TABLE III

RATES OF REACTION WITH 3-PENTANONE (**5a**) AND 2,4-DIMETHYL-3-PENTANONE (**5b**)

Organomagnesium reactant	Ketone	Reaction time, sec.	k,[a] l. mole^{-1} sec.$^{-1}$	Product composition, %		
				5	**9** (reduction)	**7** (addition)
0.261 M Et_2Mg	0.155 M **5a**	0.0251	...	3	<1	97
.261 M Et_2Mg	.155 M **5a**	.0186	>2500	3	<1	97
.261 M $Et_2Mg_2Br_2$	.155 M **5a**	...[b]	...	1	1	98
.261 M $Et_2Mg_2Br_2$	.155 M **5a**	.101	37	46	<1	54
.261 M $Et_2Mg_2Br_2$	.155 M **5a**	.0312	50	69	<1	31
.261 M $Et_2Mg_2Br_2$	.155 M **5a**	.0186	44	83	<1	17
.261 M $Et_2Mg_2Br_2$	.077 M **5a**	.0789	28	58	<1	42
.261 M $Et_2Mg_2Br_2$	.077 M **5a**	.0320	48	68	<1	32
.137 M $Et_2Mg_2Br_2$	.074 M **5a**	.0935	45	60	<1	40
		average	43 ∓ 6			
.261 M Et_2Mg + 0.261 M $MgBr_2$	.155 M **5a**	.0186	44	83	<1	17
.261 M $Et_2Mg_2(OR)_2$[c,d]	.155 M **5a**	...[b]	...	26	5	69
.261 M $Et_2Mg_2(OR)_2$[c,d]	.155 M **5a**	.0814	...[e]	42	2	56
.261 M $Et_2Mg_2(OR)_2$[c,d] + 0.522 M $MgBr_2$	.155 M **5a**	...[b]	...	1	1	98
.261 M $Et_2Mg_2(OR)_2$[c,d] + 0.522 M $MgBr_2$	.155 M **5a**	.0269	46	74	<1	26
.261 M $Et_2Mg_2(OR)_2$[c,f]	.155 M **5a**	.0814	...[g]	34	4	62
.261 M Et_2Mg	.155 M **5b**	...[b]	...	0	6	94
.261 M Et_2Mg	.155 M **5b**	.0821	33	54	2	43
.261 M Et_2Mg	.077 M **5b**	.0821	39	47	2	50
.137 M $Et_2Mg_2Br_2$	.074 M **5b**	.429	<0.2	100	<1	<1

[a] These rate constants were calculated using the expressions rate = $k\ [Et_2Mg_2Br_2]$ [ketone] or rate = $k\ [Et_2Mg]$ [ketone] for experiments performed in the absence of magnesium bromide. For the reactions of ethylmagnesium bromide with 3-pentanone (**5a**) first-order rate constants, calculated using the expression rate = $k[Et_2Mg_2Br_2]$, ranged from 1.7 to 6.4 sec.$^{-1}$. The reactants were brought to 25.0° prior to mixing. See ref. 37. [b] These runs, used to determine the product composition after complete reaction, were made by mixing the reactants in the flowing-stream apparatus and collecting the product from the exit under nitrogen in a dry flask. After the mixtures had been allowed to stand for 15 min. they were quenched and analyzed in the usual way. [c] R = $C_2H_5(n\text{-}C_3H_7)_2C$. [d] See Table I, footnote *h*. [e] Because of the extensive amount of enolization as a side reaction, no effort was made to calculate a rate constant. However, the data indicate that the addition reaction was 81% complete in this time period. [f] See Table I, footnote *c*. [g] These data, the result of a single run, indicate that the ethylmagnesium alkoxide **6a** prepared in this way (footnote *f*) is not substantially more or less reactive than the reagent obtained by reaction of ethylmagnesium with one equivalent of 4-heptanone (footnote *d*).

experiments demonstrated that this analytical procedure did not inadvertently fractionate the reaction products.

To correct the reaction times (Table III) determined with pure ether for the slightly increased viscosity of the reaction mixtures, duplicate measurements were made of the time required to pass a given volume of representative reaction mixtures through the apparatus. The molar concentration values listed in Table III refer to the concentration of the reactants *after mixing* if no reaction had occurred. In each case the values have been corrected for the experimentally determined mixing ratios of the reactants. The data listed in Table III are average values from two determinations. In every case the calculated yields (or recovery) of products exceeded 90% and the deviations of individual value from the average values listed in Table III did not exceed 3%.

N.m.r. Spectra.—Although the peaks attributable to the methyl groups of the various ethylmagnesium derivatives, as approximately 1 M solutions in ether, were obscured by solvent absorption, the peaks attributable to the methylene groups were readily discernible. The diethylmagnesium solution has a quartet (J = 8 c.p.s.) of doublets (J = 1 c.p.s.) centered at 10.63 τ, the ethylmagnesium bromide has a quartet (J = 8 c.p.s.) of doublets ($J \sim 1$ c.p.s.) centered at 10.68 τ and the ethylmagnesium alkoxide **6a** has a quartet (J = 8 c.p.s.) of doublets ($J \sim 1$ c.p.s.) centered at 10.67 τ.

The Chemistry of Carbanions. IV. The Stereochemistry of Conjugate Grignard Addition[1]

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The reaction of $\Delta^{8,9}$-octal-1-one with phenylmagnesium bromide, either in the presence or absence of cuprous chloride has been found to yield mixtures of the allylic alcohol **5** and the saturated ketone having the stereochemistry indicated in structure **9**. Arguments are presented in support of the view that the conjugate addition of organomagnesium compounds is comparable to the Michael reaction and does not proceed *via* a six-membered cyclic transition state.

In continuing our study of the addition of organometallic compounds to conjugated ketones,[2] we were interested in learning the preferred stereochemistry of conjugate addition. Although previous studies of the cuprous ion-catalyzed addition of methyl Grignard reagents to the $\Delta^{1,9}$-octal-2-one system **1**[3] had led to the

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(1) This research has been supported in part by a research grant from the Solvay Process Division of the Allied Chemical Corporation and in part by grant no. 594A from the Petroleum Research Fund.

(2) H. O. House, D. D. Traficante, and R. A. Evans, *J. Org. Chem.*, **28**, 348 (1963) and references cited therein.

(3)(a) R. F. Church, R. E. Ireland, and D. R. Shridhar, *ibid.*, **27**, 707 (1962); (b) A. J. Birch and R. Robinson, *J. Chem. Soc.*, 501 (1943).

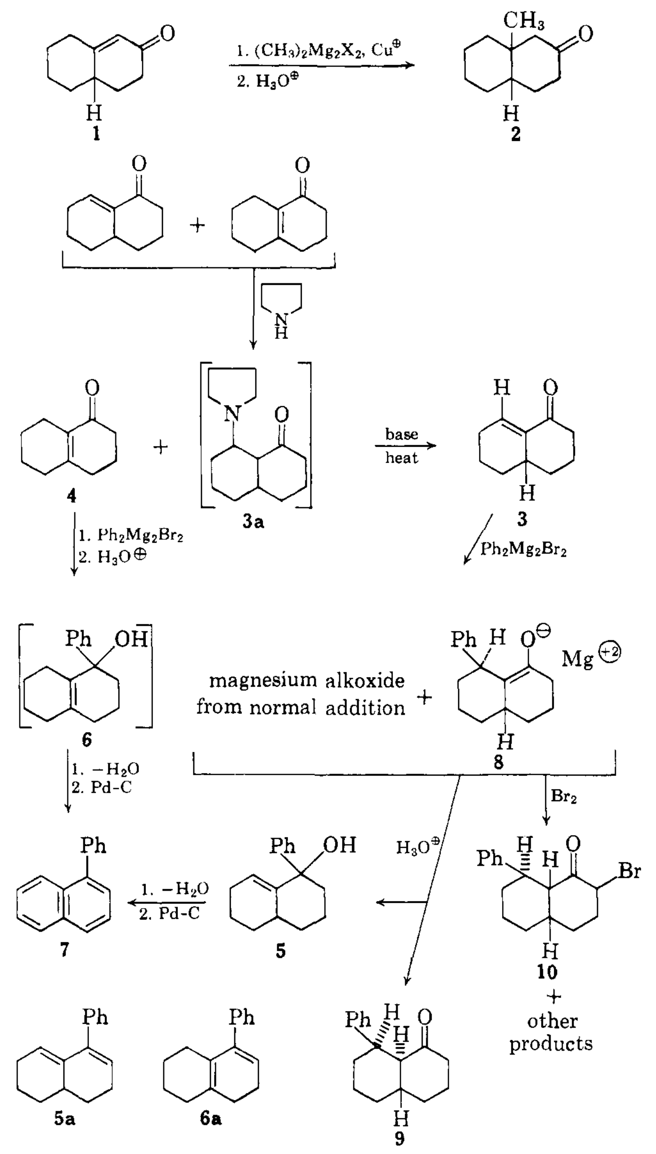

Chart I

cis-fused decalone system **2**, the fact that the unsaturated ketone **1** possesses, of necessity, a *transoid* arrangement of the conjugated double bonds causes difficulty in formulating the usual (although not necessarily valid) cyclic transition state **17**[2,4] for conjugate addition. Consequently, the stereochemistry observed in the transformation **1** to **2** might be regarded as atypical and it was desirable to examine the stereochemistry of conjugate addition to an unsaturated ketone which possessed a *cisoid* arrangement of the conjugated double bonds. For this purpose $\Delta^{8,9}$-octal-1-one (**3**)[5] seemed an ideal choice.

Accordingly, the reactions of the unsaturated ketones **3** and **4** summarized in Chart I were carried out. The greater susceptibility of the $\Delta^{8,9}$-octalone **3** to undergo conjugate nucleophilic addition when compared with the $\Delta^{9,10}$-octalone **4** was indicated both by the effective use of pyrrolidine to separate **3** and **4** and by finding that phenylmagnesium bromide adds in a conjugate manner to the ketone **3** but not to the ketone **4**. The proportion of the conjugate addition product **8** was increased, as expected, by addition of cuprous ion to the reaction mixture but the stereochemistry of the product was not altered.[6] The kinetically controlled reaction[7] of the enolate **8** with aqueous ammonium chloride afforded the ketone **9**.

The further transformations of the ketone **9**, used to establish its stereochemistry, are outlined in Chart II. The initially formed phenyl ketone **9** was epimerized to the more stable ketone **12** by treatment with base. Thus, the less stable ketone must be either **9** [destabilized by either an axial phenyl group (**9a**) or a boat conformation (**9b**) of one ring, see Chart III] or **11** [destabilized by a *cis*-decalin ring fusion (**11a** or less likely **11b**)]. The corresponding more stable epimers are consequently **12a** (conformation **12b** being most improbable because of the presence of both an axial phenyl group and a *cis*-decalin ring fusion) and **13**.[8] A

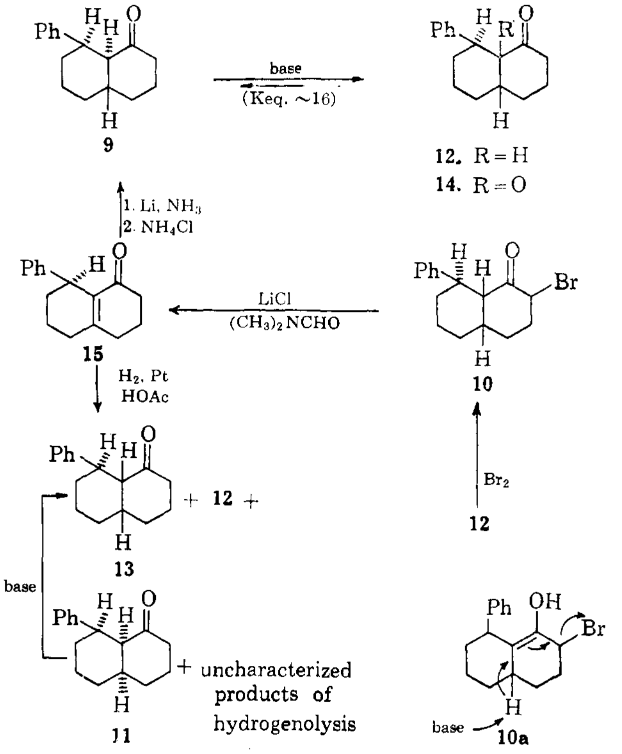

Chart II

choice from among these possible structures could be made by consideration of the n.m.r. spectra of the ketones **9** and **12** as well as the deuterated ketone **14**. In the spectrum of the less stable isomer **9**, the half band width (7 c.p.s.) of the peak (at 6.42 τ) attributable to the benzylic proton at C-8 indicates the absence (as in

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[4] (a) For a comprehensive review, see M. S. Kharasch and O. Reinmuth, "Grignard Reactions of Nonmetallic Substances," Prentice-Hall, Inc., New York, N. Y., 1954; (b) R. E. Lutz and W. G. Reverley, *J. Am. Chem. Soc.*, **63**, 3180 (1941).

[5] H. O. House and H. W. Thompson, *J. Org. Chem.*, **26**, 3729 (1961) and references therein.

[6] Y. Inouye and H. M. Walborsky [*ibid.*, **27**, 2706 (1962)] recently have found that the presence or absence of cuprous chloride does influence the direction of asymmetric induction in the conjugate addition of phenylmagnesium bromide. This example, unlike the case we have studied, indicates that when steric differences are very slight between additions to either side of a conjugated system, then the presence of cuprous chloride does alter the preferred direction of attack.

[7] (a) E. J. Corey and R. A. Sneen, *J. Am. Chem. Soc.*, **78**, 6269 (1956); (b) H. E. Zimmerman and W. H. Chang, *ibid.*, **81**, 3634 (1959); (c) H. E. Zimmerman and A. Mais, *ibid.*, **81**, 3644 (1959).

[8] For a discussion of the factors affecting the stability of cyclohexane and decalin ring systems, see E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., Inc., New York, N. Y., 1962.

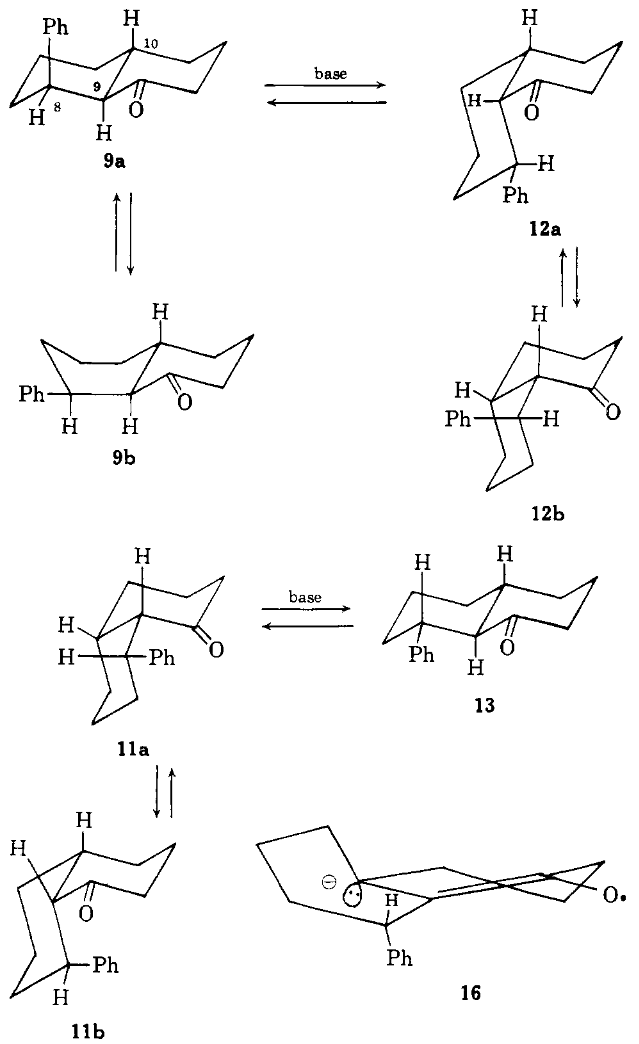
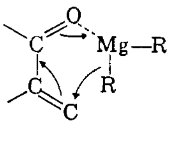


CHART III

9a) of vicinal *trans*, coplanar C-H bonds[9] as present in 11a. In the spectrum of the more stable isomer, the coupling constants (4, 10, and 10 c.p.s.) for the benzylic proton (6.87 τ) indicate the presence of two vicinal *trans*, coplanar C-H bonds and one vicinal nonplanar C-H bond[9] (as in 12a and 13), but the coupling constants (4 and 10 c.p.s.) for the proton at C-9 (7.38 τ) indicate the presence of one vicinal C-H bond which is *trans* and coplanar and a second which is not coplanar[9] as in 12a but not 13. The change in the chemical shift of the benzylic proton from 6.42 τ in 9 to 6.87 τ in 12 is also in keeping with the change from an equatorial to an axial proton.[9]

Reaction of the enolate **8** with bromine afforded a complex mixture from which two monobromo ketones, m.p. 110–112.5° and 150–157° dec., were isolated. The major product isolated, m.p. 150–157° dec., was also obtained by bromination of the ketone **12**. This product has been assigned structure **10** based on its n.m.r. spectrum and the n.m.r. spectrum of the corresponding dideuterated compound. The spectral properties (see Experimental) of this bromo ketone have led us to make the tentative stereochemical assignment indicated in structure **10.** It is probable that this product **10** is formed by isomerization of an initially formed 9-bromo ketone catalyzed by the hydrogen bromide present in the reaction mixture.[7c] The dehydrobromination (**10** → **15**) possibly involves conjugate elimination of the enol (as in **10a**).

Further evidence for the stereochemical assignments **9** and **12** was obtained by hydrogenation of the unsaturated ketone **15** to produce the ketones **13** and **11** with a lesser amount of the ketone **12** as would be anticipated from hydrogenation of the unsaturated ketone from the less hindered side. It was of interest to find that reduction of the unsaturated ketone **15** with lithium in liquid ammonia produced the ketone **9** since this reduction is usually considered to produce the most stable product provided that continuous piorbital overlap can be maintained.[10] However, an examination of molecular models suggests that one of the more stable conformations of the radical anion (or dianion) intermediate[10] in this reduction is that depicted in structure **16** in which the cyclohexane ring containing the phenyl substituent exists in a twisted boat conformation. In this conformation it is possible to relieve a serious steric interaction between the phenyl group and carbon-oxygen single bond.



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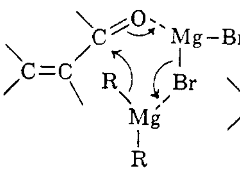

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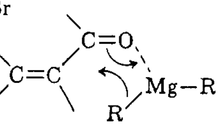

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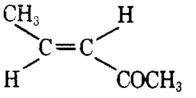
Although the structures **17** and **18** have served as rather popular representations for the transition states of conjugate (or 1,4-) and normal (or 1,2-) additions of organomagnesium compounds to α,β-unsaturated ketones,[2,4,11] we have discussed elsewhere[2,11] various reasons why the representation **18** (or any other representation requiring magnesium bromide as a necessary component of the transition state) is inadequate. The possibility that a cyclic four-center transition state (*e.g.*, **19**) is correct for normal (or 1,2-) addition remains a possibility[11] although there is certainly no evidence requiring it. The idea[4b] of a six-center transition state (*i.e.*, **17**) for conjugate addition was first seriously questioned by Alexander and Coraor.[12] These authors noted that both acyclic conjugated ketones such as **20** and cyclohexenone (**21**) gave comparable amounts of



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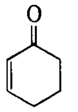

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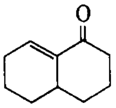

3

conjugate addition with a variety of organomagnesium compounds in spite of the fact that the necessarily *transoid* conjugated system in cyclohexenone (**21**) offers the worst possible geometry for attaining the transition state **17.** We have now found that the necessarily *cisoid* conjugated system in the octalone **3,** which should favor attaining the transion state **17,** gives 43% conju-

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[9] (a) J. I. Musher, *J. Am. Chem. Soc.*, **83**, 1146 (1961); (b) R. V. Lemieux, R. K. Kullnig, H. J. Bernstein, and W. G. Schneider, *ibid.*, **80**, 6098 (1959).

[10] (a) G. Stork and S. D. Darling, *ibid.*, **82**, 1512 (1960); (b) G. Stork and J. Tsuji, *ibid.*, **83**, 2783 (1961).

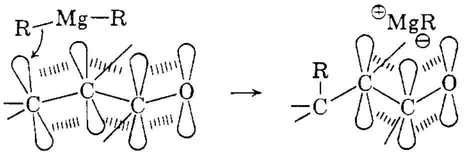
[11] H. O. House and D. D. Traficante, *J. Org. Chem.*, **28**, 355 (1963) and references cited therein.

[12] E. R. Alexander and G. R. Coraor, *J. Am. Chem. Soc.*, **73**, 2721 (1951).

gate addition with phenylmagnesium bromide whereas the acyclic ketone **20** gives 50% conjugate addition[2] under comparable conditions. This lack of sensitivity of conjugate addition to the geometry of the conjugated system, considered with the fact that there was never any experimental evidence[4] requiring a six-centered cyclic process in the first place, makes a cyclic process for conjugate addition appear most improbable.

The simplest interpretation consistent with the presently available data is that pictured in structures **22** and **23** wherein an alkyl group with its electron pair is transferred to the conjugated system, the accompanying development of negative charge in the enolate anion **23** being facilitated by electrostatic interaction with the positively charged magnesium species.[13] The question of whether the magnesium atom of the dialkylmagnesium is coordinately bound to the carbon-carbon double bond in an equilibrium step preceding the addition of the alkyl group can not be answered from the data presently available.

The presumption, anticipated on stereoelectronic grounds, that the organomagnesium compound attacks the unsaturated ketone from a direction perpendicular to the plane of the conjugated system accompanied by the assumption of attack from the less hindered side of the conjugated system serves to explain the stereochemical results observed with both ketones **1** and **3.** It should be noted that the reaction path proposed is essentially the counterpart of the mechanism of the Michael reaction except for the fact that the group being added has no discrete existence as a carbanion.[14]



21 **22**

Experimental[15]

Separation of the Octalones 3 and 4.—Preliminary experiments had established that an ethereal solution of pyrrolidine would react at room temperature with the octalone **3**, but not with the octalone **4**, to form a basic adduct (presumably **3a**) which could be separated and reconverted to the pure octalone **3**. Accordingly, the crude reaction mixtures obtained[5] by pyrolysis and distillation of 9-acetoxy-1-decalone were hydrolyzed with aqueous acid and subjected to the following separation procedure. A solution of 136 g. of the crude reaction mixture[5] and 116 g. of pyrrolidine in 136 ml. of ether was allowed to stand under nitrogen at room temperature for 24 hr. and then extracted with aqueous hydrochloric acid. This aqueous extract was made alkaline with sodium hydroxide and extracted with petroleum ether. After the petroleum ether solution had been washed with water (to remove the bulk of the pyrrolidine) it was concentrated and then heated under reflux for 1 hr. with a mixture of 600 ml. of 10% aqueous sodium hydroxide and 300 ml. of dioxane. The resulting mixture was diluted with water and extracted with petroleum ether. This organic layer was washed with aqueous hydrochloric acid, concentrated, and distilled to separate 29.4 g. of the octalone **3**, b.p. 68–71° (0.6 mm.), $n^{25}D$ 1.5154, containing[16] 96% of the unsaturated ketone **3** as well as 3% decalone and 1% of other impurities. The original neutral fraction (containing **3**, **4**, and other components) was carried through this separation procedure two more times to separate a total of 44.1 g. of $\Delta^{8,9}$-octal-1-one (**3**) from the original reaction mixture. The various fractions which failed to react with pyrrolidine were combined, concentrated to remove lower boiling materials (principally 1-decalone), and then chromatographed on Woelm, activity III, alumina to separate the octalone **4** in the early fractions.[17] Subsequent distillation separated 6.78 g. of the $\Delta^{9,10}$-octal-1-one (**4**), b.p. 77–82° (0.9 mm.), $n^{25}D$ 1.5283, containing[16] 2% of the octalone **3** and 1% of other impurities.

Reaction of $\Delta^{8,9}$-Octal-1-one (3) with Phenylmagnesium Bromide. (A) In the Presence of Cuprous Chloride.—To a solution of 35 ml. (0.063 mole) of 1.8 *M* ethereal phenylmagnesium bromide was added 500 mg. (0.005 mole) of cuprous chloride and 5 g. (0.033 mole) of the octalone **3**. After the mixture had been stirred at room temperature under a nitrogen atmosphere for 4 hr., basic, saturated aqueous ammonium chloride was added to precipitate the magnesium salts. After the mixture had been filtered and the precipitate washed with ether, the combined ether solutions were dried and concentrated. During the concentration 2.6285 g. (34.6%) of the crude saturated ketone **9**, m.p. 72–82°, separated. Recrystallization from a petroleum ether–hexane mixture followed by sublimation (90° at 0.25 mm.) afforded the pure ketone **9** as white plates, m.p. 85–86°. The product has infrared absorption[18] at 1708 cm.$^{-1}$ (C═O) with a series of weak ultraviolet maxima[19] (ϵ 230 at 259 mμ) in the region 250–270 mμ as well as a maximum at 286.5 mμ (ϵ 25.2) and n.m.r. absorption[18] at 2.88 τ (5H, aryl C—H) and at 6.42 τ (1H, see Discussion) with complex absorption in the region 7.5–9.0 τ (14H).

Anal. Calcd. for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 84.20; H, 8.99.

The mother liquors, containing[16] biphenyl, the ketone **9** (and/or **12**) and the alcohol **5** (eluted from the gas chromatograph as a diene), were chromatographed on 250 g. of Woelm, activity III, alumina to separate these components. After collection of the biphenyl (eluted with hexane), the ketone **12** (eluted with mixtures of 5–10% ether in hexane) was collected as 1.33 g. (17.5%) of white solid, m.p. 95–101°. Recrystallization from petroleum ether afforded the pure ketone **12** as white needles, m.p. 100–101°, with infrared absorption[18] at 1708 cm.$^{-1}$ (C═O) with a series of weak ultraviolet maxima[19] (ϵ 216 at 258 mμ) in the region 250–270 mμ as well as a maximum at 291.5 mμ (ϵ 37.9) and n.m.r. absorption[18] at 2.87 τ (5H, aryl C—H) with multiplets centered at 6.87 τ and 7.38 τ (1H each, see Discussion) and complex absorption in the region 7.6–8.8 τ (13H).

Anal. Calcd. for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 83.98; H, 8.96.

From the fractions eluted with 1% ether in hexane, concentration, sublimation, and subsequent recrystallization from petroleum ether afforded 10 mg. of the phenyl ketone **11** as white needles, m.p. 116.5–117.5°, identified with the subsequently described sample by a mixed melting-point determination and comparison of infrared spectra.

Concentration of the fractions eluted with 25% ether in hexane left 2.0 g. (26%) of the crude alcohol **5** (probably a mixture of stereoisomers) as a viscous liquid. Distillation of a portion of this material in a short-path still (115–120° at 0.02 mm.) afforded the alcohol as a colorless viscous liquid, $n^{25}D$ 1.5674, with infrared absorption[18] at 3595 cm.$^{-1}$ (unassoc. O—H) and 3460 cm.$^{-1}$ (assoc. O—H) and no absorption in the 6-μ region attributable to a carbonyl function. This material has a series of weak ultraviolet maxima[19] (ϵ 242 at 258.5 mμ) in the

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[13] It is probable that other ligands, *e.g.*, solvent, magnesium halide, or dialkylmagnesium, are also coördinately bound to the magnesium atom from which the alkyl group is being transferred. The primary effects expected from these ligands would be to facilitate transfer of the alkyl group (by lessening the electron deficiency about magnesium) and to increase the steric bulk of the attacking reagent.

[14] A variety of experiments have indicated that the C-Mg bond of dialkylmagnesium compounds is covalent rather than ionic. See ref. 2, footnote 18.

[15] All melting points are corrected and all boiling points are uncorrected. Unless otherwise stated magnesium sulfate was employed as a drying agent. The infrared spectra were determined with a Perkin-Elmer, Model 21, infrared recording spectrophotometer fitted with a sodium chloride prism. The ultraviolet spectra were determined with a Cary recording spectrophotometer, Model 11. The n.m.r. spectra were determined at 60 Mc. with a Varian, Model A-60, n.m.r. spectrometer. The mass spectra were obtained with a CEC, Model 21-130, mass spectrometer. The microanalyses were performed by Dr. S. M. Nagy and his associates and by the Scandinavian Microanalytical Laboratory.

[16] A gas chromatography column packed with Dow-Corning silicone fluid, no. 710, on ground firebrick was employed.

[17] Isolation of the 9-hydroxy-1-decalones from the later fractions is described elsewhere. H. O. House and H. W. Thompson, *J. Org. Chem.*, **28**, 164 (1963).

[18] Determined as a solution in carbon tetrachloride.

[19] Determined as a solution in 95% ethanol.

region 250–270 mμ and n.m.r. absorption[18] centered at 2.75 τ (5H, multiplet, aryl C—H) and at 3.99 τ (1H, triplet with J = 4 c.p.s., vinyl C—H) as well as complex absorption in the region 7.5–9.0 τ (14 H). Since repeated efforts to obtain an analytically pure sample of the alcohol **5** [found: C, 83.72; H, 8.84] were unsuccessful, the material was dehydrated by passing it through a gas chromatographic column.[16] The diene (presumably **5a**), collected and redistilled in a short-path still (130°) at 0.85 mm.), has no infrared absorption[20] in the 3- or 6-μ region attributable to a hydroxyl or carbonyl function and has ultraviolet maxima at 233 mμ (ϵ 15 500) and 242 mμ (ϵ 15 900)[21] with n.m.r. absorption[18] at 2.87 τ (5H, aryl C—H) and complex absorption in the region 4.0–4.8 τ (2H, vinyl C—H) and in the region 7.4–9.0 τ (11H) and a molecular weight of 210 (mass spectrum). A mixture of 513.2 mg. (2.25 mmoles) of the tertiary alcohol **5**, 2 g. of a 30% palladium-on-carbon catalyst and 8.5 ml. of quinoline was heated under reflux for 10 days, a slow stream of nitrogen being bubbled through the reaction mixture. The resulting mixture was diluted with ether, filtered, extracted with aqueous acid, dried, concentrated, and distilled in a short path still (145–185° at 0.7–0.8 mm.) to separate 435.5 mg. of liquid containing[16] 75% of 1-phenylnaphthalene. From an 11.0-mg. fraction of this liquid, 5.8 mg. (corresponding to a 50% yield) of pure 1-phenylnaphthalene (**7**) was collected[16] and identified with an authentic sample by comparison of retention times and infrared spectra.

From a comparable reaction employing 20.088 g. (0.134 mole) of the octalone **3**, 150 ml. (0.270 mole) of 1.8 M ethereal phenylmagnesium bromide and 2.70 g. (0.0270 mole) of cuprous chloride, the crude product was found to contain[16] 62% of the phenyl ketones **9**, **12** and **11**[22] (conjugate addition) and 38% of the alcohol **5** (detected as the diene **5a**, normal addition). From a large scale experiment employing 72.5 g. (0.483 mole) of the octalone **3**, 550 ml. (0.99 mole) of a 1.8 M ethereal solution of phenylmagnesium bromide, and 9.9 g. (0.10 mole) of cuprous chloride, the crude product was isolated as previously described, isomerized with sodium methoxide, and isolated by a combination of crystallization and chromatography as 52.65 g. (48%) of the phenyl ketone **12**, m.p. 97–101°.

(B) **In the Absence of Cuprous Chloride.**—A solution of 702 mg. (4.68 mmoles) of the octalone **3** in 5.0 ml. (9.0 mmoles) of 1.8 M ethereal phenylmagnesium bromide was stirred for 1 hr. at room temperature under a nitrogen atmosphere. After the previously described isolation procedure had been followed, 238 mg. (22.3%) of the crude ketone **9**, m.p. 76.5–84°, was obtained. Since this ketone **9** was partially epimerized, m.p. 55–98°, during attempts to purify it, a sample of the crude product **9** was converted to the more stable isomer **12**, m.p. 99–101°, by chromatography on alumina and subsequent recrystallization. This more stable isomer was shown to be identical to the previously described material **12** by comparison of infrared spectra. In a comparable reaction where o-terphenyl was added as an internal standard the crude reaction product was found to contain[16] 43% of the conjugate addition products **9** and **12** and 57% of the normal addition product **5**. The total yield of these two products was calculated[16] to be 92%.

Reaction of $\Delta^{9,10}$-Octal-1-one (4) with Phenylmagnesium Bromide.—A solution of 3.0824 g. (0.025 mole) of the octalone **4** in 35 ml. (0.063 mole) of 1.8 M ethereal phenyl magnesium bromide was stirred for 1 hr. at room temperature under a nitrogen atmosphere and then subjected to the previously described isolation procedure. The crude product exhibited two gas chromatographic peaks,[16] apart from peaks for biphenyl and solvent, neither of which corresponded to the phenyl ketones **9**, **12** and **13**. The major peak (89% of the product) was collected[16] and distilled in a short-path still (125° at 0.55 mm.) to separate a diene (presumably **6a**) as a pale yellow liquid with no infrared absorption[18,20] in the 3- or 6-μ region attributable to a hydroxyl or carbonyl function. The diene has an ultraviolet maximum[19] at 260 mμ (ϵ 12,300)[21] with n.m.r. absorption[18] centered at 2.86 τ (5H, multiplet, aryl C—H) and at 4.54 τ (1H, triplet with J = 4 c.p.s., vinyl C—H) with complex absorption in the region 7.5–9.0 τ (12H) and a molecular weight of 210 (mass spectrum). A sufficient quantity of the minor peak (11% of the product) was collected[16] to obtain an infrared spectrum[18] which established the absence of hydroxyl or carbonyl functions and suggested that this minor component is either an isomer of the diene **6a** or 5-phenyl-1,2,3,4-tetrahydronaphthalene. From a comparable reaction employing triphenylmethane as an internal standard, the yield of these two peaks representing normal addition was calculated[16] to be 88%. From a similar reaction of 721.4 mg. (4.8 mmoles) of the octalone **4** with 5.0 ml. (9.0 mmoles) of 1.8 M ethereal phenylmagnesium bromide, the crude product was dehydrogenated with 2.5 g. of a 30% palladium-on-carbon catalyst and 9.0 ml. of quinoline. After the reaction mixture had been refluxed for 19 days as previously described, the neutral fraction was isolated and distilled in a short-path still (145° at 0.55 mm.) to separate 876.3 mg. of liquid containing[16] 83% of 1-phenylnaphthalene (**7**). From an 11.35-mg. sample of this liquid, 7.2 mg. (corresponding to a 56.5% yield based on the octalone) of pure 1-phenylnaphthalene (**7**) was collected[16] and identified by comparison of the retention times and infrared spectra.

Equilibration of the Phenyl Ketones 9 and 12.—A sample of the pure ketone **9** was found to be epimerized to the more stable ketone **12** by passing the less stable ketone through either an alumina column or a gas chromatography column. After a solution of 104.6 mg. of the less stable ketone **9** (m.p. 84.5–86°) in methanolic sodium methoxide (from 1 g. of sodium and 40 ml. of methanol) had been refluxed for 48 hr., the solution was neutralized, diluted with water and extracted with an ether–petroleum ether mixture. Concentration of this extract followed by recrystallization from petroleum ether separated 44.3 mg. of the ketone **12**, m.p. 99–100°, identified by a mixed melting-point determination. Repetition of this experiment followed by an infrared analysis of the mixture, m.p. 85–96°, indicated the presence of 6% of the ketone **9** and 94% of the ketone **12**. After a solution of 100 mg. (0.44 mmole) of the ketone **9** in methanolic sodium methoxide, prepared form 437 mg. (19.0 mg.-atoms) of sodium and 6.5 ml. of methanol-d_1, had been refluxed for 5 hr., the mixture was cooled and treated successively with 2.0 ml. of acetic anhydride and water. The aqueous solution (pH 5–6) was extracted with an ether–petroleum ether mixture and the extract was concentrated and sublimed (80° at 0.15 mm.) to separate 94.1 mg. (93.5%) of the crude deuterated ketone **14**, m.p. 91.5–99.5°. Recrystallization afforded 67.8 mg. (67%) of the deuterated ketone **14**, m.p. 99.5–101.3°, whose infrared spectrum[18] differs from the spectrum of the nondeuterated sample in a number of bands in the fingerprint region and has absorption in the region 2140–2210 cm.$^{-1}$ (C—D stretching). The n.m.r. spectra[18] of the deuterated **14** and nondeuterated **12** ketones differ in the region 6.7–8.0 τ in that absorption at 7.39 τ, attributable to a proton at C-9, is absent and splitting pattern for the peak centered at 6.87 τ, attributable to the benzylic proton, is less complex.

2-Bromo-8-phenyl-1-decalone (10). (A) From the Enolate 8.—To the mixture obtained by allowing 4.843 g. (0.031 mole) of the octalone **3** to react with 35 ml. (0.063 mole) of 1.8 M ethereal phenylmagnesium bromide in the presence of 500 mg. (0.005 mole) of cuprous chloride for 3 hr. was added, dropwise with stirring and cooling, a solution of 10.1 g. (0.063 mole) of bromine in 25 ml. of chloroform. The resulting mixture was filtered, diluted with petroleum ether, and treated with excess basic, saturated aqueous ammonium chloride. After the organic layer had been separated, the aqueous phase was extracted with an ether–petroleum ether mixture and the combined organic solutions were washed with an aqueous solution of sodium sulfite and sodium bicarbonate and then with water. Concentration of the resultant organic solution and subsequent standing resulted in the separation of 2.0 g. (20%) of the crude bromo ketone **10** melting with decomposition over the range 140–150°. Recrystallization separated the pure bromo ketone **10** as white, flat needles melting with decomposition over the range 150–157°. The material has infrared absorption[23] at 1716 cm.$^{-1}$ (C=O), a series of low intensity ultraviolet maxima[19] (ϵ 229 at 258.5 mμ) in the region 250–270 mμ as well as a maximum at 292 mμ (ϵ 50, consistent with an equatorial α-bromo substituent), and n.m.r. absorption[24] at 2.82 τ (5 H, aryl C—H), at 5.28 τ (1H, quadruplet with J values of 6 and 11 c.p.s., (—CO—CHBr—)

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(20) Determined as a solution in carbon disulfide.

(21)(a) G. F. Woods, N. C. Bolgiano, and D. E. Duggan [*J. Am. Chem. Soc.*, **77**, 1800 (1955)] report 248 mμ (ϵ 9,000) for 1-phenyl-1, 3-cyclohexadiene; (b) A. C. Cope and D. S. Smith [*ibid.*, **74**, 5136 (1952)] report 256 mμ (ϵ 10,600) for 2-phenyl-1,3-cycloöctadiene and 265 mμ (ϵ 12,600) for 1-phenyl-1,3-cycloöctadiene.

(22) These three ketones (**9**, **11**, and **12**) were not resolved from one another on the column employed.

(23) Determined as a solution in chloroform.

(24) Determined as a solution in deuteriochloroform.

and at 6.86 τ (2H, broad, CO—CH< and C_6H_5CH<) with complex absorption in the region 7.2–8.8 τ (11 H).

Anal. Calcd. for $C_{16}H_{19}BrO$: C, 62.55; H, 6.23; Br, 26.01. Found: C, 62.57; H, 6.11; Br, 26.27.

The mother liquors remaining after the separation of the bromo ketone **10** were chromatographed on 206 g. of Woelm, activity II, alumina, the fractions being eluted with ether–hexane mixtures. From the earlier fractions 1.242 g. of an unknown bromo ketone, m.p. 107–111°, was isolated. Recrystallization from hexane afforded the pure bromo ketone as white prisms, m.p. 110–112.5°, with infrared absorption[18] at 1713 cm.$^{-1}$ (C=O), a series of weak ultraviolet maxima[19] (ϵ 237 at 259 mμ) in the region 250–270 mμ as well as a maximum at 299.5 mμ (ϵ 37) and n.m.r. absorption at 2.75 τ (5H, aryl C—H) and at 6.39 τ (1H, quadruplet with *J* values of 5 and 12 c.p.s., Br—CH< or C_6H_5—CH<) with complex absorption in the region 7.0–8.9 τ (13H).

Anal. Calcd. for $C_{16}H_{19}BrO$: C, 62.55; H, 6.23; Br, 26.01. Found: C, 62.45; H, 6.24; Br, 26.10.

From the later fractions of the chromatography 274.3 mg. of the phenyl ketone **12**, m.p. 98–101°, was isolated.

(B) **From the Phenyl Ketone 12.**—To a solution of 1.7168 g. (7.52 mmoles) of the phenyl ketone **12** in 28 ml. of acetic acid containing 1% of 48% aqueous hydrobromic acid was added, with stirring at room temperature, 8.0 ml. of a solution containing 8.22 mmoles of bromine in acetic acid. The mixture was diluted with water and extracted with an ether–petroleum ether mixture. After the extracts had been washed with aqueous sodium bicarbonate and concentrated, the residue was digested with petroleum ether to remove oily products and then crystallized from an ethanol–hexane mixture. The oily residue removed with petroleum ether deposited more crystalline bromo ketone on standing. The total yield was 1.88 g. (81%) of the bromo ketone **10** which melted with decomposition over the range 145–154°. Recrystallization raised the decomposition range to 153–160°. This product was identified with the previously described sample by comparison of infrared spectra.

From a comparable reaction of 500 mg. (2.2 mmoles) of the ketone **12** with 2.2 mmoles of bromine in 2.2 ml. of acetic acid-d_1 the resulting mixture was diluted with 5 ml. of deuterium oxide and then neutralized to pH 5–6 by the addition of solid sodium carbonate. After this mixture had been diluted with water and extracted with ether, the previously described isolation and purification procedure was followed to separate 263 mg. (39%) of crude dideuterated bromo ketone **10**, m.p. 135–146° dec. Recrystallization afforded 135 mg. (20%) of the pure dideuterated bromo ketone **10**, m.p. 153–155° dec., which did not depress the melting point of the undeuterated bromo ketone **10**. The n.m.r. spectrum[24] of the dideuterated product differed from the previously described spectrum of the undeuterated ketone **10** in the absence of the quartet centered at 5.28 τ and in the reduction in intensity of the broad peak centered at 6.86 τ. The remaining absorption in this region (a broad peak with a half-band width of *ca.* 11 c.p.s. centered at 6.83 τ) is attributable to the C_6H_5CH function.

8-Phenyl-$\Delta^{9,10}$-octal-1-one (15).—A solution of 540 mg. (1.76 mmoles) of the bromo ketone **10** and 745 mg. (17.6 mmoles) of lithium chloride in 5.4 ml. of dimethylformamide was heated to 120 ± 2° for 8 hr. while nitrogen was slowly passed through the solution. After the resulting mixture had been diluted with water and extracted with an ether–petroleum ether mixture, the organic extract was concentrated to separate 232.6 mg. (58.5%) of the unsaturated ketone **15**, m.p. 73–77.5°. Gas chromatographic and thin-layer chromatographic analysis of the mother liquors indicated that the predominant component present was the unsaturated ketone **15**. Recrystallization from hexane followed by sublimation afforded the pure ketone **15** as white prisms, m.p. 77–78°. The product has infrared absorption[18] at 1670 cm.$^{-1}$ (conj. C=O) and 1632 cm.$^{-1}$ (conj. C=C), an ultraviolet maximum[19] at 243.5 mμ (ϵ 12,600) and n.m.r. absorption[18] centered at 2.95 τ (5H, aryl C—H) and at 6.08 τ (1H, half-band width *ca.* 8 c.p.s., C_6H_5—CH<) with complex absorption in the region 7.5–9.0 τ (12H).

Anal. Calcd. for $C_{16}H_{18}O$: C, 84.91; H, 8.02. Found: C, 84.98; H, 8.03.

Reduction of the Phenyl Octalone 15. (A) With Lithium and Ammonia.—A solution of 226 mg. (1.0 mmole) of the octalone **15** in 50 ml. of ether was added, dropwise and with stirring over a 5-min. period, to a solution of 106 mg. (15.3 mg.-atoms) of lithium in 100 ml. of liquid ammonia. After the mixture had been stirred for an additional 5 min., 1.0 g. (18.7 mmoles) of ammonium chloride was added in portions and the ammonia was allowed to evaporate. The resulting mixture was diluted with water and extracted with ether. After the ethereal extract had been dried and concentrated, crystallization of the residue from petroleum ether afforded 187 mg. (84%) of the phenyl decalone **9**, m.p. 82–85.3°. Sublimation of a portion of this material gave the pure ketone **9**, m.p. 84–85.3°, identified by a mixed melting-point determination and comparison of infrared spectra.

(B) **Catalytic Hydrogenation.**—A solution of 500 mg. (2.21 mmoles) of the unsaturated ketone **15** in 4.5 ml. of acetic acid was hydrogenated at room temperature and atmospheric pressure over the catalyst from 121.5 mg. of platinum oxide. The hydrogenation was stopped after 7 hr. at which time 134.3 ml. (5.42 mmoles) of hydrogen had been absorbed and gas chromatographic analysis of the reaction mixture indicated the absence of starting material. The reaction mixture was filtered, diluted with ether, and washed with aqueous sodium bicarbonate. The ethereal phase was concentrated, diluted with petroleum ether, and cooled to separate 29 mg. of the crude ketone **13**, m.p. 120–133°. The mother liquor was concentrated and chromatographed on 30 g. of Woelm, activity III alumina. The early liquid fractions (256 mg.), eluted with hexane, had no infrared absorption[18] in the 3- or 6-μ regions attributable to hydroxyl or carbonyl functions and contained[25] at least four components. Further elution with hexane separated 39.8 mg. of a crude crystalline ketone, m.p. 90–99°, with infrared absorption at 1710 cm.$^{-1}$ (C=O) but lacking absorption attributable to a phenyl group. This product was not investigated further. Further elution with 1% ether in hexane separated, in order of elution, 37.5 mg. of the crude ketone **11** tentatively identified by infrared absorption and retention time on gas chromatography,[25] 18.2 mg. of the crude ketone **13**, m.p. 130–140°, and 64.3 mg. of the crude ketone **12**, m.p. 75–90°, tentatively identified by retention time on gas chromatography. Recrystallization of the last fraction (crude ketone **12**) from hexane afforded 31.7 mg. (6.3%) of the pure ketone **12**, m.p. 99–100.5°, identified with the previously described sample by a mixed melting-point determination and comparison of infrared spectra.

The combined fractions containing the crude ketone **13** from this and a comparable hydrogenation (employing 300 mg. of the unsaturated ketone **15**) were recrystallized from hexane to separate 46 mg. (5.7%) of the pure ketone **13** as white needles, m.p. 141.5–143°. An additional recrystallization raised the melting point to 143–143.5°. The product has infrared absorption[18] at 1717 cm.$^{-1}$ (C=O) with an ultraviolet maximum[19] at 289 mμ (ϵ 29) as well as a series of maxima (ϵ *ca.* 200) in the region 250–270 mμ and n.m.r. absorption[24] in the region 2.6–3.0 τ (5H, aryl C—H) with complex, poorly resolved absorption in the region 7.0–9.0 τ (15H, aliphatic C—H).

Anal. Calcd. for $C_{16}H_{20}O$: C, 84.16; H, 8.83; mol. wt., 228. Found: C, 84.20; H, 8.70; mol. wt., 228 (mass spectrum).

Fractions containing the crude ketone **11** were purified by preparative thin layer chromatography employing a silica gel coating and an ether–hexane mixture as the eluent. Recrystallization from hexane separated the pure ketone **11** as white needles, m.p. 117–118°, with infrared absorption[18] at 1715 cm.$^{-1}$ (C=O).

Anal. Calcd. for $C_{16}H_{20}O$: C, 84.16; H, 8.83; mol. wt., 228. Found: C, 84.30; H, 8.79; mol. wt., 228 (mass spectrum).

A solution of 8.7 mg. (0.038 mmole) of the ketone **11** (m.p. 110–116°) in 2.0 ml. of methanol containing 2.2 mmoles of sodium methoxide was refluxed under a nitrogen atmosphere for 10 hr. and then neutralized with aqueous hydrochloric acid. The resulting mixture was diluted with water and extracted with ether. After the ethereal extracts had been dried and concentrated, sublimation of the residue followed by recrystallization from hexane separated 6.1 mg. (70%) of the ketone **13**, m.p. 141–142.5°, which was identified with the previously described sample by a mixed melting-point determination and comparison of infrared spectra.

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(25) A gas chromatography column packed with General Electric silcone fluid, no. SE-30, suspended on ground firebrick, was employed for this analysis.