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Hydrogen-bonded structures from adamantane-based catechols

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ABSTRACT

Adamantane-based bis- and tris-catechols were synthesized to examine the effect of hydrogen bonds on the arrangement and packing of the components in the crystalline state. Single-crystal X-ray crystallographic analysis revealed that hydrogen bonds formed by the hydroxyl groups of catechol groups play essential roles in the production of various types of unique structures. 1,3-Bis(3,4-dihydroxyphenyl) adamantane (1) provided hydrogen-bonded network structures composed of helical chains in crystal from chloroform/methanol, and layer structures in crystal from ethyl acetate/hexane. The complexation of 1 with 1,3,5-trinitrobenzene or 1,2,4,5-tetracyanobenzene resulted in the formation of co-crystals, respectively. One-dimensional hydrogen-bonded structures were constructed from the adamantane-based molecules, which participated in charge-transfer interactions with guests. 1,3,5-Tris(3,4-dihydroxyphenyl)adamantane also afforded crystal, and the components were assembled into infinite polymers.

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1. Introduction

Catechol and its derivatives have elicited much attention in the areas of material science, supramolecular chemistry, and biomimetic chemistry [1-4] because they are easily available and useful key units for the development of polymers that contribute to the adhesion property of mussels [5-8], as well as porous network polymers and covalent organic frameworks for the adsorption and inclusion of gas and small molecules [9–13]. Catechol-containing molecules have been exploited as ligands for the construction of discrete metal-mediated complexes [14–19] and as building blocks for functional molecules with boronate esters [20-24] and spiroborates [25–28]. Compounds possessing two catechol moieties include 3,3',4,4'-tetrahydroxybiphenyl, 2,2',3,3'-tetrahydroxy-1,1'-5,5',6,6'-tetrahydroxy-3,3,3',3'-tetramethyl-1,1'-spibinaphthyl, robisindane, and dimethyl tetrahydroxytriptycene [29-31]. Cyclotricatechylene, a cyclic trimer composed of catechol groups linked by methylene groups, is a cyclic compound and its derivatives are broadly utilized as a scaffold for the preparation of supramolecular materials [32,33]. Several catechol-containing molecules were designed by connecting spacer parts and catechol groups. The spacer units used were phenylene, diethynylphenylene, azobenzene, and others [34–39].

In crystal engineering, diverse hydrogen-bonded crystalline materials are created by utilizing the multiple hydrogen bonds of hydroxyl groups in phenol-containing molecules [40–43]. In contrast, reports of the preparation of crystalline materials from catechol-containing molecules are rare.

Previously, we described the synthesis and structure analysis of a series of adamantane-based molecules having phenol derivatives, which were used in the generation of hydrogen-bonded crystalline solids with cavities and channels where solvents and small organic molecules were accommodated [44–48].

Adamantane has a symmetrical and spherical skeleton with aliphatic characteristics. Therefore, adamantane-based molecules possessing a few catechol groups may provide fascinating hydrogen-bonded network structures that show inclusion ability for small organic molecules in the crystalline state.

In this work, we report the preparation and the crystal structures of 1,3-bis(3,4-dihydroxyphenyl)adamantane (1) and 1,3,5tris(3,4-dihydroxyphenyl)adamantane (2). The disubstituted adamantane compound having catechol groups yielded two kinds of





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crystals depending on the recrystallization solvent, namely, a mixture of chloroform and methanol or ethyl acetate and hexane, where hydrogen-bonded network structures made up of helical chains or layer structures consisting of cyclic frameworks were formed, respectively. Further, the co-crystallization of **1** with 1,3,5-trinitrobenzene (**3**) or 1,2,4,5-tetracyanobenzene (**4**) as guest molecules in methanol or a mixture of water and ethanol resulted in the formation of charge-transfer co-crystal structures without the guest molecules. The trisubstituted adamantane compound gave one-dimensional (1D) polymers consisting of cyclic frameworks from methanol.

2. Experimental section

2.1. General

All reagents and solvents were obtained from commercial suppliers and used as received. Melting points were determined using an ATM-01. IR spectra were recorded on a Jasco FT/IR-6300. ¹H and ¹³C NMR spectra were recorded on a Bruker AV400 spectrometer at 298 K in DMSO- d_6 with tetramethylsilane as reference. X-ray crystal structure data were collected using a Bruker D8 VENTURE diffractometer with Cu K α radiation. Column chromatography was performed on a Wakogel C200, and thin-layer chromatography was carried out on 2.0-mm Merck precoated silica gel glass plates. High-resolution mass spectrometric measurements were carried out on an Exactive (Thermo Fisher Scientific) consisting of an Orbitrap analyzer and an electrospray ionization (ESI) source.

Caution! 1,3,5-Trinitrobenzene is highly explosive and should be handled carefully even in small amounts.

2.2. 1,3-Bis(3,4-dihydroxyphenyl)adamantane (1)

A mixture of 1,3-adamantanediol (2.02 g, 12.0 mmol) and catechol (3.96 g, 36.0 mmol) in methanesulfonic acid (10 mL) was stirred at 80 °C for 3 h under an argon atmosphere. After cooling to room temperature, the reaction mixture was poured into ice water and then added to ethyl acetate. The organic layers were separated and the aqueous layer was extracted with ethyl acetate. The combined organic layers were washed with water, brine, and dried over sodium sulfate. The filtrate was evaporated under reduced pressure and the residue was purified by silica gel column chromatography (eluent: chloroform:methanol = 10:1, v/v). Recrystallization from a

Table 1

Crystal data for the five crystals.

methanol solution of the resulting solids afforded the title compound as a white solid (3.05 g, 8.65 mmol) in 72% yield. M.p. 210–211 °C. FT-IR (ATR, cm⁻¹): 3499, 2913, 2846, 1603, 1520, 1464, 1326, 1266, 1190, 1106, 943, 940, 916, 866, 797, 783. ¹H NMR (400 MHz, DMSO- d_6) δ 8.61 (s, 2H), 8.57 (s, 2H), 6.76 (d, J = 2.0 Hz, 2H), 6.65 (d, J = 8.4 Hz, 2H), 6.60 (dd, J = 8.4, 2.0 Hz, 2H), 2.18 (br s, 2H), 1.77 (br d, J = 2.8 Hz, 10H), 1.69 (br s, 2H). ¹³C NMR (100 MHz, DMSO- d_6) δ 144.6, 142.8, 141.8, 115.13, 115.06, 112.3, 49.2, 42.1, 35.9, 35.4, 29.0. HRMS (ESI, m/z) Calcd for C₂₂H₂₃O₄ [M – H]⁻ 351.1602, found 351.1606.

2.3. 1,3,5-Tris(3,4-dihydroxyphenyl)adamantane (2)

The title compound was synthesized in 42% yield as a white solid in a manner similar to the preparation of 1,3-bis(3,4-dihydroxyphenyl)adamantane (1), where 1,3,5-adamantanetriol was used instead of 1,3-adamantanediol. M.p. 271–272 °C. FT-IR (ATR, cm⁻¹): 3312, 2897, 2847, 1602, 1517, 1430, 1340, 1255, 1193, 1108, 942, 870, 807, 782. ¹H NMR (400 MHz, DMSO-*d*₆) δ 8.65 (br s, 6H), 6.86 (s, 3H), 6.72 (s, 6H), 2.41 (br s, 1H) 1.85 (br d, *J* = 7.6 Hz, 12H). ¹³C NMR (100 MHz, DMSO-*d*₆) δ 144.5, 142.8, 141.4, 115.2, 115.1, 112.4, 48.3, 41.2, 36.9, 29.6. HRMS (ESI, *m/z*) Calcd for C₂₈H₂₇O₆ [M–H]⁻ 459.1813, found 459.1821.

2.4. Crystallization

Crystal **1a** was obtained from the slow evaporation of a chloroform-methanol mixture of **1**. Co-crystal **1b** was obtained from the vapor diffusion of hexane into an ethyl acetate solution of **1**. Co-crystals **1c** and **1d** were generated from the slow evaporation of a methanol solution of **1** with 1,3,5-trinitrobenzene (**3**) or a mixture of water and ethanol of **1** with 1,2,4,5-tetracyanobenzene (**4**) in a 1:1 ratio. Co-crystal **2a** was formed from the slow evaporation of **a** methanol solution of **2**.

2.5. Single-crystal X-ray crystallography

The diffraction experiment was performed on a Bruker D8 VENTURE system (PHOTON-100 CMOS detector, CuK α : $\lambda = 1.54178$ Å). Absorption correction was performed by an empirical method implemented in SADABS [49]. Structure solution and refinement were performed by using SHELXT-2014/5 [50] and SHELXL-2016/6 [51]. Summarized crystal data are shown in Table 1. CCDC 1555041–1555045 contain the supplementary

Crystal	1a	1b	1c	1d	2a
Chemical Formula	C ₂₂ H ₂₄ O ₄	C ₂₄ H ₂₈ O ₅	C ₃₄ H ₃₀ N ₆ O ₁₆	C ₃₂ H _{31,35} N ₄ O _{6,68}	C _{29.74} H _{34.98} O _{7.74}
Formula weight	352.41	396.46	778.64	578.85	516.36
Recryst. Solvent	CHCl ₃ /MeOH	n-Hexane/AcOEt	MeOH	EtOH/Water	MeOH
Crystal system	monoclinic	triclinic	orthorhombic	triclinic	triclinic
Space group	$P2_1/c$	P-1	Pbcn	P-1	P-1
a (Å)	10.9394(8)	6.4112(13)	28.177(4)	6.4290(7)	9.8257(10)
b (Å)	10.8640(8)	12.948(3)	12.7023(18)	13.6973(16)	9.9510(11)
c (Å)	14.4447(10)	13.432(3)	9.1916(13)	14.0150(16)	13.0464(14)
α (°)	90.00	63.383(5)	90.00	81.905(3)	79.263(3)
β (°)	91.965(2)	79.063(5)	90.00	78.031(3)	76.480(2)
γ (°)	90.00	84.763(5)	90.00	79.259(3)	86.219(3)
V (Å ³)	1715.7(2)	978.7(3)	3289.8(8)	1179.5(2)	1218.2(2)
Ζ	4	2	4	2	2
D_{calc} (Mg/m ³)	1.364	1.345	1.572	1.379	1.408
T (K)	100	100	100	100	100
$R_1, wR_2 [I > 2\sigma(I)]$	0.0513, 0.2015	0.0368, 0.1018	0.0415, 0.1188	0.0409, 0.1101	0.0821, 0.2057
R_1, wR_2 (all data)	0.0549, 0.2026	0.0386, 0.1035	0.0468, 0.1209	0.0441, 0.1134	0.0832, 0.2067
CCDC No.	1555041	1555042	1555043	1555044	1555045



Scheme 1. Synthesis of Two Adamantane-Based Molecules with Catechol Groups.



Fig. 1. Thermal ellipsoidal models (50% probability) of the crystal structures of adamantane-based catechols. (a) Crystal **1a**, (b) co-crystal **1b**, (c) co-crystal **1c**, (d) co-crystal **1d**, and (e) co-crystal **2a**. Solvent, guest molecules, and some disordered atoms are omitted for charity.

Table 2

Geometrical parameters of 1 in crystal 1a and Co-crystal 1b-1d.







crystallographic data. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Center, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

3. Results and discussion

We synthesized adamantane-based molecules (**1**, **2**) by performing the coupling reaction of catechol and 1,3-adamantanediol or 1,3,5-adamantanetriol in methanesulfonic acid in 72 and 42% yields, respectively (Scheme 1). Both compounds were characterized by ¹H and ¹³C NMR spectroscopy and high-resolution mass spectrometry. Crystal data and conformational parameters of all the crystals are indicated in Fig. 1 and Tables 1–3. Two or three catechol rings in **1** or **2** of all crystals exhibited a bent and twisted conformation (Fig. 1). The torsion angles between specific C–C bonds of adamantane units and C–C bonds of the catechol units in the formed crystals and co-crystals are shown in Tables 2 and 3 These values range from $-117.6-177.4^{\circ}$.

Crystal **1a** crystallized in the monoclinic system and the space group $P2_1/c$, and included one molecule of **1** in the asymmetric unit. Molecule **1** is assembled into helical chains with one pitch of two

molecules of **1** via hydrogen bonds between the hydroxyl groups in the catechol groups, where the distance between the oxygen atoms is 2.67 Å (Fig. 2a). In single helical chains, the centroid–centroid distance between adamantane parts is 10.86 Å. Further, one of the planes of the catechol rings is parallel and the other is perpendicular to the axis of the helical structures. The helical chains form layers and their network structures through the hydrogen bonds between the hydroxyl groups, where the distances between the oxygen atoms are 2.77–2.85 Å (Fig. 2b and c).

Co-crystal **1b** crystallized in the triclinic system and the space group *P*-1, and included one molecule of **1** and one molecule of ethyl acetate in the asymmetric unit. The cyclic structures are constructed from two molecules of **1** through the hydrogen bonds between the hydroxyl groups (the distance between the oxygen atoms is 2.81 Å), where the centroid–centroid distance between the adamantane parts is 11.42 Å (Fig. 3b and c). The cyclic frameworks are extended along the *c* axis via the hydrogen bonds between the hydroxyl groups (the distance between the oxygen atoms is 2.85 Å), resulting in the formation of 1D structures. 1D polymers consisting of cyclic frameworks are directed into the layers through the hydrogen bonds between the hydroxyl groups (the distance between the hydroxyl groups (the distance between the hydroxyl groups through the hydrogen bonds between the hydroxyl groups (the distance between the oxygen atoms is 2.71 Å, Fig. 3a). Thus, there are channels in the crystalline lattices, which are filled with



Fig. 2. Packing diagram of **1** in crystal **1a**. (a) Layer structures composed of helical chains from the side view. (b) Top and (c) side views of network structures. Hydrogen bonds are indicated by red dotted lines. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



Fig. 3. Packing diagram of **1** in co-crystal **1b**. (a) Side and (b) top views of network structures. (c) Top view of network structures in a space-filling model. Hydrogen bonds are indicated by red dotted lines. Solvent molecules are omitted for clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



Fig. 4. Packing diagram of **1** and **3** in co-crystal **1c**. (a) Top and (b) side views of the network structures. Hydrogen bonds are indicated by red dotted lines. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

ethyl acetate. Individual layers are assembled into the network structures via $CH\cdots\pi$ interactions between the catechol rings and the adamantane parts, where the distance between the carbon atoms of adamantane units and the center of catechol rings is 3.83 Å.

The catechol group is electron-rich and thus its derivatives can interact with electron-deficient molecules as an acceptor to form complexes through charge-transfer interactions, which display signature color in the visible region. Therefore, we examined the preparation of charge-transfer co-crystals from **1** and 1,3,5-



Fig. 5. Packing diagram of **1** and **4** in co-crystal **1d**. (a) Top and (b) side views of network structures. Hydrogen bonds are indicated by red dotted lines. Solvent molecules are omitted for clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

trinitrobenzene (**3**) as the representative acceptor molecule [52–59]. Reddish brown co-crystals **1c** were considerably different in color from both components in the solid state. Co-crystal **1c** crystallized in the orthorhombic system and the space group *Pbcn*, and included a half molecule of **1** and one molecule of **3** in the asymmetric unit. Therefore, the arrangement of **1** was notably changed in the presence of the guest molecule. Molecule **1** is

assembled into 1D polymers consisting of cyclic frameworks derived from two molecules of **1** via the hydrogen bonds between the hydroxyl groups along the *c* axis, where the distance between the oxygen atoms of them is 2.96 Å (Fig. 4 and S3). In a single polymer, the centroid–centroid distance between adamantane parts is 9.49 Å. Further, hydrogen bonds between the hydroxyl groups of the catechol groups and the oxygen atoms of **3** were observed, and the distance between the oxygen atoms was 2.89 Å. The catechol groups in the components also interacted with guest molecules via charge-transfer interactions to form the network structures (the centroid–centroid distance of aromatic rings and the dihedral angle between the planes of aromatic rings are 3.66 Å and 11.3°, respectively).





Fig. 6. Packing diagram of **2** in co-crystal **2a**. (a) Top and (b) side views of 1D polymers composed of cyclic structures. Hydrogen bonds are indicated by red dotted lines. Solvent molecules are omitted for clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Another acceptor molecule for the development of organic charge-transfer complexes, 1,2,4,5-tetracyanobenzene (4) [60,61], was also utilized. Similarly, reddish brown co-crystals 1d were obtained. Co-crystal 1d crystallized in the triclinic system and the space group P-1, and included one molecule of **1**, a half molecule of 4. and three molecules of water in the asymmetric unit. Molecule 1 is directed into infinite polymers via the hydrogen bonds between the hydroxyl groups along the *c* axis, where the distance between the oxygen atoms is 2.72 Å (Fig. 5b). One catechol group in the components interacts with 4 via charge-transfer interactions to form the layer structures (the centroid-centroid distance of aromatic rings and the dihedral angle between the planes of aromatic rings are 3.84 Å and 13.3°, respectively). Further, the oxygen atoms of the catechol groups interact with the hydrogen atoms of 4 through CH…O interactions (the distance between the oxygen atom and the carbon atom is 3.28 Å), resulting in the generation of network structures. Additionally, $CH \cdots \pi$ interactions between the catechol rings and adamantane parts (the distances between the carbon atoms of adamantane parts and the center of catechol rings are 3.90 and 3.91 Å) were observed. The guest molecules are arranged in a 1D array along the *a* axis in the crystalline state (Fig. 5a).

Co-crystal **2a** consisting of tripodal molecule **2** crystallized in the triclinic system and the space group *P*-1, and included one molecule of **2** and three molecules of methanol in the asymmetric unit. Two molecules of **2** are assembled into the cyclic structures and these structures are induced into infinite polymers via the hydrogen bonds between the hydroxyl groups. The distances between the oxygen atoms are 2.77 and 2.82 Å (Fig. 6). The 1D structures are guided into the network structures through the multiple hydrogen bonds between the catechol groups. Methanol molecules binding with catechol groups via hydrogen bonds were observed in the crystalline lattices.

4. Conclusion

In conclusion, we have designed adamantane-based bis- and tris-catechols as novel key compounds for the construction of the hydrogen-bonded organic frameworks of helical chains, polymers, layers, and network structures in the solid state. Adamantanebased catechols bearing electron-rich parts interact with 1,3,5trinitrobenzene or 1,2,4,5-tetracyanobenzene as electron-acceptor guest molecules via charge-transfer interactions, generating cocrystals. Therefore, adamantane-based bis- and tris-catechols are versatile building blocks and supramolecular synthons for crystal engineering and solid-state chemistry. The synthesis of adamantane-based molecules having other phenol derivatives, such as resorcinol, hydroquinone, and pyrogallol, and their structural analysis and applications are under investigation.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.molstruc.2018.03.011.

References

- [1] J.H. Waite, Ann. N. Y. Acad. Sci. 875 (1999) 301-309.
- [2] N.B. McKeown, P.M. Budd, K.J. Msayib, B.S. Ghanem, H.J. Kingston, C.E. Tattershall, S. Makhseed, K.J. Reynolds, D. Fritsch, Chem. Eur. J. 11 (2005)

2610-2620.

- [3] R. Nishiyabu, Y. Kubo, T.D. James, J.S. Fossey, Chem. Commun. 47 (2011) 1124-1150.
- [4] X. Feng, X. Ding, D. Jiang, Chem. Soc. Rev. 41 (2012) 6010-6022.
- [5] M. Yu, T.J. Deming, Macromolecules 31 (1998) 4739-4745.
- [6] M.J. Harrington, A. Masic, N. Holten-Andersen, J.H. Waite, P. Fratzl, Science 328 (2010) 216-220.
- [7] D. Ling, W. Park, Y.I. Park, N. Lee, F. Li, C. Song, S.G. Yang, S.H. Choi, K. Na, T. Hyeon, Angew. Chem. Int. Ed. 50 (2011) 11360-11365.
- [8] H. Xu, J. Nishida, W. Ma, H. Wu, M. Kobayashi, H. Otsuka, A. Takahara, ACS Macro Lett. 1 (2012) 457-460.
- [9] N.B. McKeown, S. Hanif, K. Msayib, C.E. Tattershall, P.M. Budd, Chem. Commun. (2002) 2782-2783.
- [10] B.S. Ghanem, K.J. Msayib, N.B. McKeown, K.D.M. Harris, Z. Pan, P.M. Budd, A. Butler, J. Selbie, D. Book, A. Walton, Chem. Commun. (2007) 67-69.
- [11] S. Makhseed, J. Samuel, Chem. Commun. (2008) 4342–4344.
- [12] M. Mastalerz, Angew. Chem. Int. Ed. 47 (2008) 445–447.
 [13] J. Jiang, Y. Zhao, O.M. Yaghi, J. Am. Chem. Soc. 138 (2016) 3255–3265.
- [14] B.F. Abrahams, N.J. FitzGerald, R. Robson, Angew. Chem. Int. Ed. 46 (2007) 8640-8643.
- [15] B.F. Abrahams, N.J. FitzGerald, R. Robson, Inorg. Chem. 49 (2010) 5953–5956. [16] B.F. Abrahams, B.A. Boughton, N.J. FitzGerald, J.L. Holmes, R. Robson, Chem. Commun. 47 (2011) 7404-7406.
- [17] M. Albrecht, I. Janser, R. Fröhlich, Chem. Commun. (2005) 157-165.
- [18] M.D. Pluth, R.G. Bergman, K.N. Raymond, Acc. Chem. Res. 42 (2009) 1650 - 1659
- [19] C.J. Brown, F.D. Toste, R.G. Bergman, K.N. Raymond, Chem. Rev. 115 (2015) 3012-3035.
- [20] N. Nishimura, K. Kobayashi, Angew. Chem. Int. Ed. 47 (2008) 6255-6258.
- [21] K. Kataoka, S. Okuyama, T. Minami, T.D. James, Y. Kubo, Chem. Commun. (2009) 1682-1684
- [22] K. Severin, Dalton Trans. (2009) 5254-5264.
- [23] B. Icli, E. Solari, B. Kilbas, R. Scopelliti, K. Severin, Chem. Eur. J. 18 (2012) 14867-14874
- [24] A. Wilson, G. Gasparini, S. Matile, Chem. Soc. Rev. 43 (2014) 1948-1962.
- [25] B.F. Abrahams, D.J. Price, R. Robson, Angew. Chem. Int. Ed. 45 (2006) 806-810.
- [26] H. Danjo, K. Hirata, S. Yoshigai, I. Azumaya, K. Yamaguchi, J. Am. Chem. Soc. 131 (2009) 1638-1639.
- [27] H. Danjo, K. Hirata, M. Noda, S. Uchiyama, K. Fukui, M. Kawahata, I. Azumaya, K. Yamaguchi, T. Miyazawa, J. Am. Chem. Soc. 132 (2010) 15556-15568.
- [28] H. Danjo, Y. Hashimoto, Y. Kidena, A. Nogamine, K. Katagiri, M. Kawahata, T. Miyazawa, K. Yamaguchi, Org. Lett. 17 (2015) 2154-2157.
- [29] J. Best, I.V. Sazanovich, H. Adams, R.D. Bennett, E.S. Davies, A.J.H.M. Meijer, M. Towrie, S.A. Tikhomirov, O.V. Bouganov, M.D. Ward, J.A. Weinstein, Inorg. Chem. 49 (2010) 10041-10056.
- [30] J.A. Bjork, M.L. Brostrom, D.R. Whitcomb, J. Chem. Crystallogr. 27 (1997)

- 223-230.
- [31] N.G. White, M.J. MacLachlan, Chem. Sci. 6 (2015) 6245-6249.
- [32] M.J. Hardie, Chem. Soc. Rev. 39 (2010) 516–527.
- [33] J.A. Hyatt, E.N. Duesler, D.Y. Curtin, I.C. Paul, J. Org. Chem. 45 (1980) 5074-5079.
- [34] A. Caneschi, A. Dei, H. Lee, D.A. Shultz, L. Sorace, Inorg. Chem. 40 (2001) 408-411.
- [35] M.K. Smith, N.E. Powers-Riggs, B.H. Northrop, Chem. Commun. 49 (2013) 6167-6169
- [36] M. Yamamura, Y. Okazaki, T. Nabeshima, Chem. Commun. 48 (2012) 5724-5726.
- [37] S. Greatorex, M.A. Halcrow, CrystEngComm 18 (2016) 4695-4698.
- [38] R. Sekiya, Y. Yamasaki, S. Katayama, H. Shio, T. Haino, CrystEngComm 13 (2013) 8404-8407.
- [39] P. Satha, G. Illa, C.S. Purohit, Cryst. Growth Des. 13 (2013) 2636–2641.
- [40] R.J. Sarma, J.B. Baruah, Cryst. Growth Des. 7 (2007) 989-1000.
- [41] B.K. Saha, S. Bhattacharya, CrystEngComm 12 (2010) 2369-2373. [42] S. Aitipamula, P.K. Thallapally, R. Thaimattam, M. Jaskólski, G.R. Desiraju, Org.
- Lett 4 (2002) 921–924
- [43] S. Aitipamula, G.R. Desiraju, M. Jaskólski, A. Nangia, R. Thaimattam, CrystEngComm 5 (2003) 447-450.
- [44] M. Tominaga, K. Katagiri, I. Azumaya, Cryst. Growth Des. 9 (2009) 3692–3696.
- [45] M. Tominaga, K. Katagiri, I. Azumaya, CrystEngComm 12 (2010) 1164–1170.
- [46] M. Tominaga, H. Masu, I. Azumaya, Cryst. Growth Des. 11 (2011) 542-546.
- [47] M. Tominaga, H. Masu, I. Azumaya, CrystEngComm 13 (2011) 5299–5302.
- [48] H. Masu, M. Tominaga, I. Azumaya, Cryst. Growth Des. 13 (2013) 752-758.
- [49] G.M. Sheldrick, SADABS, University of Göttingen, Germany, 1996.
- [50] G.M. Sheldrick, Acta Crystallogr. A71 (2015) 3-8.
- [51] G.M. Sheldrick, Acta Crystallogr. C71 (2015) 3-8.
- [52] K. Biradha, A. Nangia, G.R. Desiraju, C.J. Carrell, H.L. Carrell, J. Mater. Chem. 7 (1997) 1111-1122.
- [53] P.K. Thallapally, A.K. Katz, H.L. Carrell, G.R. Desiraju, CrystEngComm 5 (2003) 87-92
- [54] R.K.R. Jetti, R. Boese, P.K. Thallapally, G.R. Desiraju, Cryst. Growth Des. 3 (2003) 1033-1040.
- [55] P.K. Thallapally, R.K.R. Jetti, A.K. Katz, H.L. Carrell, K. Singh, K. Lahiri, S. Kotha, R. Boese, G.R. Desiraju, Angew. Chem. Int. Ed. 43 (2004) 1149-1155.
- [56] Y. Salinas, R. Martínez-Máñez, M.D. Marcos, F. Sancenón, A.M. Costero, M. Parra, S. Gil, Chem. Soc. Rev. 41 (2012) 1261-1296.
- [57] A. Das, S. Ghosh, Angew. Chem. Int. Ed. 53 (2014) 2038-2054.
- [58] Z. Hu, B.J. Deibert, J. Li, Chem. Soc. Rev. 43 (2014) 5815-5840.
- [59] X. Sun, Y. Wang, Y. Lei, Chem. Soc. Rev. 44 (2015) 8019-8061.
- [60] R.O. Al-Kaysi, A.M. Müller, R.J. Frisbee, C.J. Bardeen, Cryst. Growth Des. 9
- (2009) 1780-1785. [61] A. Khan, M. Wang, R. Usman, H. Sun, M. Du, C. Xu, Cryst. Growth Des. 17 (2017) 1251-1257.