

orientation and an approximate geometry for both CH<sub>3</sub> groups of ethyl acetate. The H peaks are diffuse but their analytical centre bears some significance, leading to the following average geometry taken over the two groups: C-H = 1.07 (11) Å; C-C-H = 112 (5), H-C-H = 106 (13)°.

A test of the above disordered model ( $B = 5 \text{ \AA}^2$  for all the atoms), based on structure factor calculations showed an increase in the value of  $[\sum w\Delta^2/(m-n)]^{1/2}$  of about 20% and yielded an  $R$  factor of 0.078. As we have pointed out, the refined planar model (Fig. 4) does not represent a single molecule and must be rejected as such. On the other hand, the model arrived at empirically by considering the aspherical electron distribution at the atomic sites of the solvent is a constrained limiting case implying a minimum number of parameters. It is clear that the introduction of additional parameters (e.g. a weighted population of conformers) could reduce  $\sum w\Delta^2$  to any desired value without necessarily increasing the physical significance of the results. This was demonstrated in refining anisotropically the disordered model in Fig. 5, considering two independent molecules with a constant weight of  $\frac{1}{2}$ . Introduction of a damping factor decreased  $R$  to 0.055 after only two cycles of refinement (planar model  $R = 0.058$ ). The initial model did not collapse into a single 'average' molecule but afforded two new different conformers slightly displaced from the initial ones. No undue values of the thermal parameters were to be noted. The geometries, though physically inconsistent, show some improvement over that of the planar model. This test might add further support to the type of disorder suggested above in an oversimplified manner. The number of parameters to be handled and the inaccuracy of the data make the least-squares method

unrealistic in the present case and we think that results obtained from a simple interpretation of the difference synthesis are more trustworthy.

Financial support by the Swiss National Science Foundation is gratefully acknowledged. We wish to thank Professor M. Geoffroy (ESR) and Dr U. Burger (NMR) for their help.

#### References

- BACHMANN, W. E. & WISELOGLE, F. Y. (1936). *J. Org. Chem.* **1**, 355-382.  
 BARTELL, L. S. & BOATES, T. L. (1976). *J. Mol. Struct.* **32**, 379-392.  
 FLEISCHER, E. B., SUNG, N. & HAWKINSON, S. (1968). *J. Phys. Chem.* **72**, 4311-4312.  
 GOMBERG, M. (1900). *Chem. Ber.* **33**, 3150-3163.  
 GOMBERG, M. (1901). *Chem. Ber.* **34**, 2726-2733.  
 HOUNSHELL, W. D., DOUGHERTY, D. A., HUMMEL, J. P. & MISLOW, K. (1977). *J. Am. Chem. Soc.* **99**, 1916-1924.  
 INGOLD, K. U. (1973). *Free Radicals*, edited by J. K. KOCHI, Vol. I, p. 52. New York: John Wiley.  
 JACOBSON, P. (1905). *Chem. Ber.* **38**, 196-199.  
 LANKAMP, H., NAUTA, W. T. & MCLEAN, C. (1968). *Tetrahedron Lett.* pp. 249-254.  
 MCBRIDE, J. M. (1974). *Tetrahedron*, **30**, 2009-2022.  
 O'GORMAN, J. M., SHAND, W. & SCHOMAKER, V. (1950). *J. Am. Chem. Soc.* **72**, 4222-4228.  
 SCHREINER, K., BERNDT, A. & BAER, F. (1973). *Mol. Phys.* **26**, 929-939.  
 STAAB, H. A., BRETTSCHEIDER, H. & BRUNNER, H. (1970). *Chem. Ber.* **103**, 1101-1106.  
 TSANG, W. (1966). *J. Chem. Phys.* **44**, 4283-4295.  
 XRAY system (1976). Version of March 1976. Tech. Rep. TR-446. Computer Science Center, Univ. of Maryland, College Park, Maryland.

*Acta Cryst.* (1978). **B34**, 2220-2223

### The Conformation of Heterocyclic Spiro Compounds.

#### III. The Crystal and Molecular Structure of *N*-( $\beta$ -Hydroxyethyl)granatanine-3-spiro-5'-hydantoin

BY F. FLORENCIO, P. SMITH-VERDIER AND S. GARCÍA-BLANCO

*Departamento de Rayos X, Instituto de Química-Física 'Rocasolano', Serrano 119, Madrid 6, Spain*

(Received 12 January 1978; accepted 21 February 1978)

*N*-( $\beta$ -Hydroxyethyl)granatanine-3-spiro-5'-hydantoin, C<sub>13</sub>H<sub>19</sub>N<sub>3</sub>O<sub>3</sub>, is monoclinic,  $a = 9.326$  (1),  $b = 11.720$  (1),  $c = 12.166$  (1) Å,  $\beta = 109.23$  (1)°,  $Z = 4$ , space group  $P2_1/c$ . The atomic positions were determined by direct methods and refined by full-matrix least squares to an  $R$  of 0.044 for 1955 reflections. The bicyclo[3.3.1]nonane system adopts a boat-chair conformation. The structure is held together by a system of hydrogen bonds.

## Introduction

This work is part of a series of studies on the crystal structures of heterocyclic spiro derivatives of nortropane and granatanine being carried out by Gonzalez Trigo, Avendaño & Martínez Moreno (1977). These compounds are interesting because of their pharmacological properties. The structures of *N*-methyltropane-3-spiro-5'-hydantoin (Smith-Verdier, Florencio & García-Blanco, 1977) and *N*-methylgranatanine-3-spiro-5'-hydantoin (Florencio, Smith-Verdier & García-Blanco, 1978) have been determined. The present work has been undertaken to determine the conformation of a molecule belonging to the bicyclo-[3.3.1]nonane system, since there is a divergence of opinion.

## Experimental

Crystals were kindly supplied by Dr C. Avendaño and Dr M. Martínez Moreno of the Departamento de Química Orgánica y Farmacéutica de la Facultad de Farmacia de la Universidad Complutense de Madrid.

The cell parameters and intensities were recorded with a Philips PW 1100 automatic four-circle diffractometer, Cu *K* $\alpha$  radiation and a graphite monochromator. Crystal data are given in Table 1. A  $\theta$ - $2\theta$  scanning mode was used to measure 2113 independent reflections with  $2\theta < 30^\circ$ , of which 1955 were considered as observed [ $I > 2.0\sigma(I)$ , where  $\sigma(I)$  was determined from counting statistics]. No absorption correction was applied ( $\mu = 8.354 \text{ cm}^{-1}$ ).

## Structure determination and refinement

The structure was solved with *MULTAN* 74 (Main, Woolfson, Lessinger, Germain & Declercq, 1974), with the 200 largest *E* values. An *E* map computed with the phases from the set with the highest combined figure of merit gave a chemically reasonable set of peaks. Isotropic refinement of the non-hydrogen atoms gave  $R = 0.140$ . Refinement was continued with anisotropic thermal parameters and converged to  $R = 0.099$ . A difference synthesis showed the positions of all the H atoms which were included with isotropic temperature factors. The data were refined to a stage at which no parameter shift was significant. Unit weight was assigned for each reflection. The final *R* was 0.044. A final difference map had no significant peaks. Scattering factors were taken from *International Tables for X-ray Crystallography* (1974). Computations were carried out with the XRAY 70 system (Stewart, Kundell & Baldwin, 1970) running on the 1108 Univac computer of the Centro de Proceso de Datos del Ministerio de

Table 1. Crystal data

Standard deviations, given in parentheses, refer to the least significant digits.

Formula $\text{C}_{13}\text{H}_{19}\text{N}_3\text{O}_3$	$V = 1255.47 (7) \text{ \AA}^3$
Molecular weight 265.32	$Z = 4$
Space group $P2_1/c$	$D_x = 1.390 \text{ g cm}^{-3}$
$a = 9.326 (1) \text{ \AA}$	$D_c = 1.41$
$b = 11.720 (1)$	$F(000) = 568$
$c = 12.166 (1)$	$\lambda(\text{Cu } K\alpha) = 1.5418 \text{ \AA}$
$\beta = 109.23 (1)^\circ$	

Table 2. Positional parameters ( $\times 10^4$ ) for the non-hydrogen atoms

	<i>x</i>	<i>y</i>	<i>z</i>
C(1)	-1987 (2)	10553 (2)	-2257 (2)
C(2)	-336 (2)	10982 (2)	-1956 (2)
C(3,5')	752 (2)	10143 (2)	-2253 (1)
C(4)	-9 (2)	9519 (2)	-3411 (2)
C(5)	-1679 (2)	9179 (2)	-3642 (2)
N(6)	-2041 (2)	9336 (1)	-2564 (1)
C(7)	-3094 (2)	11271 (2)	-3230 (2)
C(8)	-2816 (3)	11098 (2)	-4389 (2)
C(9)	-2785 (2)	9834 (2)	-4665 (2)
C(10)	-3428 (2)	8743 (2)	-2549 (2)
C(11)	-3144 (3)	8217 (2)	-1357 (2)
O(1)	-1793 (2)	7539 (1)	-1026 (1)
N(1')	2093 (2)	10764 (1)	-2311 (1)
C(2')	3381 (2)	10492 (2)	-1472 (2)
N(3')	3032 (2)	9597 (1)	-840 (1)
C(4')	1518 (2)	9342 (2)	-1227 (2)
O(2)	4637 (1)	10909 (1)	-1269 (1)
O(3)	941 (1)	8615 (1)	-796 (1)

Table 3. Positional ( $\times 10^3$ ) and isotropic thermal ( $\times 10^4$ ) parameters for the hydrogen atoms

	<i>x</i>	<i>y</i>	<i>z</i>	<i>U</i> ( $\text{\AA}^2$ )
H(1)	-233 (3)	1062 (2)	-157 (2)	4 (2)
H(21)	6 (2)	1116 (2)	-115 (2)	0 (1)
H(22)	-30 (2)	1170 (2)	-240 (2)	0 (1)
H(41)	56 (2)	883 (2)	-344 (2)	0 (1)
H(42)	4 (2)	1006 (2)	-401 (2)	0 (1)
H(5)	-175 (2)	835 (2)	-381 (2)	2 (1)
H(71)	-306 (3)	1205 (2)	-300 (2)	3 (2)
H(72)	-427 (2)	1102 (2)	-333 (2)	0 (1)
H(81)	-178 (3)	1146 (2)	-433 (2)	6 (2)
H(82)	-385 (3)	1150 (2)	-507 (2)	8 (2)
H(91)	-396 (2)	953 (2)	-485 (2)	0 (1)
H(92)	-254 (3)	973 (2)	-534 (2)	4 (2)
H(101)	-384 (3)	813 (2)	-320 (2)	4 (2)
H(102)	-446 (2)	928 (2)	-279 (2)	0 (1)
H(111)	-420 (3)	768 (2)	-142 (3)	3 (2)
H(112)	-321 (4)	881 (3)	-80 (2)	16 (3)
H(01)	-89 (3)	795 (3)	-105 (2)	5 (2)
H(1')	202 (2)	1132 (2)	-278 (2)	0 (1)
H(3')	383 (2)	932 (2)	-17 (2)	1 (1)

Educación y Ciencia (Madrid, Spain). The parameters of the heavy atoms are given in Table 2 and those of the H atoms in Table 3.\*

### Discussion

The numbering of the atoms, and bond lengths and angles are given in Fig. 1. In Table 4 the deviations of the atoms from some least-squares planes of the molecule are listed.

The molecule consists of two six-membered rings, (I) and (II), joined by a common C—N—C bridge with a —CH<sub>2</sub>—CH<sub>2</sub>OH group attached to the N atom and a hydantoin ring substituted at the C(3,5') spiro atom. The bond lengths are normal.

Several investigations (Brown, Eglinton, Martin, Parker & Sim, 1964; Webb & Becker, 1967) have established that simple [3.3.1]nonane compounds in which both three-C-atom bridges are fully saturated adopt a chair-chair conformation in which, in order to increase the non-bonded C(3)···C(7) distance, the cyclohexane rings are distinctly flattened, with ring valence angles at C(2), C(3), C(4), C(6), C(7) and C(8) rather greater than the tetrahedral value. On the other hand, Tamura & Sim (1968) found a boat-chair conformation in 9-benzoyl-3 $\alpha$ -bromo-2 $\beta$ -hydroxy-9-azabicyclo[3.3.1]nonane and considered this molecule as a model for the boat-chair form of bicyclo[3.3.1]-

\* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 33449 (11 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

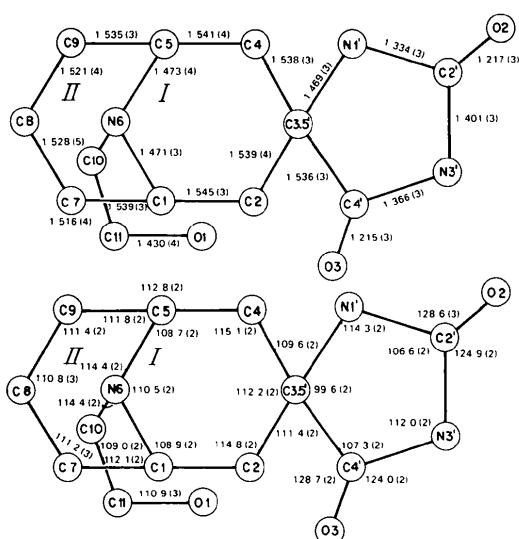


Fig. 1. Bond lengths (Å) and angles (°) involving the non-hydrogen atoms. Angles not shown: C(2)—C(3,5')—N(1') = 109.4 (2), C(4)—C(3,5')—C(4') = 113.9 (2)°.

nonan-9-one since the distance C(3)···N(9) found by them is identical with that estimated by Webb & Becker (1967) (2.56 Å).

In the present compound the bicyclo system adopts a boat-chair conformation, albeit in a flattened form. The displacements of C(3,5') and N(6) from the least-squares plane of C(1), C(2), C(4) and C(5) are 0.487

Table 4. Some least-squares planes and deviations (Å) of individual atoms from them

	Plane 1	Plane 2	Plane 3	Plane 4
C(1)	0.0038*	-0.0041*		
C(2)	-0.0036*	1.4266		
C(3,5')	0.4872	1.8950	0.0089*	0.0269*
C(4)	0.0036*	1.4260		
C(5)	-0.0038*	0.0041*		
N(6)	0.7261	-0.6635		
C(7)	-1.4226	0.0039*		
C(8)	-2.2094	0.6312		
C(9)	-1.4207	-0.0039*		
C(10)	1.1362	-2.1286		
C(11)	2.5413	-2.7621		
O(1)	3.4281	-2.2671		
N(1')			-0.0062*	-0.0345*
C(2')			0.0575	-0.0032*
N(3')			0.0068*	-0.0320*
C(4')			-0.0096*	-0.0023*
O(2)			0.1341	0.0325*
O(3)			-0.0208	0.0126*

Plane 1:  $0.0593X - 0.6833Y + 0.7278Z = -2.2751$   
 Plane 2:  $0.8436X + 0.5287Y - 0.0935Z = 1.5303$   
 Plane 3:  $-0.3709X + 0.6860Y + 0.6259Z = 14.6075$   
 Plane 4:  $-0.4022X + 0.6763Y + 0.6172Z = 14.4709$

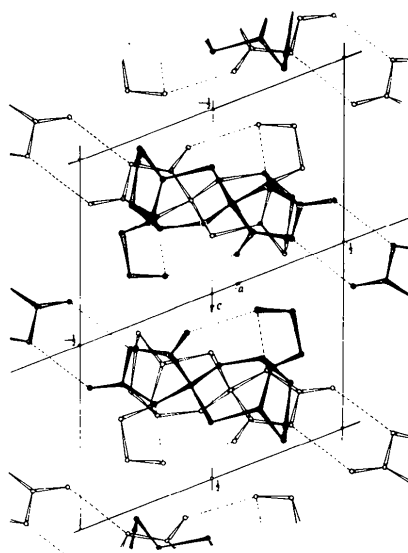


Fig. 2. Packing diagram. The broken lines indicate hydrogen bonds.

and 0.726 Å so that ring (I) adopts a boat conformation. In ring (II) the displacements of N(6) and C(8) from the plane through C(1), C(5), C(7) and C(9) are -0.247 and 0.211 Å, indicative of a chair conformation. These displacements show that N(6) is displaced further from the mean plane through C(1), C(2), C(4) and C(5) than is C(3,5') from the same plane; therefore the C(1), C(2), C(3,5'), C(4), C(5) part of the boat is somewhat flattened whilst the C(1), C(2), C(4), C(5), N(6) part presents a similar form to that of the ideal boat. The bond angles at positions C(2), C(3,5') and C(4) are rather greater than tetrahedral values (114.8, 112.2 and 115.1° respectively) whilst the angles at C(1), N(6) and C(5) are closer to tetrahedral (108.9, 110.5 and 108.7° respectively). In ring (II) the displacements of N(6) and C(8) from the plane C(1), C(5), C(7), C(9) are similar and smaller than the values given for the ideal chair (0.73 Å); consequently the C(1), C(5), N(6), C(7), C(8), C(9) chair is flattened and the angles at C(1), C(5), N(6), C(7), C(8) and C(9) average 111.3°.

The deformations of the two cyclohexane rings are shown by the values of the asymmetry parameters (Duax & Norton, 1975). In the boat, ring (I), the relevant parameters are  $\Delta C_S^{(3,5')} = 0.78$  and  $\Delta C_S^{(1-2)} = 38.5^\circ$ , which indicate a mirror plane through C(3,5') and N(6) and the flattening of the C(1), C(2), C(3,5'), C(4), C(5) part of the boat. In ring (II), with a chair conformation, the asymmetry parameters are  $\Delta C_S^8 = 0.96$ ,  $\Delta C_S^{(5-6)} = 2.3$  and  $\Delta C_S^{(1-7)} = 7.05^\circ$  showing that the mirror symmetry is dominant with an approximate  $C_S$  plane passing through N(6) and C(8). The distance C(8)···C(3,5') is 2.678 Å, a little larger than the corresponding distance in the ideal boat (2.56 Å) (Webb & Becker, 1967).

Another peculiarity of the structure is the configuration of N(6) of the bridge. In *N*-methylgranatanine-3-spiro-5'-hydantoin this atom is pyramidal and the substituent group at the N atom of the bridge is in an equatorial position with respect to ring (II) and is an acceptor of the proton of N(3') of the hydantoin ring to form a hydrogen bond; in the present compound, also with N(6) pyramidal, this hydrogen bond is not present because the substituent group at N(6) is axial with respect to ring (II).

Table 5. *Interatomic distances (Å) and angles (°) in the hydrogen bonds*

<i>a</i>	<i>b</i>	<i>c</i>	<i>ab</i>	<i>bc</i>	<i>ac</i>	$\angle abc$
O(1)—H···O(3) ( <i>x</i> , <i>y</i> , <i>z</i> )	0.980	1.807	2.775	168.5		
N(1')—H···O(1) ( $-x, \frac{1}{2} + y, \frac{3}{2} - z$ )	0.855	1.998	2.851	176.4		
N(3')—H···O(2) ( $1-x, 2-y, 2-z$ )	0.963	1.879	2.826	167.3		

The flattening of ring (I) with a boat conformation could be due to the O—H···O interaction between the substituent group —CH<sub>2</sub>—CH<sub>2</sub>OH and O(3) of the hydantoin ring. Because of the deformation of the boat the flattening of ring (II) is not avoided, as is shown by the displacements of the ring atoms from the mean planes (Table 4).

The hydantoin ring is practically planar; the only atom deviating significantly from it is O(2) (0.134 Å). The distances in the ring are similar to those found in *N*-methyltropane-3-spiro-5'-hydantoin and *N*-methylgranatanine-3-spiro-5'-hydantoin.

A projection of the structure along **b** showing the hydrogen bonds is in Fig. 2. O(1) participates in two hydrogen bonds acting as both donor and acceptor; in the first case it forms an intramolecular [O(1)—H(1)···O(2)] and in the second an intermolecular [N(1')—H(1')···O(1)] hydrogen bond. A third hydrogen bond is N(3')—H(3')···O(2), formed between a pair of molecules related by a centre of symmetry. The geometries of these hydrogen bonds are shown in Table 5. The other intermolecular contacts correspond to normal van der Waals interactions.

The authors thank the Centro de Proceso de Datos del Ministerio de Educación y Ciencia, Madrid, Spain, for providing facilities for the use of the 1108 Univac computer.

#### References

- BROWN, W. A. C., EGLINTON, G., MARTIN, J., PARKER, W. & SIM, G. A. (1964). *Proc. Chem. Soc. London*, pp. 57–58.
- DUAX, W. L. & NORTON, D. A. (1975). *Atlas of Steroid Structure*. New York: Plenum.
- FLORENCIO, F., SMITH-VERDIER, P. & GARCÍA-BLANCO, S. (1978). *Acta Cryst.* B34, 1317–1321.
- GONZALEZ TRIGO, G., AVENDAÑO, C. & MARTÍNEZ MORENO, M. (1977). Private communication.
- International Tables for X-ray Crystallography* (1974). Vol. IV, pp. 72–98. Birmingham: Kynoch Press.
- MAIN, P., WOOLFSON, M. M., LESSINGER, L., GERMAIN, G. & DECLERCQ, J. P. (1974). *MULTAN 74, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data*. Univ. York, England, and Louvain, Belgium.
- SMITH-VERDIER, P., FLORENCIO, F. & GARCÍA-BLANCO, S. (1977). *Acta Cryst.* B33, 3381–3385.
- STEWART, J. M., KUNDELL, F. A. & BALDWIN, J. C. (1970). The XRAY 70 system. Computer Science Center, Univ. of Maryland, College Park, Maryland.
- TAMURA, C. & SIM, G. A. (1968). *J. Chem. Soc. B*, pp. 1241–1248.
- WEBB, N. C. & BECKER, M. R. (1967). *J. Chem. Soc. B*, pp. 1317–1321.