[Contribution from the Chemistry Laboratory of the
Ohio State University]

A NEW METHOD FOR THE PREPARATION OF ORGANIC IODIDES

HERMAN STONE and HAROLD SHECHTER

Received September 12, 1949

During the synthesis of various macrocyclic ketones it became necessary to develop an efficient method for converting large quantities of complex ethers into their corresponding iodides. This method was then applied for the preparation of iodides from olefins and alcohols.

The more efficient procedures for cleaving ethers into halides involve the use of either gaseous or aqueous hydrogen iodide (1, 2, 3, 4) and hydrogen bromide (5, 6), acetyl iodide (7), acetyl chloride (8), and various halogenated derivatives such as phosphorus oxychloride (9), aluminum chloride (10), and phosphorus pentabromide and chloride (5). A similar conversion of ethers into esters of inorganic acids has been effected with phosphoric anhydride (11) and sulfuric acid (12). Gaseous or aqueous hydrogen iodide has been the reagent most frequently used; however, it has the disadvantages that large excesses of an expensive reagent are required, extensive reduction of the reaction product often occurs, and reaction is slow in heterogeneous medium.

In an effort to obviate these disadvantages the reactions of various ethers with excess orthophosphoric acid and potassium iodide were studied. Phosphoric acid and potassium iodide are of value in that they serve as a convenient, readily available source of hydrogen iodide, and advantage is taken of the acid-catalyzed solvolytic cleavage of ethers by strong acids (13). Cleavage of simple aliphatic ethers by these reagents is illustrated by the following equation:

$$R\text{—}O\text{—}R + 2\,KI + 2\,H_3PO_4 \rightarrow 2\,RI + 2\,KH_2PO_4 + H_2O$$

In initial experiments (Table I) with dibutyl ether, potassium iodide, and excess 50% phosphoric acid at 110° it was found that no reaction occurred. When the concentration of the phosphoric acid was increased to 85% by weight and finally to an optimum concentration of 95%, cleavage of the ether proceeded rapidly, with minimum reduction and dehydration, to give 1-iodobutane in 75.1% and 81.0% yields respectively. Since anhydrous phosphoric acid and tetraphosphoric acid were found to have marked dehydrating action and hydrogen iodide is relatively insoluble in these solvents, a general routine procedure using excess 95% orthophosphoric acid was adopted. Sodium iodide could be substituted for potassium iodide without appreciably altering the reaction efficiency.

Upon extension of the method to various aliphatic and alicyclic ethers (Table II), it was found that the procedure was generally applicable and had many advantages over previous methods. Cleavage of the mixed aryl-alkyl ether, β-naphthyl ethyl ether, into β-naphthol and iodoethane occurred readily, but the reagent had no effect on diphenyl ether. No attempt was made to obtain maximum yields in this series; however, the reaction was accelerated and made almost quantitative by increasing the mole ratio of potassium iodide to ether.

Because of the general efficiency obtained with the potassium iodide-orthophosphoric acid reagent, the method (Table III) was extended to various alcohols and olefins as indicated:

$$\mathrm{ROH + KI + H_3PO_4 \rightarrow RI + KH_2PO_4 + H_2O}$$
$$\mathrm{RCH{=}CH_2 + KI + H_3PO_4 \rightarrow RCHICH_3 + KH_2PO_4}$$

TABLE I

EFFECT OF PHOSPHORIC ACID CONCENTRATION[a] ON THE CLEAVAGE OF DIBUTYL ETHER

ACID CONC., %	TIME, HRS.	CONVERSION[b] TO 1-IODOBUTANE, %	YIELD[b] OF 1-BUTANOL, %	YIELD[b] OF 1-IODOBUTANE, %
50	3	0	0	0
85	3[c]	56.0	5.7	56.0
85	3	57.2	17.1	72.4
85	6	61.6	7.6	75.1
95	4	73.0	9.6	77.7
T.P.A.[d]	5	47.5	3.9	52.8[e]

[a] All experiments were conducted with dibutyl ether, potassium iodide, and phosphoric acid in a mole ratio of 1:3:3.9 at 135°; with tetraphosphoric acid a mole ratio of 1:3:1.3 was used. [b] Conversions are based on dibutyl ether added to the reaction; yields are based on ether consumed. [c] Sodium iodide was used instead of potassium iodide. [d] The tetraphosphoric acid was 82–84% phosphoric anhydride. [e] An 8.3% yield of 1-butene was obtained.

TABLE II

CLEAVAGE OF ETHERS WITH POTASSIUM IODIDE AND 95% PHOSPHORIC ACID[a]

COMPOUND	TIME, HRS.	CONVERSION TO IODIDE, %	YIELD OF IODIDE, %
Dibutyl ether	5	77.7[b]	81.0
Diisopropyl ether	3	68.7	89.8
Tetrahydrofuran	5	96.0	96.0
Diphenyl ether	6	0	0
β-Naphthyl ethyl ether	3	60.5	77.7[c]

[a] Experiments were conducted with an ether, potassium iodide, and 95% phosphoric acid mole ratio of 1:4:5.9 at the reflux temperature of the reaction mixture. With dibutyl and diisopropyl ethers, mole ratios of 1:3.5:5.3 and 1:6:8.7 were used. [b] A 7.3% yield of 1-butanol was obtained. [c] A yield of β-naphthol of 89.9% was obtained.

Previous studies have shown that alcohols are converted into iodides by aqueous hydrogen iodide (14) and phosphorus and iodine (15) and that addition of hydrogen iodide to alkenes may be effected either in aqueous medium or in glacial acetic acid or by the action of sodium iodide either in aqueous hydrochloric acid or in glacial acetic acid (16, 17).

A study (Table IV) of the effect of the phosphoric acid concentration on the reaction of alcohols and olefins gave further evidence that these reactions are acid-catalyzed (18, 19), and maximum efficiency was obtained with 95% phosphoric acid. Excellent yields of iodides (88.0–95.3%) were obtained from various

TABLE III

Conversion of Alcohols and Olefins into Iodides with Potassium Iodide and 95% Phosphoric Acid

COMPOUND[a]	TIME, HRS.	YIELD OF IODIDE, %
Cyclohexanol	6	79.5[b]
1-Propanol	6	90.5
2-Methyl-1-propanol	5	88.0
2-Methyl-2-propanol	5	89.8
1,6-Hexanediol	3	95.3
Phenol	5	0
Cyclohexene	3	90.5
Cyclohexene	6	90.7[c]
1-Hexene	5	93.3
2,3-Dimethyl-2-butene	4	91.4

[a] All experiments conducted with alcohols had an alcohol, potassium iodide, and phosphoric acid mole ratio of 1:2:2.96; that with 1,6-hexanediol, 1:4:6; those with olefins, 1:3–3.2:4.1–4.3. [b] 85% Phosphoric acid was used. A 16.6% yield of cyclohexene, identified as the dibromide, was obtained. [c] A mole ratio of cyclohexene, potassium iodide, and phosphoric acid of 1:1.5:2.1 was used.

TABLE IV

Effect of Phosphoric Acid Concentration on the Conversion of Alcohols and Olefins into Iodides

COMPOUND[a]	ACID CONC., %	TIME, HRS.	CONVERSION, %	YIELD OF IODIDE, %
2-Methyl-2-propanol	85	5	30.0[b]	30.0
	95[c]	5	89.8	89.8
2-Methyl-1-propanol	85	5	45.0	79.0[d]
	95	5	64.2	88.0
1-Propanol	85	6	44.8	74.8
	95	6	75.3	90.3
	95	5	75.5	90.5
Cyclohexene	50[e]	5	14.3	48.7
	85	6	52.4	87.8
	95	6	90.5	90.5

[a] All experiments using phosphoric acid were conducted with an alcohol or olefin, potassium iodide, and phosphoric acid mole ratio of 1:2:2.1; those conducted with 95% phosphoric acid had a mole ratio of 1:2:2.9–3.0. [b] An 18.5% yield of 2-methylpropene was obtained. [c] This experiment was conducted at 40°; all other experiments were conducted at the reflux temperature of the reaction mixture. [d] The only products isolated were the iodide and either unreacted alcohol or olefin. [e] A mole ratio of cyclohexene, potassium iodide, and phosphoric acid of 1:1.5:2.0 was used.

primary, secondary, and tertiary alcohols and olefins; however, phenols were not converted into iodides. No organic phosphates were found as products of these reactions.

EXPERIMENTAL

Since the procedures for the reactions of potassium iodide and orthophosphoric acid with various ethers, alcohols, and olefins are essentially the same, a detailed procedure is described for only a single member of each class of compounds. Characterization of all compounds was based on their densities, refractive indices, and boiling and melting points. Volatile olefins produced during the reaction were converted into dibromides and identified in the preceding manner. The composition of binary azeotropes was determined by the methods of Lorentz and Lorenz (20).

Phosphoric acid of the desired concentration was prepared by adding the calculated quantity of 85% phosphoric acid to either water or phosphoric anhydride with stirring and cooling. The quantity of potassium iodide varied from 1.5–3.0 times the theoretical. The mixture was cooled before adding the potassium iodide to prevent evolution of hydrogen iodide and oxidation to iodine. The reaction proceeded more rapidly with large excesses of potassium iodide. Separation of the reaction products was accomplished either with a precision rectifying-column or a modified Claisen distilling-flask at various pressures.

Dibutyl ether, potassium iodide, and 95% phosphoric acid. Orthophosphoric acid (85%; 346 g.; 202 ml; 3.0 moles) was added, with stirring, to 79 g. of phosphoric anhydride (= 95% phosphoric acid) in a dry 1-l. three-necked flask equipped with a sealed stirrer, a reflux condenser, and a thermometer. After the mixture had cooled to room temperature, 445 g. (2.68 moles) of potassium iodide and 100 g. (0.77 moles) of dibutyl ether (b.p. 139.5–140.5°) were added. The mixture was stirred and heated at reflux temperature for five hours during which time a dense oil separated from the acid layer. The stirred mixture was cooled to room temperature, and 150 ml. of water and 250 ml. of diethyl ether were added. The ether layer was separated, decolorized with sodium thiosulfate solution, washed with a cold saturated sodium chloride solution, and dried over sodium sulfate. The ether was evaporated, and the mixture was rectified at atmospheric pressure in a four-foot rectifying-column packed with glass-helices. Three fractions were obtained: (a) an azeotrope (19 g.; b.p. 110°) consisting of 11 g. of 1-iodobutane and 8 g. of 1-butanol, (b) 1-iodobutane (200 g.; b.p. 129.5–130.5°; n_D^{20} 1.504; d_4^{20} 1.630), and (c) dibutyl ether (4 g.; b.p. 140°; n_D^{20} 1.402; d_4^{20} 0.770). Yield of 1-iodobutane; 77.7%.

2,3-Dimethyl-2-butene, potassium iodide, and 95% phosphoric acid. Anhydrous potassium iodide (250 g.; 1.5 moles) and 2,3-dimethyl-2-butene (42 g.; 0.5 moles; b.p. 72.6–72.8°; n_D^{20} 1.4141) were added to 95% orthophosphoric acid (216 g.; 2.1 moles) in a 1-l. flask equipped with a reflux condenser, a sealed stirrer, and a thermometer. The mixture was stirred and refluxed for four hours during which time a dense oil separated. The reaction mixture was cooled and extracted with 150 ml. of water and 250 ml. of diethyl ether. The ether layer was separated, decolorized with sodium thiosulfate, extracted with a saturated sodium chloride solution, and dried over sodium sulfate. The ether was evaporated on a water-bath, and the residue distilled from a modified Claisen flask at atmospheric pressure to yield, after a small fore-run, 96 g. (91.4%) of 2,3-dimethyl-2-iodobutane, n_D^{20} 1.495; d_4^{20} 1.448.

1,6-Hexanediol, potassium iodide, and 95% phosphoric acid. Recrystallized 1,6-hexanediol, (60 g.; 0.5 moles), m.p. 40–41°, was added to a stirred mixture of potassium iodide (332 g.; 2 moles) and 95% orthophosphoric acid (296 g.; 3.02 moles) at room temperature in a 1-l. three-necked flask equipped with a reflux condenser, a stirrer, and a thermometer. The reaction mixture was heated for three hours at 100–120° during which time two phases separated and finally the organic product settled through the acid layer. After the reaction mixture had cooled, it was extracted with 150 ml. of water and 250 ml. of diethyl ether. The ether layer was separated, decolorized with sodium thiosulfate solution, extracted with a saturated sodium chloride solution, and dried over sodium sulfate. The ether was evaporated on a steam-bath and the residue was distilled from a modified Claisen flask under reduced pressure. The fraction boiling at 112.5–113.5° at 3 mm. was collected. Yield of 1,6-diiodohexane (n_D^{20} 1.585; d_4^{20} 2.03; m.p. 8.5–9.0°), 161 g. (95.3%).

SUMMARY

A general method for the conversion of ethers, alcohols, and olefins into iodides by reaction with potassium iodide or sodium iodide and phosphoric acid has been described. Both the rates of reaction and the yields of iodide obtained from ethers, alcohols, and olefins are markedly influenced by the concentration of the orthophosphoric acid used.

Columbus 10, Ohio

REFERENCES

(1) Michael and Wilson, *Ber.*, **39**, 2569 (1906).
(2) Lippert, *Ann.*, **276**, 196 (1893).
(3) Leuchs, German Patent 659,927, May 13, 1938.
(4) Ziegler, Weber, and Gellert, *Ber.*, **75**, 1715 (1942).
(5) Houben, *Die Methoden der Organischen Chemie*, 3rd Ed., George Thieme, Leipzig, 1930, Vol. III, pp. 174, 1165.
(6) Birosel, *J. Am. Chem. Soc.*, **52**, 1944 (1930).
(7) Gustus and Stevens, *J. Am. Chem. Soc.*, **55**, 378 (1933).
(8) Goldfarb and Smorgonskii, *J. Gen. Chem.* (*U.S.S.R.*), **8**, 1516 (1938).
(9) Auger and Dupuis, *Compt. rend.*, **146**, 1151 (1908).
(10) Hartman and Gatterman, *Ber.*, **25**, 3531 (1892).
(11) Wagner-Jauregg and Griesshaber, *Ber.*, **70**, 1 (1937).
(12) Vanscheidt and Lozovski, *J. Gen. Chem.* (*U.S.S.R.*), **3**, 329 (1933).
(13) Skrabal and Skrabal, *Z. physik. Chem.*, **181**, 449 (1938).
(14) Pickard and Kenyon, *J. Chem. Soc.*, **99**, 65 (1911).
(15) Adams and Voorhees, *J. Am. Chem. Soc.*, **41**, 797 (1919).
(16) Houben, *Die Methoden der Organischen Chemie*, 3rd Ed., George Thieme, Leipzig, 1930, Vol. III, p. 1184.
(17) Michael and Leighton, *J. prakt. Chem.*, (2), **60**, 445 (1899).
(18) Lucas, *J. Am. Chem. Soc.*, **52**, 803 (1930).
(19) Lucas and Eberz, *J. Am. Chem. Soc.*, **56**, 460 (1934).
(20) Glasstone, *Textbook of Physical Chemistry*, D. Van Nostrand Co., Inc., New York, 1940, p. 522.