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Note

Syntheses, structures, and photoluminescence of a series of d^{10} coordination complexes from *N*,*N*'-bidentate imidazo[4,5-f][1,10]phenanthroline and benzene-1,3,5-tricarboxylic acid

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1. Introduction

ABSTRACT

Four new d¹⁰ metal-organic complexes, $[Cd(L)(HBTC)(H_2O)]_n$ (1), $[Cd_2Cl(L)_2(BTC)(H_2O)_2]_n$ (2), $[Zn(L)(HBTC)(H_2O)_2]_2 \cdot 2H_2O$ (3) and $[Zn(L)(HBTC)(H_2O)]_n$ (4) were prepared through hydrothermal reactions of L and H₃BTC (L = imidazo[4,5-f][1,10]phenanthroline and H₃BTC = benzene-1,3,5-tricarboxylic acid). These complexes were structurally characterized by elemental analysis, IR spectroscopy, and X-ray single-crystal diffraction. Complexes 1 and 4 are analogous, showing 2D network with the Schläfil symbol of 4.8², which further linked into 3D supramolecular architecture by aromatic π - π interactions. Complex 2 possesses a 1D chain structure. Two neighboring chains of 2 are linked through the π - π interactions into a double chain supramolecular structure. Complex 3 features a dinuclear structure and further forms a 2D layer by π - π interactions. The thermal stabilities and photoluminescent properties of the coordination compounds have also been investigated.

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Recently, metal–organic frameworks (MOFs) have become an area of increasing interest due to their fascinating structures with potential applications in adsorption, catalysis, chirality, fluorescence and magnetism, etc. [1–5]. However, the rational design and syntheses of MOFs with specific topologies and useful properties still remain a significant challenge to chemists. The most effective and facile approach for the preparation of predictable MOFs is the skillful combination of the appropriate organic ligands or building blocks, together with the metal centers with various coordination preferences [6–10]. In this regard, a lot of multidentate N- or O-do-nor ligands have been explored extensively as organic spacers in the construction of desirable frameworks, such as 4,4'-bipyridine, 1,10-phenanthroline (phen), and related species or polycarboxylates [11–20]. In particular, N-donor chelating ligands phen's derivatives such as Pyphen (Dpq) [21], DPPZ (dpdp) [22–24] or TTBT [25] have

been widely used to build MOFs because of its excellent coordinating ability and large conjugated system that may provide potential supramolecular recognition sites for $\pi - \pi$ interactions, but the nitrogen atoms of these large planar molecules can only act as hydrogen acceptors enabling the formation of metal-organic supramolecules. Nevertheless, another kind of building blocks derived from the appropriate modification of phen, such as bidentate imidazo [4,5-f][1,10]phenanthroline (L) [26] or 2-phenyl-1H-1,3,7,8-tetraazacyclopenta[1]phenanthrene (PTCP) [27] ligand has also received considerable attention in which the imidazole rings are both hydrogen donors and hydrogen acceptors. Furthermore, O-donor ligand benzene-1,3,5-tricarboxylic acid (H₃BTC) exhibits a variety of coordination fashions and holds the capability of generating the unusual multidimensional MOFs [28-32]. Additionally, the H₃BTC can also serve as both hydrogen bond donor and hydrogen bond acceptor. In this context, we choose L ligand incorporated with H₃BTC as the building blocks to construct four novel d¹⁰ metal Cd(II) and Zn(II) complexes $[Cd(L)(HBTC)(H_2O)]_n$ (1), $[Cd_2Cl(L)_2(BTC)(H_2O)_2]_n$ (2), $[Zn(L)(HBTC)(H_2O)_2]_2 \cdot 2H_2O(3)$ and $[Zn(L)(HBTC)(H_2O)]_n(4)$. Interestingly, by varying the ratios of the reactants and pH values, four complexes exhibit varied structural dimensionality (from 0D to 3D). The photoluminescent properties of four complexes have also been studied.

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Table 1	
Crystallographic data	for complexes 1-4.

Compound	1	2	3	4
Formula	C ₂₂ H ₁₄ CdN ₄ O ₇	C35H23Cd2ClN8O8	$C_{44}H_{36}Zn_2N_8O_{18}$	C22H14ZnN4O7
Formula mass	558.77	943.86	1095.55	511.74
Space group	$P2_1/n$	ΡĪ	ΡĪ	$P2_1/c$
Crystal size (mm)	$0.39 \times 0.32 \times 0.26$	$0.40 \times 0.32 \times 0.25$	$0.41 \times 0.36 \times 0.30$	$0.33 \times 0.26 \times 0.20$
a (Å)	9.3200(19)	9.6373(19)	8.5875(17)	8.8932(18)
b (Å)	16.041(3)	12.802(3)	9.0836(18)	16.118(3)
c (Å)	14.167(3)	14.049(3)	14.313(3)	14.415(3)
α (°)	90	98.04(3)	82.15(3)	90
β(°)	107.49(3)	91.10(3)	87.49(3)	107.75(3)
γ (°)	90	106.72(3)	73.34(3)	90
V (Å ³)	2019.9(7)	1640.4(6)	1059.5(4)	1967.9(7)
Ζ	4	2	1	4
$M ({ m mm^{-1}})$	1.138	1.447	1.226	1.307
Goodness-of-fit on F ²	1.064	1.163	1.071	1.145
Reflections collected/unique	19041/4559	16114/7446	10263/4729	18286/4422
D_{calc} (Mg m ⁻³)	1.837	1.911	1.717	1.727
θ Range (°)	3.02-27.48	3.15-27.48	3.09-27.48	3.20-27.48
$R (I > 2\sigma(I))$	0.0248, 0.0587	0.0321, 0.0953	0.0292, 0.0772	0.0338, 0.0876
R (all data)	0.0321, 0.0611	0.0405, 0.1042	0.0353, 0.0785	0.0466, 0.1014

2. Experimental

2.1. Materials and general methods

All analytical grade chemicals and solvents were purchased and used as received. The chelating ligand L was synthesized according to the literature [33]. Elemental analyses of carbon, hydrogen and nitrogen were performed on a Perkin-Elmer 240C element analyzer. IR spectra were recorded on a Perkin-Elmer 2400LSII spectrometer within 4000–400 cm⁻¹ using the samples prepared as

Table 2

Selected bond distances (Å) and angles (°) for 1–4.

1			
Cd-N(1)	2.3671(18)	Cd-N(2)	2.3212(19)
Cd-O(1)	2.3030(14)	Cd-O(1W)	2.286(2)
Cd-O(5)A	2.3328(18)	Cd-O(4)B	2.1810(17)
O(1W)-Cd-O(5)A	161.01(7)	N(2)-Cd-N(1)	70.75(6)
O(4)B-Cd-O(1)	111.87(6)	O(4)B-Cd-N(1)	87.78(6)
N(2)-Cd-N(1)	70.75(6)		
2			
Z = Cd(1) - N(1)	2 325(4)	Cd(1) - N(2)	2 326(3)
Cd(2) - N(5)	2,338(3)	Cd(2) - N(6)	2.327(4)
Cd(1) = O(1)	2,428(3)	Cd(1) = O(2)	2.314(3)
Cd(1) = O(1W)	2.268(4)	Cd(2) = O(3)	2.279(3)
Cd(2) = O(2W)	2.271(3)	Cd(2) - O(4)	2.527(3)
Cd(1)-Cl	2.5657(13)	Cd(2)-Cl	2.5130(12)
O(1W) - Cd(1) - N(1)	15043(17)	O(2) - Cd(1) - O(1)	5463(11)
N(2)-Cd(1)-Cl	130.26(9)	O(2) - Cd(1) - Cl	89.53(9)
O(1W) - Cd(1) - N(2)	88.13(14)	O(2W) - Cd(2) - N(5)	160.07(13)
O(3)-Cd(2)-Cl	94.69(8)	N(6) - Cd(2) - Cl	118.01(10)
N(6)-Cd(2)-O(4)	93.77(11)	O(3)-Cd(2)-O(4)	54.36(10)
2			
3 7n N(1)	2 1279(17)	7n N(2)	2 1200(17)
2n - N(1) 7n - O(1)	2.1270(17) 2.0388(14)	$Z_{n-\Omega(2)}$	2.1203(17) 2.3108(16)
2n = O(1)/(2n = O(1)	2.0368(14)	2n = O(2) 7n = O(2W/)	2.0158(10)
$\Omega(1) - 7n - N(1)$	173 65(5)	O(1W) - 7n - N(2)	94 85(6)
N(2) - 2n - O(2)	88 43(6)	O(2W) - 7n - O(2)	84 64(6)
$\Omega(1W) = 7n = \Omega(2W)$	92 34(7)	0(211) 211 0(2)	04.04(0)
0(111) 211 0(211)	52.54(7)		
4	2 201/2)	7 1/2)	2444(2)
Zn-N(1)	2.201(2)	Zn-N(2)	2.141(2)
Zn = O(1)	2.0084(17)	Zn = O(TW)	2.089(2)
$Z_{II} = U(3)$	2.121(2)	LII = U(5)	2.2321(16)
U(1 VV) - 2n - U(3)	1/1.36(9)	U(1) - Zn - IN(1)	90.09(7)
N(2) - 2n - N(1)	/5.64(/)	N(2) - 2n - O(5)	8/.41(/)
U(1) - 2n - U(5)	106.86(7)		

Symmetry code for A: x + 1/2, -y + 1/2, z - 1/2; B: -x + 1/2, y - 1/2, -z + 1/2.

pellets with KBr. Powder XRD patterns of samples **1–4** were collected on a Bruker D8-ADVANCE X-ray diffractometer with graphite monochromated Cu K α radiation (λ = 0.154 nm) and 2 θ ranging from 5° to 40°. Thermogravimetric analysis (TGA) was performed on a TA Instruments with a heating rate of 10 °C min⁻¹ under air atmosphere. The photoluminescent behaviors of the complexes were studied using a Perkin-Elmer LS55 spectrometer.

2.2. Synthesis and characterization

2.2.1. Synthesis of complex **1**

CdCl₂·2H₂O (0.110 g, 0.5 mmol), L (0.110 g, 0.5 mmol) and H₃BTC (0.105 g, 0.5 mmol) were dissolved in distilled water (15 mL), and NaOH aqueous solution was added until the pH value of the system was adjusted to about 5. The resulting solution was sealed in a 23 mL Teflon-lined stainless autoclave and heated at 140 °C for 3 d under autogenous pressure. The reaction system was then cooled slowly to room temperature. The obtained solid is a mixture of yellow block crystals and powder. The crystals of **1** are picked out from the solid mixture in 62% yield based on CdCl₂·2H₂O. IR (KBr, cm⁻¹): 3398 s, 2341 w, 1859 w, 1615 s, 1551 s, 1439 s, 1367 s, 1110 m, 928 m, 759 s, 735 s, 531 m. *Anal.* Calc. for **1** C₂₂H₁₄CdN₄O₇: C, 47.29; H, 2.53; N, 10.03. Found: C, 47.31; H, 2.57; N, 10.02%.

2.2.2. Synthesis of complex 2

CdCl₂·2H₂O (0.110 g, 0.5 mmol), L (0.110 g, 0.5 mmol) and H₃BTC (0.105 g, 0.5 mmol) were dissolved in distilled water (15 mL), and NaOH aqueous solution was added until the pH value of the system was adjusted to about 7. The resulting solution was sealed in a 23 mL Teflon-lined stainless autoclave and heated at 140 °C for 3 d under autogenous pressure. The reaction system was then cooled slowly to room temperature. The obtained product is a mixture of yellow crystals and powder. The crystals of **2** are picked out from the solid mixture in 68% yield based on CdCl₂·2H₂O. IR (KBr, cm⁻¹): 3412 m, 1708 m, 1630 s, 1540 s, 1463 m, 1371 m, 1202 m, 830 s, 754 m, 727 m. 549 m. *Anal.* Calc. for **2** C₃₅-H₂₃Cd₂ClN₈O₈: C, 44.54; H, 2.46; N, 11.87. Found: C, 44.55; H, 2.48; N, 11.85%.

2.2.3. Synthesis of complex 3

An identical procedure with **2** was followed to prepare **3** except CdCl₂·2H₂O was replaced by ZnCl₂·6H₂O. The obtained product is also a mixture of yellow block crystals and powder. The crystals



Fig. 1. (a) Crystal structure of complex **1**, the hydrogen atoms are omitted for clarity. (b) 2D coordination layer of **1**. The L ligands are omitted. (c) Schematic representation of the 2D 4.8^2 network in **1**. The L ligands are omitted and the HBTC linkers are simplified as rods for clarity. (d) The 3D framework of **1** showing the π - π interactions between the adjacent HBTC and L ligands.

of **3** are picked out from the solid mixture in 71% yield based on $ZnCl_2 \cdot 6H_2O$. IR (KBr, cm⁻¹): 3460 s, 3077 s, 1947 w, 1670 s, 1615 s, 1568 s, 1431 s, 1372 s, 1282 s, 1077 s, 942 m, 812 m, 759 m, 732 m, 714 m, 545 m. *Anal.* Calc. for **3** $C_{44}H_{36}Zn_2N_8O_{18}$: C, 48.24; H, 3.31; N, 10.23. Found: C, 48.21; H, 3.34; N, 10.21%.

2.2.4. Synthesis of complex 4

An identical procedure with **1** was followed to prepare **4** except $CdCl_2 \cdot 2H_2O$ was replaced by $ZnCl_2 \cdot 6H_2O$. The obtained product is also a mixture of yellow block crystals and powder. The crystals of **4** are picked out from the solid mixture in 87% yield based on $ZnCl_2 \cdot 6H_2O$. IR (KBr, cm⁻¹): 3331 s, 3027 w, 1694 s, 1600 s, 1547

m,1399 s, 1271 s, 1091 m, 933 m, 832 m, 754 m, 540 m. Anal. Calc. for ${\bf 4}$ C_{22}H_{14}ZnN_4O_7: C, 51.63; H, 2.76; N, 10.95. Found: C, 51.64; H, 2.80; N, 10.96%.

2.3. X-ray crystallography

Single-crystal X-ray diffraction data for complexes **1–4** were recorded on a Rigaku RAXIS-RAPID diffractometer with graphitemonochromated Mo K α radiation (λ = 0.71073 Å) at 292(2) K using the ω scan technique. All the structures were solved by direct methods using the program SHELXS-97 [34] and refined by full-matrix least-squares techniques against F^2 using the SHELXTL-97 [35]



Fig. 2. (a) Crystal structure of complex **2**, the hydrogen atoms are omitted for clarity. (b) The π - π interactions.

crystallographic software package. All of the non-hydrogen atoms were easily found from the different Fourier map and refined anisotropically, whereas the hydrogen atoms of the compounds were placed by geometrical considerations and were added to the structure factor calculation. The detailed crystallographic data and structure refinement parameters for four complexes are summarized in Table 1. Selected bond distances and angles are listed in Table 2.

3. Results and discussion

3.1. Description of crystal structures

3.1.1. Structure description of 1

The molecular structure of **1** is shown in Fig. 1a. The geometry of each Cd(II) ion, comprising of N₂O₄ from one L ligand, one coordination water molecule and three different HBTC ligands, can be described as a slightly distorted octahedron. The bond lengths of Cd–O (2.1810(17)–2.3328(18) Å) and Cd–N (2.3212(19)–2.3671 (18) Å) are similar to previously reported results [36]. The adjacent Cd ions are interconnected through the HBTC anions, which display the tri-monodentate coordination mode, to yield a 2D network with the Schläfli symbol of 4.8² with the shortest Cd···Cd distance is 6.711 Å (Fig. 1b and c). This topological net is very similar to [In(BTC)(H₂O)(phen)] reported in the literature [37]. These independent 2D layers are further formed by aromatic π – π stacking

interactions between the adjacent HBTC and L ligands to stack in a novel 3D architecture, with the shortest centroid-to-centroid distance being 3.599 Å (Fig. 1d). Otherwise, the $O-H\cdots O$, $O-H\cdots N$ and $N-H\cdots O$ hydrogen bonds (see Table S1), forming among L ligands, water molecules and oxygen atoms of the HBTC anions, play a key role during the construction of the 3D supramolecular architecture of **1**.

3.1.2. Structure description of 2

X-ray analysis reveals that **2** contains two crystallographically unique Cd(II) ions, two L ligands, one BTC^{3–} ligands, one μ_2 -Cl ion and two coordinated water molecules. Cd1 and Cd2 are all six coordinated N₂O₃Cl and resides in the distorted octahedral coordination environment: two oxygen atoms (01, 02 or 03, 04) from one BTC³⁻ ligand, O1W or O2W from a coordinated water molecule, and two nitrogen atoms (N1, N2 or N5, N6) from one L ligand (Fig. 2a). The Cd–N, Cd–O and Cd–Cl bond lengths are in the range of 2.325(4)-2.338(3), 2.268(4)-2.527(3) and 2.5130(12)-2.5657(13) Å, respectively. The Cd1...Cd2 distance bridged by the one μ_2 -Cl ion is 4.015 Å. The neighboring dinuclear Cd(II) units are linked by BTC³⁻ in bis-chelating mode to form an infinite 1D chain along the [001] direction with the L ligands are all attached to one side (Cd1... Cd2A 10.038 Å). The neighboring 1D chains interact through π - π stackings between the L ligands (centroidto-centroid distance ca. 3.537 Å, Fig. 2b) to yield a double chain, which is further cross-linked by the strong O-H···O and N-H···O hydrogen-bond interactions between the coordinated water



Fig. 3. (a) Crystal structure of complex **3**, the hydrogen atoms and free water molecule are omitted for clarity. (b) The 2D supramolecular layer in the *ab* plane *via* π - π interactions.

molecules or -NH- groups and carboxylate O atoms, thus leading to the construction of a stable 3D network (Fig. S1). The related hydrogen-bonding geometries with the symmetry codes are given in Table S1.

3.1.3. Structure description of **3**

As shown in Fig. 3a, the crystal structure of 3 consists of a discrete dinuclear [Zn(L)(HBTC)(H₂O)₂]₂. The [Zn(L)(HBTC)(H₂O)₂]₂ dimer comprises two L ligands, two HBTC ligands, four water molecules and two Zn(II) atoms. Each Zn(II) atom in 3 is coordinated by two nitrogen atoms from a chelating L ligand, two coordinated water molecules and two oxygen atoms from two different HBTC ligands in a distorted octahedral geometry. The distances of the Zn-O bond (2.0388(14)-2.3198(16) Å) and Zn-N bonds (2.1209(17) and 2.1278(17) Å) are near to those of reported [38,39]. The adjacent Zn(II) atoms are bridged by two HBTC ligands to form a dimer with Zn · · · Zn distance of 4.684 Å. These discrete dimers are stacked to furnish a 2D supramolecular layer in the ab plane (Fig. 3b) via two types of π - π interactions: one is between L ligands (centroid-to-centroid distance ca. 3.706 Å), and another is between L ligand and HBTC anion (centroid-to-centroid distance ca. 3.729 Å). In addition, the O-H···O, O-H···N and N-H···O hydrogen bonds (Table S1) involving the water molecules, the carboxylic groups of HBTC anions and L ligands further extend the 2D supramolecular arrays into an interesting 3D supramolecular structure (Fig. S2).

3.1.4. Structure description of 4

The X-ray diffraction analysis reveals that complex **4** is of analogous architectures with **1**, exhibiting interesting 3D supramolecular framework. The metal center is in a distorted octahedral geometry and coordinated by two N atoms (Zn–N1 2.201(2) Å and Zn–N2 2.141(2) Å) of one L ligand, one water molecule (Zn–O1W 2.089(2) Å), three oxygen atom (Zn–O1 2.0084(17) Å, Zn–O3A 2.121(2) Å and Zn–O5B 2.2321(16) Å) of three HBTC ligands (Fig. S3). Similar to **1**, adjacent Zn(II) ions are bridged by the carboxylate groups of the HBTC ligands to a 2D 4.8² net in the *bc* plane with the shortest Zn···Zn distance of 6.934 Å. Moreover, there also exist π – π stacking interactions between the HBTC and L ligands (centroid-to-centroid distance ca. 3.539 Å) and intramolecular and intermolecular hydrogen bonds (Table S1), resulting in a 3D supramolecular network.

3.1.5. Structural comparison of 1-4 complexes

From the above structural discussion of the series of metal complexes, we can see that the carboxylate ligand and metal–L coordination can furnish kinds of dimensional supramolecular structures ranging from 0D to 3D networks. Through varying the pH values of reaction system under similar synthetic conditions, four related complexes were successfully obtained and they exhibit some differences in their architectures. Complexes **1** and **4** are isomorphic when pH value of the system was adjusted to about 5. In compound **1** or **4**, the neighboring Cd(II) or Zn(II) atoms are bridged by three HBTC^{2–} carboxylates in monodentate mode, generating a 2D network



Scheme 1. Three different coordination modes of H₃BTC ligand found in the complexes 1 and 4 (type a), 2 (types b) and 3 (type c).



Fig. 4. Solid-state photoluminescent spectra of 1-4 and L ligand at room temperature.

structure. Remarkably, only two of three carboxyl groups of each H₃BTC are deprotonated, and the third protonated one also coordinates to the Cd(II) or Zn(II) center, respectively. Under the same pH value (pH 7), complex **2** adopts a one-dimensional single chain and complex **3** is observed as discrete unit. In complex **2**, H₃BTC is completely deprotonated and two of three carboxylates of each H₃BTC coordinate to the central Cd(II) atom in bidentate mode and the third one remains free of coordination. In complex 3, two neighboring Zn(II) atoms are bridged by two HBTC²⁻ ligands, forming a dimer. In contrast with 1 and 4, two of three carboxyl groups of each H₃BTC are also deprotonated, among of them, one carboxylate coordinates to the central Zn(II) atom in μ_2 -COO⁻ mode and the other is free of coordination. Furthermore, the third protonated one also remains free of coordination. Coordination modes of H₃BTC groups in complexes 1-4 are shown in Scheme 1. In particular, chelating coordination mode of L in **1–4** is different from $[Cd(L_3)(IP)]_n$ [26d].

3.2. Thermal study

In order to substantiate the phase purity of the measured product 1-4, their powder XRD were performed before their TGA and photoluminescent properties were measured. The experimental powder XRD patterns are in good agreement with the corresponding simulated ones (Figs. S4-S7) except for the relative intensity variation because of preferred orientations of the crystals. We examined 1-3 using TGA. (The X-ray crystallographic study revealed that complexes 1 and 4 are isostructural, so 1 represents 4 for detailed TGA) As shown in Figs. S8–S10, the first obvious weight loss of 3.40%, 3.92% and 9.95% for 1-3 are in the range 130-210, 105-219 and 90-240 °C, assigned to the release of the water molecules (calcd. 3.22%, 3.81% and 9.86%). The second sharp weight loss of 75.73%, 67.02% and 78.15% are ascribable to the decompositon of organic ligands $HBTC^{2-}/BTC^{3-}$ and L (calcd. 76.66%, 68.61% and 78.21%) occurring from 280 to 645 °C, 305 to 690 °C and 315 to 630 °C, respectively. The final products may be CdO for 1, 2 and

ZnO for **3**, respectively. Although the compositions of these three complexes are similar, the TGA of them are somewhat different. We believe that different coordinated modes are the main reasons that lead to the difference in their TGA.

3.3. Photoluminescence properties

As we all know, Cd(II) and Zn(II) can produce a variety of complexes that not only exhibit appealing structures but also possess photoluminescence (PL) properties. The PL spectra of four complexes were investigated in the solid state at room temperature. As indicated in Fig. 4, the emission peaks are 553 nm (1), 536 nm (2), 543 nm (3) and 558 nm (4) upon excitation at 365 nm, respectively. By comparison, the four complexes with L ligand shows similar photoluminescent bahavior. In order to understand the nature of these emission bands, the PL properties of free ligands H₃BTC and L were analyzed, showing they exhibit the strongest emission peaks at about 380 nm [21a] and 460 nm [26g] from 300 to 800 nm, respectively. Compared with the PL spectra of free ligand, the emission spectra of four complexes are obviously similar to that of L, which might be attributable to chelating coordination of the planar L ligand in both complexes. The PL emissions of 1-4 also mainly originate from the intraligand fluorescent emissions of L [22]. The reason for different emissive peak positions of four complexes was presumably owing to the differences of coordination mode of complexes.

4. Conclusion

In summary, four novel d¹⁰ metal coordination complexes with different dimensionality based on L and H₃BTC have been prepared and structurally characterized. The results suggest that π - π stackings and hydrogen-bond interactions played important roles in formation of supramolecular structures. At the same time, the structural diversification of coordination complexes may result from the varied pH values. In addition, complexes **1–4** exhibit intense fluorescence emissions and may be candidates for fluorescent materials. The work may provide helpful information for the design and construction of MOFs.

Acknowledgments

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Appendix A. Supplementary material

CCDC 796175, 796176, 796177 and 796178 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via http://www.ccdc.cam.ac.uk/data_request/cif. Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ica.2012.09.007.

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