Carbon–Phosphorus Heterocycles. I. Synthesis and Resolution of 1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium Salts[1]

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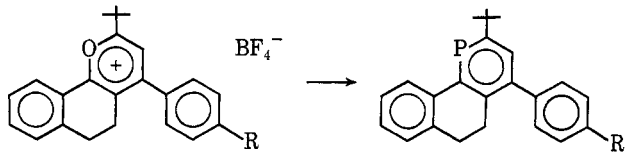
Synthesis of the novel C–P heterocycles, 1-ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium salts (**3a–c**), was achieved. Intramolecular quaternization proved to be successful for the crucial cyclization. Pyrolysis of the bromide salt **3a** gave 1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinoline (**14**). The corresponding phosphine oxide **15** was isolated as a result of partial oxidation of **14** in air. Partial resolution of **3a** was attained *via* silver hydrogen D(−)- and L(+)-dibenzoyltartrates. Several related potential precursors, [3-(2-naphthyl)-propyl]phosphonic acid (**17**), [3-(2-naphthyl)propyl]phosphonic dichloride (**18**), and [3-(2-naphthyl)propyl]-phosphonous dichloride (**19**), were also synthesized, but attempted cyclizations by cyclodehydration and cyclodehydrohalogenation were unsuccessful.

To date, the only C–P heterocycle reported in the phenanthrene family, where P is situated at the 4 position, is a phosphorin derivative **2**, synthesized by treating $P(CH_2OH)_3$ with the corresponding pyrylium fluoroborate **1** in pyridine.[4] However, there is difficulty

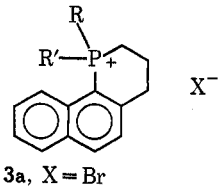


1 **2**

R = H, OCH_3, Cl, CH_3

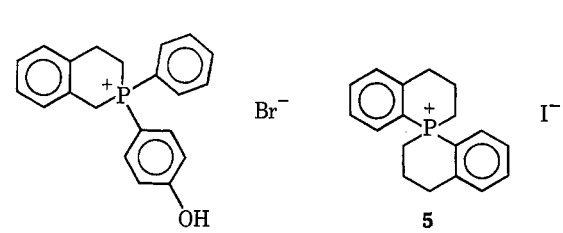
in preparing the necessary cyclic carboxonium salts and only phosphorin structures[4] could be obtained.

We elected to attempt the synthesis and resolution of 1-ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium bromide (**3a**). Although optically active



3a, X = Br
b, X = ClO_4
c, X = picrate
R = C_6H_5; R′ = C_2H_5

phosphonium salts are accessible since Kumli and coworkers[5] introduced the resolving agents silver hydrogen D(−)- and L(+)-dibenzoyltartrates (HDBTs), very little work has been reported on the resolution of cyclic quaternary phosphonium salts. To date, only two such salts are recorded. Holliman and Mann,[6] on one occasion, reported the resolution of **4** through its (+)-camphorsulfonate. However, later attempts to repeat its separation were unfruitful. *P*-spiro bis-1,2,3,4-tetrahydrophosphinolinium iodide (**5**) was successfully resolved *via* silver (−)-menthoxyacetate,[7a] but, it is to be noted that, in this case, the optical activity was attributed to the molecular dissymmetry of the P-spiro geometry rather than to a truly asymmetric phosphorus atom of the system [abcdP⁺]X⁻. Recently, an optically active 2,2,3,3,-tetramethylphosphetanium salt appeared in a brief communication[7b] on the study of its alkaline hydrolysis. Unfortunately, no method of resolution was reported. Partial resolution of **3a** was attained through its D(−)- and L(+)-HDBTs. This appears to be the first case reported in the literature to use silver D(−)- and L(+)-HDBTs to effect resolution of a dissymmetric cyclic phosphonium salt.



4 **5**

Results and Discussion

Synthesis and Structure Proof.—The synthesis of **3a** was accomplished as outlined in Scheme I. 2-(3-Bromopropyl)naphthalene (**6**) was prepared according to a known procedure[8] from 2-methylnaphthalene. Subsequent methoxylation followed by nuclear bromination in the presence of ferric bromide with the exclusion of light (ice cooling) afforded 1-bromo-2-(3-methoxypropyl)naphthalene (**8**) in good yield. The key intermediate **8** with bromine at C-1 was supported by the following evidence. (1) Electrophilic substitution in 2-substituted derivatives of naphthalene is known to be favored at the C-1 position for ortho-,-para-directing and activating substituents, since this is activated both by the substituent and by the second ring.[9] (2) The nmr spectra of certain substituted 1-bromonapthalene derivatives reported in the litera-

(1) We are very grateful for major support by a grant from the Cancer Institute, Grant CA 11967-07. We gratefully acknowledge initial support from an institutional grant from the American Cancer Society, Grant IN-91A.

(2) Continental Oil Company Fellow, summer, 1970. Submitted in partial fulfillment of the degree of Doctor of Philosophy in the Oklahoma State University, 1971.

(3) To whom inquiries should be directed.

(4) (a) W. Fischer and E. Hellner, *Tetrahedron Lett.*, 6227 (1968). (b) The subject of C–P heterocycles has been reviewed; see K. D. Berlin and D. M. Hellwege, "Topics in Phosphorus Chemistry," Vol. 6, M. Grayson and E. Griffith, Ed., Interscience, New York, N. Y., 1969, pp 1–186.

(5) K. F. Kumli, W. E. McEwen, and C. A. VanderWerf, *J. Amer. Chem. Soc.*, **81**, 248 (1959).

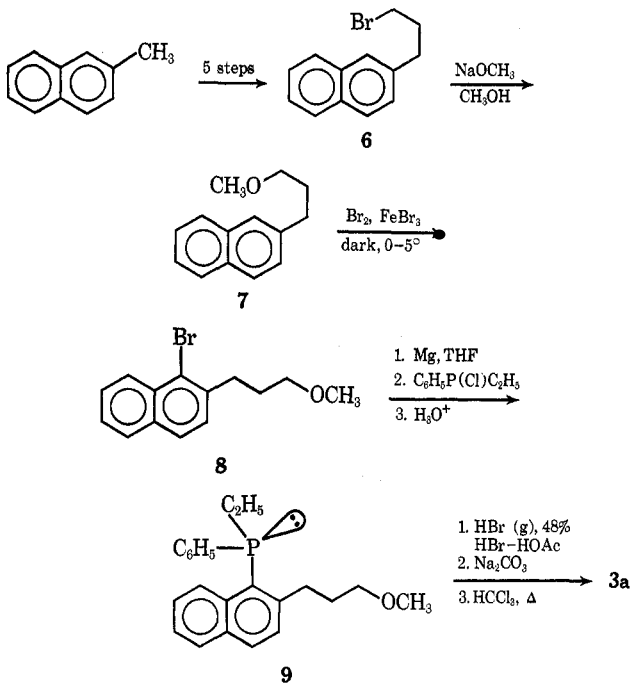
(6) F. G. Holliman and F. G. Mann, *J. Chem. Soc.*, 1634 (1947).

(7) (a) F. A. Hart and F. G. Mann, *ibid.*, 4107 (1955); (b) J. R. Corfield, J. R. Shutt, and S. Trippett, *Chem. Commun.*, 789 (1969).

(8) E. Campaign and B. G. Heaton, *J. Org. Chem.*, **29**, 2372 (1964).

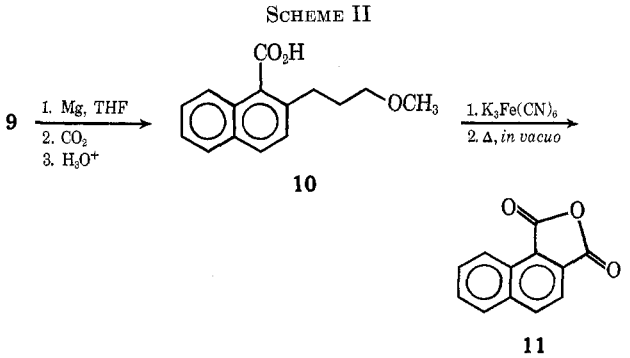
(9) P. B. D. de La Mare and J. H. Ridd, "Aromatic Substitution; Nitration and Halogenation," Academic Press, New York, N. Y., 1959, p 179.

SCHEME I

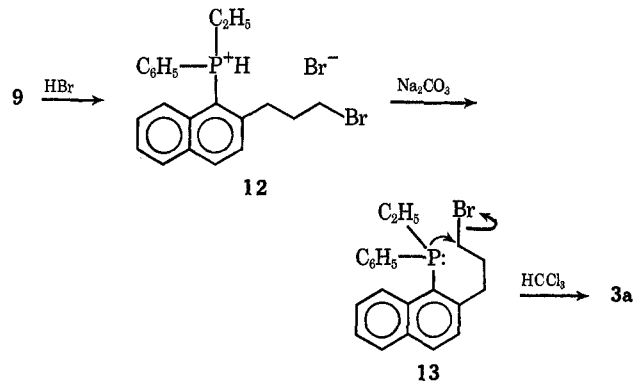


ture[10] seem to have a characteristic feature in that their C-8 protons (presumably influenced by the adjacent electronegative Br at C-1) usually resonate further downfield and are distinctly separated from the rest of the aromatic proton absorptions. This spectroscopic feature, which is also observed in **8** [δ 8.12–8.35 (m, 1) and 7.07–7.87 (m, 5)] is sufficiently distinguishing to permit one to differentiate Br at C-1 from other possible monobromo-substituted naphthalene derivatives resulting from the reaction. (3) The structure of **8** was further confirmed by the synthesis of 2-(3-methoxypropyl)-1-naphthoic acid (**10**) which was oxidatively degraded with potassium ferricyanide to 1,2-naphthalenedicarboxylic acid. The latter was dehydrated by vacuum sublimation to the known 1,2-naphthalenedicarboxylic anhydride (**11**) (Scheme II). The

SCHEME II



asymmetric phosphorus moiety was introduced by reacting ethylphenylphosphinous chloride[11] with the corresponding Grignard reagent from **8** to give **9** in 64% yield. The phosphine **9**, a high boiling and very viscous liquid, was not obtained in analytically pure form. Its structure was supported by nmr, ir, and mass spectral analyses. A sample purified by short-path distillation proved satisfactory and sufficiently pure enough for use in the subsequent cyclization. Intramolecular quaternization, which was first introduced in 1947[6] and later developed by Mann and coworkers,[12] was applied in effecting the crucial cyclization of **9** to the desired **3a**. The cyclization presumably involved the intermediate **12** which would result from cleavage of the methoxy group in **9** and simultaneous protonation of the phosphine moiety by HBr. The phosphine **13**, which would be generated



in situ by neutralizing **12** with base, could cyclize to **3a** by an intramolecular nucleophilic displacement process involving the ethylphenylphosphinous group. The evidence for the cyclization and the structure of **3a** is provided by nmr analysis in which the general absorption patterns of the substituted propyl group[13] ($ArCH_2CH_2CH_2Y$—namely, 2 triplets and a multiplet at region δ 2.0–4.5) and a sharp singlet for the methoxy group that appeared consistently in all the precursors **7**–**9** are absent. Due to the rigid cyclic system, the six nonequivalent protons of the methylene groups (2 protons are now adjacent to P) display a very complex splitting pattern as expected over the region at δ 1.54–4.7 (m, 6), $-\overline{PCH_2CH_2CH_2Ar}$. Other distinguishable characteristic proton absorptions are at δ 1.00, 1.32 (t, t, 3, J_{HCCH} = 7.5 and J_{PCCH} = 20.5 Hz, PCH_2CH_3) and 7.35–8.45 (m, 11, Ar H). It is interesting to note that, upon recrystallization of **3a** from $HCCl_3$–ether, a trace of a nonstoichiometric amount of $HCCl_3$ [but it could not all be removed even on heating at 100–102° (1.5–2 μ) for 90 hr] was incorporated in the crystalline salt as observed by mass spectral analysis. Thus, although the spectroscopic data were appropriate, the elemental analysis of the phosphonium bromide **3a** did not yield the theoretical results. Further proof of the structure was obtained by converting **3a** to the corresponding perchlorate **3b** and picrate **3c**. Excellent elemental analyses were obtained for these derivatives.

Pyrolyses of phosphonium bromides (or chlorides) bearing ethyl substituents are known to be useful in the syntheses of certain cyclic phosphines.[12,14] Upon decomposition, ethylene and HBr (or HCl) are given off and the residual phosphine, partly in the form of the HBr (or HCl) salt and partly in free form, when fully

(10) "The Sadtler Standard NMR Spectra," Sadtler Research Laboratories, Inc., Pa., 1967, No. 143, 2004, 2109, 2123, and 2124.

(11) L. Maier, *J. Inorg. Nucl. Chem.*, **24**, 1078 (1962).

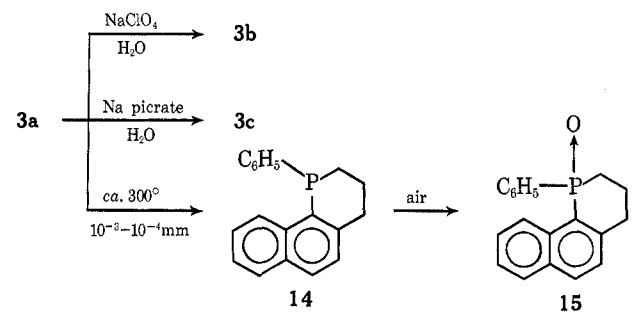
(12) M. H. Beeby and F. G. Mann, *J. Chem. Soc.*, 411 (1951); F. G. Mann and I. T. Millar, *ibid.*, 2205 (1951); F. G. Mann, I. T. Millar, and F. H. C. Stewart, *ibid.*, 2832 (1954); F. G. Mann, I. T. Millar, and H. R. Watson, *ibid.*, 2516 (1958).

(13) See ref 10, 1965, No. 116M and 237V.

(14) L. Maier, *Progr. Inorg. Chem.*, **5**, 99 (1963).

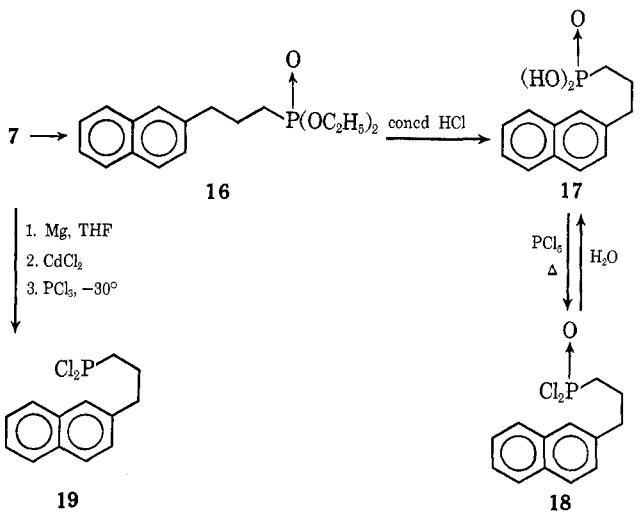
liberated with alkali, can be purified in the usual way. It was found that the phosphonium bromide **3a** decomposed smoothly near 300° under high vacuum (10^{-3}–10^{-4} mm) to give the cyclic phosphine, 1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinoline (**14**), which was purified by column chromatography (eluted with reagent hexanes) followed by recrystallization from the eluting solvent. The isolation of 1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinoline 1-oxide (**15**) was rather fortuitous. Apparently, it resulted from partial oxidation by air of the phosphine **14** during the work-up. The successful syntheses and characterizations of the corresponding cyclic phosphine **14** and its oxide **15** are confirmatory evidence for the structure of the precursor, namely 1-ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]-phosphinolinium bromide (**3a**) (Scheme III).

SCHEME III



Several potential precursors of related C–P heterocycles, such as **16**–**19**, were also synthesized (Scheme IV). However, their subsequent cyclizations *via*

SCHEME IV



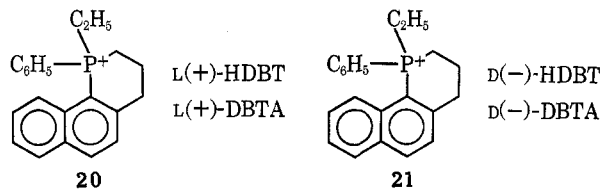
cyclodehydration[15] and cyclodehydrohalogenation[16] reactions were unsuccessful.[17] Attempted cyclization of **17** by heating *in vacuo* gave only polymeric mixtures.

(15) E. R. Lynch, *J. Chem. Soc.*, 3729 (1962) [British Patent 933,800 (1963)].

(16) I. G. M. Campbell and J. K. Way, *ibid.*, 2133 (1961); J. B. Levy, L. D. Freedman, and G. O. Doak, *J. Org. Chem.*, **33**, 474 (1968); I. Granoth, A. Kalir, Z. Pelah, and E. D. Bergmann, *Tetrahedron*, **25**, 3919 (1969); G. M. Kosolapoff, "Freidel-Crafts and Related Reactions," Vol. IV, G. A. Olah, Ed., Interscience, New York, N. Y., 1965, pp 213–233.

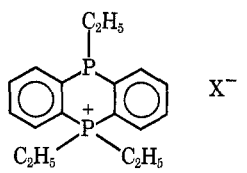
(17) The failure of **18** or **19** to cyclize is unusual since phosphorylation at C-1 in naphthalene is known; see J. Lindner and M. Strecker, *Monatsh. Chem.*, **53**, 274 (1929).

Resolution.—Partial resolution of a cyclic quaternary phosphonium bromide **3a** *via* silver D(−)- and L(+)-HDBTs was attained. Two diastereoisomeric salts **20** [mp 150° dec; $[\alpha]^{24.5}D$ + 83° [*c* 0.013, CH_3OH)] and **21** [mp 149–149.5° dec; $[\alpha]^{25}D$ −83° (*c* 0.0196, CH_3OH)] were synthesized and separated by treatment of



HDBT = hydrogen dibenzoyltartrate
DBTA = dibenzoyltartaric acid

the (+)-**3a** with excess Ag D(−)-HDBT and Ag L(+)-HDBT, respectively, in water. The identical melting point and opposite specific rotations of **20** and **21** strongly indicate their enantiomeric nature. The stoichiometric inclusion of 1 equiv of L(+)-DBTA found in the crystal of **20**, as revealed by its elemental analysis, is novel but not without precedent. A similar phenomenon was encountered by Davis and Mann[18] in the synthesis of 9,9,10-triethyl-9,10-dihydrophosphathrene picrate **22a**, **b**, in which 1 equiv of the picric acid was found included in **22a** and 1 equiv of sodium picrate was found in **22b**. While metathesis of **20**



22a, X = picrate–picric acid; mp 120–121°
b, X = picrate–sodium picrate; mp 209–210°

directly to the optically active phosphonium perchlorate **3b** (with NH_4ClO_4 in methanol) was unsuccessful (starting material **20** was quantitatively recovered), the metathesis to the dextrorotatory phosphonium bromide **3a** with NH_4Br in methanol did yield positive results. After two recrystallizations from $HCCl_3$–ether, the (+)-**3a** isolated had constant mp 259° dec and a specific rotation of $[\alpha]^{25}D$ + 28° (*c* 0.0175, $HCCl_3$). The structure of the resolved (+)-**3a** was supported by its ir spectrum which was essentially superimposable on that of the authentic (±)-**3a**. Further proof of the structure of (+)-**3a** was provided by its conversion to the corresponding perchlorate **3b** (mp 171.5–172.5°), which again had virtually the same ir spectrum as that of the authentic racemic **3b** (mp 159–159.5°). These data are additional evidence for the structure of (+)-**3a**. Additional work is in progress on these systems.

Experimental Section

Melting points are uncorrected and were determined on a Thomas-Hoover capillary melting point apparatus. Infrared spectra were obtained on a Beckman IR-5A spectrometer as films on sodium chloride or as potassium bromide pellets. Nuclear magnetic resonance spectra were determined on a Varian A-60 high-resolution spectrometer. Tetramethylsilane was used as an internal standard and chloroform-*d* was used as the solvent

(18) M. Davis and F. G. Mann, *J. Chem. Soc.*, 3770 (1964).

unless otherwise noted. Rotations were determined on a Rudolf Model 80 polarimeter at the sodium D line using a Curtin micro polariscope tube. Mass spectra were determined on an LKB-9000 prototype, single-focusing magnetic sector instrument. Commercial anhydrous ether and benzene were dried over sodium, and anhydrous THF was obtained by distilling the commercial reagent over $LiAlH_4$ immediately before use. Unless otherwise specified, commercial reagent grade chemicals were used directly without further purification. Micro thin layer chromatographic (tlc) plates were prepared with Merck silica gel PF_{254} (purchased from Brinkmann Instruments, Inc.) on 3 by 1 in. micro slides. Column chromatography separations were performed with Baker analyzed reagent silica gel (80–200 mesh). The solvent systems for tlc and column chromatography are listed where used. Gas–liquid chromatographic analyses were performed with a Varian Aerograph 1520 instrument. The column packing used was 5% SE-30 on 60–80, AW, DMCS-treated Chromsorb G (5 ft by 1/8 in.). Elemental microanalyses were determined by Galbraith Laboratories, Knoxville, Tenn., and Midwest Microlab, Inc., Indianapolis, Ind.

2-(3-Bromopropyl)naphthalene (6).—The bromide **6** was prepared as described by Campaign and Heaton[8] from 2-methylnaphthalene in five steps, namely, *via* 2-bromomethylnaphthalene, diethyl 2-naphthylmethylmalonate, 3-(2-naphthyl)propanoic acid, and 2-(3-hydroxypropyl)naphthalene. The nmr of the pure bromide, mp 42–43.5° (lit.[8] mp 43.5–44.5°), showed the expected proton absorptions (2-$C_{10}H_7CH_2CH_2CH_2Br$) at δ 2.0 (quint, 2, $CH_2CH_2CH_2$), 274 (t, 2, J = 7.5 Hz, CH_2CH_2Br), 3.19 (t, 2, J = 7 Hz, $ArCH_2CH_2$), and 7.05–7.88 (m, 7, Ar H).

2-(3-Methoxypropyl)naphthalene (7).—2-(3-Bromopropyl)-naphthalene (**6**) (10.3 g, 0.0414 mol) in 50 ml of CH_3OH–benzene (1:1 v/v) was added dropwise at room temperature under N_2 to 3.0 g (0.055 mol) of sodium methylate (Fisher purified reagent) dissolved in 120 ml of CH_3OH in a three-neck, round-bottom flask (fitted with a mechanical stirrer, N_2 inlet, condenser and $CaCl_2$ tube). The reaction could be followed by hydrolyzing (*ca.* 0.5 ml of H_2O) a sample (2–3 drops) taken from the reaction mixture intermittently and analyzing the organic product (in ether) by glc. A total of 25 hr of heating at 95–100° (sand bath) was required to bring the reaction to completion. The white suspension was decomposed by addition of H_2O (100 ml) with cooling (ice), followed by saturating with NaCl. The resulting mixture was extracted thoroughly with ether. The ethereal extract was washed with 10% NH_4OH and brine (until neutral), dried ($MgSO_4$), concentrated, and fractionated to give 6.9 g (83.5%) of the methyl ether **7**: bp 112–113° (0.8 mm); $n^{28.5}D$ 1.5751; ir 1120 cm^{-1} (COC); nmr (2-$C_{10}H_7CH_2CH_2CH_2OCH_3$) δ 1.90 (m, 2, $CH_2CH_2CH_2$), 2.75 (t, 2, $CH_2CH_2OCH_3$), 3.24 (t, 2, $ArCH_2CH_2$), 318 (s, 3, OCH_3), and 7.05–7.85 (m, 7, Ar H)

Anal. Calcd for $C_{14}H_{16}O$: C, 84.00; H, 8.00. Found: C, 83.96; H, 7.99.

1-Bromo-2-(3-methoxypropyl)naphthalene (8).—Light was carefully excluded during the experiment by covering the reaction vessels with black tape. Bromine (4.6 g, 0.029 mol) in CS_2 (12 ml) was added dropwise with stirring and ice cooling to a three-neck, round-bottom flask, equipped as usual, containing 5.3 g (0.0265 mol) of **7** in 15 ml of CS_2 and 0.2 g of anhydrous $FeBr_3$ (K&K Chem. Co.) under N_2. During the period of addition (1.25 hr), the temperature was kept below 5° and HBr evolution was observed in the reaction. After being stirred at ice bath temperature for 5 hr, the reaction mixture was decomposed by addition of 10% NaOH (15 ml) and extracted with ether. The ethereal extract was washed with H_2O (until neutral), dried ($MgSO_4$), evaporated, and distilled giving 5.6 g (76%) of **8**: bp 130–131° (0.15 mm); $n^{26}D$ 1.6057; ir 1118 cm^{-1} (COC); nmr [2-(1-$BrC_{10}H_6$)$CH_2CH_2CH_2OCH_3$] δ 1.96 (m, 2, $CH_2CH_2CH_2$), 3.0 (t, 2, $CH_2CH_2OCH_3$), 3.35 (t, 2, $ArCH_2CH_2$), 3.27 (s, 3, OCH_3), 7.07–7.78 (m, 5, Ar H), and 8.12–8.35 [m, 1, Ar H (C-8)].

An additional 1.0 g of slightly impure (87%) **8** was also obtained as a separate fraction and could be used in the next step leading to **9**.

Anal. Calcd for $C_{14}H_{15}BrO$: C, 60.21; H, 5.37; Br, 28.69. Found: C, 60.49; H, 5.39; Br, 28.65.

2-(3-Methoxypropyl)-1-naphthoic Acid (10).—The Grignard reagent was prepared by the usual method[19] from 1.7 g (0.0061 mol) of **8**, 0.149 g (0.0061 g-atom) of Mg turnings, and a trace of I_2 in 25 ml of anhydrous THF. Dry gaseous CO_2 was passed over the dark-brown Grignard reagent, which was vigorously stirred and maintained at about 0–5° (ice bath). A slight positive pressure of CO_2 was maintained throughout the reaction, which was practically complete within 1 hr as a distinctive color change from dark brown to dark green was noted. After being stirred for an additional 30 min under CO_2 (while the temperature rose to 10°), the reaction mixture was decomposed by adding dropwise 10% H_2SO_4 (25 ml) with ice cooling. The reaction mixture was extracted with ether, and the ethereal extract was washed with brine (until neutral) and extracted thoroughly with saturated aqueous $NaCO_3$. The base extracts, after being washed with ether (to remove any neutral organics), was acidified (20% H_2SO_4) carefully and extracted with ether. The ethereal solution was dried ($MgSO_4$) and evaporated, and the last traces of ether were removed *in vacuo* to give 1.35 g (87%) of the carboxylic acid **10**. The product thus collected was shown to be pure by tlc analysis ($HCCl_3$). The ir spectrum showed the characteristic band for the carboxylic acid group at 2500–3500 cm^{-1}, and the nmr spectrum [2-(1-CO_2H-$C_{10}H_6$)$CH_2CH_2CH_2OCH_3$] displays expected proton absorptions at δ 2.05 (m, 2, $CH_2CH_2CH_2$), 3.02 (t, 2, $CH_2CH_2OCH_3$), 3.46 (t, 2, $ArCH_2CH_2$), 3.33 (s, 3, OCH_3), 7.2–8.3 (m, 6, Ar H), and 11.2 (s, 1, COOH). An analytical sample of **10** [bp 168–172° (0.35 mm); $n^{30}D$ 1.5888] could be obtained by short-path distillation.

Anal. Calcd for $C_{15}H_{16}O_3$: C, 73.77; H, 6.56. Found: C, 73.66; H, 6.47.

Oxidative Degradation of 10. Preparation of 1,2-Naphthalenedicarboxylic Anhydride (11).—The procedure was essentially that of Cope.[20] The acid **10** (0.135 g, 0.55 mmol), 7.1 g of $K_3Fe(CN)_6$, and 1.26 g of KOH were dissolved in 26 ml of distilled H_2O in a 50-ml, round-bottom flask (fitted with a magnetic stirrer and a condenser). After being warmed at 70–75° (oil bath) for 66 hr, the turbid dark-orange reaction mixture was filtered. The clear filtrate, after being carefully acidified (concentrated HCl), was extracted with ether. Without drying, the ethereal solution was evaporated and the residue was carefully sublimed to give 0.1 g (91%) of crude anhydride **11**. The sublimate was recrystallized from ethanol to give light yellowish fine needles of pure **11**: mp 167–168° (lit.[21] mp 168°); ir 1830 and 1770 cm^{-1} (conjugated five-membered cyclic anhydride C=O). The structure of **11** was confirmed by mixture melting point determination (melting point undepressed) with the authentic sample of 1,2-naphthalenedicarboxylic anhydride.

Synthesis of Crude Ethyl [2-(3-methoxypropyl)-1-naphthyl]-phenylphosphine (9).—All the work-ups described in this experiment were performed under N_2. The Grignard reagent was prepared by the general method[19] from 1-bromo-2-(3-methoxypropyl)naphthalene (**8**) (6.7 g, 0.024 mol), 0.61 g (0.025 g-atom) of Mg turnings, and a few crystals of I_2 in 45 ml of anhydrous THF in a 100-ml three-neck, round-bottom flask equipped as usual. After being held at 75–80° (oil bath) for 2.5 hr, the dark-brown Grignard reagent was allowed to cool to around 20°. Ethylphenylphosphinous chloride [bp 73.5–74° (2.1–2.2 mm), prepared by the method of Maier,[11] lit. bp 73–75° (2 mm)], (4.15 g, 0.024 mol) in 25 ml of anhydrous benzene was added dropwise to the Grignard reagent with ice cooling in 30 min. The reaction mixture was stirred at room temperature overnight, and excess THF was distilled and replaced with ether–benzene (70 ml). After having been decomposed slowly with 30 ml of saturated NH_4Cl (ice cooling), the reaction mixture was separated, and the aqueous solution was extracted with more ether (250 ml). The combined ethereal extracts were washed with saturated Na_2CO_3 followed by brine (until neutral), dried ($MgSO_4$), concentrated, and distilled (short-path in high vacuum) to give 5.14 g (64%) of the crude phosphine **9** (an extremely viscous greenish liquid): bp 194–197° (0.063 mm); ir 1115 cm^{-1} (COC); nmr δ 0.86, 1.17 (t, t, 3, J_{PCCH} = 18.7, J_{HCCH} = 7.5 Hz, PCH_2CH_3), 1.96 (m, 2, $ArCH_2CH_2CH_2$), 2.35 (t, 2, $CH_2CH_2OCH_3$), 3.27 (s, 3, OCH_3), 3.39 (t, 2, $ArCH_2CH_2$), *ca.* 3.30 (m, 2, PCH_2CH_3), and 6.95–8.0 (m, 11, Ar H). While an analytical sample was difficult to obtain, further proof of the structure was provided by mass spectral analysis (70 eV), which shows an intense molecular ion at m/e 336 for the phosphine **9** and only a trace of impurity, m/e 352 (the oxidized product of **9**). The crude **9** was found suitable and pure enough for the next experiment.

(19) M. S. Kharasch and O. Reinmuth, "Grignard Reaction of Nonmetallic Substances," Prentice-Hall, New York, N. Y., 1954, Chapter II.

(20) A. C. Cope, *J. Amer. Chem. Soc.*, **78**, 2551 (1956).

(21) E. F. Bradbrook and R. P. Linstead, *J. Chem. Soc.*, 1739 (1936).

Cyclization of the Crude Phosphine 9. Synthesis of 1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium Bromide (3a).—All reactions described herein were performed under N_2. The crude ethyl[2-(3-methoxypropyl)-1-naphthyl]phenylphosphine (**9**) (1.75 g, 5.2 mmol) in 10 ml of glacial HOAc was heated at 120° (oil bath) with 50 ml of 48% HBr (Fisher reagent) in 300-ml three neck, round-bottom flask fitted with a magnetic stirrer, N_2 inlet, reflux condenser, $CaCl_2$ tube, and sintered glass gas inlet (half immersed in the reaction mixture). A gentle stream of anhydrous HBr (The Matheson Co.) was passed into the reaction mixture during the 2.5 hr period of reflux. Gaseous HBr was then removed and the slightly yellow, turbid reaction mixture was allowed to stir at room temperature overnight. Excess aqueous HBr and HOAc was distilled at 48° (35 mm). The concentrated reaction mixture (*ca.* 20 ml) was chilled with ice, taken up in $HCCl_3$ (50 ml), and neutralized carefully by adding dilute $NaHCO_3$ and solid $Na_2CO_3 \cdot H_2O$. Stirring was continued at room temperature for at least 1 hr before working up (as more $HCCl_3$ and H_2O were added). The colorless $HCCl_3$ extracts (*ca.* 200 ml) were carefully separated, dried ($MgSO_4$) heated (oil bath 75–80°), and concentrated under N_2. The residue, after the last trace of $HCCl_3$ being depleted *in vacuo* at room temperature, gave a white solid which was extremely hygroscopic. Recrystallization was achieved by carefully dissolving the crude bromide **3a** in a small amount of $HCCl_3$, filtering the insolubles, and following with the addition of anhydrous ether dropwise until cloudy. Colorless needles crystallized out overnight at room temperature. After being carefully collected on a sintered glass funnel and dried immediately *in vacuo* in the presence of P_2O_5 and wax chips, 1.0 g (2.6 mmol) of **3a**, mp 227.5–228.5° (melted to a brown liquid), was collected in yield of 50% (based on the crude phosphine **9**). The melting point was unchanged by further recrystallization. The phosphonium bromide **3a** is soluble in H_2O, CH_3OH, and C_2H_5OH; it is sparingly soluble in ethyl acetate and insoluble in ether. It gives a positive halogen test ($AgNO_3$). The nmr spectrum, δ 1.5–4.7 (m, 8, $\overline{PCH_2CH_2CH_2Ar}$ and PCH_2CH_3), 1.0, 1.32 (t, t, 3, J_{HCCH} = 7.5, J_{PCCH} = 20.5 Hz, PCH_2CH_3), and 7.35–8.45 (m, 11, Ar H), supported the proposed structure. However, a satisfactory elemental analysis was not obtained, as there was revealed the presence of a trace of a nonstoichiometric amount of $HCCl_3$ in the crystalline salt. $HCCl_3$ was not removed even by heating the bromide **3a** at 100–102° (1.5–2 μ) for 90 hr. Further proof of the structure of **3a** was obtained by analyses of its perchlorate and picrate derivatives **3b** and **3c**.

1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium Perchlorate (3b).—Excess saturated aqueous $NaClO_4$ was added dropwise to the phosphonium bromide **3a** (250 mg, 0.64 mmol) in *ca.* 5 ml of H_2O at room temperature with stirring. White solid immediately precipitated. After being filtered and carefully washed with distilled H_2O (to remove any excess $NaClO_4$ and unreacted bromide **3a**), the solid was dried *in vacuo* in the presence of P_2O_5 at 55° for 27 hr to give 205 mg (75%) of crude perchlorate **3b**, mp 156.5–158°. After two consecutive recrystallizations (slowly) from 2-propanol, 151 mg of pure **3b**, mp 159–159.5° was obtained. The melting point was unchanged by further recrystallization. Compound **3b** is soluble in $HCCl_3$ and CH_3OH, but not in benzene, ethyl acetate, H_2O, or 95% C_2H_5OH. The ir [1095 cm^{-1} (ClO_4^-)], and the nmr spectra (which is essentially identical with that of **3a**) [δ 0.94, 1.28 (t, t, 3, J_{HCCH} = 7.5, J_{PCCH} = 20.5 Hz, PCH_2CH_3), 1.5–3.7 (m, 8, $\overline{PCH_2CH_2CH_2Ar}$ and PCH_2CH_3), and 7.83–8.45 (m, 11, Ar H)] supported the structure of **3b**.

Anal. Calcd for $C_{21}H_{22}ClO_4P$: C, 62.30; H, 5.44; Cl, 8.78; P, 7.66. Found: C, 62.41; H, 5.23; Cl, 9.01; P, 7.42.

1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium Picrate (3c).—The picrate derivative **3c** was made by treating the bromide **3a** in H_2O with excess aqueous sodium picrate. Yellow precipitate immediately formed. The gummy solid, after being washed thoroughly with H_2O (to remove any excess sodium picrate and unreacted bromide) *via* decantation, was dried *in vacuo* in the presence of P_2O_5 at room temperature overnight. Attempted recrystallization of the gummy material from a variety of solvents was unsuccessful. However, when the crude **3c** was dissolved in a small amount of absolute C_2H_5OH and anhydrous ether was added dropwise until a very slight cloudiness appeared, yellow rhombic crystals of the pure picrate **3c**, mp 109.5–110.5°, slowly crystallized out. Repeated recrystallizations did not improve the melting point.

Anal. Calcd for $C_{27}H_{24}N_3O_3P$: P, 5.81. Found: P, 5.81.

Thermal Decomposition of 3a. 1,2,3,4-Tetrahydro-1-phenylbenzo[*h*]phosphinoline (14) and 1,2,3,4-Tetrahydro-1-phenylbenzo[*h*]phosphinoline 1-Oxide (15).—The bromide **3a** (0.3994 g, 1.03 mmol) in a 10-ml, round-bottom flask (fitted with vacuum autlet and stirrer) was heated in a sand bath (250–300°) under a diffusion pump vacuum of 1.5×10^{-4} mm. Decomposition occurred quite smoothly under these conditions as a colorless liquid was observed to reflux in the flask and gas evolution was also detected as soon as the solid began to melt. The decomposition was essentially complete within 30 min, as it could be followed conveniently by observing the rise in pressure (to *ca.* 0.2 mm) while the reaction was taking place, and finally returned to 7.5×10^{-4} mm as decomposition practically ceased. The reaction mixture was kept at the sand bath (290–308°) for another 25 min before heating was terminated. The mixture was taken up immediately in $HCCl_3$ and neutralized with 15 ml of saturated $NaHCO_3$ under N_2. The mixture was carefully separated and the aqueous solution was extracted twice with 30 ml of $HCCl_3$. The combined $HCCl_3$ extracts were dried ($MgSO_4$), evaporated, and purified by column chromatography (eluted with reagent hexanes) to give 80.6 mg (28% based on **3a**) of the phosphine **14**: mp 120–122°; nmr δ 1.3–2.3 (m, 4, $\overline{PCH_2CH_2CH_2Ar}$), 2.6–3.3 (m, 2, $\overline{PCH_2CH_2CH_2Ar}$), and 7.0–8.4 (m, 11, Ar H); mass spectrum (70 eV) *m/e* (rel intensity) M^+ 276 (100). An analytical sample of **14**, mp 120.5–121.5°, could be obtained *via* recrystallization several times from a small amount of hexanes.

Anal. Calcd for $C_{19}H_{17}P$: C, 82.61; H, 6.61; P, 11.23. Found: C, 82.79; H, 6.31; P, 10.98.

Some solid, which was found insoluble in hot hexanes during the recrystallization of **14**, was collected (8 mg) and purified by recrystallizing from reagent heptanes in the form of soft, fine crystals, mp 147.5–148.5°. The spectroscopic data and elemental analysis supported the proposed structure for the phosphine oxide **15**: ir 1180 cm^{-1} (P→O shoulder at 1160 cm^{-1}); nmr (which is very similar to that of **14**) δ 1.6–2.8 (m, 4, $\overline{PCH_2CH_2CH_2Ar}$), 2.8–3.4 (m, 2, $\overline{PCH_2CH_2CH_2Ar}$), and 7.1–8.5 (m, 11, Ar H); mass spectrum (70 eV) *m/e* (rel intensity) M^+ 292 (45), 291 (100), 165 (51).

Anal. Calcd for $C_{19}H_{17}OP$: P, 10.61. Found: P, 10.62.

Silver Hydrogen L(+)- and D(−)-Dibenzoyltartrates (HDBTs).—Silver hydrogen L(+)-HDBT and silver hydrogen D(−)-HDBT were prepared according to the procedure described by Coyne and coworkers[21] from L(+)-dibenzoyltartaric acid monohydrate [mp 86–89°, $[\alpha]^{23.5}D$ +108.8° (*c* 0.02996, acetone) (lit.[22] mp 84–86°, $[\alpha]^{25}D$ +109°)] and D(−)-dibenzoyltartaric acid monohydrate [mp 86.5–89°, $[\alpha]^{23}D$ −111° (*c* 0.03086, acetone) (lit.[22] mp 88–89.8°, $[\alpha]^{11}D$ −114.8°)], respectively.

Resolution of (±)-1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]-phosphinolinium Bromide (3a). Synthesis and Separation of (+)-1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium L(+)-Hydrogen Dibenzoyltartrate (HDBT)–L(+)-Dibenzoyltartaric Acid (DBTA) (20).—The phosphonium bromide **3a** (297 mg, 0.772 mmol) in 3 ml of distilled H_2O was added dropwise to 800 mg (1.72 mmol) of silver L(+)-HDBT in 140 ml of distilled H_2O with stirring at room temperature. White solids immediately precipitated, and the reaction mixture was stirred for *ca.* 5 min before working up by filtration. The creamy solid collected was carefully washed with 50 ml of distilled H_2O [to remove any unreacted bromide **3a** and Ag L(+)-HDBT] and dried immediately *in vacuo* in the presence of P_2O_5 at 35° for 20 hr. The dried solid was quickly dissolved in 50 ml of CH_3OH, and the resulting suspension was filtered to remove insoluble AgBr in the form of a dark gray powder (120.3 mg, 0.64 mmol; 83% of theoretical). The methanol-soluble portion was evaporated, and the last traces of methanol were removed under vacuum (0.2 mm) to give a white gummy solid. Three recrystallizations (slowly at room temperature) from 1-propanol were performed (until reaching a constant melting point and specific rotation) giving 132.4 mg of **20**: mp 150° dec; $[\alpha]^{24.5}D$ +83° (*c* 0.0134, CH_3OH); ir 3400 (br) [C(=O)OH], 2950 (w), 1725 (s), (C=O), 1600 (w), 1450 (w), 1330 (m), 1270 (s), 1180

(22) D. M. Coyne, W. E. McEwen, and C. A. VanderWerf, *J. Amer. Chem. Soc.*, **78**, 3061 (1956).

(m), 1115 (s), 1070 (w), 1028 (w), 774 (w), 751 (m), and 712 cm^{-1} (s). The elemental analysis strongly implies the stoichiometric inclusion of 1 equiv of L(+)-dibenzoyltartaric acid ($C_{18}H_{14}O_8$) in the crystalline salt **20**.

Anal. Calcd for $C_{36}H_{35}O_8P \cdot C_{18}H_{14}O_8$: C, 66.82; H, 4.81; P, 3.04. Found: C, 66.87; H, 4.85; P, 3.10.

Synthesis and Separation of (−)-1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium D(−)-HDBT–D(−)-DBTA (21).—The (−) isomer **21** was prepared in the same manner as that for the (+) isomer above, namely, from 49.0 mg (0.127 mmol) of **3a** in 2 ml of distilled H_2O and 140.7 mg (0.31 mmol) of Ag D(−)-HDBT in 24 ml of distilled H_2O. Silver bromide (21.5 mg, 0.117 mmol; 92% of theoretical) was collected by filtration of the CH_3OH solution. The methanol soluble portion, after removal of CH_3OH, gave, after three slow recrystallizations from 1-propanol (until reaching constant melting point and specific rotation), 6 mg of pure **21**: mp 149–149.5° dec; $[\alpha]^{25}D$ −83° (*c* 0.0196, CH_3OH). The structure of **21** was confirmed by its ir spectrum, which is superimposable with that of (+) isomer **20**.

Metathesis of (+) Isomer 20. Synthesis and Separation of (+)-1-Ethyl-1,2,3,4-tetrahydro-1-phenylbenzo[*h*]phosphinolinium Bromide (3a).—The (+) isomer **20** (100 mg, 0.098 mmol) dissolved in *ca.* 8 ml of CH_3OH was mixed with excess NH_4Br (89.8 mg, 0.915 mmol; Mallinckrodt Chem. Works, analytical reagent) in a 50-ml, round-bottom flask. The homogeneous reaction mixture was stirred at room temperature for 15 hr, followed by a period at reflux *via* an oil bath (70°) for 4 hr; the mixture was then stirred at room temperature overnight. Methanol was completely stripped off under vacuum and replaced with *ca.* 30 ml of $HCCl_3$. The resulting suspension was gently boiled at 70° for 6.5 hr, and the white, $HCCl_3$-insoluble solid (147.4 mg), which contained mainly the excess NH_4Br and ammonium L(+)-DBTA, was removed by filtration. The clear filtrate was concentrated to *ca.* 5 ml on an evaporator at 35°. After being cooled to room temperature, the solution was carefully filtered through a disposable pipet (plugged with glass wool, to remove any insolubles) into a 25-ml erlenmeyer flask. Anhydrous ether was added dropwise to the solution until it turned distinctively cloudy. Colorless, fine needles were observed to crystallize out gradually at room temperature, giving, after being dried *in vacuo* in the presence of P_2O_5 at 35–40° for 5 hr, 20.6 mg (0.0535 mmol; 55% of theoretical) of (+)-**3a**. Further purification was achieved by repeated recrystallizations from $HCCl_3$–ether in the same manner, giving (+)-**3a**: mp 259° dec; $[\alpha]^{25}D$ +28° (*c* 0.0175, $HCCl_3$). The structure of (+)-**3a** was supported by its ir spectrum, which is essentially superimposable with that of the authentic racemic **3a**. Further evidence was provided by the successful conversion of (+)-**3a** to the corresponding perchlorate derivative [mp 171.5–172.5° (2-propanol)], which again has a virtually identical ir spectrum with that of the authentic perchlorate **3b**. Unfortunately, the small amount of the perchlorate obtained was only sufficient for a melting point determination.

Diethyl [3-(2-Naphthyl)propyl]phosphonate (16).—2-(3-Bromopropyl)naphthalene (**6**) (17 g, 0.0683 mol) was heated with 17 g (0.1 mol) of redistilled $(C_2H_5O)_3P$ in a 50-ml, three-neck, round-bottom flask at 165–180° (sand bath) for 1.5 hr. Effervescence was immediately observed as solution temperature reached 128°; evolution of gas became very vigorous at 152–154° as a gas smoothly distilled out. At the end of the reaction (effervescence practically ceased), the sand bath temperature was raised and kept at 190–195° for 3 min before heat was terminated. After cooling, excess $(C_2H_5O)_3P$ was evaporated off at 40° (0.2 mm), and the residue was distilled giving 19.6 g (90.8% based on **6**) of the phosphonate **16**: bp 178–183° (0.0036–0.00085 mm); $n^{21}D$ 1.5444; ir 1235 cm^{-1} (P→O); nmr δ 1.23 [t, 6, $P(OCH_2CH_3)_2$], 1.4–2.4 (m, 4, $PCH_2CH_2CH_2$), 2.6–3.0 (t, 2, $ArCH_2CH_2$), 4.02 [quint, 4, $P(OCH_2CH_3)_2$] and 7.1–7.9 (m, 7, Ar H). An analytical sample was obtained by redistillation at bp 155–160° (0.3–0.4 μ).

Anal. Calcd for $C_{17}H_{23}O_3P$: P, 10.13. Found: P, 9.91.

[3-(2-Naphthyl)propyl]phosphonic Acid (17).—Diethyl [3-(2-naphthyl)propyl]phosphonate (**16**) (17.7 g, 0.056 mol) was boiled with 90 ml of concentrated HCl at 136–140° (sand bath) for 6 hr in a 200-ml, round-bottom flask. White solid, which crystallized out immediately after cooling, was collected by filtration and washed thoroughly with H_2O (until neutral). After being dried *in vacuo* (P_2O_5, 35–37° for 3 hr), the white solid was recrystallized from 500 ml of ethyl acetate (containing 20 ml of CH_3OH) giving, after drying, 13.7 g (94.5% based on **16**) of the phosphonic acid **17**: mp 181–182°; ir 25000–3400 (br) (POH), and 1185 cm^{-1} (P→O); nmr (DMSO-d_6) δ 1.2–3.0 (m, $ArCH_2CH_2CH_2P$), 7.25–8.0 (m, Ar H), and 8.5 [s, $PO(OH)_2$].

Anal. Calcd for $C_{13}H_{15}O_3P$: P, 12.40. Found: P, 12.27.

[3-(2-Naphthyl)propyl]phosphonic Dichloride (18).—Phosphonic acid **17** (4 g, 0.016 mol) was heated at 100–110° (sand bath) with 6.7 g (0.035 mol) of PCl_5 for 6 hr in a 50-ml, round-bottom flask. Generated $POCl_3$ was observed boiling out of the dark-brown reaction mixture. At the end of heating, $POCl_3$ was removed at 101°. The residue was distilled *via* a Bantam-ware short-path still (using an air condenser and illuminating ir lamp) to give 3 g (65% based on **17**) of the phosphonic dichloride **18** at bp 177.5–180° (6 μ), which solidified gradually at room temperature. The product, mp 64–67°, was extremely hygroscopic as HCl evolution was visible when the compound was exposed to air. It is soluble in benzene and $HCCl_3$ but not in hexane. The nmr spectrum [external TMS reference δ 1.5–2.9 (m, $ArCH_2CH_2CH_2P$), 6.9–7.8 (m, Ar H), and the absence of any acid protons] supported the proposed structure of **18**. While the extremely labile nature of the compound prohibited an elemental analysis, further support for the structure was obtained by mass spectral analysis (70 eV), which revealed the molecular ion at *m/e* (rel intensity) 286 (45), 288 (28) (from ^{36}Cl) and only a trace of impurity *m/e* 250 (the hydrolyzed product). The latter probably resulted during transport of the compound to the probe before the mass spectrum was taken.

[3-(2-Naphthyl)propyl]phosphonous Dichloride (19).—The reactions and work-ups described herein were all performed under N_2. The Grignard reagent was prepared by the usual procedure[19] from 9.75 g (0.0391 mol) of **6** and 0.96 g (0.0395 g-atom) of Mg turnings in 110 ml of anhydrous THF containing a trace of I_2. Anhydrous $CdCl_2$ (3.6 g, 0.0195 mol; Fisher certified reagent, dried at 110–120° for 8 hr before use) was added to the dark-brown Grignard solution with vigorous stirring and cooling (ice). Stirring was continued at room temperature for 12 hr, and the organocadmium reagent in THF was forced out by N_2 through a glass delivery tube into a 500-ml, three-neck, round-bottom flask (fitted with N_2 inlet, condenser, and $CaCl_2$ tube) containing 7 g (0.05 mol) of PCl_3 (Baker analyzed reagent) in anhydrous ether (200 ml) prechilled (−30 to −40°) with acetone–Dry Ice bath. A white precipitate was immediately formed. After being stirred at room temperature for 24 hr, the reaction mixture was filtered, and the clear filtrate was evaporated and distilled (*via* a short-path semimicro still) giving 6.3 g (59.5% based on **6**) of the phosphonous dichloride **19**: bp 161.5–163° (0.05 mm); $n^{25}D$ 1.6282. The ir (shows the absence of P→O absorption) and nmr (δ 1.7–2.55 (m, 4, $PCH_2CH_2CH_2$), 2.6–3.0 (t, 2, $ArCH_2CH_2$), and 7.0–7.9 (m, 7, Ar H)] spectra support the proposed structure of **19**.

Anal. Calcd for $C_{13}H_{13}Cl_2P$: P, 11.44. Found: P, 11.28.

Registry No.—(+)-**3a**, 30541-74-3; (+)-**3b**, 30651-45-7; (±)-**3c**, 30541-75-4; **6**, 27650-59-5; **7**, 30541-77-6; **8**, 30541-78-7; **9**, 30541-79-8; **10**, 30541-80-1; **14**, 30597-71-8; **15**, 30541-81-2; **16**, 30541-82-3; **17**, 30541-83-4; **18**, 30541-84-5; **19**, 30541-85-6; **20**, 30522-86-2; **21**, 30522-87-3.