

Direct Formation of λ^5 -Phospholes from Trialkyl Phosphites and Dimethyl Acetylenedicarboxylate. Alkoxyphosphonium Ylides as Reactive Intermediates and Stable Products

Julian C. Caesar and D. Vaughan Griffiths*

Department of Chemistry, University of Keele, Staffordshire ST5 5BG

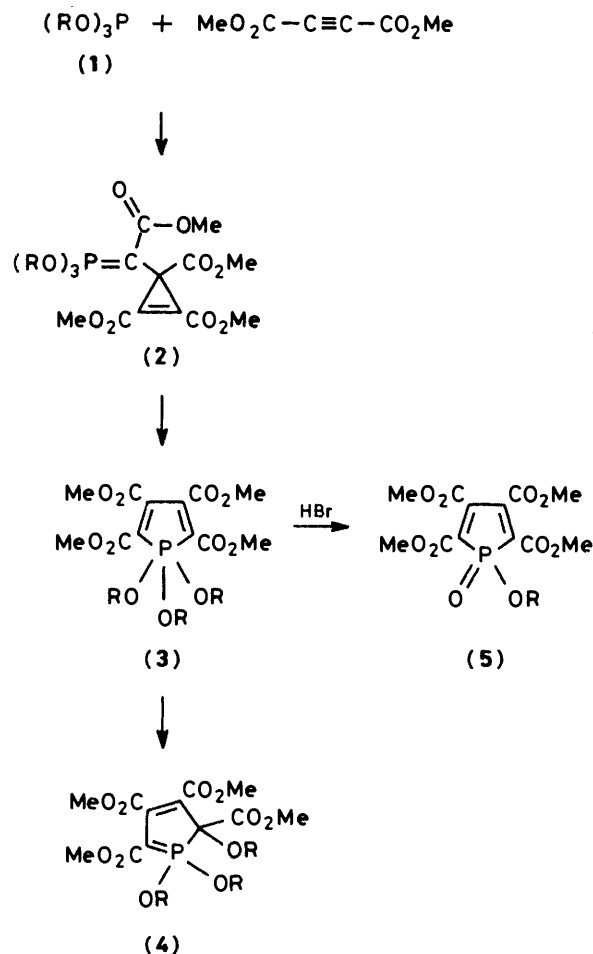
John C. Tebby and Stuart E. Willetts

Department of Chemistry and Biology, North Staffordshire Polytechnic, Stoke-on-Trent, Staffordshire ST4 2DE

Trialkyl phosphites and dimethyl acetylenedicarboxylate react in toluene below -10°C to form high yields of tetramethyl 1,1,1-trialkoxy- $1\lambda^5$ -phosphole-2,3,4,5-tetracarboxylates (**3**). These phospholes can either rearrange thermally to stable dialkoxyphosphonium ylides (**4**) or be converted by addition of hydrogen bromide to give stable tetramethyl 1-alkoxy-1-oxo- $1H$ - $1\lambda^5$ -phosphole-2,3,4,5-tetracarboxylates (**5**). The unstable trialkoxy [methoxycarbonyl-(1,2,3-trimethoxycarbonylcyclopropenyl)-methylene]phosphorane precursors of (**3**) can be formed almost quantitatively by carrying out the reaction in toluene below -50°C .

The reactions of tertiary phosphines with electrophilic acetylenes have produced a wide range of organophosphorus compounds¹. Although these reactions must proceed *via* a sequence of reactive intermediates, these intermediates have proved difficult to identify and study. For this reason, the reaction pathways have remained largely a matter of conjecture. However, by assuming that most of the products arise from the same basic pathway it has been possible to identify a number of likely intermediates.²

We have now completed a detailed investigation of the reaction of trialkyl phosphites with dimethyl acetylenedicarboxylate, and have found that intermediates of the type previously proposed for the tertiary phosphine reactions can be observed spectroscopically at low temperatures³ (see Scheme 1). This tends to suggest an enhanced stability of these oxyphosphorane intermediates over the all-carbon phosphorane which has been proposed as being involved in the tertiary phosphine reaction. Thus, the addition of a solution of a trialkyl phosphite (**1**; R = Me, Et, or Prⁱ) in toluene at -70°C to 2 mol equiv. of dimethyl acetylenedicarboxylate in toluene at about -70°C produced, after 1–2 h at -50°C , an almost quantitative yield of the ylide (**2**; R = Me, Et, or Prⁱ). These ylides were observed in the ^{31}P n.m.r. spectrum as two rotamers (Scheme 2) (δ_{P} 49–62 p.p.m.). This is a common feature in the low temperature spectra of ylides with an ester group on the α -carbon atom⁴ and arises because of restricted rotation around the bond to the α -methoxycarbonyl group. This interpretation of the two ^{31}P n.m.r. signals is further supported by the temperature-dependent nature of the ratio of the two signals. Thus, for example, whereas the minor rotamer from the reaction with trimethyl phosphite accounted for only 25% of the ^{31}P n.m.r. signal intensity at -60°C , this increased to about 40% at -20°C . The reversibility of this effect on cooling confirmed the existence of an equilibrium between the species responsible for the two ^{31}P n.m.r. signals. The rotamer ratio was also affected by the nature of the phosphite used, the proportion of the minor rotamer increasing as the bulk of the alkoxy groups on the phosphorus increased. Further support for the proposed ylide structures (Scheme 2) came from the shifts and multiplicities of the proton-coupled ^{31}P n.m.r. signals, which showed three alkoxy groups still attached to phosphorus. The ^{13}C n.m.r. spectrum also supported the proposed structures (see Table). Thus, for example, for (**2**; R = Me) the ylidic carbon of the major rotamer showed a large $^1J_{\text{PC}}$ coupling of 225 Hz, which we have found to be characteristic of such quasi-phosphonium ylides.



Scheme 1.

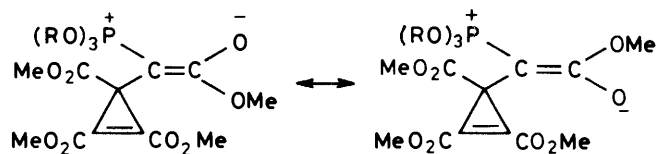
On raising the temperature of the solutions of (**2**) to -10°C , the ylides rearranged quantitatively during 15–30 min to give λ^5 -phospholes (**3**) characterised by their high-field ^{31}P resonances [for (**3**; R = Me) δ_{P} –37.9 p.p.m.]. The presence of three alkoxy groups on phosphorus was confirmed by the multiplicity of the proton-coupled ^{31}P n.m.r. signal, and the symmetrical nature of the structure of (**3**) was confirmed by the

presence of only two doublets for the ring carbons in the ^{13}C n.m.r. spectrum. The ^{13}C n.m.r. spectral data for (3; R = Me) are given in the Table.

The phospholes (3) could also be produced by carrying out the reaction between the trialkyl phosphite and the dimethyl acetylenedicarboxylate at -10°C , an observation confirmed by other workers.⁵ Under these circumstances the reaction is so rapid that no sign of the ylides (2) is observed. Although compound (3; R = Me) would be expected to undergo pseudorotation, we were unable to slow down this process sufficiently to observe different methoxy environments on the phosphorus in the low-temperature ^1H n.m.r. spectrum. At -90°C significant broadening of the signals was observed but this appeared to be due largely to the increased viscosity of the sample.

The phosphoranes (3) are the first λ^5 -phospholes of this type to be reported, and although these monocyclic derivatives were found to be unstable at room temperature the corresponding bicyclic systems have since been shown to be more stable.⁵

Although the phospholes (3) were stable for many hours at -10°C , raising the temperature to room temperature caused them to rearrange to the cyclic dialkoxyphosphonium ylides (4), the migration of one of the alkoxy groups from phosphorus being readily confirmed by the proton-coupled ^{31}P n.m.r. spectrum. Although these ylides have rather low-field shifts in the ^{31}P n.m.r. spectra (δ_{P} 76–84 p.p.m.) it should be noted that the corresponding ylide from triphenylphosphine also has a chemical shift (48.5 p.p.m.) well downfield of those of acyclic ylides.⁶ At low temperatures (-50°C) the ^{31}P n.m.r. spectrum of (4; R = Me) in deuteriochloroform shows the presence of four rotamers (δ_{P} 85.9, 85.3, 83.1, and 82.4 p.p.m.). This is consistent with the proposed structure for (4) where there is some double bond character, and hence restricted rotation, in

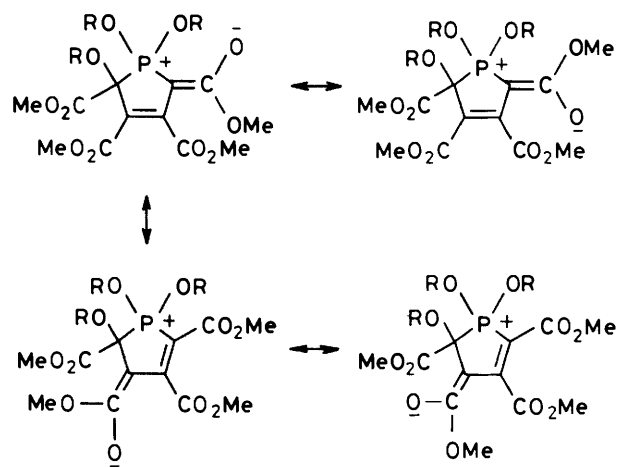


Scheme 2.

those bonds to both the α - and γ -methoxycarbonyl groups (see Scheme 3). The spectral data for (4; R = Me) are given in the Table. In general these cyclic ylides were sufficiently stable to be isolated in good yield and in high purity although some difficulties were experienced in isolating a pure sample of (4; R = Me).

We have now developed procedures for diverting the reaction pathway from the previously described route to give novel oxo- λ^5 -phospholes (5) in good yield. In our preliminary communication³ we reported the production of the phosphole (5; R = Et) in 25–30% yield. Since then we have improved our trapping procedures so that our yield has increased to 50–60%. Although the conversion of (3; R = Me) into (5; R = Me) could also be carried out efficiently, the isolation of (5; R = Me) proved much more difficult, this being reflected in a lower yield (about 32%).

In order to form the oxo-phospholes (5) it is necessary to dealkylate the trialkoxy-phospholes (3) by addition of appropriate quantities of hydrogen bromide. Unfortunately, although toluene was found to be an excellent solvent for the formation of (3) it proved unsuitable for the dealkylation step. The hydrogen bromide gas tended to bubble through the



Scheme 3.

Table. N.m.r. data

$\delta(^{13}\text{C})^a$ R	(2; R = Me)	(3; R = Me)	(3; R = Et)	(4; R = Me)	(5; R = Me)	(5; R = Et)
	53.77 (4) ^b	54.76 (11) ^c	16.34 (9) ^d 63.34 (10)	54.45 (7) ^e 57.53 (7) 58.49 (8)	53.94 (7) ^f	16.49 (6) ^f 64.35 (7)
α -C	42.02 (225)	142.85 (143)	144.25 (135)	63.81 (139)	127.06 (125)	127.55 (125)
β -C	36.55 (18)	134.61 (33)	133.83 (32)	162.62 (38)	144.28 (27)	144.03 (28)
γ -C	115.99			100.28 (27)		
δ -C				83.75 (113)		
C=O	158.89 158.89 168.44 (21) 173.04 (5)	164.01 (27) 166.32 (9)	163.88 (27) 166.93 (9)	163.29 (9) 163.45 (17) 165.59 (24) 166.93	160.27 (12) 162.14 (23)	160.16 (12) 162.20 (23)
OMe	49.90 52.48 ^g 52.48 52.48	51.96 52.20	52.26 52.67	50.54 50.89 52.01 52.49	53.20 53.30	53.13 53.25
$\delta(^{31}\text{P})^h$	61.6 (major) 59.4 (minor)	-37.4 ^b (dect, 14)	-41.84 ^f (sept, 9)	84.40 ^f (sept, 12)	36.88 (q, 12)	35.28 (t, 9)

^a Shifts in p.p.m. from Me_4Si ; J_{PC} in Hz in parentheses. ^b [$^2\text{H}_8$]Toluene, -50°C . ^c [$^2\text{H}_8$]Toluene, -15°C . ^d [^2H]Chloroform, -30°C . ^e [$^2\text{H}_8$]Toluene 50°C . ^f [^2H]Chloroform, 26°C . ^g Tentative assignment as region complicated by signals from minor rotamer and small quantities of starting material. ^h Shifts in p.p.m. from 85% phosphoric acid; positive shifts to low field of reference; J_{PH} in Hz in parentheses.

toluene without reacting, thus making it difficult to estimate when the reaction was complete. This problem was overcome by using diethyl ether rather than toluene as solvent. Although the diethyl ether gave a slightly less pure sample of (3) it readily absorbed the hydrogen bromide thus making it easier to control the amount of hydrogen bromide added to the solution of (3).

Two approaches were found suitable for the addition of the hydrogen bromide to the solution of (3). In the first, a known volume of hydrogen bromide was absorbed into some diethyl ether. This solution was then added slowly to a cooled solution of (3) in diethyl ether. In the second method the cooled solution of (3) in diethyl ether was added dropwise to an appropriate volume of hydrogen bromide in a cooled flask. Both these methods gave good yields of the oxo-phospholes (5). The identity of the resulting phospholes was confirmed by the multiplicity of the proton-coupled ^{31}P n.m.r. signals together with the ^{13}C n.m.r. spectra which clearly showed the symmetrical nature of (5).

This synthesis of (5) therefore represents a convenient route for the synthesis of some novel phospholes, particularly if methods can be developed for removing or modifying the methoxycarbonyl groups. These and other aspects are under investigation.

Experimental

N.m.r. spectra were determined with a JEOL FX100 spectrometer.

Trialkoxy[methoxycarbonyl-(1,2,3-trimethoxycarbonyl-cyclopropenyl)methylene]phosphoranes (2; R = Me, Et, or Prⁱ).—A trialkyl phosphite (1; R = Me, Et, or Prⁱ) (1 mmol) in dry [$^2\text{H}_8$]toluene (0.5 cm³) was cooled to about -70°C and then added to a solution of dimethyl acetylenedicarboxylate (0.25 g, 2 mmol) in dry [$^2\text{H}_8$]toluene (2 cm³) also at about -70°C in an n.m.r. tube (1 cm diam.). The tube was quickly transferred into the n.m.r. probe and the reaction monitored at -50°C . ^{31}P N.m.r. spectroscopy showed that the trialkyl phosphite reacted over about 2 h to give an essentially quantitative yield of the ylide (2; R = Me, Et, or Prⁱ). The structure of the ylide (2; R = Me) was established by low temperature (-50°C) ^{13}C and ^{31}P n.m.r. spectroscopy (see Table). Under similar conditions the ylide (2; R = Et) showed δ_{p} 55.8 and 54.1 p.p.m. and the ylide (2; R = Prⁱ) δ_{p} 51.0 and 49.3 p.p.m.

Tetramethyl 1,1,1-Trialkoxy-1 λ^5 -phosphole-2,3,4,5-tetracarboxylates (3; R = Me, Et, or Prⁱ).—The solution of the ylide (2; R = Me, Et, or Prⁱ) in [$^2\text{H}_8$]toluene at -50°C was allowed to warm up to -10°C . At this temperature a rapid rearrangement occurred to give the phosphole derivative (3; R = Me, Et, or Prⁱ). These phospholes were unstable at room temperature with half-lives ca. 10–12 min in toluene. The ^{13}C and ^{31}P n.m.r. spectra of (3; R = Me or Et) are given in the Table. For (3; R = Prⁱ) δ_{p} was -48.5 p.p.m.

Tetramethyl 1,1,2-Trimethoxy-2H-1 λ^5 -phosphole-2,3,4,5-tetracarboxylate (4; R = Me).—Trimethyl phosphite (2 g) in dry diethyl ether (15 cm³) at about -50°C was added to a solution of dimethyl acetylenedicarboxylate (4.58 g) in diethyl ether (15 cm³) also at about -50°C . The mixture was allowed to warm to room temperature and then kept at this temperature

for several hours. The ether was then decanted off to leave a viscous oil. This oil was warmed gently under reduced pressure (about 0.5 mmHg) to remove any volatile components. N.m.r. spectroscopy (Table) showed the resulting material to be the cyclic ylide (4; R = Me) (Found: C, 43.8; H, 5.4. C₁₅H₂₁O₁₁P requires C, 44.1; H, 5.2%).

Tetramethyl 1-Methoxy-1-oxo-1H-1 λ^5 -phosphole-2,3,4,5-tetracarboxylate (5; R = Me).—A solution of trimethyl phosphite (1.31 g) in dry diethyl ether (20 cm³) at -50°C was rapidly added to a solution of dimethyl acetylenedicarboxylate (3 g) in dry diethyl ether (20 cm³) also at -50°C . The mixture was kept at this temperature for about 20 min and then allowed to warm slowly to -10°C . Diethyl ether (20 cm³), saturated with hydrogen bromide (1 g), was then added to the mixture. After ca. 5 min at -10°C the mixture was allowed to warm to room temperature. The solvent and other volatile components were then removed under reduced pressure to give a viscous oil. A little chloroform was added to make this oil less viscous and the result was then triturated with hexane. This produced a cloudy suspension of the desired product in hexane. The hexane was then removed and filtered. This procedure was repeated with further quantities of hexane until no further product could be obtained. The phosphole (1.15 g, 32%) was obtained as a white solid (Found: C, 43.35; H, 4.2. C₁₃H₁₅O₁₀P requires C, 43.1; H, 4.2%).

Tetramethyl 1-Ethoxy-1-oxo-1H-1 λ^5 -phosphole-2,3,4,5-tetracarboxylate (5; R = Et).—A solution of triethyl phosphite (1.70 g) in dry diethyl ether (15 cm³) at -50°C was quickly added to a solution of dimethyl acetylenedicarboxylate (2.91 g) in dry diethyl ether (15 cm³) at -50°C . This mixture was then quickly transferred to a thermally insulated pressure-equalised dropping funnel, which was mounted on a 500 cm³ round-bottomed flask, filled with hydrogen bromide at atmospheric pressure, and cooled to about 0°C . The contents of the pressure-equalised dropping funnel were allowed to drip slowly into the flask whereupon a vigorous reaction was observed. At the end of the addition the contents of the flask were shaken to ensure that the reaction was complete, and then the phosphole which had formed was filtered off and washed with ether. The filtrate and washings were combined and the ether then removed under reduced pressure to give a viscous oil. Trituration of this oil with a little diethyl ether gave more phosphole as a white solid (2.22 g, 59%) (Found: C, 44.45; H, 4.65. C₁₄H₁₇O₁₀P requires C, 44.7; H, 4.5%).

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