to Mrs. E. C. Grim and Dr. J. A. Kuck for microanalyses, to N. Colthup for assistance in interpreting infrared spectra, and to Dr. J. E. Lancaster for measurement and interpretation of the NMR spectra.

STAMFORD, CONN.

[CONTRIBUTION FROM CHEMICAL RESEARCH DEPARTMENT, CENTRAL RESEARCH DIVISION, AMERICAN CYANAMID CO.]

Reactions of Bis(2-cyanoethyl)phosphine Oxide

M. M. RAUHUT AND HELEN A. CURRIER

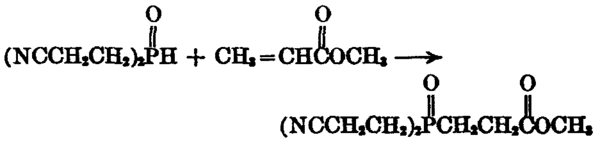
Received May 4, 1961

Bis(2-cyanoethyl)phosphine oxide reacted with α,β-unsaturated carbonyl compounds in the presence of strong organic bases, and with aldehydes and acetone without catalyst or in the presence of tertiary amines to give good yields of unsymmetrical tertiary phosphine oxides. Bis(2-cyanoethyl)phosphine oxide also reacted with *p*-chlorophenyl isocyanate and with 2,4-dichlorobenzyl chloride to give corresponding tertiary phosphine oxides. Reaction with isopropyl alcohol and carbon tetrachloride gave isopropyl bis(2-cyanoethyl)phosphinate. Additional reactions are described.

Secondary phosphine oxides can be prepared by the reaction of Grignard reagents[1,2] or aryl lithium compounds[3] with dialkyl phosphites, by reduction of phosphinyl chlorides with lithium aluminum hydride,[1] by hydrolysis of dialkyl[4] or diaryl[5] halo phosphines, and by controlled oxidation of secondary phosphines.[6] The latter method appears best suited for the preparation of secondary phosphine oxides containing reactive substituents. Thus bis(2-cyanoethyl)phosphine oxide was prepared in 90% yield by the air oxidation of bis(2-cyanoethyl)phosphine.[6] Reactions of secondary phosphine oxides had received little study at the time the work described here was in progress, and the chemistry of bis(2-cyanoethyl)phosphine oxide was studied in some detail. Recently, Hamilton and co-workers have reported the sodium ethoxide-catalyzed addition reactions of di-*n*-octylphosphine oxide and dibenzylphosphine oxide to unsaturated nitrile and carbonyl compounds[7] and to aldehydes and ketones.[8]

RESULTS AND DISCUSSION

Bis(2-cyanoethyl)phosphine oxide reacted with α,β-unsaturated carbonyl compounds in the presence of the strong organic bases pentamethylguanidine (PMG) or heptamethylbiguanide (HMB) to give unsymmetrical tertiary phosphine oxides (Table I). The reactions were carried out under mild conditions and generally provided good yields.



$$\mathrm{(NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}H + CH_2{=}CH\overset{O}{\overset{\|}{C}}OCH_3 \longrightarrow (NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}CH_2CH_2\overset{O}{\overset{\|}{C}}OCH_3}$$

TABLE I

ADDITION OF BIS(2-CYANOETHYL)PHOSPHINE OXIDE TO α,β-UNSATURATED CARBONYL COMPOUNDS

Unsaturated Compound	Catalyst	Solvent	Yield, %
$\mathrm{CH_3O\overset{O}{\overset{\|}{C}}CH{=}CH_2}$	PMG	Isopropyl alcohol	99
$n\text{-}\mathrm{C_{12}H_{25}O\overset{O}{\overset{\|}{C}}CH{=}CH_2}$	PMG	Isopropyl alcohol	98
cis-$\mathrm{C_2H_5O\overset{O}{\overset{\|}{C}}CH{=}CH\overset{O}{\overset{\|}{C}}OC_2H_5}$[a]	HMB	None	40
$\mathrm{H_2N\overset{O}{\overset{\|}{C}}CH{=}CH_2}$	HMB	Isopropyl alcohol	100
$\mathrm{CH_3\overset{O}{\overset{\|}{C}}CH{=}C(CH_3)_2}$[a]	PMG[b]	Methanol	40

[a] The molar ratio of oxide to unsaturated carbonyl compound was 1:2. [b] When PMG was replaced by triethylamine, no reaction took place.

Pentamethylguanidine did not catalyze the addition of di-*n*-octylphosphine oxide to acrylonitrile. The reactivity of bis(2-cyanoethyl)phosphine oxide under these conditions is evidently a consequence of its greater acidity, which results from the inductive effect of the nitrile substituents.

The free radical addition of bis(2-cyanoethyl)phosphine oxide to octene-1 was initiated by α,α-azobisisobutyronitrile and gave *n*-octylbis(2-cyanoethyl)phosphine oxide in 48% yield.

---

(1) R. H. Williams and L. A. Hamilton, *J. Am. Chem. Soc.*, **74**, 5418 (1952).

(2) R. H. Williams, L. A. Hamilton, *J. Am. Chem. Soc.*, **77**, 3411 (1955); B. B. Hunt, B. C. Saunders, *J. Chem. Soc.*, 2413 (1957).

(3) J. L. Willians, *Chem. & Ind. (London)*, 235 (1957).

(4) R. C. Miller, *J. Org. Chem.*, **24**, 2013 (1959).

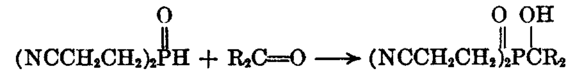
(5) A. W. Frank, *J. Org. Chem.*, **24**, 966 (1959).

(6) M. M. Rauhut and H. A. Currier, *J. Org. Chem.*, **26**, 4626 (1961).

(7) R. C. Miller, J. S. Bradley, and L. A. Hamilton, *J. Am. Chem. Soc.*, **78**, 5299 (1956).

(8) R. C. Miller, C. D. Miller, W. Rogers, and L. A. Hamilton, *J. Am. Chem. Soc.*, **79**, 424 (1957).

Bis(2-cyanoethyl)phosphine oxide reacted with aldehydes and acetone to give good yields of bis(2-cyanoethyl)-1-hydroxyalkyl phosphine oxides (Table II). Although active aldehydes such as

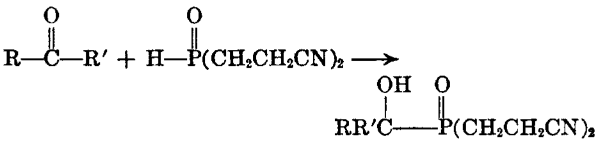


$$(NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}H + R_2C{=}O \longrightarrow (NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}\overset{OH}{\overset{|}{C}}R_2$$

formaldehyde and chloral reacted readily in the absence of a catalyst, in many cases the use of a tertiary amine catalyst was desirable in order to shorten the reaction time. Pentamethylguanidine catalyzed the reaction powerfully. The addition of a drop of pentamethylguanidine to a suspension of bis(2-cyanoethyl)phosphine oxide in acetone at room temperature caused an instantaneous, though mild, reaction and provided the tertiary phosphine oxide in 88% yield.

TABLE II

ADDITION OF BIS(2-CYANOETHYL)PHOSPHINE OXIDE TO ALDEHYDES AND KETONES

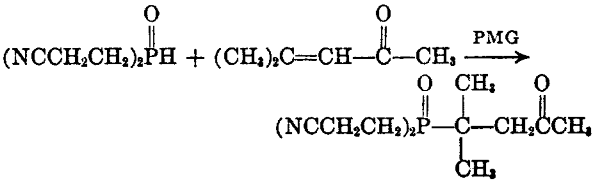


$$R{-}\overset{O}{\overset{\|}{C}}{-}R' + H{-}\overset{O}{\overset{\|}{P}}(CH_2CH_2CN)_2 \longrightarrow RR'\overset{OH}{\overset{|}{C}}{-}\overset{O}{\overset{\|}{P}}(CH_2CH_2CN)_2$$

Carbonyl Compound	Catalyst	Solvent	Yield, %
$H\overset{O}{\overset{\|}{C}}H$	None	Water	82
$(CH_3)_2CH\overset{O}{\overset{\|}{C}}H$	$(C_2H_5)_3N$	Ethanol	88
$C_6H_5\overset{O}{\overset{\|}{C}}H$	$(C_2H_5)_3N$	Isopropyl alcohol	70
$Cl_3CCH(OH)_2$	None	Isopropyl alcohol	89
Glucose	$(C_2H_5)_3N$	Methanol	30
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}CH_3$	$(C_2H_5)_3N$	None	88
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}CH_3$	$(n\text{-}C_4H_9)_2NH$	None	88
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}CH_3$	PMG	None	88
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}CH_3$	None	None	Small
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}CH_2{-}CH(CH_3)_2$	$(C_2H_5)_3N$	None	0
$CH_3\overset{O}{\overset{\|}{C}}{-}CH{=}C(CH_3)_2$	$(C_2H_5)_3N$	Methanol	0

Methyl isobutyl ketone did not react with bis(2-cyanoethyl)phosphine oxide either in the presence of triethylamine or pentamethylguanidine. In the former case, all the bis(2-cyanoethyl)phosphine oxide was recovered unchanged; in the latter case an unidentified solid was obtained which could not be satisfactorily purified for analysis. This same material was also formed when pentamethylguanidine or sodium methoxide was allowed to react with bis(2-cyanoethyl)phosphine oxide alone in methanol. This side reaction appears to become important whenever a strong base is used to catalyze relatively slow reactions involving bis(2-cyanoethyl)phosphine oxide.

Bis(2-cyanoethyl)phosphine oxide added to mesityl oxide at the olefinic double bond in the presence of pentamethylguanidine, to give 1,1-dimethyl-3-oxobutylbis(2-cyanoethyl)phosphine in 40% yield. The infrared spectrum of the product



$$(NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}H + (CH_3)_2C{=}CH{-}\overset{O}{\overset{\|}{C}}{-}CH_3 \xrightarrow{PMG} (NCCH_2CH_2)_2\overset{O}{\overset{\|}{P}}{-}\underset{CH_3}{\underset{|}{\overset{CH_3}{\overset{|}{C}}}}{-}CH_2\overset{O}{\overset{\|}{C}}CH_3$$

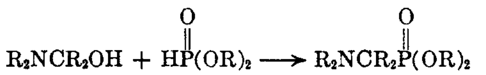
clearly indicated the presence of a carbonyl group and the absence of an olefinic double bond.

Fields has reported that aldehydes or ketones react with secondary amines and dialkyl phosphites to give α-dialkylaminophosphonate esters in a Mannich-type reaction[9]:

$$(RO)_2\overset{O}{\overset{\|}{P}}H + R_2C{=}O + HNR_2 \longrightarrow (RO)_2\overset{O}{\overset{\|}{P}}CR_2NR_2$$

His results indicated that the reaction mechanism involved addition of the amine to the carbonyl compound followed by reaction of the resulting α-hydroxyalkylamine with the phosphite:

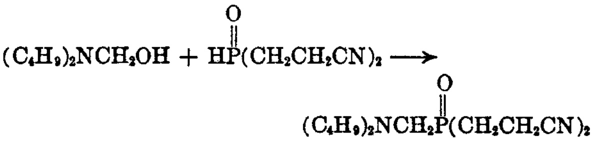
$$R_2NH + R_2C{=}O \longrightarrow R_2NCR_2OH$$



$$R_2NCR_2OH + H\overset{O}{\overset{\|}{P}}(OR)_2 \longrightarrow R_2NCR_2\overset{O}{\overset{\|}{P}}(OR)_2$$

The corresponding reaction with bis(2-cyanoethyl)phosphine oxide appears to follow a similar pattern. Bis(2-cyanoethyl)phosphine oxide reacted with dibutyl(hydroxymethyl)amine, prepared separately, to give (dibutylaminomethyl)bis(2-cyanoethyl)phosphine oxide in 37% yield.

$$(C_4H_9)_2NH + CH_2O \longrightarrow (C_4H_9)_2NCH_2OH$$



$$(C_4H_9)_2NCH_2OH + H\overset{O}{\overset{\|}{P}}(CH_2CH_2CN)_2 \longrightarrow (C_4H_9)_2NCH_2\overset{O}{\overset{\|}{P}}(CH_2CH_2CN)_2$$

Addition of excess dibutylamine to a mixture of the phosphine oxide and acetone, however, gave only (2-hydroxy-2-propyl)bis(2-cyanoethyl)phosphine oxide, which did not react with the amine under the conditions used.

Bis(2-cyanoethyl)phosphine oxide reacted with *p*-chlorophenyl isocyanate in the presence of triethylamine to give bis(2-cyanoethyl)-*p*-chloro-

---

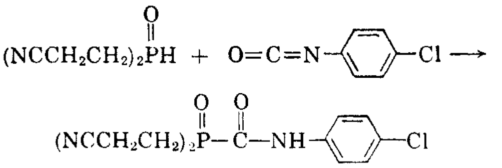
[9] E. K. Fields, *J. Am. Chem. Soc.*, 74, 1528 (1952).

TABLE III

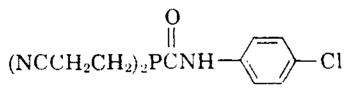
ANALYTICAL DATA FOR TERTIARY PHOSPHINE OXIDES $R\overset{\overset{O}{\|}}{P}(CH_2CH_2CN)_2$

R	M.P.	Carbon, %		Hydrogen, %		Phosphorus, %		Nitrogen, %	
		Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found
$CH_3O\overset{\overset{O}{\|}}{C}CH_2CH_2—$	79–81[a]	49.58	49.48	6.24	6.38	—	—	—	—
$n\text{-}C_{12}H_{25}O\overset{\overset{O}{\|}}{C}CH_2CH_2—$	65–67[b]	—	—	—	—	7.81	7.86	7.07	7.04
$C_2H_5O\overset{\overset{O}{\|}}{C}CH_2$ $C_2H_5O\underset{\underset{O}{\|}}{C}\overset{|}{C}H—$	72–73[c]	—	—	—	—	9.43	9.39	8.53	8.63
$H_2N\overset{\overset{O}{\|}}{C}CH_2CH_2—$	161–163[d]	47.57	47.12	6.21	6.47	13.67	13.80	18.49	18.69
$CH_3\overset{\overset{O}{\|}}{C}CH_2C(CH_3)_2—$	111–112[c]	56.67	56.68	7.53	7.35	12.18	12.34	—	—
$HOCH_2—$	99–101[a]	45.16	45.28	5.96	5.89	16.64	16.91	—	—
$(CH_3)_2CH\overset{\overset{OH}{|}}{C}H—$	77–79[e]	52.62	52.50	7.50	7.57	13.57	13.78	—	—
$C_6H_5\overset{\overset{OH}{|}}{C}H—$	113–115[a]	59.54	59.45	5.77	5.79	—	—	—	—
$Cl_3C\overset{\overset{OH}{|}}{C}H—$	159–160 dec.[f]	31.65	31.76	3.32	3.35	—	—	—	—
$C_5H_6(OH)_5\overset{\overset{OH^h}{|}}{C}H—$	146–147[f]	—	—	—	—	9.21	9.00	—	—
$(CH_3)_2\overset{\overset{OH}{|}}{C}—$	124–125[g]	50.45	50.70	7.05	7.07	—	—	—	—

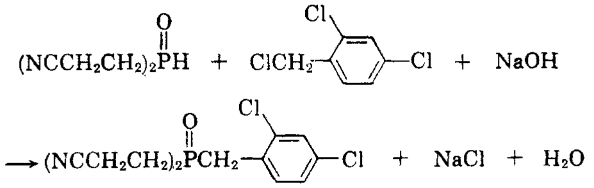
[a] Recrystallized from isopropyl alcohol. [b] Recrystallized from a mixture of ethyl acetate and petroleum ether (b.p. 40–60°). [c] Recrystallized from benzene. [d] Recrystallized from aqueous methanol. [e] Recrystallized from a mixture of benzene and isopropyl alcohol. [f] Recrystallized from methanol. [g] Recrystallized from acetone. [h] From reaction of glucose.



phenylcarbamoylphosphine oxide in 67% yield. The analogous reaction in the dialkyl phosphite series has been reported by Fox and Venezky.[10] Bis(2-cyanoethyl)phosphine reacted with p-chlorophenyl isocyanate in a similar manner to give bis(2 - cyanoethyl) - p - chlorophenylcarbamoylphosphine.

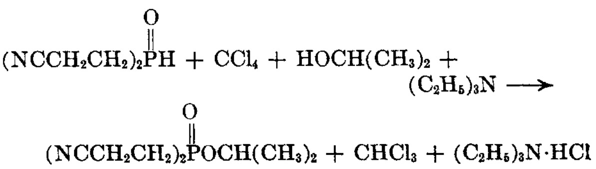


Reaction of bis(2-cyanoethyl)phosphine oxide with 2,4-dichlorobenzyl chloride in methanolic sodium hydroxide solution gave bis(2-cyanoethyl)(2,4-dichlorobenzyl)phosphine oxide in 70% yield.



Hydrolysis of the product with concentrated hydrochloric acid gave bis(2-carboxyethyl)(2,4-dichlorobenzyl)phosphine oxide in 95% yield.

Bis(2-cyanoethyl)phosphine oxide reacted with isopropyl alcohol and carbon tetrachloride in the presence of either triethylamine or dibutylamine to give isopropyl bis(2-cyanoethyl)phosphinate.



$$(NCCH_2CH_2)_2\overset{\overset{O}{\|}}{P}H + CCl_4 + HOCH(CH_3)_2 + (C_2H_5)_3N \longrightarrow (NCCH_2CH_2)_2\overset{\overset{O}{\|}}{P}OCH(CH_3)_2 + CHCl_3 + (C_2H_5)_3N\cdot HCl$$

---

[10] R. B. Fox and D. L. Venezky, *J. Am. Chem. Soc.*, **78**, 1661 (1956).

The product ester was characterized by hydrolysis to bis(2-carboxyethyl)phosphinic acid, which did not depress the melting point of an authentic sample. The corresponding reaction in the dialkyl phosphite series is well established.[11]

Hydrolysis of bis(2-cyanoethyl)phosphine oxide with concentrated hydrochloric acid provided an 84% yield of bis(2-carboxyethyl)phosphine oxide, which when oxidized with hydrogen peroxide provided bis(2-carboxyethyl)phosphinic acid.

EXPERIMENTAL[12]

Materials. Bis(2-cyanoethyl)phosphine oxide was prepared by the air oxidation of bis(2-cyanoethyl)phosphine.[6] Heptamethylbiguanide[13] was prepared by the alkylation of hexamethylbiguanide[14] with dimethyl sulfate. Pentamethylguanidine was prepared by the method of Lecher and Graf.[15] Other starting materials were obtained from commercial sources.

Reactions of bis(2-cyanoethyl)phosphine oxide with α,β-unsaturated carbonyl compounds. The reactions shown in Table I, with the exception noted, were carried out by combining 0.1 mole of the phosphine oxide with 0.1 mole of the unsaturated carbonyl compound in 100 ml. of solvent and adding 0.3 g. of pentamethylguanidine (PMG) or heptamethylbiguanide (HMB). After the evolution of some heat, the mixtures were warmed on the steam bath for 1 hr., and the products were obtained by filtration or by evaporation of the solvent under reduced pressure. The melting points and analytical data of the recrystallized products are shown in Table III.

n-Octylbis(2-cyanoethyl)phosphine oxide. A mixture of 15.6 g. (0.10 mole) of bis(2-cyanoethyl)phosphine oxide, 20 ml. (14 g., 0.13 mole) of octene-1, 3.0 g. (0.018 mole) of α,α′-azobisisobutyronitrile, and 5.0 ml. of methanol was heated at 77° for 2 hr. The reaction mixture was then cooled and diluted with excess ether to obtain 2.5 g. (16%) of unchanged bis(2-cyanoethyl)phosphine oxide, m.p. 96–98°, mixed m.p. 96–98°. The filtrate after standing for 3 hr. at −10° deposited 13.0 g. (48%) of the tertiary phosphine oxide, m.p. 63–66°. Recrystallization from a benzene–petroleum ether (b.p. 40–60°) mixture gave 11.5 g., m.p. 64–66°.

Anal. Calcd. for $C_{14}H_{25}N_2OP$: C, 62.65; H, 9.39; P, 11.54. Found: C, 62.88; H, 9.41; P, 11.8.

Reactions of bis(2-cyanoethyl)phosphine oxide with aldehydes and ketones. The reactions shown in Table II were run by combining 0.1 mole of the oxide with 0.1 mole of the aldehyde or ketone and (when desired) 1.0 g. of triethylamine or pentamethylguanidine in 100 ml. of solvent and heating the mixtures on the steam bath for 2 hr. The products were obtained by filtration or by evaporation of the solvent under reduced pressure. The melting points and analytical data for the recrystallized products are shown in Table III.

(Di-n-butylaminomethyl)bis(2-cyanoethyl)phosphine oxide. Di-*n*-butylamine (12.9 g., 0.1 mole) was added dropwise to a stirred mixture of 8 ml. (0.1 mole) of 36.6% aqueous formaldehyde solution and 25 ml. of water. The temperature was held below 30° by cooling. Bis(2-cyanoethyl)phosphine oxide (15.6 g., 0.1 mole) was added, and the mixture was stirred at room temperature for 30 min., and then at 60° for 30 min. The organic layer was separated, dissolved in 5% hydrochloric acid, and the solution was decolorized with activated charcoal. The solution was made alkaline with sodium hydroxide solution and extracted with benzene. The extract was dried with anhydrous potassium carbonate and evaporated to obtain 11 g. (37%) of the product, a pale yellow oil which crystallized when cooled to −10° but melted below room temperature.

One gram of the oil was combined with 2.0 g. of methyl iodide and the mixture was warmed briefly on the steam bath. Addition of ethyl acetate caused the methiodide to crystallize. The white solid (1.5 g.) was recrystallized from 10 ml. of acetone to obtain 1.1 g. of the purified methiodide, m.p. 129–131°.

Anal. Calcd. for $C_{16}H_{31}ON_3OP$: I, 28.88; P, 7.05. Found: I, 28.59; P, 7.02.

(p-Chlorophenylcarbamoyl)bis(2-cyanoethyl)phosphine oxide. A solution of 5.0 g. (0.029 mole) of bis(2-cyanoethyl)phosphine oxide, 4.9 g. (0.032 mole) of *p*-chlorophenyl isocyanate, and 5 drops of triethylamine in 45 ml. of chloroform was refluxed for 30 min. The reaction mixture was cooled and filtered, and the white solid was recrystallized from chloroform; 6.0 g. (67%) of the tertiary phosphine oxide, m.p. 145°, was obtained.

Anal. Calcd. for $C_{13}H_{13}ClN_3O_2P$: N, 13.57; P, 10.00. Found: N, 13.63; P, 9.86.

(p-Chlorophenylcarbamoyl)bis(2-cyanoethyl)phosphine. A solution of 5.0 g. (0.036 mole) of bis(2-cyanoethyl)phosphine and 6.0 g. (0.039 mole) of *p*-chlorophenyl isocyanate in 25 ml. of benzene was heated to reflux under a nitrogen atmosphere. Heating was discontinued and 5 drops of triethylamine was added. When the mild reaction subsided, heat was again applied and the solution was refluxed for 1 hr. The reaction mixture was filtered while hot, and the filtrate when cool was diluted with petroleum ether (b.p. 40–60°). The oil which separated was combined with a small quantity of benzene, and crystallization was induced by scratching. After recrystallization from acetone–petroleum ether (b.p. 40–60°), the m.p. was 125°.

Anal. Calcd. for $C_{13}H_{13}ClN_3OP$: C, 53.15; H, 4.46; P, 10.54. Found: C, 53.03; H, 4.70; P, 10.34.

Bis(2-cyanoethyl)(2,4-dichlorobenzyl)phosphine oxide. To a stirred solution of 8.6 g. (0.055 mole) of bis(2-cyanoethyl)phosphine oxide and 9.8 g. (0.050 mole) of 2,4-dichlorobenzyl chloride in 50 ml. of methanol was added dropwise a solution of 2.1 g. (0.05 mole) of sodium hydroxide in 20 ml. of methanol. The temperature was held between 35° and 40° by intermittent cooling. When the addition was complete, the mixture was stirred at room temperature for 30 min. and filtered, yielding 1.9 g. (65%) of sodium chloride. The filtrate was boiled for 10 min., cooled to room temperature, and filtered, yielding an additional 0.9 g. (31%) of sodium chloride. Concentration of the filtrate under reduced pressure afforded 11.0 g. (70%) of the white, crystalline oxide, m.p. 134–136°. Recrystallization from water provided an analytical sample, m.p. 136–137°.

Anal. Calcd. for $C_{13}H_{13}Cl_2N_2OP$: C, 49.54; H, 4.15. Found: C, 49.56; H, 4.23.

Bis(2-carboxyethyl)(2,4-dichlorobenzyl)phosphine oxide. A solution of 3.0 g. of the dinitrile in 25 ml. of concd. hydrochloric acid was refluxed for 3.5 hr. and evaporated to dryness under reduced pressure. Recrystallization of the solid residue from water afforded 3.2 g. (95%) of white plates, m.p. 170–172°.

Anal. Calcd. for $C_{13}H_{13}Cl_2O_5P$: C, 44.21; H, 4.28. Found: C, 44.29; H, 4.36.

Isopropyl bis(2-cyanoethyl)phosphinate. A solution of 5.2 g. (0.04 mole) of di-*n*-butylamine in 5 ml. of isopropyl alcohol was added dropwise to a stirred mixture of 3.4 g. (0.02 mole) of bis(2-cyanoethyl)phosphine oxide, 3.1 g. (0.02 mole) of carbon tetrachloride, and 20 ml. of isopropyl alcohol. The reaction was exothermic, and the temperature was maintained at 50–55° by cooling. At the end of the

---

[11] G. M. Steinberg, *J. Org. Chem.*, **15**, 637 (1950).

[12] Melting points are uncorrected.

[13] I. Hechenbleikner and F. C. Schaefer, unpublished work.

[14] I. Hechenbleikner, U. S. Patent **2,768,204** (Oct. 23, 1956); I. Hechenbleikner and D. W. Kaiser, U. S. Patent **2,768,205** (Oct. 23, 1956).

[15] H. Lecher and F. Graf, *Ber.*, **56B**, 1326 (1923).

addition the solution was heated briefly at 80° and then evaporated under reduced pressure. The residual brown gum was dissolved in 50 ml. of cold benzene. Addition of 75 ml. of petroleum ether (b.p. 40–60°) precipitated 7.7 g. of a white solid. The solid was dissolved in 40 ml. of water and the solution was made slightly alkaline with 10% sodium hydroxide solution. Di-*n*-butylamine, 2.8 g., separated and was removed. The remaining aqueous solution was extracted with three 5-ml. portions of chloroform, and the extract was dried with anhydrous sodium sulfate and evaporated to dryness. The residual white solid was recrystallized from a benzene–petroleum ether (b.p. 40–60°) mixture to obtain 0.7 g. (16%) of the isopropyl phosphinate, m.p. 79–80°.

Anal. Calcd. for $C_9H_{15}N_2O_2P$: C, 50.48; H, 7.05; P, 14.46; N, 13.08. Found: C, 50.16; H, 7.03; P, 14.66; N, 13.30.

In an experiment where di-*n*-butylamine was replaced with triethylamine, similar results were obtained.

Hydrolysis of isopropyl bis(2-cyanoethyl)phosphinate. A solution of 5.0 g. (0.023 mole) of the phosphinate in 20 ml. of concd. hydrochloric acid was refluxed for 2 hr. The solution was evaporated to dryness under reduced pressure, and the residual solid was dissolved in 40 ml. of 10% sodium hydroxide solution. The solution was heated to reflux, and nitrogen was bubbled through it until the liberation of ammonia was complete. The solution was acidified with dilute hydrochloric acid and evaporated to dryness under reduced pressure. The residual solid was extracted with 50 ml. of hot glacial acetic acid. Addition of 50 ml. of acetone to the cooled extract precipitated 2.7 g. (56%) of bis(2-carboxyethyl)phosphinic acid, m.p. 153–158°. Recrystallization from a mixture of acetone and acetic acid gave an analytical sample, m.p. 159–160°. A mixed melting point with an authentic sample prepared by hydrogen peroxide oxidation of bis(2-carboxyethyl)phosphine oxide[16] was not depressed.

Anal. Calcd. for $C_6H_{11}O_6P$: C, 34.29; H, 5.28; P, 14.74. Found: C, 34.56; H, 5.25; P, 14.84.

Bis(2-carboxyethyl)phosphine oxide. A solution of 40.0 g. (0.25 mole) of bis(2-cyanoethyl)phosphine oxide in 200 ml. of concd. hydrochloric acid was refluxed for 2.5 hr. and then evaporated to dryness on the steam bath. The crystalline residue was dried at 60° in a vacuum oven for 24 hr. and extracted with 200 ml. of boiling glacial acetic acid. The extract was cooled, filtered, and evaporated to dryness under vacuum. The white crystalline residue was washed with acetonitrile and dried in a vacuum desiccator over potassium hydroxide to obtain 46 g. (84%) of the acid, m.p. 124–125°. A portion was recrystallized from isopropyl alcohol to furnish an analytical sample, m.p. 131.5–133°.

Anal. Calcd. for $C_6H_{11}O_5P$: C, 37.12; H, 5.71; P, 15.96. Found: C, 37.25; H, 5.76; P, 16.25.

Acknowledgment. The authors wish to thank Dr. V. P. Wystrach for his continuing interest and encouragement. The authors are also indebted to Mrs. E. C. Grim and Dr. J. A. Kuck for microanalyses, and to Mr. N. Colthup for assistance in interpreting infrared spectra.

STAMFORD, CONN.

---

[16] W. C. Firth, unpublished work.

[CONTRIBUTION FROM U. S. BORAX RESEARCH CORP.]

Direct Preparation of Some Cyclic Boron-Nitrogen Compounds from Alkoxyboranes[1]

R. J. BROTHERTON AND H. STEINBERG

Received April 12, 1961

Borazine derivatives have been prepared by reactions of trialkoxyboranes with *o*-phenylenediamine or *o*-aminophenol. Comparable reactions of a trialkoxyborane with an aromatic monofunctional or *para* difunctional amine resulted in much slower alcohol evolution. Tris(anilino)borane was isolated from the reaction of isopropyl borate with aniline.

INTRODUCTION

There have been few reported attempts to displace allkoxy groups in esters of boric or boronic acids with amines. Previous work in this laboratory and earlier reports[2,3] in the literature suggest that this type of amine displacement is extremely difficult, and that the equilibrium shown in Equation 1 must lie far to the left in the direction of the trialkoxyborane. It should be pointed out, however, that in some cases orthoborates form intermediate complexes with amines.[4] More recently, several syntheses of cyclic materials containing boron-nitrogen bonds from boron-oxygen derivatives have been reported.[5–8] During the course of the present investigation, several new syntheses of cyclic boron-nitrogen compounds from boric and boronic acid esters have been developed including the first re-

$$B(OR)_3 + 3RNH_2 \rightleftharpoons B(NHR)_3 + 3ROH \qquad (1)$$

---

[1] This work was presented in part by A. L. McCloskey, H. Goldsmith, R. J. Brotherton, H. Steinberg, and G. W. Willcockson at the 135th Meeting of the American Chemical Society, Boston, Mass., April 1959.

[2] W. Gerrard, M. F. Lappert, and C. A. Pearce, *J. Chem. Soc.*, 381 (1957).

[3] R. G. Jones and C. R. Kinney, *J. Am. Chem. Soc.*, **61**, 1378 (1938).

[4] See M. F. Lappert, *Chem. Revs.*, **56**, 959 (1956) for a summary of reactions in which orthoborate-amine complexes are formed.

[5] R. L. Letsinger and S. B. Hamilton, *J. Am. Chem. Soc.*, **80**, 5411 (1958).

[6] E. Nyilas and A. H. Soloway, *J. Am. Chem. Soc.*, **81**, 2681 81959).

[7] J. M. Sugihara and C. M. Bowman, *J. Am. Chem. Soc.*, **80**, 2443 (1958).

[8] S. S. Chissack, M. J. S. Dewar, and P. M. Maitlis, *J. Am. Chem. Soc.*, **81**, 6329 (1959).