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Inclusion Properties of the New Host Compound 1,2,4,5-Tetra(morpholinocarbonyl)-benzene and X-Ray Crystal Structure of Its 1:4 Complex with Water

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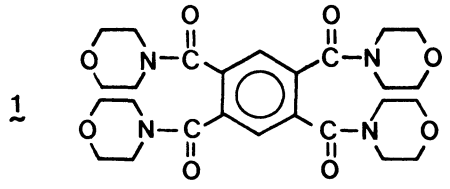
The title host compound has been prepared and found to form inclusion complexes with water and a variety of alcohols. In its 1:4 crystalline complex with water, the host molecule occupies a centrosymmetric site, each non-adjacent pair of carbonyl oxygen atoms being bridged by two end-to-end hydrogen-bonded water molecules. The water molecules are further interconnected by hydrogen bonds to form two-fold screw spirals parallel to the *b* axis, giving rise to a layer structure.

Recently we have been involved in the molecular design of suitable amide host systems for selective complexation of a wide variety of organic guest species, and concomitant investigation of the relationship between structure and inclusion behavior.[1-6] We now report the preparation of the title host compound (1) and its inclusion complexes with water and various alcohols.



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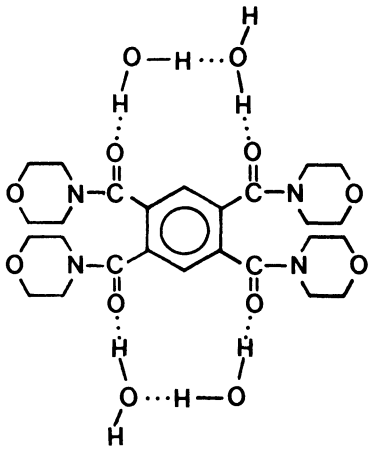

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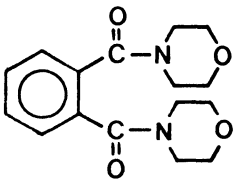

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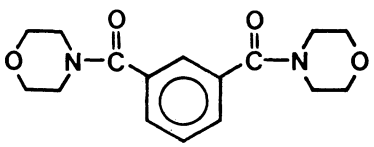

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The reaction of benzene-1,2,4,5-tetracarboxylic acid with phosphorus pentachloride yielded the tetrachloro derivative, which was treated with morpholine in benzene to give 1 in almost quantitative yield: mp 316 °C (decomp.); IR (Nujol mull) 1630 cm^{-1} (CO). Compound 1 is much more soluble in water than in common organic solvents except chloroform. When an aqueous solution of 1 is slowly evaporated at room temperature, a 1:4 complex (2) of 1 with water is obtained as colorless prisms: mp not clear; IR (Nujol mull) 3485, 3420, and 3225 cm^{-1} (OH), 1620 cm^{-1} (CO); ^{1}H NMR ($CDCl_3$, δ) 1.73 (s, H_2O, 8H), 3.00-3.97 (m, CH_2, 32H), and 7.20 (s, Ar, 2H). Anal. for 2. Found: C, 52.09; H, 7.11; N, 9.34%. Calcd for $C_{26}H_{42}N_4O_{12}$: C, 51.82; H, 7.02; N, 9.30%. The stoichiometry of 2 was also established by TG analysis; DSC measurement yielded a dissociation enthalpy of 185.3 kJ mol^{-1} at 98 °C.

When methanol (1:2), ethylene glycol (1:2), 1,4-butanediol (1:1), propargyl alcohol (1:2), and allyl alcohol (1:1) were each added to a chloroform solution of 1, crystalline complexes of 1 with the corresponding alcohols (combining ratio given in parentheses) were obtained. On the other hand, 1 by itself is almost insoluble in these alcohols, and furthermore does not form inclusion complexes with ethanol, *n*-propanol and *n*-butanol.

Since neither 1,2- (3) nor 1,3-di(morpholinocarbonyl)benzene (4) forms analogous crystalline adducts with alcohols and water, the inclusion ability of 1 is probably due to its higher molecular symmetry arising from substitution at the 1,2,4,5-positions. In order to acertain the correctness of this hypothesis, we have carried out an X-ray analysis of the crystal structure of 2.

Crystal data of $C_{26}H_{34}N_4O_8.4H_2O$ (2) are as follows: FW = 602.63, monoclinic, space group $P2_1/c$, a = 12.590(3), b = 7.802(1), c = 15.542(5) Å, β = 101.86(2)°, v = 1494.1(7) Å^3, z = 2, D_c = 1.340, D_m = 1.336 g cm^{-3} (flotation in *n*-hexane/CCl_4), MoKα radiation (monochromatized), λ = 0.71069 Å, μ = 0.99 cm^{-1}, F(000) = 644.

A selected crystal of size 0.44 x 0.40 x 0.32 mm^3 was used, and intensity data were collected on a Nicolet R3m diffractometer ($2\theta_{max}$ = 52°, 2473 unique reflections) as described previously.[7] Absorption corrections were applied by fitting a pseudo-ellipsoid to the azimuthal scan data of 18 strong reflections over a range of 2θ-values.[8]

The structure was solved by direct phasing guided by negative quartets.[9] All 21 non-hydrogen atoms in the asymmetric unit (Fig. 1) were subjected to anisotropic refinement. The aromatic and methyl H atoms were generated geometrically and allowed to ride on their respective parent C atoms; the water protons were located from a difference map. All H atoms were included in structure factor calculations with assigned isotropic thermal parameters. Convergence for 2176 observed data [$|F_o| > 3\sigma(|F_o|)$] and 190 variables was reached at R_F = 0.058.[10] All computations were performed on a Data General Nova 3/12 minicomputer with the SHELXTL package,[11] the weighting function employed being $w = [\sigma^2(|F_o|) + 0.0008|F_o|^2]^{-1}$.

In the crystal structure of tetrahydrate 2, molecule 1 occupies a center of symmetry. To lessen intramolecular overcrowding, the morpholinocarbonyl groups are inclined to the central aromatic ring [torsion angles are C1-C2-C9-O3 =

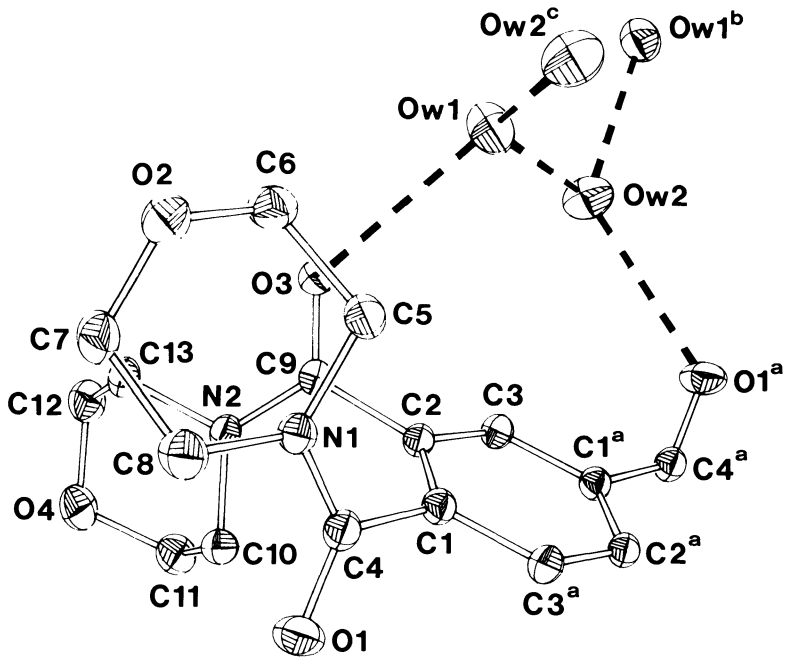

Fig. 1. Host-guest interaction and atom labelling, with the O-H...O hydrogen bonds represented by broken lines. Thermal ellipsoids are drawn at the 30% probability level. Symmetry transformations: $-x, 1-y, -z$; [b] $-x, -\frac{1}{2}+y, \frac{1}{2}-z$; [c] $-x, \frac{1}{2}+y, \frac{1}{2}-z$. Bond lengths (Å, standard deviations in parentheses): C1-C2 1.406(3), C2-C3 1.387(3), C1-C3[a] 1.390(3), C1-C4 1.512(3), C4-O1 1.234(3), C4-N1 1.347(3), N1-C5 1.457(3), C5-C6 1.513(3), C6-O2 1.427(3), O2-C7 1.415(3), C7-C8 1.493(3), C8-N1 1.466(3), C2-C9 1.338(3), C9-O3 1.233(3), C9-N2 1.338(3), N2-C10 1.470(3), C10-C11 1.518(4), C11-O4 1.433(3), O4-C12 1.429(3), C12-C13 1.499(4), C13-N2 1.461(3); Ow1...O3 2.816(5), Ow2...O1[a] 2.866(5), Ow1...Ow2 2.746(5), Ow1...Ow2[c] 2.774(5).

106.1(2)° and C2-C1-C4-O1 = 111.4(2)°], such that a pair of adjacent amides are oriented *anti* with respect to each other (see Fig. 1). The sums of the bond angles at N1 and N2 are 357.5° and 359.9°, respectively; these values, together with the short N-C(amide) and C(aromatic)-C(amide) bond lengths (Fig. 1), indicate that electron delocalization in each amide group is restricted to the N-C=O fragment.

The two independent water molecules are joined by an Ow2-H...Ow1 hydrogen bond, and together they bridge two non-adjacent *syn* morpholinocarbonyl groups by forming donor hydrogen bonds to the respective amido O atoms (Fig. 1). The occurrence of 'dimeric water bridges' results in a molecular aggregate which faithfully reflect the stoichiometric formula of 2.

As illustrated in Fig. 2, water molecules belonging to neighboring molecular aggregates are further interlinked by hydrogen bonds to form helical chains about the 2_1 axes in the unit cell, generating a crystal structure of the layer type.

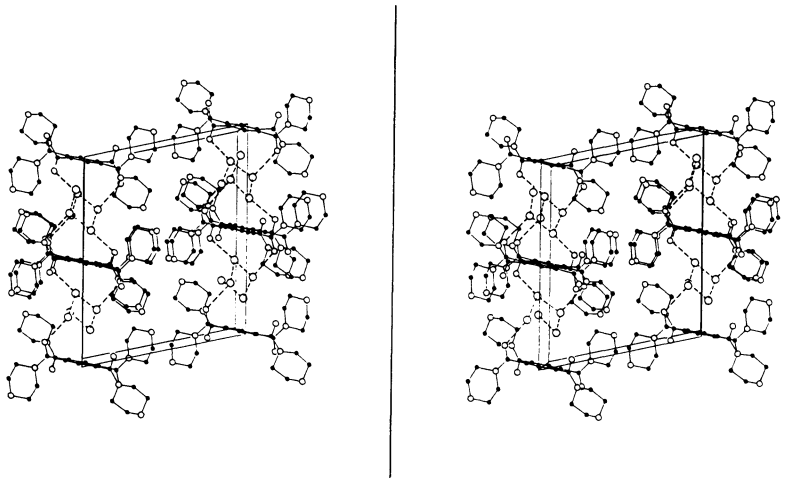

Fig. 2. Stereodrawing of the crystal structure of 2. The origin of the unit cell lies at the upper left corner, with *a* pointing from left to right, *b* towards the reader, and *c* downwards. Broken lines represent O-H...O hydrogen bonds.

Hydrogen bonding interactions occur in the neighborhood of the (100) family of planes, and the (200) plane, across which the morpholino groups are in van der Waals contact, corresponds to the boundary of adjacent layers.

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References

1) F. Toda, K. Tanaka, Y. Tagami, and T.C.W. Mak, Chem. Lett., 1985, 195.
2) F. Toda, M. Khan, and T.C.W. Mak, Chem. Lett., 1985, 1867.
3) F. Toda, Y. Tagami, and T.C.W. Mak, Chem. Lett., 1986, 113.
4) F. Toda, Y. Tagami, and T.C.W. Mak, Bull. Chem. Soc. Jpn., 59, 1189 (1986).
5) F. Toda, Y. Tagami, and T.C.W. Mak, Chem. Lett., 1986, 1909.
6) F. Toda, Y. Tagami, Q. Hao, H. Fan, and T.C.W. Mak, Chem. Lett., 1986, 1913.
7) F. Toda, K. Tanaka, and T.C.W. Mak, Bull. Chem. Soc. Jpn., 58, 2221 (1985).
8) G. Kopfmann and R. Huber, Acta Crystallogr., Sect. A, 24, 348 (1968); A.C.T. North, D.C. Phillips, and F.S. Mathews, Acta Crystallogr., Sect. A, 24, 351 (1968).
9) G.T. DeTitta, J.W. Edmonds, D.A. Langs, and H. Hauptman, Acta Crystallogr., Sect. A, 31, 472 (1975).
10) The atomic co-ordinates have been deposited with the Cambridge Crystallographic Data Centre. Structure factors are obtainable on request from the last author.
11) G.M. Sheldrick, "Computational Crystallography," ed by D. Sayre, Oxford University Press, New York (1982), p. 506.

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