intensity) 130 (100), 129 (64.9), 138 (36.6), 127 (17.6), 115 (97.5), 77 (15.4), 65 (12.7), 63 (21.8), 51 (29.3), and 39 (20.9). 2-Methylindene was isolated by glpc from the same fraction [lit.[20] bp 79° (10 mm)]: nmr $\delta_{TMS}^{CCl_4}$ 2.10 [s (fine splitting), 3 H, C=CCH$_3$], 3.17 (s, 2 H, CH$_2$), 6.36 [s (fine splitting), 1 H, C=CH], and 6.9–7.2 (m, 4 H, C$_6$H$_4$); ir spectrum identical with that of 2-methylindene.[22] The mass spectrum shows nearly the same cracking pattern as 3-methylindene and the mass spectra of both indenes are similar to that of a mixture of methylindenes found in the literature.[23] These same products were isolated and identified from the SSPA reactions of butyrophenone, 1-phenyl-2-butanone, 4-phenyl-2-butanone, 1-phenyl-1-butyne, and 4-phenyl-1-butyne. 1-Methylindan was isolated and identified similarly from the SSPA reactions of 4-phenyl-1-butene and 1-phenyl-2-butene.

Pivalophenone was prepared by a reverse Grignard reaction[24] and subjected to the catalyst in the same manner as described previously. Benzene, 1-methylindan, and 1,2-dimethylindan were isolated by preparative glpc and identified by comparison of their ir and nmr spectra and glpc retention times with those of authentic samples. 1- and 2-methylnaphthalene were isolated as a 1:1 mixture and identified by comparison of their physical and spectral properties with those of an authentic 1:1 mixture. A distillation fraction, bp 110–125° (30 mm), yielded 3.87 g of 2,3-dimethylindene by preparative glpc: mp 9–10° (lit.[25] mp 11°); ir spectrum identical with that for 2,3-dimethylindene;[22] nmr $\delta_{TMS}^{CCl_4}$ 1.75 (s, 6 H, CH$_3$C=CCH$_3$), 2.81 (br s, 2 H, CH$_2$), and 7.05 [s (fine splitting), 4 H, C$_6$H$_4$].

3-Methyl-2-butanone was allowed to react with the catalyst, and the 2,3-dimethylindene product, obtained by preparative glpc, was dissolved in benzene and subjected to fresh catalyst. The products were analyzed by glpc and nmr, showing 28% conversion of the indene into the same products obtained from pivalophenone and 3-methyl-3-phenyl-2-butanone.

Registry No.—**3**, 3910-35-8; **4**, 2177-47-1; **7**, 767-60-2; **9**, 767-58-5; 1,1-dimethylindan, 4912-92-9; 2,3-dimethylindene, 4773-82-4.

(22) T. L. Yarboro, C. Karr, Jr., and P. A. Estep, *J. Chem. Eng. Data*, **6**, 421 (1961).

(23) American Petroleum Institute, "Catalog of Mass Spectral Data," Serial No. 1250, Project No. 44, Carnegie Institute of Technology, Pittsburg, Pa.

(24) J. Ford, C. Thompson, and C. Marvel, *J. Amer. Chem. Soc.*, **57**, 2619 (1935).

(25) G. Egloff, "Physical Constants of Hydrocarbons," Vol. IV, Reinhold Publishing Corp., New York, N. Y., 1947, p 48.

The Reduction–Methylation of Derivatives of 3-Buten-2-one[1a]

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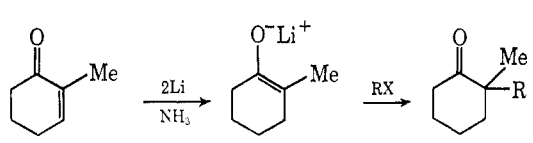
The lithium–liquid ammonia reduction and reduction–methylation of 3-buten-2-one derivatives *trans*-4-phenyl-3-buten-2-one (**1a**), 3-methyl-4-phenyl-3-buten-2-one (**1b**), and 4-methyl-3-penten-2-one (**1c**) have been investigated. In each case the only monomethylation product obtained was derived from the specific lithium enolate generated reductively. Unlike 2-cyclohexenone derivatives, open-chain enones **1a–1c** also gave much polymethylation, ascribed to the effect of the conjugate base of the proton donor employed in the reduction step. Polymethylation was minimized by the use of triphenylmethanol as proton donor or by the addition of excess acetone with the alkylating agent.

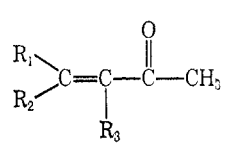
Stork and coworkers[2] have developed a procedure for the reduction–alkylation of an α,β-unsaturated ketone to give the α-alkyl saturated ketone uncontaminated with the α'-alkyl isomer. The procedure consists of treatment of an α,β-unsaturated ketone with 2 equiv of lithium in liquid ammonia to produce a specific lithium enolate, followed by treatment of the enolate with an alkyl halide in an appropriate solvent, as shown for 2-methyl-2-cyclohexenone in Scheme I.

SCHEME I

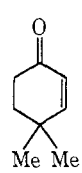


The specificity of the reduction–alkylation depends upon the relatively slow equilibration among structurally isomeric lithium enolates[2–6] and has been confirmed in several studies on reduction–alkylation in cyclic systems.[7–9]

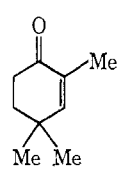
Side reactions leading to polyalkylation products are generally moderate in extent for the reduction–alkylation of derivatives of 2-cyclohexenone[2,9] but extensive for systems in which the enone moiety is not part of a ring. In the present study, the reduction–methylation of some 3-buten-2-one derivatives (**1a–1c**) has been carried out with a view toward investigating the reaction pathway by which polymethylation occurs and finding optimum conditions for monomethylation. Some further work on cyclic systems has been carried out with 4,4-dimethyl-2-cyclohexenone (**1d**) and 2,4,4-trimethyl-2-cyclohexenone (**1e**).



1a, R_1 = Ph; R_2 = R_3 = H
b, R_1 = Ph; R_2 = H; R_3 = Me
c, R_1 = R_2 = Me; R_3 = H



1d



1e

(1) (a) Supported by the National Science Foundation and the Research Corporation. (b) Undergraduate Research Participant, National Science Foundation.

(2) G. Stork, P. Rosen, N. Goldman, R. V. Coombs, and J. Tsuji, *J. Amer. Chem. Soc.*, **87**, 275 (1965).

(3) (a) R. E. Schaub and M. J. Weiss, *Chem. Ind.* (London), 2003 (1961); (b) R. Deghenghi and R. Gaudry, *Tetrahedron Lett.*, 489 (1962); (c) M. J. Weiss, R. E. Schaub, J. F. Poletto, G. R. Allen, Jr., and C. J. Coscia, *Chem. Ind.* (London), 118 (1963); (d) R. Dehgenghi, C. Revesz, and R. Gandry, *J. Med. Chem.*, **6**, 301 (1963); (e) M. J. Weiss, R. E. Schaub, G. R. Allen, Jr., J. F. Poletto, C. Pidacks, R. B. Conrow, and C. J. Coscia, *Tetrahedron*, **20**, 357 (1964); (f) H. O. House and T. M. Bare, *J. Org. Chem.*, **33**, 943 (1968).

(4) D. Caine, *ibid.*, **29**, 1868 (1964).

(5) H. O. House and B. M. Trost, *ibid.*, **30**, 2502 (1965).

(6) H. O. House, B. A. Tefertiller, and H. D. Olmstead, *ibid.*, **33**, 935 (1968).

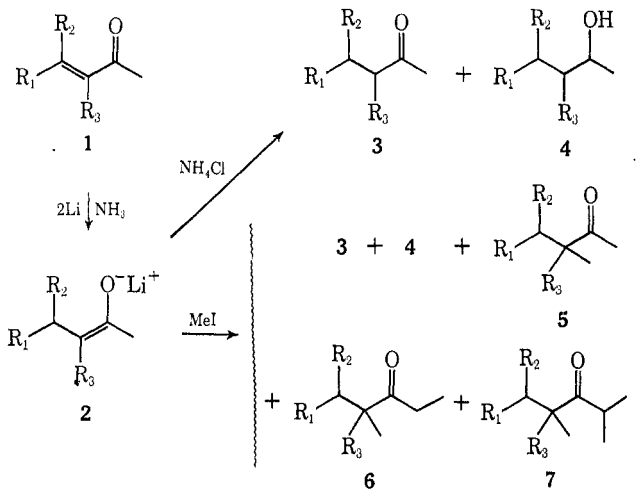
(7) D. Caine and B. J. L. Juff, *Tetrahedron Lett.*, 4695 (1966).

(8) D. Caine and B. J. L. Huff, *ibid.*, 3399 (1967).

(9) H. A. Smith, B. J. L. Huff, W. J. Powers, and D. Caine, *J. Org. Chem.*, **32**, 2851 (1967).

In order to establish that generation of the lithium enolates from **1** could be carried out in good yield, simple lithium–liquid ammonia reductions of enones **1a–1e** were performed. The enone (usually admixed with 1 equiv of a proton donor[9]) was added to 2 equiv of lithium in ammonia, followed by the addition of excess ammonium chloride to the mixture. The structures of the products isolated from enones **1a–1c** are shown in Scheme II, where **3** represents the α,β-dihydro product and **4** the saturated alcohol product in each case.

SCHEME II



Product analyses for the reduction experiments are shown in Table I. Every enone gave a satisfactory yield of **3**, either pure or containing no more than 7% of the saturated alcohol (**4**), when 1 equiv of *t*-butyl alcohol was added along with the enone. Significant quantities of alcohols have not been obtained in previous work on the reduction or reduction–alkylation of cyclic enones; in the present work they were likely formed by protonation of the enolate by the proton donor followed by further reduction by lithium. Smooth reduction to give **3** also resulted when triphenylmethanol was the proton donor; however, significant quantities (17–51%) of **4** were obtained with other donors. The extent of overreduction to give **4** does not correlate with the thermodynamic acidities of the donors.[10] However, such a correlation does obtain among the oxygen acid donors in Table I as well as between the nitrogen acid donors. It may be that the extent of overreduction depends upon the rate of attack of the donor on lithio carbanion aggregates and that initial coordination of nitrogen with lithium enhances the rate for nitrogen acids.

TABLE I
LITHIUM–LIQUID AMMONIA REDUCTIONS OF ENONES

Enone	Proton donor (1 equiv) used	Product composition, % 3	4	Yield, %
1a	*t*-BuOH	100	0	66[a]
1a	Ph_3COH	100	0	54[a]
1a	MeOH	83	17	
1b	*t*-BuOH	97	3[b]	61[a]
1c	*t*-BuOH	93[c]	7[c]	40,[a] 65[d]
1c	Ph_3COH	96	4	51[a]
1c	MeOH	78	22	
1c	Pyrrole	49	51	
1c	Ph_2NH	72	28	
1c	None	42	38[e]	
1d	*t*-BuOH	100	0	62[a]
1d	None	60	0[f]	
1e	Various[g]	100	0	97[d,h]
1e[i]	None	53	0[j]	

[a] Based on distilled material. [b] Not conclusively identified. [c] Average of two runs. [d] Based on vpc analysis using *m*-xylene as internal standard. [e] The product mixture also contained 20% starting enone **1c**. [f] The product mixture also contained 40% starting enone **1d**. [g] Separate trials gave the indicated product analysis with the following donors: acetic acid, water, pyrrole, *t*-butyl alcohol, diphenylamine, and triphenylmethane. [h] For trial using diphenylamine. [i] Data from ref 9. [j] The product mixture also contained 47% starting enone **1e**.

Previous work[9] has indicated that reduction of 2-cyclohexenones in the absence of a proton donor leads to recovery of significant quantities of starting enone, except with 3-methyl-2-cyclohexenone, which has a fully substituted β carbon. In contrast, Table I records that **1c**, which also has a fully substituted β carbon, gave 20% starting enone in the absence of a donor. It is noteworthy that **1e** was reduced smoothly to pure **3e** with a variety of proton donors, ranging from acetic acid (pk = 5) to triphenylmethane (pk = 33).[10] Conjugate addition by amide ion to form a reduction-resistant species has been suggested[9] to explain the recovery of enone in the reduction of **1e**; if so, it is interesting that even a proton donor so weakly acidic as triphenylmethane led to complete reduction of **1e**.

Results of Reduction–Methylation Experiments.—Reduction–methylations were carried out with compounds **1a–1d** by generating the enolate as described above for reduction and treating it with methyl iodide. An equal volume of ether was added before alkylation, as recommended previously.[9] The structures of the principal products (determined by spectroscopic techniques using samples collected by preparative-scale vpc) were as shown in Scheme II, where **5**, **6**, and **7** represent the mono-, di-, and trimethylation products, respectively. Each α,β-dihydro product (**3**) was identical with that produced by simple reduction. In addition, **5a**, the monomethylation product from **1a**, was identical with **3b**, the simple reduction product from **1b**; similarly, **5d** was identical with **3e**. In each case, the only monomethylation product (**5**) obtained was that derived from the specific enolate produced in the reduction step; *i.e.*, the α-methyl derivative was obtained but not the α'-methyl. This observation agrees with the established principle that the *lithium* enolates of ketones can be trapped by reactive alkylating agents without appreciable equilibration among the structurally isomeric enolates.[2–9]

Table II records the product analyses for some reduction–methylation experiments. Unlike substituted cyclohexenones[9] and other cyclic enones,[2] reduction–methylation of open-chain enones **1a–1c** gave rise to substantial quantities of polymethylation products (**6**, **7**), even when 1 equiv of methyl iodide was employed (Table II, expt 1, 2, and 8–10).

As a consequence of the proton donor employed in the reduction step, 1 equiv of the conjugate base of the donor (*e.g.*, lithium *t*-butoxide when *t*-butyl alcohol was

(10) D. J. Cram, "Fundamentals of Carbanion Chemistry," Academic Press Inc., New York, N. Y., 1965, Chapter 1.

TABLE II

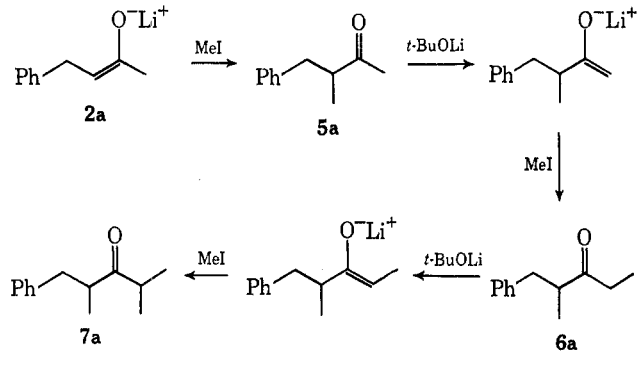
REDUCTION–METHYLATION OF ENONES IN ETHER–LIQUID AMMONIA

Expt	Enone	Proton donor (1 equiv) used	Equiv of compound added before methylation	Equiv of MeI	Product composition, % 3	4	5	6	7	Yield,[a] %
1[b]	1a	*t*-BuOH	...	1	23	0	54	16	7	66[c]
2	1a	*t*-BuOH	...	6	2	0	48	41	9	
3	1a	*t*-BuOH	1.0 *t*-BuOLi	6	1	0	13	20	66	
4	1a	Ph_3COH	...	6	20	0	73	7	0	69[d]
5	1a	Ph_3COH	0.5 Ph_3COLi	6	23	0	58	19	0	
6	1a	*t*-BuOH	1.0 **3d**[e]	6	5	0	50[f]	26	10	
7	1a	*t*-BuOH	...	24[g]	12	0	85	1	2	
8[b]	1b	*t*-BuOH	...	1	28	0	62	8[h]	2[h]	75[c]
9[b]	1c	*t*-BuOH	...	1	21	8	52	10	6[i]	79[c]
10[b]	1c	*t*-BuOH	...	3–5	1	9	34	33	23	
11	1c	Ph_3COH	...	3	9	7	75	8	0	84[d]
12	1d	*t*-BuOH	...	4	14	0	86	0	0	90[d]
13	1d	*t*-BuOH	1.0 **3a**[j]	6	10	0	90	0	0	
14[k]	1e	*t*-BuOH	...	6	7	0	93	0	0	46

[a] The total yield of all products, including starting material, is recorded. [b] Average of two runs. [c] Based on distilled material considering it to be only monoalkylation product. [d] Based on vpc analysis using *m*-xylene as internal standard. [e] 4,4-Dimethylcyclohexanone. Vpc indicated that 12% of **3d** was converted into 2,4,4-trimethylcyclohexanone (**5d**) in this experiment. [f] An unidentified product, 8%, with vpc retention time similar to that of **5** was detected. [g] Six equivalents of acetone added with MeI. [h] Not conclusively identified. [i] Vpc showed 3% unidentified high-boiling material. [j] Vpc indicated that 41% of **3a** had been converted into alkylation products in this experiment. [k] Data from ref 9.

the donor) was present during the alkylation step. A comprehensive study by House and Trost[5] of the alkylation of lithium enolates in 1,2-dimethoxyethane solution in the presence of lithium *t*-butoxide[11] indicated that this base was principally responsible for the polyalkylation they observed. In the present study, polymethylation products would be expected to result from the lithium alkoxide present during methylation, as depicted for the polymethylation of **2a** in Scheme III.

SCHEME III



Ancillary data on the effect of lithium alkoxides was provided by an investigation of the methylation of some saturated ketones in conditions similar to reduction–methylation experiments, and the results are recorded in Table III. The literature contains several examples of the alkylation of ketones in the presence of sodium or potassium alkoxides in solvents such as ethers, hydrocarbons, and alcohols,[12] but the use of lithium alkoxides in ammonia has not been reported.

Each of the open-chain saturated ketones **3a–3c** underwent substantial mono- and dimethylation in ether–ammonia when treated with 1 equiv of lithium *t*-butoxide followed by excess methyl iodide. The methylation products in each case were those derived from successive replacement of hydrogen at the *less* highly substituted α carbon. The methylation of **3b** was particularly noteworthy in that the starting material was identical with **5a**, the monomethylation product in reduction–methylation of **1a** (Table II, expt 2). The higher methylation products had identical structures in the two experiments. Although methylation could also be carried out using lithium amide (see Table III), the presence of this base during reduction–methylation is ruled out by the presence of the proton donor, an acid much stronger than ammonia. Also, lithium amide forms a suspension in ether–ammonia, whereas homogeneous mixtures were observed in reduction–methylation.

Further evidence for the effect of lithium *t*-butoxide was obtained by the addition of an equimolar amount of that compound (thus doubling its concentration)

TABLE III

METHYLATION[a] OF KETONES IN ETHER–LIQUID AMMONIA USING LITHIUM *t*-BUTOXIDE

Ketone	Product composition, % Starting material	Monomethylation product	Dimethylation products
3a[b]	50	43[c]	7[d]
3b (**5a**)[e,f]	43	46[g]	11[h]
3c	24	58[i]	18[j]
3c[k]	45	55	0
3d	70	30[l]	0
3e (**5d**)[m]	75	25[n]	0

[a] Unless otherwise indicated, 6 equiv of MeI and 1 equiv of *t*-BuOLi were employed in each experiment. [b] Total ketone recovery was 65% using *m*-xylene internal vpc standard. [c] Probably 1-phenyl-3-pentanone. [d] Mixture of two components believed to be isomeric dimethylation products. [e] Average of two runs. [f] Total ketone recovery was 70% using *m*-xylene internal vpc standard. [g] Identical with **6a**. [h] Identical with **7a**. [i] 5-Methyl-3-hexanone. [j] Mixture of three or more components; major component 2,5-dimethyl-3-hexanone. [k] Lithium amide was employed as base in this experiment. [l] 2,4,4-Trimethylcyclohexanone. [m] Four equivalents of MeI were employed in this experiment. [n] 2,4,4,6-Tetramethylcyclohexanone.

(11) One equivalent lithium *t*-butoxide was produced as a consequence of the reaction by which specific enolates were generated by these workers: the treatment of 1 equiv of an enol acetate with 2 equiv of methyllithium.

(12) See H. O. House, "Modern Synthetic Reactions," W. A. Benjamin, Inc., New York, N. Y., 1965, pp 184–189.

to **2a** before methylation (Table II, expt 3). A substantial increase in total polymethylation products resulted (*cf.* expt 2). The increase in the *extent* of polymethylation was greater than indicated by a simple comparison of percentages, since the trimethylation product (**7a**) (66% in expt 2) was derived from a monomethylation product which had been alkylated two additional times.

In an effort to find an effective proton donor whose conjugate base would cause less polymethylation, triphenylmethanol was employed (Table II, expt 4 and 11). Much less polymethylation resulted (*cf.* expt 2 and 10) and a good yield of relatively pure **5** was obtained. The addition of lithium triphenylmethoxide before methylation (expt 5) increased polymethylation, but not as much as *t*-butoxide.

Triphenylmethanol is the reagent of choice as proton donor in reduction–methylation syntheses, based on its effect in promoting effective reduction and minimizing polymethylation. The lower extent of polymethylation may be due to steric factors, the base strength of triphenylmethoxide, or aggregation of lithium triphenylmethoxide.

It is possible that part of the polymethylation comes as a result of ionization of ketonic products (*e.g.*, **5**) by unreacted enolate **2**. This proton-transfer reaction would result in formation of the α,β-dihydro product **3**, which was indeed obtained in each reduction–methylation experiment. Direct evidence against appreciable proton transfer of this type came from expt 6 and 13 of Table II, in which an equimolar quantity of a structurally dissimilar, saturated ketone was added to enolate **2** *before* methylation. No appreciable increase in the proportion of **3** compared with control experiments (expt 2 and 12) was found. It seems likely that **3** arose, as suggested previously,[9] from protonation of **2** by methylammonium ion derived from methyl iodide solvolysis. This view is supported by an experiment in which methyl iodide was stirred in liquid ammonia for 15 min and then added to a solution of enolate **2e**. No methylation products were detected and 79% **3e** was obtained.

The failure to observe appreciable enolate equilibration suggested a procedure to minimize polymethylation. A large excess of methyl iodide admixed with excess acetone was added to enolate **2a** (Table II, expt 7). The monomethylation product (**5a**) comprised 85% of the product mixture, total polymethylation amounted to only 3%, and only a moderate quantity of **3a** (12% compared with 2% in expt 2) was obtained.

The structures of the methylation products obtained in the experiments of Tables II and III indicates that each is derived from the less highly substituted *kinetic* enolate.[4,13] The failure to observe substantial amounts of products derived from the more highly substituted enolates[14] suggests that lithium alkoxides may be more selective kinetically than trityllithium previously employed.[4,13]

The extent of polymethylation in the open-chain ketones investigated here is greater than in alicyclic ketones because the kinetic acidity of the former is greater. The possibility that alicyclic ketones are thermodynamically less acidic and do not transfer a proton to alkoxides in ammonia is eliminated by the successful methylation of **3d** and **3e** using lithium *t*-butoxide (Table III). Modest differences in the extent of polymethylation have previously been observed in the reduction–methylation of substituted 2-cyclohexenones.[9] The differences can probably be ascribed to slight differences in the kinetic acidities of the ketonic products.

(13) H. O. House and B. M. Trost, *J. Org. Chem.*, **30**, 1341 (1965).

(14) Kinetic studies[7,8] have shown comparable alkylation rates for structurally isomeric lithium enolates derived from cyclohexanones.

Experimental Section[15]

trans-**4-Phenyl-3-buten-2-one** (**1a**), **4-methyl-3-penten-2-one**[16] (**1c**), **4-methyl-2-pentanone** (**3c**), **and 4-methyl-2-pentanol** (**4c**) were commercial products.

2,4,4-Trimethyl-2-cyclohexenone (**1e**), bp 85–88° (20 mm), **2,4,4-trimethylcyclohexanone** (**3e**), bp 82° (20 mm), and **4,4-dimethyl-2-cyclohexenone** (**1d**), bp 79–80° (20 mm), were prepared as previously described.[9]

3-Methyl-4-phenyl-3-buten-2-one (**1b**) gave the following data: bp 117° (5 mm) [lit.[17] bp 130° (12 mm)]; ir 6.00 and 6.14 μ; nmr δ 1.82 (d, 3, J = 1 Hz, C-3 Me), 2.16 (s, 3, C-1 Me), 6.73 (s), and 6.81 (d, J = 1 Hz), total area 6 (C_6H_5 and —CH=, respectively). This compound was prepared in 58% yield by published methods.[18]

Anal. Calcd for $C_{11}H_{12}O$: C, 82.46; H, 7.55. Found: C, 82.36; H, 7.49.

Lithium *t*-butoxide was prepared by refluxing lithium metal with excess *t*-butyl alcohol (freshly distilled from sodium) and evaporating the excess alcohol *in vacuo* at 70°. Lithium triphenylmethoxide was prepared by treating triphenylmethanol in hexane under N_2 with *n*-butyllithium in hexane, heating to reflux, and distilling two-thirds of the solvent. The product was collected by suction filtration and dried *in vacuo*.

General Procedure for Lithium–Liquid Ammonia Reduction of Enones.—The reductions of the various α,β-unsaturated ketones were carried out as described previously[9] by adding dropwise under N_2 over a 20–30-min period an equimolar mixture of enone and proton donor in three volumes of ether to a stirred solution of *ca.* 2.2 g-atoms of lithium/1 mol of ketone in dry ammonia (distilled from sodium, *ca.* 0.5–1 ml per 1 mg of lithium). The reaction mixture usually remained blue; occasionally the blue color was discharged after *ca.* 90% of the enone was added, in which case the addition was stopped. The mixture was stirred for 20–30 min and excess NH_4Cl was added. After evaporation of the ammonia at room temperature and reaction mixture was worked up as before[9] in water and ether. The combined ether extracts were dried and concentrated to a small volume under reduced pressure. Vpc analysis[19] was carried out at this point; a weighed quantity of *m*-xylene was added to some product mixtures as an internal standard. In some trials, no internal standard was added and distillation was carried out after vpc analysis. In the reductions of **1c**, only about two-thirds of the ether was removed under reduced pressure; the remainder was taken off at atmospheric pressure by flash distillation through a 1 × 30 cm unpacked column.

(15) Melting points, determined on a Fisher-Johns apparatus, and boiling points were uncorrected. Ir spectra were determined with a Perkin-Elmer 137b spectrophotometer. Nmr spectra were determined at 60 MHz with a Varian A-60 spectrometer and unless otherwise stated are in CCl_4 solution relative to internal TMS. Analytical vpc was performed on an F & M Model 700 gas chromatograph with helium as the carrier gas. Product composition was calculated by the area normalization method. Preparative vpc was performed on a Microtek 2500R with nitrogen as the carrier gas. *t*-Butyl alcohol was refluxed over sodium and distilled. Methyl alcohol was distilled from magnesium methoxide. Acetic acid was distilled from acetyl borate. Pyrrole was dried over potassium hydroxide. Triphenylmethanol, diphenylamine, and triphenylmethane were used as received. Methyl iodide was distilled from phosphorus pentoxide. All ketone starting materials were distilled and were at least 99% pure by vpc. Lithium metal wire was a low-sodium product from Lithium Corp. of America. Microanalyses were carried out by Galbraith Laboratories, Inc., Knoxville, Tenn.

(16) Dried over Drierite and distilled using a spinning-band column.

(17) I. Heilbron, Ed., "Dictionary of Organic Compounds," Vol. IV, 4th ed, Oxford University Press, New York, N. Y., 1965, p 2294.

(18) (a) M. T. Bogert and D. Davidson, *J. Amer. Chem. Soc.*, **54**, 335 (1932); (b) J. D. Gettler and L. B. Hammett, *ibid.*, **64**, 1826 (1942).

(19) Unless otherwise noted, vpc analyses were carried out using a column packed with SE-30 silicone gum rubber.

Reductions of *trans*-4-Phenyl-3-buten-2-one (1a).—From 14.6 g (0.1 mol) of **1a**, 7.41 g (0.1 mol) of *t*-BuOH, and 1.60 g (0.23 g-atom) of lithium in 500 ml of ammonia was obtained 9.76 g (66%) of pure 4-phenyl-2-butanone (**3a**): bp 80–85° (8 mm) [lit.[20] bp 115° (13 mm)]; ir 5.83 μ; nmr δ 1.93 (s, 3), 2.34–3.00 (br, 4), and 7.12 (s, 5).

Anal. Calcd for $C_{10}H_{1}O_2$: C, 81.04; H, 8.16. Found: C, 81.15; H, 8.10.

In a similar run using MeOH as the proton donor, vpc analysis indicated that the product mixture consisted of 83% **3a** and 17% **4a**, identified by vpc retention time.

Reduction of 3-Methyl-4-phenyl-3-buten-2-one (1b).—From 12.6 g (0.079 mol) of **1b**, 5.84 g (0.079 mol) of *t*-BuOH, and 1.22 g (0.18 g-atom) of lithium in 1000 ml of ammonia was obtained 7.69 g (61%) of 3-methyl-4-phenyl-2-butanone (**3b**): bp 78–79.5° (1 mm) [lit.[18a] bp 127–130° (12 mm)]; ir 5.85 μ; nmr δ 0.91 (d, 3, J = 5.5 Hz, C-3 Me), 1.78 (s, 3, C-1 Me), 2.17–2.78 (br, 3), and 6.52 (s, 5). Vpc analysis indicated the presence of 3% of an impurity whose retention time was that expected for **4b**.

Anal. Calcd for $C_{11}H_{14}O$: 81.44; H, 8.70. Found: C, 81.26; H, 8.77.

Reductions of 4-Methyl-3-penten-2-one (1c).—From 9.82 g (0.1 mol) of **1c**, 7.42 g (0.1 mol) of *t*-BuOH, and 1.68 g (0.24 g-atom) of lithium in 500 ml of ammonia was obtained 3.98 g (40%) of material, bp 110–114°. Vpc analysis of the crude mixture indicated that it consisted of 94% 4-methyl-2-pentanone (**3c**) and 6% 4-methyl-2-pentanol (**4c**). The ir spectrum of the product was identical with that of authentic **3c** except for a small hydroxylic absorption at 2.85 μ. The vpc retention times of both **3c** and **4c** were identical with those of authentic compounds.

Additional runs were carried out with other proton donors, using *ca.* 2 g of enone and 400 ml of ammonia. In a run in which no donor was used, the product mixture contained 20% of starting enone **1c**, identified by vpc retention time.

Reductions of 4,4-Dimethyl-2-cyclohexenone (1d).—From 5.14 g (0.41 mol) of **1d**, 3.31 g (0.45 mol) of *t*-BuOH, and 0.65 g (0.94 g-atom) of lithium in 500 ml of ammonia was obtained 3.12 g (62%) of pure 4,4-dimethylcyclohexanone (**3d**), bp 88–91° (45 mm) [lit.[21] bp 73° (14 mm)], ir 5.83 μ.

Anal. Calcd for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 76.08; H, 11.11.

In a run in which no proton donor was added, the product mixture consisted of 60% **3d** and 40% starting enone **1d**, identified by vpc[22] retention times.

General Procedure for Reduction–Methylation of Enones.—The reduction step was carried out by the same general procedure described for the reduction runs. Approximate solubility measurements indicated limited solubility for lithium enolates and lithium *t*-butoxide in ammonia at −33°; however, the solubilities were greater in ether. Therefore, after 20–30 min of stirring the enolate mixtures were generally diluted with an equal volume of dry ether. The blue color was discharged during the addition. The enolate mixtures in ammonia usually contained suspended white solid material; the material dissolved when ether was added and clear, apparently homogeneous mixtures resulted. For the alkylation step, MeI (usually 6 equiv/mol of ketone used) in three volumes of ether was added dropwise with stirring over 10–20 min. The ammonia was allowed to evaporate at room temperature, and the reaction mixture was worked up in a manner identical with that described for the reduction runs. Vpc analysis was carried out after removal of most of the solvent but before distillation. In duplicate runs, the percentages of a given component generally agreed within 5%. In some runs a final distillation was carried out to obtain the yield of distillable material; yields were obtained in other runs by use of *m*-xylene as an internal standard for vpc analysis. Product analyses for various runs are recorded in Table II.

Reduction–Methylations of *trans*-4-Phenyl-3-buten-2-one (1a).—From 14.6 g (0.1 mol) of **1a**, 7.41 g (0.1 mol) of *t*-BuOH, 1.53 g (0.22 g-atom) of lithium in 600 ml of ether–ammonia, and 14.2 g (0.1 mol) of MeI was obtained 11.6 g (66% yield, assuming product to be only **5a**) of a mixture of ketones, bp 94–97° (3 mm), with the following composition: **3a**, 24%; **5a**, 55%; **6a**, 14%; and **7a**, 5%. In a similar run on *ca.* one-fifth the scale in 500 ml of ammonia, the product analysis was as follows: **3a**, 22%; **5a**, 52%; **6a**, 16%; and **7a**, 11%. The components were collected by preparative vpc, and (in order of elution) were identified as follows: **3a**, 4-phenyl-2-butanone, ir and nmr spectra and vpc retention time identical with those of **3a** from reduction runs; **5a**, 3-methyl-4-phenyl-2-butanone, ir and nmr spectra and vpc retention time identical with those of **3b** from reduction of **1b**; **6a**, 2-methyl-1-phenyl-3-pentanone, ir 5.83 μ, nmr δ 0.90 (t, J = 6 Hz) and 1.03 (d, J = 5 Hz), total area 6 (C-5 and C-2 Me, respectively), 1.92–3.03 (br, 5), and 7.13 (s, 5), 2,4-dinitrophenylhydrazone mp 94–95° (lit.[23] mp 95–96°). The nmr spectrum indicated small quantities (<10%) of another compound, which was probably an isomer of **6a**. Compound **7a** was eluted last, and although the spectral data were not conclusive in this case, the structure most consistent with the data was 2,4-dimethyl-1-phenyl-3-pentanone: ir 5.83 μ; nmr δ 0.80 (d, J = 7 Hz), 0.97 (d, J = 7 Hz), 9.04 (d, J = 6.5 Hz) (total area 0.70–1.20, 9), 1.91–3.17 (br, 4), and 7.13 (s, 5).

In expt 3 and 5, Table II, lithium alkoxide was added after generation of the enolate in the usual manner. The mixture was stirred for 10 min before addition of MeI.

In expt 6, Table II, 1 equiv of 4,4-dimethylcyclohexanone (**3d**) was added to the enolate mixture, followed immediately by MeI. An unidentified compound, 8% of the total material derived from **1a**, eluted between **3a** and **5a** upon vpc analysis. Of the material derived from **3d**, 88% was recovered **3d** and 12% was **5d**.

In expt 7, Table II, a mixture of 6 equiv of dry acetone and 24 equiv of MeI was added as rapidly as possible to the enolate generated from **1a**.

Reduction–Methylations of 3-Methyl-4-phenyl-3-buten-2-one (1b).—From 16.0 g (0.1 mol) of **1b**, 7.41 g (0.1 mol) of *t*-BuOH, 1.53 g (0.22 g-atom) of lithium in 600 ml of ether–ammonia, and 14.2 g (0.1 mol) of MeI was obtained 10.6 g of material, bp 101–110° (6 mm). The blue color was discharged after 80% of **1b** had been added and the addition was stopped. The yield was 75%, based upon the quantity of **1b** added and assuming the mixture to consist of only **5b**. The major components of the product mixture were collected by preparative vpc and were identified as follows (in order of elution): **3b**, 2-methyl-4-phenyl-2-butanone, ir spectrum and vpc retention time identical with those of **3b** obtained in reduction runs; **5b**, 3,3-dimethyl-4-phenyl-2-butanone, ir 5.83 μ, nmr δ 1.07 (s, 6, CMe_2), 1.99 (s, 3, COMe), 2.74 (s, 2, $PhCH_2$), and 7.13 (s, 5). Compounds **6b** and **7b** were not isolated but gave vpc retention times expected for di- and trimethylation products. The crude product composition was as follows: **3b**, 35%; **5b** 57%; **6b**, 7%; and **7b**, 1%. In a similar run the composition was as follows: **3b**, 21%; **5b**, 67%; **6b**, 10%; and **7b**, 2%.

Reduction–Methylations of 4-Methyl-3-penten-2-one (1c).—From 9.82 g (0.1 mol) of **1c**, 7.41 g (0.1 mol) of *t*-BuOH, 1.53 g (0.22 g-atom) of lithium in 800 ml of ether–ammonia, and 14.2 g (0.1 mol) of MeI was obtained 9.1 g (79%, assuming the mixture to be only **5c**) of distilled material. The major components of the product mixture were collected by preparative vpc and identified as follows (in order of elution): **3c**, 4-methyl-2-pentanone, vpc retention time identical with that of **3c** from reduction runs; **4c**, 4-methyl-2-pentanol, ir 2.95 μ, nmr δ 0.91 (d, 6, J = 6 Hz), 1.14 (d, 3, J = 6 Hz), 1.67–2.34 (br, 3), 3.79 (br, 1, CHOH), and 4.77 (br s, 1, OH), vpc retention time identical with that of authentic **4c**; **5c**, 3,4-dimethyl-2-pentanone, ir 5.83 μ, nmr δ 0.84 (d, J = 6.5 Hz), 0.90 (d, J = 6 Hz), 0.98 (d, J = 6.5 Hz) (total area 0.70–1.10, 9), 2.05 (s, 3), 1.61–2.53 (br, 2), 2,4-dinitrophenylhydrazone mp 94.5–95.5° (lit.[24] mp 94–95°); **6c**, 4,5-dimethyl-3-hexanone, ir 5.83 μ, nmr δ 0.83 (d, J = 6.5 Hz), 0.90 (t, J = 6.5 Hz), 0.91 (d, J = 7 Hz), 1.01 (d, J = 7.5 Hz) (total area 0.70–1.20, 12), 1.50–2.60 (br, 2), and 2.40 (q, J = 7.5 Hz). The nmr spectrum was nearly identical with that of **5c** in the δ 1.0 region except for the triplet at δ 0.90. The nmr spectrum is clearly consistent with the postulated structure and inconsistent with 3,3,4-trimethyl-2-pentanone, which would result from methylation of **5c** at the more highly substituted α position. Compound **7c**, 2,4,5-trimethyl-3-hexanone, was eluted

(20) I. Heilbron, Ed., "Dictionary of Organic Compounds," Vol. IV, 4th ed, Oxford University Press, New York, N. Y., 1965, p 2675.

(21) I. Heilbron, Ed., "Dictionary of Organic Compounds," Vol. II, 4th ed, Oxford University Press, New York, N. Y., 1965, p 1163.

(22) A Carbowax 20M column was used; SE-30 did not separate **1d** and **3d**.

(23) R. Jacquier, *Bull. Soc. Chim. Fr.*, 1653 (1956); *Chem. Abstr.*, **51**, 8023*e* (1958).

(24) A. P. Meshcheryakov and L. V. Petrov, *Izv. Akad. Nauk SSSR Otd. Khim. Nauk*, 1057 (1955); *Chem. Abstr.*, **50**, 11239*f* (1956).

next: ir 5.83 μ; nmr δ 0.70–1.15 (complex set of sharp peaks, 15), *ca.* 1.80 (m, 1, J = 7 Hz), and *ca.* 2.40 (m, 2, J = 7 Hz). The nmr spectrum is clearly consistent with the postulated structure. The alternative structure, 4,4,5-trimethyl-3-hexanone, which would result from methylation of **6c** at the more highly substituted α position, is inconsistent in that it requires a quartet centered at *ca.* δ 2.40; the spectrum has a clear multiplet of at least sixth order in this region. The crude product composition follows: **3c**, 24%; **4c**, 5%; **5c**, 53%; **6c**, 11%; **7c**, 4%; and unidentified high-boiling material, 4%. A similar run on a smaller scale gave the following composition: **3c**, 17%; **4c**, 11%; **5c**, 51%; **6c**, 9%; **7c**, 7%; and unidentified high-boiling material, 3%.

Reduction–Methylations of 4,4-Dimethylcyclohex-2-enone (1d).—From 2.00 g (0.016 mol) of **1d**, 1.197 g (0.016 mol) of *t*-BuOH, 0.255 g (0.037 g-atom) of lithium in 750 ml of ether–ammonia, and 9.0 g (0.06 mol) of MeI was obtained 0.89 g (45% assuming the product to be only **5d**) of material, bp 75–85° (40 mm). Analysis by vpc[25] gave a composition of 30% **3d** and 70% **5d**, identified by comparison of retention times with those of authentic compounds from reduction runs.

In another run, the enolate was generated as usual from 1.243 g (0.01 mol) of **1d**, 0.741 g (0.01 mol) of *t*-BuOH, and 0.152 g (0.022 g-atom) of lithium in 800 ml of ether–ammonia. 4-Phenyl-2-butanone (**3a**), 1.485 g (0.01 mol), was added to the stirred mixture followed immediately by 8.52 g (0.06 mol) of MeI. For the material derived from **1d**, vpc analysis gave the following composition: **3d**, 10%; **5d**, 90%. For the material derived from **3a**, vpc analysis gave the following composition: **3a**, 59%; and two later eluting components, 38 and 3%. These two components gave vpc retention times similar, but not identical, with those of **5a** and **6a** and were probably isomeric mono- and dimethylation products.

Methylation of Saturated Ketones.—The saturated keton in three volumes of ether was added dropwise with stirring over 10 min to a solution of *t*-BuOLi in 1:1 ether–ammonia under N_2. The mixture was stirred for 10 min and MeI in three volumes of ether was added dropwise over 5 min. After 15 min, excess NH_4Cl was added and the mixture was worked up and analyzed as usual. The methylation of **3a** gave a monomethylation product with a vpc retention time similar but not identical with that of **5a**, probably the isomeric compound 1-phenyl-3-pentanone. The major dimethylation product had a vpc retention time identical with that of **6a**. Compounds **3d** and **3e** gave 2,4,4-trimethylcyclohexanone and 2,4,4,6-tetramethylcyclohexanone, respectively, with vpc retention times identical with those of authentic materials. Compound **3b** (**5a**) gave a mixture of three components which were collected by vpc and shown to be **5a**, **6a**, and **7a** by comparison of ir and nmr spectra with those of material from reduction–methylation runs. Compound **3c** gave a mixture of four or more methylation products. The two major components were collected by vpc and assigned structures as follows: 5-methyl-3-hexanone, nmr δ 0.90 (d, 6, J = 6 Hz, $CHMe_2$), 0.99 (t, 3, J = 7.5 Hz, CH_2CH_3), 2.22 (d, 2, J = 2 Hz, $CHCH_2$), *ca.* 2 (br, CH), and 2.33 (q. 2, J = 7.5 Hz, CH_2CH_3); and 2,5-dimethyl-3-hexanone, nmr 0.90 (d, 6, J = 6 Hz, CMe_2), 1.03 (d, 6, J = 6.5 Hz, CMe_2), 2.23 (d, 2, J = 2 Hz, CH_2), and *ca.* 2–2.5 (br, 2, CH).

(25) An Apiezon L column was used for the analysis. A second analysis on Carbowax 20M indicated the absence of starting material (**1d**).

Registry No.—**1a**, 1896-62-4; **1b**, 1901-26-4; **1c**, 141-79-7; **4c**, 108-11-2; **5b**, 13705-37-8; **5c**, 565-78-6; **6a**, 23936-95-0; **6c**, 6137-14-0; **7a**, 23936-97-2; **7c**, 23936-98-3; 5-methyl-3-hexanone, 623-56-3; 2,5-dimethyl-3-hexanone, 1888-57-9.

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On the Conformation of *endo*-Bicyclo[3.3.1]nonan-3-ol. A New Synthesis of Oxaadamantane

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The results of spin-decoupling and variable-temperature nmr studies show a conformational equilibrium to be occurring in *endo*-bicyclo[3.3.1]nonan-3-ol. From the magnitude of the coupling constants, it is concluded that the major conformer is the chair–boat form. On the basis of a facile radical oxidation of the alcohol to the bridged ether, oxaadamantane, it is suggested that the minor conformer is the chair–chair form.

Transannular reactions commonly observed in medium-ring compounds have been widely studied, and generally interpreted on the basis of proximity effects.[2] As part of a continuing investigation on transannular radical and carbenoid reactions,[3] we have examined the bicyclo[3.3.1]nonane system, a potentially interesting homolog of cyclooctane.

In cyclooctane itself, the theoretically most stable conformation is the boat–chair, **1**.[4] Calculations also show that the crown form, **2**, and slightly modified

1 2 3

forms thereof are somewhat disfavored relative to **1**, the differences in energy content being small and on the order of 2–3 kcal/mol.[4] Another conformer, **3**, is easily excluded in all calculations owing to the nonbonded interactions between the *endo* hydrogens. These theoretical conclusions have been supported by

(1) (a) To whom inquiries should be addressed. (b) Chargé de Recherches au CNRS; Boursier de l'OTAN, 1968–1969.

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