



Synthesis, Characterization and Antibacterial Evaluation of Some Mixed-metal Mixed-ligand Complexes

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ABSTRACT

Attempt has been taken to prepare and study some of the mixed metal complexes using varied ligand systems. Investigation of the spectral properties (like IR, UV), magnetic susceptibility, conductance values of the prepared complexes helped to the characterization of their structural features. The mixed metal complexes have been found to be of the type $[ML_x][M'L_y]$ where, $M = Cu, Cd, Ni, Co, Zn$ and $M' = Hg$, $L_x =$ ethylenediamine, aniline, NH_3 and $L_y = I^-, SCN^-$. Antibacterial activities of some of the prepared complexes were studied.

Keywords: Mixed-metal complexes, antibacterial activities, ethylenediamine

1. INTRODUCTION

Numerous heterobimetallic and homobimetallic complexes have been prepared in which metals are linked by unsaturated or saturated ligands. Also that, mixed metal complexes shows some exceptional structural behavior. A series of heterobinuclear, thiocyanato-bridged complexes of macrocyclic ligands of copper(II) and nickel(II) have been characterized by variable-temperature magnetic susceptibility (1.72–300 K) by Tomkiewics *et al.* [1]. Xiang *et al.* [2] prepared $[Zn(bipy)_3][Zn(SCN)_4]$ complex and characterized by X-ray diffraction analysis. Pryma *et al.* [3] have synthesized three heterometallic Cu/Cd complexes, (1) $[Cu(en)_2CdBr_2] \cdot dmsso$, (2) $[Cu(en)_2CdI_4] \cdot dmf$ and (3) $\{[Cu(en)_2]_3[Cd(NCS)_6](NCS)_2\}$.

Ohba *et al.* [4] synthesized the polymeric complex $[Ni(en)_2]_3[Fe(CN)_6]_2 \cdot 2H_2O$ ($en =$

ethylenediamine) bridged by cyanide ligands between Ni(II) ($S=2$) and Fe(III) ($S=1/2$). $[Ni(en)_2]_3[Fe(CN)_6]_2 \cdot 2H_2O$ [4] and $[Ni(pn)_2][Fe(CN)_6]ClO_4 \cdot 2H_2O$ [5] ($pn = 1,2$ -diaminopropane) have chain and 2D sheet structure. Whereas complex $[Ni(tren)]_3[Fe(CN)_6]_2 \cdot 6H_2O$ ($tren =$ tris (2-aminoethyl)amine) characterized to have a 3D structure consisting of $-Fe-CN-Ni-NC-Fe-CN-$ chains [6].

Langenberg *et al.* [7] studied structural and magnetic properties of the pentanuclear complexes $[(Ni(bpm)_2)_3(Fe(CN)_6)] \cdot 7H_2O$ ($bpm =$ bis(1-pyrazolyl)methane) and $[(Ni(bpy)_2)_3(Fe(CN)_6)] \cdot 7H_2O$ ($bpy = 2,2$ -bipyridine). Kou *et al.* [8] studied ferromagnetic complex $[Cu(en)_3][Fe(CN)_6] \cdot 3H_2O$. Suzuki *et al.* [9] prepared and characterized double complex salts $[Cu(en/tn)_2][Fe(CN)_6] \cdot nH_2O$ ($tn = 1, 3$

diaminopropane) and cyanide-bridged complexes, $[\{\text{Cu}(\text{dien}/\text{dpt})\}_2(\text{NC})_2\text{Fe}(\text{CN})_4] \cdot 4\text{H}_2\text{O}$ (dpt = dipropylenetriamine). Zou *et al.* [10] studied crystal structure and magnetic properties of trinuclear complex $[(\text{Cu}(\text{tren}))_2\text{Fe}(\text{CN})_6] \cdot 12\text{H}_2\text{O}$. Xiang *et al.* [11] prepared $[\text{NiL1}]_3[\text{Cr}(\text{CN})_6]_2 \cdot 18\text{H}_2\text{O}$ from the reaction of $\text{K}_3[\text{Cr}(\text{CN})_6]$ and $[\text{NiL1}](\text{ClO}_4)_2$ in water medium [where, L1= 3,10-bis (2-hydroxyethyl)-1,3,5,8,10,12-hexaazacyclotetradecane].

Bertini *et al.* [12] synthesized and studied the compounds $\text{K}[\text{Cu}(\text{en})_2][\text{Fe}(\text{CN})_6]$ and $[\text{Cu}(\text{L})_3][\text{Fe}(\text{CN})_6]_2 \cdot x\text{H}_2\text{O}$ (L = (N-ethyl) ethylenediamine, $x = 4$; L = (N-propyl) ethylenediamine, $x = 5$). The structures of the compounds of the type $[\text{Ni}(1,1\text{dmen})_2]_2[\text{Fe}(\text{CN})_6]_x \cdot y\text{H}_2\text{O}$ (1,1-dimen = 1,1 dimethylethylene diamine; $x = \text{CF}_3\text{SO}_3$, $y = 2$; $x = \text{BzO}$, $y = 6$; $x = \text{N}_3$, $y = 4$) were solved [13]. Kundu *et al.* [14] studied spectral and magnetic properties of the complexes $[\text{CuL}_2][\text{L}_2\text{Cu}(\text{CN})\text{Fe}(\text{CN})_5]_2 \cdot x\text{H}_2\text{O}$ (L = piperazine, $x = 5$, L = N-methylpiperazine, $x = 6$, L = N, N-dimethylpiperazine, $x = 6$).

The literature survey reveals that very little work has been done on the coordination chemistry of mixed metal complexes. The present work has been an attempt to prepare and study some mixed metal complexes using varied ligand systems. Investigation of the spectral properties (like IR, UV), magnetic susceptibility, conductance values of the prepared complexes helped to the characterization of their structural features. Antibacterial activities of some of the prepared complexes were also studied.

2. MATERIALS AND METHODS

2.1 Instrumentations

The analyses of the metal contents of the prepared complexes were obtained by Atomic Absorption Spectrophotometer

(model Thermo Scientific ICE-3000) from B.C.S.I.R. Laboratory, Chittagong. The Infrared spectra of the prepared complexes were obtained by FTIR spectrophotometer (Model- 8900, Shimadzu, Japan) using KBr as the matrix in the range $400\text{-}4000\text{ cm}^{-1}$ from research laboratory of the Department of Chemistry, C.U.E.T., Chittagong. Electronic absorption spectra were run on Shimadzu UV-Visible Recording Spectrophotometer (Model-1800) using 1 cm cells. An electro thermal melting point apparatus was used for the determination of the melting or decomposition points of the complexes. Conductivity measurement was performed on a Philips Conductivity Meter (Model-HI 9255). Determination of conductivity of an electrolytic solution involves measuring of the electrical resistance of that solution at a particular temperature, usually 25°C . Magnetic susceptibility values of some of the prepared complexes were determined using the Magnetic Susceptibility Balance, (Sherwood Scientific) from Rajshahi University and in the laboratory of Chittagong University, Bangladesh.

2.2 Chemicals

Ethylenediamine, aniline, methanol, chloroform and N, N-dimethylformamide (DMF) were obtained from Aldrich Chemical Company Ltd. Ammonium nitrate and potassium iodide were obtained from M|S Merak (Germany). Perchloric acid, nitric acid, sulphuric acid and ammonia were obtained from BDH Chemicals Ltd. All chemicals except solvent were used as received. Solvents were dried by standard methods and distilled under an inert atmosphere.

2.3 Preparation of Mixed Metal Complexes

Preparation of $[\text{HgI}_4]^{2-}$ or $[\text{Hg}(\text{SCN})_4]^{2-}$: 2 mmol (0.54 g) of mercuric chloride (HgCl_2)

was dissolved in about 40 cm³ of water. Then a slight excess of 10% KI or NH₄SCN solution was added dropwise. A clear solution of [HgI₄]²⁻ or [Hg(SCN)₄]²⁻ was formed.

Preparation of [M(en)₃]²⁺: In another beaker, 2 mmol (0.589 g) of metal sulphate or nitrate was dissolved in about 50 cm³ of water. An excess amount of ethylenediamine was added to it dropwise. A small amount (10-15 crystals) of ammonium nitrate and potassium iodide (KI) or ammonium thiocyanide (NH₄SCN) was added. The mixture was heated to boil for about 2-3 minutes. NH₃ or aniline was used as ligand for the preparation of [M(NH₃)₆]²⁺ or

[M(aniline)₆]²⁺, respectively.

Mixed Metal Complexes, [ML_x][M'L_y]: Two solutions were mixed together in their hot states. The mixture was stirred for sometimes and allowed to cool with frequent stirring. The precipitate was formed almost immediately and the solid product was filtered off and washed with water, dried over calcium chloride.

Color, M.P. and percentage of yield and metal contents of the prepared mixed metal and mixed ligand complexes are included in table 1. Percentage of metal contents was determined by AAS.

Table 1. Color, % of Yield, M.P., % of Metal contents of the prepared mixed metal and mixed ligand complexes.

Complexes	Color	Yield (%)	M.P. (°C)	% of Metal (Calc.)	Complexes	Color	Yield (%)	M.P. (°C)	% of Metal (Calc.)
[Zn(en) ₃][HgI ₄]	Yellow	95	198(d)	7.83 (6.86)	[Cu(en) ₂][Hg(SCN) ₄]	Violet	95	164-166	10.97 (10.31)
[Cd(en) ₃][HgI ₄]	Yellow	95	198(d)	9.10 (11.23)	[Cd(en) ₃][Hg(SCN) ₄]	White	95	128-129	16.84 (15.49)
[Ni(en) ₃][HgI ₄]	White	95	200(d)	6.74 (6.20)	[Ni((en) ₃][Hg(SCN) ₄]	Purple	95	182-184	9.20 (8.73)
[Co(en) ₃][HgI ₄]	Brown	90	200(d)	6.15 (6.22)	[Zn(en) ₃][Hg(SCN) ₄]	White	95	146-148	10.21 (9.64)
[Zn(NH ₃) ₆][HgI ₄]	Yellow	95	200(d)	7.80 (7.47)	[Zn(Aniline) ₆][Hg(SCN) ₄]	White	95	200(d)	6.87 (6.19)
[Ni(NH ₃) ₆][HgI ₄]	Green	95	210(d)	6.95 (6.75)	[Co(NH ₃) ₅ Cl][Hg(SCN) ₄]	Blue	90	200(d)	10.50 (9.62)
[Cd(Aniline) ₆][HgI ₄]	White brown	90	210(d)	9.39 (8.15)					

*The mercury content of the complexes could not be determined

2.4 Evaluation of Bacterial Activities

For the detection of antibacterial activities and sensitivity spectrum analysis, the disc diffusion method by Bauer *et al.*[15,16] was followed. Nutrient Agar (NA) was used as basal medium for culture of test bacteria and N, N-dimethylformamide (DMF) was used as a solvent to prepare the desired solution (1%) of the compounds initially.

Nutrient Agar (NA) medium was prepared using the composition; Beef extract, Peptone, NaCl, Agar, Distilled water. 1000 mL of distilled water was taken in a beaker and then

15 gm of agar powder, 3 gm of beef extract, 5 gm of peptone and 0.5 gm of NaCl were added slowly in that water and they were mixed thoroughly with a glass rod, heated to boiling for 10 minutes. After 10 minutes of boiling, the medium was transferred in 250 mL conical flasks at the rate of 200 mL per flask. The conical flask was closed with the cotton plug and autoclaved at 121°C and 15 psi pressure for 15 minutes, then culturing of different micro-organisms was performed.

Sensitivity spectrum analysis: Paper discs of

5 mm diameter were soaked with 10 mL from 2% solution of test complexes. 0.2 mL of the suspension of test organism was taken in sterilized glass Petri plates of 100 cm diameter and then the molted and cooled (45°C) NA medium was poured at the rate of 10 mL per Petri plate and shaken gently. Then the discs with test complexes were placed on the seeded agar plate. A control plate was also maintained in each case with solvent. The plates were kept firstly for 24 hours at low temperature (4°C) and the test complex diffused from disc to the surrounding medium by this time. The plates were then incubated at 35±2°C for growth of test organisms and were observed at 24 hours interval for two days. The activity was determined by measuring the diameter of the zone of inhibition in mm.

Test organisms: In the present study, to screen the antibacterial activities of different complexes, a variety of bacterial strains were used as test organism. Bacterial strains were collected from the microbiology laboratory of the Department of Microbiology, University of Chittagong. Collected pathogens are listed as: Gram-positive, a) *Bacillus cereus* BTCC 19, Gram-negative, b) *Salmonella typhi* AE 14612, c) *Escherichia coli* ATCC 25922.

A number of mixed-metal complexes have been tested for antibacterial evaluation.

3. RESULTS AND DISCUSSION

Mixed-metal mixed-ligand complexes were prepared by using water as the solvent. Mixed metal complexes were prepared by the reaction of one metal complex with a different metal complex in molar ratio 1:1. All the complexes were obtained almost immediately after mixing of the component metal complex solutions. During preparation of $[\text{Cd}(\text{aniline})_6][\text{HgI}_4]$, the $[\text{Cd}(\text{aniline})_6]^{2+}$ complex mixture was heated to dissolve the oily layer formed due to the presence of

aniline. After that, both solutions were added at hot state. Then the mixture was heated again for about one hour at low temperature. The precipitate formed was separated out by filtration and preserved in a desiccator.

The complex $[\text{Cd}(\text{Aniline})_6][\text{Hg}(\text{SCN})_4]$ was formed immediately. To avoid possibility of decomposition of $[\text{Hg}(\text{SCN})_4]$ to some blackness of HgS, heat was avoided during preparation of the complexes $[\text{Cd}(\text{en})_3][\text{Hg}(\text{SCN})_4]$, $[\text{Zn}(\text{en})_3][\text{Hg}(\text{SCN})_4]$ and $[\text{Co}(\text{NH}_3)_5\text{Cl}][\text{Hg}(\text{SCN})_4]$.

All the complexes are insoluble in chloroform. Some of them are moderately soluble in methanol. All complexes are highly soluble in DMF except $[\text{Co}(\text{en})_3][\text{Hg}(\text{SCN})_4]$. This complex is moderately soluble in DMF. The metal analysis data indicate formation of the desired complexes with 1:1 metal ratio of the complex cation and the complex anion.

Primarily, the complexes were characterized qualitatively by the following procedure:

- A little amount of the prepared complex was taken in a test tube. Then concentrated nitric acid (HNO_3) was added to the sample and gently warmed on a water bath for the decomposition.

- The presence of Cu, Cd, Ni, Co or Zn with mercury was determined by passing H_2S gas to the acidified solution. The black precipitate formed indicated the presence of Hg. Then the filtrate solutions were treated by adding NH_4OH and H_2S . The white precipitate formed indicated the presence of Zn, black precipitate formed for Ni and yellow precipitate formed for Cd. Cu and Co in mercury containing complexes were determined by formation of brown and blue colors, respectively with the addition of potassium ferrocyanide.

3.1 Infra-red Spectra

Tentative infrared spectral bands of some mixed metal complexes in table 2. Representative IR spectrum of $[\text{Cd}(\text{Aniline})_6][\text{HgI}_4]$ is shown in figure 1. The bands 3320-3295, 2990-2965 and 1600-1585 cm^{-1} are assigned to $\nu_{\text{N-H}}$, $\nu_{\text{C-H}}$, $\nu_{\text{C-C}}$, respectively for mixed metal complexes by Pryma and Hamza *et al.*[3,17]. The bands appearing at 1315-1400 cm^{-1} (specially the highest frequency ones near 1400 cm^{-1}) have been assigned to $\nu_{\text{C-N}}$ mode. Dobrzanska *et al.*[18] have prepared some mixed metal complexes where $\nu_{\text{Ca}\equiv\text{N}}$ frequency was observed at 2130-2060 cm^{-1} . Pryma and Cernak *et al.*[3,19] have assigned a band near 2095 cm^{-1} and 2136 cm^{-1} to $\nu_{\text{Ca}\equiv\text{N}}$ for copper-cadmium and copper-palladium mixed metal complexes. Rao and Tomkiewicz *et al.* [1,20] also have described the location of the $\nu_{\text{C}\equiv\text{N}}$ bonds in the approximate same region in several mixed metal complexes containing $\text{C}\equiv\text{N}$ groups. On the basis of these studies, the band observed for the present complexes in the regions

of 1200-1000, 1520-1600, 1360-1401, 2000-2250 cm^{-1} have been assigned as due to $\nu_{\text{C-C}}$, $\nu_{\text{C=C}}$, $\nu_{\text{C-N}}$ and $\nu_{\text{Ca}\equiv\text{N}}$, respectively. In addition frequency near 690-820 cm^{-1} has been assigned to $\nu_{\text{C-S}}$ for the prepared complexes [21].

Appearance of strong $\nu_{\text{Ca}\equiv\text{N}}$ bands in the regions 2020-2096 and 2100 cm^{-1} in the present complexes is a good indication of M-SCN-M coordination of the thiocyanate group. Navarro *et al.* [22] using normal coordination analysis have assigned the bands for $\nu_{\text{Hg-I}}$ frequency at 155 cm^{-1} . No Hg-I stretching frequency could be detected in the present study since IR spectrum could not be run below 400 cm^{-1} . El-ajaily *et al.* [23,24] have prepared and investigated new Schiff base complexes of Cr(II), Pb(II) and TiO(IV) and observed new bands at 444-540 cm^{-1} attributed to $\nu_{\text{M-N}}$ vibrations. The bands of prepared complexes appearing at 444-540 cm^{-1} have been assigned to $\nu_{\text{M-N}}$ vibrations [25].

Table 2. Infrared spectral bands of some mixed metal complexes.

Complexes	$\nu_{\text{N-H}}$	$\nu_{\text{C-C}}$	$\nu_{\text{C=C}}$	$\nu_{\text{C-N}}$	$\nu_{\text{Ca}\equiv\text{N}(\text{cyanide})}$	$\nu_{\text{C-S}}$	$\nu_{\text{S-Ca}\equiv\text{N}}$	$\nu_{\text{M-N}}$
[Cd(en) ₃][Hg(SCN) ₄]	3157(w)	997(m)		1317(w)	2102(s)	709(m)	596(s)	430(s)
	3265(ms)	1049(m)		1448(m)	2154(ms)	740(w)	663(s)	474(w)
[Ni(en) ₃][Hg(SCN) ₄]	3277(s)	999(s)		1365(w)	2079(vs)	711(m)	601(w)	446(w)
	3331(ms)	1020(m)		1452(s)	2104(s)	731(w)		503(s)
[Cu(en) ₃][Hg(SCN) ₄]	3309(w)	1031(m)		1388(m)	2096(w)	694(m)		439(m)
		1087(s)		1454(vs)	2065(w)			532(m)
[Zn(en) ₃][HgI ₄]	3261(w)	1006(w)		1369(w)				472(w)
		1274(m)		1460(w)				507(w)
[Cd(en) ₃][HgI ₄]	3257(w)	1020(ms)		1325(ms)				462(ms)
		1055(ms)		1456(m)				594(w)
[Ni(en) ₃][HgI ₄]		1095(w)		1315(w)				491(ms)
		1124(m)		1390(m)				578(m)
[Cd(Aniline) ₆][Hg(SCN) ₄]	3253(ms)	1006(s)	1582(ms)	1340(w)	2113(ms)	690(vs)	557(s)	449(s)
	3336(s)	1058(ms)	1600(s)	1352(w)	2071(sh)	819(ms)	690(s)	462(s)
[Zn(en) ₃][Hg(SCN) ₄]	3275(m)	1001(m)		1319(m)	2119(w)	711(m)	653(m)	445(s)
	3331(w)	1103(s)		1365(w)	2160(w)	785(ms)		459(s)
[Cd(Aniline) ₆][HgI ₄]	3298(w)	1489(s)	1330(w)				420(w)	690(s)
		1570(ms)	1450(w)				435(w)	

* vs = very strong; s = strong; ms = medium strong; m = medium; w = weak; vw = very weak; sh = shoulder.

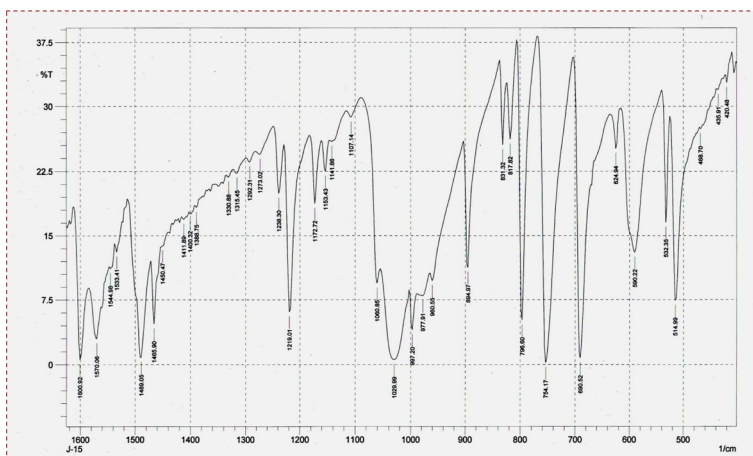


Figure 1. IR spectrum of compound, $[\text{Cd}(\text{Aniline})_6][\text{HgI}_4]$.

3.2 Electronic Spectra

The UV-vis spectroscopy is a simple but powerful tool for the interpretation of chemical bonds and structure of most chelates. Because of the insolubility of the presently prepared complexes in common organic solvents, the spectra of the prepared complexes were run in dimethylformamide. The bands at around 530 nm in the visible region for the prepared complexes can be

assigned to $d-d$ transition. The peaks observed below 350 nm are assumed as due to $\pi \rightarrow \pi^*$, $n \rightarrow \pi^*$ and $n \rightarrow \sigma^*$ transitions. Figure 2 shows the electronic Spectra of $[\text{Ni}(\text{en})_3][\text{Hg}(\text{SCN})_4]$ (lower) and $[\text{Cu}(\text{en})_2][\text{Hg}(\text{SCN})_4]$ (upper). And the peaks observed at 983 nm may be assumed as due to the presence of mercury tetraiodide or mercury tetrathiocyanate.

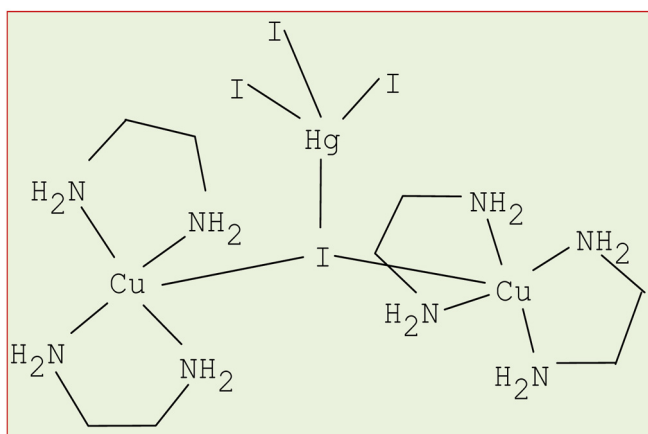


Figure 2. The proposed structure of the complex, $[\text{Cu}(\text{en})_2][\text{HgI}_4]$.

3.3 Magnetic Measurements

From the experimental values of magnetic measurements of some of the prepared complexes, it is found that magnetic moments of some of the mixed metal complexes are lower than the expected theoretical spin only values. The possible reason of such lower magnetic moment may be due to some antiferromagnetic interactions in the mixed metal complex. The exchange interactions seem to be super exchange type and most likely through the thiocyanato or the iodo groups as shown by figure 2 resemblance to the crystal structure of $[\text{Cu}(\text{en})_2\text{CdI}_4]$ [3]. However, weak bonds and longer bond lengths may hide or prevent possibility of exchange interactions.

Table 3. The electronic spectral data, magnetic data and conductivity data for the mixed metal complexes.

Complexes	Medium	Spectral bands	μ_{eff} (B.M)	Molar Conductivity $\lambda_{\text{m}}^{\circ}$, $\text{ohm}^{-1}\text{cm}^2\text{mol}^{-1}$
$[\text{Cd}(\text{en})_3][\text{Hg}(\text{SCN})_4]$	DMF	983,533,507,459,433,393,355,341,273		105
$[\text{Ni}(\text{en})_3][\text{Hg}(\text{SCN})_4]$	DMF	982,533,510,483,460,433,393,355,341		
$[\text{Cu}(\text{en})_2][\text{Hg}(\text{SCN})_4]$	DMF	983,556,533,518,484,460,433,393,341,278	2.12	166.2
$[\text{Zn}(\text{en})_3][\text{HgI}_4]$	DMF	983,533,507,483,460,433,393,328,305		85.4
$[\text{Cd}(\text{en})_3][\text{HgI}_4]$	DMF	983,533,510,483,460,433,393		96.6
$[\text{Zn}(\text{Aniline})_3][\text{Hg}(\text{SCN})_4]$	DMF	983,533,507,483,459,433,393		123.4
$[\text{Co}(\text{NH}_3)_5\text{Cl}][\text{Hg}(\text{SCN})_4]$	DMF	982,533,510,483,460,433,393,276		101.4
$[\text{Ni}(\text{en})_3][\text{HgI}_4]$	DMF	982(sh),533,510,483,459,433,392	3.69	83.4
$[\text{Ni}(\text{NH}_3)_6][\text{HgI}_4]$	DMF	982(sh),533,508,483,459,433, 392	2.64	68.4
$[\text{Co}(\text{en})_3][\text{HgI}_4]$	DMF	983,533,507,482,459,433,392	2.27	79.8
$[\text{Ni}(\text{en})_3][\text{Hg}(\text{SCN})_4]$			4.21	131.8
$[\text{Zn}(\text{NH}_3)_6][\text{HgI}_4]$				91.6
$[\text{Cu}(\text{NH}_3)_4][\text{HgI}_4]$				91.6
$[\text{Cd}(\text{Aniline})_3][\text{Hg}(\text{SCN})_4]$				82.4
$[\text{Zn}(\text{en})_3][\text{Hg}(\text{SCN})_4]$				52.8

3.5 Effect on the Bacterial Growth

In the present work, some of the prepared mixed-metal complexes as shown in table 4 were selected for antibacterial activity against three human pathogenic bacteria. The evaluation results of the inhibition zone due to the effect of compounds are presented in figure 3. figure 4 shows Zone of inhibition against *Salmonella typhi* by complexes J_9 , J_{10} , J_{11} and J_{12} . It is found that, except J_{15} , all compounds are comparatively more effective against *Escherichia coli*. The

3.4 Molar Conductance

Using N, N-dimethylformamide (DMF) as the solvent the solutions of the complexes (of the order of 10^{-3} M) were used for conductivity measurements. The molar conductance values of the presently prepared complexes are shown in table 2. The conductance values of $105\text{-}53 \text{ ohm}^{-1}\text{cm}^2\text{mol}^{-1}$ in DMF solutions corresponding to 1:1 electrolytes⁶ strongly support proposed formulation of the prepared complexes. This suggests +2 oxidation states of the metal ions present in such complexes.

The electronic spectral, magnetic and conductivity data for the mixed metal complexes are given in table 3.

tested complexes are generally quite effective against *Salmonella typhi* and *Bacillus cereus*. The enhanced activity as shown in figure 3 of the complexes can be explained in terms of chelation theory¹³. Although chelation is not the only criteria for antibacterial activity, some important factor such as nature of the metal ion, metal ion coordinating site, hydrophilicity, hypophilicity and presence of coligands may have considerable influence on the antibacterial activity. The chelate complexes may deactivate various cellular enzymes which play vital role

in various metabolic pathways of these microorganisms. Other factors such as solubility, conductivity and dipole moment affected by the presence of metal ions, may be the reasons for the increased biological

activities of the metal complexes. Therefore the antibacterial activity of the metal complexes cannot be ascribed to chelation alone but it's an intricate blend of all of the above contributions.

Table 4. Identification no. and name of the inorganic synthetic compounds.

Identification No.	Name of the complex	Zone of inhibition in diameter (mm)		
		<i>Bacillus cereus</i>	<i>Escherichia coli</i>	<i>Salmonella typhi</i>
J ₁	[Cd(en) ₃][Hg(SCN) ₄]	19	28	21
J ₂	[Ni(en) ₃][Hg(SCN) ₄]	--	24	14
J ₃	[Cu(en) ₂][Hg(SCN) ₄]	12	25	--
J ₄	[Zn(en) ₃][HgI ₄]	24	35	31
J ₅	[Cd(en) ₃][HgI ₄]	19	30	27
J ₆	[Zn(NH ₃) ₆][HgI ₄]	27	28	21
J ₇	[Zn(Aniline) ₆][Hg(SCN) ₄]	--	24	21
J ₈	[Co(NH ₃) ₅ Cl][Hg(SCN) ₄]	--	24	21
J ₉	[Ni(en) ₃][HgI ₄]	27	29	28
J ₁₀	[Ni(NH ₃) ₆][HgI ₄]	24	28	25
J ₁₁	[Co(en) ₃][HgI ₄]	13	24	26
J ₁₂	[Cu(NH ₃) ₆][HgI ₄]	29	27	25
J ₁₃	[Cd(Aniline) ₆][Hg(SCN) ₄]	--	13	9
J ₁₄	[Zn(en) ₃][Hg(SCN) ₄]	24	22	20
J ₁₅	[Cd(Aniline) ₆][HgI ₄]	--	12	12

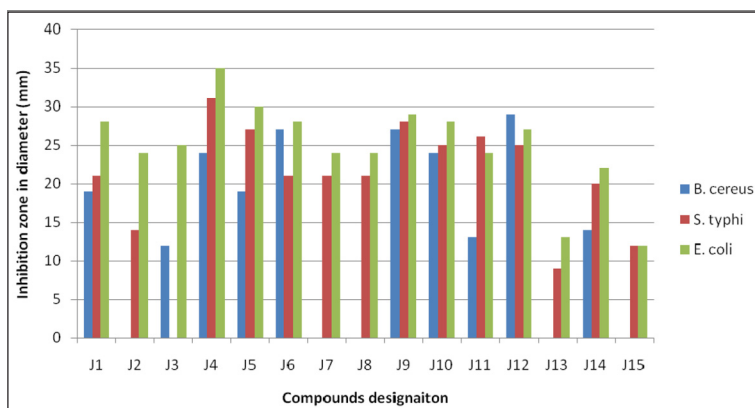


Figure 3. Evaluation results of the synthetic compounds against the test organism (Bacteria).



Figure 4. Inhibition zone against *Salmonella typhi* by complexes of J_9 , J_{10} , J_{11} , J_{12} .

4. CONCLUSION

The mixed metal complexes have been found to be of the type $[ML_x][M'L_y]$ where, $M = Cu, Cd, Ni, Co, Zn$ and $M' = Hg$, $L_x =$ ethylenediamine, aniline, NH_3 and $L_y = I^-$. The infrared spectra and metal analysis data indicate the formation of such complexes. Conductivity measurements indicate their electrolytic nature and +2 oxidation state of the metal ions present in such complexes. The magnetic measurements indicate some of the complexes to show antiferromagnetic interactions. The exchange interactions seem to be super exchange type and most likely through the iodo groups³ giving the molecular structure as figure 2. The high yield of the complexes indicates good possibilities of their analytical uses to determine metal contents of some related compounds. Further works are required to exploit and ascertain such possibilities.

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