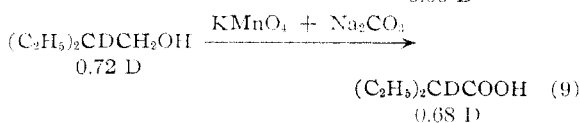
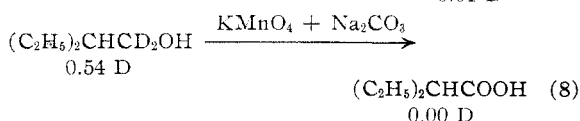
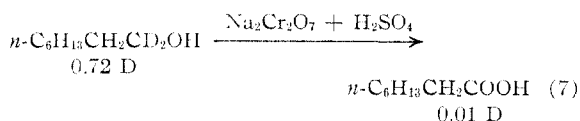


It will be seen that the alcohols obtained on reduction of the esters with sodium and deuterioacetic acid in (3) and (4) had essentially the theoretical amounts of deuterium, and that the deuterium content did not decrease on their conversion to halides. In (4), in which the deuterium resides on the β -carbon, this conversion involved several steps including the carbonation of a Grignard reagent and the reduction of the resulting acid with lithium aluminum hydride. However, the alcohol obtained in (5) probably did not have quite the theoretical amount of deuterium since the bromide prepared from it did not. This halide may have consisted not only of the dideuterated and some undeuterated bromide, but also some of the monodeuterated bromide. The fact that in (6), ethyl diethylacetate did not take up the theoretical amount of deuterium is not surprising since the reaction mixture of potassium triphenylmethide and the ester still retained the deep red color of the triphenylmethide ion when deuterium oxide was added.

During the reduction with sodium and deuterioacetic acid, the ester might have undergone hydrogen-deuterium exchange leading to the formation of alcohol with deuterium on the β -carbon atom. Therefore samples of the alcohols produced in (3) and (5), after dilution with undeuterated alcohol, were oxidized to carboxylic acids (equations 7 and 8). The fact that essentially no deuterium was found upon analysis of the acids shows that the



alcohols contained deuterium only on the α -carbon atom. Oxidation of a sample of the alcohol having deuterium on the β -carbon atom obtained in (6) gave a carboxylic acid of practically the same deuterium content (equation 9).

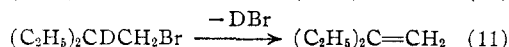
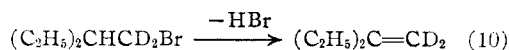
Elimination Reactions.—The deuterio alkyl halides were treated with an equivalent or slight excess of potassium amide in liquid ammonia, and, after separating from amine,⁵ the olefin was isolated and analyzed for deuterium. In certain experiments the reaction was stopped before completion by adding ammonium chloride, and the unreacted halide as well as the olefin analyzed for deuterium. The results are given in Table I.

TABLE I
DEUTERIUM CONTENT OF HALIDES AND OLEFINS

Type	Formula	Halide D per molecule Initial	Halide D per molecule Recovered	Olefin D per molecule
I	$\text{C}_6\text{H}_{13}\text{CH}_2\text{CD}_2\text{Br}$	1.98		1.75
	$\text{C}_6\text{H}_{13}\text{CH}_2\text{CD}_2\text{Br}$	0.46 ^a		0.37
	$\text{C}_6\text{H}_{13}\text{CH}_2\text{CD}_2\text{Cl}$	1.98	1.97	1.84
II	$\text{C}_6\text{H}_{13}\text{CD}_2\text{CH}_2\text{Br}$	1.99	1.99	1.07
	$\text{C}_6\text{H}_{13}\text{CD}_2\text{CH}_2\text{Br}$	1.02 ^a		0.26
	$\text{C}_6\text{H}_{13}\text{CD}_2\text{CH}_2\text{Cl}$	0.18 ^a		0.03
III	$(\text{C}_2\text{H}_5)_2\text{CHCD}_2\text{Br}$	1.92		1.92
	$(\text{C}_2\text{H}_5)_2\text{CHCD}_2\text{Br}$	0.23 ^b	0.23	0.21
IV	$(\text{C}_2\text{H}_5)_2\text{CDCH}_2\text{Br}$	0.19 ^c	0.38	0.00

^a Prepared by diluting essentially pure deuterated halide with halide having no D. ^b Diluted from preparation with 0.53 D with halide having no D. ^c Diluted from preparation with 0.43 D with halide having no D.

It can be seen from Table I that elimination from 2-ethylbutyl bromide was exclusively of the β -type. Thus, bromide III which contained deuterium only on the α -carbon formed an olefin having the same deuterium content, while bromide IV, which contained deuterium only at the β -carbon, gave an olefin having no deuterium in accordance with equations (10) and (11), respectively. Although recovered halide III had the same deute-



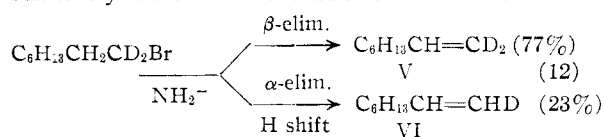
rium content as before reaction, recovered halide IV contained considerably more deuterium than initially. This is explained on the basis that the undeuterated fraction which comprised 81% of the sample underwent elimination several times faster than the deuterated compound, thereby allowing the latter to accumulate. In general hydrogen has been found two to three times more reactive than deuterium in reactions in which a proton or deuterium is removed.⁶

However, elimination from the *n*-octyl halides was not exclusively of the β -type. Thus, pure bromide and chloride I, which contained deuterium only on the α -carbon atom formed olefins having somewhat less deuterium. Likewise, pure bromide II, which contained deuterium only on the β -carbon atom, gave olefin having slightly more deuterium

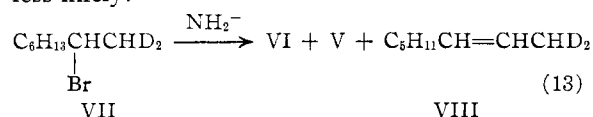
(5) Amine is formed simultaneously by the competing displacement reaction. It amounted to about 20% of the product with 2-ethylbutyl bromide, but to about 80% with the *n*-octyl halides.

(6) C. L. Wilson, *J. Chem. Soc.*, 1550 (1936); W. F. K. Wynne-Jones, *J. Chem. Phys.*, 2, 381 (1934).

than the amount calculated for β -elimination. Since essentially pure chloride I was recovered from the reaction mixture, the loss of deuterium from the α -carbon atom cannot be ascribed to a deuterium-hydrogen exchange with the medium, followed by β -elimination. Evidently with these halides, β -elimination is accompanied by some α -elimination, the maximum extent (23%) being observed with bromide I (equation 12).⁷ The α -elimination observed with chloride I was less (14%), while that with bromide II was only 8%. Apparently the α -elimination of deuterium bromide accompanied by the shift of hydrogen (as with bromide I) occurs more readily than the α -elimination of hydrogen bromide accompanied by the shift of deuterium (as with bromide II). The results with the diluted samples of halides I and II may be accounted for on the basis that the undeuterated halides reacted relatively faster than the deuterated halides.



These results with *n*-octyl halides might be accounted for by exclusive β -elimination if sufficient carbonium ion type rearrangement were to occur in the conversion of the deuterio alcohols to halides. Thus if sufficient primary alcohol in (3) were to be converted to secondary bromide VII the loss of deuterium observed in the subsequent reaction with potassium amide could be explained by β -elimination of deuterium bromide to form olefin VI (equation 13). Since β -elimination of hydrogen bromide from the methylene side of bromide VII to form olefin VIII would predominate⁸ and β -elimination of hydrogen bromide from the deuterio methyl side to form olefin V should also occur, considerable secondary halide would have to be present to account for the loss of deuterium observed. Less rearrangement would be required if the primary alcohol were to be converted to the primary bromide having deuterium on the β -carbon (involving the shift of the *n*-hexyl group) but such a rearrangement appears less likely.



Rearrangement to secondary bromide VII evidently did not occur since treatment of *n*-octyl alcohol with hydrogen bromide under similar conditions gave 1-bromooctane uncontaminated with a detectable amount of 2-bromooctane.⁹ The absence of the secondary bromide was established by reaction with potassium amide to yield only octene-1 which was identified by physical properties and by conversion to octanediol-1,2 and, finally, to

(7) The occurrence of some α -elimination with the amide ion does not necessarily mean that this mode of elimination also occurs with weaker bases such as hydroxide ion.

(8) M. L. Dhar, E. D. Hughes and C. K. Ingold, *J. Chem. Soc.*, 2058 (1948).

(9) The action of hydrobromic acid on *n*-butyl alcohol or of thionyl chloride on *n*-amyl alcohol has been shown to form the corresponding halide without rearrangement; F. C. Whitmore, F. A. Karnatz and A. H. Popkin, *THIS JOURNAL*, **60**, 2340 (1938).

formaldehyde and *n*-heptaldehyde. Had any 2-bromooctane been present, it would have been detected readily, since a blank experiment with this halide gave more octene-2, corresponding to VIII, than octene-1, corresponding to V and VI. Moreover, the secondary halide produced relatively much more olefin and much less amine than the primary halide. It may be concluded that bromide I (equation 3) was not contaminated with more than 2% of the secondary halide. This is very much less than the amount required to account for the results of the elimination reaction (Table I). Even the deuterio-2-ethylbutyl alcohols shown in (5) and (6), which should be more susceptible to rearrangement because of the possible conversion to tertiary halide, must have been converted to bromides III and IV without appreciable rearrangement since, had rearrangement occurred, our results of elimination with these halides would be difficult to explain.

The mechanism of α -elimination apparently involves the simultaneous removal of H and X, since no deuterium-hydrogen exchange was observed. The shift of H from the β - to the α -carbon atom presumably occurs at the same time.

The mechanism for β -elimination is generally considered to involve the simultaneous removal of the hydrogen and the halide ions. Experimental support for this mechanism has been found in the failure of β -phenylethyl bromide to take up deuterium in the presence of sodium ethoxide and deuterio-ethanol.¹⁰ More conclusive evidence is our observation that deuterio bromide II, which had deuterium on the β -carbon atom, lost deuterium only when halogen also was lost. The halide recovered from the reaction mixture along with olefin had the same deuterium content as the original halide, whereas, had an intermediate carbanion been formed during β -elimination, hydrogen would have been acquired from the medium, liquid ammonia.

Experimental

Deuterium oxide (99.8% D₂O) was obtained on allocation from the Atomic Energy Commission. Pure deuterioacetic acid was prepared by mixing equivalents of freshly distilled acetic anhydride and deuterium oxide in a dry-box and refluxing for 12 hours in a water-free atmosphere. A trace of concentrated sulfuric acid was added prior to the last half hour of refluxing.

Preparation of Deutero Alkyl Halides.—These compounds were prepared by the reactions represented in equations 3–6.

The reduction of esters with sodium and deuterioacetic acid (or acetic acid) was performed by the method of Prins¹¹ modified to avoid all traces of water. The ester, dissolved in six to ten times its volume of anhydrous ether containing a trace of phenolphthalein as an indicator, was cooled to about -5° . Four equivalents each of sodium (in small pieces) and of deuterioacetic acid was added to the stirred solution simultaneously and very slowly, taking care that the solution always remained slightly acid. After the reaction was complete, cold water was added cautiously, the ether layer separated and the ether removed on the steam-bath. The residue was heated with ethanolic potassium hydroxide to saponify any unchanged ester and the deuterio alcohol extracted with ether, dried and distilled.

Carbonation of the Grignard reagent was carried out in the usual manner. The reduction of the resulting carboxylic acid with lithium aluminum hydride was performed according to the method of Nystrom and Brown.¹²

(10) P. S. Skell and C. R. Hauser, *ibid.*, **67**, 1661 (1945).

(11) H. F. Prins, *Rec. trav. chim.*, **42**, 1050 (1923).

(12) R. F. Nystrom and W. G. Brown, *THIS JOURNAL*, **69**, 2548 (1947).

For equation (4) potassium triphenylmethide in ether suspension¹³ was stirred with an equivalent of ethyl diethylacetate for two hours, a slight excess of deuterium oxide added and the deuterated ester isolated.

Alcohols were converted to bromides by gaseous HBr at 100°. Alcohols were converted to chlorides with thionyl chlorides by the procedure of Clark and Streight.¹⁵

The boiling points and refractive indexes of the deuterio halides and of the intermediates were close to those of the corresponding hydrogen compounds reported in the literature.

Reaction of Deuterio Alkyl Halides with Potassium Amide.

—The halide (0.1–0.2 mole), usually in anhydrous ether, was added to a stirred solution of an equivalent or slight excess of potassium amide in liquid ammonia (100–150 ml.), and, after completion or approximately 50% completion of the reaction (as determined by preliminary experiments) excess of solid ammonium chloride was added. Water was added, the ammonia evaporated and the mixture extracted with ether. After washing with water, dilute hydrochloric acid and again with water and drying over Drierite or sodium sulfate, the ether solution was fractionated to isolate the olefin and, in certain cases, the unreacted halide, both of which were then analyzed for deuterium.

Deuterium Analysis.—The organic compound was burned for analysis and the resulting water purified as described by Rittenberg and Schoenheimer.¹⁶ It was protected from atmospheric moisture at all times.

The deuterium content was determined by measuring the refractive index in a Zeiss portable interferometer, using a 10-mm. cell in which as little as 0.3 ml. could be measured. In most cases enough compound was available to produce about one ml. of water. Distilled water from the laboratory was used as reference liquid, experiments having shown that redistillation did not change its refraction. The instrument was standardized against dilutions by weight of 99.8% D₂O over the range from 0–6% D₂O. When the reading came near a band skip, the solution was diluted and remeasured to check the value reported. The instrument was read to one division, which corresponds to $\pm 0.042\%$ D₂O. Allowing for other errors, a reasonable precision for our data is 0.1% D₂O, which in the compounds measured amounts to about 0.02 D per molecule.

Evidence for Absence of Rearrangement in Conversion of *n*-Octyl Alcohol to Bromide.—*n*-Octyl alcohol, b.p. 96° at 17 mm., was treated at 100° with HBr by the method¹⁴ used with the deuterated alcohols. The resulting bromide¹⁷ (0.02 mole), b.p. 100.3–101° at 30 mm., n_D^{25} 1.4500 (reported n_D^{25} 1.4503),¹⁸ in 50 ml. of ether was added during two minutes to a stirred solution of 0.21 mole of potassium amide in 150 ml. of liquid ammonia. After stirring for seven minutes, excess ammonium chloride was added and the reaction mixture worked up as described for the experi-

ments with deuterio alkyl halides. There was isolated a 14% yield of essentially pure octene-1, b.p. 120–122°, n_D^{25} 1.4060 (reported b.p. 121.85–122.15°, n_D^{25} 1.4088)¹⁹ 25% of the original bromide being recovered. An estimated yield of 60% amine was obtained from the acid extracts of the reaction mixture.

Hydroxylation of 2 g. of the octene with performic acid followed by potassium hydroxide hydrolysis according to the method of Roberts and co-workers²⁰ gave 1.4 g. (67%) of octanediol-1,2, b.p. 147–148° at 20 mm., n_D^{25} 1.4461, m.p. 29.5–30.5° after two recrystallizations from petroleum ether (reported b.p. 135–136° at 10 mm., m.p. 30–30.5°).²¹

A sample of the unrecrystallized glycol was cleaved with potassium metaperiodate in water,²² and the reaction mixture distilled under reduced pressure into a receiver cooled with Dry Ice. After filtering, the distillate was separated into an insoluble oil and an aqueous solution. The insoluble oil was dissolved in methanol and treated with 2,4-dinitrophenylhydrazine reagent to give the 2,4-dinitrophenylhydrazone of heptaldehyde, m.p. 105–106° after one recrystallization from methanol; a mixed melting point with an authentic sample was the same. The aqueous solution was treated with excess methone reagent²³ and a few grams of sodium chloride to give a mixture of solids which was refluxed for seven hours with glacial acetic acid and poured onto ice. The resulting solid was stirred with sodium carbonate solution. After filtering, the filtrate was acidified to give formaldehyde dimethone, m.p. 190–191° after one recrystallization from methanol (reported m.p. 191.4°).²³ The carbonate-insoluble solid was heptaldehyde dimethone anhydride, m.p. 110.5–111° after recrystallization from ethanol-water (reported m.p. 110, 112).²⁴

When 2-bromo-octane, b.p. 92–93° at 30 mm., n_D^{25} 1.4478 (reported n_D^{25} 1.4442, 1.4482)¹⁹ was treated with potassium amide under the same conditions, there was obtained a 45% yield of a mixture of octene-1 and octene-2, b.p. 122–125°, n_D^{25} 1.4089,¹⁹ 45% of the original bromide being recovered. Only a 5% yield (estimated) of amine was obtained from the acid extracts. Hydroxylation of the octene mixture gave a mixture of glycols, b.p. 135–140° at 20 mm., n_D^{25} 1.4424 which could not be crystallized. Cleavage of the glycol mixture gave a mixture of formaldehyde, acetaldehyde, caproaldehyde and heptaldehyde. On the basis of a polarographic analysis,²⁵ the relative proportions of acetaldehyde and formaldehyde were estimated to be 83% and 17%, $\pm 10\%$.²⁶

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(13) R. Levine, E. Baumgarten and C. R. Hauser, *THIS JOURNAL*, **66**, 1230 (1944).

(14) *Org. Syntheses*, **15**, 24 (1935).

(15) R. H. Clark and H. R. L. Streight, *Trans. Roy. Soc. Canada*, [3] **23**, Sec. 3, 77 (1929).

(16) D. Rittenberg and R. Schoenheimer, *J. Biol. Chem.*, **111**, 169 (1935).

(17) The deuterio bromide prepared from *n*-octanol-1-*d*₂ and used in the experiments in which approximately 20% α -elimination occurred had the following physical properties: b.p. 104–104.6° at 40 mm., n_D^{25} 1.4501.

(18) I. M. Heilbron, "Dictionary of Organic Compounds," Oxford University Press, New York, N. Y., 1936, p. 310.

(19) Selected Values of Properties of Hydrocarbons, Natl. Bur. Stand. Circular 461, p. 50.

(20) J. D. Roberts, R. E. McMahon and J. S. Hine, *THIS JOURNAL*, **72**, 4243 (1950).

(21) D. Swern, G. H. Billen and J. T. Scanlan, *ibid.*, **68**, 1504 (1946).

(22) J. F. Walker, "Formaldehyde," Reinhold Publishing Corp. New York, N. Y., 1944, p. 263.

(23) E. H. Huntress, "Identification of Pure Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 1941, p. 50.

(24) *Ibid.*, p. 56.

(25) M. J. Boyd and K. Bambach, *Ind. Eng. Chem., Anal. Ed.*, **15**, 314 (1943).

(26) It was assumed that equal amounts of formaldehyde and heptaldehyde and equal amounts of acetaldehyde and caproaldehyde were present. Gelatine was used as a maximum suppressor. Experiments with known mixtures of acetaldehyde and formaldehyde were found to be in error by as much as 10%.