

Reaction of Phosphites with Unsaturated Acid Chlorides: Synthesis and Reactions of Dimethyl But-2-enoylphosphonate

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Dimethyl *trans*-but-2-enoylphosphonate has been prepared in moderate yield from the reaction of trimethyl phosphite with excess of *trans*-but-2-enoyl chloride. When the reaction is carried out using equimolar quantities of reactants the major product is the *trans*-but-2-enoyl ester (5). This ester is formed by the facile reaction of the *trans*-but-2-enoyl phosphonate with trimethyl phosphite to give the pentacovalent oxaphospholen (6) which is then attacked by *trans*-but-2-enoyl chloride. The reactions of trialkyl phosphites with 2-methylpropenoyl and propenoyl chlorides follow similar pathways but at different relative rates.

A WIDE variety of acylphosphonates^{1,2} (1; Y = OR), aroylphosphonates³ (2; Y = OR) and related amides, phosphinates, and phosphine oxides^{4,5} have been reported. Studies of their properties have mainly concerned their conformations and the reactivities of their carbonyl groups. They have usually been prepared by the Arbuzov reactions of phosphites with carboxylic acid chlorides, but the reactions involving dialkyl phosphonates,^{2,5,6} or diaryl- and dialkyl-phosphinoids^{5,7} have also been used. Furthermore, an α -ketophosphine sulphide and an α -ketophosphonium salt have been prepared from an α -ketophosphine.⁸ There has been less success in the preparation of $\beta\gamma$ -unsaturated α -ketophosphonates (3)⁹ and the results presented in this paper indicate that little confidence can be placed on the claim for the preparation of diethyl propenoylphosphonate.¹⁰ Some di- and tri-substituted propenoylphosphonates have, however, been prepared and characterised.¹¹ We now report our studies of the Arbuzov reaction of trimethyl and triethyl phosphites with *trans*-

but-2-enoyl, propenoyl, and 2-methylpropenoyl chlorides.

RESULTS AND DISCUSSION

Pure dimethyl *trans*-but-2-enoylphosphonate (4; R = Me) may be prepared in 50% yield by the slow addition of trimethyl phosphite to a three-fold excess of *trans*-but-2-enoyl chloride at room temperature, followed by removal of the excess of butenoyl chloride and distillation under pressure. The structure of the but-2-enoylphosphonate was confirmed by ¹H, ¹³C, and ³¹P n.m.r. spectroscopy (see Table 1) and conversion into its 2,4-dinitrophenylhydrazone.

If the reaction is carried out with equimolar quantities of trimethyl phosphite and *trans*-but-2-enoyl chloride, which is the normal procedure in the preparation of α -ketophosphonates, the main product is a much higher boiling viscous yellow oil. This product is an ester (ν_{CO} 1735 cm⁻¹) containing two different phosphorus groups (δ_P 11 and 30, J_{PP} 6 Hz) which does not form a

TABLE I

¹H, ¹³C, and ³¹P N.m.r. parameters of the products and intermediates from the reaction of trimethyl phosphite with *trans*-but-2-enoyl chloride

	(4; R = Me)	(5; R = Me, R ¹ = <i>trans</i> -MeCH=CH)	(6; R = Me)	(8)	(9)
δ_P (J_{PP})					
α P	0.2	11.0 (6)	11.9 (17)	13.7 (11)	-1.6 (10)
γ P		29.7	-19.1	33.6	34.6
δ_C (J_{PC})					
PO-Me	54.3 (7)	ca. 52.4	52.8 (6) 54.7 (10)	51.8-54.3	51.8-54.3
C $_{\alpha}$	196.7 (172)	138.1 (225, 13)	142.1 (13, 229)	144.0 (218, 11)	207.2 (173, 15)
C $_{\beta}$	130.8 (66)	133.6 (27, 9)	118.3 (9, 26)	115.7 (31, 10)	44.1 (58, 1)
C $_{\gamma}$	150.9 (0)	29.5 (12, 142)	33.6 (170, 8)	28.5 (15, 140)	24.5 (4, 145)
C $_{\delta}$	18.7 (0)	13.1 (6)	16.1 (6, 3)	13.5 (6)	14.2 (6)
C $_{\alpha'-\delta'}$		a			
δ_H (J_{PH})					
α -P-OMe	3.86 (11)	3.75 (11)	3.80 (11, 0.3)	ca. 3.8 (11)	ca. 3.8 (11)
γ -P-OMe		3.77 (11)	3.59 (0, 12)	ca. 3.8 (11)	ca. 3.8 (11)
H $_{\beta}$	6.41 (17)	6.4 (10, 6)	2.61 ^b	5.4 (6, 5)	ca. 3 ^b
H $_{\gamma}$	7.52	2.95	5.84 (45, 7)	3.1 ^{b,c}	ca. 2.6 ^{b,c}
H $_{\delta}$	2.03	1.33 (18)	1.27 (0.6, 22)	1.3 (18)	1.2 (18)
H $_{\beta'-\delta'}$		d			
J (H $_{\beta}$ H $_{\gamma}$)	16	11	3	8	
J (H $_{\beta}$ H $_{\delta}$)	2	0	0	0	0
J (H $_{\gamma}$ H $_{\delta}$)	7	7	7	7	7

^a δ (C $_{\alpha'}$) 162.1, δ (C $_{\beta'}$) 119.8, δ (C $_{\gamma'}$) 147.6, and δ (C $_{\delta'}$) 17.7 ^b Spectrum too complex for analysis. ^c Position determined by homonuclear decoupling. ^d δ (H $_{\beta}$) 5.95; δ (H $_{\gamma}$) 7.15; δ (H $_{\delta}$) 1.96; J (H $_{\beta}$ H $_{\gamma}$) 16, J (H $_{\gamma}$ H $_{\delta}$) 7, and J (H $_{\beta}$ H $_{\delta}$) 2 Hz.

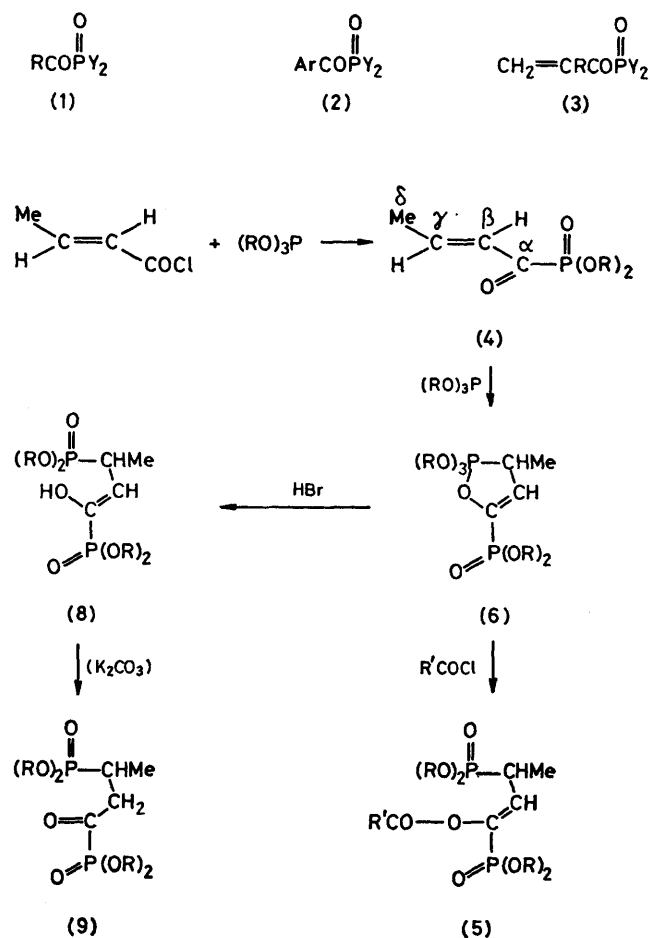
TABLE 2

³¹P N.m.r. parameters of the products and intermediates from the reaction of trimethyl phosphite with propenoyl chloride and 2-methylpropenoyl chloride

Propenoyl compounds	(3; R = H, Y = OMe)	(10; R ¹ = H)	(11; R ¹ = H, R ² = H)	(11; R ¹ = H, R ² = CH ₂ =CHCO)	(12)
δ _P (J _{PP})					
α-P	0.36	11.8 (22)	13.6 (10)	10.4 (7)	-1.3 (7)
γ-P		-18.6	31.5	26.4	32.8
2-Methylpropenoyl compounds	(3; R = Me, Y = OMe)	(10; R ¹ = Me)	(11; R ¹ = Me, R ² = H)	(11; R ¹ = Me, R ² = CH ₃ =CMeCO)	a
δ _P (J _{PP})					
α-P	-0.4	12.5 (20)	15.4 (11)	10.7 (11)	a
γ-P		-23.7	30.2	27.2	

^a Treatment of the enol (11; R¹ = Me, R² = H) with solid potassium carbonate did not produce the keto-tautomer but led to fragmentation to give (MeO)₂PHO.

2,4-dinitrophenylhydrazone. Its ¹H and ¹³C n.m.r. spectra showed it to be the butenoyl ester (5; R = Me, R¹ = *trans*-MeCH=CH).



The mechanistic pathway leading to the formation of the high boiling butenoyl ester (5; R = Me, R¹ = *trans*-MeCH=CH) was elucidated by studying the reaction of the dimethyl butenoylphosphonate (4; R = Me) with further trimethyl phosphite. A facile reaction occurs with the formation of the pentacovalent 1,2-oxaphospholen (6; R = Me), δ_P -19 and 12, J_{PP} 17 Hz.

Attempts to isolate the oxaphospholen in a pure state led to its decomposition even though it showed little decomposition as a chloroform solution at room temperature over a period of 24 h. In common with many other pentacovalent 1,2-oxaphospholens, *e.g.* (7),¹² its ¹H n.m.r. spectrum was temperature-dependent and at -80 °C the methoxy-resonances associated with the pentaco-ordinate phosphorus atom separated into three signals. One of the signals showed a J_{PH} 14 Hz and is assigned to the apical methoxy-group in a trigonal bipyramidal arrangement, whilst the two remaining signals with J_{PH} 11 Hz were assigned to the radial methoxy groups. Non-equivalence of the two radial methoxy groups can be explained by the presence of the asymmetric centre in the ring.

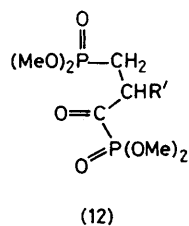
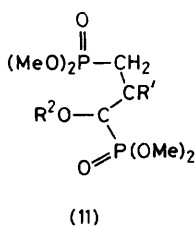
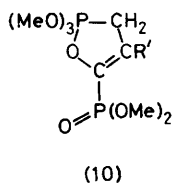
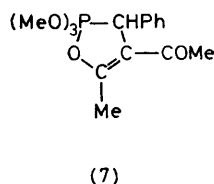
The addition of *trans*-but-2-enoyl chloride to the solution of the oxaphospholen (6; R = Me) led to the formation of the ester (5; R = Me, R¹ = *trans*-MeCH=CH). A small amount of the enol (8; R = Me) was also produced which was unreactive towards excess of butenoyl chloride, indicating that formation of ester (5) does not involve this enol as an intermediate. The formation of the enol is attributed to the presence of hydrogen chloride in the reaction mixture. This conclusion is based on an n.m.r. study which showed that treatment of a chloroform solution of the oxaphospholen with gaseous hydrogen bromide produced a substantial proportion of the enol (8; R = Me) together with some of its keto-tautomer. The enol was stable in solution if excess of hydrogen bromide was present, but treatment with solid potassium carbonate converted the enol into its keto-tautomer (9; R = Me). Neither the enol nor its keto-tautomer were isolated but the solutions were sufficiently pure to permit their structures to be confidently assigned on the basis of their ¹H, ¹³C, and ³¹P n.m.r. spectra (Table 1).

Treatment of the oxaphospholen (6; R = Me) with acetyl chloride and 3,5-dinitrobenzoyl chloride gave products with δ_P 34.6 and -1.6, J_{PP} 10 Hz and δ_P 28.6, 9.32, J_{PP} 6 Hz, respectively, which is consistent with the formation of esters (5; R = R¹ = Me) and (5; R = Me, R¹ = 3,5-dinitrophenyl).¹³ Thus the reaction of oxaphospholens with carboxylic acid chlorides appears to be

general and could provide a route to a wide range of useful 1,3-diphosphonic acid derivatives.¹⁴

The reaction of triethyl phosphite with *trans*-but-2-enoyl chloride was also studied and it was found to follow the same pathway, producing very similar quantities of products and intermediates.

N.m.r. studies of the reaction of propenoyl chloride and 2-methylpropenoyl chloride with trimethyl phosphite (see Table 2) indicated that although the same basic reaction pathways were followed, the relative rates of the various steps were different from those observed for butenoyl chloride. Thus in the 2-methylpropenoyl chloride reaction, trimethyl phosphite reacts with the α -ketophosphonate (3; R = Me, Y = OMe) more slowly than with 2-methylpropenoyl chloride and hence the ketophosphonate is the major component in the product even upon using equimolar quantities of starting materials. On the other hand, in the propenoyl chloride reaction, trimethyl phosphite reacts with the α -ketophosphonate (3; R = H, Y = OMe) more rapidly than with propenoyl chloride and hence the products are mainly the oxaphospholen (10; R = H) and the diphosphonate ester (11; R = H) with the α -ketophosphonate (3; R = H, Y = OMe) being a minor component, even when a large excess of propenoyl chloride is present. This latter observation accounts for the difficulties en-



countered by previous workers in their attempts to prepare diethyl propenoylphosphonate.¹⁰ Furthermore we note that the diphosphonate esters have the same elemental composition as the α -ketophosphonates. This could easily explain how the earlier workers obtained material which analysed correctly for the α -ketophosphonate but contained additional carbonyl bands in the i.r. spectra.

EXPERIMENTAL

¹H, ¹³C, and ³¹P n.m.r. spectra were determined on a JEOL FX 100 spectrometer.

Dimethyl trans-But-2-enoylphosphonate (4; R = Me).—Redistilled trimethyl phosphate (13.6 g; 0.11 mol) was added dropwise during 70 min to redistilled *trans*-but-2-enoyl

chloride (35 g, 0.33 mol). The exothermic reaction maintained a temperature of 35–43 °C. The excess of butenoyl chloride was removed from the yellow oil by distillation at reduced pressure. The product was then distilled under reduced pressure to give a pale yellow oil (10.4 g, 53%), b.p. 92–94.5 °C at 0.4 Torr. Its 2,4-dinitrophenylhydrazone was obtained as orange needles, m.p. 110–111 °C (from methanol) (Found: C, 39.95; H, 4.05; N, 15.7. C₁₂H₁₄N₂O₆P requires C, 40.2; H, 4.2; N, 15.6%).

1,3-Bis(dimethoxyphosphonyl)but-1-enyl trans-But-2-enoate (5; R = Me, R¹ = MeCH=CH).—Trimethyl phosphite (93 g, 0.75 mol) was added dropwise during 1 h to stirred re-distilled *trans*-but-2-enoyl chloride (78 g, 0.75 mol). The reaction, which was exothermic, was maintained at 60 °C. After 18 h, at room temperature the reaction mixture was distilled at reduced pressure (0.3 Torr) and six fractions were collected: (i) b.p. 60–100 °C, 10.1 g; (ii) b.p. 102–120 °C, 6.3 g; (iii) 120–180 °C, 10.4 g; (iv) 182–198 °C, 54 g; (v) 202–204 °C, 18.7 g; (vi) 210–270 °C, 16.0 g. Fractions (iv) and (v) were predominantly the ester (5; R = Me, R¹ = *trans*-MeCH=CH). Re-distillation of these fractions at reduced pressure gave almost pure ester. Preparative layer chromatography on Merck Kieselgel 60 PF₂₅₄ using an eluant of 5% methanol in ethyl acetate gave analytically pure ester (Found: C, 40.4; H, 6.45. C₁₂H₂₂O₈P₂ requires C, 40.45; H, 6.2%).

Investigations of the Mechanism of Formation of Ester (5; R = Me, R¹ = *trans*-MeCH=CH).—(a) *Reaction of dimethyl trans-but-2-enoylphosphonate with trimethyl phosphite*. Trimethyl phosphite (0.124 g) was added to dimethyl *trans*-but-2-enoylphosphonate (0.104 g) in dry chloroform (2 cm³) at room temperature and the reaction followed by ³¹P n.m.r. spectroscopy. As the resonance at δ_P 0.2 due to the butenoylphosphonate disappeared it was replaced by two doublets at δ_P 11.94 and –19.3 (J_{PP} 17 Hz). This compound was identified as the oxaphospholen (6; R = Me) from its ¹H, ¹³C, and ³¹P n.m.r. spectra (Table 1).

(b) *Reaction of the oxaphospholen* (6; R = Me) with *trans-but-2-enoyl chloride*. *trans*-But-2-enoyl chloride (0.4 g) was added to the solution of oxaphospholen (6; R = Me) prepared in the previous experiment and the reaction followed by ³¹P n.m.r. spectroscopy. The resonances corresponding to the oxaphospholen were replaced by two different doublets at δ_P 29.4 and 10.6 (J_{PP} 6 Hz) corresponding to the high-boiling ester (5; R = Me, R¹ = *trans*-MeCH=CH).

(c) *Reaction of the oxaphospholen* (6; R = Me) with *hydrogen bromide*. Hydrogen bromide gas was passed repeatedly into a chloroform solution of the oxaphospholen (6; R = Me) for periods of 5–10 s and the reaction followed by ³¹P n.m.r. spectroscopy. The resonances corresponding to (6; R = Me) were replaced by two doublets at δ_P 33.6 and 13.7 (J_{PP} 11 Hz) corresponding to the enol (8; R = Me) and a less intense pair of doublets at δ_P 34.6 and –1.6 (J_{PP} 10 Hz) corresponding to the α -ketophosphonate (9; R = Me). Treatment of the solution with solid potassium carbonate removed the signals of the enol and enhanced the signals of the α -ketophosphonate. The enol (8; R = Me) and α -ketophosphonate were identified by ¹H, ¹³C, and ³¹P n.m.r. spectroscopy (Table 1).

Reactions of Trialkyl Phosphites with Propenoyl Chloride and 2-Methylpropenoyl Chloride.—The reactions were followed by ³¹P n.m.r. spectroscopy, the products and intermediates being identified by comparing the n.m.r. parameters with those of the butenoyl series. A range of reaction conditions were studied including: (i) the addition

of small quantities of phosphite to excess of acid chloride, (ii) the addition of small quantities of acid chloride to excess of phosphite, and (iii) mixing equimolar amounts of phosphite and acid chloride. Treatment of solutions containing the oxaphospholens with hydrogen bromide gas produced new n.m.r. signals corresponding to the enols (11; $R^1 = R^2 = H$) and (11; $R^1 = Me, R^2 = H$), respectively, for each reaction but the conversion of the enols into the keto-tautomers (12) upon treatment with potassium carbonate was observed for the 2-methylpropenoyl system only. The n.m.r. parameters of the products derived from trimethyl phosphite are given in Table 2.

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