

The effect of solvent polarity on the rate of rearrangement of 9-(*trans*-2,3-dimethylcyclopropylmethyl)-9-borabicyclo[3.3.1]nonane

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Abstract

The rate of the ring-opening rearrangement of the borane derived from hydroboration of *trans*-2,3-dimethylmethylenecyclopropane with 9-BBN was measured in hexane, tetrahydrofuran, and methylene chloride. The modest increase in rate which was observed with increasing polarity is interpreted to imply a transition state only slightly more polar than the reactant.

Introduction

There have been a number of reports of the kinetics of ring-opening rearrangements of cycloalkylmethyl Grignard reagents, and of cyclizations which are the reverse process [1,2]. It is generally found that these rearrangements occur somewhat more rapidly in ethyl ether than in the more polar tetrahydrofuran (THF), and that the rate is also increased by addition of a nonpolar diluent. The greater rate in less polar media and the relatively small magnitude of the effect were interpreted to support a non-ionic concerted mechanism in which the transition state is slightly less polar than the reactant [1]. However, another major difference which could also affect the rearrangement rate is the stronger coordination of THF to the magnesium [3]. Thus, the net solvent effect may be a multi-dimensional quantity whose interpretation is not so straightforward as the initial analysis suggested. (There could also be indirect effects on the rate, since the solvent influences association and redistribution (Schlenk) equilibria of Grignard reagents [3]. However, these may be less important, since the change between THF and ethyl ether produces similar effects on the ring cleavage rates of di(cyclobutylmethyl)magnesium and the corresponding Grignard reagent [2b]).

Cyclopropylmethyl- and cyclobutylmethylboranes undergo similar ring-cleavage rearrangements [4,5]. Unlike the organomagnesium compounds, trialkylboranes appear to exhibit little coordination affinity toward ethers, and they may be

prepared in non-coordinating media. Although differences in mechanistic detail between the rearrangements of the organomagnesium and boron compounds are likely, the latter do provide a closely related reaction in which the effect of solvent should be less complex.

In previous work, we found that boranes derived from hydroboration of methyl-substituted methylenecyclopropanes rearrange in THF at conveniently measured rates [4]. The progress of the reaction could be monitored either by oxidation to the corresponding alcohols, or by direct ^{13}C NMR examination of the borane solutions. However, a complication appeared when hydroboration was done with borane-methyl sulfide, since the B-alkyl group may occupy a multiplicity of slightly different environments in the resultant trialkylborane [4]. However, if 9-borabicyclo[3.3.1]nonane (9-BBN) is used in the hydroboration, a single borane species should be produced, whose spectra and rearrangement avoid this complication.

We report here the effect of solvent variation on the rate of ring-cleavage rearrangement of the trialkylborane from *trans*-2,3-dimethylmethylenecyclopropane and 9-BBN.

Results and discussion

trans-2,3-Dimethylmethylenecyclopropane was prepared and subjected to hydroboration with 9-BBN in hexane, THF, and methylene chloride (eq. 1). ^{13}C NMR spectra indicated formation of the expected borane [4]. Single sharp peaks were observed for each carbon of the dimethylcyclopropylmethyl group (except that the methylene attached to boron was broadened). Heating led cleanly to the appearance of a new set of peaks assigned to the rearranged borane. First-order rearrangement rate constants, derived from ^{13}C NMR spectra of the boranes and by GC analyses of the alcohol mixtures formed from them by oxidation, are listed in Table 1.

The rate of rearrangement may be seen to increase with the polarity (dielectric constant) of the solvent, but the effect is relatively small. Although the macroscopic

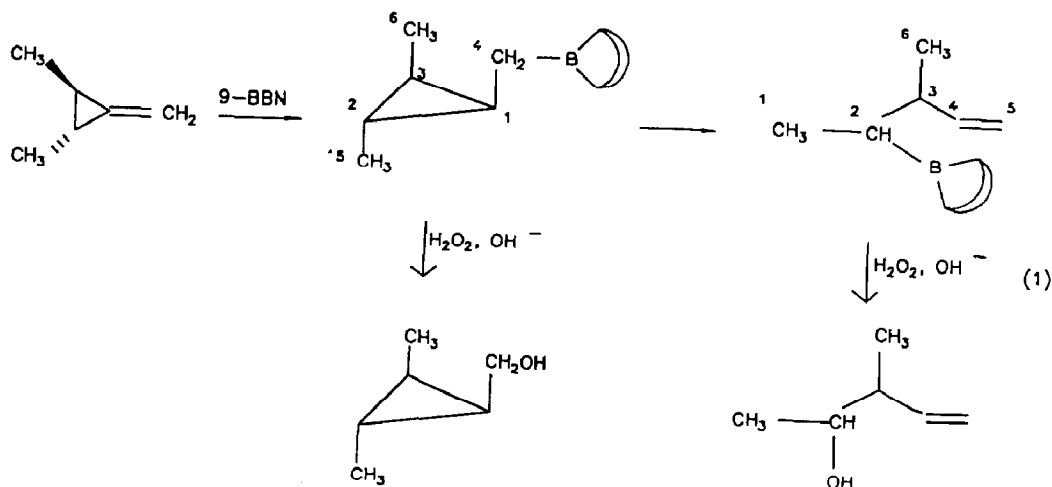


Table 1

Rate constants for rearrangement of 9-(*trans*-2,3-dimethylcyclopropylmethyl)-9-borabicyclo[3.3.1]nonane

Solvent	Dielectric Constant ^a (25°C)	10 ⁵ × <i>k</i> (s ⁻¹), 61°C ^b
Hexane	1.9	5.1 ± 0.5 ^c
Tetrahydrofuran	7.6	12.2 ± 0.4
Methylene chloride	8.9	16.0 ± 0.5

^a J.A. Riddick, W.B. Bunger and T.K. Sakano, *Organic Solvents*, in: A. Weissberger (Ed.), *Techniques of Chemistry*, Vol. II, 4th edition, Wiley, New York, 1986. ^b Derived from least-squares analysis of plot of ln(fraction unrearranged) vs. time. Uncertainties are standard deviations. ^c In earlier preliminary study: 5.6 ± 0.5.

dielectric constants may not be an appropriate measure of solvent polarity for quantitative correlation of reaction rates [6], the direction and magnitude of the solvent effect imply qualitatively that rearrangement occurs via a transition state slightly more polar than the trialkylborane reactant. The rate in THF relative to the two non-coordinating solvents tends to confirm the unimportance of coordination to the boron by THF.

As noted in the introduction, analogous organomagnesium rearrangements occur more rapidly in ethyl ether than in the more polar THF [1,2], so that the effects of solvent polarity on rearrangements of the boron and magnesium compounds appear on the surface to be in opposite directions. However, it is found that addition of an equivalent of pyridine strongly inhibits the borane reactions [5a,c], probably because it coordinates to a vacant orbital on the boron which is necessary for rearrangement. If the organomagnesium rearrangements require a similar vacant orbital or coordination site on the metal, then THF should retard the rearrangement more than ethyl ether because of its greater basicity [3]. The resulting rate decrease could be enough to obscure a rate-increasing solvent polarity effect. Thus, it is at least possible that the organoboron and -magnesium rearrangements do have similar inherent responses to the polarity of the medium, despite the different net effects observed. In any event, both solvent effects are relatively small, indicating transition states not much different from their reactants in polarity.

Another point might also be mentioned briefly. The rearrangement appeared to go essentially to completion; the NMR spectra showed no detectable starting material at long reaction time in hexane, and 2% or less after about 12 h in the other two solvents. In contrast, the 2,2,3-trimethyl analog approached an equilibrium at long heating time which included about 25% of the cyclic isomer [4]. The difference may be attributed to increased steric congestion in the open-chain product with the additional methyl group.

Experimental

NMR spectra were run on a Bruker WM-250 spectrometer with about 10% of C₆D₆ added as lock and reference (128.0 ppm). Gas chromatograms were on a Varian Aerograph A90-P3 instrument with a 6 ft × 1/4 in. column of 20% Ucon 50-HB-280 on 60–80 mesh acid-washed Chromosorb W. Commercial solutions of 0.5 M 9-BBN in THF and hexane were used as obtained, and a solution of similar

concentration in methylene chloride was prepared from solid 9-BBN (Aldrich). *trans*-2,3-Dimethylmethylenecyclopropane was prepared as described previously [4,7]. It was found, as observed before [4], that some of the *cis* isomer was also formed. This was limited to about 5% by reducing contact of the product with base during dehydrohalogenation. Some samples were also contaminated with a small fraction of hexane from the preparation. Glassware was oven-dried at 130 °C, assembled while hot, and filled with nitrogen during cooling and use.

Preparation, rearrangement, and analysis of borane solutions

A small excess of the alkene was added by syringe to a solution of 9-BBN. After stirring for 30 min, 1-ml samples were transferred by syringe to nitrogen-filled glass tubes attached to a manifold. These were sealed under partial vacuum, and stored in a freezer until use. A portion was also transferred to a 10 mm NMR tube (sealed or septum-capped), and remaining solution was worked up oxidatively.

The tubes were heated for appropriate periods in a thermostatted bath at 61 °C. In a nitrogen-filled glove bag, the tubes were opened and the contents poured into a small flask assembly. This was removed from the glove bag, cooled (under nitrogen) to 0 °C, and NaOH (0.15 ml of 3 M solution) and H₂O₂ (0.30 ml of 30% solution) were added dropwise. After completion of the oxidation, the aqueous layer was saturated with anhydrous K₂CO₃, and the organic layer was separated for GC analysis. The composition of the alcohol mixture was calculated as the product of height times width of the GC peaks, assuming equal sensitivity for the isomeric components. The alcohol products were also separated preparatively and shown by NMR to be identical to those obtained previously [4].

The ¹³C NMR spectra of the 9-alkyl groups of the 9-alkyl-9-BBN species were assigned as follows based on previous work [4] and single-frequency off-resonance decoupled spectra (δ , measured relative to C₆D₆ at 128.0 ppm; numbering of carbons as in eq. 1; shifts in the order hexane, THF, methylene chloride; b = broad, x = obscured): *trans*-2,3-dimethylcyclopropylmethyl: C(1): 22.08, 21.90, 21.70; C(2) and C(3): 18.60 and 20.73, 18.39 and 20.63, 18.23 and 20.37; C(4): ca. 28 (b); C(5): 19.25, 19.00, 19.03; C(6): 13.22, 12.94, 13.02; *cis*-2,3-dimethylcyclopropylmethyl: C(1): x, ca. 14.00, 13.75; C(2) and C(3): ca. 11.5, 11.50, 11.34; C(4): x; C(5) and C(6): 7.64, 7.41, 7.47; 3-methyl-4-penten-2-yl: C(1): x, 11.20, 11.17; C(2) ca. 36.5 (b); C(3): 40.40, 40.11, 39.83; C(4): 145.73, 145.77, 145.92; C(5): 112.54, 112.32, 112.18; C(6): 18.78, 18.39, 18.40. Resonances of the 9-BBN portion were at about 33.5–34 and 23.5–23.9 ppm, as observed previously [4]. Approximate analyses of the composition of the borane mixture were derived from the averaged peak intensities of rearranged and unrearranged alkyl groups.

Rate constants were evaluated from a least-squares analysis of the first-order plot of ln(fraction of unrearranged structure) vs. time. GC and NMR analyses were mutually consistent, and were combined in the rate plots. Results are summarized in Table 1.

In the reactions in hexane and methylene chloride, there was evidence of radical side-reaction during the oxidation. Variable amounts of the *erythro* isomer of 3-methyl-4-penten-2-ol were formed along with the principal *threo* isomer (which results from retention of configuration in both ring-cleavage and oxidation steps [4]). Cyclooctanone, *cis*-cyclooctene, and bicyclo[3.3.0]octane were also identified [8]. ¹³C NMR spectra gave no evidence for the presence of diastereomers or

degradation products before oxidation of the borane. Several approaches were examined for recalculation of the rate constants to allow for possible consequences of partial product formation via radicals. Only minor variations in rate constants or statistical parameters resulted, without substantial change of relative rates, so it was concluded that the reported rate constants are little perturbed by this potential complication.

Hydroboration of the *cis*-2,3-dimethylmethylenecyclopropane impurity was indicated in the ^{13}C NMR spectrum (see above) and by formation of a small amount of the all-*cis* isomer of 2,3-dimethylcyclopropylmethanol on oxidation. Both modes of analysis indicated a nearly constant concentration of about 5% throughout the period for which the rearrangement was followed.

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