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KINETICS AND MECHANISM OF THE ADDITION OF ALLYL MAGNESIUM BROMIDE TO THE DOUBLE BOND OF CINNAMYL ALCOHOL. CATALYSIS BY MAGNESIUM BROMIDE.

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Continued interest^{1,2} in the scope and mechanism of the recently discovered addition of Grignard reagents to non-activated carbon-carbon multiple bonds³ prompts this preliminary report of a kinetic study of the addition of allyl magnesium bromide to the double bond of cinnamyl alcohol. We have found that the reaction is strongly catalysed by magnesium bromide, which is in accord with the "intermolecular" mechanism previously suggested⁴ for additions of this type.

Allyl Grignard and cinnamyl alcohol 1 in ether lead quantitatively (99% by GC), via 2 and 3,⁵ to the addition product 4.⁶ The reaction is considerably faster than with allyl alcohol;⁴ the kinetic runs were conveniently done at 25° and were followed by gas chromatography.⁷



The initial concentrations of "active allyl" groups $[C_3H_5^-]$ (determined by titration with iodine)⁸ and of bromide [Br⁻] (determined by titration with silver nitrate) in ethereal solutions of allyl Grignard reagent were adjusted by adding either diallyl magnesium in ether or magnesium bromide in ether. The initial concentration of "active allyl" $[C_3H_5^-]$ was always at least 0.10M, <u>i.e.</u>, at least ten times greater than that of the alkoxide 2 (0.01M).

When excess dially magnesium was present ($[C_3H_5] > [Br]$), the reaction

was very slow and showed mixed-order kinetics.⁹ When, however, excess bromide was present ([Br] > $[C_3H_5]$), the reaction was found to be cleanly first order:

$$\underline{\mathbf{k}} = (1/\underline{\mathbf{t}})\ln(\underline{\mathbf{r}} + 1)$$

<u>r</u> being the ratio 4/1, determined by GC.⁷ As shown in Figs. 1A and 1B, the experimental first order rate constant <u>k</u> varied considerably with the initial concentrations of $[C_3H_5^-]$ and $[Br^-]$. Whereas it increased almost linearly by a factor of about 15 as $[Br^-]$ was increased from 0.18M to 0.58M, $[C_3H_5^-]$ being kept constant at 0.17M (Fig. 1A), it went through a maximum and then decreased as $[C_3H_5^-]$ was increased from 0.10M to 0.32M, $[Br^-]$ being kept constant at 0.334M (Fig. 1B).

If the Schlenk equilibrium constant K for the allyl Grignard reagent is

$$(C_3H_5)_2Mg + MgBr_2 \xrightarrow{k} 2C_3H_5MgBr$$

large (and this appears to be a reasonable assumption¹⁰), then the above data (Figs. 1A and 1B) fit the following rate equation:

$$-\underline{d}[A]/\underline{dt} = \underline{k}[A] = \underline{k}_{3}[A][C_{3}H_{5}MgBr][MgBr_{2}] = \underline{k}_{3}.Z.[A]$$

where [A] is the concentration of the alkoxide 2 and $Z = [C_3H_5MgBr][MgBr_2]$. This is shown in Fig. 1C, in which <u>k</u> is plotted against Z, calculated assuming a value of 100 for the Schlenk equilibrium constant K; most of the experimental points from both Fig. 1A and Fig. 1B now fit the same straight line.¹¹ The two points that are below the line are from the two runs in which one of the reagent concentrations was very high ($[C_3H_5^-] \sim 0.3M$ or [Br⁻] ~ 0.6M); these deviations are therefore probably due to association¹² of the various species present in the solution. The slope of the straight line in Fig. 1C gives the third-order rate constant $\underline{k}_3 = \underline{k}/Z = 9.7 \times 10^{-3}$ $1^2 \cdot \text{mol}^{-2} \cdot \text{sec}^{-1}$, and the curves in Figs. 1A and 1B were <u>calculated</u> using this value of \underline{k}_a and K = 100.

These results therefore strongly suggest that the transition state for the rate-determining step in this addition reaction contains at least one molecule of alkoxide 2, one molecule of ally1 magnesium bromide, and one molecule of magnesium bromide (and, of course, a good deal of ether). A plausible mechanism is the following (ether omitted):





Figure 1.- Variation of the experimental first-order rate constant <u>k</u> for the reaction between cinnamyl alcohol (initial concentration 0.01M) and excess allyl magnesium bromide in ether at 25°, as a function of [Br⁻] (Fig. 1A), [C₃H₅⁻] (Fig. 1B), and Z = [C₃H₅MgBr][MgBr₂] (calculated assuming K = 100) (Fig. 1C). The slope of the straight line in Fig. 1C is <u>k</u>₃ = 9.7 x 10⁻³1².mol⁻².sec⁻¹; the curves in Figs. 1A and 1B represent the <u>calculated</u> values of <u>k</u> (see text).

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A concerted addition of this kind, involving simultaneous intramolecular electrophilic assistance by the magnesium bound to the oxygen, and intermolecular nucleophilic attack by allyl magnesium bromide, is consistent not only with the kinetic data, but also with the stereochemical course of the reaction in allylic and propargylic systems: preferential formation of the erythro isomer from a-methallyl alcohol, 4 and trans addition to the triple bond of 2-butyn-1-01.2,13

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Footnotes

- 1. J.J.Eisch and J.H.Merkley, J.Organometal.Chem., 20, P27 (1969).
- 2. H.G.Richey and F.W.von Rein, J.Organometal.Chem., 20, P32 (1969).
- 3. Earlier work is reviewed in refs. 1, 2 and 4a; see also B.Mauzé, G.Courtois, and L.Miginiac, Comptes-rendus, 269C, 1225 (1969).
- 4. M.Chérest, H.Felkin, C.Frajerman, C.Lion, G.Roussi, and G.Swierczewski, (a) <u>Tetrahedron Letters</u>, 875 (1966); (b) unpublished work.
- 5. As in ref. 4a, the intermediate magnesio-adduct 3 is formulated as being cyclic. This is for convenience only; we have no proof.
 6. Preparative yield, 86%; bp₁₂ 136°, <u>n</u>_D²⁵ 1.5228; <u>p</u>-nitrobenzenesulphonate,
- mp (Et₂0) 61.5-62.5° (ref. 4b).
- 7. With a polypropyleneglycol column (7%, 90 cm) at 145°, and a low injector temperature, decomposition of cinnamyl alcohol [cf. R.F.Heck, J.Amer.Chem. Soc., 90, 5526 (1968)] could be avoided entirely, and both 1 and 4 could be quantitatively analysed.
- 8. G.Champetier and R.Kullmann, Bull.Soc.chim.France, 693 (1949).
- 9. These results will be discussed in the full paper; see C.Kaeseberg, Thèse de 3e cycle, Paris (1969).
- 10. The Schlenk equilibrium constant for allyl magnesium bromide does not appear to have been determined. In the case of ethyl magnesium bromide, it is about 500 [M.B.Smith and W.E.Becker, <u>Tetrahedron</u>, <u>22</u>, 3027 (1966)].
- 11. The scatter is about the same for values of K > 100; it is much worse if it is assumed K = 10.
- 12. E.C.Ashby and F.Walker, J.Organometal.Chem., 7, P17 (1967).
- 13. It remains to be seen whether a similar "intermolecular" mechanism is valid for homoallylic and homopropargylic systems, or whether these react by the "intramolecular" mechanism proposed by Eisch (ref. 1).