(620 mg.), m.p. 90–91° (acetone–petroleum ether), which was identified as the amide of 7-oxooctanoic acid.

Anal. Calcd. for $C_8H_{15}NO_2$: C, 61.12; H, 9.62; N, 8.91. Found: C, 60.84; H, 9.51; N, 8.91.

The 2,4-dinitrophenylhydrazone showed m.p. 142–144° (ethanol).

Anal. Calcd. for $C_{14}H_{19}N_5O_5$: C, 49.84; H, 5.68; N, 20.76. Found: C, 49.86; H, 5.85; N, 20.95.

H. 1-Hexene and Formamide in Sunlight.—Heptananide (1.31 g.), m.p. 98–100° (acetone–petroleum ether), lit.[31] m.p. 96°, was obtained from 4.2 g. of 1-hexene. The residue[32] from the combined mother liquors was chromatographed and yielded a mixture of telomers (800 mg.), and a 2:1 telomer (510 mg.), m.p. 67–68° (*n*-pentane).

Anal. Calcd. for $C_{13}H_{27}NO$: C, 73.18; H, 12.76; N, 6.57; mol. wt., 213. Found: C, 73.00; H, 12.78; N, 6.40; mol. wt., 206.

Also found were heptanamide (1.3 g.) and a glassy oil (720 mg.) which had the following analysis.

Anal. Found: C, 64.21; H, 11.60; N, 7.68.

An additional 600 mg. of heptanamide was obtained in the usual manner from the recovered formamide distillate.

I. Propylene and Formamide in Sunlight.—A mixture of propylene (3.5 ml. as liquid), formamide (40 g.), *t*-butyl alcohol (25 ml.), and acetone (15 ml.) was left in direct sunlight in a sealed Pyrex tube for 1 week. After work-up, an oil (1.1 g.) was obtained and was chromatographed on alumina (55 g.) to yield 360 mg. of crude 3-methylhexanamide, m.p 55–60°. Crystallization from acetone–petroleum ether gave a pure sample, m.p. 96–97°, lit.[33] m.p. 97°, and 130 mg. of crude butyramide which was sublimed on a steam bath and showed m.p. 114–116°, lit.[34] m.p. 115°.

J. 1-Octene and Formamide without Acetone.—A mixture of 1-octene (5.6 g.), formamide (40 g.), and *t*-butyl alcohol (55 ml.) was irradiated for 44 hr. (A quartz immersion tube was used for this experiment.) Work-up led to 400 mg. of crude nonanamide, m.p. 90–92°.

The residue from the mother liquors (2.6 g.) was chromatographed on alumina (130 g.) to yield a mixture of telomer (1.0 g.), a 2:1 telomer (350 mg.) which was identical with the 2:1 telomer obtained from the acetone-initiated reaction, nonanamide (710 mg.), and an oil (460 mg.) which had the following analysis.

Anal. Found: C, 69.45; H, 11.48; N, 7.05.

Acknowledgment.—We are indebted to Professor F. Sondheimer for his interest and encouragement and to The Weizmann Graduate School in the Natural Sciences for maintenance of a Fellowship to one of us (J. R.).

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[31] J. S. Lumsden, *J. Chem. Soc.*, **87**, 90 (1905).

[32] In experiments carried out with ultraviolet light (unpublished results from this laboratory) *n*-butylsuccinamide, m.p. 216–217° (ethanol), was isolated. *Anal.* Calcd. for $C_8H_{16}N_2O_2$: C, 55.79; H, 9.36; N, 16.27. Found: C, 55.97; H, 9.40; N, 16.49.

[33] A. Dewall and A. Weckering, *Bull. soc. chim. Belges*, **33**, 495 (1924).

[34] W. A. Hofmann, *Ber.*, **15**, 977 (1882).

Ester Formation and Coupling at Phosphorus on Reaction of Diphenylphosphinous Chloride with Diols and Tertiary Amines[1]

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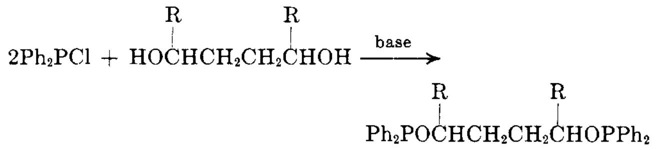
1,4-Butanediol and 2,5-hexanediol reacted smoothly with diphenylphosphinous chloride in the presence of diethylaniline to yield solid bisphosphinites. Ethylene glycol failed to yield a solid bisphosphinite; on distillation the product of the Arbuzov rearrangement of this ester, ethylene bis(diphenylphosphine oxide), was obtained. From the diol reaction mixtures, trace to appreciable amounts of a by-product identified as tetraphenyldiphosphine dioxide were obtained. It was also found that the reaction of ethanol with diphenylphosphinous chloride gave this unusual by-product, apparently not previously observed in such reactions.

Phosphinous chlorides are known to react with alcohols to form phosphinites in the presence of a tertiary amine.[3] We have used this reaction to prepare bisphosphinites, desired for anticancer screening, from certain glycols and diphenylphosphinous chloride.

1,4-Butanediol and 2,5-hexanediol reacted smoothly with diphenylphosphinous chloride in the presence of diethylaniline in ether solution. The bisphosphinites so produced were recovered as low-melting, crystalline solids. Compound Ia showed strong infrared absorption at 1045 cm.$^{-1}$, attributable to the P–O–C group.[4] The spectrum of Ib possessed two medium intensity peaks (1000 and 1055 cm.$^{-1}$) in the P–O–C region.



$$2Ph_2PCl + HO\overset{R}{\overset{|}{C}}HCH_2CH_2\overset{R}{\overset{|}{C}}HOH \xrightarrow{\text{base}} Ph_2PO\overset{R}{\overset{|}{C}}HCH_2CH_2\overset{R}{\overset{|}{C}}HOPPh_2$$

Ia, R = H
b, R = CH_3

Neither ester exhibited absorption in the phosphoryl region (1175–1250 cm.$^{-1}$), and thus Arbuzov rearrangement to isomeric phosphine oxides had not occurred. In further confirmation of their structures, esters Ia and Ib rapidly decolorized iodine solutions, and on neutral hydrolysis gave diphenylphosphine oxide, identified by its infrared spectrum and by its chloral adduct.[5] Hydrolysis of phosphinites to *sec*-phosphine oxides has been observed previously.[6]

Compound Ia was converted to the known[7] tetramethylene bis(diphenylphosphine oxide) by Arbuzov rearrangement with a small amount of ethyl iodide in refluxing heptane. Phosphoryl absorption for this compound occurred as a singlet at 1177 cm.$^{-1}$; in the spectrum of ethylene bis(diphenylphosphine oxide) (*vide infra*), a doublet at 1170–1180 cm.$^{-1}$ is present. No rearrangement was detected on simply heating Ia at 150–200° for 2 hr. Compound Ib failed to undergo rearrangement in the presence of ethyl iodide in either refluxing heptane or dodecane at 145°.

Attempts to prepare ethylene bis(diphenylphosphinite) (II) have been unsuccessful. A nearly quanti-

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[1] Supported in part by Research Grant CA-05507 from the National Cancer Institute, Public Health Service.

[2] Philip Morris Research Assistant, 1962–1963.

[3] A. E. Arbuzov and K. V. Nikonorov, *Zh. Obshch. Khim.*, **18**, 2008 (1948).

[4] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y., 1958, Chapter 18.

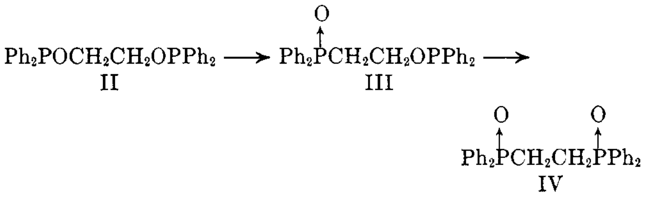
[5] L. D. Quin and R. E. Montgomery, *J. Org. Chem.*, **28**, 3315 (1963).

[6] (a) M. Sander, *Ber.*, **93**, 1220 (1960); (b) M. I. Kabachnik and E. N. Tsvetkov, *Dokl. Akad. Nauk. SSSR*, **135**, 323 (1960).

[7] A. Mondon, *Ann.*, **603**, 115 (1957).

tative yield of amine hydrochloride resulted when diphenylphosphinous chloride and ethylene glycol reacted as above, but the ether solution left a noncrystallizing oil on evaporation. This oil consumed only about one-half of the calculated amount of iodine on titration. Its infrared spectrum was complex and indicative of a gross mixture, but P–H and phosphoryl absorptions were recognizable. Numerous attempts to recover any II present by distillation were unsuccessful. Distillates did not possess the expected composition or infrared spectra, and were indicated by the former to contain an excess of oxygen and by the latter to contain phosphoryl groups.

In all distillations, there remained a large amount of a crystalline residue whose infrared spectrum showed no P–O–C absorption, but did show strong phosphoryl absorption. A pure sample had m.p. 273° and was identified as ethylene bis(diphenylphosphine oxide) (IV). This compound has been prepared previously by different methods[8]; a recently reported[8d] melting point is 273–275°. Compound IV could have two precursors in the mixture subjected to distillation. It could have arisen either from bisphosphinite II by double Arbuzov rearrangement or from the half-rearranged compound III. If III were the precursor, then an Arbuzov rearrangement must also have occurred prior to attempted distillation, perhaps during the initial reaction. The phosphoryl absorption and iodine titer of the oil obtained initially suggest this to have occurred. No further effort was made to elucidate the course of the ethylene glycol–diphenylphosphinous chloride reaction; the system was markedly different from the others examined, and appeared unlikely to yield a bisphosphinite.



$$\underset{\text{II}}{\mathrm{Ph_2POCH_2CH_2OPPh_2}} \longrightarrow \underset{\text{III}}{\mathrm{Ph_2\overset{O}{\overset{\uparrow}{P}}CH_2CH_2OPPh_2}} \longrightarrow \underset{\text{IV}}{\mathrm{Ph_2\overset{O}{\overset{\uparrow}{P}}CH_2CH_2\overset{O}{\overset{\uparrow}{P}}Ph_2}}$$

On allowing the ether filtrate from any of the diol–phosphinous chloride reaction mixtures to stand for a day or two, deposition of a white, crystalline solid occurred. While only small amounts formed in preparations of Ia and Ib, significant amounts were obtained in reactions involving ethylene glycol. The yield was as high as 22% in one reaction, but values around 10% were more common. This compound, m.p. 167°, showed strong phosphoryl absorption at 1175 cm.$^{-1}$. Analysis indicated the empirical formula, $(C_6H_5)_2PO$, and suggested the structure, $(C_6H_5)_2P(O)$-$P(O)(C_6H_5)_2$, a most unexpected product. This compound, tetraphenyldiphosphine dioxide (V), has been prepared previously by a different method.[9] It had m.p. 167° and an infrared spectrum identical with our sample. It was reported to be readily cleaved by alkaline hydrolysis to diphenylphosphinic acid, and we also observed this property. In addition, we found neutral hydrolysis to effect cleavage of the P–P bond.

$$(C_6H_5)_2P(O)P(O)(C_6H_5)_2 \xrightarrow{H_2O} (C_6H_5)_2P(O)H + (C_6H_5)_2P(O)OH$$

This milder treatment allowed recovery of the other product of cleavage, diphenylphosphine oxide, which in an alkaline medium is rapidly disproportionated.

In some other work, we had occasion to prepare ethyl diphenylphosphinite by the same general reaction. On distillation, 50–75% yields of the ester were obtained. The distillation residue crystallized on cooling. It was initially assumed that this residue was either diphenylethylphosphine oxide, formed from Arbuzov rearrangement of the ester during distillation, or diphenylphosphinic acid, as mentioned by Arbuzov and Nikonorov.[3] However, the residue was later examined and found to be largely insoluble in sodium bicarbonate and to have a crude melting point of 147–150°. The tertiary phosphine oxide has m.p. 121°.[10] On recrystallization, the residue had m.p. 167–169° and an infrared spectrum identical with that of tetraphenyldiphosphine dioxide. The yield was 11.4%. This compound must have been formed in a side reaction accompanying the esterification reaction; it did not form during distillation of the ester, as none was produced when a pure sample of the ester was heated.

The formation of this diphosphine derivative in alcohol–phosphinous chloride–amine reactions apparently has not been detected previously. In their identification of the distillation residue as diphenylphosphinic acid, Arbuzov and Nikonorov[3] performed a recrystallization from ethanol. The diphosphine dioxide is readily cleaved by nucleophiles, one product being diphenylphosphinic acid, and it is possible that some of the acid they obtained came from this source. We have also observed that recrystallization of V often gives the phosphinic acid if the solvent is not adequately dried.

The origin of V is of some interest, as the P–P bond is not generally encountered so casually.[11] Work is now in progress to identify the reaction giving rise to V.[12]

Experimental

General.—Analyses were performed by Galbraith Laboratories, Knoxville, Tenn. Melting and boiling points are uncorrected. Infrared spectra were obtained with a Perkin-Elmer Model 137 spectrophotometer. Reactions of diphenylphosphinous chloride were conducted in a nitrogen atmosphere.

Diphenylphosphinous chloride was kindly donated by Victor Chemical Division, Stauffer Chemical Co., Chicago, Ill. It was redistilled before use. Glycols were dried with sodium and distilled. Diethylaniline and solvents were dried and distilled.

Preparation of Tetramethylene Bis(diphenylphosphinite).—To a solution of 4.5 g. (0.05 mole) of 1,4-butanediol and 22.4 g. (0.15 mole) of diethylaniline in 75 ml. of ether was added in 1 hr. a solution of 22.1 g. (0.10 mole) of diphenylphosphinous chloride. The temperature was held at 20–25°. After stirring an additional 2 hr., the precipitated amine salt was removed by filtration. The filtrate on standing 2 days deposited 0.1 g. of a solid, m.p.

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[8] (a) K. Issleib and D. W. Muller, *Ber.*, **92**, 3175 (1959); (b) G. M. Kosolapoff and R. F. Struck, *J. Chem. Soc.*, 2423 (1961); (c) M. I. Kabachnik, T. Y. Medved, Y. M. Polikarpov, and K. S. Yudina, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 2029 (1961); (d) P. T. Keough and M. Grayson, *J. Org. Chem.*, **27**, 1817 (1962).

[9] W. Kuchen and H. Buchwald, *Ber.*, **91**, 2871 (1958).

[10] A. Michaelis and H. von Soden, *Ann.*, **229**, 295 (1885).

[11] The subject has been recently reviewed: J. E. Huheey, *J. Chem. Educ.*, **40**, 153 (1963).

[12] NOTE ADDED IN PROOF.—It has since been observed that exposure to the atmosphere of an ether solution of a diarylphosphinous chloride and a tertiary amine results in the formation of the tetraaryldiphosphine dioxide in good yield. It is likely that this is the source of tetraphenyldiphosphine dioxide found in the present study. L. D. Quinn and H. G. Anderson, *J. Am. Chem. Soc.*, **86**, 2090 (1964).

167–169°, later identified as tetraphenyldiphosphine dioxide. The ether solution was stripped, leaving an oil that rapidly crystallized. The solid was washed with ice-cold pentane; 18.3 g. (80%) of m.p. 67–70° was obtained. A sample recrystallized from pentane had m.p. 74–75°. It was reasonably resistant to air oxidation; no special precautions were taken in the recrystallization.

Anal. Calcd. for $C_{28}H_{28}O_2P_2$: C, 73.35; H, 6.16; P, 13.51. Found: C, 73.05; H, 6.20; P, 13.41.

Arbuzov Rearrangement of Tetramethylene Bis(diphenylphosphinite).—A 1-g. sample of Ia was heated in a bath at 150° for 1 hr., and then at 200° for 1 hr. The melting point of the sample was unchanged.

A 1.3-g. (0.0028 mole) sample of Ia in 25 ml. of heptane was treated with 4 drops of ethyl iodide. A crystalline solid began to form after several hours at reflux. After 16 hr., the mixture was filtered while hot. The residue was washed with cold acetone, leaving 0.65 g. (50%) of tetramethylene bis(diphenylphosphine oxide). After recrystallization from ethanol–ether, m.p. 259–261° was obtained (lit.[7] m.p. 256–257°). Strong phosphoryl absorption at 1177 cm.$^{-1}$ was noted and no decolorization of iodine occurred.

Preparation of 1,4-Dimethyltetramethylene Bis(diphenylphosphinite).—A solution of 22.1 g. (0.1 mole) of diphenylphosphinous chloride in 75 ml. of ether was added over 1.3 hr. to a solution of 5.9 g. (0.05 mole) of 2,5-hexanediol and 22.4 g. (0.15 mole) of diethylaniline in 125 ml. of ether held at 18–20°. After stirring 9 hr., the precipitate was removed. The filtrate deposited a trace of tetraphenyldiphosphine dioxide overnight. The solvent was removed from the filtrate, and the residual oil was mixed with acetone. Crystallization occurred on chilling in a Dry Ice bath. The product (15.8 g., 65.0%) was recrystallized from acetone, m.p. 73°.

Anal. Calcd. for $C_{30}H_{32}O_2P_2$: C, 74.06; H, 6.63; P, 12.74. Found: C, 74.26; H, 6.50; P, 12.65.

Hydrolysis of Bisphosphinites.—A 1.25-g. (0.0027 mole) sample of Ia was placed in 20 ml. of water and refluxed for 5 hr. The mixture then was extracted with ether; the ether was removed from the extract; and the semisolid residue (0.95 g., 86%) was dried *in vacuo*. The infrared spectrum of the residue was identical with that of diphenylphosphine oxide, prepared by hydrolysis of diphenylphosphinous chloride.[5] Further confirmation was obtained by preparing the chloral adduct, whose melting point and infrared spectrum agreed with a known specimen. Little hydrolysis of Ib occurred after 3-hr. reflux, but a 79.6% yield of diphenylphosphine oxide was obtained after 16 hr.

Tetraphenyldiphosphine Dioxide from Ethylene Glycol–Diphenylphosphinous Chloride Reactions.—The following procedure is typical of several runs. A solution of 3.1 g. (0.05 mole) of ethylene glycol and 29.8 g. (0.20 mole) of diethylaniline in 75 ml. of ether was treated with a solution of 22.1 g. (0.10 mole) of diphenylphosphinous chloride in 75 ml. of ether. Addition time at 18–20° was 1 hr. After stirring for 2 hr. longer, the amine salt was removed by filtration and the filtrate was allowed to stand. White crystals slowly formed on the flask walls. After 2 days, 1.5 g. (8%) was recovered by filtration. Following recrystallization from ethyl acetate or toluene, the solid had m.p. 167–169°. The recrystallization requires dry solvents to prevent phosphinic acid formation.

Anal. Calcd. for $C_{24}H_{20}O_2P_2$: C, 71.64; H, 5.01; P, 15.40. Found: C, 71.37; H, 4.93; P, 15.18.

The compound decolorized iodine and neutral potassium permanganate solutions. On refluxing 0.66 g. with 5% sodium hydroxide for 3 hr. followed by acidification, diphenylphosphinic acid (0.7 g.), m.p. 193–195°, was obtained. On refluxing 0.76 g. in 25 ml. of water for 30 min., 0.23 g. of diphenylphosphinic acid, m.p. 192°, precipitated. Evaporation of the water left 0.38 g. of an oil having an infrared spectrum essentially identical with that of a known specimen of diphenylphosphine oxide, and which formed a chloral adduct, m.p. 168°, lit.[5] m.p. 171.5–172.5°, whose infrared spectrum agreed with that of a standard.

Ethylene Bis(diphenylphosphine oxide) from Ethylene Glycol and Diphenylphosphinous Chloride.—The filtrate from removal of tetraphenyldiphosphine dioxide, in a preparation such as that above, was evaporated to leave a noncrystallizing oil. Its infrared spectrum was complex, but P–H (2275 cm.$^{-1}$) and phosphoryl (1180–1220 cm.$^{-1}$) absorptions were present. Its trivalent phosphorus content was 6.9% (calcd. for $C_{26}H_{24}O_2P_2$, 14.4%). On distillation at 0.01 mm., a fraction was received at 150–160°; thereafter, no further distillation without decomposition occurred. The pot contents crystallized on cooling. After two recrystallizations from toluene, this solid had m.p. 271–273°, lit.[8d] m.p. 273–275°. The infrared spectrum included a doublet at 1170–1180 cm.$^{-1}$ for the phosphoryl group. The yield of this compound was variable, but generally was around 30–40%.

Anal. Calcd. for $C_{26}H_{24}O_2P_2$: P, 14.39. Found: P, 14.71.

The distillation fractions gave some diphenylphosphinic acid after refluxing 2 hr. in 10% sodium hydroxide, and generally showed infrared absorption characteristic of P–H at 2350 cm.$^{-1}$, phosphoryl groups at 1190 and 1220 cm.$^{-1}$, and P–O–C at 1025 cm.$^{-1}$. Variable results, inconsistent with any definite compound, were obtained on analysis of the distillates.

Modifications involving reversal of reagent addition, use of benzene or dioxane as solvents, and purification of the oil by washing with dilute hydrochloric acid and sodium bicarbonate prior to distillation led to substantially the same results. In no case was evidence for the desired bisphosphinite obtained.

Reaction of Ethanol with Diphenylphosphinous Chloride.—A mixture of 11.5 g. (0.25 mole) of ethanol and 37.3 g. (0.25 mole) of diethylaniline in 125 ml. of ether was treated over a period of 1.5 hr. with a solution of 44.2 g. (0.20 mole) of diphenylphosphinous chloride in 75 ml. of ether. The temperature was held at 20°. After 2 hr., the mixture was filtered and the filtrate was distilled. Ethyl diphenylphosphinite (34.8 g., 76%) was collected at 111–114° (0.45–0.50 mm.). On cooling, the pot residue crystallized and had m.p. 147–150°. It was washed with ether and dilute sodium bicarbonate, leaving 4.6 g. (11.4%) of white solid. After recrystallization from toluene, it had m.p. 167–169° and an infrared spectrum identical with that of tetraphenyldiphosphine dioxide.

Effect of Heat on Ethyl Diphenylphosphinite.—A 3.6-g. sample of ethyl diphenylphosphinite was held for 8 hr. just below reflux at atmospheric pressure. A pale yellow viscous oil remained on cooling. Addition of ether caused formation of a crystalline mass and extracted some unchanged ethyl diphenylphosphinite, detected by infrared spectroscopy. A benzene solution of the crystallized solid was extracted with sodium bicarbonate; this extract on acidification gave 0.70 g. of diphenylphosphinic acid (crude m.p. 188–190°). The benzene solution on evaporation left 1.40 g. of diphenylethylphosphine oxide, m.p. 118–119°, lit.[10] m.p. 121°, having an infrared spectrum in agreement with that of a known specimen.