Supramolecular synthons in crystal engineering. Structure simplification, synthon robustness and supramolecular retrosynthesis

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The analogy between crystal engineering and traditional organic synthesis is outlined with reference to a family of crystal structures which incorporate iodo···nitro and carboxyl dimer supramolecular synthons.

Crystal engineering, or the understanding of intermolecular interactions in the context of designing new solids with desired physical and chemical properties is concerned with the systematic architecture of crystal structures.[1] Noting that crystals may be accurately considered as the supramolecular equivalents of molecules,[2,3] then we may think of crystal engineering as a supramolecular equivalent of organic synthesis[4] among other forms of supramolecular synthesis.[5,6] In particular, it is possible to define a supramolecular synthon as *a structural unit within a supermolecule which can be formed and/or assembled by known or conceivable synthetic operations involving intermolecular interactions,*[4] by analogy with Corey's definition of a synthon in traditional organic synthesis.[7] Thus a supramolecular synthon is a spatial arrangement of intermolecular interactions and plays the same focussing role in supramolecular synthesis that a conventional synthon does in molecular synthesis. In this communication, we report the crystal structures of 4-iodonitrobenzene, **1**, and the 1:2 complex, **2**, of 1,4-dinitrobenzene and 4-iodocinnamic acid. These structures along with that of the 1:1 complex, **3**, of 1,4-dinitrobenzene and 1,4-diiodobenzene, reported previously,[8] illustrate the utility of the supramolecular synthon concept in developing strategies for systematic and general crystal engineering.

Targets in molecular synthesis are usually defined in terms of covalent bond connectivity. Similarly, targets in crystal engineering are best defined in terms of the topological characteristics and geometrical connectedness of non-bonded interactions. The target in the present work is a linear ribbon (Scheme 1) and we wished to explore the possibility of constructing such a ribbon based on the iodo···nitro synthon **4**,

formed from two convergent, polarisation-induced I···O interactions, which have been described by us previously.[9] If one alternates synthon **4** with phenyl rings, compound **1** suggests itself retrosynthetically as a molecule which has few other crystallisation options. The crystal structure of **1**† is shown in Fig. 1 and it may be observed that the desired ribbon pattern is obtained. The strategy may be extended to the crystal structure of complex **3** (Scheme 1) where again synthon **4** alternates, but in opposite senses, with the phenyl rings.

We note that *all* organic crystal structures may be considered to be networks with the supramolecular synthons acting as connections between nodes (molecules) in the network structure. Therefore, the dissection of a crystal structure into supramolecular synthons enables a certain structural simplification which is essential in the planning of a synthetic strategy towards a new or modified target network. In particular, it is possible that the linear ribbon networks in compounds **1** and **3** may be extended by spacer groups to generate structures such as are shown in Scheme 2, wherein the spacers do not perturb the iodo···nitro synthons, **4**. A possible spacer is a phenyl ring and a possible target crystal structure is that of the 1:1 complex, **5**, between 4,4″-diiodo-*p*-terphenyl and 1,4-dinitrobenzene. However, the effect of a phenyl spacer may be achieved more easily by using the carboxyl dimer synthon, **6**, as a surrogate for the phenyl ring. This strategy derives from the close similarity between the crystal structures of benzoic acid and *p*-terphenyl which arises because the carboxyl dimer ring in the benzoic acid crystal structure is the supramolecular equivalent of the central phenyl ring in the *p*-terphenyl molecular structure.[4,10] Accord-
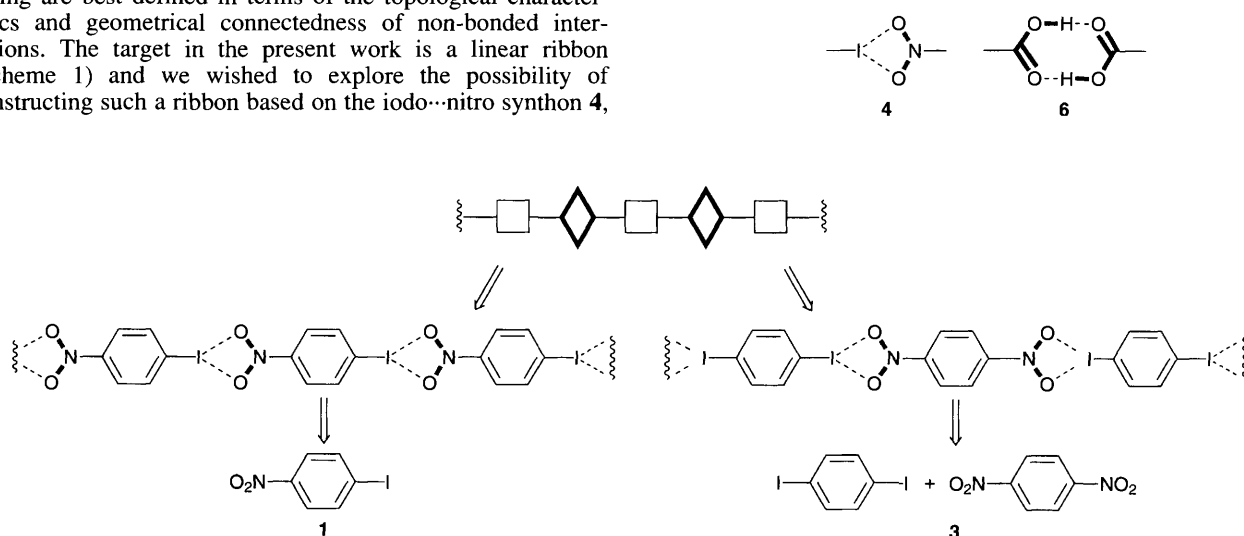

Scheme 1 Retrosynthetic analysis for the linear ribbon pattern leading to 4-iodonitrobenzene, **1** or alternatively to complex **3**. Supramolecular synthons are shown as heavy lines. Notice the equivalence of these two structures.
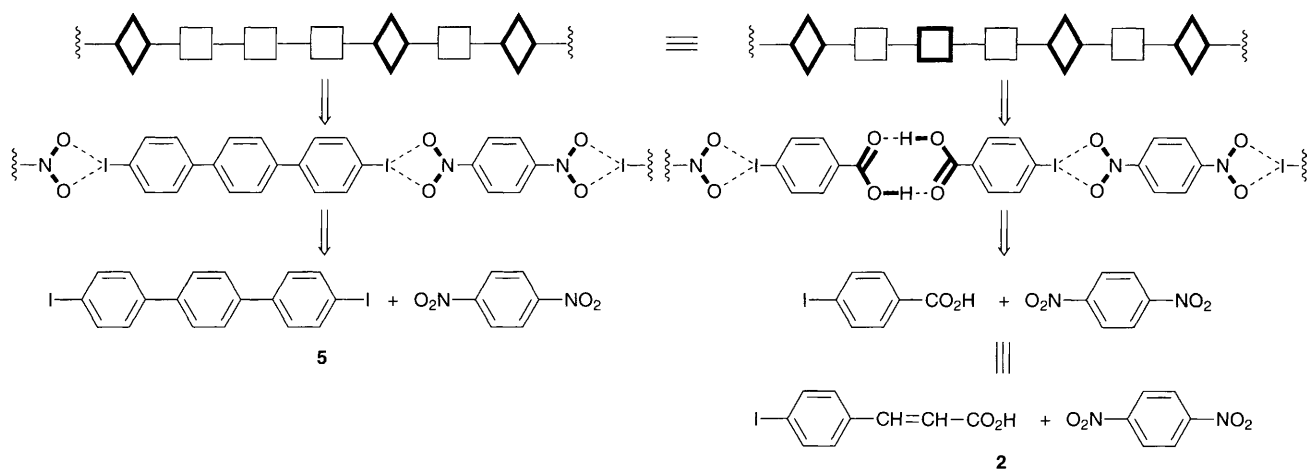
Scheme 2 Retrosynthetic analysis for the extended linear ribbon pattern leading to complex **5** (hypothetical structure) or to complex **2** (observed structure). Supramolecular synthons are shown as heavy lines. Notice the equivalence of the central phenyl ring in the terphenyl moiety on the left (molecular synthon) and the carboxyl dimer ring **6** on the right (supramolecular synthon).
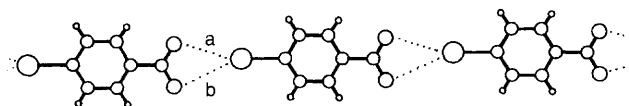
Fig. 1 Linear ribbon in the crystal structure of 4-iodonitrobenzene, **1**. The I⋯O interactions are indicated: a I⋯O 3.466 Å, C–I⋯O 157.89°; b I⋯O 3.327 Å, C–I⋯O 163.78°; cf. Scheme 1.
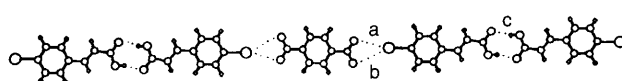
Fig. 2 Linear ribbon structure in the crystal structure of complex **2**. The I⋯O interactions and O–H⋯O hydrogen bonds are indicated: a I⋯O 3.306 Å, C–I⋯O 169.87°; b I⋯O 3.655 Å, C–I⋯O 154.69°; c O⋯O 2.649 Å, O–H⋯O 167.8°; cf. Scheme 2.

ingly, we sought to co-crystallise a complex from a 1 : 2 mixture of 1,4-dinitrobenzene and 4-iodobenzoic acid (Scheme 2). For solubility reasons, this combination proved unsatisfactory and 4-iodocinnamic acid was substituted for 4-iodobenzoic acid. Complex **2** was obtained and its crystal structure‡ is shown in Fig. 2. In this structure, the now elongated supramolecular diiodo moiety is able to link to 1,4-dinitrobenzene molecules. The robustness of the iodo ⋯nitro synthon, **4** with respect to the manipulations involving (the presumably more reliable) carboxyl synthon **6** may be noted. Synthons **4** and **6** may thus be used in a modular fashion without mutual perturbation and interference. Such synthon robustness is always a desirable situation in crystal engineering.

It should be noted that we have outlined here a strategy for supramolecular synthesis of one-dimensional motifs mediated by iodo⋯nitro synthons, **4**. Real, that is three-dimensional, crystals are mediated by three-dimensional arrangements of supramolecular synthons. In the present case, the linear motifs in Figs. 1 and 2 are further linked laterally via C–H⋯O hydrogen bonds as observed previously by us[8] and further via stacking interactions to complete the three-dimensional structure. The strategies outlined here can, in principle, therefore be extended to the entire structure.

A recurring theme in crystal engineering is that quite different covalent bond frameworks and chemical functionalities in the molecular structures can still result in similar supramolecular (crystal) structures. It has long been known that molecules with similar sizes, shapes and functionalities have similar crystal structures, and this principle of structural mimicry explains for instance phenomena such as solid solution formation.[11] However, a more powerful generalisation in the crystal engineering context is that molecular and/or *supramolecular* fragments with similar sizes, shapes and topologies have similar effects on crystal structures. Such a generalisation is more useful because it recognises the interchangeability of molecular and supramolecular synthons within a particular family of crystal structures.

Footnotes

† *Crystal data* for compound **1**: $C_6H_4INO_2$, $M = 249.00$, triclinic, space group $P\bar{1}$, $a = 7.545(2)$, $b = 7.802(2)$, $c = 6.599(1)$ Å, $\alpha = 91.43(3)$, $\beta = 92.03(3)$, $\gamma = 66.00(3)°$, $U = 354.6(1)$ Å^3, $Z = 2$, $F(000) = 232$, μ(Mo-Kα) = 4.45 mm^{-1}, empirical absorption corrections applied, $D_c = 2.332$ Mg m^{-3}, $T = 150$ K, 2560 non-zero reflections out of 2725 collected with $2.8 < \theta < 32.5°$, $R_{(int)} = 0.0076$, index ranges hkl 0–11, −10 to 11, −9 to 9, $\omega/2\theta$ scanning mode, solution SHELXS-86, refinement SHELXL-93 on F^2, $R = 0.025$, $wR_2 = 0.047$, C, I, N, O anisotropic, H isotropic.

‡ *Crystal data* for complex **2**: $C_6H_4N_2O_4 \cdot C_{18}H_{14}I_2O_4$, $M = 716.20$, triclinic, space group $P\bar{1}$, $a = 7.719(2)$, $b = 9.246(2)$, $c = 9.988(2)$ Å, $\alpha = 111.43(3)$, $\beta = 107.76(3)$, $\gamma = 94.03(3)°$, $U = 618.5(2)$ Å^3, $Z = 2$, $F(000) = 346$, μ(Mo-Kα) = 2.59 mm^{-1}, empirical absorption corrections applied, $D_c = 1.923$ Mg m^{-3}, $T = 150$ K, 2165 non-zero reflections out of 2313 collected with $2.6 < \theta < 25°$, $R_{(int)} = 0.0170$, index ranges: hkl −9 to 9, 0–10, −11 to 11, data collected and refined as above, $R = 0.048$, $wR_2 = 0.067$, C, I, N, O anisotropic, H isotropic.

Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre. See Information for Authors, Issue No. 1.

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