C(9)—C(11)	1.545 (3)	C(22)—N(16)	1.404 (3)
C(9)—C(10)	1.562 (2)	C(22)—C(23)	1.491 (3)
C(10)—C(19)	1.547 (3)	N(16)—N(20)	1.387 (3)
C(11)—C(12)	1.540 (3)		

C(2)—C(1)—C(10)	113.7 (2)	C(17)—C(13)—C(18)	106.9 (2)
C(3)—C(2)—C(1)	112.8 (2)	C(12)—C(13)—C(18)	111.3 (2)
O(3)—C(3)—C(4)	121.2 (2)	C(17)—C(13)—C(14)	98.43 (14)
O(3)—C(3)—C(2)	121.7 (2)	C(12)—C(13)—C(14)	106.72 (15)
C(4)—C(3)—C(2)	117.0 (2)	C(18)—C(13)—C(14)	113.5 (2)
C(5)—C(4)—C(3)	123.6 (2)	C(8)—C(14)—C(15)	120.01 (15)
C(4)—C(5)—C(6)	120.0 (2)	C(8)—C(14)—C(13)	112.15 (14)
C(4)—C(5)—C(10)	122.7 (2)	C(15)—C(14)—C(13)	106.42 (14)
C(6)—C(5)—C(10)	117.1 (2)	C(16)—C(15)—C(14)	97.84 (15)
C(5)—C(6)—C(7)	112.9 (2)	C(17)—C(16)—N(16)	107.2 (2)
C(6)—C(7)—C(8)	110.6 (2)	C(17)—C(16)—C(15)	114.5 (2)
C(14)—C(8)—C(7)	112.35 (14)	N(16)—C(16)—C(15)	137.9 (2)
C(14)—C(8)—C(9)	107.31 (14)	C(16)—C(17)—C(20)	106.3 (2)
C(7)—C(8)—C(9)	109.28 (14)	C(16)—C(17)—C(13)	110.0 (2)
C(11)—C(9)—C(8)	113.99 (14)	C(20)—C(17)—C(13)	142.2 (2)
C(11)—C(9)—C(10)	112.1 (2)	N(20)—C(20)—C(17)	110.4 (2)
C(8)—C(9)—C(10)	112.34 (15)	N(20)—C(20)—C(21)	120.7 (2)
C(5)—C(10)—C(1)	109.7 (2)	C(17)—C(20)—C(21)	128.8 (2)
C(5)—C(10)—C(19)	107.0 (2)	O(22)—C(22)—N(16)	119.4 (2)
C(1)—C(10)—C(19)	109.8 (2)	O(22)—C(22)—C(23)	124.6 (2)
C(5)—C(10)—C(9)	109.69 (15)	N(16)—C(22)—C(23)	116.0 (2)
C(1)—C(10)—C(9)	108.8 (2)	C(16)—N(16)—N(20)	110.4 (2)
C(19)—C(10)—C(9)	111.8 (2)	C(16)—N(16)—C(22)	127.7 (2)
C(12)—C(11)—C(9)	114.5 (2)	N(20)—N(16)—C(22)	121.8 (2)
C(13)—C(12)—C(11)	110.4 (2)	C(20)—N(20)—N(16)	105.6 (2)
C(17)—C(13)—C(12)	119.6 (2)		

C(10)—C(1)—C(2)—C(3)	−50.9 (3)
C(1)—C(2)—C(3)—C(4)	25.5 (3)
C(2)—C(3)—C(4)—C(5)	2.4 (3)
C(3)—C(4)—C(5)—C(10)	−5.0 (3)
C(4)—C(5)—C(10)—C(1)	−19.8 (3)
C(5)—C(10)—C(1)—C(2)	47.1 (3)
C(10)—C(5)—C(6)—C(7)	−47.7 (3)
C(5)—C(6)—C(7)—C(8)	53.5 (2)
C(6)—C(7)—C(8)—C(9)	−59.4 (2)
C(7)—C(8)—C(9)—C(10)	59.5 (2)
C(8)—C(9)—C(10)—C(5)	−50.9 (2)
C(9)—C(10)—C(5)—C(6)	45.4 (2)
C(14)—C(8)—C(9)—C(11)	−49.6 (2)
C(8)—C(9)—C(11)—C(12)	46.3 (2)
C(9)—C(11)—C(12)—C(13)	−50.8 (3)
C(11)—C(12)—C(13)—C(14)	58.6 (2)
C(12)—C(13)—C(14)—C(8)	−67.3 (2)
C(13)—C(14)—C(8)—C(9)	61.2 (2)
C(17)—C(13)—C(14)—C(15)	35.2 (2)
C(13)—C(14)—C(15)—C(16)	−32.2 (2)
C(14)—C(15)—C(16)—C(17)	17.2 (2)
C(15)—C(16)—C(17)—C(13)	5.0 (3)
C(16)—C(17)—C(13)—C(14)	−24.7 (2)
N(16)—C(16)—C(17)—C(20)	−0.2 (2)
C(16)—C(17)—C(20)—N(20)	0.7 (2)
C(17)—C(20)—N(20)—N(16)	−0.9 (2)
C(20)—N(20)—N(16)—C(16)	0.8 (2)
N(20)—N(16)—C(16)—C(17)	−0.4 (2)
C(16)—N(16)—C(22)—O(22)	5.2 (4)
N(20)—N(16)—C(22)—C(23)	6.0 (3)

Program(s) used to solve structure: *SHELXTL-Plus* (Sheldrick, 1987). Program(s) used to refine structure: *SHELXL93* (Sheldrick, 1993).

This publication was prepared with financial support from the American Crystallographic Association and International Scientific Foundation.

Lists of structure factors, anisotropic displacement parameters and H-atom coordinates have been deposited with the IUCr (Reference: AB1175). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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Acta Cryst. (1994). C**50**, 2056–2058

1,6-Dimethyltetrahydroimidazo[4,5-*d*]imidazole-2,5(1*H*,6*H*)-dione Monohydrate

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(*Received* 6 *December* 1993; *accepted* 25 *April* 1994)

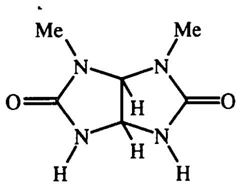
Abstract

The bicyclic system of the title compound, $C_6H_{10}N_4O_2.H_2O$, (I), consists of two planar five-membered heterocycles (maximum deviations of atoms from the mean planes do not exceed 0.03 Å). The dihedral angle formed by the average mean planes of the rings is 121.4 (1)°. Bond lengths and angles in (I) are in good agreement with the relevant parameters of acyclic urea derivatives.

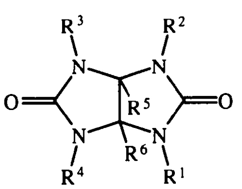
Comment

The title compound (I), prepared according to Nematollahi & Ketcham (1963), belongs to the class of bicyclic bisurea (BBU) derivatives of the general formula (II), where R^1, R^2, R^3 and R^4 = H, alkyl, and R^5 and R^6 = H, CH_3, which exhibit strong psychotropic activity. It has been shown that the type and degree of pharmacological activity depends on the nature and the number of substituents in the BBU molecule (Suvorova, Yeres'ko, Yepishina, Lebedev & Khmelnitsky, 1979). Among the

N-alkyl derivatives of BBU, the tetra-*N*-substituted compounds are usually the most active, the activity decreasing markedly with the decrease in the number of *N*-alkyl substituents.



(I)



(II)

It was believed that the biological activity might be correlated with certain geometric features of the bicyclic framework of the molecules, in particular, with the dihedral angle formed by the mean planes of the five-membered heterocycles. Therefore, structural studies of a series of BBU derivatives with various *N*-alkyl substituents have been carried out by several groups (Pletnev, Mikhailova, Sobolev, Galitskii, Verenich, Khmelnitsky, Lebedev, Kravchenko & Suvorova, 1993; Himes, Hubbard, Mighell & Fatiadi, 1978; Boileau, Wimmer, Gilardi, Stinecipher, Gallo & Pierrot, 1988). Within the framework of these studies, we have undertaken the X-ray structural study of the 2,8-dimethyl-BBU derivative.

The conformation of the bicyclic moiety of molecule (I) is quite typical for *N*-alkyl-BBU compounds (Fig. 1). The dihedral angle formed by the mean planes of the five-membered rings (which are planar within 0.03 Å) is 121.4 (1)°, which is somewhat larger than the relevant angle in 1,5-dimethyl-BBU (115°; Himes *et al.*, 1978) and in tri- and tetraalkyl-BBU (118.3–119.6°; Pletnev *et al.*, 1993).

The C—N and C=O bond lengths of the urea moiety in (I) [1.362 (3), 1.364 (3), 1.355 (3) and 1.359 (3), and 1.235 (3) and 1.238 (3) Å, respectively] agree with those found in unsubstituted BBU (R^1 = R^2 = R^3 = R^4 = R^5 = R^6 = H) [1.347 (4) and 1.244 (1) Å; Boileau *et al.*, 1988] and with the bond lengths observed in its 1,5-dimethyl derivative (R^1 = R^2 = R^3 = R^4 = H, R^5 = R^6 = Me) [1.338 (2) and 1.237 (3) Å; Himes *et al.*, 1978]. These bond lengths do not differ significantly from the standard values of 1.347 and 1.241 Å, reported for acyclic urea derivatives (Allen, Kennard, Watson, Brammer, Orpen & Taylor, 1987).

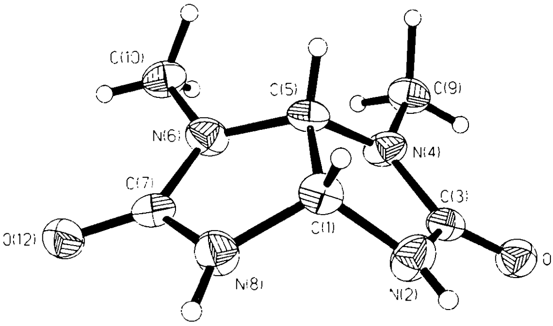


Fig. 1. Perspective view of (I) showing the labelling of the non-H atoms with ellipsoids drawn at the 50% probability level.

Each of the four active H atoms is involved in hydrogen bonding, which links the molecules of (I) and the water molecules into a three-dimensional network. The carbonyl O atoms are different with respect to their participation in hydrogen-bonding. One of them functions as an acceptor of two hydrogen bonds [O(1*W*)—H(2*W*)···O($12^{\rm i}$): O···O 2.780 (4), O···H 1.83 Å, O—H···O 178.5°, (i) $\frac{1}{2} - x, 2 - y, -\frac{1}{2} + z$; N(2)—H(2)···O($12^{\rm ii}$): N···O 2.892 (3), H···O 2.16 (3) Å, O···H—N 165 (3)°, (ii) $1 - x, -\frac{1}{2} + y, \frac{1}{2} - z$], whereas another takes part in only one hydrogen bond [N(8)—H(8)···O($11^{\rm iii}$): N···O 2.872 (3), H···O 1.96 (3) Å, O—H···N 172 (3)°, (iii) $1 - x, \frac{1}{2} + y, \frac{1}{2} - z$]. The fourth and weakest hydrogen bond links adjacent water molecules to each other [O(1*W*)—H(1*W*)···O(1*W*): O···O 2.945 (4), O···H 2.26 Å, O—H···O 117.6°, (iv) $-\frac{1}{2} + x, \frac{3}{2} - y, -z$].

Experimental

Crystal data

$C_6H_{10}N_4O_2.H_2O$
M_r = 188.20
Orthorhombic
$P2_12_12_1$
a = 5.5080 (10) Å
b = 10.828 (2) Å
c = 14.363 (3) Å
V = 856.6 (3) Å^3
Z = 4
D_x = 1.459 Mg m^{-3}

Mo $K\alpha$ radiation
λ = 0.71069 Å
Cell parameters from 24 reflections
θ = 11.5–12°
μ = 0.120 mm^{-1}
T = 153 (2) K
Needle
0.5 × 0.1 × 0.1 mm
Colourless

Data collection

Siemens *P*3/*PC* diffractometer
$\theta/2\theta$ scans
Absorption correction: none
1845 measured reflections
1751 independent reflections
1427 observed reflections [$I > 2\sigma(I)$]

$R_{\rm int}$ = 0.1347
$\theta_{\rm max}$ = 30.06°
$h = -7 \rightarrow 7$
$k = -2 \rightarrow 15$
$l = -4 \rightarrow 20$
2 standard reflections monitored every 98 reflections intensity variation: 1%

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)]$ = 0.0563
wR(all reflections) = 1.675
S = 1.087
1746 reflections
158 parameters
All H-atom parameters refined
$w = 1/[\sigma^2(F_o^2) + (0.1131P)^2 + 0.0965P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max}$ = 0.004
$\Delta\rho_{\rm max}$ = 0.606 e Å^{-3}
$\Delta\rho_{\rm min}$ = −0.260 e Å^{-3}

Extinction correction: none
Atomic scattering factors from *International Tables for Crystallography* (1992, Vol. C, Tables 4.2.6.8 and 6.1.1.4)
Absolute configuration: refinement according to Flack (1983) yielded inconclusive results due to the lack of strong enough anomalous scatterers

Table 1. *Fractional atomic coordinates and equivalent isotropic displacement parameters* (Å²)

$$U_{\rm eq} = (1/3)\Sigma_i\Sigma_jU_{ij}a_i^*a_j^*\mathbf{a}_i.\mathbf{a}_j.$$

	x	y	z	$U_{\rm eq}$
C(1)	0.1737 (4)	0.7740 (3)	0.22501 (14)	0.0260 (4)
N(2)	0.3005 (4)	0.6605 (2)	0.2426 (2)	0.0324 (5)
C(3)	0.2055 (4)	0.5950 (2)	0.3148 (2)	0.0245 (5)
N(4)	0.0195 (4)	0.6612 (2)	0.35282 (15)	0.0286 (4)
C(5)	−0.0284 (3)	0.7733 (3)	0.30110 (14)	0.0242 (4)
N(6)	0.0160 (4)	0.8859 (2)	0.3521 (2)	0.0293 (5)
C(7)	0.2074 (4)	0.9502 (2)	0.3173 (2)	0.0256 (5)
N(8)	0.3093 (4)	0.8848 (2)	0.24709 (15)	0.0305 (5)
C(9)	−0.1483 (5)	0.6094 (3)	0.4193 (2)	0.0311 (6)
C(10)	−0.1487 (5)	0.9343 (3)	0.4213 (2)	0.0319 (6)
O(11)	0.2733 (3)	0.4921 (2)	0.34124 (13)	0.0316 (4)
O(12)	0.2778 (3)	1.0523 (2)	0.34529 (14)	0.0334 (4)
O(1*W*)	0.2632 (8)	0.7981 (3)	0.0018 (2)	0.097 (2)

Table 2. *Selected geometric parameters* (Å, °)

C(1)—N(2)	1.435 (4)	N(4)—C(5)	1.448 (3)
C(1)—N(8)	1.449 (3)	C(5)—N(6)	1.443 (3)
C(1)—C(5)	1.560 (3)	N(6)—C(7)	1.359 (3)
N(2)—C(3)	1.362 (3)	N(6)—C(10)	1.445 (3)
C(3)—O(11)	1.235 (3)	C(7)—O(12)	1.238 (3)
C(3)—N(4)	1.364 (3)	C(7)—N(8)	1.355 (3)
N(4)—C(9)	1.442 (3)		
N(2)—C(1)—N(8)	114.8 (2)	N(6)—C(5)—N(4)	114.6 (2)
N(2)—C(1)—C(5)	102.7 (2)	N(6)—C(5)—C(1)	103.4 (2)
N(8)—C(1)—C(5)	102.6 (2)	N(4)—C(5)—C(1)	103.5 (2)
C(3)—N(2)—C(1)	113.1 (2)	C(7)—N(6)—C(5)	112.2 (2)
O(11)—C(3)—N(2)	126.0 (2)	C(7)—N(6)—C(10)	123.7 (2)
O(11)—C(3)—N(4)	125.3 (2)	C(5)—N(6)—C(10)	123.3 (2)
N(2)—C(3)—N(4)	108.6 (2)	O(12)—C(7)—N(8)	125.4 (2)
C(3)—N(4)—C(9)	122.8 (2)	O(12)—C(7)—N(6)	125.5 (2)
C(3)—N(4)—C(5)	111.9 (2)	N(8)—C(7)—N(6)	109.1 (2)
C(9)—N(4)—C(5)	123.3 (2)	C(7)—N(8)—C(1)	112.5 (2)

Refinement was on F^2 for all reflections except for three low-angle reflections flagged for potential systematic errors.

All H atoms were located in the difference Fourier map. However, the H atoms of the water molecule were included in the refinement only in the riding-model approximation. Symmetry equivalents were measured for only several hundred high-order and, therefore, weak reflections, which account for the high value of $R_{\rm int}$.

Program(s) used to solve structure: *SHELXTL-Plus* (Sheldrick, 1987). Program(s) used to refine structure: *SHELXL93* (Sheldrick, 1993).

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and complete geometry have been deposited with the IUCr (Reference: NA1080). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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Acta Cryst. (1994). C**50**, 2058–2060

Redetermination of the Structure of *N*-Carbamyl-D,L-aspartic Acid

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(*Received* 21 *December* 1993; *accepted* 13 *June* 1994)

Abstract

The structure of the free acid form of *N*-carbamyl-D,L-aspartate, $C_5H_8N_2O_5$, has been redetermined. There are substantial differences between the conformation of the free acid form and the deprotonated form of *N*-carbamyl-L-aspartate. Detailed comparison with the structure of L-dihydroorotate shows that cyclization of *N*-carbamyl-L-aspartate results in only two significant changes in bond lengths and does not cause substantial stress.

Comment

The enzyme dihydroorotase catalyses the conversion of *N*-carbamyl-L-aspartate to L-dihydroorotate, which is the third reaction of the *denovo* pathway for pyrimidine nucleotide biosynthesis (Christopherson & Jones, 1980). It has been shown that the active site of this enzyme contains a Zn atom (Christopherson & Jones, 1980) and we have been studying zinc complexes of natural substrates and inhibitors of dihydroorotase. Crystals of *N*-carbamyl-D,L-aspartic acid were obtained as a byproduct of an attempt to grow crystals of a zinc complex of *N*-carbamyl-D,L-aspartate. The structures of this acid form of *N*-carbamyl-D,L-aspartate (Jagannatha Rao, Krishna Murthy, Appaji Rao & Vijayan, 1982) and of the dicyclohexylammonium salt of *N*-carbamyl-

Acta Crystallographica Section C
ISSN 0108-2701 ©1994