Acta Crystallographica Section C
Crystal Structure Communications
ISSN 0108-2701

$R_4^4(30)$ rectangular rings in 2,5-dioxopiperazine-1,4-diacetic acid

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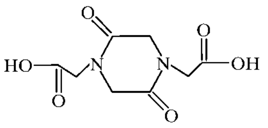
Received 15 July 2003
Accepted 11 August 2003
Online 23 September 2003

Molecules of the title 2,5-dioxopiperazinedione derivative, $C_8H_{10}N_2O_6$, occupy centres of symmetry in the crystal structure. The six-membered ring has an almost planar conformation, with the substituent on nitrogen nearly perpendicular to the ring. The ideal geometry of the isolated molecule, as determined by *ab initio* HF–LCAO quantum-mechanical calculations, is slightly more puckered than that observed in the solid state. In the crystal structure, a strong hydrogen bond joins neighbouring molecules, thus forming a network of rectangular $R_4^4(30)$ rings.

Comment

The condensation of amino acids or their esters leads to 2,5-piperazinediones, an important class of nitrogen-containing organic compounds. These cyclic compounds are found in nature as the result of protein degradation (Bray *et al.*, 1991; Steinberg & Lada, 1983) and are also described as antibiotics (Nakatsuka *et al.*, 1983), antitumorals (Arison & Beck, 1973) and models for protein studies (Benedetti *et al.*, 1976; Radding *et al.*, 1980). The dimerization of iminodiacetic acid or its esters leads naturally to *N*-substituted 2,5-piperazinediones, although the synthesis is generally a low-yield process (Jongkees, 1908; Dubsky & Granacher, 1917; Tapia-Benavides *et al.*, 1997). We have synthesized the title compound, (I), by the cyclization of iminodiacetic acid dimethyl ester in the presence of $NiCl_2$.



(I)

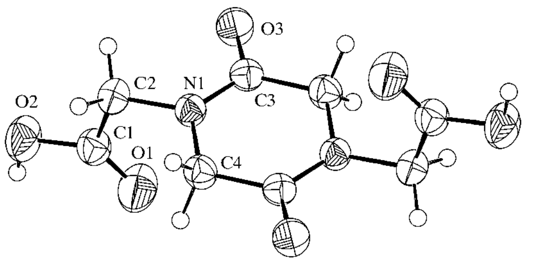


Figure 1
An *ORTEP*II plot (Johnson, 1976) of (I). Displacement ellipsoids are drawn at the 50% probability level.

The title *N*-substituted 2,5-piperazinedione molecule occupies a crystallographic centre of symmetry. The six-membered ring has an almost planar conformation (extremely flattened chair), with a weighted average torsion angle of 7.63 (12)° and puckering parameters (Cremer & Pople, 1975) Q, θ and φ of 0.067 (2) Å, 7.5 (2)° and 0°, respectively (Fig. 1 and Table 1). The ideal geometry of the isolated molecule as determined by an *ab initio* HF–LCAO (Hartree–Fock linear combination of atomic orbitals) quantum-mechanical calculation using the *GAMESS* program (Schmidt *et al.*, 1993) and a 631(d,p) basis set, shows a slightly more puckered conformation, with an average torsion angle within the ring of 13.09°. *N*,*N*′-Dimethyldiketopiperazine (Groth, 1969) exhibits a ring conformation close to that of (I), with a weighted average torsion angle of 6.9 (4)°; however, greater degrees of puckering have been found, for example, in 1,6-bis(methoxycarbonylmethyl)-2,5-piperazinedione, for which a weighted average torsion angle of 18.1 (2)° was reported (Tapia-Benavides *et al.*, 1997). Atoms O3 and C2 share the plane of the ring atoms, their deviations from the least-squares plane being 0.087 (4) and 0.086 (4) Å, respectively. The substituent on nitrogen is also planar and is almost perpendicular to the ring, the angle between the two least-squares planes being 89.55 (8)°. The C4—N1—C2—C1 and C3—N1—C2—C1 torsion angles are −84.4 (2) and 85.7 (3)°, respectively; the corresponding ideal values for the isolated molecule are −84.76 and 81.04°, and the corresponding torsion angles in 1,6-bis(methoxycarbonyl-

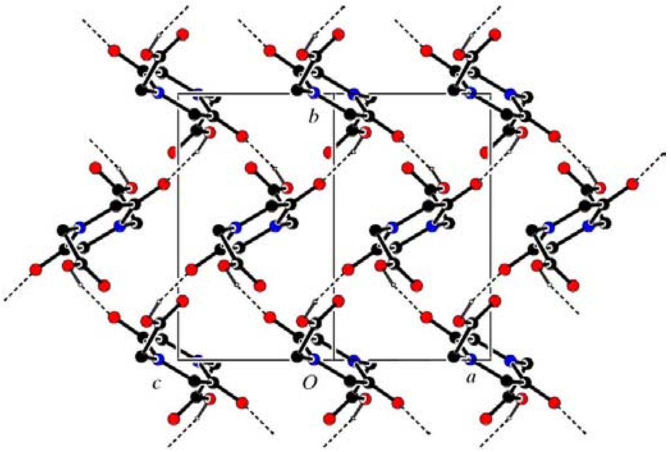


Figure 2
A view of the extended structure of (I), with hydrogen bonds shown as dashed lines. H atoms not participating in hydrogen bonding have been omitted for clarity.

DOI: 10.1107/S0108270103017803

methyl)-2,5-piperazinedione (Tapia-Benavides *et al.*, 1997) are −78.04 and 84.94°.

The large asymmetry in the two carboxy C—O distances [O1—C1 = 1.192 (3) Å and O2—C1 = 1.317 (3) Å] reflects the fact that the H atom is retained by the carboxy group. This H atom is involved in a strong O2—H2···O3($x - 1$, $-y - \frac{1}{2}$, $z - \frac{1}{2}$) hydrogen bond that links the molecules, with a donor–acceptor distance of 2.726 (3) Å and a *D*—H···*A* angle of 166 (3)° (Table 2). Using graph-set analysis (Bernstein *et al.*, 1995) to describe patterns in the hydrogen-bond network, we find rectangular-shaped $R_4^4(30)$ rings (Fig. 2).

Experimental

Iminodiacetic acid was mixed with $NiCl_2$ in a solution of ethanol and water and heated at 333 K overnight. The solution was left to cool and evaporate slowly at room temperature; after a few months, small single crystals had grown (with a slight green superficial tint caused by impurities). Prior to data collection, Laue photographs of the crystal were taken in order to appraise its quality.

Crystal data

$C_8H_{10}N_2O_6$
$M_r = 230.18$
Monoclinic, $P2_1/c$
$a = 5.5322$ (6) Å
$b = 9.1505$ (13) Å
$c = 9.8235$ (8) Å
$\beta = 108.189$ (7)°
$V = 472.44$ (9) Å^3
$Z = 2$

$D_x = 1.618$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 14 reflections
$\theta = 7.7$–13.6°
$\mu = 0.14$ mm^{-1}
$T = 293$ (2) K
Plate, colourless
0.27 × 0.23 × 0.09 mm

Data collection

Enraf–Nonius CAD-4 diffractometer
ω–2θ scans
2943 measured reflections
872 independent reflections
604 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.045$

$\theta_{\rm max} = 25.5°$
$h = -6 \rightarrow 6$
$k = -11 \rightarrow 11$
$l = -11 \rightarrow 11$
3 standard reflections
frequency: 180 min
intensity decay: 3%

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.042$
$wR(F^2) = 0.117$
$S = 1.05$
872 reflections
76 parameters
H atoms treated by a mixture of independent and constrained refinement

$w = 1/[\sigma^2(F_o^2) + (0.0482P)^2 + 0.2592P]$
where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.31$ e Å^{-3}
$\Delta\rho_{\rm min} = -0.26$ e Å^{-3}

The position of the carboxy H atom was determined from a difference Fourier map and refined freely, with the $U_{\rm iso}$ value constrained to $1.5U_{\rm eq}$(O). The remaining H atoms were constrained to an ideal geometry and were allowed for as riding on their parent atoms. Examination of the crystal structure with *PLATON* (Spek, 2003) showed that there are no solvent-accessible voids in the crystal lattice.

Data collection: *CAD*-4 *Software* (Enraf–Nonius, 1989); cell refinement: *CAD*-4 *Software*; data reduction: *HELENA* (Spek, 1997); program(s) used to solve structure: *SHELXS*97 (Sheldrick, 1997); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *ORTEP*II (Johnson, 1976); software used to prepare material for publication: *SHELXL*97.

Table 1
Selected geometric parameters (Å, °).

O1—C1	1.192 (3)	N1—C3	1.329 (3)
O2—C1	1.317 (3)	N1—C2	1.455 (3)
O3—C3	1.236 (3)		
C3—N1—C4	124.31 (18)	O1—C1—O2	124.1 (2)
C2—N1—C4	115.65 (17)	N1—C2—C1	110.26 (18)
C3—N1—C2—C1	85.7 (3)	C2—N1—C3—O3	4.8 (3)
O1—C1—C2—N1	−5.0 (4)	C4—N1—C3—O3	174.0 (2)
O2—C1—C2—N1	176.95 (19)		

Table 2
Hydrogen-bonding geometry (Å, °).

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
O2—H2···O3$^{\rm i}$	0.89 (4)	1.85 (4)	2.726 (3)	166 (3)

Symmetry code: (i) $x - 1, -\frac{1}{2} - y, z - \frac{1}{2}$.

Financial assistance from Fundação para a Ciência e a Tecnologia (Sapiens POCTI/QUI/42536) and Chymiotechnon, Portugal, is acknowledged.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: FA1026). Services for accessing these data are described at the back of the journal.

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