Experimental Section

Preparation of Benzyl-α-*d* Alcohol. Under mechanical stirring of a lithium aluminum deuteride (99.8% Aldrich) suspension in anhydrous ether (2.0 g, 0.48 mol) was added dropwise freshly distilled benzaldehyde (20.0 g, 1.90 mol). The reaction mixture was heated to reflux after all the benzaldehyde was added and maintained at reflux for 12 h. After the mixture cooled to ambient temperature, 5 mL of water was added dropwise, followed by 5 mL of 10% aqueous KOH. The precipitated salts were filtered with a sintered-glass funnel, and the filtrate was washed with saturated salt solution. After the mixture was dried over $MgSO_4$, the solvent was stripped off on a rotary evaporator. The residue consisting of nearly pure product was used directly in the following procedure.

Preparation of Benzyl-α-*d* Chloride. The crude alcohol from the preceding procedure was added to 100 mL of benzene. Pyridine (24.4 mL) was then added dropwise under stirring, following which the reaction flask was cooled in a water–ice mixture while thionyl chloride (21.9 mL) was added slowly under stirring. After all the reagents were in, the mixture was heated to reflux and maintained at reflux for 12 h. After cooling, the mixture was diluted with water and extracted with ether. The combined ether extracts were washed with 10% aqueous NaOH and then 6 N HCl, followed by distilled water washing to neutrality. The neutral ether solution was then dried over $MgSO_4$ and the solvent stripped off on a rotary evaporator. The crude residue was shown to be almost pure product and was used as such in the following procedure.

Preparation of Benzyl-α-*d* Nitrate. A solution of the crude product (from the procedure above) was made with 50 mL of acetonitrile. This was added dropwise to a stirred solution of $AgNO_3$ (40.0 g, 0.236 mol) in 150 mL of acetonitrile. After all the reagents were mixed, the resulting solution was allowed to stand for 5 days at ambient temperature. The precipitated AgCl was filtered off on a sintered-glass filter, and the filtrate was poured into an ice–water mixture. The product was then extracted with methylene chloride, the combined extracts were dried over $MgSO_4$, and the solvent, was stripped off on a rotary evaporator. The residue was carefully vacuum distilled through a short packed column, with good product[10] collected in a narrow range around 115 °C (10 mm). Analysis of the product by GLC showed only a single peak on two different columns. Analysis by NMR showed complete monodeuteration within the usual precision of the 60-MHz instrument ±5%). The yield of this product resulting from the sequence of steps starting with 2 g of lithium aluminum deuteride was 8.25 g.

Preparation and Thermolysis of Octyl Nitrate and α-Phenethyl Nitrate. *n*-Octyl bromide (1.61 g, 0.0078 mol) and α-phenethyl chloride (2.32 g, 0.0166 mol) were converted to their respective nitrates in the same manner as benzyl chloride (see above) was converted to benzyl nitrate by using silver nitrate (5 g, 0.029 mol, and 10 g, 0.059 mol, respectively).

The thermolyses of the crude nitrates were carried out exactly as described in the kinetic procedure at 180 °C. The crude product remaining after evaporation of the pentane solvent was converted to the DNPH derivative, the yields of which exceeded 80% of theory on the basis of the octyl bromide and α-phenethyl chloride starting materials: acetophenone DNPH derivative, mp 105 °C (lit.[14] mp 106 °C); octanal DNPH derivative, mp 235 °C (lit.[14] mp 238 °C).

Kinetic Procedure. A Pyrex pressure bottle was charged with 50 mL of dry (distilled over CaH_2) Me_2SO and sealed with an inert elastomer stopple. The bottle was allowed to equilibrate with the thermostat at the chosen temperature (±0.05 °C). When thermal equilibrium was attained, a sample of ~300 mg of benzyl-α-*d* nitrate was rapidly injected under vigorous agitation of the contents of the bottle in the bath, while the evolving gases were vented through a fine needle inserted in the stopple and connected to an indicating bubbler tube. When gas evolution had completely subsided and the reaction was completed, the bottle was withdrawn from the bath. After cooling, the resulting Me_2SO solution of the product was diluted with 100 mL of water and extracted with three 30-mL portions of pentane. The combined extracts were dried, and the solvent was carefully stripped to leave a nearly quantitative yield (>95%) of benzaldehyde (as determined gravimetrically via the DNPH derivative).

In each case, the benzaldehyde residue after removal of most of the pentane was immediately converted to the 2,4-dinitrophenylhydrazone derivative. Mass ratio analysis via the high-precision mass spectrometric technique previously described[8] was performed directly on the DNPH derivative;[15] (see Table I).

Registry No. Benzyl-2-*d* alcohol, 4546-45-6; benzaldehyde, 100-52-7; benzyl-2-*d* chloride, 79449-94-8; benzyl-2-*d* nitrate, 76946-77-5; octyl nitrate, 629-39-0; α-phenethyl nitrate, 7214-65-5; octyl bromide, 111-83-1; α-phenethyl chloride, 672-65-1; acetophenone DNPH, 1677-87-8; octanal DNPH, 1726-77-8; dimethyl sulfoxide, 67-68-5; benzaldehyde DNPH, 1157-84-2.

(14) Shriner, R. L.; Fuson, R. C.; Curtin, D. Y.; Morrill, T. C. "The Systematic Identification of Organic Compounds", 6th Ed.; Wiley: New York, 1980.

(15) The likelihood of biasing the isotope ratio measurements by partial recovery of the labeled reaction product was deemed to be very remote for two reasons: (a) the >95% recovery of the DNPH derivative (by gravimetric determination) and (b) calibration experiments where the known isotope ratio in a benzaldehyde sample was determined by an independent (mass spectral) method.

New Approach to the Mechanism of the Reaction between Benzyl Grignard Reagents and Carbonyl Compounds

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The reaction of the [(1-naphthyl)methyl]magnesium chloride with ketones can lead to the formation of ortho alcohols **4**, normal alcohols **3**, or enolates. We propose a mechanism for the reaction whose first step, as in the case of aldehydes, is a reversible attack of the ketone at the ortho position of the benzylic Grignard reagent, which can then lead to the formation of the normal alcohol and/or enolate. The fact that benzylmagnesium chloride reacts with cyclobutanone to give a diol analogous to that obtained in reactions with aldehydes, while its reaction with 1,1,1-trifluoro-2-propanone does not give a diol, leads us to propose an interpretation involving steric effects in the rearrangement alkoxide. In the case of ketones, these steric interactions generally prevent the Prins-type reaction leading to diols.

In a previous study of the reaction of [(1-naphthyl)-methyl]magnesium chloride with monomeric formaldehyde[1] we proposed a mechanism to explain the formation of diols in the reaction of this benzyl Grignard

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Table I. Reaction of [(1-Naphthyl)methyl]magnesium Chloride with Ketones

ketone	substituents R_1	substituents R_2	exptl conditions[a]	product (% yield) 3	4	5	recovered 1
1a	CH_3	CH_3	A	0	73[b]	23[b]	
			B	0	54[b]	37[b]	
			C	0	70[b]	30[b]	
1b	CH_3	C_2H_5	A	0	54[b] (59)[c]	38[b]	
			B	8[c]	33[b]	45[b]	
1c	C_2H_5	C_2H_5	A	0	36[b]	48[b]	
			B	36[b] (30)[c]	26[c]	30[c]	
1d	CH_3	i-C_3H_7	D	12[b]	55[c]		
			A	24[b]	38[c]		
			B	65[b]	trace[c]	35[b]	
1e	CH_3	t-C_4H_9	A	71[b]	0	13[b]	
1f	i-C_3H_7	i-C_3H_7	A	59[b]	0	18[b]	
			B	89[b]	0	10[b]	
1g	t-C_4H_9	t-C_4H_9	A	34[b]	0	40[b]	
			B	61[b]	0	21[b]	
1h	cyclopropyl	cyclopropyl	A	43[b]	0	34[b]	
			B	55[b]	0	20[b]	
1i	CH_3	C_6H_5	A	26[b]	trace[c]	58[b]	35[b]
			B[d]	24[b]	0	50[b]	15[b]
1j	C_2H_5	C_6H_5	A	86[b]	0	10[b]	4[b]
1k	n-C_3H_7	C_6H_5	A	78[b]	0	22[b]	4[b]
1l	C_6H_5	C_6H_5	D[e]	18[b]	0	25[b]	37[b]
			A[e]	37[b]	0	11[b]	29[b]
			A[f]	39[b]	0	9[b]	21[b]
			B[f]	25[b]	0	6[b]	18[b]
1m	C_6H_5	$CH_2C_6H_5$	A	55[b]	0	30[b]	
1n	CH_3	$CH_2C_6H_5$	A	0	45[c]	34[c]	
			B	23[b]	30[c]		
1o	$CH_2C_6H_5$	$CH_2C_6H_5$	A	23[b]	0	70[b]	62[b]
			B	24[b]	0	69[b]	55[b]
1p	cyclohexyl		A	0	50[c]	40[c]	
			B	5[c]	42[c]	43[c]	
1q	cyclobutyl		A	0	55[c]	42[c]	
			B	0	38[c]	57[c]	
1r	CH_3	CF_3	A	0	68[b]	26[b]	
			B	0	78[c]	17[c]	

[a] A, 1 h at 0 °C; B, 4 days at room temperature; C, 1 h at reflux; D, addition of the ketone was followed by immediate hydrolysis of the reaction mixture. [b] Calculated after column chromatographic separation. [c] Yield determined from the ^1H NMR spectrum of the crude product. [d] Unidentified products were also formed. [e] Mg, 99.5% purity. [f] Mg, 99.9% purity.

reagent with unhindered aldehydes. According to this mechanism, the first step in the reaction is a reversible rearrangement followed by a Prins-type reaction on the resulting alkoxide (Scheme I).

A reversible Grignard reaction has been observed by Benkeser in the reaction of the crotyl Grignard reagent with highly sterically hindered ketones.[2] On the other hand, we have found that [(1-naphthyl)methyl]magnesium chloride reacts with 2-propanone to give not the expected normal alcohol but only the rearrangement alcohol.[1] This alcohol, analogous to the one obtained with formaldehyde, is unstable and decomposes slowly into 1-methylnaphthalene and 2-propanone. These results led us to reexamine the reaction of [(1-naphthyl)methyl]magnesium chloride with ketones, since the only reactions mentioned in the literature are rather inconclusive.[3]

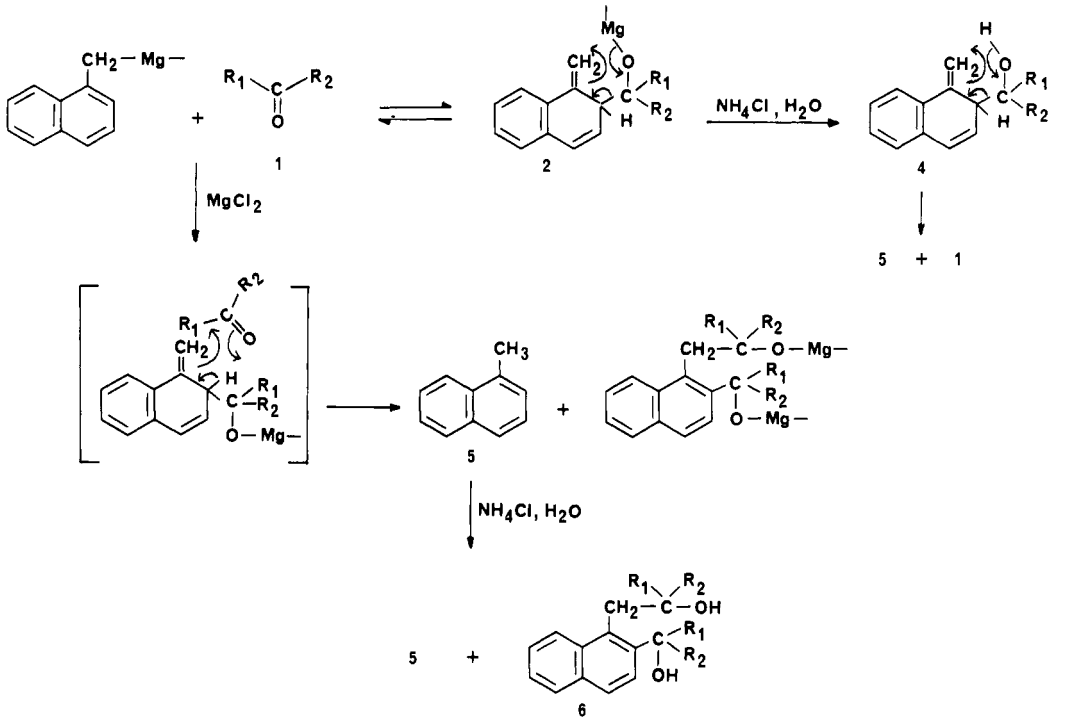
Results and Discussion

Reactions. An examination of Table I shows that [(1-naphthyl)methyl]magnesium chloride can react with ketones to form rearrangement alcohols **4**, the normal alcohols **3**, or a mixture of the two. When mixtures are formed, the yield of **4** decreases with increasing time of contact between the reagents while the yield of **3** increases. This result can be explained if we assume, as in the formaldehyde reaction, that path 1 in Scheme II (the formation of the rearrangement alcoholate **2**) is reversible. The ketone and the Grignard reagent regenerated in the medium in this way can then lead to the normal alcohol **3** via path 2. The results of Table I also highlight the following facts: (1) the decrease in the yield of the rearrangement alcohol **4** may not be accompanied by the appearance of the normal alcohol **3**, as in the case of acetone (**1a**); (2) the reaction may lead quickly to a constant percentage of **3** without the formation of **4**, as in the cases of acetophenone (**1i**) and 1,3-diphenyl-2-propanone (**1o**). The recovery of substantial amounts of the starting ketones as in the reactions with **1i** and **1o** leads us to postulate an enolization reaction that competes with the formation of the normal alcohol **3** (path 2, Scheme II). This has been confirmed in the case of **1o**, where we were able to trap the enolate with chlorotrimethylsilane.

In summary, there are three possible sequences of events that depend on the relative rates of paths 1–3 (Scheme II). (a) The decomposition of the rearrangement alcoholate **2** to regenerate the Grignard reagent and the ketone is slow. In this case the yield of the rearrangement alcohol **4** decreases with increasing reaction time. In parallel, there is an increase in the yield of the normal alcohol **3** along path 2 and/or enolization along path 3. (b) The reversible

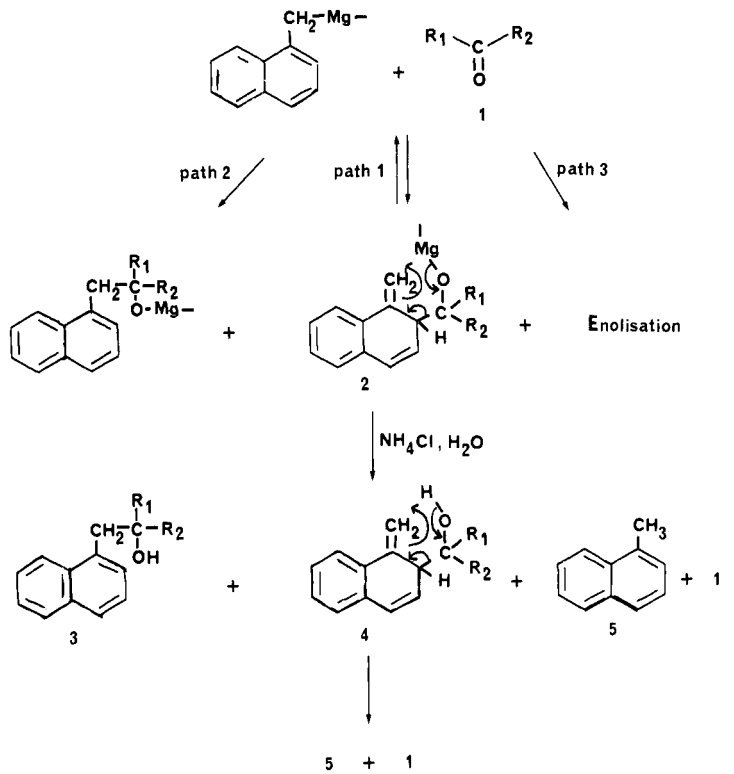
(1) C. Bernardon and A. Deberly, *J. Chem. Soc., Perkin Trans. 1*, 2631 (1980).
(2) R. A. Benkeser, M. P. Siklosi, and E. C. Mozdzen, *J. Am. Chem. Soc.*, **100**, 2134 (1978); R. A. Benkeser and M. P. Siklosi, *J. Org. Chem.*, **41**, 3212 (1976). R. A. Benkeser and W. E. Broxterman, *J. Am. Chem. Soc.*, **91**, 5162 (1969).
(3) A. M. Khaletskii and A. Y. Kaplan, *J. Gen. Chem. USSR (Engl. Transl.)*, **26**, 873 (1956).

Scheme I



Scheme II

a ; $R_1 = R_2 = CH_3$
b ; $R_1 = CH_3$, $R_2 = C_2H_5$
c ; $R_1 = C_2H_5$, $R_2 = C_2H_5$
d ; $R_1 = CH_3$, $R_2 = CH(CH_3)_2$
e ; $R_1 = CH_3$, $R_2 = C(CH_3)_3$
f ; $R_1 = R_2 = CH(CH_3)_2$
g ; $R_1 = R_2 = C(CH_3)_3$
h ; $R_1 = R_2$ = cyclopropyl-
i ; $R_1 = CH_3$, $R_2 = C_6H_5$
j ; $R_1 = C_2H_5$, $R_2 = C_6H_5$
k ; $R_1 = nC_3H_7$, $R_2 = C_6H_5$
l ; $R_1 = R_2 = C_6H_5$
m ; $R_1 = C_6H_5$, $R_2 = CH_2\text{-}C_6H_5$
n ; $R_1 = CH_3$, $R_2 = CH_2\text{-}C_6H_5$
o ; $R_1 = R_2 = CH_2\text{-}C_6H_5$
p ; cyclohexanone
q ; cyclobutanone
r ; $R_1 = CH_3$, $R_2 = CF_3$

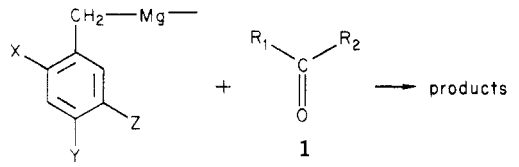


reaction of path 1 is very rapid and the normal alcohol **3** of path 2 is formed more rapidly than the enolate of path 3. The major product of the reaction is only the normal alcohol **3**. (c) The reversible reaction of path 1 is very rapid, but the normal alcohol **3** forms less rapidly than the enolate of path 3. In this case the yield of the normal alcohol **3** will be low after hydrolysis, and the ketone will be largely recovered.

The rate of decomposition of the rearrangement alcoholate **2**, which governs the later course of the reaction, depends directly on the stability of the isolated rearrangement alcohol **4**, which itself depends on the size of the R_1 and R_2 groups of the ketones. This emerges particularly clearly from comparison of the results obtained with acetone (**1a**) (the rearrangement alcohol **4a** is relatively stable and is the predominant product) and 3-methyl-2-butanone (**1d**) (the rearrangement alcohol **4d** is very unstable, and the normal alcohol **3d** becomes the predominant product as the reaction time increases).

In the case of the very sterically hindered ketones **1e–m** where it has not been possible to detect any rearrangement alcohol **4**, the rearrangement reaction is also conceivable,

Table II



7 1

compd 7	X	Y	Z	R_1COR_2 (1)	% yield[a] 10	% yield[a] 11
7a′	H	H	H	c-C_4H_6O[b]	22	25
	H	H	H	CF_3COCH_3	0	0
7b′	CH_3	CH_3	H	c-C_4H_6O[b]	6	26
7c′	CH_3	H	CH_3	c-C_4H_6O[b]	60	0
	CH_3	H	CH_3	CH_3CHO (12)	4	41

[a] Yields calculated from RMgCl. [b] Cyclobutanone.

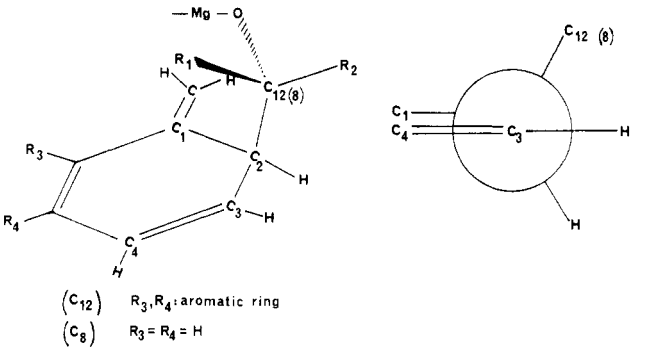
although steric hindrance might prevent it. But one cannot exclude the possibility of a direct reaction leading to the normal alcohol **3**.

The above-described results allow us to postulate a new interpretation of the reaction of benzyl Grignard reagents with ketones in which only the normal alcohol is isolated.[4] The initial step in this reaction is believed to be a reversible attack of the ketone at the ortho position of the organomagnesium compound, followed by a very rapid reaction to form the normal alcohol. This mechanism takes into account the similarity between the results obtained in the reactions of benzylmagnesium chloride and of [(1-naphthyl)methyl]magnesium chloride with formaldehyde.[1]

Steric Conditions Required for Diol Formation. According to our results, it appears that both aldehydes and unhindered ketones react initially by reversible attack at the ortho position of the benzyl Grignard reagents. However, although the benzyl Grignard reagent may react with unhindered aldehydes to form the diol **6** (Scheme I) as the major reaction product, with ketones one does not observe the formation of the corresponding diol, even with such unhindered ketones as acetone. In order to explain this difference in behavior between aldehydes and ketones, we studied the reactions of various benzylic Grignard reagents with cyclobutanone (**1q**), a very unhindered ketone, and 1,1,1-trifluoro-2-propanone (**1r**), a very electrophilic ketone.

[(1-Naphthy)methyl]magnesium chloride reacts with **1q** or **1r** to give exclusively the rearrangement alcohol **4** and 1-methylnaphthalene, even after 4 days at room temperature (Table I). On the other hand, Table II shows that a diol is obtained in the reaction of benzylmagnesium chloride with **1q**, as in the case of the reaction with aldehydes, whereas its reaction with **1r** leads to neither the diol nor to any other alcohol. Thus in the latter case the enolization reaction (path 3, Scheme II) is the only step followed. These results suggest that a Prins-type reaction on the rearrangement alkoxide obtained from ketones cannot give the diol, probably in part because of steric interactions. This steric hindrance in the Prins-type reaction is confirmed by the reaction of **1q** with (2,5-dimethylbenzyl)magnesium chloride, in which the C_5-methyl group prevents formation of the diol. In contrast, when acetaldehyde reacts with the same Grignard reagent, the corresponding diol is the major product. Thus, the steric hindrance must be the result of an interaction in the rearrangement alkoxide **2**, taking place during the Prins-type reaction, between the substituents R_1 and R_2 on the one hand and the substituents on C_3 and the methylene group on the other hand. It should be noted that the nonaromatic ring of the rearrangement alkoxide is planar, or nearly planar, and thus the group attached to C_2 will be clearly out of the plane of the rings (Chart I). Since the trienic ring is rearomatized during the Prins-type reaction, we suggest that this steric interaction can be accounted for by a geometry of the transition state in which the C_2–H bond is almost perpendicular to the nonaromatic ring, thus forcing the C_2–C_8 bond (benzyl) or the C_2–C_{12} bond (naphthyl) to approach very close to the plane of the rings (Chart II). This is only possible if R_1 and R_2 in the rearrangement alkoxide are different from CH_3 as in the unhindered aldehydes or ketones like cyclobutanone. This also explains the marked decrease in the yield of the diol in favor of the normal alcohol when the radical R of the aldehyde is made larger.[5] We also suggest that in the initial reversible rearrangement step, the carbonyl compound approaches perpendicularly to the plane of the

Chart I



(4) M. S. Kharasch and O. Reinmuth, "Grignard Reactions of Nonmetallic Substances", Prentice-Hall, New York, 1954.

(5) S. Siegel, W. M. Boyer and R. R. Jay, *J. Am. Chem. Soc.*, **73**, 3237 (1951).

Chart II

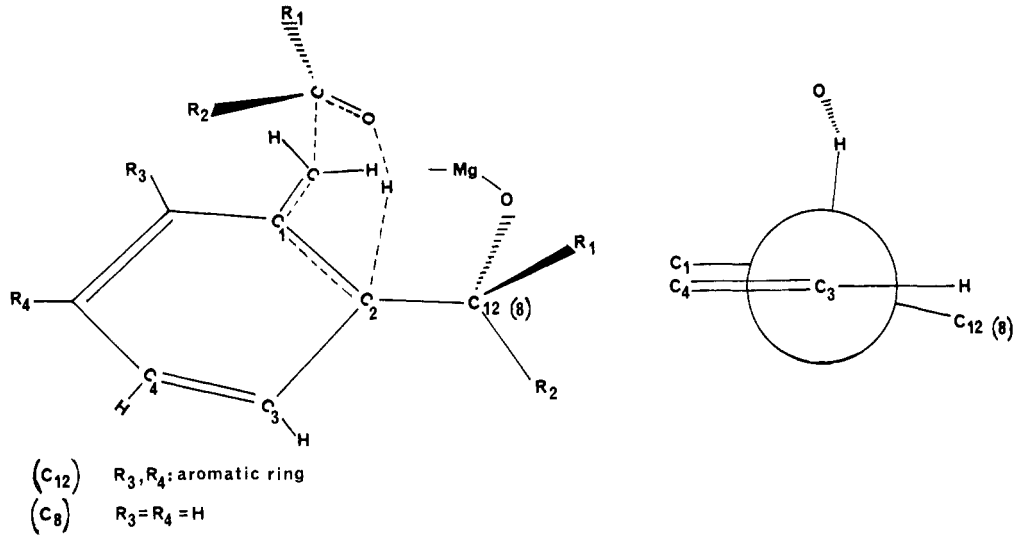
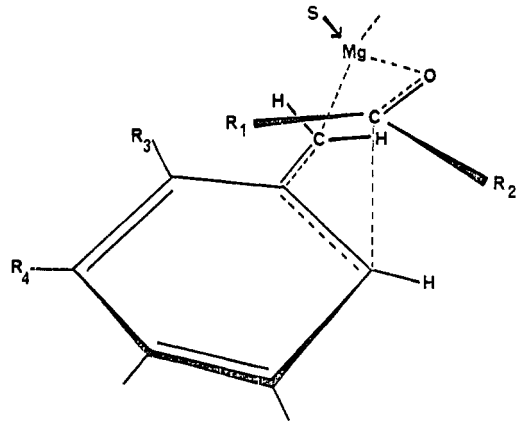


Chart III



aromatic ring at C_2 of the benzylic Grignard reagent, according to Chart III.

In conclusion, our study confirms that unhindered aldehydes and ketones react initially with benzylic Grignard reagents by a reversible rearrangement. This type of rearrangement is very similar to the one observed in the case of allylic or crotylic Grignard reagents.[6] Our interpretation also explains the various courses of events that can occur after the initial reversible rearrangement, depending on the structure of the carbonyl compound.

Experimental Section

General experimental details have been described previously for the reaction of [(1-naphthyl)methyl]magnesium chloride with acetone (**1a**).[1]

Reaction of [(1-Naphthyl)methyl]magnesium Chloride with Ketones. Identification of the products from the reactions of [(1-naphthyl)methyl]magnesium chloride with ketones **1** was by ^1H NMR. The normal alcohols **3** were isolated by column chromatography on silica gel, except for **3c,d,n**, which could not be separated from the corresponding ortho alcohols. For these reactions, heating of the crude products at 80 °C for 1 h under vacuum prior to elution decomposed the ortho alcohols **4** into 1-methylnaphthalene and the ketones, and **1c** and **1d** could be removed by distillation. In the reactions involving **1e–h,m**, separation of the normal alcohols **3** was carried out after the unreacted ketones had been removed by vacuum distillation.

Except for **4a–c**, the ratios of the unstable ortho alcohols to the normal alcohols **3** were determined from ^1H NMR spectra of the crude products by comparing the areas under the peak of the CH_2 attached to the naphthalene ring of **3** (shift between δ 3.1 and 4.1) with those of the CH_2 group in **4** [δ 5.1 (s, 1 H) and 5.6 (s, 1 H)]. The actual yields of ortho alcohols **4** were expressed in terms of those of the normal alcohols **3**, which were determined by column chromatography. The more stable ortho alcohols **4a–c** were separated by column chromatography on silica gel by elution with acetone–$CHCl_3$ (6:94 v/v) for **4a**[1] and with acetone–hexane (10:90 v/v) for **4b,c**. All the NMR spectra showed signals of 1-methylnaphthalene (**5**), [δ 2.62 (s, 1 H)] and the corresponding ketones **1a–c**, which arose from decomposition of the ortho alcohols. Values of δ for the ortho alcohols **4d,n,p** were measured on the crude products.

Enolate Trapping. To a solution of [(1-naphthyl)methyl]magnesium chloride (0.0182 mol) in 40 mL of diethyl ether was added slowly a solution of 1,3-diphenyl-2-propanone (**1o**) in 10 mL of diethyl ether at 0 °C over 15 min. The mixture was stirred for 1 h at 0 °C. Then, by use of the procedure of Stork et al.[7] there were added successively HMPA (2.5 mL) and, dropwise, a solution of chlorotrimethylsilane (4 mL) in triethylamine (5 mL) at 0 °C. The reaction mixture was stirred for 2 h at 0 °C, diluted with 20 mL of pentane, and poured into a mixture of 100 g of ice, 5 g of $NaHCO_3$, 8 mL of triethylamine, and 20 mL of pentane. The workup gave 6.19 g of product that was shown by NMR to be a mixture of 1-methylnaphthalene [δ 2.62 (s, 3H, CH_3)], the trimethylsilyl enol ether of **1o** [δ 5.47 (s, 1 H, C=CH), 3.43 (s, 2 H, CH_2)], and the trimethylsilyl ether of alcohol **3o** [δ 3.15 (s, 2 H, naphthyl CH_2), 2.72 (s, 4 H, 2 phenyl CH_2's)]; the absence of a singlet at 3.55 ppm indicated the absence of ketone **1o**. Column chromatography of 1 g of the crude product on silica gel with diethyl ether–hexane (4:96 v/v) gave 1-methylnaphthalene (0.193 g) and 0.538 g of a product identified by NMR as a mixture of the normal alcohols **3o** and ketone **1o**. This result shows that the trimethylsilyl enol ether from ketone **1o** could be trapped but was unstable. Additional evidence was provided by NMR analysis of the crude product after 6 days at room temperature, which indicated formation of ketone **1o**, as shown by the appearance of the singlet at 3.55 ppm and disappearance of the peaks of the trimethylsilyl enol ether of **1o**.

Reaction of Benzylmagnesium Chloride (7a') with Cyclobutanone (1q) and with 1,1,1-Trifluoro-2-propanone (1r). To a solution containing benzylmagnesium chloride (0.0155 mol) in 30 mL of diethyl ether was added dropwise over 5 min a solution of **1q** or **1r** (0.031 mol) in 10 mL of diethyl ether at 0 °C. The mixture was stirred for 1 h at 0 °C, hydrolyzed, and worked up. With **1q**, column chromatography of the crude product (1.91 g) with acetone–$CHCl_3$ (6:94 v/v) gave 1-benzyl-1-hydroxycyclo-

(6) E. A. Hill, *J. Organomet. Chem.*, **91**, 123 (1975); G. Courtois and L. Miginiac, *ibid.*, *69*, 1 (1974); R. A. Benkeser, *Synthesis*, 347 (1971); R. H. DeWolfe and W. G. Young, *Chem. Rev.*, **56**, 753 (1956).

(7) G. Stork and P. Hudrlik, *J. Am. Chem. Soc.*, **90**, 4462 (1968).

butane [**10a'**:0.367 g (22%); ^{1}H NMR δ 7.23 (s, 5 H, aromatic), 2.85 (s, 2 H, CH_2), 2.07 (s, 1 H, OH), 1.85 (m, 6 H, cyclobutyl)] and 1-[2-(1-hydroxycyclobutyl)benzyl]-1-hydroxycyclobutane (**11a'**): 0.59 g (64%); ^{1}H NMR δ 7.18 (s, 4 H, aromatic), 4.65 (s, 2 H, OH), 3.00 (s, 2 H, CH_2), 2.2 (m, 12 H, 2 cyclobutyls); mp 117 °C. Anal. Calcd for $C_{15}H_{20}O_2$: C, 77.55; H, 8.67. Found: C, 76.91; H, 8.70. With **1r**, hydrolysis of the reaction mixture gave 0.64 g of material that was shown to be a complex mixture by gas chromatography and TLC. NMR, IR, and mass spectra showed the absence of any normal alcohol **10** or diol **11**.

2,4-Dimethylbenzyl Chloride and 2,5-Dimethylbenzyl Chloride. To a solution of 2,4-dimethyl- or 2,5-dimethylbenzyl alcohol (5 g, 0.037 mol) in 10 mL of $CHCl_3$ was added slowly a solution of 3.17 mL of $SOCl_2$ in 5 mL of $CHCl_3$. The mixture was refluxed for 3 h and cooled. Excess $SOCl_2$ and the solvent were removed under vacuum at room temperature over 2 h. Distillation under vacuum gave 2.4-dimethylbenzyl chloride [4.86 g (85%); bp 108 °C (17 mm)] or 2,5-dimethylbenzyl chloride: 4.5 g (79%); bp 98 °C (13 mm). IR spectra showed no OH peak at 3500 cm^{-1}.

Reaction of (2,4-Dimethylbenzyl)magnesium Chloride (7b') or (2,5-Dimethylbenzyl)magnesium Chloride (7c') with Cyclobutanone (1q). To a solution of the Grignard reagent from 2,4-dimethyl- or 2,5-dimethylbenzyl chloride (0.007 mol) was added **1q** (0.014 mol) in 5 mL of diethyl ether at 0 °C over 5 min. The mixture was stirred 1 h at 0 °C, hydrolyzed, and worked up. From **7b'** was obtained 2.1 g of crude material. Column chromatography with acetone-$CHCl_3$ (6:94 v/v) gave 1-(2,4-dimethylbenzyl)-1-hydroxycyclobutane [**10b'**: 0.081 g (6%); ^{1}H NMR δ 7.05 (m, 3 H, aromatic), 2.88 (s, 2 H, CH_2), 2.3 (d, 6H, $2CH_3$), 2.05 (m, 6 H, cyclobutyl), 1.83 (s, 1 H, OH)] and 1-[2-(1-hydroxycyclobutyl)-4,6-dimethylbenzyl]-1-hydroxycyclobutane (**11b'**): 0.465 g (26%); ^{1}H NMR δ 6.92 (s, 2 H, aromatic), 4.72 (s, 2 H, OH), 3.07 (s, 2 H, CH_2), 2.45 and 2 (m, 12 H, cyclobutyl), 2.32 (s, 3 H, CH_3), 2.25 (s, 3 H, CH_3). Anal. Calcd for $C_{17}H_{24}O_2$: C, 78.42; H, 9.29. Found: C, 77.94; H, 9.23.

From **7c'**, 1.45 g of crude material was obtained. Column chromatography with acetone-$CHCl_3$ (4:96 v/v) gave 1-(2,5-dimethylbenzyl)-1-hydroxycyclobutane (**10c'**): 0.8 g (44%); ^{1}H NMR δ 7 (m, 3 H, aromatic), 2.87 (s, 2 H, CH_2), 2.32 (s, 3 H, CH_3), 2.28 (s, 3H, CH_3), 2 (m, 6 H, cyclobutyl), 1.9 (s, 1 H, OH). GLC showed only one peak.

Reaction of (2,5-Dimethylbenzyl)magnesium Chloride (7c') with Acetaldehyde (12). To a solution of Grignard reagent (0.007 mol) prepared as above was added acetaldehyde (0.014 mol) in 5 mL of diethyl ether at 0 °C over 5 min. The mixture was stirred 1 h at 0 °C, hydrolyzed, and worked up to give 1.06 g of crude product. Column chromatography with acetone-$CHCl_3$ (4:96 v/v) gave 1-(2,5-dimethylphenyl)-2-propanol [**10**: 0.05 g (4%); ^{1}H NMR δ 7.07 (s, 3 H, aromatic), 3.95 (m, 1 H, CH), 2.67 (d, 2 H, CH_2), 2 (s, 1 H, OH), 2.4 (s, 6 H, $2CH_3$), 1.2 (d, 3 H, CCH_3)] and 1-[2-(1-hydroxyethyl)-3,6-dimethylphenyl]-2-propanol (**11**): 0.596 g (41%); ^{1}H NMR δ 7.15 (m, 2 H, aromatic), 5.1 (m, 1 H, $C_6H_5CHCH_3$), 3.95 (m, 1 H, $CCHCH_3$), 3.35 (s, 2 H, OH), 2.77 (m, 2 H, CH_2), 2.27 (s, 6 H, $2C_6H_5CH_3$), 1.45 (q, 3 H, CCH_3), 1.25 (q, 3 H, CCH_3); IR 3150 cm^{-1} (OH). Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.44; H, 9.77.

Registry No. **1a**, 67-64-1; **1b**, 78-93-3; **1c**, 96-22-0; **1d**, 563-80-4; **1e**, 75-97-8; **1f**, 565-80-0; **1g**, 815-24-7; **1h**, 5009-27-8; **1i**, 98-86-2; **1j**, 93-55-0; **1k**, 495-40-9; **1l**, 119-61-9; **1m**, 451-40-1; **1n**, 103-79-7; **1o**, 102-04-5; **1o** trimethylsilyl enol ether, 79990-96-8; **1p**, 108-94-1; **1q**, 1191-95-3; **1r**, 421-50-1; **3b**, 79990-97-9; **3c**, 79990-98-0; **3d**, 79990-99-1; **3e**, 79991-00-7; **3f**, 79991-01-8; **3g**, 79991-02-9; **3h**, 79991-03-0; **3i**, 79991-04-1; **3j**, 79991-05-2; **3k**, 79991-06-3; **3l**, 79991-07-4; **3m**, 79991-08-5; **3n**, 79991-09-6; **3o**, 79991-10-9; **3o** trimethylsilyl ether, 79991-11-0; **3p**, 80010-04-4; **4a**, 76767-85-6; **4b**, 79991-12-1; **4c**, 79991-13-2; **4d**, 79991-14-3; **4n**, 79991-15-4; **4p**, 79991-16-5; **4q**, 79991-17-6; **4r**, 79991-18-7; **5**, 90-12-0; **10**, 27645-00-7; **10a'**, 73013-83-9; **10b'**, 79991-19-8; **10c'**, 79991-20-1; **11**, 79991-21-2; **11a'**, 79991-22-3; **11b'**, 79991-23-4; **12**, 75-07-0; benzyl chloride, 100-44-7; 2,4-dimethylbenzyl chloride, 824-55-5; 2,5-dimethylbenzyl chloride, 824-45-3; [(1-naphthyl)methyl]chloride, 86-52-2.

Supplementary Material Available: Tables III and IV listing eluants and ^{1}H NMR spectral data for alcohols **3** and **4** (2 pages). Ordering information is given on any current masthead page.

Chiral 1,2-Diphosphine Ligands. Synthesis and Application to Rhodium-Catalyzed Asymmetric Hydrogenations[1]

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New chiral 1,2-diphosphine ligands, (*R*)-1,2-bis(diphenylphosphino)-3-(benzyloxy)propane and (*R*)-1,2-bis(diphenylphosphino)-3-*tert*-butoxypropane, have been prepared from D-mannitol. The rhodium(I) cationic complexes of these ligands are efficient asymmetric homogeneous hydrogenation catalysts for dehydro amino acids, giving (*S*)-amino acids in high optical yield (80–90%).

Since the discovery of tris(triphenylphosphine)rhodium chloride as a homogeneous hydrogenation catalyst for various olefins,[2] a large number of chiral phosphine ligands have been synthesized and used for rhodium-catalyzed asymmetric hydrogenations of various prochiral olefinic substrates.[3] It has generally been observed that the rhodium complexes of chiral chelating phosphine ligands give high enantiomeric excesses in the hydrogenation of prochiral olefinic substrates as compared to monodentate phosphine ligands. Of the bidentate phosphine ligands, 1,2-diphosphines which form five-membered conformationally rigid complexes are able to exert high chiral preferance in asymmetric hydrogenations. A number of chiral 1,2-diphosphines such as DIPAMP,[4] Chiraphos,[5] Prophos,[6] Phellanphos,[7] Phenphos,[8] Cycphos,[9] etc. have

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