **6** (3.31 g, 0.030 mol) in 100 ml of tetrahydrofuran (distilled from $LiAlH_4$) were reduced by the dropwise inverse addition of LTAH (3.8 g, 0.015 mol) in 55 ml of tetrahydrofuran. Hydrolysis was effected in this case with water and 15% sodium hydroxide[12] after 2.5 hr of stirring. After concentration by distillation, a portion of the concentrated solution was directly analyzed by glpc while the remainder was hydrogenated over 0.3 g of 5% palladium on charcoal.

Control Experiments.—The fact that ketone ratios and ketone–alcohol ratios (of saturated compounds) did not vary significantly before and after hydrogenation lends confidence to the analytical procedure employed. In addition, a standard mixture of **1** and **10** was subjected to the hydrogenation and isolation procedures and was shown not to change in composition upon glpc analysis. Unsaturated ketones on hydrogenation also absorbed the exact amount of hydrogen (based on calibration of the apparatus) for conversion to the corresponding saturated alcohol.

Registry No.—**1**, 873-94-9; **2**, 78-59-1; **5**, 108-94-1; **6**, 16853-85-3; $LiAlH_4$, 17476-04-9.

Acknowledgment.—The author would like to thank Mr. P. Quezada for technical assistance.

---

(12) See L. F. Fieser and M. Fieser, "Reagents for Organic Synthesis," Wiley, New York, N. Y., 1967, p 584.

The Addition of Lithium Dimethylcopper to Conjugated Cyclopropyl Enones

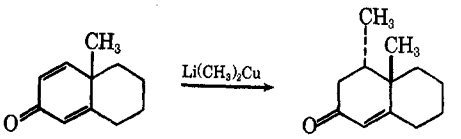
JAMES A. MARSHALL* AND RONALD A. RUDEN[1]

Department of Chemistry, Northwestern University, Evanston, Illinois 60201

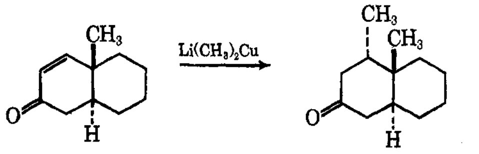
Received August 12, 1971

The addition of lithium dimethylcopper to 9,10-methano-1-octalin-3-one (**6**) affords a mixture of the expected 1,4 adducts (*ca.* 90% trans, 10% cis), a 1,6 adduct, 9-ethyl-4(10)-octalin-2-one (**8**), and a small amount of reduced cyclopropane cleavage product, 9-methyl-4(10)-octalin-2-one (**9**). Acid cleavage of the trans 1,4 adduct, *trans*-4-methyl-9,10-methanodecalin-2-one (**7a**), affords a 4:1 mixture of 4,9-dimethyl-*cis*-3-octalin-2-one (**19**) and *trans*-4,10-dimethyl-1(9)-octalin-2-one (**20a**), whereas the cis 1,4 adduct, *cis*-4-methyl-9,10-methanodecalin-2-one (**7b**), gives only *cis*-4,10-dimethyl-1(9)-octalin-2-one (**20b**) upon similar treatment. 5,10-Methano-1(9)-octalin-2-one (**16**), a cyclopropano enone isomeric with **6**, likewise affords 1,4- and 1,6-addition products upon treatment with lithium dimethylcopper.

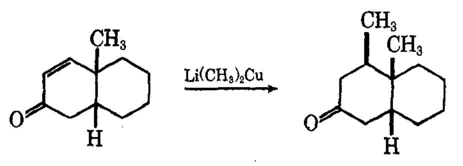
The conjugate addition of lithium dimethylcopper(I)[2] to Δ^1-3-ones (eq 1–3) has been shown to proceed cleanly and stereoselectively. In the former two cases (eq 1 and 2) the methylation occurs trans to the angular methyl group to give *trans*-dimethyl products.[3] However, the cis-fused enone (eq 3) affords mainly the cis,cis product.[4] The latter arrangement of *vic*-methyl groups is of particular interest in connection with the valencane–eremophilane family of sesquiterpenes, a class of compounds based on the *cis,cis*-1,9-dimethyldecalin framework.[5]



(1)

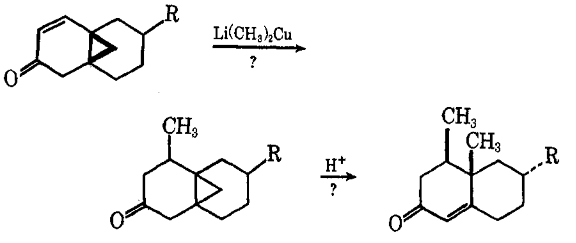


(2)



(3)

In the course of synthetic studies related to the sesquiterpene grapefruit flavor constituent nootkatone,[6] we decided to examine the conjugate methylation–cyclopropane cleavage sequence shown in eq 4. Our initial work was carried out on a model system designed to test the overall feasibility and stereochemistry of the above sequence. Accordingly, the known cyclopropyl alcohol **1** (Scheme I) was reduced (Li, NH_3, EtOH) *via* the methanesulfonate derivative **2** to the tricyclic olefin **3**.[7] Epoxidation followed by base-induced elimination afforded the allylic alcohol(s) **5**, oxidation of which gave the desired enone **6**.



(4)

Addition of lithium dimethylcopper(I) to enone **6** in ether solution at 0° afforded principally the 1,4 adduct **7** (55%) along with enones **8** (39%) and **9** (6%). The production of the latter two cyclopropane cleavage products was of special interest since a simple cyclopropyl ketone, bicyclo[4.1.0]heptan-2-one,[8] and a con-

---

(1) Predoctoral Fellow of the National Institutes of Health, Division of General Medical Sciences, Fellowship 5 F01 GM 41100.

(2) H. O. House, W. L. Respess, and G. M. Whitesides, *J. Org. Chem.*, **31**, 3128 (1966).

(3) (a) T. M. Warne, Jr., "The Synthesis of (±)-Isonootkatone," Ph.D. Thesis, Northwestern University, Evanston, Ill., 1971, p 100; (b) R. M. Coates and J. E. Shaw, *Chem. Commun.*, 47 (1968); (c) R. L. Nale and L. N. Zalkow, *ibid.*, 1249 (1968).

(4) G. M. Cohen, unpublished results. *Cf.* J. A. Marshall and G. M. Cohen, *J. Org. Chem.*, **36**, 877 (1971).

(5) *Cf.* J. A. Marshall and R. A. Ruden, *ibid.*, **36**, 594 (1971).

(6) W. D. Macleod, Jr., *Tetrahedron Lett.*, 4779 (1965).

(7) J. J. Sims, *J. Org. Chem.*, **32**, 1751 (1967).

(8) R. A. Ruden, "Stereoselective Total Synthesis of Racemic Nootkatone," Ph.D. Dissertation, Northwestern University, Evanston, Ill., 1971, p 66.