



Synthesis, Characterization and Biological Studies on Cobalt(II) and Nickel(II) Complexes with Mannich Base 2-(Pyrrolidin-1-ylmethyl)isoindoline-1,3-dione

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A new Mannich base 2-(pyrrolidin-1-ylmethyl)isoindoline-1,3-dione was synthesized by the condensation of phthalimide, formaldehyde and pyrrolidine and was characterized on the basis of elemental analysis and IR, UV-visible, ¹H and ¹³C NMR data. Cobalt(II) and nickel(II) complexes of new Mannich base were synthesized and characterized by elemental analysis, electrical conductance, electronic and IR spectra, magnetic measurements, thermal analysis and cyclic voltammetric studies. From IR data, it is inferred that the ligand is neutral bidentate bonding through pyrrolidine ring containing nitrogen and one of the two carbonyl oxygens. The magnetic moment values and electronic spectral data show that all the complexes studied are tetrahedral except Co(II) chloro complex. The electrochemical studies show that Co(II)/Co(I) redox couple exists during electrolysis. Thermal results indicate that Co(II) sulphato and Ni(II) chloro complexes undergo two stage decompositions to produce CoSO₄ and NiO, respectively as final residues and that the ligand forms a polymer of formaldehyde as an intermediate. The antimicrobial activity measured by the agar well diffusion method showed that the metal complexes are more active than the ligand probably because of the chelation effect.

Keywords: Isoindoline-1,3-dione, Mannich base, Cyclic voltammetry, Thermal decomposition, Antimicrobial activity.

INTRODUCTION

Cyclic imides such as phthalimides, succinimides, *etc.* have received attention due to their antibacterial, antifungal, analgesic [1], anxiolytic [2] and antitumor activities [3,4] and HIV-1 reverse transcriptase inhibitor property [5]. Their molecules contain an imide ring and a general structural feature -CO-N(R)-CO- and they are lipophilic/hydrophobic and neutral. They can easily diffuse through the biological cell membrane causing potential biological activities and hence can serve as pharmacophores. In particular, phthalimides are reported as herbicides, insecticides, antipsychotics and anti-inflammatory agents [6-9]. Further, when imide is transformed into a Mannich base, it can enhance its biological behaviour and coordination tendency [10]. The new Mannich base which is presently studied is having a pyrrolidine moiety in addition to phthalimide moiety. The pyrrolidine skeleton occurs in many families of biologically important compounds. Pyrrolidine derivatives are found to have antimicrobial activity against various pathogens except

Basillus subtilis [11]. They also possess anti-influenza virus [12], anticonvulsant [13,14] and other antiviral [15] activities.

There have been recent reports on the synthesis and biological properties of Mannich bases derived from imides including that of phthalimide and the isolation and characterization of transition metal complexes of those Mannich bases. Abdullahi and Rajeswari [16] have synthesized and characterized a novel Mannich base by the direct condensation of succinimide, benzaldehyde and thiourea. Tamilvendan *et al.* [17] have reported another Mannich base by condensing succinimide, benzaldehyde and morpholine. Novel Mannich bases like 1-[(phenylamino)methyl]pyrrolidine-1,3-dione and 2-[(phenylamino)methyl]isoindoline-1,3-dione have been synthesized and their complexes with Co(II), Ni(II), Cu(II) and Zn(II) ions have also been studied. Recently, we have reported synthesis and antimicrobial activity of 2-(dimethylaminomethyl)isoindoline-1,3-dione and 2-(diethylaminomethyl)isoindoline-1,3-dione and their Co(II) and Ni(II) complexes. Ramesh [18] also reported Co(II), Ni(II) and Cu(II) complexes of *N*-(morpholinomethyl)-

succinimide. In continuation, we report herein the synthesis, characterization and antimicrobial screening of Co(II) and Ni(II) complexes of 2-(pyrrolidin-1-ylmethyl)isoindoline-1,3-dione.

EXPERIMENTAL

Elemental analyses of the synthesized compounds were performed using Carlo Erba 1108, Thomas CH analyzer and Coleman N analyzer. Metal, chloride and sulphate contents of the complexes were estimated according to the standard procedures [19]. The molar conductances of metal complexes were measured in $\sim 10^{-3}$ M DMF solutions at room temperature using Systronics direct reading Conductivity Meter 304. The magnetic susceptibility measurements were done to find out the effective magnetic moments of metal ions by using a Gouy magnetic balance at room temperature, where $\text{Hg}[\text{Co}(\text{SCN})_4]$ was used as the calibrant and diamagnetic corrections were applied using Pascal's constants [20]. Infrared spectral measurements were made for the free ligand and its metal complexes as KBr pellets using Perkin Elmer Spectrum-1 FT-IR spectrometer in the region of $4000\text{--}400\text{ cm}^{-1}$. Far IR spectra were recorded on a Bruker IFS-66V FT-IR spectrometer in polythene support. The ^1H - and ^{13}C -NMR spectra of the ligand were recorded on JEOL GSX-400FT. NMR spectrometer employing TMS as internal reference and DMSO- d_6 as solvent at ambient temperature. The UV-visible spectra of the compounds in DMF solutions were measured using Perkin Elmer EZ 301 spectrometer in the working range of 1100-190 nm. Electrochemical behaviour of $\text{CoCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$ as a representative case was investigated with an electrochemical analyzer CHI-620A, USA-Version 4.01 in HPLC grade DMF containing NaClO_4 as supporting electrolyte. The three electrode assembly consisted of glassy carbon working electrode, Ag/AgCl (3 M KCl) reference electrode and Pt wire auxiliary electrode. All measurements were carried out at room temperature after purging the solutions with nitrogen gas [21]. Thermal analyses of the ligand and metal complexes were performed by recording simultaneous TG/DTA patterns on a Perkin Elmer Diamond TG/DTA thermal analyzer in an atmosphere of air at a linear heating rate of $10\text{ }^\circ\text{C}$ from ambient to $900\text{ }^\circ\text{C}$.

Synthesis of 2-(pyrrolidin-1-ylmethyl)isoindoline-1,3-dione: A new Mannich base 2-(pyrrolidin-1-ylmethyl)isoindoline-1,3-dione was synthesized by the Mannich condensation of phthalimide, formaldehyde and pyrrolidine. Phthalimide (4.71 g, 0.1 mol) was mixed with 37 % aqueous formaldehyde (7.5 mL, 0.1 mol) and pyrrolidine (12.21 mL, 0.1 mol) with constant stirring at room temperature and the clear solution obtained was kept aside for 2 h. The colourless crystalline product formed was filtered, washed with distilled water several time

and finally washed with a small amount of acetone. It was dried at $70\text{ }^\circ\text{C}$ in an air oven and stored in a vacuum desiccator (yield: 93 %). The colourless compound was recrystallized from ethanol (m.p. $122\text{ }^\circ\text{C}$).

Preparation of metal complexes: A hot ethanolic solution (20 mL) of metal(II) salt was added dropwise to hot ethanolic solution (20 mL) of Mannich base ligand in 2:1 or 1:1 mol ratio with constant stirring and the mixture was digested in a water bath for an hour. The solid metal complexes were filtered, washed with hot ethanol and dried at $80\text{ }^\circ\text{C}$ in a hot air oven and finally preserved in a vacuum desiccator.

in vitro Antimicrobial activity: The antibacterial screening of Mannich base and its metal complexes against *E. coli* and *S. aureus* was done using nutrient agar medium and antifungal assay against *C. albicans* and *A. niger* was carried out using Rose Bengal chloromphenicol agar medium. In both cases, agar well diffusion technique was employed and sample solutions (in DMF) of 25, 50, 75 and $100\text{ }\mu\text{g/mL}$ concentrations were filled into the wells. Kanamycin and tetracyclin were used as standard drugs in the antibacterial assay and amphotericin and nystatin were the standard drugs in antifungal assay.

RESULTS AND DISCUSSION

Structural characterization of Mannich base: The synthesized compound is non-hygroscopic and insoluble in water, chloroform, carbon tetrachloride, ether, benzene and *n*-hexane, but soluble in methanol, ethanol, 2-propanol, 1-butanol, DMSO and DMF. The results of elemental analysis (Table-1) and the molecular mass determined by Rast method at 229.38 indicate that the molecular formula of synthesized Mannich base is $\text{C}_{13}\text{H}_{14}\text{N}_2\text{O}_2$. The electronic spectrum of Mannich base in DMF solution registers intense bands at 273 nm due to $n\text{-}\pi^*$ transition of the carbonyl group and at 235nm due to $\pi\text{-}\pi^*$ transitions of both carbonyl group and aromatic ring [22].

The characteristic IR absorption bands of synthesized Mannich base are listed in Table-2. The bands are slightly shifted from those of pyrrolidine and phthalimide because of formation of the new compound by Mannich condensation. The absorption bands observed at 1765 (sh) and 1712 cm^{-1} are assigned to νCO of phthalimide moiety and the bands located at 1185 and 1150 cm^{-1} are due to νCNC of pyrrolidine moiety. The bands found in the region $1596\text{--}1430\text{ cm}^{-1}$ are attributed to the aromatic $\text{C}=\text{C}$ stretching vibrations while the absorptions observed at 745 and 713 cm^{-1} are due to the *ortho*-substitution of benzene ring in the phthalimide moiety [22,23].

The ^1H NMR spectrum of synthesized Mannich base showed four signals indicating four different types of protons.

TABLE-1
ANALYTICAL AND CONDUCTANCE DATA FOR Co(II) AND Ni(II) COMPLEXES OF LIGAND

Compound	m.f.	Elemental analysis (%): Found (calcd.)					Λ_M ($\Omega^{-1}\text{ cm}^2\text{ mol}^{-1}$)
		C	H	N	Metal	Anion	
L	$\text{C}_{13}\text{H}_{14}\text{N}_2\text{O}_2$	67.94 (67.82)	6.16 (6.08)	12.11 (12.17)	–	–	–
$\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$	$\text{C}_{13}\text{H}_{18}\text{N}_2\text{O}_4\text{CoCl}_2$	39.36 (39.40)	4.11 (4.04)	7.12 (7.07)	14.78 (14.88)	17.96 (17.93)	36
$2\text{Co}(\text{NO}_3)_2 \cdot \text{L}$	$\text{C}_{13}\text{H}_{14}\text{N}_4\text{O}_{14}\text{Co}_2$	26.12 (26.17)	2.39 (2.34)	14.15 (14.09)	19.73 (19.77)	– (41.61)	23
$2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$	$\text{C}_{13}\text{H}_{16}\text{N}_2\text{O}_{11}\text{S}_2\text{Co}_2$	27.98 (27.96)	2.81 (2.86)	5.06 (5.02)	21.28 (21.30)	34.44 (34.41)	19
$2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$	$\text{C}_{13}\text{H}_{16}\text{N}_2\text{O}_3\text{NiCl}_4$	27.53 (29.58)	3.44 (3.41)	5.32 (5.30)	22.28 (22.25)	26.88 (26.92)	37
$\text{Ni}(\text{NO}_3)_2 \cdot \text{L}$	$\text{C}_{13}\text{H}_{14}\text{N}_4\text{O}_8\text{Ni}$	37.91 (37.79)	3.46 (3.39)	13.52 (13.56)	14.24 (14.22)	– (30.04)	33
$\text{NiSO}_4 \cdot \text{L}$	$\text{C}_{13}\text{H}_{14}\text{N}_2\text{O}_6\text{SNi}$	40.49 (40.58)	3.71 (3.63)	7.21 (7.27)	15.31 (15.26)	24.87 (24.95)	46

TABLE-2
 IR SPECTRAL DATA (cm⁻¹) OF MANNICH BASE L AND ITS Co(II) AND Ni(II) COMPLEXES

Compound	$\nu(\text{CO})$	$\nu(\text{CNC})$	$\nu(\text{MO})$	$\nu(\text{MN})$	$\nu(\text{MX})$	$\nu(\text{OH})$	$\delta(\text{HOH})$	$\rho(\text{HOH})$
L (C ₁₃ H ₁₄ N ₂ O ₂)	1765, 1712	1185, 1150	–	–	–	–	–	–
CoCl ₂ ·L·2H ₂ O	1726, 1604	1143, 1052	532	430	360	3487	1604	842
2Co(NO ₃) ₂ ·L	1718, 1640	1139, 1053	534	440	–	–	–	–
2CoSO ₄ ·L·H ₂ O	1735, 1605	1146, 1112	487	419	–	3483	1605	881
2NiCl ₂ ·L·H ₂ O	1727, 1597	1177, 1144, 1051	530	460	340	3485	1598	909
Ni(NO ₃) ₂ ·L	1717, 1623	1141, 1045	477	422	–	–	–	–
NiSO ₄ ·L	1713, 1639	1128	534	440	–	–	–	–

The singlet at 7.84 ppm is assigned to aromatic protons. The chemical shift at 2.55–2.48 ppm is due to N(CH₂)₂ protons and that at 1.6 ppm is due to other CH₂ protons of pyrrolidine moiety. The proton signal seen at 4.5 ppm is attributed to the N-CH₂-N linkage. The intensity ratio obtained for the signals correlates with the number of protons under each chemically equivalent set.

The ¹³C NMR spectrum of Mannich base shows low intensity signal at 168.73 ppm due to carbonyl carbons and at 134.47–123.09 ppm due to aromatic carbons. The N(CH₂)₂ carbons of pyrrolidine moiety give a signal at 49.88 ppm while other CH₂ carbons resonated at 23.25 ppm. The chemical shift of methylene carbon linking the N-atoms of pyrrolidine and phthalimide moieties is observed at 54.67 ppm.

The crystal structure of synthesized Mannich base was already reported [24] and hence mass spectral study was not attempted. Thus based on physical, chemical and crystallographic studies the molecular structure is confirmed as given in Fig. 1.

Further optical transmission studies have been carried out to evaluate the optical parameters (K, α , R) and the optical band gap (E_g) [25]. As a consequence of a wide band gap (5.16 eV), this Mannich base crystal has a large transmittance in the visible

region making it suitable for non-linear optical (NLO) applications such as fabrication of various photonic devices.

Structural characterization of metal complexes: All the metal complexes isolated are coloured, stable in air and non-hygroscopic. They are insoluble in water and common organic solvents, but soluble in DMF and DMSO. The metal complexes have been analyzed for C, H, N, metal and anion contents. Their analytical and electrical conductivity data are given in Table-1. The observed molar conductance data revealed that the metal complexes are non-electrolytes and the anions are bound to the metal ions [26].

Infrared spectra: The Mannich base ligand (L) has four coordination sites *viz.* two carbonyl O, one imide N and one tertiary amino N atom. A comparison of IR spectra of metal (II) complexes with that of the ligand would suggest the actual coordination sites of the ligand and the modes of coordination of oxoanions. The structurally important IR absorption frequencies of Co(II) and Ni(II) complexes are presented in Table-2. The free ligand exhibits characteristic vibrational absorption bands at 1765 (sh) and 1712 cm⁻¹, which are due to carbonyl stretching vibrations. In the spectra of metal complexes, the ligand band at 1712 cm⁻¹ has undergone splitting into two bands

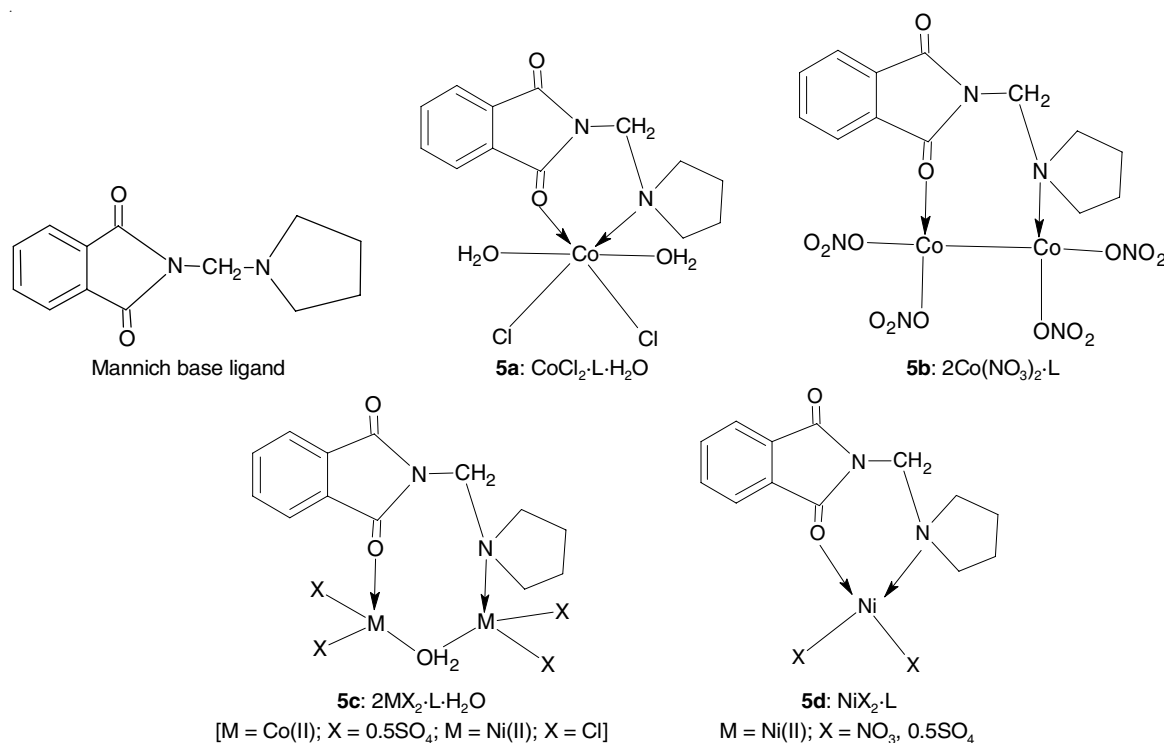


Fig. 1. Proposed structures of the Co(II) and Ni(II) complexes

in each case one at a higher region 1720-1709 cm^{-1} and another at a lower region 1639-1600 cm^{-1} , indicating the coordination of one of the two carbonyl oxygens to the metal ions [17,27,28]. Further, the C-N-C stretching vibrations of free ligand appeared at 1185 and 1150 cm^{-1} . These vibrations have lowered to 1146-1109 and 1128-1045 cm^{-1} regions in the spectra of metal (II) complexes indicating the bonding of pyrrolidine ring N to the metal centre [17,29].

The coordination of carbonyl oxygen and tertiary amino nitrogen atoms to the metal centre is also evidenced by the occurrence of $\nu(\text{M}-\text{O})$ and $\nu(\text{M}-\text{N})$ at 534-477 and 460-419 cm^{-1} , respectively. The binding of anions to the metal centre is also inferred from existence of vibrational bands in the IR spectra of nitrate and sulphate complexes. The Co(II) and Ni(II) nitrate complexes exhibit ν_5 , ν_1 and ν_2 bands at 1459-1458, 1390-1388 and 1052-1045 cm^{-1} , respectively due to unidentate coordination of the nitrate groups, as the separation between ν_5 and ν_1 is very small [30]. The bidentate coordination of sulphate groups in Co(II) and Ni(II) complexes is revealed by the ν_3 , ν_1 , ν_4 and ν_2 bands appearing at 1189-1112, 881-850, 612-611 and 534-487 cm^{-1} [30]. The IR spectra of complexes such

as $\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$, $2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$ and $2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$ exhibit absorption bands due to coordinated water at 3487-3483 ($\nu(\text{OH})$), 1605-1598 ($\delta(\text{HOH})$), 909-842 ($\rho(\text{rHOH})$), 645-612 ($\rho(\text{wHOH})$) and 540-461 cm^{-1} ($\nu(\text{M}-\text{O})$). The thermal decomposition studies on $2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$ as a representative case also indicate the presence of coordinated water molecule. The far IR absorption bands observed at 360-340 cm^{-1} are due to M-Cl vibrations in the chloro complexes.

Electronic spectral and magnetic studies: The electronic spectral band of ligand origin observed at 273 nm due to $n-\pi^*$ transition of carbonyl groups is blue shifted in all the metal complexes indicating the coordination of a carbonyl oxygen to the metal centre. The colours, magnetic moments, absorption maxima and the transition assignments of metal complexes are shown in Table-3 and the ligand field parameters are given in Table-4. The pink coloured Co(II) chloro complex exhibited electronic transition bands at 6822, 14814 and 18963 cm^{-1} due to ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{2g}(\text{F})$ (ν_1); ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{A}_{2g}(\text{F})$ (ν_2) and ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{1g}(\text{P})$ (ν_3) transitions and at 28292 cm^{-1} is due to charge transfer transition. The ν_2/ν_1 ratio for Co(II) chloro complex is 2.17, which falls in the range 2.00-2.82 indicated a high

TABLE-3
ELECTRONIC SPECTRAL AND MAGNETIC DATA OF Co(II) AND Ni(II) COMPLEXES OF LIGAND

Complex	Colour	μ_{eff} (B.M)	Coordination environment	Absorption maxima (cm^{-1})	Transition assignments
$\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$	Pinkish red	5.16	$[\text{CoO}_3\text{NCl}_2]$	6822 14814 18963 28262	${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{2g}(\text{F})$ ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{A}_{2g}(\text{F})$ ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{1g}(\text{P})$ CT
$2\text{Co}(\text{NO}_3)_2 \cdot \text{L}$	Blue	1.09	$[\text{CoO}_2\text{NCo}]$ $[\text{CoO}_3\text{Co}]$	3912 6726 14426 26168	${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_2(\text{F})$ ${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_1(\text{F})$ ${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_1(\text{P})$ CT
$2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$	Greyish blue	4.21	$[\text{CoO}_4]$ $[\text{CoO}_3\text{N}]$	3869 6938 14693 26326	${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_2(\text{F})$ ${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_1(\text{F})$ ${}^4\text{A}_2(\text{F}) \rightarrow {}^4\text{T}_1(\text{P})$ CT
$2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$	Parrot green	4.17	$[\text{NiONCl}_2]$ $[\text{NiO}_2\text{Cl}_2]$	3876 8562 15141 25612	${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{A}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_1(\text{P})$ CT
$\text{Ni}(\text{NO}_3)_2 \cdot \text{L}$	Light green	4.28	$[\text{NiO}_3\text{N}]$	3977 8658 15280 35714	${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{A}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_1(\text{P})$ CT
$\text{NiSO}_4 \cdot \text{L}$	Apple green	4.12	$[\text{NiO}_3\text{N}]$	3912 8420 15396 24454	${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{A}_2(\text{F})$ ${}^3\text{T}_1(\text{F}) \rightarrow {}^3\text{T}_1(\text{P})$ CT

TABLE-4
LIGAND FIELD PARAMETERS OF Co(II) AND Ni(II) COMPLEXES OF LIGAND

Complex	ν_2/ν_1	B (cm^{-1})	Dq (cm^{-1})	β	β %	LFSE (kcal cm^{-1})
$\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$	2.171	887.4	799.2	0.914	8.61	27.40
$2\text{Co}(\text{NO}_3)_2 \cdot \text{L}$	1.719	627.7	391.2	0.646	35.36	13.41
$2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$	1.793	668.3	386.9	0.688	31.20	27.70
$2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$	2.209	805.0	468.6	0.773	22.70	16.07
$\text{Ni}(\text{NO}_3)_2 \cdot \text{L}$	2.177	800.4	468.1	0.773	22.70	16.04
$\text{NiSO}_4 \cdot \text{L}$	2.152	805.3	450.8	0.774	22.61	15.45

Note: B_0 for Co(II): 971 cm^{-1} , LFSE = 12 Dq and 1 kcal mol^{-1} = 350 cm^{-1} ; B_0 for Ni(II): 1041 cm^{-1} , LFSE = 12 Dq and 1 kcal mol^{-1} = 350 cm^{-1}

spin octahedral geometry around Co(II) [31,32]. The effective magnetic moment of Co(II) chloro complex is 5.16 B.M., which is expected for a high spin octahedral complex. The blue coloured Co(II) nitrate and sulphato complexes exhibited an absorption maxima at 3912-3869 cm^{-1} due to ${}^4A_2(F) \rightarrow {}^4T_2(F)$ (ν_1); 6938-6726 cm^{-1} due to ${}^4A_2(F) \rightarrow {}^4T_1(F)$ (ν_2); and 14693-14426 cm^{-1} due to ${}^4A_2(F) \rightarrow {}^4T_1(P)$ (ν_3) transitions and at 26326-26168 cm^{-1} due to charge transfer transitions. The very low magnetic moment value of 1.09 B.M. measured for Co(II) nitrate complex may be attributed to anti-ferromagnetic interaction between the adjacent Co(II) ions in a binuclear pseudo-tetrahedral geometry. The magnetic moment of Co(II) sulphato complex measured at 4.21 B.M. is indicative of a tetrahedral geometry. The ν_2/ν_1 ratios for Co(II) nitrate and sulphato complexes measured at 1.719 and 1.793, respectively are also supportive of tetrahedral stereochemistry around Co(II) ion.

The green coloured Ni(II) chloro, nitrate and sulphato complexes exhibited bands at 3977-3876 cm^{-1} due to ${}^3T_1(F) \rightarrow {}^3T_2(F)$ (ν_1); at 8658-8420 cm^{-1} due to ${}^3T_1(F) \rightarrow {}^3A_2(F)$ (ν_2); at 15641-15280 cm^{-1} due to ${}^3T_1(F) \rightarrow {}^3T_1(P)$ (ν_3) and at 35714-24454 cm^{-1} due to charge transfer transitions. The ν_2/ν_1 ratios observed for Ni(II) complexes are within the stipulated range of 2.00-2.24 for T_d symmetry of Ni(II). The magnetic moment values of Ni(II) complexes are within the range of 4.12-4.28 B.M. indicating tetrahedral geometry around Ni(II) ion [33,34].

Electrochemical studies: The redox behaviour of $\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$ was studied as a representative case. The cyclic voltammograms of this complex were recorded at 50, 250 and 500 mV s^{-1} scan rates (ν) and the redox properties are shown in Table-5. The cyclic voltammogram of complex scanned at 250 mV s^{-1} is represented in Fig. 2. The cyclic voltammograms feature the reduction of Co(II) to Co(I) at cathodic peak potentials

1.5613-1.512 V [35,36]. The separations between the anodic and cathodic peak potentials (ΔE_p) measured at 31-37 mV indicate reversible one electron process. The voltammetric $E_{1/2}$ values taken as the average of E_{pc} and E_{pa} are at 1.5576-1.5292 V showed that the present complex cannot undergo reduction easily at a more positive potential as the σ donating ability of the chelating(NO) Mannich base would tend to stabilize Co(II) ion in the chelate. The peak current ratios (i_{pa}/i_{pc}) are greater than unity at all scan rates showing that the electron transfer is not followed by a chemical reaction. The peak current increases with increase in $\nu^{1/2}$ to establish the electrode process to be diffusion controlled.

Thermal studies: Thermal data obtained for Mannich bases and its representative complexes are provided in Table-6.

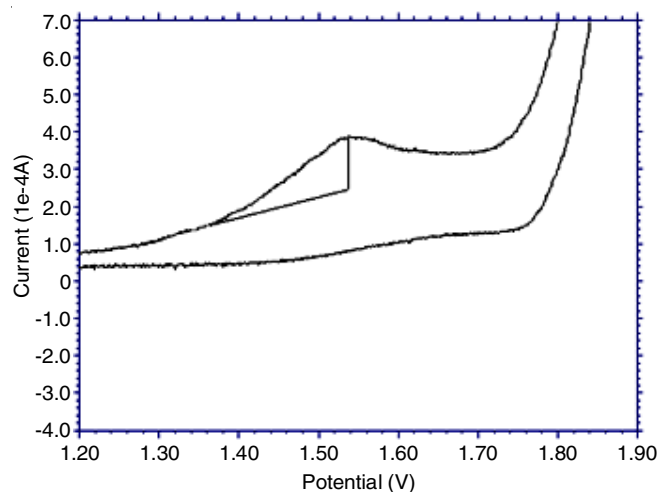


Fig. 2. Cyclic voltammogram of $\text{CoCl}_2 \cdot \text{PMID} \cdot 2\text{H}_2\text{O}$ at the scan rate of 250 mV s^{-1}

TABLE-5
ELECTROCHEMICAL DATA OF $\text{CoCl}_2 \cdot \text{L} \cdot 2\text{H}_2\text{O}$ AT VARIOUS SCAN RATES

Scan rate (mVs^{-1})	E_{pa} (V)	E_{pc} (V)	ΔE_p (mV)	$E_{1/2}$ (V)	i_{pa} (μA)	i_{pc} (μA)	i_{pa}/i_{pc}
50	1.5761	1.539	37	1.5576	112.7	27.96	4.031
250	1.5464	1.512	34	1.5292	385.4	64.48	5.977
500	1.5613	1.514	31	1.5376	627.6	69.84	8.986

TABLE-6
TG/DTG/DTA DATA FOR LIGAND AND ITS METAL COMPLEXES

Compound	Stable upto ($^{\circ}\text{C}$)	Stage	Decomposition temperature ($^{\circ}\text{C}$)		Nature of transformation/ Intermediate formed/ % Mass found (calc.)	Nature of DTA peak and temp. ($^{\circ}\text{C}$)	DTG peak temp. ($^{\circ}\text{C}$)
			Initial	Final			
$\text{L}(\text{C}_{13}\text{H}_{14}\text{N}_2\text{O}_2)$	193.2	I	193	300	Melting point Decomposition of land formation of a polymer of formaldehyde (R)	122.07 Endo	–
		II	450	500	Presence of high polymer of formaldehyde as a stable final residue.	490.0 Exo	489.5
$2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$	80.0	I	80	90	Elimination of lattice water	90.0 Endo	79.06
		II	105	140	Elimination of coordinated water to give anhydrous complex	112.5 Endo	109.14
		III	210	320	Elimination of L to give CoSO_4 as final residue (G) 57.2 (56.38)	299.7 Endo	295.3
$2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$	71.0	I	71	105	Elimination of coordinated water to form anhydrous complex (G) 87.0 (89.8)	75.0	71.0
		II	190	225	Elimination of L to form NiCl_2 as intermediate (G) 54.3 (52.85)	222.0 Endo	218.4
		III	500	800	Conversion of NiCl_2 into NiO (G). 29.2 (30.38)	556.0 Exo	579.0

Note: (R) = rapid, (G) = gradual and (S) = slow decomposition; Exo = exothermic, Endo = endothermic

TABLE-7
ANTIBACTERIAL AND ANTIFUNGAL ACTIVITIES OF MANNICH BASE LIGAND (L) AND ITS METAL COMPLEXES

Compound	Zone of inhibition (mm)															
	Antibacterial activity								Antifungal activity							
	<i>E. coli</i>				<i>S. aureus</i>				<i>A. niger</i>				<i>C. albicans</i>			
	Conc. ($\mu\text{g/mL}$)				Conc. ($\mu\text{g/mL}$)				Conc. ($\mu\text{g/mL}$)				Conc. ($\mu\text{g/mL}$)			
25	50	75	100	25	50	75	100	25	50	75	100	25	50	75	100	
L ($\text{C}_{13}\text{H}_{14}\text{N}_2\text{O}_2$)	11	12	13	14	9	11	13	14	7	9	12	13	8	9	12	13
$\text{CoCl}_2 \cdot 2\text{H}_2\text{O}$	11	14	17	20	12	15	18	21	12	15	18	21	11	14	17	20
$2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$	11	13	15	19	11	14	17	19	11	14	17	19	11	13	15	19
$2\text{NiCl}_2 \cdot \text{L} \cdot \text{H}_2\text{O}$	10	12	14	18	10	12	15	18	10	12	15	18	10	12	14	18
$\text{NiSO}_4 \cdot \text{L}$	11	14	17	20	12	15	18	21	12	15	18	21	11	14	17	20
Kanamycin	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tetracyclin	–	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–
Amphotericin	–	–	–	–	–	–	–	–	10	–	–	–	–	–	–	–
Nystatin	–	–	–	–	–	–	–	–	–	–	–	–	9	–	–	–

The TG/DTA thermogram obtained for the ligand shows a two stage decomposition. An endotherm found at 122.07 °C indicates the melting of Mannich base, but compound is stable upto 193 °C. The first stage of decomposition and weight loss occurred in the temperature range 193-300 °C as indicated by DTG peak at 241.64 °C. The second stage of slow decomposition occurs in the range 450-500 °C as shown by exotherm at 490 °C and DTG peak at 489.5 °C. The final residue existing above 500 °C may be a polymer of formaldehyde (one of the decomposition products of ligand).

The aqua complex $2\text{CoSO}_4 \cdot \text{L} \cdot \text{H}_2\text{O}$ eliminates coordinated water in the temperature range 105-140 °C as evidenced by the endotherm at 112.54 °C and a DTG peak centered at 109.14 °C. The anhydrous complex undergoes gradual decomposition in the range 210-320 °C with the loss of organic ligand to give a residue of CoSO_4 , as indicated by the endotherm at 299.7 °C and also by the DTG peak at 295.3 °C.

The Ni(II) aqua complex rapidly loses water in the range 75-105 °C as indicated by the endotherm at ~75 °C to form the anhydrous complex. This in the range 190-225 °C eliminates the organic ligand to form NiCl_2 as intermediate, as evidenced by the endothermic DTA peak at 222 °C and the DTG peak at 218.4 °C, NiCl_2 intermediate undergoes gradual conversion into NiO above 500 °C. The exotherm found at 556 °C and DTG peak at 579 °C are supportive of formation of NiO as final residue.

Antimicrobial activity: Imide molecules possess a -CO-N(R)-CO- structural feature and a ring structure making them lipophilic and neutral and hence they can cross the biological membranes easily. Thus, the imide derivatives are known to exhibit several biological activities. When imides are transformed into Mannich bases they may have enhanced activities. In view of this, *in vitro* antibacterial and antifungal activities of ligand and its Co(II) and Ni(II) complexes have been evaluated. All the metal complexes as well as Mannich base ligand exhibited a significant antimicrobial activity (Table-7). The metal complexes are more active against bacteria and fungi than the free ligand. This reason might be ascribed due to the chelation, which reduces the polarity of metal atom and enhances the lipophilic nature of metal complex favouring the diffusion of the chelate molecule through the lipid layer of microbial cell membrane. Thus, the higher activity of metal(II) complexes

may be ascribed to increase in lipophilic nature of the complexes arising from chelation [37]. The hydrogen bonding and other interactions between the donor groups present in the enzymes of microbes and imido carbonyl groups present in the chelate molecules may interfere in the process of protein synthesis and cell wall synthesis leading to the lysis of cells. Also the activity increases when concentrations of test compounds are increased. The activities of metal complexes at higher concentrations are comparable to those of the standard drugs. The Co(II) complexes have enhanced antimicrobial activities when compared with Ni(II) complexes (Table-7).

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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