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Original Research Article

Synthesis, Spectral and Thermal Characterization with Antimicrobial Activity Studies on Some Metal Complexes Containing Schiff Base Ligand

Abstract

Some metal complexes of Ni(II), Zn(II), Mn(II), Sn(II), Co(II) and Cd(II) ions were synthesized with three different synthesized Schiff base ligands. The ligands and metal complexes were isolated in solid state from the reaction medium and characterized by molar conductivity measurement, magnetic susceptibility, Infrared, electronic spectral, thermal analysis and some physical measurements. The overall reactions were monitored by TLC analysis. Molar conductance study have shown that all the complexes were non electrolytic in nature. FTIR studies suggested that Schiff bases act as deprotonated bidentate ligands and metal ions are attached with the ligands through N, O/S coordinating sites during complexation reaction. Magnetic susceptibility data coupled with electronic spectra revealed that Zn(II), Mn(II), Sn(II), and Cd(II) complexes have tetrahedral, Ni(II) complexes has square planer and Co(II) complexes has octahedral geometry. Thermal analysis (TGA and DTG) data showed the possible degradation pathway of the complexes and also indicated that most of the complexes were thermally stable up to 200^0C. The Schiff bases and their metal complexes have been found moderate to strong antimicrobial activity.

Keywords: Schiff Base, Thiosemicarbazide, TGA, DTG, Antimicrobial activity

1 INTRODUCTION

Multidentate ligands are extensively used for the preparation of metal complexes with interesting properties [1-5]. Among these ligands, Schiff bases containing nitrogen and phenolic oxygen donor atoms are of considerable interest due to their potential application in catalysis, medicine and material science [6-9]. Transition metal complexes of these ligands exhibit varying configurations, structural liability and sensitivity to molecular environments. The central metal ions in these complexes act as active sites for pharmacological agent. This feature is employed for modeling active sites in biological systems.

Thiosemicarbazones obtained by the condensation reaction of thiosemicarbazide and different aldehydes or ketones are important chemicals due to their broad profile of pharmacological activity. The transition metal complexes of thiosemicarbazone are also played important role in antimicrobial, antitumer and anticancer activities.

Therefore, in view of our interest in synthesis of new Schiff base complexes, which might find application as pharmacological and as luminescence probes, we have synthesized and characterized new transition metal complexes of Schiff bases formed by the condensation reaction of different aldehydes and amino acids. The results of our studies are presented in this article.

2. Experimental

2.1 Materials and Methods

All chemicals and solvents used were of Analar grade. All metal(II) salts were used as chloride and sulphate. The solvents such as Ethanol, methanol, chloroform, Diethyl ether, petroleum ether, DMSO (dimethyl sulfoxide) and acetontrile were purified by standard procedure. The melting point or the decomposition temperature of all the prepared ligand and metal complexes were observed in an electro thermal melting point apparatus model No. AZ6512. Vibrational spectra (IR) were recorded with a NICOLET 310, FTIR spectrophotometer, Belgium, in the range 4000-225 cm^{-1} with a KBr disc as reference. UV-Visible spectra of the complexes in DMSO (0.5x 10^{-3}M) were recorded in the region 200-800 nm on a Thermoelectron Nicolet evolution 300 UV-Visible spectrophotometer. The SHERWOOD SCIENTIFIC Magnetic Susceptibility Balance that following the Gouy Method were used to measure the magnetic moment of the solid complexes. The electrical conductance measurements were made at room temperature in freshly prepared aqueous solution (10^{-3} M) and in DMSO using a WPACM35 conductivity meter and a dip-cell with a platinum electrode. some conductivity were also measured in PTI-18 Digital conductivity meter. The purity of the ligand and metal complexes ware tested by Thin Layer Chromatography (TLC).

2.1 Synthesis of Schiff base Ligand $C_8H_9ON_3S$ (L^1)

The ligand was prepared by condensation reaction of 20 mmole of salisylaldehyde (1.048ml) with 20 mmole (1.82gm) of thiosemicarbazide in a clean round bottomed flask. Salisylaldehyde was dissolved in 20ml ethanol and thiosemicarbazide was dissolved in hot ethanol with water. The solutions were mixed and refluxed for 3-4 hours. On cooling off white colored product was formed which was washed with ethanol, acetone, and diethyl ether and dried in vacuum desiccators over anhydrous $CaCl_2$. The purity of ligand was tested by TLC using different solvents. The product was found to be soluble in methanol, chloroform and DMSO. It provided 80% yield at 34°C. The target Schiff base was synthesized according to Figure-1.

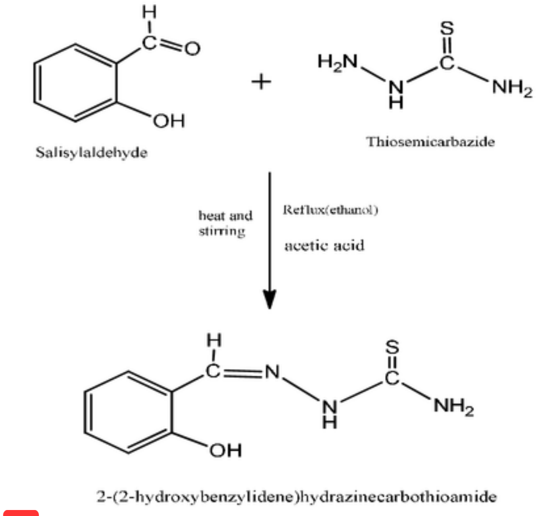

Figure-1: Synthesis pathway of Schiff base ligand $C_{14}H_{11}O_3N$ (L^1)

2.3 Synthesis of Metal Complexes Using Schiff Base Ligand $C_{14}H_{11}O_3N$ (L^1)

The synthesized complexes have the general formula $[M(SB)_2]$; where M= Zn(II), Ni(II) and Mn(II) and SB = synthesized Schiff base ligand (Fig-3). During complexation reaction,15ml methanolic solution of Zinc(II) sulphate (0.2875g, 1mmol)/ Ni(II) chloride hexahydrate (0.238g, 1mmol)/ Manganege(II) chloride tetrahydrate (0.198g, 1mmol) was taken in a two necked round bottom flask and kept on a magnetic stirring. A methanolic solution (20 mL) of prepared Schiff base ligand (0.390g, 2mmol) was added drop wise and a methanolic solution (10mL) of KOH (0.1122g,1mmol) was added slowly then the resultant mixture was heated with constant stirring on a magnetic stirrer for 4-5 hours. On cooling colored solid product was formed which was washed with methanol, acetone, ether and dried in vacuum over anhydrous $CaCl_2$. The reaction was monitored by TLC using petroleum ether, toluene, ethyl acetate and methanol as solvent. The common structure of metal complexes has shown in (Figure-2-6).

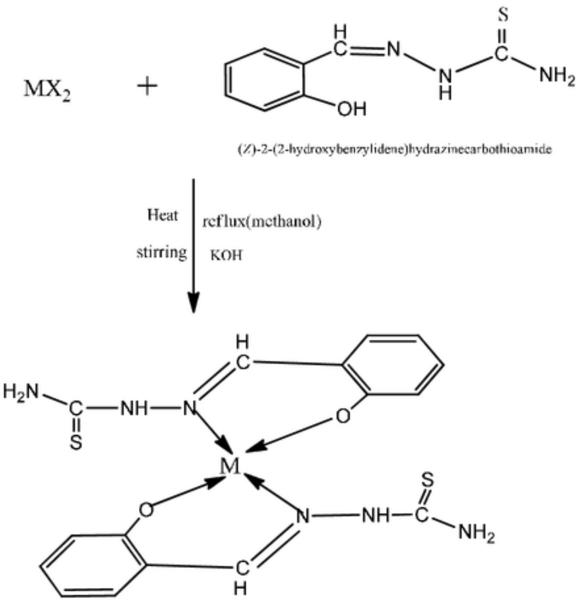

Figure-2: Synthesis pathway of Schiff Base Ligand (L^2) Metal Complexes

Where, M=Zn(II), Ni(II), Mn(II), and Sn(II) ions and X=Cl^-,SO_4^{2-} ions

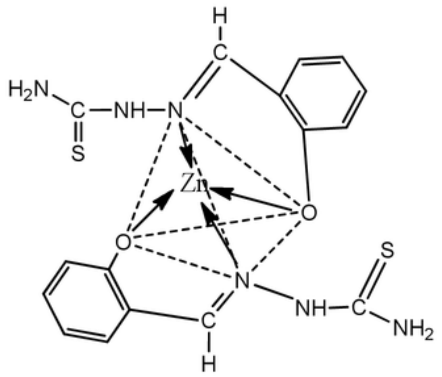

Figure-3: Structure of [$C_{16}H_{16}ZnO_2N_6S_2$] Comp

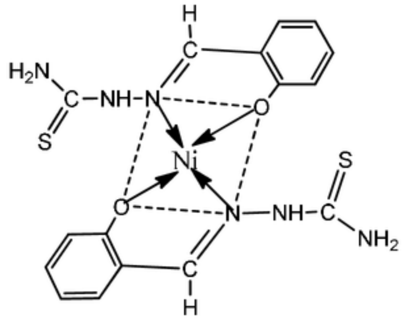

Figure-4: Structure of [$C_{16}H_{16}NiO_2N_6S_2$] Complex

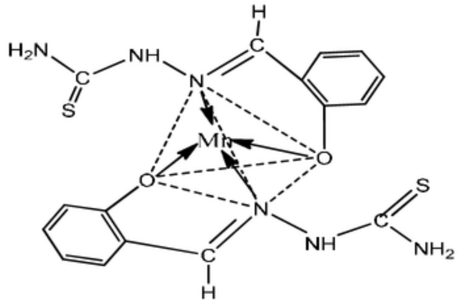

Figure-5: Structure of [$C_{16}H_{16}MnO_2N_6S_2$] Complex

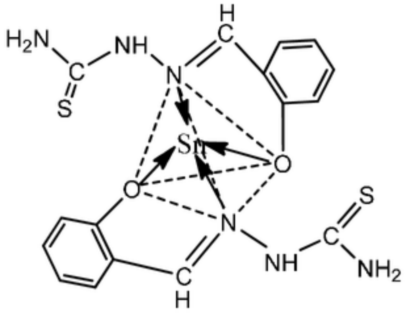

Figure-6: Structure of [$C_{16}H_{16}SnO_2N_6S_2$] Complex

2.4 Synthesis of Schiff Base Ligand $C_{14}H_{11}O_3N$ (L^2)

4-hydroxy benzaldehyde (2.44g, 20 mmol) dissolved in absolute ethanol (20-25 mL) was added drop wise to a constant stirring solution of 4-aminobenzoic acid(2.76 g, 20 mmol) in 30 mL ethanol and 2 mL of conc. glacial acetic acid was added slowly. Then the mixture was refluxed for (4-5)h. On cooling, a solid yellow product was formed which was filtered, washed with ethanol and diethyl ether and dried in vacuum over anhydrous $CaCl_2$. The reaction was monitored by TLC using petroleum ether, ethyl acetate, toluene and methanol solvents. The product was found to be soluble in methanol, chloroform and DMSO. It provided 65% yield at 34°C. The target Schiff base was synthesized according to Figure-7.

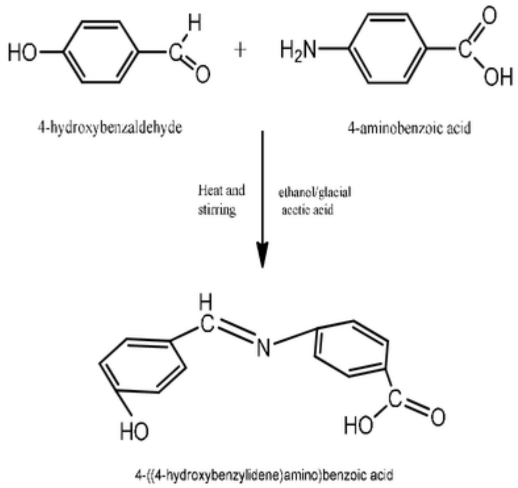

Figure-7: Synthesis pathway of Schiff base ligand $C_{14}H_{11}O_3N$ (L^2)

2.5 Synthesis of Metal Complex Using Schiff Base Ligand (L^2)

The complex was prepared in 1:2 molar ratio (metal : ligand). A methanolic solution (20 mL) of cobalt(II) chloride hexahydrate (0.24 g, 1 mmol)) was taken in a two necked round bottom flask and kept on magnetic stirring and a methanolic solution (20 mL) of prepared Schiff base ligand (0.483 g, 2 mol) was added drop wise and stirred with heating for 4-5h. On cooling, precipitate was formed which was filtered, washed with ethanol, acetone, and diethyl ether and dried in vacuum desiccators over anhydrous $CaCl_2$. The purity of complex was tested by TLC using different solvents. The complex was soluble in DMSO with heat. The proposed structure of complex was shown in (Figure-8).

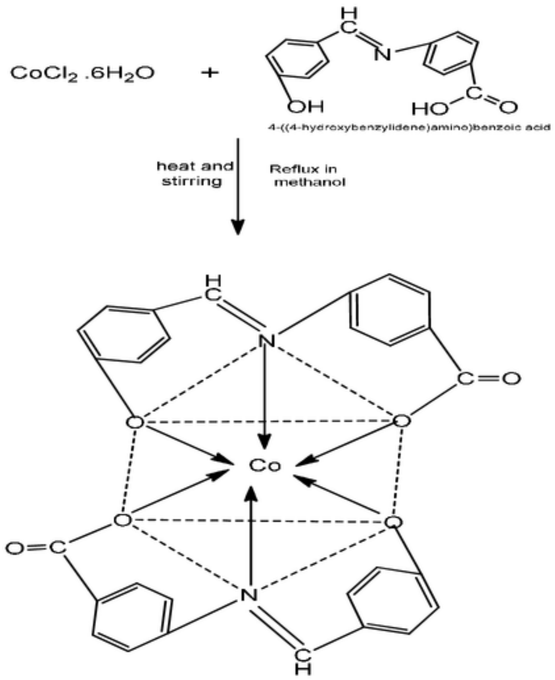

Figure-8: Synthesis pathway of Co(II) complex with Schiff Base Ligand (L^2)

2.6 Synthesis of Schiff base Ligand $C_9H_{11}N_3OS$ (L^3)

To a stirring solution of thiosemicarbazide (0.91 gm, 10 mmol) dissolved in 20mL of ethanol with water, a solution of Anisaldehyde(1.22mL,10mmol) in 10mL ethanol was added drop wise. After sometime 2ml of glacial acetic acid was added with the reaction mixture and the solution was refluxed for 5-6 h and allowed to cool overnight in room temperature. The off white product was filtered washed several times with ethanol and finally with diethyl ether and dried in vacuum over anhydrous $CaCl_2$. The reaction was monitored by TLC using petroleum ether, ethyl acetate, toluene and methanol solvents .The product was found to be soluble in methanol, DMF and DMSO. It provided 62% yield. The Schiff base was synthesized according to Figure-9.

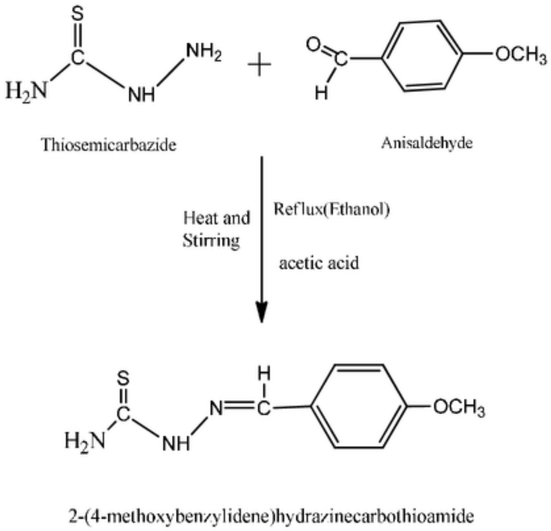

Figure-9: Synthesis pathway of Schiff base ligand $C_9H_{11}N_3OS$ (L^3)

2.7 Synthesis of Metal Complex Using Schiff Base Ligand (L^3):

The complex was prepared in 1:2 molar ratio (metal : ligand). Methanolic solution (20 mL) of cadmium(II) chloride dihydrate (0.228g, 1mmol) was taken in a two necked round bottom flask and kept on magnetic stirring. A methanolic solution (20 mL) of prepared Schiff base ligand (L^3) (0.418g, 2mmol) was added drop wise and stirred with heating for 4-5h. On cooling, precipitate was formed which was filtered, washed with ethanol, acetone, and diethyl ether and dried in vacuum desiccators over anhydrous $CaCl_2$. The reaction was monitored by TLC using different solvents. The complex was soluble in DMSO with heat. The proposed structure of complex was shown in (Figure-10).

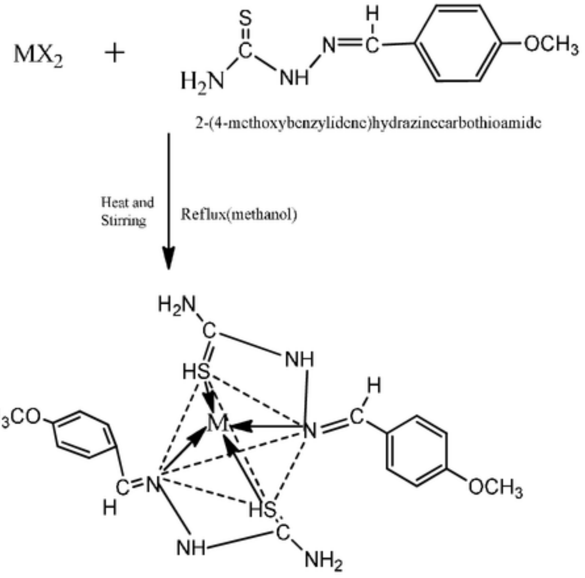

Figure-10: Synthesis pathway of Schiff Base Ligand (L^4) Metal Complex

Where, M=Cd(II) ions

3. Characterization of the Ligands and Complexes

The structures of the complexes were characterized by melting point, conductivity measurements, magnetic susceptibility, IR spectra and UV visible spectra [10] analysis. The purity of the ligands and metal complexes was monitored by Thin Layer Chromatography (TLC). The ligands and complexes are characterized below by these methods.

3.1 Melting point

Melting point gives an approximate idea about the nature of the complexes and can suggest whether it is covalent or ionic [11]. The melting point of all the synthesized ligands and complexes are shown in Table-1.

Table-1: Physical characteristics and analytical data of ligands and complexes

Compound/Empirical Formula	Formula Weight	Color	Yield(%)	Melting Point/ Decomposition temp.(^{0}C)

Ligand (L^1) $C_8H_9ON_3S$	195	off white	80 %	215^0C - 217^0C
[Zn (L^1)$_2$] .$2H_2O$ [$ZnC_{16}H_{16}O_2N_6S_2$].$2H_2O$	491.38	cream color	67 %	above 300^0C
[Ni (L^1)$_2$].H_2O [$NiC_{16}H_{16}O_2N_6S_2$].H_2O	466.93	yellow green	70 %	275^0C - 280^0C
[Mn (L^1)$_2$] .H_2O [$MnC_{16}H_{16}O_2N_6S_2$].H_2O	462.94	golden rod	65 %	275^0C - 280^0C
[Sn (L^1)$_2$] [$SnC_{16}H_{16}O_2N_6S_2$]	508.71	greenish yellow	60%	240^0C - 250^0C
Ligand (L^2) $C_{14}H_{11}O_3N$	241	yellow	65 %	241^0C - 245^0C
[Co(L^2)$_2$] .$2H_2O$ [$CoC_{28}H_{18}O_6N_2$].$2H_2O$	576.93	golden rod	56 %	above 300^0C
Ligand (L^3) $C_9H_{11}N_3OS$	209	off white	62%	145^0C - 150^0C
[Cd(L^3)$_2$] [$CdC_{18}H_{22}O_2N_6S_2$]	530.41	white	75 %	260^0C - 265^0C

3.2 Characterizations by Conductivity

The molar conductivities were obtained using the formula

$$\Lambda = \frac{1000}{C} \times \text{Cell constant} \times \text{Observed conductivity.}$$

Where, Λ=molar conductance

C= concentration

The molar conductance is calculated from the measured specific conductance at room temperature by using the above equation. The experimental results are shown in Table-2.

Table-2: Data for the determination of Molar conductivity

Name of Complex	Observed conductivity (ohm^{-1} cm^2 mol^{-1})	Molar conductance $\Lambda = \left(1000/_{c}\right) \times specificconductance$ Scm^2mol^{-1}	μ_{eff} in B.M.	No. of unpaired electron
[Zn $(L^1)_2$] $.2H_2O$ [$ZnC_{16}H_{16}O_2N_6S_2$]$.2H_2O$	3	3	0.567	–
[Ni $(L^1)_2$] $.H_2O$ [$NiC_{16}H_{16}O_2N_6S_2$]$.H_2O$	6	6	1.471	–
[Mn $(L^1)_2$] $.H_2O$ [$MnC_{16}H_{16}O_2N_6S_2$]$.H_2O$	8	8	2.576	1
[Sn $(L^1)_2$] [$SnC_{16}H_{16}O_2N_6S_2$]	9	9	0.639	–
[Co$(L^2)_2$] $.2H_2O$ [$CoC_{28}H_{18}O_6N_2$]$.2H_2O$	8	8	4.017	3
[Cd$(L^3)_2$] [$CdC_{18}H_{22}O_2N_6S_2$]	6	6	0.461	–

From the above table data it is showed that all the complexes are non-electrolyte.

3.3 Characterizations by Magnetic Susceptibility

Measurement of magnetic susceptibility: The measurements of magnetic susceptibilities were made at about constant temperature; Curie-law was used and was calculated from the equation.

$$\mu_{eff} = 2.83 \sqrt{\chi_m^{corr} .T} \quad \text{B.M.}$$

Thus μ_{eff} obtained is known as effective magnetic moment. All the values and weight were expressed in C.G.S. units. The observed values of effective magnetic moment (μ_{eff}) of the complexes at room temperature are given in table 2. From the above data it is showed that the Zn(II), Ni(II), Sn(II) and Cd(II) ions complexes are diamagnetic and Mn(ll) and Co(II) ions complexes are paramagnetic in nature[13].

3.4 Measurement of IR spectra: At first the complexes heat six hour and KBr overnight in oven. Then the complexes and KBr grind with pestle in mortar. Infrared spectra disc were recorded as KBr with a NICOLET 310, FTIR spectrophotometer, Belgium, from 4000-225 cm^{-1}.

3.4.1 IR spectra of Schiff Base ligand $C_8H_9ON_3S$ (L^1) and It's metal complexes

a. IR spectra of Schiff Base ligand $C_8H_9ON_3S$ (L^1)

The spectrum of ligand showed a strong absorption band at 1616 cm^{-1} due to the azomethine υ(C=N) stretching frequency of the free ligand [14-18] indicating that the condensation have taken place between the CHO moiety of salisylaldehyde and $–NH_2$ moiety of thiosemicarbazide. The IR spectra of the free ligand (figure-11) showed two bands at 3320 cm^{-1} and 3174 cm^{-1} may be attributed to the free $-NH_2$ and υ(N–H) groups respectively. These bands remains in the same region in all complexes spectra, suggesting nonparticipation in coordination of one terminal $–NH_2$ group in thiosemicarbazone [15,19-21] The band observed at 3444 $cm^{-1}$was assigned to the υ(O-H) of hydroxyl group [14,15,22]. The strong band 776 cm^{-1} for υ(C=S) indicated that C=S bond was present in the Schiff base ligand [14,22].

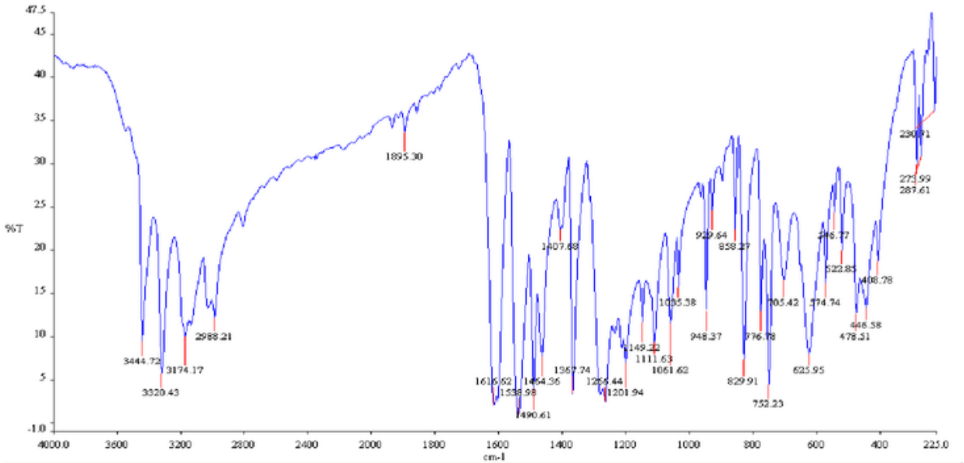

Figure-11: IR spectra of Schiff base ligand $C_8H_9ON_3S$ (L^1)

b. IR spectra of $[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$ complex

In order to determine the mode of coordination of ligand to metal in complexes, IR spectrum of ligand was compared with IR spectrum of metal complexes (figure-12). The band at 1616 cm^{-1} due to the azomethine υ(C=N) stretching frequency of the free ligand that shifted to lower frequency in the spectra of the Zn (II) complex at 1607 cm^{-1} which indicated the coordination through azomethine N atom. The band 3444 cm^{-1} due to the υ(O-H) of hydroxyl group in the IR spectra of the ligand was absent and shifted to lower absorption frequency in the IR spectra of Ni(II) complex indicated the coordination through the phenolic oxygen [23,24]. This is confirmed by the shift of υ(C-O) stretching vibration observed at 1266cm^{-1} in the spectra of free ligand to 1285 cm^{-1} stretching vibration of complex after coordination [16], which corresponds to forming of weaker C-O(Zn) bond comparing to C-O(H) and confirms coordination of ligand to Ni(II) via deprotonated phenolic oxygen [25,26]. Also the medium intensity bands observed at 566cm^{-1}is attributed to M-O and 448 cm^{-1} is attributed to M-N bonds [27].

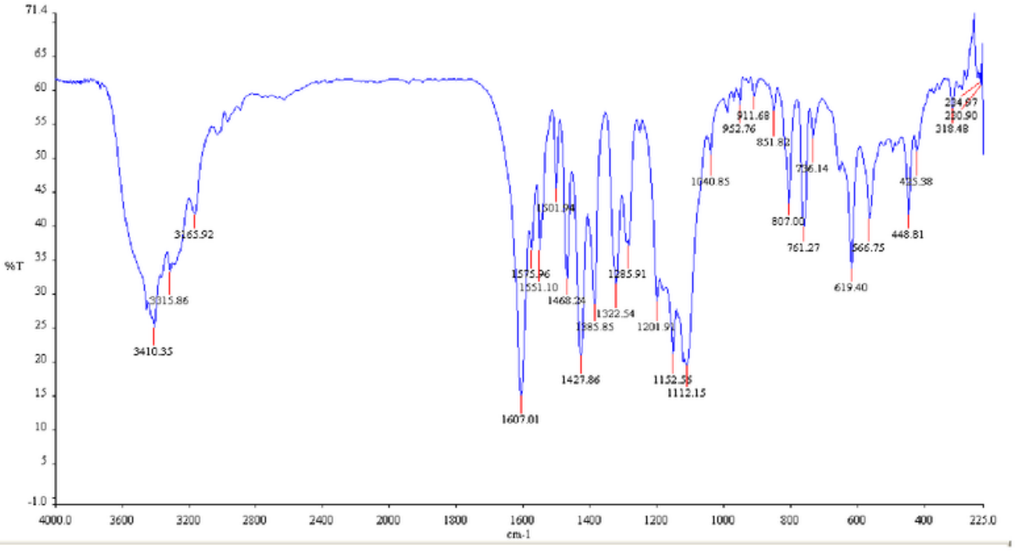

Figure-12: IR spectra of $[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$ complex

c. IR spectra of $[NiC_{16}H_{16}O_2N_6S_2].H_2O$ complex

In order to determine the mode of coordination of ligand to metal in complexes IR spectrum of ligand was compared with IR spectrum of metal complexes [14, 23]. The band at 1616 cm^{-1} due to the azomethine υ(C=N) stretching frequency of the free ligand that shifted to lower frequency in the spectra of the Ni(II) complex (figue-13) at 1607cm^{-1} indicating the coordination through N atom [5-9]. The band 3444 cm^{-1} due to the υ(O-H) of hydroxyl group in the IR spectra of the ligand was absent and shifted to lower absorption frequency in the IR spectra of Ni(II) complex indicated the coordination through the phenolic oxygen [22,24]. This is confirmed by the shift of υ(C-O) stretching vibration observed at 1266 cm^{-1} in the spectra of free ligand to 1294 cm^{-1} stretching vibration of complex after coordination

[16], which corresponds to forming of weaker C-O(Ni) bond comparing to C-O(H) and confirms coordination of ligand to Ni(II) via deprotonated phenolic oxygen. Also the medium intensity bands observed at 567 $cm^{-1}$is attributed to M-O and 457cm^{-1} is attributed to M-N bonds [27].

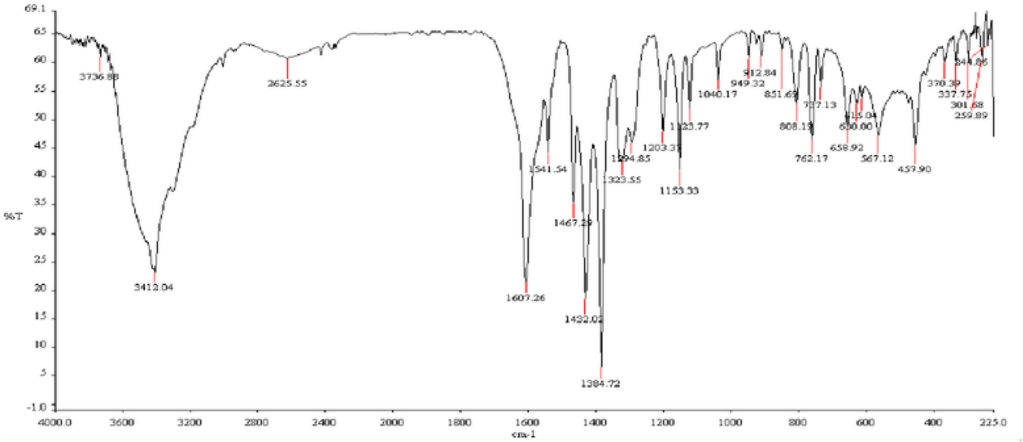

Figure-13: IR spectra of $[NiC_{16}H_{16}O_2N_6S_2].H_2O$

d. IR spectra of $[MnC_{16}H_{16}O_2N_6S_2]$

In order to determine the mode of coordination of ligand to metal in complexes IR spectrum of ligand was compared with IR spectrum of metal complexes. The band at 1616 cm^{-1} due to the azomethine υ(C=N) stretching frequency of the free ligand that shifted to lower frequency in the spectra of the Mn(II) complex (figure-14) at 1600 cm^{-1} indicating the coordination through N atom. The band 3444 cm^{-1} due to the υ(O-H) of hydroxyl group in the IR spectra of the ligand was absent and shifted to lower absorption frequency in the IR spectra of Mn(II) complex indicated the coordination through the phenolic oxygen. This is confirmed by the shift of υ(C-O) stretching vibration observed at 1266 cm^{-1} in the spectra of free ligand to 1296 cm^{-1} stretching vibration of complex after coordination , which corresponds to forming of weaker C-O(Mn) bond comparing to C-O(H) and confirms coordination of ligand to Mn(II) via deprotonated phenolic oxygen [5,17]. Also the medium intensity bands observed at 570$cm^{-1}$is attributed to M-O and 442cm^{-1} is attributed to M-N bonds [27].

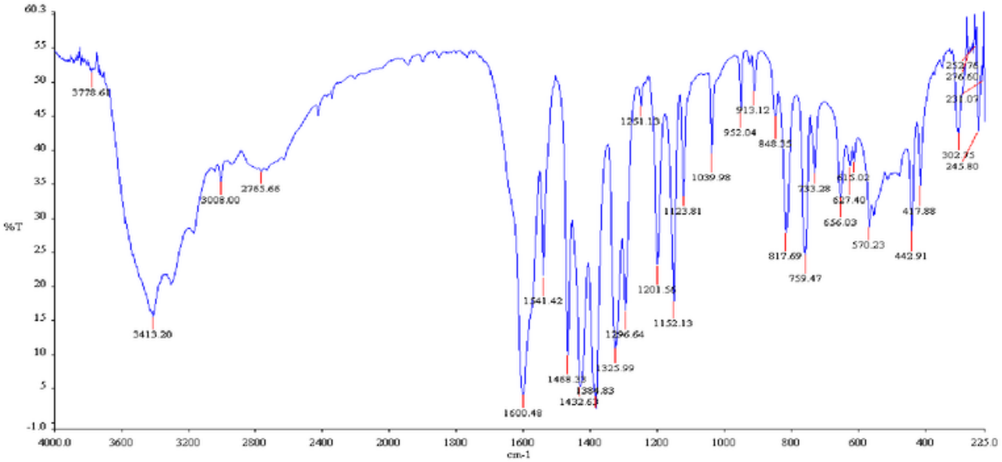

Figure-14: IR spectra of $[MnC_{16}H_{16}O_2N_6S_2].H_2O$

e. IR spectra of $[SnC_{16}H_{16}O_2N_6S_2]$

In order to determine the mode of coordination of ligand to metal in complexes IR spectrum of ligand was compared with IR spectrum of metal complexes. The band at 1616 cm^{-1} due to the azomethine υ(C=N) stretching frequency of the free ligand that shifted to lower frequency in the spectra of the Sn(II) complex (figure-15) at 1610 cm^{-1} indicating the coordination through N atom .The band 3444 cm^{-1} due to the υ(O-H) of hydroxyl group in the IR spectra of the ligand was absent and shifted to lower absorption frequency in the IR spectra of Sn(II) complex indicated the coordination through the phenolic oxygen. This is confirmed by the shift of υ(C-O) stretching vibration observed at 1266 cm^{-1} in the spectra of free ligand to 1286 cm^{-1} stretching vibration of complex after coordination, which corresponds to forming of weaker C-O(Sn) bond comparing to C-O(H) and confirms coordination of ligand to Sn(II) via deprotonated phenolic oxygen . Also the medium intensity bands observed at 594$cm^{-1}$is attributed to M-O and 458cm^{-1} is attributed to M-N bonds.

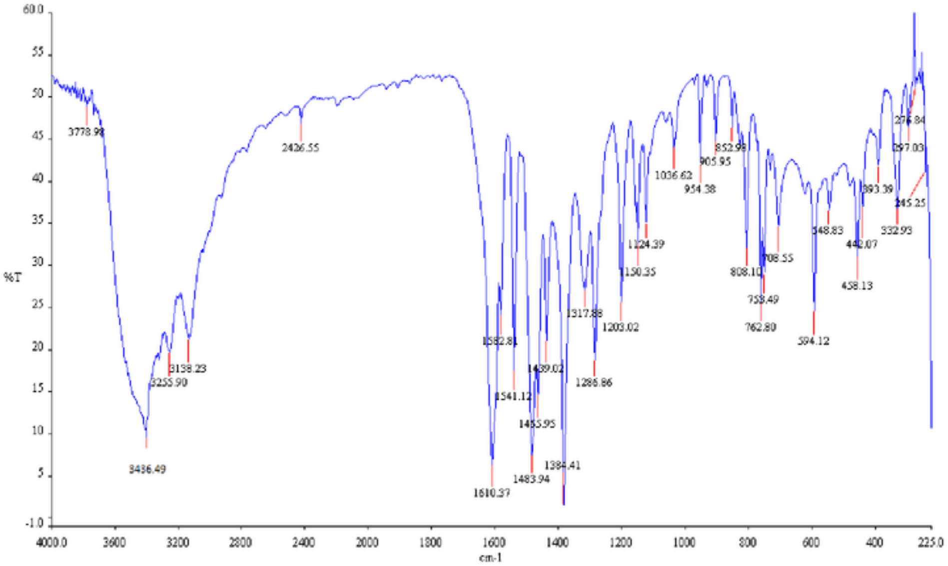

Figure-15: IR spectra of $[SnC_{16}H_{16}O_2N_6S_2]$

Table-3: FTIR spectral data of the ligand $C_8H_9ON_3S$ (L^1) and it's metal complexes (in cm^{-1})

Ligand / Metal Complexes	IR/cm^{-1}				
	ν(O-H)	ν(C=N)	ν(C-O)	ν(M-O)	ν(M-N)
$C_8H_9ON_3S$	3444	1616	1266	-	-
$[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$	3410	1607	1285	566	448
$[NiC_{16}H_{16}O_2N_6S_2].H_2O$	3412	1607	1294	567	457
$[MnC_{16}H_{16}O_2N_6S_2].H_2O$	3413	1600	1296	570	442
$[SnC_{16}H_{16}O_2N_6S_2]$	3436	1610	1286	594	458

3.4.2 IR spectra of Schiff Base ligand $C_{14}H_{11}O_3N$ (L^2) and It's metal complex

a. IR spectra of Schiff Base ligand $C_{14}H_{11}O_3N$ (L^2)

The bands at 1735 cm^{-1} and 3420 cm^{-1} due to carbonyl (C=O) and NH_2 stretching vibrations of the starting reagents respectively were absent in the spectra of ligand (figure-16) and a strong new band at 1620 cm^{-1} was appeared which assigned to the azomethine (HC=N) linkage, a fundamental feature of Schiff base ligand [28,29]. This indicated that amino and aldehyde moieties of the starting reagents have been converted into the azomethine moiety. The bands at 1320 cm^{-1} due to υ(C-O) of phenolic group and 3410 cm^{-1} due to the phenolic υ(OH) were also observed in the spectra of ligand [23]. The bands at 1680 cm^{-1} due to υ(C=O) stretching vibration and 3080 cm^{-1} due to carboxylic – υ(OH) were observed in the IR spectra of ligand [30-33].

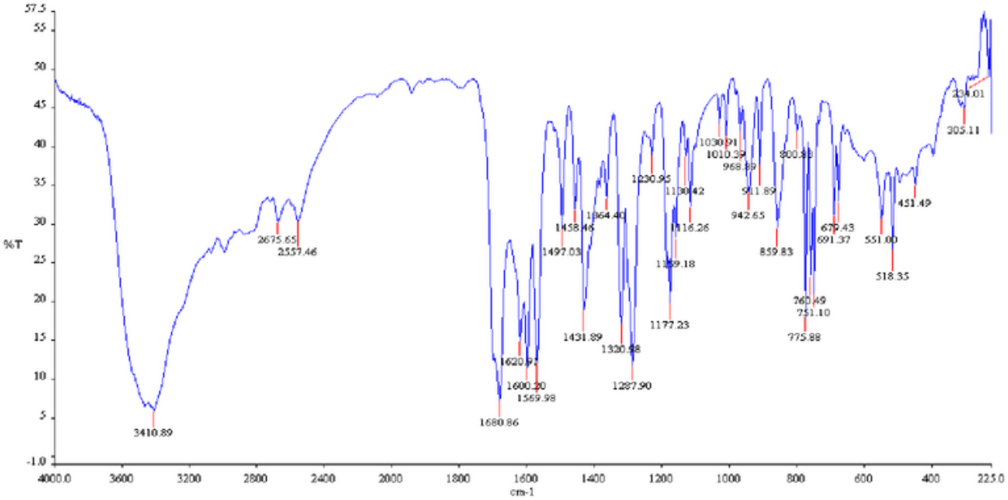

Figure-16: IR Spectra of 4-((hydroxybenzylidene)amino)benzoic acid ligand(L^2)

b. IR Spectra of [$CoC_{28}H_{18}O_6N_2$].$2H_2O$

The band at 1620 cm^{-1} due to the azomethine –HC=N stretching vibration was shifted to lower frequency at 1541 cm^{-1} in the metal complex compared to free ligand, suggested the coordination of metal ion through nitrogen of azomethine group [34-36]. The N atom of azomethine would reduce the electron density in the azomethine link and thus lower the –HC=N absorption after coordination. This is further substantiate by the presence of a new band at 457 cm^{-1} assignable to υ(M-N). The disappearance of phenolic υ(OH) band at 3410 cm^{-1} in Co(II) complex suggested the co-ordination by the phenolic oxygen after deprotonation to the metal ions. This is further supported by shifting of υ(C-O) phenolic band at 1320 cm^{-1} to lower wave number at 1305 cm^{-1} in the metal complex. The appearance of a new band at 590cm^{-1} due to υ(M-O) in the Co(II) complex (figure-17) which further substantiate . The band at 1680 cm^{-1} assigned to υ(C=O) in the spectra of ligand also shifted to lower frequency range in the metal complex. That suggested the involvement of oxygen atom of carboxylic υ(-OH) group to the coordination with metal ions. The comparison of the

IR spectra of the Schiff base and it's metal chelates indicated that the Schiff base ligand coordinated to metal ions by three donor atoms representing the ligand acting in a tri-dentative manner.

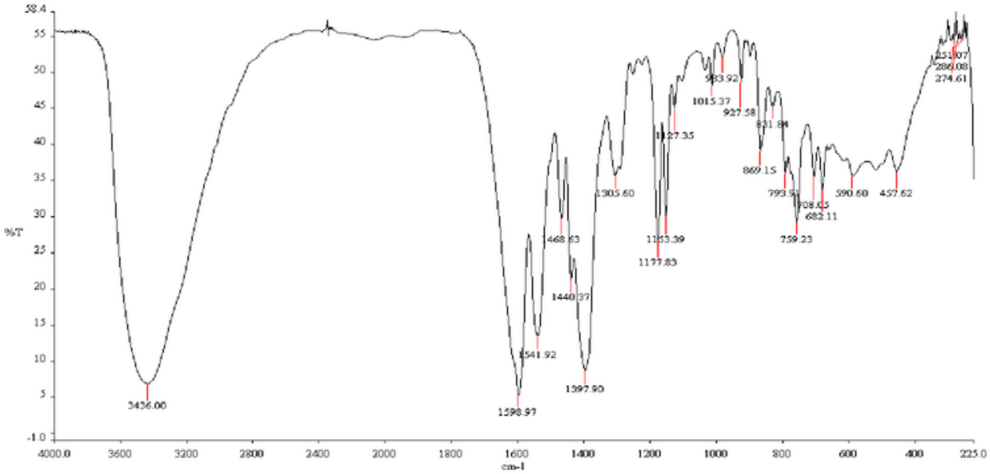

Figure-17: IR Spectra of $[CoC_{28}H_{18}O_6N_2].2H_2O$ with ligand (L^2)

Table-4: FTIR spectral data of the ligand L^2 and its Co(II) metal complex (in cm^{-1})

Ligand / Metal Complexes	IR/cm^{-1}					
	ν(O-H)	ν(C=N)	ν(C=O)	ν(C-O)	ν(M-O)	ν(M-N)
$C_{14}H_{11}O_3N$	3410	1620	1680	1320	-	-
$[CoC_{28}H_{18}O_6N_2].2H_2O$	3436	1541	1598	1305	590	457

3.4.3 IR spectra of Schiff Base ligand $C_9H_{11}N_3OS$ (L^3) and It's metal complex

a. IR-Spectra of Schiff base $C_9H_{11}N_3OS$ (L^3)

The peaks obtained at 3406cm^{-1} and 3291cm^{-1}may be assigned to symmetric and asymmetric υ(–N-H) stretching frequency of primary amino group. The broad peak obtained between 3282 and 2829 cm^{-1} may be assigned to overlapping of peaks of hydrogen bonded υ(N-H) and aromatic C-H stretching frequency. The bands obtained between 1183 cm^{-1} and 1252 cm^{-1} in ligand were due to υ(-OCH_3)groups (figure-18). The peaks observed at 1606 cm^{-1} and 834 cm^{-1} may be assigned to υ(C=N) and υ(C=S) [37-39].

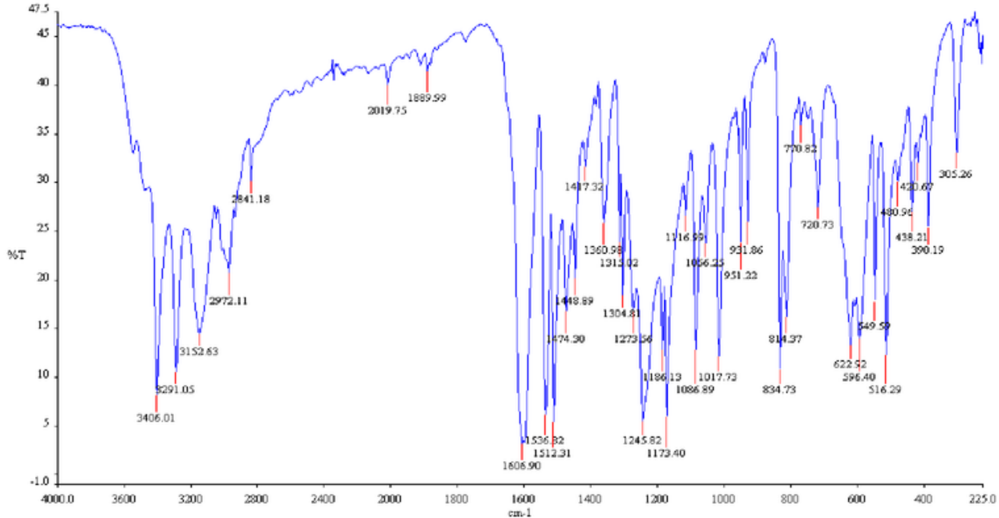

Figure-18: IR Spectra of Schiff base ligand $C_9H_{11}N_3OS$ (L^3)

b. IR-Spectra of [$C_{18}H_{22}CdO_2N_6S_2$] with ligand (L^3)

The bands at 1606 cm^{-1} and 834 cm^{-1} assigned to υ(C=N) and υ(C=S) modes and these bands shifted towards lower frequency in the spectra of Cd(II) complex (figure-19), which indicated that coordination takes place through nitrogen of υ(C=N) group and sulphur of υ(C=S) group. At lower frequency the complex exhibited new bands at 540 and 397 cm^{-1} which further supported the coordination site υ(M–N) and υ(M–S) vibrations.

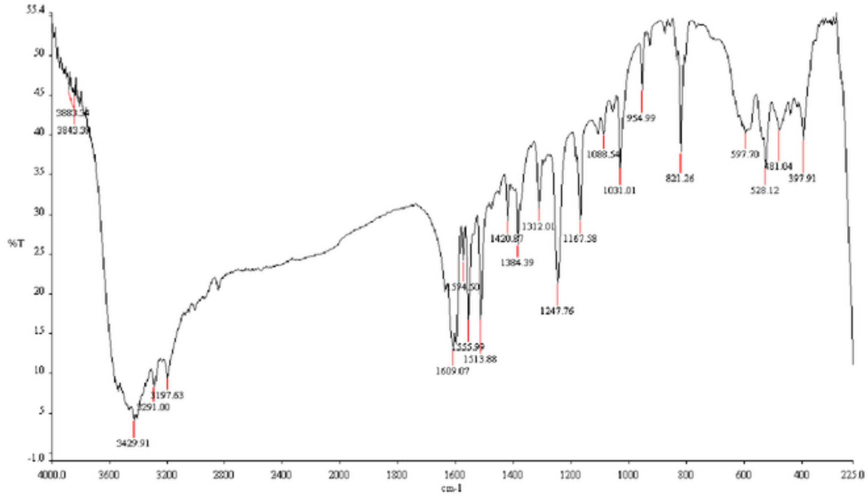

Figure-19: IR Spectra of [$CdC_{18}H_{22}O_2N_6S_2$]

Table-5: FTIR spectral data of the ligand L^3 and its Cd(II) metal complex (in cm^{-1})

Ligand / Metal Complexes	IR/cm^{-1}			
	ν(C=N)	ν(C=S)	ν(M-N)	ν(M-S)
Ligand (L^3) $C_9H_{11}N_3OS$	1606	834	-	-
$[Cd(L^3)_2]$ $[CdC_{18}H_{22}O_2N_6S_2]$	1574	821	528	397

3.5 Characterization by UV-visible Spectra

a. UV-vis spectra and magnetic moment of Zn(II) complex with ligand $C_8H_9ON_3S$ (L^1)

The electronic spectral data for the ligand and their metal complex recorded in DMSO are summarized in Table-6. There are two absorption bands, assigned to n–π* and π–π* transitions, in the electronic spectrum of the ligand. These transitions are also found in the spectra of the complexes, but they are shifted towards lower and higher frequencies, indicating the coordination of the ligand to the metallic ions [40]. The UV spectra of the ligand shows three absorption bands at 260nm,310nm and 355nm.The first two bands are assigned to π–π* transitions of azomethine chromospheres and a benzene ring and the third is assigned to n–π* transition of a lone pair of electrons of an azomethine nitrogen and an antibonding π orbital. The absorption band n-π*at 355 nm due to an imine group in the ligand, whereas for the zinc complex, the same was observed at 390 nm with weak absorption intensity which indicate the coordination of zinc with imine group [41]. The zinc complex shows only the charge transfer transition which can be assigned to charge transfer from the ligand to the metal and vice versa, no d-d transitions are expected for d^{10} Zn(II) complex [42].

b. UV-vis spectra and magnetic moment of Ni(II) complex with ligand $C_8H_9ON_3S$ (L^1)

The UV–Vis absorption spectra of the ligand and complex were recorded after dissolving into DMSO solvent at room temperature. There are two absorption bands, assigned to n–π* and π–π* transitions, in the electronic spectrum of the ligand. These transitions are also found in the spectra of the complexes, but they are shifted towards lower and higher frequencies, confirming the coordination of the ligand to the metallic ions [43]. The electronic spectrum of ligand exhibits three intense absorption peaks at 260 nm, 310 nm and 350nm.The first and second peaks were attributed to benzene π–π*and imino π–π*transitions and the third peak in the spectra was assigned to n–π*transition [44]. The electronic spectra of the Ni(II) complex with an electronic configuration of d^8 shows three new absorption bands in the visible region and these three bands of the transitions $^1A_{1g}\rightarrow{}^1A_{2g}$ (355nm), $^1A_{1g}\rightarrow{}^1B_{1g}$ (380nm) and $^1A_{1g}\rightarrow{}^1E_g$ (420 nm) were observed in the spectra of a square-planar Ni(II) complex [45,46].

c. UV-vis spectra and magnetic moment of Mn(II) complex with ligand $C_8H_9ON_3S$ (L^1)

The UV–Vis absorption spectra of the ligand and complex were recorded after dissolving into DMSO solvent at room temperature. There are two absorption bands, assigned to n–π* and π–π* transitions, in the electronic spectrum of the ligand. These transitions are also found in the spectra of the complexes, but the ligand to the metallic ions [47]. The electronic spectrum of ligand exhibits three intense absorption peaks at 260 nm, 310 nm and 350nm. The first and second peaks were attributed to benzene π–π*and imino π–π*transitions and the third peak in the spectra was assigned to n–π*transition. Due to Forbidden transition, several bands were observed in the visible region of Mn(II) complex, and the band at 430 nm is attributed to (d-d) transition of type $^6A_1\rightarrow{}^4T_2$.

d. UV-vis spectra and magnetic moment of Sn(II) complex with ligand $C_8H_9ON_3S$ (L^1)

The electronic absorption spectra of ligand L^1 and its Sn (II) complex in DMSO solution were carried out in the range of 200-800 nm at room temperature. There is a shift of the bands to longer wave length in spectra of complex is a good evidence of complex formation. There were various bands in the ligand spectra assigned to inter ligand and charge transfer of n-π* transitions according to their energies and intensities. Ligand exhibits three intense absorption peaks at 260 nm, 310 nm and 350nm.The first and second peaks were attributed to benzene π–π*and imino π–π*transitions and the third band in the spectra was assigned to n–π*transition .The complex showed an intense band at 410nm due to the n–π* transition of azomethine chromosphere and the band at 340 nm may be assigned as charge transfer band. It has been reported that the metal is capable of forming dπ-pπ* bonds with ligands containing nitrogen as the donor atom. The Sn atom has its 5d orbital completely vacant and hence Sn←N bonding can take place by the acceptance of the lone pair of electrons from the azomethine nitrogen of the ligand [48-50].

Table-6: Magnetic moments and electronic spectral data for ligand (L^1) and its metal complexes

Compound	λ_{max} n.m	Wave number cm^{-1}	μ_{eff} B.M	Assignment
$C_8H_9ON_3S$	260	38461	–	$\pi \rightarrow \pi^*$
	310	32258		$\pi \rightarrow \pi^*$
	350	38571		$n \rightarrow \pi^*$
$[NiC_{16}H_{16}O_2N_6S_2].H_2O$	355	28169	1.469	$^1A_{1g} \rightarrow {}^1A_{2g}$
	380	26315		$^1A_{1g} \rightarrow {}^1B_{1g}$
	420	23809		$^1A_{1g} \rightarrow {}^1E_g$
$[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$	265	37735	0.5197	C.T (M→L)
	320	31250		C.T (M→L)
	390	25641		C.T (M→L)
$[MnC_{16}H_{16}O_2N_6S_2].H_2O$	325	30769	2.507	
	380	26315		
	430	23255		$^6A_1 \rightarrow {}^4T_2$

e. UV-vis spectra and magnetic moment of Co(II) complex with ligand $C_{14}H_{11}O_3N$ (L^2)

The magnetic moment and electronic spectra are very effective in the evaluation of results obtained by other methods of structural investigation. Information regarding the geometry of the complex of Co(II) ions was obtained from electronic spectral studies and magnetic moments (table-7). The electronic spectra of ligand and their metal complexes were recorded in DMSO. Electronic spectrum of ligand shows strong absorption band at 330nm region can be assigned to the n→π*transition of the azomethine group of ligand, which slightly shifted to lower frequency in the spectra of the complex, indicating that the azomethine nitrogen atom is involved in coordination to the metal ion. The Co(II) complex was found the magnetic moment 4.0137 B.M which indicated the three unpaired electrons per Co(II) ion attaining an octahedral environment [60]. The electronic spectrum of Co(II) complex shows bands at 264nm and 274nm are assignable to metal-ligand charge transfer band and the band 400nm is assignable to$^4T_{1g}$(F)→ $^4T_{1g}$(P) transition.

Table-7: The electronic spectral data and magnetic moments for ligand (L^2) and it's metal complex

Compound	λ_{max} n.m	Wave number cm^{-1}	μ_{eff} B.M	Assignment
$C_{14}H_{11}O_3N$	330	30303	-	n→π*
$[CoC_{28}H_{18}O_6N_2].2H_2O$	264	37878	4.0137	Charge transfer(C.T)
	274	36496		C.T (M→L)
	400	25000		$^4T_{1g}(F) \rightarrow {}^4T_{1g}(P)$

f. UV-vis spectra and magnetic moment of Cd(II) complex with ligand $C_9H_{11}N_3OS$ (L^3)

The electronic spectral data for the ligand and it's metal complex recorded in DMSO are summarized in Table-8. There are two absorption bands, assigned to n–π* and π–π* transitions, in the electronic spectrum of the ligand. These transitions are also found in the spectra of the complexes, but they are shifted towards lower and higher frequencies, indicating the coordination of the ligand to the metallic ions. The UV spectra of the ligand shows three absorption bands at 280nm,330nm and 350nm.The first two bands are assigned to π–π* transitions of azomethine chromospheres and a benzene ring and the third is assigned to n–π* transition of a lone pair of electrons of an azomethine nitrogen and an anti-bonding π orbital. The absorption band n-π*at 350nm due to an imine group in the ligand, whereas for the Cd(II) complex, the same was observed at 400 nm with weak absorption intensity which indicate the coordination of cadmium with imine group. The cadmium complex show only the charge transfer transition which can be assigned to charge transfer from the ligand to the metal and vice versa, no d-d transition are expected for diamagnetic d^{10} Cd(II) complex. The shifting of ligand absorption in the UV region, in the spectra of the complex confirming the coordination of the ligand to metal like Cd (II) ions.

Table-8: Magnetic moments and electronic spectral data for ligand (L^3) and it's Cd(II) Complex

Compound	λ_{max} n.m	Wave number cm^{-1}	μ_{eff} B.M	Assignment
$C_9H_{11}N_3OS$	280	35714	–	$\pi \rightarrow \pi^*$
	330	30303		$\pi \rightarrow \pi^*$
	350	28571		$n \rightarrow \pi^*$
$[CdC_{18}H_{22}O_2N_6S_2]$	295	33898	0.4606	C.T (M→L)
	340	29412		C.T (M→L)
	400	25000		C.T (M→L)

3.6 Characterization by Thermogravimetric Analysis

Thermogravimetric analysis of Zn(II),Ni(II),Mn(II) and Sn(II) complexes of ligand $C_8H_9ON_3S$ (L^1)

The thermal decomposition analysis of solid Zn(II), Ni(II), Mn(II) and Sn(II) metal complexes were carried out under nitrogen atmosphere and heating rate was suitably controlled at 30°C min^{-1} and the weight loss was measured from the ambient temperature up to 800°C.The data from TGA and DTG clearly indicated that the decomposition of the complexes proceed in three or four steps. There were some minor steps and asymmetry of TGA/DTG curves also observed. The weight losses for each complex were calculated within the corresponding temperature ranges. The different thermodynamic parameters are listed in Table-9.

a. For $[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$ Complex

The TGA and DTG curve of Zn(II) complex shown in (figure-20), indicated that the complex was decomposed into four main steps. In the first step of decomposition, two molecules of water were lost at the temperature range of 85-110°C (calculated 7.36%, experimental 7.20%). In this temperature range the loss of water molecules indicates that the water molecules are of lattice type [51,52].In the temperature range 130-335°C (calculated 24.00% and experimental 23.10%), the part of ligand-$2CSNH_2$ were decomposed at the second step. The other part of the ligand $2C_6H_4O$- were decomposed in third step at 335-740°C (calculated 37.50%, experimental 32 .00%). At above 750°C temperature the complex was decomposed and removed as Zn/ZnO (calculated 31.14%, experimental 37.70%) polluted with few carbon atoms [53].

b. For $[NiC_{16}H_{16}O_2N_6S_2].H_2O$ Complex

The TGA and DTG curve of Ni(II) complex shown in (figure-21) that the complex was decomposed into four main steps. The 1^{St} step involves the removal of one molecule of hydrated water (calculated 3.87%, experimental4.00% weight) at temperature range 80-190°C [54,55].In the 2^{nd} step the part of the ligand $2C_6H_4O^-$ was decomposed at 280-350°C (calculated 39.59%, experimental 34.82% weight). At the 3^{rd} step the fragmentation of coordinated ligand $2C_2H_4N_3$ S was decomposed from the complex at the temperature range 360-750°C (calculated 43.90%,experimental 44.20% weight) and above 750°C temperature the complex was completely decomposed and removed as Ni/NiO (calculated 12.64%, experimental 16.98%).

c. For $[MnC_{16}H_{16}O_2N_6S_2].H_2O$ Complex

In the case of Mn(II) complex the TGA and DTG curve indicated in (figure-22) that the complex was decomposed into four main steps. At 1^{St} step one molecule of hydrated water was removed at 80-180°C(calculated 3.90%, experimental 4.00%) [54,55]. Then the dehydrated complex was gradually decomposed and the part of ligand $2C_6H_4O^-$ was removed at the temperature range 180-350°C (calculated 39.92%, experimental 38.10%). The 3^{rd} step involves the decomposition of the ligand part $2CH_3N_2S$ at the temperature range 350-770°C(calculated 32.54%, experimental 32.22%). At above 770°C temperature finally the complex was completely decomposed and removed as Mn/MnO (calculated 23.64%, experimental 25.68%).

d. For $[SnC_{16}H_{16}O_2N_6S_2]$ Complex

The Sn(II) complex showed high thermal stability and decomposed above 170 °C, indicating the absence of any lattice water molecules[69].This complex was decomposed into four main steps shown in (figuare-23). At first step the part of ligand (-$2CH_2NS$) were decomposed at temperature 170-275°C (calculated 23.67%, experimental 22.00%). In 2^{nd} step the decomposition of (-2CHN-) moiety was take place at temperature 275-330°C (calculated 12.0%, experimental 10.65 %). The ligand part ($2C_6H_4O^-$) were decomposed at the 3^{rd} step at temperature range 330-750°C (calculated 36.29%, experimental 36.10 %) and finally the complex was completely decomposed and removed as Sn/SnO (calculated 28.04%, experimental 31.25%).

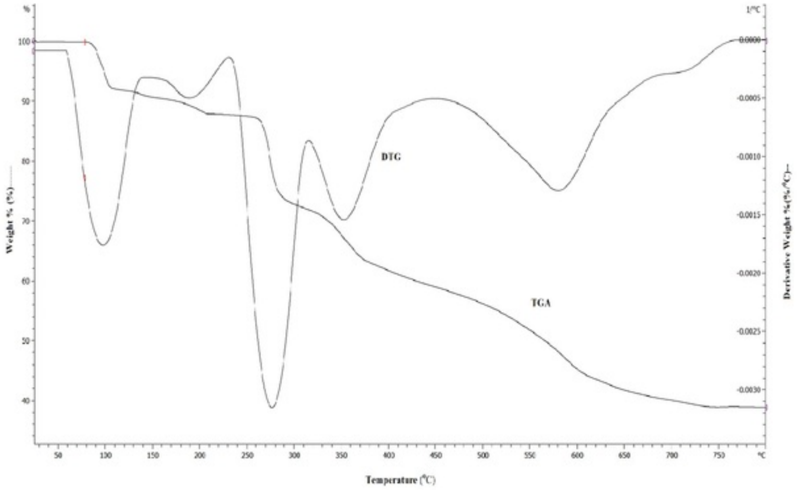

Figure-20: TGA and DTG curve of $[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$

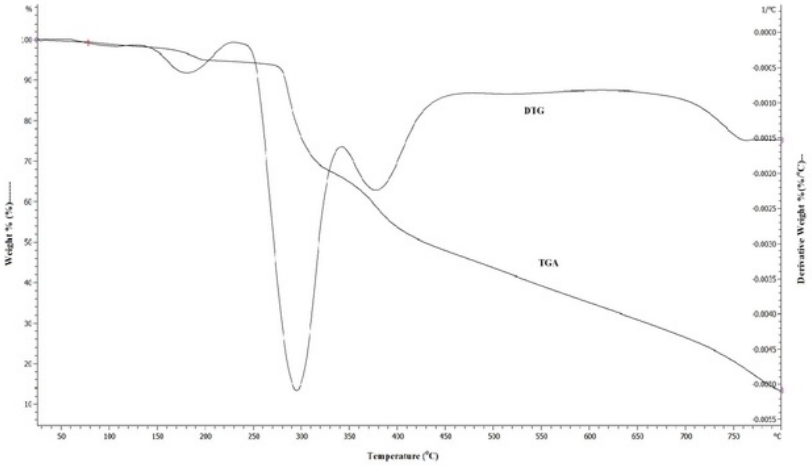

Figure-21: TGA and DTG curve of $[NiC_{16}H_{16}O_2N_6S_2].H_2O$

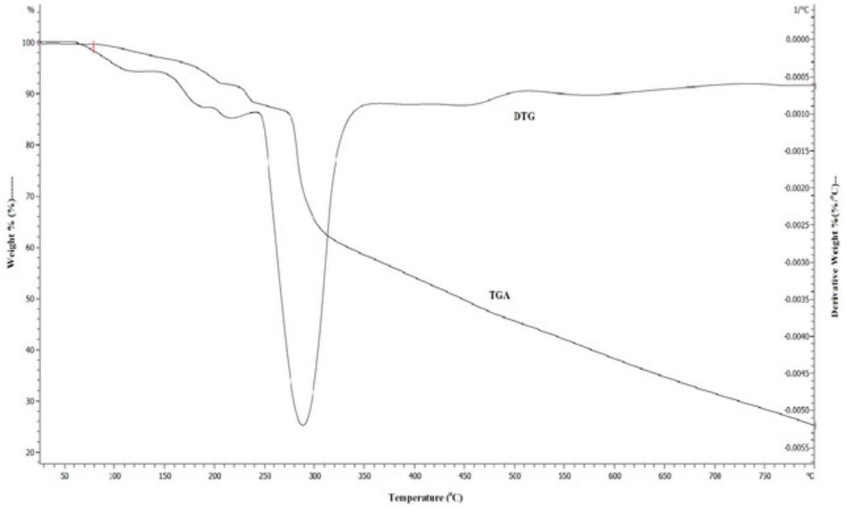

Figure-22: TGA and DTG curve of $[MnC_{16}H_{16}O_2N_6S_2].H_2O$

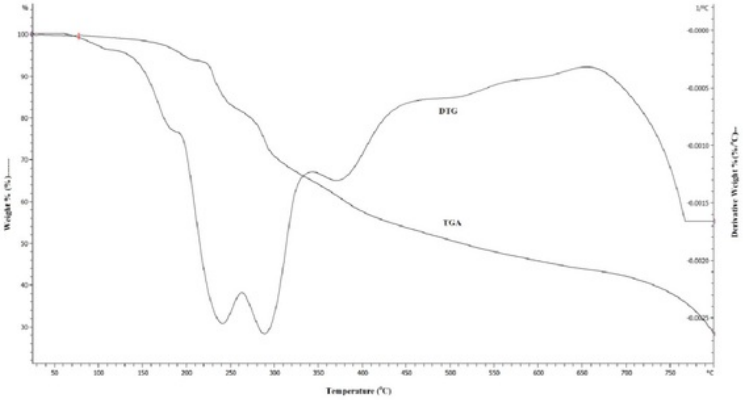

Figure-23: TGA and DTG curve of $[SnC_{16}H_{16}O_2N_6S_2]$

Table- 9: Thermal data of Zn(II), Ni(II), Mn(II) and Sn(II) complexes of ligand $C_8H_9ON_3S$ (L^1)

Complexes	Steps	Temperature Range/ °C	DTG Peak/ ^0C	TG mass loss% calc./found	Assignments

$[ZnC_{16}H_{16}O_2N_6S_2].2H_2O$	1st	85-110	97	7.36/7.20	$2H_2O$
	2nd	130-335	278	24.00/23.10	$2CSNH_2$
	3rd	335-740	350	37.50/32.00	$2C_6H_4O$-
	4th	>750		31.14/37.7	Zn/ZnO
$[NiC_{16}H_{16}O_2N_6S_2].H_2O$	1st	80-190	180	3.87/4.00	H_2O
	2nd	280-350	295	39.59/34.82	$2C_6H_4O^-$
	3rd	360-750	382	43.90/44.20	$2C_2H_4N_3S$
	4th	>750		12.64/16.98	Ni/NiO
$[MnC_{16}H_{16}O_2N_6S_2].H_2O$	1st	80-180	118	3.90/4.00	H_2O
	2nd	180-350	290	39.92/38.10	$2C_6H_4O^-$
	3rd	350-770		32.54/32.22	$2CH_3N_2S$
	4th	>770		23.64/25.68	Mn/MnO
$[SnC_{16}H_{16}O_2N_6S_2]$	1st	170-275	240	23.67/22.00	$2CH_2NS$
	2nd	275-330	290	12.00/10.65	2CHN-
	3rd	330-750	370	36.29/36.10	$2C_6H_4O^-$
	4th	>750		28.04/31.25	Sn/SnO

Thermogravimetric analysis of Co(II) complex of ligand $C_{14}H_{11}O_3N$ (L^2)

TGA was carried out for solid Co(II) metal complex under N_2 flow. The heating rate was suitably controlled at 30°C min^{-1} and the weight loss was measured from the ambient temperature up to 800°C. The thermogram of complex exhibits three clear cut decomposition stages in (figure-24). The first stage with estimated mass loss of 6.32% (calculated mass loss 6.28%) within the temperature range 40–110°C corresponding to the loss of water molecules [56,57]. The second stage occurs at 110–480°C, with a mass loss of 49.20% (calculated 51.31%) , corresponding to the loss of $2C_8H_5O_2N$ parts of the ligand. The third stage of decomposition occurs at the temperature range 480–650°C, with a mass loss of 28.80% (calculated 32.12%), corresponding to the loss of $2C_6H_4O$ moiety. At above 650°C temperature the complex was completely decomposed and removed as of 15.72% (calculated 10.29%). The different TG and DTG data are given in Table-10.

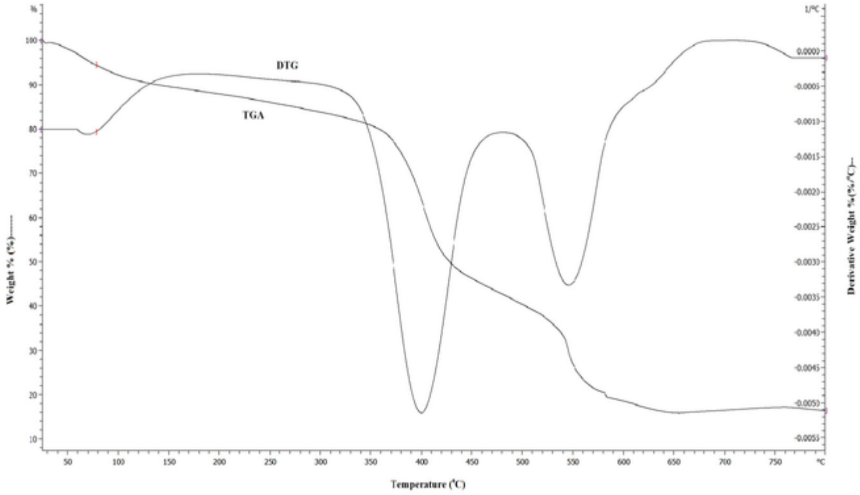

Figure-24: TGA and DTG curve of $[CoC_{28}H_{18}O_6N_2].2H_2O$

Table- 10: Thermal data of Co(II) complex of ligand $C_{14}H_{11}O_3N$ (L^2)

Complexes	Steps	Temperature Range/ °C	DTG Peak/ ^0C	TG mass loss% calc./found	Assignments
$[CoC_{28}H_{18}O_6N_2].2H_2O$	1st	40-110	65	6.28/6.32	$2H_2O$
	2nd	110-480	400	51.31/49.20	$2C_8H_5O_2N$
	3rd	480-650	548	32.12/28.80	$2C_6H_4O^-$
	4th	>650		10.29/15.72	Co/CoO

Thermogravimetric analysis of Cd(II) complex of ligand $C_9H_{11}N_3OS$ (L^3)

Thermogravimetric analysis of solid Cd(II) metal complex under N_2 flow. The heating rate was suitably controlled at 30°C min^{-1} and the weight loss was measured from the ambient temperature up to 800°C.The TGA curve of the Cd(II) complex showed no mass loss up to 230 °C, indicating the absence of lattice / coordinated water [58,59] and the high thermal stability of the complex. The thermogram of Cd(II) complex is given in Fig.4.24, which shows two stage decomposition pattern. The first stage was exhibited a maximum mass loss of 49.23% (calculated 50.53%) of ligand part ($2C_8H_8ON$) at 230-455°C. The second stage occurs at 455–740°C, with a mass loss of 27.05% (calculated 28.28%) attributed to the loss of ($2CH_3N_2S$) moiety. Finally at above 750°C temperature the complex was completely decomposed and removed as Cd/CdO of 24.0% (calculated 21.19%). The different TG and DTG data are given in Table-11.

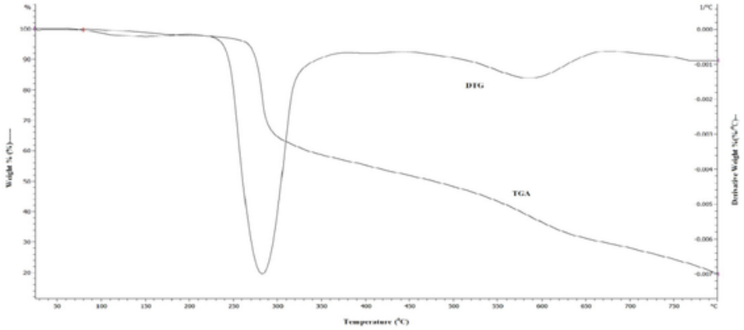

Figure-25: TGA and DTG curve of [$CdC_{18}H_{22}O_2N_6S_2$]

Table- 11: Thermal data of Cd(II) complex of ligand $C_9H_{11}N_3OS$ (L^3)

Complexes	Steps	Temperature Range/ °C	DTG Peak/ ^{0}C	TG mass loss% calc./found	Assignments
[$CdC_{18}H_{22}O_2N_6S_2$]	1^{st}	230-455	282	50.53/49.23	$2C_8H_8ON$
	2^{nd}	455-740	570	28.28/27.05	$2CH_3N_2S$
	3^{rd}	>740		21.19/24.00	Cd/CdO

Antibacterial activity

The prime objective of performing the antibacterial screening is to determine the susceptibility of the pathogenic microorganism to test the compound which, in turn is used to selection of the compound as a therapeutic agent. The free Schiff base ligand and their metal complexes were screened for their antibacterial activity against strains the *Bacillus cereus ATCC25923*, *Streptococcus agelactiae*, *Escherichia coli ATCC 25922*, *Shigella dysenteriae* The compounds were tested at a concentration of 30 µg/0.01 mL in DMSO solution using the paper disc diffusion method with Kanamycin as standard. The susceptibility zones were measured in diameter (mm) and the result are listed in Table-12. The susceptibility zones were the clear zones around the discs killing the bacteria.

Table 12. Antibacterial activities of the complexes.

Bacterials strains	**Zone of inhibition, diameter in mm**						
	A (10µg /disc)	**B (10µg /disc)**	**C (10µg /disc)**	**D (10µg /disc)**	**E (10µg /disc)**	**F (10µg /disc)**	**K (30µg /disc)**
Gram positive							
Bacillus cereus	22	10	19	12	11	14	36
Streptococcus agelactiae	19	09	21	08	14	16	35
Gram negative							
Escherichia coli	23	12	24	09	12	18	32
Shigella dysenteriae	09	11	10	12	08	14	36

Where, A = $[C_{16}H_{16}ZnO_2N_6S_2].2H_2O$, B = $[C_{16}H_{16}NiO_2N_6S_2].H_2O$, C = $[C_{16}H_{16}MnO_2N_6S_2].H_2O$, D = $[C_{16}H_{16}SnO_2N_6S_2]$, E = $[C_{28}H_{18}CoO_6N_2].2H_2O$, F = $[C_{18}H_{22}CdO_2N_6S_2]$ and K = Kanamycin

Conclusion

In this paper we have explored the synthesis and coordination Chemistry of Ni(II), Zn(II), Mn(II), Sn(II), Co(II) and Cd(II) ions were synthesized with three different synthesized Schiff base ligands viz (L^1) [2-(2-hydroxybenzylidene)hydrazinecarbothioamide, (L^2) [4-((4-hydroxybenzylidene)amino)benzoic acid and (L^3) [2-(4-methoxybenzylidene)hydrazinecarbothioamide]. The ligands and metal complexes were characterized by molar conductivity measurement, magnetic susceptibility, Infrared, electronic spectral, thermal analysis and some physical measurements. The overall reactions were monitored by TLC analysis. Molar conductance study have shown that all the complexes were non electrolytic in nature. FTIR studies suggested that Schiff bases act as deprotonated bidentate ligands and metal ions are attached with the ligands-(L^1), (L^2) by N, O and ligand-(L^3) by N, S coordinating sites during complexation reaction. Magnetic susceptibility data coupled with electronic spectra revealed that [$ZnC_{16}H_{16}O_2N_6S_2$].$2H_2O$, [$MnC_{16}H_{16}O_2N_6S_2$].H_2O, [$SnC_{16}H_{16}O_2N_6S_2$] and [$CdC_{18}H_{22}O_2N_6S_2$] complexes have tetrahedral, [$NiC_{16}H_{16}O_2N_6S_2$].H_2O has square planer and [$CoC_{28}H_{18}O_6N_2$].$2H_2O$ has octahedral geometry. Thermal analysis (TGA and DTG) data showed the possible degradation pathway of the complexes and also indicated that most of the complexes were thermally stable up to 200^0C. The Schiff bases and their metal complexes have been found moderate to strong antimicrobial activity.

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