Synthesis of Substituted Dibenzophospholes. Part 1.†

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Approaches to the synthesis of 4,6-diaryl-5-hydroxydibenzophosphole 5-oxides are described. 3,5,7-Trihydroxydibenzophosphole 5-oxide and several of its *O*-substituted derivatives were made either from 5-hydroxydibenzophosphole 5-oxide (convenient preparation described) by dinitration, reduction and tetrazotization or from 2,2'-dibromo-4,4'-dimethoxybiphenyl *via* lithiation and reaction with dichloromorpholinophosphine with subsequent oxidation. 3,5,7-Trihydroxydibenzophosphole 5-oxide could be selectively blocked in the 2,8-positions by methyl groups generated *via* a Mannich reaction. The bis-2-iodobenzyl ethers of 3,7-dihydroxy-5-methoxydibenzophosphole 5-oxide and of its 2,8-dimethyl derivative were cyclized by photolysis to form 4,6-diaryl derivatives in poor yield.

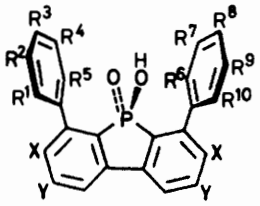
For reasons set out in detail in a review lecture [1] we decided to attempt the synthesis of phosphinic acids wherein the acidic group is oriented in a shaped hydrophobic cleft. Particular attention has been given to 5-hydroxydibenzophosphole 5-oxides (1) § carrying substituted aryl groups in the 4- and 6-positions and hydrophilic groups in (preferably) the 3- and 7-positions. The criteria for a satisfactory synthesis were (i) it should allow flexibility in the choice of groups, X, Y, and R^1—R^{10}, preferably without *de novo* synthesis for each choice; (ii) it should not be too expensive of time, labour, or materials; (iii) operations should be practicable on a large (>1 mol) scale.

The first strategic plan was to synthesize the dibenzophosphole structure and then to introduce aryl groups, already substituted or amenable to later substitution, at the 4- and 6-positions. This paper, the first of a sequence, is devoted to that approach.

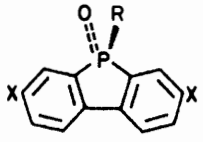
5-Hydroxydibenzophosphole 5-oxide (2) was obtained first in low overall yield by Freedman and Doak [2] from a palladium-catalysed reductive cyclization of bis-(2-bromophenyl)phosphinic acid (3).

Since then it has been made by the cleavage of 5-phenyldibenzophosphole (4) by alkali metals in tetrahydrofuran, the intermediate dibenzophosphole (5) being oxidized by hydrogen peroxide without isolation.[3] Since 5-phenyldibenzophosphole (4) is readily available [4] by treatment of tetraphenylphosphonium bromide with strong bases, a large-scale synthesis of compound (2) from triphenylphosphine was limited only by the inconvenience of the reduction step. This was improved by using sodium in liquid ammonia, and the required acid (2) was obtained in 49% overall yield from triphenylphosphine. This type of synthesis does not seem directly useful for the preparation of 4,6-disubstituted derivatives of compound (2): tri-*o*-tolylphosphine (6), for example, could not be quaternized by aryl halides in any conditions tried.

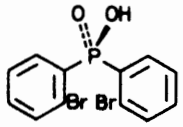
de Boer and Bright [5] kindly undertook to examine the crystal structure of compound (2) and obtained useful measurements of bond lengths and angles, and of length and direction of intermolecular hydrogen bonds in the crystal. For planning further synthesis it was especially useful to know that the structure could be modelled with fair accuracy from Corey–Pauling–Koltun units.



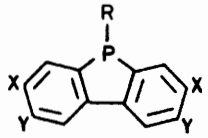
(1)



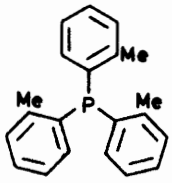
(2) R = OH, X = H
(7) R = OH, X = NO_2
(8) R = OH, X = NH_2
(9) R = X = OH
(10) R = X = OAc
(11) R = X = OMe
(14) R = Bu^n, X = H
(15) R = Et, X = H
(16) R = X = H
(17) R = OH, X = OMe



(3)



(4) R = Ph, X = Y = H
(5) R = H, X = Y = H
(12) R = NEt_2, X = Y = H
(13) R = O⟨ ⟩N–, X = Y = H
(18) R = OEt, X = H, Y = OMe



(6)

Nitration [6] of compound (2) gave a dinitro-derivative in 97% crude yield; this was reduced to 76% by recrystallization indicating the possible presence of more than one isomer. The major product was assigned [6] the structure (7) by analogy with the arsenic analogue and this structure has been proved correct by the al-

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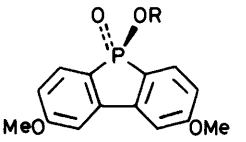
§ The dibenzophospholes described herein are all dibenzo-5*H*-phospholes.

ternative syntheses reported later. Reduction to the diamine (8), previously executed [6] in moderate yield by hydrogenation in very dilute neutral solution, was effected on a large scale in excellent yield in aqueous hydrazine with catalytic amounts of Raney nickel.[7]

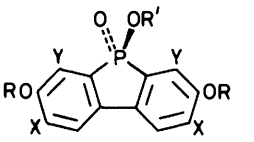
Tetrazotization of the diamine (8) presented some difficulties, but proceeded satisfactorily in strong sulphuric acid solution with nitrosylsulphuric acid, and addition of the resulting solution to boiling acetic acid gave 3,5,7-trihydroxydibenzophosphole 5-oxide (9) in 70% yield. Purification was effected *via* the triacetyl derivative (10) and several derivatives were prepared including the trimethoxy-compound (11).

An alternative route to compounds of the same type, based on the observation [8] that 2,2′-dilithiobiphenyl gave 5-diethylaminodibenzophosphole (12) in 23% yield with dichloro-*NN*-diethylaminophosphine, was followed at the same time. With dichloro-*N*-morpholinophosphine and a dilithiobiphenyl prepared from 2,2′-dibromobiphenyl and butyl-lithium, oxidation of the intermediate (13) by hydrogen peroxide or manganese dioxide and subsequent acid hydrolysis gave the acid (2) in 33% overall yield from the dibromide. Interesting but irrelevant results were obtained when the dichlorophosphine was replaced by diethyl phosphite. With a dilithiobiphenyl, prepared as above, the product was 5-butyldibenzophosphole 5-oxide (14); dilithiobiphenyl obtained from dibromobiphenyl and lithium wire gave the 5-ethyl-analogue (15). Evidently, alkylation of the intermediate dibenzophosphole oxide (16) was occurring; the structures were in fact confirmed by synthesis of compound (14) from compound (5) by alkylation and subsequent oxidation. It may be stated here that all attempts to use pentavalent phosphorus derivatives in analogous reactions, aimed at synthesis of 5-hydroxydibenzophosphole 5-oxides without an oxidative step, gave negative or extremely poor results, although the reaction goes well when diarylphosphinic acids are made from monofunctional aryl-lithium compounds (see Part 2, following paper).

From 2,2′-dibromo-4,4′-dimethoxybiphenyl (prepared from 3-bromonitrobenzene *via* a benzidine rearrangement of the hydrazo-compound,[9] followed by tetrazotization and methylation of the phenolic product) the cyclic phosphinic acid (17) was prepared. The methyl ester (11) was identical with material prepared from the acid (2). This synthesis proves the structures of compounds (7) and (11). From the known [10] 2,2′-dibromo-5,5′-dimethoxybiphenyl the isomeric 5-oxide (19) was prepared by the same general method. Here the intermediate morpholinodibenzophosphole was alcoholysed by warming it in ethanol. The resulting 5-ethoxyphosphole (18) was then hydrolysed by acid and the crude phosphinous acid was disproportionated to the phosphinic acid and hydrogen in ethanolic alkali. These procedures follow known analogies.[11,12] The ethyl ester (20) was also prepared by oxidation of compound (18). A surprising result from an attempted demethylation of the acid (19) with boiling hydrogen



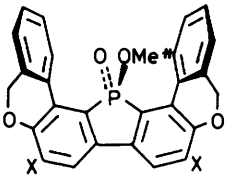
(19) R = H
(20) R = Et



(21) R = R′ = Me, X = Br, Y = H
(22) R = R′ = Me, X = Y = Br
(23) R = R′ = H, X = Me_2NCH_2, Y = H
(24) R = R′ = Ac, X = $AcOCH_2$, Y = H
(25) R = Ac, R′ = H, X = $AcOCH_2$, Y = H
(26) R = Ac, R′ = Me, X = $AcOCH_2$, Y = H
(27) R = Ac, R′ = X = Me, Y = H
(28) R = R′ = H, X = Me, Y = H
(29) R = H, R′ = X = Me, Y = H
(30) R = R′ = X = Me, Y = H
(31) R = R′ = X = Me, Y = NO_2
(32) R = R′ = X = Me, Y = NH_2
(33) R = R′ = X = Me, Y = I

(34) R =  , R′ = Me, X = Y = H

(35) R =  , R′ = X = Me, Y = H



(36) X = H
(37) X = Me

iodide was the smooth formation of 3,3′-dihydroxybiphenyl which was also formed from 2,2′-dibromo-5,5′-dimethoxybiphenyl with the same reagent.

It had been expected that the paired positions 2,8 and 4,6 in the dihydroxy-acid (9) or its derivatives would differ in electrophilic activity enough to allow specific substitution at one pair or the other. In fact, this was found very difficult. Bromination in acetic acid, followed by methylation, did indeed give some of the 2,8-dibromo-ester (21), but only after tedious separations. The 2,4,6,8-tetrabromo-ester (22) was obtained easily with an excess of bromine. Among many reactions tried, only the Mannich reaction gave clean 2,8-disubstitution. The best secondary base found was dimethylamine, and the product (23) was isolated as an oxalate. It was decided to convert the dialkylaminomethyl groups into relatively inert methyl groups before operating on the 4- and 6-positions. This could not be done by direct reduction, chemical or catalytic, but treatment with acetic anhydride gave the penta-acetate (24). Partial hydrolysis and methylation then gave, *via* the acid (25), the acetylated ester (26) which could be hydrogenolysed in acetic acid–ethanol over palladium-on-carbon to the desired ester (27), which could be

hydrolysed by alkali to the dihydroxy-acid (28). Methanolysis gave, instead, the methyl ester (29), as also did hydrolysis by cold sulphuric acid. Methylation of the dihydroxy-acid (28) by methyl sulphate followed by diazomethane gave the trimethoxy-compound (30).

With the 2- and 8-positions blocked, attempts were now made to introduce aryl substituents at positions 4 and 6. Cyclohexylation of the ester (29) with cyclohexene and toluene-4-sulphonic acid or sulphuric acid, or with cyclohexanol and hydrogen fluoride, did not succeed, nor did reaction with benzhydrol and sulphuric acid. Iodination could not be effected; bromination, in contrast, gave impure material containing a tribromo-compound. The Mannich reaction on the acid (28) was successful, but the product was not found useful. Nitration, preferably with acetyl nitrate, on the trimethoxy-compound (30) gave smoothly the 4,6-dinitro-derivative (31) which was reducible to the diamine (32). The diiodo-derivative (33) was prepared from the diamine in high yield. Unfortunately, attempts to replace the iodine atoms by aryl groups by photolysis in benzene did not succeed.

Concluding that steric hindrance (probably increased by a buttressing effect from the 2- and 8-methyl groups) was limiting intermolecular reactions at the 4- and 6-positions we turned to intramolecular photolysis. The 3,7-bis-2-iodobenzyl ethers (34) and (35) were readily prepared from the acid (9) and the ester (29) respectively. Photolysis of these compounds in benzene gave mixtures from which a yellow crystalline substance was isolated in each case, albeit in low yields. The mass spectra of these substances showed base peaks at the expected mass ratio for the molecular ions of compounds (36) and (37), and very little fragmentation was observed. A feature of both spectra was the presence of a doubly charged ion arising from loss of 2H: evidently a bis-dibenzopyrylium ion. The n.m.r. spectra were also similar: the product from compound (35) had the expected sharp signal for the two *C*-methyl groups and this was absent in the product from compound (34). Both spectra showed a 2-proton doublet (*J ca.* 8 Hz) around δ 8.9, far downfield of the other aromatic protons. This is not attributable to the hydrogens at positions 1 and 9 of the dibenzophosphole nucleus, since the characteristic P–H coupling (3.2—4.2 Hz in all the many examples we have examined) is absent: the coupling is typical of that between *ortho* hydrogens on a benzene ring. We attribute these signals to the protons in the starred positions of structures (36) and (37), which are constrained to lie very close to the P=O bond. The ether (34) has alternative modes of cyclization and perhaps these were represented in the product: the yield of crystalline material was lower in this case and the separation more laborious.

Thus the method of synthesis had been technically successful in producing 4,6-diaryldibenzophospholes. However, the multiplicity of steps and the low yield obtained, uniquely, in the last step made the route unattractive as a general synthesis. We turned in consequence to the superior method described in the following papers.

EXPERIMENTAL

Unless otherwise specified, melting points were taken in capillaries and are corrected; i.r. spectra were from paraffin pastes; n.m.r. spectra were at 60 MHz or 100 MHz in deuteriochloroform; mass spectra were recorded on MS-9 or MS-30 instruments. Mixtures of solvents are given by volume.

5-Phenyldibenzophosphole (4).—Tetraphenylphosphonium bromide and 5-phenyldibenzophosphole were prepared by the methods of Horner *et al.*[13] and of Britt and Kaiser,[3] respectively. Since both procedures were optimized for convenience and yield we give the experimental detail here. Triphenylphosphine (262 g), anhydrous nickel(II) chloride (71.5 g), bromobenzene (173 g; redistilled), and sulpholane (125 ml; redistilled) were stirred and heated under nitrogen to gentle reflux. After 23 h the internal temperature was 225 °C; the mixture was cooled to 120 °C and water (1 l.) was added. The mixture was stirred for 15 min and was then cooled in ice and filtered. The solid was washed well with diethyl ether which was then discarded. The aqueous filtrate was extracted with dichloromethane (4 ×) which was united with a solution of the solid in dichloromethane. This solution was washed with water (2 × 500 ml), dried ($MgSO_4$), and evaporated. The tetraphenylphosphonium bromide (338.6 g; 81%), after being dried at 100 °C (vacuum oven), had m.p. 298—300 °C.

Lithium diethylamide (1.25 mol) in diethyl ether (900 ml) was prepared by making phenyl-lithium as usual in diethyl ether from bromobenzene (203 g) and lithium (17.27 g) and then adding redistilled diethylamine (90 g). To the stirred mixture at room temperature under nitrogen was added powdered, dried tetraphenylphosphonium bromide (155.4 g; 0.37 mol). There was a gentle evolution of heat. The mixture was stirred overnight, heated under reflux (bath 50—55 °C) for 3 h, cooled in ice and treated during 45 min with hydrochloric acid (616 ml of 4M). After 10 min more the mixture was filtered, the layers were separated, and the aqueous layer was extracted once with diethyl ether. The diethyl ether solution was washed (2 × saturated sodium chloride, 1 × saturated potassium hydrogencarbonate), dried ($MgSO_4$), and evaporated, finally in high vacuum. The solid was triturated with methanol–pentane (1 : 1), collected, dried (84 g), recrystallized from ethanol (125 ml), washed with cold methanol, and dried. The 5-phenyldibenzophosphole (4) (71.75 g; 74.4%) had m.p. 95—97 °C (Hoffmann [4] gave m.p. 93—94 °C). The product was always slightly contaminated by its 5-oxide which could be isolated from the mother liquor and was reducible,[14] by trichlorosilane, to 5-phenyldibenzophosphole (4).

5-Hydroxydibenzophosphole 5-Oxide (2).—The phosphole (4) prepared as above was used as soon as possible, to minimize autoxidation. Liquid ammonia (1 450 ml) was condensed in a 5 l flask which was cooled in an isopropyl alcohol–carbon dioxide bath at −50 °C. Under nitrogen, 5-phenyldibenzophosphole (150.4 g, 0.58 mol; powdered) was added, with stirring, followed during 1.5 h by sodium (27.76 g) cut into small pieces. After a further 1.5 h at −50 °C ammonium chloride (33.55 g) was added during 5 min. An uncooled bath of isopropyl alcohol was then used to aid evaporation of ammonia; when this was nearly at an end, water-saturated diethyl ether (230 ml) was added and

the mixture was stirred in a warm water bath. Water (580 ml) followed by tetrahydrofuran (THF) (350 ml) was added slowly with stirring. The solution was transferred to a beaker and stirred magnetically at 45—53 °C during addition (1.25 h) of hydrogen peroxide (116 ml of 30%). After 0.5 h at 45 °C the mixture was stirred at room temperature overnight. Sodium hydroxide (69.4 g) was added and the solution was stirred and heated at 100 °C until most of the ammonia had been driven off (1.5 h). The crystalline sodium salt was collected from the ice-cooled mixture and washed with saturated sodium chloride (2 × 200 ml). It was transferred to a beaker and dissolved in water at 60 °C, filtered, and precipitated at 60 °C, with stirring, by the addition of hydrochloric acid (280 ml of 5M). The mixture was then cooled in ice and concentrated hydrochloric acid (580 ml) was added. The solid was collected and washed first with a little 5M hydrochloric acid, then with water until the filtrate was almost chloride-free. The phosphinic acid was dried in a vacuum oven (50 then 100 °C). It weighed 107 g (85.6%) and had m.p. 256—260 °C. It could be recrystallized from isopropyl alcohol or 95% ethanol, but was suitable for use as crystallized by precipitation. The pK_a in 10% aqueous dimethyl sulphoxide (DMSO) was 3.2 ± 0.15, corresponding to pK_a 2.8 in water (determination kindly made by Dr. N. McFarlane).

The methyl ester, *5-methoxydibenzophosphole 5-oxide*, prepared by means of diazomethane, was crystallized from benzene–light petroleum; m.p. 114—115 °C (Found: C, 67.9; H, 4.7; P, 13.6. $C_{13}H_{11}O_2P$ requires C, 67.8; H, 4.8; P, 13.5%). The anhydride, *bis-(5-oxo-5-dibenzophospholyl) anhydride*, was obtained as a by-product when the acid in chloroform was heated with thionyl chloride and a little dimethylformamide (DMF); it formed a residue insoluble in hot ethyl acetate; m.p. 262—264 °C when heated from room temperature (Found: C, 69.2; H, 3.8; P, 14.6. $C_{24}H_{16}O_3P_2$ requires C, 69.55; H, 3.9; P, 15.0%).

5-(2-Iodophenoxy)dibenzophosphole 5-Oxide.—The title oxide was prepared for an (unsuccessful) experiment on photolysis. The phosphinic acid (2) (2.16 g) in dichloromethane (5 ml) was stirred at reflux for 75 min with thionyl chloride (0.8 ml; redistilled) and DMF (0.1 ml; dry). The cooled solution was added dropwise with vigorous stirring, to a solution of 2-iodophenol (2.2 g) and triethylamine (1.6 ml) in dichloromethane (10 ml). After 1 h the mixture was stirred at reflux for 75 min and water was added. The washed (1M $NaHCO_3$, 1M NaOH, NaCl) and dried ($MgSO_4$) solvent was evaporated to leave a crystalline residue which was recrystallized from toluene to yield the *2-iodophenyl ester* (3.3 g), m.p. 158—160 °C after another crystallization (Found: C, 51.7; H, 3.0; I, 30.3; P, 7.8. $C_{18}H_{21}IO_2P$ requires C, 51.7; H, 2.9; I, 30.4; P, 7.4%).

5-(2-Acetamidophenoxy)dibenzophosphole 5-oxide was prepared similarly, using 2-acetamidophenol. The product crystallized from toluene in a solvated form, m.p. 144—145 °C, raised to 145—147 °C by another crystallization (Found: C, 69.2; H, 4.7; N, 3.6. $C_{20}H_{16}NO_3P$ requires C, 68.8; H, 4.6; N, 4.0%).

5-Hydroxy-3,7-dinitrodibenzophosphole 5-Oxide (7).—5-Hydroxydibenzophosphole 5-oxide (107 g) in sulphuric acid (297 ml, d 1.84) was stirred and cooled to 10 °C, then treated for 1 h at <25 °C with fuming nitric acid (99 ml, *d* 1.5), added dropwise. Next day water (400 ml) was added dropwise with stirring (temperature controlled at 50—60 °C). The crystalline solid was collected and sucked well, then washed once with water (400 ml). The receiver was changed and the solid was washed again with water (4 × 200 ml); the final washing was tested for virtual absence of sulphate. Acidification of these four washings with hydrochloric acid (40 ml; *d*, 1.16) gave additional solid (10 g) which was washed with water and united with the main crop for drying (vacuum oven, finally at 100 °C). The total yield was 147.75 g. This was recrystallized from redistilled DMF (3 ml/g). The crystals were washed once with DMF (50 ml) and then ethanol (4 × 100 ml) and dried to constant weight in a vacuum oven (100, then 110 °C) to yield the pure dinitro-acid (115.5 g, 76%). Only a small further amount (1.3 g) could be obtained from the mother liquors. The substance melted with decomposition at *ca.* 340 °C (lit.,[6] decomp. >260 °C) (Found: C, 47.2; 47.4; H, 2.3, 2.4; N, 9.2, 9.6. Calc. for $C_{12}H_7N_2O_6P$: C, 47.2; H, 2.3; N, 9.2%); *m/e* 320 (M^+). The crude nitration product also had N, 9.2%.

3,7-Diamino-5-hydroxydibenzophosphole 5-Oxide (8).—The recrystallized dinitro-acid (7) (105.8 g) was stirred in water (1 200 ml) during addition of hydrazine hydrate (90 ml) followed by Raney nickel (*ca.* 1 ml settled suspension). The mixture was stirred for 20 h (during which time the temperature reached 54 °C and subsided), then heated to 100—110 °C for 30 min, cooled in ice, passed through a fine sinter, and acidified with acetic acid (121 ml). The solid was collected, washed (1 × 230 ml water, 2 × 230 ml ethanol), and dried *in vacuo* at 80 °C; yield 82.6 g (97%). The substance did not melt below 360 °C (lit.,[6] m.p. >300 °C) (Found: N, 11.2; P, 12.7. Calc. for $C_{12}H_{11}N_2O_2P$: N, 11.4; P, 12.6%).

3,5,7-Trihydroxydibenzophosphole 5-Oxide (9).—Approximately 75% sulphuric acid was made by adding concentrated sulphuric acid to water (2 : 1, v/v). The diamino-acid (8) (12.3 g) was dissolved in 75 ml of this acid and nitrosylsulphuric acid (14 g) was dissolved in another 76 ml. The nitrosylsulphuric acid was stirred at −10 to −5 °C during addition (18 min) of the amino-acid. After 3 h at 0 °C the mixture was cooled again while water (75 ml) was added dropwise <5 °C. Urea (2 g) was added and cooling and stirring were continued for 40 min. The mixture was added dropwise during 13 min to refluxing acetic acid (300 ml). After a further 5 min the mixture was cooled in ice and left at 0 °C for 19 h. The solid was collected, washed with water (1 × 100 ml, 4 × 50 ml), and dried under reduced pressure at 65 °C [yield 9.48 g (76.5%)]. Further amounts (4.16 g) of less pure material could be recovered from the mother liquors and washings. The acid gave a green colour with ferric chloride and green crystals separated with time.

The acid was best purified *via* its triacetate. The acid (41.4 g) was boiled under reflux for 30 min with acetic anhydride (600 ml) and pyridine (3 ml). The product crystallized when the mixture was cooled and seeded; it was collected, washed (2 × acetic acid, 2 × diethyl ether), and dried under reduced pressure (65 °C) to yield *3,5,7-triacetoxydibenzophosphole 5-oxide* (10) (31.6 g; 83%) (Found: C, 57.9; H, 4.1; P, 8.5. $C_{18}H_{15}O_7P$ requires C, 57.8; H, 4.0; P, 8.3%). When heated the substance evolved acetic anhydride at *ca.* 200 °C and formed the phosphinic anhydride, which had m.p. 247—248 °C.

By partial hydrolysis of the triacetate, *3,7-diacetoxy-5-hydroxydibenzophosphole 5-oxide* was made, either by adding water gradually to an acetylation mixture or by heating the triacetate briefly at 140 °C with DMF–H_2O (9 : 1). It crystallized from acetic acid; m.p. 235—237 °C (Found: C, 58.2; H, 4.1; P, 9.7. $C_{16}H_{13}O_6P$ requires C, 57.8; H,

3.9; P, 9.3%). The methyl ester, 3,7-*diacetoxy*-5-*methoxydibenzophosphole* 5-*oxide*, was formed with diazomethane; it crystallized from ethyl acetate; m.p. 195—196 °C (Found: C, 59.2; H, 4.6; P, 9.2. $C_{17}H_{15}O_6P$ requires C, 59.0; H, 4.3; P, 9.0%).

For complete hydrolysis the triacetate (70.2 g) was heated in aqueous sodium hydroxide (700 ml of 2N) for 10 min on a steam-bath. A little sodium dithionite was added to the filtered solution, which was reheated until pale yellow, then acidified (280 ml 2.5M sulphuric acid). The crystalline solid was collected after 2 h at 0 °C, washed free from sulphate, and dried under reduced pressure at 65 °C.

The 3,5,7-*trihydroxydibenzophosphole* 5-*oxide* (9) (44 g) had m.p. 335—336 °C. It could not be recrystallized and appeared difficult to obtain anhydrous (Found for different preparations: C, 56.5, 56.8, 56.8, 56.8, 57.0; H, 4.0, 4.1, 3.8, 3.8, 3.9; P, 11.9, 12.6. $C_{12}H_9O_4P$ requires C, 58.05; H, 3.6; P, 12.5%).

3,5,7-*Trimethoxydibenzophosphole* 5-*Oxide* (11).—The above trihydroxy-compound (1.24 g) was dissolved in aqueous sodium hydroxide (10.5 ml). Dimethyl sulphate (1.5 ml) was added and the mixture was stirred and heated under reflux, more alkali (2.5 ml) and dimethyl sulphate (0.5 ml) being added after 1 h and after 1.5 h. After 2 h the mixture was left stirring at room temperature. Next day the crystalline sodium salt was collected, washed twice with saturated sodium chloride, and dissolved in water. The hot solution was acidified with dilute sulphuric acid. The product (1.16 g, 84%) was collected after cooling, washed free of sulphate, and dried; m.p. 269—270 °C. This was 5-hydroxy-3,7-dimethoxydibenzophosphole 5-oxide. Its anhydride, 5,5′-*oxybis*-(3,7-*dimethoxy*-5-*oxodibenzophosphole*) was made by heating the acid in acetic acid–acetic anhydride, isolating the 5-acetoxy-compound by evaporation and trituration with diethyl ether and heating this at 150—170 °C for 20 min. The acetic anhydride formed was removed at 15 mmHg and the crystalline residue of anhydride was washed with dry diethyl ether; m.p. 277—280 °C (Found: C, 62.9; H, 4.7; P, 11.5, 11.8. $C_{28}H_{24}O_7P_2$ requires C, 62.9; H, 4.5; P, 11.6%).

Esterification of the acid in a chloroform–methanol (3 : 1) suspension was effected by ethereal diazomethane. The 5-*oxide* (11) showed dimorphism, a form with m.p. 127—128 °C being obtained as well as the form with m.p. 140—141 °C (see later) (Found: C, 62.2; H, 5.3. $C_{15}H_{15}O_4P$ requires C, 62.1; H, 5.2%).

Experiments with 2,2′-*Dilithiobiphenyl*.—(*a*) 2,2′-Dibromobiphenyl (3.01 g) in diethyl ether (75 ml) at 0 °C under nitrogen was treated with an ethereal solution of butyllithium (2.05 equiv. by titration) during 15 min. The mixture was stirred at 0 °C for 45 min and then at room temperature for 30 min. The clear pale yellow solution was stirred at 0 °C during addition of dichloro(morpholino)phosphine [15] (1.77 g) in diethyl ether (10 ml) over 15 min. The mixture was stirred at 0 °C for a further 15 min, then heated under reflux for 1 h. Evaporation of the filtered solution left an oil which crystallized from a little diethyl ether to yield a pale yellow solid (1.2 g), m.p. 95—97 °C. Recrystallization of a portion from diethyl ether gave 5-*morpholinodibenzophosphole* (13) as thick prisms, m.p. 95—97 °C (Found: C, 71.5; H, 5.9; N, 5.0. $C_{16}H_{16}NOP$ requires C, 71.4; H, 6.0; N, 5.2%); *m/e* 269 (M^+). This product (1.1 g) in dry benzene (50 ml) was heated for 3 h under reflux with active manganese dioxide (2 g). After filtration the solution was evaporated to leave the crystalline 5-oxide (1.14 g), m.p. 147.5—149 °C. This product (1.1 g) was boiled under reflux with hydrochloric acid (40 ml of 5M) for a total of 36 h. The crystalline product [largely compound (2)] was collected from the cooled solution, dissolved in hot 1M sodium hydroxide, filtered from some unchanged morpholide, and purified as described above *via* the sodium salt. Recrystallization from ethanol gave, in two crops (total 0.64 g), the 5-oxide (2); *m.p.* 255—256 °C; i.r. spectrum identical with that of the material prepared from triphenylphosphine (above). The oxidation could also be effected by alkaline hydrogen peroxide but was less satisfactory.

(*b*) 2,2′-Dilithiobiphenyl was prepared as above from 2,2′-dibromobiphenyl (0.994 g) and butyl-lithium. Into this solution at 0 °C under nitrogen was slowly added with stirring diethyl phosphite (0.45 g) in diethyl ether (7 ml). The mixture was heated under reflux for 15 min then shaken with hydrochloric acid (40 ml of 3M). Water (40 ml) was added; the diethyl layer was separated off and evaporated to yield a colourless oil (0.555 g) which was chromatographed on silica (30 g). Less polar products were eluted with diethyl ether–light petroleum (1 : 1) and with diethyl ether; the main product was eluted with diethyl ether–ethyl acetate (1 : 1) and was a colourless oil (214 mg). This product, after distillation [230 °C (bath)/0.2 mmHg], solidified to a waxy solid. This was shown to be 5-butyldibenzophosphole 5-oxide by a synthesis from 5-phenyldibenzophosphole. To a solution of sodium (0.474 g; 0.0206 g atom) in liquid ammonia (50 ml) at −70 °C was added 5-phenyldibenzophosphole (2.608 g; 0.01 mol). The mixture was stirred for 30 min, then treated with ammonium chloride (0.542 g; 0.01 mol). After a further 15 min, butyl bromide (1.38 g; 0.01 mol) in diethyl ether (5 ml) was added dropwise; then the mixture was warmed to reflux (−33 °C) for 1.5 h. The ammonia was evaporated and diethyl ether (50 ml) and water (20 ml) were added. From the ethereal solution by distillation 5-*butyldibenzophosphole* (1.722 g) was obtained; b.p. 140 °C/0.2 mm Hg (Found: C, 8.04; 7.2. $C_{16}H_{17}P$ requires C, 80.0; H, 7.1%). To a stirred solution of the phosphole (0.73 g) in acetone (15 ml) hydrogen peroxide (5 ml of 3%) was added dropwise; after 1.5 h the acetone was evaporated and the residue was extracted with benzene. By distillation from the extract a colourless oil was obtained, b.p. 210—230 °C (bath)/0.2 mmHg, which solidified. The i.r. spectrum was identical with that of the product from diethyl phosphite and 2,2′-dibromobiphenyl (above). The 5-*butyldibenzophosphole* 5-*oxide* (14) formed colourless waxy crystals; m.p. 80.5—82 °C (Found: C, 75.2; H, 6.6%. $C_{16}H_{17}OP$ requires C, 75.0; H, 6.6%); *m/e* 256 (M^+), 227, 214 (100%; *m** 178.9, 256→214), 199, and 152 (*m** 116.1, 199→152).

(*c*) To chopped lithium wire (0.102 g) in diethyl ether (5 ml) under nitrogen was added 2,2′-dibromobiphenyl (1.20 g) in diethyl ether (15 ml). After 3 h residual traces of the metal were removed and diethyl phosphite (0.528 g) in diethyl ether (5 ml) was added. Next day water and diethyl ether (20 ml each) were added. The aqueous layer yielded, after acidification, some 5-hydroxydibenzophosphole 5-oxide. The diethyl ether solution, on evaporation, left an oil which was chromatographed on silica as described in method (*b*). A polar component (0.132 g) was eluted with methanol–ethyl acetate (1 : 4) and solidified slowly. Recrystallization from benzene–light petroleum gave 5-ethyl dibenzophosphole 5-oxide (15) as colourless needles, m.p. 139—141 °C, which was identified by synthesis from 5-

phenyldibenzophosphole as described in method (b) using ethyl iodide in place of butyl bromide. The intermediate 5-ethyldibenzophosphole was a *liquid*, b.p. 130 °C (bath)/0.2 mmHg (Found: C, 79.1; H, 6.2. $C_{12}H_{13}P$ requires C, 79.2; H, 6.2%); *m/e* 212(M^+), 199, 198, 184, 183 (100%), 181, 157, and 152. Oxidation gave *5-ethyldibenzophosphole 5-oxide* (15), b.p. 200—210 °C (bath)/0.2 mmHg; m.p. 139—141 °C (Found: C, 73.5; H, 5.5. $C_{14}H_{13}OP$ requires C, 73.7; H, 5.7%); *m/e* 228 (M^+), 200 (*m** 175.3), 199, and 152 (*m** 116.1, 199→152). The i.r. spectra of the two specimens were identical.

4,4′-Diamino-2,2′dibromobiphenyl.—To a stirred solution of 3-bromonitrobenzene (5.5 g) in ethanol (60 ml) were added in portions, alternately, a solution of sodium hydroxide (2.5 g) in water (15 ml), and zinc powder (10 g). The mixture was brought to 70 °C; after 15 min, more zinc (6 g) was added. The mixture became pale yellow after a further 15 min; it was then brought to the boil and filtered under nitrogen, the zinc being washed with ethanol (10 ml). Water (50 ml) was added to the filtrate; the mixture was cooled in an ice-bath and the pale yellow hydrazobenzene was collected under nitrogen. It was added to hydrochloric acid (50 ml of 6M) and stirred at 60 °C for 15 min, then cooled rapidly. The solid benzidine hydrochloride was collected, washed with 6M hydrochloric acid and with diethyl ether, dissolved in warm water, and added to an excess of aqueous sodium hydroxide. The crude benzidine (3.6 g) was recrystallized from ethanol–water; m.p. 151—153 °C (lit.,[9] m.p. 151.5—152 °C).

2,2′-Dibromo-4,4′-dihydroxybiphenyl.—The above benzidine (5.13 g) was dissolved in dilute hydrochloric acid (110 ml of 1M). After further dilution with water to 500 ml, sulphuric acid (20 ml, *d* 1.84) was added when the sulphate precipitated. To the stirred mixture, cooled to < 5 °C, was added dropwise sodium nitrite (2.07 g) in water (20 ml). The mixture was stirred until a clear brown solution was formed, then heated slowly to 100 °C. Evolution of nitrogen began at about 70 °C and ceased after 20 min. The cold solution was extracted with diethyl ether, which was in turn extracted with aqueous sodium hydroxide (3 × 80 ml of 2M). Acidification of this extract gave a red oil (5.14 g), isolated by means of diethyl ether. This oil was chromatographed on silica (190 g) using diethyl ether–light petroleum (1 : 9, then 1 : 1). This gave an orange solid (total 4.19 g) which was sublimed at 160 °C/0.05 mmHg. The sublimate, on trituration with chloroform, was white and crystalline. *2,2′-Dibromo-4,4′-dihydroxybiphenyl* (3.19 g) had m.p. 161—163 °C (Found: C, 42.2; H, 2.4; Br, 46.1. $C_{12}H_8Br_2O_2$ requires C, 41.9; H, 2.3; Br, 46.5%). Methylation of this substance in the normal manner with dimethyl sulphate and aqueous sodium hydroxide at 100 °C gave *2,2′-dibromo-4,4′-dimethoxybiphenyl* (which crystallized from chloroform–light petroleum), m.p. 117—119 °C (Found: C, 45.6; H, 3.3; Br, 43.0. $C_{14}H_{12}Br_2O_2$ requires C, 45.5; H, 3.2; Br, 43.0%). The diallyl ether, *4,4′-diallyloxy-2,2′-dibromobiphenyl*, was prepared by heating the diphenol in acetone with an excess of potassium carbonate and of allyl bromide; it formed a pale yellow oil (Found: C, 51.1; H, 3.9; Br, 37.3. $C_{18}H_{16}Br_2O_2$ requires C, 51.0; H, 3.8; Br, 37.7%).

5-Hydroxy-3,7-dimethoxybenzophosphole 5-Oxide (17) *and Derivatives*.—Butyl-lithium (6.7 ml of 1.5M in hexane, diluted with 10 ml diethyl ether) was added dropwise at 0 °C under nitrogen to a stirred mixture of 2,2′-dibromo-4,4′-dimethoxybiphenyl (1.85 g) and diethyl ether (20 ml). The mixture was heated at reflux for 1.5 h, cooled again, and treated with dichloro-*N*-morpholinophosphine (0.96 g). The pale yellow mixture, after being heated at reflux for 45 min, was filtered hot and evaporated. The residue (1.68 g) was heated in ethanol (20 ml) for 0.5 h on a steam-bath. Evaporation then left a semi-solid residue (1.63 g). Sulphuric acid (28 ml of 0.5M) was added and the mixture was heated on a steam-bath for 1 h, cooled, and extracted with chloroform. The pale yellow solution was evaporated and the residue was heated on the steam-bath for 1 h with a mixture of aqueous sodium hydroxide (50 ml of 4M) and ethanol (10 ml). The hot solution was filtered and acidified. The precipitate was collected and dissolved in aqueous sodium hydrogencarbonate. Acidification of the filtered solution gave a white precipitate (0.74 g; 54%). Two recrystallizations from ethanol gave *5-hydroxy-3,7-dimethoxydibenzophosphole 5-oxide*, m.p. 268—272 °C (Found: P, 11.2. $C_{14}H_{13}O_4P$ requires P, 11.1%).

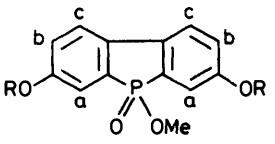
The methyl ester, 3,5,7-trimethoxydibenzophosphole 5-oxide, was prepared by means of diazomethane; it crystallized from ethanol as colourless needles, m.p. 140—141 °C, alone or mixed with the specimen (above) prepared from 5-hydroxy-dibenzophosphole 5-oxide. The spectra (n.m.r., mass, i.r.) were identical, as were the retention times on g.l.c. (3% SE-30), and R_F on silica (acetone).

The corresponding ethyl ester was obtained by isolating the ethoxyphosphole intermediate in the above procedure and oxidizing it. The semi-solid residue obtained by ethanolysis (above) was recrystallized from ethanol to yield *5-ethoxy-3,7-dimethoxydibenzophosphole* as pale yellow prisms, m.p. 88—90 °C (Found: C, 67.0; H, 6.0; P, 10.8. $C_{16}H_{17}O_3P$ requires C, 66.7; H, 5.9; P, 10.7%); *m/e* 228 (M^+), 199 (100%), 183, and 152. On oxidation at room temperature with hydrogen peroxide in aqueous acetone this gave *5-ethoxy-3,7-dimethoxydibenzophosphole 5-oxide* as small colourless needles, m.p. 168—170.5 °C from chloroform–light petroleum (Found: C, 63.1; H, 5.7. $C_{16}H_{17}O_4P$ requires C, 63.2; H, 5.6%); *m/e* 304 (M^+).

3,7-Diallyloxy-5-hydroxydibenzophosphole 5-oxide was prepared from 4,4′-diallyloxy-2,2′-dibromobiphenyl (see above) in the same manner as for the dimethoxy-analogue. Recrystallized from ethanol the product had m.p. 199—200 °C (decomp.) (Found: C, 65.7; H, 5.2. $C_{18}H_{17}O_4P$ requires C, 65.9; 5.2%); *m/e* 328 (M^+). A methyl ester was prepared with diazomethane; *m/e* 342 (M^+).

2,8-Dimethoxydibenzophospholes.—2,2′-Dibromo-5,5′-dimethoxybiphenyl (3.85 g) in diethyl ether (100 ml) under nitrogen was treated with butyl-lithium (10 ml of 2.11M in hexane). After being stirred for 75 min the solution was treated with dichloro-*N*-morpholinophosphine (2.05 g) and heated at reflux for 2 h. Evaporation of the filtered solution left a pale yellow oil (3.6 g) from which a pale yellow powder (2.47 g) was obtained by treatment with ethanol (15 ml), cooling, and centrifugation. Two crystallizations from ethanol gave *5-ethoxy-2,8-dimethoxydibenzophosphole* (18) (1.14 g) as pale yellow prisms, m.p. 88—90 °C (Found: C, 67.0; H, 6.0; P, 10.8. $C_{16}H_{17}O_3P$ requires C, 66.7; H, 5.9; P, 10.7%). Hydrolysis of this substance (610 mg) for 1.5 h at reflux in dilute sulphuric acid (10 ml of 0.5M) gave, after addition of sodium hydroxide and extraction with chloroform, a white crystalline solid (590 mg) apparently of a phosphinous–phosphinic anhydride [*m/e* 536 (M^+), 276, and 259] which was not further examined but heated on a steam-bath with aqueous sodium hydroxide (15 ml of 2.7M) for 45 min. Acidification of the

N.m.r. measurements on derivatives of 3,7-dihydroxy-5-methoxydibenzophosphole 5-oxide



Chemical shift, δ	R = Me	R = Ac	R = $CH_2CH{=}CH_2$
H_a	7.23	7.48	7.22
H_b	7.03	7.30	7.02
H_c	7.53	7.71	7.43
P–OMe	3.71	3.76	3.68
OMe	3.84		
Coupling constant, Hz	R = Me	R = Ac	R = $CH_2CH{=}CH_2$
H_a–H_b	2.5	2.2	2.2
H_a–P	11.8	11.1	11.8
H_b–H_c	8.5	8.2	8.5
H_b–P	1.0	1.0	0.8
H_c–P	4.2	4.1	4.2
P–OMe	12.0	12.0	12.0

filtered solution gave a white solid which was recrystallized from aqueous ethanol to yield colourless crystals (450 mg) of *5-hydroxy-2,8-dimethoxydibenzophosphole 5-oxide* (19), m.p. 276.5—277 °C (Found: C, 60.6; H, 4.8; P, 11.5. $C_{14}H_{13}O_4P$ requires C, 60.9; H, 4.7; P, 11.2%).

The ethyl ester, *5-ethoxy-2,8-dimethoxydibenzophosphole 5-oxide* (20) was prepared from the ethoxyphosphole (18) by oxidation with hydrogen peroxide in acetone at room temperature. It formed colourless crystals (from ethanol), m.p. 166—170 °C (Found: C, 63.1; H, 5.7. $C_{16}H_{17}O_4P$ requires C, 63.2; H, 5.6%); *m/e* 304 (M^+). The methyl ester, prepared from the acid and diazomethane, had m.p. 135—136 °C.

3,3'-Dihydroxybiphenyl.—A mixture of 5-hydroxy-2,8-dimethoxydibenzophosphole 5-oxide (0.88 g) and hydroidic acid (20 ml of 56%) was heated at reflux for 2.5 h. The crystalline precipitate obtained on cooling was purified by dissolution in aqueous sodium hydroxide and reprecipitation with acid. The white powder (520 mg) was identified as 3,3'-dihydroxybiphenyl by comparison with material obtained from 3,3'-dimethoxybiphenyl and from 2,2'-dibromo-5,5'-dimethoxybiphenyl by similar treatment with hydriodic acid. The substance crystallized from ethanol–water as colourless needles, m.p. 125.5—126.5 °C (lit.,[16] m.p. 125.5—126 °C).

Bromination of 3,5,7-Trihydroxydibenzophosphole 5-Oxide.—To the phosphinic acid (9) (0.62 g) in methanol (15 ml) and acetic acid (5 ml) was added bromine (0.8 g) in acetic acid (5.5 ml). The bromine was consumed after 70 h at room temperature. Evaporation left a yellow solid (1.08 g) which was methylated by treatment (under reflux, 30 min) with sodium ethoxide (0.7 g sodium in 50 ml ethanol) then with methyl iodide (0.65 ml; reflux overnight). The total product (1.03 g) was recovered after neutralization and methylated in diethyl ether with diazomethane. This gave a solid (1.04 g) which was put on a silica column (70 g) prepared in light petroleum (b.p. 40—60 °C). The column was eluted with light petroleum–ethyl acetate (2 : 1, 1 : 1, 1 : 2), ethyl acetate, ethanol–ethyl acetate (1 : 19, 1 : 9, 1 : 3, 1 : 1, 3 : 1), and ethanol, and fractions were monitored by t.l.c. (in ethyl acetate). From the early ethyl acetate fractions and those immediately preceding them were recovered one combined eluate (118 mg); from later ethyl acetate fractions a mixture (207 mg) was recovered; from eluates containing much ethanol a third eluate (187 mg) was separated. The first eluate on recrystallization from ethanol gave long colourless needles, of *2,4,6,8-tetrabromo-3,5,7-trimethoxydibenzophosphole 5-oxide*, m.p. 245—246.5 °C (Found: C, 29.4; H, 1.85. $C_{15}H_{11}Br_4O_4P$ requires C, 29.7; H, 1.81%); tetrabromo-pattern centred on *m/e* 602 (M^+); δ 7.78 (d, $J_{P\text{-}H}$ 3.5 Hz, 2 × Ar–H) (*cf.* Table). The third eluate, on similar recrystallization, gave pale yellow clustered prisms, m.p. 259—261 °C, of *2,8-dibromo-3,5,7-trimethoxydibenzophosphole 5-oxide* (Found: C, 40.1; H, 2.9. $C_{15}H_{13}Br_2O_4P$ requires C, 40.2; H, 2.9%); dibromo-pattern centred on *m/e* 446 (M^+); δ 3.73 (3 H, d, $J_{P\text{-}H}$ 12 Hz) 3.97 (3 H, s), 7.23 (2 H, d, $J_{P\text{-}H}$ 12 Hz, 4-, 6-H), and 7.83 (2 H, d, $J_{P\text{-}H}$ 4 Hz, 1-, 9-H).

Mannich Bases from 3,5,7-Trihydroxydibenzophosphole 5-Oxide.—The trihydroxydibenzophosphole 5-oxide (9.92 g) and water (28 ml) were stirred during addition of aqueous dimethylamine (23.75 ml of 26.1%; 6.2 g). To the cooled solution, aqueous formaldehyde (6.99 ml of 40.3%) was added. The flask was filled with nitrogen, stoppered, and stirred for 24 h. Oxalic acid (8 g) in ethanol (40 ml) was added. The mixture was heated on a steam-bath during slow addition of hot ethanol (200 ml). The mixture was left at 0 °C for 3 days and the oxalate was then collected, washed well with ethanol, and dried under reduced pressure at 35 °C. This gave 13.94 g (77%) of the *mono-oxalate mono-hydrate* of *2,8-bis(dimethylaminomethyl)-3,5,7-trihydroxydibenzophosphole 5-oxide* (23) which could be recrystallized by solution in hot water (20 ml/g) and addition of ethanol (10 ml /g) (Found: C, 50.7, 50.8;, H, 6.4, 6.4; N, 5.7, 5.8; P, 6.4. $C_{20}H_{25}N_2O_8P{\cdot}H_2O$ requires C, 51.0; H, 5.8; N, 6.0; P, 6.6%). The *mono-acetate*, prepared by use of acetic instead of oxalic acid, was less convenient for isolation of the product; it crystallized from acetic acid (5 ml/g) (Found: N, 6.2; P, 7.2. $C_{20}H_{27}N_2O_6P$ requires N, 6.6; P, 7.35%). The positions of substitution in the Mannich base are shown by the n.m.r. chemical shifts and H–P coupling constants of the aromatic protons (in D_2O): δ 7.17 (2 H, d, $J_{P\text{-}H}$ 10.5 Hz, 4-, 6-H) and 7.58 (2 H, d, $J_{P\text{-}H}$ 4 Hz, 1-, 9-H). By substituting piperidine and morpholine for dimethylamine, 3,5-7-trihydroxy-2,8-bis(morpholinomethyl)dibenzophosphole 5-oxide and 3,5,7-trihydroxy-2,8-bis(piperidinomethyl)dibenzophosphole 5-oxide were isolated as the *mono-acetates* (Found for the morpholino-compound: N, 6.5; P, 6.6. $C_{24}H_{31}N_2O_8P$ requires N, 6.0; P, 6.6%); Found for the piperidino-compound: N, 5.3; P, 6.0. $C_{26}H_{35}N_2O_6P$ requires N, 5.6; P, 6.2%). The n.m.r. spectra confirmed the positions of substitution in these compounds also.

3,7-Diacetoxy-2,8-diacetoxymethyl-5-methoxydibenzophosphole 5-Oxide (26).—The Mannich base oxalate described above (7.32 g) was heated at reflux with acetic anhydride (58 ml) for 6 h. The mixture was evaporated at low pressure, finally at 50 °C for 1 h. Water (30 ml) was added and the product, 3,5,7-triacetoxy-2,8-diacetoxymethyldibenzophosphole 5-oxide (24) (6.76 g) was collected, washed with water and diethyl ether, and dried. It formed white crystals, m.p. 223—225 °C (decomp.) [*m/e* 518 (M^+)]. To remove the 5-acetyl group compound (24) was heated at reflux with acetic acid (34 ml) for 45 min. Next day diethyl ether (68 ml) was added and the product *3,7-diacetoxy-2,8-diacetoxymethyl-5-hydroxydibenzophosphole 5-oxide* (25) (5.26 g) was collected. A small further quantity (0.54 g) was obtained by reheating the evaporated filtrate with acetic

acid as above. The acid formed white crystals, m.p. 248—250 °C (Found: C, 53.7; H, 4.4; P, 6.1. $C_{22}H_{21}O_{10}P\cdot H_2O$ requires C, 53.4; H, 4.7; P, 6.3%); δ ([$^2H_6$]DMSO) 2.06 (6 H, s, CH_2OAc), 2.30 (6 H, s, Ar-OAc), 5.11 (4 H, s, CH_2), 5.57br (3—4 H, s, OH), 7.49 (2 H, d, J 11.4 Hz, 4-, 6-H), and 8.10 (2 H, d, *J* 3.6 Hz, 1-, 9-H). The total product in chloroform–methanol (4 : 1; 120 ml) was esterified with ethereal diazomethane. Evaporation and trituration of the residue with ice-cold methanol (6 ml) yielded 3,7-*diacetoxy*-2,8-*bisacetoxymethyl*-5-*methoxydibenzophosphole* 5-*oxide* (26) (5.69 g), m.p. 224—226 °C. The overall yield in many preparations from 3,5,7-trihydroxydibenzophosphole 5-oxide, without purification of intermediates, was 53—58%. Recrystallization from methanol gave colourless crystals, m.p. 227—228 °C (Found: C, 56.3; H, 4.9; P, 6.2. $C_{23}H_{23}O_{10}P$ requires C, 56.3; H, 4.7; P, 6.3%), or from acetic anhydride; δ 2.08 (6 H, s), 2.31 (6 H, s), 3.75 (3 H, d, *J* 11.5 Hz, OMe), 5.11 (4 H, s), 7.48 (2 H, d, *J* 11.5 Hz), and 7.80 (2 H, d, *J* 3.9 Hz).

3,7-*Diacetoxy*-5-*methoxy*-2,8-*dimethyldibenzophosphole* 5-*Oxide* (27).—The hydrogenolysis was most effectively conducted on a small scale, using a Brown and Brown hydrogenator [17] and a magnetically stirred reaction mixture. The tetra-acetate methyl ester (26) (1.225 g) in acetic acid (15 ml) and ethanol (10 ml) with 10% palladium-on-carbon (0.5 g) was hydrogenated at 70—75 °C for 24 h. A mass spectrum then showed (absence of peaks at *m/e* 490 and 432) that hydrogenolysis was complete. The crude product, recovered by filtration and evaporation, was treated at reflux with acetic anhydride (5 ml) and pyridine (0.05 ml) for 15 min to correct a partial deacetylation. Evaporation and treatment of the residue with water (5 ml) gave the *diacetoxy dimethyl ester* (27) (721 mg), m.p. 234—236 °C which could be recrystallized from methanol (Found: C, 61.0; H, 5.2; P, 8.1. $C_{19}H_{19}O_6P$ requires C, 61.0; H, 5.1; P, 8.3%); δ 2.24 (6 H, s, Ar-Me), 2.31 (6 H, s, OAc), 3.68 (3 H, d, *J* 11.2 Hz), 7.36 (2 H, d, *J* 10.6 Hz), and 7.57 (2 H, d, *J* 3.5 Hz); *m/e* 374 (M^+, 8%), 332 (25), and 290 (100).

Removal of the acetyl groups in compound (27) was effected either by prolonged boiling with methanol, a little water, and imidazole (10% wt); or better by acid hydrolysis. The diacetyl ester (27) (100 mg) was dissolved in sulphuric acid–water (2 : 1 v/v, 0.2 ml). After 15 min water was added, the crystalline solid was collected and dried (74 mg; m.p. 288—290 °C). Recrystallization from DMF gave solvated crystals, m.p. 288—289 °C (decomp.) of 3,7-*dihydroxy*-5-*methoxy*-2,8-*dimethyldibenzophosphole* 5-*oxide* (29) [Found (after drying at 100 °C under reduced pressure): C, 61.9; H, 5.3; P, 10.5. $C_{15}H_{15}O_4P$ requires C, 62.1; H, 5.2; P, 10.7%].

For preparation of the dihydroxy-acid (28) it was sufficient to filter and evaporate the hydrogenolysis mixtures from two runs on the above scale and to heat the residue under nitrogen on a steam-bath with aqueous sodium hydroxide (20 ml of 2M) for 40 min. A little sodium dithionite was added and the hot solution was acidified with hot dilute sulphuric acid (8 ml of 0.5M). The mixture was cooled after a further 10 min heating and the solid dihydroxy-acid (1.35 g) was collected, washed well, and dried under reduced pressure at 65 °C. This substance could not be recrystallized and was used directly for methylation; *m/e* 270 (M^+; 100%).

3,5,7-*Trimethoxy*-2,8-*dimethyldibenzophosphole* 5-*Oxide* (30).—The dihydroxy-acid (28) (2.85 g) was dissolved in aqueous sodium hydroxide (25 ml of 2M), stirred, and treated with two portions of dimethyl sulphate (2 ml each), the second being added after 20 min. The temperature was raised to 60—70 °C and sodium hydroxide (2.5 ml of 5M) and dimethyl sulphate (1 ml) were successively added; this addition was repeated three more times at 20 min intervals. Finally, the mixture was heated at 100 °C for 30 min and acidified with sulphuric acid (3 ml of 2.5M) whilst hot. The solid was collected after cooling, washed, and dried at 80 °C *in vacuo*. It was taken up in chloroform–methanol (4 : 1) and esterified with ethereal diazomethane. Evaporation left a solid which was dissolved in chloroform, washed once with ice-cold aqueous sodium hydroxide (5 ml of 1M), then with brine, dried ($MgSO_4$), and evaporated. The crude product (3.045 g), m.p. 185—187 °C, was recrystallized from toluene (14 ml) to yield the *trimethoxy-compound* (30), m.p. 193—195 °C (Found: P, 9.7. $C_{17}H_{19}O_4P$ requires P, 9.75%); δ 2.25 (6 H, s), 3.65 (3 H, d, *J* 12.1 Hz), 3.86 (6 H, s), 7.14 (2 H, d, *J* 11.4 Hz), and 7.42 (2 H, d, *J* 4.2 Hz); (*m/e* 318 (M^+, 100%), 303 (M − *Me*, 47), and 159 (M^{2+}, 14); no other significant peak.

3,5,7-*Trimethoxy*-2,8-*dimethyl*-4,6-*dinitrodibenzophosphole* 5-*Oxide* (31).—The trimethoxy-compound (30) (2.54 g) was dissolved in acetic acid (4 ml) and acetic anhydride (16 ml), stirred, and kept at 30 °C during dropwise addition of acetyl nitrate solution [20 ml; prepared by the addition of 68% nitric acid (2.1 ml) to acetic anhydride (20 ml) kept at <35 °C; concentrated sulphuric acid (40 mg) added before use] during 20 min. After a further 14 min ice and water were added; the mixture was stirred for 45 min, left for 16 h, diluted with water (200 ml) and filtered. The solid was washed with water, dried at 100 °C *in vacuo* and recrystallized from acetic acid (20 ml), to yield the *dinitro-derivative* (31) (2.20 g), m.p. 277—279 °C (Found: C, 49.6; H, 4.1; N, 6.5; P, 7.9. $C_{17}H_{17}N_2O_8P$ requires C, 50.0; H, 4.2; N, 6.9; P, 7.6%); δ 2.33 (6 H, s), 2.80—3.08 (9 H, m), and 7.51br (2 H, d, *J* 3.6 Hz). The Ar-OMe and P–OMe signals were both complex, perhaps because of atropisomerism; *m/e* 408 (M^+, 85%), 394 (100), 364 (20), 363 (25), 349 (60), 348 (60), 333 (60), and 318 (40). Nitration in acetic acid gave the mononitro-compound, 3,5,7-*trimethoxy*-2,8-*dimethyl*-4-*nitrodibenzophosphole* 5-*oxide* (which crystallized from toluene), m.p. 225—228 °C; δ 2.26 (3 H, s, 8-Me), 2.39 (3 H, s, 2-Me), 3.84 (3 H, d, *J* 12 Hz), 3.87 (6 H, s), 7.13 (1 H, d, *J* 12 Hz, 6-H), 7.41 (1 H, d, *J* 4.5 Hz, 9-H), and 7.60 (1 H, d, *J* 3.2 Hz, 1-H); *m/e* 363 (M^+, 100%), 348 (15), and 237 (20).

4,6-*Diamino*-3,5,7-*trimethoxy*-2,8-*dimethyldibenzophosphole* 5-*Oxide* (32).—The above dinitro-compound (31) (3.06 g) and palladium-on-charcoal (5%; 307 mg) were suspended in methanol and stirred under hydrogen for 6.5 h; no uptake was observed during the last 2 h. The filtered solution was evaporated and the residue was recrystallized from hot methanol (10 ml) by addition of hot water (10 ml) to yield the *diamine* (32) (2.33 g), m.p. 212—214 °C (Found: C, 58.5; H, 6.1; N, 7.7. $C_{17}H_{21}N_2O_4P$ requires C, 58.5; H, 6.1; N, 8.0%; δ 2.21 (6 H, s), 3.51 (3 H, d, *J* 12 Hz), 3.65 (6 H, s), 4.35 br (4 H, s), and 6.68 (2 H, d, *J* 4 Hz); *m/e* 348 (M^+, 86%), 333 (100), and 318 (35).

4,6-*Di-iodo*-3,5,7-*trimethoxy*-2,8-*dimethyldibenzophosphole* 5-*Oxide* (33).—The above diamine (32) (696 mg) was dissolved in sulphuric acid–water (2 : 1 v/v; 3 ml) by warming, then cooled to room temperature, and added as drops to nitrosylsulphuric acid [4 ml of 1.1M in sulphuric acid–water (2 : 1)] stirred, and cooled in ice-salt; the temperature was kept below 0 °C. The solution was stirred below 0 °C for

10 min, then at 0 °C for 1 h, then cooled in ice-salt during addition(< 5 °C) of urea (200 mg) in water (4 ml). Evolution of nitrogen had ceased after 30 min at 0 °C; the cold solution was added during 15 min to a vigorously stirred mixture of iodine (1.27 g) and sodium iodide (1.5 g) in water (25 ml) and chloroform (10 ml). Stirring was continued overnight; chloroform (10 ml) was added and the mixture was heated at reflux for 30 min. The cooled mixture was filtered and the solid washed with water and chloroform. Iodine in the filtrate was reduced by titration with sodium thiosulphate and the chloroform layer was evaporated. The residue, combined with the collected solid, was suspended in chloroform–methanol (4 : 1) and esterified with diazomethane. After evaporation the residue was dissolved in chloroform, washed with 1M sodium hydroxide and with brine, dried, and evaporated. The product was recrystallized from acetic acid (12 ml) and dried under reduced pressure 100 °C, to leave the *di-iodide* (33) (899 mg), m.p. 292—293 °C (Found: C, 36.2; H, 3.1; I, 44.2; P, 5.3. $C_{17}H_{17}I_2O_4P$ requires C, 35.8; H, 3.0; I, 44.5; P, 5.4%); δ 2.36 (6 H, s), 3.76 (6 H, s), 3.95 (3 H, d, *J* 12.6 Hz), and 7.26 (2 H, d, *J* 4 Hz); *m/e* 570 (M^+, 100%), 555 (40), and 285 (M^{2+}, 13).

3,7-*Bis*-(2-*iodobenzyloxy*)-5-*methoxydibenzophosphole* 5-*Oxide* (34).—3,5,7-Trihydroxydibenzophosphole 5-oxide (620 mg) was dissolved in methanolic sodium methoxide (7.9 ml of 1.04M), 2-iodobenzyl bromide (1.64 g) was added, and the mixture was stirred at reflux for 6 h. Hydrochloric acid (2 ml of 5M) was added to the hot suspension and stirring was continued for 10 min. Next day water (10 ml) was added. The solid was collected, washed well with water and diethyl ether, and dried. It was esterified in chloroform–methanol with diazomethane as described in the previous experiment. The product was recrystallized from butanol (10 ml) to yield the *bio-iodobenzyl ether* (34) (1.18 g), m.p. 192—193 °C (Found: C, 46.9; H, 3.1; P, 4.7 $C_{27}H_{21}I_2O_4P$ requires C, 46.7; H, 3.0; P, 4.5%); *m/e* (M^+, 20%), 566 (M^+ − HI, 3), 477 (16), 350 (12), 349 (12), 217 (100), and 90 (55).

3,7-*Bis*-(2-*iodobenzyloxy*)-5-*methoxy*-2,8-*dimethyldibenzophosphole* 5-*Oxide* (35).—3,7-Dihydroxy-5-methoxy-2,8-dimethyldibenzophosphole 5-oxide (29) (290 mg) was dissolved in methanolic sodium methoxide (2.11 ml of 1.04 M); 2-iodobenzyl bromide (653 mg) and methanol (2.5 ml) were added. The mixture was stirred at reflux for 6 h, diluted with water, and filtered. The dried precipitate was twice recrystallized from butanol yielding the *bis-iodobenzyl ether* (35) (502 mg), m.p. 196—198 °C (Found: C, 47.8; H, 3.5; P, 4.3. $C_{29}H_{25}I_2O_4P$ requires C, 48.2; H, 3.5; P, 4.3%); *m/e* 722 (M^+, 12%), 594 (5), 505 (18), 377 (12), 289 (11), 217 (100), 142 (14), 128 (22), 127 (45), and 90 (45).

Photolysis of the Bis-iodobenzyl Ether (34).—The bis-iodobenzyl ether (34) (0.5 g) in benzene (170 ml) with sodium thiosulphate (0.5 g pentahydrate) and water (5 ml) were stirred at *ca.* 40 °C during irradiation with a low-pressure Hanovia lamp jacketed with water at 45 °C. After 23.5 h the mixture was filtered and the benzene layer was washed with water, saturated sodium hydrogencarbonate, 1M sodium hydroxide, and water. Evaporation left a gum (304 mg) containing no starting material (mass spectrum). Preparative t.l.c. on silica (first toluene, then twice with diethyl ketone) gave several bands; the major one, the most mobile apart from a small band containing biphenyl, contained 36% of the product and was yellow. Another preparation was worked up by t.l.c. in toluene–ethanol (19 : 1). Material from the yellow band crystallized from ethanol and then from butanol to afford yellow crystals, m.p. (decomp.) 258—260 °C (in at 250 °C). Though possibly not quite pure this is considered to be essentially *methyl* 10H,10'H-9,9'-*dioxa*-6,6'-*biphenanthrene*-5,5'-*diylphosphinate* (36) (Found: P, 7.0. $C_{27}H_{19}O_4P$ requires P, 7.1%); δ 3.44 (3 H, d, *J* 12.4 Hz, P–OMe), 5.09 (4 H, s, CH_2), 7.18—7.60 (10 H, m), and 8.94 (2 H, d, *J* 7.5 Hz, 5-, 5-'H); *m/e* 438 (M^+, 100%), 219 (M^{2+}, 30), and 218 [$(M - 2H)^{2+}$, 40]; no other major peak. The yield was < 10% of the theoretical.

Photolysis of the Bis-iodobenzyl Ether (35).—The bis-iodobenzyl ether (35) (0.5 g) was photolysed as described in the previous experiment. Again a yellow band was observed on t.l.c. as above (toluene–ethanol, 19 : 1) and elution gave material which crystallized on trituration with ethanol. Crystalline material could also be obtained by trituration of the crude product with ethanol. This material was boiled with butanol, cooled, centrifuged next day, and the precipitate was crystallized from 1,2-dibromoethane. This gave yellow crystals in 10% yield, m.p. (microscope hot-stage) 315 °C (decomp.); m.p. (capillary) 285—295 °C (decomp.), of *methyl* 8,8'-*dimethyl*-10H,10'H-9,9'-*dioxa*-6,6'-*biphenanthrene*-5,5'-*diylphosphinate* (37). A sample recrystallized from anisole was analysed after being dried at 100 °C under reduced pressure (Found: C, 74.6; H, 4.9; P, 6.3. $C_{29}H_{23}O_4P$ requires C, 74.7; H, 5.0; P, 6.6%); δ 2.39 (6 H, s, Ar-Me), 3.41 (3 H, d, *J* 12.5 Hz, P–OMe), 5.12 (4 H, s, CH_2), 7.1—7.7 (8 H, m, Ar-H), and 8.90 (2 H, d, *J* 8.5 Hz, 5-,5'-H); *m/e* 466 (M^+, 100%), 233 (M^{2+}, 10), 232 [$(M - 2H)^{2+}$, 15] ,and 225 (10).

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