A Stereochemical Study of Some Reactions of Compounds in the 4-Methyl-1,3,2-dioxaphosph(v)orinan Series

By **Colin L. Bodkin** and **Peter Simpson,*** School of Molecular Sciences, University of Sussex, Brighton BN1 9QJ

Stereochemistries are assigned to the geometrical isomers of the secondary phosphite 4-methyl-2-oxo-1,3,2-dioxaphosphorinan (I) on the basis of n.m.r. and dipole moment measurements. Chlorination of the isomers of (I) leads stereospecifically to isomers of the chloridate (III). Both isomers of (III) react stereospecifically with piperidine to yield the corresponding piperidide. The *cis*-form undergoes methanolysis with high stereospecificity whereas the *trans*-form is methanolysed with low stereospecificity. The stereochemistries of some reactions of the chloridite 2-chloro-4-methyl-1,3,2-dioxaphosphorinan (II) and the phosphite 2-methoxy-4-methyl-1,3,2-dioxaphosphorinan are also described. The interconversion and relative stabilities of the isomers of (I) have been examined.

A FEW stereochemical studies of nucleophilic displacement reactions at pentavalent phosphorus have been described in which the phosphorus atom forms part of a cyclic system.[1,2] We describe here a stereochemical study of some reactions of compounds in the 4-methyl-1,3,2-dioxaphosphorinan series, some of which were derived indirectly from 4-methyl-2-oxo-1,3,2-dioxaphosphorinan (I).

As Mikolajczyk has reported,[3] hydrolysis of 2-chloro-4-methyl-1,3,2-dioxaphosphorinan (II) results in a mixture of two isomers (A and B) of the phosphite (I). This mixture can be partially crystallised to give a product, solid at room temperature, which is isomerically pure (isomer A). Isomer B has not been obtained pure in this laboratory, but a (liquid) mixture containing it in predominance may be obtained by distillation of the crude hydrolysis product under reduced pressure. [The isomeric composition of a mixture of isomers of (I) is readily determined from its ^{1}H n.m.r. spectrum.[3]]

The 220 MHz ^{1}H n.m.r. spectrum of (IA) in benzene solution is essentially first order, and can be largely interpreted without the use of spin decoupling; the chemical shifts and coupling constants derived from the spectrum are given in Table 1. The ^{1}H n.m.r. spectrum of isomer B could not be analysed, since a pure enough sample was not available.

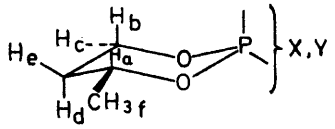
The values given in Table 1 indicate that in (IA) the dioxaphosphorinan ring adopts the chair conformation,

[1] W. S. Wadsworth, jun., *J. Org. Chem.*, 1967, **32**, 1603.
[2] W. S. Wadsworth, jun., and H. Horton, *J. Amer. Chem. Soc.*, 1970, **92**, 3785.
[3] M. Mikolajczyk, *Chem. Comm.*, 1969, 1221.

and that the 4-methyl group is equatorial.[4] The i.r. stretching frequency of the phosphoryl group in (IA) is 1262 cm^{-1}, and in the mixture of (IA) and (IB) is

TABLE 1

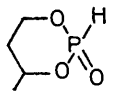
^1H N.m.r. data for the solid isomer of (I) in benzene at 220 MHz



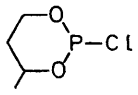
Proton	Chemical shift (τ)	Coupling constant (Hz) to a	b	c	d	e	f	P
a	5·80				12	2·5	6·5	
b	5·97			*ca.* 11	*ca.* 11	2—3		2—3
c	*ca.* 6·0		*ca.* 11		6	2		
d	*ca.* 8·5	12	*ca.* 11	6		15	n.o.	
e	*ca.* 8·8	2·5	2—3	2	15		n.o.	
f	8·84	6·5			n.o.	n.o.		2

n.o. = Not observed.

1260—1285 cm^{-1}. Furthermore, the chemical shift of the phosphorus-bound proton and the coupling constant $^1J_{PH}$ are different for each isomer,[3] suggesting that the



(I)



(II)

isomers differ in their conformation at phosphorus. It seems, therefore, that (IB) also adopts the chair conformation with the 4-methyl group equatorial.

We have obtained a value of 5·7 ± 0·1 D for the electric dipole moment of (IA) in benzene solution at 25 °C and 4·6 ± 0·1 D for a mixture of (IA) and (IB) containing 68% B. Correction for the isomeric composition of the mixture indicates the dipole moment of pure (IB) to be *ca.* 4·1 D. Assuming that the ring adopts an undistorted chair conformation, and assuming values of 0·55 D for the $\overset{+\rightarrow}{H-P}$ bond moment,[5] 3·5 D for the $\overset{+\rightarrow}{P=O}$ bond moment [5] together with the accepted values for the $\overset{+\rightarrow}{H-C}$ and $\overset{+\rightarrow}{C-O}$ bond moments (see ref. 6), it is possible to calculate molecular dipole moments of *cis*- and *trans*-(I) for a range of assumed values for the $\overset{+\rightarrow}{P-O}$ single bond moment. [The terms *cis* and *trans* as used here refer to the relationship between the 4-methyl group and the exocyclic oxygen atom of (I), *i.e.* in the sense opposite to that used by Mikolajczyk in ref. 3.] Some values of the calculated dipole moments are given in Table 2. From this it will be seen that for a wide range of values for the $\overset{+\rightarrow}{P-O}$ bond moment the *trans*-isomer of (I) should have a

TABLE 2

Calculated molecular dipole moments of *cis*- and *trans*-(I) for a range of values of $\mu(\overset{+\rightarrow}{P-O})$

$\mu(\overset{+\rightarrow}{P-O})$/D	μ_{calc}/D *cis*-(I)	*trans*-(I)
1·3	5·33	2·21
0	6·08	3·42
−0·8	6·61	4·27

smaller dipole moment than *cis*-(I). This suggests that the configuration of A is *cis* and that of B *trans*.* Further evidence in support of the present conclusion comes from the observation that the crude hydrolysis product from 2-chloro-4-methyl-1,3,2-dioxaphosphorinan contains A in predominance; since the phosphorochloridite is very probably *trans* (see ref. 4, and below) it would be expected to give *cis*-(I) on hydrolysis.

We have investigated the effect of heat on the isomeric composition of (I). Heating either the pure *cis*-isomer or the mixture of isomers which is predominantly *trans* for 4·5 h in refluxing toluene (dry) in an atmosphere of dry nitrogen gave a mixture of isomers containing *ca.* 80% of the *cis*-isomer. Similarly, the predominantly *trans*-mixture slowly changes to a mixture of similar composition if allowed to stand at room temperature in a desiccator for several weeks. This behaviour is different to that described by Nifant'ev *et al.*[8,9] who found that a mixture of isomers gave only one compound after heating. In view of our observation that the addition of a little water to a mixture of *cis*- and *trans*-(I) gives almost pure (>95%) *cis* after 5 h at room temperature, it seems possible that the findings of Nifant'ev *et al.* could be attributable to traces of moisture in the system. It is clear, however, that the *cis*-isomer of (I) is the more thermodynamically stable of the two. This is consistent with the phosphoryl group being equatorial in this compound, since this group appears to show a marked preference for the equatorial conformation in similar compounds.[10,11]

* After the completion of this work, an assignment of the configurations of the isomers of (I) has appeared [7] based on substantially the same arguments as above, and in complete agreement with them. The authors did not, however, undertake a complete analysis of the n.m.r. spectrum of *cis*-(I), and reported values of the molecular dipole moments somewhat higher than those reported here. It is interesting to note that they claim to have obtained an isomerically pure sample of *trans*-(I).

[4] C. L. Bodkin and P. Simpson, *J. Chem. Soc.* (*B*), 1971, 1136; *Chem. Comm.*, 1969, 829.

[5] B. A. Arbuzov and T. G. Shavsha-Tolkacheva, *Izvest. Akad. Nauk S.S.S.R., Otdel. khim. Nauk*, 1954, 812 (*Chem. Abs.*, 1955, **49**, 4352d).

[6] A. C. Vandenbroucke, jun., E. J. Boros, and J. G. Verkade, *Inorg. Chem.*, 1968, **7**, 1469.

[7] E. E. Nifant'ev, A. A. Borisenko, I. S. Nasonovskii, and E. I. Matrosov, *Bull. Acad. Sci. U.S.S.R.*, 1971, **196**, 28.

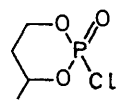
[8] E. E. Nifant'ev and A. A. Borisenko, *Tetrahedron Letters*, 1972, 309.

[9] E. E. Nifant'ev, I. S. Nasonovskii, and A. A. Borisenko, *J. Gen. Chem.* (*U.S.S.R.*), 1970, **40**, 1239.

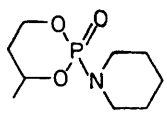
[10] Mazhar-ul-Haque, C. N. Caughlan, and W. L. Moats, *J. Org. Chem.*, 1970, **35**, 1446; H. J. Geise, *Rec. Trav. chim.*, 1967, **86**, 362; J. P. Majoral and J. Navech, *Bull. Soc. chim. France*, 1971, 95.

[11] K. Bergesen and A. Berge, *Acta Chem. Scand.*, 1970, **24**, 1844.

The *cis*-form reacts with chlorine or *N*-chlorosuccinimide to give 2-chloro-4-methyl-2-oxo-1,3,2-dioxaphosphorinan (III), which, when treated with two moles of

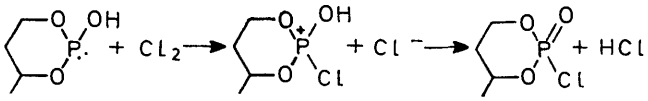


(III)



(IV)

piperidine, gives >95% of a single isomer of 4-methyl-2-oxo-2-piperidino-1,3,2-dioxaphosphorinan (IV). Similarly, a mixture of isomers of (I) leads to a mixture of isomers of (IV) in almost the same proportion. This suggests that both the reaction of chlorine with (I) and the reaction of (III) with piperidine are stereospecific,

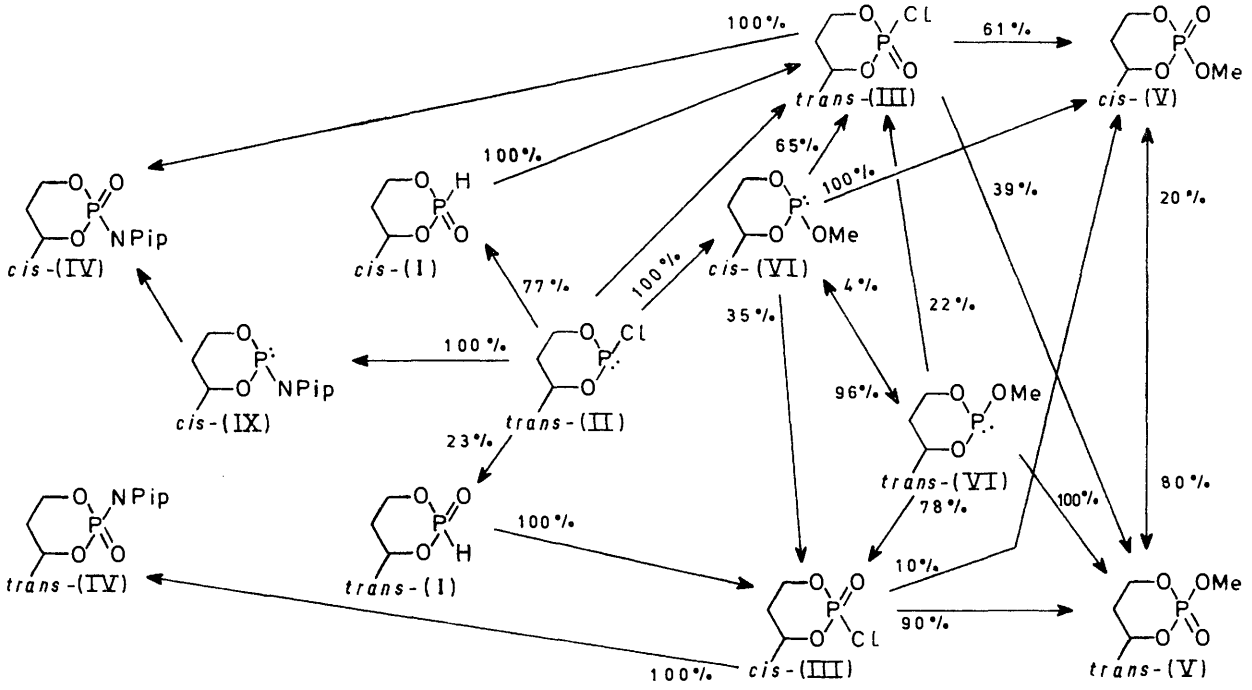


or almost so. Since it is very probably the tricoordinate tautomer of (I) which is involved in the reaction with chlorine,[12] *cis*-(I) should lead to *trans*-(III) [for the P^V compounds, other than the P^V tautomer of (I), the terms *cis* and *trans* refer to the relationship between the methyl group and the exocyclic group other than phosphoryl attached to phosphorus, in this case chlorine].

Further evidence that this is so is presented below. Because of the observed stereospecificity of the reaction of (III) with piperidine, the isomeric composition of a mixture of *cis*- and *trans*-(III) could be determined by treating the mixture with piperidine and analysing the products formed by g.l.c. (see Experimental section).

We have examined a number of reactions of (I)—(III) in order to investigate the stereochemical course of some processes occurring at the phosphorus centre. These reactions are depicted in the Scheme.

Further evidence that the configurations of the phosphorochloridates (III) are as shown in the Scheme derives from the ascribed configurations of the methyl phosphates (V). The evidence that the configurations of these are as shown in as follows. (i) Oxidation of either isomer of the methyl phosphite (VI) by dinitrogen tetroxide or by t-butyl hydroperoxide is stereospecific, and in the case of dinitrogen tetroxide has been shown by Denney *et al.*[13] and by Michalksi *et al.*[14] to proceed with retention of configuration at phosphorus. The configurations of the isomers of (VI) are known [4] and are as shown. (ii) Treatment of either isomer of (V) with sodium methoxide results in a mixture of isomers of (V) containing 80% of the isomer obtained by oxidation of *trans*-(VI). [Mixtures of isomers of (V) were analysed by g.l.c. (see Experimental section)]. Bergesen and Berge have shown [11] the energy of the *cis*-form of 2-ethoxy-6-methyl-2-oxo-1,2-oxaphosphorinan (VII) to be 1·5 kcal mol^{-1} higher than that of the *trans*-form.



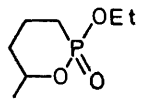
SCHEME

[12] A. J. Kirby and S. G. Warren, 'The Organic Chemistry of Phosphorus,' Elsevier, Amsterdam, 1967, p. 105.

[13] D. Z. Denney, G. Y. Chen, and D. B. Denney, *J. Amer. Chem. Soc.*, 1969, **91**, 6838.

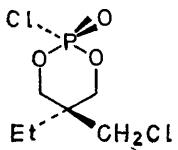
[14] J. Michalski, A. Okruszek, and W. Stec, *Chem. Comm.*, 1970, 1495.

This suggests that the more stable form of (V) is the *trans*-form and provides further evidence that the oxidation of (VI) described above proceeds with retention of configuration at phosphorus.



(VII)

The methyl phosphates (V) may also be obtained by the treatment of phosphorochloridates (III) with methanol. This reaction proceeds with considerable loss of stereospecificity (see Scheme), but each isomer of (III) leads predominantly to a different isomer of (V); that obtained from *cis*-(I) gives 61% *cis*-(V), and that obtained from *trans*-(I) gives 95% *trans*-(V). Thus, either the reaction of (I) with chlorine proceeds with retention of configuration and the reaction of (III) with methanol proceeds with predominant inversion of configuration, as expected, or both reactions must proceed by some unexpected mechanism, each giving the opposite stereochemical consequence. This is highly unlikely, and consequently we believe the assignment of the configurations of the isomers of (III) shown in the Scheme to be justified. Furthermore, the observation [1] that the *trans*-isomer of the closely-related phosphorochloridate (VIII) reacts with piperidine with inversion of configuration confirms this assignment.



(VIII)

A sample of (III) prepared from butane-1,3-diol and phosphorus oxychloride by a method similar to that for (II) [4] was shown to contain 81% of the *trans*-isomer before distillation. Since the products of this reaction are subject to thermodynamic control, this demonstrates that the *trans*-isomer of (III) is of lower energy than the *cis*; this is consistent with an axial preference for the chlorine atom,[14] and an equatorial preference for the phosphoryl group.[10,11]

Oxidation of the phosphorochloridite (II) (of which only one isomer has been obtained) by dinitrogen tetroxide gives *trans*-(III) of 93% isomeric purity. Since there appears to be no reason why this oxidation should not proceed by the same stereochemical course as does the oxidation of (VI) by the same reagent, it provides further evidence (see also ref. 4) that the available isomer of (II) has the *trans*-configuration.* Oxidation of (II) by molecular oxygen also gives (III), but the ratio of *cis* to *trans* is in this case *ca.* 3 : 1 (see below).

Treatment of the phosphorochloridite (II) with piperidine gave an isomer of 4-methyl-2-piperidino-1,3,2-dioxaphosphorinan (IX) which is oxidised by t-butyl hydroperoxide to give *cis*-(IV). This leads to the assignment of a *cis*-configuration to (IX), consistent with its production by aminolysis of (II) with inversion of configuration. Treatment of the *cis*-isomers of some 2-alkoxy-4-methyl-1,3,2-dioxaphosphorinans with a solution of hydrogen chloride in benzene brings about inversion of configuration at phosphorus to give the *trans*-isomers.[4,16] Similar treatment of *cis*-(IX), however, failed to provide any inversion of configuration in this compound. This suggests that, in contrast to an alkoxy-group in (VI),[4] the piperidino-group shows a preference for the equatorial conformation in (IX). This may result from the greater bulk of the piperidino-group and the smaller anomeric effect displayed by nitrogen substituents.[17]

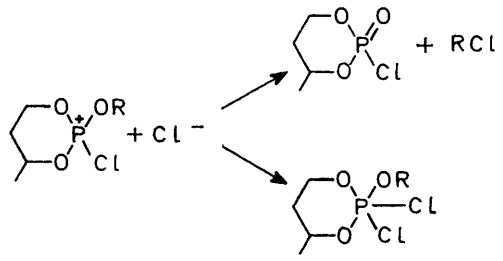
We have treated the methyl phosphites (VI) with a solution of chlorine in carbon tetrachloride at 0°. This reaction gave isomers of (III) but was observed to proceed with considerable stereomutation. We note that other workers [18] have observed stereospecificity, however, at about −50°. Separately, we showed that the composition of a mixture of isomers of (III) was unaffected by the addition of chlorine in carbon tetrachloride, and that excess of phosphite remaining after treatment with chlorine was essentially unisomerised. Our observation is in contrast to the stereospecificity noted above in the reaction of (I) with chlorine. As in the case of the Arbuzov reaction, whose stereochemical course we have studied,[19] the best explanation of these results appears to be the intervention at some stage in the reaction of a pentaco-ordinate intermediate which can, by pseudorotation [20] or otherwise, lead to stereomutation. At −50°, pseudorotation is presumably too slow to lead to stereomutation.[18] It is probable that the reaction of chlorine with (I) and (VI) proceeds by a similar mechanism in each case, very probably involving initial attack by phosphorus on chlorine. Attack by chloride ion on the phosphonium ion so formed may occur either at R, of the exocyclic OR group, which will lead stereospecifically to the product, or at phosphorus. The latter route can lead to a symmetrical pentaco-ordinate species which will give rise to some product of inverted configuration,

* It has recently been suggested [15] that this isomer of (II) has the chlorine atom in the equatorial conformation. Since we have shown [4] that the 4-methyl group is equatorial in this compound, its configuration would then be *cis*. This would imply that alcoholysis proceeds with retention of configuration (see ref. 4 and refs. therein) which is most unlikely. The details of this investigation were not published however, and must be awaited before its importance can be assessed.

[15] B. A. Arbuzov and R. P. Arshinova, *Bull. Acad. Sci. U.S.S.R.*, 1971, **195**, 859.
[16] G. Aksnes, R. Eriksen, and P. Mellingen, *Acta Chem. Scand.*, 1967, **21**, 1028.
[17] S. J. Angyal, *Angew. Chem. Internat. Edn.*, 1959, **8**, 157.
[18] W. J. Stec, personal communication.
[19] C. L. Bodkin and P. Simpson, *Chem. Comm.*, 1970, 1579; *J.C.S. Perkin II*, 1972, 2049.
[20] For a review of the application of pseudorotation to reactions at the phosphorus centre see F. H. Westheimer, *Accounts Chem. Res.*, 1968, **1**, 70.

but the attack by chloride ion on R will be more favourable when R is hydrogen as opposed to methyl and this serves to explain the observed stereospecificity in this case.

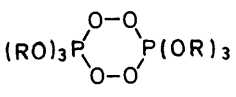
The observation that the reaction of phosphorochloridate (III) with methanol is of low stereospecificity is in agreement with the findings of Wadsworth and Horton,[2] who observed that *cis*-(VIII) reacts with methanol to



give a 2 : 1 preponderance of the 'unexpected' isomer of the product. The authors proposed an $S_N1(P)$ mechanism for the reaction to explain this, but the intervention of a pentaco-ordinate species could also provide an explanation of this lack of stereospecificity. Such a species will be formed if the phosphorus–oxygen bond is formed before the phosphorus–chlorine bond is broken, and loss of stereospecificity would occur if it has a sufficiently long life time to undergo a number of pseudorotations before dissociation.

The fact that the hydrolysis of the phosphorochloridite (II) results in a mixture of isomers suggests that a pentaco-ordinate intermediate may be involved in this reaction too, although stereomutation of the products *after* reaction cannot be ruled out. A process involving protonation at phosphorus followed by displacement of chloride ion by water can give rise to such a species in a manner similar to that described above. Alternatively, a process of valency expansion at phosphorus can lead directly to a pentaco-ordinate species, and then the ultimate configuration of the product depends only on the orientation of the incoming water molecule.[21]

Finally, the stereomutation observed in the oxidation of phosphorochloridite (II) by molecular oxygen merits comment. This stereomutation is less readily explained than are the other cases mentioned above. However, it is noteworthy that a peroxide intermediate Ph_3PO_2 has been postulated [22] during the oxidation of triphenyl phosphine by oxygen. This could be dimeric, like the



(X)

species (X) suggested [23] as an intermediate in the oxidation of trialkyl phosphites by ozone, and if a structure analogous to this were to be formed in the oxidation of (II) by oxygen, its pseudorotation would not be a process of high energy [20] and could lead to some product of inverted configuration.

In contrast, the formation of an intermediate $[(RO)_3\overset{+}{P}OH][OBu^t]^-$ has been suggested by Denney *et al.*[24] in the oxidation of trialkyl phosphites by t-butyl hydroperoxide; the formation of a pentaco-ordinate species from this would involve preferential attack of t-butoxide at phosphorus rather than the hydrogen of the hydroxy-group. This seems very unlikely.

EXPERIMENTAL

The ^1H n.m.r. spectrum of *cis*-(I) at 220 MHz was recorded on the S.R.C. instrument at Runcorn. G.l.c. was performed on a Pye 104 model 64 chromatograph. Two different columns were used: column (a), 5 ft × 4 mm, packed with 5% Carbowax 20M on 100—120 mesh silanised Chromosorb G; and column (b), similar to (a), but packed with 3% Carbowax 20M on 100—120 mesh silanised Supasorb. For column (a) the oven temperature was 200 °C and for column (b) 170°. In each case the flow rate of nitrogen carrier gas was 50 ml min^{-1}. The m.p. was measured in a sealed tube and is uncorrected. The dipole moments were measured and the phosphorochloridite (II) and the methyl phosphites (VI) were prepared by methods described previously.[4]

4-Methyl-2-oxo-1,3,2-dioxaphosphorinan.—This was prepared in 78% yield by method A of Zwierzak,[25] but using a 10% excess of triethylamine. The crude product before distillation contained the *cis*- and *trans*-isomers in the ratio 77 : 23. Distillation of this under reduced presure gave an oil whose composition was 74% *trans*, b.p. 82—88 °C at 0·25 mmHg (lit.,[24] 90—91 °C at 0·05 mmHg). Treatment of the crude hydrolysis product with benzene and diethyl ether caused an oil to separate which deposited crystals on cooling to −10 °C which were recrystallised from benzene–diethyl ether, m.p. 50—53 °C (lit.,[3] 55—58 °C), yield 63% based on (II).

Dinitrogen Tetroxide.—This was prepared by a standard procedure.

Oxidation of 2-Chloro-4-methyl-1,3,2-dioxaphosphorinan (II) with Dinitrogen Tetroxide.—A solution of (II) in dichloromethane (*ca.* 100 g l^{-1}) was cooled in a slurry of dry ice and acetone, and a solution of dinitrogen tetroxide in dichloromethane was added dropwise with stirring until the initial yellow-brown colour of the reactants became a permanent blue-green. The mixture was then allowed to return to room temperature, and solvent was removed under reduced pressure. The product, *2-chloro-4-methyl-2-oxo-1,3,2-dioxaphosphorinan* could then be obtained in essentially quantitative yield by allowing the resulting oil to stand at room temperature and 0·1 mmHg pressure for 2 h. Distillation of this material was always found to cause considerable decomposition of the product and resulted in low yields. [Similarly, attempted g.l.c. of mixtures of isomers of (III), only resulted in their decomposition.] The product had b.p. 101—102 °C at 0·1 mmHg, n_D^{19} 1·4649 (Found: C, 28·25; H, 5·0. $C_4H_8ClO_3P$ requires C, 28·15; H, 4·75%). Oxida-

[21] C. L. Bodkin, D.Phil. Thesis, University of Sussex, 1971.
[22] P. D. Bartlett, E. F. Cox, and R. E. Davis, *J. Amer. Chem. Soc.*, 1961, **83**, 103.
[23] Q. E. Thompson, *J. Amer. Chem. Soc.*, 1961, **83**, 845.
[24] D. B. Denney, W. E. Goodyear, and B. Goldstein, *J. Amer. Chem. Soc.*, 1960, **82**, 1393.
[25] A. Zwierzak, *Canad. J. Chem.*, 1959, **37**, 1498.

tion of phosphite (VI) by dinitrogen tetroxide was carried out by an identical procedure.

Oxidation of Phosphorochloridite (II) *by Oxygen Gas.*—A standard procedure was used.

Reaction of (I) *with Chlorine.*—This was carried out at 0 °C by the dropwise addition of a small excess of a standardised solution of chlorine in carbon tetrachloride to a solution of (I) (0·77 g) in the same solvent (50 ml). On addition of the last few drops of the chlorine solution the mixture became pale yellow in colour. Again, no purification of the product was necessary beyond the removal of solvent under reduced pressure. The reaction of the methyl phosphites (VI) with chlorine was carried out in an identical way.

Reaction of (I) *with* N-*Chlorosuccinimide.*—Compound (I) (0·53 g), carbon tetrachloride (50 ml), and *N*-chlorosuccinimide (0·53 g) were heated together under reflux in an atmosphere of dry nitrogen for 2·5 h after which time the solvent was removed under reduced pressure, benzene was added, and the resulting precipitate was removed by decantation. Concentration of the solution gave a pale yellow oil.

4-*Methyl*-2-*oxo*-2-*piperidino*-1,3,2-*dioxaphosphorinan* (IV).—To a well stirred solution of piperidine (2·2 g) in dichloromethane (50 ml) at 0 °C was added a solution of phosphorochloridite (II) (1·59 g) in dichloromethane (50 ml) over *ca.* 30 min. The resulting mixture was concentrated somewhat under reduced pressure and filtered. To the filtrate was added portionwise a solution of a mixture (1·16 g) of di-t-butyl peroxide (30%) and t-butyl hydroperoxide (70%) dissolved in dichloromethane. The reaction mixture was allowed to stand at room temperature for 1 h, was washed once with an equal volume of water, dried ($MgSO_4$), concentrated, and distilled under reduced pressure from glass wool to give the 2-*piperidino-compound*, b.p. 113—114° at 0·04 mmHg, n_D^{19} 1·4794.

Reactions of the Phosphorochloridate (III) *with Piperidine.*—These were in general carried out by dissolving crude (III) (from whatever source) in a little dichloromethane and adding a solution of 2·2 mol. equiv. of piperidine in the same solvent in small portions. The resulting mixture was left for 1 h at room temperature and was filtered. The filtrate was concentrated under reduced pressure for analysis by g.l.c. using column (b). The *cis*-isomer of (IV) had R_t 11 min, and the *trans*-isomer 16 min. A small sample of (IV) obtained in this way was distilled, and shown by g.l.c. to contain a *ca.* 1 : 1 mixture of the two isomers (Found: C, 49·1; H, 8·25; N, 6·4. Calc. for $C_9H_{18}NO_3P$: C, 49·3; H, 8·3; N, 6·4%).

Reaction of (III) *with Methanol.*—This was carried out by mixing ethereal solutions of (III) (1·71 g, 10 mmol), methanol (0·35 g, 11 mmol), and triethylamine (1·11 g, 11 mmol) and leaving the mixture for 24 h before filtration and concentration under reduced pressure. The products were analysed by g.l.c. [column (a)] without distillation.

We are grateful to the S.R.C. for the award of a research studentship (to C. L. B.) and for the use of their 220 MHz n.m.r. instrument.

[2/2152 *Received*, 15*th September*, 1972]