THE STEPWISE ALKOXYLATION OF PHENYL PHOSPHORODICHLORIDATE

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The reaction of phenylphosphorodichloridate (P.P.D.C.) with various alcohols in the presence of a tertiary base has been studied. With equimolar proportions of the P.P.D.C. and the requisite alcohol in light petroleum, the following compounds have been obtained: phenyl *n*-undecyl, phenyl *n*-butyl and phenyl methyl hydrogen phosphates. When two molar proportions of the alcohol in acetonitrile are added to P.P.D.C., phenyl bis-*n*-undecyl, phenyl bis-*n*-butyl and phenyl bis-*n*-amyl phosphates may be isolated. By hydrogenolysis (of the phenyl group diundecyl, dibutyl, and dimethyl hydrogen phosphates result.

THE occurrence of phosphodiester linkages in biologically important compounds such as the phosphatides and the nucleic acids has stimulated research on mixed phosphoric esters. Methods of synthesising compounds of structure I have been devised, based upon the reactions of
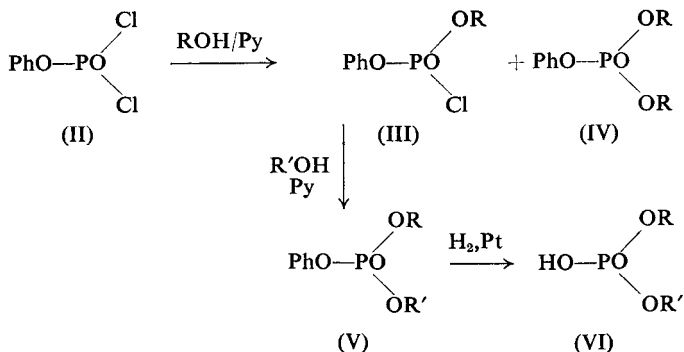
$$\begin{array}{c} RO \\ \diagdown \\ PO\text{-}OH \\ \diagup \\ R'O \end{array}$$

(I)
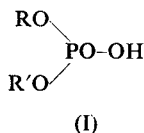
hydroxylic compounds with phosphoric acid or phosphorus pentoxide[1,2], phosphorohalidates[3-9] or alkyl metaphosphates[29]. Alternatively, the reaction of metallic phosphates with halogen compounds has been employed and the synthesis of certain phosphatides by this method has been claimed[10-14]. Although the identity of many earlier products is in doubt, recent applications of this route have been more definitive[15].

Apart from this, the synthesis of phosphatides has been based almost entirely upon the stepwise replacement of the chlorine atoms of phosphoryl chloride or its derivatives in the presence of tertiary base[16-18]. Monoalkoxylation of phosphoryl chloride is difficult to achieve, and the most successful synthetic application of this type[19] has involved the stepwise alkoxylation of phenyl phosphorodichloridate (II). For example, a number of lecithins (VI, $R = CH_2OCOR''\cdot CHOCOR''\cdot CH_2-$, $R' = CH_2CH_2{}^+NMe_3$) have been produced in this manner[19].

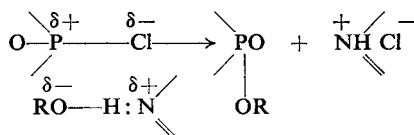* Present address: National Institute for Medical Research, Mill Hill, London, N.W.7.

$$\underset{\text{(II)}}{\text{PhO--PO}\diagup\overset{\displaystyle\text{Cl}}{\diagdown\text{Cl}}} \xrightarrow{\text{ROH/Py}} \underset{\text{(III)}}{\text{PhO--PO}\diagup\overset{\displaystyle\text{OR}}{\diagdown\text{Cl}}} + \underset{\text{(IV)}}{\text{PhO--PO}\diagup\overset{\displaystyle\text{OR}}{\diagdown\text{OR}}}$$

$$\Bigg\downarrow \begin{array}{c}\text{R'OH}\\ \text{Py}\end{array}$$

$$\underset{\text{(V)}}{\text{PhO--PO}\diagup\overset{\displaystyle\text{OR}}{\diagdown\text{OR'}}} \xrightarrow{\text{H}_2,\text{Pt}} \underset{\text{(VI)}}{\text{HO--PO}\diagup\overset{\displaystyle\text{OR}}{\diagdown\text{OR'}}}$$

Whilst in the case of glycerides with acyl chains C_{18} and C_{16} (stearoyl and palmitoyl) the amount of unwanted tertiary ester IV remained small[20], repetition by us of published details using glycerides with smaller acyl chains (C_{10} and C_{12})[30] led to much greater amounts of tertiary ester being formed. In addition we were unable to isolate any lecithin.

For this reason the present work was undertaken to study the relative rates of the two alkoxylation steps (II → III and III → V) and to delineate, if possible, conditions which would permit their definite separation.

The reaction of an aliphatic alcohol with phenyl phosphorodichloridate and pyridine was followed by determination of the chloride ion liberated according to the equation

$$\begin{array}{c}\overset{\displaystyle\diagdown\;\delta+}{\text{O--P}}\text{---}\overset{\delta-}{\text{Cl}} \\ \diagup\diagdown \\ \underset{\delta-}{\text{RO}}\text{---}\underset{\delta+}{\text{H}}:\text{N}\diagdown\end{array} \longrightarrow \begin{array}{c}\diagdown\\ \text{PO}\\ \diagup\;|\\ \text{OR}\end{array} + \overset{+}{\text{N}}\text{H}\diagup^{\displaystyle-}_{\displaystyle\text{Cl}}$$

Since the reaction takes place initially by way of a dipole-dipole interaction[21] the rate at which it proceeds should be small, and hence more amenable to investigation, in a non-polar solvent.

Initially the case of *n*-undecanol and phenyl phosphorodichloridate was considered. When molar proportions of these and pyridine were allowed to react in light petroleum at 5°, formation of chloride ion was fairly rapid, and by the end of 60 minutes was equivalent to the complete removal of one chlorine of phenyl phosphorodichloridate (Fig. 1, Expt. 1). If two molar proportions of *n*-undecanol were used, this same amount of chloride ion was formed almost immediately. Thereafter, the rate of reaction decreased markedly (Fig. 1, Expt. 2). It thus appeared that in light petroleum at low temperature and using only the theoretical quantity of the alcohol, alkoxylation could largely be limited to substitution of one chlorine only.

Accordingly the isolation of an intermediate phosphorochloridate was attempted. Although this proved impracticable for the pure halides, hydrolysis of these with alkali yielded the free acids, and reaction with an amine, the amides: alkyl phenyl phosphates (VII), and alkyl phenyl
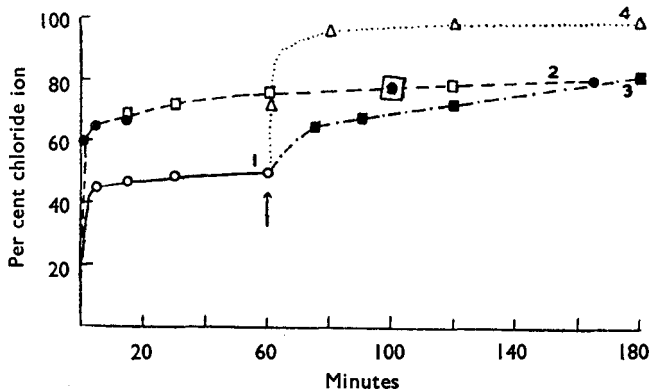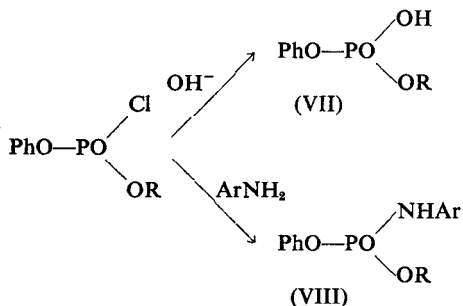
Fig. 1.   Reaction of alcohols with P.P.D.C. in the presence of pyridine.   At arrow, pentanol added in expt. 3 and 4.

O———O   *n*-Undecanol 1, P.P.D.C. 1 mol. eq.

●———●   *n*-Undecanol 2, P.P.D.C. 1 mol. eq., direct method.

□———□   Ditto, indirect method.

■———■   *n*-Undecanol, 1, P.P.D.C., 1, followed after 1 hour by *n*-pentanol 1 mol. equiv. in petroleum.

△———△   Ditto, *n*-pentanol in acetonitrile.

phosphoroamidates (VIII) respectively.   In this way compounds 1 to 6 in Table I were prepared.   Yields of the derivatives VII and VIII with *n*-undecanol and *n*-butanol provide confirmatory evidence that the main reaction in this stage is as stated above.

$$PhO—PO\underset{OR}{\overset{Cl}{\Big\langle}} \quad \overset{\displaystyle OH^-}{\underset{\displaystyle ArNH_2}{\Big\langle}} \quad \begin{array}{l} PhO—PO\underset{OR}{\overset{OH}{\Big\langle}} \\ (VII) \\[2ex] PhO—PO\underset{OR}{\overset{NHAr}{\Big\langle}} \\ (VIII) \end{array}$$

In light petroleum the replacement of the second chlorine was extremely slow.   Thus, when one molar equivalent of a second alcohol (*n*-pentanol) was added in light petroleum to crude phenyl undecyl phosphorochloridate in the presence of pyridine, the amount of chloride liberated was only 60 per cent of theory even after 2½ hours (Fig. 1, Expt. 3).   Reactions of this type, as has been shown by Dostrovsky and Halmann[22,23] are bimolecular nucleophilic substitutions, and as such are accelerated in polar solvents.   When crude phenyl *n*-undecyl phosphorochloridate was allowed to react as above with *n*-pentanol, in acetonitrile instead of light petroleum, elimination of a second equivalent of chloride ion was much more rapid, being essentially complete in about 60 minutes (Fig. 1, Expt. 4).

Tertiary esters (V; R = R' = alkyl) were therefore readily prepared by allowing phenyl phosphorodichloridate to react with two molar equivalents of an alcohol and base in acetonitrile. Compounds 7 to 9 (Table I) were prepared in this manner. Hydrogenolysis of these dialkyl phenyl phosphates gave the free acids (VI; R = R' = alkyl) in good yield as indicated (compounds 10 and 11).

TABLE I

ESTER DERIVATIVES OF PHOSPHORIC ACID

$$R-PO \begin{array}{l} R' \\ \\ R'' \end{array}$$
Ph = C_6H_5 Bu = n-C_4H_9
Un = n-$C_{11}H_{23}$ Am = n-C_5H_{11}
Me = CH_3

No.	R	R''	R'	cpd. isolated	m.p.	yield* per cent
1	PhO	UnO	PhNH	amide	51–51·5°	59
2	PhO	UnO	HO	Ba salt	—	66
3	PhO	BuO	β-$C_{10}H_7$,NH	amide	93–93·5°	59
4	PhO	BuO	HO	Ag salt	—	59
	PhO	MeO	PhNH	amide	77–77·5°	32
6	PhO	MeO	HO	Ba salt	—	43
7	PhO	UnO	UnO	ester	—	73
8	PhO	BuO	BuO	ester	b·p·125°/0·1	58
9	PhO	AmO	AmO	ester	b·p·135°/0·05	48
10	HO	UnO	UnO	free acid	53·5–54	72
11	HO	BuO	BuO	Ba salt	—	54
12	HO	MeO	MeO	Pb salt	141–142°	15

* Based upon P.P.D.C.

While yields of the alkylphenyl secondary, and symmetrical dialkyl-phenyl tertiary esters, actually isolated (reactions II → III and III → IV respectively) were fair for preparative purposes, they fell short of those suggested by estimation of the chloride ion produced. The discrepancy seems unlikely to be due to experimental methods of isolation, and the reaction

$$\text{PhOPOCl}_2 + \text{ROH} + \text{Py} \longrightarrow \text{PhOPO} \begin{array}{l} \text{OR} \\ \\ \text{Cl} \end{array} + \text{PyHCl}$$
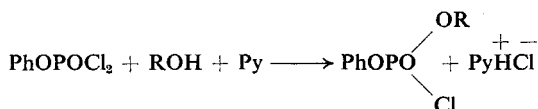
appears to be complicated by a consecutive side reaction.

Attempts to synthesize mixed dialkylphenyl phosphates under the reaction conditions delineated above, were less successful When Experiment 4 (see p. 616) was repeated on a preparative scale, we were unable to isolate any single pure fraction using chromatographic methods employed successfully elsewhere in this paper, although some of the required n-amyl phenyl n-undecyl phosphate was undoubtedly formed Exchange of alkyl radicles in highly polar solvents such as acetonitrile would seem a likely competing side reaction: attack of any tertiary base used upon the phosphorochloridate has already been suggested[21] The nature of such side reactions however has not been investigated.

Melting and boiling points are uncorrected. Microanalyses were performed by Mr. G. S. Crouch of this school, and by Drs. Weiler and Strauss, Oxford.

Materials

Phenyl phosphorodichloridate, prepared by the interaction of phenol and phosphoryl chloride[24,25], had b.p. 241 to 242°. Found: C, 34·3; H, 2·2; Cl, 33·6. Calc. for $C_6H_5O_2PCl_2$, C, 34·2; H, 2·4; Cl, 33·6 per cent.

n-*Undecanol* obtained by $LiAlH_4$ reduction of ethyl 9-undecenoate followed by hydrogenation of the double bond over palladium black, had b.p. 131°/14 mm., $n_D^{23°}$ 1·4392, saponification value zero.

Other materials, of reagent grade, were dried and redistilled.

Methods. Rate of Reaction of Phenyl Phosphorodichloridate (P.P.D.C.) with some Aliphatic Alcohols in the Presence of Pyridine

All reactions were conducted at 2 to 5°. The results of the undernoted experiments 1 to 4 are given graphically in Figure 1.

n-*Undecanol*

1. In each of five 50 ml. flasks a 2M solution of P.P.D.C. in light petroleum (b.p. 40 to 60°) (2·0 ml.) was rapidly mixed with a 2M solution of pyridine and n-undecanol (2·0 ml.). At intervals the contents of a flask were filtered, the precipitate washed rapidly with solvent and dissolved in water. Ionised chlorine in the aqueous solution was estimated gravimetrically as silver chloride. (Direct method.)

2. The experiment was repeated with twice the volume of alcohol-base solution. A duplicate experiment was made in which the reaction mixture was diluted with light petroleum (50 ml.), the chloride extracted with half-saturated ammonium nitrate solution and estimated gravimetrically. (Indirect method.) This procedure gave results which agreed well with those obtained by the direct method, and which were unaffected by the addition of acetonitrile (6·0 ml.).

n-*Undecanol* and n-*Pentanol*

Experiment 1 was prepared again and the reaction allowed to proceed for 1 hour. A 2M solution of pyridine and n-pentanol in light petroleum (b.p. 40 to 60°: 2·0 ml.) was added to the contents of each flask, and chloride determined in successive flasks at intervals by the direct method.

4. Experiment 3 was repeated with acetonitrile as solvent for the second stage: after one hour's reaction between n-undecanol, pyridine and P.P.D.C., light petroleum was removed *in vacuo* without heating. A molar solution of n-pentanol and pyridine in acetonitrile (4·0 ml.) was added, and chloride estimated in successive flasks at intervals by the indirect method.

n-*Undecanol* and 2-*Nitroethanol*

5. Experiment 4 was repeated with 2-nitroethanol in place of n-pentanol. After initial difficulties due probably to interaction of the

base with 2-nitroethanol[27], the same type of curve as in experiment 4 was obtained.

Derivatives of Alkyl Phenyl Phosphorochloridates

Phenyl n-*undecyl phosphorochloridate.* In a flask equipped with dropping funnel, sealed stirrer and guard tube was placed a solution of P.P.D.C. (2·11 g., 0·01 mole) in dry light petroleum (b.p. 60 to 80°; 20 ml.). The flask was immersed in an ice bath, and a solution in the same solvent (20 ml.) of *n*-undecanol (1·72 g., 0·01 mole) and dry pyridine (0·79 g., 0·01 mole) was added dropwise with stirring over a period of 15 min. The addition complete, stirring was continued at room temperature for 1 hr. The precipitated pyridine hydrochloride (1·16 g. calculated, 1·18 g.) was filtered off, and the filtrate concentrated at the pump, yielding crude *phenyl undecyl phosphorochloridate.* The n-*butyl* and *methyl* homologues were similarly prepared. An attempt to distil the methyl homologue under reduced pressure resulted in decomposition.

ON-*Diphenyl* O-n-*undecyl phosphoroamidate.* Crude phenyl undecyl phosphorochloridate (from 2·11 g. P.P.D.C.) was refluxed with aniline (1·86 g., 0·02 mole) in dry ethanol-free chloroform (40 ml.) for 4 hr. Solvent was removed at the pump, the residue dissolved in light petroleum (b.p. 60 to 80°) and the solution washed successively with N HCl, 1 per cent NaHCO$_3$ and water. After drying (Na$_2$SO$_4$) the solution was concentrated at the pump to yield a reddish-brown oil (3·64 g., 73 per cent) which was chromatographed on silica gel[30]. Isorefractive fractions were bulked, dissolved in dry ether, filtered (charcoal) and the ether evaporated. Colourless crystals of ON-*diphenyl* O-*undecyl phosphoroamidate* (2·41 g., 59 per cent) were obtained, m.p. 49 to 50°. For analysis the compound was twice recrystallised from aqueous ethanol; m.p. 51 to 51·5°. Found: C, 68·5; H, 8·5; N, 3·5; P, 7·7. C$_{23}$H$_{34}$NO$_3$P requires: C, 68·5; H, 8·5; N, 3·5; P, 8·1 per cent. The following were prepared similarly:

O-n-*Butyl* N-2-*naphthyl* O-n-*phenyl phosphoroamidate*, isolated in 59 per cent yield as an oil which was crystallised from aqueous ethanol; m.p. 90 to 91°. For analysis the compound was recrystallised from ether-light petroleum (2:5); m.p. 93 to 93·5°. Found: C, 67·2; H, 6·5; N, 4·0; P, 8·5. C$_{20}$H$_{22}$NO$_3$P requires: C, 67·6; H, 6·2; N, 3·9; P. 8·7 per cent.

O-*Methyl* ON-*diphenyl phosphoroamidate*, isolated in 36 per cent crude yield: m.p. 65 to 70°. The compound, twice recrystallised from ether-light petroleum (1:10), had m.p. 77 to 77·5°. Found: C, 60·5; H, 5·2; N, 5·1; P, 11·4. C$_{13}$H$_{14}$O$_3$NP requires: C, 59·3; H, 5·4; N, 5·3; P, 11·8 per cent.

Phenyl n-*undecyl phosphate.* Crude phenyl *n*-undecyl phosphorochloridate (from 10·55 g. P.P.D.C.) was shaken with N NaOH (100 ml.) for 2 hr., the solution neutralised with N HCl, extracted with chloroform and treated with a slight excess of 10 per cent BaCl$_2$ solution. The precipitate, washed well with water and dried *in vacuo*, weighed 13·0 g. (66 per cent). For analysis the salt was twice recrystallised from methanol-acetone (2:1). Found: C, 51·9; H, 7·4; P, 8·7. C$_{34}$H$_{56}$O$_8$P$_2$Ba requires: C, 51·6; H, 7·1; P, 7·8 per cent.

The barium salt (1·00 g.) was dissolved in boiling methanol and a slight excess of 0·1N HNO_3 added. The methanol was distilled off and the residue extracted with chloroform. The chloroform extract was divided into two parts, each of which was concentrated and dried to constant weight. Yield of *phenyl n-undecyl phosphate*, 0·81 g. (98 per cent), titration equivalent 332. $C_{17}H_{29}O_4P$ requires 328.

n-Butyl phenyl phosphate. Crude *n*-butyl phenyl phosphorochloridate (from 10·55 g. P.P.D.C.) was hydrolysed with N NaOH (100 ml.), the neutralised solution extracted with chloroform and acidified. The liberated acid was extracted into chloroform. Removal of the solvent left crude *n-butyl phenyl phosphate* (8·88 g., 77 per cent), titration equivalent 238; $C_{10}H_{15}O_4P$ requires 230.

The crude acid (8·0 g.) dissolved in acetonitrile (90 ml.) was shaken with silver oxide (3·2 g.) for 2 hours, the unreacted oxide filtered off and the filtrate diluted with ether (400 ml.).* After standing overnight at 0° the precipitate was collected, washed with ether and dried. Yield of *silver butyl phenyl phosphate*, 7·2 g. (59 per cent). For analysis the salt was thrice recrystallised from chloroform-benzene (1:4). Found: C, 35·8; H, 4·3; P, 9·2; Ag 32·3; equivalent weight (by titration with 0·1N KCl) 339. $C_{10}H_{14}O_4PAg$ requires: C, 35·6; H, 4·2; P, 9·2; Ag, 32·0 per cent; equivalent weight 337.

Extraction of an acidified aqueous solution of the silver salt (1·10 g.) with chloroform and removal of the solvent gave n-*butyl phenyl phosphate* (0·74 g., 99 per cent) as an oil. Titration equivalent 231; $C_{10}H_{15}O_4P$ requires 230.

Methyl phenyl phosphate. Crude methyl phenyl phosphorochloridate (from 10·55 g. P.P.D.C.) was hydrolysed as described for the butyl homologue. To the neutralised aqueous solution was added sodium chloride (30 g.) and 2N H_2SO_4 (25 ml.). Extraction with chloroform and removal of the solvent gave a residue (6·25 g.) which was dissolved in water. The solution was warmed with a slight excess of barium carbonate and filtered into a large excess of acetone. The precipitate was collected, washed with acetone and dried. Yield 4·4 g., (43 per cent). For analysis the compound was thrice recrystallised from methanol-ethanol (1:7). Found: C, 32·7; H, 3·2; P, 11·9. $C_{14}H_{16}O_8P_2Ba$ requires: C, 32·9; H, 3·2; P, 12·1 per cent. The free acid, isolated in a manner similar to that described for the butyl homologue, had a titration equivalent of 189. $C_7H_9O_4P$ requires 188.

Dialkyl Phenyl Phosphates and Dialkyl Phosphates

Phenyl di-n-undecyl phosphate. In a flask equipped with sealed stirrer, dropping funnel and guard tube was placed a solution of P.P.D.C. (7·03 g.) in dry acetonitrile (17 ml.). A solution of *n*-undecanol (11·46 g.) and dry pyridine (5·20 g.) in dry acetonitrile (10 ml.) was added dropwise over a period of 15 min. Stirring was continued for 3 hr. The solution was poured into 0·1N HCl (250 ml.) and the ester extracted into light

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* The silver salt was protected from light as far as possible.

petroleum. The organic layer was washed with N HCl and dried over Na_2SO_4 in the presence of $NaHCO_3$. The dry, filtered solution was diluted with dry light petroleum to 100 ml., and 10 ml. chromatographed upon silica gel.[30] Isorefractive fractions totalled 1·17 g. (73 per cent). This material was again chromatographed for analysis. Found: C, 70·3; H, 10·9; P, 6·3. $C_{28}H_{51}O_4P$ requires: C, 69·7; H, 10·6; P, 6·4 per cent. $n_D^{17·5°}$ 1·4691; d_4^{22} 0·979. R_L found, 138; calculated, 140. The remainder of the crude product was worked up similarly.

Di-n-undecyl phosphate. Phenyl di-*n*-undecyl phosphate (4·84 g.) dissolved in ethanol (30 ml.) was hydrogenated at atmospheric pressure over Adams' platinum oxide (0·5 g.) until the theoretical volume of hydrogen had been absorbed. The catalyst was filtered off and the filtrate adjusted to 100 ml. Titration of two 10 ml. portions confirmed that hydrogenolysis was virtually complete. Treatment of a further 10 ml. portion with benzylamine (0·11 ml.) and evaporation of the solvent gave a gummy residue; the benzylamine salt, if formed, could not be crystallised.

The remaining 70 ml. was evaporated to small volume and set aside at room temperature. After two days a crystalline mass (2·80 g., 98 per cent) was obtained; this was purified through its sodium salt. Dissolved in ethanol, the crude acid was treated with the theoretical volume of boiling 0·1N NaOH, the solution cooled to about 50° and acetone added until a slight permanent turbidity was produced. After some hours at 0° the sodium salt was collected, washed with water, acetone and ether and dried at 100°. Yield, 2·05 g. (70 per cent.) For analysis the salt was twice recrystallised from ethanol-water-acetone (1:2:7). Found: C, 59·5; H, 10·9; P, 6·7. $C_{22}H_{46}O_4PNa,H_2O$ requires: C, 59·2; H, 10·8; P, 6·9 per cent. The water of crystallisation was not completely removed by drying at 100°/0·1 mm. for 24 hr.

The pure acid was recovered by dissolving the sodium salt (1·0 g.) in ethanol (10 ml.) and adding a slight excess of 0·1N HCl. The suspension was warmed until the precipitate started to melt, cooled a little, and ethanol added until a clear solution resulted. After some hours at room temperature the crystalline product was collected, washed with 25 per cent ethanol and dried *in vacuo*. Yield, 0·75 g. (79 per cent), m.p. 53·5 to 54°. Found: C, 65·6; H, 11·7; P, 7·5; titration equivalent, 407. $C_{22}H_{47}O_4P$ requires C, 65·0; H, 11·6 P, 7·6 per cent; titration equivalent 407.

Di-n-butyl phenyl phosphate. The crude ester, prepared from 31·6 g. P.P.D.C. as described for the undecyl homologue, was purified by fractional distillation. Two distillations gave 24·5 g. (58 per cent), b.p. 125 to 125·5°/0·1 mm., n_D^{22} 1·4740, d_4^{22} 1·079, R_L found, 75; calculated, 75. Found: C, 58·8; H, 8·2; P, 10·7. $C_{14}H_{23}O_4P$ requires: C, 58·7; H, 8·1; P, 10·8 per cent.

Di-n-amyl phenyl phosphate was similarly prepared in 48 per cent yield, b.p. 134 to 135°/0·05 mm., n_D^{22} 1·4715, d_4^{22}1·053, R_L calculated, 84; found, 84. Found: C, 61·0; H, 8·9; P, 9·7. $C_{16}H_{27}O_4P$ requires: C, 61·2; H, 8·6; P, 9·9 per cent.

Di-n-butyl phosphate. Di-*n*-butyl phenyl phosphate (14·3 g.) dissolved in ethanol (40 ml.) was hydrogenolysed as described for the undecyl homologue. The filtered solution was adjusted to 100 ml. and two 10 ml. aliquots titrated to confirm complete hydrogenolysis. The rest was treated with a solution of crystalline barium hydroxide (6·3 g.) in boiling water (10 ml.), then with excess acetone. The collected gelatinous precipitate was washed with acetone and dried. Yield, 10·3 g. (93 per cent). For analysis the salt was twice recrystallised from absolute ethanol-water (60 : 1). Found: C, 34·6; H, 6·5; P, 11·2. $C_{16}H_{36}O_8P_2Ba$ requires: C, 34·6; H, 6·5; P, 11·1 per cent.

The free acid was isolated in 84 per cent yield as described for butyl phenyl phosphate. Titration equivalent, 212; $C_8H_{19}O_4P$ requires 210.

Dimethyl phenyl phosphate. The crude ester, prepared as described for the butyl homologue from 21·1 g. P.P.D.C., gave after extensive fractionation 4·45 g. of a liquid, b.p. 92·5°/0·1 mm., the analytical figures for which corresponded poorly with those required for the ester. Found: C, 45·9; H, 5·7; P, 14·3. $C_8H_{11}O_4P$ requires: C, 47·5; H, 5·5; P, 15·3 per cent.

Dimethyl phosphate. The above compound (7·4 g.) was hydrogenated as described for the butyl homologue until uptake ceased. The filtered solution was diluted to 200 ml. with ethanol, refluxed gently for 10 min. with lead monoxide (4·1 g.) and filtered while hot. The cooled solution deposited lead dimethyl phosphate (6·7 g., 80 per cent), m.p. 141·5 to 142·5°. The m.p. was not raised by recrystallisation from ethanol. A previous claim to have obtained this compound, m.p. 155°, would seem to be in doubt[28]. Found: C, 10·7; H, 2·7; P, 13·2; Pb, 46·3. $C_4H_{12}O_8P_2Pb$ requires: C, 10·5; H, 2·7; P, 13·5; Pb, 45·3 per cent.

The free acid was obtained by passing H_2S through a warm ethanol solution of the lead salt, filtering and concentrating the filtrate. Yield of dimethyl phosphate 98 per cent. Titration equivalent 127; $C_2H_7O_4P$ requires 126.

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