Crystal and Molecular Structure of 2,3-Dichloro-5-ethylamino-6-methoxypyrazine

By **David R. Carter** and **F. Peter Boer**,*† Dow Chemical U.S.A., Midland, Michigan 48640, U.S.A.

The crystal structure of the title compound has been determined from three-dimensional diffractometer data. Crystals are monoclinic, space group $P2_1/c$, with unit cell parameters $a = 9{\cdot}167 \pm 0{\cdot}003$, $b = 12{\cdot}558 \pm 0{\cdot}005$, $c = 8{\cdot}602 \pm 0{\cdot}003$ Å, $\beta = 99{\cdot}46 \pm 0{\cdot}02°$, $Z = 4$. The structure was solved by Patterson and Fourier methods and refined by full-matrix least-squares to R 4·3% for 1885 observed reflections. Bond angles and distances indicate a preferred resonance structure.

THIS X-ray diffraction investigation was directed toward establishing the positional isomer and detailed aspects of the structure for the title compound. We also wished to obtain data for studies of the relation of molecular geometry to herbicidal and fungicidal activity.[1] The crystal structure determination showed the material to be 2,3-dichloro-5-ethylamino-6-methoxypyrazine. It was synthesized by heating under reflux trichloromethoxypyrazine with 70% aqueous ethylamine for 3 h with a dry-ice condenser and crystals were isolated (after quenching) by extraction with benzene and precipitation with hexane. The structure analysis established that amination had occurred adjacent to the methoxy-substituent, to yield the *ortho*-dichloro-isomer.

DISCUSSION

The molecular structure and atom numbering system are shown in Figure 1,[2] and bond distances and angles in Table 1. All nine hydrogen atoms were successfully located in chemically reasonable positions.

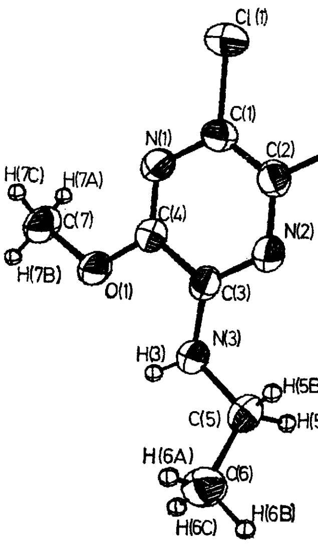

FIGURE 1 The molecule; ellipsoids represent 50% probability of occupancy, and hydrogen atoms are shown as spheres of diameter 0·1 Å

The molecule is predominantly planar with the ethylamino-group bent out of the nominal least-squares plane[3] (through the ring atoms and the atoms directly bonded to the ring) given by $7{\cdot}132x + 6{\cdot}749y + 3{\cdot}682z - 1{\cdot}822 = 0$. Deviations (Å) from this plane are, (*a*) atoms included in the least-squares calculation: (i) ring, N(1) 0·005, C(1) −0·013, C(2) 0·005, N(2) 0·017, C(3) −0·006, and C(4) 0·014; (ii) substituents, Cl(1) −0·040, Cl(2) 0·034, N(3) −0·057, and O(1) 0·042; (*b*) atoms not included in the calculation: C(5) −0·133, C(6) −0·856, and C(7) 0·020. The dihedral angle between the plane of the pyrazine ring and that of the ethylamino-group is 30·5° as given by a clockwise rotation about the N(3)–C(5) bond looking toward N(3). The methoxy-atoms are nearly coplanar with the ring, dihedral angle 0·9°.

TABLE 1

Bond distances (Å) and angles (deg.) with errors in parentheses

(*a*) Distances			
N(1)–C(1)	1·345(2)	C(4)–O(1)	1·342(2)
C(1)–C(2)	1·354(3)	O(1)–C(7)	1·439(2)
C(2)–N(2)	1·335(2)	N(3)–H(3)	0·85(2)
N(2)–C(3)	1·322(2)	C(5)–H(5A)	1·02(3)
C(3)–C(4)	1·435(2)	C(5)–H(5B)	0·87(3)
C(4)–N(1)	1·293(2)	C(6)–H(6A)	0·97(3)
C(1)–Cl(1)	1·731(2)	C(6)–H(6B)	1·01(2)
C(2)–Cl(2)	1·737(2)	C(6)–H(6C)	0·91(3)
C(3)–N(3)	1·336(2)	C(7)–H(7A)	0·98(3)
N(3)–C(5)	1·455(3)	C(7)–H7B)	0·97(3)
C(5)–C(6)	1·480(3)	C(7)–H(7C)	0·99(3)
(*b*) Angles			
N(1)–C(1)–C(2)	121·3(2)	N(3)–C(5)–H(5B)	108(2)
C(1)–C(2)–N(2)	122·9(2)	H(5A)–C(5)–H(5B)	103(2)
C(2)–N(2)–C(3)	117·3(2)	C(6)–C(5)–H(5A)	111(1)
N(2)–C(3)–C(4)	118·8(2)	C(6)–C(5)–H(5B)	112(2)
C(3)–C(4)–N(1)	122·9(2)	C(5)–C(6)–H(6A)	108(2)
C(4)–N(1)–C(1)	116·7(2)	C(5)–C(6)–H(6B)	109(2)
N(1)–C(1)–Cl(1)	115·9(1)	C(5)–C(6)–H(6C)	114(2)
N(2)–C(2)–Cl(2)	115·8(1)	H(6A)–C(6)–H(6B)	107(2)
N(2)–C(3)–N(3)	121·4(2)	H(6A)–C(6)–H(6C)	111(2)
C(3)–N(3)–C(5)	123·4(2)	H(6B)–C(6)–H(6C)	108(2)
N(3)–C(5)–C(6)	112·2(2)	O(1)–C(7)–H(7A)	113(2)
C(3)–C(4)–O(1)	115·1(2)	O(1)–C(7)–H(7B)	105(2)
N(1)–C(4)–O(1)	121·9(2)	O(1)–C(7)–H(7C)	110(2)
C(4)–O(1)–C(7)	117·3(1)	H(7A)–C(7)–H(7B)	105(2)
C(3)–N(3)–H(3)	120(1)	H(7B)–C(7)–H(7C)	116(2)
C(5)–N(3)–H(3)	117(1)	H(7A)–C(7)–H(7C)	108(2)
N(3)–C(5)–H(5A)	111(1)		

The crystal packing is shown stereoscopically in Figure 2. The molecular plane lies in the {2,2,1} family

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† *Present address:* Central Laboratory, Dow Chemical U.S.A., Freeport, Texas 77541, U.S.A.

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[3] J. Gvildys, ' Least-squares Plane and Line Fitter,' Program Library B125, Argonne National Laboratory, Argonne, Illinois. See V. Schomaker, J. Waser, R. E. Marsh, and G. Bergman, *Acta Cryst.*, 1959, **12**, 600.

of crystal lattice planes to form a staggered arrangement which allows the bulky substituents of one molecule to fit *into the* open areas between substituents on its neighbour. Intermolecular contacts <3·7 Å are listed in Table 2. All distances are equal to or greater than the sums of the van der Waals radii (4) except N(2) $\cdots$ H(3), which may represent a weak interaction along the *c*-glide [N(2) $\cdots$ N(3) 3·311 Å]. The sum of the van der Waals radii[4] is 2·7 Å, which N(2) $\cdots$ H(3) 2·469 Å represents a reduction of only 8%. However, *X*-ray diffraction generally gives systematically short bond lengths for hydrogen atoms, and if we assume[5] 1·01 Å instead of 0·85 Å for the H(3)–N(3) bond length, the H(3) $\cdots$ N(2) contact becomes 2·3 Å, representing a more substantial 16% reduction. The near-linearity (173°) of the N(3)–H(3) $\cdots$ N(2) angle also supports the presence of an interaction.

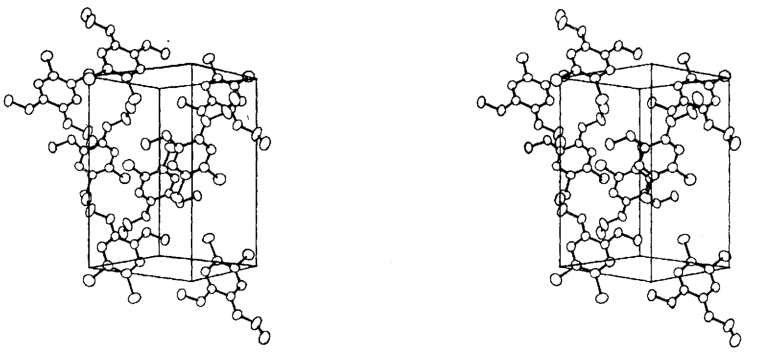


FIGURE 2 Packing of molecules in unit cell. Origin is left lower rear corner with positive *x* to the right, *y* vertical, and *z* forward

TABLE 2

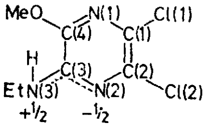
Close intermolecular distances (Å)

H(3) $\cdots$ N(2$^{\text{I}}$)	2·469	N(2) $\cdots$ O(1$^{\text{VIII}}$)	3·195
H(5B) $\cdots$ O(1$^{\text{II}}$)	2·785	C(3) $\cdots$ O(1$^{\text{VIII}}$)	3·274
H(6C) $\cdots$ N(1$^{\text{III}}$)	3·013	N(2) $\cdot\cdot$ N(3$^{\text{VIII}}$)	3·311
H(6B) $\cdots$ Cl(2$^{\text{IV}}$)	3·020	N(3) $\cdots$ O(1$^{\text{IX}}$)	3·364
H(5B) $\cdots$ Cl(2$^{\text{IV}}$)	3·059	N(1) $\cdots$ C(6$^{\text{X}}$)	3·409
H(7B) $\cdots$ Cl(1$^{\text{V}}$)	3·065	C(5) $\cdots$ O(1$^{\text{II}}$)	3·470
H(6C) $\cdots$ Cl(2$^{\text{I}}$)	3·076	Cl(1) $\cdots$ C(7$^{\text{VII}}$)	3·473
H(5B) $\cdots$ N(3$^{\text{II}}$)	3·094	Cl(1) $\cdots$ O(1$^{\text{VII}}$)	3·485
H(7C) $\cdots$ N(1$^{\text{V}}$)	3·124	N(1) $\cdots$ C(7$^{\text{V}}$)	3·525
H(7A) $\cdots$ Cl(1$^{\text{VI}}$)	3·156	C(1) $\cdots$ Cl(1$^{\text{XI}}$)	3·557
H(6B) $\cdots$ N(1$^{\text{III}}$)	3·164	C(3) $\cdots$ C(7$^{\text{VIII}}$)	3·580
H(6C) $\cdots$ N(2$^{\text{I}}$)	3·169	N(3) $\cdots$ C(7$^{\text{II}}$)	3·594
H(7B) $\cdots$ N(3$^{\text{I}}$)	3·171	Cl(1) $\cdots$ C(7$^{\text{V}}$)	3·612
H(7B) $\cdots$ Cl(1$^{\text{VI}}$)	3·184	Cl(2) $\cdots$ C(5$^{\text{XII}}$)	3·674

Roman numeral superscripts denote the following equivalent positions relative to the reference molecule at *x*, *y*, *z*.

I $x, \frac{1}{2} - y, \frac{1}{2} + z$
II $x, \frac{1}{2} - y, -\frac{1}{2} + z$
III $-x, \frac{1}{2} + y, \frac{1}{2} - z$
IV $-x, \frac{1}{2} + y, -\frac{1}{2} - z$
V $1 - x, -y, 1 - z$
VI $1 - x, \frac{1}{2} + y, \frac{1}{2} - z$
VII $1 - x, -\frac{1}{2} + y, \frac{1}{2} - z$
VIII $x, \frac{1}{2} - y, -z$
IX $x, \frac{1}{2} - y, -\frac{1}{2} + z$
X $-x, -\frac{1}{2} + y, \frac{1}{2} - z$
XI $1 - x, -y, -z$
XII $-x, -\frac{1}{2} + y, -\frac{1}{2} - z$

The bond distances (Table 1) indicate that the normal pyrazine resonance may be disturbed to give some localization of double bonds. Expected values for bonds in the pyrazine ring are: C–N 1·33, C–C (un- and mono-substituted) 1·38, and C–C (disubstituted) 1·41—1·47 Å, depending upon the bulkiness of the substituents.[6-9] C(1)–C(2) (1·354 Å) and N(1)–C(4) (1·293 Å) are considerably shortened, although the latter is shorter than the 1·23—1·26 Å found[10,11] for C=N in other compounds. Carbon–nitrogen single bonds involving sp^3 carbons average 1·47 Å,[5] which agrees well with the 1·455 Å found for N(3)–C(5). The N(3)–C(3) distance (1·336 Å) however, is intermediate between C–N and C=N, and agrees well with values for the resonant C–N bonds in pyrazine itself. The observed bond distances thus suggest an important contribution to the bonding from the resonance structure (I).



(I)

Table 3 gives root-mean-square components of vibration along the principal axes of the thermal

TABLE 3

Root-mean-square components (Å) of thermal displacement along ellipsoid principal axes, with estimated standard deviations in parentheses

Atom	Major axis	Intermediate axis	Minor axis
N(1)	0·236(3)	0·193(2)	0·176(2)
C(1)	0·264(3)	0·190(3)	0·170(2)
C(2)	0·258(3)	0·203(3)	0·166(2)
N(2)	0·234(3)	0·207(2)	0·170(2)
C(3)	0·227(3)	0·196(3)	0·159(2)
C(4)	0·222(3)	0·195(3)	0·163(2)
Cl(1)	0·322(1)	0·247(1)	0·178(1)
Cl(2)	0·318(1)	0·255(1)	0·175(1)
N(3)	0·264(2)	0·196(3)	0·172(2)
C(5)	0·328(3)	0·197(3)	0·190(3)
C(6)	0·308(3)	0·252(3)	0·192(3)
O(1)	0·250(2)	0·198(2)	0·185(2)
C(7)	0·262(3)	0·220(3)	0·193(3)

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[4] L. Pauling, 'The Nature of the Chemical Bond,' 3rd edn., Cornell University Press, Ithaca, 1960, p. 260.

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[6] P. J. Wheatley, *Acta Cryst.*, 1957, **10**, 182.

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[10] F. P. van Remoortere and F. P. Boer, *J. Chem. Soc.* (*B*), 1971, 911.

[11] F. P. Boer and F. P. van Remoortere, *J. Amer. Chem. Soc.*, 1970, **92**, 801.

ellipsoids. A least-squares analysis[12] determined the degree to which the motion could be described by a rigid-body assumption, and the magnitude of corrections in bond distances thus imposed.

If the ring atoms and those atoms bonded directly to them are assumed to form the rigid body, the root-mean-square. ΔU_{ij} is quite small (0·0011 Å^2), maximum 0·0027 Å^2 (see ref. 13, p. 449 for a discussion of U and β values in anisotropic motion). Bond-distance corrections, with the rigid-body assumption are: C(5)–C(6) 0·001; C(3)–N(3) 0·002; N(1)–C(1), N(1)–C(4), N(3)–C(5), C(4)–O(1), and C(7)–O(1) 0·003; N(2)–C(3) and C(1)–Cl(1) 0·004, N(1)–C(1), C(1)–C(2), and C(2)–Cl(2) 0·005; and C(3)–C(4) 0·006 Å. If all heavy atoms are assumed to be part of the rigid body (a poor assumption) the root-mean-square ΔU_{ij} is much higher (0·0039 Å^2), maximum 0·0160 Å^2 for U_{22} of C(5).

EXPERIMENTAL

Data Collection.—A well-formed prism (0·70 × 0·24 × 0·52 mm) was mounted in a capillary and preliminary space-group and unit-cell data were obtained from Weissenberg photographs. The crystal was then transferred to a Picker four-circle goniostat, and aligned with c^* coincident with ϕ. Least-squares refinement of the goniostat angles for 13 reflections produced the final unit cell dimensions.

Crystal Data.—$C_7H_9Cl_2N_3O$, $M = 222\cdot08$. Monoclinic, $a = 9\cdot167 \pm 0\cdot003$, $b = 12\cdot558 \pm 0\cdot005$, $c = 8\cdot602 \pm 0\cdot003$ Å, $\beta = 99\cdot46 \pm 0\cdot02°$, $U = 976\cdot8$ Å^3, $D_m = 1\cdot51$, $Z = 4$, $D_c = 1\cdot509$, $F(000) = 456$. Space group $P2_1/c$ (C^5_{2h}) from systematic absences: $0k0$ for $k = 2n + 1$, $h0l$ for $l = 2n + 1$. Mo-K_α radiation, $\lambda = 0\cdot71069$ Å; μ(Mo-K_α) = 6·282 cm^{-1}.

Intensity data were collected for 2231 reflections by use of the θ—2θ scan technique. Monochromatic (oriented-graphite) Mo-K_α radiation was used. Attenuators prevented counting rates $>12{,}000$ s^{-1}. The take-off angle was 3°, and counter aperture 6·0 × 6·0 mm, placed 30 cm from the crystal; 1·5 mm diameter incident- and exit-beam collimators restricted stray radiation. The scan speed was 2° min^{-1} over 2θ angles of $2° + \Delta$, where Δ is the separation of the K_α doublet; this range was sufficient to allow for the observed mosaic spread of the crystal. Stationary-crystal–stationary-counter background counts of 10 s were taken at each end of the scan. The reciprocal lattice was recorded out to sin θ 0·461, equivalent to the Cu-K_α sphere. A test reflection monitored every 50 measurements showed no significant variation. An error $\sigma(I) = [(0\cdot02I)^2 + N_0 + k^2N_b]^{\frac{1}{2}}$ was assigned to the net intensity $I = N_0 - kN_b$ of each reflection in order to establish the weights $w(F) = 4F^2/\sigma^2(F^2)$ for subsequent least-squares refinement, in which the quantity $\Sigma w(|F_o| - |F_c|)^2$ was minimized (N_0 is the gross count, N_b the background count, k the ratio of scan time to background time, and F^2 intensities corrected for Lorentz and polarization effects). The 346 reflections having $I < 0$ or $I/\sigma(I) < 2\cdot0$ were considered unobserved and omitted from the refinement. No absorption correction was applied, but transmission coefficients vary by an estimated 10%.

TABLE 4

Final structure parameters, with standard deviations in parentheses

(*a*) Heavy atoms (anisotropic thermal parameters *) × 10^4

Atom	x	y	z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
N(1)	0·3519(2)	0·0337(1)	0·2358(2)	105(2)	48(1)	107(2)	4(1)	12(2)	6(1)
C(1)	0·3205(2)	−0·0159(2)	0·0957(2)	119(3)	44(1)	120(3)	5(1)	30(2)	−2(1)
C(2)	0·2205(2)	0·0246(2)	−0·0228(2)	128(3)	51(1)	97(3)	−4(2)	23(2)	−5(2)
N(2)	0·1453(2)	0·1141(1)	−0·0084(2)	115(2)	53(1)	89(2)	3(1)	8(2)	2(1)
C(3)	0·1703(2)	0·1631(1)	0·1295(2)	99(2)	48(1)	87(2)	1(1)	13(2)	8(1)
C(4)	0·2799(2)	0·1204(1)	0·2521(2)	92(3)	47(1)	94(3)	−1(1)	12(2)	4(1)
Cl(1)	0·4170(1)	−0·1325(1)	0·0773(1)	192(9)	59(1)	170(1)	37(1)	26(1)	−10(1)
Cl(2)	0·1840(1)	−0·0372(1)	−0·2057(1)	228(1)	72(1)	109(1)	11(1)	9(1)	−26(1)
N(3)	0·0953(2)	0·2505(1)	0·1567(2)	132(3)	62(1)	85(2)	27(1)	−3(2)	−2(1)
C(5)	−0·0215(3)	0·2967(3)	0·0416(3)	154(4)	99(2)	101(3)	55(2)	−3(3)	13(2)
C(6)	−0·1343(3)	0·3519(3)	0·1169(3)	136(4)	98(2)	156(4)	42(2)	2(3)	−11(3)
O(1)	0·3029(2)	0·1771(1)	0·3861(2)	132(2)	58(1)	95(2)	19(1)	−15(2)	−3(1)
C(7)	0·4083(3)	0·1359(2)	0·5145(3)	147(4)	69(2)	110(3)	17(2)	−36(3)	−2(2)

(*b*) Hydrogen atoms (isotropic thermal parameters)

Atom	x	y	z	B
H(3)	0·114(2)	0·281(2)	0·245(3)	4·3(5)
H(5A)	−0·059(3)	0·245(2)	−0·020(3)	6·1(7)
H(5B)	0·022(3)	0·345(2)	−0·034(3)	6·1(6)
H(6A)	−0·184(3)	0·298(3)	0·170(4)	9·8(9)
H(6B)	−0·210(3)	0·384(2)	0·031(3)	5·0(5)
H(6C)	−0·096(4)	0·405(3)	0·184(4)	9·3(9)
H(7A)	0·507(3)	0·128(2)	0·488(3)	5·7(6)
H(7B)	0·417(3)	0·191(2)	0·594(3)	6·3(7)
H(7C)	0·375(3)	0·064(2)	0·545(3)	5·6(6)

* In the form $\exp[-(h^2\beta_{11} + k^2\beta_{22} + l^2\beta_{33} + 2hk\beta_{12} + 2hl\beta_{13} + 2kl\beta_{23})]$.

Solution and Refinement of the Structure.—Because the asymmetric portion of the unit cell contained only one molecule with two chlorine atoms, the structure was solved by Patterson techniques. A point-atom sharpened vector map indicated the chlorine positions and an electron-density difference map based on those atoms revealed the positions of the remaining non-hydrogen atoms. Atomic scattering factors were taken from ref. 14(*a*), those for hydrogen from ref. 14(*b*). R was then 0·26 and R' 0·22

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$\{R' = [\Sigma w(F_0 - F_c)^2/\Sigma wF_0^2]^{\frac{1}{2}}\}$. In a sequence of full-matrix least-squares refinement cycles, the following parameters were entered successively as variables: non-hydrogen atom positions with isotropic temperature factors,[15] anisotropic temperature factors[16] for those atoms, and hydrogen atom positions with isotropic temperature factors.[15] Four additional cycles converged at R (and R') 0·043 with an average change in parameters equal to 0·2% of their uncertainty in the final cycle. A final electron-density difference map showed no residual peaks $>$0·3 eÅ^{-3}. The standard errors in Tables 1, 3, and 4 were computed[17] from the variance–covariance matrix obtained in the final least-squares cycle. Table 4 lists final atomic parameters; final observed and calculated structure factors are listed in Supplementary Publication No. SUP 21084 (2 pp.).*

We thank A. H. Gulbenk, Western Division Research Laboratories, Dow Chemical Company, for the crystals.

[4/805 *Received*, 22*nd April*, 1974]

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* See Notice to Authors No. 7 in *J.C.S. Perkin II*, 1973, Index issue.

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