SYNTHESIS, SPECTRAL AND BIOLOGICAL STUDIES OF COMPLEXES OF ZINC(II), CADMIUM(II) AND MERCURY(II)

8.1. Introduction

Zinc is the second most abundant transition element in the human organism, following iron; the metal also plays an important role in many other living systems. Cadmium and mercury have no known beneficial biological role and are amongst the most toxic of elements. Today more than 200 different zinc proteins are known which include numerous essential enzymes [1]. Zn is present as enzyme in most body cells of human beings, but its concentration is very low. The two Zn enzymes which have received most attention are carboxypeptidase A and carbonic anhydrase. Metallothioneins, proteins containing zinc, remain unique in character but are encountered both in animals and microorganisms [2,3]. The wound healing effect of zinc containing ointment was already known in the ancient world and during the last decades, zinc has increasingly been used as a remedy for growth disorders due to malnutrition [4].

The elements Zn, Cd and Hg have a filled $(n-1)d$ shell plus two ns electrons. In view of the stability of the filled d shell, these elements show few of the characteristic properties of transition metals despite their position in the d block of the periodic table. Zinc and cadmium resemble the transition elements in forming stable complexes not only with O-donor ligands but also with N and S donor ligands and with halides and CN⁻. Hg has a preference for N, P and S donor ligands, with which Hg(II) forms complexes whose stability is rarely exceeded by those of any other divalent cation. Compounds of the M(II) ions of this group are characteristically diamagnetic [5].

Since the d^{10} configuration affords no crystal field stabilization, the stereochemistry of a particular compound depends on the size and polarizing power of the M(II) cation and the steric requirement of the ligands. The M^{2+} ion with their d^{10} configuration shows no stereochemical preferences arising from ligand field stabilization effects. Therefore they display a variety of coordination numbers and geometries based on the interplay of electrostatic forces, covalence and the size factor. Both Zn(II) and Cd(II) favour 4-coordinate tetrahedral complexes though Cd(II), being the larger one, forms 6-coordinate octahedral complexes more readily than does Zn(II). However, Hg(II) adopts a tetrahedral stereochemistry, an octahedral 6-coordination is less prevalent. Coordination numbers 4, 5 and 6 are the common ones for all the three elements, although linear 2-coordination is often seen for Hg^{2+} [4].

This Chapter describes the synthesis of three Zn(II) complexes, one Cd(II) complex and one Hg(II) complex and characterization of these complexes using electronic, infrared and ^1H NMR spectral studies. Antimicrobial studies on Zn(II) complexes are also included in this Chapter.

8.2. Experimental

8.2.1. Materials

The method used for the synthesis of HL^1 and HL^2 are dealt with in Chapter 2. All the metal salts were used as received and the solvents were purified by the usual methods.

8.2.2. Synthesis of the complexes

$[ZnL^{1}OOCCH_{3}]$ (22)

An aqueous solution of $Zn(CH_{3}COO)_{2}\cdot 2H_{2}O$ (5 mmol, 1.09 g) and an ethanolic solution of HL^{1} (5 mmol, 1.69 g) were mixed and stirred for 2 hrs. The yellow colored solids, which separated, were filtered, washed with water, ethanol and ether and dried over $P_{4}O_{10}$ in vacuo.

$[ZnL^{1}Cl]\cdot 2H_{2}O$ (23)

Methanolic solutions of $ZnCl_{2}$ (5 mmol, 0.68 g) and HL^{1} (5 mmol, 1.69 g) were mixed and refluxed for 4 hrs. The pale yellow solids that separated were filtered, washed with methanol, water and ether and dried in vacuo over $P_{4}O_{10}$.

$[CdL^{1}NO_{3}]$ (24)

Solutions of $Cd(NO_{3})_{2}\cdot 4H_{2}O$ (5 mmol, 1.54 g) and HL^{1} (5 mmol, 1.54 g) in methanol were mixed and refluxed for 4hrs. The yellow crystals separated on keeping over night, were filtered, washed with water, methanol and ether and dried over $P_{4}O_{10}$ in vacuo.

$[Hg(HL^{1})Cl_{2}]$ (25)

Methanolic solutions of $HgCl_{2}$ (5 mmol, 1.36 g) and HL^{1} (5 mmol, 1.69 g) were mixed and stirred for 2 hrs. The colorless solids separated, were filtered washed with methanol and ether and dried over $P_{4}O_{10}$ in vacuo.

$[ZnL^{2}OCOCH_{3}]$ (26)

Methanolic solutions of $Zn(CH_{3}COO)_{2}\cdot 2H_{2}O$ (5 mmol, 1.09 g) and HL^{2} (5 mmol, 1.66 g) were mixed and refluxed for 4 hrs. The yellow solids, which

Table 8.1. Analytical data

Compound	Empirical formula	Colour	Found(Calculated) %			Λ_M* (in DMF)	μ (B.M.)
			C	H	N		
[ZnL^{1}OAc] (22)	C$_{21}$H$_{24}$N$_4$SO$_2$Zn	Yellow	54.75(54.62)	5.55(5.20)	12.05(12.13)	3.5	Diamagnetic
[ZnL^{1}Cl]·2H$_2$O (23)	C$_{19}$H$_{25}$N$_4$SOClZn	Yellow	49.63(49.79)	4.97(5.46)	11.91(12.23)	7.54	Diamagnetic
[CdL^{1}NO$_3$] (24)	C$_{19}$H$_{21}$N$_5$SO$_3$Cd	Pale yellow	44.72(44.58)	4.75(4.11)	14.13(13.69)	7.6	Diamagnetic
[Hg(HL^1)Cl$_2$] (25)	C$_{19}$H$_{22}$N$_4$SCl$_2$Hg	White	37.51(37.40)	3.80(3.61)	8.76(9.19)	20.5	Diamagnetic
[ZnL^{2}OAc)] (26)	C$_{21}$H$_{18}$N$_4$SO$_3$Zn	Yellow	53.15(53.45)	4.05(3.82)	12.30(11.88)	5.21	Diamagnetic

*Molar conductivity of 10^{-3}M solution, in ohm^{-1}cm^2 mol^{-2}

separated, were filtered, washed with water, methanol and ether and dried over P_4O_{10} *in vacuo*.

8.3. Results and discussion

8.3.1. Physical measurements

The colors, partial elemental analyses, stoichiometries, molar conductivities and magnetic moments of the complexes are presented in Table 8.1. The five complexes are found to be diamagnetic as expected. Molar conductivity measurements of the solutions of the metal complexes in DMF solution indicate their non-conducting nature. This suggests the coordination of gegenions to the metal.

8.3.2. Infrared spectra

The main IR spectral bands of HL^1, HL^2 and their Zn(II), Cd(II) and Hg(II) complexes are listed in Table 8.2. The strong bands observed in the spectra of HL^1 and HL^2 at 1582 and 1591 cm^{-1} respectively can be assigned to the $v(C=N)$ band. The $v(C=N)$ band shifts to lower frequencies in the spectra of all the complexes suggesting the coordination of the azomethine nitrogen to the metal ions. The involvement of this nitrogen in bonding is also supported by a shift in the $v(N-N)$ band of the thiosemicarbazones to higher frequencies. In the spectrum of compound 22, a new band of medium intensity is found at 1588 cm^{-1} which is due to the formation of a new C=N bond formed during the formation of the complex *via* enolisation. The coordination *via* the azomethine nitrogen is confirmed by the presence of the $v(M-N)$ band at *ca.* 490 cm^{-1} [6].

In the IR spectra of the complexes containing the deprotonated ligand L^1, the v(C-S) band is found to be shifted by 45-90 cm^{-1} to lower frequencies, indicating the coordination *via* the sulfur atom [7]. The strong bands observed in the far IR spectra of the complexes at *ca.* 350 cm^{-1} confirm the coordination *via* the S atom. In the Hg(II) complex containing the protonated ligand HL^1, the v(C-S) band remains slightly shifted to higher frequency.

Coordination *via* the pyridine nitrogen atom is indicated by a shift in the deformation band of the pyridine ring. In the complexes [ZnL^1OAc] and [ZnL^2OAc], the strong bands observed at *ca.* 1590 and 1409 cm^{-1}, when the acetate ion is bonded to the metal as a unidentate ligand [8], can be assigned to $v_a(COO)$ and $v_s(COO)$ of the acetate ion. In [CdL^1NO_3] the three bands observed at 1472,1385 and 1078 cm^{-1} can be assigned to $v_a(NO_2)$, $v_s(NO_2)$ and v(NO) of the nitrato group and this confirms the unidentate nature of the nitrato group. In the complexes [ZnL^1Cl]·$2H_2O$ and [$Hg(HL^1)Cl_2$] the strong bands observed at 297 and 271 cm^{-1} indicate the presence of M-Cl bond [9,10].

Table 8.2 IR spectral assignments (cm^{-1}) of HL^1 and HL^2 and their Zn (II), Cd(II), Hg(II) complexes

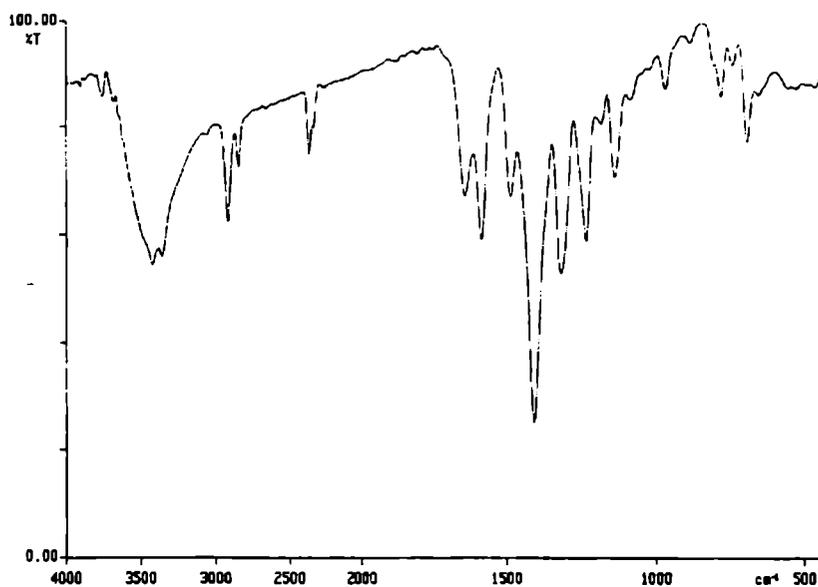| Compound	v(C=N)	v(C-S)	v(py)	v(N-N)	v(M-N)	v(M-S)	v(M-X)
HL^1	1582m	833s	607s	1118m	--	--	--
[ZnL^1OAc] (22)	1588s	787m	657m	1144m	487s	353s	--
[ZnL^1Cl]·$2H_2O$ (23)	1553s	748m	665m	1160m	490s	341s	297s
[CdL^1NO_3] (24)	1563s	740s	638w	1161m	491s	375s	--
[$Hg(HL^1)Cl_2$] (25)	1555s	840m	636w	1154m	491s	--	271s
HL^2	1591s	835m	622m	1102s	--	--	--
[ZnL^2OAc)] (26)	1567s	753s	657m	1128m	467s	334s	--

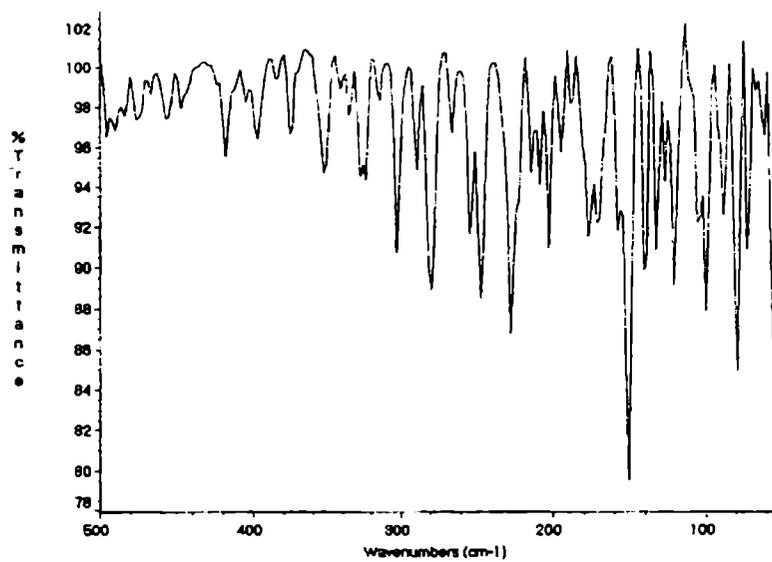Fig. 8.1. IR spectrum of compound 22

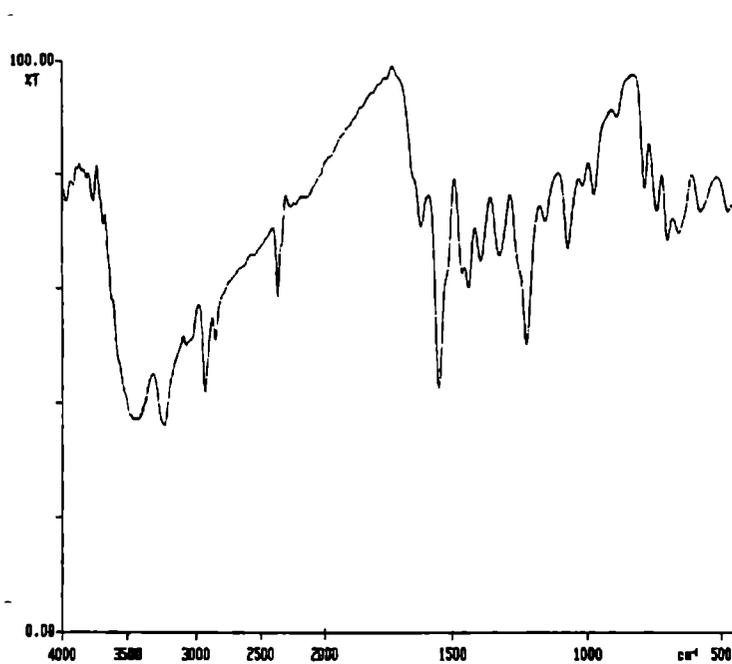Fig. 8.2. Far IR spectrum of compound 22
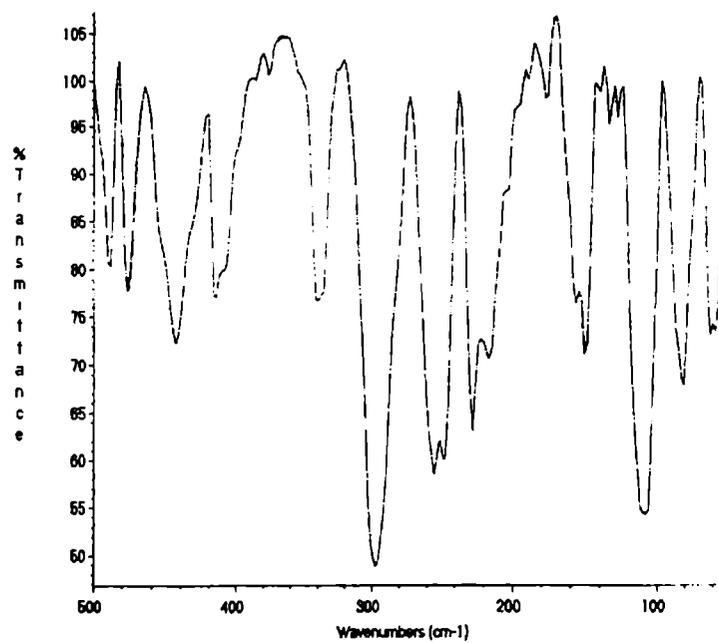
Fig. 8.3. IR spectrum of compound 23

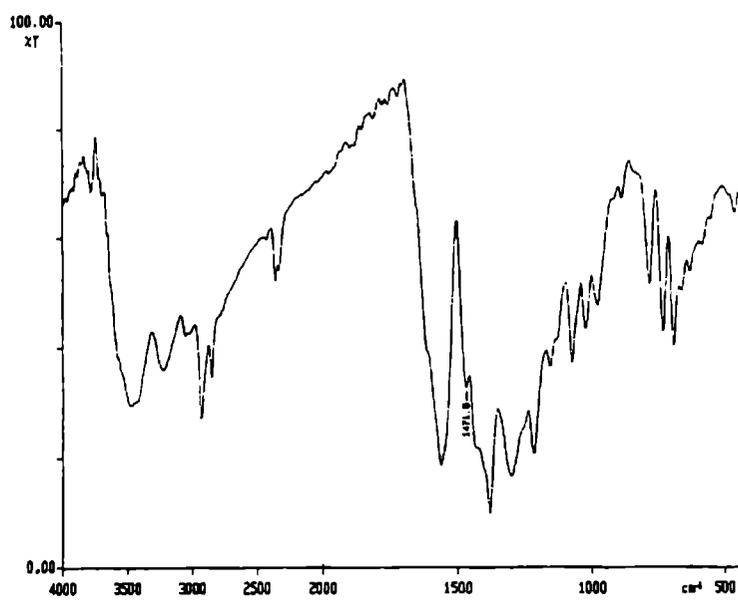Fig. 8.4. Far IR spectrum of compound 23
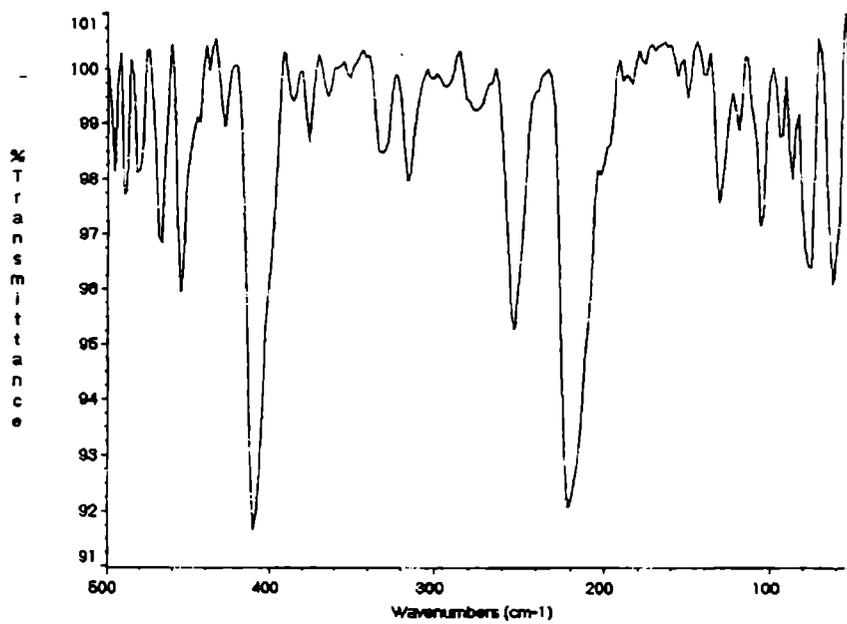
Fig. 8.5. IR spectrum of compound 24
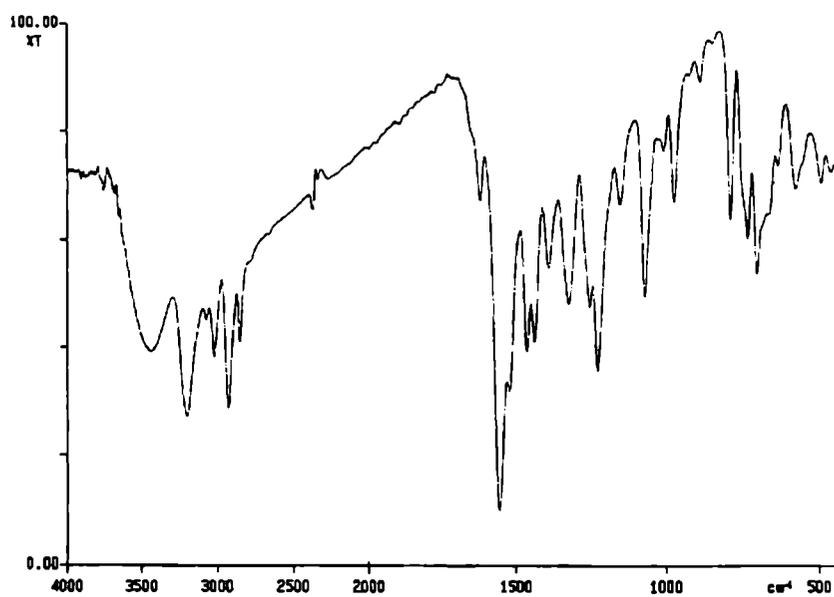

Fig. 8.6. Far IR spectrum of compound 24
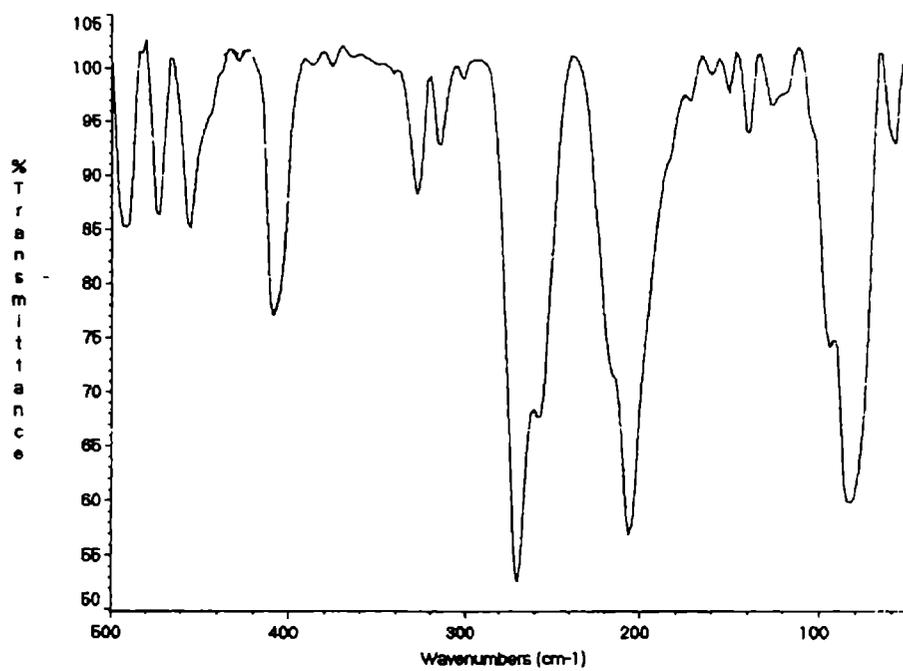
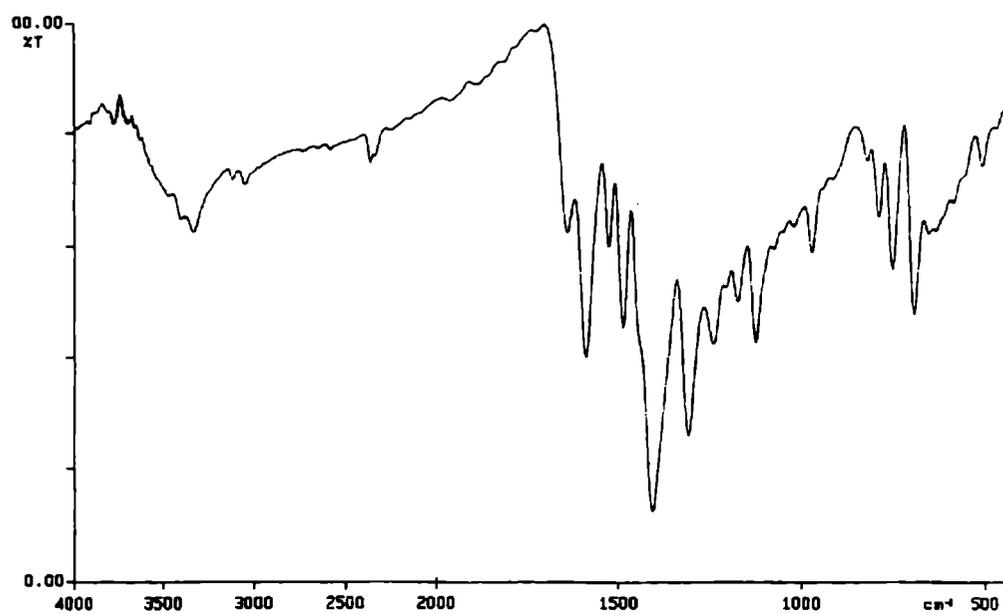Fig. 8.7. IR spectrum of compound 25

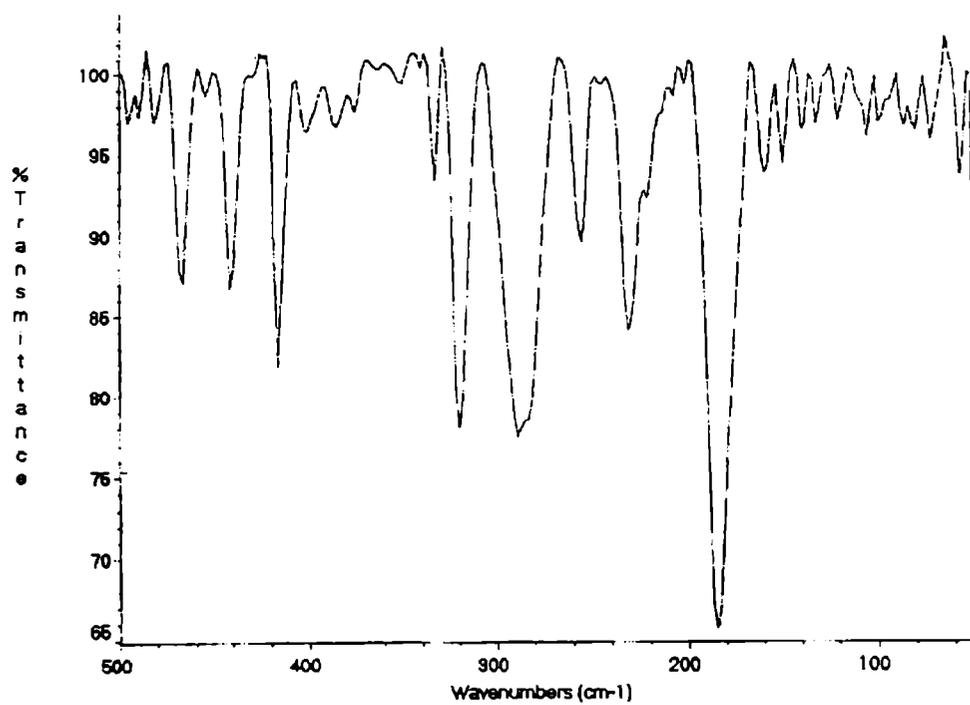Fig. 8.8. Far IR spectrum of compound 25

Fig.8.9. IR spectrum of compound 26

Fig.8.10. Far IR spectrum of compound 26

8.3.3. Electronic spectra

The ligand HL[1] has absorption bands at 270 and 348 nm due to the $\pi \to \pi^*$ and $n \to \pi^*$ transitions. The absorption due to $\pi \to \pi^*$ transition remains almost unchanged in position in the spectra of the Zn(II) complexes. The absorption band due to the $n \to \pi^*$ transitions at *ca.* 348 nm is found to be shifted to longer wavelength in the spectra of the Zn(II) complexes. This bathochromic shift may be due to the donation of a lone pair of electrons to the metal and hence the coordination of azomethine nitrogen [11,12]. A broad intense band observed at *ca.* 425 nm is assigned to the S → Zn(II) charge transfer transitions. The complexes show no appreciable absorption in the region above 500 nm which is in accordance with the d^{10} electronic configuration of the Zn(II) ion [13].

Table 8.3. Electronic spectral assignments of HL[1] and HL[2] and their Zn(II), Cd(II), Hg(II) complexes.

Compound	$\pi \to \pi^*$	$n \to \pi^*$	LMCT
HL[1]	270	348	--
[ZnL[1]OAc] (22)	265	360	425
[ZnL[1]Cl]·2H$_2$O (23)	266	372	430
[CdL[1]NO$_3$] (24)	273	351	420
[Hg(HL[1])Cl$_2$] (25)	274	370	435
HL[2]	262	345	--
[ZnL[2]OAc)] (26)	265	371	440

In the electronic spectrum of complex [CdL^{1}NO$_3$], absorption bands appearing at 273 and 324 nm can be assigned to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ respectively, of the thiosemicarbazone moiety and the intense band at 419 nm can be assigned to the S $\rightarrow$ Cd(II) charge transfer transition. There are no absorption bands above 480 nm indicating the absence of $d \rightarrow d$ bands in accordance with the d^{10} configuration. In the spectrum of Hg(II) complex, a broad band observed at 376 nm may be due to the $n \rightarrow \pi^*$ transition of the thiosemicarbazone moiety.
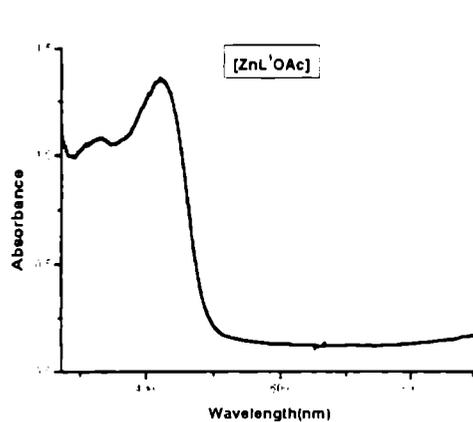

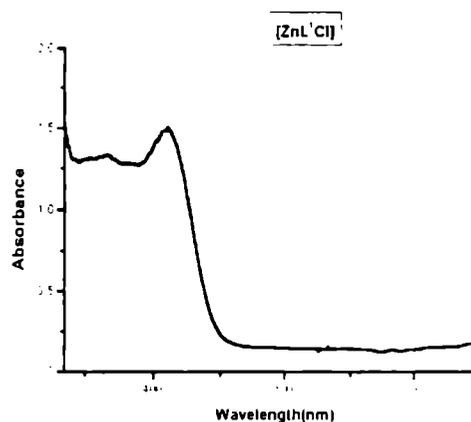Fig. 8.11. Electronic spectrum of compound 22
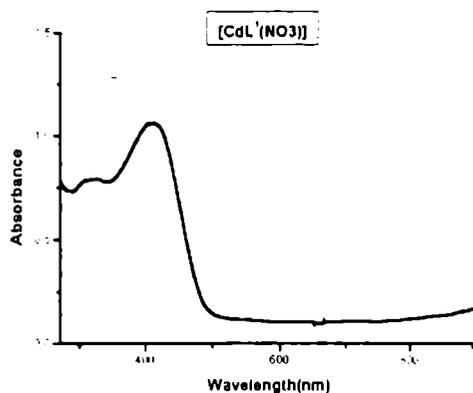

Fig. 8.12. Electronic spectrum of compound 23

Fig. 8.13.Electronic spectrum of compound 24

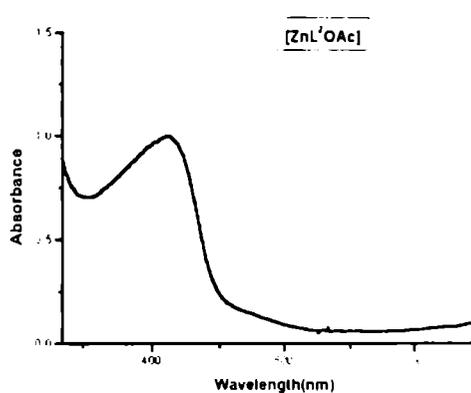Fig. 8.14. Electronic spectrum of compound 26

8.3.4. ^1H NMR spectra

The ^1H NMR signals of the two ligands HL^1, HL^2 and the complexes are listed in Table 8.3. (The positions of the atoms are as given in Fig.2.1.) The ligands HL^1 and HL^2 have signals at $\delta = 13.48$ and 14.06 ppm respectively. These signals are due to the ^2NH proton that disappears on D_2O exchange. This signal disappears in the three zinc(II) complexes as a consequence of the complete deprotonation of the ligand and coordination via the thiolate sulfur during complexation. In the spectrum of $[Hg(HL^1)Cl_2]$, the N-H proton signal appears at 14.08 ppm which supports the existence of the ligand in the neutral form in this complex. There is a slight shift in the signals corresponding to the protons of the pyridine ring, in all the complexes in support of the coordination *via* the pyridine nitrogen. In compound **24**, the downfield shift of the signals corresponding to all protons of the pyridyl ring and phenyl ring are remarkably high compared to that in other compounds.
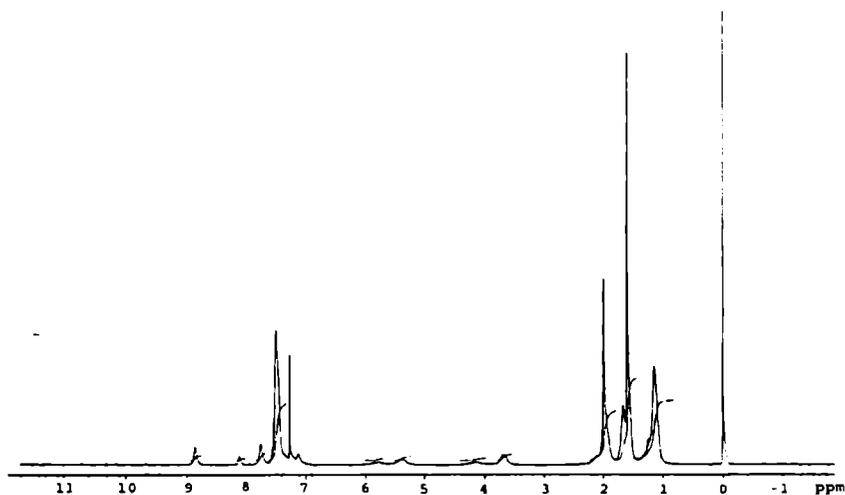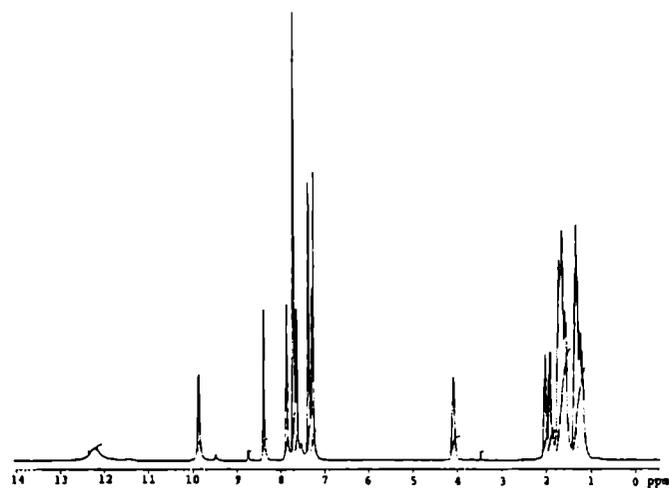

Fig. 8.15. ^1H NMR spectrum of compound **22**
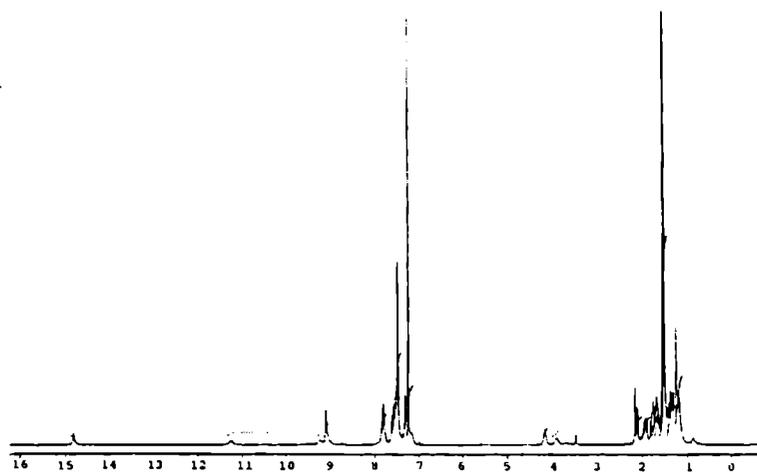
Fig. 8.16. ^{1}H NMR spectrum of compound 24

Fig. 8.17. ^{1}H NMR spectrum of compound 25

Table 8.4 ^{1}H NMR signals of HL^1, HL^2 and their Zn(II), Cd(II).

Hg(II) complexes (δ. ppm)

Compound	^{2}NH	^{4}NH	^{6}C	Aromatic protons	Aliphatic protons
HL^1	13.48	7.63	8.81	7.26, 7.43, 7.63, 7.75	4.32, 2.12, 1.14-1.74
[ZnL^{1}OAc] (22)	--	7.45	8.87	7.27, 7.48, 7.75, 8.11	3.8, 1.12, 1.59, 1.9
[ZnL^{1}Cl].2H$_2$O (23)	--	7.38	8.89	7.25, 7.46, 7.89	4.2, 1.15, 1.56, 1.78
[CdL^{1}NO$_3$] (24)	—	7.4	9.85	7.25, 7.65, 7.97, 8.3,	4.16, .2.1, 1.9, 1.3
[Hg(HL^1)Cl$_2$] (25)	14.82	7.38	9.10	7.25, 7.49, 7.81	4.16, 2.16, 1.53, 1.75
HL^2	14.06	9.54	8.86	7.21, 7.40, 7.54, 7.77, 8.85	--
[ZnL^{2}OAc)] (26)	--	9.61	8.5	7.25, 7.42, 7.78, 8.82	--

8.4. Antimicrobial studies

The three Zn(II) complexes are screened for antimicrobial activity using the Disc diffusion method against the five types of bacteria: 1. *Staphylococcus aureus*. 2. *Bacillus* sp (Gram Positive) 3. *Escherichia coli* 4. *Salmonella paratyphi* 5. *Vibrio cholerae* Ol(Gram Negative). All the Zn(II) complexes are found to be microbial inactive.

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