

THE POSITION OF ELECTROPHILIC SUBSTITUTION OF 2-METHYL-2H-CYCLOPENTA[d]PYRIDAZINE AND THE CRYSTAL STRUCTURES OF TWO SUBSTITUTION PRODUCTS

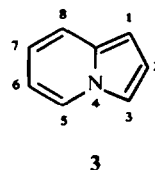
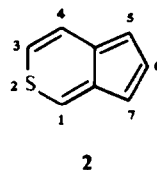
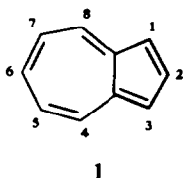
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Abstract—2-Methyl-2H-cyclopenta[d]pyridazine reacts with trifluoroacetic anhydride to give the 5- and 7-trifluoroacetyl products in about a 1:3 ratio. A series of HMO calculations have been made for similar ten π -electron heterocycles in an attempt to predict the positions in the 5-membered rings which would be most reactive to electrophilic substitution. The predictions based on the relative π -electron stabilities of the possible cationic intermediates are in accord with the available experimental data. If the atoms in the 6-ring are numbered 1–6 with the π -excessive heteroatom at the 1-position, then the most reactive site to electrophilic substitution in the 5-ring will be the atom which is linked to either the 1-, 3- or 5-positions. The structures of the major and minor trifluoroacetyl isomers of 2-methyl-2H-cyclopenta[d]pyridazine have been determined by X-ray crystallographic analyses, and the HMO predictions agree with the finding that C(7) is the most reactive position. 2-Methyl-5-trifluoroacetyl-2H-cyclopenta[d]pyridazine crystallizes in the monoclinic space group $P2_1/m$, cell constants $a = 8.109$, $b = 6.713$, $c = 8.768$ Å, $\beta = 91.88^\circ$, with two molecules per unit cell. All of the atoms have been located and refined by full-matrix least-squares and the final residual is 0.056. The bond lengths appear to be influenced by a contribution of a pyridazinium form to the resonance hybrid. 2-Methyl-5-bromo-7-trifluoroacetyl-2H-cyclopenta[d]pyridazine crystallizes in the orthorhombic space group $Pnam$, cell constants $a = 12.920$, $b = 12.513$, $c = 6.752$ Å, with four molecules per unit cell. Although the quality of the diffraction data was severely limited by rapid decomposition of the specimen in the X-ray beam, the gross features of the structure were revealed. The residual following isotropic refinement was 0.19.

PREVIOUS investigations of the reactions of electrophiles with azulene¹ (1) and with the iso- π -electronic hetero-analogs cyclopenta[c]thiapyran² (2) and indolizine³ (3) have shown that substitution occurs in the five-membered ring. Thus, reaction takes



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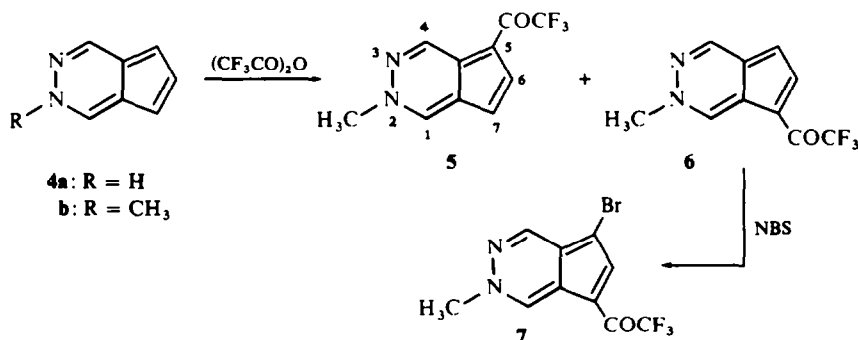
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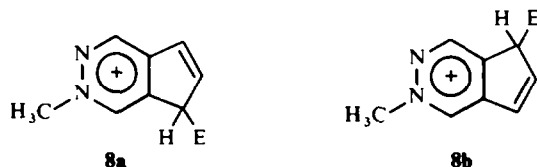
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place at C(1) and C(3) in azulene and indolizine and at the corresponding 5- and 7-positions in cyclopenta[*c*]-thiapyran. These same atoms are also the sites of protonation.^{2, 4} With the inclusion of a π -equivalent* N atom in the ten π -electron skeleton, the position of protonation is N in the case of 5-azaazulene⁵ and the 1-, 2- and 3-azaindolizines,⁴ but it changes to the 5- and 7-C atoms in the case of 2*H*-cyclopenta[*d*]pyridazine⁶ (4).



The reaction of 2-methyl-2*H*-cyclopenta[*d*]pyridazine (4b) with trifluoroacetic anhydride yields two trifluoroacetyl derivatives in the ratio of 1:2.6.⁷ Although the NMR spectra of the products indicated that substitution had occurred in the 5-ring, it was not possible to make a definitive distinction between the two isomers. However, the establishment of the structures of the minor isomer (5) and that of the bromo derivative (7) of the major isomer (6) by X-ray crystallographic analyses (*vide infra*), has identified C(5) and C(7) as the locations of electrophilic attack and C(7) as the most reactive position. We have done a series of Huckel molecular orbital calculations for some of the π -excessive azulene hetero-analogs in an attempt to predict the direction of electrophilic substitution reactions in the five-membered ring. Two extreme models were considered to have merit for these predictions. One was based on the π -electron densities (q_r) of the ring atoms as an index of the relative reactivities if the transition state more nearly resembles the reactants, and the second was based on the localization energy (L_r^+)⁸ as an index if the transition state more nearly resembles the cation intermediate (e.g. 8a or 8b). The localization energy is the amount



of energy required to localize a π -electron pair onto a ring atom, providing a measure of the relative stability of the possible intermediate. The smaller the value of L_r^+ for a molecular configuration the more probable is electrophilic substitution at the designated atom. The HMO parameters suggested by Streitwieser⁹ were used in the calculations, details of which are given in the experimental section.

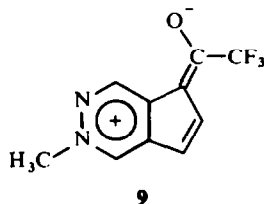
The localization energy and electron density calculations gave opposite predictions for the preferred position of electrophilic substitution, with that based on localization

* π -Equivalent and π -excessive heteroatoms furnish one and two electrons respectively to the π -electron system.

energy paralleling all of the known results (Table 1). From these data, the most reactive position in the 5-ring of **4b** should be C(7), and the major isomer was thus predicted to be 2-methyl-7-trifluoroacetyl-2*H*-cyclopenta[*d*]pyridazine, structure **6**. This prediction was verified by the X-ray experiments described below. It is of interest that this same conclusion was reached by consideration of the relative resonance stabilization of the positive charge in the two intermediate species involved (**8a** and **8b**), and also, that the 1:2.6 ratio of the two isolated substitution products corresponds closely to the 1:2.7 ratio of the isomeric conjugate acids (**8a** and **8b**, E = H) formed in trifluoroacetic acid.⁶

Several of the compounds in Table 1 are as yet unknown and for certain of the known ones the most reactive position for electrophilic substitution has not been determined. Further work is therefore needed to determine the general applicability of these predictions. The results thus far, however, indicate that (a) if the π -excessive heteroatom is in the 1-position the 5-position will be the more reactive, (b) if the π -excessive heteroatom is in the 2-position, the 7-position will be the more reactive, and (c) the presence of a π -equivalent nitrogen atom in the 6-membered ring does not alter the predictions in (a) and (b).

Compound **5** crystallizes in the monoclinic space group $P2_1/m$ with two molecules per unit cell, a situation which requires that each molecule have C_s symmetry and be located on a crystallographic mirror plane. Thus, the atoms in each molecule are all coplanar with the exception of two of the fluorines in the trifluoromethyl group and two of the H atoms in the N—Me moiety. The observed bond distances (Fig 1) show substantial deviations from those values expected for the formally written structure (i.e. **5**) with alternating single and double bonds. For example, the lengths of the C—N and C=N bonds differ by only 0.01 Å and distances in the C(1)—N(2)—N(3)—C(4) moiety show close agreement with the lengths of similar bonds in other N-containing aromatics (e.g. 1,2,4-triazole).¹⁰ A very interesting feature is the C(4a)—C(7a) distance of 1.431 Å, which is shorter than the transannular distances in other azulene-like compounds (1.47–1.50 Å).¹¹ This difference, in conjunction with the lengths of the C(5)—C(6), C(6)—C(7) and C(5)—C(9) bonds, suggests that canonical form **9** makes an important contribution to the ground state resonance hybrid.



We have been unable to discover any crystal packing explanation for the asymmetry of the exocyclic bond angles at N(2) and for the carbonyl group angles at C(9), but a rationale can be made by considering the relative electronegativities of the atoms linked to the central atoms in question. In the case of N(2), the greater electronegativity of the N substituent, N(3), with respect to the C substituents, C(1) and C(8), causes a polarization of the N(2) orbitals toward N(3). Since *p* orbitals are more readily deformed than *s* orbitals, the *2p* orbital distribution should shift toward N(3). Thus, the N(2) σ -bond hybrid orbitals which are oriented toward N(3) will be richer in *p* character and the σ -orbitals to C(1) and C(8) will have proportionately more *s*

character, creating a situation which should effect a decrease in the bond angles adjacent to N(3).¹²

A similar argument can also explain the difference in bond angles at C(9). The highly electronegative fluorine atoms linked to C(10) could increase the electronegativity of C(10), which could in turn interact with the carbonyl carbon and produce a decrease in the C(9) angles adjacent to the C(9)—C(10) bond.

A diagram of the unit cell viewed down [010] is shown in Fig 2. The two molecules are located on the mirror planes at y coordinates of $\frac{1}{4}$ and $\frac{3}{4}$ and their relative positions along c are such that molecular overlap in the b direction is small. The length of the b axis (6.713 Å) is almost twice the van der Waals thickness of an aromatic ring ($2 \times 3.4 = 6.8$ Å).

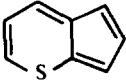
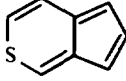
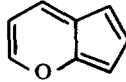
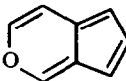
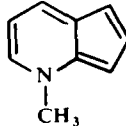
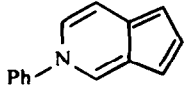
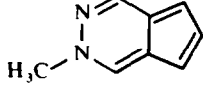
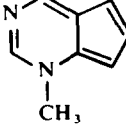
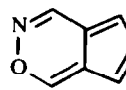
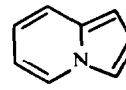
The conformation of the trifluoroacetyl substituent may be governed by the formation of two H-bonds between a molecule and its translational equivalent along c . These interactions, which can be seen in the C(7)—H(7) ... F(1) and C(1)—H(1) ... O distances of 2.39 and 2.44 Å respectively, stabilize the *s-cis* conformation of F(1) and O about the trifluoromethyl-carbonyl bond C(9)—C(10) relative to the *s-trans* conformation. The F and O atoms are eclipsed in this arrangement and the resulting O ... F distance of 2.58 Å is less than the 2.75 Å sum of the van der Waals radii of the atoms.¹³

The magnitude of B_{22} for F(1), 19.7 Å², is sizable compared to the temperature factors of the other atoms. This large a value, which corresponds to an rms displacement of 0.50 Å along b , is not found in the other components of the thermal ellipsoids of F(1), nor is F(2) appreciably anisotropic. Thus, an oscillatory motion of the trifluoromethyl group about the C(9)—C(10) bond does not appear to be responsible for the anisotropy of F(1). Rather, B_{22} might reflect a small positional disorder of the atom normal to the crystallographic mirror plane which could be caused by the proximity of the oxygen atom. There was no evidence for a 180° rotational disorder of the trifluoromethyl group in a difference map computed with the final atomic parameters. A 'riding motion' correction¹⁴ has been made to the two C—F distances, the effect of which was to increase C(10)—F(1) from 1.300 Å to 1.368 Å and C(10)—F(2) from 1.328 Å to 1.355 Å. The corrected lengths are *ca* 0.03 Å longer than the distances usually observed in polyfluoro compounds.*¹⁵

The features of the crystal structure of the 5-bromo-7-trifluoro derivative **7**, are similar to those found for the 5-trifluoroacetyl compound **5**. The material crystallizes in the orthorhombic space group $Pnam$ with four molecules per unit cell and each molecule is located on a crystallographic mirror plane normal to c . Although the material was very sensitive to the X-radiation, the measured diffraction intensities served to identify the molecule as 2-methyl-5-bromo-7-trifluoroacetyl-2*H*-cyclopenta[*d*]pyridazine (**7**) and to reveal its gross structural features. Unfortunately, the finer details of the structure such as accurate bond lengths and angles were not available in the data. The conformation of the trifluoroacetyl group, with the O atom nearest the 6-membered ring, is similar to that observed in the structure of **5**. There appears to be a rotational disorder of the trifluoroacetyl group about the C(9)—C(10) bond. The lengths of the c axis in the $Pnam$ cell and of the b axis in the $P2_1/m$ cell are very similar, 6.752 Å and 6.713 Å respectively, since both are dictated by twice the thickness of the cyclopenta[*d*]pyridazine ring.

* The C—F distance in molecules containing only one fluorine per C atom is about 1.38 Å, whereas, that found in cases such as the trifluoromethyl group is 1.33 Å.¹⁶

TABLE I. REACTIVITY INDICES FOR ELECTROPHILIC SUBSTITUTION OF HETEROAZULENES^a

Compound	Reference or Footnote	Position	q_r (e)	L_r^+ (β)
	25	5 7	1.145 1.214	0.692 0.726
	2	5 7	1.174 1.120	0.741 0.722
	<i>c</i>	5 7	1.133 1.194	0.737 0.781
	<i>b</i>	5 7	1.156 1.108	0.785 0.760
	26	5 7	1.162 1.238	0.651 0.673
	2	5 7	1.174 1.120	0.741 0.722
	6	5 7	1.190 1.137	0.956 0.944
	<i>b</i>	5 7	1.146 1.220	0.582 0.608
	<i>d</i>	5 7	1.110 1.082	0.891 0.862
	27, <i>e</i>	1 3	1.155 1.060	0.782 0.682

^a All of the electron density and localization energy data reported in this table were calculated by the authors using the HMO technique with the coulomb and resonance integral parameters given in the experimental section.

^b Compound not known.

^c Boyd²⁸ has reported the 2,4,6-triphenyl derivative. Borsdorf²⁹ and Boyd and Ellis³⁰ have carried out HMO calculations on this system.

^d Linn and Sharkey³¹ have reported the 1,4-diphenyl derivative.

^e Longuet-Higgins and Coulson³² and Aussems, Jaspers, Leroy and van Remoortere³³ computed π -electron densities for the 1- and 3-positions which were essentially the reverse of these values. Atom localization energies reported by Galbraith *et al.*³⁴ predicted that C(1) would be more reactive than C(3) to electrophilic substitution.

TABLE 2. INITIAL REFLECTION SET FOR THE PHASE PYRAMID

Reflection	<i>E</i>	Symbol ^a
0 2 0	2.481	A = -
1 1 1	2.045	B = -GJ
0 6 0	3.083	C = -
0 4 0	2.627	D = +
4 3 2	2.231	E = FK
-1 1 8	3.056	F = + (origin)
-7 2 2	2.098	G
1 4 0	2.025	H
-3 1 6	2.822	I = -F
-6 1 3	2.832	J = + (origin)
-5 2 6	3.073	K = + (origin)

^a The phrase relationships deduced for the starting set are also listed.

EXPERIMENTAL

X-ray crystallographic study of 2-methyl-5-trifluoroacetyl-2H-cyclopenta[d]pyridazine (5). A sample of the minor isomer (5) was dissolved in acetone and the soln was placed in an enclosed jar along with a beaker of water. The water was changed daily and after 10 days the needles which had formed were collected, washed with water and dried over P₂O₅ at 1 mm. The diffraction symmetry and systematic absences, 0*k*0 absent for *k* odd, were consistent with the monoclinic space groups *P*2₁ (acentric, *Z* = 2) and *P*2₁/*m* (centric, *Z* = 4). All of the unit cell parameters and intensity measurements were obtained using a 0.3 mm cube-shaped sample mounted along *b* and using a PDP-8 controlled Picker diffractometer with Zr-filtered Mo radiation ($\lambda = 0.71069 \text{ \AA}$). The Bragg angles for twelve planes were carefully measured and used for the least-squares refinement of the cell constants. The crystal density was measured by the neutral buoyancy method in KI aq.

Crystal data: C₁₀H₇OF₃N₂, mol. wt. 228.2. Monoclinic, *a* = 8.109 ± 0.002; *b* = 6.713 ± 0.002; *c* = 8.768 ± 0.003 Å; $\beta = 91.88 \pm 0.04^\circ$. $\rho_{\text{meas}} = 1.580 \text{ g cm}^{-3}$; *Z* = 2, $\rho_{\text{calcd}} = 1.588 \text{ g cm}^{-3}$.

The intensity data were collected using the 2 θ - θ scan method with a scan rate of 2° min⁻¹ and two 15 sec background counts. Measurements of three standard reflections, performed at 30 reflection intervals, were used to monitor and later correct for intensity fluctuations. Scale factors ranging from 0.98 to 1.01 were applied to the data. There were 1199 unique reflections within a total of 1530 data measured to a maximum 2 θ of 55°. 576 (48%) of the corrected intensities were found to be at least 1.5 standard deviations above background and were coded as "observed"; the remaining data were coded "unobserved" and given intensities equal to 1.5 σ .

The data were reduced in the normal way and a scale and overall isotropic temp factor were computed using the *X-ray 67* subprogram DATFIX.¹⁷ The condition used in DATFIX to determine these factors is that $\bar{E}^2 = 1.0$ taken over all of the reflections. A comparison of the distribution of the normalized structure factor amplitudes (*E*) with the theoretical statistical distributions expected for centric and acentric space groups¹⁸ clearly indicated that the space group contained a center of symmetry and was therefore *P*2₁/*m*. Since this space group has four general equivalent positions and crystal density measurements had indicated that there were only two molecules per cell, each molecule must have C₂ symmetry and be located on one of the crystallographic mirror planes. Additional evidence for this space group was available from the Patterson function, which showed major concentrations of vector density at *u*,0,*w* and *u*, $\frac{1}{2}$,*w*.

The structure was solved using the symbolic addition procedure and the computer code PHASER.¹⁹ The initial steps in the process involved calculating the unique set of Σ_2 equations for the 187 largest |*E*|'s followed by the construction of a "symbolic" phase pyramid with the eleven reflections shown in Table 2 as a starting point. These 187 reflections, which had a minimum *E* value of 1.234, gave 2400 Σ_2 equations, the maximum number of equations that could be handled by the program. It was possible to reduce the number of unknown phases in the starting set from 11 to 5, three of which could be used to specify the unit cell origin. Thus, there were really only two unknown starting phases which limited to four the number of possible phase solns. Three of the four *E* maps²⁰ which were subsequently computed were characterized

TABLE 3. FRACTIONAL ATOMIC COORDINATES AND THERMAL PARAMETERS^{a,b} FOR COMPOUND 5

Atom	x	y	z	B_{11}	B_{22}	B_{33}	B_{12}	B_{13}	B_{23}
C(1)	0.607(6)	0.2500	0.4007(5)	3.2(2)	3.1(3)	3.9(2)	0.0	-0.6(2)	0.0
C(4)	0.7270(5)	0.2500	0.6946(4)	3.3(2)	4.1(3)	3.1(2)	0.0	-0.4(2)	0.0
C(4a)	0.5558(5)	0.2500	0.6709(4)	2.8(2)	3.2(2)	2.7(2)	0.0	-0.5(2)	0.0
C(5)	0.4177(5)	0.2500	0.7655(4)	2.9(2)	3.5(2)	2.9(2)	0.0	-0.1(2)	0.0
C(6)	0.2741(5)	0.2500	0.6648(5)	2.6(2)	3.6(3)	4.2(2)	0.0	0.1(2)	0.0
C(7)	0.3202(5)	0.2500	0.5167(5)	2.8(2)	4.3(3)	3.3(2)	0.0	-0.6(2)	0.0
C(7a)	0.4951(5)	0.2500	0.5159(5)	2.5(2)	2.9(2)	3.0(2)	0.0	-0.1(2)	0.0
C(8)	0.8958(5)	0.2500	0.3216(5)	3.6(2)	6.3(3)	4.4(2)	0.0	1.1(2)	0.0
C(9)	0.4251(5)	0.2500	0.9299(5)	3.8(2)	3.4(3)	3.4(2)	0.0	0.1(2)	0.0
C(10)	0.2597(6)	0.2500	1.0129(6)	3.3(3)	7.8(3)	4.4(3)	0.0	0.1(2)	0.0
N(2)	0.7685(4)	0.2500	0.4392(4)	2.7(2)	3.8(2)	3.3(2)	0.0	0.2(1)	0.0
N(3)	0.8343(4)	0.2500	0.5833(4)	2.7(2)	4.8(2)	3.4(2)	0.0	-0.6(2)	0.0
O	0.5500(3)	0.2500	1.0118(3)	4.0(2)	6.1(2)	3.4(2)	0.0	-0.6(1)	0.0
F(1)	0.2810(3)	0.2500	1.1605(3)	5.6(2)	19.7(4)	2.6(1)	0.0	0.8(1)	0.0
F(2)	0.1661(2)	0.0945(3)	0.9744(2)	5.0(1)	7.7(1)	7.9(1)	-2.1(1)	2.0(1)	0.1(1)
H(1)	0.575(3)	0.250	0.290(3)	4.4(7)					
H(4)	0.775(4)	0.250	0.802(3)	5.0(8)					
H(6)	0.163(3)	0.250	0.697(3)	4.5(7)					
H(7)	0.254(3)	0.250	0.431(3)	3.0(8)					
H(8a)	0.849(4)	0.250	0.239(4)	6.1(8)					
H(8b)	0.963(3)	0.109(4)	0.335(3)	9.5(9)					

^a Estimated standard deviations are given in parentheses.^b All B values are in \AA^2 with the B_{ij} in the form: $\exp[-0.25(h^2 B_{11} \sigma_i^2 + \dots + 2k_i B_{22} \beta_i^* \sigma_i^*)]$.

by a single large peak at $y = \frac{1}{2}$,* whereas the remaining map contained the image of a 6-membered ring with two *para*-substituents.† With these eight atom positions as a starting point, the remaining atoms were located from a series of structure factor and electron density and difference synthesis calculations.

The structure was refined by full-matrix least-squares,‡ using anisotropic temp factors for the C, N, O and F atoms. The H atoms were located from a difference synthesis and were included in the refinement with isotropic temp factors. The least-squares weights (w_i) were evaluated from $w_i = 0.4/\text{MAX}1(\sigma(F), 0.0116|F_i|)$, where MAX1 refers to the FORTRAN maximum value function and the σ 's are the structure factor standard deviations estimated from counting statistics. This function served to reduce the contributions of both the small and large F 's in the refinement, giving a median value of about 1.0 for F 's of about 40 electrons. The unobserved data were given zero weight if $|F_o| < |F_c|$, otherwise these terms were weighted normally. The average and maximum parameter shift-error ratios computed from the last cycle of least squares were 0.011 and 0.071 respectively; the final R index was 0.056 and the weighted R was 0.049.§ The atomic form factors used in the calculations were from the following sources: C, N, F and O—Berghuis *et al.*;²¹ H—Stewart *et al.*²² Table 3 lists the atomic coordinates and temp factors and the bond lengths and angles are shown in Fig. 1. A structure factor list can be obtained from the authors.||

X-ray crystallographic study of 2-methyl-5-bromo-7-trifluoroacetyl-2H-cyclopenta[d]pyridazine (7). This compound, which was prepared by the reaction of N-bromosuccinimide with 6,⁷ recrystallized as yellow needles from hexane-methylene chloride. The crystal symmetry and systematic absences, $0kl$ absent for $k + l$ odd and $h0l$ absent for h odd, were consistent with the orthorhombic space groups $Pna2_1$ (acentric, $Z = 4$) and $Pnam$ (centric, $Z = 8$). The cell parameter and intensity measurements were all obtained with a single $0.2 \times 0.2 \times 0.4$ mm specimen mounted parallel to the needle axis (b), using a Datex-automated, General Electric XRD-6 diffractometer and Nb-filtered, Mo radiation ($\lambda = 0.71069 \text{ \AA}$). A carefully measured set of 12 Bragg angles were used for a least-squares determination of the unit cell lengths. The crystal density was not measured because of the small quantity of sample, but the value calculated for four molecules per unit cell is about what one would expect for a bromine-containing organic molecule.

Crystal data: $C_{10}H_6OF_3N_2Br$, mol. wt. 307.1. Orthorhombic, $a = 12.920 \pm 0.004$; $b = 12.513 \pm 0.006$; $c = 6.752 \pm 0.001 \text{ \AA}$. $Z = 4$, $\rho_{\text{calcd}} = 1.868 \text{ g cm}^{-3}$.

The intensity data were gathered with the 2θ - θ scan method using a 2° min^{-1} scan rate and two 20 sec background counts. Four standard reflections, measured at intervals of 75 reflections, were used to monitor intensity fluctuations and crystal decomposition. During the first 24 hr of data collection, the sum of the standard reflection intensities had decreased by ca 50% and the color of the specimen was considerably darker than it had been at the start. The intensity measurements were continued for another 24 hr and then terminated, at which time the standards showed an overall 75% decline. The data subsequently were scaled assuming that the sample decomposition was a linear function of the standard intensities. Of the 864 unique data measured to a maximum 2θ of 50° , 417 were 1.5 standard deviations above background and were coded as "observed".

The data were reduced in the normal way, and a scale and overall temp factor were computed using the *X-ray 67* subprogram DATFIX. A three-dimensional E^2-1 Patterson function was calculated and the structure was solved with conventional heavy atom techniques in the centric space group $Pnam$. Since there are eight equivalent positions in $Pnam$ and only half as many molecules per unit cell, each molecule must

* Each of these peaks led to the same Harker section vector in the Patterson map. This vector was the largest peak in the map and corresponded to a non-Harker vector located at the center of the 6-membered ring.

† 184 phases were used to calculate this E map. The two *para*-substituent peaks were substantially larger (2–4 times) than the other six maxima. Although these original 184 phases were expanded to a set of 438 phases using the program ADDPHAS, an E map computed with the 438 terms still showed the same two large peaks and no more detail than the original 184 term synthesis. A comparison of these phases with those from the final structure factor calculation showed that 50 of the initial set of 184 phases and 109 of the added set of 329 phases were incorrect. This large number of discrepancies would explain the poor quality of the original E map.

‡ The quantity minimized in these computations was $\sum_i w_i (|F_{o,i}| - |F_{c,i}|)^2$.

§ $R = \frac{\sum_i (|F_{o,i}| - |F_{c,i}|)}{\sum_i |F_{o,i}|}$. Weighted $R = \frac{(\sum_i w_i (|F_{o,i}| - |F_{c,i}|)^2)^{1/2}}{\sum_i w_i (F_{o,i})^2}$.

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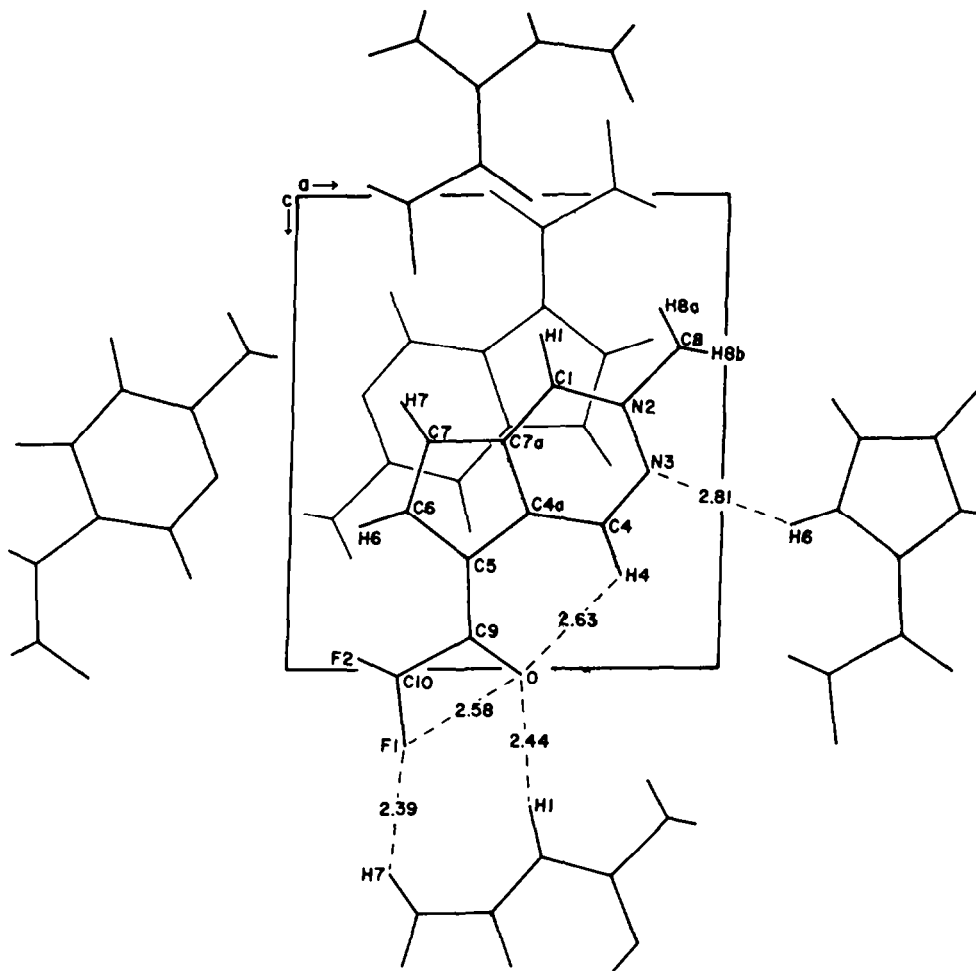


FIG 2. A view along [010] of the 2-methyl-5-trifluoroacetyl-2H-cyclopent[a]pyridazine unit cell. Some of the closer intermolecular contacts are shown (Å).

Parameters used for the intermediate ions

$h(\text{N}^+) = 2.0$	$k = 1.0$ (for all bonds in the six-membered rings)
$h(\text{O}^+) = 2.5$	$k(\text{C}=\text{C}) = 1.1$ (in 5-ring)
$h(\text{S}^+) = 2.0$	$k(\text{C}-\text{C}) = 0.9$ (in 5-ring)
$h(\text{CH}_3-\text{N}^+) = 1.5$	
$h(\text{N}\cdot) = 0.5$	

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