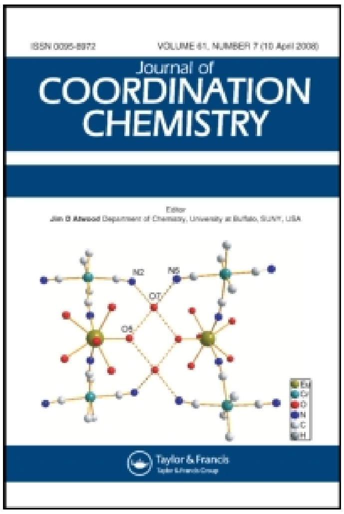
This article was downloaded by:
On: *23 January 2011*
Access details: *Access Details: Free Access*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of Coordination Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455674

Syntheses, structures and properties of di-, trinuclear cobalt compounds

Xiang He[a]; Can-Zhong Lu[a]; Chuan-De Wu[a]
[a] The State Key Laboratory of Structural Chemistry, Fujian Institute of Research on the Structure of Matter, The Chinese Academy of Science, Fuzhou, Fujian 350002, P.R. China

To cite this Article He, Xiang , Lu, Can-Zhong and Wu, Chuan-De(2006) 'Syntheses, structures and properties of di-, trinuclear cobalt compounds', Journal of Coordination Chemistry, 59: 9, 977 — 984

To link to this Article: DOI: 10.1080/00958970500440553

URL: http://dx.doi.org/10.1080/00958970500440553

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

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

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Journal of Coordination Chemistry
Vol. 59, No. 9, 15 June 2006, 977–984

Downloaded At: 12:20 23 January 2011

Syntheses, structures and properties of di-, trinuclear cobalt compounds

XIANG HE, CAN-ZHONG LU* and CHUAN-DE WU

The State Key Laboratory of Structural Chemistry,
Fujian Institute of Research on the Structure of Matter,
The Chinese Academy of Science, Fuzhou, Fujian 350002, P.R. China

(*Received 16 May 2005; in final form 11 August 2005*)

Reactions of bis-(2-hydroxyacetophenone)trimethylenediimine (hapt) with cobalt cations lead to formation of two compounds $[Co^{II}(OAc)_2(hapt)_2Co_2^{III}(Py)_2](ClO_4)_2$ (**1**) and $[Co^{III}(hapt)(OH)]_2 \cdot 2CH_2Cl_2$ (**2**). The structure of **1** is a linear trinuclear mixed-valence compound, while **2** is a binuclear Schiff-base compound bridged by double hydroxyl. Magnetic susceptibility data were measured in the temperature range 300 to 2 K. μ_{eff} values of **1** are almost constant ranging from 4.37 to 5.00 B.M., suggesting that the oxidation states are $Co^{III}(S=0)$–$Co^{II}(S=3/2)$)–$Co^{III}(S=0)$. The magnetic susceptibilities of **2** are negative, typical diamagnetic behavior.

Keywords: Schiff base; cobalt; polynuclear; magnetic property

1. Introduction

The chemistry of transition-metal compounds with Schiff base ligands has been studied extensively [1–6]. Many of these compounds are relevant to the biochemistry of vitamins, enzymes and coenzymes [7, 8]. Cobalt Schiff-base compounds have also drawn considerable attention for their important biological applications [9]. Conjugated tetradentate Schiff-base ligands are chelating reagents that coordinate to metal centers through four equatorial positions of octahedral structures, and serve as models for vitamin B_{12} and its co-enzyme. Studies of polynuclear transition metal compounds give a better understanding of the magnetic properties for these compounds. However, only a limited number of linear trinuclear compounds have been structurally and magnetically characterized. Here we present the syntheses and the structural characterizations of two compounds $[Co^{II}(OAc)_2(hapt)_2Co_2^{III}(Py)_2](ClO_4)_2$ (**1**) and $[Co^{III}(hapt)(OH)]_2 \cdot 2CH_2Cl_2$ (**2**). Compound **1** is a linear trinuclear mixed-valence

---

*Corresponding author. Email: czlu@ms.fjirsm.ac.cn

Journal of Coordination Chemistry
ISSN 0095-8972 print: ISSN 1029-0389 online © 2006 Taylor & Francis
DOI: 10.1080/00958970500440553

cobalt compound, while compound **2** is a Schiff-base binuclear compound bridged by two hydroxides.

2. Experimental

2.1. *Materials and general methods*

All chemicals were reagent grade and were used as received. Elemental analyses were performed with a Vario EL *III* CHNOS Elemental Analyzer. The infrared spectra of KBr pellets were recorded on a FTS-40 spectrophotometer. UV-visible spectra were recorded on a Lambda 35 spectrometer. Variable temperature magnetic susceptibilities in the temperature range 2–300 K in a 10 kOe applied field were measured on a model CF-1 superconducting extracting sample magnetometer with the powdered sample kept in the capsule for weighing.

CAUTION! Perchlorate salts of metal complexes with organic ligands are potentially explosive and should be handled with care.

Downloaded At: 12:20 23 January 2011

2.2. *Synthesis*

Synthesis of the ligand. The Schiff base ligand (hapt) was obtained by reaction of propane-1,3-diamine (1 mmol) with o-hydroxyacetophenone (2 mmol) in methanol solution at room temperature. Yellow precipitates were collected by filtration, washed with cold ethanol and dried under vacuum.

Compound 1, $[Co^{II}(OAc)_2(hapt)_2Co_2^{III}(Py)_2](ClO_4)_2$. 1 mmol $Co(OAc)_2 \cdot 4H_2O$ and 3 mmol pyridine were added to a warm solution of 1 mmol hapt and an appropriate amount of triethylamine in methanol (50 mL). The reaction mixture was stirred overnight at room temperature. To the resulting green solution 2.5 mmol $NaClO_4$ was added and the final mixture was stirred for 1 h. The formed green precipitate was collected and recrystallized from dichloromethane–ethanol (1 : 1 v/v) mixture. The green crystals were isolated by filtration, washed with cold ethanol and dried in vacuum. (Yield 45%, based on Co). Anal. Calcd for $C_{52}H_{54}Cl_2Co_3N_6O_{16}$ (1266.70): C, 49.26 (Calcd 49.31); H, 4.33 (4.30); N, 6.61 (6.63)%. IR (solid KBr pellet/cm^{-1}): 3417m, 3118m, 1598s, 1562s, 1481m, 1416s, 1307s, 1245s, 1145m, 1087s, 863m, 756m, 704m, 623m, 529w, 481w.

Compound 2, $[Co^{III}(hapt)(OH)]_2 \cdot 2CH_2Cl_2$. To a mixture of 1 mmol hapt and an appropriate amount of triethylamine in pure methanol (30 mL) was added 1 mmol $CoCl_2 \cdot 6H_2O$. After the resulting green mixture was stirred at room temperature for about 2 h, green precipitate was obtained. Crystals suitable for X-ray crystallography were obtained by recrystallization from dichloromethane–ethanol (2 : 1 v/v) at room temperature, and were isolated by filtration and washed with cold ethanol and dried in vacuum. (Yield 40%, based on Co). Anal. Calcd for $C_{40}H_{46}Cl_4Co_2N_4O_6$ (938.47): C, 51.23 (Calcd 51.19); H, 5.10 (4.94); N, 6.01 (5.97)%. IR (solid KBr pellet/cm^{-1}): 3551m, 3395m, 1600s, 1537s, 1523s, 1461m, 1400s, 1334s, 1261s, 1232s, 1207m, 1137m, 1033w, 935w, 874m, 860m, 852s, 754s, 615m, 582w, 536m, 460m.

2.3. *X-ray crystallography*

Green crystals of **1** and **2** were carefully selected and glued to thin glass fibers with epoxy resin. Crystal structure measurements were performed on a Siemens SMART CCD diffractometer with graphite-monochromated Mo-Kα radiation ($\lambda = 0.71073$ Å) at room temperature. An empirical absorption correction was applied using SADABS program [10]. The structures were solved using direct methods. The metal atoms were first located, and the carbon, nitrogen, and oxygen atoms were found in the final difference Fourier maps. All the H atoms were placed geometrically. The structures were refined on F^2 by full-matrix least-squares methods using the SHELX97 program package [11]. All non-hydrogen atoms were refined anisotropically. For **1**, a total of 3514 independent reflections were collected and all non-hydrogen atoms were refined with anisotropic thermal parameters for 1513 reflections with $I > 2\sigma(I)$ to final $R_1 = 0.0969$, $wR_2 = 0.1874$. The maximum and minimum peaks on the final difference Fourier map were 1.429 and -0.876 e Å^{-3}, respectively. For **2**, a total of 3242 independent reflections was collected and all non-hydrogen atoms were refined with anisotropic thermal parameters for 2665 reflections with $I > 2\sigma(I)$ to final $R_1 = 0.0511$, $wR_2 = 0.1313$. The maximum and minimum peaks on the final difference Fourier map were 0.857 and -0.493 e Å^{-3}, respectively. Experimental details for the structural determinations of **1** and **2** are presented in table 1. Selected bond distances and angles for **1** and **2** are listed in table 2.

Downloaded At: 12:20 23 January 2011

Table 1. Crystallographic data for compounds **1** and **2**.

Compound	**1**	**2**
Formula	$C_{52}H_{54}Cl_2Co_3N_6O_{16}$	$C_{40}H_{46}Cl_4Co_2N_4O_6$
Formula weight	1266.70	938.47
Crystal size (mm^3)	0.36 × 0.34 × 0.22	0.20 × 0.10 × 0.08
Crystal color	Green	Green
Crystal system	Monoclinic	Triclinic
Space group	$P2(1)/c$	$P\bar{1}$
a (Å)	13.3942(3)	9.8781(19)
b (Å)	14.0607(4)	9.8966(19)
c (Å)	15.1854(3)	11.088(2)
α (°)		105.842(3)
β (°)	107.141(1)	92.312(3)
γ (°)		105.107(3)
V (Å ^{3})	2732.86(11)	999.5(3)
Z	2	1
D_{Calcd} (g cm^{-3})	1.539	1.559
$F(000)$	1302	484
Absorption coefficient (mm^{-1})	1.073	1.150
θ for data collection (°)	2.15 to 25.01	2.62 to 25.16
Reflections collected	8469	5304
Unique reflections	4744	3514
(R(int))	[R(int) = 0.0400]	[R(int) = 0.0487]
Parameters	359	254
GOF	1.093	1.014
R_1, wR_2 [$I > 2\sigma(I)$]	0.0622, 0.1457	0.0969, 0.1874
R_1, wR_2 (all data)	0.0927, 0.1706	0.1952, 0.2356

$R_1 = \sum(|F_o| - |F_c|)/\sum|F_o|$, $wR_2 = [\sum w(F_o^2 - F_c^2)^2/\sum w(F_o^2)^2]^{0.5}$.

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

Compound ***1***					
Co(1)–O(2)	1.896(3)	O(2)–Co(1)–O(1)	82.37(15)	O(3)^{I}–Co(2)–O(1)^{I}	94.74(14)
Co(1)–O(1)	1.903(4)	O(2)–Co(1)–N(3)	92.76(17)	O(2)–Co(2)–O(1)^{I}	108.00(13)
Co(1)–N(3)	1.948(4)	O(1)–Co(1)–N(3)	91.35(17)	O(2)^{I}–Co(2)–O(1)^{I}	72.00(13)
Co(1)–N(1)	1.949(4)	O(2)–Co(1)–N(1)	171.18(18)	O(3)–Co(2)–O(1)	94.74(15)
Co(1)–N(2)	1.958(5)	O(1)–Co(1)–N(1)	90.19(18)	O(3)^{I}–Co(2)–O(1)	85.26(15)
Co(1)–O(4)	1.938(4)	N(3)–Co(1)–N(1)	92.15(19)	O(2)–Co(2)–O(1)	72.00(13)
Co(2)–O(3)	2.020(4)	O(2)–Co(1)–N(2)	90.68(18)	O(2)^{I}–Co(2)–O(1)	108.00(13)
Co(2)–O(2)	2.116(4)	O(1)–Co(1)–N(2)	172.71(18)	O(1)^{I}–Co(2)–O(1)	180.0
Co(2)–O(1)	2.141(3)	N(3)–Co(1)–N(2)	86.8(2)	O(3)–Co(2)–O(3)^{I}	180.0(2)
		N(1)–Co(1)–N(2)	96.9(2)	O(3)–Co(2)–O(2)	92.70(15)
		O(2)–Co(1)–O(4)	89.04(16)	O(3)^{I}–Co(2)–O(2)	87.30(15)
		O(1)–Co(1)–O(4)	90.59(16)	N(1)–Co(1)–O(4)	86.29(18)
		N(3)–Co(1)–O(4)	177.52(17)	N(2)–Co(1)–O(4)	91.48(19)
Compound ***2***					
Co(1)–O(1)	1.880(4)	O(1)–Co(1)–O(2)	87.49(15)	O(2)–Co(1)–N(1)	90.9(3)
Co(1)–O(2)	1.906(4)	O(1)–Co(1)–O(3)	88.01(15)	O(3)–Co(1)–N(1)	174.2(3)
Co(1)–O(3)	1.920(4)	O(2)–Co(1)–O(3)	94.46(16)	O(3)^{I}–Co(1)–N(1)	93.9(3)
Co(1)–O(3)^{II}	1.927(4)	O(1)–Co(1)–O(3)^{II}	92.01(15)	N(2)–Co(1)–N(1)	89.3(3)
Co(1)–N(2)	1.941(8)	O(2)–Co(1)–O(3)^{II}	175.18(8)	O(1)–Co(1)–Co(1)^{II}	90.02(12)
Co(1)–N(1)	1.943(8)	O(3)–Co(1)–O(3)^{II}	80.73(16)	O(2)–Co(1)–Co(1)^{II}	134.92(13)
Co(1)–Co(1)^{II}	2.932(3)	O(1)–Co(1)–N(2)	175.9(2)	O(3)–Co(1)–Co(1)^{II}	40.46(11)
		O(2)–Co(1)–N(2)	88.5(3)	O(3)^{I}–Co(1)–Co(1)^{II}	40.27(11)
		O(3)–Co(1)–N(2)	93.1(3)	N(2)–Co(1)–Co(1)^{II}	93.4(2)
		O(3)#1–Co(1)–N(2)	92.1(3)	N(1)–Co(1)–Co(1)^{II}	134.1(2)
		O(1)–Co(1)–N(1)	90.0(3)		

Symmetry transformations used to generate equivalent atoms: I: $-x, -y+1, -z$; II: $-x+1, -y+3, -z+1$.

Downloaded At: 12:20 23 January 2011

3. Results and discussion

3.1. *Structure*

Single X-ray crystal structure analysis revealed that **1** contains one $[\mathrm{Co_3(hapt)_2(AcO)_2Py_2}]^{2+}$ cation, and two $\mathrm{ClO_4}^-$ anions. The $[\mathrm{Co_3((hapt)_2(AcO)_2)Py_2}]^{2+}$ contains three cobalt atoms, all in Jahn-Teller-distorted octahedral environments. Each terminal cobalt is coordinated by two amine nitrogen atoms and two oxygen atoms from the Schiff-base ligand (Co–N = 1.949(4) and 1.958(5) Å) (Co–O = 1.896(3) and 1.903(4) Å), occupying the four equatorial positions [O(1)–Co(1)–O(2) = 82.37(15)°, O(1)–Co(1)–N(1) = 90.19(18)°, O(2)–Co(1)–N(2) = 90.68(18)°, N(1)–Co(1)–N(2) = 96.9(2)°]. Two axial positions for each terminal cobalt are occupied by pyridine and bridging acetate [Co–N = 1.948(4) Å, Co–O = 1.938(4) Å, N(3)–Co(1)–O(4) = 177.52(17)°]. The central cobalt is coordinated by four bridging oxygen atoms from hapt and two oxygen atoms from acetates (Co–O = 2.020(4)–2.141(3) Å). The dihedral angle between the Co(1)O(1)Co(2) plane and the Co(1)O(2)Co(2) plane is 24.85(2)°. By careful comparison of the coordination environments and bonding parameters of cobalt atoms in **1**, the oxidation states of these metal centers should be different. Based on charge balance requirements and bond-valence sum calculations [12], Co(1) atom should be +3, while Co(2) is +2. The conclusions have also been confirmed by magnetic susceptibilities studies (see below). The Co(1)···Co(2) distance is 3.1025(7) Å, while the Co(1)–O–Co(2) angles of each pair of neighbors are 100.04(15)° and 101.15(16)° respectively for O(1) and O(2). Thus **1**, shown in figure 1, is a linear trinuclear mixed ligand compound. Very few trinuclear cobalt compounds with $\mathrm{Co^{III}}$–$\mathrm{Co^{II}}$–$\mathrm{Co^{III}}$ arrangement are found in the CSD database [1a].

Downloaded At: 12:20 23 January 2011

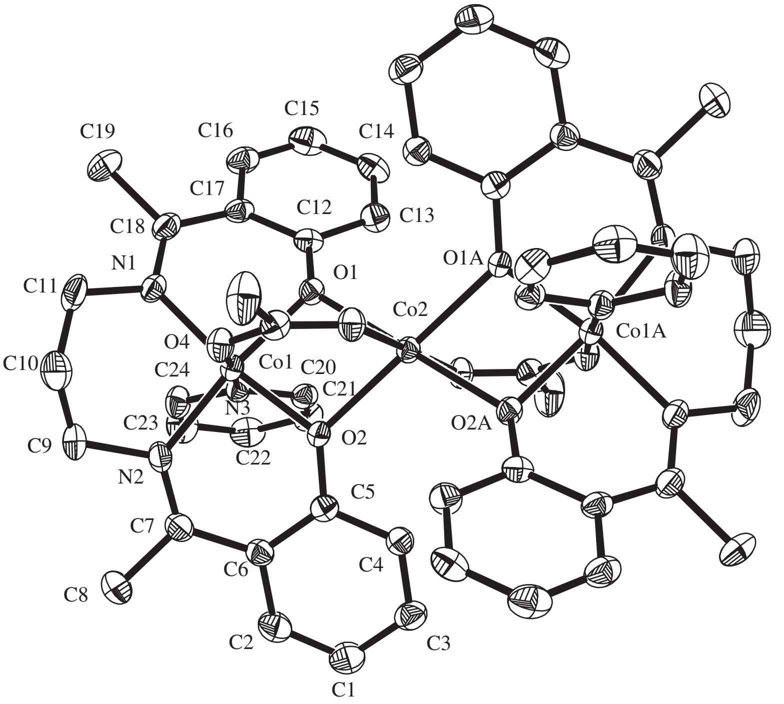


Figure 1. ORTEP representations of the trinuclear unit for **1** (30% probability ellipsoids, for clarity hydrogen atoms and two ClO_4^- were omitted).

As shown in figure 2, the structure of **2** shows that cobalt is in a distorted octahedral environment. In the dimeric unit, two cobalt atoms are held together by μ-hydroxy while each cobalt atom is surrounded by two nitrogen atoms, two oxygen atoms from ligand (Co–N = 1.941(8) and 1.943(8) Å) (Co–O = 1.880(4) and 1.906(4) Å), and two oxygen atoms from two μ-OH groups (Co–O = 1.920(4) and 1.927(4) Å). The four equatorial positions are occupied by two μ-hydroxyl oxygen atoms, one nitrogen atom, and one oxygen atom from ligand [O(1)–Co(1)–O(2) = 87.49(15)°, O(1)–Co(1)–O(3) = 88.01(15)° O(1)–Co(1)–O(3A) = 92.01(15)°, O(1)–Co(1)–N(1) = 90.0(3)°], while two apical positions are occupied by one nitrogen and one oxygen from the ligand [O(1)–Co(1)–N(1) = 176.1(3)°]. Co(1)···Co(1A) distance is 2.932(3) Å. Bond lengths and bond angles in compound **2** are in good agreement with values found in compound **1**.

3.2. *Electronic spectra*

The electronic spectra of the two compounds in dichloromethane were recorded in the range of 200–800 nm. Three absorption peaks (239, 355 and 585 nm) of **1** were observed, while **2** has two absorption peaks (257 and 376 nm). The intense absorption bands at short wavelength, 239 nm for **1** and 257 nm for **2**, may be assigned to intra-ligand π–π^* transitions in the compound. The absorptions at 355 nm for **1** and

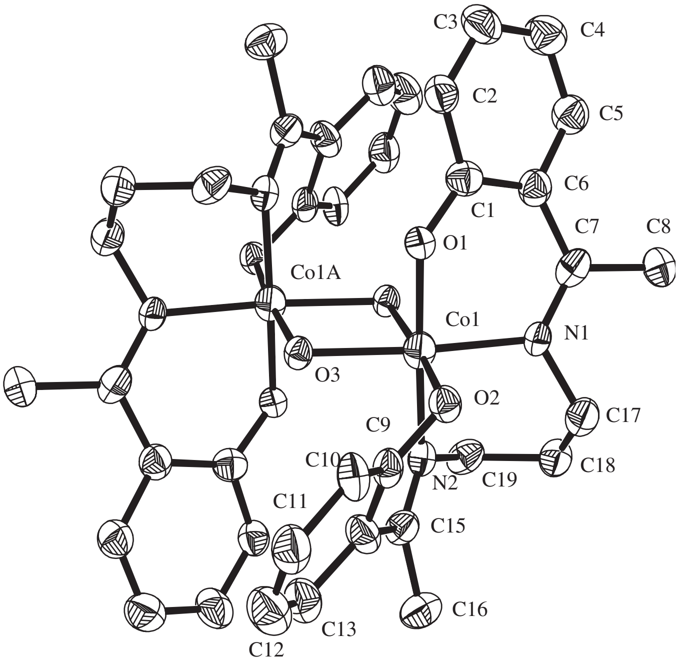


Figure 2. ORTEP representations of the binuclear unit for **2** (30% probability ellipsoids, for clarity hydrogen atoms and solvent were omitted).

Downloaded At: 12:20 23 January 2011

376 nm for **2** may be assigned to Schiff base to metal ion charge transfer bands. A weak band in the visible range at 585 nm for **1** is assigned to a d–d transition [13].

3.3. *IR spectra*

The IR spectrum of **1** displays the characteristic bands of $\nu(C{=}N)$ at $1598\,cm^{-1}$. The value of $\Delta((\nu_{as}(COO)-\nu_s(COO))$ is $146\,cm^{-1}$ in complex **1**, which is closed to the corresponding value in sodium acetate ($144\,cm^{-1}$). Such values indicate that the COO^- groups are coordinated to Co in bridging modes in accord with the X-ray diffraction analysis. The absorption at $1087\,cm^{-1}$ is characteristic for ClO_4^{-1}. The IR spectrum of **2** displays the characteristic bands of $\nu(C{=}N)$ at $1600\,cm^{-1}$, and the ν(O–H) at $3395\,cm^{-1}$ indicated the oxygen of OH is coordinated to the cobalt ions.

3.4. *Magnetic property*

The temperature dependence of the magnetic susceptibilities of **1** have been studied from 300 to 2 K in a 10 kOe applied magnetic field and all data were corrected for diamagnetism of the ligands estimated from Pascal's constants [14]. The magnetic properties of **1** are shown in figure 3. At room temperature, the measured μ_{eff} (effective magnetic moment) is about 4.75 B.M., greater than one high-spin Co^{II} ($S=3/2$) (3.87 B.M.), but much smaller than three spin-only Co^{II} ($S=3/2$) (11.61 B.M.). The results confirm that compound **1** is in the mixed valence state $Co^{III}(S=0)$–$Co^{II}(S=3/2)$–$Co^{III}(S=0)$. The high μ_{eff} value is due to the orbital contribution

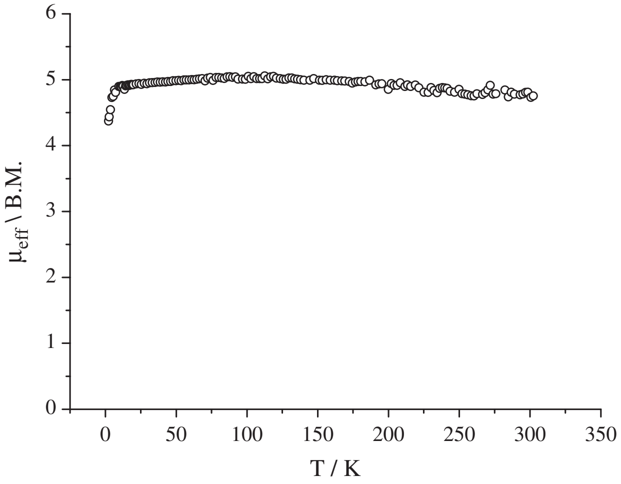


Figure 3. Plots of the experimental temperature dependences of μ_{eff} for **1**.

Downloaded At: 12:20 23 January 2011

as found in many $\mathrm{Co^{II}}$ compounds [15–18]. The magnetic susceptibilities of **2** are negative, typical diamagnetic behavior, indicating that the cobalt in **2** is low spin $\mathrm{Co^{III}}(S=0)$.

Supplementary material

CCDC-244759–244760 contains the supplementary crystallographic data for this article. These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; Fax: (internat.) +44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

Acknowledgements

This work was supported by the 973 program of the MOST (001CB108906), the National Science Foundation of China Science Foundation of China (20425313, 90206040, 20333070, 20303021) The NSF of Fujian and the Chinese Academy of Sciences.

References

[1] (a) M. Rat, R.A.D. Sousa, A. Tomas, Y. Frapart, J.P. Tuchagues, I. Artand. *Eur. J. Inorg. Chem.*, 759 (2003); (b) A.J. Markwell, J.M. Pratt, M.S. Shaikjee, J.G. Toerien. *J. Chem. Soc., Dalton Trans.*, **6**, 1349 (1987); (c) G.A. Morris, H.-Y. Zhou, C.L. Stern, S.T. Nguyen. *Inorg. Chem.*, **40**, 3222 (2001); (d) M. Kondo, K. Nabari, T. Horiba, Y. Irie, M.K. Kabir, R.P. Sarker, E. Shimizu, Y. Shimizu, Y. Fuwa. *Inorg. Chem. Commun.*, **6**, 154 (2003).
[2] N. Mondal, D.K. Dey, S. Mitra, K.M. Abdul Malik. *Polyhedron*, **19**, 2707 (2000).
[3] M. Zhao, C. Zhong, C. Stern, A.G.M. Barrett, B.M. Hoffman. *Inorg. Chem.*, **43**, 3377 (2004).

[4] H. Miyasaka, R. Clerac, W. Wernsdorfer, L. Lecren, C. Bonhomme, K. Sugiura, M. Yamashita. *Angew. Chem. Int. Ed.*, **43**, 2801 (2004).

[5] C. Gonzalez-Arellano, E. Gutierrez-Puebla, M. Iglesias, F. Sanchez. *Eur. J. Inorg. Chem.*, 1955 (2004).

[6] (a) H.-L. Shyu, H.-H. Wei, Y. Wang. *Inorg. Chim. Acta*, **290**, 8 (1999); (b) Y. Song, P. Gamez, O. Roubeau, M. Lutz, A. L. Spek, J. Reedijk. *Eur. J. Inorg. Chem.*, 2924 (2003); (c) H. Torayama, T. Nishide, H. Asada, M. Fujiwara, T. Matsushita. *Polyhedron*, **17**, 105 (1998); (d) C.R. Choudhury, S.K. Dey, R. Karmaker, C.-D. Wu, C.-Z. Lu, M.S.E. Fallah, S. Mitra. *New J. Chem.*, **27**, 1360 (2003).

[7] C.P. Pradeep, T. Htwe, P.S. Zacharias, S.K. Das. *New J. Chem.*, **28**, 735 (2004).

[8] R.K. Parashar, R.C. Sharma, A. Kumar, G. Mohan. *Inorg. Chim. Acta*, **151**, 201 (1998).

[9] D.C. Ware, B.D. Palmer, W.R. Wilson, W.A. Denny. *J. Med. Chem.*, **36**, 1839 (1993).

[10] G.M. Sheldrick. *A Program for the Siemens Area Detector ABSorption Correction*, University of Göttingen, Göttingen, Germany (1997).

[11] G.M. Sheldrick. *SHELXS97 Program for Solution of Crystal Structures*, University of Göttingen, Göttingen, Germany (1997).

[12] I.D. Brown, D. Altermatt. *Acta Crystallogr., Sect. B*, **41**, 244 (1985).

[13] A. Bottcher, T. Takeuchi, K.I. Hardcastle, T.J. Meade, H.B. Gray. *Inorg. Chem.*, **36**, 2498 (1997).

[14] P. Pascal. *Ann. Chim. Phys.*, **19**, 5 (1910).

[15] C. Hermmert, H. Gornitzlca, B. Meunier. *New J. Chem.*, **24**, 949 (2000).

[16] L.J. Charbonniere, A.F. Williams, C. Piguet, G. Bernardinelli, E.R. Minten. *Chem. Eur. J.*, **4**, 485 (1998).

[17] B.-L. Li, H.-B. Liu, Y. Xu, G. Yin, J.-T. Chen, Z. Xu. *J. Mol. Struc.*, **597**, 21 (2001).

[18] M. Mikuriya, N. Nagao, K. Kondo. *Chem. Lett.*, **5**, 516 (2000).

Downloaded At: 12:20 23 January 2011