

- KUPCHAN, S. M., HEMINGWAY, R. J. & SMITH, R. M. (1969). *J. Org. Chem.* **34**, 3898–3902.
- MERCIER, D., LÉBOUL, J., CLEOPHAX, J. & GERO, S. D. (1971). *Carbohydr. Res.* **20**, 299–304.
- MERCIER, D., LÉBOUL, J., RICHE, C. & GERO, S. D. (1971). *C. R. Acad. Sci. Paris*, **272**, 1503–1505.
- MIZUSHIMA, S. (1954). *Structures of Molecules and Internal Rotation*. New York: Academic Press.
- PETHRICK, R. A. & WYN-JONES, E. (1969). *Quart. Rev.* pp. 301–324.
- RICHE, C. (1970). *C. R. Acad. Sci. Paris*, **271**, 396–398.
- RICHE, C. (1971). *C. R. Acad. Sci. Paris*, **272**, 1422–1424.
- RICHE, C. (1972). Thèse, A. O. du CNRS 6513, Paris.
- RICHE, C. (1973). *Acta Cryst.* **A29**, 133–137.
- SHEPPARD, N. (1959). *Advanc. Spectrosc.* **1**, 288–353.
- SUTTON, L. E. (1965). *Tables of Interatomic Distances and Configuration in Molecules and Ions*. London: The Chemical Society.
- TURNER, T. E. & HOWE, J. A. (1956). *J. Chem. Phys.* **24**, 924–925.

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The Crystal and Molecular Structure of 2-Piperidino-5-chloromethyl-5-methyl-2-oxo-1,3,2-dioxaphosphorinan*

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The crystal and molecular structure of 2-piperidino-5-chloromethyl-5-methyl-2-oxo-1,3,2-dioxaphosphorinan was determined by means of the symbolic addition phase-determination procedure. The space group is $P2_1/c$ and the cell constants for the tetramolecular unit cell are: $a=10.035$ (8); $b=6.503$ (4); $c=20.19$ (1); and $\beta=96.8$ (3)°. Anisotropic refinement carried out for all nonhydrogen atoms resulted in a final weighted agreement index of $R=0.033$. The molecule has a chair conformation with the piperidinyl group equatorial to the phosphorus ring system.

Introduction

The direction of nucleophilic substitution at phosphorus has been of interest to chemists for a number of years (Hudson, 1965; McEwen, 1965; Bruice & Benkovic, 1966; Kirby & Warren, 1967; Gallagher & Jenkins, 1968). Most studies have involved the use of optically active substrates, which, in many cases, have limited the value of the results because of facile racemization. Stereochemical studies have primarily involved the use of optically active phosphonium salts as substrates. On the other hand, investigations concerning the stereochemical outcome resulting from substitution at phosphorus in phosphates has received less attention.

We have previously shown (Wadsworth, 1967) that two isomeric 2-piperidinyl-5-chloromethyl-2-oxo-1,3,2-dioxaphosphorinans may be formed by treating the phosphorochloridate, obtained from methyl bicyclic phosphite and sulfur chloride, with piperidine or by treating methyl bicyclic phosphite with *N*-chloropiperidine. The structure of the phosphorochloridate (I) is assumed to be as shown in Fig. 1. This assumption is based on the fact that the crystal structure for the cor-

responding bromidate has already been determined (Beineke, 1969). Two compounds, (II) and (III) are not interconvertible by heating to over 200°C or by dissolving in refluxing polar solvents. Thus, it appears highly probable that the two are indeed geometrical isomers.

To prove that our assumption with respect to the conformation at the 5 position is correct as well as to elucidate the geometrical configuration at the phosphorus atom, a single-crystal X-ray analysis was carried out on the low-melting isomer (III).

Experimental

Crystals of (III) were prepared by recrystallization from a benzene-hexane mixture. The dimensions for the crystal used in this study are $0.2 \times 0.2 \times 0.3$ mm. Unit cell data for this compound are given in Table 1. Intensity measurements were carried out on a computer controlled, four-circle diffractometer (Busing, Ellison, Levy, King & Roseberry, 1968). Integrated intensities corrected for background were measured for one quarter of the reciprocal sphere out to a 2θ cutoff of 40°. The radiation used was Zr-filtered Mo $K\alpha$ ($\lambda=0.71069$ Å). Standard deviations were obtained from

$$\sigma(F) = \frac{k}{2\sqrt{Lp}} \left[\frac{I_B}{I} \right]^{1/2},$$

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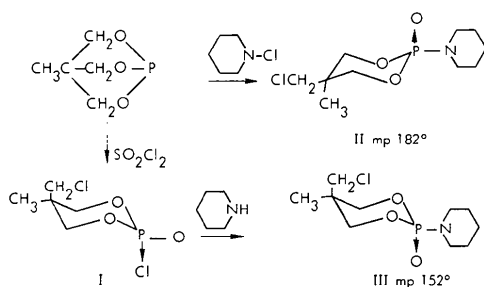


Fig. 1. Preparation of 2-piperidino-5-chloromethyl-5-methyl-2-oxo-1,3,2-dioxaphosphorinane.

where I = total integrated intensity minus background, and I_B = the total integrated intensity. Reflections with $I \leq 3\sigma$ were not used in the refinement. No absorption correction ($\mu = 4.2 \text{ cm}^{-1}$) or dispersion correction was made.

The method of symbolic addition (Karle & Karle, 1966) revealed the positions of chlorine and phosphorus. This permitted the rest of the molecule to be obtained in a straightforward manner by conventional Fourier techniques. In the block-matrix least-squares refinement procedure used, some of the parameters were fixed while about sixty parameters at a time were varied. We resorted to this procedure because of computer-time limitations. Nonhydrogen atomic scattering factors were those given by Cromer (1968); hydrogen scattering factors were from *International Table for X-ray Crystallography* (1962). Hydrogen atoms, located

Table 1. *Crystal data*

$a = 10.035$ (8) Å	Space group $P2_1/c$
$b = 6.503$ (4)	F.W. = 267.68
$c = 20.19$ (1)	$F(000) = 568$
$\beta = 96.8$ (3)	$Z = 4$
$V = 1310$ Å ³	$\rho_c = 1.36$
Formula $\text{ClC}_{10}\text{H}_{19}\text{NO}_3\text{P}$	$\rho_o = 1.37$

Table 2. *Final atomic parameters* ($\times 10^4$) *for nonhydrogen atoms*

Standard deviations given in parentheses are for least significant figures. The temperature factor expression is $\exp[-(h^2\beta_{11} + k^2\beta_{22} + l^2\beta_{33} + hk\beta_{12} + hl\beta_{13} + kl\beta_{23})]$.

	x	y	z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
Cl	7088 (2)	7043 (3)	4370 (1)	288 (1)	260 (7)	36 (7)	112 (9)	30 (3)	31 (4)
P	7651 (2)	1725 (3)	2587 (1)	103 (2)	173 (5)	14 (7)	13 (2)	13 (2)	-10 (4)
N	8356 (5)	2707 (7)	1983 (2)	198 (2)	171 (32)	25 (3)	32 (44)	81 (13)	0 (15)
O(1)	6204 (4)	2741 (6)	2522 (2)	85 (1)	231 (31)	20 (2)	-10 (31)	-10 (9)	-30 (15)
O(2)	8342 (4)	2775 (6)	3257 (2)	107 (11)	209 (28)	21 (2)	-50 (32)	0 (89)	0 (11)
O(3)	7639 (4)	-516 (6)	2609 (2)	147 (9)	185 (17)	32 (2)	-10 (24)	34 (7)	5 (11)
C(1)	8000 (7)	5350 (10)	1130 (4)	190 (17)	304 (36)	33 (4)	58 (45)	13 (13)	56 (21)
C(2)	5477 (6)	2893 (10)	4315 (3)	152 (10)	273 (23)	32 (2)	-60 (28)	68 (9)	-10 (13)
C(3)	6250 (6)	3449 (10)	3732 (3)	99 (9)	175 (21)	22 (2)	-50 (23)	22 (7)	0 (11)
C(4)	5464 (6)	2518 (9)	3102 (3)	91 (18)	248 (48)	29 (4)	-80 (51)	30 (16)	-30 (26)
C(5)	7636 (6)	2506 (9)	3841 (3)	99 (11)	276 (30)	18 (2)	20 (31)	27 (9)	35 (15)
C(6)	8391 (6)	4940 (10)	1853 (3)	194 (15)	204 (31)	25 (3)	-70 (38)	34 (12)	-30 (17)
C(7)	8882 (6)	4166 (10)	0712 (3)	245 (19)	393 (39)	28 (3)	55 (46)	21 (13)	27 (20)
C(8)	9266 (6)	1500 (10)	1608 (3)	133 (13)	268 (32)	29 (3)	115 (36)	34 (11)	-30 (18)
C(9)	8863 (7)	1850 (10)	0869 (3)	153 (21)	509 (66)	18 (4)	113 (70)	-10 (10)	-90 (32)
C(10)	6291 (6)	5800 (10)	3629 (3)	152 (14)	233 (32)	18 (3)	-4 (33)	15 (9)	10 (14)

on a difference Fourier map, were included in least-squares refinements but with fixed isotropic thermal parameters of 6.0 Å^2 . All other atoms were refined anisotropically. A weighting scheme based on counter statistics (Stout & Jensen, 1968) was applied. The final weighted residual,

$$R_w = \left(\frac{\sum |w_i| |F_o| - w_i |F_c|}{\sum w_i |F_o|} \right),$$

0.033 was obtained for 944 reflections greater than 3σ . The corresponding residual for all data (1252 reflections) was 0.074. Refinement was terminated when the average parameter shift was 15% of the estimated standard deviation for that parameter. The Table of observed and calculated structure factors has been de-

Table 3. *Final atomic parameters for hydrogen atoms*

Values for positional parameters are $\times 10^3$. An isotropic thermal parameter $B = 6.0$ (Å²) was used for all hydrogen atoms.

	x	y	z
H(1)	910 (5)	-9 (8)	170 (2)
H(2)	967 (5)	112 (8)	62 (2)
H(3)	452 (5)	325 (8)	296 (2)
H(4)	597 (5)	344 (9)	476 (2)
H(5)	540 (5)	150 (8)	435 (2)
H(6)	453 (5)	361 (8)	427 (2)
H(7)	533 (5)	632 (8)	359 (2)
H(8)	680 (5)	618 (8)	329 (2)
H(9)	762 (5)	93 (8)	394 (2)
H(10)	821 (5)	321 (8)	420 (2)
H(11)	522 (5)	101 (9)	313 (2)
H(12)	793 (5)	563 (9)	217 (2)
H(13)	934 (5)	549 (8)	199 (2)
H(14)	806 (5)	680 (9)	100 (2)
H(15)	700 (5)	492 (9)	99 (2)
H(16)	986 (5)	426 (8)	80 (2)
H(17)	854 (5)	460 (8)	25 (2)
H(18)	785 (5)	124 (8)	74 (2)
H(19)	1017 (5)	217 (8)	177 (2)

posited.* Final parameters are given in Tables 2 and 3, bond distances and angles are presented in Table 4.

Table 4. *Interatomic distances (Å), angles (°) and estimated errors*

Cl—C(10)	1.802 (7)	C(8)—H(1)	1.07 (6)
P—O(3)	1.458 (4)	C(8)—C(9)	1.515 (8)
P—O(1)	1.586 (4)	C(9)—H(3)	1.09 (5)
P—O(2)	1.598 (5)	C(9)—H(19)	1.10 (5)
P—N	1.613 (6)	C(10)—H(13)	0.93 (5)
N—C(6)	1.474 (8)	C(10)—H(14)	1.02 (5)
N—C(8)	1.480 (8)	O(3)—P—O(1)	114.1 (2)
C(1)—H(7)	0.98 (6)	O(3)—P—O(2)	113.9 (2)
C(1)—H(6)	1.05 (5)	O(3)—P—N	115.1 (3)
C(1)—C(6)	1.490 (9)	O(1)—P—O(2)	101.2 (3)
C(1)—C(7)	1.50 (1)	O(1)—P—N	104.6 (3)
C(2)—H(16)	0.91 (5)	O(2)—P—N	106.6 (2)
C(2)—H(17)	1.04 (5)	C(6)—N—C(8)	113.7 (5)
C(2)—H(15)	1.05 (5)	C(6)—N—P	123.1 (4)
C(2)—C(3)	1.528 (9)	C(8)—N—P	122.0 (4)
C(3)—C(5)	1.513 (9)	C(4)—O(1)—P	115.9 (4)
C(3)—C(4)	1.539 (9)	C(5)—O(2)—P	115.5 (4)
C(3)—C(10)	1.546 (9)		
C(4)—H(10)	1.02 (6)	C(5)—C(3)—C(2)	109.5 (5)
C(4)—H(18)	1.07 (5)	C(5)—C(3)—C(4)	109.4 (5)
C(4)—O(1)	1.467 (8)	C(5)—C(3)—C(10)	112.5 (5)
C(5)—H(11)	0.99 (5)	C(2)—C(3)—C(4)	106.7 (5)
C(5)—H(12)	1.04 (5)	C(2)—C(3)—C(10)	111.3 (5)
C(5)—O(2)	1.457 (7)	C(4)—C(3)—C(10)	107.2 (5)
C(6)—H(9)	0.95 (5)	O(1)—C(4)—C(3)	111.3 (5)
C(6)—H(8)	1.03 (5)	O(2)—C(5)—C(3)	111.1 (5)
C(7)—H(5)	0.98 (5)	N—C(6)—C(1)	110.1 (5)
C(7)—H(4)	1.01 (5)	C(1)—C(7)—C(9)	111.3 (6)
C(7)—C(9)	1.54 (1)	N—C(8)—C(9)	108.4 (5)
C(8)—H(2)	1.03 (5)	C(8)—C(9)—C(7)	110.1 (6)
		C(3)—C(10)—Cl	110.3 (4)

Discussion

The crystal structure confirms that the isomer (III) has the expected *trans* configuration with the piperidine group equatorial and the chloromethyl group axial. The molecular configuration is shown in Fig. 2. It follows that (II) must be the *cis* isomer. This conclusion stems from the known mechanism of the Arbuzov (Rakoff & Rose, 1966) reaction. Thus, piperidine must react with the phosphorochloride *via* inversion of configuration at phosphorus.

The n.m.r. spectra of (II) and (III) reveal something about the structures of the compounds. Signals for hydrogen atoms on the chloromethyl group of compound (III) are deshielded relative to those from the chloromethyl group in compound (II). Likewise, methyl hydrogen signals in compound (II) are deshielded relative to those in compound (III). It would be likely that oxygen atoms on the phosphorus ring system would exert a deshielding influence on atoms axial to the ring system greater than the influence on equatorial atoms on the five-ring position. Conformational mobility of the

* This table has been deposited with the National Lending Library, England, as Supplementary Publication No. 30105. Copies may be obtained through the Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CH1 1NZ, England.

two isomers does not hinder their detection by this means. Compound (II) does indeed show considerable mobility as measured by changes in chemical shifts of the hydrogen atoms on the groups at the five positions, and especially ring hydrogen atoms, when the temperature of the solutions are allowed to vary (Edmundson & Mitchell, 1968, 1970; Katritsky, Nesbit, Michalski, Tulimowski & Zwierzak, 1970; White, McEwen, Bertrand & Verkade, 1971). Such variations are not observed with the lower-melting isomer, compound (III), which indicates that it exists predominately in a single conformation. This may be a consequence of a dipole-dipole interaction between the ring oxygen atoms and the chloromethyl group. Two of the phosphorus-oxygen bond distances are longer than any previously reported. This may be a consequence of the piperidinyll group being in an equatorial position to the phosphorus ring system.

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References

- BEINEKE, T. A. (1969). *Acta Cryst.* B25, 413–419.
 BRUCE, T. C. & BENKOVIC, S. J. (1966). *Bioorganic Mechanisms*, Vol. 2, Chap. 5, pp. 1–109. New York: Benjamin.
 BUSING, W. R., ELLISON, R. D., LEVY, H. A., KING, S. P., & ROSEBERRY, R. T. (1968). Report ORNL-4143, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
 CROMER, D. T. (1968). *Acta Cryst.* A24, 321–323.
 EDMUNDSON, R. S. & MITCHELL, E. W. (1968). *J. Chem. Soc. (C)*, pp. 3033–3036.
 EDMUNDSON, R. S. & MITCHELL, E. W. (1970). *J. Chem. Soc. (C)*, pp. 752–759.
 GALLAGHER, M. J. & JENKINS, I. D. *Topics in Stereochemistry*, Edited by E. L. ELIEL and N. L. ALLINGER. Vol. 3, Chap. 1, pp. 1–96. New York: John Wiley.
 HUDSON, R. F. (1965). *Structure and Mechanism in Organophosphorus Chemistry*, Chap. 8 pp. 250–288. New York: Academic Press.
International Tables for X-ray Crystallography (1962). Vol. III, pp. 202–203. Birmingham: Kynoch Press.
 KARLE, J. & KARLE, I. L. (1966). *Acta Cryst.* 21, 849–859.

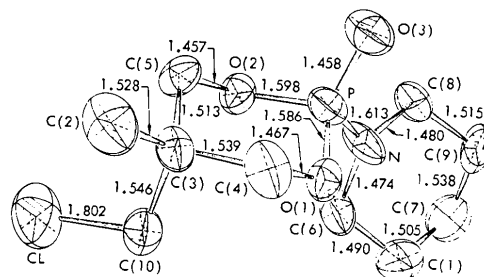


Fig. 2. Molecular conformation of 2-piperidino-5-chloromethyl-5-methyl-2-oxo-1,3,2-dioxaphosphorinan.

- KATRITSKY, A. R., NESBIT, M. R. MICHALSKI, J., TULIMOWSKI, Z. & ZWIERZAK, A. (1970). *J. Chem. Soc. (B)*, pp. 140–147.
- KIRBY, A. I. & WARREN, S. G. (1967). *The Organic Chemistry of Phosphorus*, Chap. 10. pp. 274–364. Amsterdam: Elsevier.
- MCEWEN, W. E. (1965). *Topics in Phosphorus Chemistry*, Vol. 2, pp. 2–39. Edited by M. GRAYSON AND E. J. GRIFFITH. New York: John Wiley.
- RAKOFF, H. & ROSE, N. C. (1966). *Organic Chemistry*, p. 640, New York: Macmillan.
- STOUT, G. H. & JENSEN, L. H. (1968). *X-ray Structure Determination*, pp. 456–458. New York: Macmillan.
- WADSWORTH, W. S. (1967). *J. Org. Chem.* **32**, 1603–1604.
- WHITE, D. W., MCEWEN, G. K., BERTRAND, R. D. & VERKADE, J. G. (1971). *J. Chem. Soc. (B)*, pp. 1454–1461.

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The Crystal and Molecular Structure of Glycocyanine

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Glycocyanine, $\text{NH}_2 \cdot \text{NH} \cdot \text{C}(\text{NH}) \cdot \text{CH}_2\text{COOH}$, crystallizes in the monoclinic system with $a = 5.09$ (1), $b = 6.16$ (1), $c = 17.47$ (3) Å, $\beta = 95.2$ (2)°. The space group is $P2_1/n$. Three-dimensional intensities were collected by equi-inclination Weissenberg photography around **a** and **b** with Cu $K\alpha$ radiation and estimated visually. The structure was solved from Patterson projections down **a** and **b** and refined by the full-matrix least-squares method. Hydrogen atoms were located from a difference Fourier synthesis. The non-hydrogen atoms were assigned anisotropic and the hydrogen atoms isotropic temperature factors. The final R is 0.075 for 868 observed reflexions, or 0.082 if 108 unobserved reflexions are included. The average standard deviation for bonds between non-hydrogen atoms is 0.004 Å. Glycocyanine is a zwitterion, the two C–O bond lengths being 1.262 and 1.247 Å. The proton from the carboxyl group is attached to the guanidinium group. Both the carboxyl and guanidinium groups are planar. The double-bond orders of the C–N bonds in the guanidinium group are 0.29, 0.38, and 0.34. All the hydrogen atoms available for hydrogen-bond formation are satisfied.

Introduction

Glycocyanine or guanidinoacetic acid, $\text{C}_3\text{H}_7\text{N}_3\text{O}_2$, plays an important biological role in the formation of creatine. In the present paper the crystal and molecular structure of glycocyanine is reported.

Experimental

Glycocyanine crystallizes from aqueous solution as transparent prisms elongated along **a**. The crystals are stable under normal conditions of temperature and humidity. Rotation and Weissenberg photographs taken about **a** and **b** (λ for Cu $K\alpha = 1.542$ Å) showed that the crystals are monoclinic with $a = 5.09$ (1), $b = 6.16$ (1), $c = 17.47$ (3) Å, $\beta = 95.2$ (2)°. The only systematic absences are $0k0$ with k odd and $h0l$ with $(h+l)$ odd indicating that the space group is $P2_1/n$. The density measured by flotation is 1.44 while that calculated for 4 molecules of $\text{C}_3\text{H}_7\text{N}_3\text{O}_2$ per unit cell is 1.42 g cm^{-3} .

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Intensities were collected for $0-4kl$ and $h, 0-2, l$ using the multiple-film, equi-inclination Weissenberg technique with Cu $K\alpha$ radiation. Intensities were estimated by visual comparison with a calibrated strip. The crystals used for collecting data along **a** and **b** had cross sections 0.30×0.35 and 0.40×0.30 mm respectively. No absorption correction was applied. The intensities were corrected for Lorentz, polarization, and spot-size effects (Phillips, 1954, 1956), correlated through common reflexions, and put on an absolute scale by Wilson's (1942) method.

Structure determination

The dimensions of the end groups in glycocyanine are similar. Also, it is to be expected that these groups take part in hydrogen bonding. A model was constructed satisfying these conditions. From the projections of the model on (100) and (010), the interatomic vectors were calculated and shown to be in good agreement with the Patterson syntheses. The Patterson synthesis projected down **a** is shown in Fig. 1. R for the three-dimensional data using the above model was 0.42.