Table II. Stereoselectivity of Reductions of Hindered Ketones with Complex Metal Hydrides in THF[a]

	$LiAlH_4$	$NaAlH_4$	$LiBH_4$
3,3,5-Trimethylcyclohexanone	80	59	53
Camphor	91	88	69

[a] The numbers listed are the percentages of the less stable alcohol found in the products.

the solvent-separated ion pair, a comparison was made of the stereochemical results obtained from the reduction of two hindered ketones with the parent hydrides in THF.[12] The results are tabulated in Table II. With the ketones studied, the yield of the less stable alcohol found in the product is significantly smaller for $NaAlH_4$ compared with that of $LiAlH_4$. A comparison of the data for $LiBH_4$ shows that the percentage of the less stable alcohol found in the product is also smaller for $LiBH_4$ with the ketones studied. A similar conclusion is reached when the results of $LiBH_4$ are compared with those of $NaAlH_4$. Apparently the enhanced selectivity of the solvent-separated $LiAlH_4$ ion pairs can be attributed to the ability of the lithium ion to complex the carbonyl oxygen with the displacement of solvent. The decreased selectivity of $LiBH_4$ can be attributed to the decreased availability of the lithium ion to complex the ketones, because triple ions are present with the ions in intimate contact. Intermediate results are obtained for $NaAlH_4$, because substantial amounts of contact ion pairs are present, and because the sodium ion is a poorer complexing cation than lithium ion.

Obviously, the ketone plays an important role in the selectivity and cannot be entirely discounted. The evaluation of other complex metal hydrides in reactions with various ketones is presently under study. Our results, however, suggest strongly that initial complexation by the cation with displacement of solvent occurs in these reductions and may provide an explanation for the enhanced selectivity of the solvent-separated ion pair.[13]

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Composition of Grignard Compounds. X. NMR, Ir, and Molecular Association Studies of Some Methylmagnesium Alkoxides in Diethyl Ether, Tetrahydrofuran, and Benzene

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Abstract: A combination of NMR, ir and molecular association studies has been applied to the study of methylmagnesium alkoxides [where OR = $OC(C_6H_5)_2CH_3$, *t*-OBu, *i*-OPr, and *n*-OPr in diethyl ether, tetrahydrofuran, and benzene. It was found that the steric bulk of the alkoxy group and the coordinating ability of the solvent determine the thermodynamically preferred solution composition. In tetrahydrofuran, solvated dimers are preferred. In diethyl ether, linear oligomers and cubane tetramers are preferred provided the alkoxy group is not bulkier than the *tert*-butoxy group. In benzene, cubane tetramers are observed for alkoxy groups of intermediate bulk such as *tert*-butoxy and isopropoxy, but the less bulky *n*-propoxy group permits the formation of an oligomer containing seven to nine monomer units. For the reagents with alkoxy groups less bulky than *tert*-butoxy, the equilibria involving various structures are established very rapidly. However, the dimer-linear oligomer $\rightleftharpoons$ cubane tetramer equilibrium is established very slowly for methylmagnesium *tert*-butoxide compounds. The cubane form is very inert and does not exchange or otherwise interact with dimethylmagnesium in diethyl ether. The dimer-linear oligomer form is quite labile and readily exchanges with dimethylmagnesium forming mixed-bridged compounds. However, in diethyl ether, the mixed bridge is not sufficiently strong to prevent slow conversion of methylmagnesium *tert*-butoxide to the cubane form thus releasing dimethylmagnesium.

The solution composition and solid state structure of organomagnesium alkoxides appear to be more complex and diverse than those of organomagnesium halides.[1] The alkoxy group forms very strong bridge bonds where the oxygen can be either tri- or tetravalent. Coates and coworkers[2a] investigated several alkylmagnesium alkoxide systems by a combination of elemental analysis, molecular association, and NMR studies. They found that bulky alkoxy groups favored the formation of solvated dimers, while compounds with less bulky alkoxy groups often formed unsolvated molecules containing four or even seven monomer units. Structures were proposed, in some cases, which accounted for the

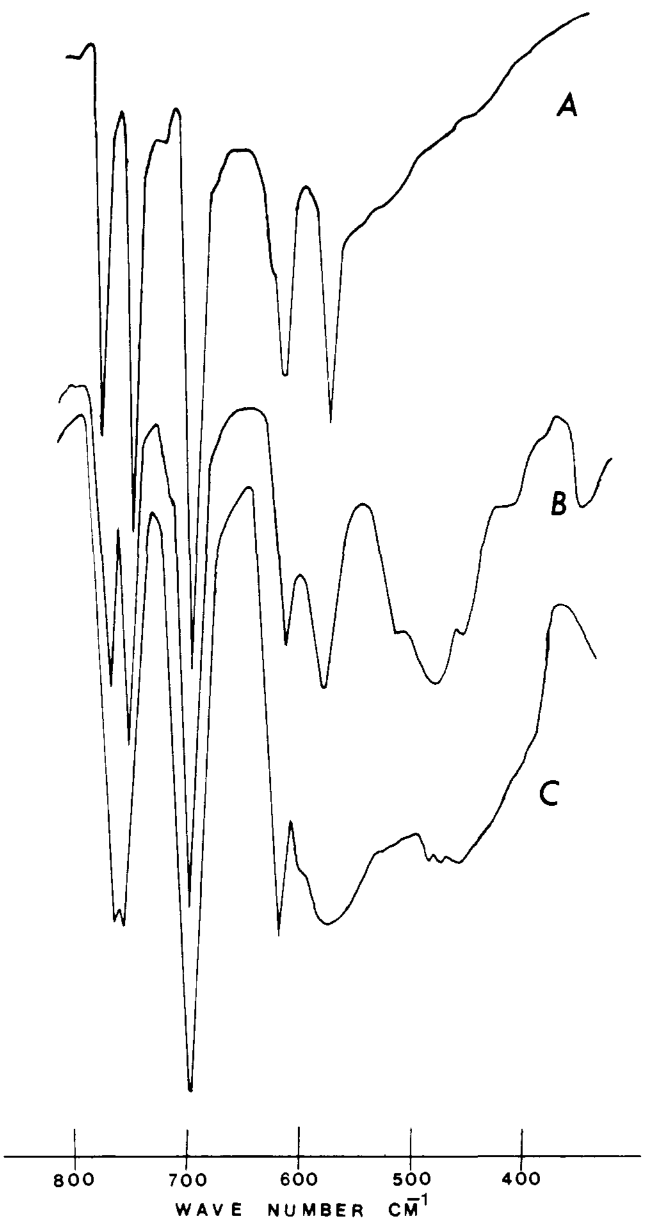
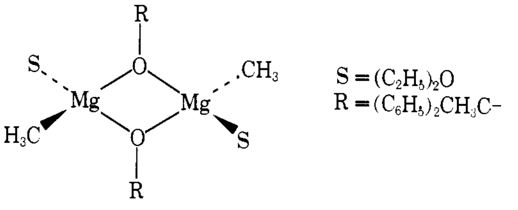


Figure 1. Infrared spectra of (A) 1,1-diphenylethanol, (B) $CH_3MgOC(C_6H_5)_2CH_3\cdot O(C_2H_5)_2$, and (C) $CH_3MgOC(C_6H_5)_2CH_3$.

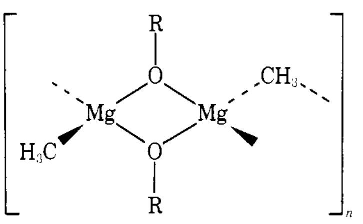
molecular association results. However, the NMR spectra were often more complex than these structures suggested and were described by the authors as "anomalous in unexplained ways". Alkylmagnesium alkoxides are of interest as intermediates in Grignard reagent addition to ketones, potential stereoselective alkylating agents, and as precursors for synthesis of new and novel organomagnesium compounds. The present investigation involves the systematic investigation of a series of methylmagnesium alkoxides in diethyl ether, tetrahydrofuran, and benzene by NMR, ir, and molecular association studies in an effort to determine the composition of these compounds in solution.

Results and Discussion

Methylmagnesium 1,1-Diphenylethoxide. Solutions of methylmagnesium 1,1-diphenylethoxide were prepared by reacting 1 mol equiv of benzophenone with $(CH_3)_2Mg$ in diethyl ether at low temperature. The maximum solubility of the product was found to be about 0.3 *m* but, when prepared at higher concentrations, a metastable supersaturated solution is obtained. Crystals deposited by the supersaturated solution on standing at room temperature proved to be "$CH_3MgOC(C_6H_5)_2CH_3\cdot O(C_2H_5)_2$". Over a period of time at room temperature and atmospheric pressure, some of the ether is lost whereas, at 100° under vacuum, all of the ether is lost. In Figure 1, the ir spectra of 1,1-diphenylethanol (A), $CH_3MgOC(C_6H_5)_2CH_3\cdot O(C_2H_5)_2$ (B), and the desolvated material (C) are compared in the 850-350 cm^{-1} region. The broad, intense bands in this region are due to carbon-magnesium vibrations. The single intense band at 490 cm^{-1} in the spectrum of the monoetherate (B) is assigned to terminal magnesium-methyl stretching vibration. The presence of several broad bands, particularly the main band at 580 cm^{-1} in the spectrum of the desolvated material, is indicative of methyl bridge bonds.[3,4] The degree of association (*i* value) for diethyl ether solutions of $CH_3MgOC(C_6H_5)_2CH_3$ examined in these studies (0.288 to 0.045 *m*) does not vary significantly from 2.0. The infrared and molecular association data are interpreted as support for the solvated, alkoxy-bridged dimer[5] (I). Desolvation of this material results in a linear oligomer (II) as indicated by the methyl bridge bands in the ir spectrum.



I



II

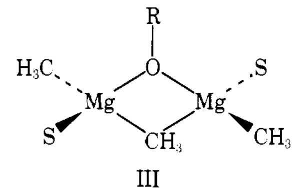
Table I.[a,b] Variable-Temperature NMR Data for $CH_3MgOC(C_6H_5)_2CH_3\cdot(CH_3)_2Mg$ and $CH_3MgOC(C_6H_5)_2CH_3$ in Diethyl Ether

	$CH_3MgOC(C_6H_5)_2CH_3\cdot Mg(CH_3)_2$	$CH_3MgOC(C_6H_5)_2CH_3$
+40°	11.48	11.46
−80°	11.24 (1), 11.56 (4.9)	11.18 (1), 11.51 (20)

[a] All chemical shifts are τ values. [b] Relative area ratios are in parentheses.

Interaction of Methylmagnesium 1,1-Diphenylethoxide and Dimethylmagnesium. In Table I, the results of a variable-temperature NMR study of a 1:1 mixture of methylmagnesium 1,1-diphenylethoxide and dimethylmagnesium in diethyl ether are compared with that of methylmagnesium 1,1-diphenylethoxide in the same solvent.[5]

We have suggested in a preliminary report[5] that the NMR spectra and molecular association studies are consistent with the representation of $CH_3MgOC(C_6H_5)_2CH_3$ predominantly as a double alkoxy-bridged dimer (I), whereas the methyl-alkoxy mixed-bridge compound (III) is



III

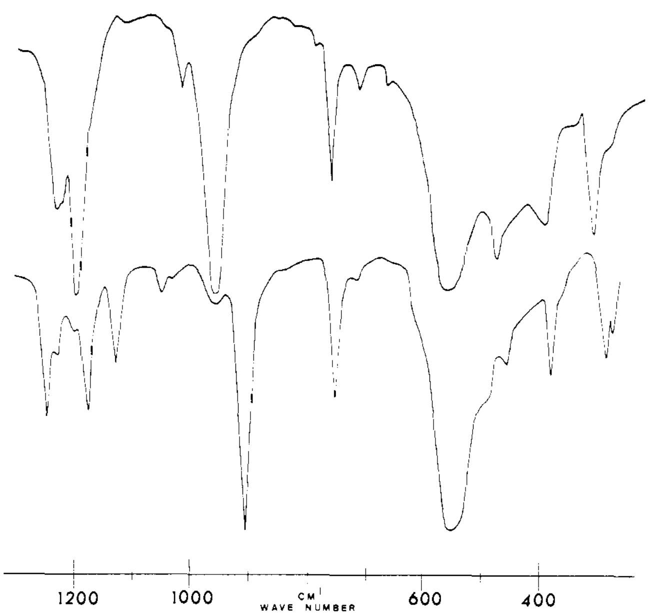
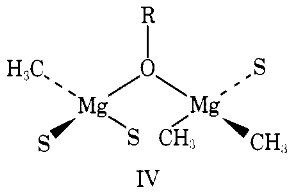


Figure 2. Low-frequency infrared spectra of the kinetic form of methylmagnesium *tert*-butoxide, top; and cubane form of methylmagnesium *tert*-butoxide, bottom.

the predominant species when $(CH_3)_2Mg$ is added to $CH_3MgOC(C_6H_5)_2CH_3$. However, the system obviously involves other species since the ratio of the bridging signal at −80° in the mixture (τ 11.24) to the terminal signal (τ 11.56) is only 1:4.9. The excess of terminal methyl sites can be accounted for by a species with only one alkoxy bridge (IV) which rapidly exchanges with the terminal sites of the mixed-bridge compound.



IV

Methylmagnesium *tert*-Butoxide. In these studies, it has been found that unsolvated methylmagnesium *tert*-butoxide can be isolated in at least two forms. When prepared under conditions favoring isolation of a kinetic product, one form is isolated (F_K) but, when thermodynamic equilibrium is achieved in some solvents, a different form (F_C) is isolated. The interconversion of these two forms is very slow under most conditions and appears to involve small concentrations of intermediates (F_X) which have not been isolated in pure form. These intermediates often contaminate the principal forms of methylmagnesium *tert*-butoxide and are responsible for the anomalous spectra reported by Coates and coworkers.[2a] Without resorting to structural arguments or assignments, the interconversions of the various forms are outlined below:

$$(CH_3)_2Mg + (CH_3)_3COH \xrightarrow{\text{fast}} F_K + \text{methane}$$

$$F_K \underset{}{\overset{\text{slow}}{\rightleftharpoons}} F_X \overset{\text{slow}}{\rightleftharpoons} F_C$$

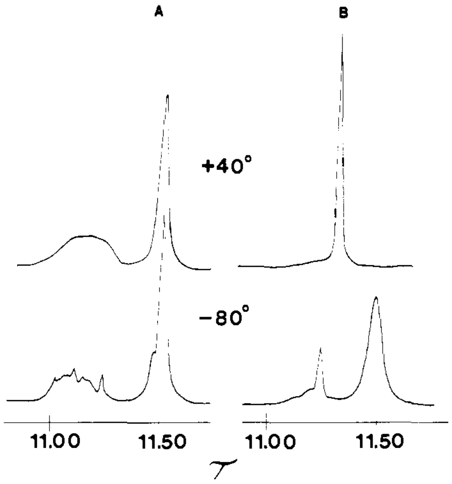
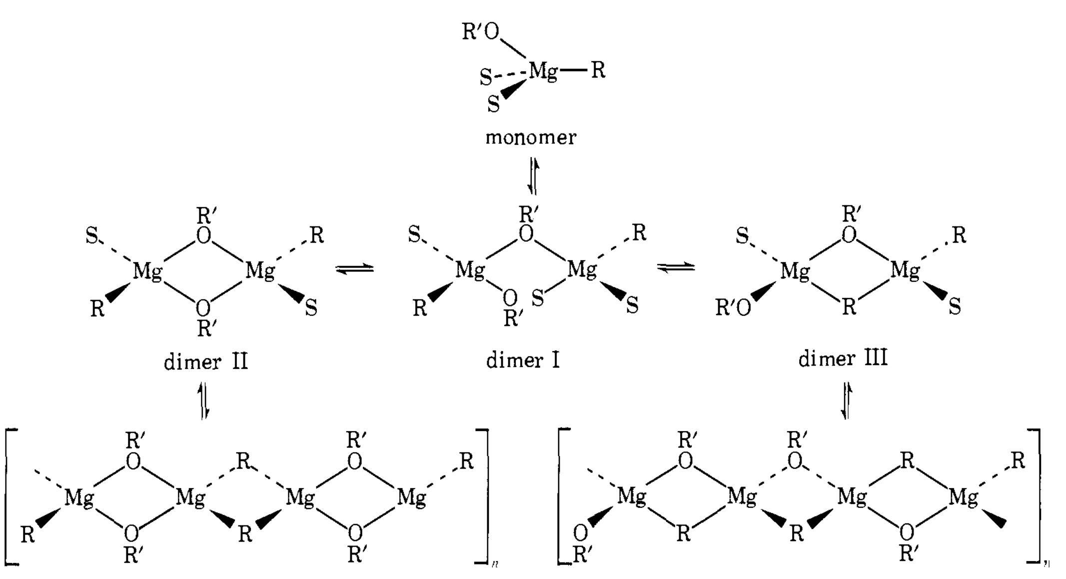


Figure 3. NMR spectra of the kinetic form $CH_3MgOC(CH_3)_3$ (A) and $CH_3MgOC(CH_3)_3{\cdot}Mg(CH_3)_2$ (B) in diethyl ether at +40 and −80°.

When 1 mol equiv of *tert*-butyl alcohol was allowed to react with dimethylmagnesium in diethyl ether at low temperature and the solvent removed in vacuo below 0°, unsolvated $CH_3MgOC(CH_3)_3$ was isolated in a form (F_K) which is not soluble in aromatic solvents and does not sublime at temperatures below which decomposition becomes rapid (i.e., 200°). In the infrared spectrum of this form (Figure 2), the presence of strong, broad bands at 570, 480, and 390 cm^{-1} is consistent with a methyl bridge-bond system with local D_{2h} symmetry.[3,4] The presence of methyl bridge bonds and the involatility and insolubility in aromatic solvents of this form suggest that it has a linear oligomeric structure similar to solid dimethylmagnesium.

The kinetic form of methylmagnesium *tert*-butoxide dissolves readily in diethyl ether or tetrahydrofuran. Its composition in these solvents was studied by ebulliometry and variable-temperature NMR. In diethyl ether, the apparent degree of association (*i* value) varied from 3.79 ± 0.05 near saturation (0.406 *m*) to 2.0 ± 0.1 in dilute solution (0.047 *m*). There was no indication that a preferred degree of association was being approached at high concentration; however, extrapolation to infinite dilution suggests that the compound is dimeric at low concentration. This result indicates that, in diethyl ether, the kinetic form exists as a complex mixture of oligomers which are in rapid, concentration-dependent equilibrium. The results of a low-temperature NMR study on a saturated solution is shown in Figure 3. At +40°, there is a slightly broadened signal at τ 11.45 assigned to terminal methyl sites and a very broad signal centered at τ 11.20, assigned to bridging methyl sites. At −80°, these two general signals are partially resolved into a number of individual signals. It is impossible to assign each methyl signal to a particular chemical structure; however, it is obvious that there are many slightly different methyl sites. For example, comparison of these spectra with the spectra of methylmagnesium *tert*-butoxide in the presence of an equivalent amount of dimethylmagnesium, (Figure 3) suggests that the sharp signal at τ 11.33 and the shoulder at τ 11.50 are due to the same chemical species in both systems. The *tert*-butoxy signal falls under the diethyl ether triplet and was not observed. Thus, the composition of the kinetic form of methylmagnesium *tert*-butoxide in diethyl ether is best represented by a set of complex equilibria. At low concentration, dimers I, II, and III predominate while, at high concentration, there are appreciable amounts of linear oligomers like II and III. The involatile solid obtained by removing solvent in vacuo is probably a mixture of oligomer II and oligomer III.

In tetrahydrofuran, the apparent degree of association (*i* value) of the kinetic form of methylmagnesium *tert*-butoxide indicates dimeric association even at relatively high concentrations (e.g., greater than 0.4 *m*). The degree of association does not appear to be greatly affected by concentration (*i* = 2.02 ± 0.03 at 0.434 *m* and *i* = 1.93 ± 0.03 at 0.299 *m*). The variable-temperature NMR spectrum at



monomer

dimer II

dimer I

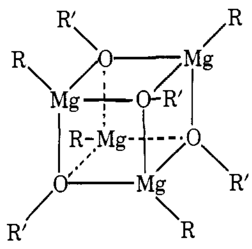
dimer III

oligomer II

oligomer III

−80° is consistent with the equilibrium, dimer I ⇌ dimer II, with the major species in solution being dimer II. The major *tert*-butoxy signal, τ 8.80, and major methylmagnesium signal, τ 11.60, are assigned to dimer II. The minor signals at τ 8.70 and 11.70 are assigned to the *tert*-butoxy signal and methylmagnesium signal of dimer I.

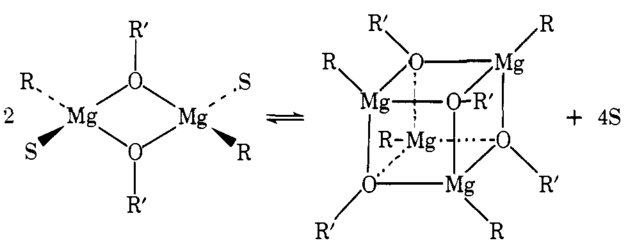
Coates and coworkers[2a] have reported obtaining methylmagnesium *tert*-butoxide in a cubane form (V); however, their NMR spectra contained unexpected signals. In the present study, it has been found that the cubane form (F_C) can be prepared without significant impurities by refluxing the diethyl ether solution of the kinetic form (F_K) in benzene as cosolvent. The cubane form prepared by this technique is soluble in aromatic solvents and readily sublimes without change at 140° in vacuo. The apparent degree of association (*i* value) of the sublimed cubane form was found to be 4.0 ± 0.2 at 0.202 *m*, 4.1 ± 0.3 at 0.159 *m* and 4.4 ± 0.4 at 0.148 *m* by cryoscopy in benzene. The NMR spectrum of the pure cubane form contains no unexpected signals.



V

$R = CH_3$, $R' = (CH_3)_3C$

The equilibrium between the kinetic form and cubane form of methylmagnesium *tert*-butoxide is solvent dependent. In diethyl ether or diethyl ether-benzene (relatively nonpolar solvents), the unsolvated cubane form is thermodynamically preferred. However, in THF (a relatively polar solvent), the solvated kinetic form is thermodynamically preferred. Even though the forward reaction above results in greater association of the organometallic reagent, the entropy of the forward reaction is very likely to be large and positive because of loss of solvation. The enthalpy for the reaction depends upon the heat of solvation and, in diethyl ether, the enthalpy for the forward reaction is probably unfavorable (positive) but not great enough to override the entropy effect. On the other hand, in tetrahydrofuran, the unfavorable enthalpy of the forward reaction is large enough to drive the equilibrium to the left. The formation of linear oligomers in concentrated diethyl ether solutions of the kinetic form also appears to be a manifestation of the low heat of solvation by diethyl ether.



In a qualitative kinetic experiment, the $F_K \rightarrow F_C$ conversion in diethyl ether was followed by a combination of NMR and ir techniques. The time dependence of the room-temperature NMR spectra is demonstrated in Figure 4. The spectra are marked with the symbols K and C to denote absorptions due to kinetic form and cubane form, respectively. At room temperature in diethyl ether, about 30 days (720 hr) are required for the reaction to proceed halfway to completion. It was verified that the equilibrium lies far in favor of the cubane form by dissolving the cubane form in diethyl ether and observing that there was no detectable change in its NMR or ir spectra over a period of several weeks.

In a similar experiment, a sample of the cubane form of methylmagnesium *tert*-butoxide was dissolved in THF. The sample was stored at room temperature, and the NMR spectrum was obtained at different time intervals (Figure 4). Once again, the equilibrium between the principal forms is established very slowly. The equilibrium was found to lie far in favor of the solvated dimer of the kinetic form by dissolving a sample of the kinetic form in THF and observing that there was no indication of the signals for the cubane form after several weeks. The equilibrium $F_F \rightleftharpoons F_C$ was studied by ir as well as NMR spectroscopy in both diethyl ether and THF. The results of the ir study were entirely consistent with those of the NMR study.

Interaction of Methylmagnesium *tert*-Butoxide and Dimethylmagnesium. Because of the very slow interconversion of the linear oligomer and cubane forms, it is possible to examine their interactions with dimethylmagnesium in diethyl ether independently. It was found by NMR that the alkoxy and alkyl groups of cubane methylmagnesium *tert*-butoxide do not exchange with $(CH_3)_2Mg$ between −100 and

Table II. NMR Chemical Shifts for Various Forms of Methylmagnesium Alkoxides in Several Solvents at 25°

			Chemical shift, (τ)	
Compound	Form	Solvent	OCR$_2$–CH$_3$	Mg–CH$_3$
CH$_3$MgO-*t*-Bu	Cubane	Benzene	8.53	10.66
		Diethyl ether	8.45	11.11
		Tetrahydrofuran	8.45	11.12
CH$_3$MgO-*t*-Bu	Oligomer	Diethyl ether	8.8	11,20 11.45
CH$_3$MgO-*t*-Bu	Dimer	Tetrahydrofuran	8.80	11.60
CH$_3$MgO-*i*-Pr	(Cubane)	Benzene	8.70	10.76
	(Cubane, oligomer)	Diethyl ether	8.56	11.30
	(Dimer)	Tetrahydrofuran	8.88	11.66
CH$_3$MgO-*n*-Pr	(Unsolvated oligomer)	Benzene		10.82
	(Cubane, oligomer)	Diethyl ether		11.33
	(Dimer)	Tetrahydrofuran		11.70

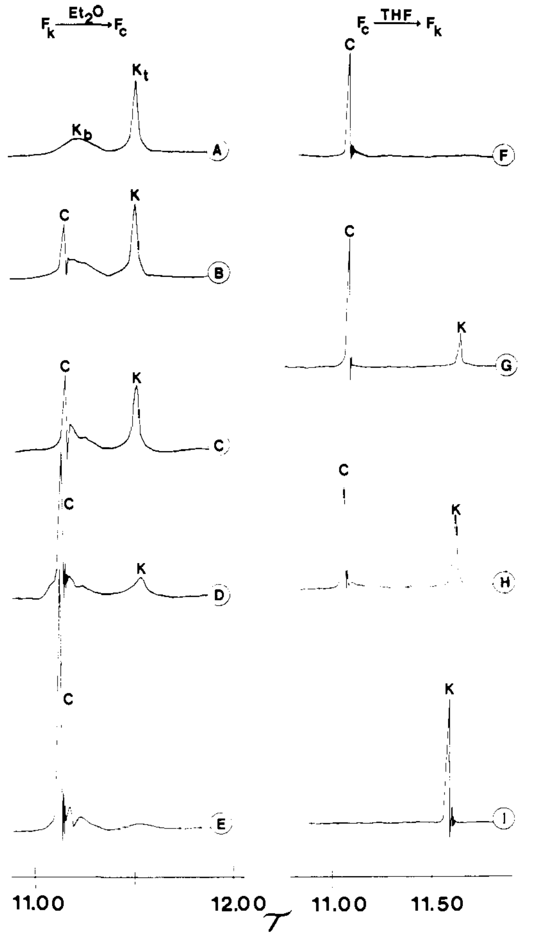


Figure 4. Time-dependent, ambient-temperature NMR spectra of methylmagnesium *tert*-butoxide. In spectra A through E, the kinetic form (K) is shown to convert to the cubane form (C) in diethyl ether: (A) at 0 hr; (B) at 50 hr; (C) at 75 hr; (D) at 266 hr; and (E) at 386 hr. In spectra F through H, the cubane form (C) is shown to convert to the kinetic form (K) in THF: (F) at 0 hr; (G) at 142 hr; and (H) at 396 hr. Spectrum I is pure kinetic methylmagnesium *tert*-butoxide in THF which does not change with time. Note the difference between spectra A and I which shown the pure kinetic form in diethyl ether and THF, respectively.

+100°. On the other hand, the kinetic form readily exchanges methyl groups with $(CH_3)_2Mg$ and forms complexes containing mixed alkoxy-alkyl bridge bonds.[5] The variable-temperature NMR spectrum of a solution prepared by reaction of 1 mol equiv of *tert*-butyl alcohol with 2 mol equiv of dimethylmagnesium is shown in Figure 3. At room temperature, the methyl groups bound to magnesium give only a time-averaged signal. At −54°, two signals are resolved. The signal at τ 11.33 is assigned to bridging methyl groups, and the signal at τ 11.45 is assigned to an exchange-averaged signal for terminal methyl groups since lowering the temperature to −80° results in broadening of the high-field signal. Unfortunately, the high-field signal could not be resolved into other signals below −100°, where resolution of the spectrum markedly deteriorated. The ir spectrum of the material obtained by removing solvent from this reagent soon after preparation was qualitatively very similar to the kinetic form of methylmagnesium *tert*-butoxide suggesting that the two materials have a similar structure. As in the case of the methylmagnesium 1,1-diphenylethoxide–dimethylmagnesium system,[5] the bridging methyl signal and i value = 1.0 can be explained best by an equilibrium involving a mixed bridge structure (III) and a single alkoxy-bridged dimer, although it is difficult to rule out some contribution of uncomplexed dimethylmagnesium and the alkoxy-bridged dimer. Furthermore, it is significant that, when this reagent is allowed to age, it slowly converts to a mixture of the cubane form of methylmagnesium *tert*-butoxide and dimethylmagnesium. While mixed bridged species undoubtedly exist in these systems, dimethylmagnesium does not appear to complex methylmagnesium *tert*-butoxide sufficiently strongly to prevent conversion to the cubane.

Methylmagnesium Isopropoxide. When 1 mol equiv of isopropyl alcohol was allowed to react wih dimethylmagnesium in diethyl ether at low temperature and the solvent removed below room temperature in vacuo, unsolvated methylmagnesium isopropoxide was isolated in a form which is soluble in diethyl ether, THF, and benzene. The solid sublimed at 100–105° in vacuo but simultaneously decomposed to a nonvolatile, pale-yellow solid even under these mild conditions.

The NMR chemical shifts of the signals representing the isopropoxy methyl groups and the methyl groups bound directly to magnesium are similar to the shifts of the *tert*-butoxy methyl groups and methyl groups bound to magnesium of the cubane form of methylmagnesium *tert*-butoxide in diethyl ether or benzene (Table II). This result is consistent with the description of methylmagnesium isopropoxide as a cubane structure in these solvents. Alternatively, there could be a rapid equilibrium in which the cubane is a major constituent. These arguments are supported by molecular association results since the unsolvated compound dissolves readily in benzene where cryoscopic measurements indicate that it is tetrameric (i = 4.08 ± 0.07 at 0.474 m, i = 4.21 ± 0.10 at 0.353 m, and i = 4.29 ± 0.14 at 0.277 m). In diethyl ether, the apparent degree of association is consistent with a rapid equilibrium between cubane tetramers, oligomers, and dimers, because the i values vary significantly with concentration (i = 3.67 ± 0.07 at 0.492 m to i = 2.83 ± 0.14 at 0.140 m). The low-temperature NMR spectrum of methylmagnesium isopropoxide in diethyl ether shows that

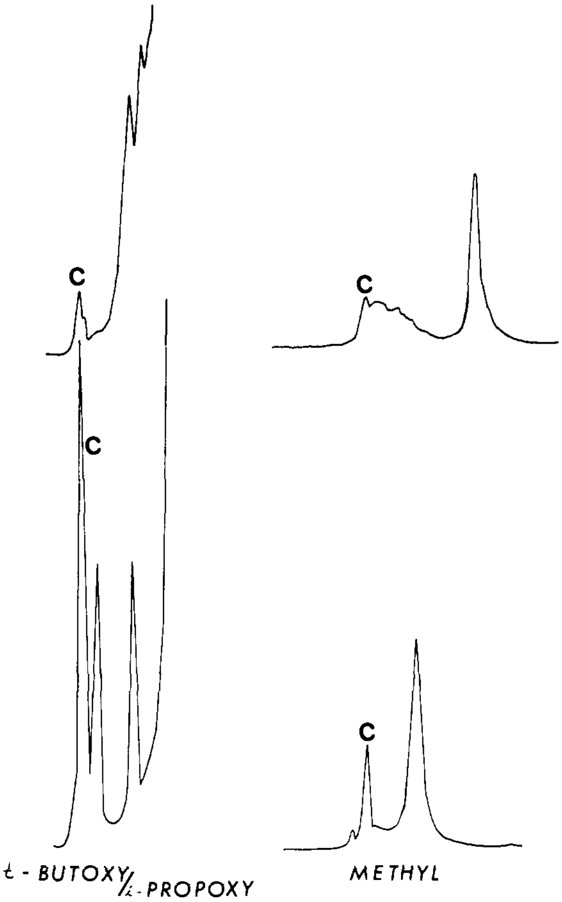


Figure 5. Ambient-temperature NMR spectra of methylmagnesium *tert*-butoxide, top; and a mixture of methylmagnesium *tert*-butoxide and methylmagnesium isopropoxide, bottom. Showing relative amounts of conversion to cubane tetramers (C).

the signal observed at room temperature is an exchange-averaged signal. It resolves into two fairly broad signals at τ 11.37 and 11.60 at −60°. The predominant lower field signal is believed to be due to the cubane sites and bridging methyl sites in linear oligomers.

When methylmagnesium isopropoxide is dissolved in THF, its NMR chemical shifts for the isopropoxy methyl groups and methylmagnesium groups are similar to those of the *tert*-butoxy groups and methylmagnesium groups of the dimeric form(s) of methylmagnesium *tert*-butoxide in THF (Table II). The molecular association data for CH_3MgO-*i*-Pr in THF also indicate a dimeric composition (i = 1.78 ± 0.06 at 0.124 m, i = 2.07 ± 0.06 at 0.153 m and i = 2.00 ± 0.05 at 0.189 m). Thus, the molecular association and NMR results for methylmagnesium isopropoxide indicate a similar solution composition to that observed for methylmagnesium *tert*-butoxide in similar solvents; the only difference is that the equilibrium composition is achieved much more rapidly.

If the conclusion that the isopropoxy system in diethyl ether contains labile cubane tetramers, while the *tert*-butoxy cubane tetramers are inert to exchange in the same solvent is correct, it should be possible to obtain an equilibrium mixture of mixed alkoxy cubane tetramers in which some of the mixed cubane tetramers are labile, and some are fairly inert depending upon the number of *tert*-butoxy and isopropoxy groups which they incorporate. This hypothesis was tested by adding some methylmagnesium isopropoxide to a sample of the kinetic form of methylmagnesium *tert*-butoxide in diethyl ether. The room-temperature NMR spectrum of the mixed system was compared with the spectrum of a sample of the kinetic *tert*-butoxy compound which was prepared simultaneously (Figure 5). Whereas the pure *tert*-butoxy compound contained only a very small quantity of the thermodynamically preferred cubane form (marked C in the top spectrum of Figure 5) because of the slow interconversion process, the mixed system (bottom spectrum, Figure 5) contains a large percentage of *tert*-butoxy and methyl groups in cubane sites of presumably mixed cubanes which are formed rapidly. This experiment lends support to the conclusion that methylmagnesium isopropoxide forms labile cubane tetramers in diethyl ether solution.

Table III. Variable-Temperature NMR Data for $CH_3MgOC(CH_3)_2H \cdot Mg(CH_3)_2$ and $CH_3MgOC(CH_3)_2H$ in Diethyl Ether

	$CH_3MgOC(CH_3)_2H \cdot Mg(CH_3)_2$		$CH_3MgOC(CH_3)_2H$	
+40°	8.57	11.40	8.56	11.30
−80°	8.58	11.51		11.37 (1), 11.63 (7)
−100°	8.58	11.58 (broad)		
−120°		11.38 (1), 11.68 (7)		

Interaction of Methylmagnesium Isopropoxide and Dimethylmagnesium. In Table III, the variable-temperature NMR spectrum of a mixture of methylmagnesium isopropoxide and dimethylmagnesium is compared with that of pure methylmagnesium isopropoxide in diethyl ether.

Unlike methylmagnesium 1,1-diphenylethoxide and kinetic methylmagnesium *tert*-butoxide noted above, the interaction of methylmagnesium isopropoxide with dimethylmagnesium is potentially a very complex system, because the presence of cubane tetramers cannot so easily be excluded. Both the NMR results and ebullioscopic measurements of diethyl ether solutions containing molar equivalents of methylmagnesium isopropoxide and dimethylmagnesium are consistent with the formation of a complex of stoichiometry $CH_3MgOCH(CH_3)_2 \cdot Mg(CH_3)_2$ (i = 0.93 – 1.06, m = 0.078–0.232). While only one signal is observed in the room-temperature NMR spectrum of this solution, at −100° a spectrum with a minor signal at τ 11.38 and a major signal at τ 11.68 is observed. This result is consistent with an equilibrium between a mixed bridge dimer (III) and a dimer with only one alkoxy bridge (IV).

Methylmagnesium *n*-Propoxide. When 1 mol equiv of 1-propanol was allowed to react with dimethylmagnesium in diethyl ether at low temperature and the solvent removed in vacuo, unsolvated methylmagnesium *n*-propoxide was isolated in a form which is soluble in diethyl ether, THF, and benzene. When heated to 120–130° in vacuo, an unrecoverably small amount of solid sublimed and the remainder turned yellow.

The NMR spectra of methylmagnesium *n*-propoxide (Table IV) suggest that its compositions in diethyl ether and THF are different since, in diethyl ether, the chemical shift of the methyl groups bound directly to magnesium is in the region where cubane tetramers or bridging methyl groups of linear oligomers absorb while, in THF, the chemical shift is in the region expected for terminal methyl sites only. The molecular association results in these solvents also suggest composition differences since, in diethyl ether, i = 4.31 ± 0.08 at 0.539 m and only decreases to i = 3.54 ± 0.41 at 0.076 m while, in THF, i = 2.30 ± 0.03 at 0.426 m and decreases slightly to i = 1.93 ± 0.08 at 0.111 m. These results indicate that the preferred structures in diethyl ether solution are the cubane and linear oligomers, while the dimer predominates even at relatively high concentration in THF. In diethyl ether, the NMR spectrum of methylmagnesium *n*-propoxide at −110° shows signals at τ 11.28,

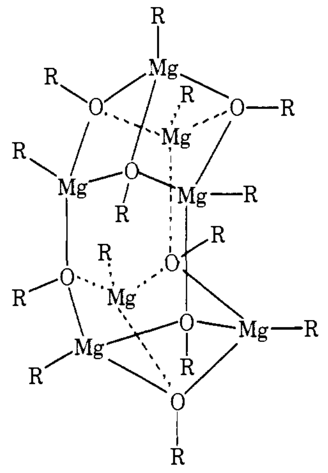
Table IV. Variable-Temperature NMR Data for $CH_3MgOCH_2CH_2CH_3 \cdot Mg(CH_3)_2$ and $CH_3MgOCH_2CH_2CH_3$

	$CH_3MgOCH_2CH_2CH_3 \cdot Mg(CH_3)_2$		$CH_3MgOCH_2CH_2CH_3$		
+40°		11.43	11.33		
−40°	11.26	11.45[a]	11.28	11.34[b]	11.42
−80°	11.28	11.53[a]	11.28	11.34	11.59
−110°			11.28[c]	11.35[c]	11.61

[a] Large relative to the downfield signal. [b] The τ 11.33–11.34 signal is larger relative to the overlapping τ 11.26–11.28 signal. [c] The relative area ratio of the τ 11.28 and 11.35 signals relative to the τ 11.61 is 8:1.

11.33, and 11.61. The main signal τ 11.33 is assigned to the cubane structure, while the small signals are assigned to bridging and terminal sites in linear oligomers.

In benzene, the apparent degree of molecular association of methylmagnesium *n*-propoxide was found by cryoscopy to be i = 7 to 9 in the concentration range 0.209 to 0.324 m. This result is similar to the observations of Coates and coworkers[2a] who observed that methylmagnesium *n*-propoxide and isopropylmagnesium ethoxide and methoxide all exhibited a molecular association in the range i = 7 to 9 in benzene. Recently, it has been suggested that these compounds may have a heptameric structure in solution (VI).[6]



VI

Three different NMR signals in the ratio 3:3:1 are expected[7] for both the alkoxy and alkyl group in VI. Coates[2a] reported that some of the signals observed for the compounds he studied were split unexpectedly, but there were usually two signals rather than three, and one of the compounds showed no unexpected splittings at all. The *n*-propoxy methyl NMR signal of methylmagnesium *n*-propoxide studied here is a sharp singlet at room temperature, and no additional signals were observed at temperatures as low as −70° in toluene. However, the *n*-propoxy methyl group is more complex than that observed in other solvents where it is a distorted triplet. From current studies, little can be added to the understanding of the structures of the alkylmagnesium alkoxides which show high degrees of association, e.g., i = 7–9. As in the previous case of aluminum-nitrogen compounds,[6,7] X-ray crystallographic results will probably be required to clear up this enigma.

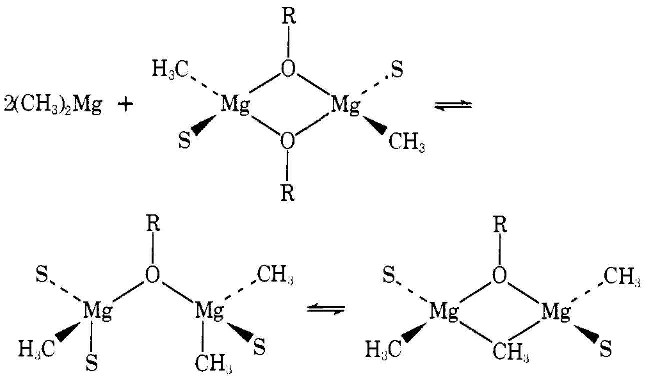
Interaction of Methylmagnesium *n*-Propoxide and Dimethylmagnesium. In Table IV, the variable-temperature NMR spectrum of a mixture of methylmagnesium *n*-propoxide and dimethylmagnesium is compared with that of pure methylmagnesium *n*-propoxide in diethyl ether.

As in the methylmagnesium isopropoxide system, interaction of methylmagnesium *n*-propoxide with a molar equivalent of dimethylmagnesiu in diethyl ether can be described by an equilibrium involving a mixed alkoxy-alkyl bridged dimer (III) and a dimer with only one bridging alkoxy group (IV). The molecular association results calculated on the basis of the empirical formula $CH_3MgOCH_2CH_2CH_3 \cdot Mg(CH_3)_2$ are i = 1.05-0.96, m = 0.068-0.11. The low-temperature NMR spectra contain a minor signal at τ 11.28 and a major signal at τ 11.53. The low-field signal can reasonably be attributed to the methyl group of a mixed-bridge system (III), while the high-field signal is assignable to terminal sites in mixed-bridge dimers (III) and the dimer with only one alkoxy bridge bond (IV).

Conclusions

Methylmagnesium Alkoxides. The thermodynamically preferred solution composition of the methylmagnesium alkoxides studied here is determined by the solvent and the steric bulk of the alkoxy group. Tetrahydrofuran strongly coordinates magnesium preventing the formation of relatively weak μ_3 oxygen bridge bonds and methyl bridge bonds. However, μ_2 oxygen bridge bonds are sufficiently strong to cause dimerization of the methylmagnesium alkoxides even in tetrahydrofuran. In diethyl ether solution, μ_3 alkoxy bridge bonds and methyl bridge bonds can form resulting in linear oligomers and cubane tetramers, provided the alkoxy groups are not too bulky to be accommodated as substituents on the magnesium-oxygen skeleton. The 1,1-diphenylethoxide group appears to block linear oligomer and cubane formation completely, while the *tert*-butoxide group is small enough that the solvated dimer is converted to the cubane tetramer, although the process is slow. Less bulky alkoxy groups permit the rapid formation of linear oligomers, cubane tetramers, and even more highly associated species in nonpolar solvents which do not cleave even weak alkoxide or methyl bridge bonds.

Interaction of Methylmagnesium Alkoxides with Dimethylmagnesium in Diethyl Ether. In these studies, it has been found that the presence of 1 mol equiv of dimethylmagnesium in diethyl ether solution of a methylmagnesium alkoxide interacts with the methylmagnesium alkoxide and affects its solution composition. The simplest cases to consider are those in which there are no cubane tetramers (i.e., methylmagnesium 1,1-diphenylethoxide, and the kinetic form of methylmagnesium *tert*-butoxide). In both these cases, NMR and molecular association studies suggest the formation of a complex containing mixed alkoxy-methyl bridge bonds in equilibrium with other methylmagnesium compounds. Although methyl group exchange is rapid at room temperature, the signal due to the methyl group in the mixed bridge is resolved at low temperature.

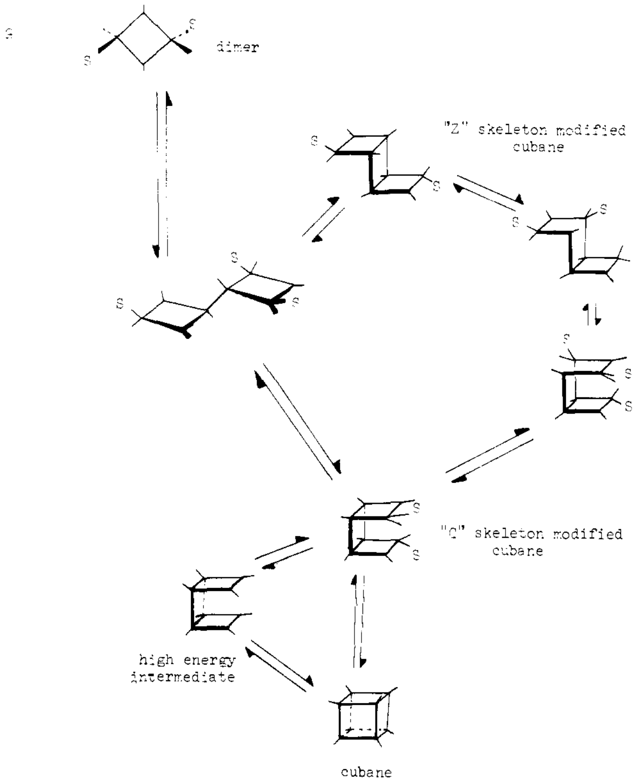


In the case of the cubane tetramer form of methylmagnesium *tert*-butoxide, there is no apparent interaction with dimethylmagnesium. The observation that methyl exchange between the cubane and dimethylmagnesium is very slow even at room temperature suggests that there is no mechanism for methyl exchange without reversion of the cubane to one of the labile intermediate forms. The same conclusion probably applies to the cubanes of methylmagnesium isopropoxide and *n*-propoxide.

The cases in which the dimer-linear oligomer ⇌ cubane equilibrium is rapidly established are the most complicated to interpret. In the simpler cases, precedent for mixed-bridge complex formation has been established. However, at least in the case of methylmagnesium *tert*-butoxide, mixed-bridge complex formation does not prevent conversion to the cubane. Thus, in the cases where the dimer–linear oligomer ⇌ cubane equilibrium is established rapidly, it is not obvious whether the exchange-averaged NMR signal observed at room temperature is due to (1) rapid reversion of a cubane to a labile intermediate which exchanges rapidly with dimethylmagnesium, (2) rapid exchange of methyl groups in the mixed-bridge complex with terminal sites of the complex, or (3) a combination of (1) and (2). Ebullioscopic measurements on these systems tend to support (2). However, it should be recognized that a system composed of cubane tetramer and dimethylmagnesium would give boiling-point elevations which are not exceptionally different from those observed. The low-temperature NMR spectra of these systems contain small signals in the region expected for the mixed-bridge methyl groups (Tables III and IV). There is also a large signal which even at −100° appears to be an exchange-averaged signal. This signal can be accounted for entirely by an equilibrium between the mixed-bridge complex and a dimer bridged by only one alkoxy group, but there does not seem to be any compelling evidence to overrule contributions to this signal from cubane sites.

Comments on the Mechanism of Dimer ⇌ Cubane Interconversion. Starting with solvated dimers, the first step in conversion to the cubane tetramer is believed to be formation of a μ_3 oxygen bridge by either concerted or stepwise displacement of solvent by a μ_2 oxygen (Scheme I). Formation of the second μ_3 oxygen bridge could also be preceded by or concerted with loss of solvent. At this point, the exact sequence of bond breaking and bond making are relatively unimportant. In either case, the formation of a second μ_3 oxygen bridge could reasonably lead to a "Z" skeleton or "C" skeleton modified cubane. These two structures should be readily interconvertible by several mechanisms involving various intermediates. Some of these intermediates could logically be the starting point for formation of complex cage oligomers like VI. There is probably more steric strain in the "C" skeleton modified cubane than the "Z" skeleton, particularly for compounds with bulky alkoxy groups. Up to this point, no obvious differences in the mechanism for bulky and nonbulky systems are noted which could account for the observed differences in rate of the interconversion reaction.

Scheme I



However, final closure of the "C" skeleton modified cubane very likely involves *simultaneous* formation of the third and fourth μ_3 oxygen bridge bonds since sequential closure would require severe distortion of the existing four-membered rings. Models show that, for systems less bulky than methylmagnesium *tert*-butoxide, a concerted displacement of solvent by the μ_2 oxygens is possible. For the methylmagnesium *tert*-butoxide system, the models indicate that the cubane is so crowded that the solvent must be completely dissociated before the μ_2 oxygen and magnesium atoms can come within bonding distance. Thus, the sequence of bond breaking and bond making is probably different for the bulky and nonbulky systems in the final closure step. The nonbulky systems have available a low-energy concerted pathway, whereas the bulky systems are limited to a pathway involving a high-energy intermediate.

Experimental Section

General Procedures. All methylmagnesium compounds are air sensitive. Therefore all reactions were carried out under nitrogen using dry box[8] and Schlenk tube techniques.[9] All solvents were distilled from reactive hydrides prior to use (benzene and toluene from NaH, THF from $NaAlH_4$, and diethyl ether from $LiAlH_4$). Alcohols (*tert*-butyl, isopropyl, and *n*-propyl alcohols) were dried by refluxing over CaH_2 followed by fractional distillation.

Synthesis and Analysis. Dimethylmagnesium was prepared by reacting neat dimethylmercury (Orgmet) with a 100% excess of sublimed magnesium metal (Dow) at room temperature for 24 hr.[10] After removal of unreacted dimethylmercury under vacuum, the dimethylmagnesium was extracted from the amalgam by adding the solvent of choice (diethyl ether or THF). Clear, colorless solutions were obtained by filtration. Usually the reaction was scaled to obtain about 500 ml of a 0.5 *M* solution. Typically the hydrolyzable methyl to magnesium ratio was 1.96:1.00.

Methylmagnesium 1,1-Diphenylethoxide. Benzophenone (0.025 mmol, 4.55 g in 30 ml of diethyl ether) was added to a stirred solution of dimethylmagnesium (0.025 mol, 45 ml of a 0.56 *M* solution in diethyl ether) at Dry Ice temperature. The orange-colored reaction mixture was allowed to warm slowly. After 2 hr, the solution had warmed to room temperature and was colorless. When left undisturbed overnight, a deposit of colorless, translucent crystals formed. These crystals were filtered in the dry box and dried under nitrogen (yield 5.1 g). A weighed sample was analyzed by vacuum line techniques and EDTA titration for CH_4:Mg ratio and percent Mg.

Anal. Calcd for $CH_3MgOC(C_6H_5)_2CH_3{\cdot}O(C_2H_5)_3$: Mg, 7.82. Found: Mg, 7.82. The CH_4:Mg ratio was found to be 1.00:1.00.

A sample of the solid monoetherate lost less than 1% in weight at 25° (10^{-4} mm) for 1 day. When heated at 100° (10^{-4} mm) for 18 hr, 24% of the total weight was lost (theoretical weight loss for desolvation is 23.8%). Further heating at 100° and then at 125° in vacuo for a total of 2 days resulted in no significant change in weight. No tendency to sublime or decompose was noted under these conditions.

Methylmagnesium 1,1-Diphenylethoxide–Dimethylmagnesium. To 100 ml of 0.6765 *M* 1,1-diphenylethoxy(methyl)magnesium (7.64 mmol), cooled in a Dry Ice–acetone bath, was added 11.61 ml of 0.659 *M* dimethylmagnesium (7.64 mmol) in diethyl ether.

At Dry Ice-acetone and room temperature, no precipitate was formed, yielding a clear solution. Analysis of the solution gave an active methyl to magnesium ratio of 1.51:1.00.

Methylmagnesium *tert*-Butoxide (Kinetic Form). Dimethylmagnesium in diethyl ether (typically 0.5 *M*) was placed in a round-bottomed flask with a stirring bar and equipped with a three-way stopcock. The solution was cooled in a Dry Ice-acetone bath to maintain as low a temperature as possible without inducing precipitation. From a syringe, 1 mol equiv of a solution of *tert*-butyl alcohol in either diethyl ether or benzene (typically 2×10^{-3} mol/g of solution) was added dropwise to the dimethylmagnesium solution. After addition of all the *tert*-butyl alcohol, the reaction mixture was stirred briefly to ensure that evolution of methane was complete. The cold bath was removed and a vacuum applied to the reaction flask. Evaporation of the solvent kept the reaction mixture cool, and virtually all the solvent was evaporated below 0°. Typically the ratio of hydrolyzable methyl groups to magnesium in solution prior to isolation of the solid was 0.96:1.00. Typical magnesium analysis of the solid was 20.9% (calcd for "$CH_3MgOC(CH_3)_3$": Mg, 21.6%). This material was found to be insoluble in benzene. It did not sublime at 160° in vacuo, and it decomposed rather than sublime when heated in vacuo at 200°.

Methylmagnesium *tert*-Butoxide (Cubane Form). Dimethylmagnesium was allowed to react with 1 mol equiv of *tert*-butyl alcohol in diethyl ether or diethyl ether-benzene solvent at −70°. The reaction mixture was allowed to warm to room temperature then refluxed for 4 days. Ether solvent was removed by distillation and replaced with pure benzene during the reflux period. When the benzene was removed, the product was initially a waxy solid but soon crystallized.

This material was soluble in benzene to the extent of 0.26 *m* and was sublimed at 140° in vacuo. The infrared spectra of the sublimed and unsublimed material were virtually identical. While this form of methylmagnesium *tert*-butoxide and the kinetic form both have bands characteristic of CH_3 and $(CH_3)_3CO$ groups bound to magnesium in their infrared spectra, there are distinct differences in the spectra. Typical magnesium analysis for the sublimed product was 22.1% (calcd for "$CH_3MgOC(CH_3)_3$": Mg, 21.6%).

Reaction of Kinetic Methylmagnesium *tert*-Butoxide with Dimethylmagnesium. Following the procedure described for preparation of the kinetic form of methylmagnesium *tert*-butoxide, 1 mol equiv of *tert*-butyl alcohol was allowed to react with 2 mol equiv of dimethylmagnesium in diethyl ether. The ir spectrum of the unsolvated product, obtained by removing solvent in vacuo at 25°, was qualitatively very similar to the kinetic form of *tert*-butoxy(methyl)magnesium.

Methylmagnesium Isopropoxide. Dimethylmagnesium in diethyl ether (typically 0.5 *M*) was placed in a round-bottomed flask with a stirring bar and equipped with a three-way stopcock. The solution was cooled in a Dry Ice-acetone bath. Via syringe, 1 mol equiv of isopropyl alcohol in diethyl ether (typically 2×10^{-3} mol/g of solution) was added slowly to the dimethylmagnesium solution. After addition of the isopropyl alcohol, the reaction mixture was stirred and allowed to warm to room temperature. In representative preparations, the ratio of hydrolyzable methyl groups to magnesium in solution was 1.00:1.00. Integration of NMR spectra indicated the ratio of alkoxy groups to methyl groups bound to magnesium was one to one. The solvent was removed in vacuo to obtain the unsolvated solid product.

Anal. Calcd for "$CH_3MgOCH(CH_3)_2$": Mg, 24.7. Found: Mg, 25.0.

The unsolvated product obtained in this fashion is readily soluble in diethyl ether, THF, or benzene. When heated to 100 to 105° in vacuo, some white material readily sublimed, but the bulk of the material yellowed. The ir spectrum of the sublimed material was virtually identical with that of the material originally isolated from solution, but the yellowed material had a substantially different ir spectrum. It seems that the product which was obtained by removing solvent sublimes readily without change. However, it simultaneously decomposes to an involatile yellow substance. No changes were observed in the NMR spectra of methylmagnesium isopropoxide in diethyl ether, THF, or benzene over a period of weeks.

Methylmagnesium Isopropoxide-Dimethylmagnesium. To 50.5 ml of 0.706 *M* dimethylmagnesium (35.6 mmol) in diethyl ether, cooled by a Dry Ice-acetone bath, was added 4.02 ml of 4.44 *M* isopropyl alcohol (17.8 mmol) in diethyl ether. On warming to room temperature, no precipitate occurred, and analysis of the solution resulted in an active methyl to magnesium ratio of 1.51:1.00.

Methylmagnesium *n*-Propoxide. Dimethylmagnesium in diethyl ether (typically 0.5 *M*) was placed in a round-bottomed flask equipped with a stirring bar and a three-way stopcock. The solution was cooled in a Dry Ice-acetone bath. Via syringe, 1 mol equiv of 1-propanol in diethyl ether (typically 2×10^{-3} mol/g of solution) was added to the dimethylmagnesium solution. After addition of the alcohol solution, the reaction mixture was allowed to warm to room temperature. In representative preparations, the ratio of hydrolyzable methyl to magnesium in solution was 1.02:1.00. Integration of NMR spectra indicated that the ratio of alkoxy to methyl groups bound to magnesium is 1:1. The solvent was removed in vacuo to obtain the unsolvated solid product.

Anal. Calcd for $CH_3MgOCH_2CH_3CH_3$: Mg, 24.7. Found: Mg, 24.5.

The unsolvated product obtained in this fashion is readily soluble in diethyl ether, THF, and benzene. When heated to 120 to 130° in vacuo, the solid yellowed slightly, and its ir spectrum changed considerably. A very small (unrecoverable) amount of white solid sublimed.

Methylmagnesium *n*-Propoxide-Dimethylmagnesium. To 40 ml of 0.356 *M* dimethylmagnesium (14.2 mmol) in diethyl ether at room temperature was added 42.6 ml of 0.334 *M* *n*-propoxy(methyl)magnesium (14.2 mmol) in diethyl ether. No precipitation occurred, and analysis of the clear solution indicated an active methyl to magnesium ratio of 1.55:1.00.

Physical Studies. Infrared spectra were obtained in Nujol (1375-250 cm^{-1}) mulls between cesium iodide plates on a Perkin-Elmer 621 spectrometer. Proton magnetic resonance spectra were obtained on a Varian A-60 spectrometer with the standard variable-temperature unit. Temperature was calibrated with a methanol standard. The ebullioscopic constant for diethyl ether was 2.01 and for THF 2.20 (740.0 mmHg). For each system, at least three concentrations were studied and, in several cases, as many as three different measurements on two or more independent samples were made. Because of the low concentration and high degree of association, the experimentally determined ΔT_{bp}'s were quite small, usually 0.5 to 0.05°. Thus, the experimental uncertainty in this measurement is very significant in some cases and rather minor in others. An estimation of the experimental uncertainty for each value has been included in the text for purposes of interpretation. Cryoscopic measurements were made in an apparatus adopted for handling air-sensitive compounds.[11] The cryoscopic constant of benzene was taken to be 4.90 which has been recommended for experimental measurements in preference to the theoretical value of 5.12.[9] All concentrations refer to the gram formula weight (e.g., the number of moles of magnesium per 1000 g of solvent).

Interconversion Experiments Involving Methylmagnesium *tert*-Butoxide. Two grams of the kinetic form of methylmagnesium *tert*-butoxide (F_K) was dissolved in 125 ml of diethyl ether. A small sample was placed in an NMR tube, and the remainder was split into five equal portions stored in tightly stoppered 50-ml flasks. The samples were stored in a dry box at 20-25°. At intervals, the solvent was evaporated from a flask, and ir spectra of the isolated solids were obtained (Nujol mulls). At similar intervals, NMR spectra of the initial solution were made. In the NMR spectra, there is a tendency to overestimate the contribution of the cubane form (F_C), because its signals are sharp and stand out above the broad signals of the kinetic form. In the ir spectra, it is clear that about 3 weeks are required for half of the kinetic form to be converted to the thermodynamic form under these mild conditions. Because of the very slow rate of the forward reaction, $F_K \rightarrow F_C$, it was impractical to allow these solutions to spontaneously proceed to equilibrium. However, samples of the pure cubane form (F_C) prepared by the codistillation procedure and isolated by sublimation were dissolved in diethyl ether and maintained at 20 to 25° for 14 days. The solvent was removed in vacuo, and the ir spectrum of the solid (Nujol mull) was found to be identical with that of the pure cubane (F_C).

In a similar experiment, a sample of the cubane form of methylmagnesium *tert*-butoxide (F_C) was dissolved in THF and stored at room temperature for 14 days. The solvent was removed in vacuo, and the ir spectrum of the solid was recorded (Nujol mull). In this spectrum, bands for the kinetic and cubane forms of methylmagnesium *tert*-butoxide appeared in about equal intensity. Thus, THF seems to drive the equilibrium $F_K \rightleftarrows F_C$ in favor of the kinetic form. To measure the extent of this reversal of the equilibrium, samples of the kinetic and cubane forms were used to prepare two NMR samples using THF as the solvent. The samples were kept at 20 to 25° in sealed NMR tubes, and spectra were obtained at convenient intervals. Whereas the NMR spectrum of the kinetic form in THF showed no change after several weeks, signals for the kinetic form slowly appeared in the sample of the cubane form after the same time period. Thus, the kinetic form is thermodynamically favored in THF.

Mixed CH_3MgOR Systems. A sample of unsolvated, kinetic methylmagnesium *tert*-butoxide was divided into two portions. One portion was dissolved in diethyl ether and placed in an nmr tube. To the other portion, a similar amount of unsolvated methylmagnesium isopropoxide (which appears to be the cubane form, although it was isolated under conditions which yielded the kinetic, linear oligomer form of methylmagnesium *tert*-butoxide) was added. This mixture was placed in a second NMR tube and also dissolved in diethyl ether. The room-temperature NMR spectra of these samples were obtained approximately 30 min after preparation and then at specific intervals of time for several days. Whereas, the pure *tert*-butoxy system contained only a small percent of *tert*-butoxy and methyl groups in cubane sites, the mixed system contained a large percentage of *tert*-butoxy and methyl groups in cubane sites.

Kinetic Methylmagnesium *tert*-Butoxide–Dimethylmagnesium. A sample of the solid product obtained by reacting 1 mol equiv of *tert*-butyl alcohol with 2 mol equiv of dimethylmagnesium in diethyl ether and removing solvent rapidly in vacuo was redissolved in diethyl ether and observed over a period of time. Its NMR spectrum initially showed only a sharp methyl rapid exchange signal. Over a period of days, the signals characteristic of the cubane form of methylmagnesium *tert*-butoxide appeared and slowly developed. Ultimately, the spectrum was consistent with a nonexchanging mixture of the cubane form of methylmagnesium *tert*-butoxide and dimethylmagnesium.

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Hydrolysis of N,N-Disubstituted Imidate Esters

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Abstract: The influence of pH on the nature of the products of hydrolysis of six N,N-disubstituted imidate esters has been investigated. The yield of amine decreases invariably as pH is increased, but imidates derived from dimethyl- and diethylamine are converted to amine in unusually high yield in solutions as alkaline as pH 12.7. These findings are interpreted in terms of a recently suggested[7] mechanism involving tetrahedral addition intermediates which are not at equilibrium with respect to proton transport. The relevance of this work to the proposal[13] that orbital orientation controls the decomposition of tetrahedral intermediates is discussed.

The importance of understanding the mechanism of hydrolysis of imidate esters and its relation to the mechanism of ester aminolysis has been emphasized in a number of recent investigations, beginning with the study of thiazoline hydrolysis in 1959.[1-7] The observation that the products of imidate hydrolysis vary with pH has been a prominent element in the studies which have sought to identify the rate-determining steps in the aminolysis of esters.[4,7,8] Imidates derived from aliphatic alcohols and aliphatic and aromatic amines generally yield amines (and esters) on hydrolysis at low pH, and amides (and alcohols) at high pH.[4,8-10] The product transition occurs at pH 5.5–9.5, depending mainly on the basicity of the resident amine, which has varied in the range of $pK_a = 1–10$. Imidates, derived from phenols,[3,7,11] and thioimidates[12] yield largely amides through most of the pH range, although some of them form amines below pH 2–3. With the exception of imidates derived from very weakly basic amines (di- and trinitroaniline, *p*-toluenesulfonamide),[6] the hydrolysis of most imidate esters does not produce amines in significant yield at pH >10.

In a recent publication, Deslongchamps et al.[13] reported that several cationic imidate esters were converted in high yield to amines during hydrolysis at basic pH. These reactions were carried out usually in mixed aqueous-organic solvents of uncertain pH, and sometimes in the presence of carbonate buffers, which are known to increase markedly the yield of amine produced on hydrolysis of some imidates.[9,14] The importance of these observations for the mechanism of imidate hydrolysis, particularly with respect to the properties of the tetrahedral intermediates formed in these reactions, led us to reexamine the hydrolysis of certain cationic imidate esters in predominantly aqueous solution, over a range of pH values. The results which are presented in this paper confirm and extend the observations of Deslongchamps et al.[13] that some imidate esters derived from basic amines afford mostly amines upon hydrolysis in alkaline solutions.

Results

Kinetic measurements of the hydrolysis of six cationic imidate esters (**1**–**6**) were made in 0.5% acetonitrile–water ($\mu = 0.5$, KCl), at 30°, by spectrophotometric means. The unsymmetrical *N*-methyl-*N*-ethyl imidate **4** consisted mainly of one isomer (>85%) to which the structure shown