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Secondary α -Deuterium Isotope Effects in the Reaction of 2-Phenylethyltrimethylammonium Ion by Hydroxide Ion in Aqueous Solution and by Ethoxide Ion in Ethanol

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Secondary α -deuterium isotope effects in the reaction of 2-phenylethyltrimethylammonium iodide with hydroxide ion in aqueous solution at 97.0° and with ethoxide ion in ethanol at 40.0° have been found to be very small. The results suggest that the hydrogen compound reacts slightly faster than the deuterium compound. The secondary α -deuterium isotope effect in the reaction of 2-phenylethyl bromide with sodium ethoxide in ethanol is appreciably larger and amounts to 9 per cent per deuterium atom at 59.8°. The mechanistic implications of these results are discussed.

It was previously shown^{1,2} that the secondary β -deuterium isotope effect in the S_N1 solvolysis (aquation) of 2,2-dideutero-1,1-di-(trideuteromethyl) propyl-dimethyl-sulphonium iodide amounts to 25% (3.3% per deuterium atom), while the isotope effect in the solvolysis of the corresponding chloride [2,2-dideutero-1,1-di-(trideuteromethyl) propyl chloride] in 80% aqueous ethanol was found by Shiner to be 135% (17% per deuterium atom).

It was also of interest to determine the magnitude of the secondary α -deuterium isotope effect in the reaction of an »onium« salt. In reactions involving carbonium ion transition states when deuterium is linked to α -carbon the retardation usually amounts to 10–20 per cent per deuterium atom³⁻⁶. The effect is explained in terms of the reduction in the force constant for the bending of the C—H bond in the sp^2 -hybridized activated complex⁵.

It has also been shown² that in the concerted E_2 reaction of 2-phenylethyl-1,1- d_2 bromide with sodium ethoxide in ethanol there is a secondary α -deuterium isotope effect of 9 per cent per deuterium atom at 59.8°. On the other hand a very small secondary α -deuterium isotope effect was found in the reaction of 2-phenylethyldimethylsulphonium-1,1- d_2 bromide with sodium hydroxide in aqueous solution ($k_H/k_D = 1.015$)². The importance of this observation is lessened very much because of the extensive α -hydrogen exchange in the sulphonium salt^{2,7,8}.

We have now determined the secondary α -deuterium isotope effects for the reaction of 2-phenylethyltrimethylammonium-1,1- d_2 iodide with sodium hydroxide in aqueous solution and with sodium ethoxide in ethanol and obtained in both cases very small isotope effects. In the case of the ammonium salt there is no observable α -hydrogen exchange⁸ as shown by mass spectrometric mea-

measurements of trimethylamine collected from the reactions with deuterium oxide in deuterium oxide solution and with ethoxide ion in ethanol-O-d. Therefore the difficulties caused by the α -hydrogen exchange in the reaction of 2-phenylethyl-dimethylsulphonium salt are not present in the elimination reaction from the corresponding ammonium salt.

RESULTS

Secondary α -deuterium isotope effects in the reaction of 2-phenylethyl-trimethylammonium-1,1-d₂ iodide with sodium hydroxide in aqueous solution.

Trimethylamine formed in the reaction was removed from the aliquots taken at definite reaction times by a stream of nitrogen and the rate was followed potentiometrically by titration with hydrochloric acid. The results are presented in Table I.

TABLE I

Rates of the E₂ reaction of 0.1 M 2-phenylethyltrimethylammonium-1,1-d₂ iodide with 0.2 M sodium hydroxide in aqueous solution at 97.0° C

Compound	Atom D per Molecule	10 ⁴ k mole ⁻¹ sec ⁻¹ l	k _H /k _D
PhCH ₂ CH ₂ N(CH ₃) ₃ I	—	1.47 ^a ± 0.07 ^c	1.023
PhCH ₂ CD ₂ N(CH ₃) ₃ I	1.79	1.43 ^b ± 0.07 ^c	

^a Mean of: 1.40, 1.50, 1.55, 1.42, 1.47.

^b Mean of: 1.37, 1.40, 1.48, 1.48.

^c Standard error of the mean

The isotope effect amounted to 1.3 per cent per deuterium atom at 97.0° C, taking into account the incomplete deuteration. Because of the large standard error the results only suggest that the hydrogen compound reacts slightly faster than the deuterium compound.

Secondary α -deuterium isotope effect in the reaction of 2-phenylethyl-trimethylammonium-1,1-d₂ iodide with ethoxide ion in ethanol.

The kinetics of the reaction was followed spectrophotometrically by measurements of absorption of styrene at 248 m μ . The results are presented in Table II.

TABLE II

Rates of the E₂ reaction of 0.0025 M 2-phenylethyltrimethylammonium-1,1-d₂ iodide with 0.1437 M sodium ethoxide in absolute ethanol at 40.0° C

Compound	Atom D per Molecule	10 ⁵ k mole ⁻¹ sec ⁻¹ l	k _H /k _D
PhCH ₂ CH ₂ N(CH ₃) ₃ I	—	52.0 ^a ± 1.3 ^c	1.032
PhCH ₂ CD ₂ N(CH ₃) ₃ I	1.79	50.4 ^b ± 1.1 ^c	

^a Mean of: 52.7, 51.1, 52.5, 52.1, 51.6

^b Mean of: 51.9, 49.3, 51.0, 49.2

^c Standard error of the mean

The isotope effect calculated for complete deuteration was 1.8 per cent per deuterium atom. Again, because of the large standard error, the results suggest that also in ethanol the hydrogen compound reacts slightly faster than the deuterium compound.

DISCUSSION

The mechanism of the elimination reaction from 2-phenylethyltrimethylammonium ion in alcoholic media has been studied by Ayrey *et al.*⁹ by measurements of nitrogen-15 kinetic isotope effect. They found a substantial nitrogen isotope effect of 0.9 per cent in the reaction with ethoxide ion in ethanol at 60° (maximum nitrogen isotope effect at this temperature would be about 3.2 per cent). We measured the nitrogen isotope effect in aqueous base at 97° and obtained a small nitrogen isotope effect of 0.2 ± 0.1 per cent (rejecting one negative value of the isotope effect)¹⁰.

The difference between the nitrogen isotope effects found in alcoholic and aqueous solutions would be somewhat reduced, if the experiments in alcoholic solutions were performed at 97° where the isotope effect would amount to about 0.7 per cent. However, 0.7 per cent is still a substantial isotope effect and suggests that the rupture of the C—N bond in the transition state is appreciable. Bourns *et al.*¹¹ also measured the nitrogen isotope effect in aqueous media and found an isotope effect of approximately 1/3 of the maximum value, which was in agreement with their previous measurements in alcoholic media. Our results are being reinvestigated. The appreciable nitrogen isotope effects obtained by Bourns *et al.* in alcoholic and aqueous media suggest that in both solvents the rupture of the carbon-nitrogen bond is appreciably advanced in the transition state.

In this paper we have shown that there is practically no secondary α -deuterium isotope effect in the elimination in aqueous and ethanolic media. One could assume that the heterolysis of the C—N⁺ bond in the ammonium salt requires a smaller electron transfer than the heterolysis of the corresponding halide, since for an equivalent bond extension the incipient carbonium ion of the ammonium salt must carry a larger net positive charge. In such a case when the hybridization changes from sp^3 to sp^2 without the development of positive charge on carbon, it might be expected that the out of plane bending frequency would go down which could lead to an isotope effect near zero.

The solvation difference needed to heterolyze the initially non-ionic C—halide bond and the C—N⁺ must be appreciable. The solvation change is much smaller in the heterolysis of C—N, where the total ionic change remains the same.

EXPERIMENTAL

2-Phenylethyltrimethylammonium Iodide

Methyl iodide was slowly added (in 100 per cent excess) to 2-phenylethylamine in absolute ethanol at its boiling point and then the solution refluxed for two hours in the presence of sodium carbonate to assure neutral reaction. Excess of methyl iodide and alcohol were distilled off and the ammonium salt recrystallized from

water. It decomposed at about 226°. The decomposition point is unreliable as a criterion of purity.

Anal. $C_{11}H_{18}IN$ (291.16) calc'd: C 45.4; H 6.2; I 43.6; N 4.8%
found: C 45.2; H 6.3; I 43.0; N 4.5%

2-Phenylethyltrimethylammonium-1,1- d_2 Iodide

2-Phenylethylamine-1,1- d_2 was prepared by reduction of benzyl cyanide with lithium aluminium deuteride (Metal Hydrides, Inc., 95.5% deuterium) as described by Nystrom¹². The undeuterated amine was prepared in an analogous way. 2-Phenylethyltrimethylammonium-1,1- d_2 iodide and its undeuterated analogue were then prepared from the amines as already mentioned. 2-Phenylethyltrimethylammonium iodide prepared in this way decomposed at about 226°.

Anal. $C_{11}H_{16}D_2IN$ (293.17) found: C 45.4; I 43.6; N 4.8%

The deuterated salt $C_{11}H_{16}D_2IN$ was found to contain 1.79 atoms D per molecule. Deuterium analyses — were performed by the »falling drop« method¹³. Duplicate analyses agreed to within 1.5%.

Kinetics Measurements in Aqueous Solution

The reaction vessel made of alkali resistant boron free glass (Corning Glass Works, Corning, N. Y., U. S. A.) was fitted with a condenser and thermostated at $97 \pm 0.01^\circ$. Blanks showed that alkali did not react with the glass of the vessel during five reaction times. 2-Phenylethyltrimethylammonium iodide was 0.1 M and sodium hydroxide 0.2 M. Aliquots of 2 ml were withdrawn at definite times, diluted with water to 50 ml and a stream of nitrogen led through the solution during one hour to expel trimethylamine. The decrease of sodium hydroxide concentration was then determined potentiometrically.

Kinetic Measurements in Alcoholic Solution

The reactions of 0.0025 M 2-phenylethyltrimethylammonium-1,1- d_2 iodide and of the corresponding undeuterated salt, were carried out with 0.1437 M ethoxide ion in ethanol at $40 \pm 0.01^\circ C$ in the reaction vessel described above. The volume of the reaction mixture was 25 ml. At definite reaction times aliquots of 2 ml were withdrawn, made up to 50 ml with 96 percent ethanol and the light absorption was measured at 248 m μ using a Hilger H 700 spectrophotometer and quartz cells. The concentration of styrene was then determined using the molar extinction coefficient of freshly distilled styrene in ethanol at 248 m μ which amounts to 1.35×10^4 mole⁻¹ cm⁻¹ 1¹⁴.

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IZVOD

Sekundarni α -deuterijski izotopski efekti u reakciji 2-feniletiltrimetilamonijeva iona sa hidroksilnim ionom u vodenoj otopini i sa etoksi ionom u etanolu

S. Ašperger, L. Klasinc i D. Pavlović

Određeni su sekundarni α -deuterijski izotopni efekti u reakciji 2-feniletiltrimetilamonijeva jodida sa hidroksilnim ionom u vodenoj otopini kod 97.0° i sa etoksi ionom u apsolutnom etanolu kod 40.0° i nađeno je da su ti efekti vrlo mali. Dobiveni rezultati govore za to da vodikov spoj reagira nešto brže od α -deuteriranog spoja. Sekundarni α -deuterijski izotopski efekti u reakciji 2-feniletil bromida sa natrijevim etilatom u apsolutnom etanolu znatno je veći i iznosi oko 9% po atomu deuterija kod 59.8°. Diskutirani su uzroci za mali izotopski efekt i značenje tog efekta za reakcijski mehanizam.

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