Pergamon

SCIENCE @ DIRECT®

Tetrahedron Letters 44 (2003) 3943–3945

TETRAHEDRON
LETTERS

On the mechanism derived from kinetic solvent effects of Grignard reactions with silanes

Ants Tuulmets,* Dmitri Panov and Meeri Sassian

Institute of Organic and Bioorganic Chemistry, University of Tartu, Tartu 51014, Estonia

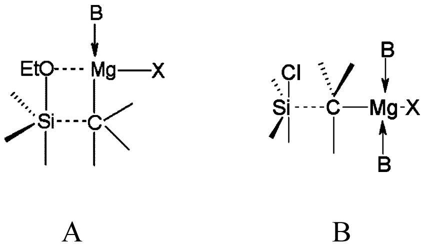
Received 18 February 2003; revised 10 March 2003; accepted 21 March 2003

Abstract—In this communication we present the results of initial kinetic studies in which we have established that alkoxysilanes and chlorosilanes react with Grignard reagents in entirely different ways. The Grignard reaction with alkoxysilanes consists of replacement of a donor molecule at the magnesium centre by silane, followed by a subsequent rearrangement of the complex to the products. Chlorosilanes react without solvent molecule replacement. © 2003 Elsevier Science Ltd. All rights reserved.

Although a number of direct methods have been developed, Grignard chemistry remains a vital and versatile method for the production of organosilanes.[1] However, despite the increasing industrial use of the reaction, only a few investigations into the kinetics have been implemented.[2] To date, Reid and Wilkins have only disclosed the activation parameters for the reactions of trimethylhalosilanes.[2a] We have so far confined ourselves to some particular cases of the reaction with ethoxysilanes.[2b,c] Continuation of our investigation was motivated by matters emerging in Grignard technology when ether solvents were replaced by hydrocarbons of higher boiling points. The use of hydrocarbon solvents in large-scale organomagnesium syntheses is preferable because of lower fire-hazard risks. Toluene proved to be a particularly suitable solvent for Grignard reagents.[3]

Kinetic investigations have revealed that addition of toluene accelerates the reaction of phenylmagnesium bromide with hex-1-yne in both diethyl ether and THF.[4] The same was observed for the reaction between ethyltriethoxysilane and ethylmagnesium chloride. At a molar ratio of 0.8 for toluene in ether, the reaction proceeded 12 times faster than in pure ether.[2b] The reagent n-BuMgCl·Et_2O in toluene, in comparison with n-BuMgCl in diethyl ether, was at least 200 times more reactive towards tetraethoxysilane.[2c]

These phenomena can be explained by the necessity to substitute a donor molecule at the magnesium center by the substrate. The concept of replacement of an ether molecule by a carbonyl compound as the first step in its reaction is generally accepted.[5] We have shown using Density Functional Theory calculations that for the Grignard reaction with alkynes preliminary replacement of a solvent molecule is energetically preferable.[4a] The magnitude of the calculated equilibrium constants is about 10^{-6}. Experimentally, the estimated complexation constants for ketones and ethers range from unity to 14 l/mol.[6] Alkoxysilanes probably lie somewhere in between since due to both electronic and steric reasons they should be weaker Lewis bases than ethers and carbonyl compounds. Thus replacement of the donor solvent by a non-donating one, e.g. diethyl ether by toluene (vide supra, and Ref. 2b,c), shifts the complexing equilibrium towards a more favorable position, thereby enhancing the reaction rate. On the other hand, increasing the solvating power of the solvents is unfavorable for complexing between the reagents and in this way suppresses the reaction rate. This has been clearly demonstrated by our experimental data, viz. pseudo-first order rate constants for the reaction of 1 M



Scheme 1. (A) A four-center transition state for the reaction with alkoxysilanes. (B) An open transition state for the reaction with chlorosilanes.

---

* Corresponding author Tel.: +3727 375 238; fax: +3727 375 245; e-mail: tuulmets@chem.ut.ee

doi:10.1016/S0040-4039(03)00809-8

Table 1. Pseudo-first order rate constants for reactions with methyltrichlorosilane (formation of methylphenyl- or *n*-butylmethyldichlorosilanes) at 20°C

Grignard reagent	Solvent	Concentration of R-Mg moiety mol/l	$k \times 10^3$ s^{-1} in ether[a]	Monosolvated in toluene
PhMgBr	MTBE[b]	0.90	0.77 ± 0.14	–
	Et_2O	0.60	2.9 ± 0.4	2.8 ± 0.2
	THF	0.77	42.5 ± 6.0	–
Ph_2Mg	Et_2O	0.70[c]	2.6 ± 0.1	2.2 ± 0.4
PhMgCl	THF	0.90	120 ± 10	43.4 ± 5.5
n-BuMgCl	Et_2O	1.01	1.86 ± 0.3	–
n-Bu_2Mg	Et_2O	1.03[c]	1.25 ± 0.2	–

[a] Method B.

[b] Methyl *tert*-butyl ether.

[c] Approximately equal concentrations of R-Mg were used for a Grignard reagent and corresponding diorganomagnesium. Although the concentration of the R_2Mg species is halved, the rate constant must be divided by the statistical factor of 2.

n-BuMgCl with tetraethoxysilane (formation of *n*-butyltriethoxysilane) at 20°C were determined ($k\times10^3$, s^{-1}) in methyl *tert*-butyl ether (MTBE) to be 39 ± 3,[7a] in diethyl ether, 14 ± 3,[7a,b] and in THF, 0.18 ± 0.03.[7b] Similarly, additions to ketones or nitriles and oxirane ring openings, in which complexation with the metal precedes the reaction, are slower in more coordinating solvents.[5,8] Consequently, the four-center transition state with a S_Ei mechanism at the carbon atom generally accepted for Grignard reactions with carbonyl compounds,[5] probably can be adopted for the Grignard reaction with alkoxysilanes (Scheme 1A).

Solvent effects in reactions with methyltrichlorosilane (Table 1) reveal different behaviors of chlorosilanes.

In contrast with alkoxysilanes, replacement of ethers by toluene does not affect, or slightly reduces the reaction rate, and with the increasing solvating power of ethers the reaction rate increases. These findings exclude the substitution of an ether molecule in the Grignard reagent as the first step of the reaction. The data also points to the decisive role of the donor solvent in determining the nucleophilicity of the carbon center. Thus, the mechanism of the Grignard reaction with chlorosilanes must be different to that with alkoxysilanes and most probably is S_E2 at the carbon atom and S_N2 at silicon (Scheme 1B).

The kinetic investigation was extended to diorganomagnesium compounds. On the basis of numerous experimental facts it was believed that the reactivity of a dialkyl- or diarylmagnesium largely exceeds that of the corresponding Grignard reagent.[5] Our preliminary observations indicate that this is also true for the reaction with alkoxysilanes. In contrast to this (Table 1), diphenylmagnesium and dibutylmagnesium react slightly slower with methyltrichlorosilane than corresponding Grignard reagents do. To the best of our knowledge, this is the first observation of the higher reactivity of Grignard reagents in comparison with the corresponding diorganomagnesium compounds. However, this apparently exceptional observation is well in line with the suggested mechanism for the reaction with chlorosilanes. Diorganomagnesiums as weaker Lewis acids are weakly solvated. This causes lower nucleophilicity of the reagent, and accordingly a lower reactivity. Also, similar reactivity of diphenylmagnesium in diethyl ether and in toluene is in good accordance with the proposed mechanism.

In conclusion, we have carried out a kinetic investigation into solvent effects in the Grignard reaction with silanes. In initial studies we have established that the reaction with alkoxysilanes consists of replacement of a donor molecule at the magnesium center by the silane followed by subsequent rearrangement of the complex to products through a four-center transition state. Chlorosilanes react differently without solvent molecule replacement. Ongoing work is focused on enhancing our understanding of the solvent effects in these industrially relevant reactions.

Experimental

Tetraethoxysilane (98% GC) was purchased from Aldrich, methyltrichlorosilane (99.0%) was donated by Dow Corning Corp. Grignard reagents were prepared by conventional methods.[9] The reagents and solutions were operated on under dry argon and transferred by use of cannulas or syringes.

Kinetic measurements

Method A. Flasks (7–8 for each run) equipped with magnetic stirrers and containing 8 ml of the Grignard reagent were thermostated. To start the reaction, 0.1–0.2 ml of tetraethoxysilane (providing a 9–20-fold excess of the Grignard reagent) was injected into each flask. At appropriate time points the reaction mixtures were quenched with iced water. The organic layer was promptly separated, dried and analyzed on a Varian 3700 gas chromatograph with a flame ionization detector.

Method B. Fast reactions were investigated in a thermostatic flask equipped with a stirrer and a thermistor. The thermistor was connected through a bridge circuit to a recording potentiometer. To a 15 ml sample of the Grignard reagent 0.05 ml of silane (providing a 20–40-fold excess of the Grignard reagent) was added and the temperature change of the reaction solution (up to 1°C) was recorded as a plot of temperature versus time. Use of a differential method for calculation of rate constants eliminated the contribution of heat exchange with the reaction vessel. Experiments were carried out in triplicate and average rate constants are given.

Acknowledgements

This work was supported by Dow Corning Corp., and the Estonian Science Foundation (grant no. 4630).

References

1. Arkles, B. In *Handbook of Grignard Reagents*; Silverman, G. S.; Rakita, P. E., Eds.; Marcel Dekker, 1996; Chapter 32.
2. (a) Reid, A. F.; Wilkins, C. J. *J. Chem. Soc.* **1955**, 4029–4034; (b) Tuulmets, A.; Hõrak, M.; Kõopere, T.; Ruotsi, J. *Org. React. (USSR)* **1982**, *19*, 102–119; (c) Sassian, M.; Panov, D.; Tuulmets, A. *Appl. Organomet. Chem.* **2002**, *16*, 525–529.
3. (a) Klokov, B. A. *Zh. Prikl. Khim. (St. Petersburg)* **1995**, *68*, 120–126; (b) Tuulmets, A.; Mikk, M.; Panov, D. *J. Organomet. Chem.* **1996**, *523*, 133–138; (c) Tuulmets, A.; Panov, D. *J. Organomet. Chem.* **1999**, *575*, 182–186.
4. (a) Tuulmets, A.; Pällin, V.; Tammiku, J.; Burk, P.; Raie, K. *J. Phys. Org. Chem.* **2002**, *15*, 701–705; (b) Pällin, V.; Tuulmets, A.; Raie, K. *Main Group Met. Chem.* **2002**, *25*, 297–300.
5. (a) Blomberg, C. In *Handbook of Grignard Reagents*; Silverman, G. S.; Rakita, P. E., Eds.; Marcel Dekker, 1996; Chapter 11; (b) Holm, T.; Crossland, I. In *Grignard Reagents: New Developments*; Richey, H. G., Jr., Ed.; J. Wiley, 2000; Chapter 1.
6. (a) Holm, T. *Acta Chem. Scand.* **1966**, *20*, 2821–2828; (b) Laemmle, J.; Ashby, E. C.; Neumann, H. M. *J. Am. Chem. Soc.* **1971**, *93*, 5120–5127; (c) Rudolph, S. E.; Charbonneau, L. F.; Smith, S. G. *J. Am. Chem. Soc.* **1973**, *95*, 7083–7093.
7. (a) Method B; (b) Method A. See Experimental.
8. Lindsell, W. E. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Ed.; Pergamon Press, 1982; Vol. 1, Chapter 4 and references cited therein.
9. Wakefield, B. J. *Organomagnesium Methods in Organic Synthesis*; Academic Press, 1995.