Kinetics of the Reaction of Dimethylmagnesium with 4-Methylmercaptoacetophenone[1]

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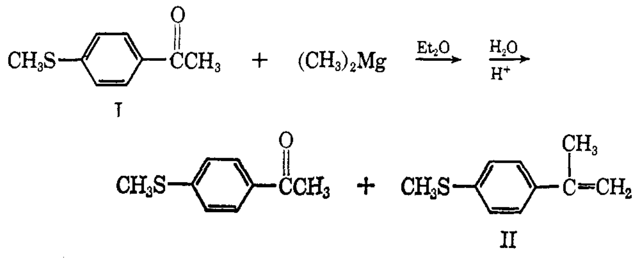
Abstract: The reaction of 4-methylmercaptoacetophenone with dimethylmagnesium in diethyl ether at 25.0° has been studied by a stopped-flow and rapid-scan spectrophotometric technique. In addition to ketone absorbance, the ultraviolet spectrum of reacting solutions displays an absorbance with $\lambda_{\max}$ 337 mμ (ϵ 1.4 $\times$ 10^4), which is attributed to a ketone–dimethylmagnesium complex or set of such complexes with an equilibrium constant for formation of 6.2 l./mole. Increasing the dimethylmagnesium concentration from 0.01 to 0.6 *M* increases the observed pseudo-first-order rate constant for disappearance of ketone from 1.1 to 16 sec^{-1}. The kinetic data are consistent with a first-order conversion of complex to products.

In our previous publications, spectroscopic[3] and kinetic[4] studies of the reaction of methylmagnesium bromide with substituted benzophenones were presented in support of addition mechanisms generally involving rapid complex formation followed by relatively slow conversion to product. The lack of definitive knowledge of the nature of the Grignard reagent in diethyl ether over the concentration range employed allows a variety of reaction schemes to be quantitatively consistent with the experimental data available.

Since dialkylmagnesium[5] may make a contribution to the total description of the Grignard reagent and contribute to the total rate of the reaction of many Grignard reagents[6] with ketones, it is important to have an understanding of the kinetics of the reaction of a typical dialkymagnesium with a representative ketone. In this paper a kinetic and spectroscopic study of the reaction of dimethylmagnesium with 4-methylmercaptoacetophenone (I) is presented. The behavior of this system is compared with the considerably less reactive case of the addition of methylmagnesium bromide to the hindered ketone, 2,4-dimethyl-4′-methylmercaptobenzophenone, reported earlier.[4]



Results

The dimethylmagnesium reagents used in these studies were prepared under argon from Dow[7] single-sublimed magnesium in an apparatus previously dried under vacuum. A desired quantity of methyl bromide was slowly distilled into a stirred mixture of a *ca.* 2 *M* excess of magnesium in anhydrous diethyl ether that was freshly distilled from a degassed preparation of methylmagnesium bromide. The dimethylmagnesium reagent was subsequently prepared from the methyl Grignard by the dioxane precipitation method,[8] filtered through two sintered-glass disks, and delivered into sealed vessels. Dilution was accomplished by distilling diethyl ether into these vessels. Quantitative analyses were performed by withdrawing aliquots and determining the iodine, total base, and total halide titers.

Spectrophotometry. Stopped-flow,[9] rapid-scan spectrophotometry indicates that in the presence of dimethylmagnesium in diethyl ether, 4-methylmercaptoacetophenone (I) has an absorbance with $\lambda_{\max}$ 308 mμ which is attributed to free ketone[10a] and an additional absorbance, $\lambda_{\max}$ 337 mμ, formed essentially instantaneously[10b] on the time scale of the reaction. The latter absorbance is attributed to a complex between the ketone and dimethylmagnesium. The observed spectrum given in Figure 1 was recorded 18.2 times per second. The first recorded spectrum in Figure 1 corresponds to continuous-flow conditions making relative absorbance at various wavelengths independent of the time required to sweep through the spectral region. The remaining traces were obtained after the mixed reagents stopped flowing through the monitoring cell. It is apparent that absorbance due to both ketone and complex rapidly decreases at the same rate to the dimethylmagnesium base line.

Although ketone I is transparent, under these conditions, at the absorbance maximum of the complex, 337 mμ, contribution by the complex to the absorbance at the ketone maximum, 308 mμ, needs to be considered.

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[1] Research supported by a grant from the National Science Foundation.

[2] (a) Alfred P. Sloan Fellow; (b) Sinclair Oil Fellow.

[3] S. G. Smith, *Tetrahedron Letters*, 409 (1963).

[4] (a) S. G. Smith and G. Su, *J. Am. Chem. Soc.*, **86**, 2750 (1964); (b) *ibid.*, **88**, 3995 (1966).

[5] H. O. House and D. D. Traficante, *J. Org. Chem.*, **28**, 355 (1963).

[6] For recent reviews, see: (a) B. J. Wakefield, *Organometal. Chem. Rev.*, 1, 131 (1966); (b) W. Tochtermann, *Angew. Chem.*, **5**, 351 (1966); (c) R. E. Dessy and W. Kitching, *Advan. Organometal. Chem.*, **4**, 280 (1966).

[7] We are indebted to the Dow Chemical Co. for the supply of magnesium used in these experiments.

[8] W. Schlenk, *Ber.*, **64B**, 736 (1931).

[9] For reviews of flow methods and detailed descriptions of typical experimental apparatus, see: (a) F. J. W. Roughton and B. Chance in "Investigation of Rates and Mechanisms of Reactions," Part II, S. L. Friess, E. S. Lewis, and A. Weissberger, Ed., Interscience Publishers, Inc., New York, N. Y., 1963, Chapter 14; (b) E. F. Caldin, "Fast Reactions in Solution," John Wiley and Sons, New York, N. Y., 1964, Chapter 3.

[10] (a) The ketone $\lambda_{\max}$ in diethyl ether is 300 mμ. The apparent shift of 8 mμ may be attributed to a bathochromic medium effect, absorbance contributed by the complex in this spectral region, and/or experimental error. (b) The ultraviolet absorbance attributed to the organomagnesium–ketone complex is present at the first spectrophotometric measurement, *ca.* 0.16 sec after mixing equal volumes of the reagents.

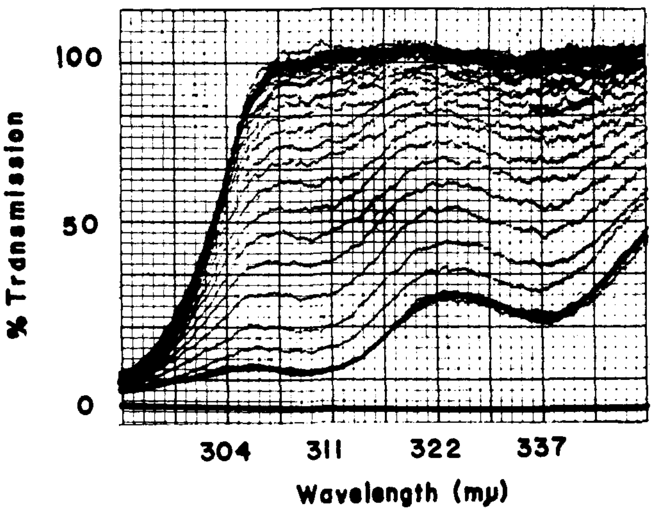

Figure 1. Transmission spectrum of *ca.* 10^{-4} M ketone I in *ca.* 0.1 M dimethylmagnesium in diethyl ether at 25.0° recorded 18.2 times per second. The first recorded spectrum was recorded under continuous-flow conditions. The base-line absorbance below *ca.* 305 mμ is due to the presence of excess dimethylmagnesium.

The ultraviolet spectrum of ketone I in the presence of sufficient methylmagnesium bromide to complex essentially completely the ketone can be measured. Above 0.5 M methylmagnesium bromide, 10^{-4} M ketone I displays a ratio of absorbance at the ketone maximum to the complex maximum (340 mμ) of 2.8, with the absorbance between 300 and 310 mμ being relatively constant. The calculations for determining the equilibrium constant for complex formation with dimethylmagnesium, described below, assume that the complex of ketone I with methylmagnesium bromide is a good model for the dimethylmagnesium complex.

The apparent extinction coefficient of the dimethylmagnesium complex of ketone I at its absorbance maximum may be calculated from the measured absorbance, the flow cell path length, and the equilibrium concentration of complex. The equilibrium concentration of complex is equal to the difference between the initial and equilibrium concentration of ketone before any reaction has occurred. The equilibrium concentration of ketone may be calculated from the difference between the total absorbance at the ketone maximum and the absorbance at the ketone maximum contributed by the complex. The latter is $^1/_{2.8}$ the absorbance at the complex maximum, based on the methylmagnesium bromide complex model.

The apparent extinction coefficient of the complex at its absorbance maximum decreases with increasing dimethylmagnesium reagent concentration since increasing fractions of the reaction occur before the reacting solutions have reached the spectrophotometric flow cell. Therefore, with increasing dimethylmagnesium concentration, the apparent equilibrium concentration of complex, calculated from the difference between the initial and observed concentrations of ketone, becomes larger than the actual value. As a result the calculated apparent extinction coefficient is too small. Extrapolation of a plot of calculated extinction coefficient *vs.* dimethylmagnesium reagent concentration (Figure 2) to zero reagent concentration, however, yields the extinction coefficient of the complex at zero reaction (ϵ_{337} 1.4 × 10^4).

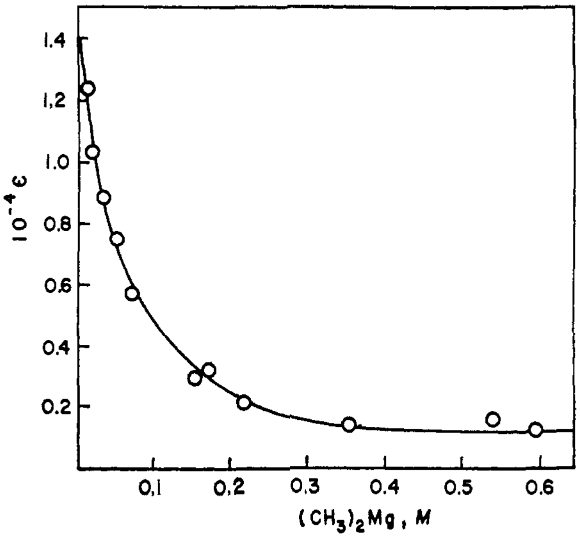

Figure 2. Plot of apparent extinction coefficient at 337 mμ for the dimethylmagnesium complex of ketone I *vs.* dimethylmagnesium concentration in diethyl ether at 25.0°.

Equilibrium constants for complex formation, based on a 1:1 complex of dimethylmagnesium and ketone I, were calculated using the observed absorbances, the extrapolated extinction coefficient of the complex (1.4 × 10^4), and the extinction coefficient of ketone I (2.04 × 10^4) for a number of dimethylmagnesium reagent concentrations, yielding an average value of 6.2 ± 0.7 l./mole (Table I). Calculations for a 2:1 complex, $(R_2Mg)_2$-ketone, does not give a constant value for the equilibrium constant.

Table I. The Apparent Equilibrium Constant for the Complexation of *ca.* 10^{-4} M Ketone I with Dimethylmagnesium in Diethyl Ether at 25.0°

$(CH_3)_2Mg$,[a] M	K, l./mole
0.050	7.5
0.071	7.5
0.155	6.1
0.170	5.4
0.216	5.9
0.352	4.5
0.536	6.1
0.592	6.5
	Av 6.2 ± 0.7

[a] Base titration.

Kinetics. The rate of disappearance of the complex between ketone I and dimethylmagnesium was spectrophotometrically determined at a single wavelength by a stopped-flow technique which enabled measurement of reaction half-lives as short as *ca.* 10 msec. While the mixed reagent concentration of ketone I was *ca.* 10^{-3} M, the dimethylmagnesium concentration was varied from 0.01 to 0.6 M, giving pseudo-first-order kinetics. First-order rate constants were calculated by reproducing transmittance *vs.* time oscillographs (Figure 3) with an analog computer programmed for electronic simulation of the first-order rate equation. Table II summarizes a digital least-squares analysis of the sample kinetic run presented in Figure 3.

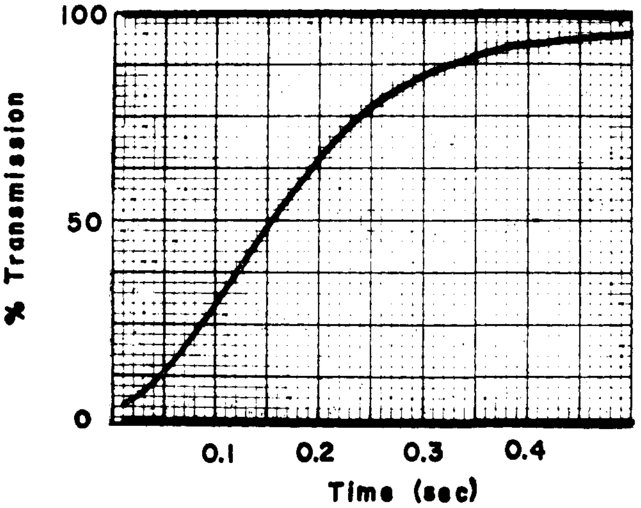

Figure 3. Plot of per cent transmission at 337 mμ *vs.* time for the reaction of *ca.* 10^{-3} M ketone I with 0.185 M dimethylmagnesium in diethyl ether at 25.0°.

Table II. Reaction of 0.185 M Dimethylmagnesium with *ca.* 10^{-3} M Ketone I in Diethyl Ether at 25.0°

Time, sec	Rel A (337 mμ)	k_{obsd}, sec^{-1} (integrated)
0.050	9.26	
0.075	7.08	10.5
0.100	5.48	10.4
0.125	4.30	10.3
0.150	3.24	10.5
0.175	2.49	10.5
0.200	1.92	10.5
0.225	1.46	10.5
0.250	1.12	10.5
0.275	0.89	10.4
0.300	0.70	10.4
	Least squares	10.5

The observed pseudo-first-order rate constant, k_{obsd}, is appropriately independent of the initial concentration of ketone I from 5×10^{-4} to 10^{-2} M (Table III) and increases from 1.1 to 16 sec^{-1} as the dimethylmagnesium reagent concentration is increased from 0.01 to 0.6 M (Figure 4). Table IV summarizes first-order rate constants for various concentrations of dimethylmagnesium.

Table III. Effect of Ketone Concentration on the Rate of Reaction of 0.160 M Dimethylmagnesium with Ketone I in Diethyl Ether at 25.0°

Initial ketone, 10^3 M	k_{obsd}, sec^{-1}
0.480	9.68
1.04	9.72
5.07	9.44
10.2	9.56

The rates of reaction of methylmagnesium chloride and methylmagnesium bromide with ketone I in diethyl ether at 25.0° were similarly determined. As in the case of dimethylmagnesium, the observed first-order rate constants increase with increasing methylmagnesium halide concentration. The relative reactivity of dimethylmagnesium, methylmagnesium chloride, and methylmagnesium bromide toward ketone I in diethyl ether was estimated from plots of k_{obsd} *vs.* methylmagnesium reagent concentration. Table V summarizes these data and shows that for 0.30 M methylmagnesium reagents, the reactivity order is Me_2Mg, 9.3 > MeMgCl, 7.9 > MeMgBr, 1.0.

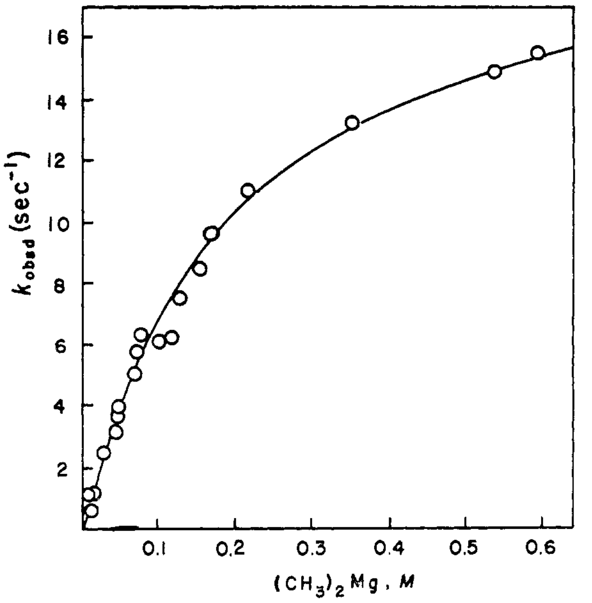

Figure 4. Plot of k_{obsd} *vs.* concentration for the reaction of *ca.* 10^{-3} M ketone I with dimethylmagnesium in diethyl ether at 25.0°.

Table IV. Reaction of Dimethylmagnesium with *ca.* 10^{-3} M Ketone I in Diethyl Ether at 25.0°

$(CH_3)_2Mg$,[a] M	k_{obsd}, sec^{-1}
0.0104	1.10
0.0120	0.610
0.0180	1.18
0.0312	2.48
0.0471	3.17
0.0503	3.95
0.0520	3.70
0.0700	5.08
0.0711	5.86
0.0757	6.26
0.109	6.09
0.115	6.19
0.128	7.52
0.155	8.49
0.170	9.67
0.216	11.1
0.352	13.3
0.536	15.0
0.592	15.6

[a] Base titration.

Table V. Relative Reactivity of 0.30 M Methylmagnesium Reagents with *ca.* 10^{-2} M Ketone I in Diethyl Ether at 25.0°

Methylmagnesium reagent	k_{obsd}, sec^{-1}	k_{obsd}/k_{CH_3MgBr}
$(CH_3)_2Mg$	13	9.3
CH_3MgCl	11	7.9
CH_3MgBr	1.4	1.0

Products. The products of the reaction of a 20 M excess of dimethylmagnesium with ketone I in diethyl ether were determined by vapor phase chromatography. Work-up with sulfuric acid, followed by dehydration in benzene with *p*-toluenesulfonic acid, gave 65 ± 5% 4-methylmercaptoacetophenone (I) and 34 ± 6% 2-(4-methylmercaptophenyl)propene (II), the products of enolization and the dehydration of the expected tertiary alcohol addition product, respectively.

Discussion

It has been found that 4-methylmercaptoacetophenone (I) in diethyl ether solutions of dimethylmagnesium exhibits a new absorbance which can be attributed to an organomagnesium-ketone complex (Figure 1). This complex exhibits λ_{max} 337 mμ (ϵ 1.4 × 10^4) and an apparent equilibrium constant for formation of 6.2 l./mole at 25.0°. The rates of subsequent disappearance of ketone and complex are the same within experimental error. Increasing the dimethylmagnesium reagent concentration from 0.01 to 0.6 *M* increases the observed pseudo-first-order rate constant from 1.1 to 16 $\sec^{-1}$ (Figure 4).

The spectral and kinetic data obtained for the reaction of dimethylmagnesium with ketone I in diethyl ether are consistent with the simple reaction mechanism outlined in eq 1 where $n \geq 1$. For $n = 1$, formulating the conversion of the complex[11] to products as a first-order process yields the mathematical relationship between the pseudo-first-order rate constant, k_{obsd}, and the concentration of dimethylmagnesium reagent, given in eq 2. A graphical[12,13] test of this relationship is provided by eq 3, since a plot of $1/k_{obsd}$ *vs.* $1/[Me_2Mg]$ should be a straight line with a slope of $1/k_1K_1$ and an intercept of $1/k_1$. Figure 5 is such a plot and yields least-squares values for K_1 of 3.8 l./mole and for k_1 of 23.5 $\sec^{-1}$. In practice, however, since the values of K_1 and k_1 are very sensitive to the slope of such a plot, a family of values for K_1 and k_1 gives a satisfactory fit of the kinetic data to eq 2. The line in Figure 4 was calculated with eq 2, using the measured equilibrium constant of 6.2 l./mole and a rate constant for conversion of complex to products of 19.5 $\sec^{-1}$. The products may be the result of two competitive processes for one complex or represent competition between two

$$\text{ketone} + Me_2Mg \overset{K_1}{\rightleftharpoons} n(\text{complex}) \xrightarrow{k_1} \text{products} \quad (1)$$

$$k_{obsd} = \frac{k_1K_1[Me_2Mg]}{1 + K_1[Me_2Mg]} \quad (2)$$

$$\frac{1}{k_{obsd}} = \frac{1}{k_1K_1[Me_2Mg]} + \frac{1}{k_1} \quad (3)$$

reaction paths. The present data do not distinguish between these possibilities.

The scheme outlined in eq 1 designates monomeric dimethylmagnesium as the reactive organomagnesium species, although there is a paucity of definitive data on the nature of dialkylmagnesium reagents in solution. Attributing the deviations from theoretical molecular weights in ether to association[14a] suggests that dimethylmagnesium is weakly associated above 0.1 *M*. Unsolvated dimethylmagnesium has been found to be polymeric.[14b] Diethylmagnesium is reported to be monomeric[15a] in the concentration range 10^{-3} to 10^{-2} *M*, with apparently weak association[14,15b] above 0.1 *M*. Recently House[15c] and co-workers have reported that a 0.13 *M* ether solution of dimethylmagnesium has an apparent molecular weight of 67.6 ± 2.3 corresponding to 1.24 ± 0.04 times the value for the monomer. In the solid state, diphenylmagnesium[16] is a dietherate; however, further removal of ether results in polymerization. Thus, while unambiguous information on the nature of dimethylmagnesium in ether solution is lacking, changes in the gross nature of the reagent as a function of concentration need not be invoked to describe quantitatively the present kinetic data for the reaction of dimethylmagnesium with dilute solutions of ketone I. However, changes in the state of aggregation of dimethylmagnesium with concentration would change the physical significance of the derived parameters of eq 3.

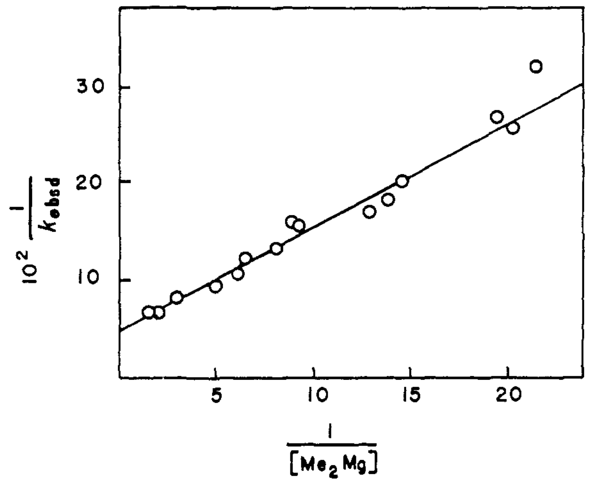

Figure 5. Plot of the reciprocal of k_{obsd} *vs.* the reciprocal of the dimethylmagnesium concentration.

The kinetic data obtained for the reaction of dimethylmagnesium with ketone I in diethyl ether, while being consistent with the scheme outlined in eq 1, are not consistent with the mechanism, outlined in eq 4 and 5. The latter was suggested by Swain[17] for the addition of Grignard reagents to ketones and recently modified and promoted by Ashby.[18a] In the proposed generalization of this mechanism for the reaction of organomagnesium reagents and ketones, Ashby[18a] suggested rate-determining complex formation between the ketone and organomagnesium reagent is followed by rapid reaction of the complex with a second organomagnesium species. In the case of the reaction of dimethylmagnesium and ketone I, however, spectro-

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[11] While the proposed reaction scheme is consistent with the spectral and kinetic data, more than one type of complex may in fact be involved. The products of enolization (I) and addition (II) could thus arise from the same or different complexes. Furthermore, the observed complexes, although having the likely composition of the transition state, may not actually be on the reaction path leading to product.

[12] (a) F. R. Duke, *J. Am. Chem. Soc.*, **69**, 3054 (1947); (b) E. T. Kaiser and S. W. Weidman, *ibid.*, **86**, 4354 (1964).

[13] Recently Ashby, *et al.*, have proposed that eq 2 be rearranged to

$$[G]_0 = \frac{k[G]_0}{k_{obsd}} - \frac{1}{K}$$

and that data such as these be treated by plotting $[G]_0$ *vs.* $[G]_0/k_{obsd}$.

[14] (a) E. C. Ashby and F. Walker, *J. Organometal. Chem.* (Amsterdam), **7**, 17 (1967); (b) E. Weiss, *ibid.*, **2**, 314 (1964).

[15] (a) A. D. Vreugdenhil and C. Blomberg, *Rec. Trav. Chim.*, **82**, 453, 461 (1963); (b) M. B. Smith and W. E. Becker, *Tetrahedron*, **22**, 3027 (1966); (c) H. O. House, R. A. Latham, and G. M. Whitesides, *J. Org. Chem.*, **32**, 2481 (1967).

[16] G. D. Stucky and R. E. Rundle, *J. Am. Chem. Soc.*, **86**, 4825 (1964).

[17] C. G. Swain and H. B. Boyles, *ibid.*, **73**, 870 (1951).

[18] (a) E. C. Ashby and M. B. Smith, *ibid.*, **86**, 4364 (1964); (b) E. C. Ashby, R. B. Duke, and H. M. Newmann, *ibid.*, **89**, 1964 (1967); (c) E. C. Ashby, *Quart. Rev.* (London), **21**, 259 (1967).

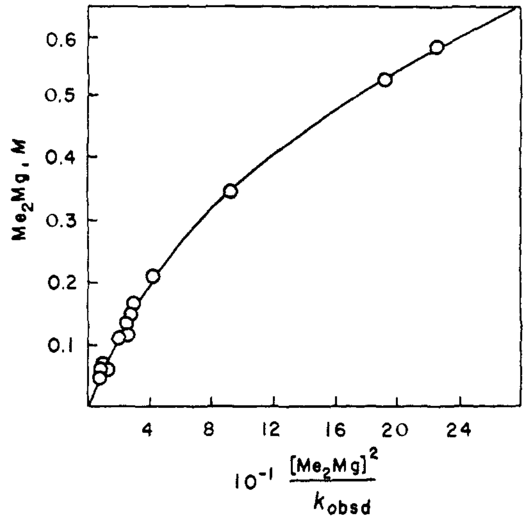

Figure 6. Plot of the concentration of dimethylmagnesium *vs.* $[Me_2Mg]^2/k_{obsd}$ for the reaction of dimethylmagnesium with ketone I in diethyl ether at 25.0°.

photometry indicates that complex formation is fast[10b] on the time scale of conversion to products.

In earlier discussions Ashby suggested that the addition of a Grignard reagent to a ketone could occur by a slow attack of monomeric or dimeric RMgX species or by an attacking ionic species.[18a] Recently, based on their own kinetic data for the reaction of methylmagnesium bromide with benzophenone in ether, Ashby, *et al.*,[18b] have suggested that complex formation is fast followed by a relatively slow reaction with a second Grignard molecule resulting in an over-all termolecular process. The experimental basis for the latter proposal appears to be the conviction that in a plot of the pseudo-first-order rate constant *vs.* Grignard concentration in the reaction of benzophenone with methylmagnesium bromide a straight line through the data points fails to go through the origin. Actually the data are not convincing and his treatment leads to the conclusion[18c] that the equilibrium constant for complex formation with benzophenone and methylmagnesium bromide is 1040 l./mole, a value *ca.* 10^2 larger than expected on the basis of experimental values with similar systems.[4] Ashby further notes that his method of testing the fit of the data to eq 2 does not give parameters with physical significance. However, failure to detect a complex by kinetics of this accuracy in dilute solutions with the compounds employed is the expected result since equilibrium constants tend to be relatively small.

The present data for the reaction of dimethylmagnesium with ketone I in diethyl ether may be subjected to Ashby's[18c] proposed termolecular scheme, eq 4–7. As pointed out by Ashby,[18c] a plot of $[Me_2Mg]$ *vs.* $[Me_2Mg]^2/k_{obsd}$ should be a straight line with a slope of k_2 and an intercept of $-1/K_2$. The data plotted in Figure 6, however, exhibit distinct curvature and graphically illustrate that the mechanism outlined in eq 4 and 5 is not sufficient to describe the kinetics of the reaction of dimethylmagnesium and ketone I in diethyl ether under the conditions of this investigation. Although the mechanism outlined in eq 1 is adequate to describe the observed kinetics, a higher order reaction of the type outlined in eq 4 and 5 could become sufficiently important at high dimethylmagnesium concentrations to be detected. Changes in the state of aggregation of dimethylmagnesium with concentration could, of course, balance a contribution from higher order terms in such a way as to result in a deceptively simple picture of the actual reaction scheme.

$$\text{ketone} + Me_2Mg \overset{K_2}{\rightleftharpoons} \text{complex} \qquad (4)$$

$$\text{complex} + Me_2Mg \xrightarrow{k_2} \text{products} \qquad (5)$$

$$k_{obsd} = \frac{k_2K_2[Me_2Mg]^2}{1 + K_2[Me_2Mg]} \qquad (6)$$

$$[Me_2Mg] = \frac{k_2[Me_2Mg]^2}{k_{obsd}} - \frac{1}{K_2} \qquad (7)$$

The relatively simple scheme which reproduces the observed kinetic and spectral data for the reaction of dimethylmagnesium and ketone I does not apply to the more hindered ketone, 2,4-dimethyl-4′-methylmercaptobenzophenone and methylmagnesum bromide, above *ca.* 0.3 *M*. At concentrations >0.3 *M* contributions from medium effects, changes in the Grignard reagent with concentration and/or higher order terms have to be considered to describe the observed kinetics.[4] Clearly, however, the hindered ketone is not a special case of an unreactive ketone whose organomagnesium complex reacts more slowly than it is formed.[19] Ketone I, which reacts with dimethylmagnesium *ca.* 2000 times faster than the hindered ketone reacts with methylmagnesium bromide, also exhibits rapid formation of complex. Apparently, complexation between representative ketones and organomagnesium reagents is not necessarily rate determining.

Other kinetic studies of the reaction of dialkylmagnesium reagents with ketones have appeared in the literature. One first-order rate constant was reported for the reaction of dimethylmagnesium with acetone in di-*n*-butyl ether[20] under unspecified conditions. The reaction of 0.25 *M* dibutylmagnesium with 0.1 *M* acetone in diethyl ether[21] is reported to be first order in ketone and zero or very low order in organomagnesium reagent. This observation and corollary infrared spectral evidence for complexation between organomagnesium reagents and ketones[21] are consistent with the mechanism outlined in eq 1, since an essentially complete formation of complex reduces eq 2 to a form independent of the organomagnesium reagent concentration.

The reported relative reactivity of butylmagnesium reagents toward acetone in diethyl ether[21] is also consistent with the relative reactivity of methylmagensium reagents toward ketone I in diethyl ether (Table V): $R_2Mg > RMgCl > RMgBr$. Experiments designed to relate the role of dialkylmagnesium to the reaction of Grignard reagents with ketones are in progress.

Experimental Section

All reported melting points are uncorrected. Microanalyses were done by J. Nemeth and associates, University of Illinois. Spectra were recorded as follows: nmr, Varian A-60 spectrometer; infrared, Perkin-Elmer Infracord; ultraviolet (slow scan), Perkin-Elmer 202 spectrophotometer.

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(19) See reference 6a, p 145.

(20) J. G. Aston and S. A. Bernard, *Nature*, **165**, 485 (1950).

(21) (a) T. Holm, *Acta Chem. Scand.*, 20, 1139 (1966); (b) T. Holm, *ibid.*, **19**, 1819 (1965).

All methylmagnesium reagents were prepared under argon in an all-glass, vacuum-tight, grease-free apparatus. Dow single-sublimed magnesium was cut into suitable form with carbide tools, washed with ether, and dried under vacuum before use. Anhydrous diethyl ether (Mallinckrodt reagent) was freshly distilled from a *ca.* 0.5 *M* preparation of methylmagnesium bromide, through a 10-in. Vigreux column directly into the reaction vessel used for the preparation of the methylmagnesium reagents employed in kinetic and spectrophotometric experiments. The Grignard drying agent was degassed by bubbling purified argon through it for at least 1 hr, followed by refluxing for at least 1 hr.

Linde high-purity argon was further purified by passing through a column of activated BTS catalyst to remove traces of oxygen and then through a tower of Linde 4-A Molecular Sieves to remove any residual moisture.

Methyl bromide and methyl chloride (Matheson) were dried by passing through a flushed tower containing Linde 4-A Molecular Sieves and condensed in a cooled, dry, evacuated vessel. The methyl halides were degassed by repeated evacautions at *ca.* −70°, followed by refilling with argon. Methyl bromide and methyl chloride were subsequently distilled directly into their respective reaction mixtures.

Typically, a Grignard reagent was prepared by slow distillation of the methyl halide into a stirred mixture of *ca.* 200 ml of diethyl ether and a 2 *M* excess of magnesium. Reagents so prepared were clear and colorless and, after two filtrations through sintered-glass disks, were delivered into silicon rubber, serum-capped vessels. Dilution of the organomagnesium reagents was accomplished by distillation of solvent directly into these vessels.

Dimethylmagnesium was prepared by the dioxane precipitation method.[8] The 1,4-dioxane (Baker reagent) was refluxed with sodium for 48 hr, then distilled and stored in dark bottles under nitrogen. A 1.2 mole equiv quantity, based on the magnesium content of a methylmagnesium bromide preparation, was slowly added to the well-stirred Grignard reagent over a period of 1 hr. The reaction mixture was vigorously stirred for an additional hour and allowed to stand several hours before filtration. The diethyl ether and residual dioxane were removed from the filtered reagent under vacuum. The white to pale yellow solid dimethylmagnesium was then heated to 100° (0.5 mm) for 2 hr. Freshly distilled diethyl ether was added to the cooled solid under argon. A clear and colorless solution of dimethylmagnesium was obtained after vigorous stirring for several hours.

Reagent Analyses. Aliquots of methylmagnesium reagents were variously analyzed for total base,[22] halide, and iodine[23] titers. The iodine titer was determined by injecting a syringe[24] aliquot of reagent into a known excess of iodine in benzene solution. To dissolve the excess iodine an aqueous solution of potassium iodide was added and the resulting solution was titrated with standard sodium thiosulfate. Total base titers were determined by back-titration of excess hydrochloric acid with standard sodium hydroxide and total halide by the Volhard method. The iodine titer was usually 1–2% lower and less reproducible than the total base and halide titers. The reproducibility of the latter was *ca.* 1–2%.

4-Methylmercaptoacetophenone. Ketone I was prepared by the Friedel–Crafts acylation of thioanisole (Aldrich) with acetyl chloride (Baker), in 40–60% yields, as previously described.[25] Recrystallization to constant melting point from 95% ethanol and then petroleum ether (bp 60–68°), followed by purification in a Fischer zone refiner, gave material with mp 81–81.5°. The nmr spectrum displays a singlet absorbance at τ 7.58 (6 H) and a complex aromatic multiplet centered at 2.55 (4 H). The ultraviolet spectrum (diethyl ether) has a maximum at 300 mμ (ϵ 2.04 × 10^4) and the infrared spectrum (CCl_4) exhibits characteristic carbonyl absorbance at 1670 cm^{-1}.

Anal. Calcd for $C_9H_{10}OS$: C, 65.02; H, 6.06; S, 19.29. Found: C, 64.92; H, 6.04; S, 19.41.

Product Analysis. To 100 ml of a 0.3 *M* solution of dimethylmagnesium was added, with rapid stirring, 0.2200 g (1.33 mmoles) of ketone I dissolved in 50 ml of diethyl ether. The reaction mixture was vigorously stirred for 20 min and then hydrolyzed with just enough 0.5 *M* sulfuric acid to dissolve all the magnesium salts. The ether layer was subsequently washed with two portions of saturated sodium carbonate, followed by distilled water. The ether was then carefully removed by heating in an oil bath. To the residue was added 50 ml of benzene and 50 mg of *p*-toluenesulfonic acid. The benzene was removed by distillation and, after cooling, the residue was dissolved in ether and washed successively with saturated sodium carbonate and distilled water. The product solution was then dried over magnesium sulfate and the solvents were carefully removed by mild heating in an oil bath, followed by evacuation at room temperature to 0.5-mm pressure for 2 hr. The product was then melted in a nitrogen atmosphere, cooled, and again evacuated to 0.5-mm pressure for 2 hr. The process was repeated a total of two times. The product (0.2152 g) was subsequently analyzed by vapor phase chromatography using a 30% Apiezon L on Chromosorb W column, with benzophenone as internal standard and authentic samples of the olefin II[26] dehydration product of the expected tertiary alcohol[27] (34 ± 6%) and ketone I (64 ± 5%).

Spectrophotometry. A stopped-flow apparatus coordinated with a rapid-scan spectrophotometer and auxiliary oscillographic equipment were used to obtain oscillographic transmittance spectra of reacting solutions of ketone I and organomagnesium reagents. The stopped-flow apparatus consisted of two Hamilton Co. gas-tight, gas-flush syringe reagent reservoirs, a Gibson–Chance[9] eight-jet Teflon mixer, a stainless steel valve block immersed in a thermostated water bath maintained at 25.00 ± 0.05°, and a Pyrex flow cell and stop syringe. For rapid-scan spectrophotometry, the collimating mirror of a Bausch and Lomb high-intensity grating monochrometer was oscillated by a mechanism consisting of a loud speaker-type coil suspended in a permanent magnetic field and powered by a 20-w amplifier and audiooscillator. The spectral sweep of *ca.* 70 mμ, scanned 36.4 times per second, was monitored through a 1P28 photomultiplier and follower amplifier and displayed on a Tektronic oscilloscope equipped with a C-12 Polaroid camera. Blanking of the oscilloscope back trace provided 18.2 spectra per second. In the typical reaction mixture spectrum illustrated in Figure 1, the first spectrum was recorded during the flow of mixed reagents through the spectrophotometric flow cell, while a time-independent level of absorbing species was maintained. The successive traces, recorded after the flow of mixed reagents had stopped, show the rapid decrease of absorbance due to both ketone I and its organomagnesium complex to the dimethylmagnesium base line.

Kinetics. The rate of disappearance of the organomagnesium complex of ketone I was measured by a stopped-flow method. The initial ketone concentration was adjusted to give a high initial absorbance at the maximum of its complex. The oscilloscope was triggered at a desired light level and oscillographic displays of transmittance *vs.* time were obtained. An EAI TR analog computer, programmed to generate theoretical transmittance *vs.* time plots for the first-order rate equation, was used to reproduce visually the oscillographic outputs of transmittance *vs.* time and to calculate the pseudo-first-order rate constants. A typical oscillograph is illustrated in Figure 3.

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