Solid State Conformations of Six 1,3,2-Oxazaphospholidines Derived from (−)-Ephedrine: X-Ray Crystal Structures of the 2-Phenoxy-2-oxo, 2-Phenyl-2-oxo and 2-Phenyl-2-thio Analogues

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The crystal structure of (2*R*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3,2-oxazaphospholidin-2-one (**7**) exhibits a C(5) envelope in which this atom is below the O(1)–P(2)–N(3)–C(4) plane. The diastereoisomer, (2*S*,4*S*,5*R*) **8** adopts a half-chair conformation with C(4) above and C(5) below the O(1)–P(2)–N(3) plane. Both (2*S*,4*S*,5*R*)- and (2*R*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one (**9** and **10**), and (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-thione (**12**) adopt C(4) envelopes in the crystal structures, with C(4) above the C(5)–O(1)–P(2)–N(3) plane for **9** and below for **10** and **12**. (2*R*,4*S*,5*R*)-3,4-Dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine-2-thione (**11**) exists as a half-chair with O(1) above and C(5) below the P(2)–N(3)–C(4) plane. The C(4) and C(5) envelope conformations for **7**, **9**, **10** and **12** are consistent with the P–O–C–H vicinal coupling constants derived from ^{1}H NMR spectra in solution.

The saturated ring of 1,3,2-oxazaphospholidines can exist in several conformations on the cyclopentane pseudorotation pathway,[1] including half-chairs and envelopes as well as intermediate structures (Fig. 1).[2–6] The conformation adopted depends on the substituents both at phosphorus and on the ring, and here, the solid state conformations of the five-membered ring of 1,3,2-oxazaphospholidines derived from (−)-ephedrine are presented. Previously we have reported the structure of (2*R*,4*S*,5*R*)-2,3,4-trimethyl-5-phenyl-1,3,2-oxazaphospholidin-2-one (**1**), for which the configuration at phosphorus was required to assign the chirality of [^{16}O,^{17}O,^{18}O]phosphonopyruvate.[7] This resembles an envelope conformation with C(4) below the C(5)–O(1)–P(2)–N(3) plane. In contrast, (2*R*,4*S*,5*R*)-3,4-dimethyl-5-phenyl-2-thiomethyl-1,3,2-oxazaphospholidin-2-one (**2**) most resembles a half-chair with C(4) above and C(5) below the O(1)–P(2)–N(3) plane.[8] Three 2-thio structures have also been published, **3**, **4** and **5**, and these most closely adopt an N(3)–C(4) half-chair, a C(4) envelope and a P(2) envelope, respectively.[9,10,11] More recently, X-ray crystallography of the 2-borane analogue **6** shows that this most closely resembles a C(4)–N(3) half-chair.[12] In an attempt to rationalise the conformations adopted, the crystal structures of three pairs of diastereoisomeric 1,3,2-oxazaphospholidines are discussed. The first pair, (2*R*,4*S*,5*R*)- and (2*S*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3,2-oxazaphospholidin-2-ones, **7** and **8**, were of interest because of their role in the synthesis of chiral phenyl (^{16}O,^{17}O,^{18}O)-phosphate.[13] After completion of our refinement, Setzer and co-workers[6] reported the crystal structure of the enantiomer of **8**, however because of the poor quality of their crystal (R = 10.3%) we have included our data. In contrast to Setzer, we had little difficulty in growing good quality single crystals, possibly because of the high purity achieved with flash chromatography. The second pair, (2*R*,4*S*,5*R*)- and (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-ones, **9** and **10**, were intermediates in the synthesis of chiral arylphosphine oxides, and the structures presented confirm the configuration of the final product.[14] The third pair were the thio analogues, (2*R*,4*S*,5*R*)- and (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-thiones **11** and **12**, which were also of interest in the synthesis of chiral arylphosphine oxides.

Results

A mixture of (2*R*,4*S*,5*R*)- and (2*S*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3,2-oxazaphospholidin-2-one (**7** and **8**), was prepared by the reaction of phenyl phosphorodichloridate with (−)-ephedrine in the presence of triethylamine.[5] Devillers and Navech[5] only isolated one compound from their reaction; however, it was apparent from both TLC and ^{1}H NMR spectroscopy that two compounds were formed in a *ca.* 4:1 ratio. They were separated by flash column chromatography[15] and the compounds were characterised by ^{1}H NMR spectroscopy (Table 1). The ^{1}H NMR spectrum recorded by Devillers and Navech[5] agrees with that for the major diastereoisomer; however, the absolute configuration at phosphorus for this product was not unambiguously assigned, with both possible diastereoisomers being reported.[5,16] Cooper *et al.*[2] have prepared a compound with an identical ^{1}H NMR spectrum to the major diastereoisomer by the reaction of sodium phenoxide with (2*R*,4*S*,5*R*)-2-chloro-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidin-2-one. Such displacements occur with retention of configuration at phosphorus, and the product formed was assigned as **7**. It seems surprising that **7** is the major product from the reaction of phenyl phosphorodichloridate with (−)-ephedrine, because this diastereoisomer is sterically the more hindered, with the two aromatic groups arranged *syn* in the five-membered ring. The structure of the major diastereoisomer was confirmed by X-ray crystallography. The atomic coordinates are given in Table 2, and the PLUTO plot[17] (Fig. 3) shows that the phenyl rings are indeed arranged *syn* within the five-membered ring. In agreement with the assignments made by Cooper *et al.*,[2] the major diastereoisomer has structure **7** with an *R* configuration at phosphorus. Examination of molecular models (CHEM-X) revealed an absence of serious non-bonded interactions involving the phenoxy group; therefore it is reasonable that steric constraints do not dictate the diastereoisomeric ratio of the products. For comparison of the ring conformations, the crystal structure of the minor diastereoisomer **8** was also solved. The atomic coordinates are given in Table 3 and the PLUTO plot[17] is shown in Fig. 4. This structure is in broad agreement with that proposed for the enantiomer of **8** by Setzer *et al.*,[6] however their standard

Table 1 ^{1}H NMR data for 1,3,2-oxazaphospholidines in $CDCl_3$

Compound	MHz	2 × Ph (10 H, m)	H-5 (1 H)	H-4 (1 H)	NMe (3 H)	CMe (3 H)
7	300	7.4–7.1	5.74, d *J* 6.2	3.68, ddq J_{PH} 18, *J* 6.2, *J* 6.7	2.83, d J_{PH} 10	0.60, d *J* 6.7
8	300	7.4–7.1	5.34, dd *J* 6.3, J_{PH} 3.75	3.585, ddq J_{PH} 12, *J* 6.3, *J* 6.5	2.78, d J_{PH} 10.3	0.78, d *J* 6.5
9	500	8.0–7.2	5.96, d *J* 6.3	3.80, ddq J_{PH} 10.6, *J* 6.3, *J* 6.6	2.76, d J_{PH} 9.3	0.82, d *J* 6.6
10	500	7.9–7.2	5.60, dd *J* 6.2, J_{PH} 4.9	3.80, ddq J_{PH} 14, *J* 6.2, *J* 6.5	2.63, d J_{PH} 10.1	0.92, d *J* 6.5
11	500	7.9 7.2	5.92, d *J* 6.1	3.80, ddq J_{PH} 9.8, *J* 6.1, *J* 6.5	2.77 J_{PH} 11.9	0.85, d *J* 6.5
12	500	8.0–7.2	5.60, dd *J* 6.4, J_{PH} 3.5	3.80, ddq J_{PH} 17.0, *J* 6.4, *J* 6.6	2.66 J_{PH} 12.5	0.93, d *J* 6.6

Table 2 Atomic coordinates for (2*R*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1.3.2-oxazaphospholidin-2-one (**7**) (× 10^4), except coordinates × 10^5 for P

Atom	*x*	*y*	*z*
O(1)	6 750(2)	6 780(1)	4 520(1)
P(2)	64 548(7)	81 520(5)	42 456(4)
N(3)	4 835(2)	7 909(2)	3 799(1)
C(4)	4 363(3)	6 610(2)	3 803(1)
C(5)	5 344(3)	6 045(2)	4 487(1)
O(6)	6 514(3)	9 130(2)	4 851(1)
C(7)	8 416(3)	7 581(2)	3 068(2)
C(8)	7 920(3)	7 581(3)	2 268(2)
C(9)	8 561(4)	6 767(3)	1 723(2)
C(10)	9 663(4)	5 956(4)	1 957(2)
C(11)	10 160(3)	5 979(3)	2 755(2)
C(12)	9 552(3)	6 787(3)	3 317(2)
C(13)	3 742(4)	8 855(3)	3 564(2)
C(14)	4 532(4)	6 027(3)	2 968(2)
C(15)	5 750(3)	4 715(2)	4 378(1)
C(16)	7 092(4)	4 337(3)	4 021(3)
C(17)	7 376(5)	3 102(4)	3 905(3)
C(18)	6 363(5)	2 241(3)	4 145(2)
C(19)	5 018(5)	2 606(3)	4 509(2)
C(20)	4 702(4)	3 838(3)	4 624(2)
O(21)	7 817(2)	8 430(2)	3 625(1)

Table 3 Atomic coordinates for (2*S*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3,2-oxazaphospholidin-2-one (**8**) (× 10^4), except coordinates × 10^5 for P

Atom	*x*	*y*	*z*
O(1)	6 656(2)	4 478(2)	4 494(2)
P(2)	61 382(9)	58 518(7)	42 755(6)
N(3)	4 512(3)	5 504(2)	4 183(2)
C(4)	4 322(3)	4 148(3)	4 086(2)
C(5)	5 498(3)	3 632(3)	4 642(2)
O(6)	6 860(3)	6 493(2)	3 572(2)
C(7)	5 924(3)	6 355(3)	5 966(2)
C(8)	4 824(4)	6 978(3)	6 325(3)
C(9)	4 422(5)	6 755(4)	7 166(3)
C(10)	5 136(7)	5 895(5)	7 644(3)
C(11)	6 245(7)	5 274(5)	7 296(4)
C(12)	6 662(5)	5 503(4)	6 448(4)
C(13)	3 508(6)	6 374(4)	3 806(4)
C(14)	4 345(5)	3 717(4)	3 143(3)
C(15)	5 926(3)	2 305(3)	4 457(2)
C(16)	7 031(3)	2 012(3)	3 931(2)
C(17)	7 380(4)	783(3)	3 765(2)
C(18)	6 620(4)	−169(3)	4 129(3)
C(19)	5 504(5)	109(3)	4 650(3)
C(20)	5 177(4)	1 349(3)	4 820(2)
O(21)	6 361(2)	6 680(2)	5 124(2)

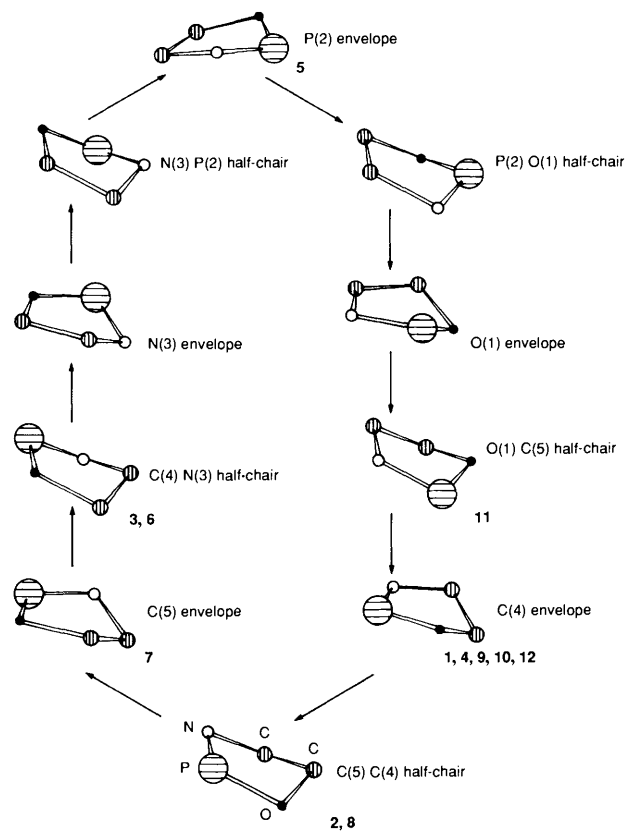

Fig. 1 Pseudorotation itinerary for oxazaphospholidines; the closest approximation of X-ray structures to conformers is indicated. Atom shadings are indicated in the bottom structure.

deviations on atomic coordinates, bond lengths and bond angles are much higher. More seriously, some values do not agree; for example, we found the length of the P(2)–O(1) bond to be 0.034 Å (3σ) longer and the O(1)–P(2)–N(3) angle 1.9° (3σ) smaller.[6]

Both diastereoisomers of 3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one **9** and **10** were isolated by flash chromatography after oxidation of the product from the reaction of dichlorophenylphosphine with (−)-ephedrine. They were fully characterised and the ^{1}H NMR data are summarised in Table 1. The structure of the minor diastereoisomer was solved by X-ray crystallography and was shown to have the *S* configuration at phosphorus **9**. The atomic coordinates are given in Table 4 and the PLUTO plot[17] is shown in Fig. 5. The structure of the major diastereoisomer **10**, which was substantially predominant if the P^{III} intermediate was allowed to equilibrate for one day before oxidation,[13] was solved by X-ray

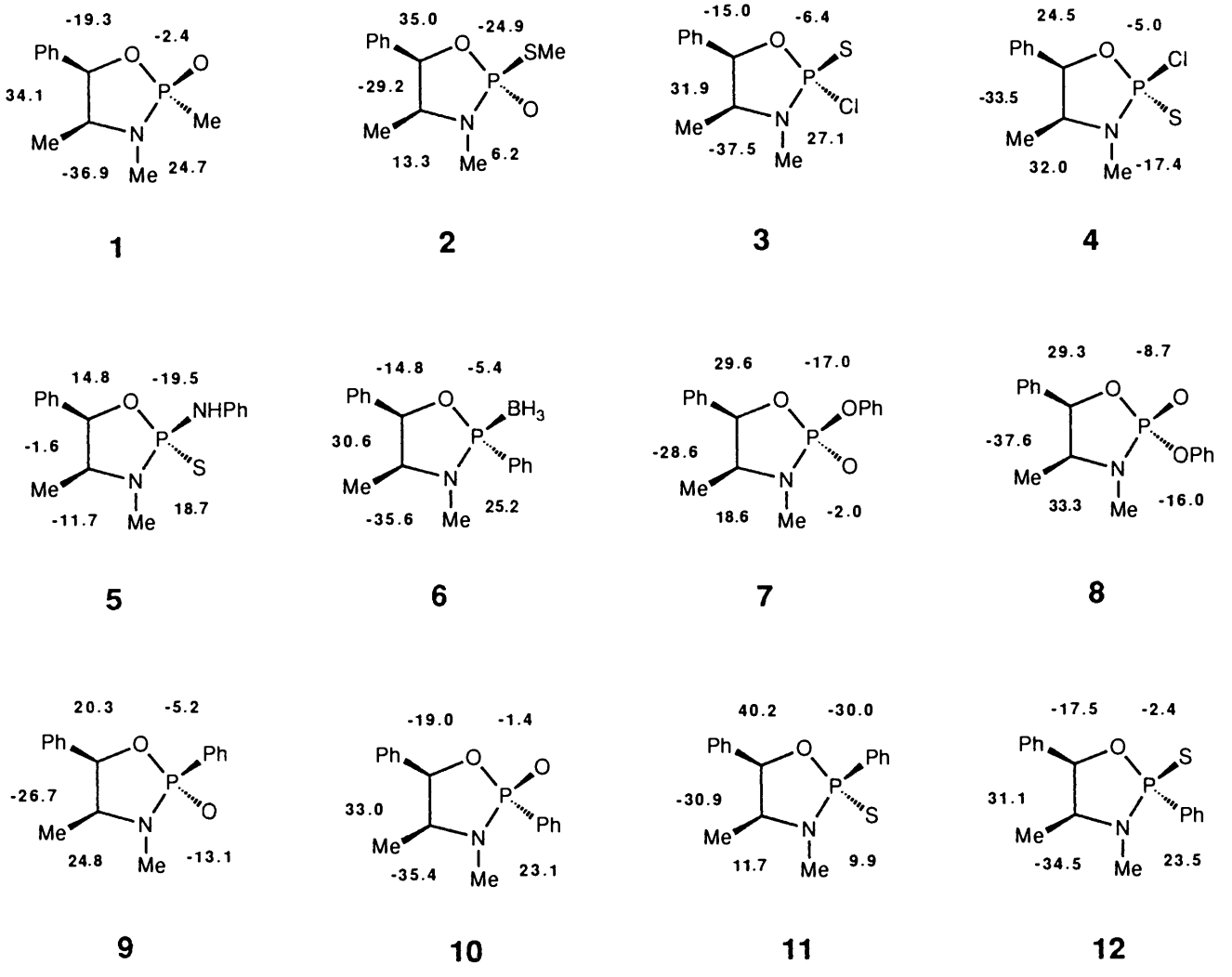

Fig. 2 Structures discussed in this paper. Ring torsion angles are displayed.

Table 4 Atomic coordinates for (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one (**9**) ($\times 10^4$), except coordinates $\times 10^5$ for P

Atom	*x*	*y*	*z*
O(1)	2 409(2)	3 996(2)	7 006(1)
P(2)	16 155(8)	51 695(7)	65 462(4)
N(3)	228(3)	4 325(2)	6 168(2)
C(4)	459(4)	2 924(3)	6 226(2)
C(5)	1 569(4)	2 801(3)	6 968(2)
O(6)	1 246(3)	6 277(2)	7 075(1)
C(7)	2 905(3)	5 645(3)	5 744(2)
C(8)	2 599(4)	5 470(3)	4 903(2)
C(9)	3 584(5)	5 858(4)	4 300(2)
C(10)	4 902(5)	6 435(3)	4 519(2)
C(11)	5 256(5)	6 610(4)	5 354(3)
C(12)	4 242(4)	6 222(4)	5 959(2)
C(13)	−1 100(4)	4 841(4)	5 761(3)
C(14)	997(5)	2 341(4)	5 411(2)
C(15)	2 650(4)	1 691(3)	6 924(2)
C(16)	2 136(4)	449(3)	7 053(2)
C(17)	3 083(4)	−588(3)	7 006(2)
C(18)	4 568(4)	−397(4)	6 845(2)
C(19)	5 117(4)	830(4)	6 730(2)
C(20)	4 155(4)	1 872(3)	6 763(2)

Table 5 Atomic coordinates for (2*R*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one (**10**) ($\times 10^4$), except coordinates $\times 10^5$ for P

Atom	*x*	*y*	*z*
O(1)	10 690(3)	7 331(3)	1 019(1)
P(2)	90 400(10)	88 890(10)	9 792(20)
N(3)	10 175(4)	10 515(4)	1 261(1)
C(4)	12 281(5)	10 146(4)	1 257(1)
C(5)	12 400(5)	7 972(4)	1 261(1)
O(6)	7 085(4)	8 389(5)	1 132(9)
C(7)	8 979(5)	9 481(5)	421(1)
C(8)	7 339(7)	10 419(6)	258(1)
C(9)	7 270(9)	10 965(7)	−168(1)
C(10)	8 789(8)	10 544(5)	−436(1)
C(11)	10 411(9)	9 617(6)	−282(1)
C(12)	10 512(6)	9 099(5)	149(1)
C(13)	9 455(8)	12 444(5)	1 287(1)
C(14)	13 369(6)	11 097(6)	1 623(1)
C(15)	12 443(5)	7 047(4)	1 696(1)
C(16)	14 223(6)	6 410(6)	1 857(1)
C(17)	14 324(7)	5 559(7)	2 256(1)
C(18)	12 652(9)	5 349(7)	2 500(1)
C(19)	10 887(7)	5 970(7)	2 343(1)
C(20)	10 780(6)	6 798(6)	1 940(1)

crystallography. The atomic coordinates of **10** are given in Table 5 and the PLUTO plot[16] is shown in Fig. 6.

The thio analogues of **9** and **10** were similarly prepared, except that the P^{III} intermediate was treated with sulphur to give a mixture of **11** and **12**, which were readily separated by flash column chromatography. The minor, first-eluted, diastereoisomer **11** has the *R* configuration at phosphorus. The atomic coordinates are given in Table 6 and the PLUTO plot in Fig. 7.

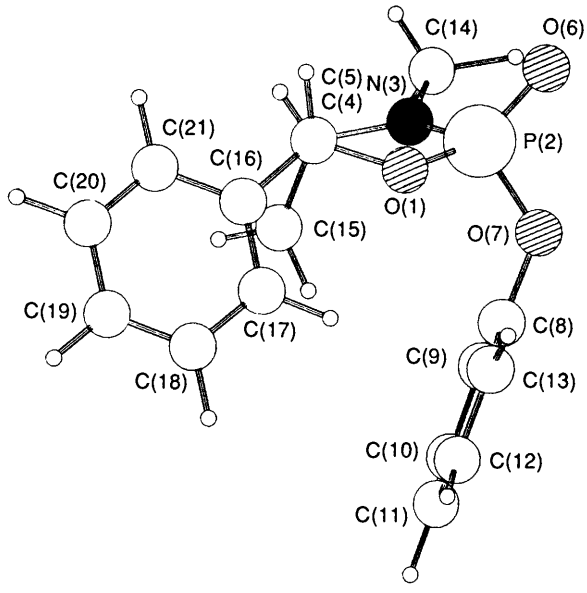

Fig. 3 PLUTO plot of (2*R*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3.2-oxazaphospholidin-2-one (**7**) viewed down the C(4)–C(5) bond

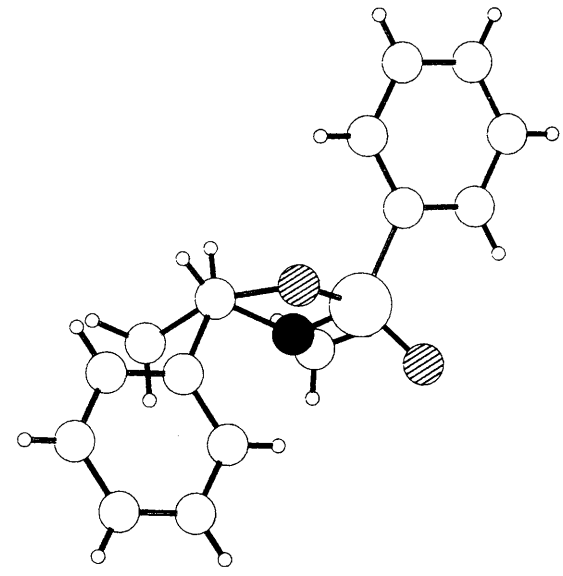

Fig. 6 PLUTO plot of (2*R*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one (**10**) viewed down the C(4)–C(5) bond

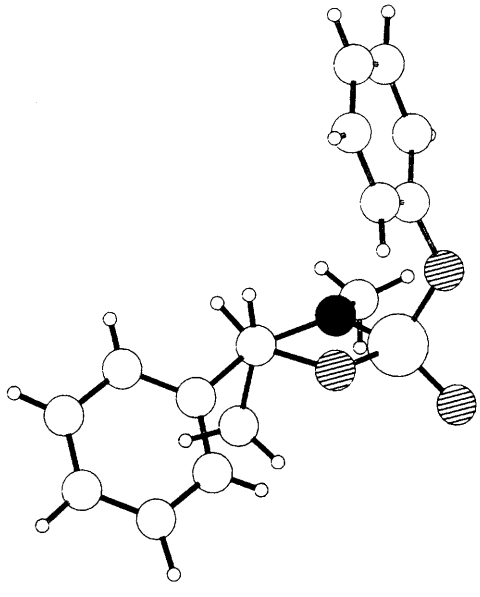

Fig. 4 PLUTO plot of (2*S*,4*S*,5*R*)-3,4-dimethyl-2-phenoxy-5-phenyl-1,3,2-oxazaphospholidin-2-one (**8**) viewed down the C(4)–C(5) bond

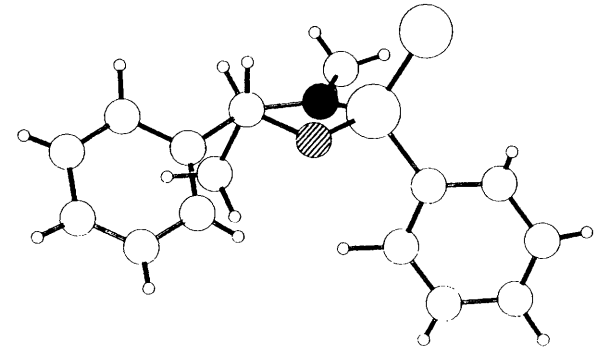

Fig. 7 PLUTO plot of (2*R*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine-2-thione (**11**) viewed down the C(4)–C(5) bond

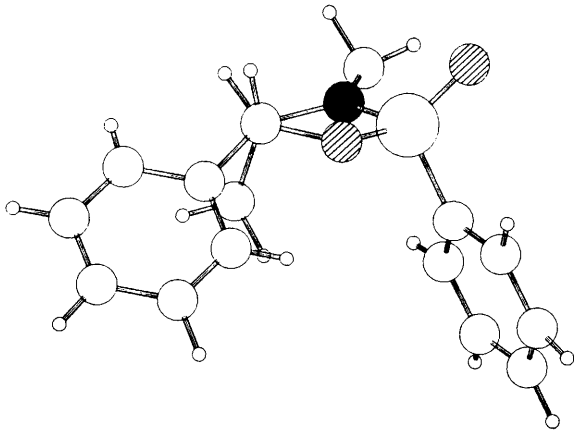

Fig. 5 PLUTO plot of (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidin-2-one (**9**) viewed down the C(4)–C(5) bond

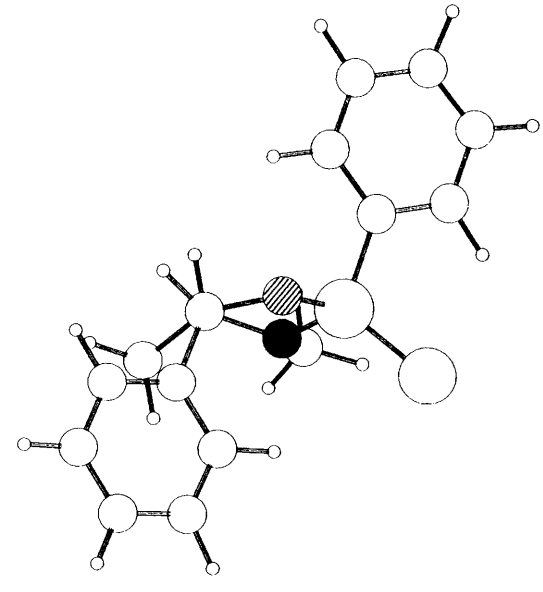

Fig. 8 PLUTO plot of (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine-2-thione (**12**) viewed down the C(4)–C(5) bond

Table 6 Atomic coordinates for (2*R*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine-2-thione (**11**) (× 10^4)

Atom	*x*	*y*	*z*
O(1)	4241(4)	7475(2)	6696(2)
P(2)	3294(1)	6947(1)	7466(1)
N(3)	1276(4)	7505(3)	7365(2)
C(4)	1109(6)	8051(3)	6605(2)
C(5)	2802(6)	7709(3)	6092(2)
S(6)	3296(2)	5561(1)	7456(1)
C(7)	4515(6)	7424(3)	8345(3)
C(8)	4533(8)	8408(4)	8491(3)
C(9)	5430(9)	8775(5)	9174(4)
C(10)	6289(8)	8152(6)	9721(3)
C(11)	6283(7)	7203(5)	9585(3)
C(12)	5393(7)	6835(5)	8900(3)
C(13)	−365(9)	7277(7)	7850(4)
C(14)	1049(10)	9129(4)	6760(4)
C(15)	3556(6)	8407(3)	5479(2)
C(16)	5146(8)	8935(3)	5625(3)
C(17)	5772(11)	9582(4)	5042(4)
C(18)	4855(12)	9718(4)	4338(4)
C(19)	3240(13)	9187(5)	4175(3)
C(20)	2607(9)	8523(4)	4742(3)

Table 7 Atomic coordinates for (2*S*,4*S*,5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine-2-thione (**12**) (× 10^4)

Atom	*x*	*y*	*z*
O(1)	3827(4)	5342(7)	4941(3)
P(2)	3156(1)	5368(−)	6108(1)
N(3)	2251(5)	3592(8)	5601(5)
C(4)	2844(6)	2491(9)	4798(6)
C(5)	3432(6)	3859(9)	4056(6)
S(6)	2134(2)	7390(4)	6278(2)
C(7)	4562(5)	4976(7)	7598(6)
C(8)	4527(6)	5602(10)	8818(6)
C(9)	5601(7)	5269(13)	9988(6)
C(10)	6708(8)	4350(11)	9924(7)
C(11)	6768(7)	3729(10)	8720(8)
C(12)	5703(6)	4030(9)	7565(7)
C(13)	1561(7)	2718(11)	6458(7)
C(14)	1798(8)	1264(10)	3882(8)
C(15)	2488(6)	4407(8)	2704(6)
C(16)	1299(6)	5353(12)	2592(6)
C(17)	400(7)	5760(11)	1330(7)
C(18)	688(7)	5243(14)	200(7)
C(19)	1871(9)	4335(11)	311(7)
C(20)	2765(7)	3912(10)	1564(6)

For the major diastereoisomer **12**, the atomic coordinates are given in Table 7 and the PLUTO plot in Fig. 8.

For the six structures **7**–**12**, the crystal data summarised in Table 8 show that the coordinates are of good quality with *R* values between 2.90 and 5.30%. All crystals occupy the space group $P2_12_12_1$, except for **12** which is $P2_1$. Selected bond lengths are given in Table 9, bond angles in Table 10, and torsion angles in Table 11. The endocyclic bond lengths and bond angles for the six structures are similar to those reported for other analogues.[7–11] The P–N bonds in the compounds with a PhO group are *ca.* 0.02 Å shorter than the corresponding analogues with a Ph group. This is likely to be attributable to the anomeric effect,[18] as the lone pair of electrons in the p orbital on the planar nitrogen overlaps better with the antibonding orbitals on phosphorus when the electronegative phenoxy group is the substituent at phosphorus. The anomeric effect may also be operating further in structures **7** and **8**, as in each case the phenoxy group resides over the five-membered ring, allowing the lone pairs of electrons on the oxygen of the phenoxy group to be antiperiplanar to both the P–N and P–O ring bonds facilitating orbital overlap.

The P=O bond lengths range between 1.453 and 1.466 Å and are typical for phosphoryl P=O double bonds. For the six crystal structures, the sum of angles at N(3) [P(2)–N(3)–C(4) + P(2)–N(3)–C(13) + C(4)–N(3)–C(13)] are 358.8, 353.4, 359.9, 351.6, 358.0 and 350.2°, consistent with almost trigonal planar geometry at nitrogen.[19] In all structures, the O(1)–P(2)–X(6) and N(3)–P(2)–X(6) angles are greater than normal tetrahedral angles to separate the electronegative heteroatoms. The C(5)–C(4)–C(14) and C(4)–C(5)–C(15) angles are also greater than tetrahedral and the plane of the C(5)–phenyl ring is always perpendicular to the oxazaphospholidine ring, both factors minimising steric clashes between the C(4)–methyl and C(5)–phenyl substituents.

Discussion

Five-membered rings are highly fluctional and capable of adopting a range of non-planar conformations separated by very small energy barriers in solution.[1] In the solid state, depending on the effects of substituents and crystal packing, a single conformation may result. With the availability of a number of closely related structures based on the oxazaphospholidine ring system, it was of interest to see if systematic trends could be identified. Since the endocyclic P–N and P–O bonds are somewhat longer than other endocyclic bonds (Table 9) and the geometry at N is best approximated as sp^2, there is an inbuilt preference for conformations in the region of the C(4) and C(5) envelopes on the pseudorotation pathway (Fig. 1). This is reinforced by a need to avoid eclipsing of the substituents on C(4) and C(5).

The asymmetry parameters were calculated to establish whether the rings adopt an envelope (ΔC_S) or half-chair (ΔC_2) conformation.[20] The smaller the value, the closer the structure approaches the ideal envelope or half-chair. The deviations of the flap atom from the appropriate four-atom plane were calculated to give further information on the envelope conformations; and for the half-chairs, the deviation of the atoms from the three-atom plane were determined. The results are summarised in Table 12.

The oxazaphospholidin-2-one **7** adopts an envelope in which C(5) is below the O(1)–P(2)–N(3)–C(4) plane. The ring C(4)–methyl is pseudoaxial and the C(5)–phenyl pseudoequatorial which minimises the steric interactions with the phenoxy ring (Fig. 3). In contrast, the diastereoisomer **8** exists as a half-chair, with C(4)–Me above and C(5)–Ph below the O(1)–P(2)–N(3) plane, with C(4)–Me in a pseudoaxial position and C(5)–Ph pseudoequatorial (Fig. 4). The 2-phenyl-2-oxo diastereoisomers both exist as C(4) envelopes. Where the two phenyl groups are *syn* (**9**), the C(4) flap is above the C(5)–O(1)–P(2)–N(3) plane, which puts the C(4)–methyl group pseudoaxial and the C(5)–phenyl group pseudoequatorial (Fig. 5). For the *anti* isomer (**10**), the C(4) flap is below the C(5)–O(1)–P(2)–N(3) plane, with the C(5)–phenyl pseudoaxial and the C(4)–methyl pseudoequatorial. The *anti* 2-phenyl-2-thio analogue (**12**), adopts an identical C(4) envelope to **10**, the torsion angles of these structures showing remarkable similarity. The *syn* 2-phenyl-2-thio isomer (**11**) exists as an O(1)–C(5) half-chair, with O(1) above and C(5) below the P(2)–N(3)–C(4) plane, placing C(5)–phenyl pseudoequatorial and C(4)–methyl pseudoaxial.

Some information on the solution conformation may be obtained from the relevant $^3J_{P-H(5)}$ coupling constants (assumed to be positive over the torsion angle range), and these have been the subject of analysis by three independent groups.[2–5] For the *syn* compounds **2**, **4**, **5**, **7**, **9** and **11** where the substituent on phosphorus is *syn* to the ring methyl and phenyl groups, the $^3J_{P-H(5)}$ value at H(5) is <1 Hz (Table 1),

Table 8 Crystal data for 1,3,2-oxazaphospholidines

	7	8	9	10	11	12
Molecular formula	$C_{16}H_{18}NO_3P$	$C_{16}H_{18}NO_3P$	$C_{16}H_{18}NO_2P$	$C_{16}H_{18}NO_2P$	$C_{16}H_{18}NOPS$	$C_{16}H_{18}NOPS$
Molecular weight	303.3	303.3	287.3	287.3	303.4	303.4
Melting point/°C	97–98	129–130.5	146–147	169–170	147–148	99–100
Lit. m.p./°C	93–94 [7]		134–136 [2]	159–161 [2]		
Crystal form	Colourless prism	Colourless hexagonal prism	Colourless lath	Colourless prism	Colourless prism	Single colourless needle
Size/mm	0.4 × 0.6 × 0.9	0.75 × 0.38 × 0.25	0.6 × 0.3 × 0.15	0.4 × 0.6 × 0.8	0.6 × 0.3 × 0.2	0.8 × 0.3 × 0.2
Space group	$P2_12_12_1$	$P2_12_12_1$	$P2_12_12_1$	$P2_12_12_1$	$P2_12_12_1$	$P2_1$
Cell dimensions						
a/Å	8.720(1)	9.674(2)	8.933(1)	6.844(1)	7.126(1)	10.328(3)
b/Å	10.883(1)	10.692(3)	10.392(1)	7.055(2)	13.937(1)	7.662(5)
c/Å	16.391(2)	15.267(4)	15.990(2)	31.170(4)	16.263(2)	10.554(3)
β/°	—	—	—	—	—	108.64(2)
V/Å^3	1555.6	1579.1	1484.4	1505.0	1615.2	791.4
Z	4	4	4	4	4	2
d_{calcd}/g cm^{-3}	1.29	1.28	1.29	1.27	1.25	1.27
F(000)/e	640	640	608	608	640	320
No. of unique reflections	1590	1781	1516	1751	1659	1508
No. of observed reflections	1488	1404	1330	1510	1333	1108
Absorption coeff./cm^{-1}	1.43	1.41	1.44	15.2	2.49	2.54
Final residuals						
R	0.030	0.034	0.029	0.053	0.038	0.048
R_w	0.041	0.036	0.034	0.062	0.0425	0.048
Weighting scheme $1/[\sigma^2(F) + nF^2]$. n =	0.000 361	0.000 159	0.000 166	—	0.000 741	0.001 514
Largest diff peak/e Å^{-3}	0.14	0.16	0.20	0.17	0.37	0.28
Largest diff hole/e Å^{-3}	−0.21	−0.23	−0.16	−0.54	−0.29	−0.23
Extinction parameter [a]	0.00504	0.003 76	0.005 54	—	0.003 38	—

[a] The value of X in the correction factor $[1 - 0.0001 F_c^2 X/(\sin\theta)]$ to be applied to the calculated structure factor F_c.

Table 9 Selected bond lengths (Å) with esds in parentheses for 1,3,2-oxazaphospholidines

	7	8	9	10	11	12
O(1)–P(2)	1.581(2)	1.588(2)	1.591(2)	1.581(2)	1.602(3)	1.594(4)
O(1)–C(5)	1.465(3)	1.458(4)	1.452(3)	1.463(4)	1.457(5)	1.444(8)
P(2)–N(3)	1.613(2)	1.623(3)	1.635(2)	1.641(3)	1.643(3)	1.640(6)
P(2)–O(6)	1.457(2)	1.453(3)	1.466(2)	1.463(3)		
P(2)–S(6)					1.931(1)	1.915(3)
N(3)–C(4)	1.473(3)	1.468(4)	1.474(4)	1.465(5)	1.456(5)	1.462(8)
N(3)–C(13)	1.455(4)	1.463(5)	1.455(4)	1.450(4)	1.447(6)	1.479(8)
C(4)–C(5)	1.539(3)	1.524(4)	1.552(4)	1.536(4)	1.542(6)	1.545(8)
C(4)–C(14)	1.516(4)	1.512(5)	1.516(4)	1.519(4)	1.524(8)	1.522(9)
C(5)–C(15)	1.500(3)	1.505(4)	1.505(4)	1.505(4)	1.493(5)	1.508(8)
P(2)–O(21)	1.593(2)	1.583(2)				
O(21)–C(7)	1.399(3)	1.398(4)				
P(2)–C(7)			1.794(3)	1.790(3)	1.800(5)	1.793(6)
C(4)–H(1)	0.90(3)	1.00(3)	1.07(3)	0.90	0.98(5)	1.08
C(5)–H(2)	1.03(3)	0.91(3)	0.94(3)	0.90	0.95(4)	1.08

consistent only with an averaged P–O–C–H torsion angle close to 90°. From similar results, Cooper [2] proposed that these rings adopt an envelope conformation, with O(1) out of the plane of the other four atoms. In contrast, Navech [3] proposed half-chairs, with C(4) and C(5) out of plane of the other three atoms, and Setzer [4] proposed a twist envelope conformation, in which the aromatic substituent on phosphorus is pseudoaxial. For the *syn* structures **4**, **7** and **9** the P–O–C–H torsion angles are −98, −87 and −96° in the crystals, consistent with the small $^3J_{P-H(5)}$ coupling constants. For these molecules, the envelope conformations observed in the crystals may reflect the conformations adopted in solution and they are in broad agreement with those proposed by Setzer.[4] In contrast, Cooper's proposal of an O(1) envelope, which would cause eclipsing of the C(4)–Me and C(5)–Ph groups, is not supported by the X-ray data. The conformations of the *syn* compounds **2** and **11** appears to support the claim of Navech [3] that these compounds adopt half-chair conformations, however the P–O–C–H torsion angles of −66 and −73° are inconsistent with a small $^3J_{P-H(5)}$ coupling constant of less than 1 Hz, therefore the conformation in solution must be different than that observed in the solid state.

For the *anti* compounds **1**, **3**, **6**, **8**, **10** and **12** $^3J_{P-H(5)}$ values of 3–6.5 Hz are observed, so that the torsion angle is removed

Table 10 Selected bond angles (°) with esds in parentheses for 1,3,2-oxazaphospholidines

	7	8	9	10	11	12
P(2)–O(1)–C(5)	111.7(1)	111.4(2)	114.0(2)	113.4(2)	109.5(2)	114.0(4)
O(1)–P(2)–N(3)	96.7(1)	96.4(1)	95.6(1)	96.1(1)	94.2(2)	94.6(2)
O(1)–P(2)–O(6)	119.4(1)	116.1(1)	115.9(1)	117.4(2)		
O(1)–P(2)–S(6)					116.9(1)	118.1(2)
N(3)–P(2)–O(6)	117.4(1)	120.7(2)	117.6(1)	115.3(2)		
N(3)–P(2)–S(6)					118.3(1)	115.3(2)
P(2)–N(3)–C(4)	113.6(2)	110.9(2)	113.6(2)	109.7(2)	113.9(3)	111.6(4)
P(2)–N(3)–C(13)	125.3(2)	122.1(3)	125.9(2)	121.7(3)	123.3(4)	120.8(4)
C(4)–N(3)–C(13)	119.9(2)	120.4(3)	120.4(3)	120.2(3)	120.8(4)	117.8(6)
N(3)–C(4)–C(5)	103.4(2)	102.0(2)	102.6(2)	103.3(3)	103.5(3)	101.9(5)
N(3)–C(4)–C(14)	111.7(2)	113.3(3)	112.7(3)	113.4(3)	112.2(4)	112.4(5)
C(5)–C(4)–C(14)	115.9(2)	114.2(3)	114.9(3)	114.2(3)	114.6(4)	114.3(5)
O(1)–C(5)–C(4)	105.9(2)	105.2(2)	107.0(2)	105.2(3)	104.8(3)	106.4(4)
O(1)–C(5)–C(15)	109.5(2)	110.1(2)	109.0(2)	110.2(3)	110.1(3)	110.9(5)
C(4)–C(5)–C(15)	115.4(2)	116.3(3)	115.9(2)	116.1(2)	116.2(3)	115.4(5)
C(5)–C(15)–C(16)	122.8(2)	122.6(3)	119.6(3)	118.9(3)	122.1(4)	120.6(5)
C(5)–C(15)–C(20)	118.4(2)	118.8(3)	121.9(3)	122.4(3)	118.6(4)	119.9(6)
O(1)–P(2)–O(21)	103.9(1)	107.6(1)				
N(3)–P(2)–O(21)	113.2(1)	109.3(1)				
O(6)–P(2)–O(21)	105.7(1)	106.0(1)				
P(2)–O(21)–C(7)	124.7(2)	124.9(2)				
O(21)–C(7)–C(8)	120.2(2)	118.9(3)				
O(21)–C(7)–C(12)	119.3(3)	120.1(3)				
C(7)–P(2)–O(1)			104.8(1)	104.8(1)	104.3(1)	104.2(1)
C(7)–P(2)–O(6)			109.9(1)	110.5(2)		
C(7)–P(2)–S(6)					112.1(2)	111.7(2)
C(7)–P(2)–N(3)			111.7(1)	111.6(1)	109.1(2)	111.4(3)
C(8)–C(7)–P(2)			122.1(2)	118.9(3)	120.2(3)	120.2(4)
C(12)–C(7)–P(2)			119.8(2)	122.4(3)	121.5(4)	121.3(4)
H(1)–C(4)–N(3)	110.9(19)	107.4(16)	106.9(15)	110.5	106.2(24)	112.1
H(1)–C(4)–C(5)	105.3(19)	107.4(15)	107.8(16)	113.5	108.1(24)	111.3
H(1)–C(4)–C(14)	109.3(19)	111.8(15)	111.2(16)	102.4	111.7(25)	105.0
H(2)–C(5)–O(1)	104.8(14)	106.6(19)	105.5(15)	112.3	107.2(23)	113.5
H(2)–C(5)–C(4)	110.7(15)	111.1(20)	109.6(15)	109.8	107.2(24)	110.2
H(2)–C(5)–C(15)	109.9(14)	107.2(19)	109.4(15)	103.4	110.9(21)	100.7

Table 11 Selected torsion angles (°) for 1,3,2-oxazaphospholidines

	7	8	9	10	11	12
P(2)–O(1)–C(5)–C(4)	29.6	29.3	20.3	−19.0	40.2	−17.5
P(2)–O(1)–C(5)–C(15)	154.7	155.3	146.3	106.9	165.9	108.7
C(5)–O(1)–P(2)–N(3)	−17.0	−8.7	−5.2	−1.4	−30.0	−2.4
C(5)–O(1)–P(2)–O(6)	109.7	−137.6	119.3	−124.0		
C(5)–O(1)–P(2)–S(6)					94.7	−124.4
O(1)–P(2)–N(3)–C(4)	−2.0	−16.0	−13.1	23.1	9.9	23.5
O(1)–P(2)–N(3)–C(13)	165.0	−167.4	170.4	171.0	173.6	168.4
O(6)–P(2)–N(3)–C(4)	−130.1	109.6	−136.2	147.2		
S(6)–P(2)–N(3)–C(4)					−113.7	147.6
P(2)–N(3)–C(4)–C(5)	18.6	33.3	24.8	−35.4	11.7	−34.5
P(2)–N(3)–C(4)–C(14)	−106.8	−89.9	−99.3	−159.6	−112.4	−157.4
C(13)–N(3)–C(4)–C(5)	−149.2	−174.7	−158.4	176.0	−152.4	179.3
N(3)–C(4)–C(5)–O(1)	−28.6	−37.6	−26.7	33.0	−30.9	31.1
N(3)–C(4)–C(5)–C(15)	−149.9	−159.8	−148.5	−89.2	−152.6	−92.3
C(14)–C(4)–C(5)–O(1)	94.0	84.9	96.0	156.6	91.5	152.6
C(14)–C(4)–C(5)–C(15)	−27.3	−37.2	−25.8	34.4	−30.2	29.2
O(1)–P(2)–O(21)–C(7)	37.3	−50.2				
P(2)–O(21)–C(7)–C(8)	97.0	−107.6				
P(2)–O(21)–C(7)–C(12)	−85.9	77.9				
C(5)–O(1)–P(2)–O(21)	−133.0	104.0				
O(21)–P(2)–N(3)–C(4)	106.3	−127.2				
O(1)–P(2)–C(7)–C(8)			111.5	162.5	57.7	152.9
O(1)–P(2)–C(7)–C(12)			−69.4	−19.5	−124.5	−27.8
C(5)–O(1)–P(2)–C(7)			−119.4	112.9	−141.0	111.0
C(7)–P(2)–N(3)–C(4)			95.3	−85.5	116.7	−83.8
P(2)–O(1)–C(5)–H(2)	−87	−89	−96	−139	−73	−139
P(2)–N(3)–C(4)–H(1)	131	146	138	86	125	85
C(13)–N(3)–C(4)–H(1)	−37	−62	−45	−62	−38	−62
N(3)–C(4)–C(5)–H(2)	85	77	87	154	83	155
H(1)–C(4)–C(5)–O(1)	−145	−151	−139	−87	−143	−89
H(1)–C(4)–C(5)–H(2)	−32	−36	−26	34	−30	35

Table 12 Conformational details of oxazaphospholidines

	7	8	9
ΔC_s	1.33, C(5)	9.88, C(4)	5.27, C(4)
ΔC_2	13.15, C(4)–C(5)	5.89, C(4)–C(5)	6.43, C(4)–C(5)
4-Atom plane	O(1)–P(2)–N(3)–C(4)	C(5)–O(1)–P(2)–N(3)	C(5)–O(1)–P(2)–N(3)
Deviations from it (Å)	C(5), −0.433	C(4), 0.529	C(4), 0.394
	C(15), 0.128	C(15), 0.637	C(15), 0.816
3-Atom plane	O(1)–P(2)–N(3)	O(1)–P(2)–N(3)	O(1)–P(2)–N(3)
Deviations from it (Å)	C(4), 0.047	C(4), 0.378	C(4), 0.306
	C(5), −0.399	C(5), −0.206	C(5), −0.119
	C(15), 0.180	C(15), 0.375	C(15), 0.670
	10	**11**	**12**
ΔC_s	3.36, C(4)	14.50, C(5)	4.88, C(4)
ΔC_2	14.28, C(4)–N(3)	1.39, O(1)–C(5)	11.95, N(3)–C(4)
4-Atom plane	C(5)–O(1)–P(2)–N(3)	O(1)–P(2)–N(3)–C(4)	C(5)–O(1)–P(2)–N(3)
Deviations from it (Å)	C(4), −0.517	C(5), −0.531	C(4), −0.502
	C(15), 1.347	C(15), −0.154	C(15), 1.326
3-Atom plane	C(5)–O(1)–P(2)	P(2)–N(3)–C(4)	C(5)–O(1)–P(2)
Deviations from it (Å)	N(3), 0.041	O(1), 0.276	N(3), 0.069
	C(4), −0.484	C(5), −0.303	C(4), −0.445
	C(15), 1.352	C(15), 0.227	C(15), 1.335

from orthogonality here. For structures **1**, **10** and **12**, all of which adopt C(4) envelopes with C(4) below the plane of the ring, the P–O–C–H torsion angles of −136, −139 and −139° are consistent with the observed $^3J_{P-H(5)}$ coupling constants and the conformations adopted in solution could be similar to those observed in the solid state. In contrast, compound **8**, with a P–O–C–H torsion angle of −89° is incompatible with the ^{1}H NMR data, and the half-chair adopted in the solid state is unlikely to be a major conformer in solution.

The $^3J_{P-H(4)}$ values do not display any evident trend although they are all much larger, in the range 10.6–18 Hz, implying that the torsion angle P–N–C–H is well removed from orthogonal in the average structure.

It is not possible to make generalisations by comparison of NMR and X-ray data. The crystal structures fall into a defined region of the pseudorotation pathway between the N(3)–C(4) half-chair and C(5)–O(1) half-chair, with a small preponderance of C(4) or C(5) envelopes (Fig. 1). In contrast, the solution NMR spectra seem to indicate that the averaged conformations of *syn* isomers **7**, **9** and **11** are in one region, probably close to the C(4) envelope. The *anti* isomers **8**, **10** and **12** fit into a related but slightly distinct conformational pattern. In a broad sense, the results are consistent with the suggestions of Setzer[4,6] and those of Devillers and Navech,[3] but inconsistent with the proposal of Cooper *et al.*[2] that compounds in this class adopt O(1) envelope conformations.

Experimental

Manipulations involving dichlorophenylphosphine were carried out under an argon atmosphere using standard vacuum line techniques[21] and all solvents were deoxygenated prior to use. Toluene, triethylamine and *N*-methylmorpholine were freshly distilled from CaH_2. All reagents were obtained from either BDH or Aldrich Chemical Co. Silica gel for flash chromatography was 60 'Merck' 230–300 mesh. Components were identified by TLC in suitable solvents on Merck Kieselgel 60F 254 plastic plates coated with 0.2 mm of silica visualised by UV light.

^{1}H Nuclear magnetic resonance (NMR) spectra were recorded on Bruker AM 500 (500 MHz) and AM 300 (300 MHz) spectrometers. ^{31}P NMR spectra were recorded on Bruker AM 250 (101.3 MHz) and AM 300 (121.5 MHz) spectrometers and are ^{1}H decoupled. ^{13}C NMR spectra were recorded on a Bruker AM 250 (63 MHz) spectrometer. Chemical shifts (δ) are given in ppm relative to tetramethylsilane (^{1}H, ^{13}C) or 85% phosphoric acid (^{31}P). *J* Values are in Hz. IR spectra were determined on a Perkin-Elmer 781 spectrometer. Mass spectra were recorded on a VG Micromass ZAB-1F/16F spectrometer using Electron Impact. Optical rotations were measured on a Perkin-Elmer 241 polarimeter using the 589.3 nm D line of sodium, and are in 10^{-1} deg cm^2 g^{-1}.

(2R,4S,5R)- *and* (2S,4S,5R)-3,4-*Dimethyl*-2-*phenoxy*-5-*phenyl*-1,3,2-*oxazaphospholidin*-2-*ones* **7** *and* **8**.—These were prepared by a literature method from phenyl phosphorodichloridate with (1*R*,2*S*)-(−)-ephedrine in the presence of triethylamine.[5] The diastereoisomers were separated by flash column chromatography on silica, eluting the column with ethyl acetate–hexane (1:1). The minor diastereoisomer **8** eluted first with an R_f of 0.35, and was recrystallised from hexane–diethyl ether (2:1); δ_P(121.5 MHz, $CDCl_3$) 14.0. The major diastereoisomer **7** eluted second with an R_f of 0.2, and was recrystallised from hexane–toluene (1:1); δ_P(121.5 MHz, $CDCl_3$) 14.1. Further data are given in Tables 1 and 8.

(2S,4S,5R)- *and* (2R,4S,5R)-3,4-*Dimethyl*-2,5-*diphenyl*-1,3,2-*oxazaphospholidin*-2-*ones* **9** *and* **10**.—Dichlorophenylphosphine (36.51 cm^3, 0.269 mol) was added dropwise *via* cannula over 30 min to a cooled (0 °C) and vigorously stirred solution of (1*R*,2*S*)-(−)-ephedrine (44.52 g, 0.269 mol) and *N*-methylmorpholine (59.25 cm^3, 0.54 mol) in dry toluene (600 cm^3) under an argon atmosphere. Stirring was continued at this temperature for 1 h after which a portion (2 cm^3) was removed and its ^{31}P NMR spectrum recorded: δ_P(101.3 MHz, toluene) 152.9 (s), 139.31 (s) which confirmed the presence of the two phenyloxazaphospholidine diastereoisomers. The solid *N*-methylmorpholine hydrochloride was removed by standard Schlenk filtration and washed with dry toluene (3 × 30 cm^3). The combined filtrate was cooled to 0 °C and *tert*-butylhydroperoxide (90 cm^3, 0.27 mol, 3.0 mol dm^{-3} in hexanes) was added with vigorous stirring. After 1 h the solution was left to stir at

ambient temperature for 18 h. White crystals were deposited which were collected by filtration and dried *in vacuo*. Concentration of the filtrate yielded a second crop which was treated similarly. Comparison of the ^{1}H NMR spectrum with the pure (2*R*,4*S*,5*R*) diastereoisomer prepared stereospecifically[14] showed a 3.3:1 ratio, with the (2*R*,4*S*,5*R*) diastereoisomer as the major product. TLC in diethyl ether–dichloromethane (1:1) showed the two diastereoisomers of R_f 0.38 (2*R*,4*S*,5*R*) and 0.14 (2*S*,4*S*,5*R*). The pair of diastereoisomers were separated by flash chromatography in diethyl ether–dichloromethane (1:1). The (2*R*,4*S*,5*R*) diastereoisomer **10** was recrystallised from hot toluene (19.5 g, 25.4%) as white crystals (Found: C, 67.15; H, 6.3; N, 4.75; P, 10.85. $C_{16}H_{18}NO_2P$ requires C, 66.87; H, 6.31; N, 4.86; P, 10.87%); $[\alpha]_D^{21}$ (*c* 1 in $CDCl_3$) −37.5; ν_{max}(Nujol)/cm^{-1} 1438 (s, P–Ph), 1295 (s, P=O), 1040 (s, P–C–alkyl); δ_C(63 MHz, $CDCl_3$) 14.50 (s, 4-Me), 28.55 (d, *J* 6.0, P–N–Me), 59.22 (d, *J* 10.11, C-4), 82.56 (s, C-5), 126–136 (m, aromatics); δ_P(101 MHz, $CDCl_3$) 29.7 (s); *m*/*z* (EI): 287 (M^+, 45), 272 (50), 196 (12), 181 (55), 146 (15), 104 (27), 77 (34). The (2*S*,4*S*,5*R*) diastereoisomer **9** was recrystallised from hot toluene (5.8 g, 7.6%) as white crystals, and recrystallised from hexane–toluene (1:2) to give a sample for crystallography (Found: C, 66.75; H, 6.25; N, 4.9; P, 11.1. $C_{16}H_{18}NO_2P$ requires C, 66.87; H, 6.31; N, 4.86; P, 10.87%); $[\alpha]_D^{21}$ (*c* 1 in $CDCl_3$) −52.0; ν_{max}(Nujol)/cm^{-1} 1438 (s, P–Ph), 1295 (s, P=O), 1040 (s, P–C–alkyl); δ_C(63 MHz, $CDCl_3$) 14.38 (s, 4-Me), 29.36 (d, *J* 6.3, P–N–Me), 60.79 (d, *J* 8.76, C-4), 80.26 (s, C-5), 126–136 (m, aromatics); δ_P(101 MHz, $CDCl_3$) 28.55 (s); *m*/*z* (EI): 288 (M^+, 100), 272 (15), 181 (15), 146 (5). Further data are given in Tables 1 and 8.

(2R,4S,5R)- *and* (2S,4S,5R)-3,4-*Dimethyl*-2,5-*diphenyl*-1,3,2-*oxazaphospholidine*-2-*thione* **11** *and* **12**.—Dichlorophenylphosphine (3.86 cm^3, 0.028 mol) was added dropwise *via* cannula over 30 min to a cooled (0 °C) and vigorously stirred solution of (1*R*,2*S*)-(−)-ephedrine (5.1 g, 0.028 mol) and triethylamine (7.93 cm^3, 0.056 mol) in dry toluene (200 cm^3) under an argon atmosphere. Stirring was continued at this temperature for 1 h after which the mixture was left to stir at ambient temperature for 18 h. A portion (2 cm^3) was removed and its ^{31}P NMR spectrum recorded: δ_P(101 MHz; toluene) 139.31 (s) which confirmed the presence of a single diastereoisomer. The solid triethylammonium hydrochloride was removed by standard Schlenk filtration and washed with dry toluene (3 × 30 cm^3). The combined filtrate was cooled (0 °C) and a saturated solution of sulphur in CS_2 was added with vigorous stirring. After 1 h, the solution was left to stir at ambient temperature for 18 h. Concentration of the filtrate yielded a white crystalline solid. ^{1}H NMR showed the presence of a pair of diastereoisomers in 10:1 ratio. TLC in 60–80 light petroleum–dichloromethane (1:1) showed the two diastereoisomers of R_f 0.61 (2*R*,4*S*,5*R*) **11** and 0.5 (2*S*,4*S*,5*R*) **12**. The pair of diastereoisomers were separated by flash chromatography in 60–80 light petroleum–dichloromethane (1:1). The minor diastereoisomer (2*R*,4*S*,5*R*) **11** was recrystallised from toluene (0.3 g, 3.2%) as colourless crystals suitable for X-ray crystallography (Found: C, 63.8; H, 5.85; N, 4.25; P, 9.15. $C_{16}H_{18}NOPS$ requires C, 63.35; H, 5.98; N, 4.62; P, 10.21%); $[\alpha]_D^{21}$ (*c* 1 in $CDCl_3$) +29.55; ν_{max}(Nujol)/cm^{-1} 880 (s, POCPh), 730 (s, P=S); δ_C(63 MHz, $CDCl_3$) 15.53 (s, 4-Me), 30.76 (d, *J* 6.1, P–N–Me), 61.00 (d, *J* 6.77, C-4), 80.89 (s, C-5), 126–136 (m, aromatics); δ_P(101 MHz, $CDCl_3$) 91.66 (s); *m*/*z* 304 (M^+, 100), 256 (33). The major (2*S*,4*S*,5*R*) diastereoisomer **12** was recrystallised from toluene (2.7 g, 31.8%) as colourless crystals, and subsequently recrystallised from toluene–hexane (1:1) for X-ray crystallography (Found: C, 63.0; H, 5.85; N, 4.25; P, 9.15. $C_{16}H_{18}NOPS$ requires C, 63.35; H, 5.98; N, 4.62; P, 10.21%); $[\alpha]_D^{21}$ (*c* 1 in $CDCl_3$) −139.3; ν_{max}(Nujol)/cm^{-1} 890 (s, POCPh), 730 (s, P=S); δ_C(63 MHz, $CDCl_3$) 13.48 (s, 4-Me), 29.14 (d, *J* 4.9, P–N–Me), 60.10 (d, *J* 7.3, C-4), 83.54 (s, C-5), 126–136 (m, aromatics); δ_P(101 MHz, $CDCl_3$) 90.27 (s); *m*/*z* 304 (M^+, 100), 256 (38), 224 (22), 192 (40), 160 (42), 96 (20), 64 (100). Further data are given in Tables 1 and 8.

Crystal Structure Determination.—Crystal data for the oxazaphospholidines were measured using Enraf–Nonius CAD4-F 4-circle diffractometers. Graphite monochromated X-radiation was used to collect reflected intensities by the $\omega - 2\theta$ scan technique, with Mo-Kα radiation (λ = 0.710 69 Å) for **7**, **8**, **9**, **11** and **12** out to Bragg angles θ of 25, 26, 25, 25 and 25°, respectively, and with Cu-Kα (λ = 1.5418 Å) for **10** to θ = 75°. The space group was determined unambiguously as a result of structure analysis. The unit cell parameters were obtained by least-squares refinement, the setting angles of 25 accurately centred reflections being used for this purpose. The ω scan angle was calculated from $[M + N(\tan\theta)]°$, where M = 1.00, N = 0.35 for **7**, **8**, **9**, **11** and **12** and M = 1.10, N = 0.14 for **10**, and increased by 25% on each side for background determination. The scan speed was varied from 1.0 to 4.0, 0.8 to 3.3, 1.0 to 3.3, 1.0 to 6.7, 1.0 to 3.3 and 0.6 to 2.5° min^{-1} depending upon intensity for **7**–**12** respectively. Several standard reflections were measured every hour during data collection and showed no appreciable variation with time. The data were corrected for Lorentz and polarisation effects. An absorption correction[22] was also applied to **10** to obtain relative intensities. All calculations for **7**, **8**, **9**, **11** and **12** were performed on a VAX8650 computer using SHELX,[23] and for **10** on a VAX11/750 computer using the CRYSTALS[24] software package incorporating SHELXS[25] and MULTAN 80.[26] Positional and thermal parameters for all hydrogen atoms of **7**, **8**, **9** and **11** were freely refined; H atoms of **10** were assumed to ride on attached atoms and were placed in observed positions except H(9) and H(10) which were placed in calculated positions since they were not found on the difference map; H atoms of **12** were placed in calculated positions with methyl groups treated as rotatable rigid bodies. The structures were refined by full-matrix (**7**, **8**, **9**, **11** and **12**) or large-block (**10**) least-squares which included parameters for atomic coordinates, temperature factors (anisotropic for non-hydrogen atoms), an overall scale factor and an extinction parameter. Reflections for **7**, **8**, **9**, **11** and **12** were weighted according to $1/[\sigma^2(F_o) + nF_o^2]$, and for **10** by applying a three term Chebychev series of the form $w = 1/[1095.4t_0(X) + 1489.4t_1(X) + 441.5t_2(X)]$ where $X = F_o/F_{max}$. Final Fourier series showed no significant residual electron density and there were no exceptional discrepancies between observed and calculated structure factors.*

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* Complete tables of temperature factors, hydrogen atom co-ordinates and bond lengths and angles have been deposited at the Cambridge Crystallographic Data Centre. For details of the deposition scheme see 'Instructions for Authors (1991),' *J. Chem. Soc., Perkin Trans. 2*, 1991, issue 1.

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