New Preparations of Cyanophosphonate Salts

Patrick J. Lennon,* Sergey G. Vulfson, and Eric Civade

Chemical Sciences Department, Monsanto Company, 800 N. Lindbergh Boulevard, St. Louis, Missouri 63167

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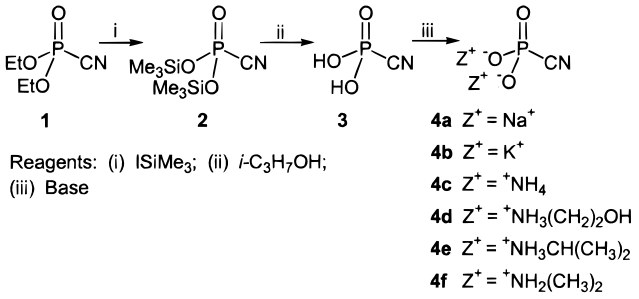
Phosphorocyanidate (cyanophosphonate) anions[1] are interesting species whose organic chemistry has been little explored. These compounds were critical models for our synthetic studies of novel ways to prepare cyanophosphonates[2a] from oxides of phosphorus, and their transformation into aminomethylphosphonate,[2b] an important intermediate of the herbicide Roundup. We needed a rapid, one-pot preparation of previously uncharacterized cyanophosphonates from a commercially available starting material. McKenna and co-workers recently reported the first characterized cyanophosphonate dianion as the bis(dicyclohexylammonium) salt, and the NMR spectra of related compounds prepared[3] from dimethyl cyanophosphonate[1], which is itself prepared from trimethyl phosphite and cyanogen bromide.[4] This note reports the isolation and characterization of a series of new organic and inorganic salts of cyanophosphonate dianions **4a**−**f** via a streamlined synthesis, as well as a facile general synthesis of new salts of ethyl cyanophosphonate monoanions **6a**−**g**, all utilizing the commercially available diethyl cyanophosphonate as starting material for both types of reactions. These are novel and potentially useful organophosphorus synthons featuring the P−C−N linkage.

Since diethyl cyanophosphonate should be more difficult to dealkylate than dimethyl cyanophosphonate, we decided to employ iodotrimethylsilane[5] rather than bromotrimethylsilane as our silyldealkylating reagent, in view of the longer reaction time needed for the dimethyl cyanophosphonate−bromotrimethylsilane reaction. Neat diethyl cyanophosphonate was briefly treated with iodotrimethylsilane, giving an exothermic reaction, which could either be moderated, or allowed to heat up to about 80 °C, to effect conversion to the bis(trimethylsilyl) ester, **2**, as shown in Scheme 1.

The resulting reaction mixture was placed on the vacuum line for a few hours to remove volatile components. Protiodesilylation could be effected with methanol to give cyanophosphonic acid, **3**, but there was always a small amount of phosphate or phosphate ester byproduct formed due to hydrolysis. These byproducts, when present, could be very difficult to remove, especially as the alkali metal salts. Isopropyl alcohol proved to be the most useful quenching reagent since either very little or no isopropyl phosphate ester was observed, and, when it was present, it was easily removed due to higher solubility. Both inorganic and organic salts of the cyanophosphonate dianion could be prepared, which offer a range of aqueous and organic solubilities. The inorganic salts were most easily prepared by reaction of the desired hydroxides, such as NaOH or NH_4OH. The organic salts derived from amines were prepared either by addition of the amine to solutions of cyanophosphonic acid or by reaction of a hydroxide of a quaternary ammonium cation with cyanophosphonic acid. The latter method was also used with a sulfonium salt. For example, bis(ammonium) cyanophosphonate **4c** gave a singlet in the ^{31}P NMR (D_2O) at −15.1 ppm and a doublet in the ^{13}C NMR (D_2O) at 121.1 ppm, $^1J_{CP}$ = 146.3 Hz (cf. bis(dicyclohexylammonium) cyanophosphonate:[1] ^{31}P NMR δ −15.1 (s) and ^{13}C NMR δ 124.57 (d, $^1J_{CP}$ = 142.8 Hz)).

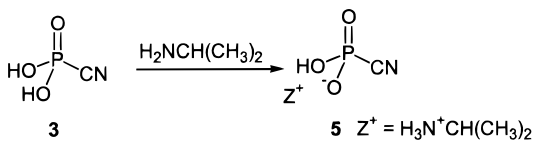
Scheme 1



Different salts were analyzed and showed different, usually small, amounts of water. Our observations suggested that the amount of water varied with the cation used and the length of time that the isolated product was placed under vacuum, and, in limited data, appeared reproducible. For example, the bis(ammonium) cyanophosphonate, **4c**, in two preparations which were dried under vacuum overnight, contained very little water, showing 0.32 and 0.33% water, corresponding to about 0.03 waters per cyanophosphonate. In contrast, the bis(sodium) cyanophosphonate, **4a**, contained higher amounts of water after being on the vacuum line overnight (5.43%), but the water content of the same sample decreased to 3.02% after 2 days on the vacuum line. Another preparation of **4a** was analyzed and showed a similar amount of water, 2.99%, after 2 days on the vacuum line, corresponding to a molecular formula of $Na_2(O_3PCN)(H_2O)_{0.26}$, or, about one water per four cyanophosphonates.

A single salt of the monoanion of cyanophosphonate was prepared by the stoichiometric monodeprotonation of cyanophosphonic acid by isopropylamine, Scheme 2.

Scheme 2



Comparison of the ^{31}P NMR chemical shifts for **5** (−21.1 ppm) and the corresponding bis(isopropylammonium)

(1) Kashemirov, B. A.; Ju, J.-Y.; Bau, R.; McKenna, C. E. *J. Am. Chem. Soc.* **1995**, *117*, 7285.

(2) (a) Lennon, P. J.; Vulfson, S. G. PCT Int. Appl. WO 9829106 A2 19980709; CAN 129:122763, 1998. Lennon, P. J.; Vulfson, S. G. PCT Int. Appl. WO 9829420 A1 19980709; CAN 129:109211, 1998. (b) Lennon, P. J. PCT Int. Appl. WO 9829423 A1 980709; CAN 129:109214, 1998.

(3) McKenna, C. E.; Higa, M. T.; Cheung, N. H.; McKenna, M.-C. *Tetrahedron Lett.* **1977**, 155; McKenna, C. E.; Schmidhauser, J. *J. Chem. Soc., Chem. Commun.* **1979**, 739.

(4) Shiori, T.; Yokoyama, Y.; Kasai, Y.; Yamada, S. *Tetrahedron* **1976**, *32*, 2211.

(5) Blackburn, G. M.; Ingleson, D. *J. Chem. Soc., Chem. Commun.* **1978**, 870. Zygmunt, J.; Kafarski, P.; Mastalerz, P. *Synthesis* **1978**, 609.

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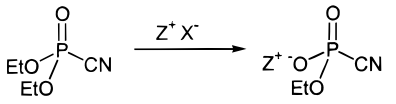
cyanophosphonate **4e** (−15.5 ppm), both in D_2O, shows a difference in the expected direction. The corresponding isopropylammonium ethyl cyanophosphonate,[6] **6g**, prepared as described in the next section, was isolated as a liquid and gave a ^{31}P NMR chemical shift in CD_2Cl_2 similar to that of **5**, at −21.2 ppm.

Dealkylation of a single alkyl ester of a phosphonate diester is a procedure which often requires forcing conditions or reagents which are not compatible with sensitive functional groups, particularly where the esters are other than benzyl or methyl. For the monodealkylation of diethyl phosphonate esters, fewer reagents have been reported. These include metal halides,[7] hydroxides,[8] azides,[7b] thiolates,[9] and tertiary amines[10] (the latter working only for activated diethyl phosphonate esters). For the preparation of methyl cyanophosphonate monoanion, McKenna treated dimethyl cyanophosphonate with sodium iodide in acetone.[1] We found that this reaction worked well for diethyl cyanophosphonate to give sodium ethyl cyanophosphonate, **6a** (Scheme 3), though we found

Scheme 3



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6a $Z^+ = Na^+$
6b $Z^+ = {}^+S(CH_3)_3$
6c $Z^+ = {}^+P(CH_3)_4$
6d $Z^+ = {}^+NH(C_2H_5)_3$
6e $Z^+ = {}^+NH_3CH_2CO_2C_2H_5$
6f $Z^+ = {}^+N(C_4H_9)_4$
6g $Z^+ = {}^+NH_3CH(CH_3)_2$

acetonitrile to be useful as solvent because the starting materials are soluble in it, but the product is not. The coupled ^{31}P NMR spectrum of **s**odium ethyl cyanophosphonate (D_2O) shows a triplet at −19.8 ppm, $^3J_{PH} = 9.2$ Hz, and a doublet in the ^{13}C NMR (D_2O) at 117.9 ppm, $^1J_{CP} = 189.3$ Hz (cf. sodium methyl cyanophosphonate[1] at pH = 1.5: ^{31}P NMR (D_2O) δ −17.44 (q, $^3J_{PH} = 13$ Hz), ^{13}C NMR (D_2O) δ 117.41 (d, $^1J_{PC} = 181$ Hz)). We were particularly interested in the synthesis of monoester monoanions featuring organic cations and found that iodides, bromides, and chlorides of organic cations functioned well in this type of reaction. For example, tetramethylphosphonium bromide readily gave the tetramethylphosphonium ethyl cyanophosphonate, **6f**, at 80 °C; triethylamine hydrochloride similarly gave triethylammonium ethyl cyanophosphonate, **6d**, at 80 °C. Although these reactions were often run at 80 °C, they were sometimes run at lower temperatures in good yield. Tetrabutylammonium bromide in dichloromethane at 40 °C gave **6f**, in good yield. Cyanide was also an effective deethylating agent. In NMR experiments tetrabutylammonium cyanide could be used to prepare tetrabutylammonium ethyl cyanophosphonate; potassium and lithium cyanides also effected this dealkylation reaction. Additional NMR experiments established that tertiary amines such as quinuclidine and triethylamine could dealkylate diethyl cyanophosphonate. The mild conditions which can be used to dealkylate diethyl cyanophosphonate relative to other diethyl phosphonates attests to the strongly activating nature of the cyano group which renders the phosphoryl group even more electrophilic.

In summary, we have provided straightforward synthetic methods to a series of new inorganic and organic salts of both the cyanophosphonate dianion and the monoanion of ethyl cyanophosphonate which have been characterized, each starting with the commercially available diethyl cyanophosphonate via deethylation pathways. The ready access to these interesting starting materials allows investigation of the organic chemistry of cyanophosphonate salts, which we shall elaborate on in due course.

Experimental Section

General Methods. All experiments were performed under argon or nitrogen atmosphere unless otherwise indicated. Organic solvents were Aldrich Anhydrous grade, used as received. Diethyl cyanophosphonate was obtained from Aldrich and used without additional purification. NMR spectra were collected on Varian VXR-300 and VXR-300S spectrometers. Matrixes used in fast-atom bombardment (FAB) mass spectroscopy include the following: DTE, dithioerythritol; DTT, dithiothreitol; TGL, thioglycerol. FAB^+ and FAB^- refer to positive and negative ion fast atom bombardment mass spectra, respectively.

Disodium Cyanophosphonate, 4a. Trimethylsilyl iodide (50 g, 0.25 mol) was added to neat diethyl cyanophosphonate (15 g, 0.092 mol), cooled in a water bath, and stirred for 10 min. The water bath was removed, and the reaction mixture was stirred for 15 min. After the volatile components were removed under vacuum (oil pump) for 3 h, isopropyl alcohol (15 mL) was added at 0 °C, and then aqueous sodium hydroxide (4 mL, 3.7 g NaOH, 0.09 mol) was added dropwise over 5 min. Five minutes after the end of this addition, a second portion of aqueous sodium hydroxide (4 mL, 3.7 g NaOH, 0.09 mol) was again added dropwise over a 5 min period. Two layers and a precipitate were formed. The bottom layer and precipitate were separated from the top (isopropyl alcohol) layer, and the precipitate was filtered. On dissolving the bottom layer in methanol (15 mL), an additional precipitate formed. The combined precipitates were washed with acetone (30 mL) and then dissolved in a 10:1 methanol−water solution (110 mL). Ethyl ether (500 mL) was added, precipitating a white solid, which was filtered and dried under vacuum for about 2 days, yielding 11.8 g of product (85% yield). ^{31}P NMR (D_2O) δ (ppm) −17.0; ^{13}C NMR (D_2O) δ (ppm) 123.4 (d, $^1J_{CP} = 143.7$ Hz). Anal. Calcd for $CNa_2O_3P(H_2O)_{0.26}$: C, 7.72%; H, 0.34%; N, 9.00%. Found: C, 7.65%; H, <0.5%; N, 8.76%; H_2O, 2.99% (Karl Fisher titration).

Dipotassium Cyanophosphonate, 4b. Trimethylsilyl iodide (25 g, 0.125 mol) was added dropwise to neat diethyl cyanophosphonate (9.0 g, 0.055 mol) at room temperature and stirred for 7 min. The temperature of reaction mixture increased to about 80 °C. After the volatile components were removed under vacuum (oil pump) over 3 h, the residue was cooled to −30 °C, and isopropyl alcohol (12 mL) was added dropwise over 10 min, followed by aqueous potassium hydroxide (10 mL containing 6.15 g, 0.11 mol), keeping the bath temperature at −30 °C for about 10 min. As a result, two layers and a precipitate were formed. The bottom layer and precipitate were separated from the top (isopropyl alcohol) layer, and then the precipitate was filtered.

(6) Isopropylammonium ethyl cyanophosphonate, **6g**. Diethyl cyanophosphonate (0.50 g, 3.06 mmol) and isopropylammonium chloride (0.29 g, 3.03 mmol) were added to DMF (3 mL) and stirred overnight. Removal of solvent under reduced pressure gave 0.48 g (88% yield) of an oil which could not be crystallized, and was, by NMR, about 85% pure. ^{31}P NMR (CD_2Cl_2) δ (ppm) −21.2 (t, $^3J_{PH} = 8.4$ Hz); ^{13}C NMR (CD_2Cl_2) δ (ppm) 16.0 (d, $^3J_{CP} = 7.5$ Hz), 20.9 (s), 42.1 (s), 63.2 (d, $^2J_{CP} = 6.3$ Hz), 121.0 (d, $^1J_{CP} = 177.8$ Hz). MS (FAB, TGL) *m/z* 195, $[{}^+NH_3CH(CH_3)_2{}^-O(C_2H_5O)POCN + H^+]$, 60 $[{}^+NH_3CH(CH_3)_2]$; (FAB^-, TGL) *m/z* 134 $[NCP(O)(OC_2H_5)O^-]$.

(7) (a) Chadwick, D. H. U. S. Patent 2,784,206, 1957. (b) Holý, A. *Synthesis* **1998**, 381.

(8) Gryszkiewicz-Trochimowski, E.; Quinchon, J.; Bosquet, M. *Bull. Soc. Chim. Fr.* **1962**, 1645.

(9) Harvey, R. G.; Jacobson, H. I.; Jensen, E. V. *J. Am. Chem. Soc.* **1963**, *85*, 1623.

(10) Vepsäläinen, J. J.; Kivikoski, J.; Ahlgrén, M.; Nupponen, H. E.; Pohjala, E. K. *Tetrahedron* **1995**, *51*, 6805.

The bottom layer was dissolved in methanol (20 mL), causing an additional precipitate. The combined precipitates were washed with acetone (30 mL), yielding 9.1 g of crude product (91% yield) after drying under vacuum. This material was fairly pure, containing about 2% of inorganic phosphate. It could be further purified by dissolving in a mixture of methanol (60 mL) and water (6 mL) and precipitating by adding ethyl ether (500 mL), giving 5.6 g (53%) of pure salt after drying under vacuum for 1 day. ^{31}P NMR (D_2O) δ (ppm) −16.8; ^{13}C NMR (D_2O) δ (ppm) 123.3 (d, $^1J_{CP}$ = 142.8 Hz). Anal. Calcd for $CK_2NO_3P(H_2O)_{0.23}$: C, 6.41%; H, 0.25%; N, 7.48%. Found: C, 6.69%; H, 0.40%; N, 7.21%; H_2O, 2.19% (Karl Fisher titration).

Bis(ammonium) Cyanophosphonate, 4c. Trimethylsilyl iodide (5.35 g, 26.74 mmol) was added dropwise to neat diethyl cyanophosphonate (2.0 g, 12.26 mmol) at room temperature and stirred for 5 min (exothermic). The temperature of the reaction mixture increased to about 80 °C. After the volatile components were removed under vacuum (oil pump) for 2 h, the residue was cooled to 0 °C, and isopropyl alcohol (3 mL) was added dropwise over 5 min, forming cyanophosphonic acid, which was not isolated. Then 3.35 g of 28.4% aqueous solution of NH_4OH (27.11 mmol base) was slowly added at −20 °C (around 10 min). A white precipitate was formed. It was diluted with dry, cold methanol (5 mL) and filtered, giving 1.5 g of salt (10.6 mmol, 86% yield) after drying under vacuum overnight. ^{31}P NMR (D_2O) δ (ppm) −15.1; ^{13}C NMR (D_2O) δ (ppm) 123.1 (d, $^1J_{CP}$ = 146.3 Hz). Anal. Calcd for $CH_8N_3O_3P(H_2O)_{0.03}$: C, 8.48%; H, 5.74%; N, 29.67%. Found: C, 8.74%; H, 5.72%; N, 29.55%; H_2O, 0.32% (Karl Fisher titration).

Bis(2-hydroxyethylammonium) Cyanophosphonate, 4d. Cyanophosphonic acid was prepared as for compound **4c** using the same molar quantities. The isopropyl alcohol was evaporated and replaced with acetone (6 mL), and the solution was cooled to −25 °C. 2-Aminoethanol (1.7 g, 28.86 mmol) in methanol (4 mL) was added, causing a white precipitate to form. It was filtered, yielding 2.38 g of crude product (84% yield) which was dissolved in methanol (10 mL) and precipitated by addition of excess ether, yielding 1.6 g (6.93 mmol, 57%) of pure salt after drying under vacuum for 26 h. ^{31}P NMR (D_2O) δ (ppm) −14.5; ^{13}C NMR (D_2O) δ (ppm) 124.5 (d, $^1J_{CP}$ = 145.7 Hz). MS: (FAB$^+$, DTT:DTE, 1:1) *m/z* 230 [$(H_3N^+(CH_2)_2OH)_2$ $^=O_2POCN + H^+$], 62 [$(H_3N^+(CH_2)_2OH)$]; (FAB$^-$, DTT:DTE, 1:1) *m/z* 106 [(NC)P(O)(OH)O$^-$]. HRMS: *m/z* Calcd for [$C_5H_{16}PN_3O_5 + H^+$] 230.0906; Found: 230.0901. Anal. Calcd for $C_5H_{16}N_3O_5P(H_2O)_{0.1}$, C, 26.02%; H, 7.07%; N, 18.21%. Found, C, 26.03%; H, 6.92%; N, 17.87%; H_2O, 0.74% (Karl Fisher titration).

Bis(isopropylammonium) Cyanophosphonate, 4e. Cyanophosphonic acid was prepared according to the procedure for compound **4c** using the same molar quantities. The isopropyl alcohol was removed under reduced pressure and replaced with methanol (6 mL). To this solution was slowly added isopropylamine (1.7 g, 0.029 mol) in methanol (2 mL) at −20 °C. A white precipitate formed. It was filtered and dried (2.16 g), dissolved in a 10:1 mixture of methanol and ether (20 mL), and precipitated by addition of ether (50 mL), yielding 1.8 g of the product (7.97 mmol, 65% yield) after drying overnight under vacuum. ^{31}P NMR (D_2O) δ (ppm) −15.5; ^{13}C NMR (D_2O) δ (ppm) 123.4 (d, $^1J_{CP}$ = 144.3 Hz). MS (FAB$^+$, DTT:DTE, 1:1) *m/z* 226 [$(^+NH_3CH(CH_3)_2)_2$ $^=O_2POCN + H^+$], 60 [$^+NH_3CH(CH_3)_2$]; (FAB$^-$, DTT:DTE, 1:1) *m/z* 106 [NCP(O)(OH)O$^-$]. HRMS: Calcd for [$C_7H_{20}N_3O_3P + H^+$], *m/z* 226.1320; Found, 226.1323. Anal. Calcd for $C_7H_{20}N_3O_3P(H_2O)_{0.03}$: C, 37.24%; H, 8.96%; N, 18.61%. Found: C, 37.06%; H, 8.85%; N, 18.45%; H_2O, 0.28% (Karl Fisher titration).

Bis(dimethylammonium) Cyanophosphonate, 4f. Cyanophosphonic acid was prepared according to the procedure described for compound **4c**. The isopropyl alcohol was removed under reduced pressure and replaced by dry acetone (10 mL). To this solution was slowly added 20 mL of a 2 M solution of $NH(CH_3)_2$ (40 mmol) in THF at −20 °C. A white precipitate formed which was filtered and washed three times with dry, cold acetone (50 mL each). After drying under vacuum, 2.3 g of crude product was obtained. It was filtered and washed three times with dry, cold acetone (50 mL) and once with ether (10 mL) and dried under vacuum overnight, giving the product as a white solid (1.7 g, 8.60 mmol, 70% yield). ^{31}P NMR (D_2O) δ (ppm) −15.4; ^{13}C NMR (D_2O) δ (ppm) 124.1 (d, $^1J_{CP}$ = 145.2 Hz). MS (FAB$^+$, DTT:DTE, 1:1) *m/z* 198, [$(^+NH_2(CH_3)_2)_2$ $^=O_2POCN + H^+$], 46 [$^+NH_2(CH_3)_2$]; (FAB$^-$, DTT:DTE, 1:1) *m/z* 106 [NCP(O)(OH)O$^-$]. HRMS: Calcd for [$C_5H_{16}N_3O_3P + H^+$], *m/z* 198.1007. Found: 198.1002.

Mono(isopropylammonium) Cyanophosphonate, 5. Cyanophosphonic acid was prepared according to the procedure described for compound **4c** using the same molar quantities. The isopropyl alcohol was removed and replaced by 6 mL of a mixture of dry acetone and ether (2:1). To this solution, isopropylamine (0.72 g, 12.18 mmol) dissolved in a mixture of dry acetone and ether (6 mL, 2:1) was slowly added at −30 °C. A clear solution was formed. The solvent was removed to give a yellow oil, which was dissolved in dry methanol (10 mL). To this solution was added 20 mL of a solution of ether and acetone (5:1). A small amount (about 0.1 g) of white crystals precipitated. They were removed from the solution which was then evaporated to give a solid residue. The solid was washed twice with chloroform (10 mL) and dried under vacuum overnight, yielding 0.6 g (3.61 mmol) of product (30% yield). ^{31}P NMR (D_2O) δ (ppm) −21.1; ^{13}C NMR (D_2O) δ (ppm) 119.2 (d, $^1J_{CP}$ = 176.9 Hz); MS (FAB$^+$, DTT:DTE, 1:1): *m/z* 167, [$(^+NH_3CH(CH_3)_2)_2$ $^=O_2POCN + H^+$], *m/z* 60 [$^+NH_3CH(CH_3)_2$]; (FAB$^-$, DTT:DTE, 1:1); *m/z* 106 [NCP(O)(OH)O$^-$]. HRMS: Calcd for [$C_4H_{11}N_2O_3P + H^+$], *m/z* 167.0585.

Sodium Ethyl Cyanophosphonate, 6a. Diethyl cyanophosphonate (4.0 g, 24.5 mmol) and sodium iodide (3.68 g, 24.5 mmol) were added to dry acetonitrile (10 mL) which was stirred at room temperature for 20 min, giving a white solid which was filtered, washed with ether (15 mL), and dried under vacuum overnight, yielding 3.0 g (78% yield) of product. ^{31}P NMR (D_2O) δ (ppm) −19.8 (t, $^3J_{PH}$ = 9.2 Hz); ^{13}C NMR (D_2O) δ (ppm) 117.9 (d, $^1J_{CP}$ = 189.3 Hz), 63.5 (d, $^2J_{CP}$ = 6.3 Hz), 15.1 (d, $^3J_{CP}$ = 6.9 Hz). MS (FAB$^+$, TGL): *m/z* 316.1 [$(Na^+$ $^-O(OC_2H_5)POCN)Na^+$]; (FAB$^-$, TGL) *m/z* 133.9 [NCP(O)$(OC_2H_5)O^-$]; 290.9 [$Na^+[^-O(OC_2H_5)POCN]_2$]. Anal. Calcd for $C_3H_{10}NNaO_3P$: C, 22.95%; H, 3.21%; N, 8.92%. Found, C, 22.70%; H, 3.33%; N, 8.75%.

Trimethylsulfonium Ethyl Cyanophosphonate, 6b. Diethyl cyanophosphonate (0.50 g, 3.06 mmol) and trimethylsulfonium iodide (0.624 g, 3.06 mmol) were added to dimethylacetamide (1 mL) and heated at 80 °C for 3 h. Then ether (9 mL) containing acetone (1 mL) was added, giving an oil which crystallized within 15 min. This solid was dissolved in dry, cold acetone (1 mL) and precipitated with ether (10 mL). Filtration and drying under vacuum overnight gave 0.48 g (74% yield) of product. ^{31}P NMR (acetone-d_6) δ (ppm) −22.2 (t, $^3J_{PH}$ = 7.6 Hz); ^{13}C NMR (acetone-d_6) δ (ppm) 122.0 (d, $^1J_{CP}$ = 154.3 Hz), 61.8 (d, $^2J_{CP}$ = 6.3 Hz), 26.9 (s), 16.6 (d, $^3J_{CP}$ = 7.2 Hz). MS (FAB$^+$, DTT:DTE, 1:1): *m/z* 288 [-O(OC_2H_5)POCN ($^+S(CH_3)_3)_2$]; 77 [$^+S(CH_3)_3$]; (FAB$^-$, DTT:DTE, 1:1) *m/z* 134 [NCP(O)$(OC_2H_5)O^-$]. Anal. Calcd for $C_6H_{14}NO_3PS$: C, 34.12%; H, 6.68%; N, 6.63%. Found: C, 33.89%; H, 6.42%; N, 6.48%; I, 0.0%.

Tetramethylphosphonium Ethyl Cyanophosphonate, 6c. Diethyl cyanophosphonate (0.50 g, 3.06 mmol) and tetramethylphosphonium bromide (0.523 g, 3.06 mmol) were added to dimethylacetamide (0.5 mL) which was heated to 80 °C for 3 h. The dimethylacetamide was removed under vacuum to give a solid residue. Ether (10 mL) was added, the mixture was filtered, and the solid was dried overnight under vacuum, yielding 0.39 g (57% yield) of product. ^{31}P NMR (CD_2Cl_2) δ (ppm) −33.9 (m, $^2J_{PH}$ = 15.0 Hz), −19.8; ^{13}C NMR (CD_2Cl_2) δ (ppm) 121.3 (d, $^1J_{CP}$ = 152.9 Hz), 61.2 (d, $^2J_{CP}$ = 6.6 Hz), 15.8 (d, $^3J_{CP}$ = 7.5 Hz), 9.1 (d, $^2J_{CP}$ = 55.8 Hz). MS (FAB$^+$, TGL) *m/z* 316.1, [$(-O(OC_2H_5)POCN)$ ($^+P(CH_3)_4)_2$], 90.9 [$^+P(CH_3)_4$]; (FAB$^-$, TGL) *m/z* 133.9 [NCP(O)$(OC_2H_5)O^-$]. Anal. Calcd. for $C_7H_{17}NO_3P_2$: C, 37.34%; H, 7.61%; N, 6.22%. Found, C, 37.14%; H, 7.26%; N, 6.16%; I, 0.0%.

Triethylammonium Ethyl Cyanophosphonate, 6d. Diethyl cyanophosphonate (0.50 g, 3.06 mmol) and triethylamine hydrochloride (0.421 g, 3.06 mmol) were added to dimethylacetamide (0.5 mL) which was heated to 80 °C for 3 h. The dimethylacetamide was removed under vacuum to give 0.42 g (67% yield) of a viscous residue which was dried under vacuum overnight and was not further purified. ^{31}P NMR (D_2O) δ (ppm) major peak (94.7%) −19.6 (t, $^3J_{PH}$ = 9.3 Hz), minor peak (5.3%) −12.1; ^{1}H NMR (D_2O) δ (ppm) 1.25 (t), 3.20 (q), and 4.05 (quint); ^{13}C NMR (D_2O) δ (ppm) 9.1 (s), 16.0 (d, $^3J_{CP}$ = 6.8 Hz), 47.0 (t, $^2J_{CN}$ = 4.0 Hz), 63.9 (d, $^2J_{CP}$ = 6.6 Hz), 119.9 (d, $^1J_{CP}$ = 174.35 Hz). MS (FAB$^+$, TG) *m/z* 338.4 [$(^+HN(C_2H_5)_3)_2$ $^-O(OC_2H_5)POCN$], 102

$[^{+}HN(C_2H_5)_3]$; (FAB$^-$, TG), *m/z* 133.9 $[NCPO(OC_2H_5)O^-]$, 268.9 $[H^+ + (^-O(OC_2H_5)POCN)_2]$, 370.1 $[^{+}HN(C_2H_5)_3(^-O(OC_2H_5)POCN)_2]$.

(Ethyl 2-Ammonium Acetate) Ethyl Cyanophosphonate, 6e. Diethyl cyanophosphonate (5.0 g, 30.65 mmol) and ethyl glycinate hydrochloride (4.279 g, 30.65 mmol) were added to DMF (30 mL) which was then heated to 83 °C for 1.5 h. After cooling, the solvent was removed under reduced pressure to give an oil, which was placed on the vacuum line. Some crystals formed after a few days, which were diluted with ethyl acetate and filtered and were determined to be the starting ethyl glycinate hydrochloride. The filtrate was stripped down to an oil, which was again placed on the vacuum line overnight, and did not crystallize, 4.8 g, 20.0 mmol, 65% yield. ^{31}P NMR (CD_2Cl_2) δ (ppm) −20.5 (t, $^3J_{PH}$ = 7.6 Hz); ^{13}C NMR (CD_2Cl_2) δ (ppm) 168 (s), 121.0 (d, $^1J_{CP}$ = 178.9 Hz), 62.9 (d, $^2J_{CP}$ = 6.3 Hz), 62.5 (s), 41.6 (s), 16.0 (d, $^3J_{CP}$ = 7.4 Hz), 13.9 (s). MS (FAB$^+$, DTT:DTE, 1:1): *m/z* 239, $[^{+}NH_3CH_2COOC_2H_5\ ^-O(OC_2H_5)POCN + H^+]$; 104 $[^{+}NH_3CH_2COOC_2H_5]$; (FAB$^-$, DTT:DTE, 1:1) *m/z* 134 $[NCP(O)(OC_2H_5)O^-]$. Anal. Calcd for $C_7H_{15}N_2O_5P(H_2O)_{0.80}$: C, 35.04%; H, 6.38%; N, 11.67%. Found: C, 34.82%; H, 6.62%; N, 11.50%; Cl, 0.0%; H_2O, 0.80% (Karl Fisher titration).

Tetrabutylammonium Ethyl Cyanophosphonate, 6f. Diethyl cyanophosphonate (0.50 g, 3.06 mmol) and tetrabutylammonium bromide (0.990 g, 3.06 mmol) were added to dichloromethane (2 mL) which was heated to 40 °C for 3 h. The dichloromethane was removed under vacuum to give 1.03 g (89% yield) of a white solid product after drying overnight on the vacuum line, which was not further purified. ^{31}P NMR (CD_2Cl_2) δ (ppm) −19.6 (t, $^3J_{PH}$ = 8.4 Hz), (D_2O) −20.1 (t, $^3J_{PH}$ = 9.15 Hz) ^{1}H NMR (D_2O) δ (ppm) 0.85 (t), 1.30 (sext), 1.55 (quint), 3.10 (t), and 4.05 (quint); ^{13}C NMR (D_2O) δ (ppm) 15.0 (d, $^3J_{CP}$ = 6.58 Hz), 18.4, 23.0, 57.8, 63.1 (d, $^2J_{CP}$ = 6.6 Hz), 118.5 (d, $^1J_{CP}$ = 177.2 Hz). MS (FAB$^+$, TG) *m/z* 242.3 $[^{+}N(C_4H_9)_4]$; (FAB$^-$, TG) *m/z* 133.9 $[NCP(O)(OC_2H_5)O^-]$, 268.9 $[H^+ + (^-O(C_2H_5O)POCN)_2]$, 510.6 $[^{+}N(C_4H_9)_4\ (^-O(C_2H_5O)POCN)_2]$.

Supporting Information Available: Copies of the ^{31}P and ^{13}C NMR spectra for compounds **4f**, **5**, **6d**, **6f**, and **6g**. This material is available free of charge via the Internet at http://pubs.acs.org.

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