

APPLICATION OF ULTRASONIC WAVES TO THE INVESTIGATION OF GRIGNARD REAGENT FORMATION

Ants TUULMETS

Tartu Ülikooli orgaanilise keemia instituut (Institute of Organic Chemistry, University of Tartu),
Jakobi 2, EE-2400 Tartu, Eesti (Estonia)

Received 16 March 1995, accepted 28 March 1995

Abstract. This is a synopsis of sonochemical contributions from the Institute of Organic Chemistry of the University of Tartu together with a brief discussion of some aspects of the mechanism of Grignard reagent formation in hydrocarbon media.

Key words: Grignard reagent, ultrasound, kinetics.

Sonochemical methods have proved to be extremely useful in many fields of organic synthesis, particularly for the promotion or acceleration of the formation of organometallic compounds and their reactions [1–3]. However, kinetic investigations of the influence of ultrasound have been incidentally performed.

The main purpose of the use of sonication in this laboratory was to reveal some new aspects of the Grignard reagent formation in order to improve our knowledge of the mechanism of the process.

We studied the effect of ultrasonic waves on the kinetics of the reaction of alkylbromides with magnesium in toluene in the presence of catalytic amounts of organic bases [4, 5], and also on the duration of the induction period of the reaction in diethyl ether and in its mixtures with toluene [5, 6].

The formation of partially solvated Grignard reagents in toluene has been a reaction of our interest for a long period (for a review see Ref. [7]), since big-scale organomagnesium syntheses require the replacement of easily inflammable solvents by safer hydrocarbons of high boiling points. Another advantage of toluene is its considerably lower vapour pressure in comparison with diethyl ether. This makes a sonochemical process in this medium more efficient.

In order to elucidate the effect of ultrasonic waves, the measurements were carried out in similar conditions both with sonication and without it.

The most important feature of the reaction is that the formation of a Grignard reagent in toluene in the presence of small additions of an organic base (less than one mole per mole of an organic halide) proceeds in two stages [8]. After a rapid formation of the monosolvated Grignard reagent, a slow completion of the reaction occurs. In this stage, the reaction is catalyzed by the monosolvated Grignard reagent formed in the first step of the reaction.

Sonication exerts an accelerating effect on all steps of the reaction. However, the final yield of the Grignard reagent does not increase with irradiation. Also, sonication did not influence the relative rates of the formation of the Grignard reagent and the Wurtz type side products [4].

When diethyl ether forms the catalyst, sonication enhances the rate constant of the slow stage on the average by a factor of two. However, the dependence of rate constants on the molar ratio ether to halide is of approximately the same quadratic type in either case [4].

The reaction rate constants for the slow stage of the reaction were determined also for a variety of alkylbromides and THF as the organic base [5]. No distinct dependence of the rate constant on the structure of the halide alkyl group was observed either under sonication or in silent reaction conditions. The average accelerating effect of sonication in the case of THF is six times, thus higher than in that of diethyl ether.

The reaction between metallic magnesium and organic halide begins only after a certain induction period. We have shown [9] that the Grignard reagent formed within the induction period dissolves magnesium oxide, gradually uncovering the surface of magnesium metal.

The induction period was determined both in the absence and in the presence of additions of various inhibitors, and also under sonication and without it. For the comparison of the results we introduced the initiation constants that can be calculated from induction periods [9].

Our investigations confirm quantitatively the observation [2, 3] that sonication promotes the Grignard reagent formation even in the presence of considerable amounts of water or ethanol.

The replacement of ether by toluene in the silent reaction causes difficulties in the initiation. In case of sonication, toluene does not suppress the initiation but even accelerates the process. Under sonication the value of the intrinsic initiation constant in toluene in the presence of diethyl ether is about 15 times higher than in pure ether [5, 6]. Most probably this is associated with a more substantial cavitation in toluene in comparison with diethyl ether. This confirms the decisive role of the destruction of the oxidic magnesium film in the induction period.

The information obtained from the sonochemical experiments is in good accordance with the assumption that the induction period of the Grignard reagent formation is mainly conditioned by the necessity of cleansing the magnesium surface by the Grignard reagent formed in the reaction [9]. Ultrasonic waves facilitate the destruction of the oxide film and counteract the deposition of reaction products on the surface of magnesium.

The ordinary reaction of alkylhalides with magnesium in toluene in the presence of organic bases exhibits a somewhat lower susceptibility to sonication in comparison to the initiation process. It is remarkable that sonication does not influence the yields of products, the formation of side products, or the structure–reactivity relationships. It follows that ultrasonic irradiation does not interfere in the reaction mechanism and most probably acts through the microstreaming effect [2], suppressing the diffusion layer at the metal surface. This is compatible with the conclusion that the kinetics of the Grignard reagent formation may often be mass-transport limited ([10] and Refs. therein) and also with the supposition [7] that the catalysis by the monosolvated Grignard reagent consists in an exchange of the organic base between a solvated Grignard compound and the organomagnesium halide formed on the surface of magnesium metal, followed by the subsequent dissolution of the compound.

The latter conception permits to uniquely comprehend the catalysis by a free organic base and by a partially solvated Grignard reagent, as well as the influence of sonication. An exchange of the organic base between the catalyst and a newly formed organomagnesium particle is also compatible with the zeroth order kinetics of the process in both the silent and the sonic conditions [4, 8], because the rate of the reaction is determined by the rate of the liberation of the surface: the solvated particle dissolves immediately and the concentration of the catalyst remains unchanged.

It is generally accepted that in the Grignard reagent formation process free radical intermediates are involved. Under ultrasonic conditions, free radical processes should be especially favoured [1]. On the strength of our experimental results, it seems plausible that at least in toluene media free radicals do not occur in the rate limiting and product determining steps of the reaction. Thus, the rate limiting step of the process under catalytic conditions in hydrocarbon media seems to be the dissolution of the product, indeed, as supposed above.

ACKNOWLEDGEMENTS

I thank my colleagues and students for their contributions to our studies that have been summarized herein, Estonian Science Foundation for partial support of this work and AIRE Ltd. for a generous gift of chemicals.

REFERENCES

1. Einhorn, C., Einhorn, J., Luche, J. L. Sonochemistry – the use of ultrasonic waves in synthetic organic chemistry. – *Synthesis*, 1989, 787–813.
2. Mason, T. J. *Practical Sonochemistry*. Ellis Horwood, Chichester, 1991.
3. Mason, T. J. (ed.). *Advances in Sonochemistry*. JAI Press, London, 1990, vol. 1; 1991, vol. 2; 1993, vol. 3.
4. Tuulmets, A., Hõrak, M., Kaubi, K. Ultrasonic acceleration of Grignard reagent formation. A kinetic study. – *Organic Reactivity (Tartu)*, 1986, 23, 397–402.

5. Tuulmets, A., Kaubi, K., Heinoja, K. Influence of sonication on Grignard reagent formation. – *Ultrasonics Sonochemistry*, 1995, **2**, (in press).
6. Tuulmets, A., Heinoja, K. Influence of sonication on the induction period of the Grignard reaction. – *Organic Reactivity (Tartu)*, 1990, **27**, 63–73.
7. Tuulmets, A. Formation of partially solvated Grignard reagents in toluene. – *Acta et Comment. Univ. Tartuensis*, 1993, **966**, 175–187.
8. Tuulmets, A., Hõrak, M., Pill, E., Riikoja, A. Kinetics of formation of Grignard reagent with small additions of ethyl ether. – *Organic Reactivity (Tartu)*, 1985, **22**, 93–101.
9. Tuulmets, A., Heinoja, K. Influence of inhibitors on initiation of the Grignard reaction. Nature of induction period. – *Organic Reactivity (Tartu)*, 1990, **27**, 42–62.
10. Root, K. S., Deutch, J., Whitesides, G. M. Mechanism of formation of Grignard reagents. – *J. Am. Chem. Soc.*, 1981, **103**, 5475–5479.

ULTRAHELII KASUTAMINE GRIGNARD'I REAKTIIVI MOODUSTUMISE UURIMISEKS

Ants TUULMETS

Töös on lühidalt kokku võetud Tartu Ülikooli orgaanilise keemia instituudis tehtud kvantitatiivsete sonokeemiliste uuringute olulisemad tulemused ning nendest lähtudes lühidalt arutletud Grignard'i reaktiivi moodustumisreaktsiooni mehhanismi mõningaid aspekte.

ПРИМЕНЕНИЕ УЛЬТРАЗВУКА В ИССЛЕДОВАНИИ ОБРАЗОВАНИЯ РЕАКТИВА ГРИНЬЕРА

АНТС ТУУЛМЕТС

Дан обзор количественных сонохимических исследований, проведенных в Институте органической химии Тартуского университета, и в свете их результатов коротко обсуждены некоторые вопросы механизма образования реактива Гриньяра.