Experimental Section

cis,trans-**5,6,7,8-Diepoxy-8-carboxamido-5,6,7,8-tetrahydrotetrazolo[1,5-*a*]pyridine (2).**—To a solution of 1.45 g (0.01 mol) of 8-cyanotetrazolo[1,5-*a*]pyridine (**1b**) in 30 ml of ethanol was added 3 ml of 30% hydrogen peroxide and 3.5 ml of 3 *N* potassium hydroxide, and the reaction mixture was stirred at room temperature for 3 hr. After cooling in an ice–water bath the precipitated crystalline **2** was collected by filtration and washed well with ice-cold water. After recrystallization from water–methanol the product melted at 240° with decomposition.

Anal. Calcd for $C_6H_5N_5O_3$ (195.04): C, 36.93; H, 2.58; N, 35.89. Found: C, 36.81; H, 2.39; N, 36.14.

Registry No.—**1b**, 40306-97-6; **2**, 40306-98-7; hydrogen peroxide, 7722-84-1; potassium hydroxide, 1310-58-3.

o-Iodosophenylphosphoric Acid[1]

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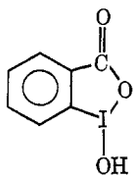
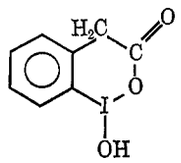
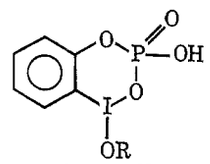
Heterocyclic compounds whose rings contain polyvalent iodine include the five-membered "*o*-iodosobenzoic acid" **1**,[2] several 3-butyl-2-phenylbenziodolium and tetraphenyliodolium salts,[3] and several benziodazoles[4] and benzdiiodoxoles.[5] The compound "*o*-iodosophenylacetic acid" is believed to have the six-membered cyclic structure **2**.[6] The present note describes the synthesis and properties of "*o*-iodosophenylphosphoric acid" and its methyl ester, to which we have assigned the six-membered cyclic structures **3a** and **3b**.



1



2



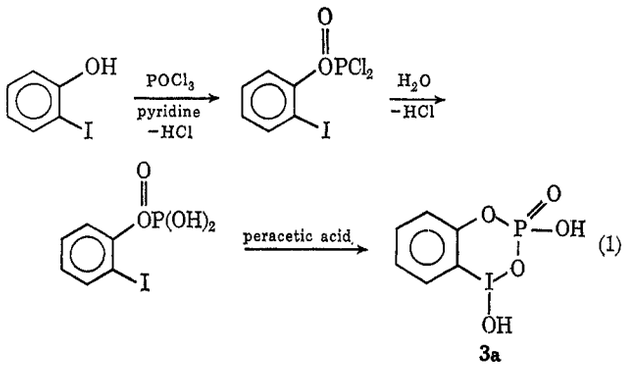
3a, R = H
b, R = CH_3

Compounds **3** and **3a** were synthesized from *o*-iodophenol by the route shown in eq 1.

Hydrolysis of the iodosodichloride (eq 2) gave 4-chloro-2-iodophenylphosphoric acid (**4**) instead of the desired *o*-iodosophenylphosphoric acid.

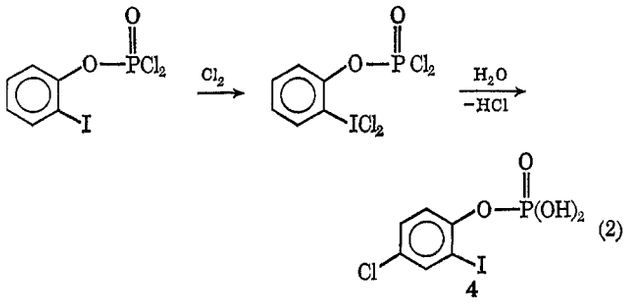
The phosphoric acid (**4**) gives mass spectral peaks at M^+ and $M^+ - I$ as chlorine doublets. It also has a characteristic 1,2,4-substituted benzene infrared absorption pattern. In the pmr spectrum the proton ortho to iodine appears as a multiplet centered at τ 2.20, downfield from the other aromatic protons.

o-Iodosophenylphosphoric acid (**3a**) has a very broad hydrogen-bonded OH absorption in the ir with



(1)

3a



(2)

4

maxima at 3130 and 1643 cm^{-1}, a P=O stretch at 1236 cm^{-1}, and two peaks at 713 and 710 cm^{-1} assigned to the I–O bond.[7] The pmr spectrum in DMSO-d_6 shows a D_2O-exchangeable broad singlet at τ 1.60 for the hydroxyl protons. The proton ortho to the polyvalent iodine atom appears as a doublet at τ 2.06 (with further splitting evident).

Recrystallization of **3a** from anhydrous methanol gave the methyl derivative **3b**. The ir spectrum of **3b** has a very broad hydrogen-bonded OH absorption with maxima at 2284, 2162, and 1674 cm^{-1} similar to the spectrum of **3a**, a P=O stretch at 1230 cm^{-1}, and weak absorptions at 2945, 2923, and 2822 cm^{-1} characteristic of the methyl group. A sharp peak at 713 cm^{-1} is assigned to the I–O bond. The pmr spectrum of **3b** in DMSO-d_6 has a poorly resolved aromatic region, a singlet at τ 6.00 for the methyl group, and a singlet at τ 6.76 attributed to methanol formed by reaction with adventitious water. Upon addition of D_2O the resolution improved, giving a spectrum essentially identical with that of an equimolar mixture of **3a** and methanol in the presence of D_2O.

The equivalent weights of **3a** and **3b** were determined by iodometry, titration with base to a Methyl Red end point, and by potentiometric titration. The molecular weights were obtained by vapor phase osmometry to exclude alternative polymeric structures.

The potentiometric titration curves of **3a** and **3b** are essentially identical due to the instantaneous hydrolysis of **3b** to **3a**. The first end point (pK_{a_1} = 2.84) is sharp. The second (pK_{a_2} = 7.86), corresponding to the ionization of the weakly acidic I–OH proton, is characteristically broad. For comparison, the pK_a of **1** is 7.35[8] and the first and second pK_a's of phosphoric acid are 2.12 and 7.21.

Structure Assignments.—Structures **3a** and **3b** can be

(1) This research was supported by PHS Grant No. AM 10498 from the National Institute of Arthritis and Metabolic Diseases.

(2) C. Willgerodt, *Chem. Ber.*, **26**, 357 (1893).

(3) F. M. Beringer, P. Gavis, G. Avitabile, and H. Jaffe, *J. Org. Chem.*, **37**, 879 (1972).

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assigned to *o*-isodosophenylphosphoric acid and its methyl ester on the basis of pmr data. The position of the signal from the hydrogen ortho to iodine in **3a** (τ 2.06) is consistent with a covalent rather than an ionic structure such as $-I^+-O^-$ or $-I^+-OH$. The proton ortho to positively charged iodine in 3-butyl-2-phenylbenziodolium chloride, for example, gives a signal much further downfield at τ 1.05.[3]

A phosphate ester structure for the methyl derivative appears to be eliminated because of the absence of any phosphorus splitting (J_{POCH_3} = 7 to 15 Hz).[9] Crystals of both compounds have been subjected to X-ray diffraction,[10] but, because of complexities introduced by twinning, confirmation of the suggested structures is not yet available. The cyclic structure of **1**, however, has been confirmed by X-ray diffraction.[11]

Experimental Section

o-Iodophenoxyphosphorus Oxychloride.—A solution of 82.30 g (0.374 mol) of *o*-iodophenol in 300 ml of dry hexane was added dropwise over a period of 35 min to a solution of 59.80 g (0.390 mol) of phosphorus oxychloride and 30.85 g (0.390 mol) of dry pyridine in 250 ml of dry hexane. The resulting suspension was refluxed for 1 hr and filtered through a fine sintered-glass funnel. The cloudy filtrate was concentrated under vacuum and distilled through a short column at reduced pressure giving 87 g (69%) of *o*-iodophenoxyphosphorus oxychloride as a pale yellow viscous liquid: bp 117° (0.025 mm); ir (neat) 3087, 3065, 3009, 1574, 1467, 1441, 1308 (P=O), 1264, 1201, 1121, 1050, 1039, 957, 770 (1,2 substitution), 709, and 650 cm^{-1}; nmr (neat) τ 2.08–3.20 (m, Ar H); mass spectrum *m/e* 340 (M^+ for ^{37}Cl), 338 (M^+ for ^{37}Cl and ^{35}Cl), 336 (M^+ for ^{35}Cl), 213 ($M^+ - I$ for ^{37}Cl), 211 ($M^+ - I$ for ^{37}Cl and ^{35}Cl), 209 ($M^+ - I$ for ^{35}Cl), 191, 139 ($M^+ - I - 2Cl$), 128, 127 (I^+), 92 ($C_6H_4O^+$), 76 ($C_6H_4^+$), 75, 74, 64, and 63 (PO_2^+).

Anal. Calcd for $C_6H_4ICl_2PO_2$: C, 21.39; H; 1.20; P, 9.19. Found: C, 21.77; H, 1.13; P, 9.20.

o-Iodophenylphosphoric Acid.—To a flask containing 35.0 g (0.104 mol) of *o*-iodophenoxyphosphorus oxychloride was added 200 ml of distilled water. The reactants were vigorously stirred for 30 min during which an exothermic reaction suddenly ensued and a solution resulted. The solution was cooled to room temperature and extracted seven times with ether. The extracts were washed with water, dried ($MgSO_4$), evaporated, and pumped at high vacuum to give crude *o*-iodophenylphosphoric acid as a hygroscopic semisolid.

***o*-Iodosophenylphosphoric Acid (3a).**—The crude *o*-iodophenylphosphoric acid was taken up in acetone and transferred to a small flask. After removal of the solvent, the flask was thoroughly chilled in an ice–water bath and 38 g (0.250 mol) of 34.4% peracetic acid added dropwise over a period of 45 min. After addition, the frozen reaction mixture was gradually melted and warmed up to room temperature over a period of 100 min, during which it was occasionally shaken and then magnetically stirred after enough solid had melted. The resulting white suspension was poured into acetone, vigorously stirred, filtered, washed with acetone, and dried to give 23 g (70%) of crude *o*-iodosophenylphosphoric acid (**3a**). Recrystallization from 1270 ml of distilled water[12] maintained at 75–78° gave 7.0 g (22%) of pure **3a** as fine white needles: mp 123–124° dec to red oil (tube in at 120° and heated at 1–2°/min); ir (Nujol and hexachlorobutadiene) 3130 (br, OH), 3082, 1643 (br, OH), 1465, 1459, 1448, 1272, 1236 (P=O), 1140, 1122, 1031, 972, 950, 910, 869, 781 (1,2 substitution), 761, 713, and 710 cm^{-1}; nmr (DMSO-d_6) τ 1.60 (br s, 2, hydroxyl protons, exchangeable with D_2O), 2.06 (d with further splitting evident, 1, proton ortho to iodine), 2.24–2.89 (m, 3, other aromatic H).

Anal. Calcd for $C_6H_6IPO_5$: C, 22.81; H, 1.91; P, 9.80. Found: C, 22.64; H, 1.61; P, 9.74.

Equivalent weights: calcd 158; found 160 (iodometric), 159.2 (Methyl Red end point), 160.2 (potentiometric). Osmometric mol wt 314.

Disilver Salt of *o*-Iodophenylphosphoric Acid.—To a solution of the crude acid in water was added excess aqueous silver nitrate. The resulting voluminous white precipitate was filtered, washed with water, and dried to give disilver *o*-iodophenylphosphate as a white powder: mp *ca.* 170–230° dec; ir 3051, 1581, 1469, 1462, 1439, 1377, 1274, 1252, 1102, 1042, 1020, 980, 910, 853, 760, 750, 732, and 643 cm^{-1}.

Anal. Calcd for $C_6H_4Ag_2IO_4P$: C, 14.03; H, 0.78; P, 6.03. Found: C, 14.14; H, 0.52; P, 6.09.

Methyl *o*-Iodosophenylphosphoric Acid (3b).—Recrystallization of 3.00 g (0.00910 mol) of crude *o*-iodosophenylphosphoric acid (**3b**) from 425 ml of anhydrous methanol gave 1.60 g (53%, two crops) of methyl *o*-iodosophenylphosphoric acid (**3b**) as white fluffy needles: mp 122–123° dec to red oil (tube in at 122° and heated at *ca.* 1–2°/min); ir (Nujol and Fluorolube) 3070, 2944 (CH_3), 2923 (CH_3), 2822 (CH_3), 2284 (OH), 2162 (OH), 1674 (br, OH), 1581, 1461, 1448, 1439, 1263, 1232 (P=O), 1135, 1043, 1031, 1022, 978, 952, 909, 873, 781 (1,2 substitution), 759, 713, and 652 cm^{-1}.

The nmr spectrum in DMSO-d_6 exhibits a poorly resolved aromatic region consisting of a doublet at τ 2.06 (proton ortho to iodine) and a multiplet at τ 2.3–2.8 all superimposed on a broad hydroxyl absorption. There is also a sharp singlet at τ 6.00 for the iodosyl methyl, and a sharp singlet at τ 6.76 for methanol formed by hydrolysis of **3b** to **3a** by small amounts of water present in the DMSO-d_6. The intensity of these methyl singlets varies from sample to sample because of the different amounts of water present. On adding D_2O, **3b** is completely hydrolyzed, the resolution in the aromatic region improved, and the hydroxyl absorption is shifted. The resulting spectrum is identical with that of a mixture of **3a** and CH_3OD.

Anal. Calcd for $C_7H_8IPO_5$: C, 25.48; H, 2.44; P, 9.39. Found: C, 25.50; H, 2.38; P, 9.53.

Equivalent weights: calcd 165; found 168.5 (iodometric), 166.0 (Methyl Red), 168.3 (potentiometric). Osmometric mol wt 355.

***o*-Iodosodichloridephenoxyphosphorus Oxychloride.**—A stirred solution of 12.00 g (.0356 mol) of *o*-iodophenoxyphosphorus oxychloride in 27 ml of dry $CHCl_3$ was chilled in an ice–salt bath and treated with dry chlorine for 3 hr after which the precipitate was filtered, washed with hexane, and dried on the filter to give 11.0 g (76%) of *o*-iodosodichloridephenoxyphosphorus oxychloride as a yellow solid: mp 67–70° dec (gas evolution, with prior softening); ir (Nujol) 3073, 3055, 3008, 1583, 1562, 1469, 1448, 1433, 1304 (P=O), 1274, 1215, 1159, 1141, 1121, 1050, 1041, 1011, 978, 952, 889, 773 (1,2 substitution), 756, 700, and 645 cm^{-1}.

Reaction of *o*-Iodosodichloridephenoxyphosphorus Oxychloride and Water.—A suspension of 10.00 g (0.00245 mol) of *o*-iodosodichloridephenoxyphosphorus oxychloride in 12.5 ml of distilled water was vigorously stirred in the dark for 1 hr. The resulting light orange solution was extracted with ether. The ether extracts were dried ($MgSO_4$) and evaporated to give 8.20 g of a semisolid. Recrystallization from solvent–nonsolvent mixtures, such as $CHCl_3$–hexane or acetone–benzene, gave a low yield of colorless crystals of 4-chloro-2-iodophenylphosphoric acid (**4**): mp 162–164° dec to dark oil (tube in at 150° and heated at *ca.* 1–2°/min); ir (KBr) 3074, 2740 (br, OH), 1569, 1464, 1373, 1256, 1231, 1200, 1068, 1040, 1002, 945, 872 (1,2,4 substitution), 821 (1,2,4 substitution), 798, 710, 669, and 639 cm^{-1}; nmr (acetone-d_6) τ −0.94 (br s, OH, partially exchanged with acetone-d_6), 2.00–2.40 (m, 1, proton ortho to iodine), 2.40–3.25 (m, 2, other aromatic H); mass spectrum *m/e* 336 (M^+ for ^{37}Cl), 334 (M^+ for ^{35}Cl), 256 ($M^+ - PO_3H$ for ^{37}Cl), 254 ($M^+ - PO_3H$ for ^{35}Cl), 209 ($M^+ - I$ for ^{37}Cl), 208, 207 ($M^+ - I$) for ^{35}Cl), 143, 128, 127 (I^+), 99, 81, and 63.

Anal. Calcd for $C_6H_5O_4PClI$: C, 21.55; H, 1.51; P, 9.26. Found: C, 21.68; H, 1.26; P, 9.27.

Addition of silver nitrate solution to a solution of **4** in water gave a voluminous white precipitate of what was probably the disilver salt of **4**. Filtering, washing with water, and drying gave a somewhat hygroscopic white solid: mp 203–260° dec; ir (KBr) 3280 (br, H_2O), 1688, 1579, 1465, 1375, 1265, 1248, 1155, 1130, 1038, 990, 895, 875, 840, 765, 710, and 660 cm^{-1}.

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(12) The material can also be crystallized from 50% aqueous THF.

Registry No.—**3a**, 40329-00-8; **3b**, 40329-01-9; **4**, 40329-02-0; **4** disilver salt, 40329-03-1; *o*-iodophenoxyphosphorus oxychloride, 40329-04-2; *o*-iodophenol, 533-58-4; phosphorus oxychloride, 10025-87-3; *o*-iodophenylphosphoric acid 40329-05-3; disilver salt of *o*-iodophenylphosphoric acid, 40329-06-4; silver nitrate, 7761-88-8; *o*-iodosodichloridephenoxyphosphorous oxychloride, 40329-07-5; chlorine, 7782-50-5.

Thermal Decomposition of a β-Ketophosphonic Acid[1]

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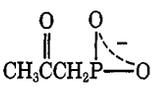
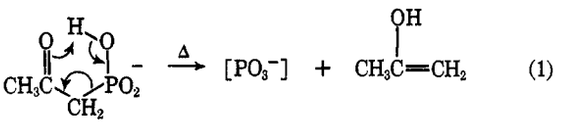
Received January 22, 1973

The decarboxylation of β-ketocarboxylic acids is a well-known reaction of synthetic[2] and mechanistic[3] interest. The reaction has received considerable kinetic study[4] and studies on its solvent dependence suggest that the reaction proceeds *via* an internally hydrogen-bonded transition state.[5] It has been proposed that β-ketosulfonamides, generated *in situ* by oxidation of 3-hydroxysulfoamides, decompose in an analogous fashion, although the intermediate keto compound has not been isolated.[6] A decomposition reaction of β-ketophosphonic acids by a similar route would be expected to lead to the initial production of the postulated (but never observed) species, monomeric metaphosphate,[7] and residual ketone. In neutral aqueous solution at room temperature, spontaneous decomposition of protonated β-ketophosphonic acids is not observed,[8] whereas protonated β-ketocarboxylic acids are readily decarboxylated.[4] We have examined the thermal lability of the monosodium salt of acetonylphosphonic acid (**1**) and of its methyl ester (**2**) in



1, R = H
2, R = CH_3

order to determine if conversion to metaphosphate and ketone (eq 1) can be brought about if more extreme conditions than those required for the analogous decarboxylation reaction are employed.



(1)

Experimental Section

The dimethyl ester of acetonylphosphonate can be conveniently prepared by published procedures.[8,9,10] Dimethyl acetonylphosphonate was converted to the monosodium salt of methyl acetonylphosphonate (**2**) by refluxing in acetone with a twofold excess of sodium iodide. The white precipitate was isolated by filtration and was recrystallized from ethanol to which ether was added, needles, mp 181–182°. *Anal.* Calcd for $C_4H_8O_4PNa$: C, 27.60; H, 4.63; P, 17.79. Found: C, 27.62; H, 4.64; P, 17.95. The sodium salt of acetonylphosphonic acid (**1**) was prepared as reported from the monomethyl ester.[8]

Studies of the thermal decomposition of these compounds were performed utilizing a bulb-to-bulb distillation apparatus under high vacuum, in order to permit the quantitative isolation of products. Acetonylphosphonic acid monosodium salt (0.30 g) was placed in one arm of the apparatus and, after pressure was below 0.1 Torr, heat was applied with an oil bath; the other arm of the apparatus was cooled in liquid nitrogen. Decomposition of the compound occurs at its melting point (146°) and heating to 150° was required to affect complete conversion. The material in the liquid nitrogen cooled arm was readily identified by its physical properties as being acetone; the isolated yield of acetone was 0.11 g (90%). The residue in the heated arm (0.18 g) was a high-melting white powder whose infrared spectrum was identical with that reported by Corbridge and Lowe[11] for $(NaPO_3)_n$, polymetaphosphate glass. Heating the sodium salt of the monomethyl ester of acetonylphosphonate to 185° (above its melting point) did not lead to the salt's decomposition.

Discussion

The reaction proposed in eq 1 (or its intermolecular counterpart) appears to be operative under the conditions studied (150°, no solvent) for **1**. The monomethyl ester of the phosphonate **2** is stable under conditions which lead to the immediate decomposition of the parent salt. Therefore, the availability of the proton of the phosphonic acid appears to be a requirement for the decomposition reaction; methyl transfer does not occur. This conforms with (but does not necessarily require) the mechanism in eq 1. The fact that the polymer of metaphosphate (rather than the elusive monomer or a lower oligomer[12]) is isolated is presumably a result of the reactive monomeric anion being produced under the conditions of high temperature necessary for the decomposition.

The thermal decomposition reaction of β-ketophosphonates is potentially of synthetic utility where the stability of the phosphonate relative to a carboxylate may be of value in an acetoacetic ester type synthesis.[13] The enolate of the phosphonate diester is a well-studied species[9] which should be readily alkylated.[13a] Ketones containing an α-halo substituent can be converted to β-ketophosphonate compounds by the Arbusov or related reactions[14] involving addition of a

(1) Support of this work by the Research Corporation is gratefully acknowledged.

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(7) W. W. Butcher and F. H. Westheimer, [*J. Amer. Chem. Soc.*, **77**, 2420 (1955)] invoked this species to explain the peculiar pH dependence of the rate of hydrolysis of methyl phosphate, noting that Todd proposed in a lecture in 1954 that metaphosphate was an intermediate in phosphorylation reactions. The current status and applications of the metaphosphate hypothesis have recently been summarized by D. G. Gorenstein [*J. Amer. Chem. Soc.*, **94**, 2523 (1972)].

(8) R. Kluger and P. Wasserstein, *ibid.*, **95**, 1071 (1973).

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(13a) NOTE ADDED IN PROOF.—P. A. Grieco and C. S. Pogonowski [*J. Amer. Chem. Soc.*, **95**, 3071 (1973)] have recently developed methods for alkylation of the 4 position of dimethyl acetonylphosphonate.

(14) G. M. Kosolapoff, *Org. React.*, **6**, 273 (1951).