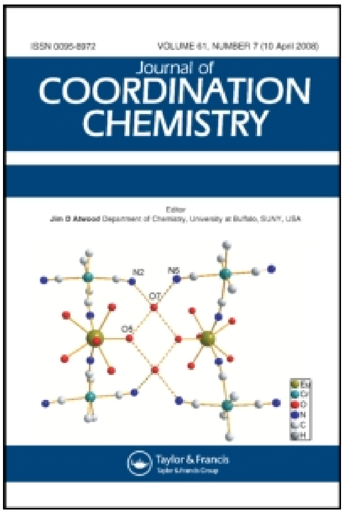

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Synthesis and antimicrobial activities of metal(II) complexes with 2,4-diiodo-6-phenyliminomethyl-phenol

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Synthesis and antimicrobial activities of metal(II) complexes with 2,4-diiodo-6-phenyliminomethyl-phenol

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A bidentate ligand, 2,4-diiodo-6-phenyliminomethyl-phenol (HL) has been synthesized from 3,5-diiodosalicylaldehyde and phenylamine in ethanol. Five mononuclear complexes have been synthesized from 2,4-diiodo-6-phenyliminomethyl-phenol reaction with $CuCl_2 \cdot 2H_2O$, $NiCl_2 \cdot 6H_2O$, $CoCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 4H_2O$, and $ZnCl_2$ in ethanol or tetrahydrofuran (THF). The complexes were characterized by UV, infrared, ESI-MS, and elemental analyses. Complexes bis(2,4-diiodo-6-phenyliminomethyl-phenol)-copper(II) (**1**) and bis(2,4-diiodo-6-phenyliminomethyl-phenol)-zinc(II)-THF (**5**) were characterized by X-ray crystallography. Based on the crystal structure analysis of **1** and **5**, coupled to their spectral similarity with other complexes prepared (**2**, **3**, **4**), we conclude that **2**, **3**, and **4** have similar structures to **1**. The metal(II) in each complex is four-coordinate by two nitrogens and two oxygens from two ligands. All the complexes were assayed for antibacterial (*Bacillus subtilis*, *Staphylococcus aureus*, *Streptococcus faecalis*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Enterobacter cloacae*) activities by the MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide) method. Among the complexes tested, **1** showed the most favorable antimicrobial activity with minimum inhibitory concentrations of 3.125, 6.25, 6.25, 3.125, 3.125, 6.25 $\mu g\,mL^{-1}$ against *B. subtilis*, *S. aureus*, *S. faecalis*, *P. aeruginosa*, *E. coli*, and *E. cloacae*, respectively.

Keywords: 3,5-Diiodosalicylaldehyde; Phenylamine; Metal complexes; Antibacterial activity

1. Introduction

Salicylaldehyde Schiff-base metal complexes have a wide range of antibacterial activity [1–6] with many studies of the synthesis, characterization, and structure-activity relationships (SAR) of Schiff bases [7–10]. Salicylaldehyde derivatives, with one or more halogens in the aromatic ring, showed antibacterial and antifungal activities [11]. Schiff-base ligands play important roles in the development of coordination chemistry related to catalysis and enzymatic reactions, magnetism, and molecular architecture, and also exhibit biological activities [12–15]. In this article, five new mononuclear complexes have been synthesized from the condensation of 3,5-diiodosalicylaldehyde with phenylamine and different metal ions. All the complexes were assayed for

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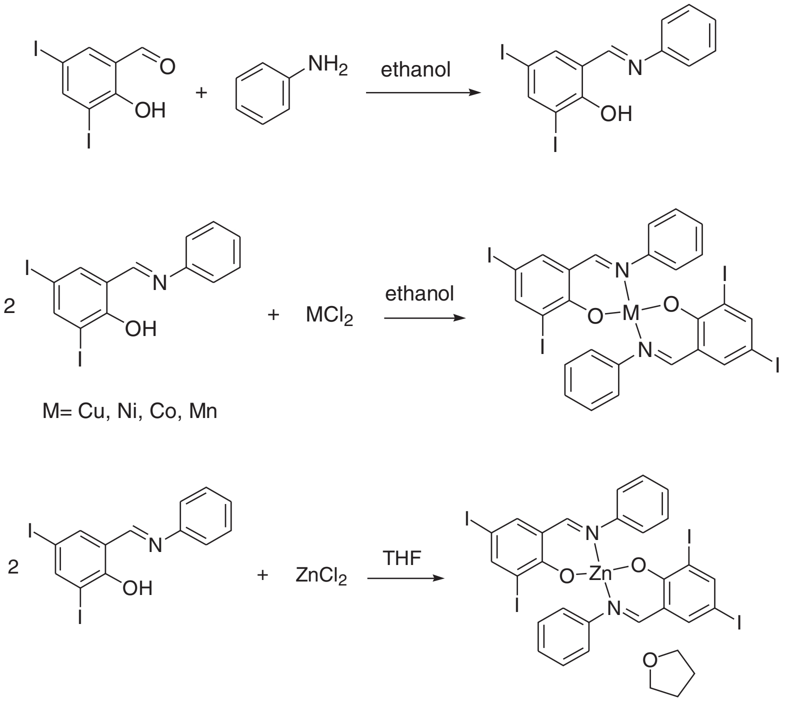


Scheme 1. Syntheses of the complexes.

antibacterial activities against three Gram-positive bacterial strains (*Bacillus subtilis*, *Staphylococcus aureus*, and *Streptococcus faecalis*) and three Gram-negative bacterial strains (*Escherichia coli*, *Pseudomonas aeruginosa*, and *Enterobacter cloacae*) by the MTT method. The results gain more understanding of the antimicrobial activity of metal(II) complexes with 3,5-diiodosalicylalidene Schiff bases.

2. Experimental section

2.1. *Chemistry*

Reaction of 2,4-diiodo-6-phenyliminomethyl-phenol (HL) with $CuCl_2 \cdot 2H_2O$, $NiCl_2 \cdot 6H_2O$, $CoCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 4H_2O$ in ethanol solvent, and $ZnCl_2$ in tetrahydrofuran (THF) led to the formation of five new mononuclear complexes (scheme 1). All the complexes gave satisfactory chemical analyses (±0.4%). UV, infrared (IR) spectroscopy, and ESI-MS spectra were consistent with the assigned structures. The crystal structures of **1** and **5** were determined using SMART 1000 CCD diffractometer instrument. Single crystals of **1** and **5** with dimensions 0.43 mm × 0.39 mm × 0.16 mm and 0.45 mm × 0.43 mm × 0.18 mm were chosen for X-ray diffraction. The data were collected with graphite-monochromated Mo-Kα radiation ($\lambda = 071073$ Å) using ω-2θ scan technique. Complex **1** is a green prism crystal. A total of 13,225 reflections were collected and 4779 were independent ($R_{\text{int}} = 0.0893$), of which 3314 observed reflections

Table 1. Crystallographic and experimental data for **1** and **5**.

	1	**5**
Empirical formula	$C_{26}H_{16}I_4N_2O_2Cu$	$C_{30}H_{24}I_2N_2O_3Zn$
Formula weight	959.55	1033.48
Crystal system	Monoclinic	Monoclinic
Space group	$P2(1)/c$	$C2/c$
Unit cell dimensions (Å, °)		
a	21.559(2)	22.287(2)
b	15.06190(17)	11.6994(13)
c	8.479(8)	26.065(3)
α	90	90
β	97.7910(10)	104.930(2)
γ	90	90
Volume (Å^3), Z	2728.1(5), 4	6566.7(12), 8
Temperature (K)	298(2)	298(2)
Density (g cm^{-3})	2.336	2.091
μ (mm^{-1})	5.354	4.541
F(000)	1772	3872
Max. and min. transmission	0.4813 and 0.2067	0.4953 and 0.2344
Data/restraints/parameters	4779/0/316	5774/0/361
θ range (°)	1.65–25.02	1.62–25.02
Index ranges (h, k, l)	$-16 \le h \le 25$; $-17 \le k \le 17$; $-10 \le l \le 9$	$-17 \le h \le 26$; $-13 \le k \le 13$; $-29 \le l \le 31$
Reflections collected/unique	13225/4779	16180/5774
R_{int}	0.0893	0.0442
R ($I > 2\sigma(I)$)	0.0519	0.0547
wR ($I > 2\sigma(I)$)	0.1278	0.1316
$(\Delta\rho)_{\max}$ and $(\Delta\rho)_{\min}$ (e Å^{-3})	1.011 and −1.871	1.573 and −1.345

$R = \sum||F_o| - F_c|/\sum|F_o|, wR = [\sum[w(F_o^2 - F_c^2)^2]/[w(F_o^2)^2]]^{1/2}$.

had $I > 2\sigma(I)$. Complex **5** is a brown prism crystal. A total of 16,180 reflections were collected and 5774 were independent ($R_{\text{int}} = 0.0442$), of which 3685 were observed with $I > 2\sigma(I)$. The structures were solved using direct methods and refined by full-matrix least-squares. All non-hydrogen atoms were assigned anisotropic displacement parameters in the refinement. All hydrogens were added at calculated positions and refined using a riding model. The structures were refined on F^2 using SHELXTL-97 [16]. The crystals used for diffraction showed no decomposition during data collection. The crystal data and refinement data are listed in table 1. Selected bond lengths and angles are given in table 2.

The 3,5-diiodosalicylalidene was synthesized with salicylaldehyde, KI, and KIO_3 [17]; other chemicals (reagent grade) used were commercially available. UV spectra were recorded on a U-3000 spectrophotometer. IR spectra were recorded on a Nexus 870 FT-IR. ESI-MS spectra were recorded on a Mariner System 5304 Mass spectrometer. Elemental analyses were performed on a CHN-O-Rapid instrument and were within ± 0.4% of the theoretical values. Melting points were measured on a Boetius micromelting point apparatus.

Quantities (4 mmol) of 3,5-diiodo-salicylaldehyde and phenylamine with 2 mmol $CuCl_2 \cdot 2H_2O$, $NiCl_2 \cdot 6H_2O$, $CoCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 4H_2O$ were dissolved in ethanol (12 mL) (2 mmol $ZnCl_2$ was dissolved in 10 mL THF) and stirred at room temperature for 30 min to give a clear solution. After standing for approximately 7–10 days,

Table 2. Selected bond lengths (Å) and angles (°) of **1** and **5**.

Bond	Distance	Bond	Distance	Bond	Distance
1					
Cu(1)–O(2)	1.893(6)	Cu(1)–O(1)	1.922(6)	Cu(1)–N(2)	1.966(7)
Cu(1)–N(1)	2.001(7)	I(1)–C(4)	2.093(8)	I(2)–C(6)	2.106(8)
I(3)–C(17)	2.103(9)	I(4)–C(19)	2.088(8)	N(1)–C(1)	1.290(11)
N(1)–C(8)	1.435(11)	N(2)–C(14)	1.297(10)	N(2)–C(21)	1.459(10)
O(1)–C(3)	1.290(10)	O(2)–C(16)	1.288(10)		
5					
Zn(2)–O(2)	1.903(7)	Zn(2)–O(1)	1.919(6)	Zn(2)–N(1)	2.004(7)
Zn(2)–N(2)	2.010(7)	I(1)–C(4)	2.091(9)	I(2)–C(6)	2.105(10)
I(3)–C(17)	2.112(11)	I(4)–C(19)	2.109(11)	N(1)–C(1)	1.294(11)
N(1)–C(8)	1.448(12)	N(2)–C(14)	1.298(13)	N(2)–C(21)	1.422(13)
O(1)–C(3)	1.291(10)	O(2)–C(16)	1.291(10)	O(3)–C(27)	1.42(3)
O(3)–C(30)	1.45(3)				
Bond	Angle(°)	Bond	Angle(°)	Bond	Angle(°)
1					
O(2)–Cu(1)–O(1)	158.7(3)	O(2)–Cu(1)–N(2)	91.6(3)	O(1)–Cu(1)–N(2)	92.4(3)
O(2)–Cu(1)–N(1)	91.7(3)	O(1)–Cu(1)–N(1)	92.6(3)	N(2)–Cu(1)–N(1)	157.4(3)
C(1)–N(1)–C(8)	115.7(7)	C(1)–N(1)–Cu(1)	123.4(6)	C(8)–N(1)–Cu(1)	120.9(6)
C(14)–N(2)–C(21)	116.6(7)	C(14)–N(2)–Cu(1)	124.4(6)	C(21)–N(2)–Cu(1)	118.9(5)
C(3)–O(1)–Cu(1)	127.0(5)	C(16)–O(2)–Cu(1)	127.4(5)	N(1)–C(1)–C(2)	126.7(8)
O(1)–C(3)–C(2)	124.2(7)	O(1)–C(3)–C(4)	120.4(7)	C(5)–C(4)–I(1)	119.7(6)
C(3)–C(4)–I(1)	117.8(6)	C(7)–C(6)–I(2)	120.3(6)	C(5)–C(6)–I(2)	118.9(6)
C(13)–C(8)–N(1)	121.6(9)	C(9)–C(8)–N(1)	119.0(9)	N(2)–C(14)–C(15)	125.6(8)
O(2)–C(16)–C(15)	125.2(8)	O(2)–C(16)–C(17)	120.0(8)	C(18)–C(17)–I(3)	119.9(6)
C(16)–C(17)–I(3)	116.9(6)	C(18)–C(19)–I(4)	118.3(6)	C(20)–C(19)–I(4)	122.4(7)
C(26)–C(21)–N(2)	116.6(8)	C(22)–C(21)–N(2)	122.9(8)		
5					
O(2)–Zn(2)–O(1)	116.1(3)	O(2)–Zn(2)–N(1)	112.5(3)	O(1)–Zn(2)–N(1)	97.3(3)
O(2)–Zn(2)–N(2)	97.7(3)	O(1)–Zn(2)–N(2)	113.6(3)	N(1)–Zn(2)–N(2)	120.8(3)
C(1)–N(1)–C(8)	120.1(7)	C(1)–N(1)–Zn(2)	118.9(6)	C(8)–N(1)–Zn(2)	121.0(6)
C(14)–N(2)–C(21)	119.6(8)	C(14)–N(2)–Zn(2)	118.2(7)	C(21)–N(2)–Zn(2)	122.1(6)
C(3)–O(1)–Zn(2)	125.1(6)	C(16)–O(2)–Zn(2)	125.5(7)	C(27)–O(3)–C(30)	111(2)
N(1)–C(1)–C(2)	129.0(8)	O(1)–C(3)–C(4)	119.9(8)	O(1)–C(3)–C(2)	124.4(8)
C(5)–C(4)–I(1)	118.1(7)	C(3)–C(4)–I(1)	117.7(6)	C(5)–C(6)–I(2)	119.0(8)
C(7)–C(6)–I(2)	119.3(7)	C(13)–C(8)–N(1)	118.1(8)	C(9)–C(8)–N(1)	122.7(9)
N(2)–C(14)–C(15)	129.3(9)	C(20)–C(19)–I(4)	119.7(9)	C(18)–C(19)–I(4)	119.9(10)
C(22)–C(21)–N(2)	125.0(10)	C(26)–C(21)–N(2)	116.8(9)		

the precipitates were separated by filtration, washed with methanol three times, and dried in a vacuum desiccator containing anhydrous $CaCl_2$.

2.1.1. 2,4-Diiodo-6-phenyliminomethyl-phenol (HL). Nacarat pole crystal, yield 92%, m.p.: 145–147°C, UV (λ nm): 435.4; 256.5. ^{1}H NMR [300 MHz, $CDCl_3$] (δ ppm): 14.688 (s, 1H); 8.456 (s, 1H); 8.107 (d, $J = 2.1$ Hz, 1H); 7.671 (d, $J = 2.1$ Hz, 1H); 7.433 (d, $J = 7.8$ Hz, 2H); 7.303 (d, $J = 1.8$ Hz, 1H); 7.267 (d, $J = 7.8$ Hz, 2H). Selected IR data (cm^{-1}, KBr): 3133.4(s); 1621.6(s); 1580.9(s); 1439.3(s); 1349.0(m); 1279.4(m); 1198.0(m); 1150.2(s); 855.5(m); 764.6(m); 738.3(m). ESI-MS: 449.9 ($C_{13}H_{10}I_2NO^+$, $[M+H]^+$). Anal. Calcd for $C_{13}H_9I_2NO$ (%): C, 34.77; H, 2.02; N, 3.12; Found (%): C, 34.65; H, 1.96; N, 3.08.

2.1.2. Bis(2,4-diiodo-6-phenyliminomethyl-phenol)-copper(II) (1). Green prism crystal, yield 86%, m.p.: 243–245°C. UV (λ nm): 406.5; 255.5. Selected IR data (cm^{-1}, KBr): 3059.8(m); 1611.8(s); 1581.4(s); 1439.6(s); 1349.9(m); 1150.5(s); 855.5(m); 764.8(m); 738.5(m); 692.0(m); 658.8(m). ESI-MS: 960.56 ($C_{26}H_{17}I_4N_2O_2Cu^+$, $[M+H]^+$). Anal. Calcd for $C_{26}H_{16}I_4N_2O_2Cu$ (%): C, 32.54; H, 1.68; N, 2.92; Cu, 6.62. Found (%): C, 32.75; H, 1.69; N, 2.87; Cu, 6.58.

2.1.3. Bis(2,4-diiodo-6-phenyliminomethyl-phenol)-nickel(II) (2). Glaucous pole crystal, yield 82%, m.p.: 281–286°C. UV (λ nm): 410.5; 256.5. Selected IR data (cm^{-1}, KBr): 3060.0(m); 1611.9(s); 1581.5(s); 1439.7(s); 1350.0(m); 1280.4(m); 1198.5(m); 1150.5(s); 855.7(m); 764.8(m); 738.6(m); 692.2(m); 658.9(m). ESI-MS: 955.72 ($C_{26}H_{17}I_4N_2O_2Ni^+$, $[M+H]^+$). Anal. Calcd for $C_{26}H_{16}I_4N_2O_2Ni$ (%): C, 32.71; H, 1.69; N, 2.93; Ni, 6.15. Found (%): C, 32.63; H, 1.65; N, 3.04; Ni, 6.20.

2.1.4. Bis(2,4-diiodo-6-phenyliminomethyl-phenol)-cobalt(II) (3). Brown pole crystal, yield 75%, m.p.: 145–147°C. UV (λ nm): 413.7; 256.5. Selected IR data (cm^{-1}, KBr): 3060.2(m); 1611.9(s); 1581.4(s); 1439.8(s); 1350.0(m); 1280.2(m); 1150.6(s); 855.7(m); 765.0(m); 738.7(m); 692.3(m); 659.0(m). ESI-MS: 955.97 ($C_{26}H_{17}I_4N_2O_2Co^+$, $[M+H]^+$). Anal. Calcd for $C_{26}H_{16}I_4N_2O_2Co$ (%): C, 32.70; H, 1.69; N, 2.93; Co, 6.17. Found (%): C, 32.75; H, 1.66; N, 2.88; Co, 6.14.

2.1.5. Bis(2,4-diiodo-6-phenyliminomethyl-phenol)-manganese(II) (4). Brown pole crystal, yield 70%, m.p.: 151–154°C. UV (λ nm): 412.0; 257.5. Selected IR data (cm^{-1}, KBr): 3060.4(m); 1611.8(s); 1581.3(s); 1439.5(s); 1349.8(m); 1280.1(m); 1198.5(m); 1150.4(s); 855.5(m); 764.8(m); 738.4(m); 692.0(m); 658.8(m). ESI-MS: 951.97 ($C_{26}H_{17}I_4N_2O_2Mn^+$, $[M+H]^+$). Anal. Calcd for $C_{26}H_{16}I_4N_3O_2Mn$ (%): C, 32.84; H, 1.70; N, 2.95; Mn, 5.78. Found (%): C, 32.88; H, 1.69; N, 2.89; Mn, 5.75.

2.1.6. Bis(2,4-diiodo-6-phenyliminomethyl-phenol)-zinc(II) tetrahydrofuran (5). Brown prism crystal, yield 78%, m.p.: 287–289°C. UV (λ nm): 413.0; 257.0. Selected IR data (cm^{-1}, KBr): 3059.7(m); 1602.5(s); 1578.4(s); 1489.6(s); 1426.6(s); 1404.2(s); 1289.7(m); 1228.6(m); 1188.5(m); 1145.1(s); 1116.4(m); 870.2(m); 829.3(m); 762.9(m); 747.8(m); 688.7(m); 674.4(m). ESI-MS: 1034.48 ($C_{30}H_{25}I_4N_2O_3Zn^+$, $[M+H]^+$). Anal. Calcd for $C_{30}H_{24}I_4N_2O_3Zn$ (%): C, 34.86; H, 2.34; N, 2.71; Zn, 6.38. Found (%): C, 34.85; H, 2.32; N, 2.75; Zn, 6.36.

2.2. *Antimicrobial activity*

The antibacterial activities of the synthesized complexes were tested against *B. subtilis*, *S. aureus*, *S. faecalis*, *P. aeruginosa*, *E. coli*, and *E. cloacae* using MTT medium. The minimum inhibitory concentrations (MICs) of the complexes were determined by a colorimetric method using the dye MTT [18]. A stock solution of the synthesized complex ($50\,\mu g\,mL^{-1}$) in DMSO was prepared and graded quantities of the test complexes were incorporated in a specified quantity of sterilized liquid medium. A specified quantity of the medium containing the complex was poured into

Table 3. MICs of the synthetic complexes.

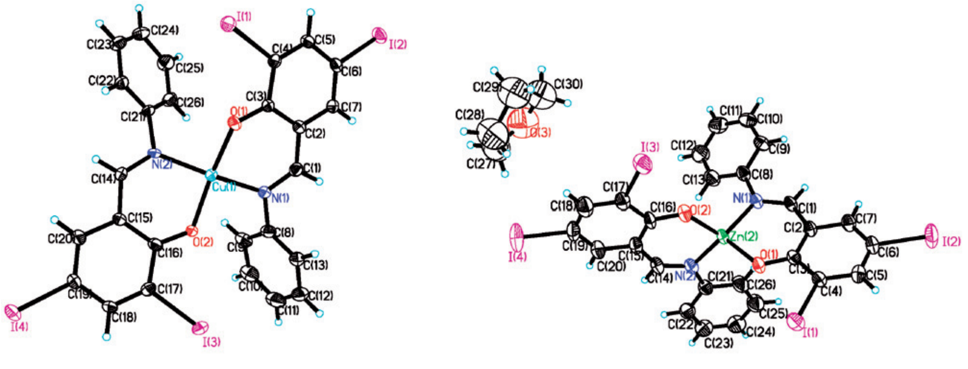
	Microorganisms MICs ($\mu g\,mL^{-1}$)					
	Gram positive			Gram negative		
Compound	*B. subtilis*	*S. aureus*	*S. faecalis*	*P. aeruginosa*	*E. coli*	*E. cloacae*
1	3.125	6.25	6.25	3.125	3.125	6.25
2	12.5	12.5	6.25	6.25	6.25	12.5
3	6.25	12. 5	12.5	6.25	6.25	12.5
4	12.5	12.5	25	12.5	25	12.5
5	6.25	25	12.5	6.25	12.5	12.5
HL	3.125	25	6.25	3.125	3.125	6.25
Penicillin	1.562	1.562	1.562	6.25	6.25	3.125
Kanamycin	0.39	1.562	3.125	3.125	3.125	1.562

microtitration plates. Suspension of the microorganism was prepared to contain approximately 10^5 cfu mL^{-1} and applied to microtitration plates with serially diluted complexes in DMSO to be tested and incubated at 37°C for 24 h for bacterial suspensions. After the MICs were visually determined on each of the microtitration plates, 50 μL of phosphate buffered saline (PBS 0.01 mol L^{-1}, pH 7.4: $Na_2HPO_4 \cdot 12H_2O$ 2.9 g, KH_2PO_4 0.2 g, NaCl 8.0 g, KCl 0.2 g, distilled water 1000 mL) containing 2 mg mL^{-1} of MTT was added to each well. Incubation was continued at room temperature for 4–5 h. The content of each well was removed and 100 μL of isopropanol containing 5% 1 mol L^{-1} HCl was added to extract the dye. After 12 h of incubation at room temperature, the optical density (OD) was measured with a microplate reader at 570 nm. The observed MICs are presented in table 3.

3. Results and discussion

Complexes **1**–**4**, $C_{26}H_{16}I_4N_3O_2M$ (M = Cu, Ni, Co, Mn) were prepared from 2,4-diiodo-6-phenyliminomethyl-phenol ($C_{13}H_9I_2NO$) in ethanol, as described in Section 2, in moderate yields (70–86%). Complex **5**, $C_{30}H_{24}I_4N_2O_3Zn$, was prepared from 2,4-diiodo-6-phenyliminomethyl-phenol in THF. The IR spectra of the complexes (KBr pellets) display an intense absorption at *ca* 1602–1612 cm^{-1} attributable to $\nu_{(C=N)imine}$. This band shifts *ca* 10–19 cm^{-1} to lower wavenumbers compared to the *ca* 1622 cm^{-1} attributable to $\nu_{(C=O)imine}$. The UV spectra of the complexes display intense absorptions at 255–257 nm ($\pi \rightarrow \pi^*$) and 406–414 nm ($n \rightarrow \pi^*$).

The molecular structure of **1** crystallizes in monoclinic space group $P2(1)/c$. A perspective view of the crystal structure and packing diagram of **1** are shown in figures 1 and 2, respectively. The Cu(II) adopts a distorted square plane coordinated by two nitrogens and two oxygens from L. The Cu(1)–O(1), Cu(1)–N(1), Cu(1)–O(2), and Cu(1)–N(2) bond lengths are 1.922(6), 2.001(7), 1.893(6), and 1.966(7) Å, respectively. The dihedral angle between Cu(1)/O(1)/N(1) and Cu(1)/O(2)/N(2) planes is 149.3°. The dihedral angle between Cu(1)/O(1)/N(1) and C(1)/C(2)/C(3) planes is 14.3°. The dihedral angle between Cu(1)/O(2)/N(2) and C(16)/C(15)/C(14) planes



1 **5**

Figure 1. Crystal structures of **1** and **5** showing 30% probability displacement ellipsoids (arbitrary spheres for hydrogens).

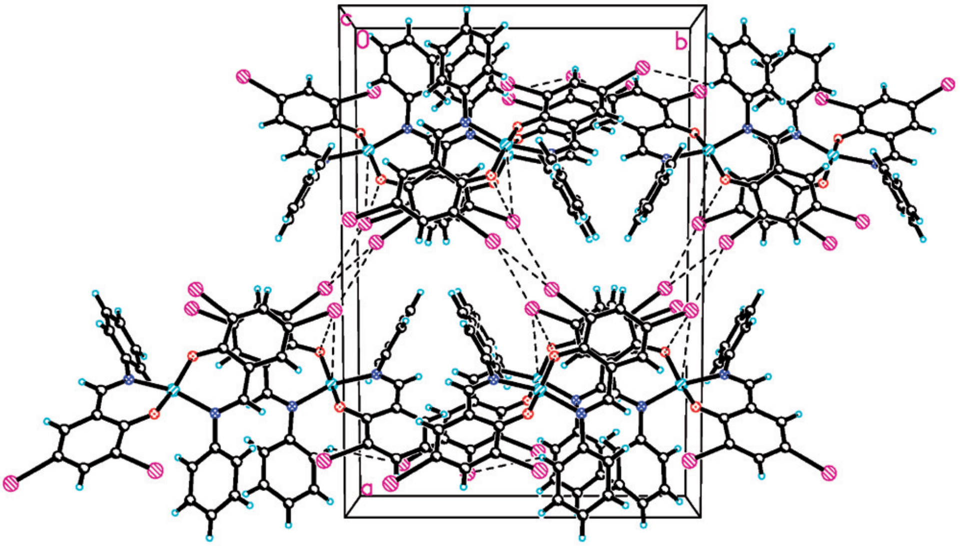


Figure 2. The packing structure of **1** along the *c*-axis.

is 19.6°. The O(1)–Cu(1)–O(2) and N(1)–Cu(1)–N(2) bond angles are 158.7(3) and 157.4(3)°. These discrete monomers in **1** are stacked to furnish a 3-D supramolecular network (figure 2). The molecular structure of **5** crystallizes in monoclinic space group $C2/c$. A perspective view of the crystal structure and packing diagram of **5** are shown in figures 1 and 3, respectively. The Zn(II) adopts a distorted tetrahedral geometry, coordinated by two nitrogens and two oxygens from L. The Zn(2)–O(1), Zn(2)–N(1), Zn(2)–O(2), and Zn(2)–N(2) bond lengths are 1.919(6), 2.004(7), 1.903(7), and 2.010(7) Å, respectively. The O(1)–Zn(2)–O(2), O(2)–Zn(2)–N(1), O(1)–Zn(2)–N(1), O(2)–Zn(2)–N(2), O(1)–Zn(2)–N(2), and N(1)–Zn(2)–N(2) bond angles are 116.1(3)°, 112.5(3)°, 97.3(3)°, 97.7(3)°, 113.6(3)°, and 120.8(3)°. These discrete monomers in **5** are

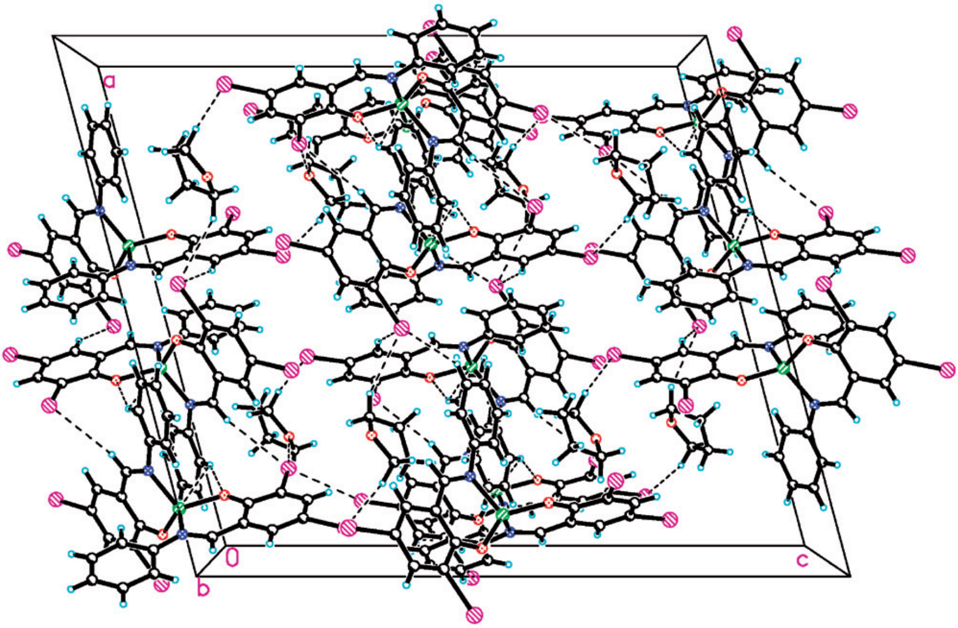


Figure 3. The packing structure of **5** along the *b*-axis.

Table 4. Hydrogen bonds for **5** [(Å) and (°)].

Complex	D–H···A	*d*(D–H)	*d*(H···A)	*d*(D···A)	∠(DHA)
5	C(9)–H(9)···O(2)	0.93	2.48	3.341(3)	155

stacked to furnish a 3-D supramolecular network (figure 3) with intramolecular hydrogen bonds (table 4).

The ways in which different metal(II) complexes react with bacteria vary due to the difference in structures. Structural analyses of these complexes provide explanation for structure–activity relationships, helpful in the design of better inhibitors. The biological activity of a particular substance depends on a complex sum of individual properties including complex structure, affinity for the target site, survival in the medium of application, survival within the biological system, transport properties, and state of the target organism [19]. In this study, we focus on the structure–activity relationships.

All the synthesized complexes were screened for antibacterial activity against three Gram (+) bacterial strains (*B. subtilis*, *S. aureus*, and *S. faecalis*) and three Gram (–) bacterial strains (*E. coli*, *P. aeruginosa*, and *E. cloacae*) by the MTT method. The MICs of the complexes against the six bacteria are presented in table 3. Also included are the activities of reference compounds penicillin (North China Pharmaceutical Co. Ltd, D0211107, Hebei 050015, China) and kanamycin (Nanjing Zhuyan Biotechnology Co. Ltd, Amresco 060D0504, Nanjing 210002, China). Complexes **1**, **3**, and **5** showed higher activity against *B. subtilis* (MICs: 3.125–6.25 $\mu g\,mL^{-1}$) than **2** and **4** (MICs: 12.5 $\mu g\,mL^{-1}$). Complex **1** showed significant activity against *S. aureus*

(MICs: 6.25 μg mL^{-1}). Complexes **1** and **2** showed higher activity against *S. faecalis* (MICs: 6.25 μg mL^{-1}) than other complexes (MICs: 12.5–25 μg mL^{-1}). Complex **1** showed higher activity against *P. aeruginosa* (MICs: 3.125 μg mL^{-1}) and *E. coli* (MICs: 3.125 μg mL^{-1}) while other complexes exhibited significant activity (MICs: 6.25–12.5 μg mL^{-1}). Complex **1** exhibited significant activity against *E. cloacae* (MICs: 6.25 μg mL^{-1}) while other complexes exhibited significant activity (MICs: 12.5 μg mL^{-1}).

Complex **1** showed the most favorable antimicrobial activity with MICs of 3.125, 6.25, 6.25, 3.125, 3.125, 6.25 μg mL^{-1} against *B. subtilis*, *S. aureus*, *S. faecalis*, *P. aeruginosa*, *E. coli*, and *E. cloacae*, respectively. Complex **2** showed moderate antimicrobial activity against *S. faecalis*, *P. aeruginosa*, and *E. coli* (MICs: 6.25 μg mL^{-1}). Complex **3** showed moderate antimicrobial activity against *B. subtilis*, *P. aeruginosa*, and *E. coli* (MICs: 6.25 μg mL^{-1}). Complex **4** showed average antimicrobial activity against *B. subtilis*, *S. aureus*, *P. aeruginosa*, and *E. cloacae* (MICs: 12.5 μg mL^{-1}). Complex **5** showed moderate antimicrobial activity against *B. subtilis* and *P. aeruginosa* (MICs: 6.25 μg mL^{-1}). HL showed high antimicrobial activity against *B. subtilis*, *S. faecalis*, *P. aeruginosa*, *E. coli*, and *E. cloacae* (MICs: 3.125–6.25 μg mL^{-1}) while all the metal salts showed no antimicrobial activity with MICs over 50 μg mL^{-1} against the six tested bacterial strains (not presented in table 3).

Comparison of antibacterial potential of the metal complexes with the parent Schiff base shows that **1** was more active than other metal complexes and the complexation of Schiff base with copper enhances its antibacterial potential.

4. Conclusion

A new Schiff-base ligand derived from 3,5-diiodosalicylaldehyde and phenylamine has been synthesized and reacted with different metal salts to form five new mononuclear complexes. All the complexes were assayed for antibacterial activities against *B. subtilis*, *S. aureus*, *S. faecalis*, *E. coli*, *P. aeruginosa*, and *E. cloacae* by the MTT method. The complexes showed potent antibacterial activity against the six bacterial strains with copper complex (**1**) showing the most favorable antibacterial activity.

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