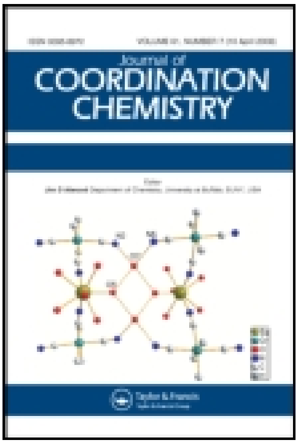
This article was downloaded by: [Renmin University of China]
On: 13 October 2013, At: 10:31
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of Coordination Chemistry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gcoo20

Synthesis, crystal structures, and properties of three helical coordination polymers with quinolinecarboxylate ligand

Hu-Jun Hao [a] [b] , Cui-Wu Lin [b] , Xian-Hong Yin [a] & Feng Zhang [a]

[a] College of Chemistry and Ecological Engineering, Guangxi University for Nationalities , 530006, P.R. China

[b] School of Chemistry and Chemical Engineering, Guangxi University , Nanning 530004, P.R. China

Published online: 03 Mar 2011.

To cite this article: Hu-Jun Hao , Cui-Wu Lin , Xian-Hong Yin & Feng Zhang (2011) Synthesis, crystal structures, and properties of three helical coordination polymers with quinolinecarboxylate ligand, Journal of Coordination Chemistry, 64:6, 965-974, DOI: 10.1080/00958972.2011.558194

To link to this article: http://dx.doi.org/10.1080/00958972.2011.558194

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms &

Journal of Coordination Chemistry
Vol. 64, No. 6, 20 March 2011, 965–974

Taylor & Francis
Taylor & Francis Group

Synthesis, crystal structures, and properties of three helical coordination polymers with quinolinecarboxylate ligand

HU-JUN HAO†‡, CUI-WU LIN‡, XIAN-HONG YIN*†
and FENG ZHANG†

†College of Chemistry and Ecological Engineering, Guangxi University for Nationalities,
530006, P.R. China
‡School of Chemistry and Chemical Engineering, Guangxi University,
Nanning 530004, P.R. China

(*Received 31 July 2010; in final form 8 December 2010*)

Three mixed-ligand complexes [**M**(**L**)(Phen)(H_2O)]$_n \cdot n H_2O$ [**M** = Ni (**1**), Co (**2**), Zn (**3**)], (**L** = 2-methylquinoline-3,4-dicarboxylate dianion; phen = 1,10-phenanthroline) have been synthesized by the reaction of **M**Cl_2 with 2-methylquinoline-3,4-dicarboxylate acid, sodium hydroxide, and 1,10-phenanthroline under hydrothermal conditions and were characterized by single-crystal X-ray diffraction. Complexes **1**–**3** crystallize isomorphously in the orthorhombic space group *P*bca and feature 1-D helical chains. These helical chains are linked to form a 2-D layer through π–π stacking interactions, which are further linked by hydrogen bonds to form a 3-D network. Solid-state properties such as thermal stability and fluorescence emission of the polymeric Zn complex **3** have also been investigated.

Keywords: Crystal structure; Coordination polymers; Helical chains; Fluorescent properties; Quinolinecarboxylate acid

1. Introduction

There has been intense research on metal–organic framework structures (MOFs) [1, 2]. The rapid development of MOFs is due to their intriguing structural topologies and properties, such as adsorption, ion-exchange, non-linear optical (NLO) materials, and heterogeneous catalysis [3–7]. A particularly interesting and challenging area is the synthesis of helical coordination polymers and exploration of their potential utility in asymmetric catalysis and non-linear optics [8, 9]. The synthesis of such species is often based on self-assembly of suitable building blocks to give supramolecular networks constructed by coordination and/or hydrogen bonds or other weak supramolecular interactions, such as π–π stacking interactions. Metal–organic helical structures containing single-, double-, and multi-stranded helices [10–12] have been constructed; the chemistry of coordination polymers with helical structures has been reviewed [13].

The pyridinecarboxylic acid unit is widely used in the synthesis of coordination polymers [14, 15]. In contrast, research on metal quinolinecarboxylate systems is

---

*Corresponding author. Email: yxhphd@163.com

Journal of Coordination Chemistry
ISSN 0095-8972 print/ISSN 1029-0389 online
DOI: 10.1080/00958972.2011.558194

limited [16]. 2-Methylquinoline-3,4-dicarboxylate, which is the close analog of pyridinecarboxylic acid, presents different functional groups and a large conjugated π-system, allowing for diversity in the coordination mode. Chelating bipyridine-like ligands such as 1,10-phenanthroline and 2,2′-bipyridine are important in maintaining the one dimensionality of the coordination polymers and may provide supramolecular recognition sites for π–π aromatic stacking interactions to form interesting supramolecular structures, such as double-stranded helices and molecular zippers [17, 18]. Many helical architectures based on bipy-like and carboxylate ligands have been reported [19].

As a continuation of our research, we report herein three, 1-D coordination polymers with 2-methylquinoline-3,4-dicarboxylate (**L**), including $[Ni(\mathbf{L})(Phen)(H_2O)]_n \cdot nH_2O$ (**1**), $[Co(\mathbf{L})(Phen)(H_2O)]_n \cdot nH_2O$ (**2**), and $[Zn(\mathbf{L})(Phen)(H_2O)]_n \cdot nH_2O$ (**3**). Thermal stability and fluorescence emission of **3** has also been explored.

2. Experimental

2.1. *Materials and analyses*

All reagents and solvents were commercial materials of analytical grade and used without purification, except that 2-methylquinoline-3,4-dicarboxylate was synthesized according to the reported procedure [20]. Elemental analyses for C, H, and N were carried out on a Perkin-Elmer 2400 II elemental analyzer. Infrared spectra on KBr pellets were performed on a BRUKER EQUINOX-55 spectrometer from 4000 to 400 cm^{-1}. Diamond TG/DTA thermal analyzer was used to record simultaneous TG and DTG curves in static air at a heating rate of 10 K min^{-1} from 25°C to 1000°C using platinum crucibles. Fluorescence spectra were recorded on Perkin-Elmer instruments LS55 Luminescence Spectrometer.

2.2. *Syntheses of the complexes*

2.2.1. Synthesis of $[Ni(L)(Phen)(H_2O)]_n \cdot nH_2O$ (1). A solution of phen (0.1982 g, 1 mmol) in 10 mL methanol was added dropwise with stirring at room temperature to a solution of $NiCl_2 \cdot 6H_2O$ (0.2377 g, 1 mmol), NaOH (0.0800 g, 2 mmol), and 2-methylquinoline-3,4-dicarboxylate (0.2312 g, 1 mmol) in 5 mL water. The resulting mixture was sealed in a 23 mL Teflon-lined stainless reactor, kept under autogenous pressure at 120°C for 5 days, and then slowly cooled to room temperature at a rate of 5°C h^{-1}. Green block crystals suitable for X-ray diffraction were isolated directly, washed with ethanol, and dried in air (Yield: 68%, based on Ni). Anal. Calcd for $C_{24}H_{19}N_3O_6Ni$ (%): C, 57.18; H, 3.80; N, 8.34. Found: C, 57.32; H, 3.91; N, 8.32. IR data (KBr pellets, cm^{-1}): 3510–3100w ν(O–H), 1589s ν(C=O).

2.2.2. Synthesis of $[Co(L)(Phen)(H_2O)]_n \cdot nH_2O$ (2). The same synthetic procedure as for **1** was used except that $NiCl_2 \cdot 6H_2O$ was replaced by $CoCl_2 \cdot 6H_2O$ (0.2379 g, 1 mmol). Red block crystals of **2** were obtained in 54% yield based on Co. Anal. Calcd for $C_{24}H_{19}N_3O_6Co$ (%): C, 57.15; H, 3.80; N, 8.33. Found: C, 57.20; H, 3.89; N, 8.30. IR data (KBr pellets, cm^{-1}): 3510–3100w ν(O–H), 1585s ν(C=O).

Table 1. Crystal data and structure refinement of **1**–**3**.

Complex	**1**	**2**	**3**
Empirical formula	$C_{24}H_{19}N_3O_6Ni$	$C_{24}H_{19}N_3O_6Co$	$C_{24}H_{19}N_3O_6Zn$
Formula weight	504.11	504.35	510.81
Crystal system	Orthorhombic	Orthorhombic	Orthorhombic
Space group	*P*bca	*P*bca	*P*bca
Unit cell dimensions (Å)			
a	19.64(2)	19.882(2)	19.949(6)
b	9.115(9)	9.133(1)	9.190(3)
c	23.50(2)	23.539(3)	23.493(7)
V	4207(7)	4274.3(9)	4307(2)
Volume (Z)	8	8	8
Calculated density ($g\,cm^{-3}$)	1.592	1.568	1.576
Absorption coefficient (mm^{-1})	0.972	0.852	1.189
$F(000)$	2080	2072	2096
Reflections collected, Independent	22960/4133	24328/4199	24145/4229
Max. and min. transmission	0.8219/0.7725	0.8549/0.8347	0.7883/0.7474
Data/restraints/parameters	4133/0/308	4199/0/308	4229/0/308
Goodness-of-fit on F^2	0.962	0.955	1.035
Final R indices $[I > 2\sigma(I)]$	$R_1 = 0.0429$, $wR_2 = 0.1228$	$R_1 = 0.0446$, $wR_2 = 0.1230$	$R_1 = 0.0418$, $wR_2 = 0.1142$
R indices (all data)	$R_1 = 0.0673$, $wR_1 = 0.1318$	$R_1 = 0.0862$, $wR_2 = 0.1378$	$R_1 = 0.0645$, $wR_2 = 0.1260$

2.2.3. Synthesis of $[Zn(L)(Phen)(H_2O)]_n \cdot nH_2O$ (3). The same synthetic procedure as for **1** was used except that $NiCl_2 \cdot 6H_2O$ was replaced by $ZnCl_2$ (0.1363 g, 1 mmol). Light yellow block crystals of **3** were obtained in 72% yield based on Zn. Anal. Calcd for $C_{24}H_{19}N_3O_6Zn$ (%): C, 56.43; H, 3.75; N, 8.23. Found: C, 56.40; H, 3.80; N, 8.29. IR data (KBr pellets, cm^{-1}): 3510–3100w ν(O–H), 1572 ν(C=O).

2.3. *X-ray diffraction data collection and refinement*

Suitable single crystals of **1**–**3** were mounted on a Bruker SMART CCD diffractometer equipped with graphite-monochromated Mo-Kα radiation ($\lambda = 0.71073$ Å) at 298 K. All absorption corrections were performed with SADABS [21]. The structures were solved by direct methods and refined with full-matrix least-squares and expanded using Fourier techniques. Anisotropic thermal parameters were assigned to all non-hydrogen atoms. Hydrogens were fixed at calculated positions and refined by using a riding mode. All calculations were performed using SHELXTL-97 [22]. The crystallographic data are summarized in table 1 and selected bond distances and angles for **1**–**3** are listed in table 2. Crystal drawings were produced by Diamond soft.

3. Result and discussion

3.1. *Crystal structures of 1–3*

Single-crystal X-ray diffraction on **1**–**3** reveal that they are extremely similar in structure with the formula $[\mathbf{M}(\mathbf{L})(Phen)(H_2O)]_n \cdot nH_2O$ [**M** = Ni(**1**), Co(**2**), Zn(**3**)]. All the

Table 2. Selected bond lengths (Å) and angles (°) for **1**–**3**.

1			
Ni1–O3	2.113(3)	Ni1–O4	2.135(3)
Ni1–O5	2.039(3)	Ni1–N1	2.054(3)
Ni1–N2	2.066(3)	Ni1–O1A	2.051(3)
O3–Ni1–O4	62.08(10)	N1–Ni1–O1A	93.40(11)
O3–Ni1–O5	89.45(11)	N2–Ni1–O1A	93.89(11)
O4–Ni1–O5	86.09(10)	O5–Ni1–O1A	90.80(11)
N1–Ni1–N2	80.45(13)	O3–Ni1–O1A	100.42(10)
N2–Ni1–O3	93.09(12)	N1–Ni1–O4	104.34(10)
N2–Ni1–O4	90.47(11)	N1–Ni1–O5	95.84(12)
2			
Co1–O3	2.145(2)	Co1–O4	2.193(2)
Co1–O5	2.075(2)	Co1–N1	2.115(3)
Co1–N2	2.129(3)	Co1–O1A	2.064(2)
O3–Co1–O4	60.64(9)	N1–Co1–O1A	94.65(10)
O3–Co1–O5	91.55(10)	N2–Co1–O1A	95.90(10)
O4–Co1–O5	86.31(10)	O5–Co1–O1A	89.93(10)
N1–Co1–N2	78.21(11)	O3–Co1–O1A	100.29(9)
N2–Co1–O3	93.43(10)	N1–Co1–O4	104.86(10)
N2–Co1–O4	90.17(10)	N1–Co1–O5	95.25(11)
3			
Zn1–O3	2.157(2)	Zn1–O4	2.260(3)
Zn1–O5	2.085(2)	Zn1–N1	2.123(3)
Zn1–N2	2.154(3)	Zn1–O1A	2.041(2)
O3–Zn1–O4	59.66(8)	N1–Zn1–O1A	98.05(10)
O3–Zn1–O5	92.82(10)	N2–Zn1–O1A	97.18(10)
O4–Zn1–O5	85.31(9)	O5–Zn1–O1A	90.75(9)
N1–Zn1–N2	78.23(11)	O3–Zn1–O1A	99.40(9)
N2–Zn1–O3	92.23(10)	N1–Zn1–O4	103.47(9)
N2–Zn1–O4	89.58(10)	N1–Zn1–O5	94.34(11)

Symmetry code: A = 2 − *x*, 0.5 + *y*, 0.5 − *z*.

complexes consist of 1-D helical chains formed by distorted MN_2O_4 octahedra linked by the dicarboxylic acid. Therefore, the structure of **3** is described in detail to represent their frameworks.

A single crystal X-ray diffraction study shows **3** crystallizes in the orthorhombic *Pbca* space group. As shown in figure 1, each six-coordinate Zn(II) is in a slightly distorted octahedral geometry, defined by two nitrogens (N1, N2) from one chelating phen, three oxygens (O1, O3, and O4) from carboxylate of two different **L**, and O5 from H_2O. The Zn–O(N) bond distances are in the range 2.041–2.260 Å, with an average value of 2.136 Å. Each quinolinecarboxylate links two zincs, giving a half turn unit of the helical 1-D chain (figure 2). The neighboring Zn–Zn distances are 5.619 Å and the pitches of the helical chains are 9.190 Å. Face-to-face $\pi\cdots\pi$ stacking between two well-overlapping phen molecules from two adjacent chains cause the 2-D supramolecular network [23]. The two adjacent phen molecules from different helical chains are almost parallel (dihedral angle 0.428°). The interchain π–π interactions between the two adjacent phen molecules of two adjacent helical chains are at very short distances (3.530 and 3.531 Å) (figure 3). Coordination water molecules (O5) are situated within a tube-like helix through O5-H5C···O2 and O5-H5D···O3 hydrogen bonding. Lattice water molecule (O6) is stabilized by forming hydrogen bonds (table 3) between

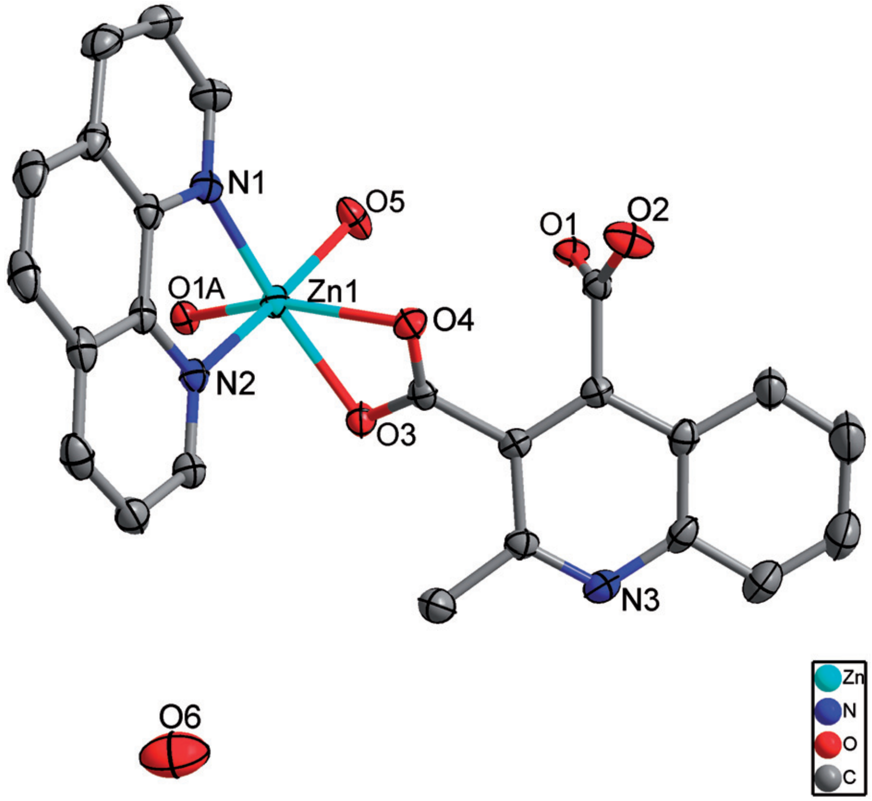


Figure 1. Molecular structure of **3** with 30% thermal ellipsoids. All hydrogens are omitted for clarity. Symmetry codes: A = 2 − x, 0.5 + y, 0.5 − z.

different helical chains. These weak interactions (O6–H6C···O2 = 2.900(4) Å, O6-H6D···N3 = 3.002(5) Å) play a vital role in determining the crystal packing and construction of the extended 3-D supramolecular network.

3.2. *Vibrational spectroscopy*

IR spectra of all three complexes are similar, indicating similar structures. The strong and broad absorptions at 3510–3100 $\mathrm{cm^{-1}}$ are attributed to symmetric O–H stretch of lattice and/or coordinated water in the crystal. The IR spectrum of free ligand shows strong bands at 1712 $\mathrm{cm^{-1}}$, which can be assigned as ν(C=O). In the complexes, the band shifted by 123–140 $\mathrm{cm^{-1}}$ for ν(C=O). The shift suggests that the relevant oxygen of the ligand coordinates to metal.

3.3. *Photoluminescence properties*

Coordination polymers of d^{10} metal ions and conjugated ligands are potential hybrid photoactive materials due to their thermal stability and photoluminescence properties.

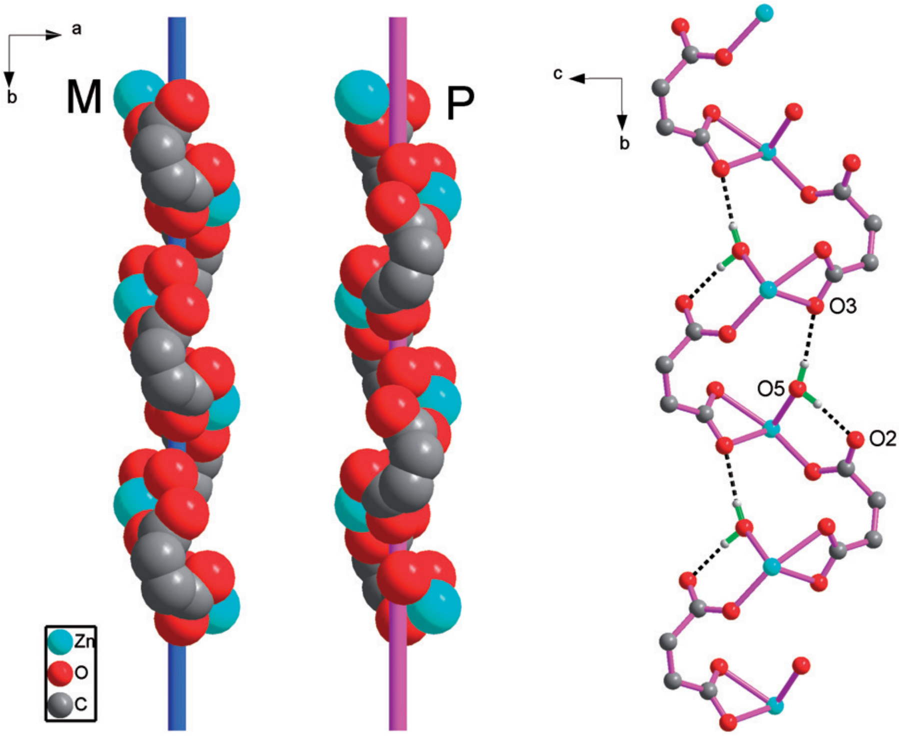


Figure 2. View of the helices in **3**: one is left-handed (left) and the other right-handed (right). Unnecessary atoms are omitted for clarity.

Solid-state emission spectrum of **3** at room temperature is shown in figure 4. The fluorescence spectrum shows that **3** exhibits a broad and strong emission band with a maximum wavelength of 414 nm upon photoexcitation at 347 nm. In addition, free **L** exhibits a broad and strong emission band with a maximum wavelength of 390 nm when excited with light of 348 nm, assigned to intraligand π–π* charge transfer. Further, the free phen generally displays a weak luminescence at *ca* 530 and 365 nm [24] in the solid state at room temperature. Hence, the emission of **3** can be tentatively attributed to coordination of **L**. The red-shift of the emission energy from the free ligand to the complex may be related to the inter-planar π–π stacking interactions, which result in decrease in HOMO–LUMO energy gap of the complex [25].

3.4. *Thermal analysis*

To investigate thermal stabilities, TG and DTG of **3** were examined at a heating rate of $10^\circ C\,min^{-1}$ from 25°C to 1000°C under N_2. As shown in figure 5, the TGA indicates that **3** loses 7.7% of total weight from 25°C to 216°C ($DTG_{max} = 209^\circ C$), corresponding to the removal of the lattice and coordinated water molecules. Good agreement between experimental and calculated values was observed for the weight loss (Calcd 7.05%). The anhydrous complex is stable to 240°C. The products lose 36.2% of the total weight

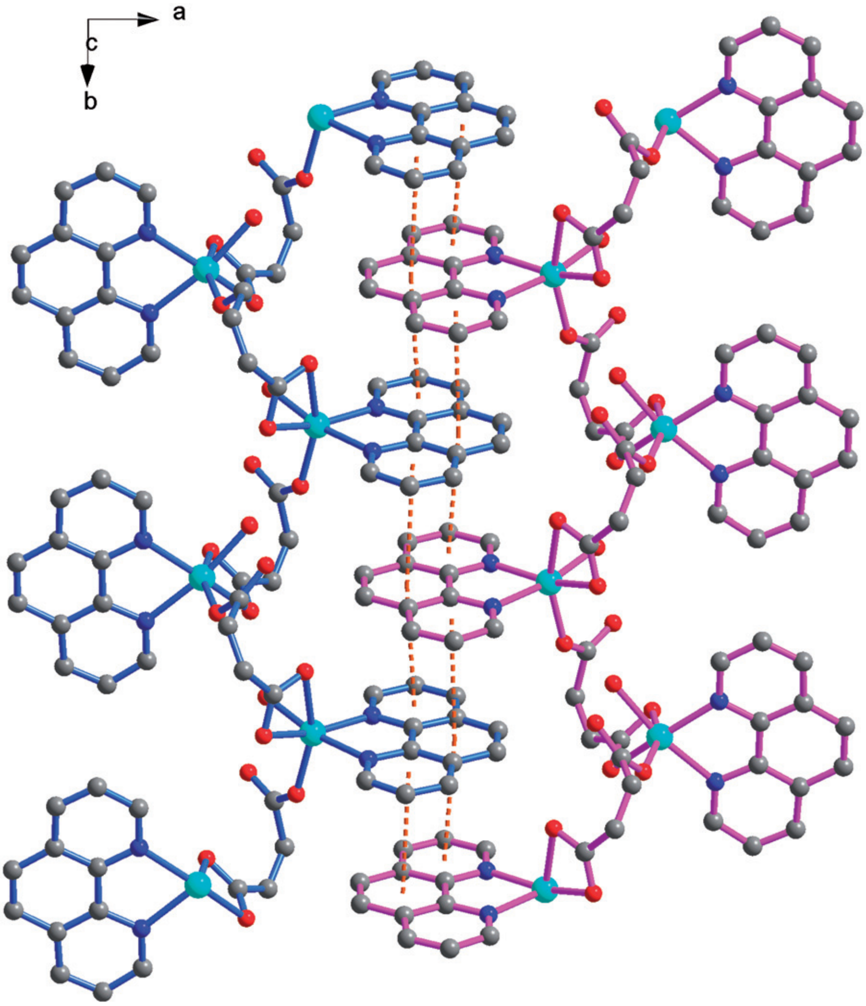


Figure 3. View of the π–π intramolecular stacking interaction in **3**. All hydrogens are omitted for clarity.

Table 3. Distances of the hydrogen bond interactions (Å) for **3**.

Donor–H ··· Acceptor	D–H	H ··· A	D ··· A	D–H ··· A
O5–H5C ··· O2a	0.85	1.77	2.614(4)	174.1
O5–H5D ··· O3b	0.85	2.01	2.853(3)	174.5
O6–H6C ··· O2c	0.85	2.06	2.900(4)	170.8
O6–H6D ··· N3d	0.85	2.16	3.002(5)	171.0

Symmetry code: a = 2 − x, 0.5 + y, 0.5 − z; b = 2 − x, −0.5 + y, 0.5 − z; c = x, 1 + y, z; d = 2 − x, 1 − y, −z.

from 240°C to 470°C, which is related to the endothermic decomposition of phen (Calcd 35.3%; $\mathrm{DTG_{max}} = 265°\mathrm{C}$, 286°C, 314°C). Upon temperature increase, the quinolinecarboxylate decomposes gradually, a series of complicated and consecutive weight losses occur.

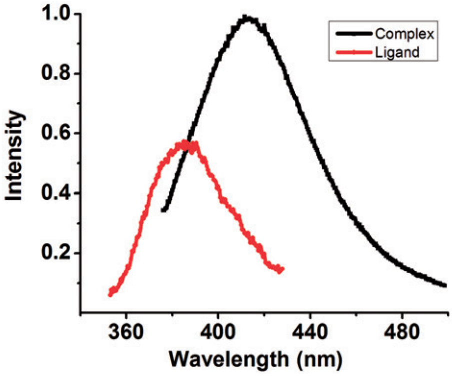


Figure 4. Room-temperature solid-state emission spectrum of **L** and **3**.

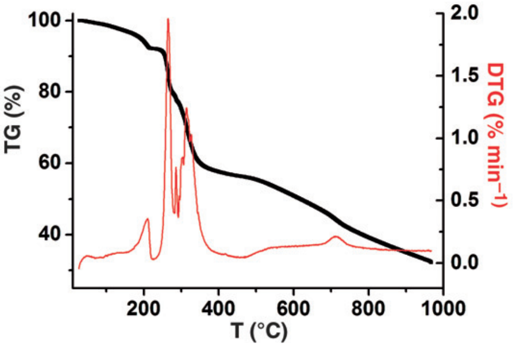


Figure 5. The TG-DTG curves of **3**.

4. Conclusion

Three helical coordination polymers $[\mathbf{M}(\mathbf{L})(\mathrm{Phen})(\mathrm{H_2O})]_n \cdot n\mathrm{H_2O}$ [$\mathbf{M} = \mathrm{Ni}$ (**1**), Co (**2**), Zn (**3**)] were synthesized under hydrothermal conditions. Theoretically, the rigid 2-methylquinoline-3,4-dicarboxylate building blocks can be considered as T-shaped connectors to construct high-dimensional coordination polymers. Nevertheless, it seems not the case here. In fact, the larger conjugated π-systems as well as the steric hindrance of benzene rings and the methyl group weaken the coordination abilities of the quinoline N donor, leading to 1-D helical architectures.

The preparation of **1–3** shows that π–π stacking interactions and hydrogen bonds play important roles in affecting the final structure of the coordination polymers and provides a valuable approach for the construction of other helical complexes containing 2,2'-bipyridyl-like and carboxylate ligands.

Supplementary material

Crystallographic data for the structural analysis have been deposited with the Cambridge Crystallographic Data Centre as Supplementary Publication Nos CCDC

773537–773539. Copies of the data can be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge CB21EZ, UK (Fax: +44 1223 336 033; E-mail: deposit@ccdc.cam.ac.uk).

Acknowledgments

This work was supported by the National Natural Science Foundation of China (20761002), P.R. China, and the Natural Science Foundation of Guangxi (0832080), P.R. China.

References

[1] L. Carlucci, G. Ciani, D.M. Proserpio. *Coord. Chem. Rev.*, **246**, 247 (2003).
[2] N.W. Ockwig, O. Delgado-Friedrichs, M. O'Keeffe, O.M. Yaghi. *Acc. Chem. Res.*, **38**, 176 (2005).
[3] B. Moulton, M.J. Zaworotko. *Chem. Rev.*, **101**, 1629 (2001).
[4] M. Eddaoudi, H.L. Li, O.M. Yaghi. *J. Am. Chem. Soc.*, **122**, 1391 (2000).
[5] S. Noro, S. Kitagawa, M. Kondo, K. Seki. *Angew. Chem. Int. Ed.*, **39**, 2082 (2000).
[6] L.C. Tabares, J.A.R. Navarro, J.M. Salas. *J. Am. Chem. Soc.*, **123**, 383 (2001).
[7] O.R. Evans, W.B. Lin. *Acc. Chem. Res.*, **35**, 511 (2002).
[8] (a) M.J. Hannon, V. Moreno, M.J. Prieto, E. Moldrheim, E. Sletten, I. Meistermann, C.J. Isaac, K.J. Sanders, A. Rodger. *Angew. Chem. Int. Ed.*, **40**, 880 (2001); (b) G.W. Orr, L.J. Barbour, J.L. Atwood. *Science*, **285**, 1049 (1999); (c) O.S. Jung, Y.J. Kim, Y. A. Lee, J.K. Park, H.K. Chae. *J. Am. Chem. Soc.*, **122**, 9921 (2000).
[9] (a) T. Nakano, Y. Okamoto. *Chem. Rev.*, **101**, 4013 (2001); (b) M. Albrecht. *Chem. Rev.*, **101**, 457 (2001); (c) B. Moulton, M.J. Zaworotko. *Chem. Rev.*, **101**, 1629 (2001); (d) Z. Shi, S.H. Feng, S. Gao, L. Zhang, G. Yang, J. Hua. *Angew. Chem. Int. Ed.*, **39**, 2325 (2000).
[10] (a) L. Jiang, T.B. Lu, X.L. Feng. *Inorg. Chem.*, **44**, 7056 (2005); (b) L. Jiang, X.L. Feng, C.Y. Su, X.M. Chen, T.B. Lu. *Inorg. Chem.*, **46**, 2637 (2007); (c) J. Heo, Y.-M. Jeon, C.A. Mirkin. *J. Am. Chem. Soc.*, **129**, 7712 (2007); (d) R. Mondal, T. Basu, D. Sadhukhan, T. Chattopadhyay, M.K. Bhunia. *Cryst. Growth Des.*, **9**, 1095 (2009).
[11] (a) L. Han, H. Valle, X.-H. Bu. *Inorg. Chem.*, **46**, 1511 (2007); (b) D.R. Xiao, E.B. Wang, H.Y. An, Y.G. Li, L. Xu. *Cryst. Growth Des.*, **7**, 506 (2007); (c) A. Jouaiti, M.W. Hosseini, N. Kyritsakas. *Chem. Commun.*, 472 (2003).
[12] (a) P. Byrne, G.O. Lloyd, K.M. Anderson, N. Clarke, J.W. Steed. *Chem. Commun.*, 3720 (2008); (b) W. Zhang, Z.Q. Wang, O. Sato, R.G. Xiong. *Cryst. Growth Des.*, **9**, 2050 (2009).
[13] (a) L. Han, M.C. Hong. *Inorg. Chem. Commun.*, 406 (2005); (b) X.D. Zheng, T.B. Lu. *CrystEngComm.*, **12**, 324 (2010).
[14] (a) S. Kitagawa, R. Matsuda. *Coord. Chem. Rev.*, **251**, 2490 (2007); (b) H.Y. Wu, N. Wang, S.T. Yue, Y.L. Liu. *J. Coord. Chem.*, **62**, 2511 (2009); (c) L. Xue, F. Lou, Y.X. Che, J.M. Zheng. *J. Coord. Chem.*, **61**, 363 (2008).
[15] (a) P.J. Steel. *Acc. Chem. Res.*, **38**, 243 (2005); (b) S.L. James. *Chem. Soc. Rev.*, **32**, 276 (2003).
[16] (a) H.-S. Lin, P.A. Maggard. *Inorg. Chem.*, **46**, 1283 (2007); (b) D. Dobrzyńska, L.B. Jerzykiewicz, J. Jezierska, M. Duczmal. *Cryst. Growth Des.*, **5**, 1945 (2005); (c) X.H. Bu, M.L. Tong, Y.B. Xie, J.R. Li, H.C. Chang, S. Kitagawa, J. Ribas. *Inorg. Chem.*, **44**, 9837 (2005); (d) X.H. Bu, M.L. Tong, J.R. Li, H.C. Chang, L.J. Li, S. Kitagawa. *CrystEngComm.*, **7**, 411 (2005); (e) M.A.M. Abu-Youssef, A. Escuer, V. Langer. *Eur. J. Inorg. Chem.*, 3177 (2006); (f) M.A.M. Abu-Youssef, V. Langer. *Polyhedron*, **25**, 1187 (2006).
[17] X.M. Chen, G.F. Liu. *Chem. Eur. J.*, **8**, 4811 (2002).
[18] G.F. Liu, B.H. Ye, Y.H. Ling, X.M. Chen. *Chem. Commun.*, 1442 (2002).
[19] B.H. Ye, M.L. Tong, X.M. Chen. *Coord. Chem. Rev.*, **249**, 545 (2005).
[20] R.W. Irvine, J.C. Summers, W.C. Taylor. *Aust. J. Chem.*, **36**, 1419 (1983).
[21] G.M. Sheldrick. *SADABS*: *Program for Empirical Absorption Correction of Area Detector*, University of Göttingen, Germany (1996).

[22] G.M. Sheldrick. *SHELXTL V5.1 Software Reference Manual*, Bruker AXS, Inc., Madison, WI, USA (1997).

[23] C. Janiak. *J. Chem. Soc., Dalton Trans.*, 3885 (2000).

[24] X.W. Wang, F.P. Chen, L. Chen, J.Z. Chen, W.J. Jiang, T.J. Cai, Q. Deng. *J. Mol. Struct.*, **842**, 75 (2007).

[25] S.N. Wang. *Coord. Chem. Rev.*, **215**, 79 (2001).