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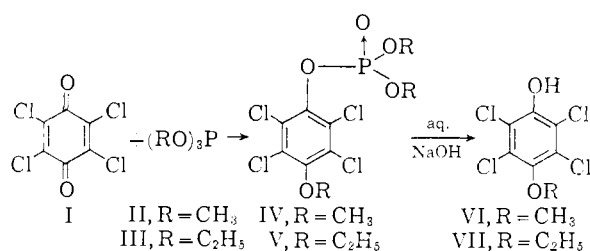
Reaction of Trialkyl Phosphites with *p*-Benzoquinone and with Other Symmetrically Substituted *p*-Quinones. A New Synthesis of Hydroquinone Monoalkyl Ethers^{1,2}

BY FAUSTO RAMIREZ,³ EUGENE H. CHEN AND SAMUEL DERSHOWITZ

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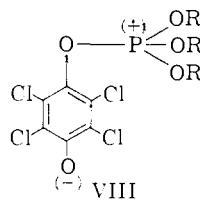
Trialkyl phosphites derived from primary alcohols react with monocyclic *p*-quinones to form alkyl ethers of *p*-hydroxyaryldialkyl phosphates. This constitutes a new route to monoalkyl ethers of polyhydric phenols by hydrolysis of the ether-phosphate esters. The reaction was carried out with *p*-benzoquinone, 2,5-dichloro-*p*-benzoquinone, 2,5-dimethyl-*p*-benzoquinone and duroquinone. The quinones (except duroquinone) are able to oxidize trialkyl phosphites to trialkyl phosphates, in the presence of water: $(RO)_3P + Q + H_2O \rightarrow (RO)_3PO + QH_2$. Mechanisms for the reaction of quinones with trivalent phosphorus compounds are discussed.

We described recently⁴ the conversion of chloranil (I) into tetrachlorohydroquinone monoalkyl ethers (VI, VII) by means of trialkyl phosphites II, III. The intermediate *p*-alkoxyaryldialkyl



phosphates IV, V can be isolated in high yield and, at least in the cases of trimethyl and triethyl phosphites, there was no indication of halogen displacement from the quinone ring.⁵

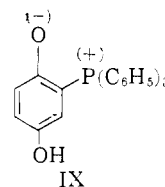
This novel transformation is made possible by the tendency of quaternized phosphite esters to undergo group translocations. An intermediate of type VIII was suggested.⁴



Trialkyl phosphites can be oxidized to trialkyl phosphates by means of chloranil, if the reactions are carried out in the presence of some water. Indeed, this oxidation is more general and takes place also with triphenyl phosphite and with triphenylphosphine. The reaction, in which tetrachlorohydroquinone is also formed, involves probably an intermediate of the type $\text{HOC}_6\text{Cl}_4\text{OP}(\text{OH})(\text{OR})_3$ formed from VIII.

The preparation of monoalkyl ethers of other polyhydric phenols from the corresponding quin-

ones and trialkyl phosphites seemed feasible. However, some difficulties might be anticipated from our previous observations on the behavior of certain quinones toward trivalent phosphorus compounds. For instance, we showed^{4d} that *p*-benzoquinone and triphenylphosphine form an adduct IX in which a phosphorus-carbon bond (instead of a phosphorus-oxygen bond) is established.⁶ Likewise, in the complex reaction of 2,5-dichloro-*p*-benzoquinone with triphenylphosphine, a displacement of one of the halogens occurs.^{4d}



It has now been found that trimethyl phosphite and triethyl phosphite react with *p*-benzoquinone (X) predominantly at the oxygen atom. Very little of the products of ring addition were formed. The ether-phosphates (see Fig. 1), dimethyl-(4-methoxyphenyl) phosphate (XIV) and diethyl-(4-ethoxyphenyl) phosphate (XV), were isolated in good yield and could be hydrolyzed to the corresponding hydroquinone-monoalkyl ethers (XXII and XIII) by aqueous-alcoholic alkali.

A search for by-products in the triethyl phosphite-*p*-benzoquinone reaction afforded small amounts (less than 2%) of hydroquinone-diethyl ether and some phenolic material which contained phosphorus (ca. 6–8% yield based on quinone). The latter is very probably diethyl-2,5-dihydroxyphenylphosphonate (XVI) on the basis of elementary analysis and of infrared and ultraviolet spectra.

An interesting feature of these reactions, which were carried out at room temperature in benzene solution and in a nitrogen atmosphere, is the initial appearance of a deep-red color. The final solutions were nearly colorless.

The reaction of trimethyl phosphite and of triethyl phosphite with 2,5-dichloro-*p*-benzoquinone (XI) took place very cleanly at room temperature in benzene solution and gave dimethyl-(4-methoxy-2,5-dichlorophenyl) phosphate (XVII) and diethyl-(4-ethoxy-2,5-dichlorophenyl) phosphate (XVIII), respectively. No significant amount of chlorine displacement was detected. 2,5-Dichlorohydroquin-

(1) The Structure of Quinone-Donor Adducts. VI. We are grateful to the National Cancer Institute of the National Institutes of Health for financial support (Grant CV-3250).

(2) Part V, F. Ramirez and E. H. Chen, *J. Org. Chem.*, **24**, in press (1959).

(3) Department of Chemistry, State University of New York, College on Long Island, Oyster Bay, N. Y.

(4) (a) F. Ramirez and S. Dershowitz, *THIS JOURNAL*, **81**, 587 (1959); (b) *J. Org. Chem.*, **23**, 778 (1958); (c) **22**, 856 (1957); (d) *THIS JOURNAL*, **78**, 5614 (1956).

(5) Th. Reetz, J. F. Powers and G. R. Graham, Abstract of Papers, A.C.S. Meeting, Chicago, Ill., September, 1958, p. 86 P.

(6) See also L. Hörner and Klüpfel, *Ann.*, **591**, 76 (1955); H. Hoffmann, L. Hörner and G. Hassel, *Chem. Ber.*, **91**, 58 (1958).

one-monomethyl ether (XXIV) and 2,5-dichloro-*p*-hydroquinone-monoethyl ether (XXV) were obtained by hydrolysis of the corresponding ether-phosphates.

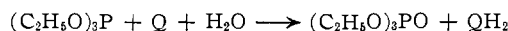
The reaction of the trialkyl phosphites with 2,5-dimethyl-*p*-benzoquinone (XII) was sluggish at room temperature. However, the ether-phosphates, dimethyl-(4-methoxy-2,5-dimethylphenyl) phosphate (XIX) and diethyl-(4-ethoxy-2,5-dimethylphenyl) phosphate (XX) were obtained in good yield in refluxing benzene. The 2,5-dimethylhydroquinone-monoalkyl ethers XXVI and XXVII were formed in the usual alkaline hydrolysis.

Duroquinone (XIII) gave diethyl-(4-ethoxy-2,3,5,6-tetramethylphenyl) phosphate (XXI) when heated with excess of triethyl phosphite as solvent. The ether-phosphate was converted into durohydroquinone-monoethyl ether (XXVIII).

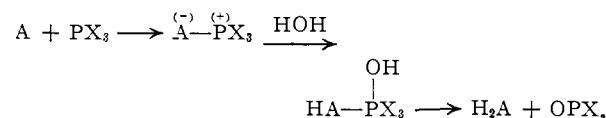
These results show that the reaction of *p*-quinones with trialkyl phosphites derived from primary alcohols is a convenient procedure for the preparation of some monoalkyl ethers of certain polyhydric phenols. The limitations imposed by the structure of the quinone and of the phosphite ester and by the susceptibility of the ether-phosphate esters to hydrolysis remain to be ascertained. It appears that methyl groups decrease and chlorine atoms increase the reactivity of a *p*-quinone toward trialkyl phosphites.

A few hydroquinone monoalkyl ethers have been prepared by an adaptation of the Elbs persulfate oxidation of phenols,⁷ as well as by more obvious partial alkylation and dealkylation reactions.⁸

It was of interest to ascertain whether, in the presence of water, *p*-benzoquinone and the methyl-substituted quinones are able to oxidize trialkyl phosphites to trialkyl phosphates, as had been the case with chloranil.⁴ The reaction



was observed with *p*-benzoquinone (X) and with 2,5-dimethyl-*p*-benzoquinone (XII), but could not be effected with duroquinone (XIII). The oxidation of certain phosphorus compounds in the presence of water could be pictured, in general, as follows, where A functions as the oxidant



At this point in our investigations,^{2,4} it is desirable to attempt to rationalize the striking differences which are observed in the behavior of trivalent phosphorus compounds toward different quinones. With *trialkyl phosphites* derived from primary alcohols, all the quinones so far investigated give predominantly or exclusively ether-phosphate esters

(7) W. Baker and N. C. Brown, *J. Chem. Soc.*, 2303 (1948).

(8) (a) Cf. Beilstein's "Handbuch der organischen Chemie," 4th ed., Vol. 6, p. 843 (I 416), (II 840); 850 (II 845); 948 (II 902); J. Springer, Berlin, 1910; (b) E. Bamberger and J. Frei, *Ber.*, **40**, 1932 (1907), p. 1944.

(9) Using the value $E^{0ox} = 0.276$ volt for the half-reaction $H_3PO_3 + H_2O = H_3PO_4 + 2H^{(+)} + 2e$, and $E^{0red} = 0.699$ volt for the quinhydrone electrode, $C_6H_4O_2 + 2H^{(+)} + 2e = C_6H_4(OH)_2$, the e.m.f. of the cell would be 0.975 volt under the usual conditions. Alkyl groups decrease, the halogen atoms increase the oxidizing power of quinones.

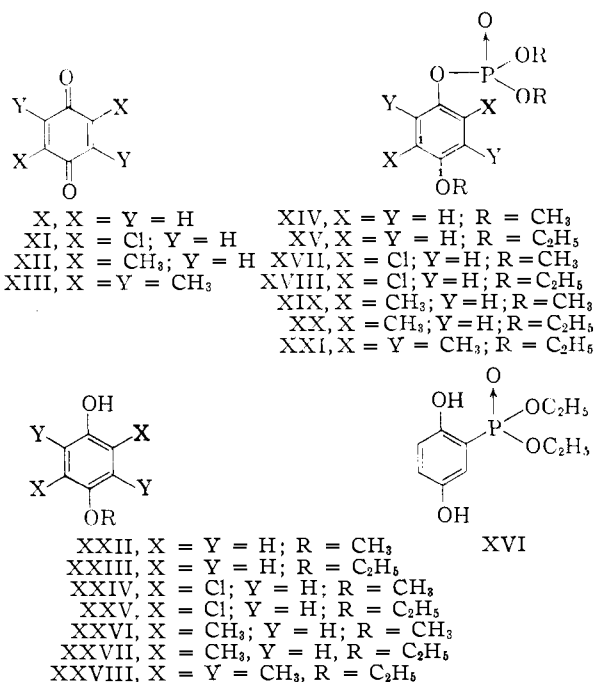
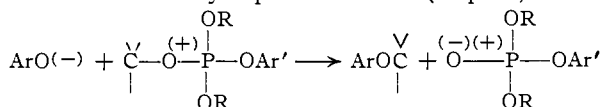


Fig. 1.

(Fig. 2, XXXI) in which a new phosphorus-oxygen bond is established. With *triphenylphosphine*, chloranil gives also an adduct in which a phosphorus-oxygen bond is formed^{4d}; however, *triphenylphosphine* reacts with *p*-benzoquinone and with 2,5-dichloro-*p*-benzoquinone to give products in which new phosphorus-carbon bonds are formed (for instance, the adduct IX).

A possible explanation might be provided by the picture of the reactions shown in Fig. 2. The immediate consequence of bringing together a quinone, which is an electron-acceptor (A), and a trivalent phosphorus compound, which can be regarded as an electron-donor (D), is probably the formation of a charge-transfer complex,^{4,10} $[(A, D) \longleftrightarrow (A-D)]$. This phenomenon would account for the appearance of deep-red colors in the solutions.⁴ Two types of adducts XXIX and XXX can then be formed, corresponding to oxygen and carbon attack, respectively.

With trialkyl phosphites, in which Z = OR, the former adduct XXIX can undergo a group-translocation to give stable ether-phosphate ester XXXI. This group-translocation is, of course, not possible when Z = C₆H₅ and it is quite unlikely—at least under relatively mild conditions¹¹—when Z = OC₂H₅. It may be regarded as a nucleophilic attack on carbon by a phenoxide ion (step 1b)



(10) (a) R. S. Mulliken, *Rec. trav. chim.*, **75**, 845 (1956); (b) H. Kainer and A. Überle, *Chem. Ber.*, **88**, 1147 (1955); (c) H. Kainer and W. Offing, *ibid.*, **88**, 1921 (1955); (d) H. Kainer, D. Bijt and A. C. Rose-Inner, *Naturwissenschaften*, **41**, 303 (1954).

(11) An interesting discussion of the behavior of tetraaryloxyphosphonium salts, $(ArO)_4P^{(+)}X^{(-)}$, has been given by H. N. Rydon, (Special Publication No. 8, The Chemical Society (London), 1957, p. 61).

Phosphate esters are to be expected from any quinone provided that the group-translocation 1b is faster than any other irreversible step.

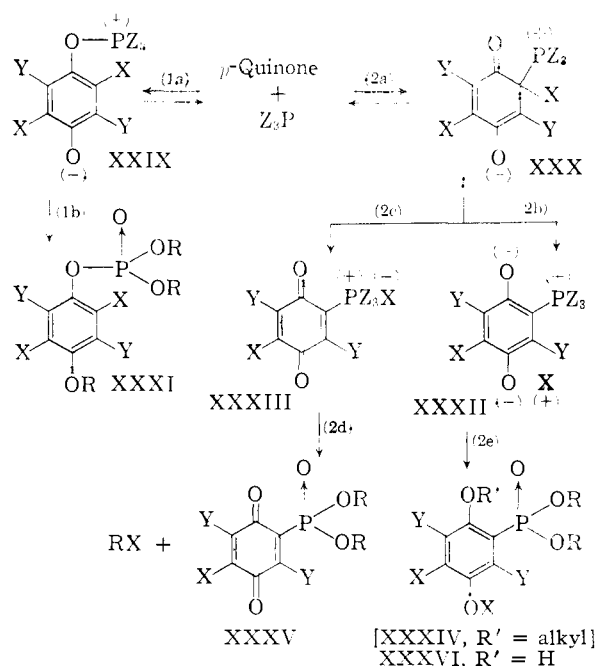


Fig. 2.

An adduct with a phosphorus-carbon bond, XXX, can either lose a proton (step 2b, X = H) as in the case of *p*-benzoquinone to give a dipolar structure XXXII, or it can lose a chloride ion (step 2c, X = Cl) as in the case of 2,5-dichloro-*p*-benzoquinone to give the quinone derivative XXXIII, precursor of the quinone-phosphonate XXXV (step 2e). Perhaps an adduct of type XXX is not possible in the chloranil-triphenylphosphine system for steric reasons, or the outcome of the reaction in benzene as the medium may be dictated by solubility consideration; in any event, the adduct which precipitates is of type XXIX.

The recent work of Reetz, Powers and Graham⁵ is of interest in this connection. They have reported that chloranil reacts with triisopropyl phosphite, and with other phosphites derived from secondary alcohols to form a quinone-phosphonate XXXV with chlorine displacement (actually the reaction proceeded further and all chlorines were replaced⁵). It is tempting to speculate that the group-translocation (step 1b) which gives rise to the ether-phosphate XXXI has a mechanism which is fairly close to the *S_N2* or *N* end of the mechanism spectrum of nucleophilic displacement reactions.¹² In such a picture, the attack by the bulky tetrachlorophenoxide ion on a secondary carbon would be more difficult than on a primary carbon. Step 1b should be slower with triisopropyl than with triethyl phosphite. The structure of the phosphite ester might affect the formation of the alkyl halide and quinone-phosphonate XXXV to a lesser ex-

(12) S. Winstein, A. Fainberg and E. Grunwald, *THIS JOURNAL*, **79**, 4146 (1957); C. G. Swain and W. P. Langsdorf, *ibid.*, **73**, 2813 (1951).

tent.¹³ The outcome of the change in the phosphite is thus to favor chlorine displacement.

It should be emphasized that diethyl (2,5-dihydroxyphenyl)-phosphonate (XXXVI, R = ethyl, X = Y = H) was actually isolated in *ca.* 8% yield from the alkaline extract of the *p*-benzoquinone-triethyl phosphite reaction mixture. There was no evidence for the formation of the ether XXXIV. An intermolecular group translocation in XXXII (step 2d) should be quite difficult for electrostatic and/or steric reasons, while an intramolecular process would not allow for colinearity of the attacking and leaving groups.

We are continuing our studies on the mechanism of action of oxidizing agents on phosphorus compounds^{2,4,14} and on possible implications in oxidative phosphorylations.

Experimental¹⁵

The quinones were purified by sublimation and recrystallization. The trialkyl phosphites were dried over sodium and freshly distilled. Anhydrous solvent and dry N₂ were employed in the best runs reported.

Reaction of *p*-Benzoquinone(X) with Triethyl Phosphite (III).—A solution of triethyl phosphite (77 g.) in 100 ml. of benzene was added to a solution of *p*-benzoquinone (50 g.) in 1 l. of benzene at 15°. The color immediately deepened and the temperature of the solution rose. External cooling was applied to maintain the temperature at *ca.* 20° during the exothermic phase of the reaction. The solution was kept in the dry-box, at room temperature, for several days and then was extracted with dilute alkali.

The benzene layer, on distillation, afforded: (1) hydroquinone-diethylether (1.2 g. as sublimate); (2) diethyl-(4-ethoxyphenyl) phosphate (XV) (97 g.) as an oil, *n*_D²⁵ 1.4830. The analytical sample of the ether-phosphate XV had b.p. 139–140° (0.25 mm.), *n*_D²⁵ 1.4829; band at 7.85 μ (non-bonded PO); λ_{max}^{OH} 280 μ (ε 2000), shoulder at 286 μ, not changed by addition of alkali. It gave no color with FeCl₃ reagent.

Anal. Calcd. for C₁₂H₁₉O₅P: C, 52.5; H, 7.0. Found: C, 52.2; H, 6.8.

The alkaline layer obtained above was made acidic and extracted with benzene. Removal of the benzene left a residue (8 g.) which on short-path distillation (at 0.1 mm. with a bath at 160–180°) afforded 5.8 g. of oil, *n*_D²⁵ 1.5043. Redistillation gave 5.3 g. of what is probably diethyl (2,5-dihydroxyphenyl)-phosphonate (XVI), *n*_D²⁵ 1.5038; λ_{max}^{OH} 282 μ shifted to 302 and 242 μ by addition of alkali. (This sample of the phosphonate XVI could be contaminated with a small amount of the isomeric diethyl (4-hydroxyphenyl)-phosphate.)

Anal. Calcd. for C₁₀H₁₅O₅P: C, 48.8; H, 6.1. Found: C, 48.8; H, 6.4.

Hydrolysis of Diethyl-(4-ethoxyphenyl) Phosphate (XV).—A solution of ether-phosphate XV (5.0 g.) in 50 ml. of 95% ethanol containing 2.5 g. of potassium hydroxide was refluxed for 20 hr. Water was added, most of the alcohol was removed and the hydroquinonemonoethyl ether (XXIII) was precipitated with CO₂; yield 2.4 g. (93%) of m.p. 64–66° alone and mixed with an authentic sample.⁹

Reaction of Triethyl Phosphite with *p*-Benzoquinone (X) in the Presence of Water.—A solution of *p*-benzoquinone (16.7 g.) in 100 ml. of benzene containing 100 ml. of 95% ethanol was slowly added (*ca.* 2 hr.) to a solution of triethyl phosphite (25 g.) in 200 ml. of benzene. After 24 hr. at room temperature the solution was evaporated and the residue was taken up in benzene.

(13) The step 2e in Fig. 1 (the "Arbusov reaction"⁴) involves now attack by chloride ion on the carbon of a trialkoxy-quinonyl-phosphonium ion.

(14) F. Ramirez and S. Dershowitz, *J. Org. Chem.*, **22**, 1282 (1957); *Chemistry & Industry*, 665 (1956); see recent reports on quinol phosphates: V. M. Clark, G. W. Kirby and A. Todd, *Nature*, **181**, 1650 (1958); Th. Wieland and F. Pattermann, *Angew. Chem.*, **70**, 313 (1958).

(15) Analyses by Micro-Tech Laboratories, Skokie, Ill., and Schwarzkopf Microanalytical Laboratories, Woodside, N. Y.

(a) One-half of the benzene solution was extracted with 5% aq. sodium hydroxide and the alkaline extract was immediately added to an excess of benzoyl chloride; 12.5 g. (57%) of hydroquinone-dibenzoate, m.p. 194–198°, was obtained. From the benzene layer, 12.1 g. (98%) of triethyl phosphate was obtained.

(b) One-half of the benzene solution obtained above was concentrated and the residue was treated with benzoyl chloride, followed by 5% aq. sodium hydroxide; 20.6 g. (93%) of hydroquinone-dibenzoate was isolated.

Reaction of *p*-Benzoquinone (X) with Trimethyl Phosphite (II).—A very vigorous reaction was observed when trimethyl phosphite (14 ml.) was added to a suspension of *p*-benzoquinone (X) (10.8 g.) in benzene (50 ml.). After 24 hr. at room temperature, the clear, pale yellow solution was evaporated. Distillation of the residue afforded 21.4 g. (92%) of colorless oil, b.p. 112–116° (0.05 mm.), n_D^{25} 1.4958. Redistillation at 0.05 mm. gave three fractions (6.5, 4.2 and 6.5 g.) with identical refractive index, n_D^{25} 1.4950 and a fourth fraction (1 g.) with a somewhat lower index, 1.4943. The analytical sample of dimethyl-(4-methoxyphenyl) phosphate (XIV) had b.p. 118–121° (0.05 mm.), n_D^{25} 1.4950, band at 7.85 μ .

Anal. Calcd. for $C_9H_{10}O_5P$: C, 46.5; H, 5.6. Found: C, 46.0; H, 5.5.

Hydrolysis of Dimethyl-(4-methoxyphenyl) Phosphate (XIV).—From 6.3 g. of ether-phosphate and 60 ml. of 5% aq. potassium hydroxide there was obtained (after 20 hr. reflux, and the CO₂ treatment) 2.9 g. (89%) of hydroquinone-monomethyl ether (XXII), m.p. 53–55°, alone and mixed with an authentic sample.⁸

Reaction of 2,5-Dichloro-*p*-benzoquinone (XI) with Triethyl Phosphite (III).—A solution containing 10.3 g. of 2,5-dichloro-*p*-benzoquinone, 10 ml. of triethyl phosphite and 100 ml. of benzene was allowed to stand overnight at room temperature. The thick oil (20.1 g.) remaining after the removal of the solvent was, on the basis of infrared spectrum, fairly pure diethyl-(4-ethoxy-2,5-dichlorophenyl) phosphate (XVIII). One distillation afforded 15.1 g. of phosphate XVIII collected at 125–137° (0.1 mm.); a second distillation gave material (14.1 g.) of essentially the same purity (during the first part of the distillation traces of a crystalline material, probably 2,5-dichlorohydroquinone-diethyl ether, sublimed); XVIII can be obtained as colorless crystals, m.p. 32–34° by solution in petroleum-ether followed by freezing at –70°. The analytical sample of phosphate XVIII had b.p. 138–140° (0.11 mm.), bands at 7.85 μ .

Anal. Calcd. for $C_{12}H_{17}O_5Cl_2P$: C, 42.0; H, 5.0. Found: C, 41.8; H, 5.1.

Hydrolysis of Diethyl-(4-ethoxy-2,5-dichlorophenyl) Phosphate (XVIII).—A solution containing 3 g. of XVIII, 1.5 g. of potassium hydroxide and 30 ml. of 95% ethanol was kept at reflux temperature of 20 hours. The solution was acidified and the precipitate which formed was collected. Dilution of the filtrate with water afforded an additional amount of 2,5-dichlorohydroquinone-monoethyl ether (XXV); combined yield 1.3 g. The analytical sample was obtained from cyclohexane and had m.p. 62–63°.

Anal. Calcd. for $C_8H_9O_2Cl_2$: C, 46.4; H, 3.9. Found: C, 46.7; H, 3.9.

Reaction of 2,5-Dichloro-*p*-benzoquinone (XI) with Trimethyl Phosphite (II) in Benzene Solution.—A solution containing 10.3 g. of 2,5-dichloro-*p*-benzoquinone (XI), 7 ml. of trimethyl phosphite and 100 ml. of benzene was allowed to stand overnight at room temperature. Removal of the solvent under reduced pressure gave crude dimethyl-(4-methoxy-2,5-dichlorophenyl) phosphate (XVII) as a thick oil which solidified on standing; yield 17.6 g., theory 17.6 g. Washing with cyclohexane afforded 16.5 g. of crystalline phosphate XVII (14.2 g. of material melting at 70–75°, after one recrystallization from benzene-petroleum ether). The analytical sample of the phosphate XVII was colorless and had m.p. 75–76° (from benzene); band at 7.85 μ .

Anal. Calcd. for $C_9H_{11}O_5Cl_2P$: C, 35.9; H, 3.7. Found: C, 36.2; H, 3.4.

Hydrolysis of Dimethyl-(4-methoxy-2,5-dichlorophenyl) Phosphate (XVII).—A solution containing 2 g. of XVII, 1 g. of potassium hydroxide and 20 ml. of 95% ethanol was kept at its reflux temperature for 24 hours. The mixture

was acidified with hydrochloric acid and extracted with ether. Evaporation of the water-washed ether solution, and recrystallization of the residue from cyclohexane, gave 1.2 g. (theory 1.3 g.) of 2,5-dichlorohydroquinone-monomethyl ether (XXIV) of m.p. 92–93°. The analytical sample of the ether XXIV had m.p. 92–93° (cyclohexane).

Anal. Calcd. for $C_7H_8O_2Cl_2$: C, 43.6; H, 3.1. Found: C, 43.7; H, 3.4.

Reaction of 2,5-Dimethyl-*p*-benzoquinone (*p*-Xyloquinone) (XII) with Triethyl Phosphite.—A solution of *p*-xyloquinone (XII) (7.95 g., recrystallized from cyclohexane) and triethyl phosphite (III) (10 ml.) in benzene (40 ml.) was kept at reflux temperature, under nitrogen, for 24 hours. Distillation of the residue obtained upon removal of solvent afforded 16.2 g. (theory 17.7 g.) of diethyl-(4-ethoxy-2,5-dimethylphenyl) phosphate (XX) collected at 108–120° (0.07 mm.). Traces of a crystalline material sublimed in the early stages of the distillation.

Fractional distillation of the ether-phosphate XX gave several fractions collected between 115 and 123° (0.07 mm.) and having essentially the same refractive index (n_D^{25} 1.4858). The analytical sample of the ether-phosphate XXI was colorless and had b.p. 122–123° (0.07 mm.), n_D^{25} 1.4858, band at 7.85 μ .

Anal. Calcd. for $C_{14}H_{23}O_5P$: C, 55.6; H, 7.7. Found: C, 56.3; H, 7.8.

In separate experiments it was established that the original benzene solution contained less than 3–5% of acidic material (extraction with aq. sodium hydroxide). When the quinone and the phosphite were mixed in benzene at room temperature, there was no immediate color change.

Hydrolysis of Diethyl-(4-ethoxy-2,5-dimethylphenyl) Phosphate (XX).—A solution containing 1.0 g. of XX, 0.6 g. of potassium hydroxide and 10 ml. of 95% ethanol was kept at reflux temperature for 20 hours. The mixture was acidified with hydrochloric acid (or CO₂) and the precipitate was collected. The filtrate was diluted with water and the additional precipitate was collected. The combined precipitates (ca. 0.55, theory 0.55 g.) afforded 0.40 g. of 2,5-dimethylhydroquinone-monoethyl ether (XXVII), m.p. 80–81° after one recrystallization from cyclohexane. The analytical sample of the ether XXVII had m.p. 82–83° (cyclohexane).

Anal. Calcd. for $C_{10}H_{14}O_2$: C, 72.3; H, 8.5. Found: C, 72.7; H, 8.5.

Reaction of 2,5-Dimethyl-*p*-benzoquinone (XII) with Triethyl Phosphite in the Presence of Water.—To a solution of triethyl phosphite (1.4 g.) in benzene (75 ml.) was added, dropwise (45 min.), a solution of *p*-xyloquinone (XII) (1.0 g.) in benzene–95% aq. ethanol (80 ml. of a 50:50 mixture). After 24 hours at room temperature, the solvent was removed from the colorless solution. The residue was treated with an excess of benzoyl chloride followed by 5% aq. sodium hydroxide (steam-bath). The colorless crystalline material (1.5 g., m.p. 154–158°) was recrystallized from methanol, and was shown to be 2,5-dimethylhydroquinone-dibenzoate by m.p. (158–159°) and by mixed melting point with authentic material.

Reaction of 2,5-Dimethyl-*p*-benzoquinone (XII) with Trimethyl Phosphite.—A solution containing *p*-xyloquinone (XII) (4.5 g.), trimethyl phosphite (5 g.) and benzene (80 ml.) was kept at reflux temperature for 12 hr. Removal of solvent and of excess phosphite left a residue which on distillation *in vacuo* afforded 8.6 g. (theory 8.6 g.) of dimethyl-(4-methoxy-2,5-dimethylphenyl) phosphate (XIX). The ether-phosphate XIX crystallized from hexane (m.p. 52–54°). The analytical sample had m.p. 58–59°.

Anal. Calcd. for $C_{11}H_{17}O_5P$: C, 50.8; H, 6.6. Found: C, 51.4; H, 6.8.

Hydrolysis of Dimethyl-(4-methoxy-2,5-dimethyl) Phosphate (XIX).—When the ether phosphate XIX was refluxed with an aqueous alcoholic solution of potassium hydroxide, a nearly quantitative yield of the known⁸ 2,5-dimethylhydroquinone monomethyl ether (m.p. 86–88°) was obtained.

Reaction of 2,3,5,6-Tetramethyl-*p*-benzoquinone (Duroquinone) (XIII) with Triethyl Phosphite (III) in Excess Phosphite as Solvent.—There was no apparent reaction when duroquinone (XIII) (3.5 g.) and triethyl phosphite (10 ml.) were mixed, at room temperature, under nitrogen. The mixture darkened when heated. After 2 hr. at reflux temperature, the mixture was distilled (for preparative pur-

poses the ether-phosphate XXI can be directly hydrolyzed, *vide infra*).

The main fraction (6.65 g., theory 7.03 g.) was collected at 125–131° (0.07 mm.). It was separated by further distillation into three fractions: (1) 2.6 g., b.p. 129–131° (0.07 mm.); (2) 2.5 g., b.p. 132–135° (0.1 mm.); and (3) residue, 0.6 g., which crystallized on standing.

Fractions 1 and 2 (total 5.1 g.) are essentially pure diethyl-(4-ethoxy-2,3,5,6-tetramethylphenyl) phosphate (XXI), n_D^{25} 1.4900, band at 7.9 μ . For analysis, fraction 2 was evaporatively distilled.

Anal. Calcd. for $C_{16}H_{27}O_5P$: C, 58.2; H, 8.2. Found: C, 58.7; H, 8.6.

Preparation of 2,3,5,6-Tetramethylhydroquinone-monoethyl Ether (Durohydroquinone-monoethyl ether) (XXVIII) from Duroquinone.—A mixture of duroquinone (0.95 g.) and triethyl phosphite (25 ml.) was kept 20 hr. at reflux temperature under nitrogen. The excess triethyl phosphite was removed under vacuum, and the residue was

treated with 40 ml. of a 5% solution of potassium hydroxide in 95% ethanol. After *ca.* 20 hr. at reflux temperature the solution was treated with carbon dioxide. The durohydroquinone-monoethyl ether (XXVIII) (0.94 g., m.p. 122–124°, theory 1.1 g.) which precipitated was suitable for further work. The analytical sample had m.p. 123–124° (ethanol-water).

Anal. Calcd. for $C_{12}H_{18}O_2$: C, 74.2; H, 9.3. Found: C, 74.2; H, 9.4.

Attempts to Reduce Duroquinone (XIII) with Triethyl Phosphite.—(a) A solution of duroquinone in a 50:50 mixture of benzene–95% aq. ethanol was slowly added to a solution of triethyl phosphite in benzene at room temperature. After 48 hr. most of the duroquinone was recovered unchanged. (b) A mixture of duroquinone, triethyl phosphite, toluene and 95% ethanol was heated to reflux temperature for 20 hr. At least 50% of the duroquinone was recovered unchanged.

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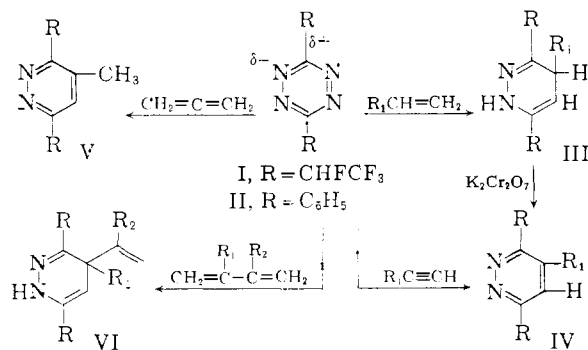
Reactions of Tetrazines with Unsaturated Compounds. A New Synthesis of Pyridazines

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3,6-Bis-(polyfluoroalkyl)-*sym*-tetrazines were found to react with remarkable ease with a variety of unsaturated compounds, including styrenes, butadienes, acetylenes, aliphatic and alicyclic olefins, and allene to yield pyridazines. 3,6-Diphenyl- and 3,6-dimethyl-*sym*-tetrazines reacted similarly though less readily. The scope of this reaction and the nature of the products are discussed.

Although a number of synthetic routes to tetrazines have been reported,¹ little is known about their chemistry. In connection with our recent studies of the synthesis of 1,2-dihydro-3,6-bis-(polyfluoroalkyl)-*sym*-tetrazines from fluoroolefins and hydrazine,² it was discovered that these substances react easily with a variety of unsaturated compounds with the evolution of one mole of nitrogen to yield 3,6-disubstituted pyridazines. The reaction apparently proceeds by 1,4-addition of the $-C=N-N=C-$ diene system of the tetrazine to the appropriate olefinic and acetylenic dienophiles.



3,6 - Bis - (1,2,2,2 - tetrafluoroethyl) - *sym*-tetrazine (I) reacts exothermically with styrene at

(1) J. G. Erickson, P. F. Wiley and V. P. Wystrach, "The Chemistry of Heterocyclic Compounds," Vol. X, "The 1,2,3- and 1,2,4-triazines, Tetrazines, and Pentazines," Interscience Publishers, Inc., New York, N. Y., 1956, Chapter IV.

(2) R. A. Carboni and R. V. Lindsey, Jr., *THIS JOURNAL*, **80**, 5793 5793 (1958).

room temperature to give a colorless, crystalline product, m.p. 131–132.5°, with the empirical formula $C_{14}H_{10}F_8N_2$ (III, R = CH_2CF_2 , $R_1 = C_6H_5$). The reaction can be moderated by cooling or by employing diluents such as ether or benzene. Completion of the reaction is signalled by the disappearance of the characteristic red or violet-red tetrazine color and by the cessation of nitrogen evolution. 3,6-Bis-difluoromethyl-*sym*-tetrazine² also reacts rapidly with styrene at room temperature while 3,6-bis-(3,3-difluoroallyl)-*sym*-tetrazine reacts somewhat more slowly. 3,6-Diphenyl-*sym*-tetrazine (II) and 3,6-dimethyl-*sym*-tetrazine behave in a similar manner, although the additions are slower and require higher temperatures. Thus, the reaction of II with styrene requires heating for 30 minutes at 75° for completion.

The enhanced reactivity of the fluoroalkyl-tetrazine derivatives toward many of the unsaturated compounds is undoubtedly associated with the electron-withdrawing effects of the polyfluoroalkyl groups which render the 3,6-positions more susceptible to attack by electron-rich olefins.

Dienophiles containing electron-releasing substituents were found to facilitate the reaction, while those with electron-attracting groups exhibited a retarding effect. Thus, isobutyl vinyl ether, butadiene, isoprene and 2,3-dimethylbutadiene reacted immediately with I at room temperature to give the corresponding dihydropyridazine derivatives. With acrylonitrile and acrolein, prolonged heating at 70° was required to complete the reaction. Negatively polysubstituted olefins such as maleic anhydride, maleic acid, diethyl azoformate and tetracyanoethylene, which are nor-