such cases the aromatic ring becomes electron deficient and may act as an acceptor in charge-transfer complexation. Whether or not this effect, with dioxane acting as donor, accounts for the large dipole moments of these molecules is problematical.

Early in this study it was speculated that an enolized form of the imide might be stabilized by intramolecular hydrogen bonding in 3-fluorophthalimide and 3-nitrophthalimide. There is no chemical evidence for such enolization, however, and concurrent ultraviolet and infrared studies by one of us (L. Y. S.) failed to reveal any spectral evidence for it. Construction of models[34] of the enol forms showed that the enol hydrogen cannot be properly oriented to permit hydrogen bonding, either to a fluorine atom or to a nitro group in the 3 position.

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Synthesis of Phosphine Oxides from Phosphorus Esters and Alkyl Halides Using Either Sodium Bis(2-methoxyethoxy)aluminum Hydride or Sodium Aluminum Diethyl Dihydride[1,2]

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Procedures are presented by which phosphorus esters (phosphates, phosphonates, and phosphinates) may be converted to phosphine oxides by reduction with either sodium bis(2-methoxyethoxy)aluminum hydride or sodium aluminum diethyl dihydride followed by addition of an appropriate primary or secondary alkyl halide. Yields are generally comparable to those obtained using a Grignard approach to the same conversions, but the procedures described offer the advantages of greater convenience and experimental simplicity. A number of examples of the synthetic method are presented including the preparations of the phosphorus-containing heterocycles, 1-phenylphospholane 1-oxide, and 1-phenylphosphorinane 1-oxide.

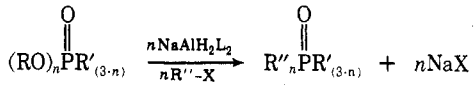
Only a few general approaches to the syntheses of phosphine oxides exist. The Arbuzov reaction of an alkyl halide with an ester of a phosphinous acid,[4] while giving respectable yields of phosphine oxides, is often rendered infeasible by the difficulty in obtaining the necessary phosphinate. Alkaline hydrolysis of quaternary phosphonium salts[5] likewise is only useful if an appropriate phosphonium salt is readily available. The reaction of Grignard reagents with various phosphorus esters[6] is generally more viable than the above methods, but it too has some disadvantages: there is an extra step, the synthesis of the Grignard reagent, and this reagent usually must be employed in large excess in the reaction with the phosphorus ester.[6,7]

We would like to report a new general procedure for the synthesis of phosphine oxides using the aluminum hydride reagents $NaAlH_2(CH_2CH_3)_2$ and $NaAlH_2(OCH_2CH_2OCH_3)_2$. Since some workers have encountered difficulties in attempting to carry out reactions with particular Grignard reagents or particular leaving groups on phosphorus, this new procedure complements the procedure using Grignard reagents. The procedure involves initial reaction of a phosphorus ester (phosphate, phosphonate, or phosphinate) with one of these two aluminum hydride regents to form an intermediate which subsequently reacts with an alkyl halide to form new carbon–phosphorus bonds. In Scheme I, R′ may be alkyl or aryl, and R″ may be a primary or secondary alkyl halide.

Results and Discussion

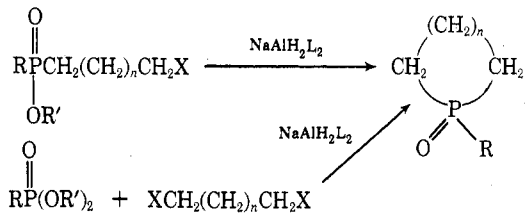
Addition of either $NaAlH_2(CH_2CH_3)_2$ or $NaAlH_2(OCH_2CH_2OCH_3)_2$ to a solution of a phosphinate

Scheme I



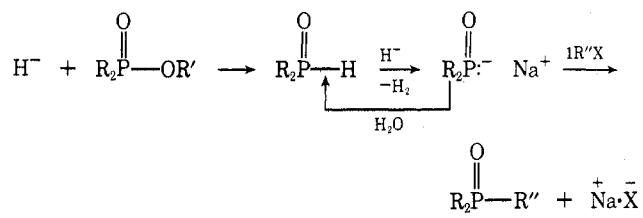
RR′P(O)OR″ in tetrahydrofuran in a 1:1 molar ratio gives the evolution of 1 molar equiv of hydrogen gas. Subsequent addition of an alkyl halide to this solution gives an opaque reaction mixture which, upon hydrolysis, yields a phosphine oxide (Scheme I). A number of examples of such reactions using phosphinates, phosphonates, and phosphates as starting materials are given in the Experimental Section. Yields range from 11 to 52% of isolated products. Additional examples have been reported elsewhere.[8]

Scheme II



The procedure is an especially convenient route to certain types of phosphorus-containing heterocycles, as shown in Scheme II. Both phosphorinanes (n = 3) and phospholanes (n = 2) have been prepared by these approaches.

Scheme III

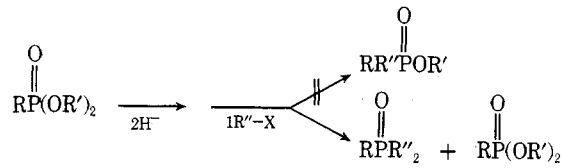


This general behavior is consistent with a mechanism, as shown in Scheme III, involving an intermediate sodium alkylarylphosphine oxide, analogous to the sodium dialkylphosphates used in the Michaelis–Becker reaction.[9] After initial displacement of alkoxide with hydride, a second hydride, acting as a base, removes the new, relatively acidic proton on phosphorus, forming the sodium dialkylphosphine oxide. There is a precedent for both this and the subsequent step in the reaction of R(R′O)P(O)H with R″-X and sodium hydride in dimethylformamide to give R(R′O)P(O)R″.[10] Once formed, the sodium dialkylphosphine oxide would be expected to react with the alkyl halide in a nucleophilic substitution to give phosphine oxide and sodium halide. Reactions involving attack by R(R′O)P(O)Na on alkyl halides to give phosphinates[11] and by RR′P(O)Na to give phosphine oxides,[12] for example, are known.

The mechanism is further supported by the following experiment. Quenching a reaction mixture of $NaAlH_2(OCH_2CH_2OCH_3)_2$ and a phosphinate with H_2O gave secondary phosphine oxide such as that proposed as an intermediate above, and reaction of this secondary phosphine oxide with additional reducing agent, followed by addition of an alkyl halide, gave phosphine oxide (see Scheme III).

The tremendous influence exerted by the cation in the alkylation chemistry of enolates[13] suggests that the sodium cation of these aluminum hydride reagents is necessary for the success of the phosphorus anion alkylation reaction. It is known that phosphorus esters, when treated with $LiAlH_4$, are generally reduced all the way to the phosphine.[14] The reaction can be stopped at the hydrogen phosphine oxide by conducting the reaction at 0°,[15] and treatment at this stage with an aklyl halide gives at least some alkylation as shown by examining a crude reaction mixture by mmr spectroscopy. In our hands this $LiAlH_4$ reaction is impractical as a synthetic route to phosphine oxides. It is because the reaction with sodium aluminum hydride proceeds completely to the sodium phosphorus anion and is stable at that point toward further reduction[16] that the new reaction is synthetically feasible.

Scheme IV



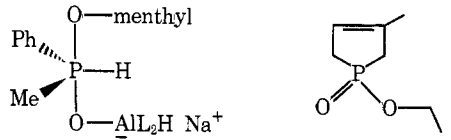
The sequence of events leading to dialkylation of a phosphonate to yield phosphine oxide (Scheme IV) is not so readily apparent. In our hands, many attempts to prepare phosphinates from phosphonates, by controlling stoichiometry and reaction conditions, have led only to a mixture of phosphine oxide (dialkylation) and starting material.[17] Addition of 1 molar equiv of aluminum hydride reagent to a phosphonate gave hydrogen evolution as usual. When bubbling had ceased, 1 molar equiv of alkyl halide was added, and precipitation of sodium halide was immediately noted, but no further evolution of gas was observed. Work-up of the reaction after a reaction time sufficient to give 90% of the theoretical amount of sodium halide gave a 25% yield of the dialkylated product and some starting material but no monoalkylated phosphinate. This evidence suggests that the phosphinate is not even formed as an intermediate, since no hydrogen evolution is observed after addition of the alkyl halide. Attempts to isolate an intermediate, by hydrolyzing the reaction mixture instead of adding alkyl halide, gave no recovery of any organic-soluble phosphorus-containing species.

The chief advantages of the new method are the ready availability and reasonable cost of the starting materials and the experimental simplicity of the one-pot reaction. All the solutions involved in the reaction are homogenous and easily handled. The work-up is simple and fast, and the conditions are very mild. In contrast to the Grignard synthesis, the new reaction generally proceeds with a 1:1 molar ratio of reactants, although reaction time can be cut down by using a 2–3 molar excess of alkyl halide. Yields are similar to those obtained in the Grignard procedure.

The chief disadvantage of the procedure is the extremely unpleasant odor encountered, presumably due to the presence of some reduced phosphorus species in the reaction mixture. Even with the precaution of conducting all aspects of the reaction in the hood, it is practically impossible to prevent some spread of the odor.

The Grignard procedure remains the method of choice in the preparation of optically active phosphine oxides. Attempts to convert an optically active menthyl phosphinate, prepared following the procedure of Mislow,[7] to an optically active phosphine oxide, led to racemized product. Racemization could be occurring either during the initial reduction, *via* stereomutation of the presumed intermediate phosphorane 1 (analogous to that proposed to explain racemization of recovered starting material in the $LiAlH_4$ reduction of phosphine oxides)[18] or after forma-

tion of the phosphine oxide.[18] The present results cannot distinguish among these possibilities.



1

2

The aluminum hydride reaction failed to give alkylation with *tert*-butyl bromide, giving, after work-up, the phosphinic acid of the starting phosphinate. Attempted alkylation of 1-ethoxy-1-oxo-3-methyl-3-phospholene[19] (2) gave no isolable phosphorus compound. Since several similar saturated phosphorus esters alkylated cleanly, it is likely that the carbon–carbon double bond is interfering in the phospholene reaction.

Attempts to alkylate a cyclic four-membered ring phosphinate were complicated by a great amount of apparent polymerization. It may be that strain in the ring renders the intermediate anion especially unstable. This may also be a factor in the failure of the phospholene reaction, since it appears to be a general rule that a double bond in a phosphorus-containing five-membered ring increases the strain in the ring.[20]

Although most of the examples described in the Experimental Section use $NaAlH_2(OCH_2CH_2OCH_3)_2$ as the reducing agent, the reagent of choice in these reactions seems to be $NaAlH_2(CH_2CH_3)_2$. While it is much more sensitive to air than the $NaAlH_2(OCH_2CH_2OCH_3)_2$, with respectful handling the former presents no danger and bestows the definite advantage of a cleaner hydrolysis mixture. Hydrolysis of $NaAlH_2(OCH_2CH_2OCH_3)_2$ reactions gives high-boiling 2-methoxyethanol, which must generally be removed by vacuum distillation at some point. The hydrolysis of $NaAlH_2(CH_2CH_3)_2$ reactions gives ethane gas, so that removal of volatile solvents after filtration of aluminum salts gives relatively uncontaminated product directly. Yields of final product, whenever direct comparisons have been made, are unaffected by choice of aluminum hydride reagent.

Experimental Section

General Methods. Microanalyses were performed by the Microanalytical Laboratory, Department of Chemistry, University of California, Berkeley, Calif. Proton nmr spectra were measured using either a Varian T-60 or A-60A spectrometer, with CCl_4 or $CDCl_3$ as solvent and tetramethylsilane as internal standard, unless otherwise specified. Hydrogen gas was detected using a Consolidated Model 21-103c mass spectrometer. Accurate mass measurements were determined on a Consolidated Model 21-110B double-focusing high-resolution spectrometer. Melting points are uncorrected.

Materials. Sodium bis(2-methoxyethoxy)aluminum hydride, a 70% solution in benzene, was obtained from Eastman. Sodium aluminum diethyl dihydride, a 25% solution in toluene, was purchased from the Ethyl Corp., Baton Rouge, La. Methyl methylphenylphosphinate was the generous gift of Dr. J. A. Virgilio, University of California, Berkeley. Diethyl benzylphosphonate, diethyl phenylphosphonite, and triethyl phosphate were purchased from Aldrich Chemical Co. Diethyl phenylphosphonate was prepared by esterification of phenylphosphonic dichloride (Aldrich) by the method of Kosolopoff and Huber.[21]

Aluminum Hydride Reductions—General Procedures. All the aluminum hydride reactions were run under a nitrogen atmosphere. It most cases no special precautions were taken to dry glassware or solvents, since a slight excess of reducing agent effectively removed water from the reaction. In some of the high-dilution cyclization reactions, however, the tetrahydrofuran (THF) solvent was dried by several hours of heating at reflux over lithium aluminum hydride followed by distillation from $LiAlH_4$ directly into a previously dried flask.

Both aluminum hydride reagents, $NaAlH_2(OCH_2CH_2OCH_3)_2$ and $NaAlH_2(CH_2CH_3)_2$, have a tendency to lose potency over a period of time after they are first opened. Satisfactory results were obtained by assuming freshly opened reagents to be of the strength indicated on the bottle. The strength of old reagent can be determined in a number of ways. Titration with a proton source such as methanol, with collection of evolved hydrogen gas, is one means. In most cases, a convenient alternative is to assume that the reagent is at its maximum strength, and use it in the reaction with the phosphorus ester. After initial addition is complete, but before adding the alkyl halide, a small aliquot of reduced ester can be worked up as discussed below; an nmr spectrum of the crude oil will indicate the amount of unreacted phosphorus ester. Comparison of the integrated area of the remaining ester protons with some other protons in the molecule gives an indication of the amount of unreacted phosphorus ester, and thus the amount of additional reagent necessary. Finally, since neither reagent is very reactive toward alkyl halides[22] or the product phosphine oxides, there is no harm in using more hydride reagent than necessary.

Hydrolysis is generally accomplished by adding water in small increments to the stirring reaction mixture at 25°. In reactions in which $NaAlH_2(CH_2CH_3)_2$ is the reducing agent, precautions should be taken to avoid the consequences of frothing due to the evolution of ethane. A reaction flask two–three times the volume of the solvent used allows plenty of room for frothing. Near the end of hydrolysis the aluminum salts polymerize and the solution becomes very viscous. Addition of a little more water and continued stirring returns the mixture to a lower viscosity. At this point the hydrolyzed mixture is filtered, and the aluminum salts are washed with $CHCl_3$. Occasionally a second filtration is necessary to remove all the aluminum salts.

When $NaAlH_2(OCH_2CH_2OCH_3)$ is used, it is necessary to evaporate the oily residue *in vacuo* to remove the high-boiling hydrolysis product, 2-methoxyethanol. Alternatively, this can be removed as the forerun of a fractional distillation.

Benzylmethylphenylphosphine Oxide. To a stirred solution of 1.60 g (9.4 mmol) of methyl methylphenylphosphinate in 150 ml of THF at 65° was added dropwise over a period of 25 min a solution of 11.3 mmol of $NaAlH_2(OCH_2CH_2OCH_3)_2$ in 50 ml of THF. Vigorous bubbling due to the evolution of hydrogen, detected in one case by a mass spectrometric analysis, occurred throughout the addition. When all the hydride solution had been added, stirring was continued several minutes until bubbling stopped; then a solution of 1.42 g (11.3 mmol) of benzyl chloride in 15 ml of THF was added. The solution, which became cloudy with NaCl after several minutes, was stirred at 65° for 3 hr. Hydrolysis of the stirring reaction mixture at 25° with a minimum amount of water (1–2 ml), followed by filtration (and a wash of the aluminum salts with 50 ml of $CHCl_3$, which was added to the filtrate) and removal of solvent, left an impure white solid which, upon crystallization from hexane–benzene, gave 1.13 g (52% yield based on phosphinate) of benzylmethylphenylphosphine oxide, mp 136–141° (lit.[23] 148–149°). Recrystallization raised the melting point range to 142–144°. In an analogous reaction in which the $NaAlH_2(OCH_2CH_2OCH_3)_2$ was replaced by $NaAlH_2(CH_2CH_3)_2$, virtually the same yield of this product was obtained. The nmr spectrum showed peaks at δ 1.52 (3 H, d, J_{PCH} = 13 Hz), 3.21 (2 H, d, J_{PCH} = 15 Hz), 7.11 (5 H, broad s), and 7.40 (5 H, m).

Ethylmethylphenylphosphine Oxide. Using the same general procedure as in the preparation above, but with toluene as solvent, 6.2 g (0.0365 mol) of methyl methylphenylphosphinate, 12 ml (0.043 mol) of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution, and 8 ml (0.107 mol) of ethyl bromide were allowed to react; the reaction mixture was heated at 55–60° for 17 hr. Hydrolysis, filtration, and removal of solvent left a crude oil which, upon fractional distillation, gave 2.47 g (40.5% yield) of ethylmethylphenylphosphine oxide, bp 110–112° (0.3 mm). The product was characterized by accurate mass measurement of its parent ion: calcd for $C_9H_{13}OP$, 168.0724; found, 168.0724. The nmr spectrum showed peaks at δ 1.06 (3 H, m), 1.73 (3 H, d, J_{PCH} = 13 Hz), ~1.83 (2 H, m), and 7.64 (5 H, m).

Dibutylbenzylphosphine Oxide. To 10.25 g (0.045 mol) of diethyl benzylphosphonate in THF was added 15.6 g (0.054 mol) of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution. After bubbling had ceased, 12.3 g (0.09 mol) of *n*-butyl bromide was added, and the cloudy reaction mixture was stirred at 55° under N_2 for 10 hr. The oil obtained on work up was fractionally distilled to give 1.0 g of starting phosphonate, bp 108–111° (0.3 mm), and 1.72 g of dibutylbenzylphosphine oxide, bp 145–154° (0.4 mm). This corresponds to a 17% yield based on unrecovered phosphonate. The phosphine oxide was crystallized from petroleum ether, giving long needles, mp 57–60°. The product was analyzed by accurate mass measurement of its mass spectral parent ion: calcd for $C_{15}H_{25}OP$,

252.1690; found, 252.1693. The nmr spectrum showed peaks at δ 0.91 (6 H, t, J = 6 Hz), 1.53 (12 H, m), 3.14 (2 H, d, J = 15 Hz), and 7.28 (5 H, s).

Dibutylphenylphosphine Oxide. Using 8.0 g (0.037 mol) of diethyl phenylphosphonate, 13 g (0.045 mol) of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution, and 10.5 g (0.076 mol) of *n*-butyl bromide, 1.25 g of dibutylphenylphosphine oxide was prepared by the same procedure as that used for benzyldibutylphosphine oxide. This corresponds to a 23% yield of phosphine oxide, based on unrecovered phosphonate: bp 147–150° (0.7 mm); mp 50–52°. The product was analyzed by accurate mass measurement of its mass spectral parent ion: calcd for $C_{14}H_{23}OP$, 238.1509; found, 238.1515. The mmr spectrum showed peaks at δ 0.90 (6 H, t, J = 6 Hz), 1.66 (12 H, m), and 7.65 (5 H, m).

1-Phenylphosphorinane 1-Oxide. A 250-ml round-bottom flask containing 100 g (0.43 mol) of 1,5-dibromopentane was fitted with a reflux condenser, on top of which was placed a pressure-equalizing addition funnel containing 21.5 g (0.109 mol) of diethyl phenylphosphonite. With stirring at 150–155° under nitrogen, the phosphonite was added dropwise over a period of 30 min, and stirring at 150° was continued for an additional 15 min. The excess dibromide was removed by vacuum distillation. A solution of the residue in CCl_4 was cooled for 6 hr, giving a clear supernatant over a thick oil. The supernatant was concentrated to give 22 g of 95% pure ethyl (5-bromopentyl)phenylphosphinate, as judged by nmr spectroscopy. The nmr showed peaks at δ 1.29 (3 H, t, J = 7 Hz), 1.73 (8 H, m), 3.39 (2 H, m), 3.97 (2 H, m), and 7.62 (5 H, m).

The phosphinate decomposed with evolution of ethyl bromide on attempted vacuum distillation, but this partially purified oil was sufficiently pure for the subsequent synthesis.

A three-neck, 2-l. round-bottom flask was fitted with two pressure-equalizing addition funnels and a mechanical stirrer. In one funnel was placed a solution of 10.6 g (0.033 mol) of the above-prepared phosphinate in 90 ml of THF, and in the other 10.6 g (0.037 mol) of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution in 90 ml of THF. These reactants were added simultaneously over a period of 1 hr to 500 ml of refluxing THF. The reaction mixture was heated at reflux for an additional hour, then stirred at room temperature for 6 hr. Work-up gave 7.7 g of oil, which upon fractional distillation started to sublime in the condenser after several forerun fractions were collected. The distillation residue was transferred at this point to a sublimation apparatus, and 1.80 g (28% yield) of 1-phenylphosphorinane 1-oxide was collected: bp 141° (0.2 mm); mp 125–127° [lit. bp 140° (1.0 mm); mp 130°].[21] The nmr spectrum showed peaks at δ 1.92 (10 H, m) and 7.72 (5 H, m).

1-Phenylphospholane 1-Oxide. Using a procedure analogous to the synthesis of ethyl (5-bromopentyl)phenylphosphinate, 35 g of diethyl phenylphosphonite and a fourfold excess of 1,4-dibromobutane were converted to 38 g of 90–95% pure ethyl (4-bromobutyl)phenylphosphinate, a yield of *ca.* 75%. The nmr spectrum showed peaks at δ 1.25 (3 H, t, J = 7 Hz), 1.92 (CH, m), 3.39 (2 H, m), 3.95 (2 H, m), and 7.64 (5 H, m). This ester was not further characterized and was used directly in the next step of the synthesis.

The ester was treated with $NaAlH_2(OCH_2CH_2OCH_3)_2$ as in the above procedure to give a 27% yield of 1-phenylphospholane 1-oxide, bp 140–150° (0.3 mm) [lit. bp 99–100° (0.15 mm)].[22] The nmr spectrum showed peaks at δ 1.95 (8 H, m) and 7.71 (5 H, m).

Ethyl (3-Bromopropyl)phenylphosphinate. Using 50.5 (0.255 mol) of diethyl phenylphosphonite and 250 g (1.24 mol) of 1,3-dibromopropane, 56 g (76% yield based on phosphonite) of ethyl (3-bromopropyl)phenylphosphinate was prepared by a Michaelis–Arbuzov reaction analogous to that used to prepare ethyl (5-bromopentyl)phenylphosphinate. The nmr spectrum showed peaks at δ 1.23 (3 H, t, J = 7 Hz), 2.07 (4 H, m), 3.45 (2 H, m), 3.94 (2 H, m), and 7.83 (5 H, m). The mass spectral parent ion was accurately mass measured: calcd for $C_{11}H_{16}{}^{79}BrO_2P$, 290.0062; found, 290.0048. This product was further characterized as described below.

2-Phenyl-1,2-oxaphospholane 2-Oxide. In order to characterize ethyl (3-bromopropyl)phenylphosphinate, which like similar compounds was too thermally unstable to be purified by distillation, 18 g (0.062 mol) of the slightly impure ester was heated at 200° for 1 hr. The residue was vacuum distilled to give 6.5 g (0.036 mol, 58% yield) of 2-phenyl-1,2-oxaphospholane 2-oxide, bp 157° (0.7 mm). *Anal.* Calcd for $C_9H_{11}O_2P$: C, 59.40; H, 6.05; P, 17.03. Found: C, 59.26: H, 5.98; P, 16.96. The nmr spectrum showed peaks at δ 2.10 (4 H, m), 4.38 (2 H, m), and 7.58 (5 H, m).

Attempted Synthesis of 1-Phenylphosphetane 1-Oxide. This reaction was carried out starting with ethyl (3-bromopropylphenylphosphinate) exactly analogous to the procedure used to prepare 1-phenylphosphorinane 1-oxide, with the exception that the addition time was decreased to 45 min and the period of subsequent reflux was decreased to 45 min. After the usual work-up, a viscous oil was obtained which did not distil at 0.35 mm up to a temperature of 210°.

Isopropylmethylphenylphosphine Oxide. To 3.2 g (0.019 mol) of methyl methylphenylphosphinate in 5 ml of benzene at room temperature was added 18.4 ml of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution. Isopropyl bromide (7 g, 0.057 mol) was added, after bubbling had ceased, in 5 ml of benzene and the solution was heated at reflux for 3 hr. The standard work-up followed by distillation gave 0.56 g (16.5% yield) of isopropylmethylphenylphosphine oxide, bp 88–91° (0.1 mm). The product was analyzed by accurate mass measurement of its parent ion: calcd for $C_{10}H_{15}OP$, 182.0862; found, 182.0863. The nmr spectrum showed peaks at δ 1.06 (6 H, m), 1.63 (3 H, d, J_{PCH} = 13 Hz), ~1.75 (1 H, m), and 7.67 (5 H, m).

Tribenzylphosphine Oxide. A solution of 3.8 g (0.021 mol) of triethyl phosphate and 13.2 g (0.105 mol) of benzyl chloride in 5 ml of dry benzene was heated at reflux under N_2, and to this stirring solution was added 61 ml of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution over a period of 2 hr, after which heating at reflux was continued 14 more hr. The cooled reaction mixture was added to 300 ml of ether, and the ether solution was slowly hydrolyzed giving insoluble aluminum salts. The supernatant was reduced to an oil which was crystallized from ether–pentane to give 1.0 g (15.5% yield) of tribenzylphosphine oxide, mp 211–214° [lit. 213°,[24] 214°[25]]. The nmr spectrum showed peaks at δ 3.08 (6 H, d, J_{PCH} = 14 Hz) and 7.28 (15 H, broad s).

Methylphenylphosphine Oxide. To a solution of 3.5 g (0.021 mol) of methyl methylphenylphosphinate in 35 ml of THF at 0° was added dropwise over a 10-min period a solution of 7.4 g of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution in 10 ml of THF. After bubbling stopped, the mixture was hydrolyzed as usual and distilled, giving 1.38 g (51.5% yield) of methylphenylphosphine oxide, bp 93–102° (0.2 mm). Accurate mass measurement of the mass spectral parent ion confirmed its composition: calcd for C_7H_9OP, 140.0391; found, 140.0395. The proton nmr spectrum showed peaks at δ 1.92 (3 H, d of d, J_{PCH} = 15 Hz, J_{HPCH} = 5 Hz), 7.58 (5 H, m), and 7.72 (1 H, d of q, J_{PH} = 478 Hz, J_{HPCH} = 5 Hz).

Benzylmethylphenylphosphine Oxide from Methylphenylphosphine Oxide. To 1.60 g (0.012 mol) of methylphenylphosphine oxide in 25 ml of THF at 25° was added 2.14 g of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution in 10 ml of THF. After bubbling had ceased, 3.1 g (0.025 mol) of benzyl chloride was added and the solution was stirred overnight. Work-up as usual gave 1.43 g (51% yield) of benzylmethylphenylphosphine oxide, which had identical spectral properties with those of the previously isolated material.

Attempted Synthesis of Optically Active Benzylmethylphenylphosphine Oxide. (*S*)-(−)-Menthyl methylphenylphosphinate was prepared following the procedure of Mislow and coworkers,[7] $[\alpha]^{23}D$ −98.7° compared to the literature value of −94°. A solution of 1.0 g (0.0034 mol) of this ester in 20 ml of THF was stirred vigorously at 35°, and to this stirring solution was added over a 45-min period a solution of 1.0 g of $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution in 20 ml of THF. Stirring was continued 15 min, after which was added at 30° 0.9 g (0.007 mol) of benzyl chloride. This reaction mixture was stirred at 25° for 43 hr and then worked up as usual. The product was recrystallized from benzene–hexane to give 0.256 g of (44% yield) benzylmethylphenylphosphine oxide, mp 136–140°, $[\alpha]^{23}D$ −3.0°, in MeOH, which should be compared to Mislow's value for (*R*)-(+)-benzylmethylphenylphosphine oxide of +51°. It is concluded that the phosphine oxide obtained was essentially racemized, perhaps completely, since the small optical rotation may be due to contamination by (−)-menthol expected as a side product.

Registry No.—$NaAlH_2(CH_2CH_3)_2$, 17836-88-3; $NaAlH_2(OCH_2CH_2OCH_3)_2$, 21608-56-0; benzylmethylphenylphosphine oxide, 33838-34-5; methyl methylphenylphosphinate, 6389-79-3; ethylmethylphenylphosphine oxide, 7309-49-1; ethyl bromide, 74-96-4; diethyl benzylphosphonate, 1080-32-6; dibutylbenzylphosphine oxide, 4042-81-3; *n*-butyl bromide, 109-65-9; dibutylphenylphosphine oxide, 10557-66-1; diethyl phenylphosphonate, 1754-49-0; 1-phenylphosphorinane 1-oxide, 4963-95-5; 1,5-dibromopentane, 111-24-0; ethyl (5-bromopentyl)phenylphosphinate, 51065-60-2; 1-phenylphospholane 1-oxide, 4963-91-1; 1,4-dibromobutane, 110-52-1; ethyl (4-bromobutyl)phenylphosphinate, 51065-81-7; ethyl (3-bromopropyl)phenylphosphinate, 51065-82-8; 1,3-dibromopro-

pane, 109-64-8; 2-phenyl-1,2-oxaphospholane 2-oxide, 16324-19-9; isopropylmethylphenylphosphine oxide, 36032-81-2; isopropyl bromide, 75-26-3; tribenzylphosphine oxide, 4538-55-0; triethyl phosphate, 78-40-0; benzyl chloride, 100-44-7; methylphenylphosphine oxide, 19315-13-0; (S)-(−)-menthyl methylphenylphosphinate, 16934-92-2; (±)-benzylmethylphenylphosphine oxide, 51153-50-5.

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(16) In one experiment the conversion of methyl methylphenylphosphinate to benzylmethylphenylphosphine oxide (see Experimental Section) was carried out with the modification that the phosphinate was added to the $NaAlH_2(OCH_2CH_2OCH_3)_2$ solution, followed, after bubbling had ceased, with addition of benzyl chloride, to give a 43% yield of the phosphine oxide.
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Two Syntheses of Optically Pure (1R,2R)-1,2-Dimethylcyclopentane

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Three syntheses of *trans*-1,2-dimethylcyclopentane are described, *viz.*, two syntheses of (1*R*,2*R*)-1,2-dimethylcyclopentane (*trans*-**12** ≡ **20**) and one of the racemic hydrocarbon. In the first synthesis (+)-pulegone was converted into (3*R*)-2,3-dimethylcyclopentanone, whose semicarbazone on Wolff reduction afforded a mixture of *trans*-**12** and *cis*-1,2-dimethylcyclopentane (*cis*-**12**). Formation of *cis*-**12** cannot be prevented because epimerization occurs during Wolff reductions of semicarbazones of α-alkyl ketones. In the second synthesis the title compound (**20**) was prepared from resolved 4-cyclohexene-1,2-dicarboxylic acid. One of the steps in this route was the $LiAlH_4$ reduction of (1*R*,2*R*)-4-cyclohexene-1,2-dimethanol ditosylate. Use of *N*-methylmorpholine instead of THF as a solvent saved labor and increased the yield considerably. **20** was found to have $[\alpha]D$ −51.5° ($CHCl_3$), in disagreement with a literature value of −35.2°. Racemic 2,3-dimethylcyclohexanone was used for the preparation of racemic **1** (and **2**) *via* 2,3-dimethylcyclopentanone.

Recently optically active *trans*-1,2-dimethylcyclopentane has been discovered in a crude oil.[1] The specific rotation found was 5.8° but a theoretical estimate made many years ago in this department resulted in a much higher value.[2] Therefore it became of interest to synthesize this substance. When we had completed the synthesis from (+)-pulegone (Scheme I) we became aware of a paper by Hill, *et al.*,[3] which we had overlooked before. In their work on the absolute configuration of the antibiotic sarcomycin they also prepared *trans*-1,2-dimethylcyclopentane from (+)-pulegone, but by a route different from ours. Taking absolute values, the angle of rotation we found was 45% higher than the highest value reported by Hill.[3] Therefore it became of importance to follow a second route to the same substance. The absolute configurations of the compounds are depicted in the schemes.[4]

The route we chose was an obvious extension of a synthesis used by Walborsky, *et al.*,[5] for the determination of the absolute configuration of resolved 4-cyclohexene-1,2-dicarboxylic acid (Scheme II). Both syntheses led to compounds with nearly identical values of the angle of rotation. Therefore it can be stated that the specific rotation of optically pure (1*R*,2*R*)-1,2-dimethylcyclopentane is $[\alpha]D$ −51.5° ($CHCl_3$).

Dimethylcyclopentane from Pulegone (Scheme I). Pulegone was hydrolyzed to give 3-methylcyclohexanone. The 6 position in this ketone was blocked by condensation with benzaldehyde, yielding α-benzylidene ketone.[6] Methylation of this compound gave a mixture of mono- and dimethylated product, together with unreacted α-benzylidene ketone. Oxidation of this mixture and decarboxylation of the acids obtained yielded a mixture of 3-methylcyclopentanone, 2,3-dimethylcyclopentanone, and 2,2,3-trimethylcyclopentanone. The ketones were separated by distillation. The semicarbazone of 2,3-dimethylcyclopentanone gave on Wolff reduction a mixture of optically active and meso dimethylcyclopentane (83.3:16.7). Corrected to chemical purity, *trans*-1,2-dimethylcyclopentane showed $[\alpha]D$ −51.2° ($CHCl_3$). Hill[3] reported $[\alpha]D$ −35.2° ($CHCl_3$). In the course of this investigation it became also of interest to study possible epimerization during Wolff-Kishner reductions. The results are described in the Experimental Section.

Dimethylcyclopentane from 4-Cyclohexene-1,2-dicar-