

of 2-methyl-2-butene from neopentyl alcohol, 2,3-dimethyl-2-butene from pinacolyl alcohol and 2,3-dimethyl-1-pentene and 2,3-dimethyl-1-pentene from 3,3-dimethyl-2-pentanol can be explained only on the basis of classical carbonium ion rearrangements.

[CONTRIBUTION FROM THE CHEMICAL RESEARCH DEPARTMENT, CENTRAL RESEARCH DIVISION, AMERICAN CYANAMID CO., STAMFORD, CONN.]

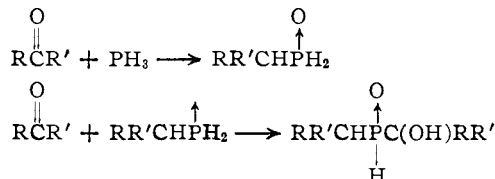
A Novel Phosphorus Heterocyclic System from the Reactions of Phosphine and Primary Phosphines with 2,4-Pentanedione

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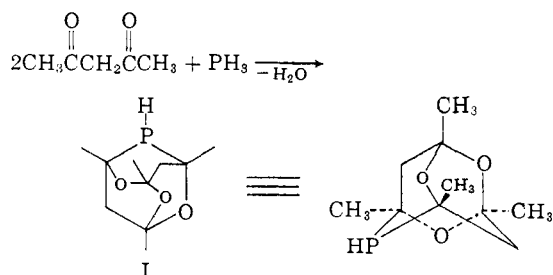
Reaction of phosphine with 2,4-pentanedione in aqueous acid solution gives a high yield of a product having the composition $C_{10}H_{17}O_3P$. On the basis of spectroscopic and chemical evidence, a cyclic acetal structure I is proposed for this substance which has the basic adamantane ring system. Similar materials (X–XII) are obtained from reactions of some primary phosphines with this diketone. In addition, compounds containing two and three phosphorus atoms have been isolated for which structures such as XIII–XV are suggested. Some reactions of these compounds are reported and a possible route for their formation is presented.

Previous reports from this Laboratory have described reactions of phosphine with a variety of aldehydes and ketones.^{1–3} The nature of the product varied considerably with structural changes in the carbonyl compound. With most ketones an "oxygen transfer" was observed resulting in the formation of a mixture of the primary phosphine oxide and hydroxy-substituted secondary phosphine oxide.¹

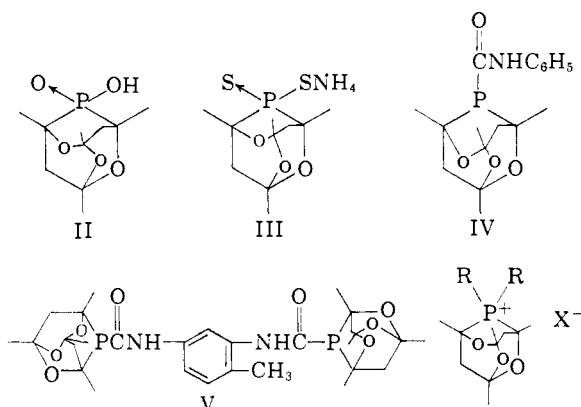


In extending this study, reactions of phosphine with a diketone, 2,4-pentanedione, have been attempted in the hope of producing a difunctional primary phosphine oxide or a four-membered ring. While the observed product was indeed heterocyclic, it was of an unexpected and unusual constitution.

Solutions of 2,4-pentanedione in aqueous hydrochloric acid absorbed phosphine readily at room temperature and a white crystalline solid precipitated having the molecular formula $C_{10}H_{17}O_3P$. Chemical and spectroscopic evidence indicates that this material is 1,3,5,7-tetramethyl-2,4,8-trioxa-6-phosphaadamantane (I).

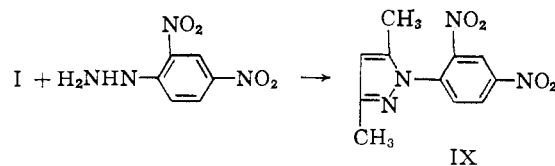


The chemical properties of I were typical of a secondary phosphine. Oxidation with hydrogen peroxide converted I to the phosphinic acid II and treatment with sulfur and ammonium hydroxide gave the ammonium salt of the dithiophosphinic acid III. Other derivatives which were prepared include the phenylcarbamoyl compound IV, the dicarbamoyl compound V, and the phosphonium salts VI–VIII.



VI, R = CH_3 ; X = I
VII, R = $n\text{-C}_4\text{H}_9$; X = I
VIII, R = CH_2OH ; X = Cl

That carbon skeleton rearrangement had not occurred in the formation of I was demonstrated by treatment with an acidic solution of 2,4-dinitrophenylhydrazine for an extended period of time, which produced a 59% yield of the 2,4-pentanedione derivative, pyrazole IX.⁴



The infrared spectrum of I exhibited P–H absorption at 2280 cm^{-1} which was shown to be due to a single P–H bond in the molecule by a 1:1 doublet

(1) S. A. Buckler and M. Epstein, *J. Am. Chem. Soc.*, **82**, 2076 (1960).

(2) S. A. Buckler, *ibid.*, **82**, 4215 (1960).

(3) S. A. Buckler and V. P. Wystrach, *ibid.*, **83**, 168 (1961).

(4) O. L. Brady, *J. Chem. Soc.*, 756 (1931).

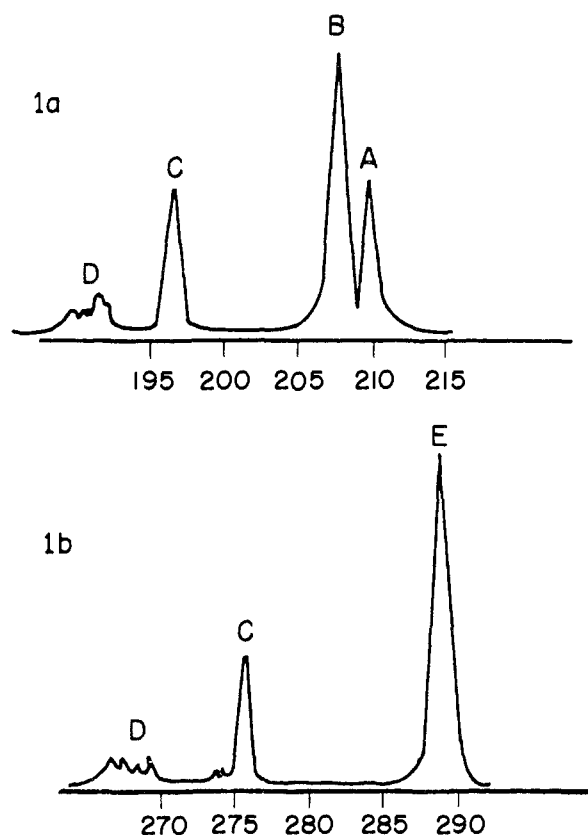


Fig. 1.—Appearance of the proton n.m.r. spectrum of I in CCl_4 solution at 40 mc. (a) and at 56.4 mc. (b). The scales are in cycles/sec., with benzene as an external reference.

at +46 and +57 p.p.m. (referred to 85% H_3PO_4) in the phosphorus n.m.r. spectrum. Infrared peaks between 1100–1230 cm^{-1} were attributed to branched C–O–C linkages; carbonyl and hydroxyl peaks were absent.

Proton n.m.r. spectra (Fig. 1) gave valuable information supporting formulation I. Part of the proton n.m.r. spectrum taken at 40 mc. is shown in 1-a. Previous work in these laboratories with compounds containing the structure P–C–C has established that the hydrogens on the β -carbon are spin-coupled to the phosphorus nucleus with a coupling of about 10–15 c.p.s.⁵ The resonance appears as a doublet with a line separation of 10–15 c.p.s. Peaks A and C in 1-a can therefore be assigned to methyl groups beta to the phosphorus. The single peak B can be assigned to the remaining methyl groups, which are evidently farther removed from the phosphorus, since splitting does not occur. The number of methyl groups represented by the intensity of peak B and the sum of peaks A and C are equal which is in accordance with the proposed structure I.

The 56.4 mc. spectrum shown in 1-b confirms this assignment. On going from 40 to 56.4 mc., chemical shifts increase by nearly 3/2 but splittings arising from spin-couplings should remain the same. This is what occurs as the chemical shift between the mean of peaks A and C and peak B has increased while the separation of A and C remains

unchanged. In 1-b peak E is the accidental superposition of peaks A and B in the 40 mc. spectrum.

The methylene groups are evidently represented by the weak lines occurring to the low field side of the methyl peaks. Since the hydrogens of each methylene group in the rigid structure are likely to be non-equivalent as well as coupled to the phosphorus nucleus, it is not surprising that a multiplicity of lines appear. Since some of these lines are obscured by the strong methyl peaks, it did not prove possible to analyze this part of the spectrum but the ratio of intensity of the absorption to that of the methyl lines appears to be of the right order of magnitude to correspond to two methylene groups. The resonance due to the hydrogen attached to the phosphorus was observed but is omitted from Fig. 1. Table I summarizes the shifts and couplings for I.

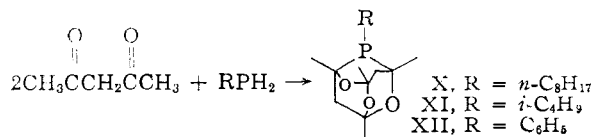
TABLE I
THE SHIFTS AND COUPLINGS OBSERVED IN THE H^1 N.M.R. SPECTRUM OF I^a

Assignment	δ, τ	J
CH_3 beta to P	8.59	13.5
CH_3 gamma to P	8.76	0
CH_2	8.21	?
PH	6.94	186

^a The chemical shifts, δ , are given in terms of τ -values^b and the couplings (J) in cycles/sec. ^b G. V. D. Tiers, *J. Phys. Chem.*, **62**, 1151 (1958).

The reaction product of phosphine and 2,4-pentanedione was first prepared in 49% yield using concentrated hydrochloric acid as the reaction medium. Subsequent attempts to repeat this experiment gave erratic results and an uptake of phosphine greater than that required by the stoichiometry was noticed frequently. These observations indicate that strong acid can attack the product at the acetal linkages to give intermediates which can incorporate additional phosphine (*vide infra*). A study of reaction conditions showed that Compound I could be obtained consistently in 80% yield when the reaction was conducted in 4–6 *N* hydrochloric acid; I has also been prepared in 66% yield using benzene as solvent with methanesulfonic acid as catalyst.

Certain primary phosphines have been treated successfully with 2,4-pentanedione to give crystalline tertiary phosphine derivatives (X–XII) of the same polycyclic ring system. Independently,

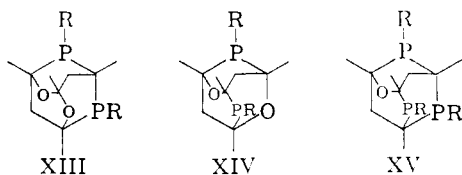


X was prepared from I by treatment with 1-octene in the presence of a free radical initiator. The methiodide and phosphine oxide derivatives of XI were obtained readily by treatment with methyl iodide and hydrogen peroxide, but X resisted reaction with these reagents.

In addition to XII, smaller quantities of two additional materials were isolated from reactions of phenylphosphine and 2,4-pentanedione having

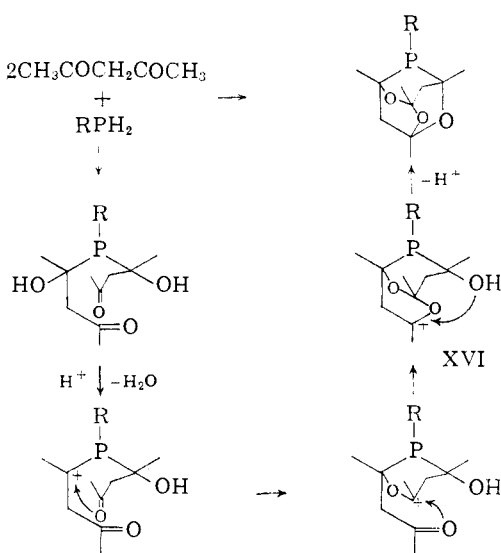
(5) J. E. Lancaster and W. G. Hodgson, unpublished observations.

the molecular formulae $C_{22}H_{26}O_2P_2$ and $C_{28}H_{31}OP_3$, respectively. Compounds having the molecular compositions $C_{22}H_{38}O_2P_2$ and $C_{16}H_{24}N_2O_2P_2$ were obtained from reactions of cyclohexylphosphine and 2-cyanoethylphosphine with the diketone. These compositions suggest replacement by RP groups of oxygen atoms of the previously proposed heterocyclic system. Therefore, structures such as XIII or XIV are indicated for the compounds having two phosphorus atoms ($R = C_6H_5$, cyclo- C_6H_{11} , $CNCH_2CH_2$), and XV is suggested for the substance having three phosphorus atoms ($R = C_6H_5$).



The infrared spectra were generally in agreement with these formulations, but the n.m.r. results obtained with the phenyl derivatives were inconclusive by virtue of their complexity. Well-characterized derivatives were not obtained from these substances by treatment with methyl iodide or hydrogen peroxide, although reactions did occur.

The following sequence is suggested for the formation of I and X-XII. The replacement of



oxygen with RP groups as in XIII-XV can be accounted for by attack of the phosphine on XVI or related species formed by acid-catalyzed ring opening.

Acknowledgment.—The authors wish to express their sincere appreciation to Dr. J. E. Lancaster for obtaining and interpreting the n.m.r. spectra.

Experimental⁶

Preparation of 1,3,5,7-Tetramethyl-2,4,8-trioxa-6-phosphaadamantane (I). A. Using Aqueous Hydrochloric Acid.—A solution of 30.0 g. (0.3 mole) of 2,4-pentanedione in 100 ml. of 5 N hydrochloric acid was placed in a pressure

(6) Melting points are uncorrected. All procedures with the exception of recrystallizations were conducted in an atmosphere of nitrogen. Analyses were carried out under the supervision of Dr. J. A. Kuck.

bottle connected to a standard Parr pressure reaction apparatus. The vessel was evacuated and filled with nitrogen a few times and finally filled with phosphine from the reservoir. The reaction was allowed to proceed with shaking under 2–3 atmospheres pressure until completed (50 minutes). The uptake of phosphine was 0.15 mole. The bottle was evacuated, filled with nitrogen a few times, and removed from the apparatus. The mixture of solution and precipitated solid was diluted with cold water and filtered to give, after drying, 26.3 g. (81%) of I, m.p. 88–90°. The m.p. was not changed by two recrystallizations from methanol-water.

Anal. Calcd. for $C_{10}H_{17}O_3P$: C, 55.55; H, 7.93; P, 14.33; mol. wt., 216.2. Found: C, 55.51; H, 7.95; P, 14.15; mol. wt., 201, 207 (ebullioscopic in benzene).

Compound I was readily soluble in all common organic solvents and relatively unreactive toward atmospheric oxygen in the solid state and in solution compared to simpler secondary phosphines; however, it should be kept in a sealed container under an inert atmosphere when stored for extended periods of time.

B. Using Benzene and Methanesulfonic Acid.—The procedure described above was repeated using 100 ml. of benzene and 2 ml. of methanesulfonic acid in place of the aqueous hydrochloric acid. After separating the small lower layer which formed, the benzene solution was evaporated to give 21.5 g. (66%) of I, m.p. 86–90°. Recrystallization from methanol-water gave a sample, m.p. 88–90°, identical with that produced by method A.

1,3,5,7-Tetramethyl-2,4,8-trioxa-6-phosphaadamantane-6-inoic acid (II).—To a solution of 6.7 g. (0.031 mole) of I in 80 ml. of warm methanol was added dropwise 9.0 g. of 30% hydrogen peroxide. After heating under reflux for 1 hour, the solution was concentrated to give 5.0 g. (65%) of II, m.p. 220–222°. Recrystallization from isopropyl alcohol gave the analytical sample, m.p. 221–222°.

Anal. Calcd. for $C_{10}H_{17}O_5P$: C, 48.39; H, 6.90; P, 12.48; mol. wt., 248.2. Found: C, 48.53; H, 6.91; P, 12.43; mol. wt., 255 (ebullioscopic in ethanol).

1,3,5,7-Tetramethyl-2,4,8-trioxa-6-phosphaadamantane-6-dithionioic Acid, Ammonium Salt (III).—A mixture of 4.0 g. of I (0.019 mole), 1.2 g. of sulfur (0.037 mole), 35 ml. of 8 N ammonium hydroxide solution and 25 ml. of methanol was heated under reflux for 3 hours. After removing the unreacted sulfur, the solution was evaporated to give 4.6 g. (84%) of III, m.p. 212–214°. A sample with m.p. 217–218° was obtained by recrystallization from acetonitrile.

Anal. Calcd. for $C_{10}H_{20}NO_3PS_2$: C, 40.39; H, 6.78; N, 4.71; P, 10.42; S, 21.57. Found: C, 40.45; H, 6.95; N, 4.62; P, 10.56; S, 21.43.

6-Phenylcarbonyl-1,3,5,7-tetramethyl-2,4,8-trioxa-6-phosphaadamantane (IV).—A solution of 4.0 g. (0.019 mole) of I, 2.3 g. of phenyl isocyanate (0.02 mole) and 0.5 g. of triethylene diamine in 50 ml. of dry benzene was kept at room temperature for 24 hours. The solvent was then evaporated and the residue recrystallized from hexane to give 3.7 g. (58%) of IV, m.p. 108–109°.

Anal. Calcd. for $C_{17}H_{22}NO_3P$: C, 60.89; H, 6.61; N, 4.18; P, 9.24. Found: C, 60.49; H, 6.91; N, 4.25; P, 9.17.

N,N'-(4-Methyl-m-phenylene)-bis-(1,3,5,7-tetramethyl-2,4,8-trioxa-6-phosphaadamantane-6-carboxamide) (V).—A solution of 11.0 g. (0.05 mole) of I, 4.4 g. of toluene-2,4-diisocyanate (0.025 mole) and 0.2 g. of triethylene diamine in 60 ml. of dry benzene was allowed to stand at room temperature for 4 days. The solid which deposited was collected and dried to give 9.0 g. (58%) of V, m.p. 208–211°. The analytical sample, m.p. 217–219°, was recrystallized from acetonitrile.

Anal. Calcd. for $C_{29}H_{46}N_2O_8P_2$: C, 57.42; H, 6.65; N, 4.62; P, 10.21. Found: C, 57.41; H, 6.81; N, 4.75; P, 10.13.

1,3,5,6,6,7-Hexamethyl-2,4,8-trioxa-6-phosphoniaadamantane Iodide (VI).—A solution of 2.0 g. of I in 30 ml. of methyl iodide was heated under reflux for 18 hours. The precipitated solid was collected and recrystallized from isopropyl alcohol to give VI, m.p. 243–244° dec.

Anal. Calcd. for $C_{12}H_{22}IO_3P$: C, 38.72; H, 5.96; I, 34.10; P, 8.32. Found: C, 38.57; H, 5.95; I, 34.07; P, 8.04.

1,3,5,7-Tetramethyl-6,6-dibutyl-2,4,8-trioxa-6-phosphoniaadamantane Iodide (VII).—A solution of 5.3 g. of I in 30 g. of butyl iodide was kept at room temperature for 70 hours. The precipitated solid was filtered and recrystallized from tetrahydrofuran to give the analytical sample of VII, m.p. 209–211° dec.

Anal. Calcd. for $C_{18}H_{34}IO_3P$: C, 47.37; H, 7.51; I, 27.81; P, 6.79. Found: C, 47.71; H, 7.97; I, 27.41; P, 6.58.

6,6-Dihydroxymethyl-1,3,5,7-tetramethyl-2,4,8-trioxa-6-phosphoniaadamantane Chloride (VIII).—To a solution of 6.0 g. (0.027 mole) of I in 50 ml. of warm methanol was added a mixture of 4.9 g. of 37% aqueous formaldehyde and 6 ml. of concentrated hydrochloric acid. After standing at room temperature for 3 days, the resulting solution was evaporated and the residue triturated with cold acetone and filtered to give 5.2 g. (62%) of VIII, m.p. 161–162°. Recrystallization from acetone did not change the m.p.

Anal. Calcd. for $C_{12}H_{22}ClO_3P$: C, 46.08; H, 7.09; Cl, 11.34; P, 9.91. Found: C, 45.79; H, 7.10; Cl, 11.39; P, 10.01.

Treatment of I with 2,4-Dinitrophenylhydrazine.—A solution of 1.5 g. of I, 3.4 g. of 2,4-dinitrophenylhydrazine, 16 ml. of concentrated sulfuric acid, 25 ml. of water and 90 ml. of ethanol was allowed to stand at room temperature for 3 weeks. Upon dilution with water a yellow solid precipitated and the odor of phosphine was detected. The solid was filtered and dried affording 2.15 g. (59%) of 1-(2,4-dinitrophenyl)-3,5-dimethylpyrazole (IX), m.p. 118–120°. Recrystallization from carbon tetrachloride raised the m.p. to 122–123°. This material was identical with an authentic specimen prepared from 2,4-pentanedione and 2,4-dinitrophenylhydrazine,⁴ m.p. 122–123°.

1,3,5,7-Tetramethyl-6-octyl-2,4,8-trioxa-6-phosphaadamantane (X).—A mixture of 5.8 g. (0.04 mole) of octylphosphine, 8.5 g. (0.085 mole) of 2,4-pentanedione and 30 ml. of concentrated hydrochloric acid was prepared with cooling and allowed to stand at room temperature for 4 days. The solution was then poured onto ice and the precipitated solid collected giving 10.5 g. (80%) of X, m.p. 38–40°. Recrystallization from water-methanol raised the m.p. to 42–43°.

Anal. Calcd. for $C_{18}H_{38}O_3P$: C, 65.82; H, 10.13; P, 9.43. Found: C, 65.62; H, 9.94; P, 9.54.

Reaction of I with 1-Octene.—A solution of 10.0 g. (0.046 mole) of I, 5.2 g. of 1-octene and 0.4 g. of azobisisobutyronitrile in 50 ml. of benzene was heated under reflux for 2 hours. The solution was evaporated to dryness and the residue recrystallized from water-methanol to give 5.0 g. (33%) of X, m.p. 42–43°, identical with the material prepared from octylphosphine and 2,4-pentanedione.

1,3,5,7-Tetramethyl-6-isobutyl-2,4,8-trioxa-6-phosphaadamantane (XI).—A solution of 5.2 g. (0.058 mole) of isobutylphosphine, 12.0 g. of 2,4-pentanedione (0.12 mole), 15 ml. of methanol and 30 ml. of concentrated hydrochloric acid was kept at room temperature for 24 hours and then poured onto ice. The solid which deposited was filtered to give 9.1 g. (58%) of XI, m.p. 75–77°. The m.p. was not changed by recrystallization from isopropyl alcohol.

Anal. Calcd. for $C_{14}H_{26}O_3P$: C, 61.74; H, 9.25; P, 11.38. Found: C, 61.81; H, 9.11; P, 11.70.

Treatment of XI with hydrogen peroxide in boiling methanol gave 1,3,5,7-tetramethyl-6-isobutyl-2,4,8-trioxa-6-phosphaadamantane-6-oxide, m.p. 109–111° (from hexane).

Anal. Calcd. for $C_{14}H_{26}O_4P$: C, 58.32; H, 8.74; P, 10.75. Found: C, 57.91; H, 8.79; P, 10.70.

When a solution of XI in excess methyl iodide was heated under reflux for several days, 1,3,5,6,7-pentamethyl-6-isobutyl-2,4,8-trioxa-6-phosphoniaadamantane iodide deposited, m.p. 202–203° (from acetone).

Anal. Calcd. for $C_{15}H_{28}IO_3P$: C, 43.49; H, 6.81; I, 30.64; P, 7.48. Found: C, 43.65; H, 6.58; I, 30.81; P, 7.27.

1,3,5,7-Tetramethyl-6-phenyl-2,4,8-trioxa-6-phosphaadamantane (XII).—To a solution of 8.4 g. of phenylphosphine (0.076 mole) in 20 ml. of concentrated hydrochloric acid and 15 ml. of ethanol was added 15.5 g. of 2,4-pentanedione (0.155 mole) with cooling and stirring. The solid which precipitated after standing for 24 hours was collected giving 9.0 g. (40%) of XII, m.p. 104–107°. The analytical sample had m.p. 105–107° (from ethanol).

Anal. Calcd. for $C_{16}H_{21}O_3P$: C, 65.74; H, 7.24; P, 10.60. Found: C, 65.68; H, 7.43; P, 10.83.

Other Products from Phenylphosphine-2,4-Pentanedione Reactions.—A solution of 9.5 g. (0.086 mole) of phenylphosphine, 17.3 g. (0.173 mole) of 2,4-pentanedione, 2 ml. of methanesulfonic acid and 50 ml. of benzene was heated under reflux for 5 hours. It was then washed with water and evaporated to dryness. The residue was triturated with acetonitrile and filtered to give 2.1 g. of a crystalline solid which had a constant m.p. of 204–205° after repeated recrystallizations from acetonitrile.

Anal. Calcd. for $C_{22}H_{25}O_3P_2$: C, 68.74; H, 6.82; P, 16.12; mol. wt., 384.3. Found: C, 68.40; H, 7.01; P, 16.13; mol. wt., 378 (ebullioscopic in benzene).

A solution of 15.2 g. (0.138 mole) of phenylphosphine, 6.9 g. (0.069 mole) of 2,4-pentanedione, 50 ml. of ethanol and 20 ml. of concentrated hydrochloric acid was heated under reflux for 44 hours. The solid which precipitated upon cooling (2.0 g.) was collected and recrystallized from acetonitrile to a constant m.p., 238–239°.

Anal. Calcd. for $C_{28}H_{31}OP_3$: C, 70.58; H, 6.56; P, 19.50; mol. wt., 476.5. Found: C, 70.62; H, 6.71; P, 19.53; mol. wt., 489 (ebullioscopic in chloroform).

Reaction of Cyclohexylphosphine with 2,4-Pentanedione.—A mixture of 9.0 g. (0.078 mole) of cyclohexylphosphine, 15.5 g. of 2,4-pentanedione (0.155 mole), 20 ml. of methanol and 30 ml. of concentrated hydrochloric acid was heated under reflux for 2 hours. After evaporating the solvent, the residue was diluted with water which precipitated a small amount of a white solid from which a sample having m.p. 123–125° was obtained by recrystallization from acetonitrile.

Anal. Calcd. for $C_{28}H_{32}O_3P_2$: C, 66.64; H, 9.66; P, 15.63. Found: C, 66.88; H, 9.55; P, 15.35.

Reaction of 2-Cyanoethylphosphine with 2,4-Pentanedione.—A solution of 9.5 g. of 2-cyanoethylphosphine⁷ (0.11 mole), 22.0 g. (0.22 mole) of 2,4-pentanedione and 2 ml. of methanesulfonic acid in 75 ml. of benzene was heated under reflux for 4 hours. A small lower layer was separated and discarded and the benzene evaporated. The residue yielded 2.5 g. of white solid upon trituration with ether from which a sample with m.p. 188–189° was obtained by recrystallization from isopropyl alcohol.

Anal. Calcd. for $C_{18}H_{24}N_2O_2P_2$: C, 56.80; H, 7.15; N, 8.28; P, 18.31. Found: C, 56.33; H, 7.11; N, 8.07; P, 18.36.

(7) M. M. Rauhut, I. Hechenbleikner, H. A. Currier, F. C. Schaefer and V. P. Wystrach, *J. Am. Chem. Soc.*, **81**, 1103 (1959).