# A Study of the Apicophilicity of the 2-Furyl Group in Five-co-ordinate Phosphoranes

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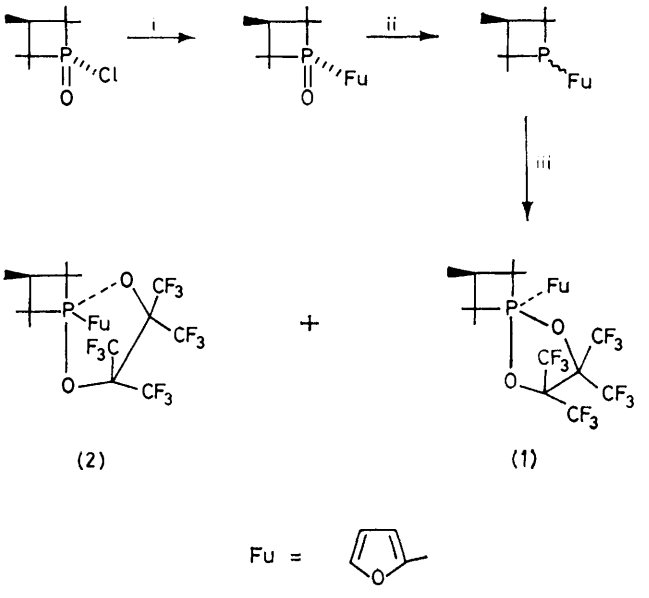
A number of 2-furylphosphoranes have been prepared; their variable temperature n.m.r. spectra were investigated and compared with those of the corresponding phenylphosphoranes. The 2-furyl group varied from being considerably more apicophilic than phenyl to being perhaps slightly less apicophilic.

A 2-FURYL group attached to phosphorus has a marked effect on the rate and course of reactions involving nucleophilic attack at a phosphonium centre.[1] Thus alkaline hydrolysis of tris-(2-furyl)methylphosphonium iodide is about $10^{10}$ times faster than the comparable hydrolysis of methyltriphenylphosphoniun iodide, and the hydrolysis of benzyltri-(2-furyl)phosphonium bromide leads to the formation of furan whereas hydrolysis of benzyltriphenylphosphonium bromide leads to the formation of toluene. Allen has ascribed these effects to (*a*) the powerful inductive effect of the 2-furyl group which, through the pre-equilibria involved in phosphonium salt hydrolysis, leads to an increase in the steady-state concentration of the anion $R_4PO^-$, and (*b*) the greater stability of the 2-furyl carbanion than of the phenyl or benzyl carbanions. One other factor that might be relevant, since the leaving group must depart from an apical position, is the relative apicophilicity of the 2-furyl group in the intermediate five-co-ordinate phosphoranes. We have prepared a number of five-co-ordinate phosphoranes containing a 2-furyl group attached to phosphorus in order to obtain evidence on this point.

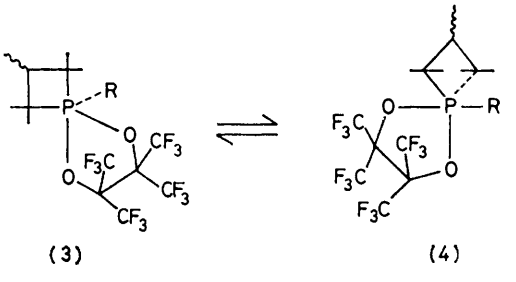
A mixture of the *trans*- (1) and *cis*-phosphoranes (2) was synthesised as shown in Scheme 1 and the pure *trans*-isomer obtained by fractional crystallisation. The two $^{19}F$ n.m.r. signals of (1) at room temperature coalesced reversibly at 79 °C ($\Delta\nu$ 200 Hz), leading [2] to a free energy of activation for the pseudorotation (3) ⇌ (4) when R = 2-furyl of 16.5 ± 0.1 kcal mol$^{-1}$.† This is to be compared with a value of 19.6 kcal mol$^{-1}$ for the corresponding *trans*-phenylphosphorane.[2] Coalescence of the two $^{19}F$ n.m.r. signals of the *cis*-isomer (2), observed in the spectrum of the mixed isomers, occurred at 97.5 °C ($\Delta\nu$ 200 Hz), leading to $\Delta G^*$ for the pseudorotation analogous to (3) ⇌ (4) of 17.3 ± 0.3 kcal mol$^{-1}$. In the corresponding *cis*-phenylphosphorane, coalescence of the two $^{19}F$ n.m.r. signals was not observed at 180 °C ,*i.e.* $\Delta G^* > 22$ kcal mol$^{-1}$.

Lower energy barriers to pseudorotations which place a 2-furyl group apical than to comparable pseudorotations which place a phenyl group apical were also observed in the systems (6) ⇌ (7) and (9) ⇌ (10) (see Table). The necessary 2-furylphosphoranes (5) and (8) were prepared as outlined in Schemes 2 and 3. Clearly

† 1 cal = 4.184 J.




SCHEME 1 *Reagents*: i, 2-lithiofuran; ii, $PhSiH_3$; iii, $(CF_3)_2CO$



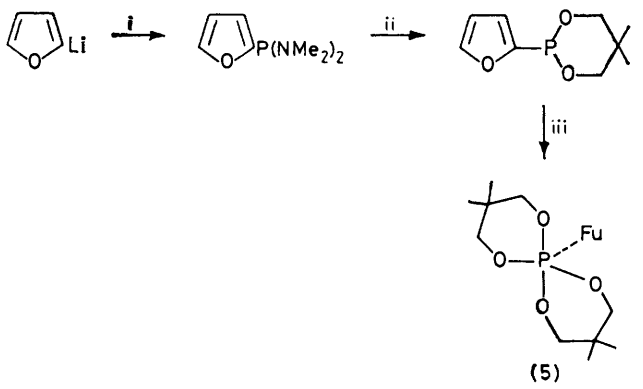

Pseudorotation energy barriers

| Pseudorotation | $\Delta G^*$ (at $T_c$; in kcal mol$^{-1}$) R = 2-Fu | R = Ph |
|---|---|---|
| (3) ⇌ (4) *trans* | 16.5 | 19.6 |
| (3) ⇌ (4) *cis* | 17.3 | >22 |
| (6) ⇌ (7) | 10.2 | 13.2 [c] |
| (9) ⇌ (10) | 10.4 | 12.6 [a,d] |
| (13) ⇌ (17) | 11.7 | 13.0 |
| (18) ⇌ (20) | 18.1 | 17.6 [e] |
| (22) ⇌ (24) | 16.8 [b] | 16.2 [b,f] |

[a] For PhO compound. [b] *trans* ⟶ *cis*. [c] S. A. Bone, S. Trippett, and P. J. Whittle, *J. Chem. Soc., Perkin Trans. I*, 1977, 437. [d] J. I. Dickstein and S. Trippett, *Tetrahedron Lett.*, 1973, 2203. [e] J. Brierley, Ph.D. Thesis, University of Leicester, 1978. [f] Ref. 4.

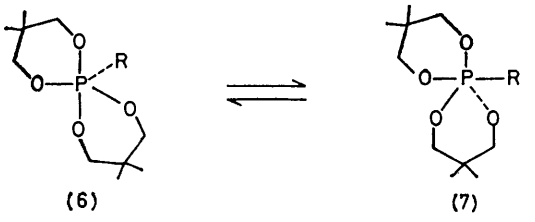
in the phosphoranes (3), (6), and (8) the 2-furyl group is substantially more apicophilic than the phenyl group.

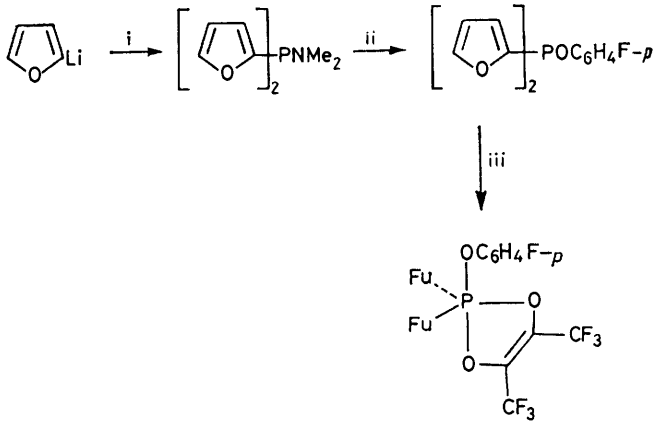
More equivocal results were obtained with phosphoranes having more complex pseudorotation pathways. For example, the methyl signals in the $^1H$ n.m.r. spectrum of the 2-phenylacrylophenone adduct (13) [for synthesis of the 2-furylphosphorane (11) see Scheme 4] coalesce when the pseudorotation process (13) ⇌ (17) becomes rapid on the n.m.r. time scale.[3] One would expect (15;




SCHEME 2 *Reagents*: i, $(Me_2N)_2PCl$; ii, $Me_2C(CH_2OH)_2$; iii, $Pr^i_2NCl$ + $Me_2C(CH_2OH)_2$ †

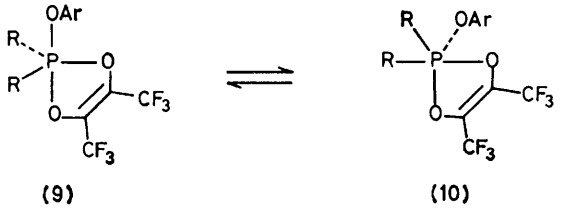
† S. Bone and S. Trippett, *Tetrahedron Lett.*, 1975, 1583.

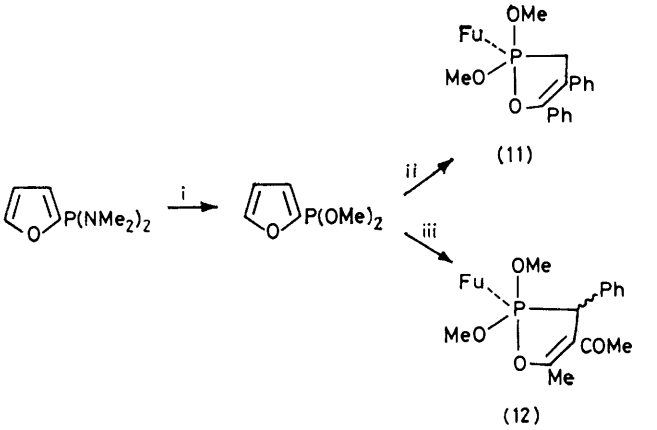



SCHEME 3 *Reagents*: i, $Me_2NPCl_2$; ii, *p*-$FC_6H_4OH$; iii, $(CF_3CO)_2$ ‡

‡ See footnote *d* of Table



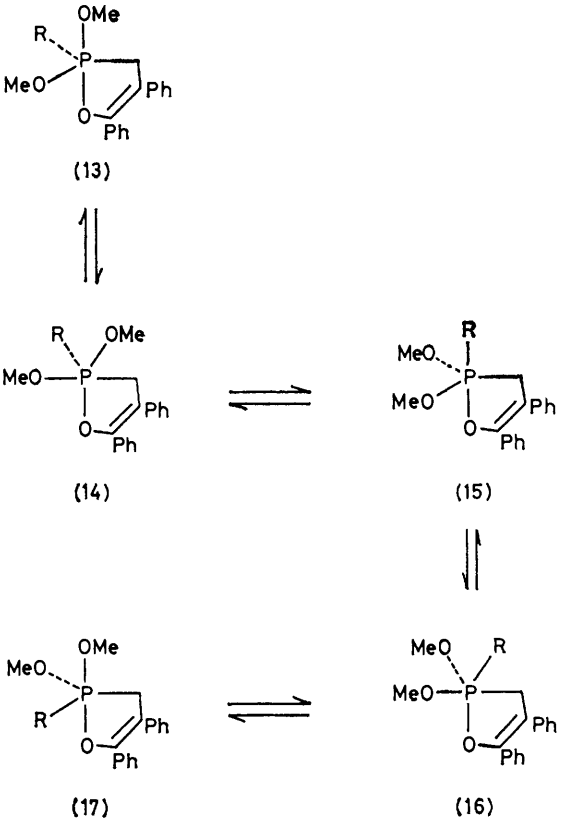




SCHEME 4 *Reagents*: i, MeOH; ii, $PhCOC(CH_2)Ph$; iii, $PhCH{=}C(COMe)_2$ ¶

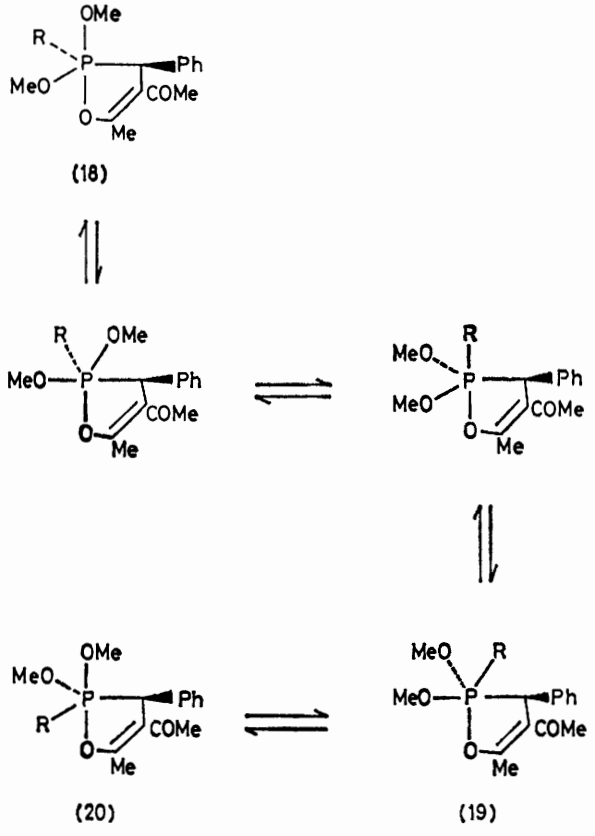
§ See footnote † to Scheme 2.

¶ Ref. 3.

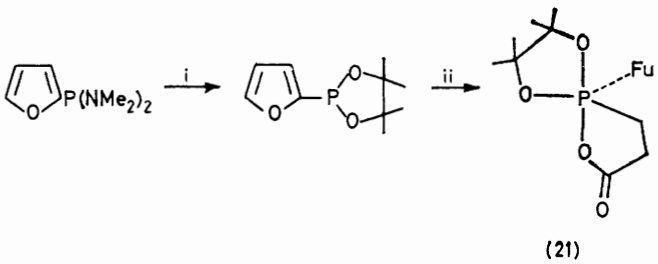
R = Ph or 2-Fu) to be of higher energy than (14) or (16) and indeed the free energies of activation for the processes (13) ⇌ (17) were 13.0 (R = Ph) and 11.7 kcal $mol^{-1}$ (R = 2-Fu) implying a smaller difference in apicophilicity between phenyl and 2-furyl than given above.



In the corresponding 3-benzylidenepentane-2,4-dione adducts [*e.g.* (12)], where the process that can be followed by $^{31}P$ or $^{1}H$ n.m.r. is interconversion of the *trans*-(18) and *cis*-(20) isomers,[4] the observed free energies of activation, for *trans* ⟶ *cis*,[5] were 16.2 (R = Ph) and 16.8 (R = 2-Fu) kcal mol$^{-1}$, *i.e.* phenyl is apparently slightly more apicophilic than 2-furyl. However, the ring phenyl group in these adducts introduces steric crowding, particularly in (19) where this group is eclipsed with the group R attached to phosphorus, and (19) is probably the highest energy phosphorane in the sequence (18) ⟶ (20). The higher barrier for (18; R = 2-Fu) therefore implies that the 2-furyl group is sterically more demanding than phenyl and this is consistent with a greater equilibrium proportion of *trans*-isomer in the *P*-(2-furyl)phosphorane than in the *P*-(phenyl)phosphorane.



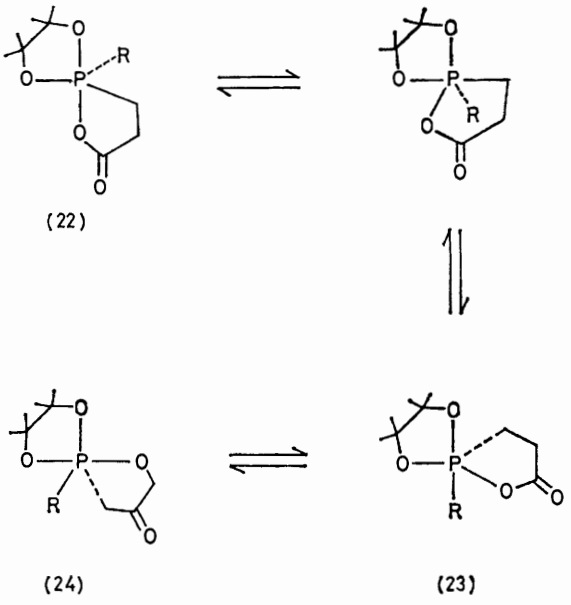

A more confusing picture was found in the acrylic acid adducts (22) [for the synthesis of the 2-furylphosphorane (21) see Scheme 5]. At room temperature there are four methyl $^{1}H$ n.m.r. signals; these coalesce in pairs as the pseudorotation sequence (22) ⇌ (24) becomes rapid on the n.m.r. time scale. The free energies of activation determined from these phenomena are 18.1 (R = 2-Fu) and 17.6 (R = Ph) kcal mol$^{-1}$ and, if regular pseudorotation processes are involved, it is difficult to avoid the conclusion that in this system the 2-furyl group is slightly less apicophilic than phenyl. The



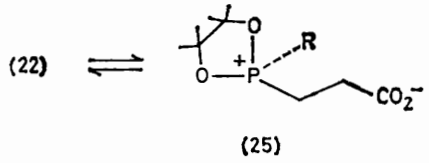

SCHEME 5 *Reagents*: i, pinacol; ii, $H_2C{=}CHCO_2H$**

** T. Saegusa, S. Kobayashi, and Y. Kimura, *J. Chem. Soc., Chem. Commun.*, 1976, 443.

observed energy barriers are considerably less than expected [6] for processes involving the highest energy phosphoranes (23) and the possibility arises that what is actually responsible for the coalescence phenomena is dissociation to the dipolar species (25). However, this is




unlikely in view of the retention of $^{31}P$—$^{13}C$ spin–spin coupling at 77 °C in the signals due to the carbonyl carbons in the $^{13}C$ n.m.r. spectra of (21) ($\delta_C$ 171.8 p.p.m., $^{2}J_{PC}$ 23.5 Hz) and (22; R = Ph) ($\delta_C$ 172.3 p.p.m., $^{2}J_{PC}$ 21.5 Hz).




In the phosphoranes investigated the 2-furyl group therefore ranges from being considerably more apicophilic than phenyl to being, perhaps, slightly less apicophilic. In these circumstances it is not possible to speculate on the role played by the relative apico-

philicity of the 2-furyl group in the hydrolysis of 2-furylphosphonium salts.

## EXPERIMENTAL

N.m.r. spectra ($^{31}P$ and $^{19}F$) were recorded for solutions in $CH_2Cl_2$ unless otherwise stated; positive chemical shifts are to low field of the standards, 85% $H_3PO_4$ and $C_6H_5CF_3$, respectively. Free energies of activation at the coalescence temperatures were calculated using the Gutowsky–Holm equation. Light petroleum refers to the fraction having b.p. 60—80 °C.

5-(2-*Furyl*)-6,6,7,8,8-*pentamethyl*-2,2,3,3-*tetrakistrifluoromethyl*-1,4-*dioxa*-5-*phosphaspiro*[3.4]*octane* [(1) *and* (2)].—Butyl-lithium (15 ml; 1.7M in hexane) was added slowly to a stirred solution of furan (1.4 g) in tetrahydrofuran (THF) (150 ml) at 0 °C and the solution set aside at room temperature for 1 h. It was then added slowly to *r*-1-chloro-2,2,*t*-3,4,4-pentamethylphosphetan 1-oxide [7] (4.1 g) in benzene (30 ml) at 0 °C and the mixture was allowed to warm up to room temperature. It was then washed with water, dried, and distilled to give *r*-1-(2-furyl)-2,2,*t*-3,4,4-pentamethylphosphetan 1-oxide (65%), b.p. 115—120 °C at 0.4 mmHg, $\delta_P$ 46.0, $\delta_H$ 0.95 (3 H, dd, *J* 2 and 7 Hz), 1.20 (6 H, d, *J* 15 Hz), 1.40 (6 H, d, *J* 12 Hz), 2.15 (1 H, dq, *J* 2 and 7 Hz), 6.55 (1 H, m), 7.35 (1 H, m), and 7.75 (1 H, m). This oxide (1.8 g) was heated with phenylsilane (0.86 g) at 100 °C for 2 h and the product distilled to give the corresponding phosphine (1.3 g; 78%) as a mixture of isomers. This was dissolved in ether (20 ml) and an excess of hexafluoroacetone was condensed into the stirred solution at −78 °C; the solution was then refluxed for 3 h under a solid $CO_2$–acetone condenser. Evaporation and chromatography on alumina, eluting with ether–light petroleum (1 : 3), gave a crystalline mixture of the isomers (1) and (2). Repeated crystallisation from light petroleum gave the *phosphorane* (1), m.p. 104—108 °C, $\delta_P$ −7.9, $\delta_H$ 0.8 (3 H, dd, *J* 2 and 6 Hz), 1.35 (6 H, d, *J* 21. Hz), 1.40 (6 H, d, *J* 13 Hz), 1.65 (1 H, m), 6.45 (1 H, m), 7.05 (1 H, m), and 7.55 (1 H, m); $\delta_F$ (toluene at room temperature −3.2 (6 F, m) and −5.3 (6 F, m) (Found: C 39.95; H, 3.4; P, 5.95. $C_{18}H_{19}F_{12}O_3P$ requires C, 39.85; H, 3.55; P, 5.7%). The minor isomer (2) showed $\delta_P$ −8.9, $\delta_F$ −3.2 and −5.3.

6-(2-*Furyl*)-3,3,9,9-*tetramethyl*-1,5,7,11-*tetraoxa*-6-*phosphaspiro*[5.5]*undecane* (5).—2-Furyl-lithium, prepared from furan (12.3 g) in THF (100 ml) as above, was added slowly to tetramethylphosphorodiamidous chloride (28.0 g) in THF (100 ml) at 0 °C and the mixture was set aside at room temperature overnight. Solvent was then removed and the residue stirred with dry ether (200 ml). Filtration and distillation then gave 2-furyl-*N*,*N*,*N*′,*N*′-tetramethylphosphorous diamide (82%), b.p. 43 °C at 0.1 mmHg, $\delta_P$ 83.9, $\delta_H$ 2.75 (12 H, d, *J* 9 Hz), 6.40 (2 H, m), and 7.55 (1 H, m). This diamide (10.0 g) and 2,2-dimethylpropane-1,3-diol (5.6 g) were heated together at 100 °C for 3 days. Distillation then gave 2-(2-furyl)-5,5-dimethyl-1,3,2-dioxaphosphorinan (43%), b.p. 70—74 °C at 0.15 mmHg, $\delta_P$ 123.6, $\delta_H$ 0.70 (3 H, s), 1.30 (3 H, s), 3.25—4.30 (4 H, m), 6.45 (1 H, m), 6.75 (1 H, m), and 7.65 (1 H, m). *N*-Chlorodiisopropylamine (1.49 g) in ether (10 ml) was added slowly with stirring to the above phosphorinan (2.0 g) and 2,2-dimethylpropane-1,3-diol (1.0 g) in ether (20 ml) at −78 °C and the mixture was set aside at room temperature for 24 h. Filtration and evaporation then gave the phosphorane (5), $\delta_P$ −65.3, $\delta_H$ ($CFCl_3$ at room temperature), 1.00 (12 H, s; $T_c$ −72 ± 2 °C, Δν 14 Hz), 3.75 (8 H, d, *J* 18 Hz), 6.45 (1 H, m), 7.25 (1 H, m), and 7.70 (1 H, m).

2-p-*Fluorophenoxy*-2,2-*di*-(2-*furyl*)-4,5-*bistrifluoromethyl*-1,3,2-*dioxaphosphole* (8).—2-Furyl-lithium, prepared from furan (11.8 g) in THF (100 ml) as above, was added slowly to dimethylphosphoramidous dichloride (12.7 g) in THF (100 ml) at 0 °C and the mixture was set aside at room temperature overnight. Solvent was then removed and the residue stirred with dry ether (200 ml). Filtration and distillation then gave di-2-furyl-*N*,*N*-dimethylphosphinous amide (45%), b.p. 70—72 °C at 0.5 mmHg, $\delta_P$ 17.7, $\delta_H$ 2.60 (6 H, d, *J* 11 Hz), 6.30 (2 H, m), 6.60 (2 H, m), and 7.55 (2 H, m). This amide (6.0 g) and *p*-fluorophenol (3.2 g) were heated together at 100 °C for 18 h. Distillation then gave *p*-fluorophenyl di-2-furylphosphinite (53%), b.p. 120—124 °C at 0.3 mmHg, $\delta_P$ 63.7, $\delta_H$ 6.30 (2 H, m), 6.6—7.0 (6 H, m), and 7.55 (2 H, m). The phosphorane (8) was prepared by the addition of hexafluorobiacetyl to a solution of this phosphinite in dichloromethane at room temperature in an n.m.r. tube until no more phosphinite remained (monitored by $^{31}P$ n.m.r.). The reaction was quantitative. The product showed $\delta_P$ −60.3, $\delta_F$ (at room temperature) −1.6 (6 F, s; $T_c$ −44 ± 4 °C, Δν 246 ± 20 Hz) and −58.7 (1 F, m).

2-(2-*Furyl*)-2,2-*dimethoxy*-4,5-*diphenyl*-1,2-*oxaphosphole* (11).—2-Furyl-*N*,*N*,*N*′,*N*′-tetramethylphosphonous diamide (2.4 g) and methanol (0.82 g) were heated together at 75 °C for 2 h. Distillation then gave dimethyl 2-furylphosphonite (73%), b.p. 38—40 °C at 0.3 mmHg, $\delta_P$ 142.8, $\delta_H$ 3.55 (6 H, d, *J* 11 Hz), 6.35 (1 H, m), 6.70 (1 H, m), and 7.60 (1 H, m). A solution containing this phosphonite (0.4 g) and 2-phenylacrylophenone (0.52 g) in benzene–light petroleum (1 : 4; 5 ml) was set aside at room temperature until the reaction was complete (monitored by $^{31}P$ n.m.r.). Evaporation then gave the phosphorane (11), $\delta_P$ −34.9, $\delta_H$ (in $CD_2Cl_2$ at room temperature), 3.20 (2 H, d, *J* 18 Hz), 3.60 (6 H, d, *J* 12 Hz; $T_c$ −37 ± 3 °C, Δν 31 Hz), 6.40 (1 H, m), and 6.85—8.0 (12 H, m).

2,2-Dimethoxy-2,4,5-triphenyl-Δ⁴-1,2-oxaphospholene, prepared by the method of Stewart,[3] showed $\delta_P$ −16.9, $\delta_H$ (at room temperature) 3.30 (2 H, d, *J* 17 Hz), 3.45 (6 H, d, *J* 11 Hz; $T_c$ −2 ± 2 °C, Δν 88 Hz), and 6.9—7.85 (15 H, m).

4-*Acetyl*-2-(2-*furyl*)-2,2-*dimethoxy*-5-*methyl*-3-*phenyl*-Δ⁴-1,2-*oxaphospholene* [(18) and (20) (R = 2-furyl)].—Dimethyl 2-furylphosphonite (0.4 g) and 3-benzylidenepentane-2,4-dione (0.47 g) in benzene–light petroleum (1 : 4, 5 ml) were set aside at room temperature until the reaction was complete (monitored by $^{31}P$ n.m.r.). Removal of solvent then gave the phosphorane as a mixture of isomers in the ratio 1 : 3, $\delta_P$ −28.4 and −34.7 [$T_c$ (in 1-bromonaphthalene) 69 ± 1 °C, Δν 151 Hz].

5-(2-*Furyl*)-2,2,3,3-*tetramethyl*-1,4,6-*trioxa*-5-*phosphaspiro*[4.4]*nonan*-7-*one* (21).—2-Furyl-*N*,*N*,*N*′,*N*′-tetramethylphosphonous diamide (7.0 g) and pinacol (4.4 g) were heated together at 100 °C for 18 days. Distillation then gave 2-(2-furyl)-4,4,5,5-tetramethyl-1,3,2-dioxaphospholan (52%), b.p. 76—79 °C at 0.1 mmHg, $\delta_P$ 150.3, $\delta_H$ 1.30 (6 H, s), 1.35 (6 H, s), 6.30 (1 H, m), 6.85 (1 H, m), and 7.50 (1 H, m). This phospholan (2.0 g) and acrylic acid (0.67 g) were dissolved in ether (20 ml) and the solution was set aside at room temperature for 16 h. Evaporation then gave the *phosphorane* (21), m.p. (from ethyl acetate) 87—90 °C, $\delta_P$ −30.7, $\delta_H$ ($C_2Cl_4$) 1.20, 1.25, 1.35, and 1.40 (each 3 H, s), 2.1—2.9 (4 H, m), 6.60 (1 H, m), 7.40 (1 H, m), and 7.80 (1 H, m); $\nu_{max.}$ 1 720 $cm^{-1}$ (Found: C, 54.1; H, 6.65; P,

10.75. $C_{13}H_{19}O_5P$ requires C, 54.55; H, 6.7; P, 10.8%). The four methyl signals coalesced reversibly to one (accidental coincidence) at 73 ± 2 °C ($\Delta\nu$ 12 Hz).

We thank the S.R.C. for a maintenance grant.

[1/1079 *Received*, 8*th July*, 1981]

REFERENCES

[1] D. W. Allen, B. G. Hutley, and M. T. J. Mellor, *J. Chem. Soc., Perkin Trans. 2*, 1974, 1690, and previous references.

[2] R. K. Oram and S. Trippett, *J. Chem. Soc., Perkin Trans. 1*, 1973, 1300.

[3] A. P. Stewart and S. Trippett, *Chem. Commun.*, 1970, 1279; A. P. Stewart, Ph.D. Thesis, University of Leicester, 1971.

[4] D. Gorenstein and F. H. Westheimer, *J. Am. Chem. Soc.*, 1970, **92**, 634; D. Gorenstein, *ibid.*, p. 644.

[5] H. Shanan-Atidi and K. Bor-Eli, *J. Phys. Chem.*, 1970, **74**, 961.

[6] S. A. Bone, S. Trippett, M. W. White, and P. J. Whittle, *Tetrahedron Lett.*, 1974, 1795.

[7] J. McBride, E. Jungermann, J. Killheffer, and R. Clutter, *J. Org. Chem.*, 1962, **27**, 1833.