The Cycloaddition of Diethyl Chlorophosphite with Norbornadiene: Synthesis and Crystal Structure of the Cycloadduct.

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In memory of Professor Nicholas Alexandrou

In the presence of Lewis acids, diethyl phosphorochloridite reacts with norbornadiene to afford the tetracyclic phosphinate ester **3**. The reaction is believed to involve formation of phosphenium ions stabilized only by alkoxy substituents. The cycloadduct of the reaction was characterized by its spectral data, by single crystal diffraction analysis of the parent acid, and ^{31}P and ^{27}Al nmr experiments.

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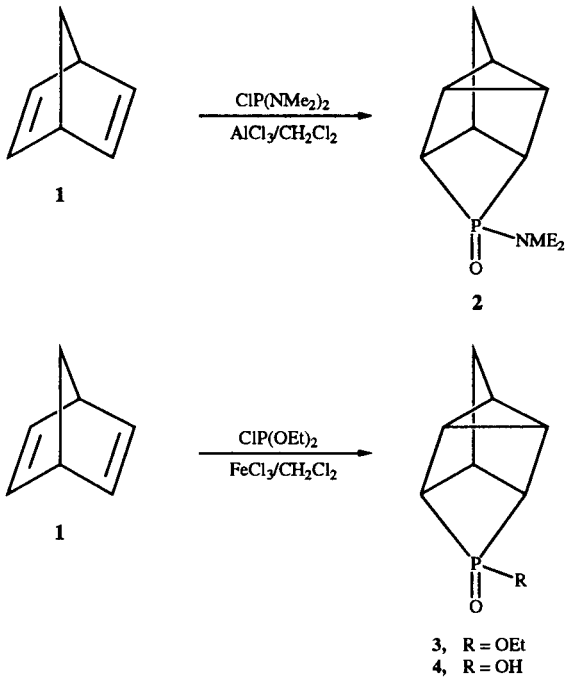
Introduction.

In the recent years, interest in phosphorus chemistry has expanded dramatically for a variety of reasons [1-5]. Dicoordinate phosphorus cations are often used as synthetic intermediates, for they can react with either electron pair acceptors or electron pair donors [6]. However, the view is widely held that formation of such a cation requires the presence of at least one dialkylamino group to provide, through, resonance adequate stabilization to the electron deficient phosphorus atom [7,8]. As part of our studies on new methods of phosphonate synthesis *via* phosphorus electrophiles [9-11], we examined the possibility of obtaining phosphenium ion chemistry from dialkyl phosphorochloridites.

Scheme 1



Results and Discussion.

Other investigators, in the past, have reported that bis(dimethylamino) phosphinium ion reacts with norbornadiene **1** to yield the phosphinamide **2** [12] (Scheme 1). When an analogous experiment was conducted utilising diethyl phosphorochloridite, aluminum trichloride or iron(III) chloride and the same diene, a single product was isolated in 84% yield (Scheme 1). When iron(III) chloride was employed complete reaction was observed within 8 hours at room temperature, while with aluminum trichloride the reaction showed only 50% conversion after 2 days. The product had spectral characteristics appropriate for the expected phosphinate **3**, but an unambiguous proof of the structure was desirable.

Since the phosphinate **3** was isolated as a colorless oil, a portion was hydrolysed to the parent phosphinic acid **4**. This acid crystallized from a mixture of hexane and ethyl acetate upon long standing yielding crystals suitable for X-ray crystallography. The results of this diffraction analysis are shown in Figure 1 and Table 1. Although the phosphinic acid **4** crystallizes in a dimeric form brought on by strong intermolecular hydrogen bonding, the essential structure of this product is that of the expected cycloadduct. Both bond distances and angles are reasonable for this type of molecule [6].

To gain insight on the mechanism of this reaction, a series of nmr experiments was conducted (Scheme 2). When the ^{31}P nmr spectrum of diethyl phosphorochloridite, in anhydrous methylene chloride, was recorded an initial resonance of +166.3 ppm shifted downfield to a value of +304.8 ppm upon addition of aluminum trichloride to the solution. This observation is in accordance with ^{31}P nmr chemical shifts for phosphenium ions formed upon reaction of various bis(dialkylamino) chlorophosphites with aluminum trichloride [13]. Furthermore when an analogous experiment was monitored by ^{27}Al nmr, it led to similar conclusions. From

Table 1

Table of Bond Distances and Angles of Compound **4**

P-O1	1.490(3)	O1-P-O2	113.0(2)
P-O2	1.543(3)	-P-C1	121.2(2)
		-P-C4	121.8(2)
P-C1	1.807(4)	O2-P-C1	110.2(2)
P-C4	1.803(4)	-P-C4	110.2(2)
		C1-P-C4	75.1(1)
C1-C2	1.513(6)	P-C1-C2	102.1(4)
C3-C4	1.530(7)	P-C4-C3	100.9(3)
C2-C3	1.490(9)	P-C1-C6	86.2(2)
		P-C4-C6	86.6(2)
C2-C5	1.482(7)	C2-C1-C6	95.9(3)
C3-C5	1.486(8)	C3-C4-C6	95.6(4)
C1-C6	1.560(6)	C1-C2-C3	103.3(3)
C4-C6	1.550(6)	C2-C3-C4	103.7(4)
C5-C7	1.491(7)	C1-C2-C5	109.9(4)
C6-C7	1.519(6)	C4-C3-C5	109.3(4)
		C3-C2-C5	60.0
O1-HO2	1.32(7)	C2-C3-C5	59.7(4)
O2-HO2	1.17(7)		
O1-O2	2.490(4)	C2-C5-C3	60.3(4)
O1-HO2-O2	179(5)	C2-C5-C7	108.2(4)
		C3-C5-C7	108.4(5)
		C1-C6-C4	90.0(3)
		C1-C6-C7	106.7(3)
		C4-C6-C7	107.0(4)
		C5-C7-C6	96.7(4)

an initial resonance of +91.3 ppm for a solution of aluminum trichloride in methylene chloride, addition of diethyl phosphorochloridite results in a shift to +103.2 ppm, in agreement with previous studies [14,15]. These findings indicate that under conditions of Lewis acid catalysis, dialkyl phosphorochloridites undergo at least some reactions which are parallel to those described for bis(dimethylamino) phosphenium ions. Therefore, further studies to explore the reactivity of dialkoxy phosphenium ions are in order.

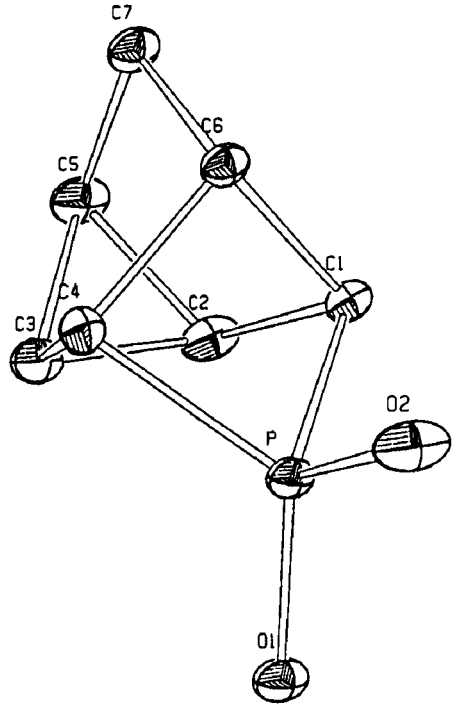
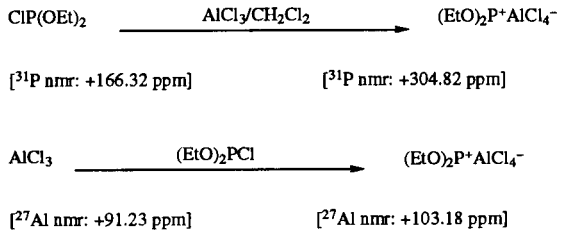


Figure 1. ORTEP drawing of 4-phosphatetracyclo[3.3.0.0.^{2,8}0^{3,6}]octane P-oxide (**4**). Hydrogen atoms are omitted for clarity.

Scheme 2



EXPERIMENTAL

Melting points were obtained on a Thomas-Hoover melting point apparatus, and are uncorrected. Flash column chromatography was done on Merck grade 60 silica gel (230-400 mesh). The nmr spectra (^{1}H, ^{13}C, ^{31}P and ^{27}Al) were recorded on either a Jeol FX-90Q or a Bruker WM-360 spectrometer, with deuteriochloroform as the solvent, unless otherwise noted. The ^{1}H and ^{13}C chemical shifts are reported in parts per million downfield from tetramethylsilane, while the ^{31}P chemical shifts are reported in parts per million relative to phosphoric acid (external standard) and an internal tube of aluminum nitrate in deuterium oxide was used as standard for the ^{27}Al spectra. Low-resolution electron-impact (EI) mass spectra were recorded with a Hewlett-Packard 5985B instrument operating at 70 eV; only selected ions are reported here. High resolution mass spectra were recorded on a ZAB-HF spectrometer at the University of Iowa Mass Spectrometry Facility. Microanalyses were conducted by Desert Analytics, Tucson, AZ. X-Ray crystallography was performed on an Enraf-Nonius CAD4 diffractometer at the Chemistry Department, University of Iowa.

X-Ray Analysis.

A colorless tabular crystal, 0.06 x 0.20 x 0.30 mm, was mounted on a glass fiber with its long axis roughly parallel to the ϕ axis of the Enraf-Nonius CAD4 diffractometer, data were collected with graphite monochromatized MoKα radiation, α aver = 0.71073, 295 K, ω/two θ scan width = 0.6 + 0.35 tan θ, and background counts were made by scanning 25% below and above this range. Peak counting time/background time = 2/1. The horizontal counter aperture ranged from 2.5 to 3 mm, depending on the angle. Scan rate varied 1 to 4 deg ω/min, depending on the intensity. Reflections were collected to a two θ maximum of 50 degrees. Lorentz polarization corrections were made, but not absorption, with linear absorption coefficient = 3.3 cm^{-1}. A total of 2465 reflections were measured, of which 339 was classed as absent. The net averaged reflections = 1232, of which 999 exceeded 3 sigma. Agreement among equivalent reflections = 0.031 based on intensity and 0.021 based on F. Cell dimensions were obtained from 24 reflections in the angular range $35<2\theta<45$

degrees. Two θ scans were resolved into α1 and α2 components and fit by least squares to the cell constants a = 6.095(5), b = 7.193(3), c = 8.455(5), α = 82.49(3), β = 71.93(5), γ = 81.07(5). The cell volume is 348. For z = 2, F.W. = 181.15, the calculated density is 1.73 g/cm^3; space group = P1. The structure was solved by direct methods and refined by full matrix least squares. All hydrogen atoms were located in the difference maps and were refined by least squares. All non-hydrogen atoms were refined anisotropically. The total number of parameters is 128 (includes scale and extinction parameter of 1 x 10^{-6}). Weights were defined as per the method of Killian and Lawrence [16] with p = 0.05 and q = 0.0. In the last cycle of refinement the maximum parameter shift was less than 0.11 of its esd. R1 = 0.074, R2 = 0.11. The standard deviation of an observation of unit weight is 1.50. Computer programs used were from the SDP/VAX package for Enfraf-Nonius diffractometers.

Ethyl 4-Phosphatetracyclo[3.3.0.0.^{2,8}0^{3,6}]octane P-Oxide (**3**).

Bicyclo[2.2.1]hepta-2,5-diene **1** (1.00 g, 10.85 mmoles) was added to a cold (0°) solution of diethyl phosphorochloridite (2.04 g, 13.07 mmoles) and iron(III) chloride (2.10 g, 13.07 mmoles) in anhydrous methylene chloride and the reaction mixture was allowed to warm up to room temperature overnight. The resulting mixture was washed with water (50 ml), the aqueous layer was extracted with methylene chloride (3 x 25 ml) and the combined organic solvents were dried over magnesium sulfate. After concentration *in vacuo* the residue was purified by flash column chromatography eluting with hexane:ethyl acetate (30:70, v/v) to afford 1.68 g (84%) pure compound **3** as colorless oil; ^{1}H nmr (360 MHz, deuteriochloroform): δ 1.25 (t, J = 7.1 Hz, 3H), 1.36 (br s, 2H), 1.52 (d, J = 4.3 Hz, 2H), 1.66 (d, J = 6.1 Hz, 1H), 2.16 (br s, 1H), 2.40 (br s, 2H), 4.13-4.05 (m, 2H); ^{13}C nmr (90 MHz) (deuteriochloroform): δ 10.5 (d, J_{CP} = 9.9 Hz), 16.7 (d, J_{CP} = 5.0 Hz), 18.8 (d, J_{CP} = 40.6 Hz), 31.2 (d, J_{CP} = 30.7 Hz), 32.5 (d, J_{CP} = 17.0 Hz), 49.5 (d, J_{CP} = 82.5 Hz), 62.2 (d, J_{CP} = 7.0 Hz); ^{31}P nmr (36.4 MHz) (deuteriochloroform): δ +51.8; ms: (70 eV, electron impact) m/z 184 (M$^+$, 8), 169 (1), 156 (23), 137 (5), 91 (100), 77 (2), 66 (12), 47 (3); hrms: Calcd. for $C_9H_{13}O_2P$: 184.0652. Found: 184.0671

4-Phosphatetracyclo[3.3.0.0.^{2,8}0^{3,6}]octane P-Oxide (**4**).

The phosphinate **3** (0.25 g, 1.36 mmoles) hydrolyzed on standing in moist ethyl acetate to the parent phosphinic acid. The resulting white crystals were recrystallized from petroleum ether to give 0.18 g (87%) compound **4**, (mp 169-171°); ^{1}H nmr (360 MHz) (deuteriochloroform): δ 1.46 (br s, 2H), 1.51 (br s, 2H), 1.71 (br s, 1H), 2.39 (br s, 1H), 2.47 (br s, 2H), 9.86 (br s, 1H); ^{13}C nmr (90 MHz, deuteriochloroform): δ 9.9 (d, J_{CP} = 8.9 Hz), 17.9 (d, J_{CP} = 40.4 Hz), 31.4 (d, J_{CP} = 31.2 Hz), 33.3 (d, J_{CP} = 17.3 Hz), 49.1 (d, J_{CP} = 84.9 Hz); ms: (70 eV, electron impact): m/z 156 (M$^+$, 15), 138 (4), 121 (1), 109 (1), 91 (100), 86 (3), 77 (7), 66 (26).

Anal. Calcd. for $C_7H_9O_2P$: C, 53.85; H, 6.16. Found: C, 54.09; H, 5.89.

REFERENCES AND NOTES

[1] S. Pollack, J. Jacobs and P. Schultz, *Science*, **234**, 1517 (1986).

[2] J. Jacobs and P. Schultz, *J. Am. Chem. Soc.*, **109**, 2175 (1987).

[3] D. W. Norbeck, J. B. Kramer and P. A. Lartey, *J. Org. Chem.*, **52**, 2174 (1987).

[4] W. S. Wadsworth Jr., *Org. React.*, **25**, 73 (1977).

[5] R. Engel, *Chem. Rev.*, **77**, 349 (1977).

[6] S. A. Weissman, S. G. Baxter, A. M. Arif and A. H. Cowley, *J. Chem. Soc., Chem. Commun.*, 1081 (1986).

[7] B. E. Maryanoff and R. O. Hutchins, *J. Org. Chem.*, **37**, 3475 (1972).

[8] A. H. Cowley and R. D. Kemp, *Chem. Rev.*, **85**, 367 (1985).

[9] P. Sampson, G. B. Hammond and D. F. Wiemer, *J. Org. Chem.*, **51**, 4342 (1986).

[10] T. Calogeropoulou, G. B. Hammond and D. F. Wiemer, *J. Org. Chem.*, **52**, 4185 (1987).

[11] V. Roussis and D. F. Wiemer, *J. Org. Chem.*, **54**, 627 (1989).

[12] S. A. Weissman and S. G. Baxter, *Tetrahedron Letters*, 603 (1987).

[13] A. H. Cowley, M. C. Cushner, M. Lattman, M. L. McKee, J. S. Szobota and J. C. Wilburn, *Pure Appl. Chem.*, **52**, 789 (1980).

[14] J. W. Akitt, *Annu. Rep. NMR Spectrosc.*, **5A**, 465 (1972).

[15] A. H. Cowley and S. K. Mehrotra, *J. Am. Chem. Soc.*, **105**, 2074 (1983).

[16] R. C. G. Killean and J. L. Lawrence, *Acta Crystallogr.*, **B25**, 1750 (1969).