



Competitive H-bonding in bicyclic bis-lactams: self-assembly in nanotubes or in unbalanced chiral threefold interpenetrated diamondoid network[†]

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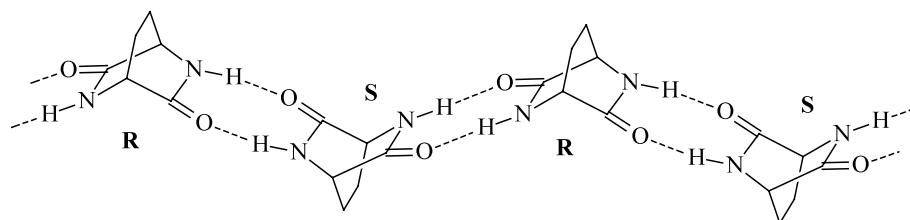
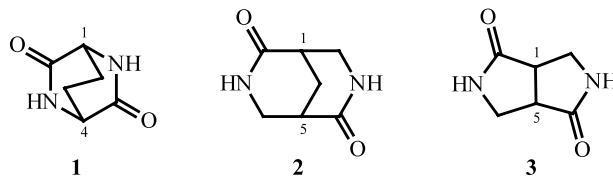
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Abstract—The first example of an H-bonded diamondoid network formed by a chiral molecule is reported. Diamondoid networks in the crystal structure of the described bicyclic bis-lactam are homochiral and threefold interpenetrated, two of them being of one chirality and the third of the other. Thus, unbalanced chiral packing (sp. gr. 141, $z=12$) and spontaneous resolution with ee 33% is observed. A slight change in the structural formula leads to an entirely different crystal structure with nanosize channels. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

Lehn et al. were the first to investigate chirality directed H-bonded supramolecular self-assembly in the crystal of the parent bicyclic bis-lactam (BBL) (\pm)- and (-)-diazabicyclo[2.2.2]octane-3,6-dione **1**.¹ We carried out similar investigations on (\pm)- and (-)-1,4-dicarboxylates of **1** and their derivatives,² and also on the parent BBLs 3,7-diazabicyclo[3.3.1]nonane-2,6-dione **2**,^{3a} 3,7-diazabicyclo[3.3.0]octane-2,6-dione **3**,⁴ and their 1,5-dicarboxylate derivatives.^{3,4} Racemates **1**, **3** and the majority of derivatives of **1** and **2** crystallize with remarkable regularity in the packing motif with lactam–lactam H-bonding in infinite tapes, consisting of strictly alternating enantiomers of BBLs (Scheme 1). However, this motif

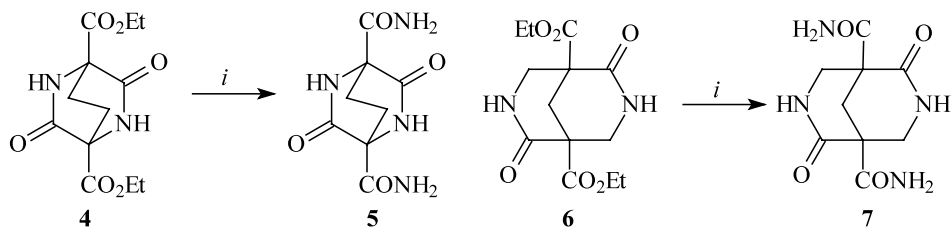
changes entirely in the case of enantiopure BBLs **1**,¹ 1-1,4-dicarboxylic acid^{2b} and diethyl 1-1,4-dicarboxylate **4**.^{2c} Based on the analysis of this difference, a qualitative concept of the design of molecules capable of homochiral crystallization (formation of conglomerates) through competitive H-bonding was developed. Thus, two new conglomerates of BBLs were found: **2**^{3c} and its 1,5-bis-carbamoyl-3,7-dimethyl derivative,^{3b} and their spontaneous resolution was achieved.



Scheme 1. Zigzag tapes formed by (\pm)-**1** and analogous bicyclic molecules.

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[†] Self-assembly of cage structures. Part 14. For Part 13, see: Kostyanovsky, R. G.; Levkin, P. A.; Lyssenko, K. A.; Strelenko, Yu. A.; Golovanov, D. G. *Mendeleev Commun.* **2002**, in press.



Scheme 2. Reagents and conditions: (i): saturated solution of NH_3 in MeOH, 2 weeks at 20°C .

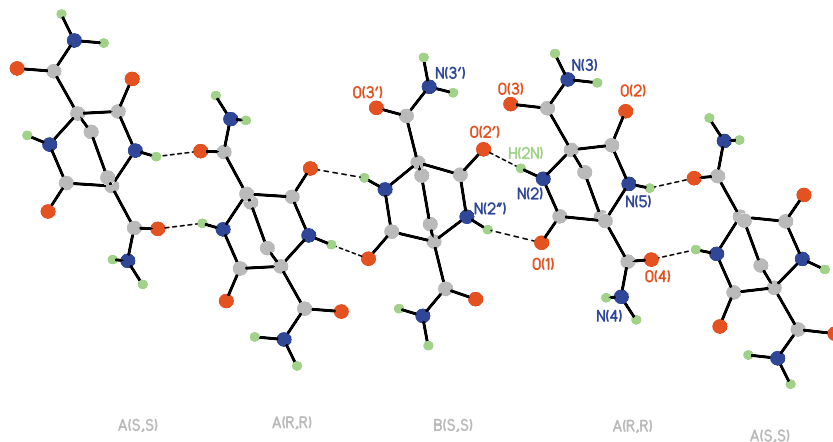


Figure 1. The scheme illustrating the competitive N–H...O bonding in the heterochiral tape in **5**.

2. Results and discussion

The work described herein was aimed at investigating the possibility of changing the type of racemic zigzag self-assembly (Scheme 1) observed in the crystals of the BBLs **4**^{2a} and **6**^{3a} via exchange of the CO_2R groups to CONH_2 , which are comparable with lactam groups in H-bonding capabilities and can thus serve as competitive H-bonding groups.

The molecular structures of racemic bis-amides BBL **5** and **7** (Scheme 2) are proved by spectral data and elemental analysis, the peculiarities of supramolecular self-assembly were investigated by XRD analysis of single crystals.

The crystal structure of **5** represents an example of a true competitive H-bonding network and is similar in some features to the previously investigated BBL derivatives.^{2d} Two symmetrically independent molecules (**A** and **B**) in **5** are assembled into heterochiral tapes (sp. group $C2/c$), both by ‘lactam–lactam’ ($R^2_2(8)$ H-bond graph)⁵ and ‘lactam–amido’ ($R^2_2(10)$ H-bond graph) N–H...O bonds of comparable strengths (N...O 2.915(3)–2.979(3) Å) (Fig. 1). In the above mentioned tapes, molecule **A** participates in H-bond both of $R^2_2(8)$ and $R^2_2(10)$ graph, while molecule **B** (lying on the twofold crystallographic axis) participates only in lactam–lactam H-bonding and thus represents supramolecular synthon identical to **1** and ester derivatives.^{1–3} The other H-donor and acceptor groups serve as the ‘binding’ of this tapes in three-dimensional net-

work. Due to variation of the H-bonding type the crosslinking of the tapes leads to the formation of the channels coated by the hydrophilic amidic groups. The nanochannels (of dimensions 5.65×10.70 Å) are filled with agglomerate of the solvate water molecules (Fig. 2). The latter represent quite a rare example of an H-bonded tetramer (O...O 2.753(3)–2.793(3) Å) with two exocyclic water ‘wings’ (Fig. 3).

In contrast to **6**^{3a} the results of XRD investigations of **7** exceeded all expectations. In the case of BBL **7** the lactam–lactam H-bonding typical of BBLs is totally absent. Three independent molecules (**A**, **B** and **C**) each

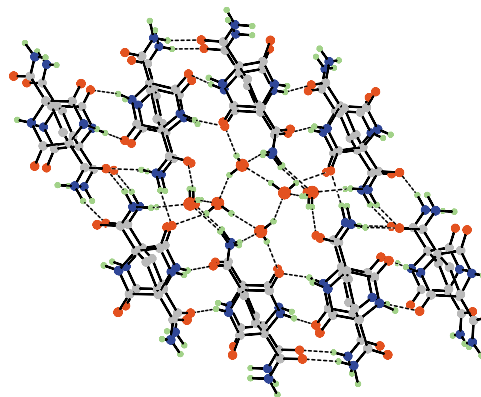


Figure 2. Formation of nanosize channels filled by agglomerate of the solvate water molecules in the crystal structure of **7**.

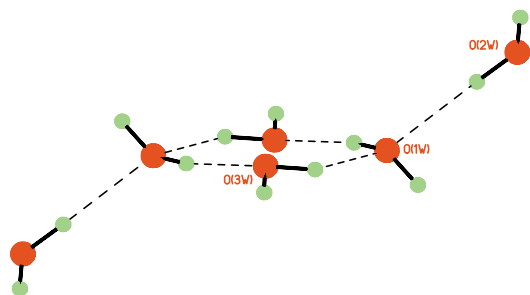


Figure 3. Winged O–H...O bonded cyclotetramers of water molecules.

lying on the twofold crystallographic axis participate in the anticipated competitive ‘amide-lactam’ N–H...O bonds of the $R^2_2(8)$ graph (N...O 2.817(3)–3.073 Å). This time, due to approximately tetrahedral orientation of amide functionalities, the molecules of **7** are assembled in diamondoid networks (Fig. 4) just as in adamantane-1,3,5,7-tetracarboxylic acid.⁶ It should be noted that each independent molecule is characterized by the fully identical diamondoid H-bonded sublattice. Thus, the distances between the C-9 bridging atoms of the bicycle in adamantane-like decamers in A–C are all equal to 8.071(3) Å and the corresponding pseudo-bond angles are 109.0–110.4°. Independent identical diamondoid networks are threefold interpenetrated (Fig. 5). Most interesting is the fact that each network is homochiral, and two of them (A, B) have the same chirality, while the chirality of the C network is opposite (Fig. 5). Thus the rare event of unbalanced packing of chiral molecules^{7,8} and spontaneous crystallizational resolution (sp. gr. $I4_1$) is observed with ee of the single crystal equal to 33.3%. The optical activity was observed for the first portion of the small crystals of **7**. The fact that it is possible to separate cyclic homochiral hexamers from diamondoid networks, corresponding to the hypothetical structure of the homochiral hexamer of **1**, described by Lehn (Fig. 6).¹ is very interesting from a supramolecular chirality point of view.

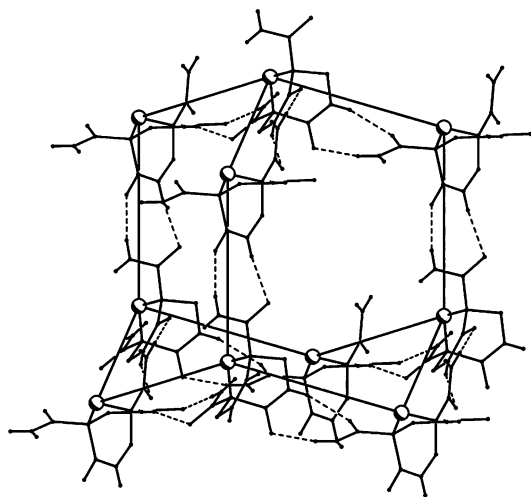


Figure 4. Decameric element of diamondoid network in the structure of **7**.

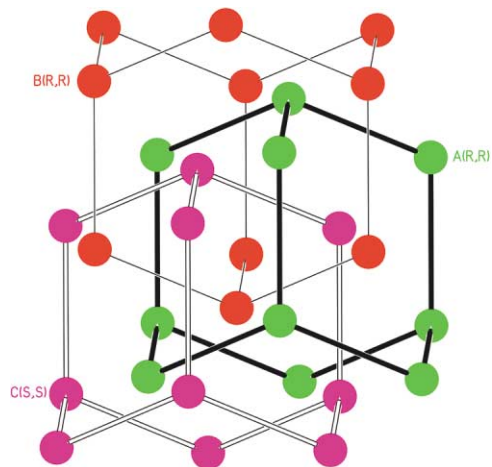


Figure 5. Threefold interpenetration of homochiral diamondoid networks A–C in **7**.

3. Conclusion

Such diamondoid networks before were described only for achiral molecules and crystallization in chiral space groups was observed only in the case of several coordination polymers with achiral ligands.⁹ So we have reported here the first example of diamondoid network formation from a chiral molecule. A peculiarity of the observed phenomenon is that a slight change in molecular structure from tetraamide **5** to tetraamide **7** produces an entirely different crystal structure, which gives new impetus to the resolution of an eternal question of crystal engineering: ‘are the crystal structures predictable?’¹⁰

It is worth mentioning that self-assembly of molecules into H-bonded or metal ion coordinated (a) diamondoids with interpenetration or interweaving phenomena,¹¹ as well as (b) porous suprastructures with inclusion phenomena¹² are rapidly developing fields in crystal engineering, and an important perspective for building new materials with important properties, including NLO activity or selective inclusion abilities.

4. Experimental

Diamides **5** and **7** were obtained as white solids precipitated from methanolic ammonia as depicted in Scheme 2 and were recrystallized from water.

4.1. 2,5-Diazabicyclo[2.2.2]octane-3,6-dione-1,4-dicarboxamide dihydrate **5**

Yield 73%, crystal for X-ray grown from EtOH–H₂O mixture (1:1) during 1 week at 20°C: mp 310–312°C (dec.), ¹H NMR (400 MHz, DMSO-*d*₆, 20°C), δ , ppm: 1.99 and 2.30 (m, 4H, 7,8-(CH₂)₂, AA'BB' spectrum), 7.65 (br.s., 2H, 2,5-NH), 7.68 and 8.31 (br.s., 4H, 1,4-CONH₂). Anal. calcd for C₈H₁₄N₄O₆: C, 36.64; H, 5.38; N, 21.37; found: C, 36.9; H, 5.35; N, 21.5%.

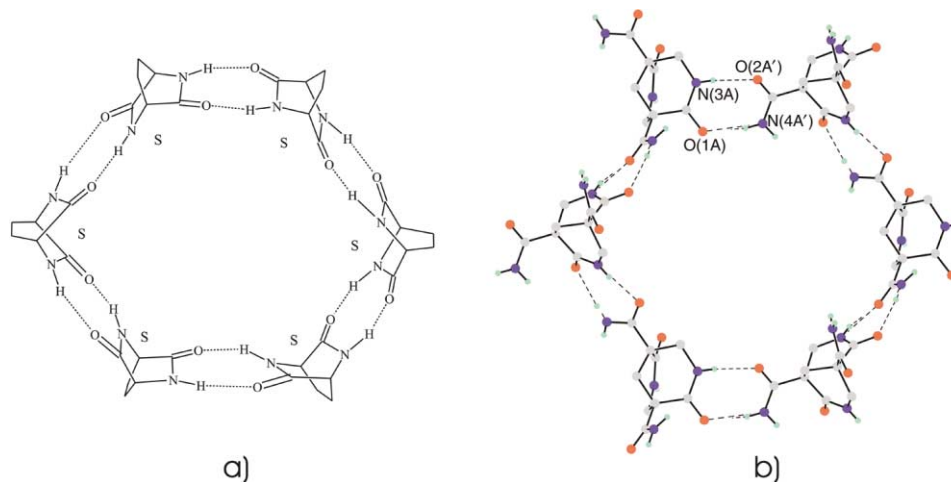


Figure 6. Two homochiral hexamers of BBLs: (a) hypothetical structure for **1** (Lehn's bracelet); (b) real hexamer observed in **7**.

4.2. 3,7-Diazabicyclo[3.3.1]nonane-2,6-dione-1,5-dicarboxamide **7**

Yield 98%, crystal for X-ray grown from H₂O during 1 week at 20°C: mp 347–352°C (dec.), ¹H NMR (400 MHz, DMSO-*D*₆, 20°C), δ , ppm, *J*, Hz: 2.42 (br.s., 2H, 9-CH₂), 3.35 (m, 4H, 4,8-CH₂, AB-spectrum, $\Delta\nu = 76.0$, ²*J*_{ab} = -12.2) 7.16 and 7.52 (br.s., 4H, 1,5-CONH₂) 8.01 (br.s., 2H, 3,7-NH). Anal. calcd for C₉H₁₂N₄O₄: C, 45.00; H, 5.04; N, 23.32; found: C, 44.8; H, 5.2; N, 23.3%. For the first portion of small crystals (9.9 mg): $[\alpha]_{\text{D}}^{20} = +4.6$; $[\alpha]_{578}^{20} = +5.0$; $[\alpha]_{546}^{20} = +7.1$; $[\alpha]_{436}^{20} = +12.1$.

4.3. Crystallographic data for **5** and **7**

At 153 K crystals of **5** (C₈H₁₄N₄O₆) are monoclinic, space group *C2/c*, *a* = 21.950(4), *b* = 5.609(1), *c* = 28.430(6) Å, $\beta = 105.33(3)^\circ$, *V* = 3376(1) Å³, *Z* = 12, *M* = 262.23, *D*_{calcd} = 1.548 g cm⁻³, $\mu(\text{MoK}\alpha) = 1.33$ cm⁻¹, *F*(000) = 1656; at 110 K crystals of **7** (C₉H₁₂N₄O₄) are tetragonal, space group *I4*₁, *a* = 13.252(1), *c* = 18.435(3) Å, *V* = 3237.4(7) Å³, *Z* = 12, *M* = 240.23, *D*_{calcd} = 1.479 g cm⁻³, $\mu(\text{MoK}\alpha) = 1.18$ cm⁻¹, *F*(000) = 1512. Intensities of 3804 (for **5**) and 19350 (for **7**) reflections were measured with a Syntex P21 at 153 K (**5**) and with Smart 1000 CCD diffractometer at 110 K (for **7**) ($\lambda(\text{MoK}\alpha) = 0.71072$ Å, $\theta/2\theta$ scans, $2\theta < 54^\circ$ (**5**) and ω -scans, $2\theta < 60^\circ$ (**7**)), and 3707 (**5**) and 4699 (**7**) independent reflections were used in further refinement. The structures were solved by direct method and refined by the full-matrix least-squares technique against *F*² in the anisotropic–isotropic approximation. Hydrogen atoms were located from the Fourier synthesis and refined in the isotropic approximation. The refinement converged to *wR*₂ = 0.0729 and GOF = 1.012 for all independent reflections (*R*₁ = 0.0345 was calculated against *F* for 2292 observed reflections with *I* > 2σ(*I*) for **5** and to *wR*₂ = 0.1638 and GOF = 1.031 for all independent reflections (*R*₁ = 0.0604 was calculated against *F* for 3819 observed reflections with *I* > 2σ(*I*) for **7**). All calculations were performed using SHELXTL PLUS 5.0 on IBM PC AT. Crystallographic data for the structures reported in this paper have been

deposited with the Cambridge Crystallographic Data Centre as supplementary publication nos. CCDC-192373 (**5**) and CCDC-192374 (**7**).

Acknowledgements

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