Structural Studies of Pyridine Oximes.
I. The Crystal and Molecular Structure of *syn*-4-Pyridinecarboxaldehyde Oxime

By M. Martínez-Ripoll*

Instituto de Química-Física 'Rocasolano' CSIC, Serrano 119, Madrid 6, Spain

and H. P. Lorenz

Chemisches Laboratorium der Universität Freiburg, Albertstrasse 21, 78 Freiburg (Breisgau), Germany (BRD)

syn-4-Pyridinecarboxaldehyde oxime crystallizes in the orthorhombic system, space group $P2_12_12_1$, with four molecules in a cell of dimensions $a = 15\cdot750$ (2), $b = 7\cdot434$ (1), $c = 5\cdot406$ (1) Å. The calculated density is $1\cdot281$ g cm^{-3}. The structure was solved by direct methods and refined by least-squares analysis to an R index of $0\cdot066$. The oxime group is twisted $13\cdot7°$ from the plane through the pyridine ring. The molecules are connected by single hydrogen bonds to form infinite chains.

Introduction

Some derivatives of 4-pyridinecarboxaldehyde oxime and 4-pyrimidinecarboxaldehyde oxime (hereafter abbreviated to 4PYCO and 4PCO, respectively) were included in several investigations carried out by Hagedorn, Stark & Lorenz (1972) in connexion with the reactivation of phosphorylated acetylcholine esterase.

The structures of *syn* and *anti* configurational 4-pyrimidinecarboxaldehyde oximes (4PCO) were recently reported by Martínez-Ripoll & Lorenz (1973, 1974). We describe here the crystalline and molecular structure of the *syn* configurational form of 4-pyridinecarboxaldehyde oxime (*syn*-4PYCO).

Experimental

Crystals of *syn*-4PYCO were obtained by slow evaporation of a purified specimen in water. They are transparent and colourless. Precise lattice parameters were obtained by least-squares refinement of the θ values for several reflexions measured on a four-circle diffractometer. The crystallographic data are listed in Table 1.

Table 1. *Crystal data for*
syn-4-pyridinecarboxaldehyde oxime

Standard deviations, given in parentheses, refer to the least significant digits.

Formula C$_6$H$_6$N$_2$O		V	$632\cdot9$ (2) Å^3
M.W.	$122\cdot127$	Z	4
λ(Mo $K\bar\alpha$) $0\cdot7107$ Å		D_{calc}	$1\cdot281$ g cm^{-3}
a	$15\cdot750$ (2) Å	μ(Mo $K\bar\alpha$)	$2\cdot16$ cm^{-1}
b	$7\cdot434$ (1)	$F(000)$	256
c	$5\cdot406$ (1)	Space group	$P2_12_12_1$

A single crystal of dimensions $0\cdot4 \times 0\cdot4 \times 0\cdot5$ mm was selected for the X-ray investigation. Intensities were measured on a Philips PW 1100 automatic four-

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circle diffractometer, using graphite-monochromated Mo $K\alpha$ radiation and pulse-height discrimination. Two reflexions were monitored periodically during the data-collection process. Subsequent analysis of these reflexions indicated no crystal decomposition during the time required to collect the intensities. 1094 reflexions were collected in the range $2° < \theta < 30°$ using a coupled ω–2θ scan. 571 reflexions were considered as unobserved according to the criterion $I < 2\sigma(I)$ and were not used in the calculations. No correction was made for absorption ($\mu R \simeq 0\cdot1$).

Determination of the structure

The structure was solved by the multisolution tangent formula using the *MULTAN* program (Main, Woolfson, Declercq & Germain, 1974) and including 200 reflexions with $E > 1\cdot3$. The reflexions 021, 704 and 14,1,0 were arbitrarily assigned phases of 360°. From these origin-fixing reflexions, three others in the starting set and two as known phases (Σ_1 formula), a total of 32 solutions were calculated. The set with the highest 'combined figure of merit' was the correct solution. The corresponding E map showed all the non-hydrogen atoms of the structure as the most prominent peaks.

Structure factors based on these coordinates and assuming an overall temperature factor of $4\cdot7$ Å^2 gave an R index of $0\cdot272$. The f curves for neutral C,O,N atoms (Cromer & Mann, 1967) and H atoms (*International Tables for X-ray Crystallography*, 1962) were used. At this stage refinement was started by the full-matrix least-squares method, where the function minimized was $\sum w(\Delta F)^2$. Several cycles assuming unit weights ($w = 1$) and isotropic temperature factors reduced the R index to $0\cdot155$. The subsequent introduction of anisotropic temperature factors resulted in a further reduction to $R = 0\cdot122$. A difference synthesis calculated with the observed reflexions within $\sin\theta/\lambda < 0\cdot5$ showed the hydrogen atoms as the most prominent peaks with electron densities ranging from $0\cdot6$ to $0\cdot3$ e Å^{-3}, with the exception of H(6) which appeared as a

broad maximum. Two more cycles of least-squares refinement with isotropic thermal parameters for the hydrogen atoms gave $R = 0.079$ but long distances (ca 1.2 Å) for the C(4)–H(4) and C(6)–H(5) bonds and a high B value for the H(6) atom (ca 20 Å²).

A weighting scheme of the type indicated in Table 2 was used to make $\langle w\Delta^2 F\rangle \sim 1$ when analysed against F_o. The H atoms were placed at the expected positions and four cycles of anisotropic refinement (isotropic for H atoms) gave acceptable values for the C–H bond lengths and for the thermal parameters of H atoms. The final atomic coordinates and thermal parameters are listed in Table 3 and correspond to $R = 0.066$, $R_m = 0.067$, $R_w = 0.076$, where $R_m = \sum m||F_o| - |F_c||/\sum m|F_o|$ and $R_w = [\sum w||F_o| - |F_c||^2/\sum w|F_o|^2]^{1/2}$, m being the multiplicity of a reflexion in the reciprocal space and w the weight assigned to each reflexion.*

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* A list of structure factors has been deposited with the British Library Lending Division as Supplementary Publication No. SUP 31688 (6 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CH1 1NZ, England.

Table 2. *Weighting scheme*

$$w = 1/[a + b|F_o|]^2.$$

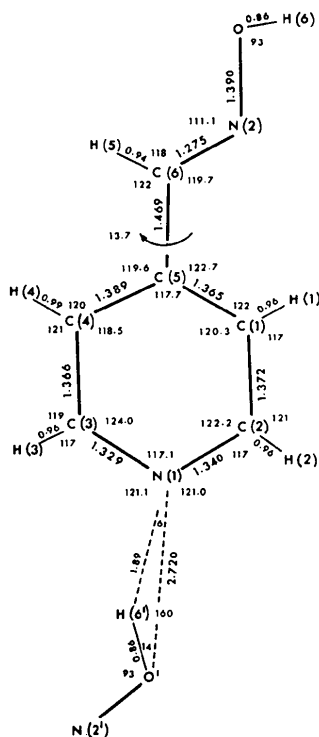|	a	b
$0 \le F_o \le 0.47$	0.48	−0.18
$0.47 < F_o \le 1.45$	0.26	0.22
$1.45 < F_o \le 3.24$	0.79	−0.15
$3.24 < F_o \le 85.00$	0.14	0.04

Fig. 1. Bond lengths (Å) and bond angles (°) in *syn*-4PYCO. The hydrogen bond is also shown.

Table 3. *Final atomic parameters*

Standard deviations are given in parentheses.

(a) Fractional coordinates

	x	y	z
C(1)	0.3288 (3)	0.1540 (8)	−0.0239 (11)
C(2)	0.4021 (4)	0.1122 (9)	−0.1480 (14)
C(3)	0.4809 (4)	0.2647 (9)	0.1363 (14)
C(4)	0.4106 (3)	0.3114 (8)	0.2700 (13)
C(5)	0.3314 (3)	0.2584 (7)	0.1837 (11)
C(6)	0.2546 (4)	0.3158 (9)	0.3161 (14)
N(1)	0.4784 (3)	0.1690 (7)	−0.0712 (11)
N(2)	0.1821 (3)	0.2984 (6)	0.2134 (9)
O	0.1178 (3)	0.3628 (8)	0.3653 (11)
H(1)	0.276 (4)	0.105 (9)	−0.087 (13)
H(2)	0.401 (3)	0.036 (8)	−0.291 (11)
H(3)	0.536 (4)	0.311 (7)	0.185 (11)
H(4)	0.415 (3)	0.395 (8)	0.412 (11)
H(5)	0.257 (4)	0.362 (8)	0.478 (12)
H(6)	0.082 (6)	0.364 (17)	0.246 (22)

(b) Thermal parameters in the form

$$\exp[-2\pi^2(U_{11}h^2a^{*2} + \ldots + 2U_{12}hka^*b^* + \ldots) \times 10^{-3}]$$

	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
C(1)	58 (3)	71 (3)	83 (4)	−12 (3)	−6 (3)	−2 (4)
C(2)	63 (3)	84 (4)	82 (4)	−2 (3)	−6 (3)	−4 (4)
C(3)	48 (3)	97 (4)	102 (5)	−13 (3)	−27 (3)	13 (4)
C(4)	64 (3)	81 (4)	87 (4)	−18 (3)	−24 (3)	−10 (4)
C(5)	60 (3)	59 (3)	72 (3)	−3 (2)	−9 (3)	3 (3)
C(6)	80 (4)	79 (4)	74 (4)	−6 (3)	−6 (3)	−11 (4)
N(1)	58 (3)	88 (3)	90 (4)	−2 (2)	−10 (2)	9 (3)
N(2)	58 (2)	72 (3)	79 (3)	−6 (2)	−3 (2)	−4 (3)
O	71 (3)	120 (4)	106 (4)	9 (3)	7 (3)	−25 (4)

	$10^3 U$		$10^3 U$
H(1)	69 (20)	H(4)	45 (16)
H(2)	40 (16)	H(5)	47 (17)
H(3)	47 (15)	H(6)	143 (49)

Description and discussion of the structure

Molecular structure

Fig. 1 shows the shape of the molecule as it exists in the crystal. The averaged values of the C–N and C–C bond lengths within the pyridine ring are 1.334 and 1.373 Å, respectively. The bond lengths C(6)–N(2), 1.275, and N(2)–O, 1.390 Å, of the oxime group indicate a structure predominantly $>$C=N–O– with a small contribution from $\geqslant$C–N=O. The bond length C(5)–C(6) of 1.469 Å indicates the presence of some double-bond character, probably due to the resonance between the pyridine ring and the oxime group. Similar results were found in the structures of *syn*- and *anti*-4PCO (Martinez-Ripoll & Lorenz, 1973, 1974). The bond lengths in the oxime group of the present compound are listed below and compared with the results for *syn*- and *anti*-4PCO:

	C(5)–C(6)	C(6)–N(2)	N(2)–O
syn-4PCO	1.469 Å	1.273 Å	1.393 Å
anti-4PCO	1.470	1.285	1.378
syn-4PYCO	1.469	1.275	1.390 .

The averaged values of the C–H (0.96 Å) and O–H (0.86 Å) bond lengths are of the usual order of magnitude.

The molecule of *syn*-4PYCO is not planar, as can be seen from the deviations of the atoms from the least-squares planes (Table 4), calculated by the method of Schomaker, Waser, Marsh & Bergman (1959). The oxime group is twisted 13·7° from the plane through

Table 4. Deviations of atoms from least-squares planes

The planes are expressed as $Ax + By + Cz = D$, where x, y and z are the fractional coordinates of the atoms. Asterisks indicate atoms not included in the calculation of the plane.

Plane I	Atom	Deviation
$A = -0.218$	C(1)	−0·105 Å
$B = 6.182$	C(2)	−0·007
$C = -3.001$	C(3)	0·066
$D = 1.057$	C(4)	−0·031
	C(5)	−0·083
	C(6)	−0·109
	N(1)	0·097
	N(2)	0·108
	O	0·064

Plane II	Atom	Deviation
$A = -1.371$	C(1)	−0·012 Å
$B = 6.202$	C(2)	−0·006
$C = -2.943$	C(3)	−0·005
$D = 0.586$	C(4)	−0·013
	C(5)	0·021
	N(1)	0·015
	*C(6)	0·093
	*N(2)	0·387
	*O	0·427

Plane III	Atom
$A = 1.522$	C(6)
$B = 6.744$	N(2)
$C = -2.213$	O
$D = 1.818$	

Angle between the normals to planes II and III = 13·7°.

Table 5. Bond lengths and bond angles in *syn*-4PYCO

Standard deviations are given in parentheses.

C(5)–C(1)	1·365 (8) Å	C(4)–C(5)–C(1)	117·7 (5)°
C(1)–C(2)	1·372 (8)	C(5)–C(1)–C(2)	120·3 (5)
C(2)–N(1)	1·340 (8)	C(1)–C(2)–N(1)	122·2 (6)
N(1)–C(3)	1·329 (9)	C(2)–N(1)–C(3)	117·1 (5)
C(3)–C(4)	1·366 (9)	N(1)–C(3)–C(4)	124·0 (6)
C(4)–C(5)	1·389 (7)	C(3)–C(4)–C(5)	118·5 (6)
C(5)–C(6)	1·469 (8)	C(1)–C(5)–C(6)	122·7 (5)
C(6)–N(2)	1·275 (8)	C(4)–C(5)–C(6)	119·6 (6)
N(2)–O	1·390 (7)	C(5)–C(6)–N(2)	119·7 (6)
C(1)–H(1)	0·96 (6)	C(6)–N(2)–O	111·1 (5)
C(2)–H(2)	0·96 (6)	C(5)–C(1)–H(1)	122 (4)
C(3)–H(3)	0·96 (6)	H(1)–C(1)–C(2)	117 (4)
C(4)–H(4)	0·99 (6)	C(1)–C(2)–H(2)	121 (3)
C(6)–H(5)	0·94 (7)	H(2)–C(2)–N(1)	117 (3)
O——H(6)	0·86 (11)	N(1)–C(3)–H(3)	117 (4)
		H(3)–C(3)–C(4)	119 (4)
		C(3)–C(4)–H(4)	121 (3)
		H(4)–C(4)–C(5)	120 (3)
		C(5)–C(6)–H(5)	122 (4)
		H(5)–C(6)–N(2)	118 (4)
		N(2)–O——H(6)	93 (7)

Hydrogen bond

O'——N(1)	2·720 (7) Å	O'–H(6')–N(1)	160 (11)°
H(6')–N(1)	1·89 (10)		

the pyridine ring around the C(5)–C(6) bond. This is probably due to the steric hindrance of the oxime group by the neighbouring hydrogen atoms. In the case of *syn*-4PCO it was only 5°. All intramolecular distances and angles are listed in Table 5 together with their standard deviations.

Crystal structure

The crystal structure of *syn*-4PYCO is shown in Fig. 2 as a partial projection along the c axis. The molecules are connected by single hydrogen bonds between the N(1) atom (pyridine ring) and the oxygen atom (oxime group) of a neighbouring molecule, forming infinite chains as in *syn*- and *anti*-4PCO. This hydrogen bond O···N(1), 2·720 Å, implies bond lengths of 0·86 and 1·89 Å for O–H(6) and H(6)···N(1), respectively, and an angle O–H(6)···N(1) of 160° (Fig. 1). Other intermolecular distances have normal values and some of the shortest are shown in Fig. 2.

Most of the computations required in this analysis were performed with the X-RAY system of crystallographic programs (Stewart, Kundell & Baldwin, 1970) on the 1108 Univac computer of the Centro de Proceso de Datos del Ministerio de Educación y Ciencia, Madrid.

References

CROMER, D. T. & MANN, J. B. (1967). Report LA-3816. Los Alamos Scientific Laboratory, Univ. of California, New Mexico.
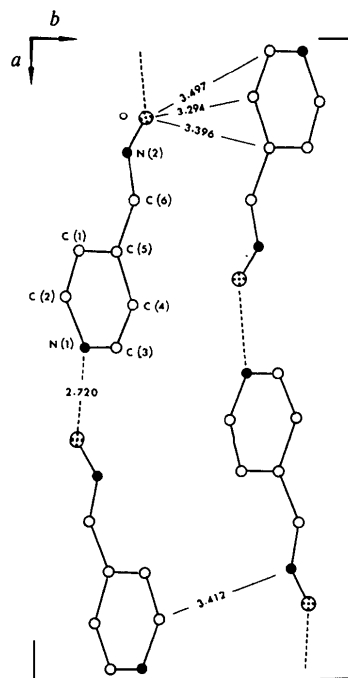HAGEDORN, I., STARK, I. & LORENZ, H. P. (1972). *Angew. Chem.* **84**, 354–356.

Fig. 2. The crystal structure of *syn*-4PYCO as viewed along the c axis. Some of the shortest intermolecular distances (Å) are given. Dashed lines represent the hydrogen bonds.

International Tables for X-ray Crystallography (1962). Vol. III, p. 202. Birmingham: Kynoch Press.

MAIN, P., WOOLFSON, M. M., DECLERCQ, J. P. & GERMAIN, G. (1974). *MULTAN, A Computer Program for the Automatic Solution of Crystal Structures.* Univ. of York, England.

MARTÍNEZ-RIPOLL, M. & LORENZ, H. P. (1973). *Acta Cryst.* B**29**, 2260–2263.

MARTÍNEZ-RIPOLL, M. & LORENZ, H. P. (1974). *Acta Cryst.* B**30**, 793–796.

SCHOMAKER, V., WASER, J., MARSH, R. E. & BERGMAN, G. (1959). *Acta Cryst.* **12**, 600–604.

STEWART, J. M., KUNDELL, F. A. & BALDWIN, J. C. (1970). The X-RAY 70 system. Computer Science Center, Univ. of Maryland, College Park, Maryland.

Structural Studies of Pyridine Oximes.
II. The Crystal and Molecular Structure of *anti*-4-Pyridinecarboxaldehyde Oxime

BY M. MARTÍNEZ-RIPOLL*

Instituto de Química-Física 'Rocasolano' CSIC, Serrano 119, Madrid 6, Spain

AND H. P. LORENZ

Chemisches Laboratorium der Universität Freiburg, Albertstrasse 21, 78 Freiburg (Breisgau), Germany (BRD)

anti-4-Pyridinecarboxaldehyde oxime crystallizes in the monoclinic system, space group $P2_1/n$, with four molecules in a cell of dimensions $a = 9.080$ (1), $b = 5.4366$ (4), $c = 12.108$ (1) Å and $\beta = 90.00$ (1)°. The calculated density is 1.357 g cm^{-3}. The structure was solved by direct methods and refined by least-squares analysis to an R index of 0.052. The oxime group is twisted $7.7°$ from the plane through the pyridine ring. The molecules are connected by single hydrogen bonds to form infinite chains similar to those found in the *syn* configuration of this compound.

Introduction

Some derivatives of 4-pyridinecarboxaldehyde oxime and 4-pyrimidinecarboxaldehyde oxime (hereafter abbreviated to 4PYCO and 4PCO, respectively) have been studied (Hagedorn, Stark & Lorenz, 1972) in connexion with the reactivation process of phosphorylated acetylcholine esterase.

The structural investigations of the two configurational isomers of 4PCO have been reported by Martínez-Ripoll & Lorenz (1973, 1974). The *syn* configurational 4PYCO is reported in the preceding paper. We describe here the crystalline and molecular structure of *anti*-4PYCO.

Experimental

anti-4PYCO was crystallized from an ethanolic solution as transparent, colourless prismatic single crystals. Precise lattice parameters were obtained by least-squares fitting of the θ values for 26 reflexions measured on a four-circle diffractometer. Table 1 shows the crystallographic data.

X-ray intensities were obtained on an automatic Philips PW 1100 diffractometer, using graphite-monochromated Mo $K\alpha$ radiation and pulse-height discrim-

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Table 1. *Crystal data for anti-4-pyridinecarboxaldehyde oxime*

Standard deviations, given in parentheses, refer to the least significant digits.

Formula	$C_6H_6N_2O$	V	597.7 (1) Å^3
M.W.	122.127	Z	4
Wavelength (Mo $K\alpha$)	0.7107 Å	D_{calc}	1.357 g cm^{-3}
a	9.080 (1) Å	μ(Mo $K\alpha$)	2.29 cm^{-1}
b	5.4366 (4)	$F(000)$	256
c	12.108 (1)	Space	
β	90.00 (1)°	group	$P2_1/n$

ination. A crystal with dimensions $0.3 \times 0.3 \times 0.3$ mm was used for collecting the intensities of 1744 independent reflexions ($2° < \theta < 30°$) using the $\omega/2\theta$ scan mode. Of these, 637 were considered as unobserved according to the criterion $I < 2\sigma(I)$ and were not used for the refinement. Two reflexions were monitored periodically during the data-collection process, and indicated no crystal decomposition. No correction was made for absorption ($\mu R \simeq 0.07$).

Determination of the structure

Phases of the 50 highest normalized structure factors (E's > 1.5) were calculated by the multisolution tangent formula using *MULTAN* (Main, Woolfson, Declercq & Germain, 1974). The best phased E map revealed all nine non-hydrogen atoms.