

590. *The Reactivity of Organophosphorus Compounds. Part VII.¹*
Reactions between Phosphites and Chloramine-T.

By J. I. G. CADOGAN and H. N. MOULDEN.

Dialkyl hydrogen phosphites react with aqueous chloramine-T to give dialkyl hydrogen phosphates. Triethyl and triphenyl phosphites similarly give the corresponding phosphates.

VARIOUS reagents have been employed with varying success for the oxidation of phosphites to the corresponding phosphates. In many cases, particularly with the triesters, the oxidation is accompanied by side reactions and poor yields of the required product are obtained.

Air or oxygen has been used with triesters and in some cases the methods have been moderately successful.^{2,3} Triesters have also been oxidised by such agents as hydrogen peroxide,⁴ oxides of nitrogen,⁵ and epoxides.⁶ Alkaline potassium permanganate appears to be a good reagent for the oxidation of monoalkyl and dialkyl phosphites,⁷ and Dimroth and Ploch^{7a} obtained high yields of 2-chloroethyl dihydrogen phosphate and di-(2-chloroethyl) hydrogen phosphate from the corresponding phosphites. This reagent, however, is of little use for the preparation of trialkyl phosphates, which were obtained in yields ranging between 10 and 40%. Anhydrous chlorination or bromination, followed by mild hydrolysis, has been used to convert dialkyl hydrogen phosphites into the corresponding phosphates. This method is successful for the preparation of dibenzyl hydrogen phosphate.⁸⁻¹⁰ Free halogens,⁹ sulphuryl chloride,^{8,11} *N*-chlorosuccinimide, and *N*,2,4-trichloroacetanilide¹⁰ have been used as halogenating agents. These methods cannot be applied to convert trialkyl phosphites into trialkyl phosphates since the former, on reaction with chlorine¹² and sulphuryl chloride¹³ give dialkyl phosphorochloridates. The reaction between triaryl phosphites and halogens has been studied by Rydon and Tonge.¹⁴ The

¹ Part VI, Cadogan and Foster, preceding paper.

² Kuznetsov and Valetdinov, *Trudy Kazan. Khim. Teknol. Inst. im S.M. Kirova*, 1956, **21**, 167; *Chem. Abs.*, 1957, **51**, 11,985 f.

³ Kamai and Koshkina, *Trudy Kazan. Khim. Teknol. Inst.*, 1953, **17**, 11 (*Referat. Zhur. khim.*, 1955, No. 526; *Chem. Abs.*, 1956, **50**, 6346 i).

⁴ Stetter and Steinacker, *Ber.*, 1952, **85**, 451.

⁵ Cox and Westheimer, *J. Amer. Chem. Soc.*, 1958, **80**, 5441; Kuhn, Doali, and Wellman, *ibid.*, 1960, **82**, 4792.

⁶ Scott, *J. Org. Chem.*, 1957, **22**, 1118.

⁷ (a) Dimroth and Ploch, *Ber.*, 1957, **90**, 801; (b) Brown and Hammond, *J.*, 1960, 4229.

⁸ Atherton, Howard, and Todd, *J.*, 1948, 1106.

⁹ Atherton, Openshaw, and Todd, *J.*, 1945, 382.

¹⁰ Kenner, Todd, and Weymouth, *J.*, 1952, 3675.

¹¹ Miyano, *J. Amer. Chem. Soc.*, 1955, **77**, 3524.

¹² McCombie, Saunders, and Stacey, *J.*, 1945, 380.

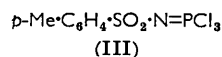
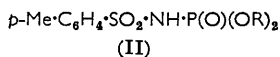
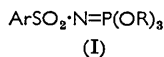
¹³ Poshkus and Herweh, *J. Amer. Chem. Soc.*, 1957, **79**, 6127.

¹⁴ Rydon and Tonge, *J.*, 1956, 3043.

reactions are complex and the products, on hydrolysis, give the corresponding triaryl phosphates, phenols, phosphoric acid, and primary and secondary aryl phosphates.

The reactions of chloramine-T and phosphites are now reported. Chloramine-T with triethyl phosphite in boiling aqueous ethanol gives triethyl phosphate (90%) and toluene-*p*-sulphonamide. Triphenyl phosphite and chloramine-T, in water, similarly give triphenyl phosphate in 69% yield. The lower yield is thought to be due to the method of its separation from the other reaction products. These reactions are thought to involve the formation of intermediate cations of the type $[(RO)_3PCl]^+$, which are then hydrolysed to the phosphate. The formation of intermediate compounds richer in chlorine can be discounted for two reasons. First, it was found that triethyl phosphite required only one molecular proportion of chloramine-T for almost complete oxidation. Secondly, Rydon and Tonge¹⁴ have indicated that compounds such as $(PhO)_3PCl_2$ on hydrolysis give phenol and diphenyl hydrogen phosphate whereas only traces of these compounds were detected in the products of the oxidation of triphenyl phosphate. Kirsanov and Shevchenko¹⁵ have reported the formation of triaryl *N*-arylsulphonylphosphorimidates (I; Ar = Ph, R = Ar) by the reaction of anhydrous chloramine-B and triaryl phosphites, and it was thought possible that these compounds were intermediates in the aqueous oxidations. This possibility is discounted since we did not isolate triethyl phosphate from the reaction between aqueous chloramine-T and the triethyl ester (I; Ar = *p*-Me·C₆H₄, R = Et). Instead, impure diethyl *N*-toluene-*p*-sulphonylphosphoramidate (II; R = Et), inorganic phosphate, and toluene-*p*-sulphonamide were isolated.

Triethyl *N*-toluene-*p*-sulphonylphosphorimidate (I; Ar = *p*-Me·C₆H₄, R = Et) was synthesised by allowing anhydrous chloramine-T to react with triethyl phosphite in dry carbon tetrachloride, and its identity was confirmed by comparison with a sample prepared from sodium ethoxide and *N*-toluene-*p*-sulphonylphosphorimidic trichloride (III). A small quantity of diphenyl *N*-toluene-*p*-sulphonylphosphoramidate (II; R = Ph) was isolated from the reaction of triphenyl phosphite and aqueous chloramine-T. Thus, in this reaction it is probable that the phosphorimidate (I; Ar = *p*-Me·C₆H₄, R = Ph) is formed to a slight extent and is subsequently hydrolysed to the phosphoramidate (II; R = Ph) and phenol, a trace of which was detected in the products. Kirsanov and Shevchenko¹⁶ found that the phosphorimidates (I) on hydrolysis gave the phosphoramidates of type (II).



Dialkyl hydrogen phosphites with aqueous chloramine-T give the corresponding dialkyl hydrogen phosphates. Diethyl and di-*n*-propyl hydrogen phosphates were obtained in yields of 90 and 80%, respectively. The yield of dimethyl hydrogen phosphate was much lower, probably because of hydrolysis. The reaction probably involves the formation of the dialkyl phosphorochloridate, by way of the phosphonate form, which is then hydrolysed, but attempts to isolate diethyl phosphorochloridate from the reaction with diethyl hydrogen phosphite were unsuccessful. Continuous ether extraction of the acidified reaction mixture, after the removal of the toluene-*p*-sulphonamide, was found to be the best method of isolating the dialkyl hydrogen phosphates.

EXPERIMENTAL

Triethyl phosphite (b. p. 52°/12 mm., n_D^{25} 1.4114) was fractionally distilled before use. Triphenyl phosphite was purified by fractional freezing. Examination of its infrared spectrum showed it not to contain phosphate. Anhydrous chloramine-T was prepared by dehydrating the trihydrate with phosphorus pentoxide at 70°/0.1 mm. Extracts were dried over magnesium sulphate and the light petroleum used had b. p. 40—60°. M. p.s are corrected.

Reaction with Aqueous Chloramine-T.—(a) *Triethyl phosphite.* Triethyl phosphite (3.97 g.)

¹⁵ Kirsanov and Shevchenko, *J. Gen. Chem. U.S.S.R.*, 1956, **28**, 75.

¹⁶ Kirsanov and Shevchenko, *J. Gen. Chem. U.S.S.R.*, 1954, **24**, 1980, 483.

and chloramine- τ (6.75 g.), in 60% aqueous ethanol (120 ml.), were boiled under reflux for 11 hr. under an atmosphere of carbon dioxide. Ethanol was distilled from the solution, and the residue was allowed to cool. Toluene-*p*-sulphonamide (3.47 g.), m. p. and mixed m. p. 138—139°, was collected and washed with light petroleum. Chloroform extracts of the filtrate, combined with the light-petroleum washings, gave triethyl phosphate (3.97 g.), b. p. 50—54°/14 mm., n_D^{25} 1.4032 (which was identified by its infrared spectrum), and more toluene-*p*-sulphonamide (0.38 g.).

(b) *Triphenyl phosphite*. Triphenyl phosphite (5.0 g.) and chloramine- τ (4.55 g.), in water (130 ml.), were boiled under reflux with stirring for 3 hr. Ether washings of the condenser gave a small quantity of impure phenol (0.02 g.) (odour and infrared spectrum). On cooling, the reaction mixture was basified (Na_2CO_3) and then extracted with ether. The ether extracts were evaporated and the residue was extracted with benzene, leaving toluene-*p*-sulphonamide (1.07 g.), m. p. and mixed m. p. 138°. The benzene extracts were evaporated and the residue adsorbed on neutral alumina. Elution with benzene (500 ml.) gave triphenyl phosphate (3.65 g.), m. p. 44—48°, which was identified by its infrared spectrum; and then with ether (500 ml.) to give toluene-*p*-sulphonamide (0.36 g.), m. p. and mixed m. p. 139°. Subsequent elution with ethanol (1500 ml.) gave the *aluminium diphenyl N-toluene-p-sulphonylphosphoramidate* (0.6 g.), m. p. 178—179° on crystallisation from ethanol-light petroleum (Found: S, 7.4. $\text{C}_{57}\text{H}_{51}\text{AlN}_3\text{O}_{15}\text{P}_3\text{S}_3$ requires S, 7.8%). It was dissolved in water and treated with hydrochloric acid. Crystallisation of the precipitate from benzene-light petroleum afforded *diphenyl N-toluene-p-sulphonylphosphoramidate*, m. p. 188—190° undepressed by admixture with a specimen described below. The original aqueous layer was acidified (hydrochloric acid) and then neutralised (sodium hydrogen carbonate). Chloroform extracts gave toluene-*p*-sulphonamide (0.41 g.), m. p. 131—136° not depressed by admixture with authentic material. The aqueous layer was acidified (hydrochloric acid) and extracted with chloroform to give a brown oil (0.34 g.) which, from its infrared spectrum, was considered to be impure diphenyl hydrogen phosphite.

(c) *Diethyl hydrogen phosphite*. Diethyl hydrogen phosphite (3.45 g.) was added to chloramine- τ (7.05 g.), in water (50 ml.). The mixture became warm and a solid was precipitated. The mixture was gently warmed to 80° until no reaction was observed with starch-iodide test papers (*ca.* 20 min.). The reaction mixture was made alkaline (sodium carbonate) and extracted continuously with ether (16 hr.). The ether extracts gave toluene-*p*-sulphonamide (40 g.), m. p. and mixed m. p. 138—139°, on recrystallisation from water. The aqueous layer was acidified (hydrochloric acid) and extracted continuously with ether (24 hr.) to give diethyl hydrogen phosphate (3.51 g.), which was identified by its infrared spectrum [Found: equiv. (by titration), 158. Calc. for $\text{C}_4\text{H}_{11}\text{O}_4\text{P}$: equiv., 154].

The experiment was repeated and the reactants were mixed at 5°. The mixture, which became warm, was set aside for 2 min. and then extracted with chloroform. The extracts were dried immediately and then distilled. No diethyl phosphorochloridate was isolated.

In preliminary experiments it was found that prolonged heating of the acidic solution, after the oxidation was complete, produced hydrolysis of the product.

(d) *Dimethyl hydrogen phosphite*. Dimethyl hydrogen phosphite (2.75 g.) and chloramine- τ (7.05 g.), in water (50 ml.), were boiled under reflux until reaction was complete. Toluene-*p*-sulphonamide (4.30 g.) and dimethyl hydrogen phosphate (1.28 g.) were isolated as described above (Found: equiv., 129. Calc. for $\text{C}_2\text{H}_7\text{O}_4\text{P}$: equiv., 126).

(e) *Di-isopropyl hydrogen phosphite*. Di-isopropyl hydrogen phosphite (4.15 g.) and chloramine- τ (7.05 g.), in water (50 ml.), were boiled under reflux until reaction was complete. Toluene-*p*-sulphonamide (4.26 g.) and di-isopropyl hydrogen phosphate (3.62 g.) were isolated as described (Found: equiv., 189. Calc. for $\text{C}_6\text{H}_{15}\text{O}_4\text{P}$: equiv., 182).

Triethyl N-Toluene-p-sulphonylphosphorimidate.—Triethyl phosphite (10.0 g.) in dry carbon tetrachloride (100 ml.) was added slowly to anhydrous chloramine- τ (11.40 g.), also in dry carbon tetrachloride, and the mixture boiled for 1 hr. After being washed with water, the organic layer was distilled to give unchanged phosphite (3.33 g.), b. p. 50—69°/14 mm., and the phosphorimidate (13.3 g.), b. p. 159—170°/0.01 mm., n_D^{25} 1.5041, whose identity was confirmed by comparison of its infrared spectrum with that of a specimen (n_D^{25} 1.5038) prepared by Kirsanov and Shevchenko's method¹⁶ from *N*-toluene-*p*-sulphonylphosphorimidic trichloride and sodium ethoxide (Found: C, 47.0; H, 6.8; N, 4.2. Calc. for $\text{C}_{13}\text{H}_{22}\text{NO}_5\text{PS}$: C, 46.6; H, 6.6; N, 4.2%).

Reaction with aqueous chloramine-T. The above phosphorimidate (5.0 g.) and chloramine-T (4.21 g.), in water (50 ml.), were boiled for 22 hr. during which time the pH of the mixture changed from 8 to 2. The mixture was made alkaline (sodium carbonate) and extracted continuously with ether (16 hr.). The ether extracts gave a semi-solid which was heated at 90—100°/0.5 mm. for 1 hr. Nothing distilled into a receiver which was cooled in ice. The semi-solid was crystallised from benzene giving toluene-*p*-sulphonamide (0.67 g.), m. p. 134—135°. The mother liquors were fractionally precipitated with light petroleum into five fractions. Spectroscopic examination showed that the first fraction was impure sulphonamide and that the remaining fractions were mixtures of unchanged phosphorimidate and toluene-*p*-sulphonamide. The original aqueous layer was acidified (hydrochloric acid) and extracted continuously with ether (16 hr.). The ether extracts gave an oil (1.19 g.) which was identified as diethyl *N*-toluene-*p*-sulphonylphosphoramidate by comparison of its infrared spectrum with that of authentic material prepared, by Ratz's method,¹⁷ from diethyl phosphorochloridate and sodium toluene-*p*-sulphonamide.

Diphenyl N-Toluene-p-sulphonylphosphoramidate.—Anhydrous chloramine-T and triphenyl phosphite gave *triphenyl N-toluene-p-sulphonylphosphorimidate*, m. p. 72—75° (aqueous ethanol), by the method described above (Found: C, 62.9; H, 4.5. $C_{25}H_{22}NO_5PS$ requires C, 62.65; H, 4.6%). Hydrolysis of the phosphorimidate with 0.4N-aqueous ethanolic sodium hydroxide¹⁶ gave *diphenyl N-toluene-p-sulphonylphosphoramidate*, m. p. 186—187.5°, from benzene-light petroleum (Found: C, 56.3; H, 4.6. $C_{18}H_{18}NO_5PS$ requires C, 56.65; H, 4.5%).

Messrs. Albright and Wilson Ltd. are thanked for gifts of chemicals.

KING'S COLLEGE, STRAND, LONDON, W.C.2.

[Received, January 24th, 1961.]

¹⁷ Ratz, *J. Org. Chem.*, 1957, **22**, 372.