TABLE VII

Acetate	$n^{25}\text{D}$	B.p., °C. (mm.)	%[a] C	H
exo-exo (**1**)	1.4780	99 (13)	71.8	8.2
endo-exo (**2**)	1.4810		72.3	8.5
exo-endo (**3**)	1.4785		72.4	8.3
endo-endo (**4**)	1.4833		72.5	8.5
Nortricyclane-3-methanol (**7**)	1.4686		72.0	8.5

[a] Calcd. for $C_{10}H_{14}O_2$: C, 72.3; H, 8.5.

and with water, it was dried over magnesium sulfate and the pentane was removed to give an essentially quantitative yield of the acetate. The data are summarized in Table VII.

Kinetic Method.—The rates of acetolysis were determined in a conventional fashion using a set of sealed vials for each run. The vials were removed at known times; a measured portion of the contents was removed and titrated with *p*-toluenesulfonic acid in glacial acetic acid to determine the remaining acetate.

The rate constants for the reactions of **2a** were obtained using an analysis similar to that of Young, Winstein, and Goering, except that the *F* values were not obtained from the solvolysis data but rather from the independently measured rate of isomerization. The reaction solution was made up as for the other kinetic runs and 20–30-ml. aliquots were removed at specified times and quenched by pouring into excess pentane. Each pentane solution was extracted twice with water and with 15% sodium carbonate solution. The pentane was removed and the residual mixture was kept at 10^{-3}-mm. pressure until no product acetates were present as was indicated by the absence of the CH_3CO peaks in the n.m.r. spectrum. The mixture of brosylates was dissolved in carbon tetrachloride and the n.m.r. spectrum was obtained. Since brosylate **1** exhibits a peak at τ 9.08 which is not present in **2**, it is possible to calculate the *F* values directly. The titrimetric and n.m.r. data are summarized in Table VIII. The x' values in the table were obtained from the x values (amount of acid liberated at time t) by multiplication by 1/0.90. The correction factor takes into account the production of about 10% of unreactive nortricyclane-3-methyl tosylate in the solvolysis. The rate constant was evaluated graphically by plotting $\ln a/(a - x)F$ against time.

TABLE VIII

RATE OF SOLVOLYSIS AND ISOMERIZATION OF BROSYLATE 2

Time × 10^{-3}, sec.	$(H_\infty - H_t)^a$	x^b	x'	F	$(a - x')F$
7.6	0.990	0.00427	0.00459	0.81	0.04252
18.9	0.898	0.00884	0.00950	0.60	0.02857
25.8	0.854	0.01102	0.01185	0.56	0.02536
34.6	0.752	0.01609	0.01730	0.50	0.01993
44.0	0.683	0.01952	0.02098	0.43	0.01556
57.4	0.592	0.02404	0.02584	0.25	0.00784

[a] H is the milliliters of 0.04966 N acid required per 2-ml. aliquot: $H_0 = 1.984$, $H_\infty = 0.910$. [b] Amount of acid formed.

The product composition was determined by carrying out the solvolysis to at least three half-lives, diluting with water, and extracting with pentane. The pentane solution was concentrated and analyzed *via* g.l.p.c. The products were identified both by using the retention times independently measured using authentic samples and by collection of the various fractions followed by a comparison of the n.m.r. spectra with those of authentic samples. In the case of the bicyclooctenyl acetate, the identification of the g.l.p.c. fraction was made after hydrogenation and hydrolysis to bicyclo[3.2.1]octanol-6.

Trialkoxyalkylidenephosphoranes from the Reaction of Trialkyl Phosphites with *cis*- and *trans*-Dibenzoylethylene. P^{31} Nuclear Magnetic Resonance Spectra[1,2]

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Trimethyl phosphite reacts with *cis*- and *trans*-dibenzoylethylene at 20° in methylene chloride to give a moderately stable *trialkoxyalkylidenephosphorane.* This *phosphitemethylene* or *ylide* undergoes a methyl group translocation which results in an enol phosphonate methyl ether. The ylide reacts with benzyl bromide and gives an enol phosphonate benzyl ether. The enol ethers are converted into a furylphosphonate on heating. The ylide is capable of reacting with a second molecule of dibenzoylethylene; the structure of the products varies with the nature of the solvent; in alcohol the products are mainly 1,2-dibenzoylethane, 1,2,3,4-tetrabenzoylbutane, and trimethyl phosphate. The main product of the reaction of trimethyl phosphite with dibenzoylethylene in boiling xylene is 2,5-diphenylfuran. The compound with pentavalent phosphorus, said to be formed in this reaction, was not observed.

Kukhtin and Orekhova[3] isolated a noncrystalline material from the reaction of *trans*-dibenzoylethylene (DBE) with triethyl phosphite in ether solution. They ascribed to this material the structure of a cyclic tetraalkoxyalkylphosphorane Ia, but gave no analysis and offered no proof of structure. When the reaction of DBE with the phosphite was carried out at elevated temperatures, the products were 2,5-diphenylfuran and triethyl phosphate (31%).

Other cyclic oxyalkylphosphoranes have been postulated as intermediates in reactions of trialkyl phosphites with α,β-unsaturated carbonyl compounds.[4,5]

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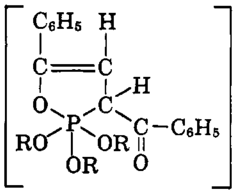
(1) (a) Stable Phosphorus Ylides. Part X; presented at the 148th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1964; Abstracts of the Division of Organic Chemistry, p. 13S. (b) Part IX: F. Ramirez, D. Rhum, and C. P. Smith, *Tetrahedron*, in press. (c) Part VIII: F. Ramirez, N. B. Desai, and N. McKelvie, *J. Am. Chem. Soc.*, **84**, 1745 (1962). (d) Part VII: F. Ramirez, N. B. Desai, B. Hansen, and N. McKelvie, *ibid.*, **83**, 3539 (1961). (e) Part VI: F. Ramirez and N. McKelvie, *ibid.*, **79**, 5829 (1957). (f) Part V: F. Ramirez and S. Levy, *J. Org. Chem.*, **23**, 2036 (1958). (g) Part IV: *ibid.*, **23**, 2035 (1958).

(2) This investigation was supported by the National Science Foundation (G 19 509), and by Public Health Service Research Grant No. CA-04769-05 from the National Cancer Institute.

(3) V. A. Kukhtin and K. M. Orekhova, *J. Gen. Chem. USSR*, **30**, 1539 (1960).

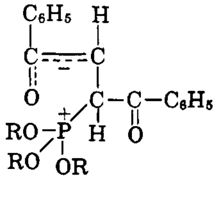
(4) (a) G. Kamai and V. A. Kukhtin, *ibid.*, **27**, 2431 (1957); (b) *ibid.*, **27**, 2436 (1957); (c) *ibid.*, **31**, 1621 (1961); (d) *cf. Chem. Abstr.*, **52**, 7127*d* (1958); **52**, 9948*f* (1958).

(5) (a) V. A. Ginsburg and A. Ya. Yakubovich, *Zh. Obshch. Khim.*, **30**, 3979 (1960); (b) *J. Gen. Chem. USSR*, **30**, 3944 (1960).

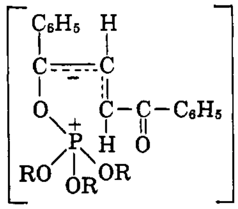


Ia (not formed)

Harvey, Jensen, and DeSombre[6] have studied these reactions in alcohol solution. They postulated the formation of a cyclic oxyalkylphosphorane Ia and assumed that this was in equilibrium with open dipolar structures Ib and Ic resulting from the cleavage of phosphorus–oxygen and of phosphorus–carbon bonds. Horner and Klupfel[7] have suggested a dipolar structure with a phosphorus–oxygen bond (analogous to Ic) for the triethylphosphine–dibenzoylethylene 1:1 adduct. Kuwajima and Mukaiyama[8] formulated in the same manner (as Ic) the adducts assumed to be formed from *trans*-dibenzoylethylene and tri-*n*-butylphosphine or triphenylphosphine. Formulas of this type, Ia–c, have found their way into recent reviews,[9] without experimental justification.



Ib



Ic (not formed)

As part of our studies on compounds with quintuply connected phosphorus,[10,11] we have examined the reactions of dibenzoylethylene with a number of trivalent phosphorus compounds.[12,13] This paper describes the reaction with trimethyl phosphite.

Results

The reaction of *trans*-dibenzoylethylene (II) with trimethyl phosphite was investigated under various conditions, which are summarized in Table I.

The course of the reaction in a nonhydroxylic solvent (expt. 1) was elucidated by means of infrared and H^1 and P^{31} n.m.r. spectra.

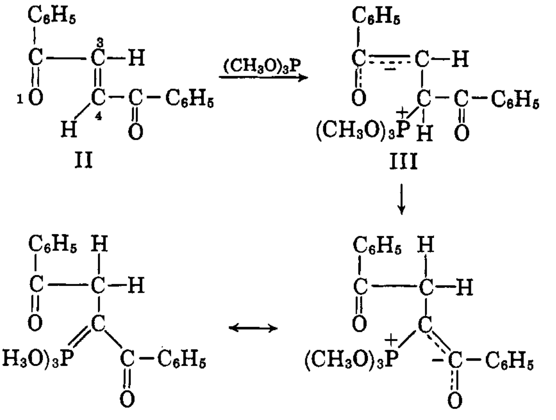
TABLE I

REACTION OF *trans*- AND *cis*-DIBENZOYLETHYLENE WITH TRIMETHYL PHOSPHITE[a]

Expt.	Solvent	Moles of DBE/ mole of TMP	DBE, M^b	Time
1[c]	CH_2Cl_2	1	2.0	10 hr., 6 days
2	CH_2Cl_2	1	0.5	2 hr., 22 hr., 6 days
3	CH_2Cl_2	1	4	16 hr.
4	CH_2Cl_2	2	2.5	7 days
5	CH_2Cl_2	1.7	2.7	4 days
6	CH_2Cl_2	1.5	2	48 hr.
7	CH_2Cl_2	0.82	1	48 hr.
8	Xylene[d]	1	1.4	14 hr.
9	CH_3CN	1	0.5	10, 16 hr 24, 40 hr.
10	CH_3OH	2	1	20 hr.
11[e]	CH_2Cl_2	1	0.2	2 hr., 18 hr.

[a] Anhydrous, under N_2, at 20°, except as indicated. [b] Based on dibenzoylethylene; the initial suspension became a clear, red solution upon reaction. [c] *trans*-Dibenzoylethylene in expt. 1–10. [d] At reflux temperature. [e] *cis*-Dibenzoylethylene.

The phosphorus of the phosphite adds to the β-carbon of the α,β-unsaturated ketone, *i.e.*, to C-4 in formula II. The product of this addition is an unstable C–phosphonium betaine III (*cf.* formula Ib), which undergoes a rapid proton shift to the moderately stable trimethoxybenzoylphenacylmethylenephosphorane (IVa $\rightleftharpoons$ IVb). There was no indication of the formation of a compound with pentacovalent phosphorus[3–6,9] such as Ia, or of a second open dipolar structure, *i.e.*, the O-phosphonium betaine Ic.[3,6–9] These conclusions are based on the data of Figures 1, 2, and 3 and those discussed below.



IVa, $\delta_{P^{31}} = -56.2$ p.p.m. *vs.* 85% H_3PO_4

The infrared bands at 5.95 (1680 cm.$^{-1}$) and 6.62 μ (1510 cm.$^{-1}$) in Figure 1 are due to the *ylide* or *phosphitemethylene*, IVa $\rightleftharpoons$ IVb. Figure 2 shows: (1) the doublet, $J_{HP} = 12.0$ c.p.s., at τ 6.10 due to the $9H^1$ of the three equivalent methoxy groups attached to the phosphorus in the ylide IV (the doublet is due to the H^1–P^{31} spin–spin splitting[14]); (2) the doublet, $J_{HP} =$ 11.5 c.p.s., at τ 6.31 due to some trimethyl phosphate, $(CH_3O)_3PO$, which is formed also during the reaction; and (3) the doublet, $J_{HP} = 10.5$ c.p.s., at τ 6.60 due to unreacted trimethyl phosphite. The nature of these phosphorus compounds was confirmed by the P^{31} n.m.r. shifts, included in Figure 2. Thus (1) the ylide IV gave a signal at -56.2 p.p.m.[14] (all shifts from 85%

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(6) (a) R. G. Harvey and E. V. Jensen, *Tetrahedron Letters*, **No. 26**, 1801 (1963); (b) E. R. DeSombre, R. G. Harvey, and E. V. Jensen, Abstracts, 146th National Meeting of the American Chemical Society, Denver, Colo., Jan. 1964, p. 21C; (c) R. G. Harvey and E. V. Jensen, Abstracts, 144th National Meeting of the American Chemical Society, Los Angeles, Calif., April 1963, p. 61M.

(7) L. Horner and K. Klupfel, *Ann.*, **591**, 69 (1955); *cf.* pp. 79 and 94.

(8) I. Kuwajima and T. Mukaiyama, *J. Org. Chem.*, **29**, 1385 (1964).

(9) R. G. Harvey and E. R. DeSombre, in "Topics in Phosphorus Chemistry," Vol. 1, M. Grayson and E. J. Griffin, Ed., Interscience Publishers, John Wiley and Sons, Inc., New York, N. Y., 1964. None of the formulas given after line 19, p. 59, represents the structure of the adduct formed from a *phosphinite*, R_2POR, and *trans*-dibenzoylethylene. The claim in footnote (*) of p. 95 that the adduct from ethyl diphenylphosphinite is a ring phosphorane is incorrect. There is no experimental evidence in support of formulas 35 (p. 92), 37 (p. 95), 38, and 39 (p. 96) in the review by Harvey and DeSombre.

(10) (a) F. Ramirez, H. J. Kugler, and C. P. Smith, *Tetrahedron Letters*, **No. 4**, 261 (1965); (b) W. C. Hamilton, S. LaPlaca, and F. Ramirez, *J. Am. Chem. Soc.*, **87**, 127 (1965); (c) F. Ramirez, A. V. Patwardhan, N. Ramanathan, N. B. Desai, C. V. Greco, and S. R. Heller, *ibid.*, **87**, 543 (1965).

(11) F. Ramirez, *Pure Appl. Chem.*, **9**, 337 (1964).

(12) F. Ramirez, O. P. Madan, and C. P. Smith, *J. Am. Chem. Soc.*, **86**, 5339 (1964).

(13) F. Ramirez, O. P. Madan, and C. P. Smith, *Tetrahedron Letters*, **No. 3**, 201 (1965).

(14) Documentation on the P^{31} and H^1 n.m.r. shifts and coupling constants will be found in ref. 10–13.

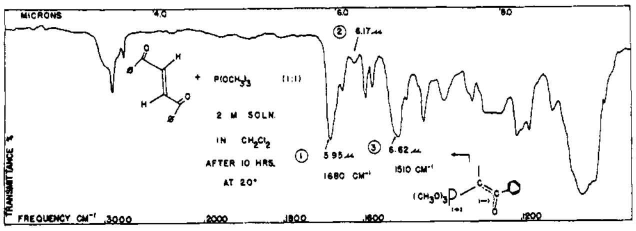


Figure 1.—Infrared spectrum of a 2 *M* solution of *trans*-dibenzoylethylene + trimethyl phosphite (1:1 mole ratio), after 10 hr. at 20°. The ylide carbonyl band is at 6.62 μ.

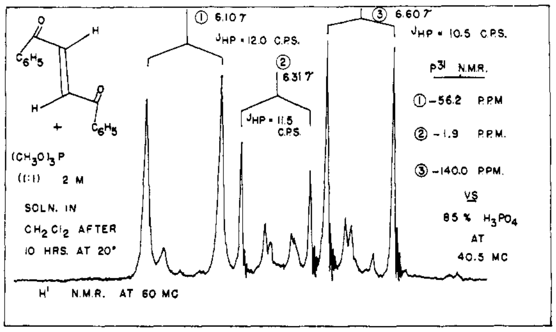


Figure 2.—H^1 n.m.r. spectrum of the methoxy region in a 2 *M* solution of *trans*-dibenzoylethylene + trimethyl phosphite (1:1 mole ratio) after 10 hr. at 20°. The shifts of the corresponding P^{31} nuclei are included: (1) ylide, τ 6.10, J_{HP} = 12.0 c.p.s., $\delta_{P^{31}} = -56.2$ p.p.m.; (2) trimethyl phosphate, τ 6.31, J_{HP} = 11.5 c.p.s., $\delta_{P^{31}} = -1.9$ p.p.m.; and (3) trimethyl phosphite, τ 6.60, J_{HP} = 10.5 c.p.s., $\delta_{P^{31}} = -140.0$ p.p.m. (*vs.* 85% H_3PO_4).

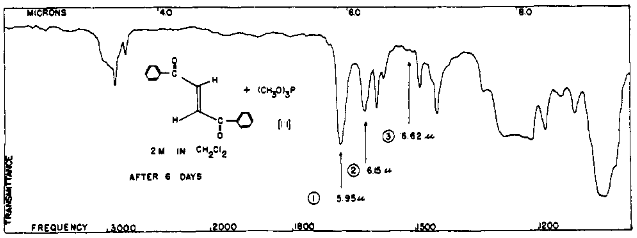
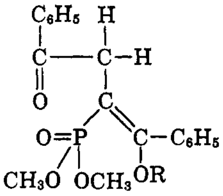


Figure 3.—Infrared spectrum of a 2 *M* solution of *trans*-dibenzoylethylene + trimethyl phosphite (1:1 mole ratio), after 6 days at 20°. The ylide carbonyl band at 6.62 μ (peak 3) has disappeared. The enol ether olefin band is at 6.15 μ (peak 2).

H_3PO_4); (2) the phosphate, at −1.9 p.p.m.[14]; and (3) the phosphite, at −140.0 p.p.m.[14]

The spectra shown in Figures 1 and 2 were determined after 10 hr. at 20°. This is, approximately, the point at which the ylide IV reached maximum concentration under the experimental conditions. Figure 3, taken after 6 days, discloses the disappearance of the ylide IV (note absence of band 3 at 6.62 μ) and the appearance of a new substance with bands at 5.95 (1) and 6.15 μ (2). This new substance is dimethyl 1-phenacyl-2-phenyl-2-methoxyvinylphosphonate (V).

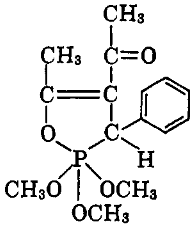
The enol phosphonate methyl ether V was formed from the ylide IV as a result of a methyl group translocation, intra- or intermolecularly. The methyl ether V was isolated in pure form as described in the Experimental section, its proton n.m.r. spectrum had a $6H^1$ doublet, J_{HP} = 11.5 c.p.s., at τ 6.26 due to the two equivalent methoxy groups on phosphorus, and a $3H^1$ singlet at τ 6.62 due to the methoxy group on the vinyl carbon. The P^{31} n.m.r. signal of the ether V at −22.0 p.p.m. was seen in the 6-day-old reaction mixture, which contained also significant amounts of trimethyl phosphate (−2.0 p.p.m.) and some trimethyl phosphite (−140 p.p.m.) still unreacted, even though at this point there was no unreacted dibenzoylethylene.



V, R = CH_3; $\delta_{P^{31}} = -22.0$
VI, R = $CH_2C_6H_5$; $\delta_{P^{31}} = -22.0$

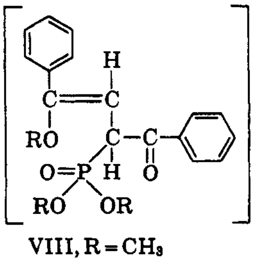
The ylide seemed to rearrange faster to the enol ether V in acetonitrile than in methylene chloride (expt. 9). The lifetime of the ylide IV appeared to depend on concentration (expt. 1–3).

Basis for the Ylide Structure IV.—The dibenzoylethylene–trimethyl phosphite 1:1 adduct can not have a cyclic tetraoxyalkylphosphorane structure,[6] Ia, because the pentacovalent phosphorus in Ia should give an n.m.r. signal at *higher* magnetic field than 85% H_3PO_4. For example, the cyclic tetraoxyalkylphosphorane[15] VII derived from 3-benzylidene-2,4-pentanedione and trimethyl phosphite has a positive shift, $\delta_{P^{31}} = +27.9$ p.p.m. Other oxyphosphoranes also have positive shifts.[10,11,16] Furthermore, the infrared spectrum of a structure like Ia should not show an infrared band at 6.6 μ, which is typical of acylphosphinemethylenes.[17]



VII, $\delta_{P^{31}} = +27.9$ p.p.m

A choice between the alkylidenephosphorane IV and the dipolar ion III (or Ib) can be made from the structure of the enol phosphonate methyl ether V.[18] The ether V can not have the isomeric structure VIII, since the latter has an asymmetric center and should give a H^1 n.m.r. spectrum with *two doublets* due to the nonequivalent methoxy groups attached to the phosphorus. This point will be illustrated below.



VIII, R = CH_3
IX, R = $CH_2C_6H_5$
(not formed)

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[15] F. Ramirez, O. P. Madan, and S. R. Heller, *J. Am. Chem. Soc.*, **87**, 731 (1965).

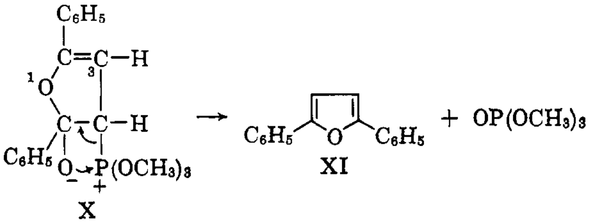
[16] (a) G. H. Birum and L. J. Dever, Abstracts, 135th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1958, p. 101P; (b) U. S. Patents 2,961,455 (1960) and 3,014,949 (1961).

[17] F. Ramirez and S. Dershowitz, *J. Org. Chem.*, **22**, 41 (1957).

[18] The formation of enol phosphonate ethers V and VI (rather than VIII and IX) shows that the proton shift from III to IV *can occur* under the experimental conditions. The ylide IV should be more stable than the dipolar ion III and should, thus, represent the structure of the 1:1 adduct.

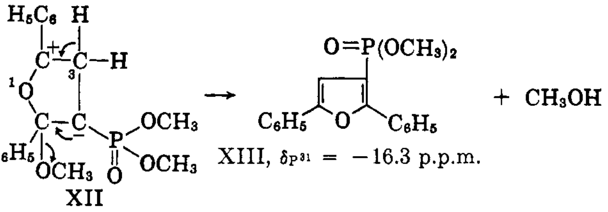
Another enol phosphonate ether, VI, was prepared in 60% yield by treatment of the ylide IV with benzyl bromide. The two methoxy groups attached to the phosphorus were magnetically equivalent (see Figure 4). Therefore, the benzyl ether can not have the isomeric structure IX, with an asymmetric center adjacent to the phosphonate group.

Formation of 2,5-Diphenylfuran (XI) and Trimethyl Phosphate from Dibenzoylethylene and Trimethyl Phosphite.—The experiments carried out in nonhydroxylic solvents (see Table I) gave small amounts (*ca.* 5–10%) of 2,5-diphenylfuran (XI). This is one of the sources of the trimethyl phosphate which was observed in the H^1 and the P^{31} n.m.r. spectra of the reaction mixtures. Experiment 8 showed that 2,5-diphenylfuran (XI) is the major product (*ca.* 50% yield) of the reaction of dibenzoylethylene (II) with trimethyl phosphite at elevated temperature.[3] The furan XI and the phosphate could arise from an intermediate like X formed by cyclization of the open dipolar structure III, prior to the proton shift (or III could be in unfavorable equilibrium with IV).



X → XI + $OP(OCH_3)_3$

Pyrolysis of the Enol Phosphonate Ethers to Furylphosphonate XIII.—The enol ether V lost methanol at 180° (0.1 mm.) and gave dimethyl 3-(2,5-diphenyl)-furyl phosphonate (XIII), probably *via* intermediate XII. This represents a satisfactory method of preparation of this type of phosphonate.



XII → XIII + CH_3OH

XIII, $\delta_{P^{31}}$ = −16.3 p.p.m.

Formation of a 2 : 1 Adduct From Dibenzoylethylene and Trimethyl Phosphite in Nonhydroxylic Solvents.—The possibility of a reaction between the ylide IV and a second molecule of dibenzoylethylene (II) was suspected from the results of expt. 1 (Table I). Experiments 4–6 confirmed that 1 mole of phosphite was capable of reacting with approximately 1.7 moles of the unsaturated ketone II in methylene chloride at 20°.

Experiment 4 gave, after chromatography over alumina, a phosphorus-free material which has not been obtained crystalline or pure enough for complete structural elucidation. This material was not affected by acetic anhydride–sulfuric acid.[19b] The molecular formula approached $C_{32}H_{24}O_3$, *i.e.*, a dimer of dibenzoylethylene minus one oxygen atom; however, this substance was not 2,5-diphenyl-3,4-diphenacylfuran[19b] or 1-(2,5-diphenylfuryl)-1,2-dibenzoylethane.[19b] The formation of this dimer accounts for part of the trimethyl phosphate observed in the reaction mixture; work on this material is continuing.

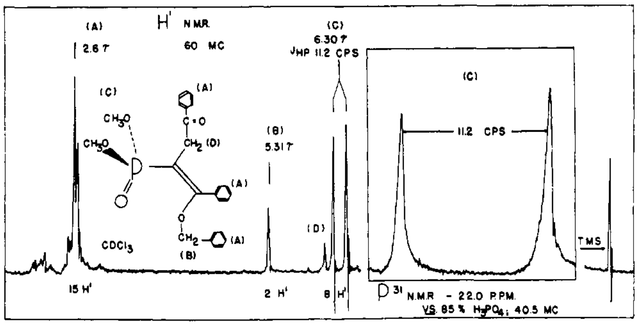
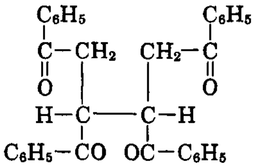
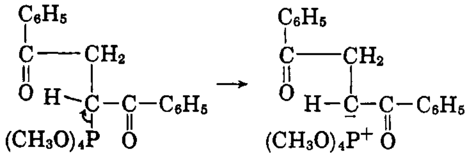


Figure 4.—H^1 n.m.r. spectrum of the enol benzyl ether VI. The two methoxy groups on phosphorus are equivalent: (c) τ 6.30, J_{HP} = 11.2 c.p.s. (see insert), $\delta_{P^{31}}$ = −22.0 p.p.m. *vs.* 85% H_3PO_4.

Reaction of Dibenzoylethylene with Trimethyl Phosphite in Alcohol Solution.—Experiment 9 was performed under the conditions employed by previous investigators.[6] We confirmed the formation of 1,2,3,4-tetrabenzoylbutane (XIV), trimethyl phosphate, and some 1,2-dibenzoylethane, when the reaction was carried out in alcohol. These products

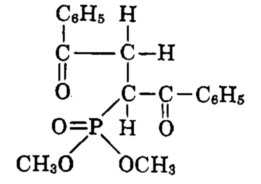

XIV

can be obtained from the ylide IV and do not require the formation of an open dipolar structure with a P–O bond, Ic, as previously suggested.[6] Thus, 1,2-dibenzoylethane and trimethyl phosphate were the main products when methanol was added to a methylene chloride solution of the ylide IV. This suggests the formation of intermediates XV and XVI.


XV → XVI

When a methanol solution of dibenzoylethylene (II) was added to a methylene chloride solution of ylide IV, significant amounts of 1,2,3,4-tetrabenzoylbutane (XIV) were produced. This can be explained by a normal 1,4-addition of the anion XVI to the α,β-unsaturated ketone II. 1,2-Dibenzoylethane and *trans*-dibenzoylethylene (II) did not condense in the absence of added base.

The ylide IV was readily hydrolyzed to 1,2-dibenzoylethane (*ca.* 55%) and to the β,γ'-diketophosphonate XVII (*ca.* 15%). These products can result


XVII, $\delta_{P^{31}}$ = −24.8 p.p.m.

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[19] (a) R. E. Lutz and F. N. Wilder, *J. Am. Chem. Soc.*, **56**, 978 (1934); (b) R. E. Lutz and F. S. Palmer, *ibid.*, **57**, 1947 (1935); (c) R. E. Lutz and R. J. Rowlet, *ibid.*, **70**, 1360 (1948).

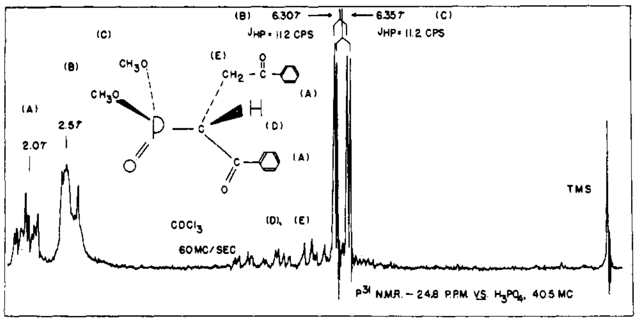


Figure 5.—H^1 n.m.r. spectrum of the β,γ'-diketophosphonate XVII. The two methoxy groups on phosphorus are not equivalent: (B) τ 6.30, J_{HP} = 11.2 c.p.s.; (C) τ 6.35, J_{HP} = 11.2 c.p.s.; $\delta_{P^{31}} = -24.8$ p.p.m. *vs.* 85% H_3PO_4.

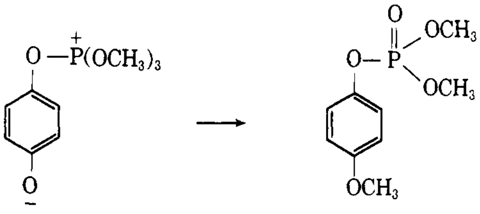
from the decomposition of the intermediate that results from the addition of water to the ylide IV; the transient intermediate could involve pentacovalent phosphorus.

The H^1 n.m.r. spectrum of the diketophosphonate XVII (Figure 5) shows that the two methoxy groups attached to the phosphorus are not magnetically equivalent, due to the asymmetric center in the molecule. The phosphonate XVII could be sublimed unchanged at 180° (0.2 mm.) without appreciable conversion to the furyl phosphonate XIII.

Reaction of *cis*-Dibenzoylethylene with Trimethyl Phosphite.—The reactions of trimethyl phosphite with *cis*- and *trans*-dibenzoylethylene were analogous, but the *cis* isomer reacted at a considerably faster rate (expt. 11).

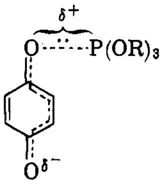
Discussion

The phosphorus of trimethyl phosphite attacks the oxygen atom of *p*-benzoquinone,[20] and of several *p*-quinones,[20] forming unstable adducts, XVIII, which undergo rapid rearrangement to ethers of *p*-quinol phosphates, XIX. The phosphite, however, attacks the carbon atom of *cis*- and *trans*-dibenzoylethylene. A possible transition state for oxygen attack in the quinone case is shown in formula XX. This notation implies some stabilization by p–d π-bonding with the phosphorus.[1b] The charge separation in the transition state is probably offset by the incipient aromatization.

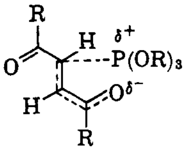


XVIII XIX

Oxygen attack does not result in aromatization in the unsaturated ketone case. Carbon attack may involve the transition state shown in formula XXI, in which charge separation is relatively small. The greater reactivity of *cis*- over *trans*-dibenzoylethylene may reflect, partly, differences in ground-state energies.

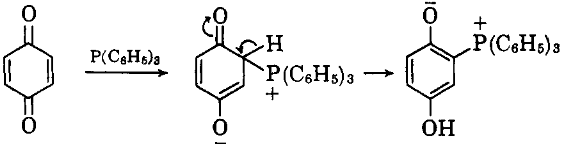


XX



XXI

The C-phosphonium betaine formed from XXI, *i.e.*, the adduct III, can undergo a proton shift if the anion which results from the shift, IV, is more stable than the original anion. The situation is somewhat analogous to that encountered in the addition of the phosphorus of triphenylphosphine to a *carbon* of *p*-benzoquinone,[21,22] XXII → XXIII → XXIV. Similar proton shifts have been encountered in the reaction of phosphines with maleic anhydride.[23]

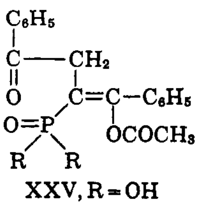


XXII XXIII XXIV

When the proton shift is not favorable, as in the case of 3-benzylidene-2,4-pentanedione, the C-phosphonium betaine cyclizes to a tetraoxyalkylphosphorane, VII.

The oxygen attack by trimethyl phosphite and the carbon attack by triphenylphosphine, in the *p*-benzoquinone case (XVIII, XXIII), emphasize another aspect of the reactions of trivalent phosphorus compounds with carbonyl compounds.[1b,11,20,21] The nature of the groups attached to the phosphorus seems to have an important effect on the course of these reactions, as has been discussed recently[1b] in the case of the reactions of *p*-chloranil with diethylphenylphosphine, triphenylphosphine, and trimethyl phosphite. Further discussion on correlations between variations in the structure of the phosphorus compounds, on the one hand, and variations in the structure of the carbonyl compounds, on the other hand, will be presented in connection with studies on the reaction of dibenzoylethylene with trisaminophosphines, trialkyl- and triarylphosphines, and esters of phosphinic acid, now in progress.[12,13]

The reaction of *trans*-dibenzoylethylene with phosphorus trichloride[24] in the presence of acetic anhydride afforded, after hydrolysis, 3-(2,5-diphenylfuryl)phosphonic acid[24] (acid derived from XIII). This phosphonic acid could have been formed from the enol phosphonic acid acetate XXV (*cf.* XII → XIII).



XXV, R = OH
XXVI, R = Cl

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(20) (a) F. Ramirez and S. Dershowitz, *J. Org. Chem.*, **22**, 856 (1957); (b) *ibid.*, **23**, 778 (1958); (c) *J. Am. Chem. Soc.*, **81**, 587 (1959); (d) F. Ramirez, E. H. Chen, and S. Dershowitz, *ibid.*, **81**, 4338 (1959).

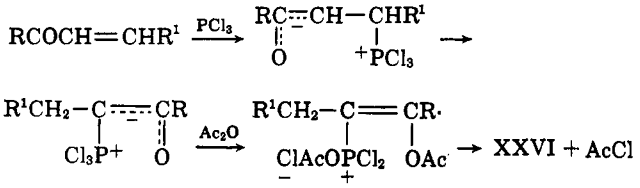
(21) F. Ramirez and S. Dershowitz, *ibid.*, **78**, 5614 (1956).

(22) See also H. Hoffman, L. Horner, and G. Hassel, *Chem. Ber.*, **91**, 58 (1958). For a previous formulation of the *p*-quinone–phosphine adduct see ref. 7, p. 76.

(23) R. F. Hudson and P. A. Chopard, *Helv. Chim. Acta*, **46**, 2178 (1963).

(24) C. E. Griffin and J. T. Brown, *J. Org. Chem.*, **26**, 853 (1961), and earlier references cited here.

The material before hydrolysis should be the enol phosphonodichloride acetate XXVI, which agrees with the infrared data given by Griffin and Brown.[24] The conjugate addition of phosphorus trichloride to this particular type of unsaturated ketone, in the presence of acetylating agents,[24] can then be pictured as follows.



The trialkoxyalkylidenephosphoranes, unlike the triarylalkylidenephosphoranes, have not received much attention.[25]

Experimental

The H^1 n.m.r. spectra were examined in a Varian 60 instrument against internal tetramethylsilane (TMS); the shifts, in parts per million, were subtracted from 10 to obtain the τ values. The P^{31} n.m.r. spectra were taken at 40.5 Mc./sec. in a Varian HR-100 instrument. External trimethyl phosphite was used for calibration[10c] and all shifts are expressed in parts per million *vs.* 85% H_3PO_4 [$\delta_{P^{31}} = -140.0$ p.p.m. for $(CH_3O)_3P$ *vs.* 85% H_3PO_4). Analyses are by Schwarzkopf Microanalytical Laboratory, Woodside, N. Y. Melting points were taken in a Mel-Temp apparatus (Laboratory Devices) and are corrected.

Reaction of *trans*-Dibenzoylethylene (II) with Trimethyl Phosphite in Methylene Chloride. A. Trimethoxy(benzoylphenacyl)methylenephosphorane (IV).—A suspension of *trans*-dibenzoylethylene (II, 2.59 g., 10.9 mmoles) in dry methylene chloride (5 ml.) was treated with 1.36 g. of trimethyl phosphite (1 mole equiv.; these amounts correspond to a 2 *M* solution when reacted). In 2 hr. a clear solution was observed. In 10 hr. the solution was deep red. The infrared, H^1 n.m.r., and P^{31} n.m.r. spectra of this solution are reproduced in Figures 1 and 2. The characteristics of the ylide IV are: bands at 5.95 and 6.62 μ; doublet at τ 6.10, $J_{HP} = 12.0$ c.p.s.; and $\delta_{P^{31}} = -56.2$ p.p.m. (expt. 1). The ylide disappeared on standing (Figure 3).

When the solution of the ylide IV was poured into hexane, a gummy material precipitated out. After 10 min. at 20°, the 6.6-μ band had disappeared.

In expt. 2, the maximum concentration of ylide IV was obtained after 20–22 hr. In expt. 4, very little ylide IV was left after 16 hr. In expt. 4, DBE (II) remained; in expt. 6, some trimethyl phosphite remained unreacted. In expt. 5, both reagents were completely consumed.

B. Dimethyl 1-Phenacyl-2-phenyl-2-methoxyvinylphosphonate or 1-Methoxy-1-phenyl-2-dimethoxyphosphinyl-3-benzoyl-1-propene (V).—A mixture of reagents identical with that of expt. 1 was kept 6 days at 20°. The infrared spectrum of this solution is reproduced in Figure 3.

After the reaction had proceeded to completion (*ca.* 6 days), the solvent was removed and the residue was dissolved in benzene (2 ml./g.). This solution was percolated through neutral Al_2O_3. The first fraction (eluted with benzene) gave *ca.* 2% of 2,5-diphenylfuran (XI). The second fraction (benzene) gave about 2% of dibenzoylethane. The third fraction was eluted with benzene and then with 60:40 benzene–chloroform and gave the enol phosphonate methyl ether, V. A second chromatography of this material gave purer enol ether V in *ca.* 30% yield. This glassy material can be distilled unchanged in a molecular still at 0.1 mm. *provided that the bath temperature is kept below* 150°.

Anal. Calcd. for $C_{19}H_{21}O_5P$: C, 63.3; H, 5.8. Found: C, 63.6; H, 5.9.

The spectral characteristics were: bands at 5.95 (C=O), 6.17 (C=C), 8.07 (P=O), 9.50, 9.70 μ ($POCH_3$) (in CCl_4); a $10H^1$ multiplet at τ 2.7, a $6H^1$ doublet, $J_{HP} = 11.2$ c.p.s., at τ 6.32, and a $3H^1$ singlet at τ 6.60 (the $2H^1$ doublet due to the phenacyl protons is partly hidden by the methoxy doublet).

Pyrolysis of the Enol Phosphonate Methyl Ether V to 2,5-Diphenyl-3-dimethoxyphosphinylfuran (XIII).—The enol ether V was heated in a molecular still at 185–195° (0.3 mm.) for several hours. The distillate crystallized and was washed with pentane. The yield of furan phosphonate XIII, m.p. 72–74°, was *ca.* 80%.

Anal. Calcd. for $C_{18}H_{17}O_4P$: C, 65.8; H, 5.2; P, 9.4. Found: C, 65.4; H, 6.0; P, 9.3.

The infrared spectrum (in CCl_4) had bands at 7.93 (s), 9.42 (vs), and 9.70 (vs) μ. The H^1 n.m.r. spectrum (in CCl_4) had an aromatic multiplet at τ 2.70 and a doublet at 3.05, $J_{HP} = 4$ c.p.s. (furyl H), these two integrated as $11H^1$; and a $6H^1$ doublet at τ 6.38, $J_{HP} = 11.2$ c.p.s. (two equivalent CH_3O–P); $\delta_{P^{31}} = -16.3$ p.p.m.

Reaction of the Adduct Formed from *trans*-Dibenzoylethylene and Trimethyl Phosphite in Methylene Chloride. A. With Benzyl Bromide. Dimethyl 1-Phenacyl-2-phenyl-2-benzyloxyvinylphosphonate or 1-Benzyloxy-1-phenyl-2-dimethoxyphosphinyl-3-benzoyl-1-propene (VI).—A mixture of *trans*-dibenzoylethylene (II, 19.1 g.) and trimethyl phosphite (10.0 g., 1 mole equiv.) in 65 ml. of methylene chloride (*ca.* 0.7 *M* solution) was kept 16 hr. at 20°. It was established that the concentration of the phosphorane reached a maximum at about this time in a 0.7 *M* solution, by examination of the infrared spectrum (band at 6.62 μ).

The above solution was treated with 15 ml. (20.7 g.) of benzyl bromide. The solution was kept 1 hr. at 20° and 5 hr. at the boiling point. The solution was evaporated to dryness *in vacuo* (last traces at 0.2 mm.). The residue was triturated with 50 ml. of ether for 3 hr. The crystals of the benzyl ether were collected, 16.9 g., m.p. 119–121°. The ether filtrate was concentrated and cooled to give 200 mg. of additional ether. The total yield of enol phosphonate benzyl ether was 56%, m.p. 122–123° (from benzene–hexane).

Anal. Calcd. for $C_{25}H_{25}O_5P$: C, 68.8; H, 5.7; P, 7.1. Found: C, 69.4; H, 5.7; P, 7.0.

Spectral characteristics were: bands at 5.93 (C=O), 6.15 (C=C), 8.06 (P=O), and 9.71 μ (in CCl_4); a $15H^1$ multiplet at τ 2.6 (aromatics), a $2H^1$ singlet at τ 5.31 (benzyl ether), a $6H^1$ doublet, $J_{HP} = 11.2$ c.p.s., at τ 6.30 (equivalent methoxy groups); the $2H^1$ doublet due to the phenacyl protons was partly hidden by the CH_3O doublet; $\delta_{P^{31}} = -22.0$ p.p.m. ($CDCl_3$).

B. With Water. Dimethyl 1,2-Dibenzoylethylphosphonate (or 1-Dimethoxyphosphinyl-1,2-dibenzoylethane) (XVII) and 1,2-Dibenzoylethane.—A solution of *trans*-dibenzoylethylene (II, 8.47 g.) and trimethyl phosphite (4.45 g., 1 mole equiv.) in 50 ml. of methylene chloride (the solution is 0.7 *M*) was kept 18 hr. at 20°. The infrared spectrum had a strong band at 6.6 μ indicative of ylide IV. Water (0.643 ml.) was added. After 1 hr. at 20°, the solution was evaporated to dryness at 25° (10 mm.), finally at 0.2 mm. The residue was triturated with 20 ml. of ether at 0° for 1 hr. Crystals of 1,2-dibenzoylethane, m.p. 146–147° (3.83 g., 45%), were filtered. The ether filtrate was concentrated and the residue was kept at 0° for 10 hr. under methanol. The residue (500 mg.) consisted of more dibenzoylethane with some unreacted dibenzoylethylene.

The methanol mother liquor was evaporated. The residue was submitted to short-path distillation. Trimethyl phosphate (2.52 g.) was collected at 26–29° (0.2 mm.). The residue from the distillation (5.0 g.) was kept 5 days at 0° under CCl_4. Crystals of dimethyl 1,2-dibenzoylethylphosphonate (XVII, 730 mg., m.p. 121–122°) were collected. The mother liquid gave more diketophosphonate XVII, total yield 15%. Recrystallization from benzene–hexane gave the analytical sample, m.p. 121–122°.

Anal. Calcd. for $C_{18}H_{19}O_5P$: C, 62.4; H, 5.5; P, 8.9. Found: C, 63.0; H, 5.6; P, 8.5.

Spectral characteristics were: bands at 5.97 (C=O), 8.20 (P=O), and 9.75 μ ($POCH_3$); $10H^1$ multiplets at τ 2.0 and 2.5; one $3H^1$ doublet, $J_{HP} = 11.2$ c.p.s., at τ 6.30 and another, $J_{HP} = 11.2$ c.p.s., at τ 6.35 (nonequivalent CH_3O); multiplets to the methylene and methine protons toward the low-field side of the methoxy doublets; $\delta_{P^{31}} = -24.8$ p.p.m. ($CDCl_3$).

The diketophosphonate XVII was collected unchanged in the condenser of a molecular still heated to 190° at 0.2 mm.

Reaction of *trans*-Dibenzoylethylene with Trimethyl Phosphite in Methanol.—A suspension of *trans*-DBE (II, 19 mmoles) in 20 ml. of methanol was treated with trimethyl phosphite (9.5 mmoles) at 20° under N_2. The light yellow suspension was kept 20 hr. at

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[25] (a) G. H. Birum, U. S. Patent 3,058,876 (1962); (b) W. J. Middleton, U. S. Patent 3,067,223 (1962).

20° and then filtered. The solid (2.41 g.) was mostly *meso*-1,2,3,4-tetrabenzoylbutane[19b] (XIV) mixed with 1,2-dibenzoylethane and some *dl*-XIV. The solid was treated with warm carbon tetrachloride (20 ml.). The CCl_4-insoluble portion (1.30 g., 30%, melting range 155–193°) was further washed with warm CCl_4 leaving 1.07 g. (24%) of pure *meso*-XIV,[19] m.p. 201–202°. The CCl_4 solution was evaporated and the residue was triturated with ether. The ether-insoluble crystals (0.9 g.) were 1,2-dibenzoylethane, m.p. 142–144°. The ether solution gave more of the latter (100 mg.), yield 24%. The methanol filtrate from above was evaporated. The residue was distilled to remove trimethyl phosphate (6.5 g.). The residue was suspended in hexane, treated with ethanol to dissolve, cooled, and filtered. Some dibenzoylethane (50 mg.) was recovered. The filtrate gave a gummy residue which could contain some diketophosphonate XVII. It was not investigated further.

Reaction of Methanol with the Ylide IV.—A mixture of DBE (II), trimethyl phosphite, and methylene chloride (1:1 mole ratio, 1 *M* solution) was kept 18 hr. at 20°. The infrared spectrum showed strong ylide absorption at 6.6 μ. Methanol (3.5 mole equiv.) was added. The 6.6-μ band still persisted after 19 hr. at 20°; most of it had disappeared after 43 hr. The solution was evaporated after 7 days. The residue was kept under ether and filtered from 1,2-dibenzoylethane, 20% yield, m.p. 146–147°. The ether solution was evaporated and the residue was distilled at 0.1 mm. to collect 40% of $(CH_3O)_3PO$. The residue was taken up in benzene; the solution was passed through neutral Al_2O_3 and evaporated. The residue was mainly the enol phosphonate methyl ether V.

Reaction of Dibenzoylethylene in Methanol Solution with the Alkylidenephosphorane IV.—A mixture of DBE (II) and trimethyl phosphite in methylene chloride (1:1 mole ratio, 1.1 *M* solution) was kept 18 hr. at 20°. The infrared spectrum showed strong 6.6-μ band. A solution of DBE (1 mole equiv.) in methanol was added. A solid separated and was collected after 1 hr.; it was *meso*-1,2,3,4-tetrabenzoylbutane (XIV), m.p. 197–199° (23% yield). The filtrate was evaporated and the residue was kept under methanol at 0° and filtered. The solid (30%) had a wide melting range (116–130°) and from the infrared spectrum is a mixture of *dl*-XIV, dibenzoylethane, and some *meso*-XIV. The filtrate was evaporated and the residue was distilled to collect 55% of trimethyl phosphate. The material balance was a mixture of more *dl*-XIV and enol phosphonate methyl ether V.

Reaction of *trans*-Dibenzoylethylene (II) with Trimethyl Phosphite in Boiling Xylene. Isolation of 2,5-Diphenylfuran[19c] (XI).—A suspension of *trans*-dibenzoylethylene (4.68 g.) and trimethyl phosphite (2.45 g.) in xylene (16 ml.) was kept at reflux temperature (oil bath at 150°). A clear red solution resulted in minutes. After 22 hr. the solution was evaporated to dryness *in vacuo*. The residue was freed from trimethyl phosphate by short-path distillation. The residue was extracted with two 50-ml. portions of hexane. The hexane solution gave 2.53 g. (50%) of 2,5-diphenylfuran,[19c] identified by infrared and proton n.m.r. spectra, m.p. 81–83° (from ethanol–water), lit.[19c] m.p. 88–89°.

The hexane-insoluble material was enol phosphonate methyl ether V and products from 2:1 condensation.

Reaction of *cis*-Dibenzoylethylene[19a] with Trimethyl Phosphite.—The infrared and H^1 and P^{31} n.m.r. spectra of the methylene chloride solutions were examined as indicated in Table I. The reaction followed the same course as in the *trans* isomer, but the alkylidenephosphorane was formed at a considerably faster rate (expt. 11 *vs.* 2).

Studies on the Pyrimidine Derivatives and the Related Compounds. XXXVII.[1] Reactions of Ethyl 3-Ethoxy-2-methoxymethylenepropionate with Thiourea Derivatives

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Ethyl 3-ethoxy-2-methoxymethylenepropionate (I) undergoes condensation with thiourea and N-substituted thioureas in ethanolic acid to 5-ethoxycarbonyl-2-oxo-6H-2,3-dihydro-1,3-thiazine (II). N-Methyl-N′-phenylthiourea gave N-methyldihydro-1,3-thiazine (IV) and aniline. N,N′-Dimethylthiourea condensed with I to give 1,3-dimethyl-5-ethoxycarbonyl-2-thio-1,2,3,4-tetrahydropyrimidine (V) and 5-ethoxycarbonyl-2-methylimino-3-methyl-6H-2,3-dihydro-1,3-thiazine (VI). N,N′-Diphenylthiourea did not condense with I. N-Methylthiourea gave II and 5-ethoxycarbonyl-2-methylamino-6H-1,3-thiazine (VII). Methylation of VII afforded VI and the N,N-dimethyl compound IX. Upon treatment of VII with hydrochloric acid the ester group was saponified, but prolonged refluxing with ethanolic acid yielded II. Rearrangement of VII into 2-thiotetrahydropyrimidine occurs on heating with aqueous formic or acetic acid to give a mixture of 5-ethoxycarbonyl-1-methyl-2-thio-1,2,3,4-tetrahydropyrimidine (XIIIa) and the 3-methyl isomer XIIIb. 2-Anilino-5-ethoxycarbonyl-6H-1,3-thiazine also rearranged in this reaction to give 5-ethoxycarbonyl-1-phenyl-2-thio-1,2,3,4-tetrahydropyrimidine (XVI) and the 3-phenyl isomer XVII.

We have previously reported the reaction of 3-ethoxy-2-methoxymethylenepropionitrile with thiourea derivatives to give 5-cyano-2-oxo-6H-2,3-dihydro-1,3-thiazine.[2] Reactions of ethyl 3-ethoxy-2-methoxymethylenepropionate (I) with urea derivatives have also been reported.[3,4] This paper deals with the reaction of I with thiourea and various N-substituted thiourea derivatives.

Reactions of I with thiourea, N-phenylthiourea, and N-α-naphthylthiourea were carried out in ethanol solution in the presence of hydrochloric acid, and the reactions took the same course as with the corresponding nitrile to give 5-ethoxycarbonyl-2-oxo-6H-2,3-dihydro-1,3-thiazine (II) together with ammonium chloride, aniline hydrochloride, and α-naphthylamine hydrochloride, respectively. From the infrared spectrum and proton magnetic resonance (n.m.r.) spectrum[5] this structure was confirmed as discussed extensively in earlier papers.[2-4,6] Acetylation of II with acetic anhydride gave the acetate III. The product II

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(1) Part XXXVI: A. Takamizawa and K. Hirai, *Chem. Pharm. Bull.* (Tokyo), in press.

(2) A. Takamizawa, K. Hirai, Y. Sato, and K. Tori, *J. Org. Chem.*, **29**, 1740 (1964).

(3) A. Takamizawa and K. Hirai, *Chem. Pharm. Bull.* (Tokyo), **12**, 804 (1964).

(4) A. Takamizawa and K. Hirai, *ibid.*, **12**, 1418 (1964).

(5) All of the n.m.r. spectra were taken with a Varian A-60 spectrometer on about a 10% solution in deuteriochloroform containing about 1% tetramethylsilane (TMS) as an internal reference. Chemical shifts are expressed in τ values and coupling constants are in cycles per second

(6) K. Tori, K. Aono, K. Hirai, and A. Takamizawa, *Shionogi Kenkyusho Nempo*, **14**, 198 (1964).