

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF MARYLAND]

Phosphorus Compounds. I. Reduction of Benzylphosphonium Compounds with Lithium Aluminum Hydride¹BY WILLIAM J. BAILEY AND SHELDON A. BUCKLER²

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Lithium aluminum hydride in tetrahydrofuran was employed to remove a benzyl group from a benzylphosphonium compound in high yield to produce a tertiary phosphine. Reduction followed by alkylation of the resulting phosphine was shown to be a very excellent method for the replacement of a benzyl group with an alkyl group. This procedure can conveniently be used for the stepwise synthesis of a variety of tertiary phosphines. Thus tribenzylmethylphosphonium bromide (I), prepared in a 74% yield from phosphorus trichloride, was reduced with lithium aluminum hydride, and the product was alkylated to produce dibenzyltrimethylphosphonium bromide (III) in an over-all yield of 85%. III, in turn, was reduced and the phosphine was alkylated in a similar manner to produce benzyltrimethylphosphonium bromide (VI) in an over-all yield of 83%. Further reduction of VI with lithium aluminum hydride produced trimethylphosphine in a 67% yield.

The reductive cleavage of benzyl groups bonded to nitrogen, oxygen and sulfur is a well-known phenomenon and has received considerable study. It recently has been the subject of a comprehensive review.³ Reductions have been effected by both catalytic and chemical means, and the chief utility of this reaction has been to remove, under relatively mild conditions, benzyl groups which had served as blocking agents in some preliminary reactions. This is a report of the extension of this reductive cleavage to benzyl-containing phosphonium compounds, accomplished most effectively by lithium aluminum hydride.

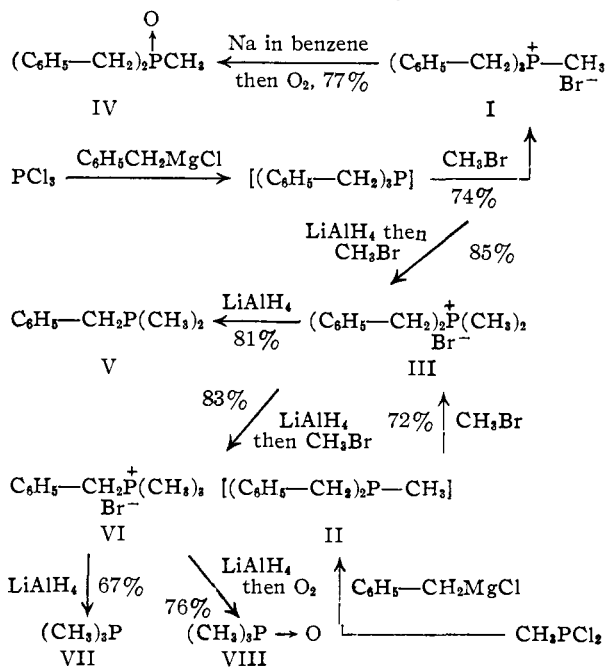
Tribenzylmethylphosphonium bromide (I) was used for the preliminary study of the reductive cleavage of benzyl groups. The bromide I was readily prepared in a 74% yield by the reaction of 3 moles of benzylmagnesium chloride with phosphorus trichloride, followed by direct treatment of the ethereal extracts with methyl bromide. The

intermediate tribenzylphosphine was not isolated because of the facile air oxidation of benzyl-containing phosphines.

Benzylammonium compounds have been reduced by hydrogen with palladium catalyst⁴ and sodium amalgam⁵; the latter method has had the widest applicability. For example, Emde^{5a} found that dibenzyltrimethylammonium chloride was reduced to benzyltrimethylamine in 91% yield by sodium amalgam in aqueous solution.

Attempts to reduce I by hydrogen and palladium were unsuccessful, even at elevated temperature and pressure. An initial success was realized by the use of sodium in liquid ammonia. When small pieces of sodium were added to a slurry of the phosphonium compound I in this medium, discharge of the blue coloration was observed until four equivalents of sodium had been consumed. No further reduction occurred. A distinct phosphine odor was present after the ammonia had been removed by evaporation, but no product corresponding to the removal of the two benzyl groups could be isolated. When the experiment was repeated with only two equivalents of sodium, the product corresponding to the removal of one benzyl group, dibenzylmethylphosphine (II), was formed. Since II was oxidized easily in air, it was not isolated but was converted to its methyl bromide derivative, dibenzyltrimethylphosphonium bromide (III), which was isolated in a 29% over-all yield. When this experiment was performed without a nitrogen atmosphere, the phosphine was converted directly to its oxidation product, dibenzylmethylphosphine oxide (IV), which was isolated in a 39% over-all yield.

Reduction of the benzylphosphonium compound I by means of sodium in warm ethanol was also successfully carried out. Again, the product was isolated as the oxide IV, in a 64% over-all yield. The I also was debenzylated by means of sodium in refluxing benzene; 77% of the theoretical amount of IV was isolated in this case. However, lithium aluminum hydride in tetrahydrofuran proved to be the most convenient as well as the most effective debenzylating agent for all the benzylphosphonium compounds studied. When a slurry of finely pow-



(1) This work was done on a subcontract with the University of Chicago in fulfillment of a contract with the Chemical Corps.

(2) Member of the Armed Forces assigned to the Army Chemical Corps.

(3) W. H. Hartung, "Organic Reactions," Vol. VII, John Wiley and Sons, Inc., New York, N. Y., 1953, p. 263.

(4) L. Birkofer, *Ber.*, **75**, 429 (1942).

(5) (a) H. Emde, *Arch. Pharm.*, **247**, 314, 351, 369 (1909); (b) H. Emde and H. Schellbach, *ibid.*, **249**, 111, 118 (1911); (c) W. H. Perkin, *J. Chem. Soc.*, **109**, 815 (1916); (d) R. H. F. Manske, L. Marion and A. E. Ledingham, *THIS JOURNAL*, **64**, 1659 (1942).

dered I was heated under reflux in a tetrahydrofuran solution of the hydride for 5.5 hr., the reduction product was obtained as its methyl bromide derivative III in an 85% over-all yield. No appreciable amount of reduction was observed, however, when diethyl ether was used as the solvent.

A similar study of the conditions required for debenzilation was carried out on the dibenzylidimethylphosphonium bromide (III). An alternative preparation of III was carried out in a 72% yield by the reaction of 2 moles of benzylmagnesium chloride with methylchlorophosphine, followed by treatment of the resulting phosphine II with methyl bromide. In contrast to the work of Emde^{5a} with dibenzylidimethylammonium compounds, III was not reduced with sodium amalgam. When the phosphonium derivative III was treated with this same reagent, no phosphine was detected and no other evidence of reduction was observed. Stannous chloride in acidic solution proved to be equally ineffectual as a reducing agent. In spite of the fact that sodium in liquid ammonia, in warm ethanol or in refluxing benzene produced some debenzilation of I, none of these combinations was at all successful for the reduction of III. Apparently the lower solubility of III, compared to I, could account for this difference. However, when the dibenzylphosphonium derivative III was reduced with lithium aluminum hydride in tetrahydrofuran, the debenzylated product, benzylidimethylphosphine (V), was isolated in an 81% yield. When the ethereal extracts from a similar reaction were treated directly with methyl bromide, benzyltrimethylphosphonium bromide (VI) was obtained in an 83% yield. VI also was successfully reduced by lithium aluminum hydride. The product, trimethylphosphine (VII), was isolated in a 67% yield by slow distillation of the reducing mixture without preliminary hydrolysis. The true yield was probably greater, and the amount obtained reflects the difficulty in the separation of a small amount of VII from the tetrahydrofuran, which boils only 27° higher. That this was the case was shown by the introduction of a slow stream of air through a solution of crude VII combined with the higher boiling tetrahydrofuran fraction. Trimethylphosphine oxide (VIII) was obtained in a 76% over-all yield.

The action of lithium aluminum hydride has thus been shown to be a very effective method for debenzylating phosphonium compounds containing one, two or three benzyl groups. All these reactions proceeded smoothly and in reasonably high yields. The reaction is thought to proceed selectively in the sense that only one benzyl group is removed at a time, since even if a large excess of lithium aluminum hydride was used, the products corresponding to the removal of one benzyl group were the only ones isolated. The reaction can be envisioned as proceeding by hydride attack on a benzyl carbon atom, followed by ejection of the neutral tertiary phosphine with its free pair of electrons. The formal positive charge on the phosphorus atom, even though partially neutralized in a complex, probably furnishes the driving force for the reaction. The tertiary phosphine formed probably does not react further because of the ab-

sence of a positive charge or because of the necessity for the development of a negative charge on the phosphorus atom during the reduction.

The over-all result of the alkylation of a benzylphosphine, followed by reductive cleavage of the product, is the replacement of a benzyl group by an alkyl group. The extension of these observations to the synthesis of unsymmetrical, tertiary phosphines will be reported separately.

Experimental⁶

Except where otherwise noted, all phosphines, solutions of phosphines and Grignard reagents were prepared and handled in an atmosphere of nitrogen purified by passage through basic pyrogallol traps.

Tribenzylmethylphosphonium Bromide (I).—Benzylmagnesium chloride, prepared in the usual way from 12.2 g. (0.5 mole) of magnesium, 63.3 g. (0.5 mole) of freshly distilled benzyl chloride and 400 ml. of anhydrous ether, was diluted with 100 ml. of additional ether and cooled in a salt-ice bath. A solution of 22.0 g. (0.16 mole) of phosphorus trichloride in 100 ml. of ether was added over a period of 1.5 hr. with cooling and stirring. After the stirring was continued for an additional 30 minutes, the mixture was hydrolyzed by the addition of 150 ml. of water, followed by 200 ml. of a saturated ammonium chloride solution, at a rate such that gentle refluxing ensued. Stirring was stopped, the solids were allowed to settle and most of the ether solution was removed through a glass tube by the application of an excess nitrogen pressure. After 250 ml. of chloroform was added and the mixture was stirred, the layers were separated. The organic layers were combined, cooled in an ice-bath and treated with 30.4 g. (0.32 mole) of methyl bromide. The mixture was allowed to stand under a Dry Ice condenser for 40 hr. The precipitated crystalline salt was then removed by filtration and was washed thoroughly with ether to give 47.5 g. (74%) of slightly impure tribenzylmethylphosphonium bromide (I), m.p. 222–226°. Two recrystallizations from the minimum quantity of ethanol gave 41.0 g. (64%) of pure material, m.p. 229–229.5°.

Anal. Calcd. for C₂₂H₂₄BrP: C, 66.17; H, 6.06. Found: C, 66.00; H, 5.90.

Reduction of Tribenzylmethylphosphonium Bromide (I) with Sodium in Liquid Ammonia.—To a stirred slurry of 10.0 g. (0.025 mole) of finely powdered tribenzylmethylphosphonium bromide (I) in 100 ml. of liquid ammonia were added small pieces of sodium at a rate sufficient to allow the blue coloration to be discharged between additions. (A progressively deepening orange color was observed as successive portions of the sodium were discharged.) A total of 2.32 g. (0.101 mole) of sodium was consumed in 265 minutes. When additional sodium was added, no further reduction was observed in 2.5 hr. The ammonia was allowed to evaporate and water and ether were added to the residue. The ether layer (with a strong phosphine odor) was dried with sodium sulfate and was saturated with anhydrous hydrogen chloride. No precipitate was formed even after the solution had remained at 0° for a long time.

In a similar fashion, 20.0 g. (0.05 mole) of the bromide I was suspended in 200 ml. of liquid ammonia and was reduced with 2.30 g. (0.1 mole) of sodium (added in six portions). The mixture was stirred vigorously for 10 minutes after the discharge of each portion of sodium to ensure saturation of the solvent with starting material. After the ammonia was removed by evaporation, 100 ml. of water and 50 ml. of chloroform were added to the residue. The layers were separated and the aqueous layer was extracted with 100 ml. of ether. The combined organic solutions were treated with 7.1 g. (0.075 mole) of methyl bromide, and the mixture was allowed to stand in a tightly stoppered flask for 40 hr. The oil which separated was removed and it crystallized when it was stored at -20°. Recrystallization from methylisobutylcarbinol yielded 4.45 g. (29%) of dibenzylidimethylphosphonium bromide (III), m.p. 138–141°. Further recrystallization from methylisobutylcarbinol-petroleum ether produced analytically pure III, m.p. 141–142°.

(6) The authors are grateful to Dr. Mary Aldridge and Kathryn Gardeman for the analyses. All melting points and boiling points are corrected.

Anal. Calcd. for $\text{C}_{16}\text{H}_{20}\text{BrP}$: C, 59.45; H, 6.24; Br, 24.73; P, 9.59. Found: C, 59.23; H, 6.37; Br, 24.61; P, 9.43.

In a similar experiment conducted without a nitrogen atmosphere, dibenzylmethylphosphine oxide (IV) was obtained in a 39% yield by the removal of the ammonia by evaporation after reduction, followed by the addition of water and the subsequent removal of the white solid thus obtained. Recrystallization from benzene-petroleum ether gave white needles of the phosphine oxide IV, m.p. 133.5–134.0°.

Anal. Calcd. for $\text{C}_{15}\text{H}_{17}\text{OP}$: C, 73.75; H, 7.02; P, 12.68. Found: C, 73.71; H, 6.75; P, 12.61.

Reduction of I with Sodium in Alcohol.—To a solution of 5.0 g. (0.0125 mole) of tribenzylmethylphosphonium bromide (I) in 40 ml. of warm anhydrous ethanol was added 0.58 g. (0.025 mole) of sodium in three portions. After all the sodium had reacted, 150 ml. of water was added and the resulting solution was extracted with two 150-ml. portions of ether. The organic solution was dried with Drierite, and the ether and ethanol were removed by evaporation. The oily residue gradually solidified when it was exposed to air. This material was recrystallized from benzene-petroleum ether to give 1.95 g. (64%) of dibenzylmethylphosphine oxide (IV) as white needles, m.p. 133.5–134.0°. This sample of IV showed no depression of melting point upon admixture with the oxide IV obtained from the sodium in liquid ammonia reduction described above.

Reduction of I with Sodium in Benzene.—A suspension of 5.0 g. (0.0125 mole) of tribenzylmethylphosphonium bromide (I) and 0.58 g. (0.025 mole) of sodium in 100 ml. of anhydrous benzene was heated under reflux for 5 hr. Since a few specks of sodium were unreacted, 10 ml. of anhydrous ethanol was then added. When all the sodium was consumed, 100 ml. of water was added. A solid, which was insoluble in either the aqueous or organic layer, was removed by filtration and was proved to be starting material, m.p. 228.5–229.5° (no depression with an authentic sample). The benzene layer was separated and the aqueous layer was extracted with ether. The combined organic solutions were concentrated by evaporation to give an oil which solidified when it was exposed to air. The solid was recrystallized from benzene-petroleum ether to give 1.85 g. (77% yield, when corrected for the amount of starting material recovered) of dibenzylmethylphosphine oxide (IV), m.p. 133.5–134.0°. This sample of IV showed no depression of melting point upon admixture with the substance obtained from sodium in liquid ammonia reduction described previously.

Dibenzylmethylphosphonium Bromide (III). A. By Reduction of Tribenzylmethylphosphonium Bromide (I) with Lithium Aluminum Hydride.—To a suspension of 10.0 g. (0.025 mole) of finely powdered tribenzylmethylphosphonium bromide (I) in 125 ml. of dry tetrahydrofuran was added 0.6 g. (0.0158 mole) of lithium aluminum hydride, and the mixture was heated under reflux for 5.5 hr. Most of the tetrahydrofuran was then removed by distillation, and the residue was treated cautiously with 100 ml. of commercial ether and 80 ml. of 20% sodium potassium tartrate solution. The layers were separated and the aqueous layer was extracted with 75 ml. of ether. The combined ether extracts were placed in a pressure bottle with 10 ml. of methyl bromide, and the mixture was allowed to stand at room temperature for 48 hr. The crystalline solid which was deposited was removed by filtration and recrystallized from methylisobutylcarbinol-petroleum ether to give 6.90 g. (85% over-all yield) of dibenzylmethylphosphonium bromide (III), m.p. 141–142°. There was no depression of the melting point when this material was mixed with an authentic sample of III. When diethyl ether was used as a solvent, the phosphonium compound I did not gradually dissolve (as was observed when tetrahydrofuran was used) and only a slight phosphine odor was detected after the reaction mixture was heated under reflux for 24 hr.

B. From Methylchlorophosphine.—Benzylmagnesium chloride was prepared from 24.3 g. (1.0 mole) of magnesium, 126.6 g. (1.0 mole) of freshly distilled benzyl chloride and 900 ml. of anhydrous ether. The reagent was cooled in an ice-bath while 53.8 g. (0.46 mole) of freshly distilled methylchlorophosphine, b.p. 77–79°, (Army Chemical Center,

Maryland) in 200 ml. of ether was added over a 2-hr. period with stirring. The mixture was stirred for an additional hour and then was hydrolyzed with 200 ml. of water and 300 ml. of a saturated ammonium chloride solution. The layers were separated and the aqueous layer was extracted with 200 ml. of ether. To the combined ether solutions was added 87.4 g. (0.92 mole) of methyl bromide, and this mixture was allowed to stand at room temperature in a stoppered flask for 48 hr. The solid was then collected by filtration and recrystallized from methylisobutylcarbinol-petroleum ether to yield 107 g. (72%) of dibenzylmethylphosphonium bromide (III), m.p. 141–142°.

Attempted Catalytic Reduction of III.—To a solution of 5.0 g. (0.016 mole) of dibenzylmethylphosphonium bromide (III) in 35 ml. of acetic acid (distilled from potassium permanganate) was added 2.5 g. of a freshly prepared 25% palladium-on-charcoal catalyst. The mixture was shaken in a hydrogen atmosphere at 100° and 900 lb./sq. inch for 15 hr. No uptake of hydrogen was observed and 92% of the starting material was recovered in pure form. Similar low pressure experiments with either III or tribenzylmethylphosphonium bromide (I) were unsuccessful.

Benzylmethylphosphine (V).—A mixture of 45.0 g. (0.14 mole) of finely powdered dibenzylmethylphosphonium bromide (III), 2.4 g. (0.063 mole) of lithium aluminum hydride and 300 ml. of dry tetrahydrofuran was heated under reflux for 5 hr. Most of the tetrahydrofuran was then removed by distillation and 300 ml. of commercial ether and 250 ml. of 20% sodium potassium tartrate solution were added cautiously. The layers were separated and the aqueous layer was extracted with two 100-ml. portions of ether. The combined ether solutions were dried with magnesium sulfate and the ether was removed by distillation through a 12-inch Vigreux column. The residue was fractionated through the same column to yield 17.1 g. (81%) of benzylmethylphosphine (V), b.p. 87–89° (10 mm.), n_D^{20} 1.5416 [reported⁷ b.p. 93–96° (12 mm.)].

Benzyltrimethylphosphonium Bromide (VI).—When 45.0 g. (0.14 mole) of dibenzylmethylphosphonium bromide (III) was reduced by the exact procedure described above, the ether extracts were not distilled but were treated directly with an excess of methyl bromide in a stoppered flask for 48 hr. The solid was removed by filtration and recrystallized from methylisobutylcarbinol-petroleum ether to yield 28.6 g. (83% over-all yield) of benzyltrimethylphosphonium bromide (VI), m.p. 223–225° (reported⁸ m.p. 222°).

Reduction of Benzyltrimethylphosphonium Bromide (VI) with Lithium Aluminum Hydride.—To a suspension of 18.0 g. (0.073 mole) of finely powdered benzyltrimethylphosphonium bromide (VI) in 100 ml. of dry tetrahydrofuran was added 1.52 g. (0.04 mole) of lithium aluminum hydride, and the mixture was heated under reflux for 3 hr. The reaction mixture was slowly fractionated through a 12-inch Vigreux column at a reflux ratio of 17:1. A total of 3.73 g. (67%) of trimethylphosphine, b.p. 40–43° (reported⁹ b.p. 37.8°), was collected.

Distillation was then continued to collect all material boiling below 65°. This crude material was combined with the lower boiling fraction of pure trimethylphosphine (VII) and the mixture, dissolved in 100 ml. of anhydrous ether, was placed in a flask equipped with a gas-inlet tube and Dry Ice condenser. Dry air was bubbled through the solution for 5 hr., and the crystalline trimethylphosphine oxide (VIII) which formed was removed by filtration. The solid was dried in a vacuum desiccator to give 5.10 g. (76% yield based on VI) of slightly impure trimethylphosphine oxide (VIII), m.p. 135–137° (sealed capillary). Recrystallization of this crude material from tetrahydrofuran-ethyl acetate produced the pure oxide VIII, m.p. 137–138° (reported¹⁰ m.p. 137.5–138.5°).

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- (7) D. Jerchel, *Ber.*, **76**, 600 (1943).
 (8) G. W. Fenton and C. K. Ingold, *J. Chem. Soc.*, 2342 (1929).
 (9) E. J. Rosenbaum and C. R. Sandburg, *THIS JOURNAL*, **62**, 1622 (1940).
 (10) A. B. Burg and W. E. McKee, *ibid.*, **73**, 4590 (1951).