bonate solution, dried over magnesium sulfate and the ether residue distilled through the semi-micro column to yield 2.60 g. (20%) of hydrocinnamaldehyde; b.p. 62–63° (0.3 mm.), n^{25}D 1.5182. The semicarbazone melted at 127.5–129°, mixture m.p. with the semicarbazone of hydrocinnamaldehyde (m.p. 127–129°) 127.5–129°.

Repetition of the above reduction, followed by continuous ether extraction of the acidified reduction residue for 21 hours, afforded 6.51 g. (49%) of hydrocinnamaldehyde; b.p. 83–86° (6 mm.), n^{25}D 1.5200.

The intermediate 2-amino-1-butanol–hydrocinnamaldehyde anhydro compound could not be isolated from the hydrogenation mixture due to decomposition during distillation. Attempts to prepare this anhydro compound from 2-amino-1-butanol and hydrocinnamaldehyde gave a 50% yield of material, 2-(3-phenylpropyl)-4-ethyloxazolidine, that decomposed when distilled and could not be obtained analytically pure; b.p. 113–114° (0.2 mm.), n^{25}D 1.5120, d^{25}_4 0.9990; MD 61.75, calcd. 61.69.

Anal. Calcd. for $C_{13}H_{19}NO$: C, 76.05; H, 9.33; N, 6.82. Found: C, 75.31; H, 9.36; N, 6.01.

PROVIDENCE, RHODE ISLAND

[CONTRIBUTION FROM THE SCHOOL OF CHEMISTRY OF THE GEORGIA INSTITUTE OF TECHNOLOGY]

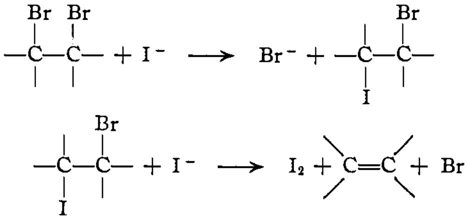
The Mechanism of the Transformation of Vicinal Dihalides to Olefins by Reaction with Iodide Ion[1]

BY JACK HINE AND W. H. BRADER, JR.

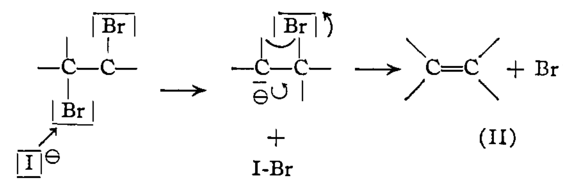
RECEIVED MAY 19, 1954

It is shown that the dehalogenation of ethylene bromide, propylene bromide and 1,2-dibromobutane by iodide ions is largely initiated by an S$_N$2 attack to form a bromoiodide which is directly dehalogenated. The dehalogenation of the 2,3-dibromobutanes is believed to be largely direct as previously suggested. In evidence is quoted the fact that ethylene bromide is the most reactive of the dibromides mentioned. Furthermore it is shown that the rate constant for the reaction of ethylene bromide is in excellent agreement with that which would be predicted for the S$_N$2 reaction of the compound with iodide ion under the conditions employed. It is improbable that a very large fraction of the reaction follows a path involving the formation of a vicinal diiodide. It is proposed that the dehalogenation reaction proper involves the formation of an intermediate in which one of the halogen atoms is bound equally to two carbon atoms.

The reaction of vicinal dihalides, particularly dibromides, with iodide ion to yield iodine and olefins has been known for some time. It has been suggested that the reaction involves the intermediate formation of a diiodide followed by its deiodination[2] and also that only the bromoiodide is an intermediate, and that this is transformed to the olefin directly[3] (mechanism I).


(I)

In addition Winstein, Pressman and Young[4] have proposed that the reaction is a direct dehalogenation of the dihalide and has a mechanism (II) somewhat analogous to the E2 mechanism[5] for β-elimination reactions.



$$\text{I-Br} + 2\text{I}^- \longrightarrow \text{I}_3^- + \text{Br}^-$$

Evidence for Mechanism I.—Kinetic data are available to show that the reaction follows good second-order kinetics, first order in iodide ion and alkyl halide, for a considerable variety of dibromides when allowance is made for the combination of the iodine formed with unreacted iodide ion.[2-4,6,7] Mechanisms involving the intermediate formation of the diiodide and/or the bromoiodide would give uncomplicated second-order kinetics only if the first step, which would have to be a bimolecular nucleophilic attack (S$_N$2)[8] by iodide ion on carbon, were rate controlling and the subsequent steps comparatively rapid. Since simple second-order kinetics are observed, it seems unlikely that much of the reaction proceeds by the diiodide mechanism because this would require the second bromine atom to undergo S$_N$2 displacement much more rapidly than the first, implying that it is activated by the first iodine atom introduced. This seems unreasonable, since in the only case which appears to have been studied, β-fluorine, -chlorine and -bromine all have about the same effect on S$_N$2 reactivity,[9] and the effect of all four halogens has been found to be approximately the same in the γ-position.[10]

In order for mechanism I to fit the observed kinetics the initial S$_N$2 displacement must be slow compared to the subsequent dehalogenation of the bromoiodide. That this subsequent reaction of the bromoiodide is indeed relatively fast is shown by the fact that the dehalogenation of ethylene bromoiodide[11] proceeds about ten times as rapidly

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[1] Paper IV in the series "The Effect of Halogen Atoms on the Reactivity of Other Halogen Atoms in the Same Molecule." For paper III see ref. 9.

[2] C. F. van Duin, *Rec. trav. chim.*, **43**, 341 (1924); **45**, 345 (1926); **47**, 715 (1928).

[3] E. Biilmann, *ibid.*, **36**, 313 (1917).

[4] S. Winstein, D. Pressman and W. G. Young, THIS JOURNAL, **61**, 1645 (1939).

[5] C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, chap. VIII.

[6] T. L. Davis and R. Heggie, *J. Org. Chem.*, **2**, 470 (1937).

[7] R. T. Dillon, THIS JOURNAL, **54**, 952 (1932).

[8] For the significance of this term see C. K. Ingold, ref. 5, chap. VII.

[9] J. Hine and W. H. Brader, Jr., THIS JOURNAL, **75**, 3964 (1953).

[10] W. H. Brader, Jr., Ph.D. Thesis, Georgia Institute of Technology, 1954.

[11] A. Slator, *J. Chem. Soc.*, **85**, 1697 (1904).

as that of ethylene bromide under the same conditions.[2]

In their observation that *dl*- and *meso*-2,3-dibromobutanes yield *cis*- and *trans*-2-butenes, respectively, Winstein, Pressman, and Young have presented rather convincing evidence that the reaction is indeed a direct *trans*-dehalogenation of the dibromide by iodide ion in these cases.[4] It would seem most reasonable that the reactivity by such a mechanism would increase with the increasing stability of the resulting olefin. It has been found to do so in most examples of the somewhat similar E2 mechanism for β-elimination of HX[5] and also appears to in the much more closely related debromination of olefin dibromides by sodium thiosulfate. In the latter reaction 2,3-dibromobutane gave 8.6%, isobutylene dibromide 19.2%, and trimethylethylene dibromide 32.4% olefin while ethylene bromide and propylene bromide gave none.[12] It is therefore difficult to interpret the relative magnitudes of the rate constants listed by Dillon (Table I) for the dehalogenation of some simple dibromoalkanes[7] on the basis of mechanism II alone. The data may be explained quite reasonably, however, by the assumption that the first three reactions proceed largely by mechanism I. If the bromine atom is assumed to have a steric effect on S_N2 reactivity about equal to that of a methyl group[13] the transformation of ethylene bromide to propylene bromide is equivalent to a change from a *n*-propyl to an isobutyl halide for the primary bromine and to a *s*-butyl halide for the secondary bromine. For such a structural change the observed 27-fold decrease in reactivity is about that which would be expected. The further structural change to 2,3-dibromobutane should produce another considerable decrease in reactivity by mechanism I. The fact that only a small decrease in rate is observed is in accord with the idea that the direct debromination mechanism, encouraged by the continued introduction of methyl groups, has now become dominant. This, of course, is indicated by the observed stereochemistry of the reaction. From the relative reactivities of the other dibromides, it seems likely that mechanism I is, as Winstein, Pressman and Young suggest, responsible for the small fraction of *cis* elimination found. It should be noted however that the rate constants in Table I are for reactions in methanol solution while the stereochemistry of the reaction was studied only in aqueous propanol and diethylene glycol solutions.[4] The suggestion that methylation of the potential double bond increases the rate of the direct dehalogenation reaction and that the order of reactivities listed in Table I is due to the incursion of mechanism II leads to the prediction that 2,3-dibromo-2-methylbutane and 2,3-dibromo-2,3-dimethylbutane should show successively increasing rates of reaction with sodium iodide in comparison to the 2,3-dibromobutanes. No data on these compounds appear to be available.

TABLE I

RATES OF DEHALOGENATION OF VICINAL DIBROMIDES IN 99% METHANOL AT 59.72°[7]

Dibromide	10 k (mole^{-1} sec.$^{-1}$ l.)
$BrCH_2CH_2Br$	83.2
$CH_3CHBrCH_2Br$	3.1
$C_2H_5CHBrCH_2Br$	4.1
meso-$CH_3CHBrCHBrCH_3$	2.5
dl-$CH_3CHBrCHBrCH_3$	1.3

Although it seems plausible from the argument above that 1,2-dibromoalkanes react by mechanism I, a stereochemical test with these compounds would be difficult, requiring the use of deuterated compounds of known configuration. However, a test may be based on an estimate of the rate constant for the S_N2 reaction of iodide ion with ethylene bromide. This should be equal to the rate constant for dehalogenation if mechanism (I) is operating. Such an estimate may be based on the rate of reaction of iodide ion with *n*-butyl iodide in ethanol at 30°[14] if we assume that the replacement of the β-ethyl group by a bromine atom reduces the rate to 19% of its value[9] and that this iodide reacts 18.5 times as fast as the corresponding bromide.[15] The estimated rate constant, 3.5×10^{-6} mole^{-1} sec.$^{-1}$ l., is in good agreement with the value 5.8×10^{-6} for the dehalogenation of ethylene bromide by iodide ions in ethanol at 30° interpolated from the data of Davis and Heggie.[6]

It would be desirable, however, to be able to make an estimate in which fewer approximations are necessary than in the preceding one. Since the bromine atom in ethylene fluorobromide has been found to have very nearly the same reactivity as one in ethylene bromide toward nucleophilic displacement by thiophenolate ions in methanol,[9] and since ethylene fluoroiodide should be relatively inert toward iodide ions, it seemed desirable to study the reaction of ethylene fluorobromide with iodide ions in methanol. We have found that the reaction is one of substitution rather than elimination since iodide ions are used up and no iodine is formed and we have determined a rate constant of 5.6×10^{-6} mole^{-1} sec.$^{-1}$ l. at 40°. Because of its two identical bromine atoms, ethylene bromide should have a rate constant for substitution by iodide ions in methanol of about 11.2×10^{-6} mole^{-1} sec.$^{-1}$ l. at this temperature. The rate constant for the formation of iodine and ethylene from iodide ion and ethylene bromide in 99% methanol interpolated from the data of Dillon[7] is 9.6×10^{-6} mole^{-1} sec.$^{-1}$ l.

It therefore seems very likely that the debrominations of ethylene, propylene and 1-butene dibromides proceed largely by mechanism I. Estimates of the type just described have been made for a number of the other dibromides whose reactions with iodide ion have been studied kinetically. Although these estimates involve a larger number of extrapolations and are probably less dependable than that described for ethylene bromide, they suggest that in at least some cases the great reactivity of α,β-dibromo acids and ketones[2,3,6] and of styrene

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[12] B. G. Gavrilov and V. E. Tishchenko, *J. Gen. Chem., U.S.S.R.*, **18**, 1687 (1948); *C.A.*, **43**, 2569h (1949).

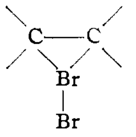
[13] The Van der Waals radii of the methyl and bromo groups are listed as 2.0 and 1.95 Å., respectively (L. Pauling, "Nature of the Chemical Bond," 2nd Ed., Cornell University Press, Ithaca, N. Y., 1945, p. 189).

[14] H. A. C. McKay, THIS JOURNAL, **65**, 702 (1943).

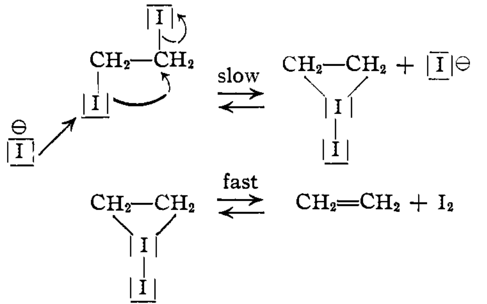
[15] E. Bergmann, M. Polanyi and A. L. Szabo, *Trans. Faraday Soc.*, **32**, 843 (1936).

dibromide[2] may be due to the great S_N2 reactivity of the α-halogen atoms. However, the direct dehalogenation mechanism would also predict an increase in reactivity in these cases, and in some examples, such as the cinnamic acid dibromide derivatives,[2] it is this mechanism which best explains the reactivity.

The Intimate Mechanism of the Direct Dehalogenation Reaction.—The iodide ion catalyzed deiodination of ethylene iodide being reversible, we may learn something of the reaction mechanism by consideration of the mechanism of the addition of iodine to ethylene and application of the principle of microscopic reversibility. Bartlett and Tarbell have shown that the addition of halogen to olefins is a stepwise rather than entirely concerted process. They give excellent evidence that in the reactive intermediate one but not both of the halogen atoms has become bound directly to carbon.[16] There are stereochemical as well as other reasons for believing that in this intermediate the halogen atom is bonded about equivalently to each of the two unsaturated carbon atoms.[17] Although the concept of the "halonium ion" type intermediate[17] is more commonly used, de la Mare has pointed out that the known facts may also be explained on the basis of an intermediate of the type[18]



Although this evidence concerning the mechanism of the addition of halogen to olefins was largely derived from studies on the addition of bromine rather than iodine, it appears to be the most applicable to the present problem of any available. On its basis we may formulate the following mechanism.



(III)

Just as this mechanism in reverse is reasonable for the addition of iodine to ethylene so is the forward mechanism reasonable for the deiodination reaction. It agrees with the kinetic observation that the formation of iodine and ethylene from ethylene iodide in the presence of iodide ion is a second order reaction, first order in each reactant.[19] The nucleophilic attack of an iodide ion on an iodine atom is plausible since the iodide ion has considerable nucleophilicity[20] and there is abundant evidence for the ease of nucleophilic attack on iodine. This evidence includes data on the relative Lewis acidity of halogens,[21] some of the unusual reactions of trifluoromethyl iodide,[22] and the fact that thiosulfate, thiophenolate, thiocyanate and ethoxide ions all transform ethylene iodide (but not ethylene bromide) into ethylene.[23] The high reactivity of iodine as a neighboring group shows that it already has a considerable tendency to perform a nucleophilic displacement of a halogen attached to an adjacent carbon atom.[24] Since a nucleophilic attack on an iodine atom would render it negative it should vastly increase its reactivity as a neighboring group as shown in the first step of mechanism III.

It is probable that the *direct* dehalogenation reactions of vicinal dibromides and bromoiodides also proceed by a mechanism of the type of III.

That the direct dehalogenating attack of iodide ions on ethylene iodide is about three times as fast as on ethylene bromoiodide[11] which is in turn vastly more rapid than the attack on ethylene bromide[25] shows that the intermediate of the type shown in mechanism III is formed much more readily when the trivalent halogen atom therein may be iodine. This is understandable in terms of the mechanism given above because of the greater ease with which iodine expands its octet and because of its much greater reactivity as a β-neighboring group.[24]

The question, then, of whether a given dibromide is more facilely dehalogenated by the direct reaction or by transformation to a much more easily dehalogenated bromoiodide depends on the ratio of its S_N2 reactivity to its reactivity in the direct dehalogenation reaction.

Experimental

Apparatus and Materials.—The constant temperature bath and the preparation and purification of the ethylene fluorobromide and methanol have been described previously.[9] The potassium iodide and potassium iodate were C.P. reagents and the former was dried in vacuum at 110°.

Kinetic Runs.—About 0.01 mole of ethylene fluorobromide was weighed into about 48 ml. of methanol in a 100-ml. volumetric flask and allowed to reach thermal equilibrium in a 40° constant temperature bath. Fifty ml. of potassium iodide in methanol (0.1 *M* in one run and 0.03 *M* in the other) also at 40° was added and also enough methanol to make the total volume 100 ml. The iodide ion concentration was determined within a few minutes by withdrawing a 5-ml. sample and titrating with potassium iodate in cold concentrated hydrochloric acid by the Andrews method.[26] A separate layer of carbon tetrachloride was used to follow the disappearance of iodine in this titration. Since the re-

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[16] P. D. Bartlett and D. S. Tarbell, This Journal, **58**, 466 (1936); D. S. Tarbell and P. D. Bartlett, *ibid.*, **59**, 407 (1937).

[17] I. Roberts and G. E. Kimball, *ibid.*, **59**, 947 (1937).

[18] P. B. D. de la Mare, *Quart. Revs.* (*London*), **3**, 130 (1949).

[19] T. Iredale and T. R. Stephan, *J. Phys. Chem.*, **49**, 595 (1945).

[20] C. G. Swain and C. B. Scott, This Journal, **75**, 141 (1953).

[21] R. L. Scott, *ibid.*, **75**, 1550 (1953).

[22] J. Banus, H. J. Emeléus and R. N. Haszeldine, *J. Chem. Soc.*, 60 (1951).

[23] Reference 9 and other sources quoted therein.

[24] S. Winstein, E. Grunwald, R. E. Buckles and C. Hanson, This Journal, **70**, 816 (1948); S. Winstein, E. Grunwald and L. L. Ingraham, *ibid.*, **70**, 821 (1948); S. Winstein and E. Grunwald, *ibid.*, **70**, 828 (1948).

[25] We have given the argument that the observed dehalogenation rate is probably almost entirely that of an S_N2 reaction. If we assume that the substitution of methyl groups on the α- and β-carbon atoms has the same effect on the rate of the direct dehalogenation reaction that it does on the rate of the sodium ethoxide E2 elimination from an alkyl bromide (C. K. Ingold, ref. 5, p. 437) then from the data in Table I we would expect the *direct dehalogenation* of ethylene bromide to proceed about one five-hundredth as fast as S_N2 attack by iodide ion and hence about one five-thousandth as fast as the direct dehalogenation of ethylene bromoiodide.

[26] L. W. Andrews, This Journal, **25**, 756 (1903).

TABLE II

REACTION OF ETHYLENE FLUOROBROMIDE WITH POTASSIUM IODIDE IN METHANOL AT 40°

$[FCH_2CH_2Br]_0 = 0.0931$

Time, sec.	$[KI]_t$	$k \times 10^6$, mole^{-1} sec.$^{-1}$ l.
0	0.0501	
85,380	.0477	6.24
202,620	.0456	5.19
367,260	.0420	5.42
606,840	.0378	5.38
966,400	.0330	5.21
		5.49 ± 0.30

action is relatively slow the concentration thus determined was taken as the initial concentration and from concentrations determined similarly at later times, rate constants were calculated from the integrated form of the second-order rate equation. Data from one of the runs are listed in Table II. In the other run the rate constant was $5.74 \pm 0.06 \times 10^{-6}$ sec.$^{-1}$ mole^{-1} l. All of the points taken gave an average value of 5.60 ± 0.27. No observable amount of iodine was formed in either run.

Acknowledgment.—The authors would like to express their appreciation to the National Science Foundation for their grant in support of this investigation.

ATLANTA, GEORGIA

[CONTRIBUTION FROM THE NOYES CHEMICAL LABORATORY, UNIVERSITY OF ILLINOIS]

Polyphosphoric Acid as a Reagent in Organic Chemistry. VII. Acylation[1]

BY H. R. SNYDER AND C. T. ELSTON[2]

RECEIVED AUGUST 9, 1954

The synthesis of ketones by intermolecular acylation with carboxylic acids in the presence of polyphosphoric acid is examined further. Thiophene and phenol are acetylated at 75°, in good yields, but less reactive compounds like benzene and toluene react with aliphatic acids only under conditions vigorous enough to cause self-condensation of the resulting ketones. Fully aromatic ketones are more stable to polyphosphoric acid; toluene and benzoic acid react at 160° to give *p*-methylbenzophenone in 70% yield. Phenyl acetate undergoes the Fries rearrangement in polyphosphoric acid, giving *p*-hydroxyacetophenone in about the same yield as can be obtained by the direct acetylation of phenol. Phenyl benzoate is more stable to polyphosphoric acid; the yield of *p*-hydroxybenzophenone obtained from it is less than that from the direct acylation of phenol. Other observations on the acylation of aromatic compounds are reported.

In a preliminary study[3] of the acylation of reactive aromatic hydrocarbons under the influence of polyphosphoric acid it was found that although mesitylene and durene reacted with aliphatic acids, the ketones formed were, for the most part, unstable in the reaction mixture under the conditions employed. In an extension of this work it now has been found that highly reactive compounds such as thiophene and phenol undergo acetylation at a temperature (75°) at which the resulting methyl or methylene ketones are fairly stable. Thus, *p*-hydroxyacetophenone and 2-acetylthiophene can be prepared in yields of 67 and 70%, respectively. Less reactive compounds such as benzene and toluene do not undergo acylation at an appreciable rate at this temperature, and higher temperatures bring about self-condensation of the ketones. Acylation with aromatic acids is not restricted in this way since the aromatic ketones produced are stable in polyphosphoric acid at 160°. Benzoic acid can be used to acylate toluene in a yield of 70%. However, electron-withdrawing substituents on the ring render an aromatic acid ineffective in acylations. For example, *p*-nitrobenzoic acid and phenol do not react even at 160°. *o*-Nitrobenzoic acid similarly fails to yield the expected ketone. The lack of reactivity of such compounds in acylation of carbon is paralleled to some extent in the data observed on the Lossen rearrangement[4] and the formation of amides.[5]

The use of unsaturated acids in acylation reactions also appears to be limited in its scope. Anisole is readily acylated by cinnamic acid giving a 50% yield of benzal-*p*-methoxyacetophenone. However, reaction of cinnamic acid with benzene is effected only at high temperatures and the product is so badly contaminated that it has not been possible to effect its purification. It is quite interesting that cinnamic acid reacts with anisole at the carbonyl carbon in the presence of polyphosphoric acid; both sulfuric acid and aluminum chloride catalyze the conjugate addition of aromatic compounds to cinnamic acid.

The formation of *p*-hydroxyacetophenone as the sole product from the acetylation of phenol suggested that the use of polyphosphoric acid might provide a convenient general method for the preparation of *p*-acylphenols. The yield of *p*-hydroxyacetophenone (69%) is about equal to that which can be obtained by the Fries rearrangement of phenyl acetate.[6] Unfortunately, an experiment with phenol and caproic acid gave only a 35% yield of *p*-caproylphenol, along with an 18% yield of phenyl caproate. The benzoylation of phenol was somewhat more attractive, *p*-benzoylphenol being obtained in 51% yield, along with a substantial amount (15%) of *p*-benzoylphenyl benzoate and a trace of phenyl benzoate. More vigorous conditions did not improve the yield of the ketone.

The acylation of substituted phenols led to divergent results. *p*-Cresol reacted with benzoic acid to give *p*-cresyl benzoate rather than the expected *o*-hydroxyketone. Acylation *ortho* to a hydroxyl group does occur in polyphosphoric acid, however.

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[1] For the preceding paper in this series, see THIS JOURNAL, **76**, 3039 (1954). P. D. Gardner [*ibid.*, **76**, 4550 (1954)] also has reported intermolecular acylations affected by polyphosphoric acid.

[2] Visking Corporation Fellow, 1953–1954.

[3] H. R. Snyder and R. W. Roeske, THIS JOURNAL, **74**, 5820 (1952).

[4] H. R. Snyder, C. T. Elston and D. B. Kellom, *ibid.*, **75**, 2014 (1953).

[5] H. R. Snyder and C. T. Elston, *ibid.*, **76**, 3039 (1954).

[6] A. H. Blatt in R. Adams, "Organic Reactions," Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1942, p. 342.