Creation of crystalline supramolecular arrays: a comparison of co-crystal formation from solution and by solid-state grinding

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The importance of appropriate chemical substitution in generating co-crystals of some dinitrobenzoic acids and anthracene from solution and by solid-state grinding is discussed.

The design of supramolecular assemblies using identifiable and specific intermolecular interactions has evolved as a powerful tool for the synthesis of new materials.[1-3] Hydrogen bonds (such as O–H⋯O, N–H⋯O and C–H⋯O *etc.*) are often used to form the assemblies[4-6] although it is clear that weaker non-hydrogen bond interactions may also be equally useful.[7] When applied to the development of three dimensional arrangements in crystals such design is frequently referred to as 'crystal engineering'.[8,9]

Supramolecular structures based upon co-crystal formation are generally created from a solution of two or more components with each component chosen so as to possess appropriate functional groups capable of forming the desired packing motif.[1-9] In certain cases, however, simple grinding of the component crystals together has also been used to generate (co-crystal) supramolecular structures.[10-13] In this communication we discuss the importance of appropriate functional groups in controlling co-crystal formation in the solid state as well as the role of solvent inclusion in stabilising desired supramolecular structures in the absence of appropriate functionality. We consider whether the inability of two crystalline phases to react is connected to the stability of the initial phases or perhaps related to an inability to generate suitable co-crystal arrangements.

When a mixture of 4-chloro-3,5-dinitrobenzoic acid **1** and anthracene **2** or of 3,5-dinitro-4-methylbenzoic acid **3** and **2** are ground together in a mortar and pestle a distinct change in the powder X-ray diffraction pattern occurs, see Fig. 1 in the case of **1** + **2**. The powder patterns of the original components [Fig. 1(*a*), (*b*)] before grinding are readily interpreted on the basis of the known crystal structures of **1** and **2**.[14] After grinding at room temperature for 30 min (using a mortar and pestle) significant changes in the PXRD pattern occur, as shown in Fig. 1(*c*). Reflections associated with both **1** and **2** decrease in intensity and new reflections appear. Similar observations are made for **3** + **2**. When a mixture of 3,5-dinitrobenzoic acid **4** and **2** is ground together, however, the original PXRD pattern, which is in agreement with the known structures of **4** and **2** [Fig. 1(*d*), (*b*)], remains unchanged even after prolonged grinding [Fig. 1(*e*)].

For **1** + **2** as well as **3** + **2** suitable crystals for single-crystal X-ray analysis were readily obtained from a variety of different solvents, with single-crystal structure analysis indicating the formation of 2:1 co-crystals.†‡ The use of the determined atomic fractional coordinates then allowed the corresponding powder X-ray pattern for the co-crystals to be simulated [Fig. 1(*f*) shows the simulated powder pattern for crystals of **1₂2** from methanol]. Comparison of the simulated pattern and the actual pattern obtained after grinding [Fig. 1(*c*)] confirms that the structures generated by grinding and from solution are identical. Comparable conclusions can be drawn for **3** + **2**. In the case of **4** + **2**, however, repeated attempts at growing co-crystals from

solution failed until benzene was used as the solvent of crystallisation. The crystals which emerged from this solvent were studied by single-crystal techniques. Structure solution§ revealed that they contained three components; **4**, **2** and benzene.¶

Fig. 2 illustrates the packing diagrams for the various co-crystals obtained from solution and highlights the similarities between them. In the three structures, an important feature appears to be the interaction of the anthracene guest, through C–H⋯O hydrogen bonds, with the surrounding molecules. The diagrams reveal that pairs of acid molecules are linked by O–H⋯O hydrogen bonds in each structure to yield cyclic hydrogen-bonded pairs and that six-membered hexagonal networks are then completed in the case of **1₂2** through Cl⋯O and O⋯O interactions and for **3₂2** *via* C–H⋯O hydrogen bonds and O⋯O interactions.

For the complex of **4** + **2**, the hexagonal network is completed by C–H⋯O hydrogen bonding between the acid and the incorporated benzene. Because of the absence of appropriate *para*-substitution of the acid this network cannot be stabilised without solvent incorporation. Co-crystal formation by grinding is therefore not possible. We conclude that mixtures of **2** and **4** fail to react upon grinding because of an inability to create the desired stable hexagonal network rather than because of any particular stability of the reactant lattices. The conclusions point to the need to consider carefully the substitution pattern in
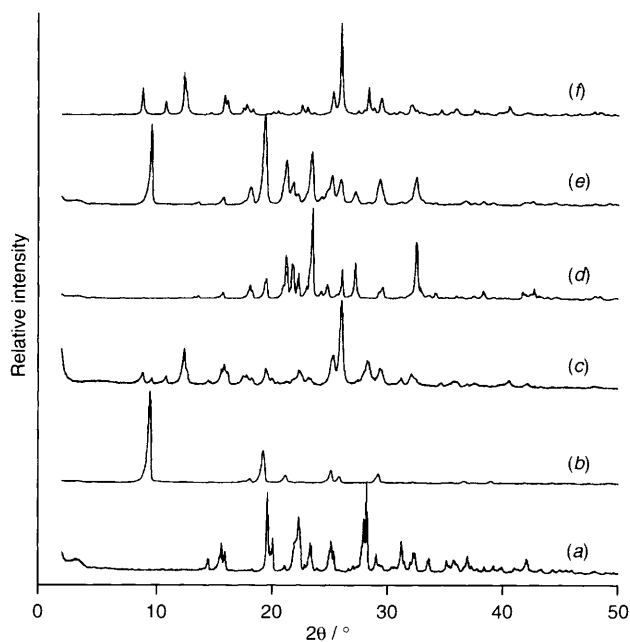

Fig. 1 Powder X-ray diffraction patterns of (*a*) 4-chloro-3,5-dinitrobenzoic acid **1**, (*b*) anthracene **2**, (*c*) ground mixture of **1** + **2**, (*d*) 3,5-dinitrobenzoic acid **4**, (*e*) ground mixture of **4** + **2**, (*f*) simulated pattern from the single-crystal structure of **1₂2** [compare with (*c*)]
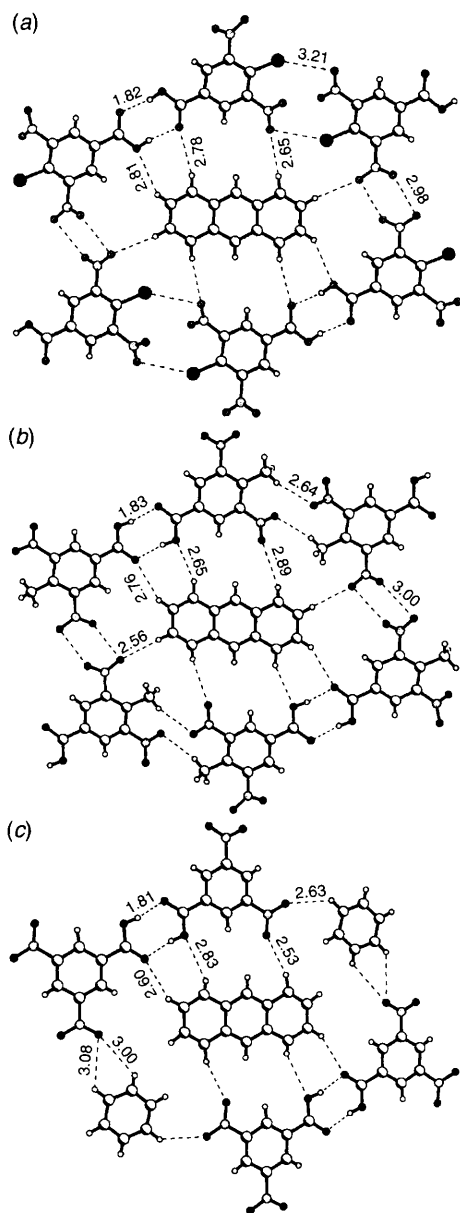
¶ The importance of benzene in stabilising the co-crystal is demonstrated by heating of the complex. At approximately 100 °C the benzene is lost and the solid product is shown (by PXRD) to be identical to the physical mixture of the two components, *i.e.* there is no evidence for co-crystal formation in the absence of benzene and the structure determining role of benzene for **4** + **2** is confirmed.

Fig. 2 Hexagonal arrangement of molecules of acids **1**, **3** and **4** around anthracene, **2** in the crystal structures of molecular complexes (*a*) $1_2\mathbf{2}$, (*b*) $3_2\mathbf{2}$ and (*c*) $4_2\mathbf{2}\cdot\text{C}_6\text{H}_6$. Dashed lines represent hydrogen bonds. The H···O distances are shown for the unique hydrogen bonds. Compare (*a*) and (*b*) with (*c*) to appreciate the importance of appropriate substitution at *para*-position to generate the surrounding hexagonal network.

molecules when trying to generate co-crystals by solid-state grinding.

Footnotes

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