SCHLENK EQUILIBRIUM IN TOLUENE SOLUTIONS OF GRIGNARD REAGENTS

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Abstract

Grignard reagents were prepared from n-butyl chloride, n-butyl bromide and bromobenzene in toluene in the presence of small amounts of diethyl ether. The reagents disproportionate according to the Schlenk equilibrium with the formation of a precipitate rich in magnesium halide. The supernatant solution comprises higly soluble complexes of the stoichiometry $x\mathbf{R}_2Mg.yMgX_2.zEt_2O$ (x>y). The extent of side-reactions during the formation of these Grignard reagents increases in the order nBuCl<nBuBr<PhBr.

Introduction

Organomagnesium compounds can be prepared not only in conventional ethers but also in hydrocarbon media or without any solvent at all [1-5]. For many purposes the replacement of ethers by hydrocarbons of higher boiling point is expedient. The process in hydrocarbons is preferable, since the reaction medium is cheap, nonhygroscopic, and fire hazards are low.

The use of unsolvated organomagnesium halides is limited to primary alkyl and aryl compounds. Branched chain primary, secondary, and tertiary alkyl halides, vinyl, allyl, and benzyl halides do not react under these conditions or produce Wurtz-type coupling products [2,6]. In the presence of one molar equivalent of complexing agents, e.g. ethers and tertiary amines, several organomagnesium compounds have been obtained in hydrocarbon media [5,7,8]. Furthermore, alkylmagnesium bromide and chloride reagents in toluene containing less than one equivalent of diethyl ether have also been prepared [9-12].

Because the Grignard reagents in donor solvents are complexed at least with two solvent molecules per atom of magnesium, the reagents obtained in the presence of smaller amounts of donors should be considered as partially solvated. As the solvating agent is firmly bound to the Grignard reagent, such solutions have almost all the advantages of unsolvated organomagnesium halides in non-solvating media.

Although partially solvated Grignard reagents have also been exploited in big-scale industrial processes [13], their chemical and physical properties have been insufficiently investigated.

Here we report some results of a study of partially solvated Grignard reagents in toluene, n-butylmagnesium bromide, n-butylmagnesium chloride, and phenylmagnesium bromide, complexed with small amounts of diethyl ether.

Results and Discussion

The preparation of partially solvated Grignard reagents was carried out at initial concentrations of diethyl ether from 1.25 M up to 3.0 M. These concentrations correspond to those for the monosolvated Grignard reagents which act as catalysts of a further Grignard reaction [9,10]. Further addition of organic halide leads to the formation of less solvated Grignard reagents. Lower concentrations were not used because (i) these are less important for the preparative scale work, (ii) the rate of the reaction dramatically decreases with a decrease in ether content [9], and (iii) the relative extent of the Wurtz reaction increases considerably with the decreasing ether concentration [9].

The systems obtained were heterogeneous and the amount of the solid phase increased with an increase in the molar ratio of halide to ether. Approximately a fourth part of the active Grignard reagent formed was usually contained in the solution. Although such reagents can be used for synthetic purposes in the form of suspensions, in this work we have focused our attention on the equilibrium between the dissolved part and the solid phase of the reagents.

The experiments were limited to such molar excess of halide over ether (3 to 7-fold) when the agitation of the reaction mixture turned hindered by the end of the process. The concentrations of basic magnesium and magnesium halide (halide ion concentration) in the solution were determined for different molar ratios: "Grignard reagent" (initial molar amount of the organic halide) to diethyl ether.

A decrease in the ether content of the Grignard reagent causes a disproportionation according to the Schlenk equilibrium [1-3]

$$2\ RMgX \rightleftharpoons R_2Mg + MgX_2$$

Also the precipitation of a considerable part of the reagent with a higher content of magnesium halide occurs. The results of some representative experiments are shown in Figures 1 and 2.

The lower the relative content of the ether in the mixture (higher values of the ratio RX/Et_2O), the higher is the excess of diorganomagnesium compound over magnesium halide in the solution. Apart from the common features described above, each of the Grignard reagents examined in this work exhibits some individual properties.

n-butyl bromide forms a very soluble monosolvated Grignard reagent $nBuMgBr.Et_2O$. It has been found [14] that the concentration of the saturated toluene solution of the complex is 3.68 M at 20° C. It is seen from Figure 1 that the Wurtz reaction is more pronounced ($MgX/RMg>1$) at lower concentrations of diethyl ether. As it is also seen from Figure 1, a deficiency of ether shifts the disproportionation equilibrium to the right and as dibutylmagnesium is more soluble, the complexes in the solution contain more dibutylmagnesium in comparison to the precipitate. The structure of the complexes is not known, however, they are probably highly associated [2]. The limit of the solubility of the complexes in these conditions seems to be 1.1M (about 2.2 molar for basic magnesium, R-Mg). Most likely, dibutylmagnesium is complexed with magnesium bromide and diethyl ether. Estimation of the ether concentration by means of GLC indicated that the ether content in the solution decreases with the decrease in the magnesium bromide concentration.

Thus, dibutylmagnesium solutions with reduced contents of magnesium bromide and of diethyl ether can be obtained. The yield of the active Grignard reagent in solution can be enhanced by the addition of appropriate amounts of toluene after the completion of the reaction. So we obtained Grignard solutions of almost unchanged concentration and composition by the dilution of heterogeneous Grignard reagents with two volumes of dry toluene.

n-butyl chloride is less prone to form side-products when reacting with magnesium [10,12], however, n-butylmagnesium chloride disproportionates even in the monosolvated form to such an extent that the reagent always contains a precipitate rich in magnesium chloride (Fig. 2). A decrease in the ether content also shifts the Schlenk equilibrium to the right. However, differently from the corresponding bromide reagents, the R_2Mg concentration in the solutions of n-butylmagnesium chloride is sensible to the overall ether content in the system and does not approach a limiting value at higher ratios RX/Et_2O (cf. Fig. 1 and 2). This is probably caused by a favoured solvation of the dissolved part of the chloride reagent, e.g. in a system with $RX/Et_2O = 4$ prepared at the initial concentration of ether equal to 1.25 M, the stoichiometries of the solute and precipitate were estimated to be $nBu_2Mg{*}0.3\ MgCl_2{*}0.6\ Et_2O$ and $nBu_2Mg{*}1.5\ MgCl_2{*}0.4\ Et_2O$, respectively. It follows that alkylmagnesium chloride reagents require more extensive solvation by diethyl ether than the corresponding bromide reagents. Obviously, relatively soft bromide complexes are more soluble than those of chloride due to a stronger solvation by easily polarizable toluene. The importance of the solvation of magnesium chloride complexes by diethyl ether was also demonstrated by the dilution experiment. Contrary to the case of n-butylmagnesium bromide, addition of dry toluene to a n-butylmagnesium chloride system only slightly increased the dissolved portion of the reagent.

Phenyl bromide reacts sluggishly with magnesium in the presence of small additions of diethyl ether in toluene. The contribution of Wurtz-type side-reactions is considerable under these conditions, e.g. in almost all the preparations 20-30 % of the initial bromobenzene was converted to biphenyl. The properties of phenylmagnesium bromide solutions are similar to those of n-butylmagnesium halide solutions. The reagents disproportionate with the formation of the precipitate rich in magnesium bromide, e.g., in the solution of a reagent with $PhBr/Et_2O = 4$, the approximate stoichiometries of the solute and precipitate were 1.5 PhMg*$MgBr_2$ and Ph_2Mg*2.3 $MgBr_2$ respectively with 1.3 M R-Mg concentration in the solution.

We did not succeed in initiating the reaction with chlorobenzene under these conditions.

To the best of our knowledge, the equilibria in toluene solutions of partially solvated Grignard reagents were first investigated in our laboratory. We found that phenyl and primary alkyl reagents disproportionated considerably while isopropyl and *tert*-butylmagnesium chlorides practically did not disproportionate in toluene solutions [12]. Evidently, the disproportionation is strongly influenced by the steric requirements of the alkyl moiety of Grignard reagents.

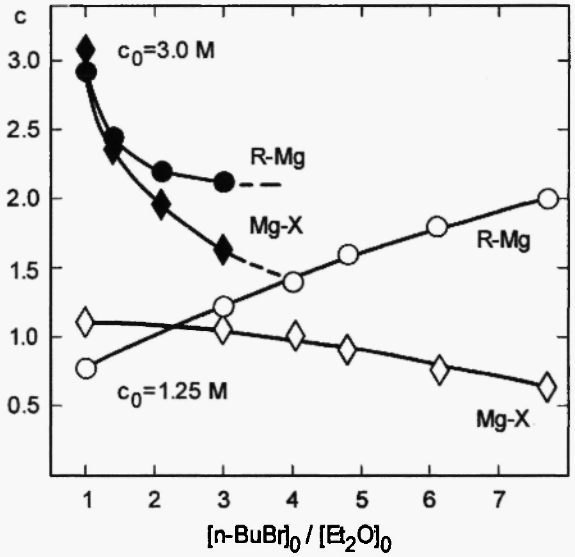

Figure 1. Molar .concentrations of basic magnesium R-Mg and Mg-X units in toluenesolutions of "nBuMgBr" prepared at various molar ratios nBuBr/Et_2O and at various concentrations of diethyl ether, C_0.

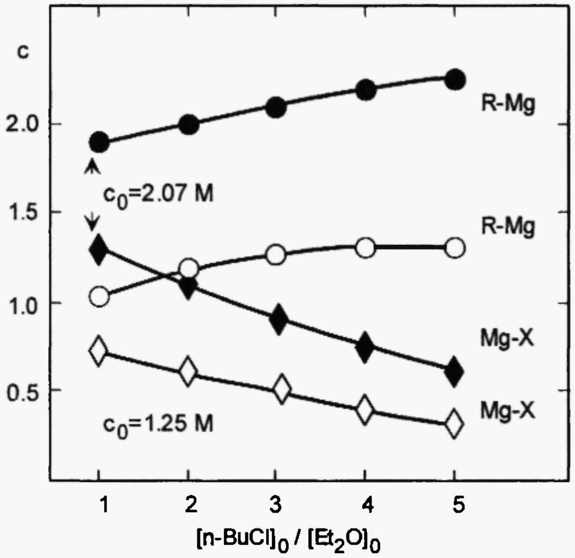

Figure 2. Molar concentrations of basic magnesium R-Mg and Mg-X units in toluene solutions of "nBuMgCl" prepared at various molar ratios nBuCl/Et_2O and at various initial concentrations of diethyl ether, C_0.

Although the Schlenk equilibrium in toluene solutions is probable masked to some extent by the equilibria between the solution and the precipitate, a parallelism with the properties of ether solutions is evident. The Schlenk equilibrium constant $K = [RMgX]^2/[R_2Mg]\ [MgX_2]$ has been determined for a number of Grignard reagents in diethyl ether and THF [15-18]. The value of K decreases in the order Et > Bu > Ph, also Br > Cl, i.e. the disproportionation is more pronounced for alkylmagnesium chlorides and increases with the increasing bulkiness of the organic group. Grignard reagents in THF disproportionate largely because of the strong solvation of magnesium halides by THF [16], however, in ethereal systems no precipitation occurs.

Experimental

Preparation of Grignard reagents. The reagents were prepared under dry argon in a 100-ml three-neck flask equipped with a mechanical stirrer. The reaction vessel was loaded with magnesium turnings (1.4 - 13 g, 1.5-fold molar excess to the halide), and with the appropriate amounts of diethyl ether (usually 4.0 ml, 38.5 mmole) and toluene (altogether 20-30 ml) The magnesium metal was activated prior to use by dry heating with 50-100 mg of iodine. Then a calculated portion of the organic halide was introduced, and the process started. The first portion of the halide was such as required to obtain a monosolvated Grignard reagent. The excess of the halide was added partwise, after the complete reaction of the previous addition. The completeness of the reaction was checked by means of GLC. The temperature of the reaction mixture was maintained at about 30 °C.

Analysis of Grignard reagents. For analysis approximately 2 ml samples were drawn from the reaction mixture, centrifuged and the supernatant solution was analyzed for the content of basic magnesium acidimetrically and for that of halide ion by the Mohr method.

Because of the high viscosity of solutions, the samples for titration were measured with calibrated tubes (about 1 cm^3). The tube was filled with the Grignard solution up to the mark and thereupon submerged in the titrated solution of sulphuric acid. After the content of the tube had completely dissolved, the excess of the acid was titrated back with a sodium hydroxide solution. The halide ion concentration was determined in the same solution after the acidimetric analysis.

Samples for the analysis of suspensions were drawn from the reaction mixture at vigorous stirring. The sample was analyzed as described above, without centrifugation.

All the experiments were repeated at least two times. The results were coincident within 10 %.

GLC analyses. The sample was quenched with a small portion of dilute sulphuric acid, the organic layer was separated and dried with anhydrous sodium sulphate. For quantitative determinations n-heptane was used as the internal standard. Gas chromatograms were recorded on a Tcvett-100 gas-chromatograph with a flame ionization detector. The column (2.5 m x 3 mm) was packed with 10 % Carbowax 20 M on Inerton Super or with Permabond Cyano DEGS.

Aknowledgement

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