Tetrahedron, 1965, Vol. 21, pp. 2379 to 2387. Pergamon Press Ltd. Printed in Northern Ireland

CYCLIC ORGANOPHOSPHORUS COMPOUNDS—III[1]

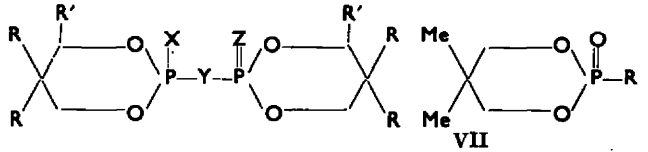
SOME STERICALLY HINDERED PYROPHOSPHATES

R. S. EDMUNDSON
Department of Chemical Technology, The Bradford Institute of Technology, England

(*Received* 14 *April* 1965)

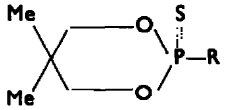
Abstract—The synthesis of four new bicyclic pyrophosphates derived from 2,2-dimethylpropane-1,3-diol is described. Their IR spectra are discussed.

IN A preliminary note[2] the synthesis of one, and probably of a second, isomeric, monothiopyrophosphate derived from 2,2-dimethylpropane-1,3-diol was reported. This paper is concerned with the preparation of other pyrophosphates from the same diol. Few other pyrophosphates based on ring systems containing phosphorus have previously been obtained. Bis(2-oxo-1,3,2-dioxaphosphorinanyl) oxide (I) was described by Khorana *et al.*[3] Lanham[4] obtained a number of similar bicyclic pyrophosphates from monocyclic phosphorochloridates by a standard procedure. Only one bicyclic dithiopyrophosphate, namely bis(4-methyl-2-thiono-1,3,2-dioxaphosphorinanyl) oxide (II) appears to have been reported.[5]



VII

I R = R′ = H; X = Y = Z = O
II R = H, R′ = Me; X = Z = S, Y = O
III R = Me, R′ = H; X = Y = Z = O
IV R = Me, R′ = H; X = Z = S, Y = O
V R = Me, R′ = H; X = Y = S, Z = O
VI R = Me, R′ = H; X = Y = Z = S



VIII

No difficulty was encountered in the synthesis of bis(5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinanyl) oxide (III) by Khorana's procedure. 2-Chloro-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (VII; R = Cl), previously described by McConnell and Coover,[6] but now prepared in slightly better yield by a modified route, was readily hydrolysed in boiling aqueous acetone to give an excellent yield of the parent acid (VII; R = OH) characterized as its cyclohexylammonium salt. The acid itself has been described as forming a monohydrate[6] but Meston[7] states that the compound is anhydrous even after crystallization from water. The present acid, similarly crystallized,

[1] Part II; R. S. Edmundson, *Tetrahedron* **20**, 2781 (1964).
[2] R. S. Edmundson, *Chem. & Ind.* 784 (1963).
[3] H. G. Khorana, G. M. Tener, R. S. Wright and J. C. Moffatt, *J. Amer. Chem. Soc.* **79**, 430 (1957).
[4] W. M. Lanham, B. Pat. 770,419 (to Union Carbide and Carbon Corp.).
[5] B. A. Arbuzov, N. V. Nikonorov, G. M. Vinokurova, O. N. Fedorova and Z. G. Shishoba, *Izvest. Kazan, Filiala Akad. Nauk S.S.S.R., Ser. Khim. Nauk*, 3 (1955); *Chem. Abstr.* **52**, 241 (1958).
[6] R. L. McConnell and H. W. Coover Jnr., *J. Org. Chem.* **24**, 630 (1959).
[7] A. M. Meston, *J. Chem. Soc.* 6059 (1963).

was not altered by heating *in vacuo* at 100° over P_2O_5. Interaction of the cyclic phosphoric acid and dicyclohexylcarbodiimide in acetonitrile, gave the desired pyrophosphate in good yield.

The same compound was isolated during preliminary attempts to prepare a mixed bicyclic phosphorous–phosphoric anhydride from 2-chloro-5,5-dimethyl-1,3,2-dioxaphosphorinane and the potassium salt of the acid (VII; R = OH). Its formation could conceivably have taken place by phosphorylation of the phosphoric acid anion by mixed anhydride produced in an initial step. Other attempts to prepare the PP'-dioxo anhydride e.g. from the same potassium salt and the phosphorochloridate, met with little success and are not described further (see later).

The present work was initiated by attempts to confirm the structure of a dithiopyrophosphate, now known to be bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) oxide (IV). In previous unpublished work[8] attempts to prepare cyclic analogues of well established organophosphorus insecticides by interaction of cyclic phosphorochloridothionates and mercaptoamides lead to dithiopyrophosphates rather than to the expected phosphorodithioates. These experiments have been partly repeated and confirmed, and to a certain extent developed further.

2-Chloro-5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinane (VIII; R = Cl) prepared from the diol and thiophosphoryl chloride in the presence of pyridine, proved to be unreactive towards triethylamine in either wet or dry dioxan. On the other hand, 18% of the dithiopyrophosphate was generated using pyridine in moist dioxan in a similar experiment. Low yields of the same compound were also obtained when the phosphorochloridothionate and pyridine were heated together in undried chloroform or di-isopropyl ether. In contrast, good yields of the anhydride were formed when the phosphorochloridothionate and pyridine were heated together in the presence of either mercaptoacetamide or N-methylmercaptoacetamide, in the same, undried solvents. The formation of the pyrophosphate bond from acid chlorides and thiols in the presence of pyridine was further exemplified when it was found that the phosphorochloridate (VII; R = Cl) and ethanethiol slowly furnished the pyrophosphate (III). Further attempts (not described in the Experimental Section) to obtain the dithiopyrophosphate (IV) or its isomer (V) by reaction between the triethylammonium or potassium salts of the phosphorothioic acid (VII; R = SH; alternatively as VIII; R = OH) and the phosphorochloridothionate were unsuccessful. The high temperatures (e.g. boiling tetralin) necessary to induce reaction, lead to intractable tars.

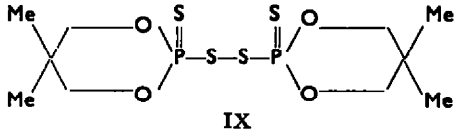
The lack of reactivity exhibited by the two acid chlorides (VII; R = Cl) and VIII; R = Cl) suggested that little success might be expected in reactions between them and the phosphorodithioic acid (VIII; R = SH) or its salts, leading to dithio- or trithiopyrophosphates. However, in two reported experiments in which the ammonium salt[9] of the dithioic acid and the phosphorochloridate were allowed to react in either hot ethyl methyl ketone or cold dimethylformamide, the phosphoric acid (VII; R = OH) and the pyrophosphate (III) were obtained respectively, together with NH_4Cl in each case. The latter result is perhaps not surprising in view of Cramer and Winter's work[10] on the interaction of dialkyl phosphorochloridates with dimethylformamide giving tetraalkyl pyrophosphates.

[8] R. S. Edmundson and A. J. Lambie, unpublished work.
[9] Dr. A. J. Lambie is thanked for a sample of this salt.
[10] F. Cramer and M. Winter, *Chem. Ber.* **94**, 989 (1961).

Michalski and Wasiak[11] recently examined the action of dialkyl phosphites on disulphides. Bis(dialkoxyphosphinyl) disulphides and bis(dialkoxyphosphinothioyl) disulphides respectively afforded monothio- (thiono) and unsymmetrical dithiopyrophosphates. The second of these reactions, (A), was adapted to prepare the dithiopyrophosphate (V).

$$(RO)_2P{\cdot}HO + (RO)_2P(:S){\cdot}S{\cdot}S{\cdot}(S:)P(OR)_2 \longrightarrow (RO)_2P(:O){\cdot}S{\cdot}(S:)P(OR)_2 + (RO)_2POSH \quad (A)$$

Bis(dialkoxyphosphinothioyl) disulphides have themselves been obtained from OO-dialkyl phosphorodithioic acids by direct chlorination,[12,13] bromination,[13,14] oxidation with N-chlorosuccinimide,[15] $NaNO_2$,[16] or 30% H_2O_2.[13] Bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide (IX) was obtained in low yield only by treatment of 5,5-dimethyl-2-thiolo-2-thiono-1,3,2-dioxaphosphorinane in aqueous alkali with $NaNO_2$ or by oxidation of the ammonium salt with H_2O_2. This latter reaction unexpectedly afforded similar amounts of the trithiopyrophosphate (VI). The best procedure for the preparation of the disulphide involved direct oxidation of salts of the phosphorodithioic acid with iodine under aqueous conditions.



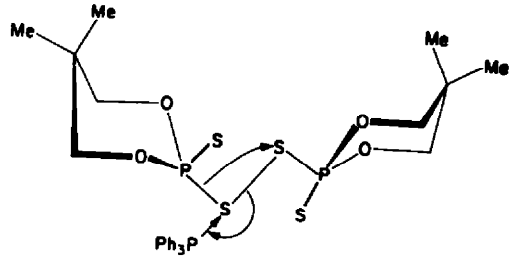
IX

Reaction between the disulphide and the hydrogen phosphonate (VII; R = H)[6] gave the unsymmetrical dithiopyrophosphate satisfactorily.

Bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide reacted exothermically with triphenylphosphine giving good yields of both triphenylphosphine sulphide and bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulphide (VI). The ease with which this reaction proceeded is remarkable bearing in mind the general lack of reactivity of substituted 5,5-dimethyl-1,3,2-dioxaphosphorinanes to nucleophilic attack, and the "low yields" of tetraalkyl trithiopyrophosphates obtained by Mel'nikov *et al.*[17] by partial desulphurization of bis(dialkoxyphosphinothioyl) disulphides by the same reagent, although much higher yields of the trithiopyrophosphates can be obtained using triphenyl phosphite.[18] Apart from the few cases reported by the Russian workers, no systematic studies on the desulphurization of bis(phosphinothioyl) disulphides by triphenylphosphine have been carried out. Moore and Trego[19] have commented on the inability of triphenylphosphine to desulphurize dialkyl and diaryl sulphides in contrast to dialkenyl disulphides, which are converted to the monosulphide

[11] J. Michalski and J. Wasiak, *J. Chem. Soc.* 5056 (1962).
[12] T. Yamasaki, *Sci. Reports Res. Inst. Tohoku Univ.* **4A**, 403 (1952). *Chem. Abstr.* **48**, 5075 (1954).
[13] Ping-Fang Hu, Shou-Chang Li and Wan-Yi Chen, *Hau Hsuëh Hsuëh Päo* **22**, 49 (1956); *Chem. Abstr.* **52**, 6156 (1954).
[14] Ping-Fang Hu, Wan-Yi Chen, *Hua Hsuëh Hsuëh Päo* **22**, 215 (1956); *Chem. Abstr.* **52**, 7186 (1954).
[15] S. Truchlík, J. Mašek and J. Drábek, *Chem. Zvesti* **11**, 579 (1957).
[16] B. Miller, *Tetrahedron* **20**, 2069 (1964).
[17] N. N. Mel'nikov, K. D. Shvetsova-Shilovskaya and T. L. Italinskaya, *Zh. Obshch. Khim.* **32**, 847 (1962); *Chem. Abstr.* **58**, 1342 (1963).
[18] N. N. Mel'nikov, K. D. Shevtsova-Shilovskaya and M. Ya Kagan, *Zh. Obshch. Khim.* **30**, 2319 (1960); *Chem. Abstr.* **55**, 9320 (1961).
[19] C. G. Moore and B. R. Trego, *Tetrahedron* **18**, 205 (1962).

(or rearranged monosulphide) albeit very slowly. Opinion is generally[20,21] that the desulphurization by tervalent phosphorus derivatives proceeds by nucleophilic attack via the lone electron pair on the phosphorus on to one sulphur atom of the disulphide bridge. Molecular models indicate that bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide probably has a structure such as X in which the two rings are twisted relative to each other. Such an arrangement leaves the disulphide bond sufficiently unhindered to be attacked either from a position vertical to the P—S—S—P plane, or by direct in-line movement. The trithiopyrophosphate could then be produced by cleavage into phosphorodithioate anion and attack of this on the residual ion $Me_2C(CH_2O)_2PS_2\cdot\overset{\oplus}{P}Ph_3$, or by simultaneous breakage of the disulphide bond with rearrangement as shown in X.



X

Confirmation of the structures of the four new pyrophosphates was obtained on the basis of their IR spectra, and their reactions with cyclohexylamine, a procedure already known[22] to split tetraalkyl- and tetraaryl pyrophosphates into phosphoramidates and the cyclohexylammonium salts of the phosphoric acids. Thus the pyrophosphate (III) with cyclohexylamine in boiling toluene gave 2-N-cyclohexylamino-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (VII; R = NHC_6H_{11}-cyclo; 75%) and the cyclohexylammonium salt of the acid (VII; R = OH; 81%).

The sulphur-containing pyrophosphates reacted with the same amine only under equally, or more forcing conditions. The anhydride bond of the symmetrical dithiopyrophosphate (IV) yielded as expected, although poorly, the N-cyclohexyl phosphoroamidothionate (VIII; R = NHC_6H_{11}-cyclo) and the amine salt of the previously described phosphorothioic acid (VIII; R = OH)[1] as the only degradation products. Paper chromatography failed to detect any of the amine salt of the phosphorodithioic acid (VIII; R = SH). This fact served to distinguish between the symmetrical and unsymmetrical dithiopyrophosphates. Michalski and Wasiak's observations on the splitting of tetraalkyl P-oxo-P'-thiono dithiopyrophosphates by sodium alkoxide giving trialkyl phosphates and OO-dialkyl phosphorodithioates suggested that in the present case, cleavage of the P—S—P system might also be specific. However, compound V gave a mixture of the amine salts of the mono- and di-thioic acids in the ratio 1:2 approximately, as indicated by elemental analysis and paper chromatography. The latter also demonstrated the simultaneous formation of the N-cyclohexyl phosphoramidothionate.

[20] C. G. Moore and B. R. Trego, *J. Chem. Soc.* 4205 (1962).
[21] J. I. G. Cadogan, *Quart. Rev.* **16**, 208 (1962).
[22] N. S. Corby, G. W. Kenner and A. R. Todd, *J. Chem. Soc.* 1234 (1952).

The trithiopyrophosphate gave the expected N-cyclohexyl phosphoramidothionate and the salt of the phosphorodithioic acid.

The forcing conditions necessary to bring about appreciable reaction between the bicyclic pyrophosphates and cyclohexylamine imply a high degree of steric resistance to the reaction on the part of the ring systems. There action between 00-dibenzyl 00-diphenyl pyrophosphate and cyclohexylamine in cold benzene takes place quickly.[22] In addition the gem dimethyl groups at C_5 also exert a pronounced retarding action in a number of reactions.[23]

Further evidence as to the structure of the pyrophosphates is available from their IR spectra. As already noted[1] for a number of other phosphoramidates and phosphoramidothionates of types VII and VIII (R = NHR'), the two derivatives here described (VII; VIII; R = NHC_6H_{11}-cyclo) show IR absorption at two positions within the range 1000 to 1070 cm^{-1} in addition to weaker absorption at around 1185 cm^{-1}.[24]

The most important feature in the spectra as regards structural assignments, is the presence or otherwise of absorption due to P=O. In both bis(5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinanyl) oxide and P-oxo-P'-thiono-bis(5,5-dimethyl-1,3,2-dioxaphosphorinanyl) sulphide, the phosphoryl group is observed as a very strong band, in the former case as a doublet centred at 1315 cm^{-1}, and in the latter at 1297 cm^{-1}. Such a band is not observed in the spectra of the remaining compounds. The above figures are in agreement with the ranges suggested by Thomas and (Miss) Chittenden.[25]

The principal differences in the spectra of the above two compounds are to be found in the region below 700 cm^{-1}. Thus the unsymmetrical dithiopyrophosphate absorbs very strongly at 684 cm^{-1} and this band is assigned to P=S following from the previous study.[1] The frequency is too high to be associated with P—S—P stretching thought to be at around 500 cm^{-1}.[26] Bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) oxide exhibits a band at 682 cm^{-1} absent from the spectrum of pyrophosphate (III) and again assigned to P=S. In neither of the spectra of compounds IV or V is there a band at around 810 to 860 cm^{-1} which would fit into the pattern as depicted by (Miss) Chittenden and Thomas.[26] The situation with respect to the disulphide (IX) and the trithiopyrophosphate (VI) is less clear, The latter shows a band at 656 cm^{-1} which might be due to P=S, but the band at 717 cm^{-1} is close enough to warrant consideration here.

The pyrophosphate (III) exhibits a fairly broad band at 948 cm^{-1}, the symmetrical dithiopyrophosphate at 930 cm^{-1}, and the monothiono-pyrophosphate at 942 cm^{-1}. This band is absent from the remaining spectra and is assigned to P—O—P.[27] It is characterized by its relative broadness compared with the numerous other bands in the range 900 to 1100 cm^{-1}. The pattern of absorption within the range 1000 to 1100 cm^{-1} follows closely that already observed for similar monocyclic compounds.[1] In general, of the three bands which may be encountered,[1] the middle band at around 1040 cm^{-1} for P-oxo derivatives, and at around a slightly lower figure for some P-thiono compounds, is absent from all the pyrophosphate spectra, suggesting that it is specifically linked with exocyclic P—O—C arrangements.

[22] See for example, R. S. Edmundson, *Chem. of Ind.* 1828 (1962).
[24] Ref. 1, Table 2, item 35: a band at 1013 cm^{-1} has been accidentally omitted.
[25] L. C. Thomas and Rosemary A. Chittenden, *Spectrochim. Acta* **20**, 467 (1964).
[26] Rosemary A. Chittenden and L. C. Thomas, *Spectrochim. Acta* **20**, 1679 (1964).
[27] L. C. Thomas and Rosemary A. Chittenden, *Spectrochim. Acta* **20**, 489 (1964).

EXPERIMENTAL

General experimental procedures are those employed previously.[1] M.ps are uncorrected. IR spectra were determined in KBr discs using an Infracord 237 spectrophotometer. Paper chromatography was carried out on Whatman No. 1 paper using the ascending technique. Sulphur-containing compounds were spotted by spraying with 0·5% w/v 2,6-dibromo-*p*-benzoquinone-4-chloroimine in CCl_4 or cyclohexane.[28] With this reagent, and more particularly on heating, compounds containing P=S give a deep purple-brown colouration, while for those containing only P—S—, orange spots are observed.

2-Chloro-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane

A solution of 2,2-dimethylpropane-1,3-diol (83·2 g) in warm benzene (400 ml) was added portionwise during 1·5 hr to a stirred mixture of $POCl_3$ (123 g) and pyridine (134 g) in benzene (200 ml) at 40–50°. The stirring was continued for a further 2 to 3 hr at the same temp. The mixture was cooled and poured into ice-cold water. The benzene layer was washed with dil. HCl, then with water, and dried (Na_2SO_4). The solvent was removed *in vacuo* leaving a solid which was recrystallized from 1,2-dichloroethane. The acid chloride (99 gm, 67%) had m.p. 104·5–106°. (Lit.[6] m.p. 102–103°.)

5,5-Dimethyl-2-hydroxy-2-oxo-1,3,2-dioxaphosphorinane

A solution of the above acid chloride (15·0 g) in 50% v/v aqueous acetone (80 ml) was heated over steam for 1·5 hr and then allowed to stand overnight. The acetone was removed by boiling, and the aqueous solution cooled to give the desired acid (12·8 g, 94%), m.p. 174–176° (from water) after drying *in vacuo* at 100° over P_2O_5. (Lit.[6] m.p. 174–176°.)

The cyclohexylammonium salt (needles from isopropanol or ethanol–ethyl acetate) had m.p. 240–245°. (Found: N, 5·4; P, 11·8; $C_{11}H_{24}NO_4P$ requires: N, 5·3; P, 11·95%.)

The potassium salt was prepared by neutralization of the acid with aqueous $KHCO_3$ solution, evaporation of this to dryness, and drying of the solid *in vacuo* over P_2O_5.

Bis(5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinanyl) oxide

Dicyclohexylcarbodiimide (1·75 g) in acetonitrile (25 ml) was added to 5,5-dimethyl-2-hydroxy-2-oxo-1,3,2-dioxaphosphorinane (2·5 g) in acetonitrile (100 ml). Precipitation of dicyclohexylurea commenced almost at once. The mixture was allowed to stand for 4 hr at room temp, and then filtered. Evaporation of the filtrate, and recrystallization of the resulting solid from ethyl acetate gave the pyrophosphate (2·05 g; 87%), m.p. 193–195.° (Found: C, 38·35; H, 6·35; P, 19·9; $C_{10}H_{20}O_7P$ requires: C, 38·3; H, 6·4; P, 19·7%.)

The IR spectrum showed bands at 1478 m, 1377 m, 1360 w, 1318 s and 1312 s (doublet), 1230 w, 1211 w, 1066 s, 1014 m, 989 s, 962 s, 948 s, 922 m, 862 m, 835 w, 787 m, 684 w.

2-N-cyclohexylamino-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane

A solution of 2-chloro-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (9·25 g) in benzene (75 ml) was added portwise to cyclohexylamine (5·0 g) and triethylamine (5·0 g) in warm benzene (25 ml). The mixture was boiled for 1 hr and allowed to stand overnight when it was diluted with $CHCl_3$ (1 vol) and washed with water. The dried organic layer was evaporated and the solid recrystallized from benzene. The phosphoramidate (9·0 g, 73%) had m.p. 187–188°. (Found: C, 53·1; H, 8·95; P, 13·3; $C_{11}H_{22}NO_3P$ requires; C, 53·5; H, 8·95; P, 12·5%.) The IR spectrum includes bands at 3200 s (NH), 1253 s (P=O), 1146 w, 1053 s, 1033 w, 1013 s.

Reaction between cyclohexylamine and bis(5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinyl) oxide

A solution of the anhydride (1·55 g) and cyclohexylamine (1·1 g) in toluene (10 ml) was boiled for 7 hr and filtered hot. The residue was the cyclohexylammonium salt of the cyclic phosphoric acid, m.p. 236–239° (from isopropanol), and amounted to 1·53 g, (81%). 2-N-Cyclohexylamino-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (0·93 g, 75%) was deposited on cooling the toluene filtrate.

2-Chloro-5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinane

A solution of 2,2-dimethylpropane-1,3-diol (20·8 g) in warm benzene (60 ml) was added portionwise during 1·5 hr to $PSCl_3$ (33·8 g) and pyridine (31·6 g) in benzene at 50–70°. The mixture was finally stirred at 70–80° for 0·5 hr, cooled and washed with ice-cold water. The dried benzene solution

[28] J. J. Mann, W. R. Erwin and H. T. Gordon, *J. Agric. Food Chem.* **5**, 601 (1957).

was evaporated yielding an oil which solidified. The phosphorochloridothionate (33·0 g, 82%) was recrystallized from petroleum ether b.p. 60–80°, when it had m.p. 90–91·5°. (Found: Cl, 17·9; P,15·5; S, 16·4; $C_8H_{10}ClO_3PS$ requires: Cl, 17·7; P, 15·1; S, 16·0%.)

Reaction between 2-chloro-5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinane and pyridine, in the presence, and absence, of mercaptoacetamide and N-methylmercaptoacetamide

A solution of the cyclic phosphorochloridothionate (20·0 g), pyridine (8·0 g) and mercaptoacetamide (10·5 g) in $CHCl_3$ (200 ml; $CaCl_2$ dried) was refluxed with stirring. The amide gradually dissolved during 3 hr. The cooled solution was washed with water, dried, and concentrated when it afforded bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) oxide, as needles (11·5 g; 66%), m.p. 229·5–230°. Repeated recrystallization of the product from benzene raised the m.p. to 233°. (Found: C, 34·8; H, 5·9; P, 17·9; S, 18·3; $C_{10}H_{20}O_6P_2S_2$ requires; C, 34·8; H, 5·85; P, 17·9; S, 18·5%.) The IR spectrum showed bands at 1482 m, 1472 m, 1462 m, 1403 m, 1387 w, 1374 m, 1368 m, 1356 w, 1312 w, 1288 w, 1227 m, 1214 m, 1182 w, 1055 s, 1005 s, 977 s, 968 s, 928 s, 915 s, 853 s, 841 s, 796 s, 778 s, 682 s.

Heating the phosphorochloridothionate with equivalent quantities of pyridine and the thiol in di-isopropyl ether (peroxide-free and dried over Na) for 4 hr gave 50% of the same dithiopyrophosphate.

Similar experiments using N-methylmercaptoacetamide gave comparable yields of the same product.

Heating the phosphorochloridothionate (10·0 g) with pyridine (4·0 g) in $CHCl_3$ (100 ml) for 5 hr gave no dithiopyrophosphate. Using undried pyridine and chloroform, ca. 2% of the dithiopyrophosphate was produced, and the same yield was obtained using di-isopropyl ether as solvent.

Heating the phosphorochloridothionate (2·0 g) with pyridine (0·8 g) and water (0·1 g) in dioxan (10 ml) for 3·5 hr gave 18% of the dithiopyrophosphate.

Stability of 2-chloro-5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinane towards triethylamine

The phosphorochloridothionate (1·00 g) and triethylamine (0·50 g) were boiled together in dry dioxan for 3 hr. There was no formation of triethylammonium hydrochloride. Water (3 drops) was added and the boiling continued for a further 20 hr, when the mixture was poured into water. Crystallization of the insoluble portion from acetone failed to give any of the dithiopyrophosphate, 86% of the acid chloride being recovered.

Action of ethanethiol and pyridine on 2-chloro-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane

A mixture of ethanethiol (8 ml), pyridine (7·9 g) and the phosphorochloridate (18·5 g) in ether (75 ml)-benzene (100 ml) was allowed to stand at room temp for 6 months. A crystalline solid was slowly deposited. This was bis(5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinanyl) oxide (3·0 g). Evaporation of the solvents yielded a further 2·0 g of the same compound.

5,5-Dimethyl-2-oxo-1,3,2-dioxaphosphorinane

This, b.p. 110–114°/0·9 mm, was prepared in 75–81% yield by McConnell and Coover's method, and in slightly lower yields by the transesterification procedure described by Ostwald.[20] The cyclohexylammonium derivative had m.p. 157–158° from ethyl acetate–$CHCl_3$. (Found: N, 5·3; P, 11·95; $C_{11}H_{24}NO_3P$ requires: N, 5·6; P, 12·4%.)

5,5-Dimethyl-2-hydroxy-2-thiono-1,3,2-dioxaphosphorinane

Sulphur (3·2 g) was added portionwise to the cyclic hydrogen phosphonate (15·2 g) and triethylamine (10·8 g) in benzene (75 ml). The solution was filtered and evaporated, and the triethylammonium salt was recrystallized from ethyl acetate. The salt (25·0 g) had m.p. 70·5–72·5°. (Found: P, 10·7; $C_{11}H_{26}NO_3PS$ requires: P, 10·9%.)

The cyclohexylammonium salt was prepared in a like manner and had m.p. 238–242° (needles from isopropanol–pet. ether) and was identical (IR spectrum and mixed m.p.) with a sample obtained previously by the initial aqueous alkaline hydrolysis of the cyclic phosphorochloridothionate.

[20] A. Ostwald, *Canad. J. Chem.* 37, 1498 (1959).

2-N-cyclohexylamino-5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinane

This was prepared in 71% yield essentially as described for the analogous 2-oxo compound. The phosphoramidothionate had m.p. 98–99° from pet ether. (Found: C, 50·3; H, 8·35; P, 11·7; $C_{11}H_{22}NO_2PS$ requires: C, 50·3; H, 8·45; P, 11·8%.)

The IR spectrum includes bands at 3315 s (NH), 1140 m, 1048 s, 1027 m, 1000 s cm^{-1}.

Reaction between bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) oxide and cyclohexylamine

A solution of the anhydride (1·6 g) and the amine (1·5 ml) in toluene (10 ml) was refluxed for 8·5 hr. Filtration of the cold mixture gave a solid (1·4 g) which on extraction with water left the insoluble unreacted anhydride (0·8 g). Evaporation of the aqueous extract gave the cyclohexylammonium salt of the cyclic phosphorothioic acid m.p. 240° from isopropanol (0·4 g; 31%).

The toluene filtrate on evaporation gave a gum which crystallized from ether. The yield of the N-cyclohexyl phosphoramidothionate was 0·3 g (26%).

5,5-Dimethyl-2-thiolo-2-thiono-1,3,2-dioxaphosphorinane

2,2-Dimethylpropane-1,3-diol (41·6 g) in hot toluene (200 ml) was added portionwise to a stirred suspension of P_2S_5 (44·8 g) in toluene at 60–80°. The mixture was boiled under reflux for 2·5 hr, filtered, and evaporated to an oil which crystallized on cooling. The cyclic phosphorodithioic acid (38·5 g; 49%) m.p. 81–82°, was recrystallized from ether or pet ether. (Found: C, 30·6; H, 6·0; P, 15·8; S, 32·3; $C_5H_{11}O_2PS_2$ requires: C, 30·3; H, 5·6; P, 15·6; S, 32·4%.) The cyclohexylammonium salt, obtained in benzene solution, had m.p. 216–217° from $CHCl_3$–pet ether. (Found: 44·0; H, 8·1; P, 9·9; $C_{11}H_{24}NO_2PS_2$ requires: C, 44·4; H, 8·15; P, 10·4%.)

Bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide

(a) A solution of 21·5 g of the ammonium salt of the above phosphorodithioic acid in water (150 ml) was stirred at room temp while I_2 (12·7 g) dissolved in KI solution (25 g in 100 ml water) was added dropwise. The brown solid was filtered off, washed with water and recrystallized from EtOH to yield the disulphide, m.p. 133·5–134°, (17·0 g, 86%). (Found: C, 30·65; H, 5·4; P, 15·85; S, 32·5; $C_{10}H_{20}O_4P_2S_4$ requires: C, 30·45; H, 5·1; P, 15·7; S, 32·55%.)

The IR spectrum showed bands at 1463 m, 1400 m, 1368 w, 1350 w, 1309 w, 1288 w, 1225 w, 1210 m, 1186 w, 1038 s, 984 s (broad) 952 s, 912 m, 842 m, 832 s, 812 s, 688 s, 668 s, 664 s.

(b) A solution of 5,5-dimethyl-2-thiolo-2-thiono-1,3,2-dioxaphosphorinane (2·6 g) in 0·1 N NaOH solution (100 ml) was treated with $NaNO_2$ (0·8 g) and the whole shaken for 3 hr during which time a white solid gradually separated. The mixture was allowed to stand for 48 hr and the solid was filtered off and washed with water. Recrystallization of this material from EtOH yielded a product (0·6 g, 23%) identical (m.p., mixed m.p., and IR spectrum) to that prepared as in (a).

(c) On allowing a solution of the aforementioned ammonium salt of the cyclic phosphorodithioic acid (4·3 g) in water (50 ml) with 5 ml H_2O_2 (100 vol) to stand for 3 days at room temp, a total of 3·0 g of white solid was gradually precipitated. It was filtered off, washed with water, dried and recrystallized from acetone yielding firstly, impure bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulphide (1·0 g) m.p. 219–220°. Evaporation of the acetone mother liquors afforded a solid which was then recrystallized from EtOH. The yield of the disulphide so obtained was 1·5 g (39%).

P-Oxo-P'-thiono-bis(5,5-dimethyl-1,3,2-dioxaphosphorinanyl) sulphide

A solution of bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide (7·8 g) and 5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (3·0 g) in benzene (40 ml) was refluxed for 5 hr. The cooled solution was extracted with saturated $KHCO_3$ solution. During this step, a solid (A) separated from the benzene layer, and was filtered off. The benzene layer was washed with water and dried, and evaporated to give solid (B). The combined solids (6·8 g) were recrystallized from benzene–ethyl acetate to give the desired unsymmetrical dithiopyrophosphate (5·9 g; 86%) m.p. 171–173° from ethyl acetate. (Found C, 34·7; H, 5·8; P, 18·45; S, 18·5; $C_{10}H_{20}O_5P_2S_3$ requires: C, 34·75; H, 5·8; P, 17·9; S, 18·5%.)

The IR spectrum showed bands at 1482 m, 1463 m, 1405 m, 1378 m, 1369 w, 1354 w, 1312 m, 1296 s, 1226 w, 1211 m, 1186 w, 1090 sh, 1046 s 998 s, 977 s, 968 s, 943 m, 920 m, 917 m, 846 s, 836 s, 824 s, 788 s, 782 s, 684 s.

Other attempts to prepare P-*oxo*-P'-*thiono-bis*(5,5-*dimethyl*-1,3,2-*dioxaphosphorinanyl*) *sulphide*

(a) 2-chloro-5,5-dimethyl-2-oxo-1,3,2-dioxaphosphorinane (1·86 g) and the ammonium salt of the phosphorodithioic acid (2·25 g) were heated together in ethyl methyl ketone (50 ml) for 13 hr. Working up the reaction mixture after it had been washed with water, gave VII (R = OH) as the only identified product.

(b) The cyclic phosphorochloridate (7·4 g) was added to a solution of the above ammonium salt (8·65 g) in dimethylformamide (80 ml). Precipitation commenced after 10 min. The mixture was allowed to stand for 5·5 hr when filtration yielded 64% NH_4Cl. Heating caused no further precipitation. The solution was concentrated *in vacuo* to 20 ml., filtered from a further small amount of NH_4Cl and cooled when 5·7 g (91%) of III separated.

Reaction between P-*oxo*-P'-*thiono-bis*(5,5-*dimethyl*-1,3,2-*dioxaphosphorinanyl*) *sulphide and cyclohexylamine*

A solution of the dithiopyrophosphate (3·1 g) and cyclohexylamine (2·0 g) in benzene (20 ml) was boiled under reflux for 3·5 hr, when the pyrophosphate gradually dissolved. The cooled solution was then washed with water.

The aqueous layer was evaporated to dryness leaving a solid (2·3 g). Recrystallization of this from ethyl methyl ketone gave three fractions: (a) m.p. 190–192° (0·7 g), (b) m.p. 213–214° (0·6 g), (c) m.p. 204–206° (0·5 g). Recrystallization of (a) from EtOH gave 0·2 g of the cyclohexylammonium salt of the phosphorodithioic acid. Fractions (b) and (c) were examined by paper chromatography. Using the chloroquinoneimine spray and a large number of solvent systems, the best of which was ethyl methyl ketone, acetone water and formic acid in the ratio 80:4:12:2, both fractions were shown to be a mixture of the salts of the cyclic mono- and di-thiophosphoric acids. Determination of sulphur in the combined fractions (b) and (c) (Found: S, 18·1%) indicated that this value corresponds to a mixture of the two salts in the ratio 1:2 approximately. Attempts to separate the two salts by conventional crystallization techniques failed.

The dried benzene layer was evaporated to leave an oil which slowly solidified and which was recrystallized from benzene affording a solid m.p. 135–148° (1·9 g) which was shown by paper chromatography to contain the cyclic N-cyclohexyl phosphoramidothionate.

Bis(5,5-*dimethyl*-2-*thiono*-1,3,2-*dioxaphosphorinanyl*) *sulphide*

Triphenylphosphine (1·3 g) was added to a solution of bis(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) disulphide (1·9 g) in benzene (10 ml). The phosphine dissolved rapidly and completely. The reaction was mildly exothermic, and within 2 min crystallization commenced, and the reaction mixture rapidly set solid. The mixture was allowed to stand for 2 hr and filtered, the insoluble portion being washed with benzene. Evaporation of the benzene gave triphenylphosphine sulphide (1·7 g).

The benzene-insoluble material (1·4 g; 80%) was recrystallized from $CHCl_3$ (in which it was only slightly soluble) when it had m.p. 223°. (Found: C, 33·2; H, 5·4; P, 17·05; S, 26·5; $C_{10}H_{20}O_4P_2S_2$ requires: C, 33·2; H, 5·55; P, 17·1; S, 26·55%.)

The IR spectrum showed bands at 1476 s, 1462 s, 1398 m, 1371 m, 1367 m, 1348 w, 1309 m, 1287 w, 1222 m, 1207 m, 1180 w, 1042 s, 992 s, 940 s, 912 s, 836 s, 822 s, 813 s, 717 s, 656 s.

Reaction between bis(5,5-*dimethyl*-2-*thiono*-1,3,2-*dioxaphosphorinanyl*) *sulphide and cyclohexylamine*

A solution of the trithiopyrophosphate (1·7 g) and cyclohexylamine (1·0 g) in toluene (20 ml) was refluxed for 7 hr, cooled and filtered from unreacted pyrophosphate (0·6 g). The solution was extracted with water, and the aqueous extract evaporated giving the cyclohexylammonium salt of the cyclic phosphorodithioic acid (0·6 g; 42%). Evaporation of the toluene gave an oil which crystallized from pet. ether. The yield of the N-cyclohexyl phosphoramidothionate was 0·8 g (63%).

Acknowledgement—Dr. A. J. Lambie and the staff of the Microanalytical Laboratory, Fisons Pest Control Limited, Cambridge, are thanked for some of the analyses.