

(-)-pivalate diester, $[\alpha]^{25D} -57.6^\circ$ (c 1.73); (+)-unsaturated ester, $[\alpha]^{25D} +58.8^\circ$ (c 1.61); (-)-unsaturated ester, $[\alpha]^{25D} -57.5^\circ$ (c 1.47); (+)-monodeoxysirenin, $[\alpha]^{25D} +47.7^\circ$ (c 3.00); (-)-monodeoxysirenin, $[\alpha]^{25D} -46.9^\circ$ (c 2.74) [lit.^{3d} $[\alpha]^{25D} -28^\circ$ (c 1.0)]; (+)-sirenin, $[\alpha]^{25D} +42.9^\circ$ (c 2.02); (-)-sirenin, $[\alpha]^{25D} -43.3^\circ$ (c 1.42) [lit.^{2a} -45° (c 1.0)].

Preparation of (+)- and (-)-Sesquicarene (15). The method was that of Corey and Achiwa.^{15,16} To a solution of distilled (-)-monodeoxysirenin^{3d} (124 mg, 0.563 mmol) in dry tetrahydrofuran (3 ml) was added at 0° pyridine-sulfur trioxide complex (218 mg, 1.37 mmol), and the mixture was stirred at 0-4° for 21 hr. A solu-

tion of 200 mg (5.28 mmol) of LiAlH_4 in 9 ml of tetrahydrofuran was added at 0° for 5 min and 25° for 5.5 hr. After careful addition of water (15 ml) the mixture was extracted with ether. The ethereal extract was dried over magnesium sulfate and the solvents were evaporated. Chromatography of the residue on silica gel (elution with hexane) gave 98 mg (85%) of (-)-sesquicarene: $[\alpha]^{25D} -75.4^\circ$ (c 0.87, chloroform) [lit.¹⁴ $[\alpha]^{25D} -76.9^\circ$ (c 0.82, chloroform)]. The infrared and nmr data obtained were identical with those reported for natural sesquicarene. (+)-Sesquicarene was prepared in an analogous manner from (+)-monodeoxysirenin^{3d} and had $[\alpha]^{25D} +75.8^\circ$ (c 0.67, chloroform).

Crystal and Molecular Structure of 1-Benzyl-1,3,3-trimethylazetidinium Iodide

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Abstract: The structure of 1-benzyl-1,3,3-trimethylazetidinium iodide ($\text{C}_{13}\text{H}_{20}\text{NI}$) has been determined by a single-crystal X-ray diffraction study. The compound crystallizes in the orthorhombic space group *Pbca* with eight molecules in a unit cell of dimensions $a = 28.312 \pm 0.005$, $b = 9.653 \pm 0.003$, and $c = 10.474 \pm 0.003$ Å. The azetidinium ring contains N-C distances of 1.52 (2) and 1.52 (2) Å in agreement with other azetidinium rings studied, and C-C distances of 1.54 (2) and 1.57 (2) Å. The ring itself is nonplanar, having a dihedral angle of 169.7°. A final value of $R = 0.038$ was obtained for the 677 statistically significant reflections.

Although azetidinium derivatives were first synthesized and characterized over 8 years ago,¹ they remained a relatively unstudied series of compounds for 50 years. Interest in these compounds was revived when it was shown that the antibiotics penicillin² and Cephalosporin C³ both contain a β -lactam ring. Further interest was generated when azetidinium compounds were postulated as possible alkylating agents in the fight against cancer.⁴

Molecular parameters for two unfused azetidinium salts^{5,6} appeared for the first time in 1968. These were followed by the structure determination of the first fused ring structure containing an azetidinium ring rather than a β -lactam ring.⁷ Finally, the structures of two substituted azetidinium compounds, one containing a planar azetidinium ring⁸ and the other a nonplanar azetidinium ring,⁹ were reported in 1969.

Crystal Data. A crystalline sample of the compound 1-benzyl-1,3,3-trimethylazetidinium iodide¹⁰ (I) was kindly furnished by Professor A. G. Anderson, Jr.

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(3) D. Crowfoot-Hodgkin and E. M. Maslen, *Biochem. J.*, **79**, 393 (1961).

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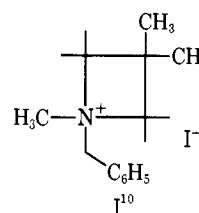
(6) H. M. Berman, E. L. McGandy, J. W. Burgner, II, and R. L. Van Etten, *J. Amer. Chem. Soc.*, **91**, 6177 (1969).

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(8) R. L. Snyder, E. L. McGandy, R. L. Van Etten, L. M. Trefonas, and R. L. Towns, *J. Amer. Chem. Soc.*, **91**, 6187 (1969).

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The compound crystallized in regular needles with the 001 axis parallel to the needle axis. The crystal symmetry is orthorhombic, and a series of precession photographs indicated the following systematic absences: $0kl$, $k = 2n + 1$; $h0l$, $l = 2n + 1$; $hk0$, $h = 2n + 1$, unambiguously determining the space group as *Pbca* (No. 61). The lattice constants were determined by a least-squares fit¹¹ of 23 reflections whose values were measured very carefully at fine conditions (1° take-off angle and 0.05° receiving slit on a G.E. XRD-5 diffractometer). The resulting lattice constants are: $a = 28.312 \pm 0.005$, $b = 9.653 \pm 0.003$, and $c = 10.474 \pm 0.003$ Å. The calculated density of 1.497 g/cm³ (assuming eight molecules per unit cell) agreed with the experimental density of 1.50 g/cm³, measured by flotation methods.

A crystal was mounted along the 001 axis. A preliminary data set was collected on a G.E. XRD-490 automated diffractometer using Cu $K\alpha$ radiation and balanced filters. Although a polar plot indicated an extremely large absorption correction, it was felt that the data would be suitable for determining a trial structure. Subsequently, a new set of data was measured

(11) Program LSLAT, K. N. Trueblood: a program of least-squares 2 θ values of a given set of reflections to determine the best fit of lattice constants.

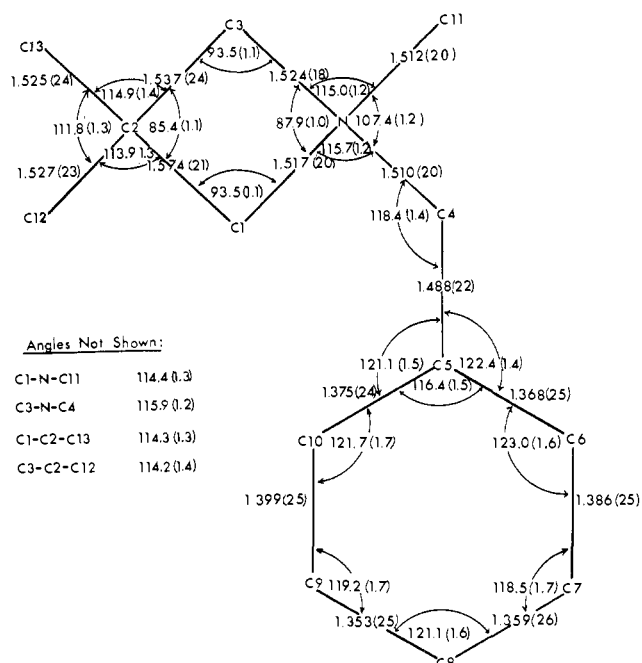


Figure 1. Schematic view of the molecule. Bond distances, bond angles, and esd values (in parentheses) are shown on the figure.

using Mo $K\alpha$ radiation and a crystal measuring 0.14 mm \times 0.11 mm \times 0.10 mm. Because of apparent crystal decay under exposure to X-rays, the counting time was limited to 10 sec and the beam shutter opened only during the actual counting periods. A monitor of three axial standards indicated a decay factor should be applied as a function of exposure time. The correction was made as a multiplicative correction, the maximum of which was 1.067.

The crystal was mounted along the $0k0$ axis, putting the $h00$ and $00l$ axes at $\chi = 0$. A total of 1543 independent reflections were measured to a 2θ maximum of 42° for Mo $K\alpha$ radiation with balanced zirconium and yttrium filters. The criterion for an observed reflection was taken as

$$(I_{Zr} - 2\sigma(I_{Zr})) - (I_Y + 2\sigma(I_Y)) > 30 \text{ counts}$$

With this requirement, 677 reflections were considered observable. Since the linear absorption coefficient for Mo radiation is only 22.5 cm^{-1} , absorption was corrected as a function of φ only; the maximum difference observed at $\chi = 90$ was 8%, agreeing with the predicted ratio calculated from the crystal size and μ .

The intensities were converted to structure factors by a program modified for the IBM 1620.¹² Lorentz polarization correction factors were applied as a function of 2θ , and absorption was corrected as a function of φ only.

Structure Determination. Using the set of preliminary data taken with filtered Cu $K\alpha$ radiation, a three-dimensional Patterson map was calculated and the iodine position obtained. Refinements using iodine coordinates led to a value of $R = 0.33$. A three-dimensional difference Fourier map based on the phases obtained from the above refinement contained only 14 peaks of significant magnitude within reasonable bond distances of each other. The only other peaks of com-

(12) Program INCON, R. E. Davis, is a program for data reduction (modified for the IBM 1620 by R. L. Towns).

parable height were $< 2 \text{ \AA}$ from the iodine and indicated pronounced anisotropic motion of the heavy atom. One of the 14 reasonable peaks was chosen as the nitrogen on the basis of previous chemical knowledge, and the subsequent isotropic refinements using unit weights substantiated the choice of the nitrogen. Cromer and Waber¹³ scattering factors, corrected for the real part of the anomalous dispersion term ($\Delta f'$) in the case of the iodine, were used.¹⁴ Further refinements after conversion to anisotropic temperature factors led to a reasonable chemical structure that refined only to a value of $R = 0.156$.

Since previous polar plots indicated severe absorption difficulties due to the size of the crystal and the use of Cu $K\alpha$ radiation, no further refinements were attempted with this data. Instead, the second set of data from the smaller crystal, taken with Mo $K\alpha$ radiation, were utilized in all subsequent refinements.

The final atomic positions from the first data set were used as the starting point in refinements based on these new data. Initial temperature factors of 4.0 were assigned to each of the atoms, and a new set of isotropic refinements using unit weights resulted in a value of $R = 0.077$. After conversion to anisotropic temperature factors, the data were refined ultimately to an R value of 0.045. A difference Fourier at this point contained peaks of the approximate height and in the appropriate regions for methylene and phenyl hydrogens. The regions about the methyl carbons were positive but very diffuse. As a further check, positions for the methylene and phenyl carbons were calculated from the usual geometric considerations and compared with the difference map. Every calculated position was in a positive region of about $0.4\text{--}0.6 \text{ electron/\AA}^3$. These hydrogens were then assigned isotropic temperature factors of 4.0 cm^2 and included in subsequent refinements, but neither their positional nor thermal parameters were varied. A further attempt was made to locate the methyl hydrogens but was unsuccessful. Refinement was finally terminated when all shifts in coordinates and temperature factors were less than one-tenth the magnitude of the estimated standard deviations. The final R value was 0.038. Fourier and difference Fourier maps were calculated at this stage. The difference map showed no peaks greater in magnitude than $0.3 \text{ electron/\AA}^3$.

Results and Discussion

Figure 1 shows the actual bond distances and angles derived from this study. The distances have estimated standard deviation (esd) on the order of $0.02\text{--}0.03 \text{ \AA}$; the bond angles have esd values less than 2.0° in all cases. The positional and thermal parameters, along with their esd's, are tabulated in Table I. The calculated hydrogen positions are listed in Table II.

The azetidinium ring is, of course, the focal point of the structure analysis. Two points are of direct interest: (1) the C-C and C-N distances and (2) the dihedral angle in the ring. A comparison of the ring parameters with those of other methyl-substituted azetidinium salts whose structures are known is given in Figure 2.

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(14) "International Tables for X-Ray Crystallography," Vol. III, K. Lonsdale, Ed., Kynoch Press, Birmingham, England, 1968.

Table I. Final Coordinates and Anisotropic Temperature Factors

Atom	Fractional coordinates ^a			Anisotropic thermal parameters ^{a,b} ($\times 10^4$)					
	X	Y	Z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
I	0.0861 (1)	0.0151 (1)	0.1977 (1)	15 (1)	139 (1)	155 (1)	-6 (1)	5 (1)	-9 (2)
N	0.0890 (5)	0.4233 (10)	0.2690 (13)	14 (2)	85 (12)	151 (22)	7 (5)	-6 (7)	-17 (14)
C-1	0.0944 (5)	0.4357 (14)	0.1133 (15)	7 (2)	123 (19)	77 (20)	1 (5)	-3 (6)	-25 (16)
C-2	0.0932 (6)	0.5857 (14)	0.1205 (18)	18 (3)	89 (17)	134 (25)	9 (7)	-7 (8)	-23 (18)
C-3	0.0948 (5)	0.5676 (14)	0.2784 (18)	6 (2)	130 (18)	140 (26)	5 (5)	-1 (7)	-30 (19)
C-4	0.1263 (5)	0.3449 (16)	0.3412 (18)	9 (2)	127 (21)	158 (34)	-8 (6)	14 (7)	-14 (21)
C-5	0.1766 (5)	0.3668 (14)	0.3036 (21)	15 (3)	110 (18)	124 (25)	-4 (6)	-26 (9)	-20 (23)
C-6	0.1992 (5)	0.2968 (15)	0.2039 (23)	12 (3)	117 (20)	194 (33)	-6 (6)	-4 (9)	-7 (27)
C-7	0.2461 (7)	0.3152 (18)	0.1688 (19)	15 (3)	197 (28)	172 (33)	6 (8)	-2 (10)	-19 (25)
C-8	0.2714 (5)	0.4039 (19)	0.2399 (19)	8 (2)	219 (28)	180 (35)	-8 (7)	-4 (7)	78 (26)
C-9	0.2513 (7)	0.4745 (20)	0.3412 (16)	15 (2)	204 (28)	157 (29)	-6 (8)	-17 (7)	-11 (26)
C-10	0.2037 (6)	0.4547 (19)	0.3737 (19)	15 (3)	197 (30)	139 (26)	18 (8)	-8 (8)	11 (25)
C-11	0.0414 (5)	0.3733 (17)	0.3154 (23)	8 (2)	172 (24)	190 (33)	-4 (6)	12 (9)	-2 (30)
C-12	0.1369 (5)	0.6498 (16)	0.0599 (20)	7 (2)	144 (23)	184 (33)	-17 (6)	6 (7)	-5 (24)
C-13	0.0477 (6)	0.6453 (17)	0.0656 (21)	14 (3)	117 (22)	171 (33)	10 (7)	-9 (8)	-17 (23)

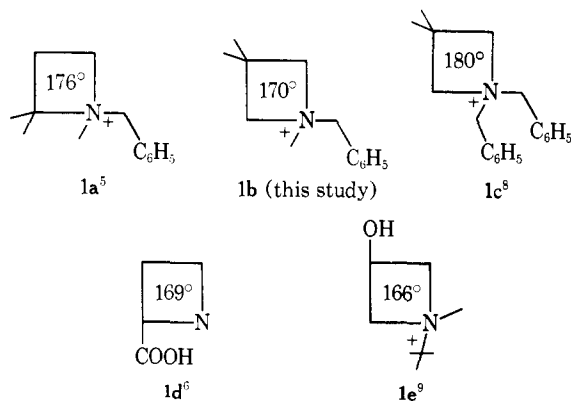
^a Standard deviations $\times 10^4$ are in parentheses. ^b Anisotropic temperature factors of the form: $\exp -[\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + 2\beta_{12}hk + 2\beta_{13}hl + 2\beta_{23}kl]$.

Table II. Calculated Hydrogen Positions

Atom	X	Y	Z
H-1 (1) ^a	0.067	0.396	0.056
H-2 (1) ^a	0.127	0.398	0.076
H-1 (3) ^a	0.126	0.595	0.326
H-2 (3) ^a	0.066	0.612	0.330
H-1 (4) ^a	0.119	0.249	0.320
H-2 (4) ^a	0.123	0.363	0.448
H-6	0.180	0.226	0.152
H-7	0.262	0.261	0.090
H-8	0.307	0.420	0.216
H-9	0.272	0.542	0.396
H-10	0.188	0.508	0.454

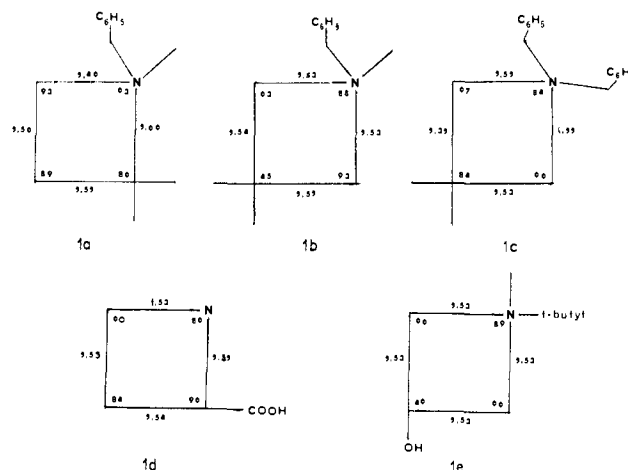
^a Second digit refers to carbon atom to which the hydrogen is bonded.

The facile ring opening at the 1-2 position when the ring has a *gem*-dimethyl in the 2 position correlates with the correspondingly long 1-2 distance in the compound **1a**. In this study, **1b**, and in compound **1c** with the *gem*-dimethyl in the 3 position, the 1-2 and 1-4 bond lengths are essentially equivalent, agreeing with the chemical fact of equally facile 1-2 and 1-4 ring opening. The puckering of the azetidine ring was of interest be-

Chart I

cause of the range of dihedral angles observed in these compounds. In this study the dihedral angle (measured as the angle between the planes containing N-C(1)-C(3) and C(1)-C(2)-C(3)) was found to be 169°. In **1a** this angle was 176°, and in **1c** the ring was planar. In compound **1a**, however, the molecule was disor-

dered, and this value for the dihedral angle may reflect the disordering. Two recent structure determinations^{6,9} of substituted azetidinium compounds **1e** and **1d** provide further insight into the geometry of the ring. A summary of the observed dihedral angles is given in Chart I. The trend seems to be toward a pucker of about 10-14° in the azetidine ring itself. The two ex-

**Figure 2.** Structures of known simple azetidines. Distances and angles in the azetidinium rings are indicated.

ceptions to this are **1a** and **1c**. As mentioned earlier, **1a** was disordered in the solid state, making an accurate assessment of the geometry of the ring somewhat difficult. In **1c** the two phenyl rings bend back over the azetidinium ring which lies in a mirror plane. The repulsion of the hydrogens on the *gem*-dimethyl group and of the phenyl electron cloud could account for the planarity of this compound. In the other systems, however, the dihedral angles are very similar, with **1e** being bent slightly more because of hydrogen bonding involving the hydroxy group. The equations of the planes used in the calculation of the dihedral angle are given in Table III.

The bonding parameters in the azetidinium ring in this study are of interest since the nitrogen is unsymmetrically substituted and there is a *gem*-dimethyl at the 3 position. The N-C distances in the ring are

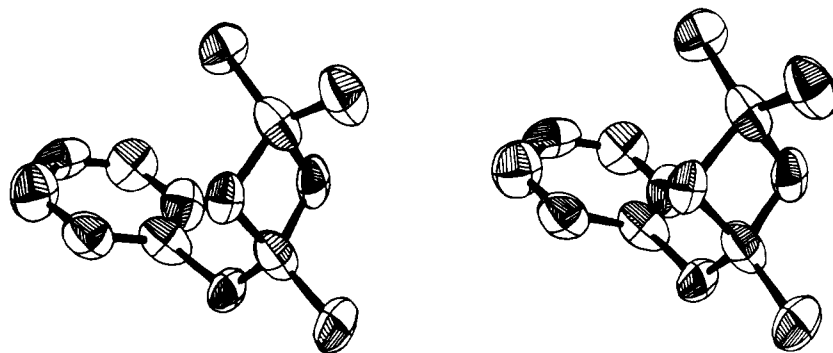


Figure 3. ORTEP stereodrawing of this molecule.

equivalent ($1.521 \pm 0.004 \text{ \AA}$), as are the C-C distances ($1.555 \pm 0.019 \text{ \AA}$). The equivalence of these bonds indicates an equal probability of 1-2 and 1-4 ring

equation of the best plane is also listed in Table III. A stereoview plotted by the Oak Ridge plotting program ORTEP¹⁶ is given in Figure 3.

Table III. Equations of Least-Squares Planes

Plane	Atoms in plane	Equation of plane	Esd, \AA
1	N, C-1, C-3	$0.989p - 0.113q + 0.091r = 2.23$	
2	C-1, C-2, C-3	$0.999p + 0.023q - 0.027r = 2.77$	
3	C-5, C-6, C-7, C-8, C-9, C-10	$-0.259p + 0.692q - 0.674r = -0.625$	0.008
4	C-4, C-5, C-6, C-7, C-8, C-9, C-10	$-0.263p + 0.691q - 0.673r = -0.653$	0.009

Table IV

C-N distances, \AA		Iodide distances, \AA	
C(11)-C(13)	3.66	C-4	3.91
C(8)-C(10)	3.90	C-11	3.91
C(7)-C(12)	3.88	N	4.19
C(7)-C(9)	3.86		
C(7)-C(10)	3.99		
C(6)-C(9)	3.89		

opening, substantiated experimentally. The N-C bond lengths not in the ring average $1.511 \pm 0.001 \text{ \AA}$ with a C-N-C angle of 107.4° . The ring carbon-methyl carbon distances in the *gem*-dimethyl group average $1.526 \pm 0.001 \text{ \AA}$ with an angle of 111.8° . The benzene ring distances average $1.373 \pm 0.013 \text{ \AA}$. The average is a little shorter than the literature¹⁵ value of 1.39 \AA , but still within one esd. The benzene is planar; the

(15) L. E. Sutton, Ed., *Chem. Soc. Spec. Publ.*, No. 11, S-13 (1958); *Suppl.*, S-16S (1964).

An investigation of the closest intermolecular contacts shows no anomalous distances exist. The closest contacts are shown in Table IV.¹⁷

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(16) C. K. Johnson, ORNL-3794, Revised, Oak Ridge National Laboratory, Nashville, Tenn., 1965.

(17) A listing of the values of the observed and calculated structure factors has been deposited as Document No. 1209 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the document number and by remitting \$1.25 for photoprints or \$1.25 for 35 mm microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.