catalysis in contrast to negative values for hydronium ion catalysis, most likely reflecting the greater importance of bond breaking with a weak acid catalyst. In both cases substituents were located in the leaving group in the reaction so that increased electron withdrawal would facilitate bond breaking.

If the steric situation is such that strain is not released in the transition state then steric strain in the ground state will not give rise to an enhancement of the rate. This must be the case with 2,6-dichlorobenzaldehyde di-*tert*-butyl acetal. The bulky ortho substituents should lead to increased restriction of groups in the ground state in comparison with the para-substituted derivatives. However, general acid catalysis is almost abolished, and the hydronium ion catalyzed reaction proceeds at a slow rate. In addition to the electronic effects exerted by the two chloro substituents it is likely that either groups are restricted in the transition state and/or coplanarity cannot be achieved for maximum stabilization of the carbonium ion intermediate.

The above considerations could be of considerable importance in regard to the mechanism of action of lysozyme. Since relief of ground state strain will lead to an enhancement of the rate and to general acid catalysis in a simple chemical system, it is apparent that distortion effects such as postulated for lysozyme,[6] in which a hexose ring is forced into a half-chair conformation, could indeed be quite important in producing general catalysis by groups in the active site even though the leaving group in the reaction is quite poor. Giudici and Bruice[16] have shown that ground state planarity will not by itself lead to general acid catalysis of acetal hydrolysis. As a consequence of the possible kinetic effects produced by binding of the substrate to lysozyme, it would appear that the introduction of strain into the substrate which will in turn facilitate bond breaking is probably of critical importance.

Acknowledgment. This work was supported by research grants from the National Institutes of Health and the National Science Foundation.

(16) T. Giudici and T. C. Bruice, *Chem. Commun.*, 690 (1970).

Mechanism for Inversion in Primary Organomagnesium Compounds

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Contribution from the Department of Chemistry, The Ohio State University, Columbus, Ohio 43210. *Received May 2, 1970*

Abstract: The kinetics of inversion of the Grignard reagents RMgX (R = 2-methylbutyl, X = Cl, Br, I, R_2Mg) have been investigated and molecular weight data obtained for ether solutions 0.1–0.15 *M*. It has been found that steric effects have relatively little influence on the rates of inversion. Reagents which are dimeric X = Cl give first-order kinetics while, for those which are monomeric, the inversion rates are second order in contained reagent. It is concluded that the inversion takes place in a dimeric species and that alkyl bridging is associated with the transition state for inversion. An intraaggregate electrophilic transfer of the bridged group between the two magnesiums in the dimeric transition state is proposed to account for the results.

The dynamic behavior of organometallic compounds in solution involves inversion at carbon bonded to metal, carbon–metal bond exchange, and solvent–metal coordination exchange.

Although rates of inversion in various organometallic compounds have been measured by means of the nmr line-shape method[1–5] very little is known about the mechanism of the inversion process. The kinetic order for inversion was found to be larger than one for 3,3-dimethylbutylmagnesium chloride,[2] 2.5 for 2-methylbutylmagnesium bromide, and 2.0 for bis(2-methylbutyl)magnesium.[3]

In principle any process which further polarized the carbon–metal bond in these reagents should facilitate inversion. One mechanism suggested to account for the high kinetic order originally observed involves attack of a magnesium in one aggregate on the methylene carbon in another.[3]

A second process responsible for carbon–magnesium bond exchange, much faster than inversion, was detected by several investigators.[6–8] For instance ether solutions of mixtures containing dialkylmagnesium and arylalkylmagnesium compounds gave single average resonance patterns indicative of fast carbon–magnesium bond exchange.[6–8] This process was found to be slowed down by tertiary amines.[8] The existing evidence on magnesium coordination exchange with ethers and

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(1) G. M. Whitesides, M. Witanowski, and J. D. Roberts, *J. Amer. Chem. Soc.*, **87**, 2854 (1965).

(2) G. M. Whitesides and J. D. Roberts, *ibid.*, **87**, 4878 (1965).

(3) G. Fraenkel and D. T. Dix, *ibid.*, **88**, 979 (1966); G. Fraenkel, D. T. Dix, and D. G. Adams, *Tetrahedron Lett.*, 3155 (1964).

(4) M. Witanowski and J. D. Roberts, *J. Amer. Chem. Soc.*, **88**, 737 (1966).

(5) G. Fraenkel, D. T. Dix, and M. J. Carlson, *Tetrahedron Lett.*, 579 (1968).

(6) G. Fraenkel, D. G. Adams, and R. R. Dean, *J. Phys. Chem.*, **72**, 944 (1968).

(7) G. Fraenkel, S. Koboyashi, and S. Dayagi, *ibid.*, **72**, 953 (1968).

(8) H. O. House, R. A. Latham, and G. M. Whitesides, *J. Org. Chem.*, **32**, 2481 (1967).

amines is that this process is also fast on the nmr time scale.[3,6,8]

In the solid state, X-ray crystallography shows most organomagnesium compounds, so far studied, to consist of monomers.[9] Since two of the three exchange processes mentioned above are fast on the nmr time scale, nmr techniques have not been useful in elucidating the structure of Grignard reagents in solution. Thus, so far, little is definitely known about the structure of $(RMgX)_n$ and $(R_2Mg)_n$ aggregates.

The purpose of this article is to present new kinetic data for inversion in three Grignard reagents and one dialkylmagnesium compound together with an investigation of steric effects on the inversion process. Consideration of the kinetic data together with the results of recent studies on aggregation or organomagnesium compounds[10] leads to a mechanism the dominant feature of which is that alkyl bridging accompanies inversion.

Results and Discussion

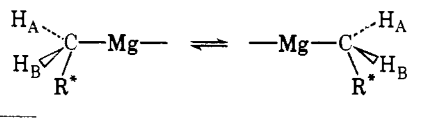
Both 2-methylbutyl bromide[5,11] and bis(2-methylbutyl)mercury were prepared as previously described. Treatment of racemic 2-methylbutanol with thionyl chloride and pyridine afforded 2-methylbutyl chloride[12] while the iodide was obtained by exchanging the 2-methylbutyl bromide with sodium iodide in acetone.[13] The reduction of methylisopropylacetic acid with lithium aluminum hydride gave 2,3-dimethyl-1-butanol. The latter was converted to 1-bromo-2,3-dimethylbutane with phosphorous tribromide and pyridine. Addition of hydrogen bromide in the presence of ascaridole to 2,3,3-trimethylbutene-1 gave 1-bromo-2,3,3-trimethylbutane. Bis(2-methylbutyl)magnesium was prepared from the mercury compound and the Grignard procedures were as described before.[3] Table I lists partial analyses of the nmr spectra of all new reagents. It is seen that the α-methylene resonance in each of these compounds consists of the AB part of an ABX system.

Table I. Nmr Parameters of Organomagnesium Compounds in Ether ($R = CH_3CH_2CH_x(CH_3)CH_AH_B$)

Solute	$\delta_{AB}{}^a$	$J_{AB}{}^b$	$J_{BX}{}^b$	$J_{AX}{}^b$
RMgCl	0.172	12.44	7.07	4.21
RMgBr	0.168	12.00	8.08	5.42
RMgI	0.184	12.48	7.22	4.59
R_2Mg[5]	0.234	11.82	7.39	4.61

[a] Parts per million. [b] Hertz.

The method[3] used to calculate rates of inversion from the nmr spectra is now briefly described. At low temperatures, the α-methylene hydrogens of the reagents used in this work are magnetically nonequivalent due to their proximity to the asymmetric center at C_β. This is independent of the rate of internal rotation of the species in question. The effect of inversion at C_α (1) is to exchange the environments of H_A and H_B and thereby average the AB shift and the AB coupling constant. Also, J_{BX} is averaged with J_{AX}. In this way the methylene line shape changes from AB of ABX to A_2 of A_2X with increasing rates of inversion. With the assumption that the AB shift is small compared to the AX and BX shifts and that the spin state of X does not change during an inversion, the α-methylene resonance can be decomposed to two pseudo-AB patterns, each due to one of the spin states of X. Line shapes for various mean lifetimes between AB exchanges, τ, due to inversion, were calculated for these two AB patterns[14] and summed. Comparison of the resulting theoretical line shapes with the experimental spectra afforded experimental τ values for inversion. The validity of the above assumptions was confirmed when, in later work, line shapes were calculated with a modified[15] Fortran computer program, due to Gutowsky and Vold,[16] which solves the density matrix equations[17] for the entire ABX system. This proved to be faster than the original approximate method. Furthermore, both methods gave nearly identical results.



(1)

The nmr spectra of ether solutions of 2-methylbutylmagnesium chloride, bromide, and iodide as well as bis(2-methylbutyl)magnesium were determined as a function of concentration and temperature and rates of inversion calculated from the α-methylene line shapes. Activation parameters for inversion in these reagents are listed in Table II. Although $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ vary by large magnitudes, the rates at 25° are very similar; in fact, these results follow an isokinetic relationship of slope 360°. This line is parallel and close to the one reported for inversion of bis(2-methylbutyl)magnesium in different solvents.[3]

Table II. Inversion Parameters from Ether Solutions (R = 2-Methylbutyl)

	$\Delta H^{\ddagger}{}^b$	$\Delta S^{\ddagger}{}^c$	$1/\tau$, sec^{-1} (25°)
RMgCl[a]	6.2	−28	126
RMgBr[a]	12.0	−11	44
RMgI[a]	20.4	+11	2
R_2Mg[a]	18.2	+5	5

[a] Results obtained with 0.5 *M* solutions. [b] ±1.2 kcal. [c] ±4 eu.

Next, we consider possible steric effects on the inversion process. Two Grignard reagents were prepared which differ from 2-methylbutylmagnesium bromide by the presence of two or three methyl groups, respectively, in the γ position, and nmr spectra were determined as a function of temperature. The results are listed in Table III together with those for 2-methylbutylmagnesium

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(9) G. D. Stucky and R. E. Rundle, *J. Amer. Chem. Soc.*, **85**, 1002 (1963); L. J. Guggenberger and R. E. Rundle, *ibid.*, **85**, 5344 (1963).

(10) E. C. Ashby and M. B. Smith, *ibid.*, **86**, 4363 (1964); E. C. Ashby and F. W. Walker, *J. Org. Chem.*, **33**, 3821 (1968); E. C. Ashby and F. W. Walker, *J. Amer. Chem. Soc.*, **91**, 3845 (1969).

(11) L. Crombie and S. H. Harper, *J. Chem. Soc.*, 2688 (1950).

(12) H. C. Brown and C. Croat, *J. Amer. Chem. Soc.*, **64**, 2566 (1942).

(13) D. H. Brauns, *J. Res. Nat. Bur. Stand.*, **18**, 315 (1937).

(14) The computer program for exchanging AB systems was written by Professor Martin Saunders, Yale University. It is based on the equations of S. Alexander [*J. Chem. Phys.*, **37**, 96 (1962)].

(15) We thank Dr. Tadashhi Tokuhiro, The Ohio State University, for modifying these computer programs.

(16) We thank Professor H. S. Gutowsky and Dr. R. Vold, University of Illinois, for supplying us with a copy of their program.

(17) J. I. Kaplan, *J. Chem. Phys.*, **28**, 278 (1958); **29**, 462 (1958).

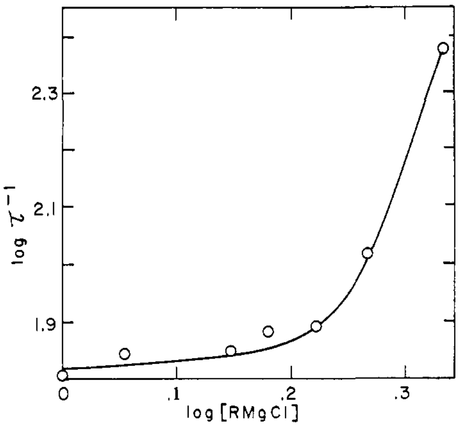


Figure 1. Kinetic plot of log τ^{-1} *vs.* log (RMgCl), contained reagent, R = 2-methylbutyl, 0° in ether.

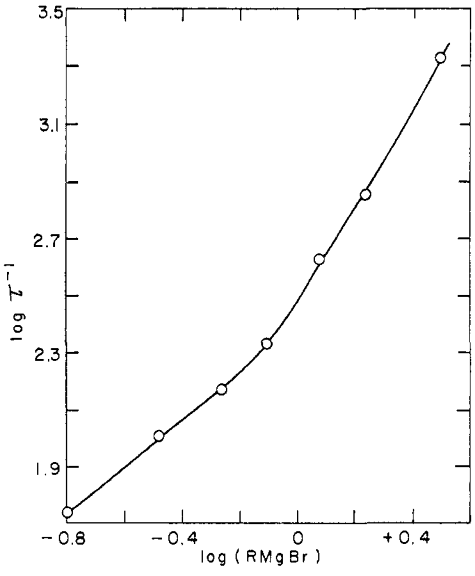
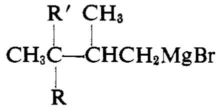


Figure 2. Kinetic plot of log τ^{-1} *vs.* log (RMgBr), R = 2-methylbutyl, 60° in ether.

bromide. It is seen that although $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ vary widely, the rate of inversion at 25° changes by less than a factor of 10. Clearly, there is not a significant steric effect on the rates of inversion.

Table III. Activation Parameters for Inversion in


$CH_3C(R)(R')–CH(CH_3)CH_2MgBr$

R	R′	$\Delta H^{\ddagger}$	$\Delta S^{\ddagger}$	$1/\tau$, sec^{-1} (25°)
H	H	12	−11	42
H	CH_3	14.7	−4.6	10
CH_3	CH_3	15.7	−3.9	4.5

The simplest kinetic treatment is to assume that the rate law consists of one term in contained organometallic reagent G

$$R_i = k(G)^n \qquad (2)$$

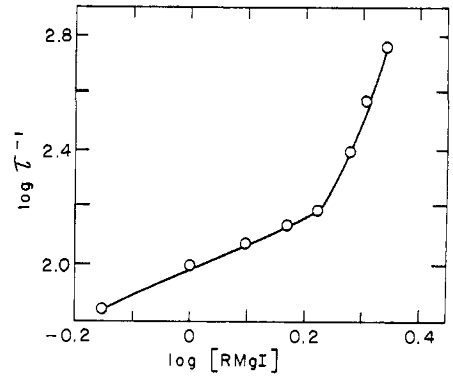


Figure 3. Kinetic plot of log τ^{-1} *vs.* log (RMgI), R = 2-methylbutyl, 60° in ether.

and since

$$\frac{1}{\tau} \equiv \frac{\text{total rate of inversion}}{(G)} \qquad (3)$$

$$1/\tau = k(G)^{n-1} \qquad (4)$$

Hence a plot of log $1/\tau$ *vs.* log G should have a slope of $n - 1$. These kinetic plots are displayed in Figures 1, 2, and 3. In the case of 2-methylbutylmagnesium chloride, the initial slope of zero corresponds to a kinetic order of one whereas for the other two Grignard reagents and bis(2-methylbutyl)magnesium[3] the order is two. At higher concentrations, the slopes of these graphs become steeper. However, in this concentration region most of the solvent is coordinated to the organometallic reagent. Such major changes in the composition of the medium alter its macroscopic properties, and it is not possible to estimate the effect of these changes on the rate constants.

A consistent interpretation of the data must take into account what is known about the aggregation[10,18,19] of organomagnesium compounds in solution. The most recent studies indicate[10] that at concentrations below 0.1 M in ether primary alkylmagnesium bromides and iodides and dialkylmagnesium compounds are *monomers*, whereas the chloride Grignard reagents are *dimers*.[20]

Molecular weight measurements by means of the boiling point technique indicate bis(2-methylbutyl)-magnesium, 2-methylbutylmagnesium bromide, and iodide to be monomeric in ether in the 0.1–0.14 M concentration range while, under the same conditions, the corresponding chloride is found to be a dimer. In THF 2-methylbutylmagnesium chloride is monomeric. These reagents behave in the same manner as similar compounds studied by Ashby and coworkers, mentioned above. Thus, it is reasonable to assume that all the reagents used in this work associate in a similar manner to that described in the preceding paragraph. On the basis of these association numbers, and the kinetic data, a consistent interpretation of these results is that the transition state for inversion is dimeric in magnesium. The overall scheme now proposed is that

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(18) E. C. Ashby, *Quart. Rev., Chem. Soc.*, **21**, 259 (1967).

(19) A. D. Vreugdenhill and G. Blomberg, *Recl. Trav. Chim. Pays-Bas*, **82**, 451, 453 (1963).

(20) At higher concentrations, 0.2–3.0 M, the data for RMgBr and RMgI in ether fit a model consisting of a mixture of polymers.[10] However, it is difficult to interpret the colligative properties of such concentrated solutions since the deviations from ideality are not well understood and cannot be accounted for, quantitatively.

a fast monomer–dimer equilibrium (5) is followed by some process, involving the dimer, which results in inversion (6). Thus, 2-methylbutylmagnesium chloride,

$$2M \rightleftharpoons D \quad (5)$$

$$D \rightleftharpoons D \quad (6)$$

being a dimer, would give first-order kinetics for inversion whereas the other three species in Table II, being monomers, would give second-order kinetics. Interestingly in THF where 2-methylbutylmagnesium chloride is a monomer the inversion process is second order in Grignard reagent at low concentrations. Furthermore, since the linearity of the kinetic plots persists up to 1.2–1.5 *M*, the results imply that these states of aggregation apply also up to this higher concentration.[21]

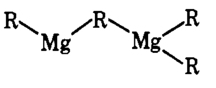
The data presented in this paper, together with previous results for other metals fit a linear free energy relationship, implying that a common mechanism for inversion applies throughout.

It is already known from other work that the bond exchange processes responsible for the monomer–dimer equilibrium are much faster than the inversion process, as is also true for magnesium–solvent coordination exchange.

In principle, inversion could result from any process which polarized the carbon–magnesium bond. However, such a process should be very sensitive to solvent polarity and should be accompanied by large negative entropies of activation. Neither of these effects are observed. Furthermore simple bond polarization should be equally probable in monomers and dimers, yet inversion takes place only in dimers.

Organomagnesium compounds are usually found to be monomers in solvents more basic than ether. 1:1 complexes of the type $RMgBr \cdot R_3{}^1N$ are well known.[22] These media coordinate more strongly with magnesium thereby reducing the equilibrium constant for dimer formation which in turn should reduce the rate of inversion. Actually it has been noted that inversion rates in organomagnesium compounds decrease with increasing solvent basicity.[3] The kinetic order for inversion of bis(2-methylbutyl)magnesium in THF is 2.[3] Dialkylmagnesium compounds of similar structure are known to be monomers in THF. Hence dimeric transition states for inversion are implicated here also.

In order to speculate further on the nature of the dimeric transition state for inversion, it is necessary to know something about the structure of Grignard reagents and dialkylmagnesium dimers. Structural information now available all comes from X-ray crystallographic studies where it is found these compounds are all monomers.[9] There is no clear information on the structure of the dimers in solution. However, it is reasonable to assume that dialkylmagnesium dimers should have at least one bridging group;[23] see **1** and **2**.



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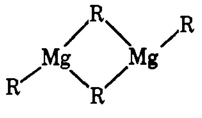
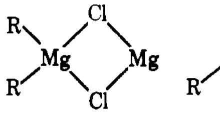


2

This suggestion is based on the finding that alkyl bridging is common to dimers of organoaluminum compounds,[24] aggregates of dimethylberyllium,[25] and polymers of dimethylmagnesium,[26] solid state. The preceding discussion leads to the conclusion that inversion in bis(2-methylbutyl)magnesium is associated with alkyl bridging in a dimeric transition state.

At the moment there is no overwhelming evidence in favor of any one of the proposed structures for Grignard dimers.[10,27] Three possible structures are shown, **3–5**. Considering that the inversion rates for the three



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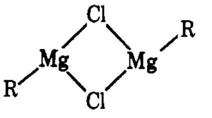

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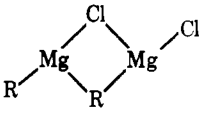

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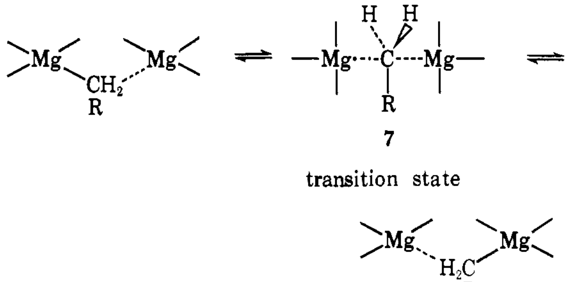
Grignard reagents and bis(2-methylbutyl)magnesium are so similar, there is a strong implication that alkyl bridging accompanies inversion in the Grignard reagents, also. It is even possible, although there is no proof now, that there is alkyl bridging in the ground states of the Grignard reagents, **5**. However, the principal conclusion reached in this work is that inversion in primary RMgX and R_2Mg compounds takes place *via* dimeric transition states where one of the R groups is in the bridging position. Then inversion is envisaged to occur as a result of intraaggregate electrophilic transfer of the bridging group from one magnesium to the other where the second magnesium assists the bond polarization process. Equation 7 is a partial representation of this mechanism.[28] It is assumed that magnesium remains four coordinate and the positions of the solvent molecules and other groups are not specified. The



(7)

proposed mechanism (7) involves one bridge. A double bridged transition state cannot be ruled out. However, it should be noted that four-center electrophilic substitution reactions proceed with retention of configuration.[29]

Since secondary alkyl groups do not bridge easily in organometallic compounds, secondary and tertiary or-

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[21] Note that deviations from ideality have a more severe effect on colligative properties than on rates of reaction.

[22] E. C. Ashby, *J. Amer. Chem. Soc.*, **87**, 2509 (1965).

[23] Ether of coordination has been omitted from these and subsequent structures.

[24] K. W. F. Kohlrausch and J. Wagner, *Z. Phys. Chem. Abt. B*, **52**, 185 (1942); K. S. Pitzer and R. K. Sheline, *J. Chem. Phys.*, **16**, 552 (1948); P. M. Lewis and R. E. Rundle, *ibid.*, **21**, 986 (1953).

[25] A. I. Snow and R. G. Rundle, *Acta Crystallogr.*, **4**, 348 (1951); N. A. Bell and G. E. Coates, quoted in G. E. Coates and K. Wade, "Organometallic Compounds," Methuen and Co. Ltd., London, 1967, pp 105–106.

[26] E. Weiss, *J. Organometal. Chem.*, **2**, 314 (1964).

[27] See G. E. Coates and K. Wade, "Organometallic Compounds," Methuen and Co. Ltd., London, pp 87–91.

[28] When eq 7 applies to R_2Mg compounds, **6** and **6′** refer to bridged dimers. If Grignard dimers are bridged in the ground state, **6** and **6′** represent these dimers. If Grignard dimers are not alkyl bridged, **6** and **6′** represent some higher energy intermediate formed by rearrangement of the dimer.

[29] F. Jensen and B. Rickborn, "Electrophilic Substitution of Organomercurials," McGraw-Hill, New York, N. Y., 1968.

ganomagnesium compounds would be expected to invert much more slowly than the primary ones. This is actually the case[30] for 3,3-dimethylcyclobutyl-,[2] 2,2-dimethylcyclopentyl,[31] and 2,2-dimethylcyclohexylmagnesium bromides,[31] respectively, 2-norbornylmagnesium bromide,[32] and 3-(2,4-dimethylpentyl)magnesium bromide.[2] These compounds invert at rates which are slow on the nmr time scale.

Experimental Section

2-Methylbutyl Chloride. Into a 500-ml round-bottomed flask equipped with a mechanical stirrer, dropping funnel, and reflux condenser was placed 2-methyl-1-butanol (88.2 g, 1 mol) and dry pyridine (79 g, 1 mol). After the slow addition of thionyl chloride (119 g, 1 mol), the reaction mixture was heated for 4 hr. Finally, the reaction mixture was poured over an ice slurry, and extracted with ether. The ether extracts were washed with dilute hydrochloric acid, potassium bicarbonate solution, and water, and then dried over calcium chloride. After removal of ether, the product was distilled at 97–99° (760 mm), yield 55%.[12]

2-Methylbutyl Iodide. Sodium iodide (100 g, 0.67 mol), 2-methylbutyl bromide (10.7 g, 0.13 mol), and 300 ml of acetone were placed in a 500-ml round-bottomed flask, fitted with a reflux condenser, and refluxed for 2 days. The excess sodium iodide and product sodium bromide were removed by filtration. After evaporation of the acetone, 2-methylbutyl iodide was distilled at 146–148° (760 mm) (lit.[13] 145–146° (760 mm)), 76% yield.

2,3-Dimethyl-1-butanol. To a stirred solution of lithium aluminum hydride (10 g, 0.29 mol) in 400 ml of anhydrous ether was added 2,3-dimethylbutyric acid (45.4 g, 0.39 mol) in 100 ml of ether. The solution was refluxed for 18 hr and after cooling, decomposed with saturated ammonium chloride solution. Ether removed and the product distilled at 142–145° (760 mm) (lit.[33] 142° (760 mm)) 26.5 g, 67% yield.

1-Bromo-2,3-dimethylbutane. Phosphorous tribromide (19.8 g, 0.68 mol) was slowly added to a cold solution of 2,3-dimethyl-1-butanol (21 g, 0.21 mol) and pyridine (6.9 g, 0.088 mol). After the addition was completed, the mixture was stirred for 2 hr at room temperature and then all volatile products were removed by vacuum distillation. The organic layer of this distillate was washed with 50 ml of 10% sulfuric acid, with two 30-ml portions of cold 96% sulfuric acid and with 50 ml of 10% potassium carbonate solution. Drying over potassium carbonate followed by distillation gave 23.3 g of 1-bromo-2,3-dimethylbutane, bp 139–140° (760 mm) (lit.[34] 140° (760 mm)), 70% yield.

1-Bromo-2,2,3-trimethylbutane. Gaseous hydrogen bromide was passed for 2 min at −78° through a solution of 2,3,3-trimethylbutene-1 (5 g, 0.051 mol) and 0.8 g of ascaridole in 100 ml of pentane. The mixture was warmed to room temperature, washed with 50 ml of 10% aqueous sodium carbonate, two 50-ml portions of cold 96% sulfuric acid, and, finally, with 50 ml of 10% aqueous sodium carbonate. The pentane solution was dried over calcium chloride to give 4.3 g of 1-bromo-2,3,3-trimethylbutane, bp 30–31° (4.7 mm), 48% yield. *Anal.* Calcd for $C_7H_{15}Br$: C, 46.94; H, 8.44; Br, 44.62. Found: C, 47.14; H, 8.41; Br, 44.63.

Generation and Handling of Organometallic Solutions. Grignard reagents were prepared and handled as described before.[5] Nmr spectra were obtained with Varian A-60 or A-60-A nmr spectrometers. The methylene resonances of the various reagents were recorded at a rate of 0.1 Hz/sec on a scale of 1 Hz/cm. The data for dilute solutions were collected with a computer of average transients. Nmr line shapes were calculated for the different ABX systems with a computer program written in Fortran IV.[15,16] The input parameters are the chemical shifts and coupling constants, T_2 for each line and τ. Other details of these techniques were published before.[5]

Molecular Weight. Measurements of the association of Grignard reagents in ether were undertaken with the boiling point method, as described by Washburn and Read[35] and modified by Walker and Ashby.[10] The two parts of the boiling point apparatus were placed side by side in an oil bath and dried in a stream of argon. Initially, both were charged with pure anhydrous solvent and, after the boiling points were measured, the magnesium compound was added to one side and the boiling point elevation measured. In this way it was found that 2-methylbutylmagnesium bromide and iodide in ether are monomeric, $i = 0.95 - 1.21$ within the range 0.14–0.44 *m* and that the corresponding chloride is a dimer, $i = 1.86 - 1.98$ within the range 0.08–0.75 *m*. Bis(2-methylbutyl)magnesium is monomeric in this concentration range.

Acknowledgment. This research was supported by the National Science Foundation Grants No. GP-8567 and GP7326, the Air Force Office of Scientific Research Grant No. 251-65, and the National Institutes of Health Grant No. GM-08686.

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(30) A second explanation of this effect is that the C–Mg bonds in the secondary reagents are probably less ionic than the primary reagents.

(31) G. Fraenkel and E. Pecchold, *J. Org. Chem.*, in press.

(32) F. R. Jensen and K. L. Nakamaye, *J. Amer. Chem. Soc.*, **88**, 3437 (1966).

(33) P. A. Levene and R. E. Marker, *J. Biol. Chem.*, **111**, 306 (1935).

(34) Reference 33, p 304.

(35) E. W. Washburn and J. W. Read, *J. Amer. Chem. Soc.*, **41**, 729 (1919).