Cyclic Organophosphorus Compounds as Possible Pesticides. Part I. 1,3,2-Dioxaphospholans

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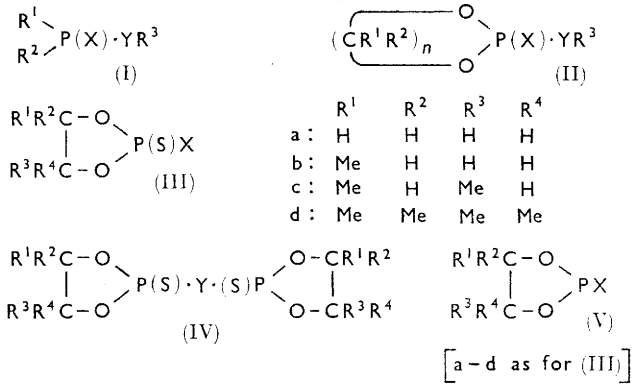
Butane-2,3-diol and 2,3-dimethylbutane-2,3-diol have been converted into substituted 2-mercapto-2-thiono-1,3,2-dioxaphospholans, and thence into 2-(*N*-substituted carbamoylmethyl)thio-derivatives. Some new ring-substituted 1,3,2-dioxaphospholans, with alkoxy, alkylthio, and dimethylamino groups attached to phosphorus, have also been prepared from aliphatic 1,2-diols. The hydrolytic stability and insecticidal activity of the esters are briefly discussed.

THE vast majority of insecticidal organophosphorus compounds so far prepared have the general structure (I; R^1,R^2 = alkoxy, generally OMe, OEt, or OPr^i; X, Y = O or S; R^3 = electron-withdrawing group).[1] In general, high toxicity of commercial value is confined to compounds in which R^1 and R^2 contain not more than three carbon atoms. This may be attributed to one or both of two possible effects. First, phosphorylation of cholinesterase may be subject to steric hindrance. Secondly, the order of nucleophilic reactivity towards the phosphorus in (I) (in the order OMe > OEt > OPr^i) also represents to a first approximation the rate of reaction with the enzyme. From a practical point of view, a balance must be sought between rate of deactivation (inhibition) and rate of activation of the enzyme, and between mammalian toxicity, insecticidal toxicity, and chemical stability. The diethoxy-esters are often the most useful as insecticides.

When we began this work, few attempts had been made to exploit, by variation in R^1 and R^2, the steric features (albeit unknown) in the enzyme molecule. Steric effects are thought to operate, as demonstrated [2] by the decrease in biological activity of the esters (I; R^1 = OEt, R^2 = alkyl, X = Y = O, R^3 = $C_6H_4{\cdot}NO_2$-*p*) with increase in chain length of R^2 to a greater degree than would be predicted on the grounds of electronic effects of R^2. Moreover, differences in reactivity of (−)- and (+)-isomers of *O*-ethyl-*S*-2-ethylthioethyl ethylphosphonothiolate (I; R^1 = OEt, R^2 = Et, R^3 = $CH_2{\cdot}CH_2{\cdot}SEt$, X = O, Y = S) have been found.[3]

This Paper and the following one describe a further attempt to modify reactivity by steric control. The compounds investigated were cyclic esters of phosphoric acid or its thio-derivatives (II; R^1, R^2 = H or alkyl,



n = 2 or 3, X = S, Y = O or S) in which R^3 was selected from among the numerous "anhydride residues," *e.g.*, *p*-nitrophenyl, carbamoylmethyl, or *N*-substituted carbamoylmethyl groups, often encountered among known active organophosphorus insecticides.

The methods which later were to prove useful for the

[1] T. R. Fukuto, *Advances in Pest Control Research*, 1957, **1**, 147; D. F. Heath, "Organophosphorus Poisons," Pergamon, London, 1961; R. D. O'Brien, "Toxic Phosphorus Esters," Academic Press, New York, 1960.

[2] T. R. Fukuto and R. Metcalf, *J. Amer. Chem. Soc.*, 1959, **81**, 372; T. R. Fukuto, R. Metcalf, and M. Y. Winton, *J. Econ. Entomol.*, 1959, **52**, 1121.

[3] T. R. Fukuto and R. Metcalf, *J. Econ. Entom.*, 1959, **52**, 739; H. S. Aaron, H. O. Michel, B. Witten, and J. I. Miller, *J. Amer. Chem. Soc.*, 1958, **80**, 456.

preparation of the simpler 2-thiono-1,3,2-dioxaphospholans could not readily be applied to more complex examples required for screening purposes. Thus, 2-chloro-1,3,2-dioxaphospholan when warmed with mercaptoacetamide and pyridine produced an intractable mixture. Mercaptoacetamide and 2-chloro-4-methyl-2-thiono-1,3,2-dioxaphospholan (IIIb; X = Cl), from propane-1,2-diol, thiophosphoryl chloride, and pyridine, gave, under essentially the same conditions, an oil. This was not examined further, but experiments in the 1,3,2-dioxaphosphorinan series suggested that this might contain the pyrophosphate (IV; R^1 = Me, R^2 = R^3 = R^4 = H, Y = O) or ring-opened products from this. The same phosphorochloridothionate with *p*-nitrophenol and triethylamine yielded the *p*-nitrophenoxy-ester (IIIb; X = O·C_6H_4·NO_2-*p*).

A more convenient route to the required esters [III; X = S·CH_2·CO·NHR′ (R′ = H, Me), S·CH_2·CO·morpholino] involved the initial preparation of the cyclic dithiophosphoric acids (III; X = SH). The tetramethyl phosphorodithioic acid (IIId; X = SH) was readily obtained from pinacol and phosphorus pentasulphide, together with a small amount of a substance probably possessing the structure (IV; R^1 = R^2 = R^3 = R^4 = Me, Y = S). This could arise by condensation of two molecules of the monocyclic phosphorodithioic acid. Treatment of the latter with ammonia in toluene gave the ammonium salt of the acid, which with *N*-methylchloroacetamide gave 4,4,5,5-tetramethyl-2-thiono-2-(*N*-methylcarbamoylmethyl)thio-1,3,2-dioxaphospholan (IIId; X = S·CH_2·CO·NHMe). The ring system evidently remained intact in this sequence, which served to characterise those which we carried out on the crude acids from propane-1,2- and butane-2,3-diols. These were prepared in the manner described for the acid from pinacol. The acid from propane-1,2-diol (IIIb; X = SH) has already been reported,[4] but we experienced explosions in attempts to distil the compound. Ethanediol gave a polymeric mass with phosphorus pentasulphide. Interaction of the phosphorodithiolic acid (IIIb; X = SH) and chloroacetamide in dry acetone in the presence of potassium carbonate gave a highly deliquescent uncharacterised substance.

In contrast, the ammonium salt from 4,5-dimethyl-2-mercapto-2-thiono-1,3,2-dioxaphospholan (IIIc; X = SH) reacted normally with chloroacetamide, *N*-methylchloroacetamide, and *N*-chloroacetylmorpholine, to give the desired esters [IIIc; X = S·CH_2·CO·NHR′ (R′ = H, Me) S·CH_2·CO·morpholino].

The insecticidal activity of the esters so far described was surprisingly low when tested against *Megoura viciae* and *Tetranychus telarius*. Soil systemic action was only slight, and the compounds showed little persistency of action. Indeed, the tetramethyl ester did not show any anticholinesterase effects *in vivo* (intraperitoneal injection in rats).

The marked anticholinergic properties of 4,5-benzo-1,3,2-dioxaphosphorinans[5,6] would seem to preclude steric resistance on the part of the enzyme as a possible explanation for the lack of activity exhibited by the 2-thiono-1,3,2-dioxaphospholans examined by us. The most attractive explanation of this appears to lie in the remarkable ease with which the 1,3,2 dioxaphospholan ring is opened under aqueous conditions,[7] suggesting that administration of the compound under biological conditions would lead to hydrolysis before the ring system had the opportunity to phosphorylate the enzyme. Such ring-opened products would be expected to exhibit little anticholinesterase effect. Phenyl 2-hydroxyethyl phosphate, HO·C_2H_4·O·P(O)(OH)OPh, and the phosphorothioic acid, HO·CMe_2·CMe_2·O·P(O)SH were obtained[8] by the hydrolysis of 2-oxo-2-phenoxy-1,3,2-dioxaphospholan and the ester (IIId; X = OEt), respectively, and shown not to possess anticholinesterase properties.

Both explanations have recently been offered for the lack of anticholinesterase activity of some 2-oxo-2-*p*-nitrophenoxy-1,3,2-dioxaphospholans studied recently.[9]

In order to study the stability of the dioxaphospholan system and the effect of ring-substitution upon reactivity of exocyclic bonds, we prepared some ring-substituted 2-thiono-1,3,2-dioxaphospholans, together with some 2-oxo-analogues, all of which had simple exocyclic groups attached to phosphorus. Aliphatic 1,2-diols were treated with phosphorus trichloride, and the resultant 2-chloro-1,3,2-dioxaphospholans (V; X = Cl) were then allowed to react with ethanol or ethanethiol in the presence of pyridine, or with 2 mol. of dimethylamine, to give 2-ethoxy-, 2-ethylthio-, and 2-*NN*-dimethylamino-1,3,2-dioxaphospholans (V; X = OEt, SEt, or NMe_2). New compounds are listed in Table 1. Addition of sulphur to the tertiary esters proceeded readily, particularly if initiated by slight warming, to yield the 2-thiono-1,3,2-dioxaphospholanes (III; X = OEt, SEt, or NMe_2). Within a particular series a, b, c, d, the ease of addition decreased in the order X = NMe_2 > SEt > OEt, and the degree of ring-substitution appeared to have little effect. Structures are readily assignable to the products from 2-*NN*-dimethylamino- and 2-ethylthio-1,3,2-dioxaphospholans, since isomerisation to thiolo forms cannot take place without rupture of the ring. The purified compounds did not contain isomers, as demonstrated by the lack of typical phosphoryl absorption in the infrared spectra. Nevertheless, the isomerisation of thionophosphates to the thiolo structure, P(S)OR ⟶ P(O)SR, is well established. Several authors[10-12] have obtained cyclic

[4] B.P. 759,334/1956.
[5] M. Eto, T. Eto, and Y. Oshima, *Agric. and Biol. Chem.* (*Japan*), 1962, **26**, 630.
[6] M. Eto, K. Hanada, Y. Namazu, and Y. Oshima, *Agric. and Biol. Chem.* (*Japan*), 1963, **27**, 723.
[7] Unpublished results; see also J. R. Cox and O. B. Ramsey, *Chem. Rev.*, 1964, **64**, 317.
[8] Unpublished results.
[9] T. R. Fukuto and R. Metcalf, *J. Medicin. Chem.*, 1965, **8**, 759.
[10] T. Yamasaki and T. Sato, *Sci. Reports Res. Inst., Tôhoku Univ.*, 1954, *A* **6**, 384; 1956, *A* **8**, 45.
[11] J. Cason, W. N. Baxter, and W. DeAcetis, *J. Org. Chem.*, 1959, **24**, 247.
[12] A. E. Arbuzov and N. A. Razumova, *Izvest. Akad. Nauk S.S.S.R., Otdel. khim. Nauk*, 1956, 187.

thioesters to which the thiono structure was assigned. The present work demonstrates that some doubt is attached to these conclusions. The 4,5-dimethyl compound (IIIc; X = OEt) could be distilled (bath temperature *ca.* 140°) with little change in the refractive index, but 2-ethoxy-2-thiono-1,3,2-dioxaphospholan was very sensitive to heat, as previously noted.[11] Perhaps, therefore, the stability of the thiono isomer is dependent on the degree of ring-substitution, and also on the size of the ring system. The method of preparation of the 2-ethoxy-2-thiono-esters was designed to ensure that the extent of isomerisation was kept to a minimum. Analyses and properties of the 2-thiono-esters, mostly new compounds, are in Table 2.

The results of our hydrolysis-rate determinations will be presented and discussed more fully elsewhere, but the main features of this study may be mentioned. Alkaline hydrolysis of 1,3,2-dioxaphospholans takes place easily, and involves ring cleavage rather than breakage of exocyclic bonds. Ring stability increases with increased substitution at carbon in the ring, and also with substitution at phosphorus in the order SEt < OEt < NMe_2. The candidate insecticides also hydrolyse rapidly, presumably in the same manner.

We had hoped that the cyclic analogues of acyclic insecticides would be sufficiently stable to phosphorylate cholinesterase without ring-opening, and so produce a phosphorylated enzyme which would then yield ring-opened derivatives either non-enzymically under biological conditions, or by an enzymic process. The resultant diesters could then be metabolised, thereby regenerating the enzyme, and thus eliminating the undesirable chronic toxicity associated with some organophosphorus insecticides. Our studies appear to demonstrate that the 1,3,2-dioxaphospholans are too unstable to allow even the initial phosphorylation reaction to proceed.

TABLE 1

2-Substituted-1,3,2-dioxaphospholans (V)

Compound	X	Yield (%)	B. p./mm.	n_D/temp.	Found (%) N	Found (%) P	Found (%) S	Formula	Reqd. (%) N	Reqd. (%) P	Reqd. (%) S
(Va)	SEt	38	53—56/1·5	1·5222/21·5°	—	20·05	21·1	$C_4H_9O_2PS$	—	20·35	21·1
(Vb)	SEt	55	47/0·4	1·5062/21·5	—	18·7	—	$C_5H_{11}O_2PS$	—	18·6	19·3
(Vc)	SEt	54	65/1·4	1·5015/22·5	—	17·0	16·9	$C_6H_{13}O_2PS$	—	17·2	17·8
(Vd)	SEt	10	81—94/2·4—3·0	1·4968/23·5	—	16·0	12·85	$C_8H_{17}O_2PS$	—*	14·85	15·35
(Vb)	NMe_2	81	56/5·5	1·4632/22·5	9·6	20·0	—	$C_5H_{12}NO_2P$	9·4	20·8	—
(Vc)	NMe_2	69	65·5/8·5	1·4619/24	7·7	18·8	—	$C_6H_{14}NO_2P$	8·6	19·0	—
(Vd)	NMe_2	92	80—81/5·0—5·5	1·4655/22	7·35	16·0	—	$C_8H_{18}NO_2P$	7·3	16·15	—

* See Experimental section.

TABLE 2

2-Substituted-2-thiono-1,3,2-dioxaphospholans (III)

Compound	X	Yield (%)	B. p./mm. (m. p.)	n_D/temp.	Found (%) N	Found (%) P	Found (%) S	Formula	Reqd. (%) N	Reqd. (%) P	Reqd. (%) S
(IIIa)	OEt[a]	87	—	1·4893/17	—	—	—	$C_4H_9O_3PS$[b]	—	—	—
(IIIb)	OEt[c]	94	—	1·4770/21	—	—	—	$C_5H_{11}O_3PS$	—	—	—
(IIIc)	OEt	94	66/0·06	1·4785/19	—	16·0	16·0	$C_6H_{13}O_3PS$[d]	—	15·8	16·35
(IIId)	OEt	81	—	1·4775/19	—	13·5	13·5	$C_8H_{17}O_3PS$[e]	—	13·8	14·3
(IIIa)	SEt	77	114/0·4	1·5540/21	—	16·6	33·9	$C_4H_9O_2PS_2$	—	16·8	34·8
(IIIb)	SEt	74	102—108/0·35—0·45	1·5407/22	—	15·7	—	$C_5H_{11}O_2PS_2$	—	15·6	32·35
(IIIc)	SEt	66	106/0·25	1·5327/23	—	14·0	29·0	$C_6H_{13}O_2PS_2$[f]	—	14·6	30·2
(IIId)	SEt	—	99—106/0·15	1·5222/20	—	13·0	26·3	$C_8H_{17}O_2PS_2$[g]	—	12·9	26·7
(IIIa)	NMe_2	84	(42·5—44)	—	8·8	18·85	19·7	$C_4H_{10}NO_2PS$	8·4	18·5	19·5
(IIIb)	NMe_2	75	98—102/0·2	1·5066/21	7·7	16·6	17·5	$C_5H_{12}NO_2PS$	7·75	17·05	17·7
(IIIc)	NMe_2	81	103—104/0·2	1·5018/21	7·1	15·7	15·85	$C_6H_{14}NO_2PS$	7·2	15·9	16·4
(IIId)	NMe_2	85	(32—33)	—	1·1	13·8	14·5	$C_8H_{18}NO_2PS$	6·3	13·85	14·4

[a] Lit.,[11] b. p. 79°/0·5 mm., n_D^{25} 1·4857. [c] Lit.,[2] b. p. 105—108°/3 mm., n_D^{20} 1·4265; lit.,[12] b. p. 102—104°/0·5 mm., n_D^{20} 1·4762.

	Found C	Found H	Reqd. C	Reqd. H
[b]	28·6	5·4	28·9	5·7
[d]	37·0	7·0	36·75	6·7
	42·6	7·75	42·9	7·65
	34·1	6·45	34·1	6·2
	40·15	7·3	39·6	7·1

EXPERIMENTAL

Melting points are corrected. Distillations were performed in a nitrogen atmosphere. Sodium sulphate was used to dry all diols and organic extracts. Benzene, toluene, and ether were dried over sodium; pyridine was

dried over sodium hydroxide. Inorganic phosphorus chlorides were distilled before use. Light petroleum had b. p. 60—80° unless otherwise stated. Infrared spectra were recorded with a Unicam S.P. 100 instrument. Liquids were examined between sodium chloride plates, and solids as potassium bromide discs or in solution in chloroform, carbon tetrachloride, or carbon disulphide.

2-*Chloro*-4-*methyl*-2-*thiono*-1,3,2-*dioxaphospholan*.—Propane-1,2-diol (152 g.) was added dropwise to thiophosphoryl chloride (339 g.) and pyridine (316 g.) in benzene (1·5 l.) at 35—40°. The mixture was stirred at this temperature for a further 1 hr., filtered, washed with water, dried, and distilled, giving the *compound* (111 g., 34%), b. p. 61—62°/0·1—0·2 mm., n_D^{20} 1·5102 (lit.,[10] b. p. 96—98°/3 mm., n_D^{16} 1·5112) (Found: Cl, 20·5; P, 17·8. Calc. for $C_3H_6ClO_2PS$: Cl, 20·6; P, 17·95%).

4-*Methyl*-2-p-*nitrophenoxy*-2-*thiono*-1,3,2-*dioxaphospholan*.—A solution of 2-chloro-4-methyl-2-thiono-1,3,2-dioxaphospholan (17·5 g.), *p*-nitrophenol (13·9 g.), and triethylamine (11·5 g.; 10% excess) in dry chlorobenzene (200 ml.) was boiled for 5 hr., cooled, washed with water, dried, and evaporated, to yield the oily *ester* (17·9 g., 65%), n_D^{18} 1·5675. The compound failed to crystallise, and could not be distilled (Found: N, 5·7; P, 11·4. $C_9H_{10}NO_5PS$ requires N, 5·1; P, 11·3%).

2-*Mercapto*-4,4,5,5-*tetramethyl*-2-*thiono*-1,3,2-*dioxaphospholan*.—Pinacol (101·5 g.; anhydrous) was added portionwise to a stirred suspension of phosphorus pentasulphide (95·5 g.) in toluene (200 ml.) at 90—100°. The mixture was then refluxed for 1 hr., cooled, filtered, and evaporated, leaving a brown crystalline solid which was recrystallised (76 g., 42%) from benzene–light petroleum, and finally from propan-2-ol, to give the cyclic *phosphorodithioic acid*, m. p. 67·5—68·5° (Found: C, 33·95; H, 6·4; P, 14·9; S, 29·7. $C_6H_{13}O_2PS$ requires C, 33·95; H, 6·2; P, 14·6; S, 30·2%).

The mother-liquors from the recrystallisation of the above acid furnished a small amount of a *substance*, m. p. 185·5—186° (from propan-2-ol) (Found: C, 38·6; H, 6·5; P, 16·8; S, 23·2. $C_{12}H_{24}O_4P_2S_3$ requires C, 37·0; H, 6·2; P, 15·9; S, 24·5%).

Dry ammonia was bubbled through a solution of the dithio-acid (21 g.) in toluene (600 ml.) below 5°. The *ammonium salt* (90%) which separated had m. p 229·5—230° (from ethyl acetate) (Found: N, 5·9; P, 13·1. $C_6H_{16}NO_2PS_2$ requires N, 6·1; P, 13·5%).

2-(N-*Methylcarbamoylmethyl*)*thio*-4,4,5,5-*tetramethyl*-2-*thiono*-1,3,2-*dioxaphospholan*.—The above ammonium salt (11·5 g.) was boiled with a solution of *N*-methylchloroacetamide (5·4 g.) in dry acetone (100 ml.) for 1 hr The mixture was filtered, the filtrate evaporated, and the residual solid recrystallised from ethyl acetate, to give the *compound* (9·0 g., 63%), m. p. 105—106° (Found: C, 38·15; H, 6·4; P, 10·9; S, 22·6 $C_9H_{18}NO_3PS_2$ requires C, 38·35; H, 6·8; P, 10·8; S, 22·65%).

4,5-*Dimethyl*-2-*mercapto*-2-*thiono*-1,3,2-*dioxaphospholan*.—Butane-2,3-diol (90 g.) was added dropwise to a stirred suspension of phosphorus pentasulphide (110 g.) in toluene (300 ml.) at 80—90°. Stirring was continued at this temperature until all the pentasulphide had dissolved. The solution was filtered, diluted to 1·5 l. with toluene, and dry ammonia passed into the solution at 0°. The *ammonium* salt (*ca.* 100 g., 50%) of 4,5-*dimethyl*-2-*mercapto*-2-*thiono*-1,3,2-*dioxaphospholan* separated, and was dried *in vacuo*. The salt could not be recrystallised, but the acid was characterised by reaction of the ammonium salt with *N*-methylchloroacetamide and *N*-chloroacetylmorpholine.

4,5-*Dimethyl*-2-(N-*methylcarbamoylmethyl*)*thio*-2-*thiono*-1,3,2-*dioxaphospholan*.—The above ammonium salt (20·1 g.) was heated with *N*-methylchloroacetamide (10·8 g.) in ethyl cellosolve (100 ml.) for 1·5 hr. Chloroform (500 ml.) was added, and the solution washed with water, dried, and evaporated, leaving a gummy residue which crystallised from propan-2-ol. The *product* (10·6 g., 42%) had m. p. 106—108° (from propan-2-ol) (Found: N, 5·75; P, 12·3; S, 25·3. $C_7H_{14}NO_3PS_2$ requires N, 5·5; P, 12·15; S, 25·1%).

4,5-*Dimethyl*-2-(N-*morpholinocarbonylmethyl*)*thio*-2-*thiono*-1,3,2-*dioxaphospholan*.—By a similar procedure, the same ammonium salt (40·3 g.) and *N*-chloroacetylmorpholine (32·8 g.) in methyl cellosolve (200 ml.) yielded the desired *ester* (44·0 g., 71%), m. p. 105—107° (from propan-2-ol) (Found: N, 4·7; P, 9·9; S, 20·9. $C_{10}H_{18}NO_4PS$ requires N, 4·5; P, 9·95; S, 20·6%).

2-*Chloro*-1,3,2-*dioxaphospholans*.—2-Chloro-1,3,2-dioxaphospholan, and its 4-methyl and 4,5-dimethyl derivatives, were prepared as described by Lucas *et al.*[13] The necessity for using freshly distilled chloroform was confirmed. 2-Chloro-4,4,5,5-tetramethyl-1,3,2-dioxaphospholan was prepared according to Arbuzov and Azanovskaya.[14]

2-*Ethoxy*-1,3,2-*dioxaphospholans*.—The cyclic phosphorochloridite was added dropwise to a mixture of ethanol and pyridine (1 mol. of each) in ether at 0—5°. The mixtures were filtered and distilled.

2-*Ethylthio*-1,3,2-*dioxaphospholans*.—The cyclic phosphorochloridite was added dropwise to ethanethiol and pyridine (1 mol. each) in ether at 0—5°.

The tetramethyl ester could not be completely freed from pyridine hydrochloride even by repeated distillation. This and the rapidity of oxidation resulted in poor analytical figures. The use of *NN*-diethylaniline to remove hydrogen chloride led to a sample of ester free from amine salt, but no improvements in analysis were obtained. The ester was characterised as its 2-thiono-derivative. Distillation of the reaction products afforded large, high-b. p. materials not examined further.

2-NN-*Dimethylamino*-1,3,2-*dioxaphospholans*.—The cyclic phosphorochloridite was added dropwise to dimethylamine (2 mol.) in ether at 0—5°. The mixtures were worked up in the usual way.

2-*Thiono*-1,3,2-*dioxaphospholans*.—Addition of a slight excess of recrystallised sulphur to the tertiary ester was carried out in a nitrogen atmosphere at 40—60° (ethoxy- and dimethylamino-esters) or at 50—70° (ethylthio-esters). The mixtures were stirred at room temperature for 2—3 hr. Dithio- and liquid dimethylamino-esters were distilled. The products from the phosphoramidites (Va, d; **X** = NMe_2) crystallised on cooling. They were purified by addition of light petroleum to a filtered solution of the reaction mixture in chloroform, and were then recrystallised from a mixture of the same solvents.

2-Ethoxy-2-thiono-compounds were warmed at 50—60° in as high a vacuum as possible to remove unattacked phosphite. 4,5-Dimethyl-2-ethoxy-2-thiono-1,3,2-dioxaphospholan was distilled unchanged. 2-Ethoxy-2-thiono-1,3,2-dioxaphospholan was very sensitive to heat. When a sample of the ester, prepared as described, was heated at

[13] H. J. Lucas, F. W. Mitchell, and C. N. Scully, *J. Amer. Chem. Soc.*, 1950, **72**, 5491.

[14] A. E. Arbuzov and M. M. Azanovskaya, *Izvest. Akad. Nauk S.S.S.R., Otdel khim. Nauk*, 1949, 473.

80—90° for 1·5 hr., the intensity of the infrared band at 690 cm.$^{-1}$ [ν(P=S)] decreased markedly. Heating a sample at 160° for 15 min. produced a change in refractive index at 25° from 1·4857 to 1·5060. The same effect was observed on distillation of the compound, with the result that the distillate contained both isomers.

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