Crystal and Molecular Structure of 6-(*p*-Bromobenzoyl)-6-azabicyclo[3.1.0]hexane

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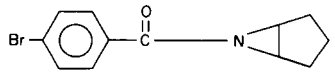
The molecular structure of 6-(*p*-bromobenzoyl)-6-azabicyclo[3.1.0]hexane has been determined by a single crystal, three-dimensional x-ray study. The compound crystallizes in the monoclinic space group ($P_{2_1/c}$) with four molecules in a unit cell of dimensions a = 8.83, b = 10.15, c = 12.63 ± 0.02Å and $\beta = 94°55' \pm 5'$. The aziridine ring is *cis* fused to the cyclopentane ring with the two rings together in a boat conformation. The fusion angle of the two rings is 110.8°. The aziridine ring has all angles of 60 ±1° and all bond distances of 1.48 ± 0.03Å. The cyclopentane ring has alternately long (1.61 ± 0.04Å) and short (1.52 ± 0.02Å) distances. Non-fusion angles in the cyclopentane ring are 106.0 ± 0.5°. Other molecular parameters are as anticipated. The 844 independent reflections obtained were refined to a final value of $R = 0.11_6$ using full-matrix least squares techniques.

Introduction

The study of 6-(*p*-bromobenzoyl)-6-azabicyclo[3.1.0]-hexane (I) was undertaken as part of a more general study of bicyclic compounds containing an aziridine ring.



(I)

It is of interest to us to see what the net effects of systematically fusing second rings of varying size to an aziridine ring would have on the molecular parameters of the aziridine ring. The structure of the free aziridine molecule in the gas phase has already been determined by microwave techniques (1) and shown to have rather unexpected molecular parameters.

Furthermore, it has been shown in this laboratory that the fusion of an aziridine ring has produced rather dramatic changes in the conformation of the second, or "larger" ring. Where this second ring is sufficiently large to accomodate the unusual dihedral angles found in aziridine (2,3,4), distortions in this larger ring can be partially anticipated. However, in the case of this larger ring being either a cycloheptane ring (5) or a cyclohexane ring (6), the distortions in this second ring became appreciable and unexpected.

A trend in which the fusion angle assumes a value of 123 ± 1° if the fusion is *cis* (2,3,5,6) and 127 ± 1° if the fusion is *trans* (4) exists provided the second ring is sufficiently large. To fully explore this possibility, compounds in which the second ring is not sufficiently large to allow such angles (7, this study) have also been undertaken.

Finally, this structure allows a comparison to be made between conformations and molecular parameters resulting when the ring fused to the aziridine contains only carbon atoms versus the entirely analogous system (3-oxa-azabicyclo[3.1.0]hexane) (7) in which oxygen is inserted as a heteroatom in the second ring.

Crystal Data.

The compound was kindly furnished to us by Professor P. E. Fanta (8). It was recrystallized from methylcyclohexane and beautiful, transparent crystals were grown. One such crystal, sufficiently small so that absorption errors would be minimized, was selected for this study.

Intensity data of the zero and first five levels about the [001] axis, the zero and first four levels about the [100] axis, and the additional zones (h,k,h), (h,k,2h) were collected using a Buerger Precession camera and filtered Mo-K_α radiation. Extinctions for the hOℓ reflections when ℓ was odd and the OkO reflections when k was odd unambigously pinpointed the space group as $P_{2_1/c}$.

The cell dimensions of this crystal were a = 8.83 ± 0.02Å, b = 10.15, c = 12.63, $\beta = 94°55' \pm 5'$. Assuming

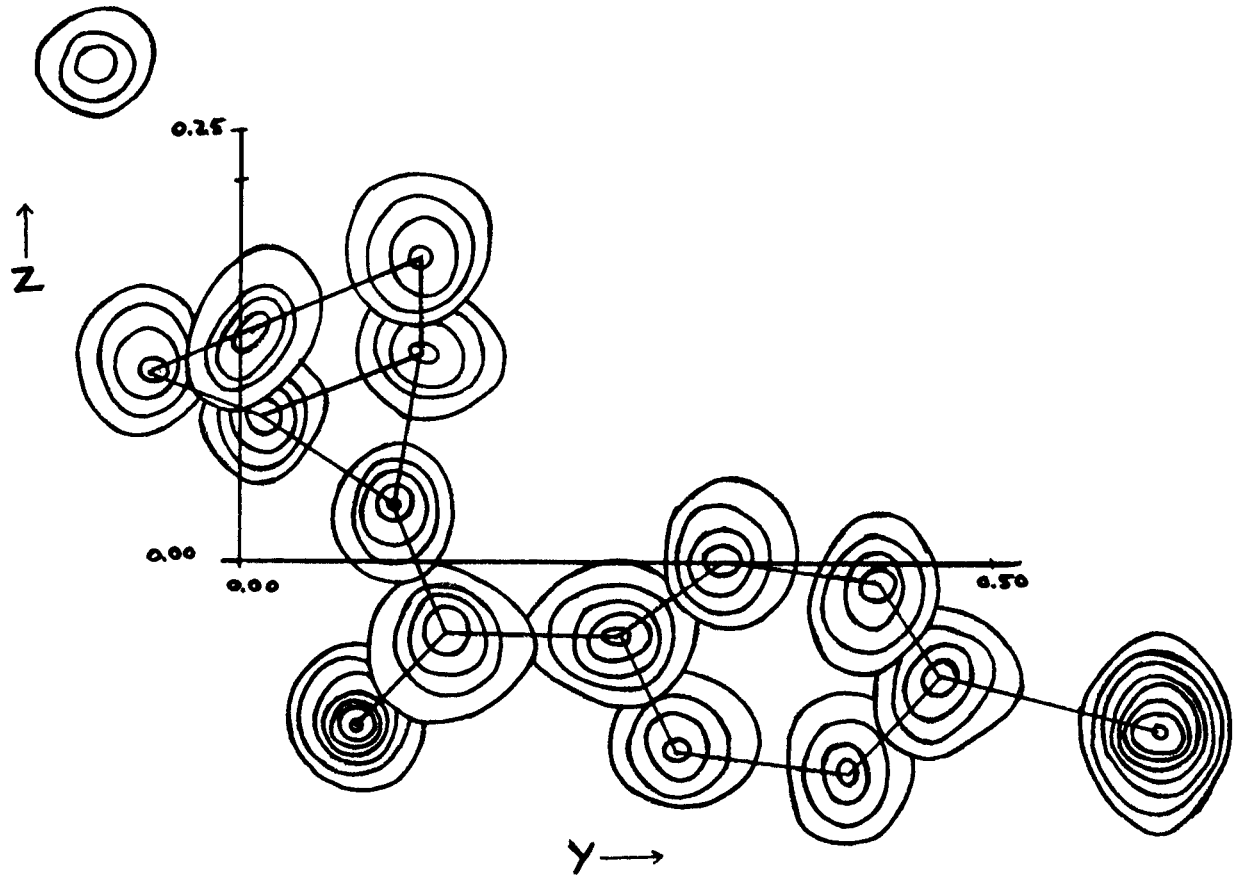


Figure II. Original Fourier Map based on phases of bromine only, projected down the a-axis. Contours at arbitrary units beginning with the zero contour. Bromine contours at five times the other contours.

four molecules per unit cell, the calculated density was found to be 1.566 g. per c.c. as compared to an experimental density (using flotation techniques) of 1.57 ± 0.02 g. per c.c.

The intensities were estimated visually, using timed exposures of a selected "typical" reflection from this crystal. Lorentz and polarization corrections were made in the usual manner (9) and then reflections common to more than one zone were utilized in putting all of the intensities on the same relative scale. A total of 844 independent reflections were observed.

Structure Determination.

A three dimensional Patterson synthesis was run utilizing the squares of the observed structure factors. The peaks due to bromine-bromine interactions were immediately obvious and trial coordinates were chosen for the bromine. Least-squares refinement of this position resulted in R,r values (10) = 0.33_6, 0.40_5. A three-dimensional Fourier map was calculated using the phases derived from the bromine position and magnitudes of the observed structure factors (Figure II). The map contained fifteen peaks (in addition to the bromine peak) with heights ranging from 14-22 (in arbitrary units). Fourteen of these peaks corresponded to a reasonable approximation to the anticipated structure with the peak which would correspond to the oxygen having a height of 22, the nitrogen peak having a height of 17.5, and the carbon peaks ranging from 14-18.2. The one extraneous peak (height = 14.2) was over two angstroms away from any other peak and was thus considered as spurious.

Appropriate scattering factor curves (11) were assigned to each of the peaks and six cycles of isotropic least-squares refinements were run, resulting in values of R,r = 0.13_1, 0.14_5. At this stage, the refinements were continued after conversion to anisotropic temperature factors. Eight additional cycles of refinement resulted in R,r = 0.11_6, 0.12_6. All shifts in coordinates were now 0.001 Å or less and all shifts in temperature factors 0.002 Å^2 or less and so the refinement was terminated. A final difference Fourier map was run which showed no regions of

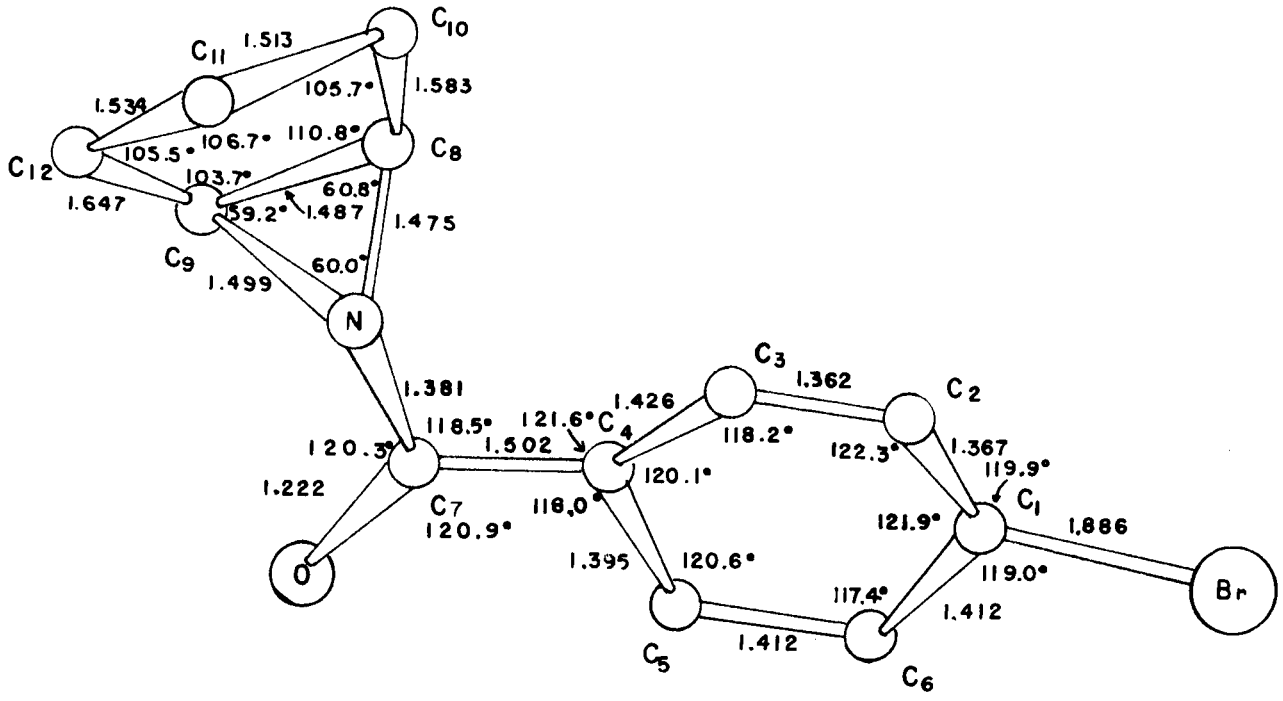


Figure III. Perspective drawing of one molecule with distances and angles indicated.

height greater than 1.3 e/Å^3.

Discussion.

Table I lists the final coordinates and anisotropic temperature factors for all of the atoms. Table II summarizes average values of bond distances and angles by type with their average deviations. Figure III shows a perspective drawing of the molecule with each of the distances and angles indicated. Estimated standard deviations based on the last cycles of least-squares were 0.01_5Å for the bromine, 0.02_0Å for the oxygen and less than 0.03_4Å for all other atoms. Estimated standard deviations for all angles was less than 2°. Final shifts in coordinates were a magnitude smaller than the E.S.D.

A comparison of our values for molecular parameters in the known part of the molecule with literature values will aid in establishing the reliability of the molecular parameters in the entire molecule. With this in mind, the Br-C distance of 1.88_6Å is in good agreement with the value (1.86 ± 0.02Å) found in bromobenzene (12) by electron diffraction techniques. The Br-benzene ring angles of 119.5 ± 1.5° again conform to the anticipated values of 120°. If one looks at the benzene ring itself, average values of 1.39_7 ± 0.01_8Å for the C-C distances and 120 ± 1.4° for the internal angles are in very good agreement with the best literature values (13). Our maximum deviations in the benzene ring (1.36_2 ± 0.035Å in the C_2-C_3 distance and 117.4 ± 2.6° in the C_5-C_6-C_1 angle) do not deviate significantly from the average values.

One can find a variety of literature values for the molecular parameters about the carbonyl carbon atom. Nevertheless, our values are well within this range. The C=O distance of 1.22_2Å is discretely larger than the 1.21Å found in cyclopropanecarbohydrazide (14) but less than that found in the succinimide molecule (1.23_8Å) (15) or the benzamide (1.24Å) (16). Our N-C=O and C-C=O angles are essentially identical (120.5 ± 0.5°) as also found in the latter two (15,16) references. The C_7-benzene ring distance of 1.50_2Å is in close agreement with the 1.48 ± 0.02Å value found in benzamide (1.31Å). Our value of 1.38Å for the C_7-nitrogen distance on the other hand, is somewhat larger than values for the similar bond in benzamide (1.31Å), cyclopropanecarbohydrazide (1.33Å) or succinimide (1.34Å).

The aziridine ring has internal angles of 60.0 ± 0.8° with C-N distances averaging to 1.48_7 ± 0.012 Å and a carbon-carbon distance of 1.48_7Å. The close similarities between these distances and the analogous distances observed in free aziridine (1) (C-N = 1.48_0Å, C-C = 1.48_0Å, C-C = 1.48_8Å) conform to the hypothesis previously

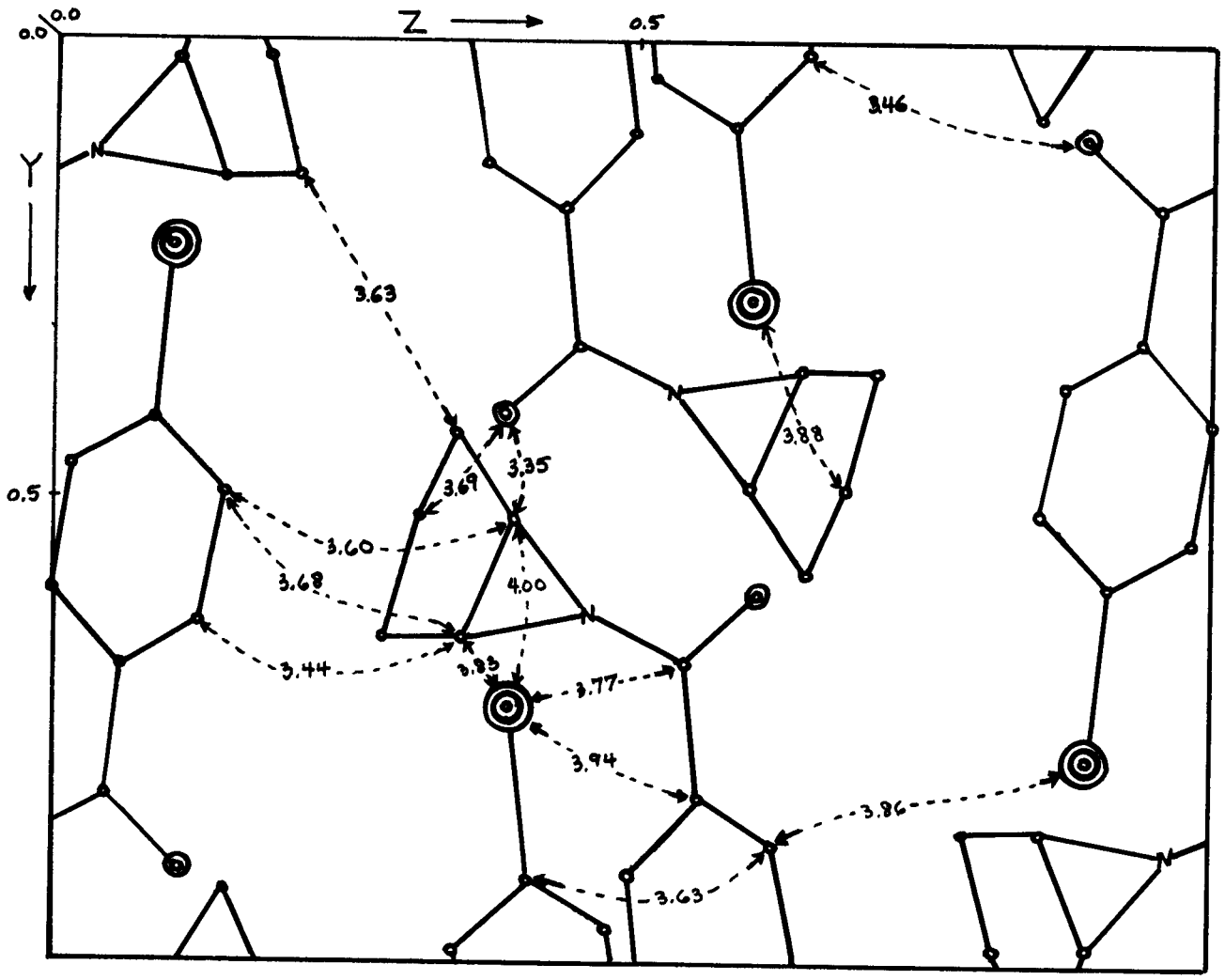


Figure IV. Contents of one unit cell projected down the a-axis. Intermolecular bromine contacts at 4.0Å or less indicated. All other contact distances less than 3.7Å also indicated.

advanced by us (17) that in these bicyclic aziridine systems, the distances in the aziridine portion of the molecule should closely parallel those in aziridine itself if the second ring is small (cyclopentane is the smallest second ring which has been fused to an aziridine) and these distances should slowly approach a maximum value of 1.54Å as the number of atoms in the second (or fused) ring is increased. This has been found to be the situation as one progresses in size in the second ring from a cyclohexane to a cyclododecane ring (2-6).

Figure IV illustrates the intermolecular contacts within the unit cell. Only those contacts are shown involving the bromine atom if the contact distance is less than 3.7Å. Of these only one is less than 3.40Å and involves atom 9 (in the aziridine ring) with a rather short C· · · · O intermolecular distance of 3.35Å. Unfortunately, it is the distortion due to this close contact that obscures an analysis of the molecular parameters observed in the cyclopentane portion of the molecule. For the bond distance involved at this point (C_9-C_{12} = 1.64$_7$Å) is longer than would be anticipated in the free molecule. Similarly the fusion angle of 103.7°, resulting at this point, is surprisingly small.

If one averages all angles and distances in the cyclopentane ring, this deviation is obscured ($\overline{C\text{-}C}$ = 1.56$_9$ ± 0.04$_6$Å and $\underline{|CCC}$ = 106.5 ± 1.8°). On the other hand, a closer analysis of the parameters, resulting in the cyclopentane ring, shows that the distances can be considered in three groupings. The C-C common to both rings is 1.48$_7$Å. The $\overline{C\text{-}C}$ distance adjacent to the fusion points is 1.61$_5$

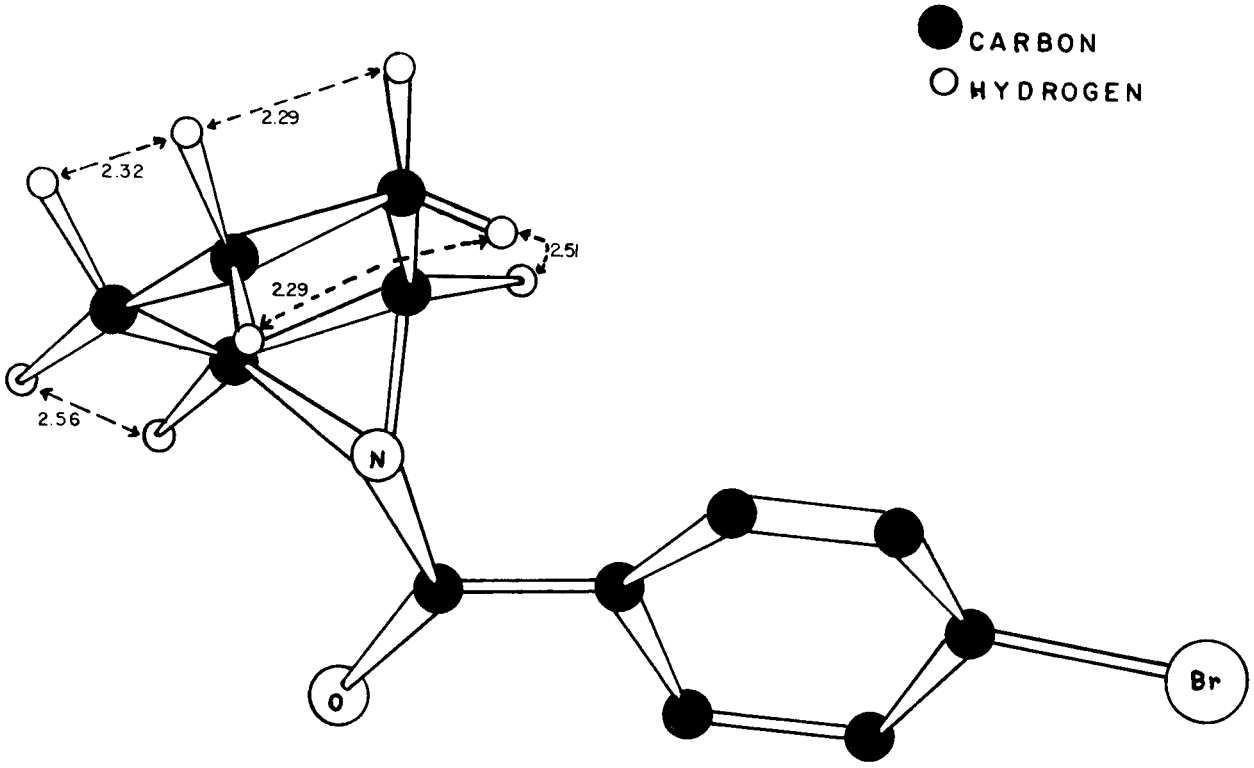


Figure V. Perspective drawing of one molecule including calculated hydrogen positions on the cyclopentane ring. Closest transannular hydrogen contacts shown.

$\pm 0.03_2$ Å and the back distances average to $1.52_3 \pm 0.01_1$ Å showing alternately long and short distances. Analogously, the back three angles not involved in the ring fusion are almost identical, averaging 106.0 ± 0.5°. The fusion angle not involved in the close intermolecular contact is 110.8° which is identical (within experimental error) to the value of 112.0 ± 1.7° found as the fusion angle when an aziridine ring is fused to an oxacyclopentane ring (7).

If one considers the fused ring system as a six-membered ring, then it is of interest to note that this ring occupies the boat conformation as had also occurred in the previously cited aziridine-oxacyclopentane system (7). That both such systems have a boat conformation in the solid state, although there are no close contacts favoring this conformation, is indicative of the low energy barrier between the expected chair conformation for six-membered rings and these resulting boat conformations. Whether in fact the boat conformation is favored even in solution is now being investigated in this laboratory.

Based on geometric considerations (C-H = 1.09Å, $\underline{\text{HCH}}$ = 109°, all other angles equally split and near 109°), positions were calculated for the hydrogen atoms attached to the cyclopentane ring. The resultant positions were then compared to the final difference Fourier map and all of the calculated peaks fell in positive regions ranging in height from 0.7 - 1.2 e/Å^3. Figure V illustrates the molecule with the calculated hydrogen positions shown. Closest transannular hydrogen contact distances are also given.

Acknowledgments.

The authors wish to express their gratitude to the National Institutes of Health (GM-08348-07) for financial assistance in support of this and subsequent studies; to Professor P. E. Fanta, Department of Chemistry, Illinois Institute of Technology; and to the Computer Centers at L.S.U.B.R. and L.S.U.N.O. (N.S.F. No. GP-2964).

TABLE I

Final Coordinates and Anisotropic Temperature Factors

Atom	Symbol	x	y	z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
Bromine	Br	0.6536	0.7757	0.8948	0.0143	0.0104	0.0095	-0.0007	0.0014	0.0008
Oxygen	O	0.6229	0.1004	0.8900	0.0071	0.0143	0.0045	0.0007	0.0043	-0.0004
Nitrogen	N	0.7897	0.1225	0.0348	0.0098	0.0098	0.0063	0.0007	0.0015	0.0004
Benz-1	1	0.6661	0.5913	0.9122	0.0052	0.0130	0.0040	-0.0033	0.0041	0.0001
Benz-2	2	0.7757	0.5380	0.9835	0.0122	0.0111	0.0065	-0.0013	0.0060	-0.0002
Benz-3	3	0.7873	0.4059	0.0014	0.0083	0.0179	0.0031	-0.0003	0.0051	-0.0005
Benz-4	4	0.6872	0.3205	0.9390	0.0068	0.0116	0.0032	0.0009	0.0029	0.0001
Benz-5	5	0.5720	0.3730	0.8690	0.0057	0.0122	0.0050	-0.0008	0.0031	0.0012
Benz-6	6	0.5616	0.5104	0.8517	0.0095	0.0146	0.0021	-0.0008	0.0042	-0.0014
Carbonyl	7	0.6920	0.1737	0.9539	0.0061	0.0101	0.0035	-0.0011	0.0044	-0.0013
Azir-1	8	0.7722	0.1490	0.1479	0.0085	0.0076	0.0021	0.0004	0.0037	0.0009
Azir-2	9	0.7314	0.0168	0.1035	0.0177	0.0086	0.0049	-0.0008	0.0014	0.0020
Pent-1	10	0.9339	0.1457	0.2126	0.0089	0.0115	0.0041	-0.0003	0.0060	-0.0004
Pent-2	11	0.0050	0.0163	0.1841	0.0156	0.0117	0.0142	0.0012	-0.0047	-0.0032
Pent-3	12	0.8737	0.9218	0.1514	0.0108	0.0142	0.0071	-0.0020	0.0069	-0.0019

TABLE II

Bond Distances and Bond Angles (by Types)

Atoms Involved	Bond Distances and Av. Dev. (A)	Atoms Involved	Bond Angles and A. Dev. (Deg)
C-Br	1.88_6	∠BrCC	$119.5 \pm 0.5°$
C-C (Benzene)	$1.39_7 \pm 0.01_8$	∠CCC(Benzene)	$120.0 \pm 1.7°$
C-C (Carbonyl)	1.50_2	∠CCC(Benzene to Carbonyl)	$119.8 \pm 1.8°$
C-N (Carbonyl	1.38_1	∠OCN(Carbonyl)	120.3°
C=O (Carbonyl	1.22_2	∠OCC(Carbonyl)	120.9°
N-C (Aziridine)	$1.48_7 \pm 0.01_2°$	∠CCN(Carbonyl)	118.5°
C-C (Aziridine)	1.58_7	∠CNC(Aziridine)	60.0°
C-C (Cyclopentane)	$1.56_9 \pm 0.04_6$	∠NCC(Aziridine)	$60.0 \pm 0.8°$
		∠CCC(Cyclopentane)	$106.5 \pm 1.8°$

Atoms Involved	Non-bonded Distances (Å)
Br · · · · · C (= 4.0Å)	3.77, 3.83, 3.86, 3.88, 3.94, 4.00Å
O · · · · · C (= 3.7Å)	3.35, 3.46, 3.69Å
C · · · · · C (= 3.7Å)	3.44, 3.60, 3.63, 3.63, 3.68Å

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$$r = \left[\frac{\Sigma w \left| |Fo| - |kF_c| \right|^2}{\Sigma W |F_o|^2} \right]^{1/2}$$

(11) Atomic scattering factors used for the appropriate atoms were taken from the International Tables for X-ray Crystallography-Vol. III (1962).

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Received March 25, 1968 New Orleans, La. 70122