A Conformational Study of Bicyclo[3.1.0]hexane. Crystal and Molecular Structure of *N*′-Isopropylidenebicyclo[3.1.0]hexane-6-*exo*-carbohydrazide

By **David G. Morris,*** Department of Chemistry, University of Glasgow, Glasgow G12 8QQ, Scotland
Peter Murray-Rust and **Judith Murray-Rust**, Department of Chemistry, University of Stirling, Stirling FK9 4LA, Scotland

A single crystal *X*-ray diffraction study shows that the bicyclo[3.1.0]hexane skeleton of the title compound (1) exists in a boat conformation and that the five-membered ring system is appreciably flattened compared to cyclopentane. Crystals are triclinic, space group $P\bar{1}$, with $a = 9.89(1)$, $b = 9.53(1)$, $c = 5.602(5)$ Å, $\alpha = 104.71(2)$, $\beta = 83.59(2)$, $\gamma = 100.20(1)^\circ$ and $Z = 2$; the structure was solved by direct methods and refined by full-matrix least-squares techniques to R 0.056 for 1 649 observed reflections. The conformational properties of the bicyclo[3.1.0]hexane ring system are discussed.

BICYCLO[3.1.0]HEXANE is a rather strained hydrocarbon and has been calculated to have 33.91 kcal mol^{-1} of strain energy compared with 1.35 for cyclohexane and 1.35 kcal mol^{-1} for cyclopentane.[1] This fused-ring system occurs in nature in thujane derivatives. A number of investigations of the conformation of the bicyclo[3.1.0]hexane ring system have been carried out on the basis of vicinal coupling constants in the ^{1}H n.m.r. spectra of thujyl alcohols,[2] amines,[3] and ketones,[4] it has been concluded that the overall six-membered ring exists in a boat conformation. A similar conclusion was reached for bicyclo[3.1.0]hexan-3-ol [5] and *trans*-thujane, whereas a half-chair conformation was proposed for *cis*-thujane.[6] In the case of sabinol both ^{1}H n.m.r. coupling constants [7] and ^{13}C chemical shifts [8] indicate boat conformations

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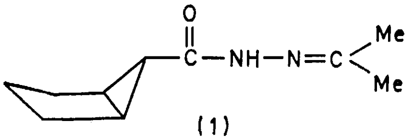
for the six-membered ring. More recently bicyclo[3.1.0]-hexane [9] itself and 3,6-dioxabicyclo[3.1.0]hexane [10] have been shown, on the basis of both i.r. and microwave spectral evidence, to contain a significant amount of the boat conformation. Likewise, boat conformations have been suggested for the six-membered ring in the hetero-atom derivatives *cis*-3,4-methyleneproline from both ^{1}H n.m.r. spectroscopic [11] and *X*-ray crystallographic investigations; [12] this latter technique also indicated a boat conformation for the six-membered ring of the hydrochloride of *trans*-3,4-methyleneproline.[12]

In these investigations it was found that the ring puckering at C(3) is less than in cyclohexane, and it has been suggested [11] that in bicyclo[3.1.0]derivatives the six-membered ring may adopt either a boat or a chair conformation depending on the nature of the substituents, and in addition, a conformation with an essentially planar five-membered ring may contribute. Accordingly it is desirable to determine the conformation in a bicyclo[3.1.0]hexane with no substituent or with a substituent likely to have a minimal influence on the conformation. We have therefore determined the solid-state conformation of the title compound (1).



(1)

The choice of substituent deserves some comment. We first hoped to grow suitable crystals of bicyclo-[3.1.0]hexane-6-*exo*-carboxylic acid,[13] but were unsuccessful. Attempts to crystallise the hydrazide of this acid from a variety of solvents also failed, and it was only after reflux of the hydrazide in acetone that it was possible to obtain crystals of (1) suitable for the present study.

DISCUSSION

The solid-state structure of (1) as determined by *X*-ray diffraction analysis is shown in Figures 1 and 2. The only close intermolecular contact is that of the intermolecular hydrogen bond N(1)–H · · · O(1′) [N(1) · · · O(1′) 2.955 Å, see Figure 2] and there is no suggestion that crystal packing forces have a significant effect on the conformation of the bicyclo[3.1.0] system. Fractional co-ordinates and isotropic thermal parameters for (1) are given in Table 1, and Tables 2—4 list the intramolecular bond lengths and angles, and selected torsion angles.

The six-membered ring has a boat conformation: C(1), C(2), C(4), and C(5) are coplanar (Table 4) and the displacements of C(3) and C(6) from this plane are shown in Figure 3. In the *X*-ray investigation of 3,4-methyleneproline derivatives [12] the nitrogen atom and the cyclopropane methylene carbon were similarly displaced on the same side of a plane defined by the remaining four ring carbon atoms by *ca.* 1.2 and 0.38 Å respectively. The mean torsion angle in the six-membered ring of (1) is 58°; however the five-membered ring is considerably flatter (*vide infra*) and C(6) more puckered than in cyclohexane (Table 4).

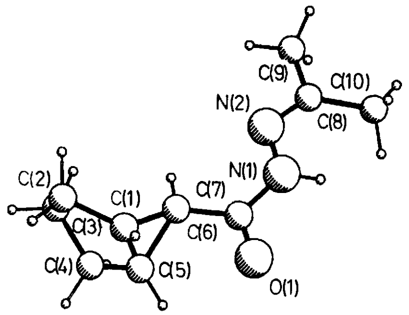


FIGURE 1 The title compound (1), showing the atom numbering system used

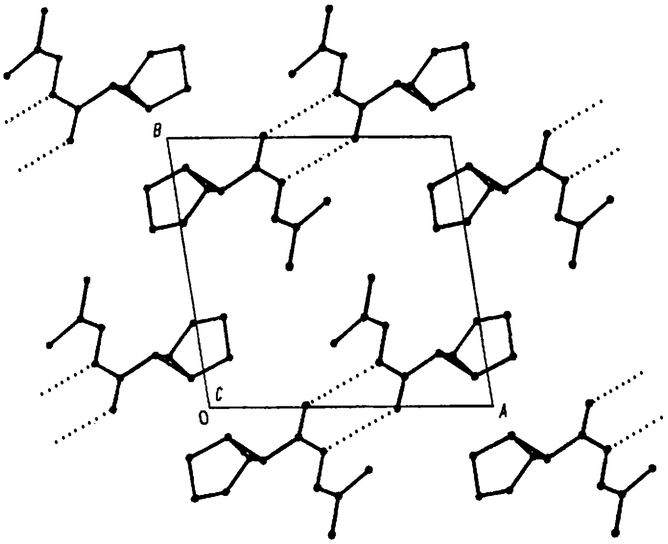


FIGURE 2 Packing diagram of (1), with H atoms omitted for clarity, viewed down the *c* axis ($A = a\sin\beta$, $B = b\sin\alpha$). H bonds are shown by dotted lines

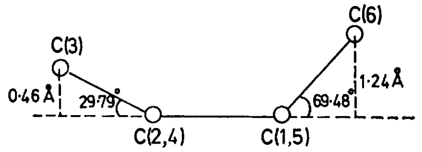


FIGURE 3 Displacements of C(3) and C(6) from the plane of C(1), C(2), C(4), C(5)

The ring junction bond C(1)–C(5) is rather short compared with the value determined for cyclopropane [1.510(2) Å] by electron diffraction,[14] while the other two

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bonds of the three-membered ring are very similar to that in cyclopropane. In the five-membered ring the bond lengths are all somewhat shorter than that found for cyclopentane [1.546 0 (12) Å] by electron diffraction;[15] the non-bonded contact C(2) · · · C(4) is 2.42 Å, compared with a mean transannular distance of 2.44 Å in cyclopentane. The out-of-plane displacement of C(3) (0.46 Å) is similar to the equilibrium out-of-plane amplitude obtained for cyclopentane (0.47 Å) by gas-phase Raman spectrum analysis.[16] However, evidence of ring flattening comes from the torsion angles C(1)–C(2)–C(3)–C(4) and C(2)–C(3)–C(4)–C(5) of *ca.* 29°, whereas force-field calculations on cyclopentane[17] indicate a maximum angle of 44°, which is consistent with i.r. spectral evidence.[18] Recently some approximate relationships between conformational parameters in slightly puckered rings have been established.[19] The torsion angles ω_{ij} in such rings are very sensitive to differences in the bond angles θ_i, such that the greater the deviation of the ring from planarity, the smaller the average of θ_i. The equilateral isogonal pentagon is constrained to lie in a plane, $\Sigma\omega_{ij}$ 0 and θ_i 108°; for the title compound $\Sigma\omega_{ij}$ 0.86° and mean θ_i 106.2°. Using the parameters defined in ref. 19, and that author's equation numbers, the mean value of q, the amplitude of deformation of C(3) from the plane of C(1), C(2), C(4), C(5) is 0.192 Å [from equations 11(*a*) and 12(*a*) of ref. 19], with $\Sigma\omega^2$(deg^2) 2 380.7 and $\Sigma\delta$ 9.1° (where $\Sigma\delta$ is the decrease in bond angle resulting from out-of-plane deformation); equation 13 is reasonably obeyed, and $\Sigma\omega^2$ and $\Sigma\delta$ interpolate nicely in Figure 2 of ref. 19. Corresponding values for cyclopentane are q 0.281, $\Sigma\omega^2$(deg^2) 4 494, and $\Sigma\delta$(deg) 17.70.

TABLE 1

Fractional co-ordinates (× 10^4) and isotropic thermal parameters with estimated standard deviations in parentheses

	x/a	*y/b*	*z/c*	
O(1)	6 608(1)	−59(1)	−1 628(2)	
N(1)	6 237(1)	1 663(2)	1 815(2)	
N(2)	6 657(1)	3 011(1)	3 403(2)	
C(1)	8 858(2)	1 890(2)	−3 366(3)	
C(2)	9 896(2)	3 154(2)	−3 893(3)	
C(3)	11 008(2)	3 378(2)	−2 080(4)	
C(4)	10 992(2)	1 864(2)	−1 641(3)	
C(5)	9 523(1)	1 108(2)	−1 980(3)	
C(6)	8 397(1)	1 980(2)	−671(3)	
C(7)	7 038(1)	1 120(2)	−217(3)	
C(8)	5 956(1)	3 332(2)	5 456(3)	
C(9)	6 416(2)	4 777(2)	7 175(3)	
C(10)	4 740(2)	2 368(2)	6 325(3)	
	x/a	*y/b*	*z/c*	*U*
H(N1)	5 375(28)	1 079(26)	1 919(47)	728(75)
H(11)	8 171(19)	1 413(20)	−4 563(32)	519(49)
H(21)	10 259(20)	2 852(21)	−5 521(39)	592(53)
H(22)	9 481(24)	4 074(26)	−3 577(44)	706(75)
H(31)	10 762(20)	4 116(22)	−499(35)	576(53)
H(32)	11 953(23)	3 828(24)	−2 748(39)	694(66)
H(41)	11 593(18)	1 266(19)	−2 892(30)	550(44)
H(42)	11 286(21)	1 918(22)	51(39)	620(54)
H(51)	9 299(18)	106(21)	−2 143(32)	542(49)
H(61)	8 620(16)	2 827(18)	493(29)	383(41)
H(91)	6 660(20)	4 614(20)	8 782(31)	725(61)
H(92)	7 209(19)	5 336(20)	6 435(39)	819(66)
H(93)	5 655(21)	5 357(21)	7 609(41)	940(80)
H(101)	3 973(19)	2 215(26)	5 284(41)	1 104(85)
H(102)	4 997(26)	1 369(21)	6 132(53)	1 382(113)
H(103)	4 443(23)	2 783(24)	7 987(34)	988(76)

TABLE 2

Intramolecular bond lengths (Å) in (1), with estimated standard deviations in parentheses

C(1)–C(2)	1.506 (3)	C(6)–C(7)	1.477 (2)
C(2)–C(3)	1.531 (3)	C(7)–O(1)	1.235 (2)
C(3)–C(4)	1.520 (3)	C(7)–N(1)	1.355 (2)
C(4)–C(5)	1.513 (2)	N(1)–N(2)	1.389 (2)
C(1)–C(6)	1.513 (2)	N(2)–C(8)	1.271 (2)
C(1)–C(5)	1.474 (3)	C(8)–C(9)	1.495 (2)
C(5)–C(6)	1.518 (2)	C(8)–C(10)	1.494 (2)

TABLE 3

Intramolecular bond angles (°) in (1), with estimated standard deviations in parentheses

C(2)–C(1)–C(6)	115.9(1)	C(1)–C(6)–C(7)	115.2(1)
C(2)–C(1)–C(5)	107.9(1)	C(5)–C(6)–C(7)	116.4(1)
C(5)–C(1)–C(6)	61.1(1)	O(1)–C(7)–C(6)	122.4(1)
C(1)–C(2)–C(3)	105.1(2)	O(1)–C(7)–N(1)	119.3(1)
C(2)–C(3)–C(4)	104.8(1)	C(6)–C(7)–N(1)	118.3(1)
C(3)–C(4)–C(5)	104.6(1)	C(9)–C(8)–C(10)	117.4(1)
C(1)–C(5)–C(4)	108.5(1)	N(2)–C(8)–C(9)	117.1(1)
C(1)–C(5)–C(6)	60.7(1)	N(2)–C(8)–C(10)	125.5(1)
C(4)–C(5)–C(6)	116.7(1)	C(7)–N(1)–N(2)	121.2(1)
C(1)–C(6)–C(5)	58.2(1)	N(1)–N(2)–C(8)	117.1(1)

TABLE 4

Selected torsion angles (°) in (1)

(*a*) [3.1.0] System			
C(5)–C(1)–C(2)–C(3)	−17.8	C(1)–C(2)–C(3)–C(4)	29.2
C(6)–C(1)–C(2)–C(3)	48.1	C(2)–C(3)–C(4)–C(5)	−29.3
C(2)–C(1)–C(5)–C(4)	0.0	C(3)–C(4)–C(5)–C(6)	−47.1
C(2)–C(1)–C(5)–C(6)	110.2	C(3)–C(4)–C(5)–C(1)	18.8
C(6)–C(1)–C(5)–C(4)	−110.8	C(4)–C(5)–C(6)–C(1)	97.2
C(2)–C(1)–C(6)–C(5)	−97.0		
(*b*) Hydrazone system			
C(7)–N(1)–N(2)–C(8)	−169.1	C(1)–C(5)–C(6)–C(7)	104.5
N(2)–N(1)–C(7)–O(1)	−177.6	C(4)–C(5)–C(6)–C(1)	97.2
N(2)–N(1)–C(7)–C(6)	1.8	C(1)–C(6)–C(7)–N(1)	−145.7
N(1)–N(2)–C(8)–C(10)	1.5	C(1)–C(6)–C(7)–O(1)	33.6
N(1)–N(2)–C(8)–C(9)	180.0	C(5)–C(6)–C(7)–N(1)	148.9
C(2)–C(1)–C(6)–C(7)	156.3	C(5)–C(6)–C(7)–O(1)	−31.8
C(5)–C(1)–C(6)–C(7)	−106.7	N(1)–C(6)–C(7)–O(1)	180.0

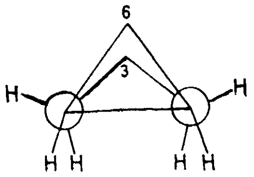

FIGURE 4 Interaction of H atoms in the six-membered ring of (1)

The origin of the preference for a boat conformation of the six-membered ring in (1) probably resides in the staggering of the hydrogen atoms on C(1) and C(5) with those on C(2) and C(4) respectively (Figure 4), whereas in the chair conformation the hydrogens on C(1) and C(5)

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are eclipsed with a hydrogen atom on C(2) and C(4) respectively. The eclipsing of hydrogen atoms in the chair conformation of bicyclo[3.1.0]hexane differs from the situation in cyclohexane, where hydrogen atoms on vicinal carbon atoms are eclipsed in the boat conformation. It is further noted that in bicyclo[3.1.0]hexane two severe 1,3 H · · · H interactions involving a cyclopropyl methylene hydrogen in the chair conformation are replaced in the boat conformation by a single, less severe 1,4 H · · · H interaction again involving a cyclopropyl methylene hydrogen, and that this interaction is lessened in a flattened boat.

EXPERIMENTAL

The yellow prismatic needles crystals had m.p. 152—153 °C (Found: C, 66.48; H, 8.65; N, 15.35. Calc. for $C_{10}H_{16}N_2O$: C, 66.63; H, 8.95; N, 15.54%) were examined by precession and oscillation photography.

Crystal Data.—$C_{10}H_{16}N_2O$ Triclinic, $a = 9.89(1)$, $b = 9.53(1)$, $c = 5.602$ Å, $\alpha = 104.71(2)$, $\beta = 83.59(2)$, $\gamma = 100.20(1)°$, $U = 501.6$ Å^3, $Z = 2$, $D_c = 1.186$ g cm^{-3}. Space group $P\bar{1}$. Crystal size 0.3 × 0.3 × 0.5 mm. Graphite-monochromated Mo-K_α radiation, $\lambda = 0.7107$ Å; μ(Mo-K_α) = 0.45 cm^{-1}.

Reflection data were collected on a STADI 2 diffractometer for layers $hk0$—6 with $4 \leqslant \theta \leqslant 27.5°$. These data were corrected for Lorentz and polarization factors, but not for absorption effects. 1 942 unique reflections were measured of which 1 649 had $I > 3\sigma(I)$. The structure was solved by standard direct-phasing methods including phase recycling. Refinement was by full-matrix least squares and in the later cycles the non-hydrogen atoms were given anisotropic temperature factors. The positions of all the hydrogen atoms except those in the methyl groups were initially given calculated position; the methyl hydrogen atoms were located from a difference map and then constrained to have acceptable bond lengths and angles. The weighting scheme used was in the form: $w = [\sigma^2(F) + 0.01F^2]^{-1}$, and refinement converged with R 0.045 (unit weights) and R' 0.052.

The SHELX program [20] was used for all calcuations. Structure factors, anisotropic thermal parameters, and bond lengths and angles involving hydrogen atoms are listed in Supplementary Publication No. SUP 22038 (16 pp., 1 microfiche).*

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* See Notice to Authors No. 7 in *J.C.S. Perkin II*, 1975, Index issue.

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