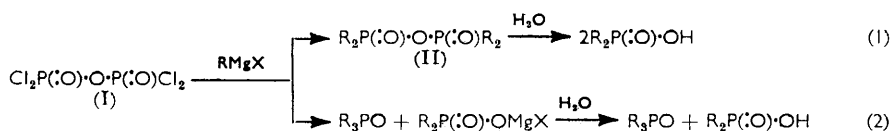


243. *The Reaction of Pyrophosphoryl Chloride with Grignard Reagents.*

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Reactions of pyrophosphoryl chloride with phenylmagnesium bromide and with 1-naphthylmagnesium bromide each give mixtures of the phosphinic acid and the tertiary phosphine oxide. Evidence that the attack on the anhydride linkage of pyrophosphoryl chloride occurs at an early stage in the overall reaction is provided by the lack of observed reaction between diphenylphosphinic anhydride and phenylmagnesium bromide. Carbon tetrachloride, or bromotrichloromethane, converts diarylphosphine oxides into phosphinic halides, and thence, if moisture is present, into phosphinic acids.

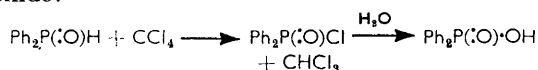
PYROPHOSPHORYL CHLORIDE (I) is both an acid chloride and an anhydride; its reactions with Grignard reagents have been investigated to discover whether the chlorine atoms are replaced without rupture of the anhydride link, to yield phosphinic anhydrides (II), and thence, after hydrolysis, phosphinic acids (reaction 1), or the anhydride linkage is attacked, yielding mixtures of tertiary phosphine oxides and phosphinic acids (reaction 2).



Aromatic Grignard reagents (R = Ph and 1-naphthyl) were chosen in order to obtain easily manageable products, and as reference compounds the two phosphinic anhydrides (II; R = Ph and 1-naphthyl) were prepared by heating the phosphinic halides (III; R = Ph, X = Cl; R = 1-naphthyl, X = Br) with the corresponding ethyl phosphinates (IV; R = Ph and 1-naphthyl).¹



For the first of these syntheses, diphenylphosphine oxide² was prepared, the intention being to convert it directly into diphenylphosphinic chloride by chlorination in an inert solvent. However, when the crude secondary phosphine oxide was dissolved in carbon tetrachloride and allowed to stand for several hours, diphenylphosphinic acid separated and fumes of hydrogen chloride were evolved without any chlorine having been passed in. It was apparent that the phosphine oxide had been oxidised by the carbon tetrachloride to diphenylphosphinic chloride which was then hydrolysed by water originally associated with the phosphine oxide:



This interesting oxidation resembles that of dialkyl phosphites by carbon tetrachloride or bromotrichloromethane in the presence of a base.³ A mechanism involving hydrogen-abstraction by trichloromethyl radicals is suggested:



Diphenylphosphinic acid was converted into the chloride (III; R = Ph, X = Cl) and thence into the ethyl ester (IV; R = Ph) by standard methods, but the oxidation process was studied further in the case of di-1-naphthylphosphine oxide and used to prepare directly the intermediates for making di-1-naphthylphosphinic anhydride. The crude secondary phosphine oxide, prepared from 1-naphthylmagnesium bromide and dibutyl phosphite was oxidised slowly by carbon tetrachloride to the phosphinic acid, as in the previous case. Another preparation of the oxide gave, after recrystallisation, analytically pure material whose identity was confirmed by the formation of an adduct with benzylideneacetophenone.⁴ A more vigorous reaction than that with carbon tetrachloride occurred on mixing the pure phosphine oxide with bromotrichloromethane, and the formation of chloroform was demonstrated by gas-liquid chromatography and the appearance of C-H bands in the infrared spectrum of the volatile material. The phosphinic acid rather than the bromide was isolated from this reaction, no doubt owing to the ease of hydrolysis of the latter; a similar reaction carried out in the presence of aniline gave the anilide, whilst in the presence of ethanol and a tertiary base the ethyl phosphinate (IV; R = 1-naphthyl) was obtained. Moreover, the crude phosphinic bromide (III; R = 1-naphthyl, X = Br), prepared from the phosphine oxide and bromotrichloromethane, was used for the final stage in which, by heating with the ethyl ester, di-1-naphthylphosphinic anhydride (II; R = 1-naphthyl) was obtained.

Pyrophosphoryl chloride reacted vigorously with phenylmagnesium bromide (six equivalents) in ether. The products were separated into an alkali-soluble fraction (diphenylphosphinic acid) and an alkali-insoluble fraction (triphenylphosphine oxide); the formation of these two in substantial and similar yields indicated that reaction (2) had occurred, in which the anhydride linkage undergoes attack by the Grignard reagent. A

¹ Kosolapoff and Watson, *J. Amer. Chem. Soc.*, 1951, **73**, 4101, 5466.

² Hunt and Saunders, *J.*, 1957, 2413.

³ Atherton, Openshaw, and Todd, *J.*, 1945, 660; Atherton and Todd, *J.*, 1947, 674; Steinberg, *J. Org. Chem.*, 1950, **15**, 637.

⁴ Miller, Bradley, and Hamilton, *J. Amer. Chem. Soc.*, 1956, **78**, 5290.

similar result, although less clear-cut, was obtained when 1-naphthylmagnesium bromide was used; much unreacted Grignard reagent remained, and the yields of the phosphinic acid and tertiary phosphine oxide were considerably lower than when using phenylmagnesium bromide. Apparently the large size of the 1-naphthyl group led to incomplete reaction; a similarly low yield of the tertiary phosphine oxide was obtained from phosphoryl chloride and 1-naphthylmagnesium bromide. However, the fact that tri-1-naphthylphosphine oxide was formed at all shows that the anhydride linkage had been attacked.

There remained the possibility that the phosphinic anhydrides had been formed and had then each reacted further with the excess of Grignard reagent. This was investigated by adding diphenylphosphinic anhydride in benzene to phenylmagnesium bromide. No reaction was observed, and on working up the mixture only diphenylphosphinic acid was obtained.

It thus appears that the reaction of pyrophosphoryl chloride with Grignard reagents involves attack on the anhydride linkage before that on the phosphorus-chlorine bonds. This higher reactivity of the anhydride linkage has been observed in other reactions of pyrophosphoryl chloride; when first describing this compound, Geuther and Michaelis⁵ reported that hydrolysis gave only orthophosphoric acid rather than pyrophosphoric acid, whilst Grunze recently isolated dichlorophosphoric acid as the first product of controlled hydrolysis⁶ and also showed⁷ that reactions with primary and secondary alcohols proceed analogously. Although the formation of compounds containing anhydride linkages has been reported as occurring in reactions of pyrophosphoryl chloride with sodium ethoxide and with sodium phenoxide,⁸ with dimethylamine,⁹ and with ammonia,¹⁰ it may well be that the anhydride linkage had been broken in these cases also, and subsequently reformed, since the products are all compounds of the type in which the formation of the anhydride linkage is known to occur rather readily.¹¹

EXPERIMENTAL

Diphenylphosphinic Acid.—Dibutyl phosphite (26.6 g.) in ether (80 ml.) was added to phenylmagnesium bromide [from bromobenzene (77.5 g.) and magnesium (12.0 g.) in ether (150 ml.). After 1 hr., hydrochloric acid (200 ml.; 3.5N) was added, followed by water (200 ml.). The remaining ether and butanol were removed under reduced pressure, leaving an aqueous layer (ca. 300 ml.) and a supernatant yellow oil; this was extracted with benzene (5 × 100 ml.), the extract was filtered, and the benzene was removed under reduced pressure, leaving crude diphenylphosphine oxide. This was dissolved in carbon tetrachloride (300 ml.), and the solution was set aside for several days, and then filtered, giving diphenylphosphinic acid (22.0 g., 73%), m. p. 189.5—190.5° (from 2-ethoxyethanol) (lit.,¹² 190°). The acid was converted into diphenylphosphinic chloride (100%), b. p. 135—140°/0.01 mm., by heating for 4 hr. with thionyl chloride, and thence into ethyl diphenylphosphinate (47%), b. p. 140—145°/0.05 mm., by reaction with ethanol in benzene under reduced pressure.

Di-1-naphthylphosphine Oxide.—Dibutyl phosphite (75.4 g.) in ether (200 ml.) was added to 1-naphthylmagnesium bromide [from 1-bromonaphthalene (228 g.) and magnesium (26.4 g.) in ether (200 ml.). After working up as in the previous experiment, the crude yellow phosphine oxide was recrystallised from toluene, to give *di-1-naphthylphosphine oxide* (41.0 g., 34%), m. p. 162—164° after further recrystallisation (Found: C, 79.2; H, 5.2; P, 10.2. C₂₀H₁₅OP requires C, 79.5; H, 5.0; P, 10.3%).

The phosphine oxide (1.5 g.) and benzylideneacetophenone (1.0 g.) were dissolved in ethanol

⁵ Geuther and Michaelis, *Ber.*, 1871, **4**, 766.

⁶ Grunze, *Z. anorg. Chem.*, 1959, **298**, 152.

⁷ Grunze, *Chem. Ber.*, 1959, **92**, 850.

⁸ Klement and Rother, *Naturwiss.*, 1958, **45**, 489.

⁹ Goehring and Niedenzu, *Angew. Chem.*, 1956, **68**, 704.

¹⁰ Klement and Benek, *Z. anorg. Chem.*, 1956, **287**, 12; Goehring and Niedenzu, *Chem. Ber.*, 1956, **89**, 1771; 1957, **90**, 151.

¹¹ Toy, *J. Amer. Chem. Soc.*, 1948, **70**, 3882; Zeile and Kruckenberg, *Ber.*, 1942, **75**, 1127; Pound and Saunders, B.P. 631,549/1949.

¹² Michaelis, *Ber.*, 1877, **10**, 627.

(25 ml.), and a few drops of ethanolic sodium ethoxide were added. (2-Benzoyl-1-phenylethyl)-di-1-naphthylphosphine oxide crystallised as needles, m. p. 220° (from ethanol) (Found: C, 82.5; H, 5.4; P, 6.0. $C_{26}H_{27}O_2P$ requires C, 82.3; H, 5.3; P, 6.1%).

Oxidation of Di-1-naphthylphosphine Oxide.—(a) *With carbon tetrachloride.* Crude di-1-naphthylphosphine oxide, prepared as described above from dibutyl phosphite (37.8 g.), was dissolved in carbon tetrachloride (300 ml.); the mixture was set aside overnight and filtered, giving di-1-naphthylphosphinic acid (30.5 g., 49%), m. p. 219–220° (from ethanol) (lit.,¹³ 220°).

(b) *With bromotrichloromethane.* Pure di-1-naphthylphosphine oxide (5.0 g.) was dissolved in bromotrichloromethane (10 ml.). The solution became warm and dinaphthylphosphinic acid crystallised (4.0 g. after 1 hr., plus 0.7 g. after two days, total 89%). The filtrate was distilled and the presence of chloroform in the distillate was demonstrated by gas-liquid chromatography and by the presence of bands at 3030 (C–H stretching) and 1214 cm^{-1} (C–H bending) in the infrared spectrum.

Di-1-naphthylphosphinic Anilide.—Di-1-naphthylphosphine oxide (1.0 g.) was dissolved in a mixture of bromotrichloromethane (1.5 ml.) and aniline (2.5 ml.). The solution became warm and a solid separated which, on recrystallisation from 2-ethoxyethanol, afforded the *anilide* (1.0 g., 77%), m. p. 289–291° (Found: C, 79.6; H, 5.3; N, 3.4. $C_{26}H_{20}NOP$ requires C, 79.4; H, 5.1; N, 3.6%).

Ethyl Di-1-naphthylphosphinate.—Di-1-naphthylphosphine oxide (5.0 g.) was dissolved in anhydrous ethanol (25 ml.), and a mixture of bromotrichloromethane (3.0 ml.) and diethylaniline (3.0 ml.) was added; the heat evolved caused the mixture to boil. After cooling, the mixture was extracted with water (2 × 20 ml.), and the residual oil was dissolved in ethanol. Partial evaporation of this solution yielded *ethyl di-1-naphthylphosphinate* (2.8 g., 49%), m. p. 138.5–139.5° (from methanol-water) (Found: C, 76.2; H, 5.5; P, 8.8. $C_{22}H_{16}O_2P$ requires C, 76.3; H, 5.5; P, 9.0%).

Diphenylphosphinic Anhydride.—Diphenylphosphinic chloride (4.8 g.) and ethyl diphenylphosphinate (5.1 g.) were heated at 200° until evolution of ethyl chloride ceased. The residue solidified and was recrystallised from toluene to give diphenylphosphinic anhydride (6.7 g., 79%) as tiny white crystals, m. p. 143.5–144.5° after further recrystallisation (lit.,¹⁴ 143°) (Found: C, 68.5; H, 4.9. Calc. for $C_{24}H_{20}O_3P_2$: C, 68.9; H, 4.8%).

Di-1-naphthylphosphinic Anhydride.—Bromotrichloromethane (4.0 ml.) was added to di-1-naphthylphosphine oxide (2.2 g.). After 10 min. the produced chloroform and the excess of bromotrichloromethane were distilled off, leaving a sticky residue of the phosphinic bromide. Ethyl di-1-naphthylphosphinate (2.5 g.) was added, and the mixture was heated (metal-bath) to 200°. Ethyl bromide was evolved; the residue solidified, giving the *anhydride*, m. p. 255–260° (Found: C, 77.5; H, 4.35. $C_{40}H_{28}O_3P_2$ requires C, 77.7; H, 4.5%). Recrystallisation was not achieved because of the insolubility of the anhydride in all common unreactive solvents.

Reactions of Pyrophosphoryl Chloride with Grignard Reagents.—(a) *With phenylmagnesium bromide.* Pyrophosphoryl chloride (20.9 g.) in ether (70 ml.) was added to phenylmagnesium bromide [from bromobenzene (77.5 g.) and magnesium (12.0 g.)] in ether (150 ml.). After 2 hr., hydrochloric acid (220 ml.; 1.5N) was added, causing much of the ether to distil. Benzene (250 ml.) was added, and the organic layer, which contained a considerable amount of suspended solid, was separated and extracted with aqueous sodium hydrogen carbonate. Acidification of the extract, and recrystallisation of the precipitated solid from 2-ethoxyethanol, gave diphenylphosphinic acid (11.0 g., 61%), m. p. and mixed m. p. 189–190.5°. Evaporation of the benzene layer and recrystallisation of the residue from toluene-light petroleum (b. p. 100–120°) afforded triphenylphosphine oxide (15.3 g., 67%), m. p. and mixed m. p. 153–154°.

(b) *With 1-naphthylmagnesium bromide.* Pyrophosphoryl chloride (12.6 g.) in ether (50 ml.) was added to 1-naphthylmagnesium bromide [from 1-bromonaphthalene (62 g.) and magnesium (7.2 g.)] in ether (150 ml.). After 1 hr., hydrochloric acid (130 ml.; 2.5N) was added, and the mixture was steam-distilled to remove naphthalene (18 g.) formed by hydrolysis of unreacted naphthylmagnesium bromide. The solid residue was separated from the aqueous solution of magnesium halides, heated with aqueous potassium hydroxide (150 ml.; 0.35N), and filtered hot from undissolved tarry material. Acidification of the filtrate and recrystallisation of the precipitated solid from ethanol gave di-1-naphthylphosphinic acid (5.0 g., 31%),

¹³ Sauvage, *Compt. rend.*, 1904, **139**, 674.

¹⁴ Kreutzkamp and Schindler, *Arch. Pharm.*, 1960, **293**, 296; Moedritzer, *J. Amer. Chem. Soc.*, 1961, **83**, 4381.

m. p. and mixed m. p. 219—220°. The undissolved tarry material was recrystallised from trichloroethylene, to give tri-1-naphthylphosphine oxide (3.5 g., 16%), m. p. and mixed m. p. 342—344° (lit.,¹⁵ 341—343°).

Treatment of Diphenylphosphinic Anhydride with Phenylmagnesium Bromide.—Diphenylphosphinic anhydride (5.0 g.) in benzene (150 ml.) was added to phenylmagnesium bromide [from bromobenzene (3.7 g.) and magnesium (0.6 g.)] in ether (25 ml.). There was no sign of reaction. After 30 min., hydrochloric acid (80 ml.; 0.4N) was added. The benzene layer, containing suspended solid, was separated and extracted with aqueous sodium hydrogen carbonate. Acidification of the extract yielded diphenylphosphinic acid (3.2 g., 62%), m. p. and mixed m. p. 189—190°; evaporation of the benzene layer left only an insignificant residue.

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¹⁵ Anschütz, Kraft, and Schmidt, *Annalen*, 1939, **542**, 14.
