

A Supramolecular Analogue of Cyclohexane Sustained by Aromatic C–H··· π Interactions: Complexes of 1,3,5-Trihydroxybenzene with Substituted Pyridines

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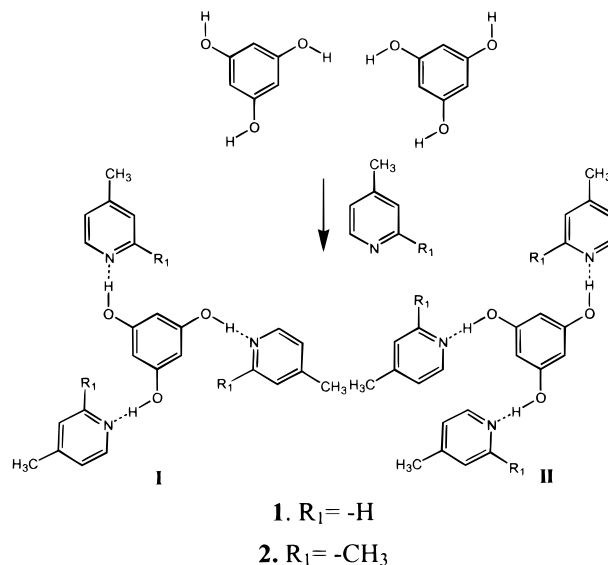
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The relatively recent emergence of crystal engineering can be attributed to both aesthetic and utilitarian considerations.^{1,2} Prototypical targets are exemplified by 2D honeycomb³ and 3D diamondoid⁴ networks sustained by strong or multiple hydrogen bonds. Furthermore, the same principles have also been used to assemble high-symmetry 0D aggregates.⁵ However, it is generally recognized that, in appropriate circumstances, even weak non-covalent bonds can sustain supramolecular synthons¹ which are structure determining. For example, it was recently reported that an organometallic cluster can be held with C–H···O hydrogen bonds in a honeycomb network formed by O–H···O hydrogen bonds.⁶ We report herein two crystal structures for which the networking is sustained by clusters of molecules which are the result of aromatic–aromatic interactions. In one of these structures, the geometry of the cluster can be regarded as being a novel supramolecular analogue of cyclohexane in which C–H··· π interactions⁷ serve the same structural function as C–C bonds.

In the absence of strong hydrogen-bond donors and acceptors, aromatic compounds tend to self-assemble via π – π (face-face) interactions, C–H··· π interactions (T-shape geometry, edge–face or herringbone interactions), or with both.^{8,9} A study of the Cambridge Structural Database¹⁰ suggested that 1,3,5-trihydroxybenzene (phloroglucinol, THB) would probably form either of two O–H···N hydrogen-bonded supramolecular isomers,¹¹ I or II, when reacted with pyridine derivatives in a 1:3 ratio.

Cocrystals of THB with 4-methylpyridine, **1**, and 2,4-dimethylpyridine, **2**, were obtained by crystallization of THB from liquid base. Both compounds were observed to lose solvent at room temperature if removed from their mother liquor. The crystal



structure of **1**¹² reveals the presence of supramolecular isomer I. The three O–H···N hydrogen bonds are crystallographically equivalent (O–H···N, 1.86(5) and 2.741(5) Å and 173(4)°) since the aggregate lies on a crystallographic 3-fold axis. The asymmetric unit therefore contains one-third of a THB molecule and one molecule of 4-methylpyridine. The C₅N rings of the 4-methylpyridine molecules subtend angles of 53.9° with the C₆ ring of THB. These aggregates cluster via aromatic C–H··· π interactions to form a honeycomb grid (Figure 1) sustained by hexamers of 4-methylpyridine molecules. To our knowledge such a cluster of aromatic molecules is unprecedented even though it could reasonably occur for other aromatics, including hydrocarbons. The cavity of the cyclic hexamer is occupied by the 4-Me groups and the hexamer adopts a chair geometry that can be reasonably described as a supramolecular analogue of cyclohexane that is sustained by aromatic C–H··· π interactions (Figure 2). The distance between the centroid of the C₅N ring of 4-methylpyridine and the nearest C-atom of the THB is 3.85 Å (H-centroid 2.920 Å; C–H···centroid 163.7°), and the interplanar angle is 88.7°. We note that these values are very close to those in the crystal structure of benzene, 3.783 Å and 85.2°, respectively.¹³ Adjacent layers are slightly slipped so that the aromatic rings of the supramolecular cyclohexane moiety interact with the THB C₆-ring in an edge-to-face manner. One might compare the cluster formed here with the sextuple phenyl embrace of PPH₃

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(10) There are only five crystal structures containing THB in the Cambridge Structural Database (CSD, Allen, F. H.; Davies, J. E.; Galloy, J. J.; Johnson, O.; Kennard, O.; Macrae, C. F.; Watson, D. G. *J. Chem. Inf. Comput. Sci.* **1991**, *31*, 187). Two structures have conformation I, one has conformation II and in the remaining two structures H-atoms were not determined. The CSD also revealed 29 compounds with O–H···N hydrogen bonds between phenolic OH groups and pyridine nitrogen atoms.

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(12) Crystal data for **1**: [C₆H₃(OH)₃][3[4-CH₃-C₅H₄N]], trigonal, *R*-3, *a* = 15.609(2), *b* = 15.609(2), and *c* = 15.734(2) Å, *V* = 3319.8(6) Å³, *Z* = 6, *D_c* = 1.217 Mg/m³, 950 reflections out of 1244 with *I* > 2 σ (*I*) were measured on a Siemens SMART/CCD diffractometer, final *R*-factors *R*₁ = 0.0684, *wR*₂ = 0.1269. Non-hydrogen atoms were refined anisotropically. Hydrogen atoms of C–H groups were located and refined using a riding model whereas H-atoms of hydroxy groups were located and refined isotropically. Crystal data for **2**: [C₆H₃(OH)₃][3[2,6-(CH₃)₂-C₅H₃N]], monoclinic, *P*2₁/*c*, *a* = 8.6573(6), *b* = 23.408(2), and *c* = 12.6645(8) Å, β = 102.805(1)°; *V* = 2502.6(3) Å³, *Z* = 4, *D_c* = 1.188 Mg/m³, 3254 reflections out of 5716 with *I* > 2 σ (*I*) were measured on a Siemens SMART/CCD diffractometer, final *R*-factors *R*₁ = 0.0778, *wR*₂ = 0.1534. All non-hydrogen atoms were refined anisotropically. Hydrogen atoms of C–H groups were located and refined using a riding model whereas H-atoms of hydroxy groups were located and refined isotropically.

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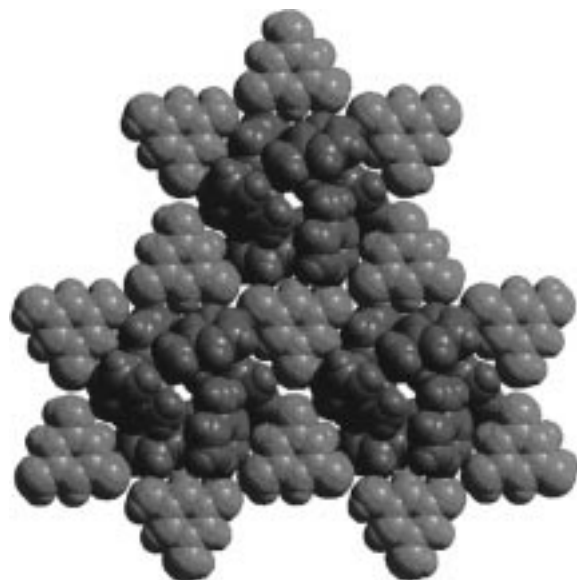


Figure 1. A space-filling representation of the honeycomb network in the crystal structure of **1**. THB molecules are magenta whereas 4-methylpyridine molecules are green. There are no interactions between THB molecules and other THB molecules.

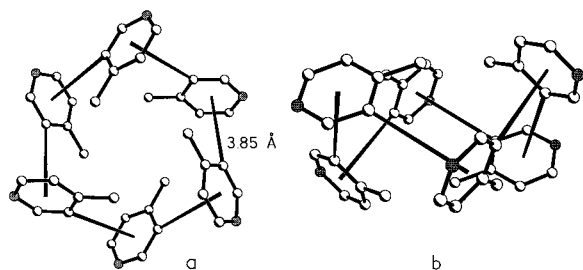


Figure 2. (a) The cluster of aromatic interactions between 4-methylpyridine molecules (top view). (b) The chair conformation of the supramolecular cyclohexane formed by 4-methylpyridine molecules in **1**.

groups.¹⁴ However, the latter is formed by the association of only two species. Transformation of molecular symmetry to crystal symmetry is not a trivial exercise except for inversion centers.¹⁵ It should therefore be unsurprising that, although THB adopts conformation I in its crystal structure, molecular symmetry is not transformed into crystal symmetry.¹⁶

The crystal structure of **2**¹² reveals the presence of supramolecular isomer II. There are three independent O—H···N hydrogen bonds (O—H···N, 1.90(4) and 2.746(3) Å and 178°(4) with ring A; 1.85(5) and 2.740(3) and 162°(3) with ring B; 1.88(4) and 2.728(4) Å and 162°(3) with ring C) and the C₅N rings of A, B, and C subtend angles of 83.0°, 68.0°, and 61.7°, respectively, with the C₆ ring of THB (Figure 3). Within the aggregate two 2,4-dimethylpyridine molecules (A and B) interact via face-to-face interactions, centroid—centroid distance and plane-plane angle being 4.220 Å and 18.6°, respectively. These aggregates self-assemble and also form hexamers of 2,4-dimethylpyridine; however, they are linear aggregates sustained via face-to-face aromatic interactions (Figure 4). The hexamers generate

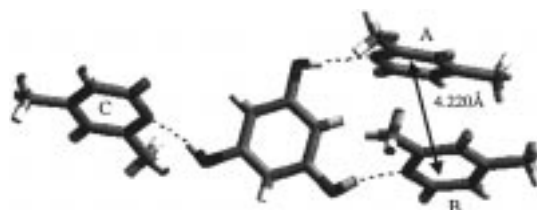


Figure 3. The O—H···N hydrogen-bonded supramolecular isomer II as seen in the crystal structure of **2**. Note the face—face interactions between two 2,4-dimethylpyridine molecules (A and B).

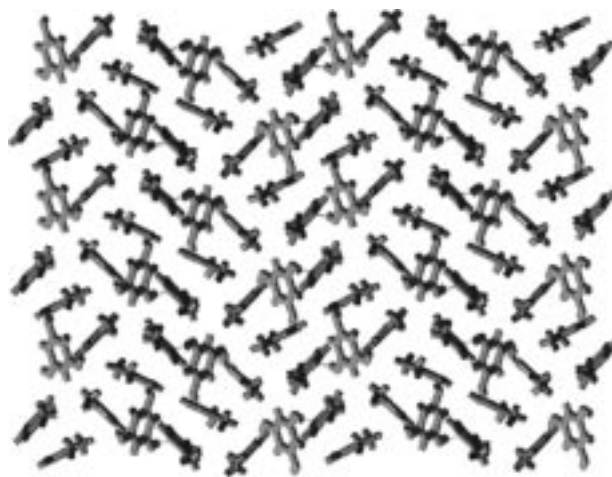


Figure 4. The two-dimensional herringbone layer in the crystal structure of **2**. THB molecules are magenta whereas 2,4-dimethylpyridine molecules are green. The 2,4-dimethylpyridine molecules form hexamers.

a layer by herringbone stacking. A related phenomenon in which face-to-face tetramers of phenyl rings stack with dimers of phenyl rings was observed in *N,N,N'*-triphenyl-1,3,5-benzenetriamine.¹⁷ THB also adopts conformation II in the crystal structures of its cocrystals with 4,4'-bipyridine and *p*-benzoquinone.¹⁸ However, these cocrystals did not generate hexamers.

In conclusion, the crystal structures of **1** and **2** clearly demonstrate how aromatic—aromatic interactions are able to critically influence structure within and between supermolecules. In **1** and **2**, the role of stronger O—H···N hydrogen bonds appears to be relegated to formation of discrete 1:3 supramolecular aggregates. The relevance of our observations should extend beyond supramolecular chemistry since it might be anticipated that the structures of **1** and **2** will aid in prediction of crystal structures of their covalent analogues, e.g., 1,3,5-tris(4-methylphenoxy)benzene and 1,3,5-tris(2,4-dimethylphenoxy)benzene, respectively. However, the problem of controlling which supramolecular aggregate forms remains an elusive goal.

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Supporting Information Available: Tables of crystal structure refinement data, positional parameters, and bond lengths and angles (11 pages, print/PDF). See any current masthead page for ordering information and Web access instructions.

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