This article was downloaded by: [The University of Texas at El Paso] On: 27 December 2014, At: 17:52 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



Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry

Publication details, including instructions for authors and subscription information: <u>http://www.tandfonline.com/loi/lsrt20</u>

Synthesis, Structures, and Antimicrobial Studies of Cobalt(III) Complexes with Tridentate Schiff Bases

Wen-Yan Fang^a, Mai Xu^a, Chuan-Gao Zhu^a, Yi-Jun Wei^a & Feng-Wu Wang^a ^a Department of Chemistry and Chemical Engineering, Huainan Normal University, Huainan, P. R. China Published online: 31 Jan 2012.

To cite this article: Wen-Yan Fang, Mai Xu, Chuan-Gao Zhu, Yi-Jun Wei & Feng-Wu Wang (2012) Synthesis, Structures, and Antimicrobial Studies of Cobalt(III) Complexes with Tridentate Schiff Bases, Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry, 42:1, 109-114, DOI: <u>10.1080/15533174.2011.609238</u>

To link to this article: <u>http://dx.doi.org/10.1080/15533174.2011.609238</u>

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 & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions



Synthesis, Structures, and Antimicrobial Studies of Cobalt(III) Complexes with Tridentate Schiff Bases

Wen-Yan Fang, Mai Xu, Chuan-Gao Zhu, Yi-Jun Wei, and Feng-Wu Wang

Department of Chemistry and Chemical Engineering, Huainan Normal University, Huainan, P. R. China

Two new cobalt(III) complexes, $[Co_2(L^1)_2(AEN)(N_3)]$ (1) and $[Co(L^2)(PEA)(N_3)]$ (2) $(L^1 = 2-[1-(2-hydroxyethylimino) ethyl]phenolate, <math>L^2 = 2-[1-(2-phenylaminoethylimino)ethyl]$ phenolate, AEN = 2-aminoethanolate, PEA = *N*-phenylethane-1,2-diamine), have been prepared and characterized by elemental analysis and infrared spectroscopy. The structures of the complexes have been determined by X-ray crystallography. The coordination geometry around cobalt atoms in both complexes is distorted octahedral with one tridentate Schiff base ligand, one bidentate ligand, and one monodentate azide ligand. The antimicrobial activity of the complexes was studied.

Keywords antimicrobial, cobalt complex, crystal structure, Schiff base, synthesis

INTRODUCTION

Schiff bases are a kind of versatile ligands, which are usually synthesized by the condensation of primary amines with carbonyl-containing compounds.^[1-4] The compounds are very important in medicinal and pharmaceutical fields. Many of them show antibacterial, antifungal, and antitumor activity.^[5-8] A number of studies indicated that the coordination of the Schiff bases to the metal atoms can increase the biological properties.^[9, 10] Cobalt complexes derived from symmetrical and nonsymmetrical Schiff bases have received considerable attention in the past few decades for their interesting biological properties.^[11-13] Study on the structures and antimicrobial activities of new cobalt complexes with Schiff bases may help us to search for novel antimicrobial agents. We report in this article the synthesis, crystal structures, and antimicrobial activity of two new cobalt(III) complexes, $[Co_2(L^1)_2(AEN)(N_3)]$ (1) and $[Co(L^2)(PEA)(N_3)]$

(2) (L¹ = 2-[1-(2-hydroxyethylimino)ethyl]phenolate, L² = 2-[1-(2-phenylaminoethylimino)ethyl]phenolate, AEN = 2-aminoethanolate, PEA = *N*-phenylethane-1,2-diamine).

EXPERIMENTAL

Materials and Methods

All the starting materials and organic solvents for synthesis were of analytical grade, purchased commercially, and purified by standard methods prior to use. Infrared spectra were recorded on a Nicolet 55XC Fourier transform spectrophotometer using KBr pellets (4000–400 cm⁻¹). Elemental analysis was carried out on a Perkin-Elmer model 240 analyzer.

Synthesis of H₂L¹

A solution of 2-acetylphenol (0.136 g, 1.0 mmol) in MeOH (20 mL) was added to a solution of 2-aminoethanol (0.061 g, 1.0 mmol) in MeOH (10 mL) under stirring. The mixture was stirred at room temperature for 30 min, and then the solvent was evaporated by distillation. The gummy product was recrystallized from ethanol to give yellow microcrystals of H₂L¹. Yield: 73%. Characteristic IR (cm⁻¹, KBr pellets): 3432 (m), 1623 (s). Anal. Calcd. for C₁₀H₁₃NO₂: C, 67.0; H, 7.3; N, 7.8. Found: C, 67.2; H, 7.4; N, 7.7.

Synthesis of HL²

A solution of 2-acetylphenol (0.136 g, 1.0 mmol) in MeOH (20 mL) was added to a solution of *N*-phenylethane-1,2-diamine (0.136 g, 1.0 mmol) in MeOH (10 mL) under stirring. The mixture was stirred at room temperature for 30 min, and then the solvent was evaporated by distillation. The gummy product was recrystallized from ethanol to give yellow microcrystals of HL². Yield: 81%. Characteristic IR (cm⁻¹, KBr pellets): 3432 (m), 1621 (s). Anal. Calcd. for C₁₆H₁₈N₂O: C, 75.6; H, 7.1; N, 11.0. Found: C, 75.3; H, 7.2; N, 11.2.

Synthesis of $[Co_2(L^1)_2(AEN)(N_3)]$ (1)

To a stirring solution of $\text{CoCl}_2.6\text{H}_2\text{O}$ (23.8 mg, 0.1 mmol) in MeOH (10 mL) was added an equimolar quantity of H_2L^1 (17.9 mg, 0.1 mmol), 2-aminoethanol (6.1 mg, 0.1 mmol), and sodium azide (6.5 mg, 0.1 mmol) in MeOH (10 mL), and a few drops of triethylamine. The mixture was stirred at room

Received 15 July 2011; accepted 27 July 2011.

This project was supported by the Natural Scientific Research Foundation of the Higher Education Institutions of Anhui Province, China (Grant No. KJ2009A008). The authors also thank the support from Professor Yang-Zhong Liu (University of Science and Technology of China).

Address correspondence to Wen-Yan Fang, Department of Chemistry and Chemical Engineering, Huainan Normal University, Huainan 232001, P. R. China. E-mail: wyfang6312@163.com

temperature for 1 h to give a deep brown solution, which was left undisturbed at room temperature to slow evaporation of the solvent. Brown crystals of the complex suitable for X-ray diffraction were obtained after a few days. The crystals were isolated by filtration, and were washed with cold methanol and dried under vacuum. Yield: 53% based on H_2L^1 . IR (cm⁻¹, KBr pellets): 3221 (sh, m), 2034 (vs), 1614 (s), 1596 (s), 1536 (m), 1438 (s), 1332 (s), 1229 (m), 1164 (w), 1136 (w), 1048 (m), 1016 (w), 930 (w), 873 (w), 755 (m), 634 (m), 598 (w), 531 (w), 505 (w), 458 (w). Anal. Calcd. for $C_{22}H_{28}Co_2N_6O_5$: C, 46.0; H, 4.9; N, 14.6. Found: C, 45.7; H, 5.1; N, 14.4.

Synthesis of $[Co(L^2)(PEA)(N_3)]$ (2)

To a stirring solution of CoCl₂.6H₂O (23.8 mg, 0.1 mmol) in MeOH (10 mL) was added an equimolar quantity of HL² (25.4 mg, 0.1 mmol), N-phenylethane-1,2-diamine (13.6 mg, 0.1 mmol), and sodium azide (6.5 mg, 0.1 mmol) in MeOH (10 mL), and a few drops of triethylamine. The mixture was stirred at room temperature for 1 h to give a deep brown solution, which was left undisturbed at room temperature to slow evaporation of the solvent. Brown crystals of the complex suitable for X-ray diffraction were obtained after a few days. The crystals were isolated by filtration, and were washed with cold methanol and dried under vacuum. Yield: 62% based on HL². IR (cm⁻¹, KBr pellets): 3321 (sh, m), 3222 (sh, m), 2039 (vs), 1592 (s), 1536 (m), 1491 (s), 1434 (s), 1335 (s), 1304 (w), 1233 (m), 1200 (w), 1160 (w), 1142 (w), 1128 (w), 1083 (w), 1049 (w), 1028 (m), 861 (w), 804 (w), 757 (m), 727 (w), 705 (m), 605 (w), 534 (w), 505 (w), 477 (w), 447 (w), 423 (w). Anal. Calcd. for C₂₄H₂₉ClCoN₇O: C, 54.8; H, 5.6; N, 18.6. Found: C, 55.0; H, 5.5; N, 18.7.

X-Ray Crystallography

X-ray diffraction data were collected on a Bruker SMART 1000 CCD area detector diffractometer, using graphite monochromatized Mo K α radiation ($\lambda = 0.71073$ Å). The structures were solved by direct methods using the program SHELXS-97.^[14] Refinements were done by the full-matrix least-squares on F^2 using SHELXL-97.^[15] Non-hydrogen atoms were refined with anisotropic displacement parameters. The H atoms attached to the secondary amino groups in (**2**) were located from a difference Fourier map and refined isotropically, with N–H distances restrained to 0.90(1) Å. All other hydrogen atoms were placed in geometrically idealized positions and constrained to ride on their parent atoms. The crystal data, data collection and refinement parameters for the two compounds are presented in Table 1. The coordinate bond lengths and angles are listed in Table 2. Hydrogen bonding information is given in Table 3.

RESULTS AND DISCUSSION

The tridentate Schiff base ligands $(H_2L^1 \text{ and } HL^2)$ were synthesized by the condensation reaction of 2-acetylphenol with 2-aminoethanol and *N*-phenylethane-1,2-diamine, respectively, in 1:1 molar ratio in MeOH. We have tried to prepare the cobalt

TABLE 1Crystal data for (1) and (2)

Compound	(1)	(2)
Chemical formula	C ₂₂ H ₂₈ Co ₂ N ₆ O ₅	C24H29ClCoN7O
Fw	574.4	525.9
T (K)	298(2)	298(2)
Crystal shape/color	block/brown	block/brown
Crystal size (mm ³)	$0.18 \times 0.17 \times 0.17$	$0.27 \times 0.26 \times 0.26$
Crystal system	Triclinic	Monoclinic
Space group	<i>P</i> -1	$P2_1/n$
<i>a</i> (Å)	8.284(2)	9.845(1)
<i>b</i> (Å)	10.959(3)	24.025(3)
c (Å)	14.083(3)	10.457(2)
α (°)	98.236(2)	90
β (°)	101.229(2)	93.632(2)
γ (°)	106.105(2)	90
$V(Å^3)$	1178.2(5)	2468.4(6)
Z	2	4
D_c (g/cm ³)	1.619	1.415
μ (MoK α) (cm ⁻¹)	1.455	0.835
<i>F</i> (000)	592	1096
θ range (°)	2.22/27.00	2.13/27.00
Index ranges	-10/10, -13/13,	-12/12, -29/28,
(h, k, l)	-14/17	-6/13
Independent	4873	5222
reflections	$(R_{\rm int} = 0.0551)$	$(R_{\rm int} = 0.0234)$
Observed	2847	4094
reflections		
$[I \ge 2\sigma(I)]$		
$T(\min)/T(\max)$	0.7797/0.7900	0.8060/0.8122
Data/restraints/ parameters	4873/0/318	5222/2/314
Goodness of fit on F^2	0.970	1.024
R_1, wR_2	0.0674.0.1536	0.0351. 0.0785
$[I > 2\sigma(I)]^a$,	
R_1 , wR_2 (all data) ^a	0.1222, 0.1812	0.0515, 0.0857
Large diff. peak	0.800 and -0.501	0.341 and -0.259
and hole $(e/Å^3)$		
$(\Delta/\sigma)_{\rm max}$	0.000	0.000

 ${}^{a}R_{I} = \sum ||F_{o}| - |F_{c}|| / \sum |F_{o}|, wR_{2} = \left[\sum w (F_{o}^{2} - F_{c}^{2})^{2} / \sum w (F_{o}^{2})^{2} \right]^{1/2}.$

complexes by the reaction of the Schiff base ligands, cobalt chloride, and sodium azide in MeOH; however, no single crystals can be obtained. Occasionally, when additional 2-aminoethanol or *N*-phenylethane-1,2-diamine is added to the reaction mixture, it can obtain well-shaped single crystals during the crystallization. The cobalt complexes are soluble in common organic solvents but insoluble in diethyl ether and water. The analytical data for the compounds are in good agreement with the calculated values.

Selected bond lengths (Å) and angles (°) for (1) and (2)			
(1)			
Co1-O1	1.848(4)	Co1-O2	1.909(4
Co1-O4	1.958(4)	Co1-O5	1.939(4
Co1-N1	1.879(5)	Co1-N4	1.942(6)
Co2-O2	1.924(4)	Co2-O3	1.863(4
Co2-O4	1.908(4)	Co2-O5	1.918(4
Co2-N2	1.874(5)	Co2-N3	1.942(5)
O1-Co1-N1	95.3(2)	O1-Co1-O2	174.4(2)
N1-Co1-O2	89.1(2)	O1-Co1-O5	94.7(2)
N1-Co1-O5	91.0(2)	O2-Co1-O5	81.7(2)
O1-Co1-N4	91.7(2)	N1-Co1-N4	88.5(2)
O2-Co1-N4	91.9(2)	O5-Co1-N4	173.6(2)
O1-Co1-O4	95.5(2)	N1-Co1-O4	165.9(2)
O2-Co1-O4	79.7(2)	O5-Co1-O4	79.0(2)
N4-Co1-O4	100.3(2)	O3-Co2-N2	95.7(2)
O3-Co2-O4	173.9(2)	N2-Co2-O4	89.3(2)
O3-Co2-O5	94.2(2)	N2-Co2-O5	170.0(2)
O4-Co2-O5	80.8(2)	O3-Co2-O2	95.5(2)
N2-Co2-O2	95.3(2)	O4-Co2-O2	80.6(2)
O5-Co2-O2	81.9(2)	O3-Co2-N3	90.1(2)
N2-Co2-N3	93.7(2)	O4-Co2-N3	93.1(2)
O5-Co2-N3	88.2(2)	O2-Co2-N3	168.9(2
(2)			
Co1-O1	1.865(1)	Co1-N1	1.911(2)
Co1-N2	2.030(2)	Co1-N3	1.959(2)
Co1-N4	2.064(2)	Co1-N5	1.939(2)
01-Co1-N1	94.9(1)	O1-Co1-N5	90.8(1)
N1-Co1-N5	90.5(1)	O1-Co1-N3	86.0(1)
N1-Co1-N3	179.1(1)	N5-Co1-N3	89.2(1)
O1-Co1-N2	177.5(1)	N1-Co1-N2	86.8(1)
N5-Co1-N2	87.3(1)	N3-Co1-N2	92.4(1
01-Co1-N4	88.0(1)	N1-Co1-N4	95.1(1
N5-Co1-N4	174.3(1)	N3-Co1-N4	85.2(1
N2-Co1-N4	93.7(1)		

TABLE 2

Infrared Spectroscopy

In the infrared spectra of the free Schiff bases, there are broad bands centered at about 3432 cm⁻¹, assigned to the vibration of the hydroxyl groups, which are absent in the cobalt complexes. The middle and sharp bands at 3337 cm⁻¹ for HL², 3321 cm⁻¹ for (1), and 3321 and 3222 cm⁻¹ for (2) are assigned to the N–H vibrations. The existence of two different peaks in (2) indicates that there are two types of N–H groups (NH and NH₂). The low values of ν (N–H) are attributed to the fact that the NH groups are coordinated to the metal atoms. The intense bands appeared at 2034 cm⁻¹ for (1) and 2039 cm⁻¹ for (2) are attributed to the azide ligands. The strong peaks at 1614 and 1596 cm⁻¹ for (1) and 1592 cm⁻¹ for (2) are attributable to the azomethine groups, ν (C = N), which are shifted toward lower frequencies compared

 TABLE 3

 Distances (Å) and angles (°) involving hydrogen bonding of (1) and (2)

D–H…A	d(H····A)	$d(D \cdots A)$	$d(D \cdots A)$	Angle $(D-H\cdots A)$
(1)				
N3-H3BN6 ^{#1}	0.90	2.13	3.004(8)	165
N3-H3AN4 ^{#2}	0.90	2.62	3.435(9)	151
(2)				
N3-H3AN7 ^{#3}	0.90	2.27	3.071(3)	147
N4-H4A…Cl1	0.90(2)	2.28(2)	3.180(2)	174(3)
N2-H2···Cl1	0.89(2)	2.37(2)	3.256(2)	175(3)

Symmetry transformations used to generate the equivalent atoms: #1: -x, 2-y, 1-z; #2: 1+x, y, z; #3: -x, 2-y, -z.

with those of the free Schiff bases, 1623 cm^{-1} for (1) and 1621 cm^{-1} for (2). The weak bands indicative of the ν (Co–N) and ν (Co–O) appear in the range 520–410 cm⁻¹.

Structure Description of (1)

The molecular structure of (1) is shown in Figure 1. The complex is a dinuclear cobalt(III) compound, with Co---Co distance of 2.561(1) Å. Each Co atom in the complex is hexacoordinated with a N₂O₄ donor set, forming an octahedral coordination. The Co1 atom is coordinated by the O1, N1, and O2 atoms of one Schiff base ligand, and by the O4 atom of another Schiff base ligand, at the equatorial plane, and by the O5 atom of a Schiff base ligand and one azide N atom at the axial positions. The Co2 atom is coordinated by the O3, N2, and O4 atoms of one Schiff base ligand, and by the O5 atom of 2-aminoethanolic ligand, at the equatorial plane, and by the N3 atom of 2-aminoethanolic ligand, and the O2 atom of another Schiff base ligand, at the axial positions. The coordination geometry is distorted in both cases, with the trans and cis angles lying in the ranges of 165.9(2)–174.4(2) and 79.0(2)–100.3(2)°, respectively. The Co-O and Co-N bond distances in the complex are comparable to those observed in similar cobalt(III) complexes with Schiff bases.^[16–18] The azide group is almost linear $[N4-N5-N6 - 174.3(5)^{\circ}]$ and coordinates to the Co atom in a bent fashion $[N5-N4-Co1 = 123.2(5)^{\circ}]$. It is very interesting that there forms three four-membered roof-shaped chelate rings between the two Co atoms.

In the crystal structure of (1), the adjacent two molecules are linked through intermolecular $N-H\cdots N$ hydrogen bonds, forming a dimer, as shown in Figure 2.

Structure Description of (2)

The molecular structure of (2) is shown in Figure 3. The complex is a mononuclear cobalt(III) compound. The Co atom in the complex is hexa-coordinated with a N_5O donor set, forming an octahedral coordination. The Co1 atom is coordinated by the O1, N1, and N2 atoms of the Schiff base ligand, and by



FIG. 1. Molecular structure of (1) with 30% probability thermal ellipsoids.

the N3 atom of the *N*-phenylethane-1,2-diamine ligand, at the equatorial plane, and by the N4 atom of the *N*-phenylethane-1,2-diamine ligand and one azide N atom, at the axial positions. The coordination geometry is distorted, with the *trans* and *cis* angles



FIG. 2. Molecular packing of (1), viewed along the *a*-axis. Intermolecular hydrogen bonds are drawn as dashed lines.

lying in the ranges of 174.3(1)–179.1(1) and 85.2(1)–95.1(1)°, respectively. The Co–O and Co–N bond distances in the complex are comparable to those observed in (1) and other similar cobalt(III) complexes with Schiff bases.^[16–18] The azide group is almost linear [N5–N6–N7 – 175.6(2)°] and coordinates to the Co atom in a bent fashion [N6–N5–Co1 = 118.8(1)°].

In the crystal structure of (2), the Cl anions are linked to the cobalt complex cations through intermolecular N–H…Cl hydrogen bonds. The adjacent molecules are further linked through intermolecular N–H…N hydrogen bonds, forming a dimer, as shown in Figure 4.

Antimicrobial Test

Antimicrobial tests were measured according to the literature method.^[19] The compounds were tested for antimicrobial activity against Bacillus subtilis, Staphylococcus aureus, Pseudomonas fluorescence, Escherichia coli, Pseudomonas aeruginosa, and Bacillus cereus. A standard inoculum was introduced onto the surface of sterile agar plates, and a sterile glass spreader was used for even distribution of the inoculum. The discs measuring 6.0 mm in diameter were sterilized by dry heat at 413 K for 1 h. The sterile discs previously soaked in a known concentration of the test compounds were placed in nutrient agar medium. Solvent and growth controls were maintained. The plates were inverted and incubated for 24 h at 310 K. Penicillin was used as a standard drug. The inhibition zones were measured and compared with the control. The minimum inhibitory concentrations of the compounds are given in Table 4. Minimum inhibitory concentration (MIC) was determined by broth dilution technique. The nutrient broth, which contained logarithmic serially twofold diluted amount of the two compounds and the control, was inoculated with approximately 5×10^5 c.f.u. of actively dividing bacterial cells. The cultures were incubated for 24 h at 310 K and the growth was monitored visually and spectrophotometrically.

The tests show that both complexes have effective activity against the bacteria, and even stronger than the penicillin for *Pseudomonas fluorescence* and *Escherichia coli*. For *Bacillus*



FIG. 3. Molecular structure of (2) with 30% probability thermal ellipsoids.



FIG. 4. Molecular packing of (2), viewed along the *a*-axis. Intermolecular hydrogen bonds are drawn as dashed lines.

TABLE 4
MIC values (μ g/ml) of the antimicrobial activity of (1) and (2)

Compound	Bacillus subtilis	Staphyl- ococcus aureus	Pseudomonas fluorescence	Escherichia coli
(1)	3.8	7.5	25.3	37.8
(2)	11.2	5.3	18.5	22.0
Penicillin	1.4	2.0	>100	>100

subtilis and *Staphylococcus aureus*, the complexes show relatively weak activity than the penicillin.

CONCLUSIONS

Two new cobalt(III) complexes with Schiff bases have been prepared, and their structures were characterized by X-ray crystallography. The complexes show effective antimicrobial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas fluorescence*, and *Escherichia coli*.

SUPPLEMENTARY MATERIALS

CCDC-833462 and 833463 contain the supplementary crystallographic data for this article. These data can be obtained free of charge at http://www.ccdc.cam.ac.uk/conts/retrieving.html or from the Cambridge Crystallographic Data Center, 12 Union Road, Cambridge CB2 1EZ, UK; Fax: +44–1223-336–033; Email: deposit@ccdc.cam.ac.uk.

REFERENCES

- Sebastian, M.; Arun, V.; Robinson, P.P.; Leeju, P.; Varsha, G.; Varghese, D.; Yusuff, K.K.M. Template synthesis and spectral characterization of some Schiff base complexes derived from quinoxaline-2-carboxaldehyde and L-histidine. J. Coord. Chem. 2011, 64, 525.
- Vyas, K.M.; Shah, V.K.; Jadeja, R.N. Synthesis and characterization of Ni(II) complexes of O,N-donor Schiff bases derived from acyl pyrazolone analogues. J. Coord. Chem. 2011, 64, 1069.
- Bayrakci, M.; Ertul, S.; Bas, S.Z.; Demir, I. Synthesis, characterization, and spectroscopic properties of a symmetrical Schiff base ligand and its bimetallic complexes. *Synth. React. Inorg. Met.-Org. Nano-Met. Chem.* 2011, 41, 484.
- Creaven, B.S.; Czegledi, E.; Devereux, M.; Enyedy, E.A.; Kia, A.F.A.; Karcz, D.; Kellett, A.; McClean, S.; Nagy, N.V.; Noble, A.; Rockenbauer, A.; Szabo-Planka, T.; Walsh, M. Biological activity and coordination modes of copper(II) complexes of Schiff base-derived coumarin ligands. *Dalton Trans.* 2010, *39*, 10854.

- Aziz, A.A.A. Mononuclear Ru(II) carbonyl complexes containing quadridentate Schiff bases as N₂O₂ donors: Synthesis, spectral, catalytic properties, and antibacterial activity. *Synth. React. Inorg. Met.-Org. Nano-Met. Chem.* 2011, 41, 384.
- Zhu, Y.; Li, W.-H. Syntheses, crystal structures and antibacterial activities of azido-bridged cobalt(III) complexes with Schiff bases. *Trans. Met. Chem.* 2010, *35*, 745.
- Chohan, Z.H.; Sumra, S.H.; Youssoufi, M.H.; Hadda, T.B. Metal based biologically active compounds: design, synthesis, and antibacterial/antifungal/cytotoxic properties of triazole-derived Schiff bases and their oxovanadium(IV) complexes. *Eur. J. Med. Chem.* **2010**, *45*, 2739.
- Kumar, G.; Kumar, D.; Devi, S.; Johari, R.; Singh, C.P. Synthesis, spectral characterization and antimicrobial evaluation of Schiff base Cu (II), Ni (II) and Co (II) complexes. *Eur. J. Med. Chem.* **2010**, *45*, 3056.
- Xue, L.-W.; Zhao, G.-Q.; Han, Y.-J.; Feng, Y.-X. Synthesis, structures, and antimicrobial activity of Schiff base zinc complexes with thiocyanate and iodide. *Synth. React. Inorg. Met.-Org. Nano-Met. Chem.* 2011, 41, 141.
- Rosu, T.; Pahontu, E.; Maxim, C.; Georgescu, R.; Stanica, N.; Gulea, A. Some new Cu(II) complexes containing an ON donor Schiff base: synthesis, characterization and antibacterial activity. *Polyhedron*, **2011**, *30*, 154.
- Saghatforoush, L.A.; Chalabian, F.; Aminkhani, A.; Karimnezhad, G.; Ershad, S. Synthesis, spectroscopic characterization and antibacterial activity of new cobalt(II) complexes of unsymmetrical tetradentate (OSN2) Schiff base ligands. *Eur. J. Med. Chem.* 2009, *44*, 4490.

- Nejo, A.A.; Kolawole, G.A.; Nejo, A.O. Synthesis, characterization, antibacterial, and thermal studies of unsymmetrical Schiff-base complexes of cobalt(II). *J. Coord. Chem.* **2010**, *63*, 4398.
- Zhang, J.S.; Pan, F.D.; Cheng, H.; Du, W.J. Synthesis, crystal structures, and antibacterial activity of cobalt(III) complexes with bidentate Schiff base ligands. Synth. React. Inorg. Met.-Org. Nano-Met. Chem. 2010, 40, 211.
- Sheldrick, G.M. Phase annealing in SHELX-90: direct methods for larger structures. Acta Crystallogr. 1990, A46, 467.
- Sheldrick, G.M. SHELXL97. Program for the Refinement of Crystal Structures. University of Göttingen, Germany, 1997.
- Mondal, N.; Dey, D.K.; Mitra, S.; Malik, K.M.A. Synthesis and structural characterization of mixed ligand η^{1–}2-hydroxyacetophenone complexes of cobalt(III). *Polyhedron*, **2000**, *19*, 2707.
- Gupta, S.K.; Hitchcock, P.B.; Argal, G.S. The effect of diamine chain length on the formation of Co^{III} Schiff base complexes: the unexpected formation of a neutral complex containing a tetradentate ligand. *Inorg. Chim. Acta*, 2008, *361*, 2139.
- Rahaman, Sk.H.; Chowdhury, H.; Milton, H.L.; Slawin, A.M. Z.; Woollins, J.D.; Ghosh, B.K. Hydrogen bond and π…π interaction based 3D supramolecular architecture of chiral cobalt(III) azido tridentate chelating Schiff base. *Inorg. Chem. Commun.* 2005, *8*, 1031.
- Sinha, D.; Tiwari, A.K.; Singh, S.; Shukla, G.; Mishra, P.; Chandra, H.; Mishra, A.K. Synthesis, characterization and biological activity of Schiff base analogues of indole-3-carboxaldehyde. *Eur. J. Med. Chem.* 2008, 43, 160.