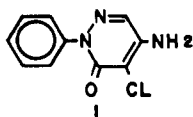


Crystal and Molecular Structure of Herbicides. 1. Pyrazon

The crystal and molecular structure of pyrazon [5-amino-4-chloro-2-phenylpyridazin-3-one, $C_{10}H_8N_3ClO$, orthorhombic, $Pca2_1$, $a = 7.816$ (3), $b = 21.297$ (6), $c = 5.707$ (1), $Z = 4$, Mo $K\alpha$ radiation, $\mu = 2.45$ cm^{-1} (no correction made)] has been determined by three-dimensional x-ray analysis. The structure was solved by direct methods and refined to a final $R = 0.077$ for 626 observed reflections ($|F_o| > 3\sigma(F_o)$). The dihedral angle of the two rings is 27.7° .

Pyrazon (I) is a known inhibitor of the Hill reaction



(photosynthetic electron transport) as it will cause 50% inhibition at a concentration of less than $10 \mu M$. As a result, the plant's energy supply is disrupted, eventually leading to death (Corbett, 1974).

One would like to have a good understanding of the exact mechanism(s) which a herbicide will undertake so that the compound will selectively eliminate unnecessary plants, yet will not harm crops or man. It is usually assumed that Hill reaction inhibitors operate by binding to some site or sites in the chloroplast. If this is correct, and it is difficult to see how some other mechanism could operate, one would ideally require information about the nature of the site. We have embarked on a series of molecular structure determinations of herbicides to better infer important structural features of this site. The distance and angle information afforded by x-ray crystallography can supply this information.

EXPERIMENTAL SECTION

Crystal Data. At $27^\circ C$ using Mo $K\alpha$ ($\lambda = 0.70954 \text{ \AA}$) radiation a rectangular prismatic crystal with dimensions $0.20 \times 0.15 \times 0.05$ mm yielded the following information: orthorhombic, $a = 7.816$ (3), $b = 21.297$ (6), $c = 5.707$ (1) \AA , $Z = 4$, space group $Pca2_1$, $\mu = 2.45$ cm^{-1} (no correction made).

Intensity Data, Structure Determination, and Refinement. Two octants of data within a 2θ sphere of 50° were collected using the method and apparatus described by Rohrbaugh and Jacobson (1974). A total of 2091 reflections were recorded in the hkl and $h\bar{k}l$ octants. Equivalent data were averaged yielding 626 observed ($|F_o| > 3\sigma(F_o)$) intensities (Lawton and Jacobson, 1968).

The structure was solved using the program MULTAN (Main et al., 1971) and successive structure factor (Busing et al., 1962) and electron density map (Hubbard et al., 1971) calculations. Refinement by full-matrix least-squares techniques (Busing et al., 1962) yielded a final $R = 0.077$ using anisotropic thermal parameters for all non-hydrogen atoms. Ring hydrogens were placed at 0.95 \AA from each respective carbon. Amide hydrogens were not seen in a difference map and hence were not used in the refinement.

Final positional parameters, bond lengths, and angles are listed in Tables I, II, and III, respectively, and a drawing of the molecule is given in Figure 1 (Johnson, 1971).

Description of Structure. Both rings are essentially planar with the largest deviation from either plane being 0.02 \AA . Since the shortest intermolecular contacts are all slightly greater than the sum of the van der Waals radii (cf. Table II), packing forces should only make a very small contribution to the molecular geometry. The dihedral angle of the ring planes of 27.7° , then, is likely a result of

Table I. Atomic Positional^a Parameters for Pyrazon

Atom	x	y	z
Cl	0.1715 (1) ^b	0.2203 (6)	0.3889
O	0.3043 (4)	0.091 (2)	0.317 (1)
N(1)	0.3451 (5)	0.600 (2)	0.554 (1)
N(2)	0.3495 (4)	0.398 (2)	0.462 (1)
N(3)	0.1769 (5)	0.668 (2)	0.595 (2)
C(1)	0.2968 (5)	0.271 (2)	0.401 (2)
C(2)	0.2382 (5)	0.364 (2)	0.453 (2)
C(3)	0.2330 (5)	0.571 (2)	0.546 (1)
C(4)	0.2913 (7)	0.677 (3)	0.592 (2)
C(5)	0.4129 (5)	0.328 (2)	0.419 (2)
C(6)	0.4505 (6)	0.489 (2)	0.340 (2)
C(7)	0.5131 (6)	0.428 (3)	0.309 (2)
C(8)	0.5367 (5)	0.218 (2)	0.368 (2)
C(9)	0.4983 (6)	0.062 (3)	0.450 (2)
C(10)	0.4353 (6)	0.112 (2)	0.476 (2)
H(1)	0.4345	0.6380	0.3066
H(2)	0.5395	0.5321	0.2466
H(3)	0.5799	0.1821	0.3515
H(4)	0.5150	-0.0830	0.4892
H(5)	0.4083	0.0025	0.5304
H(6)	0.2895	0.8176	0.6566

^a The positional parameters for all atoms are represented in fractional unit cell coordinates. ^b In this and succeeding tables, estimated standard deviations are given in parentheses for the least significant figures and include the error in the lattice constants. Since the hydrogens were not refined, no standard deviations are given.

Table II. Selected Interatomic Distances (Å) for Pyrazon

Bonding distances	Sutton, 1958	Type	
N(1)-N(2)	1.36 (1)	1.46	N-N in N_2H_4
N(2)-C(1)	1.42 (1)	1.32	N-C in N-C=O
C(1)-C(2)	1.41 (2)	1.52	C-C in C-C=O
C(2)=C(3)	1.39 (2)	1.33	C=C in C_2H_4
C(3)-C(4)	1.43 (2)	1.54	C-C in C_2H_6
C(4)=N(1)	1.26 (2)	1.33	C=C in C_2H_4
N(2)-C(5)	1.45 (1)		
C(1)=O	1.23 (2)		
C(2)-Cl	1.71 (1)		
C(3)-N(3)	1.37 (2)		
C(4)-H(6)	0.95 (1)		
C(5)-C(6)	1.37 (2)		
C(6)-C(7)	1.40 (2)		
C(7)-C(8)	1.38 (2)		
C(8)-C(9)	1.37 (2)		
C(9)-C(10)	1.39 (2)		
C(10)-C(5)	1.39 (2)		
C(6)-H(1)	0.95 (1)		
C(7)-H(2)	0.95 (1)		
C(8)-H(3)	0.95 (1)		
C(9)-H(4)	0.95 (1)		
C(10)-H(5)	0.95 (1)		

Nonbonding Distances

Interaction	Via	Observed distance	Total van der Waals distance (Pauling, 1960)
Cl...H(3)	a-glide	3.028 (3)	3.0
N(1)...H(5)	-1 cell in y	2.67 (1)	2.7
Cl...H(3)	c-glide minus	3.044 (3)	3.0
	-1 cell in y and z		
N(3)...H(1)	c-glide	2.90 (1)	2.7

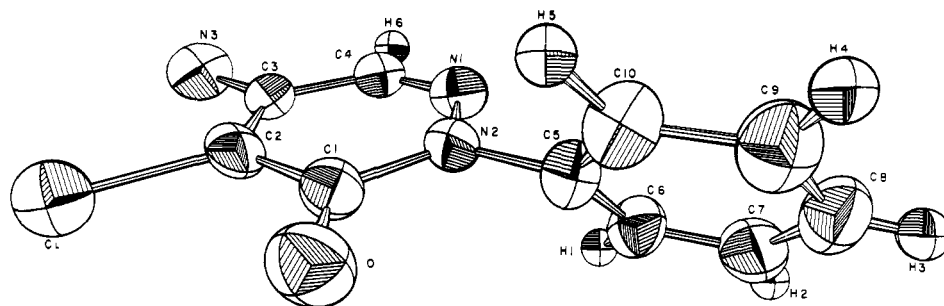


Figure 1. The pyrazon molecule showing 50% probability ellipsoids; 30% for hydrogens.

Table III. Bond Angles (Degrees) for Pyrazon^a

Angle	Degrees	Angle	Degrees
C(4)-N(1)-N(2)	119 (1)	C(10)-C(5)-C(6)	123 (1)
N(1)-N(2)-C(1)	123.7 (9)	C(5)-C(6)-C(7)	118 (1)
N(2)-C(1)-C(2)	114 (1)	C(6)-C(7)-C(8)	120 (1)
C(1)-C(2)-C(3)	122 (1)	C(7)-C(8)-C(9)	120 (1)
C(2)-C(3)-C(4)	115 (1)	C(8)-C(9)-C(10)	121 (1)
C(3)-C(4)-N(1)	125 (1)	C(9)-C(10)-C(5)	118 (1)
C(5)-N(2)-N(1)	115.0 (9)	N(2)-C(5)-C(6)	118 (1)
C(5)-N(2)-C(1)	121.2 (9)	N(2)-C(5)-C(10)	119 (1)
O-C(1)-N(2)	120 (1)	H(1)-C(6)-C(5)	121 (1)
O-C(1)-C(2)	126 (1)	H(1)-C(6)-C(7)	121 (1)
Cl-C(2)-C(1)	118 (1)	H(2)-C(7)-C(6)	120 (2)
Cl-C(2)-C(3)	119.5 (9)	H(2)-C(7)-C(8)	120 (1)
N(3)-C(3)-C(2)	124 (1)	H(3)-C(8)-C(7)	120 (1)
N(3)-C(3)-C(4)	121 (1)	H(3)-C(8)-C(9)	120 (2)
H(6)-C(4)-C(3)	117 (1)	H(4)-C(9)-C(8)	120 (1)
H(6)-C(4)-N(1)	117 (1)	H(4)-C(9)-C(10)	120 (1)
		H(5)-C(10)-C(9)	121 (1)
		H(5)-C(10)-C(5)	121 (1)

^a The dihedral angle between the two least-square ring planes is 27.7°. N(1)-N(2)-C(5)-C(10) = 146.9°.

intramolecular as opposed to intermolecular interactions and thus provides an initial model for in vivo studies.

When compared to literature values (Sutton, 1958) some of the distances given in Table II for the heterocyclic ring become interesting. On comparing the distances given in Table II to literature values (Sutton, 1958), some resonance effects in the heterocyclic ring appear to be evident. In particular, the following bond lengths appear to be shortened: C(1)-C(2), C(3)-C(4), C(4)-N(1), and N(1)-N(2), while C(2)-C(3) and N(2)-C(1) are longer. However, the C=O bond is identical with the C=O bond length of 1.23 Å in acetone and the C(5)-N(2) length is nearly identical with the 1.43 Å length in C₆H₅NHCOCH₃. Also the angles in this heterocyclic ring are closer to 120° than 90°.

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LITERATURE CITED

- Busing, W. R., Martin, K. O., Levy, H. A., "OR FLS, A Fortran Crystallographic Least Squares Program", U.S. Atomic Energy Commission Report ORNL-TM-305, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1962.
- Corbett, J. R., "The Biochemical Mode of Action of Pesticides", Academic Press, New York, N.Y., 1974.
- Hubbard, C. A., Quicksall, C. O., Jacobson, R. A., "The Fast Fourier Algorithm and the Programs ALFF, ALFFDP, ALFFPROJ, ALFFT, and FRIEDEL", U.S. Atomic Energy Commission Report IS-2625, Iowa State University and Institute for Atomic Research, Ames, Iowa, 1971.
- Johnson, C. A., "OR TEP-II: A Fortran Thermal-Ellipsoid Plot Program for Crystal Structure Illustrations", U.S. Atomic Energy Commission Report ORNL-3794 (Second Revision with Supplemental Instructions), Oak Ridge National Laboratory, Oak Ridge, Tenn 1971.
- Lawton, S. L., Jacobson, R. A., *Inorg. Chem.* 7, 2124 (1968).
- Main, P. M., Woolfson, M. M., Germain, G., "MULTAN: A Computer Program for the Automatic Determination of Crystal Structures", Department of Physics, University of York, York, England, 1971.
- Pauling, L., "Nature of the Chemical Bond", Cornell University Press, Ithaca, N.Y., 1960.
- Rohrbaugh, W. J., Jacobson, R. A., *Inorg. Chem.* 13(11), 2535 (1974).
- Sutton, L. E., Ed., "Tables of Interatomic Distances and Configuration in Molecules and Ions", The Chemical Society, Burlington House, London, W. 1, 1958.

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