

A New 3D Metal–organic Frameworks with Tetranuclear Cadmium(II) Clusters: Synthesis, Structure, and Luminescent Property

Zhu, Xiao-Fei; Wang, Ning; Xie, Xiao-Yan; Hou, Rui-Bin; Zhou, De-Feng; Li, Ya-Feng; Hu, Jun;
Li, Xin-Yuan; Liu, He; Nie, Wang

2013

Zhu, X.-F., Wang, N., Xie, X.-Y., Hou, R.-B., Zhou, D.-F., Li, Y.-F., et al. (2013). A New 3D Metal–organic Frameworks with Tetranuclear Cadmium(II) Clusters: Synthesis, Structure, and Luminescent Property. *Chinese Journal of Structural Chemistry*, 33(2), 277-283.

<https://hdl.handle.net/10356/81915>

© 2014 Editorial Board of Chinese Journal of Structural Chemistry. This paper was published in Chinese Journal of Structural Chemistry and is made available as an electronic reprint (preprint) with permission of Editorial Board of Chinese Journal of Structural Chemistry. The published version is available at: [<http://manu30.magtech.com.cn/jghx/EN/>]. One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper is prohibited and is subject to penalties under law.

Downloaded on 29 Nov 2023 20:09:10 SGT

A New 3D Metal-organic Framework with Tetranuclear Cadmium(II) Clusters: Synthesis, Structure, and Luminescent Property^①

ZHU Xiao-Fei^a WANG Ning^{b②} XIE Xiao-Yan^a
HOU Rui-Bin^a ZHOU De-Feng^a LI Ya-Feng^c
HU Jun^a LI Xin-Yuan^a LIU He^a NIE Wang^a

^a (School of Chemistry and Life Science, Changchun
University of Technology, Changchun 130012, China)

^b (School of Materials Science and Engineering, Nanyang
Technological University, Singapore 639798, Singapore)

^c (School of Chemical Engineering, Changchun
University of Technology, Changchun 130012, China)

ABSTRACT A unique metal-organic framework $[\text{Cd}_2(\text{L})_{1.5}(\mu_3\text{-OH})(\text{H}_2\text{O})_2]\cdot 2\text{H}_2\text{O}$ (**1**, H_2L = 2,5-dibenzoylterephthalic acid) has been synthesized under hydrothermal conditions, and characterized by single-crystal X-ray diffractions, elemental analyses, IR spectra and fluorescence spectrum. The compound is of triclinic system, space group $P\bar{1}$, $\text{C}_{33}\text{H}_{27}\text{CdO}_{14}$, $M_r = 870.33$, $a = 12.2939(17)$, $b = 12.5135(9)$, $c = 13.2046(10)$ Å, $\alpha = 115.3190(10)$, $\beta = 96.9140(10)$, $\gamma = 109.7950(10)^\circ$, $V = 1641.6(3)$ Å³, $Z = 2$, $D_c = 1.761$ g/cm³, $F(000) = 862$, $\mu(\text{MoK}\alpha) = 1.366$ mm⁻¹, $R_{\text{int}} = 0.0148$, $R = 0.0240$ and $wR = 0.0639$ for 5995 observed reflections with $I > 2\sigma(I)$. X-ray analysis shows that the title complex exhibits a 3D framework with $(4^{12}\cdot 6^3)$ topology, in which the tetra-nuclear $[\text{Cd}_4(\mu_3\text{-OH})_2]$ clusters act as 6-connected nodes, and the L ligands can be simplified to be linear connectors. Moreover, the thermal stability and fluorescence have been studied in detail.

Keywords: hydrothermal, tetranuclear cluster, 2,5-dibenzoylterephthalic acid, luminescence, crystal structure

1 INTRODUCTION

The design and synthesis of new coordination polymers have been of great interest as their promising potential applications in fluorescence, host-guest chemistry, ferroelectricity, magnetic properties, and catalysis^[1-6]. In general, the construction of charming structure immensely depends on the organic ligands and the coordination geometry of

central metal ions. Therefore, the selection of suitable organic ligands is crucial for self-assembly of special architectures. 1,4-benzenedicarboxylic acid (H_2BDC) with different coordination modes has been successfully employed to the synthesis of intriguing coordination polymers. The research groups of Yaghi and Férey have reported a series of metal organic frameworks (MOFs) based on H_2BDC , such as MOF-5, MOF-71, MIL-47, etc.^[7-9]. In recent

Received 28 January 2013; accepted 13 November 2013 (CCDC 901664)

① This project was supported by the NNSFC (No. 20871023), the Jilin Provincial Science Research Foundation of China (No. 20101549), and Xiaonei Foundation of Changchun University of Technology. The 12th Five-Year Plan for Science & Technology Research sponsored by Department of Education of Jilin Province (Nos. 130 and 146, 2013)

② Corresponding author. Born in 1983, majoring in inorganic chemistry. E-mail: edowise@126.com

years, the organic spacers with suitable functional groups and molecular skeletons have been illustrated to be most critical to fine-tune the coordination motifs. Among the organic ligands, the versatile dicarboxyl complexes, especially the *p*-terephthalic acid ($R = -\text{NO}_2, -\text{CH}_3, -\text{C}(\text{CH}_3)_3, -\text{Br}, -\text{I}, -\text{Cl}, -\text{NH}_2$), have been widely used in the preparation of fascinating coordination polymers^[10-12]. In our previous work^[13-17], we have obtained a series of intriguing architectures by using 4,6-dibenzoylisophthalic acid, which was utilized as excellent bridges in the self-assembly of coordination polymers. Polynuclear metal clusters always have intriguing chemical and/or physical properties, such as magnetism, heterogeneous catalysis and fluorescence, and are always employed as secondary building units (SBUs) to build coordination polymers. Especially, polynuclear d^{10} metal complexes have attracted extensive interest in recent years because of their high transparency in the UV region and photoluminescent properties^[18-19].

In order to further investigate the influence of steric bulk of isophthalic acid on the structure and properties, we choose 2,5-dibenzoylterephthalic acid (H_2L) as a bridging carboxylate ligand. In this paper, we report the synthesis and structural characterization of a new fluorescent coordination polymer $[\text{Cd}_2(\text{L})_{1.5}(\mu_3\text{-OH})(\text{H}_2\text{O})_2]\cdot 2\text{H}_2\text{O}$ (**1**), which exhibits a 3-D open framework with the default **pcu** net ($4^{12}\cdot 6^3$). The fluorescent property and thermal stability of complex **1** have been investigated in detail.

2 EXPERIMENTAL

2.1 Materials and physical measurements

All the chemicals were purchased commercially and used as received without further purification. H_2L was synthesized according to the literature^[20]. The FT-IR spectra were recorded using KBr pellets in the range of $4000\sim 400\text{ cm}^{-1}$ on a Mattson Alpha-Centauri spectrometer. Elemental analyses for C, H and N were performed on a Perkin-Elmer 2400 Ele-

mental Analyzer. Powder X-ray diffraction (PXRD) patterns were collected on a Rigaku $D_{\text{max}} 2000$ X-ray diffractometer equipped with a graphite-monochromatized $\text{Cu-K}\alpha$ radiation ($\lambda = 0.15406\text{ nm}$) and 2θ range from 5 to 50° with a step size of 0.02° . Thermogravimetric analyses (TGA) were performed on a Perkin-Elmer Thermal Analyzer under N_2 atmosphere at a heating rate of $5\text{ }^\circ\text{C}\cdot\text{min}^{-1}$. The luminescent properties and lifetime were measured on a FLS920 Edinburgh Luminescence Spectrometer.

2.2 Synthesis of $[\text{Cd}_2(\text{L})_{1.5}(\mu_3\text{-OH})(\text{H}_2\text{O})_2]\cdot 2\text{H}_2\text{O}$ (**1**)

A mixture of $\text{CdCl}_2\cdot 2.5\text{H}_2\text{O}$ (22.8 mg, 0.1 mmol), H_2L (56.10 mg, 0.15 mmol) and H_2O (10 mL) was stirred in a 50 mL beaker for 30 min. The pH was adjusted to 5.0 with 0.1 M NaOH solution. Then it was sealed in a 25 mL Teflon-lined autoclave and heated at $160\text{ }^\circ\text{C}$ for 72 h. After cooling to room temperature at the rate of $3\text{ }^\circ\text{C h}^{-1}$, colorless block crystals were obtained with a $\sim 63\%$ yield based on Cd(II). Anal. Calcd. (%) for $\text{C}_{33}\text{H}_{27}\text{Cd}_2\text{O}_{14}$ (870.33): C, 45.54; H, 3.13. Found (%): C, 45.40; H, 3.03. IR (KBr, cm^{-1}): 3453 (m), 3070 (w), 1675 (s), 1618 (s), 1539 (m), 1483 (m), 1391 (s), 1353 (s), 1176 (w), 1145 (w), 1044 (w), 923 (w), 807 (w), 720 (m), 690 (m), 554(w), 477 (w).

2.3 Structure determination

Single crystals were glued to a fiberglass for X-ray diffraction data collection. Data sets of **1** with approximate dimensions of $0.22\text{mm} \times 0.19\text{mm} \times 0.18\text{mm}$ were collected on a Bruker Smart Apex CCD diffractometer, using a graphite-monochromated $\text{Mo-K}\alpha$ radiation ($\lambda = 0.71073\text{ \AA}$) at 293 K. Absorption correction of **1** was applied by using the SADABS. The structure was solved by direct methods followed by difference Fourier method and refined by full-matrix least-squares on F^2 using the SHELXS-97 package^[21]. A total of 8538 reflections were collected in the range of $1.80 \leq \theta \leq 25.50^\circ$, of which 5995 were unique ($R_{\text{int}} = 0.0148$) and 5619 were observed with $I > 2\sigma(I)$. The O(2W) atom is split over two sites (O(2WA), O(2WB)) with equal site occupation factors of 0.3 and 0.7, respectively.

All non-hydrogen atoms were refined anisotropically. The thermals of Cd(1) and O(5) were refined with DELU restraints. Hydrogen atoms were added according to the theoretical models except for O(10), O(2WA) and O(2WB). H(10) was added by Fourier map while hydrogen atoms on O(2WA) and O(2WB) were not located. The position of hydrogen atom of

μ_3 -OH was refined using DFIX restraints ($d_{\text{O-H}} = 0.82 \text{ \AA}$). The final $R = 0.024$, $wR = 0.0639$ ($w = 1/[\sigma^2(F_o^2) + (0.0691P)^2 + 0.1088P]$, where $P = (F_o^2 + 2F_c^2)/3$), $S = 1.099$, $(\Delta\rho)_{\text{max}} = 0.499$, $(\Delta\rho)_{\text{min}} = -0.857 \text{ e/\AA}^3$ and $(\Delta/\sigma)_{\text{max}} = 0.002$. The selected bond lengths and bond angles are listed in Table 2.

Table 1. Selected Bond Lengths (Å) and Bond Angles (°)

Bond	Dist.	Bond	Dist.	Bond	Dist.
Cd(1)–O(8)	2.1698(19)	Cd(1)–O(4)	2.3104(17)	Cd(2)–O(7)#1	2.2505(18)
Cd(1)–O(10)#1	2.2419(16)	Cd(1)–O(5)	2.5720(18)	Cd(2)–O(4W)	2.301(2)
Cd(1)–O(1)	2.2503(18)	Cd(2)–O(10)	2.2247(16)	Cd(2)–O(3W)	2.307(2)
Cd(1)–O(10)	2.2668(17)	Cd(2)–O(2)	2.2497(18)	Cd(2)–O(5)	2.3653(19)
Angle	(°)	Angle	(°)	Angle	(°)
O(8)–Cd(1)–O(10)#1	101.56(7)	O(8)–Cd(1)–O(5)	168.37(8)	O(7)#1–Cd(2)–O(4W)	85.95(8)
O(8)–Cd(1)–O(1)	85.61(8)	O(10)#1–Cd(1)–O(5)	89.42(6)	O(10)–Cd(2)–O(3W)	95.31(7)
O(10)#1–Cd(1)–O(1)	172.79(7)	O(1)–Cd(1)–O(5)	83.47(8)	O(2)–Cd(2)–O(3W)	90.15(8)
O(8)–Cd(1)–O(10)	107.45(8)	O(10)–Cd(1)–O(5)	77.79(6)	O(7)#1–Cd(2)–O(3W)	85.96(8)
O(10)#1–Cd(1)–O(10)	80.96(6)	O(4)–Cd(1)–O(5)	53.48(6)	O(4W)–Cd(2)–O(3W)	91.35(9)
O(1)–Cd(1)–O(10)	96.27(7)	O(10)–Cd(2)–O(2)	88.51(7)	O(10)–Cd(2)–O(5)	83.15(6)
O(8)–Cd(1)–O(4)	122.01(8)	O(10)–Cd(2)–O(7)#1	99.32(7)	O(2)–Cd(2)–O(5)	97.04(7)
O(10)#1–Cd(1)–O(4)	89.75(6)	O(2)–Cd(2)–O(7)#1	171.54(8)	O(7)#1–Cd(2)–O(5)	87.14(7)
O(1)–Cd(1)–O(4)	87.02(7)	O(10)–Cd(2)–O(4W)	171.77(7)	O(4W)–Cd(2)–O(5)	90.86(8)
O(10)–Cd(1)–O(4)	130.54(6)	O(2)–Cd(2)–O(4W)	86.63(8)	O(3W)–Cd(2)–O(5)	172.59(8)

Symmetry transformation: #1: $-x + 1, -y + 1, -z + 1$

3 RESULTS AND DISCUSSION

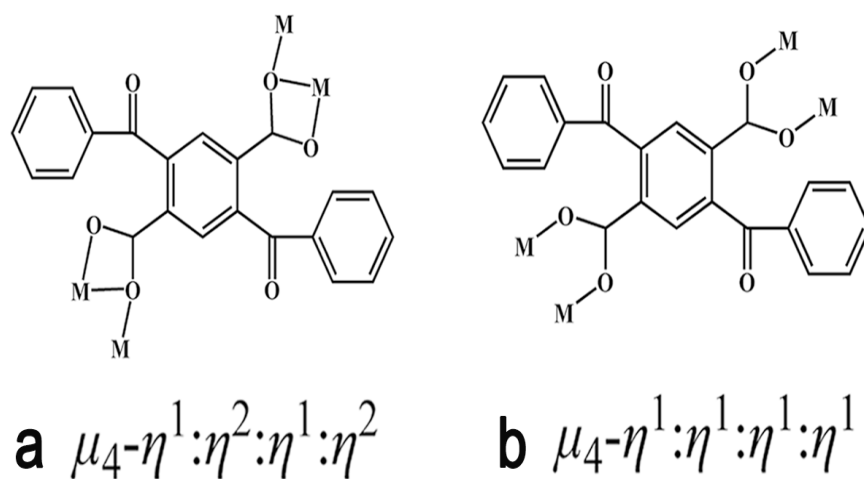
3.1 Structure description of

$[\text{Cd}_2(\text{L})_{1.5}(\mu_3\text{-OH})(\text{H}_2\text{O})_2] \cdot 2\text{H}_2\text{O} (\mathbf{1})$

Single-crystal X-ray diffraction analysis reveals that complex **1** crystallizes in triclinic space group $P\bar{1}$, which features a 3D coordination framework. The asymmetric unit of **1** comprises two crystallographically independent Cd(II) ions, one and a half L ligands, one hydroxide ion, two coordinated water molecules, and two solvent water molecules. As shown in Fig. 1b, there are two kinds of different Cd(II) atoms in the asymmetric unit of **1**. Each Cd(1) atom with distorted octahedral coordination geometry is six-coordinated by four carboxylate oxygen atoms (O(1), O(4), O(5), O(8)) from three different L ligands and two μ_3 -OH groups (O(10), O(10A)), while Cd(2) assumes the same distorted octahedral coordination geometry, but different donor set is coordinated by three carboxylate oxygen atoms

(O(2), O(5), O(7A)) from three different L ligands, one μ_3 -OH group (O(10)) and two coordinated water molecules (O(3W), O(4W)). The Cd–O bond lengths are in the range of 2.1698(19)~2.5720(18) Å (Table 1). In the polymeric structure of **1**, all carboxylic groups are deprotonated and L ligands display two types of bridging modes: $\mu_4-(\eta^1:\eta^2)-(\eta^1:\eta^2)$ -bridging and $\mu_4-(\eta^1:\eta^1)-(\eta^1:\eta^1)$, as shown in Scheme 1a–1b. As illustrated in Fig. 1b, two Cd(1) and two Cd(2) construct a rhombic tetranuclear $[\text{Cd}_4(\mu_3\text{-OH})_2]$ cluster through the bonding of two bridging μ_3 -OH groups and six carboxylate groups of L ligands. The adjacent tetranuclear $[\text{Cd}_4(\mu_3\text{-OH})_2]$ clusters are bridged by L ligands from three different directions to form a 3D architecture. From a topological perspective, the tetranuclear cadmium-oxygen clusters can be seemed as 6-connected nodes, and the L ligands can be simplified as linear connectors, as shown in Fig 2a. Thereafter, the structure of **1** can be described as a six-connected 3D network with the

default **pcu** net ($4^{12}\cdot6^3$) (Fig 2b).



Scheme 1. Two coordination modes (a–b) of L ligand

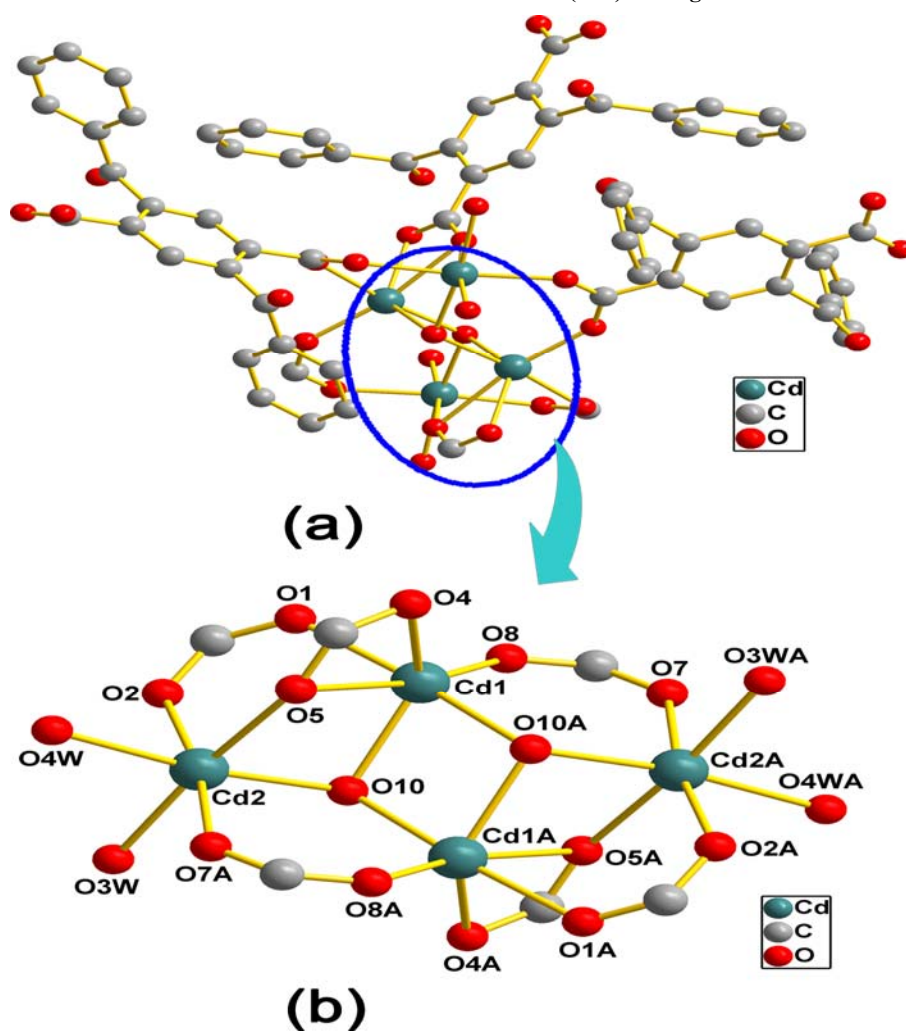


Fig. 1. (a) Coordination environment of the tetranuclear Cd(II) cluster in **1**. (b) Coordination environment of the tetranuclear $[\text{Cd}_4(\mu_3\text{-OH})_2]$ cluster (Symmetry codes: A: $-x + 1, -y + 1, -z + 1$). H atoms and lattice water molecules are omitted for clarity

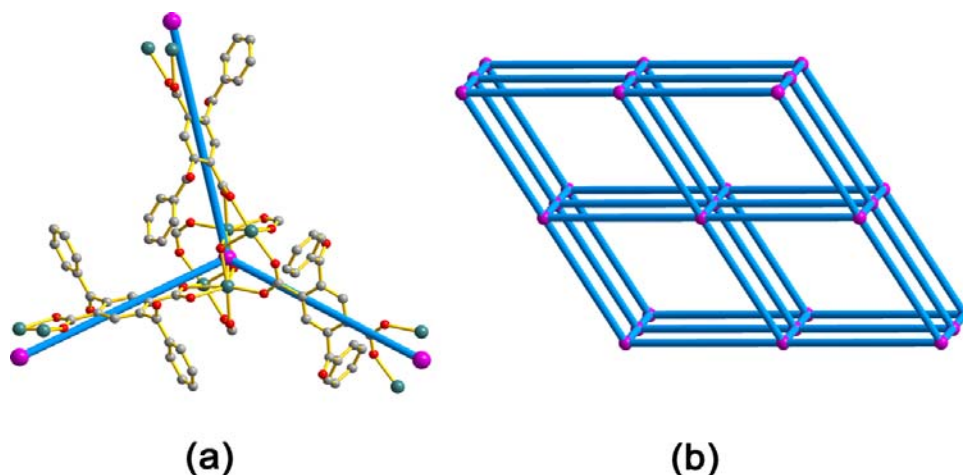


Fig. 2. (b) Tetranuclear $[\text{Cd}_4(\mu_3\text{-OH})_2]$ clusters are defined as 6-connected nodes, and the L ligands can be simplified to be linear connectors. (b) Schematic drawing of the 3D network with the default pcu net ($4^{12}6^3$)

3.2 XRD patterns and thermal analysis

The synthesized product of complex **1** has been characterized by powder X-ray diffraction (PXRD), as shown in Fig. 3. The experimental PXRD pattern is in accordance with the result simulated from the single-crystal data, indicating the high purity of the synthesized sample.

The thermal stability of complex **1** was carried out from room temperature to 900 °C under a nitrogen

atmosphere with a heating rate of 5 °C min⁻¹. As shown in Fig. 4, the TGA curve suggests a weight loss of 8.12% occurring from 70 to 170 °C, corresponding to the removal of lattice and coordinated water molecules (calcd. 8.27%). The residual framework started to decompose gradually at 390 °C and collapsed at 580 °C. The remaining weight indicated that the final product was CdO (found: 14.69%, Calcd.: 14.75%).

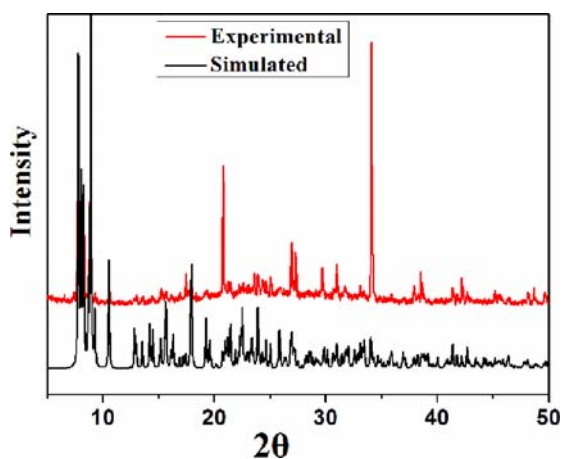


Fig. 3. Measured and calculated powder X-ray diffraction (PXRD) pattern of **1**

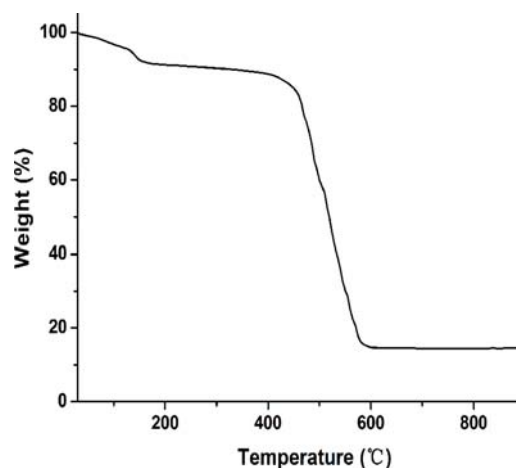


Fig. 4. TGA curve of complex **1**

3.3 Photoluminescence properties

The solid-state photoluminescent spectra of **1** and free H₂L ligand at room temperature are depicted in Fig. 5. The photoluminescent spectra of H₂L ligand displays emission peak at 473 nm upon excitation at 373 nm. The emission can be ascribed to the $\pi^* \rightarrow n$

or $\pi^* \rightarrow \pi$ transitions as previously reported^[22-23]. The emission spectra of complex **1** exhibit emission maxima at 454 nm ($\lambda_{\text{ex}} = 380$ nm). The emission peak of complex **1** is similar to that of the free H₂L ligand. Since the Cd(II) ions are difficult to oxidize or reduce due to their d^{10} configuration, the emission

shift is neither metal-to-ligand charge transfer (MLCT) nor ligand-to-metal charge transfer (LMCT) in nature^[24-25]. Compared with the emission spectrum of H₂L, the blue shift of emission bands for **1** is

probably due to the deprotonated effect and the coordination interactions of H₂L ligand to Cd(II) ions^[24, 26].

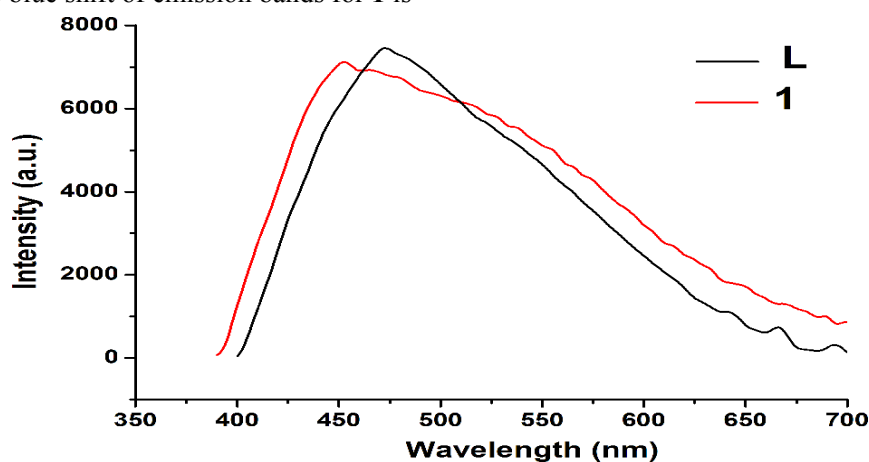


Fig. 5. Solid-state fluorescent emission spectra of free H₂L and complex **1**

4 CONCLUSION

In summary, a luminescent Cd^{II} coordination polymer [Cd₂(L)_{1.5}(μ₃-OH)(H₂O)₂]₂·2H₂O with a 3D metal-organic framework has been obtained through hydrothermal reactions, which exhibits 6-connected pcu topology with a point symbol of (4¹²-6³). The

μ₃-OH group in the crystal structure gives rise to the formation of a tetranuclear [Cd₄(μ₃-OH)₂] cluster, which is further extended into a 3D net through the bridging carboxylate ligand 2,5-dibenzoylterephthalic acid. The self-assembly of this compound extended the application of hydrothermal technique in luminescent coordination polymer synthesis.

REFERENCES

- (1) Allendorf, M. D.; Bauer, C. A.; Bhakta, R. K.; Houk, R. J. T. Luminescent metal-organic frameworks. *Chem. Soc. Rev.* **2009**, 38, 1330–1352.
- (2) Kitagawa, S.; Kitaura, R.; Noro, S. I. Functional porous coordination polymers. *Angew. Chem., Int. Ed.* **2004**, 43, 2334–2375.
- (3) Kurmoo, M. Magnetic metal-organic frameworks. *Chem. Soc. Rev.* **2009**, 38, 1353–1379.
- (4) Benelli, C.; Gatteschi, D. Magnetism of lanthanides in molecular materials with transition-metal ions and organic radicals. *Chem. Rev.* **2002**, 102, 2369–2388.
- (5) Zhang, Y.; Zhang, W.; Li, S. H.; Ye, Q.; Cai, H. L.; Deng, F.; Xiong, R. G.; Huang, S. D. Ferroelectricity induced by ordering of twisting motion in a molecular rotor. *J. Am. Chem. Soc.* **2012**, 134, 11044–11049.
- (6) Lee, J.; Farha, O. K.; Roberts, J.; Scheidt, K. A.; Nguyen, S. T.; Hupp, J. T. Metal-organic framework materials as catalysts. *Chem. Soc. Rev.* **2009**, 38, 1450–1459.
- (7) Serre, C.; Millange, F.; Thouvenot, C.; Noguès, M.; Marsolier, G.; Louër, D.; Férey, G. Very large breathing effect in the first nanoporous chromium(III)-based solids: MIL53 or Cr^{III}(OH)·{O₂C-C₆H₄-CO₂}·{HO₂C-C₆H₄-CO₂H}_x. *J. Am. Chem. Soc.* **2002**, 124, 13519–13526.
- (8) Rosi, N. L.; Kim, J.; Eddaoudi, M.; Chen, B.; O'Keeffe, M.; Yaghi, O. M. Rod packings and metal-organic frameworks constructed from rod-shaped secondary building units. *J. Am. Chem. Soc.* **2005**, 127, 1504–1518.
- (9) Barthelet, K.; Marrot, J.; Riou, D.; Férey, G. A breathing hybrid organic-inorganic solid with very large pores and high magnetic characteristics. *Angew. Chem., Int. Ed.* **2002**, 41, 281–284.
- (10) Zhang, K. L.; Gao, H. Y.; Pan, Z. C.; Liang, W.; Diao, G. W. Preparation and characterization of two three-dimensional metal-organic photoluminescent supramolecular networks. *Polyhedron* **2007**, 26, 5177–5184.
- (11) Deng, H. X.; Doonan, C. J.; Furukawa, H.; Ferreira, R. B.; Towne, J.; Knobler, C. B.; Wang, B.; Yaghi, O. M. Multiple functional groups of varying ratios in metal-organic frameworks. *Science* **2010**, 327, 846–850.

- (12) Wen, L. L.; Lu, Z. D.; Lin, J. G.; Tian, Z. F.; Zhu, H. Z.; Meng, Q. J. Syntheses, structures, and physical properties of three novel metal-organic frameworks constructed from aromatic polycarboxylate acids and flexible imidazole-based synthons. *Cryst. Growth Des.* **2006**, *7*, 93–99.
- (13) Zhao, X.; Yu, X. Y.; Chen, T. L.; Luo, Y. H.; Yang, J. J.; Zhang, H. A series of lanthanide compounds based on mixed aromatic carboxylate ligands: syntheses, crystal structures and luminescent properties. *Inorg. Chem. Commun.* **2012**, *20*, 247–251.
- (14) Zhou, Y. H.; Guan, L.; Zhang, H. Synthesis, crystal structure and properties of cobalt(II) and nickel(II) coordination polymers supported by functionalized dicarboxylate ligands. *Polyhedron* **2009**, *28*, 2667–2672.
- (15) Guan, L.; Zhou, Y. H.; Zhang, H. A new 3d coordination framework with helical chains in mixed ligands system: preparation, crystal structure and magnetic property. *Inorg. Chem. Commun.* **2010**, *13*, 985–987.
- (16) Pang, Y.; Tian, D.; Zhu, X. F.; Luo, Y. H.; Zheng, X.; Zhang, H. Copper(II) and nickel(II) coordination polymers assembled from 2,4-dibenzoylisophthalic acid and different *n*-donor co-ligands: syntheses, crystal structures, and magnetic properties. *CrystEngComm* **2011**, *13*, 5142–5151.
- (17) Pang, Y.; Tian, D.; Luo, Y.; Zhu, X.; Zhang, H. Synthesis, structure, and magnetism of a new 2-d copper(II) complex based on two different dicarboxylates. *J. Coord. Chem.* **2011**, *64*, 2002–2009.
- (18) He, Y. H.; Feng, Y. L.; Lan, Y. Z.; Wen, Y. H. Syntheses, structures, and photoluminescence of four d^{10} metal-organic frameworks constructed from 3,5-bis-oxyacetate-benzoic acid. *Cryst. Growth Des.* **2008**, *8*, 3586–3594.
- (19) Cheng, L.; Wang, J. Q.; Gou, S. H. A new three-dimensional uninodal six-connected coordination polymer constructed from butterfly-like ($Cd_4(M_3-OH)_2$) secondary building units: *pcu* net topology and luminescence. *Inorg. Chem. Commun.* **2011**, *14*, 1201–1203.
- (20) Du, D. F.; Jiang, Z. J.; Liu, C. L.; Sakho, A. M.; Zhu, D. S.; Xu, L. Macrocyclic organotin(IV) carboxylates based on benzenedicarboxylic acid derivatives: syntheses, crystal structures and antitumor activities. *J. Org. Chem.* **2011**, *696*, 2549–2558.
- (21) Sheldrick, G. M. *SHELXS 97. Program for the Refinement of Crystal Structure*. University of Gottingen, Germany **1997**.
- (22) Thirumurugan, A.; Natarajan, S. Synthesis, structure and luminescent properties of yttrium benzene dicarboxylates with one- and three-dimensional structure. *J. Chem. Soc., Dalton Trans.* **2004**, *18*, 2923–2928.
- (23) Zhang, L. P.; Ma, J. F.; Yang, J.; Liu, Y. Y.; Wei, G. H. 1D, 2D, and 3D metal-organic frameworks based on bis(imidazole) ligands and polycarboxylates: syntheses, structures, and photoluminescent properties. *Cryst. Growth Des.* **2009**, *9*, 4660–4673.
- (24) Ma, L. F.; Li, C. P.; Wang, L. Y.; Du, M. Zn(II) and Cd(II) coordination polymers assembled from a versatile tecton 5-nitro-1,2,3-benzenetricarboxylic acid and N,N' -donor ancillary coligands. *Cryst. Growth Des.* **2010**, *10*, 2641–2649.
- (25) Liu, H. Y.; Wu, H.; Ma, J. F.; Liu, Y. Y.; Liu, B.; Yang, J. Syntheses, structures, and photoluminescence of zinc(II) coordination polymers based on carboxylates and flexible bis-(pyridyl)-benzimidazole ligands. *Cryst. Growth Des.* **2010**, *10*, 4795–4805.
- (26) Yang, Y.; Du, P.; Ma, J. F.; Kan, W. Q.; Liu, B.; Yang, J. A series of metal-organic frameworks based on different salicylic derivatives and 1,1'-(1,4-butanediyl)bis(imidazole) ligand: syntheses, structures, and luminescent properties. *Cryst. Growth Des.* **2011**, *11*, 5540–5553.