617. *Esters containing Phosphorus. Part IX.*

By H. G. Cook, J. D. Ilett, B. C. Saunders, G. J. Stacey, H. G. Watson, I. G. E. Wilding, and S. J. Woodcock.

An alternative method (cf. *J.*, 1948, 1313) of preparing diaminofluorophosphine oxides is described.

Diethyl fluorophosphinate has been synthesised. It is an unstable liquid devoid of marked toxic properties. The preparation of the following is also described: diethyl chlorophosphinate, ethyl dichlorophosphinite, new derivatives of aminophosphonic acid, *ethyl anilinofluorophosphonite*, and *ethyl dimethylaminofluorophosphonite*.

The action of sodium hydroxide solution on hydrogen phosphites is discussed, and an account is given of the reaction between ethylene glycol and phosphorus trichloride.

In Part VI (*J.*, 1948, 1313; cf. also B.P. 602,446) an account was given of a convenient method for obtaining diaminofluorophosphine oxides by the action of phosphorus oxydichlorofluoride on 4 moles of the amine:

$$POCl_2F + 4NH_2R = POF(NHR)_2 + 2\ R{\cdot}NH_3Cl.$$

In Report No. 16 on Fluorophosphonates to the Ministry of Supply, Dec. 1943 (also McCombie and Saunders, *Nature*, 1946, **157**, 776), we gave an account of an alternative method of preparation, details of which are given in the present communication. The method consisted in treating an amine with the calculated quantity of phosphorus oxychloride in ethereal solution:

$$POCl_3 + 4NH_2R = POCl(NHR)_2 + 2R{\cdot}NH_3Cl \quad . \ . \ . \ . \ . \ . \ . \quad (1)$$

The diaminochlorophosphine oxide thus obtained was then fluorinated. For example, dianilinochlorophosphine oxide was readily fluorinated by heating it with potassium fluoride in benzene, $POCl(NHPh)_2 + KF = POF(NHPh)_2 + KCl$. With some diaminochlorophosphine oxides, *e.g.*, bisdimethylaminochlorophosphine oxide, $POCl(NMe_2)_2$, certain other salts (*e.g.*, zinc fluoride) were effective fluorinating agents.

The preparation of dianilinochlorophosphine oxide was first mentioned by Michaelis (*Ber.*, 1894, **27**, 2574), who heated 2 mols. of aniline hydrochloride with one mol. of phosphorus oxychloride for 48 hours. He did not give a yield and we found the method long and tedious. We have found, however, that this compound is much more simply prepared by allowing 4 mols. of aniline to react with phosphorus oxychloride in cold ethereal solution, in accordance with equation (1).

The miotic, toxic, and other physiological properties of the dialkyl fluorophosphonates, $POF(OR)_2$, are now well established (McCombie and Saunders, Ministry of Supply Report No. 1, Dec. 18th, 1941; *Nature*, 1946, **157**, 287; *J.*, 1948, 659). In 1944 (Report No. 18 to Ministry of Supply, McCombie and Saunders, July 4) we described an analogous compound of the phosphinate series, namely *diethyl fluorophosphinate*, $PF(OEt)_2$. This could not be prepared by the action of sodium fluoride on the corresponding diethyl chlorophosphinate (the preparation of which is considered below). We obtained it, however, by the action of ethyl alcohol on phosphorus dichlorofluoride, $PCl_2F + 2EtOH = PF(OEt)_2 + 2HCl$, under the following conditions: (*a*) in ether, cooled by ice–salt; (*b*) in ether, in the presence of a tertiary amine to remove hydrogen chloride, cooled by ice–salt; (*c*) without a solvent, cooled by carbon dioxide–ether; or (*d*) in ether, cooled by carbon dioxide–ether. Conditions (*a*) gave the best results, although some of the ester was obtained in each of the above experiments.

Diethyl fluorophosphinate was readily hydrolysed by water. It was only feebly toxic in comparison with the corresponding fluorophosphonate. Exposure to a concentration of 1 mg./l. for 10 minutes caused no deaths among a batch of small animals, although some miosis was produced, but all the eyes returned to normal within 24 hours.

The phosphorus dichlorofluoride required for the above condensation was prepared by the fluorination of phosphorus trichloride by a modification of the method of Booth and Bozarth (*J. Amer. Chem. Soc.*, 1939, **61**, 2927).

We prepared diethyl chlorophosphinate, $PCl(OEt)_2$, (*a*) by the action of phosphorus trichloride on triethyl phosphite, $2P(OEt)_3 + PCl_3 \longrightarrow 3PCl(OEt)_2$, or (*b*) by the action of phosphorus trichloride (1 mol.) on ethyl alcohol (2 mols.) in the presence of diethylaniline (2 mols.), $PCl_3 + 2EtOH + 2NPhEt_2 \longrightarrow PCl(OEt)_2 + 2NPhEt_2{,}HCl$. Although diethyl chlorophosphinate is hydrolysed by water it did not react readily with sodium fluoride (referred to above) or potassium cyanide, but it gave derivatives with aniline and β-naphthylamine.

Ethyl dichlorophosphinite was first prepared by Menschutkin (*Annalen*, 1866, **139**, 343) although he did not give precise details. We find that it can be isolated from the reaction product formed by adding ethyl alcohol (1 mol.) to phosphorus trichloride in ether in the absence of a tertiary base. By this means the phosphorus trichloride is always in excess. Thus the interaction of phosphorus trichloride and ethyl alcohol under a wide variety of conditions has now been recorded and may conveniently be summarised as follows :

PCl_3.	EtOH.	Addendum.	Product.	Ref.
1 Mol.	3 Mols.	3 Mols. of tertiary base.	$P(OEt)_3$	*J.*, 1945, 380.
1 Mol.	3 Mols.	No tertiary base.	$P(OEt)_2{\cdot}OH$	*Ibid.*
1 Mol.	2 Mols.	2 Mols. tertiary base.	$PCl(OEt)_2$	
1 Mol.	1 Mol.	No tertiary base.	$PCl_2(OEt)$ (mainly)	

Diethyl p-*dimethylaminoanilinophosphonate* was readily obtained as a colourless crystalline solid by the action of *NN*-dimethyl-*p*-phenylenediamine on diethyl chlorophosphonate.

The parent anilinophosphonic acid, $PO(NHPh)(OH)_2$, was obtained by a new method which consisted in the ready hydrogenolysis of dibenzyl anilinophosphonate (cf. Atherton and Todd, *J.*, 1947, 648). An attempt to prepare *dibenzyl* p-*dimethylaminoanilinophosphonate* by the action of *NN*-dimethyl-*p*-phenylenediamine on dibenzyl chlorophosphonate gave only an oil. When, however, a mixture of the amine, dibenzyl hydrogen phosphite, and trichlorobromomethane was used (cf. Atherton and Todd, *J.*, 1947, 674) a good yield of the amino-anilinophosphonate was obtained. It is a crystalline solid which causes severe dermatitis; the irritation develops slowly and with some individuals persists for weeks.

In view of the rapid toxic action and miotic effect of the dialkyl fluorophosphonates and of the high toxicity of some of the diaminofluorophosphine oxides we prepared (Report No. 15 on Fluorophosphonates to Ministry of Supply by McCombie and Saunders, 9th December, 1943), and examined a hybrid molecule containing the essential features of each type of compound. The first such compound was *ethyl anilinofluorophosphonite* (I). One mol. of phosphorus oxydichlorofluoride was added to one mol. of ethyl alcohol and the resulting ethyl chlorofluorophosphonite (which it was not necessary to isolate) was treated with aniline.

$$POCl_2F + EtOH \longrightarrow POClF{\cdot}OEt + HCl \xrightarrow{3NH_2Ph} \underset{\text{(I.)}}{POF(OEt){\cdot}NHPh} + 2PhNH_2{,}HCl$$

On subcutaneous injection into mice, (I) had a L.D. 50 of 10 mg./kg., which was unexpectedly high in view of the reduction of toxicity caused by the phenyl group in both the fluorophosphonates (Part VI, *J.*, 1948, 1010) and the aminofluorophosphine oxides (Part VII, *ibid*, p. 1314).

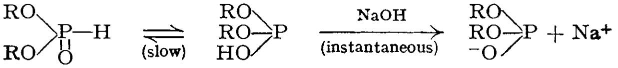
Ethyl dimethylaminofluorophosphonite was prepared by a similar method and proved to be a very toxic liquid. Its L.D. 50, on intravenous injection into rabbits and also on subcutaneous injection into mice, was 2·5 mg./kg. Toxicity was also determined by inhalation and a *Ct* ($t = 10$ minutes) of 2000 mg. min./m.^{3} killed 7 of 11 of a batch of rabbits, guinea-pigs, rats, and mice. A *Ct* of 1000 mg./min./m.^{3} killed 4 of 11. The compound also possessed miotic properties.

In view of the hyperactivity in rats caused by di-2-fluoroethyl fluorophosphonate (Part VI, *J.*, 1948, 1010) we prepared the simpler *di-2-fluoroethyl hydrogen phosphite* (II). This was easily done by the action of phosphorus trichloride on fluoroethanol without the use of a tertiary base. The identity was confirmed by the formation of the crystalline *anilinophosphonate* (III) :

$$\underset{\text{(II.)}}{(CH_2F{\cdot}CH_2{\cdot}O)_2P{\cdot}OH} \xrightarrow{Cl_2} (CH_2F{\cdot}CH_2{\cdot}O)_2POCl \xrightarrow{NH_2Ph} \underset{\text{(III.)}}{(CH_2F{\cdot}CH_2{\cdot}O)_2PO{\cdot}NHPh.}$$

Compound (II) was a liquid which, at a concentration of 0·5 g./m.^{3} ($t = 10$ minutes), killed 10 of 13 of a batch of small animals and at 0·2 g./m.^{3}, 1 of 13. It was therefore not very toxic and in addition appeared not to induce hyperactivity.

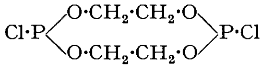
The speed of the reaction between sodium hydroxide and different hydrogen phosphites varies greatly from one compound to another. The reaction, however, is usually slow, indicating that they normally consist of a mixture of (IV) and (V) with the equilibrium to the left :

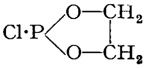

(IV.) (V.)

The reaction between certain hydrogen phosphites and sodium hydroxide was examined as follows. A known weight of hydrogen phosphite was dissolved in carbon dioxide-free water, and phenolphthalein was added. Successive 1-ml. portions of standard sodium hydroxide solution were then added (in an atmosphere of nitrogen) and the times taken for the red colour of the phenolphthalein to disappear were noted. The results are given in the Experimental section for diethyl, di*iso*propyl, and di-2-fluoroethyl hydrogen phosphite. When the experiment was carried out in this way the total time to reach the end-point with diethyl hydrogen phosphite was of the order of 120 minutes. A corresponding experiment with di*iso*propyl hydrogen phosphite started off at about one-fifteenth of the rate observed with the ethyl compound, and was so slow that the true end-point could not be observed by this method. With di-2-fluoroethyl hydrogen phosphite, the time taken for the complete reaction was less than with diethyl hydrogen phosphite.

*Di*cyclo*hexyl hydrogen phosphite* was insoluble in 0·1N-sodium hydroxide and therefore presumably exists entirely in the phosphonate form (IV). Infra-red spectroscopic examination has been carried out by Dr. G. B. B. M. Sutherland (to be published elsewhere) and excellent confirmation has been obtained that di*cyclo*hexyl hydrogen phosphite is indeed exclusively (IV), whereas diethyl and di*iso*propyl hydrogen phosphite contain a proportion of the true phosphite forms (V).

Very diverse results have been expressed concerning the action of phosphorus trichloride on glycol. Carré (*Compt. rend.*, 1903, **136**, 756) suggested that the product was (VI), whereas


(VI.)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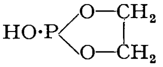
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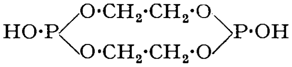
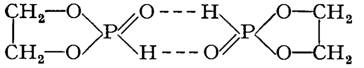

(IX.)

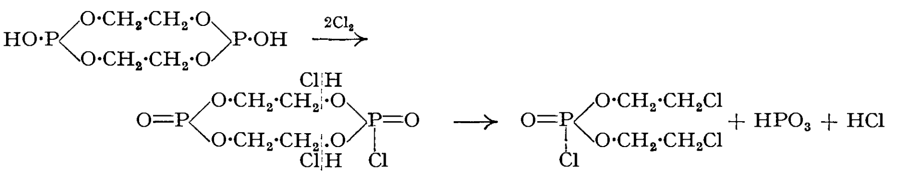
Rossiiskaya and Kabachnik (*Bull. Acad. Sci. Russia*, 1947, 509) stated that their product was (VII). Under the conditions of our experiments, with dioxan as a solvent, we obtained a compound which was chlorine-free and had the empirical formula $C_2H_5O_3P$. This could be either (VIII) or (IX), formed according to the standard equation (Part I, *J.*, 1945, 380) :

$$2PCl_3 + 3(CH_2{\cdot}OH)_2 = C_4H_{10}O_6P_2 \text{ (or } 2C_2H_5O_3P) + (CH_2Cl)_2 + 4HCl$$

It was considered that molecular-weight determinations of the product would not necessarily be diagnostic in view of the possible dimerisation of (VIII), particularly in the phosphonate form (X) (*cf.* the dimers of the carboxylic acids). The problem was then approached from a different


(X.)

angle. The product was treated with chlorine, and a compound $C_4H_8O_3Cl_3P$ obtained, together with decomposition products. The high chlorine content suggested the formation of di-2-chloroethyl chlorophosphonate according to the scheme :



Metaphosphoric acid would be produced and this would explain why an undistillable residue was obtained. Confirmation was provided by the conversion of the chlorophosphonate into di-2-chloroethyl fluorophosphonate by means of sodium fluoride in benzene. All these reactions suggest that the product of the reaction between ethylene glycol and phosphorus trichloride was most probably *bis(ethylene hydrogen) diphosphite* (IX).

In Part V (*J.*, 1948, 699) we described the preparation of diethyl thiocyanatophosphonate, by heating together diethyl chlorophosphonate and potassium thiocyanate. We have now shown that under suitable conditions the reaction will take place at room temperature. The properties of the thiocyanatophosphonate have been further examined (see p. 2927).

Experimental.

Dianilinochlorophosphine Oxide.—Aniline (37·2 g.), dissolved in ether (50 c.c.), was added slowly to phosphorus oxychloride (15·3 g.) dissolved in ether (50 c.c.) and ice-cooled. The mixture was kept overnight, and the solid which separated was filtered off and washed free from aniline hydrochloride with water. The residue, recrystallised from alcohol, had m. p. 167° (m. p.s recorded in literature vary from 159° to 174°) (Found: N, 11·0. Calc. for $C_{12}H_{12}ON_2PCl$: N, 10·5%). Yield: nearly theoretical.

Dianilinofluorophosphine Oxide.—Crude dianilinochlorophosphine oxide (10 g.) was heated with potassium fluoride (4 g.) and benzene (50 c.c.) for 5—6 hours. The mixture was then filtered hot and the remaining solid extracted again with boiling benzene. The benzene extracts were cooled and the crude fluorophosphine oxide separated. Recrystallised from aqueous ethyl alcohol, in well-formed needles, it had m. p. 144° [mixed with the authentic compound made by action of phosphorus oxydichlorofluoride on aniline (*J.*, 1948, 1010), 143—144°].

Bis(dimethylamino)chlorophosphine Oxide.—Anhydrous dimethylamine (18 g.) in ether (60 c.c.) was cooled in solid carbon dioxide–methylated spirit. A solution of phosphorus oxychloride (15·35 g.) in ether (60 c.c.) was added slowly (45 minutes) and a vigorous reaction took place. The mixture was kept overnight and the dimethylamine hydrochloride which had separated was filtered off. The ether was distilled from the filtrate, and the residue fractionated, the fraction, b. p. 79—82°/0·6 mm. (12·3 g., 68%), being collected. This oxide also boiled at 133—134°/30 mm. (Found: N, 15·8. Calc. for $C_4H_{12}ON_2PCl$: N, 16·4%).

Bis(dimethylamino)fluorophosphine Oxide.—Bis(dimethylamino)chlorophosphine oxide (18 g.) was heated in benzene (50 c.c.) with powdered zinc fluoride (9 g.) for about 2 hours. The inorganic material was filtered off and benzene distilled from the filtrate. The residue was fractionated under reduced pressure, and the chlorine-free oxide, b. p. 92—93°/15 mm., was collected.

Phosphorus Dichlorofluoride (cf. Booth *et al.*, *J. Amer. Chem. Soc.*, 1939, **61**, 2927).—The reaction was carried out in an apparatus of the type used for the partial fluorination of phosphorus oxychloride (Report No. 3 on Fluorophosphonates to the Ministry of Supply by McCombie and Saunders; for a diagram of apparatus see Chapman and Saunders, *J.*, 1948, 1010). The 3-necked flask fitted with stirrer and feed for antimony trifluoride was placed in a thermostat. The flask was connected through a vertical fractionating column and condenser to a series of traps [C (ice–salt), D_1 and D_2 (carbon dioxide–ether), and E (liquid air)], and thence to a water-pump fitted with a manometer and a constant-pressure device. The thermostat was maintained at 40° and the brine for the reflux condenser was cooled so that the temperature of the condenser was about −2°. Phosphorus trichloride (830 g., 520 c.c.) was placed in the flask, and the antimony pentachloride catalyst (15 c.c.) added slowly with stirring, heat being evolved. Antimony trifluoride (dried and powdered; 700 g., 3·9 mols.) was then placed in the feed and the pump started, the pressure being adjusted to 240 mm. The trifluoride was added at such a rate that the reflux column was not choked by the returning phosphorus trichloride, the operation taking about 2 hours. Owing to the low b. p. of phosphorus trichloride, considerable quantities always passed over into C and even into D_1; in fact, after about 3 hours there was usually no liquid left in the reaction vessel. The contents of D_1 and D_2 were united and distilled through a column cooled by water at 0°. The fraction of b. p. up to 28° was collected and consisted mainly of phosphorus dichlorofluoride (135—150 g., *ca.* 20%). On cooling it in carbon dioxide–ether a few white crystals were formed, but these disappeared on warming the mixture to room temperature. Redistillation of the product gave about 100 g. of phosphorus dichlorofluoride, b. p. <20°, which on redistillation gave a colourless liquid, b. p. 13·9°/760 mm., fuming in moist air and reacting vigorously with water, alcohols, etc. Prolonged exposure to the fumes caused chest pains, difficulty in breathing, and headache.

Diethyl Fluorophosphinate.—Phosphorus dichlorofluoride (73 g., 0·6 mol.) was dissolved in dry ether (150 c.c.), and the solution cooled to −10°. Absolute alcohol (55·2 g., 1·2 mols.) was added to the ethereal solution during 1½ hours, with occasional shaking. After a further 1½ hours, the ether was distilled off and the residue fractionated at 20 mm., the fraction, b. p. 78—84°, being collected. This was refractionated, a small quantity of liquid distilling at about 50°. The temperature then rose rapidly to 80° and the fraction, b. p. 80—81·5°/18 mm., was collected (26·5 g., 32%).

The *ester* contained phosphorus and fluorine, but not chlorine (Found: C, 34·2; H, 8·1. $C_4H_{10}O_2PF$ requires C, 34·3; H, 7·1%).

The ester was hydrolysed under conditions arranged so that the reaction, $PF(OEt)_2 + 2OH^- \longrightarrow (EtO)_2PO^- + F^- + H_2O$, took place without appreciable removal of the ethyl groups. This was effected by heating the ester under reflux with a standard alcoholic solution of sodium hydroxide for ½ hour. The excess of alkali was then back titrated [Found: equiv., 69. $PF(OC_2H_5)_2$ requires equiv., 70].

Potassium permanganate dissolved in acetone oxidised diethyl fluorophosphinate vigorously, a brown tarry material being produced.

Diethyl Chlorophosphinate.—(*a*) Triethyl phosphite (33·2 g., 0·2 mol.) and phosphorus trichloride (13·7 g., 0·1 mol.) were heated under gentle reflux for 30 minutes, the liquid gradually becoming a yellowish-green. The product was distilled at 13 mm. and the fraction, b. p. 34—42°, was collected. There was a small quantity of higher-boiling material, and an orange coloured solid remained in the flask. The chlorophosphinate was redistilled at atmospheric pressure and then had b. p. 143—148° (20·5 g.) (Found: Cl, 22·8. Calc. for $C_4H_{10}O_2ClP$: Cl, 22·6%).

(*b*) Phosphorus trichloride (200 g., 1·45 mols.) in dry ether (127 c.c.) was added slowly to a solution of ethyl alcohol (134 g., 2·9 mols.) and diethylaniline (435 g., 2·9 mols.) in dry ether (200 c.c.). The mixture was cooled in ice-water and stirred. The diethylaniline hydrochloride which separated was filtered off, and the filtrate and washings were distilled on a water-bath to remove the ether. Distillation of the residue gave diethyl chlorophosphinate of b. p. 45—53°/15 mm. (80·8 g., 35·5%) (Found: C, 31·2; H, 7·4. Calc. for $C_4H_{10}O_2ClP$: C, 30·7; H, 6·4%). The ester is a colourless liquid which fumes readily in moist air and reacts violently with water.

(*c*) *Reactions.* (i) Heating it with potassium cyanide or sodium fluoride caused no appreciable reaction.

(ii) *With aniline.* Diethyl chlorophosphinate (10 g., 1 mol.) was dissolved in dry ether (30 c.c.) and cooled in ice-water. Aniline (11·9 g., 2 mols.) was added slowly. The white precipitate of aniline hydrochloride was filtered off, the filtrate heated on a water-bath to remove ether, and the remaining solution distilled at reduced pressure. 7·9 G. of *diethyl anilinophosphinate*, b. p. 144—148°/17 mm., was obtained. Redistillation gave a fraction of b. p. 142—144°/15 mm. (Found: N, 6·9. $C_{10}H_{16}O_2NP$ requires N, 6·6%).

(iii) *With β-naphthylamine.* Diethyl chlorophosphinate (10 g., 1 mol.) was dissolved in dry ether (15 c.c.) and cooled in ice-water and β-naphthylamine (18·6 g., 2 mols). in dry ether (60 c.c.) was slowly added. The mixture was left for 1 hour, then the precipitate of β-naphthylamine hydrochloride was filtered off, the ether removed on a water-bath, and the residue distilled under reduced pressure. At 0·3 mm. a fraction (7 g.) was obtained, b. p. 133—140°. Redistillation gave *diethyl β-naphthylaminophosphinate*, b. p. 126—129°/0·3 mm. (Found: C, 63·8; H, 7·1; N, 5·8. $C_{14}H_{18}O_2NP$ requires C, 64·0; H, 6·85; N, 5·3%).

Ethyl Dichlorophosphinite.—Ethyl alcohol (34 g., 1 mol.) in dry ether (25 c.c.) was added slowly to a solution of phosphorus trichloride (100 g., 1 mol.) in dry ether (50 c.c.), cooled in ice-water. The ether was distilled off and the residue gave fractions, (i) (57 g.) b. p. 25°/25 mm., and (ii) (6 g.) b. p. 74°/15 mm. (diethyl hydrogen phosphite). Fraction (i) was redistilled at atmospheric pressure and proved to be ethyl dichlorophosphinite, b. p. 117—118°. It is a colourless, fuming liquid which reacts violently with water. Its hygroscopic character rendered determination of carbon and hydrogen difficult and its identity was established by conversion into ethyl *o*-phenylene phosphite as follows. Ethyl dichlorophosphinite (4 g.) dissolved in dry ether (10 c.c.) was slowly added to a mixture of pyrocatechol (3 g.) and diethylaniline (8·14 g.) in dry ether (25 c.c.), cooled in ice-water. After being set aside for 2 hours, the precipitate of diethylaniline hydrochloride was filtered off, the ether removed from the filtrate, and the residue distilled at 102—103°/23 mm. Yield, 2·64 g. Redistillation gave b. p. 99—100°/19 mm. (Found: C, 52·0; H, 5·3. Calc. for $C_8H_9O_3P$: C, 52·3; H, 4·9%). These b. p.s compare favourably with that of Anschülz and Walbrect (*J. pr. Chem.*, 1932, **133**, 65), who gave b. p. 83—84°/11 mm.

Diethyl p-*Dimethylaminoanilinophosphonate.*—*NN*-Dimethyl-*p*-phenylenediamine (5·44 g.) in benzene (20 c.c.) was added to diethyl chlorophosphonate (3·45 g.) in benzene (15 c.c.) with shaking. The amine hydrochloride (3·2 g., 96%) was filtered off and the filtrate evaporated to dryness. The solid was recrystallised from light petroleum (b. p. 40—60°), and *diethyl* p-*dimethylaminoanilinophosphonate* was obtained as almost colourless plates, m. p. 94° (2·3 g., 70%) (Found: N, 10·2; P, 11·3. $C_{12}H_{21}O_3N_2P$ requires N, 10·3; P, 11·4%).

Anilinophosphonic Acid.—Dibenzyl anilinophosphonate (5 g.; prepared according to the method of Atherton and Todd, *J.*, 1945, 382) was hydrogenated (7 minutes) in ethanol (150 c.c.) at room temperature and pressure with palladium oxide as catalyst. (Hydrogen, taken up 700 c.c.; the catalyst was reduced in the presence of the compound; theoretical uptake, 625 c.c.) The catalyst was filtered off, and on storage of the filtrate the highly crystalline anilinophosphonic acid (1·5 g.) separated, having m. p. 276—277° (decomp.) [Michaelis gave m. p. 276° (decomp.)].

The alcoholic mother-liquor was evaporated to dryness and the residue dissolved in water. The solution was made neutral to phenolphthalein with sodium hydroxide solution, and an excess of silver nitrate (5% solution) was added. The resulting disilver anilinophosphonate was filtered off and dried (yield, 3 g.) (Found: Ag, 56·8. Calc. for $C_6H_6O_3NPAg_2$: 55·8%). The high content of silver was probably due to traces of silver phosphate.

Disilver anilinophosphonate was prepared in a slightly different way as follows. Dibenzyl anilinophosphonate (2 g.) was dissolved in alcohol (90 c.c.) and heated under reflux for 90 minutes with Raney nickel (0·5 g.). After filtration, the solution was shaken at room temperature with hydrogen in the presence of palladised charcoal at atmospheric pressure. The uptake was initially rapid and finally 300 c.c. were absorbed (theoretical, 350 c.c.). The solution was filtered, and the solvent and toluene were removed on the water-bath, giving a sticky solid residue. This was dissolved in water, acetone was added and then a concentrated solution of silver nitrate. A white precipitate of the disilver anilinophosphonate separated (Found: Ag, 56·2%).

Dibenzyl p-*Dimethylaminoanilinophosphonate.*—*p*-Aminodimethylaniline (18 g.) and dibenzyl hydrogen phosphate (36·5 g.) were dissolved in carbon tetrachloride (100 c.c.) and cooled in ice-water. Trichlorobromomethane (25 c.c.), diluted with carbon tetrachloride (25 c.c.), was added with stirring. The solution was washed with 10% aqueous sodium hydroxide, and the precipitated solid filtered off. The solid *dibenzyl* p-*dimethylaminoanilinophosphonate* (88%), recrystallised from alcohol, had m. p. 123—124° (Found: C, 66·5; H, 6·6; N, 7·2. $C_{22}H_{25}O_3N_2P$ requires C, 66·7; H, 6·4; N, 7·1%).

Ethyl Anilinofluorophosphonite [with N. B. Chapman].—Absolute ethyl alcohol (4·6 g.) was slowly added to phosphorus oxydichlorofluoride (13·7 g., 1 mol.) contained in a flask cooled in ice and concentrated hydrochloric acid. The mixture was set aside overnight, dry ether (100 c.c.) was added, and then aniline (27·9 g., 3 mols.) dissolved in dry ether (100 c.c.) was slowly added with cooling in ice–hydrochloric acid. The precipitate of aniline hydrochloride was filtered off and the ethereal filtrate dried (Na_2SO_4). The ether was distilled off and the residual oil fractionated at 0·2 mm. in a current of nitrogen. The fraction, b. p. 100—150°/0·2 mm., was collected and solidified when cooled in ice and scratched. The *fluorophosphonite*, recrystallised from aqueous acetic acid, had m. p. *ca.* 50° (Found: N, 7·3; F, 9·5. $C_8H_{11}O_2NPF$ requires N, 6·9; F, 9·4%).

Ethyl Dimethylaminochlorophosphonite.—To a solution of ethyl dichlorophosphonite (97·8 g., 0·6 mol.) in dry ether (450 c.c.), cooled in ice–hydrochloric acid was slowly added dimethylamine (54·0 g., 1·2 mols.)

in ether (300 c.c.). The mixture was kept for 2 hours before filtration, and the filtrate dried (Na_2SO_4) before distilling off the ether. The residue was distilled under reduced pressure in an atmosphere of nitrogen, and the greater part was collected between 70° and 80°/1·2—2·0 mm. Some decomposition occurred towards the end, and distillation was finally stopped while a residue still remained. Yield, 63·6 g. (62%). On redistillation, the *chlorophosphonite* boiled at 98—100°/18 mm. A small quantity of needle-shaped crystals separated from this distillate on storage (Found: Cl, 23·0, 23·3. $C_4H_{11}O_2NClP$ requires Cl, 20·7%).

Ethyl Dimethylaminofluorophosphonite.—A mixture of the chlorophosphonite (17·2 g., 0·1 mol.), dry potassium fluoride (23·2 g., 0·4 mol.), and carbon tetrachloride was stirred and heated in an oil-bath at 100° for 3 hours. After cooling, the solid was filtered off and the solvent distilled from the filtrate. The residual liquid was distilled under reduced pressure and the greater part (10·3 g., 66%) of it came over between 72° and 78°/19 mm. A small higher-boiling fraction was also obtained. On redistillation, the *fluorophosphonite* had b. p. 76—78°/18 mm. (Found: C, 30·9; H, 7·8; N, 9·2. $C_4H_{11}O_2NFP$ requires C, 31·0; N, 7·15; N, 9·0%). The compound contained fluorine and was chlorine-free. Toluene could also be used as the solvent for fluorination.

Di-2-fluoroethyl Hydrogen Phosphite.—Phosphorus trichloride (23 g.) in carbon tetrachloride was added slowly to 2-fluoroethanol (32 g.) also in carbon tetrachloride, without external cooling. Air was then drawn through the mixture for several hours in order to remove the hydrogen chloride, the carbon tetrachloride distilled off, and the residue distilled at 140—145°/16—17 mm. This was refractionated and had b. p. 109—110°/1·7 mm. It contained fluorine and phosphorus, and was soluble in water. Its identity was confirmed by formation of a crystalline anilino-compound thus. Chlorine was passed into the hydrogen phosphite suspended in ether and cooled in ice. As the reaction proceeded, the mixture became homogeneous because of the solubility of the chlorophosphonate in ether. Air was then drawn through the mixture to remove most of the hydrogen chloride. Excess of aniline was added, with external cooling in ice, and the mixture was set aside for 1 hour and then extracted with boiling benzene. The benzene was evaporated from the extract thus obtained, and the residue solidified. The *di-2-fluoroethyl anilinophosphonate* was then recrystallised first from a mixture of ethyl alcohol and hydrochloric acid (to remove excess of aniline), and then from ethyl alcohol and water, and had m. p. 68—70° (Found: N, 6·0. $C_{10}H_{14}O_3NPF_2$ requires N, 5·4%).

*Di*cyclo*hexyl Hydrogen Phosphite.*—*cyclo*Hexanol (45·0 g., 0·45 mol.) was dissolved in carbon tetrachloride (40 ml.) and phosphorus trichloride (20·6 g., 0·15 mol.) in carbon tetrachloride (20 ml.) slowly added. The mixture was heated under reflux in an oil-bath at 90° for 1 hour and then cooled, and the low-boiling liquids removed by warming the mixture gently under reduced pressure. The residual liquid was itself distilled and the main fraction was collected between 135° and 143° as the pressure varied from 0·6 to 1·0 mm. Decomposition occurred towards the end. Yield, 60—65%. For purposes of spectroscopic examination, the material was distilled twice more and finally pure *di*cyclo*hexyl hydrogen phosphite*, b. p. 120°/0·15 mm., was collected (no decomposition occurred during the last two distillations) (Found: C, 58·3; H, 9·5; P, 12·6. $C_{12}H_{23}O_3P$ requires C, 58·5; H, 9·4; P, 12·6%).

Action of Sodium Hydroxide Solution on Dialkyl Hydrogen Phosphites.—*Diethyl hydrogen phosphite.* This (2·9940 g.) was dissolved in carbon dioxide-free water and made up to 150 ml. 20 Ml. of this solution were diluted to *ca.* 100 ml. with water, phenolphthalein was added, and nitrogen bubbled through the solution during the reaction. 1 Ml. of 0·102N-sodium hydroxide was then added and the time taken for the colour of the indicator to disappear was noted. This was repeated for successive quantities of 1 ml. Results were:

Ml. added.	Time required for colour of indicator to disappear (min.).	Total time.	Ml. added.	Time required for colour of indicator to disappear (min.).	Total time.
1, 2, 3	all *ca.* 1	1—3	11	4·5	28·5
4	2	5	12	5·5	34
5	2·5	7·5	13	8	42
6	2·5	10	14	12	54
7	3	13	15	19	73
8	3	16	16	45	118
9	4	20	17	—	—
10	4	24			

The total time was then plotted against the number of ml. added.

*Di*iso*propyl hydrogen phosphite.* 4·010 G. were used as above. Results were:

Ml. added	1	2	3	4	5	6
Time required for colour of indicator to disappear (min.)	21	28	32	36	38	39
Total time	21	49	81	117	155	194

A graph was plotted as before. The end-point could not be determined in this case by this method because the reaction is so slow. The gradient of the curve is *ca.* one-fifteenth of that at the beginning of the diethyl hydrogen phosphite curve.

Di-2-fluoroethyl hydrogen phosphite. 4·3430 G. were used as above. The whole reaction was much more rapid than with the diethyl compound. It was possible to carry out an ordinary titration on the solution, each ml. however, reacting much more slowly that the previous one. Thus a drop (about 0·1 ml.) of sodium hydroxide solution before the end-point took about 2 minutes before decolorisation of the indicator occurred, whereas the next drop required about 30 minutes. 20 Ml. of solution = 19·6 ml. of 0·102N-NaOH. Found: equiv., 173·8. $C_4H_9O_3PF_2$ requires equiv., 174.

Reaction between Ethylene Glycol and Phosphorus Trichloride.—Phosphorus trichloride (137·5 g.) was slowly added to the glycol (93 g.) in dioxan (100 g.). Hydrogen chloride was evolved copiously and, after

30 minutes, dry ammonia was passed through the mixture to precipitate ammonium chloride which was filtered off. The viscous filtrate was distilled under reduced pressure, and the chlorine-free *phosphite*, b. p. 99·5°/0·15 mm., was collected (125 g., 67%) (Found : C, 24·65; H, 4·8. $C_4H_{10}O_6P_2$ requires C, 22·2; H, 4·6%). The identity of the compound was further established by conversion into the chlorophosphonate as follows. The hydrogen phosphite was dissolved in chloroform, and dry chlorine was passed through until a faint green colour persisted. The excess of chlorine was removed by sucking air through the liquid, which was then shaken with lead carbonate, filtered, and distilled. A small fraction distilled at 122—124°/0·6 mm. (Found : C, 19·9; H, 3·3; Cl, 44·1; P, 12·8. Calc. for $C_4H_8O_3Cl_3P$: C, 19·7; H, 3·4; Cl, 44·1; P, 12·7%); the remainder did not distil.

When the phosphite was fluorinated by sodium fluoride in benzene, the fluorophosphonate, b. p. 107°/0·8 mm., was obtained (Found : F, 8·5. Calc. for $C_4H_8O_3Cl_2FP$: F, 8·4%).

Diethyl Thiocyanatophosphonate.—Diethyl chlorophosphonate (10 g.) and dry potassium thiocyanate (7·5 g.) were shaken together at room temperature for 3 hours, whereupon most of the potassium thiocyanate disappeared and a red solution was obtained. Dry ether was added to precipitate the potassium chloride formed. The solution was filtered and the filtrate distilled, giving the thiocyanatophosphonate (6·7 g., 50%), b. p. 76—78°/0·5 mm. The ester is a colourless liquid, b. p. 80—82°/1 mm., with a characteristic odour, gives a red colour with ferric chloride solution, dissolves in sodium hydroxide to a yellow solution, but is insoluble in dilute mineral acid. It darkens on storage. When it was heated on a small scale with zinc and dilute hydrochloric acid, followed by neutralisation, steam-distilled, and extracted with ether, and the ethereal layer was evaporated, a colourless oil was obtained which gave a characteristic red colour (test for a thiol group) with sodium nitroprusside and sodium hydroxide solution.

We thank the Chief Scientist, Ministry of Supply, for permission to publish details of this work.

UNIVERSITY CHEMICAL LABORATORY, CAMBRIDGE. [*Received, August 3rd*, 1949.]