Crystal and Molecular Structure of Benzotriazol-2-ylacetic Acid: Comparison between Benzotriazol-1- and -2-yl Systems

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Crystals of benzotriazol-2-ylacetic acid are monoclinic, space group $P2_1/c$ with unit-cell parameters: a = 9.94(2), b = 8.48(2), c = 10.63(2) Å, β = 112.6(1)°, Z = 4. The structure was solved by direct methods and refined to R 0.044 for 727 observed reflections by block-diagonal least-squares. The molecules are linked in infinite chains parallel to b by a strong hydrogen bond, 2.70 Å in length. The planar 2-benzotriazole ring displays large π-electron delocalization and is compared with that in crystalline benzotriazol-1-ylacetic acid. Both systems are analysed in terms of valence-bond structures and their spectroscopic and chemical properties are correlated.

MOLECULES containing either the benzotriazol-1- or -2-yl ring are of increasing interest because of their biological and pharmacological properties.[1-3] Recently a correlation analysis according to Hansch's approach was carried out to ascertain relationships between physicochemical properties of the substituents on one side, and the metabolic activity of the corresponding compounds through the series of both benzotriazol-1- and -2-yl derivatives.[4]

In order to achieve a better knowledge of the two basic hetero-systems and to correlate on a structural basis systematic differences in properties between corresponding members of the two series, parallel X-ray investigations on the crystal and molecular structures of benzotriazol-1- and -2-ylacetic acids [(I) and (II)] were carried out. A short report of the first structure has already appeared.[5]

When this project was started, no accurate crystallographic data on the benzotriazol-2-yl ring was available. However, recently, while the work was in progress, the crystal structure of 2-(3′4′-di-O-acetyl-2′-deoxy-β-L-*erithro*-pentapyranosyl)-5,6-dimethylbenzotriazole (III) was published.[6]

EXPERIMENTAL

Structure Determination of Benzotriazol-2-ylacetic Acid (II).—Crystals of (II) from ethanol were colourless prisms elongated along b. A crystal of dimensions 0.10 × 0.12 × 0.6 mm was selected for three-dimensional data collection on a Siemens AED automatic diffractometer, by use of Mo-K_α radiation. Lattice constants were obtained by least-squares from the 2θ values of 12 reflections. Of *ca.* 1 000 independent reflections measured to $\sin\theta/\lambda$ 0.65 Å^{-1} by the θ–2θ scan technique, 727 having $I > 3\sigma(I)$ were considered observed. Intensities were corrected for Lorentz and polarization factors, but no absorption correction was applied.

Crystal Data.—$C_8H_7N_3O_2$, M = 177.2. Monoclinic, a = 9.94(2), b = 8.48(2), c = 10.63(2) Å, β = 112.6(1)°, U = 826 Å^3, D_m = 1.42 g cm^{-3}, Z = 4, D_c = 1.43 g cm^{-3}, $F(000)$ = 368. Mo-K_α radiation, λ = 0.7107 Å; μ(Mo-K_α) = 1.15 cm^{-1}. Space group $P2_1/c$.

Solution of the Structure.—The structure was solved by the multisolution method using the computer program MULTAN.[7] The 333 highest E values ($E > 1.0$) were used to produce eight solutions, the two with the best figures of merit being almost coincident. The three-dimensional E map, calculated from the best phase set, showed all non-hydrogen atom positions. Their positional and isotropic thermal parameters were refined by block-diagonal least-squares. At this stage a three-dimensional difference Fourier synthesis was calculated to obtain the positions of all hydrogen atoms. Further least-squares refinement of atomic parameters with anisotropic thermal factors for the non-hydrogen atoms and isotropic for the H atoms, con-

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[6] J. López de Lerma, F. Hernandez Cano, S. García-Blanco, and M. Martinez-Ripoll, *Acta Cryst.*, 1976, **B32**, 3019.

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verged to R 0.044 for observed reflections.* The weighting scheme $w = [5 + 2|F_o| + 0.1|F_o|^2]^{-1}$ was used. Atom scattering factors were taken from ref. 8 for non-hydrogen atoms and from ref. 9 for hydrogen. Final atomic parameters and their estimated standard deviations are listed in Table 1.

TABLE 1

(*a*) Atomic co-ordinates ($\times 10^4$) of non-hydrogen atoms with estimated standard deviations in parentheses

	x/a	y/b	z/c
N(1)	1 202(4)	3 141(5)	28(4)
N(2)	2 381(4)	2 364(4)	809(4)
N(3)	2 224(4)	1 270(4)	1 641(4)
C(4)	−59(5)	411(6)	1 903(5)
C(5)	−1 530(6)	712(7)	1 372(5)
C(6)	−2 154(4)	1 885(7)	371(5)
C(7)	−1 367(5)	2 776(6)	−162(5)
C(8)	141(4)	2 477(5)	368(4)
C(9)	786(4)	1 324(5)	1 386(4)
C(10)	3 800(5)	2 679(6)	730(5)
C(11)	4 668(5)	3 895(6)	1 790(5)
O(12)	5 875(3)	4 224(5)	1 631(3)
O(13)	4 313(4)	4 417(5)	2 662(4)

(*b*) Positional ($\times 10^3$) and thermal parameters ($\times 10$) of the hydrogen atoms with standard deviations in parentheses

	x/a	y/b	z/c	B(A^2)
H(C4)	41(5)	−46(6)	259(5)	26(12)
H(C5)	−208(6)	20(7)	172(6)	46(14)
H(C6)	−310(5)	207(6)	4(4)	22(10)
H(C7)	−195(5)	355(6)	−85(4)	20(10)
H(C10)	445(7)	162(8)	90(6)	57(16)
H′(C10)	367(5)	314(6)	−15(5)	26(11)
H(O12)	649(6)	492(6)	233(5)	25(12)

RESULTS AND DISCUSSION

Description of the Structure.—Figure 1 shows the intramolecular bond lengths and angles together with the atom numbering scheme of (II), and corresponding values for the isomeric molecule (I) are given for comparison in Figure 2. The values for the benzotriazol-2-yl residue are in fair agreement with those from the crystal structure of (III).[6]

Figure 3 shows the [010] projection of the crystal structure. The packing of the molecules is closer than in (I), in agreement with the higher melting point. The nine-membered heterocycle is essentially planar, although the slight bending about the C(8)–C(9) bond, indicated by the least-squares planes (Table 2), is significant on statistical grounds. The close van der Waals interactions between the pairs of antiparallel molecules across symmetry centres can account for this distortion. The distance between the benzotriazole planes of these pairs (3.4 Å) is typical of the packing of aromatic molecules.

The carboxy-group is nearly perpendicular to the benzotriazole plane [the angle between the planes is 84°; torsion angles N(3)–N(2)–C(10)–C(11) and N(2)–C(10)–C(11)–O(13) −87.6 and 6.8°].

An outstanding feature of the packing is a strong, nearly linear OH · · · N hydrogen bond which links the molecules in infinite chains parallel to *b*. The O–H bond is approximately directed along the sp^2 direction of the nitrogen N(3) of another screw-related molecule (O · · · N 2.70, H · · · N 1.75 Å; O–H · · · N 169°). The packing of (I), although very different, also shows a strong O–H · · · N hydrogen bond with similar geometry.

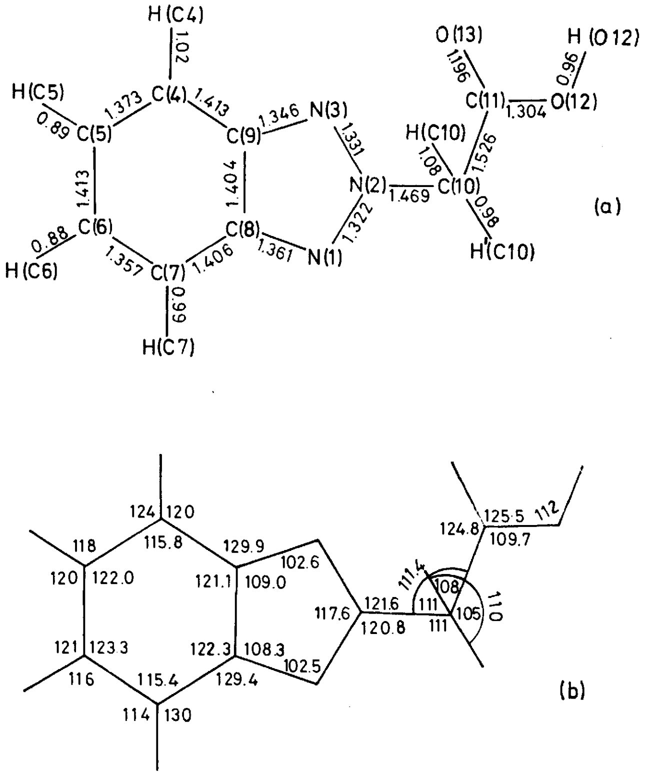

FIGURE 1 (a) Bond lengths (Å) and numbering scheme and (b) bond angles(°) for (II). Taking into account σ for cell parameters, the ranges for the estimated standard deviations are: 0.005—0.009 Å (mean 0.007) for bonds involving non-H atoms, 0.04—0.07 (mean 0.05) for bonds involving H atoms, 0.6—1.2° (mean 0.8) for angles involving non-H atoms, and 5—10 (mean 7) for angles involving H atoms

TABLE 2

Equations of least-squares best planes through the benzotriazole group with displacements (Å × 10^3) of relevant atoms given in square brackets

Plane (1): C(4)—(9)

$$-1.499x + 5.796y + 7.619z = 1.693$$

[N(1)–32, N(2)–64, N(3)–41, C(4) 4, C(5)–5, C(6) 5, C(7)–3, C(8) 2, C(9)–2, C(10)–15]

Plane (2): N(1)–(3), C(8), C(9)

$$-1.192x + 5.831y + 7.511z = 1.706$$

[N(1) 3, N(2)–3, N(3) 2, C(4)–30, C(5)–77, C(6)–71, C(7)–46, C(8)–2, C(9) 0, C(10)–48]

Plane (3): N(1)—(3), C(4)—(9)

$$-1.374x + 5.813y + 7.574z = 1.680$$

[N(1) 2, N(2)–20, N(3)–4, C(4) 9, C(5)–16, C(6)–7, C(7)–1, C(8) 19, C(9) 18, C(10)–91]

Angle between planes: (I)–(II) 1.8°

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* Observed and calculated structure factors and anisotropic thermal parameters are deposited in Supplementary Publication No. SUP 22160 (7 pp.)

[8] D. T. Cromer and J. B. Mann, *Acta Cryst.*, 1968, **A24**, 321.

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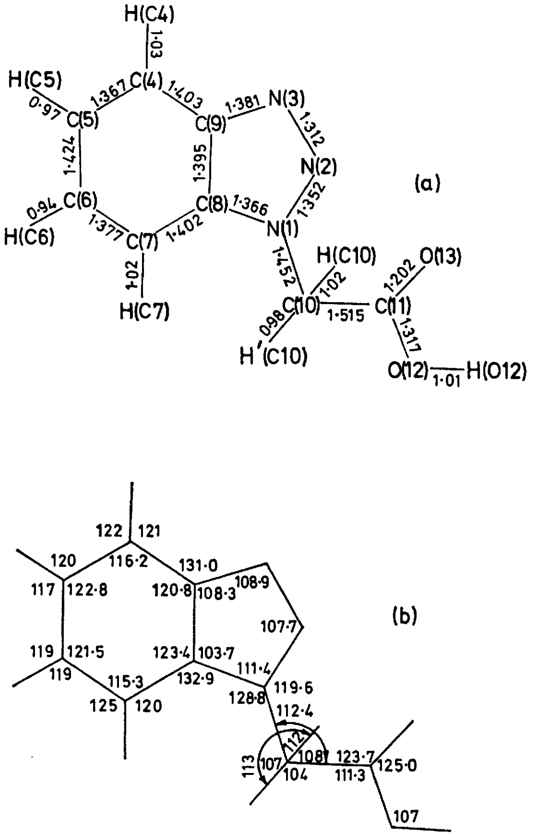

FIGURE 2 (a) Bond lengths (Å) and numbering scheme and (b) bond angles for (I)

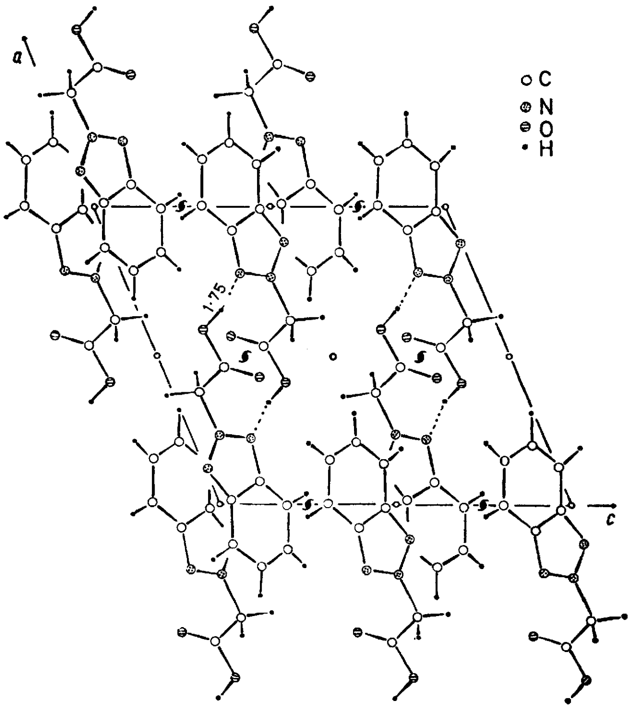

FIGURE 3 Projection of the structure of (II) along *b*

*Comparison of the Structures of the Benzotriazol-*1- *and* -2-*yl Residues.*—Crystallographic data for the two isomers (I) and (II), of comparable accuracy, have been analysed to account for some systematic similarities and differences in spectroscopic and chemical properties between the benzotriazol-1- and -2-yl derivatives.

Pauling's bond orders derived from bond lengths, using the curves given by Burke-Laing and Laing,[10] are shown in Figures 4 and 5, together with the estimated contributions of the most important resonance forms. The chemically equivalent bonds of (II) were averaged. For (I), the unreliably long C(5)–C(6) bond was excluded and the less-important forms involving formal charges on carbon atoms were neglected.

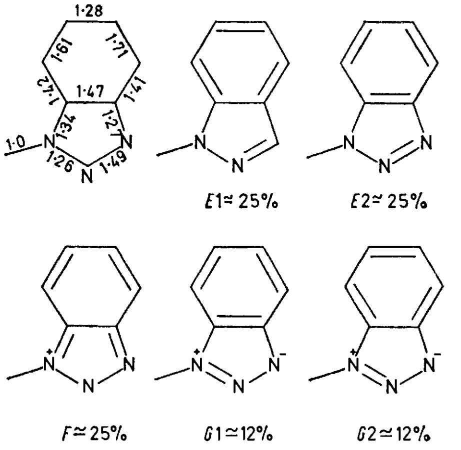

FIGURE 4 Bond orders and resonance forms with their % contributions for (I)

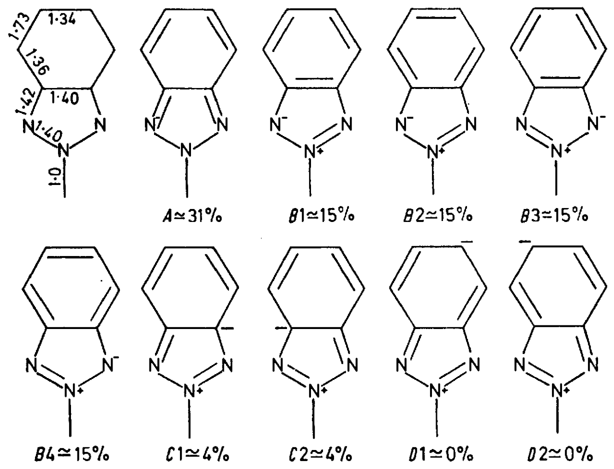

FIGURE 5 Bond orders and resonance forms with their % contributions for (II)

The patterns of bond distances for the two benzotriazolyl systems are somewhat similar and indicate a substantial π-electron delocalization which accords with the aromatic character of the compounds. In particular, the marked resemblance in the six-membered rings

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[10] M. Burke-Laing and M. Laing, *Acta Cryst.*, 1976, **B32**, 3216.

accounts for the common spectroscopic features such as the benzenoid band in the region 270—290 nm of u.v. spectra[11] and the n.m.r. coupling constants.[12] On the other hand, the bond orders within the benzenoid ring in both derivatives closely resemble those for naphthalene, in agreement with the similarity of the n.m.r. coupling constants[13] and chemical reactivity.

Larger differences occur in the two five-membered heterorings. Here bond orders indicate a greater π-electron delocalization and also enhanced aromatic character for the benzotriazol-2-yl residue.

In spite of this effect, benzotriazole has been found in the solid state,[14] in solution,[11] and in the vapour phase[15] in the 1*H*-tautomeric form. Furthermore, alkylation and acylation reactions on the benzotriazole generally give benzotriazol-1-yl derivatives as the main product.[16] These results can be understood on the basis of the distributions of the resonance forms of the hybrids shown in Figures 4 and 5. In fact, they show that the larger resonance effect in the 2-system is achieved through a greater overall contribution of higher-energy forms involving charge separation.

The resonance hybrids also show that in both the hetero-rings the pyridine nitrogens bear a negative charge which enhances their electron-donating character. In fact, the nitrogen in position 3 in the 1-system has been found to act as an excellent hydrogen-bond acceptor in various crystal structures,[5,14,17] as well as N(3) in (II).

The resonance theory predicts an enhanced stability for the benzotriazole-1,3-diyl cation in respect of the 1,2-one, and thereby, nicely accounts for the much greater basicity of the benzotriazol-1-yl derivatives[16] and the different reactivity of the two pyridine nitrogen atoms in the 1*H*-ring. Indeed, in the 1-derivatives, chemical[18] and spectroscopic[11] evidence shows that N(3) is the preferred point of attack from electrophilic reagents, while no strong hydrogen bond involving N(2) was observed in the solid state. Thus, some significance might be attached even to the slight difference in the hydrogen bond lengths in (I) and (II).

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