

ISOTOPE EFFECTS IN THE REDUCTIVE DEMERCURATION OF HEX-5-ENYL-1-MERCURIC BROMIDE BY NaBH_4 AND LiAlH_4

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Extensive studies have established the intermediacy of alkyl radicals in the reductive demercuration of alkylmercuric halides by sodium borohydride.¹⁻⁶ Mechanisms involving hydrogen atom transfer from an alkylmercuric hydride to alkyl radicals have been proposed for these reductions using a variety of metal hydrides.² We report herein novel isotope effect studies of the reductive demercuration of hex-5-enyl-1-mercuric bromide⁷ by NaBH_4 and LiAlH_4 which characterize the intermediates involved in these reactions and quantitatively account for the isotopic compositions of the products.

A summary of results of demercuration of hex-5-enyl-1-mercuric bromide with a variety of reducing agents is presented in Table 1. The major product of NaBH_4 reductions (runs 1-3) is the rearranged hydrocarbon, methylcyclopentane. In view of the known behavior of the 5-hexenyl cation⁸ and anion,⁹ these results provide evidence for the intervention of significant amounts of non-cage radicals in these reductions since the rate of rearrangement of the 5-hexenyl radical (10^5 sec^{-1} at 25°)¹⁰ would be slow relative to diffusion. In accord with our earlier observations⁴ and recent results of Hill and Whitesides,⁶ the major product of reductive demercuration by NaBH_4 in an oxygen atmosphere (run 3) is the corresponding alcohol, hex-5-en-1-ol. The production of alcohols in the presence of oxygen is consistent with the formation of intermediate radicals since oxygen is known to be an efficient radical scavenger.

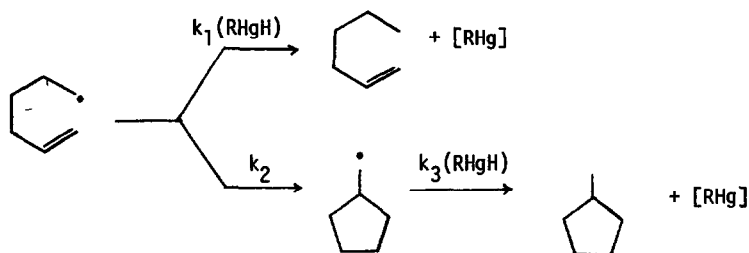
Quite surprisingly, the product distribution from these reductive demercurations is significantly affected by substituting borodeuteride for borohydride as shown in Table 1 (run 2); the yield of methylcyclopentane is increased, and the yield of 1-hexene is decreased by this substitution. These results suggest that an isotope effect is operating in the hydrogen-atom abstraction step to increase the lifetime of the 5-hexenyl radicals and thus lead to a higher proportion of rearranged hydrocarbon as shown in Scheme 1, where it is assumed that the alkylmercuric hydride (RHgH) is the hydrogen-transfer species in accord with previous mechanistic postulates. Straightforward kinetic analysis¹¹ of the effect of deuterium substitution on the product ratios (1-hexene: methylcyclopentane) provides a unique method of estimating the isotope effect for the

Table 1. Reductions of Hex-5-enyl-1-mercuric Bromide^a

Run	Reducing Agent	Solvent	Products (% yields) ^b			Product Ratio ^c (1-hexene: methyl- cyclopentane)
			1-hexene	methyl- cyclopentane	hex-5-en- 1-ol	
1.	NaBH ₄	2/3 THF-H ₂ O	30	36		.79
2.	NaBD ₄	2/3 THF-H ₂ O	23 ^d	55		.40
3.	NaBH ₄	2/3 THF-H ₂ O ^e	16	8	55	
4.	LiAlH ₄	THF	33	36		.91
5.	LiAlD ₄	THF	20 ^d	40		.50
6.	LiAlH ₄ /LiAlD ₄ ^f	THF	11 ^d	40		.28
7.	Na(Hg)	THF/D ₂ O	60			

^aReaction products were identified by glpc retention times and glpc-mass spectra compared with authentic samples. Product yields ($\pm 1-2\%$) were determined by glpc using pentane as internal standard. ^bRemainder of product is the dialkyl mercurial. ^cAverage of two or more identical runs. ^dYield of deuterated 1-hexene. ^eReaction carried out under an O₂ atmosphere. ^f[LiAlH₄]/[LiAlD₄] = 0.840.

Scheme 1.



hydrogen-atom transfer step (k_1) shown in Scheme 1, since k_2 should be sensibly constant in both systems. An isotope effect of 1.9 ± 0.1 is obtained by analysis of the product distributions for several such reactions. This result may be compared with an analogous isotope effect of 2.7-2.8 reported for the reaction of cyclohexyl radicals with tri-*n*-butyltin hydride.¹⁰ The isotopic composition of the products obtained from the borodeuteride reduction was determined directly by mass spectrometric analysis of the molecular ions. Both methylcyclopentane and 1-hexene had isotopic compositions of 86-87% d₁ and 13-14% d₀ by this method of analysis, which compares

favorably with analogous results reported by Whitesides and San Filippo.² This isotopic composition can be readily accounted for by considering the isotopic composition of NaBD_4 (94% d)¹² and the above kinetic isotope effect for the hydrogen abstraction step.¹³

Whitesides and San Filippo² have proposed a common reaction pathway for all metal hydride reductions of alkylmercuric halides on the basis of the insensitivity of the exo:endo product ratios from reductions of norbornyl-2-mercuric bromides to variations in the metal hydrides. We have examined the lithium aluminum hydride reduction of hex-5-enyl-1-mercuric bromide to test the postulated common reaction pathway for metal hydride reductions, and the results are shown in runs 4, 5, and 6 in Table 1. It is noteworthy that the rearranged hydrocarbon, methylcyclopentane, is the major product of the LiAlH_4 reductions, consistent with the formation of noncage radicals for this reaction also.¹⁴ The shift in product proportions (1-hexene: methylcyclopentane) with LiAlD_4 vs. LiAlH_4 is apparent from these results. Most significant, however, is the fact that the isotope effect calculated for the hydrogen atom abstraction step for this system from the product ratio shift is 1.8 ± 0.1 , which is in remarkable agreement with the analogous isotope effect of 1.9 ± 0.1 obtained for the sodium borohydride reduction of this mercurial. These isotope effects provide convincing support for the proposal of Whitesides and San Filippo² that metal hydride reductions of alkylmercuric halides, in general, proceed by a common mechanistic pathway involving hydrogen atom transfer from alkylmercuric hydrides to alkyl radicals. The isotopic compositions of both methylcyclopentane and 1-hexene were determined to be $> 93\% d_1$ by mass spectrometric analysis of the corresponding molecular ions. Here again, the isotopic composition of the products can be readily accounted for in terms of the isotopic composition of the LiAlD_4 (98% d)¹² and the operation of an isotope effect of 1.8 for the hydrogen abstraction step without invoking any hydrogen abstraction from the solvent.¹⁵

It should also be noted that in accord with recent results of Jensen, et al.,⁵ the sodium amalgam reduction of hex-5-enyl-1-mercuric bromide in THF/ D_2O (99.8% d)(run 7) produces only the unrearranged hydrocarbon, 1-hexene, with $> 96\% d_1$ composition as determined by mass spectrometry. On the basis of these results, the sodium amalgam reduction of alkylmercurials should be the method of choice for replacing mercury by deuterium without rearrangement or loss of stereochemistry.^{4,5} These results illustrate the unique characteristics of the 5-hexenyl system as a

probe for radical intermediates in reactions of organometallic compounds.

References and Notes

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11. L. Melander, "Isotope Effects on Reaction Rates," Ronald Press, New York, 1960. We have assumed that a) the steady-state approximation is applicable to the 5-hexenyl radical; and b) all hydrogen and deuterium are extracted from borohydride or some source derived from borohydride with the same isotopic composition.
12. Sodium borohydride (94% d) and lithium aluminum deuteride (98% d) were purchased from Ventron Corporation.
13. It is noteworthy that our analysis indicates a maximum contribution of 1% hydrogen abstraction from solvent (see ref. 5).
14. No significant deuterium incorporation was observed when the reaction mixture was quenched with D₂O and analyzed by mass spectrometry.
15. The data from run 6 in Table I provide convincing support for the assumptions, listed in footnote 11 above, since an isotope effect of 1.8 ± 0.1 is obtained from the product ratios which agrees with the isotope effect calculated from the isotopic composition of the molecular ions (40% d₁).