Unsymmetrical Tertiary Phosphines of Ferrocene by Friedel–Crafts Reactions. I. Ferrocenylphenylphosphines[1]

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Received September 7, 1962

Ferrocenylphenylphosphines have been prepared in good yield by the interaction of ferrocene with phenylphosphonous and -phosphinous chlorides in the presence of anhydrous aluminum chloride, and represent the first unsymmetrical tertiary phosphines prepared by a Friedel–Crafts process. The air-stable phosphines were also obtained as the oxides and methiodides, the former directly from the reaction mixtures. The mechanism of Friedel–Crafts trisubstitution on phosphorus is discussed.

It was recently discovered that contrary to the general behavior of aromatic compounds, ferrocene reacts with phosphorus trichloride under Friedel–Crafts conditions to give the tertiary phosphine.[2] Triferrocenylphosphine (I) is formed in addition to the expected mono- and diferrocenyl derivatives of phosphorus.

It now has been found that ferrocene undergoes reactions with phenylphosphonous dichloride ($C_6H_5PCl_2$) and diphenylphosphinous chloride [$(C_6H_5)_2PCl$] in the presence of anhydrous aluminum chloride to give the first unsymmetrical tertiary phosphines prepared by a Friedel–Crafts process. Diferrocenylphenylphosphine (II) and ferrocenyldiphenylphosphine (III), both odorless, orange crystalline solids, were demonstrated to form in at least 75% and 65% yields, respectively, after twenty hours of refluxing in *n*-heptane.

Unsymmetrical tertiary phosphines are generally prepared most conveniently by the interaction of Grignard or lithium reagents with phosphonous dichlorides and phosphinous chlorides.[3] The following are examples.

$$RPCl_2 + 2R'MgX \longrightarrow RR_2'P + 2MgXCl$$

$$R_2PCl + R'Li \longrightarrow R_2R'P + LiCl$$

The novelty and utility of the Friedel–Crafts method of producing tertiary ferrocenylphenylphosphines lie in the fact that it is unnecessary to prepare an intermediate metallic derivative of ferrocene for interaction with the acid chlorides.

The effect on yield, of increasing the reflux period from six to twenty hours in the present work, is summarized in Table I. A plot of yields *vs.* reflux times indicates that with thirty hours of reflux, phosphines II and III might be obtained in yields approaching 85% and 80%, respectively. Also included in Table I are amounts of ferrocene recovered unchanged from the ten and twenty-hour reaction mixtures. Conversions were good to excellent.

The ratios of ferrocene:acid chloride:aluminum chloride employed for the formation of II and III were 2:1:1 and 1:1:1, respectively, and are by no means considered to be optimal.

Although I is converted to the oxide by air,[2] phosphines II and III are stable to air oxidation. The behavior of I is in accord with recently reported examples of the electron donor property of the ferrocenyl group.[4] Stabilities of phosphines II and III resemble that of triphenylphosphine itself, and must be attributed to withdrawal of the lone electron pair on phosphorus by the phenyl group. The stability of diferrocenylphenylphosphine (II) in air, moreover, emphasizes the importance of the resonance effect of phenyl, since two ferrocenyl groups are not enough to offset the electron withdrawing power of the single phenyl group.

TABLE I

EFFECT OF REFLUX TIME ON YIELDS OF FERROCENYLPHENYLPHOSPHINES

Reflux time, hr.	Phosphine II,[a] %	Recovered ferrocene, %	Phosphine III,[a] %	Recovered ferrocene, %
6	45.1 (11)	. .	35.0 (1.8)	. .
10	59.7 (4.9)	34	47.2 (8.1)	35
20	75.3 (8.2)	13	65.7 (13)	15

[a] Includes the phosphine isolated as its oxide, and recorded in parentheses.

The quaternary salts, diferrocenylphenylmethylphosphonium iodide and ferrocenyldiphenylmethylphosphonium iodide, were obtained on treatment of phosphines II and III, respectively, with methyl iodide. The latter salt precipitated from benzene as a hydrated oil which solidified with loss of water on standing overnight. The former precipitated from benzene occasionally as a partial oil which solidified after several minutes.

Lesser amounts of the oxides of phosphines II and III were isolated from the reaction mixtures during the course of the work, and are indicated in Table I. In performing the reactions, only atmospheric moisture was excluded, and since triphenylphosphine is readily air-oxidized in the presence of aluminum chloride,[5] it is likely that the oxides of phosphines II and III arose in an analogous manner. The amount of phosphine oxide formed was subject to considerable variation (see particularly yields of phosphine II oxide, Table I). This could be attributed in large measure to the heterogeneous nature of the reaction mixture, and variable rates of stirring. Assignment of phosphoryl stretching frequencies will be mentioned later.

In contrast to the behavior of triferrocenylphosphine oxide,[2] no hydrate of the ferrocenylphenylphosphine oxides was obtained upon evaporation of solvent from solutions in benzene or ethanol, or upon addition of excess water to the latter.

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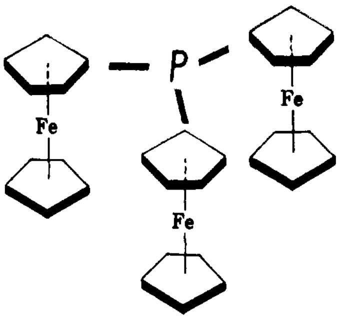
(1) Supported by the U. S. Army Research Office (Durham).

(2) G. P. Sollott and E. Howard, Jr., *J. Org. Chem.*, **27**, 4034 (1962).

(3) G. M. Kosolapoff, "Organophosphorus Compounds," John Wiley and Sons, Inc., New York, N. Y., 1950, p. 16; C. Screttas and A. F. Isbell, *J. Org. Chem.*, **27**, 2573 (1962).

(4) A. N. Nesmeyanov, E. G. Perevalova, and R. V. Golovnya, *Dokl. Akad. Nauk SSSR*, **103**, 81 (1958); A. N. Nesmeyanov, *Proc. Roy. Soc.* (London), **246**, 495 (1958); *Cf.* W. F. Little, R. A. Berry, and P. Kannan, *J. Am. Chem. Soc.*, **84**, 2525 (1962).

(5) D. R. Lyon and F. G. Mann, *J. Chem. Soc.*, 666 (1942).



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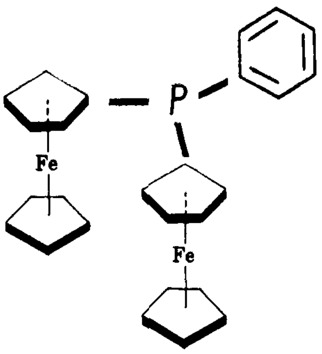

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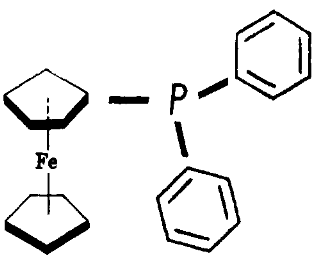

III

The results of the present work tend to confirm the mechanism suggested previously,[2] *viz.* that ferrocene reacts with phosphorus trichloride under Friedel–Crafts conditions to give trisubstitution on phosphorus by way of a stepwise process, mono- to di- to tri-. This may be illustrated as follows.

$$\mathrm{ArH} + \overset{+}{\mathrm{P}}\mathrm{Cl_2} + \mathrm{AlCl_4^-} \longrightarrow \mathrm{ArPCl_2} + \mathrm{AlCl_3} + \mathrm{HCl} \quad (1)$$

$$\mathrm{ArH} + \mathrm{Ar}\overset{+}{\mathrm{P}}\mathrm{Cl} + \mathrm{AlCl_4^-} \longrightarrow \mathrm{(Ar)_2PCl} + \mathrm{AlCl_3} + \mathrm{HCl} \quad (2)$$

$$\mathrm{ArH} + \mathrm{(Ar)_2P^+} + \mathrm{AlCl_4^-} \longrightarrow \mathrm{(Ar)_3P} + \mathrm{AlCl_3} + \mathrm{HCl} \quad (3)$$

$$(\mathrm{Ar} = \text{ferrocenyl})$$

Thus, phosphine II would arise analogously to steps 2 and 3; phosphine III, analogously to step 3. Since benzene gives disubstitution on phosphorus, but fails to give the tertiary phosphine in a Friedel–Crafts reaction with phosphorus trichloride,[6] the results of the present work indicate that in the case of ferrocene, trisubstitution on phosphorus occurs not because of any unusual activity associated with the intermediate phosphorus-containing electrophile (*i.e.*, Ar_2P^+; Ar = phenyl or ferrocenyl), but because of the high degree of reactivity of ferrocene as a nucleophile.

Further work is in progress to determine whether the Friedel–Crafts process of preparing unsymmetrical tertiary phosphines of ferrocene is general, and can be extended to include aliphatic, as well as other aromatic acid chlorides of phosphorus besides phenyl.

Experimental[7]

Diferrocenylphenylphosphine (II), Its Oxide and Methiodide.—Anhydrous aluminum chloride (0.1 mole, 13.4 g.) was stirred with a partial solution of 37.2 g. (0.2 mole) of ferrocene in 200 ml. of *n*-heptane, which had been allowed to cool to room temperature after an initial warming. A solution of 17.9 g. (0.1 mole) of phenylphosphonous dichloride in 100 ml. of *n*-heptane was added dropwise over a 20-min. period after which the blue-black mixture was refluxed for 20 hr. with protection against atmospheric moisture. After cooling, the yellow-orange heptane phase was decanted through a filter, and the brown-black solids remaining in the reaction flask were extracted with 200 ml. of hot *n*-heptane in portions. Evaporation of the combined solutions to dryness gave 3.2 g. of unchanged ferrocene. The solids in the reaction flash were treated cautiously with 200 ml. of hot water in portions, and the light blue, sometimes greenish, aqueous washings discarded.

The water-washed solids, now yellow in color, were extracted with a total of 800 ml. of hot benzene, and the remaining insoluble, brown, solid material discarded. The dark orange solution was dried over anhydrous sodium sulfate, filtered, and evaporated to dryness, and 1.8 g. of ferrocene were extracted from the residue by washing with *n*-heptane at room temperature. The remaining solids were extracted with 1 l. of boiling *n*-heptane, and repeated concentration and cooling of this extract provided 32.1 g. (67.1%) of orange, crystalline II, m.p. 188–190° dec. Recrystallization from ethanol gave golden needles, m.p. 191–193° dec.

Anal. Calcd. for $C_{26}H_{23}Fe_2P$: C, 65.31; H, 4.85; Fe, 23.37; P, 6.48. Found: C, 65.43; H, 5.12; Fe, 23.37; P, 6.53.

The heptane-insoluble solids were taken up in ethanol, and a small amount of ethanol-insoluble solids removed by filtration and discarded. Addition of water to the filtrate caused 4.0 g. (8.2%) of II oxide to separate as a yellow powder. For analysis, the product was crystallized from benzene giving orange powdery clusters, m.p. 239–241° (with gradual darkening above 190°).

Anal. Calcd. for $C_{26}H_{23}Fe_2OP$: C, 63.20; H, 4.69; Fe, 22.61; P, 6.27. Found: C, 63.15; H, 4.74; Fe, 22.61; P, 6.37.

Methyl iodide was added to a sample of phosphine II dissolved in benzene. After several minutes, the yellow-orange methiodide was collected on a filter. Crystallization from ethanol afforded a dark orange powder, soluble in hot water, m.p. 263–265° (with gradual darkening above 150°; closed capillary).

Anal. Calcd. for $C_{27}H_{26}Fe_2IP$: C, 52.29; H, 4.23; Fe, 18.01; I, 20.47; P, 5.00. Found: C, 52.94; H, 4.60; Fe, 17.77; I, 19.92; P, 4.92.

The methiodide could also be obtained by the addition of methyl iodide to the benzene extract of the water-washed solids above. Occasionally the precipitate settled out as a partial oil which solidified after several minutes.

Ferrocenyldiphenylphosphine (III), Its Oxide and Methiodide.—The reaction was performed in the same manner as above, employing 18.6 g. (0.1 mole) of ferrocene in 200 ml. of *n*-heptane, 13.4 g. (0.1 mole) of anhydrous aluminum chloride, and 22.1 g. (0.1 mole) of diphenylphosphinous chloride in 100 ml. of *n*-heptane, with a 20-hr. period of reflux. After decantation of the heptane phase, the remaining solids were extracted with fresh heptane as in the previous work-up, and the combined solutions evaporated to give 2.5 g. of unchanged ferrocene.

The solids were then treated with water as above, then extracted with a total of 500 ml. of hot benzene, and the remaining insoluble solids discarded. The benzene solution was dried over anhydrous sodium sulfate, filtered, and evaporated to dryness, and the residue extracted with 1 l. of *n*-heptane at room temperature. Repeated concentration and cooling of the heptane solution yielded 19.5 g. (52.7%) of orange, crystalline III. Recrystallization from ethanol afforded orange crystals, m.p. 122–124°.

Anal. Calcd. for $C_{22}H_{19}FeP$: C, 71.37; H, 5.17; Fe, 15.09; P, 8.37. Found: C, 71.19; H, 5.41; Fe, 15.08; P, 8.49.

Evaporation of the final heptane filtrate yielded 0.3 g. of ferrocene.

The orange, semi-solid residue remaining after extraction with *n*-heptane at room temperature was taken up in boiling *n*-heptane, and the solution decanted from some insoluble brown-orange amorphous solid (A). Concentration and cooling of the

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[6] For a review, see G. M. Kosolapoff, ref. 3, pp. 43–46.

[7] All melting points are uncorrected. The analyses were performed by Schwarzkopf Microanalytical Laboratory, Woodside 77, N. Y.

solution gave a yellow powder which, on recrystallization from *n*-heptane, afforded 2.0 g. of yellow-orange III oxide, whose infrared spectrum was identical to that of a second quantity of product isolated below. Evaporation of the mother liquor gave a hydrated, orange viscous liquid (B).

Extraction of solid A with boiling isopropyl alcohol, followed by evaporation of the solvent gave more of B. Oils B were taken up in isopropyl alcohol, and the solution diluted with water to form a stable emulsion. The emulsion was allowed to stand for a period of up to several days, after which 3.0 g. of III oxide, in the form of orange needles, were collected on a filter. Recrystallization from *n*-heptane gave orange needles, m.p. 163–165°; combined yield 5.0 g. (13%).

Anal. Calcd. for $C_{22}H_{19}FeOP$: C, 68.42; H, 4.96; Fe, 14.46; P, 8.02. Found: C, 68.37; H, 4.96; Fe, 14.16; P, 8.03.

Methyl iodide was added to a sample of phosphine III dissolved in benzene. After several minutes, the methiodide settled out as an orange, hydrated oil, which lost water and solidified on standing. The product was taken up in boiling isopropyl alcohol, and the solution concentrated and allowed to cool to room temperature. Black products separated and were removed by filtration and discarded. Dark orange crystals grew in the filtrate on standing, m.p. 187–188° dec., soluble in hot water.

Anal. Calcd. for $C_{23}H_{22}FeIP$: C, 53.93; H, 4.33; Fe, 10.90; I, 24.78; P, 6.05. Found: C, 54.64; H, 4.73; Fe, 10.55; I, 24.48; P, 5.95.

Alternately, the methiodide could be precipitated from the benzene extract of the water-washed solids above, by the addition of methyl iodide. The product settled out as the hydrated oil which solidified on standing overnight, with loss of water.

Infrared Spectra of the Tertiary Ferrocenylphenylphosphines and Derivatives.—Infrared spectra were obtained from Nujol mulls employing a Perkin–Elmer, Model 321, spectrophotometer.

Phosphines II and III, and their oxides and methiodides all show absorptions in the regions, 1310–1320 cm.$^{-1}$ and 1015–1045 cm.$^{-1}$, which were assigned earlier[2] to the ferrocenyl–phosphorus group. (The former range is now extended to include 1305 cm.$^{-1}$.) In addition, all spectra show a sharp band at 1440 cm.$^{-1}$ attributable to phenyl–phosphorus,[8] and the usual absorptions near 1110 and 1005 cm.$^{-1}$ characteristic of monosubstituted ferrocenes.[9] The band near 1005 cm.$^{-1}$, however, is often indistinguishable from the second phenyl–phosphorus absorption expected to appear near the same frequency (995 cm.$^{-1}$).[8]

The following are also common to all spectra: ferrocene C—H and C—C stretching bands in the regions, 3060–3100 cm.$^{-1}$ and 1410–1430 cm.$^{-1}$, respectively, and out-of-plane C—H bending bands in the region 810–830 cm.$^{-1}$[10]; two phenyl bands, one near 750 cm.$^{-1}$, the other in the region, 680–700 cm.$^{-1}$.[11]

Absorptions at 1180 cm.$^{-1}$ and 1200 cm.$^{-1}$ in the spectra of diferrocenylphenylphosphine (II) oxide and ferrocenyldiphenylphosphine (III) oxide, respectively, are assigned to phosphoryl stretching.[12] The latter oxide thus absorbs at nearly the same frequency as "unbonded" phosphoryl in triphenylphosphine oxide[11,13,14]; the former practically at the same frequency recently suggested for solid triferrocenylphosphine oxide.[2]

Phosphines II and III, and their methiodides absorb near 1190 cm.$^{-1}$ and in addition, the phosphines show a characteristic band near 1160 cm.$^{-1}$, all possibly due to ferrocene in-plane C—H bending.[2]

The oxide and methiodide of ferrocenyldiphenylphosphine (III) both show a strong band in the region, 1116–1120 cm.$^{-1}$, which in the case of triphenylphosphine oxide has been attributed[13] to in-plane C—H deformation of the phenyl ring. It is interesting to note that the band is absent from the spectra of ferrocenyldiphenylphosphine as well as triphenylphosphine itself, and from the spectra of diferrocenylphenylphosphine (II), its oxide, and methiodide.

As in the case of triphenylphosphine oxide,[11] the P—C (phenyl) band appears near 720 cm.$^{-1}$ in the spectra of II and III oxides, but is absent from this region in the spectra of the parent phosphines.

Acknowledgment.—The authors thank the Victor Chemical Works, Division of Stauffer Chemical Co., for generous samples of phenylphosphonous dichloride and diphenylphosphinous chloride.

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[8] L. W. Daasch and D. C. Smith, *Anal. Chem.*, **23**, 853 (1951).

[9] M. Rosenblum and R. B. Woodward, *J. Am. Chem. Soc.*, **80**, 5443 (1958).

[10] E. R. Lippincott and R. D. Nelson, *ibid.*, **77**, 4990 (1955).

[11] A. L. Geddes, *J. Phys. Chem.*, **58**, 1062 (1954).

[12] In making these assignments, it has been necessary to consider the spectra of solutions of the ferrocenylphenyl derivatives because of complicating, multiple absorptions in the region 1150–1220 cm.$^{-1}$ (II oxide: 1213, 1202, 1192, 1180, 1157 cm.$^{-1}$; III oxide: 1200, 1187, 1164 cm.$^{-1}$). A future paper will deal with this in more detail.

[13] M. Halmann and S. Pinchas, *J. Chem. Soc.*, 3264 (1958).

[14] R. A. Zingaro and R. M. Hedges, *J. Phys. Chem.*, **65**, 1132 (1961).

Total Synthesis of 19-Norsteroids. I. *d,l*-Estrone Methyl Ether

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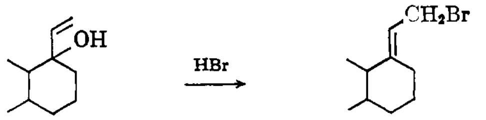
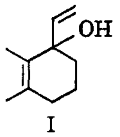
Received November 20, 1962

A four-step total synthesis of *d,l*-estrone methyl ether is described from 1,2,3,4-tetrahydro-6-methoxy-1-vinyl-1-naphthol (II) and 2-methylcyclopentane-1,3-dione.

The base-catalyzed condensation of allyl bromides with cyclic β-diketones has been described by Nazarov and co-workers[1,2] and later by Newman and Manhart.[3] Cyclohexane-1,3-dione, 2-methylcyclohexane-1,3-dione, and 2-methylcyclopentane-1,3-dione have been used as the β-diketone component and various substituted allyl bromides as the alkylating agent.

Although a number of cyclic allylic bromides have been prepared from the readily available vinylcarbinols, Nazarov, Ananchenko, and Torgov[4] have found that bisvinylcarbinols of the type (I) described as intermediates for the synthesis of D-homo steroids, failed to yield the halides required for alkylation. These authors, however, succeeded in developing a new method for the synthesis of the desired steroid intermediates by condensing these bisvinylcarbinols directly with 2-methylcyclohexane-1,3-dione.[4] This





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[1] I. N. Nazarov, S. N. Ananchenko, and I. V. Torgov, *Zh. Obshch. Khim.*, **26**, 819 (1956).

[2] I. N. Nazarov, G. P. Verkholetova, S. N. Ananchenko, I. V. Torgov, and G. V. Aleksandrova, *ibid.*, **26**, 1482 (1956).

[3] Melvin S. Newman and Joseph H. Manhart, *J. Org. Chem.*, **26**, 2113 (1961).

[4] I. N. Nazarov, S. N. Ananchenko, and I. V. Torgov, *Izv. Akad. Nauk SSSR, Otd. Khim.*, 112 (1959).