Research Article

Physicochemical, Spectral, and Biological Studies of Mn(II), Cu(II), Cd(II), Zr(OH)₂(IV), and UO₂(VI) Compounds with Ligand Containing Thiazolidin-4-one Moiety

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The Schiff base (I) upon reacting with mercaptoacetic acid in dry benzene undergoes cyclization and forms N-(2-carbamoylthienyl)-C-(3'-carboxy-2'-hydroxyphenyl)thiazolidin-4-one, LH₃ (II). A MeOH solution of II reacts with Mn(II), Cu(II), Cd(II), Zr(OH)₂(IV), and UO₂(VI) ions and forms the coordination compounds, [Mn(LH)(MeOH)₂], [Cu(LH)]₂, [Cd(LH)], [Zr(OH)₂(OAc)₂(LH₃)], and [UO₂(NO₃)(LH₂)(MeOH)]. The compounds have been characterized on the basis of elemental analyses, molar conductance, molecular weight, spectral (IR, reflectance, and EPR) studies and magnetic susceptibility measurements. LH₃ behaves as a neutral tridentate ONS donor ligand in [Zr(OH)₂(OAc)₂(LH₃)], monobasic tridentate ONS donor ligand in [UO₂(NO₃)(LH₂)(MeOH)], dibasic tridentate OOS donor ligand in [Cu(LH)]₂ and dibasic tetradentate OONO donor ligand in [Mn(LH)(MeOH)₂] and [Cd(LH)]. [Cu(LH)]₂ is dimer, while all other compounds are monomers in diphenyl. A square-planar structure for [Cu(LH)]₂, a tetrahedral structure for [Cd(LH)], an octahedral structure for [Mn(LH)(MeOH)₂], a pentagonal-bipyramidal structure for [Zr(OH)₂(OAc)₂(LH₃)], and an eight-coordinate structure for [UO₂(NO₃)(LH₂)(MeOH)] are proposed. The ligand (II) and its compounds show antibacterial activities towards *E. coli*. (Gram negative) and *S. aureus* (Gram positive).

1. Introduction

There are numerous biologically active molecules with five membered rings, containing two heteroatoms among which is the 4-thiazolidinone ring system which is a core structure in various synthetic compounds.

Thiazolidin-4-one, a saturated form of thiazole with carbonyl group on fourth carbon, has been considered as a magic moiety (wonder nucleus). It has played an important role in medicinal chemistry [1, 2] and possesses almost all types of biological activities [3, 4] like antimicrobial [5], antitubercular [6], antibacterial [7], anticonvulsant [8], antifungal [9], anticancer [10], septicidal [11], and antiviral [12]. Much attention has been paid to biologically active metal complexes in recent years. Oxygen and nitrogen donor ligands [13] have been widely studied due to their high potential to coordinate with transition metals. Compounds containing carbonyl

oxygen groups [14] have important position among organic reagents as potential donor ligands for the transition metal ions. Organic compounds and metal complexes [15] both display a wide range of pharmacological activities including anticancer, antibacterial, and fungi static effects.

A perusal of the literature indicates that very less work have been carried out on the coordination compounds of the thiazolidinones [16, 17] and there is no report on the coordination compounds of Mn(II), Cu(II), Cd(II), Zr(OH)₂(IV), and UO₂(VI) ions with N-(2-carbamoylthienyl)-C-(3'-carboxy-2'-hydroxyphenyl)thiazolidin-4-one, LH₃ (II).

In this paper, we describe the syntheses, characterization, and antibacterial studies of II and its coordination compounds.

The structures of Schiff base (I) and thiazolidin-4-one (II) are shown in Figures 1 and 2 respectively.

FIGURE 1

FIGURE 2

2. Experimental

2.1. Materials. Copper(II) acetate monohydrate (S d Fine-CHEM Limited); cadmium(II) acetate dihydrate, dioxouranium(VI) acetate tetrahydrate, and manganese(II) acetate tetrahydrate (Sarabhai); mercaptoacetic acid, dry benzene, sodium bicarbonate (Ranbaxy); thiophene-2-carboxylic acid hydrazide (Acros Organics, USA) were used as received for the syntheses. 3-Formylsalicylic acid and hexadecaquaoctahydroxotetrazirconium(IV) acetate were synthesized by following the reported procedures [18].

2.2. Analyses and Physical Measurements. The organic skeleton of the respective coordination compounds were decomposed by the slow heating of ~0.1 g of the latter, with conc. HNO_3 . The residue was dissolved in minimum amount of conc. HCl and the corresponding metal ions were estimated as follows. The Mn(II) and Cd(II) contents of the respective coordination compounds were estimated by complexometric titration method against standardized EDTA solution using eriochrome black-T and xylenol orange as the indicators, respectively. The Cu(II) content was estimated iodometrically against a standard solution of sodium thiosulphate to the starch end point. The zirconium content was estimated gravimetrically as ZrO_2 after decomposing the corresponding

compound with a few drops of conc. HNO_3 and then igniting the residue. The uranium content in $[\text{UO}_2(\text{LH})]$ was estimated gravimetrically as U_3O_8 after decomposing the compound with a few drops of conc. HNO_3 and then igniting the residue.

The C, H, and N contents of LH_3 and its coordination compounds were determined by CHN Eager analyzer model-300. The S and Cl contents of LH_3 and its coordination compounds were estimated gravimetrically as BaSO_4 and AgCl , respectively. The molecular weight measurements were carried out by the Rast method using diphenyl as the solvent [19]. The molar conductances (Λ_M) of the coordination compounds were measured in DMF with the help of a Toshniwal conductivity bridge (CL01-02A) and a dip-type cell calibrated with KCl solutions. The IR spectra were recorded in KBr pellets ($4000\text{--}400\text{ cm}^{-1}$) on a Beckman-20 spectrophotometer. The reflectance spectra were recorded on a Beckmann DU spectrophotometer attached with a reflectance arrangement. The magnetic susceptibility measurements were carried out at room temperature, using $\text{Hg}[\text{Co}(\text{NCS})_4]$ as the standard [20]. The diamagnetic corrections were computed using Pascal's constants. The magnetic susceptibilities were corrected for temperature-independent paramagnetism term (TIP) [20] using value of zero for Mn(II) ions and 60×10^{-6} cgs units for Cu(II) ions.

TABLE 1: Analytical, molar conductance (Λ_M), and molecular weight data of **II** and its coordination compounds.

Compound	Mol. formula	Λ_M (mho cm ² mol ⁻¹)	Mol. wt obsd (calcd.)	Obsd (calcd.) %				
				M	C	H	N	S
LH ₃ (II)	C ₁₅ H ₁₂ N ₂ O ₅ S ₂	—	364.0 ^a (364.0)	—	49.15 (49.45)	3.10 (3.30)	7.50 (7.69)	17.30 (17.58)
[Mn(LH)(MeOH) ₂]	MnC ₁₇ H ₁₈ N ₂ O ₇ S ₂	8.3	458.2 ^b (480.9)	11.35 (11.42)	42.30 (42.42)	3.68 (3.74)	5.76 (5.82)	13.10 (13.31)
[Cu(LH)] ₂	Cu ₂ C ₃₀ H ₂₀ N ₄ O ₁₀ S ₄	5.3	873.0 ^b (851.0)	14.40 (14.92)	41.80 (42.30)	2.25 (2.35)	6.50 (6.58)	14.95 (15.04)
[Cd(LH)]	CdC ₁₅ H ₁₀ N ₂ O ₅ S ₂	4.6	490.3 ^b (474.4)	23.50 (23.69)	37.80 (37.94)	2.00 (2.11)	5.80 (5.90)	13.10 (13.49)
[Zr(OH) ₂ (OAc) ₂ (LH ₃)]	ZrC ₁₉ H ₂₀ N ₂ O ₁₁ S ₂	9.2	638.0 ^b (607.2)	14.90 (15.02)	37.40 (37.55)	3.10 (3.29)	4.46 (4.61)	10.48 (10.54)
[UO ₂ (NO ₃)(LH ₂)(MeOH)]	UC ₁₆ H ₁₅ N ₃ O ₁₁ S ₂	10.3	705.3 ^b (727.0)	32.63 (32.74)	26.46 (26.41)	2.11 (2.06)	5.82 (5.78)	8.87 (8.80)

^aMass spectral data, ^bRast's method data.

2.3. Synthesis of Schiff Base, N-(2-Carbamoylthienyl)-3'-carboxy-2'-hydroxybenzylideneimine (I). A MeOH solution (30 mL) of thiophene-2-carboxylic acid hydrazide (1.42 g, 10 mmol) was added to a MeOH solution (30 mL) of 3-formylsalicylic acid (1.66 g, 10 mmol). The mixture was refluxed for 2 h and the precipitates formed were suction-filtered, washed with and recrystallized from MeOH, and dried *in vacuo* at room temperature over silica gel for 24 h. Yield = 80%. The elemental analyses of the title compound gave the satisfactory results.

2.4. Synthesis of N-(2-Carbamoylthienyl)-C-(3'-carboxy-2'-hydroxyphenyl)thiazolidin-4-one (II). A dry benzene solution of **I** (2.90 g, 10 mmol) and mercaptoacetic acid (0.92 g, 10 mmol) were refluxed for 12 h on a water bath. The mixture was cooled to room temperature and then washed with 10% sodium bicarbonate solution. The benzene layer was separated using a separating funnel. The evaporation of the excess of solvent gave the solid product which was recrystallized from petroleum ether. The compound was dried *in vacuo* at room temperature. Yield = 16%. *Anal.* (**II**, C₁₅H₁₂N₂O₅S₂) (obsd: C, 49.15%; H, 3.10%; N, 7.50%; S, 17.30%. Calcd.: C, 49.45%; H, 3.30%; N, 7.69%; S, 17.58%); IR bands (KBr): 2855 cm⁻¹ [ν (O-H) (intramolecular H-bonding)], 1690 cm⁻¹ [ν (C=O) (thiazolidinone ring)], 1675 cm⁻¹ [ν (C=O) (carboxylic)], 1648 cm⁻¹ [ν (C=O) (amide)], 1570 cm⁻¹ [ν (C-N) (thiazolidinone ring)], 1530 cm⁻¹ [ν (C-O) (phenolic)], 820 cm⁻¹ [ν (C-S) (thiazolidinone ring)], and 640 cm⁻¹ [ν (C-S) (thiophene ring)].

2.5. Syntheses of the Coordination Compounds of II. A MeOH solution (30–50 mL) of the appropriate metal salt (10 mmol) was added to a MeOH solution (50 mL) of **II** (3.64 g, 10 mmol) and the mixture was then refluxed for 3–4 h. The solid products formed were suction-filtered, washed with MeOH, and then dried as mentioned above. Yield = 35–55%.

3. Results and Discussion

A dry benzene solution of the Schiff base **I** reacts with mercaptoacetic acid and forms N-(2-carbamoylthienyl)-C-(3'-carboxy-2'-hydroxyphenyl)thiazolidin-4-one, LH₃ (**II**). The reaction of the latter with appropriate metal salts in 1:1 molar ratio in MeOH produces the coordination compounds: [Mn(LH)(MeOH)₂], [Cu(LH)]₂, [Cd(LH)], [Zr(OH)₂(OAc)₂(LH₃)], and [UO₂(NO₃)(LH₂)(MeOH)]. The compounds are stable in air at room temperature. They are partially soluble in MeOH and EtOH and completely soluble in DMSO and DMF. Their molar conductance measurements (Λ_M = 4.6–10.3 mho cm² mol⁻¹) indicate their nonelectrolytic nature. The analytical data of **II** and its coordination compounds are given in Table 1.

3.1. Infrared Spectral Studies. The infrared spectra of **I**, **II** and the coordination compounds of the latter were recorded in KBr and the prominent peaks (in cm⁻¹) are shown in Table 2. **I** exhibits the ν (C=N) (azomethine) stretch at 1635 cm⁻¹. This band disappears in **II** and a new band appears at 1570 cm⁻¹ due to the ν (C-N) (thiazolidinone ring) stretch [21] indicating the conversion of **I** into **II**. The formation of **II** is further supported by the appearance of a new band at 820 cm⁻¹ due to the ν (C-S) (thiazolidinone ring) stretch [22]. The ν (C-N) (thiazolidinone ring) stretch of **II** shifts to lower energy by 55 and 65 cm⁻¹ in [Mn(LH)(MeOH)₂] and [Cd(LH)], respectively, suggesting the involvement of the thiazolidinone ring N atom towards coordination [22]. However, the existence of this band at the same energy in the remaining coordination compounds indicates the noninvolvement of the thiazolidinone ring N atom towards coordination. **II** exhibits a strong band at 2855 cm⁻¹ due to the intramolecular H-bonded OH groups of phenolic and/or carboxylic acid moieties [23]. The appearance of this band almost at the same energy in the coordination compounds of the Zr(OH)₂(IV) and UO₂(VI) ions is indicative of the noninvolvement of the

TABLE 2: IR, reflectance spectral data (cm^{-1}), and magnetic moments of coordination compounds of **II**.

Compound	$\nu(\text{C=O})$ (thiazolidinone)	$\nu(\text{C-N})$ (thiazolidinone)	$\nu(\text{C-O})$ (phenolic)	ν_{as} (COO)	ν_s (COO)	$\nu(\text{C=O})$ (amide)	$\nu(\text{C-S})$ (thiophene)	$\nu(\text{C-O})$ (MeOH)	ν_{max}	Mag. moment (B.M.)
LH₃ (II)	1690	1570	1530	—	—	1648	640	—	—	Diamagnetic
[Mn(LH)(MeOH) ₂]	1690	1515	1540	1565	1347	1628	640	999	18100, 23200, 25400	5.92
[Cu(LH)] ₂	1690	1570	1550	1575	1365	1648	640	—	16600	1.55
[Cd(LH)]	1690	1505	1538	1550	1340	1613	640	—	—	Diamagnetic
[Zr(OH) ₂ (OAc) ₂ (LH ₃)]	1645	1570	1530	—	—	1648	580	—	—	Diamagnetic
[UO ₂ (NO ₃)(LH ₂)(MeOH)]	1660	1570	1530	—	—	1648	595	985	—	Diamagnetic

OH groups of the above moieties towards coordination. On the other hand, the coordination compounds of the rest of the metal ions do not show this band indicating the breakdown of H-bonding and subsequent deprotonation of the OH groups followed by the involvement of phenolic and carboxylic O atoms towards coordination. The $\nu(\text{C}=\text{O})$ (thiazolidinone ring) stretch [24] of **II** occurs at 1690 cm^{-1} . This band shifts to 1645 and 1660 cm^{-1} in the coordination compounds of $\text{Zr}(\text{OH})_2(\text{IV})$ and $\text{UO}_2(\text{VI})$ ions indicating the coordination through O atom of the carbonyl group of thiazolidinone moiety. However, the above band remains unchanged in the rest of the coordination compounds suggesting the noninvolvement of the above O atom towards coordination. The $\nu(\text{C}=\text{O})$ (carboxylic) stretch [25] of **II** occurs at 1675 cm^{-1} . This band remains unchanged in the coordination compounds of $\text{Zr}(\text{OH})_2(\text{IV})$ and $\text{UO}_2(\text{VI})$ ions indicating the noninvolvement of the O atom of carboxylic group towards coordination. However, the remaining coordination compounds display two new bands between $1550\text{--}1575\text{ cm}^{-1}$ and $1340\text{--}1365\text{ cm}^{-1}$. These bands are assigned to the $\nu_{\text{as}}(\text{COO})$ and $\nu_{\text{s}}(\text{COO})$ stretches of the carboxylato ligand. The energy separation ($\Delta\nu = 210\text{--}218\text{ cm}^{-1}$) between the $\nu_{\text{as}}(\text{COO})$ and $\nu_{\text{s}}(\text{COO})$ stretches is indicative of the monodentate nature of the carboxylato ligand [26]. The presence of a strong band at 1648 cm^{-1} due to the $\nu(\text{C}=\text{O})$ (amide) stretch in **II** indicates that it occurs in the keto form [27]. This band shifts to lower energy by 20 and 35 cm^{-1} in $[\text{Mn}(\text{LH})(\text{MeOH})_2]$ and $[\text{Cd}(\text{LH})]$, respectively, suggesting the involvement of the keto O atom towards coordination. However, the existence of this band at the same energy in the remaining coordination compounds indicates the noninvolvement of the keto O atom towards coordination. The $\nu(\text{C}-\text{O})\Phi$ stretch [28] (1530 cm^{-1}) of **II** undergoes a positive shift by $\leq 10\text{ cm}^{-1}$ in the coordination compounds of $\text{Mn}(\text{II})$ and $\text{Cd}(\text{II})$ ions, while it shifts to 20 cm^{-1} in $[\text{Cu}(\text{LH})]_2$. This band remains unchanged in the remaining compounds indicating the noninvolvement of phenolic O towards coordination. The $\nu(\text{C}-\text{S})$ (thiazolidinone ring) stretch [21] of **II** shifts from 820 cm^{-1} to lower energy by 35 cm^{-1} in $[\text{Cu}(\text{LH})]_2$, suggesting the formation of bond between the metal ions and the S atom. However, it remains unchanged in the rest of the coordination compounds indicating the noninvolvement of S atom towards coordination.

The $\nu(\text{C}-\text{S})$ (thiophene moiety) stretch [21] of **II** occurs at 640 cm^{-1} . The appearance of a band at the same energy in the coordination compounds of $\text{Mn}(\text{II})$, $\text{Cu}(\text{II})$, and $\text{Cd}(\text{II})$ ions favours the noninvolvement of S atom of thiophene moiety towards coordination. On the other hand, the negative shift by 60 and 45 cm^{-1} of this band in $[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$ and $[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$, respectively, indicates the coordination through S atom of thiophene moiety. The presence of a broadband between 3300 and 3400 cm^{-1} due to $\nu(\text{O}-\text{H})(\text{MeOH})$ stretch and the decrease of $\nu(\text{C}-\text{O})(\text{MeOH})$ stretch [28] from 1034 cm^{-1} to lower energy by 35 and 49 cm^{-1} in $[\text{Mn}(\text{LH})(\text{MeOH})_2]$ and $[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$, respectively, indicate the involvement of the O atom of MeOH towards coordination [28].

The absence of a band in the region $835\text{--}955\text{ cm}^{-1}$ due to the $\nu(\text{Zr}=\text{O})$ stretch [29] in the present $\text{Zr}(\text{OH})_2(\text{IV})$ compound suggests its formulation as $[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$ and not as $[\text{ZrO}(\text{H}_2\text{O})(\text{OAc})_2(\text{LH}_3)]$ [25]. The presence of a broadband at 3445 cm^{-1} due to coordinated OH group and the appearance of a new medium intense band at 1125 cm^{-1} due to the $\delta(\text{Zr}-\text{OH})$ bending mode [25] also support the proposed structure of the present $\text{Zr}(\text{IV})$ compound. The acetato ligand is coordinated to the metal ion in a monodentate fashion [30] as evident by the appearance of two new bands at 1580 and 1365 cm^{-1} due to the $\nu_{\text{as}}(\text{acetate})$ and $\nu_{\text{s}}(\text{acetate})$ stretches, respectively, in the spectrum of $[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$. $[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$ exhibits the $\nu_{\text{as}}(\text{O}=\text{U}=\text{O})$ stretch [31] at 920 cm^{-1} . The force constant ($f_{\text{U}-\text{O}}$) and U-O bond length in the present compound are $7.03\text{ mdyn/\AA}$ and $1.73\text{ \AA}$, respectively [25].

Nitrate group is associated with D_{3h} symmetry in free ion and exhibits three IR active vibrations: ν_2 (820 cm^{-1}), ν_3 (1380 cm^{-1}), and ν_4 (700 cm^{-1}). The D_{3h} symmetry of the free nitrate ion is lowered to C_{2v} on complex formation and six normal modes are expected to be IR active [32]. The compound does not exhibit any strong band $\sim 1380\text{ cm}^{-1}$ but displays two bands, one at 1510 cm^{-1} and another at 1290 cm^{-1} characteristic of $\nu_1(\text{NO})$ and $\nu_4(\text{NO}_{2\text{asy}})$ stretches, respectively, of C_{2v} nitrate group [33], indicating that the nitrate group in the compound is not free ion but is coordinated [34]. The molar conductance data also support this. The bidentate nature of nitrate group is indicated by the presence of bands at 1035 cm^{-1} (ν_2), 775 cm^{-1} (ν_6), 750 cm^{-1} (ν_3), and 690 cm^{-1} (ν_5) and the combination bands ($\nu_2 + \nu_3$) and ($\nu_2 + \nu_5$) at 1785 and 1735 cm^{-1} , respectively. For bidentate coordination of nitrate group [35], the values of ($\nu_3\text{--}\nu_5$) and ($\nu_1\text{--}\nu_4$) are $\sim 38\text{--}71$ and $\sim 185\text{--}235\text{ cm}^{-1}$, respectively; these energy separations lie between $13\text{--}20\text{ cm}^{-1}$ and $105\text{--}115\text{ cm}^{-1}$ in monodentate nitrate complexes [36]. We have observed the energy separations of these bands as 60 and 220 , respectively, indicating the bidentate coordination of nitrate group in the present compound. The new nonligand bands in the present coordination compounds in the low frequency region are assigned to the $\nu(\text{M}-\text{O})$ ($545\text{--}580\text{ cm}^{-1}$), the $\nu(\text{M}-\text{N})$ ($425\text{--}460\text{ cm}^{-1}$), and the $\nu(\text{M}-\text{S})$ ($350\text{--}365\text{ cm}^{-1}$) vibrations [37].

3.2. Reflectance Spectral Studies. $[\text{Mn}(\text{LH})(\text{MeOH})_2]$ exhibits three bands at 18100 , 23200 , and 25400 cm^{-1} due to ${}^6A_{1g} \rightarrow {}^4T_{1g}(\text{G})$, ${}^6A_{1g} \rightarrow {}^4T_{2g}(\text{G})$, and ${}^6A_{1g} \rightarrow {}^4A_{1g}(\text{G})$ transitions, respectively, in an octahedral environment [38]. The presence of only one broadband at $16,600\text{ cm}^{-1}$ due to the ${}^2E_g \rightarrow {}^2T_{2g}$ transitions in $[\text{Cu}(\text{LH})]_2$ suggests a square-planar arrangement of **II** around $\text{Cu}(\text{II})$ ions [39]. The absence of a band in the range $8000\text{--}10000\text{ cm}^{-1}$ precludes the presence of a tetrahedral structure [40].

3.3. EPR Studies. The EPR spectrum of $[\text{Cu}(\text{LH})]_2$ in DMSO at 77 K has been recorded in X-band, using 100 kHz field modulation, and the g values are relative to the standard marker tetracyanoethylene (TCNE) ($g = 2.0028$). The spectrum shows seven hyperfine lines ($2nI + 1 = 2 \times 2 \times (3/2) + 1 = 7$) in parallel components due to the intramolecular

exchange interaction in the dimer with no superhyperfine lines. It exhibits the half-filled line at ~ 1600 gauss due to $\Delta M_s = 2$ transition and conclusively proves the presence of the magnetic exchange interaction in this coordination compound.

The EPR spectral parameters of $[\text{Cu}(\text{LH})]_2$ are as follows: $g_{\parallel} = 2.25$, $g_{\perp} = 2.07$, $A_{\parallel} = 92 \times 10^{-4} \text{ cm}^{-1}$, $G = 3.65$, $\alpha_{\text{Cu}}^2 = 0.57$, and $g_{\text{av}} = 2.13$. The values of $A_{\parallel}$, $g_{\parallel}$, and $g_{\perp}$ obtained are close to the values reported for other dimetallic Cu coordination compounds [41]. For ionic environments, $g_{\parallel}$ is normally ≥ 2.3 and is < 2.3 for covalent environments. The $g_{\parallel}$ value (2.25) indicates that the metal-ligand bonding in the compound is covalent. The in-plane covalence parameter (α_{Cu}^2) has been calculated using the relation [20]:

$$\alpha_{\text{Cu}}^2 = (g_{\parallel} - 2.002) + \frac{3}{7} (g_{\perp} - 2.002) - \left(\frac{A_{\parallel}}{0.036} \right) + 0.04, \quad (1)$$

where α is related to the overlap integral (S) according to the relation: $\alpha^2 - 2\alpha\alpha'S + (\alpha')^2 = 1$. The smaller the value of α_{Cu}^2 , the more covalent the bonding; $\alpha_{\text{Cu}}^2 = 1$ indicates complete ionic bonding, while $\alpha_{\text{Cu}}^2 = 0.5$ indicates complete covalent bonding. On the other hand, the larger the value of $(\alpha')^2$, the more covalent the bonding; $(\alpha')^2 = 0$ suggests a complete ionic bonding. The observed value (α_{Cu}^2) of $[\text{Cu}(\text{LH})]_2$ is less than unity and this indicates that this compound possesses significant covalent character in the M-L bonding [42].

3.4. Magnetic Measurements. The magnetic moment of $[\text{Mn}(\text{LH})(\text{MeOH})_2]$ is 5.92 B.M. This value is within the normal ranges reported for the magnetically dilute octahedral compounds of Mn(II) ions [43]. The Cu(II) ion belongs to the $S = 1/2$ system and since its spin-orbit coupling constant is negative [20], the magnetically dilute Cu(II) coordination compound is expected to exhibit magnetic moment higher than the spin-only value of 1.73 B.M. due to the presence of orbital contribution [44]. The magnetic moment (1.55 B.M.) of $[\text{Cu}(\text{LH})]_2$ is substantially less than the above range of magnetic moment and this indicates the presence of antiferromagnetic exchange [20]. The coordination compounds of Cd(II), $\text{Zr}(\text{OH})_2$ (IV), and UO_2 (VI) of **II** are diamagnetic as expected.

3.5. Antibacterial Studies. The antibacterial activities of ligand (**II**) and its complexes were tested against bacteria, *E. coli* (Gram negative) and *S. aureus* (Gram positive), by using disc diffusion method. Stock solution was prepared by dissolving compounds in DMSO. Under aseptic conditions, plain sterilised discs were soaked in solution of compounds for overnight. Test culture was spread over the plates containing Mueller Hinton Agar (MHA) *E. coli* and *S. aureus* by using sterile swab. Inoculated plates were dried for 30 minutes and discs were placed on inoculated plates. The plates were left for 30 minutes at room temperature to allow diffusion. The plates were then incubated at 37°C for 24 hours for *E. coli* and *S. aureus*. After incubation, diameter of zone of inhibition was noted for each disc as shown in Table 3.

TABLE 3: Antibacterial activity of ligand (**I**) and its coordination compounds (zone of inhibition in mm).

Compound	<i>E. coli</i> (Gram negative)	<i>S. aureus</i> (Gram positive)
LH_3 (II)	6	5
$[\text{Mn}(\text{LH})(\text{MeOH})_2]$	9	6
$[\text{Cu}(\text{LH})]_2$	8	10
$[\text{Cd}(\text{LH})]$	11	11
$[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$	7	10
$[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$	10	12

TABLE 4: Minimum inhibitory concentration (MIC) of ligand (**I**) and its coordination compounds ($\mu\text{g/mL}$).

Compound	<i>E. coli</i> (Gram negative)	<i>S. aureus</i> (Gram positive)
LH_3 (II)	32	64
$[\text{Mn}(\text{LH})(\text{MeOH})_2]$	64	64
$[\text{Cu}(\text{LH})]_2$	64	32
$[\text{Cd}(\text{LH})]$	64	64
$[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$	32	32
$[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$	32	64

3.6. Determination of Minimum Inhibitory Concentration (MIC). The stock solution of compounds were prepared using distilled water as diluent. In a set of test tubes having 2 mL of Mueller Hinton Broth, compounds was serially diluted. 2 mL of the test culture was added to all tubes and tubes were incubated at 37°C for 24 hr. Lack of turbidity was noted for the determination of MIC (Table 4).

4. Conclusions

From the ongoing discussion, it may be stated that **II** behaves as a neutral tridentate ONS donor ligand in $[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$, monobasic tridentate ONS donor ligand in $[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$, dibasic tridentate OOS donor ligand in $[\text{Cu}(\text{LH})]_2$, and dibasic tetradentate OONO donor ligand in $[\text{Mn}(\text{LH})(\text{MeOH})_2]$ and $[\text{Cd}(\text{LH})]$.

Thus, on the basis of analytical, molecular weight, spectral, and magnetic studies, we propose a square-planar structure **V** for $[\text{Cu}(\text{LH})]_2$ a tetrahedral structure, **III** for $[\text{Cd}(\text{LH})]$, an octahedral structure **IV** for $[\text{Mn}(\text{LH})(\text{MeOH})_2]$, a pentagonal-bipyramidal structure **VI** for $[\text{Zr}(\text{OH})_2(\text{OAc})_2(\text{LH}_3)]$, and an eight-coordinate structure **VII** for $[\text{UO}_2(\text{NO}_3)(\text{LH}_2)(\text{MeOH})]$ as shown in Figure 3.

Disclosure

This paper is the authors' own work, and the research is original. The results have not been published (in any language or medium), and the paper is not considered and will not be offered elsewhere. Both the authors have read and approved the paper, and due care has been taken to ensure the integrity of the work.

FIGURE 3

Conflict of Interests

No conflict of interests exists in the submission of the paper.

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