ARTICLE

Spectral Characterization, DNA Binding and Antibacterial Studies of Heterolyptic Metal Complexes with 2-Acetylthiophene-4-phenyl-3-thiosemicarbazone and 2,2′-Bipyridyl

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ABSTRACT

Heterolyptic metal complexes having the composition $M(Bpy)Cl_2$ (where, M = Cu(II), Ni(II) and Co(II); Bpy = 2,2′-bipyridyl) were reacted with 2-acetylthiophene-4-phenyl-3-thiosemicarbazone (ATPT) to produce bivalent metal complexes with molecular formula $M(Bpy)(ATPT)Cl{\cdot}H_2O$. The complexes were characterized using physical (molar conductivity) and spectral (mass spectra, infrared and electronic spectroscopies) methods. Electrochemical behaviour of the complexes was revealed using cyclic voltammetry. The Cu(II)/Cu(I) couple complexes show a quasi-reversible cyclic voltammetric responses. The DNA binding properties of complexes were determined through absorption UV-visible spectrophotometry. Furthermore, the agar well diffusion method was used to screen the metal(II) complexes for their antibacterial activity against pathogenic bacterial strains, namely Gram negative strains such as *Escherichia coli* and *Klebsiella pneumonia* and Gram positve strains such as *Staphylococcus aureus* and *Bacillus cereus*. The synthesized $Cu(Bpy)(ATPT)]Cl{\cdot}H_2O$ complex strongly inhibits bacteria compared with other complexes.

KEYWORDS

Heterolyptic metal complexes, Thiosemicarbazone, 2,2′-Bipyridyl, DNA binding, Antibacterial activity.

INTRODUCTION

Thiosemicarbazones and their metal complexes are widely applied in analytical chemistry [1,2], pharmacology [3-5] and nuclear medicine [6]. Transition metal complexes of thiosemicarbazone show antibacterial [7,8], antimalarial [9], antitrypanosomal [10], antiviral [11], antitumor [12] and anticancer [13,14] activities. The pharmacological activity of the metal complexes is associated with their ability to bind/interact with DNA, which is considered as the life of a cell. The planar structure of the heterocyclic ligand 2,2′-bipyridine makes it a potential intercalating compound.

Bipyridine chelators are the potential antitumor agents [15]. Bipyridine is chosen mainly because (i) the ligand is rigid, planar and provides two aromatic nitrogens, whose unshared electron pairs can act cooperatively in binding cations and (ii) the π-electron deficiency makes 2,2′-bipyridine an excellent π-acceptor ligand. The structural and spectral studies of 2-acetylthiophene-4-phenyl-3-thiosemicarbazone (ATPT) have

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also been reported [16,17]. ATPT has been used for the spectrophotometric determination of copper(II) in alloys, edible oils, and seeds [18]. However, transition metal complexes with polypyridyl ligands and thiosemicarbazone have been seldom investigated [19].

Studying mixed ligand transition metal complexes is necessary, since they are the most general and probable coordination compounds in the biological system. Therefore, studies on heteroleptic metal complexes of biologically important compounds may serve as models for biochemical processes [20-22]. Moreover, they are characterized by extreme stability and the properties of the central metal ion are more pronounced in these complexes. Heteroleptic transition metal complexes of ATPT and 2,2′-bipyridine have not been reported so far. Additionally, in continuation with our ongoing research on mixed ligand transition metal complexes [23-25], herein the authors present the synthesis, characterization and DNA binding properties of heteroleptic Cu(II), Ni(II), and Co(II) complexes with 2,2′-bipyridine and ATPT.

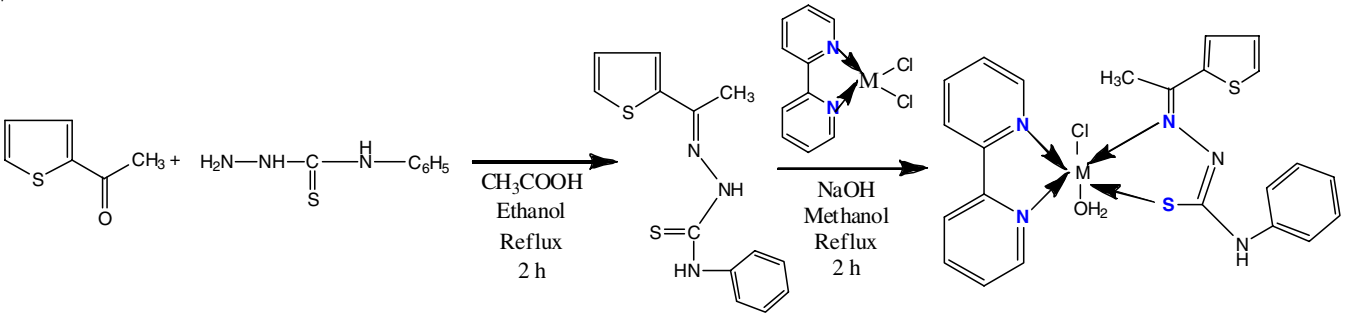
EXPERIMENTAL

The compounds *viz*. 4-phenyl-3-thiosemicarbazide, 2-acetylthiophene and 2,2′-bipyridyl were purchased from Sigma-Aldrich. All chemicals were of AR grade and used without further purification. The solvents used were distilled before use. Calf thymus DNA (CT-DNA) was purchased from Genio Bio labs (Bangalore, India). Elemental analyses were conducted using a HeraeusVario-EL III Carlo-Erba 1108 instrument. Molar conductivity measurements at 298 ± 2 K in dry and purified DMF were performed using a CM model 162 conductivity cell (ELICO). The electronic spectra were recorded in DMSO with a UV lamda50 (Perkin-Elmer) spectrophotometer. IR spectra were recorded in the range 4000-400 cm^{-1} with a Perkin-Elmer spectrum 100 spectrometer on KBr discs. The ESR spectra were recorded on a Varian E-112 X-band spectrophotometer at room temperature (RT) and liquid nitrogen temperature (LNT) in the solution (DMF). Cyclic voltammetric measurements were obtained by using a CH instrument assembly equipped with an X-Y recorder. Measurements were obtained using degassed (N_2 bubbling for 5 min) solutions (10^{-3} M) containing 0.1 M Bu_4NPF_6 as the supporting electrolyte. The three-electrode system consisted of glassy carbon (working), platinum wire (auxiliary) and Ag/AgCl (reference) electrodes.

Synthesis of 2-acetylthiophene-4-phenyl-3-thiosemicarbazone (ATPT): The ligand, ATPT, was synthesized using 4-phenyl-3-thiosemicarbazide and a carbonyl compound 2-acetylthiophene. An ethanolic solution of 4-phenyl-3-thiosemicarbazide (5 mmol) and 2-acetylthiophene (5 mmol) in ethanol was mixed in a round-bottom flask. Then, two drops of CH_3COOH were added to the reaction mixture. This reaction mixture was refluxed for 3 h and then cooled to room temperature. The ligand ATPT was obtained as shiny white crystalline product, which was subsequently used for the synthesis of metal complexes. Yield: 80%; m.p.: 180-182 ºC. IR (KBr, ν_{max}, cm^{-1}): 3297 (N-$H_{asym.}$), 1589 (C=N) and 1194 (C=S). ^{1}H NMR (δ ppm): 9.31 (s, 1H), 8.70 (s, 1H), 7.25-7.44 (m, 5H), 7.71 (dd, 3H), 7.06 (dd 3H), 2.34 (s, 3H) were assigned to phenylimine proton, >NH, phenyl protons, thiophene protons and CH_3 protons, respectively.

Synthesis of mixed ligand metal complexes: 2-Acetylthiophene-4-phenyl-3-thiosemicarbazone ligand (ATPT, 1.2 g, 0.006 mol) was dissolved in 15 mL of 0.05 N NaOH in methanol solvent in 100 mL beaker. A ligand solution and $Cu(bpy)_2Cl_2$ solution (1 g, 0.003 mol) dissolved in methanol (15 mL) were transferred into 100 mL round bottom flask and heated under reflux for 1 h. On cooling the contents of flask, light green coloured complex was formed. It was collected by filtration, washed with small quantities of methanol and dried in air. The other metal(II) complexes *viz*. Ni(Bpy)(ATPT)Cl·H_2O and Co(Bpy)(ATPT)Cl·H_2O complexes were synthesized simi-larly (**Scheme-I**).

DNA binding studies: A stock solution of CT-DNA was prepared by dissolving in appropriate buffers and kept overnight at 4 ºC for complete dissolution. A solution of CT-DNA in 5 mM Tris-HCl/50 mM NaCl (pH 7.0) gave a ratio of UV absorbance at 260 and 280 nm (A_{260}/A_{270}) of 1.8-1.9, confirmed that the DNA is sufficiently free of protein. Concentrated stock solution of DNA was prepared in 5 mM Tris-HCl/50 mM NaCl in water at pH 7.0 and the concentration of CT-DNA was determined by UV absorbance at 260 nm after 1:100 dilutions. The molar absorption coefficient was taken as 6600 cm^{-1}. Doubly distilled water was used to prepare buffer solutions. Solutions were prepared with the appropriate metal complexes (20 µM of 1.0 mM solution in DMF), CT DNA (diluted from 1 mg/mL solution), NaCl (final concentration 50 mM) and Tris-HCl (pH 7.0, final concentration 50 mM) and diluted with H_2O to a total volume of 1 mL. Spectra were recorded against an analogous blank solution containing the same concentration of DNA/NaCl and Tris-HCl buffer. After addition of DNA to metal complex, the resulting solution was allowed to equilibrate for 5-10 min, at room temperature. The absorption readings (usually corresponding to the changes at maximum absorption) were noted. The data were then fitted to the following equation to obtain the intrinsic binding constant (K_b).



Scheme-I: Synthesis of ATPT ligand and its metal complexes

TABLE-1
PHYSICO-CHEMICAL AND ANALYTICAL DATA OF Cu(II), Ni(II) AND Co(II) COMPLEXES

Complex	ESI-MS	F.W.	Melting point (°C)	Colour	Yield (%)	Molar conductivity
$Cu(Bpy)Cl_2$	289.40	291.00	Above 300	Light green	71.56	31
$[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$	537.63	538.17	253-254	Dark brown	81.10	18
$Ni(Bpy)Cl_2$	281.30	285.00	Above 300	Parrot green	81.93	28
$[Ni(Bpy)(ATPT)Cl{\cdot}H_2O]$	542.70	543.32	266-267	Light brown	78.77	19
$Co(Bpy)Cl_2$	282.32	286.00	Above 300	Blue	72.77	46
$[Co(Bpy)(ATPT)Cl{\cdot}H_2O]$	535.90	534.77	278-279	Dark brown	81.45	16

$$\frac{[DNA]}{(\varepsilon_a - \varepsilon_f)} = \frac{[DNA]}{(\varepsilon_b - \varepsilon_f)} + \frac{1}{K_b(\varepsilon_b - \varepsilon_f)}$$

where [DNA] is the concentration of DNA in base pairs, ε_a, ε_b and ε_f are the apparent extinction coefficient ($A_{obs}/[M]$), the extinction coefficient for the metal (M) complex in the fully bound form and the extinction coefficient for free metal (M) respectively. A plot of $[DNA]/(\varepsilon_a - \varepsilon_f)$ *versus* [DNA] gave a slope of $1/(\varepsilon_b - \varepsilon_f)$ and Y is the intercept equal to $1/K_b(\varepsilon_b - \varepsilon_f)$; K_b is the ratio of the intercept.

The hypochromism degree generally correlates well with the overall binding strength. In some cases, the addition of DNA to the complex solution generated a hyperchromic shift. Therefore, change in absorbance on the addition of DNA indicates the binding of the complexes with DNA. Furthermore, cationic complexes may bind with the anionic phosphate part of DNA electrostatically, which can easily be monitored through UV-visible spectroscopy. Red-shift and hyperchromic effect observed in the 194-196 nm region may be assigned to the binding of the complex with phosphate regions of DNA through electrostatic interaction.

Antibacterial activity: Pathogenic bacterial strains were purchased from National Chemical Laboratory (Pune, India). The agar well diffusion method was used for screening compounds for their antibacterial activity against bacterial strains, namely Gram negative bacteria such as *Escherichia coli* and *Klebsiella pneumoniae* and Gram positive bacteria such as *Bacillus cereus* and *Staphylococcus aureus*. Nutrient agar plates were prepared by pouring sterile nutrient agar medium into sterile Petri-dishes and allowing them to solidify. Approximately 6 mm wells were made in each nutrient agar plate by using a sterile cork borer. Different concentrations of compounds (100, 200 and 300 µg/well) were used to assess the dose-dependent activity of the product. The metal complexes were dissolved in 10% DMSO and micropipettes were used for adding compounds into the wells. Simultaneously, standard antibiotics (ciprofloxacin used as a positive control) were tested against pathogenic bacterial strains. Then, the plates were incubated at 37 ºC for 36 h. After incubation, the inhibition zone of each well was measured and the values were noted. The experiments with each compound were conducted in triplicates and the average values were calculated for determining the antibacterial activity.

RESULTS AND DISCUSSION

Metal complexes with the composition $M(Bpy)Cl_2$ (where M = Cu(II), Ni(II), and Co(II) and Bpy = 2,2′-bipyridyl) were reacted with ATPT to yield heteroleptic transition metal complexes with the molecular formula $[M(Bpy)\ ATPT]Cl{\cdot}H_2O$. All the complexes were stable at room temperature, non-hygroscopic, insoluble in water and slightly soluble in methanol and ethanol, but readily soluble in DMF and DMSO. The physicochemical data of the complexes are summarized in Table-1.

Conductivity measurements: For 1:1 electrolyte the molar conductivity values were in the range 65-90 Ω^{-1} cm^2 mol^{-1} in DMF [26]. Molar conductivity data for the complexes are summarized in Table-1. The observed values ranged in the 16-31 Ω^{-1} cm^2 mol^{-1}indicate the non-electrolytic nature of the complexes.

Electronic spectra: The electronic spectra of the metal complexes were recorded in DMF. A significant electronic spectral data and assignments are presented in Table-2. Bands observed in the 36,101 - 31,645 cm^{-1} for the metal complexes are associated with $\pi \rightarrow \pi^*$ transition of aromatic chromophore [27]. Intense bands are observed in the range of 28,248-27,777 cm^{-1}. These peaks correspond to charge transfer transition [28]. Weak bands in 16,666-13,106 cm^{-1} region may be assigned to *d-d* transitions. The electronic spectrum of complex $[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$ is shown in Fig. 1.

TABLE-2
ELECTRONIC SPECTRAL DATA FOR
Cu(II), Ni(II) AND Co(II) COMPLEXES

Complex	Wavelength (nm)	Frequency (cm^{-1})	Assignment
$Cu(Bpy)Cl_2$	301	33,222	$\pi \rightarrow \pi^*$ transition
	312	32,015	CT transition
	763	13,106	*d-d* transition
$[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$	314	31,847	$\pi \rightarrow \pi^*$ transition
	360	27,777	CT transition
	600	16,666	*d-d* transition
$Ni(Bpy)Cl_2$	298	33,557	$\pi \rightarrow \pi^*$ transition
	305	32,786	CT transition
	615	16,260	*d-d* transition
$[Ni(Bpy)(ATPT)Cl{\cdot}H_2O]$	278	35,971	$\pi \rightarrow \pi^*$ transition
	305	32,786	CT transition
$Co(Bpy)Cl_2$	295	33,898	$\pi \rightarrow \pi^*$ transition
	518	19,305	*d-d* transition
	675	14,814	*d-d* transition
	990	10,101	*d-d* transition
$[Co(Bpy)(ATPT)Cl{\cdot}H_2O]$	277	36,101	$\pi \rightarrow \pi^*$ transition
	316	31,645	CT transition
	354	28,248	*d-d* transition

Infrared spectra: The IR spectral data of the ligand ATPT and its ternary metal complexes along with peak assignments are given in Table-3. A strong band was observed in the IR spectrum of ATPT at 1593 cm^{-1}, which is assigned to the ν(C=N) group. In all the metal complexes, this band was shifted to a

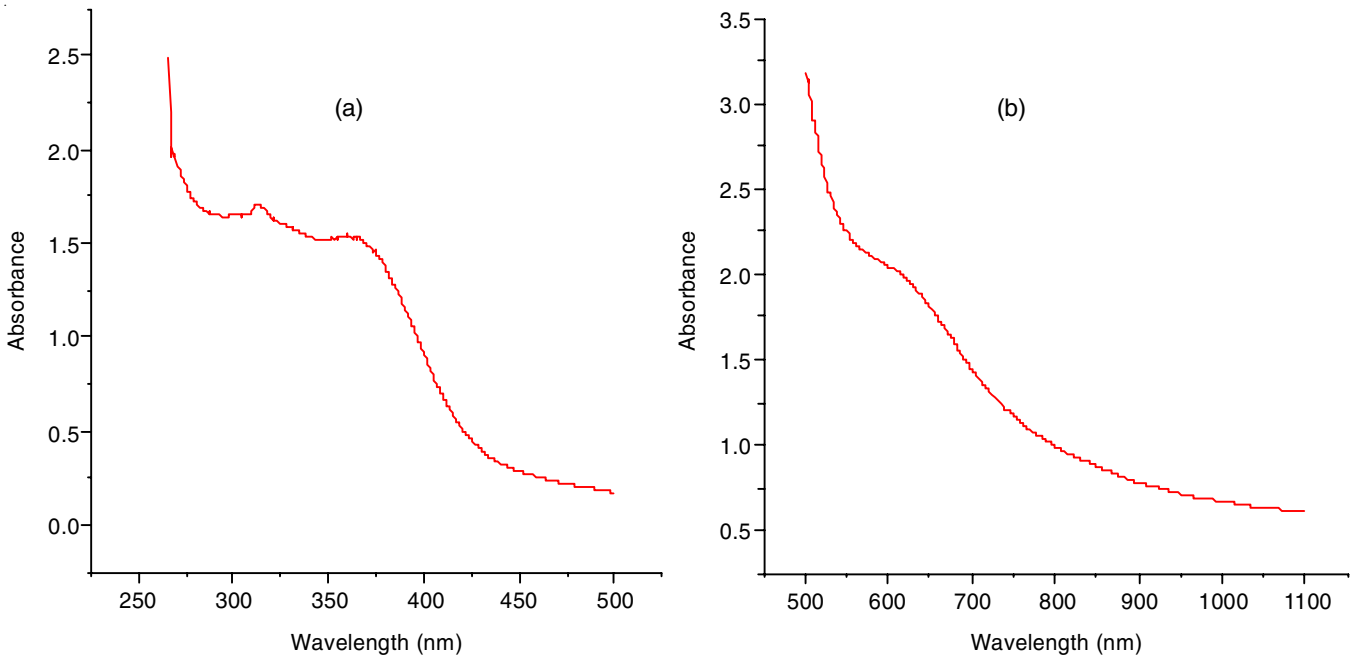


Fig. 1. Electronic spectrum of [Cu(Bpy)(ATPT)Cl·H_2O] complex, (a) Low concentration, (b) High concentration

lower frequency, indicating the participation of azomethine nitrogen atom in coordination [29,30]. A medium band appeared in the spectrum of the ATPT ligand at 1194 cm^{-1}, which was assigned to the ν(C=S) group. In all the metal complexes, this peak disappeared and a new band was formed in the 760-748 cm^{-1} region due to ν(C-S). These changes suggest the enolization of >C=S to >C-SH. In the enolic form, the ligand (ATPT) subsequently undergoes deprotonation and binds to the metal by forming a covalent bond between sulphur and the metal. In far IR region, new peaks were observed at 587-496 and 474-457 cm^{-1} regions, which were assigned to ν(M-N) and ν(M-S) vibrations [31,32], respectively.

ESR spectra: The ESR spectra of copper(II) complexes were recorded in the DMF solution at room temperature and at liquid nitrogen temperature. A typical ESR spectrum of [Cu(Bpy)(ATPT)Cl·H_2O] recorded at LNT is shown in Fig. 2. The spin Hamiltonian, orbital reduction and bonding parameters of metal complexes are given in Table-4. The $g_{\parallel}$ and $g_{\perp}$ values were computed from the spectra by using TCNE free radicals as the *g* marker. The observed $g_{\parallel}$ values of < 2.3 for complexes suggest a significant covalent character of the metal ligand bond in agreement with the observation of Kivelson & Neiman [33]. The $g_{\parallel}$ and $g_{\perp}$ values were > 2, corresponding to an axial symmetry. The trend of $g_{\parallel} > g_{\perp} > g_e$ (2.0023) observed for these complexes suggests that the unpaired electron is localized in the $d_{x^2-y^2}$ orbital [34] of copper ion. The axial symmetry parameter G is defined in a previous study [35].

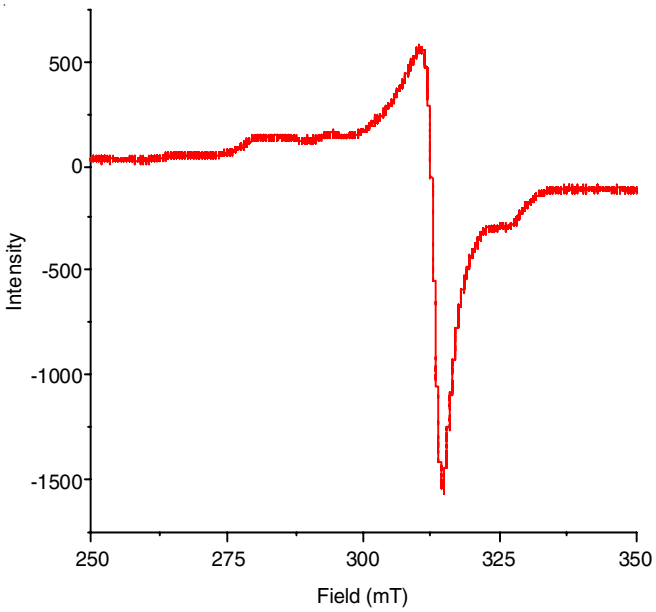


Fig. 2. ESR spectrum of [Cu(Bpy)(ATPT)Cl·H_2O] complex LNT

TABLE-3
IR THIOSEMICARBAZONE (ATPT) SPECTRAL BANDS (cm^{-1}) OF Cu(II), Ni(II) AND Co(II) COMPLEXES OF BIPYRIDINE AND 2-ACETYLTHIOPHENE

ATPT	[Cu(Bpy)(ATPT)Cl·H_2O]	[Ni(Bpy)(ATPT)Cl·H_2O]	[Co(Bpy)(ATPT)Cl·H_2O]	Assignment
1589	1553	1536	1565	ν(C=N) (azomethine)
	1497	1440	1480	ν(C–C) (thiophene)
	1309	1316	1309	
1194	845	869	850	ν(C=S) (thione)
	752	748	760	ν(C–S)
	632	626	624	
	496	587	571	ν(M–N)
	466	474	457	ν(M–S)

TABLE-4
ESR SPECTRAL DATA OF COPPER COMPLEXES

Parameter	$[Cu(Bpy)Cl_2]$		$[Cu(Bpy)(ATPT)Cl·H_2O]$	
	LNT	RT	LNT	RT
$G_{\|}$	2.28	2.14	2.10	2.09
$g_{\perp}$	2.05	2.08	2.04	2.03
g_{ave}	2.13	2.10	2.06	2.05
G	3.87	1.74	2.45	3.05
$A_{\|} \times 10^{-5}$	0.0016	–	0.00180	–
$A_{\perp} \times 10^{-5}$	–	–	0.00090	–
$K_{\|}$	0.995	–	0.979	–
$K_{\perp}$	1.027	–	0.775	–
λ	463	–	229	–
α	0.2997	–	0.1148	–

$$G = \frac{[g_{\|} - 2.0023]}{[g_{\perp} - 2.0023]}$$

The calculated G values for these complexes were < 4.0. Thus, small exchange coupling and misalignment of molecular axes are present. The $g_{\|}$, $g_{\perp}$ $A_{\|}$, and $A_{\perp}$ of complexes and the energies of *d–d* transitions were used to calculate the orbital reduction parameters ($K_{\|}$, $K_{\perp}$) and bonding parameter (α^2). The factor α^2, which is usually taken as a measure of covalence, is evaluated using the following expression:

$$\alpha^2 = -\frac{A_{\|}}{p} + (g_{\|} - 2.0023) + \frac{3}{7}(g_{\perp} - 2.0023) + 0.04$$

Hathaway pointed out that for pure σ bonding, $K_{\|} \approx K_{\perp} \approx 0.77$; for in-plane π-bonding, $K_{\|} < K_{\perp}$; and for out-of-plane π-bonding, $K_{\|} > K_{\perp}$. These simplified expressions were used to calculate $K_{\|}$ and $K_{\perp}$.

$$K_{\|}^2 = \frac{(g_{\|} - 2.0023)}{8 \times \lambda_o} \times d\text{–}d \text{ transition}$$

$$K_{\perp}^2 = \frac{(g_{\perp} - 2.0023)}{8 \times \lambda_o} \times d\text{–}d \text{ transition}$$

The observed $K_{\|} < K_{\perp}$ relation for $Cu(Bpy)Cl_2$ complex indicates the significant in plane π-bonding, and $K_{\|} > K_{\perp}$ relation for the $[Cu(Bpy)(ATPT)Cl·H_2O]$ complex indicates the significant out of plane π-bonding.

Cyclic voltammetry: The redox behaviour of complexes was investigated using cyclic voltammetry in DMF, with 0.1 M tetrabutylammonium hexafluorophosphate as the supporting electrolyte. The cyclic voltammogram of $[Co(Bpy)(ATPT)Cl·H_2O]$ complex is shown in Fig. 3 and the electrochemical data of complexes are summarized in Table-5.

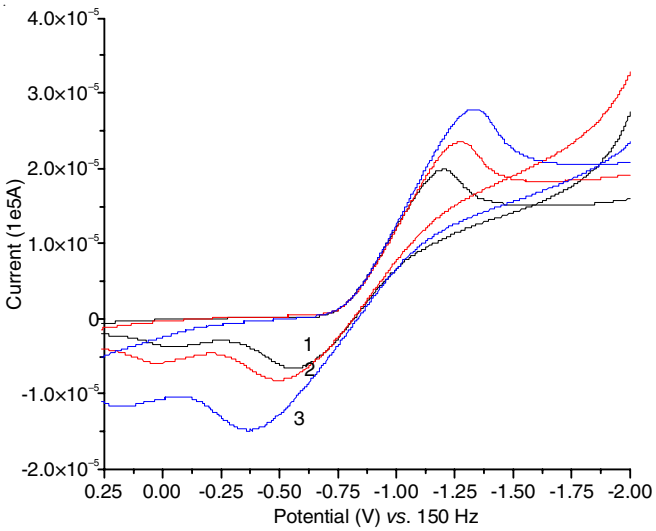


Fig. 3. Cyclic voltammogram of $[Co(Bpy)(ATPT)Cl·H_2O]$ at different scan rates (1) 0.05 (2) 0.1 (3) 0.2 mV s^{-1}

The cathodic peak current function values were independent of the scan rate. Repeated scans at various rates suggest the presence of a stable redox species in the solution. It is observed that cathodic (Ip_c) and anodic (Ip_a) peak currents are unequal. The $E_{1/2}$ values of copper(II) complexes are noted in the potential range of 0.267-0.353 V. It may be concluded that all the bivalent metal complexes undergo one electron reduction to their respective M(I) complexes. The non-equivalent current in cathodic and anodic peaks indicates quasi-reversible behaviour [36]. The difference, ΔEp, in all the metal complexes is better than the Nerstian requirement 59/n mV (n = number of electrons involved in oxidation reduction), which demonstrates the quasi-reversible character of electron transfer [37]. The complexes show a large gap between anodic and cathodic peaks, indicating its quasi-reversible character.

Based on analytical, physico-chemical and spectral data, a general structure is proposed for the metal complexes as shown in Fig. 4.

DNA binding studies: The binding of the complexes with DNA was monitored by comparing their absorption spectra with and without CT-DNA. Typical absorption spectra of the $[Cu(Bpy)(ATPT)Cl·H_2O]$ complex in the absence and presence of CT DNA are shown in Fig. 5. The molar absorptivity of complexes was found to decrease (hypochromism, Δε, +9.52 to +42.90%; Table-6) with each addition of CT-DNA of π-π* absorption band as well as a hypsochromic shift in the case of $Cu(Bpy)Cl_2$ complex and bathochromic shift for remaining complexes of a few nanometers (0.5-1.5 nm). The intrinsic binding constants (K_b) were determined using an equation.

TABLE-5
CV DATA OF Cu(II), Ni(II) AND Co(II) COMPLEXES

Complex	E_{pc}	E_{pa}	ΔEp (mV)	$E_{1/2}$	$-i_c/i_a$	log K_c[a]	$-\Delta G°$[b]
$Cu(Bpy)Cl_2$	-0.047	0.488	535	0.267	1.510	0.062	362
$[Cu(Bpy)(ATPT)Cl·H_2O]$	0.134	0.572	438	0.353	1.637	0.076	443
$Ni(Bpy)Cl_2$	-1.291	-0.743	548	-1.017	2.740	0.061	354
$[Ni(Bpy)(ATPT)Cl·H_2O]$	-1.077	-0.704	373	-0.890	2.318	0.090	519
$Co(Bpy)Cl_2$	-1.034	-0.726	308	-0.880	0.895	0.010	629
$[Co(Bpy)(ATPT)Cl·H_2O]$	-1.279	-0.513	766	-0.896	2.153	0.043	253

[a]log $K_c = 0.434ZF/RT\Delta E_p$; [b]$\Delta G° = -2.303$ RTlog K_c

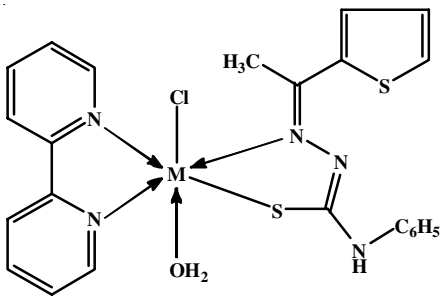


Fig. 4. Structure of [M(Bpy)(ATPT)Cl·H_2O] complex, [M = Cu(II), Ni(II) and Co(II)]

The intrinsic binding constants of bivalent metal complexes are given in Table-6.

$$\frac{[DNA]}{\varepsilon_a - \varepsilon_f} = \frac{[DNA]}{\varepsilon_a - \varepsilon_f} + \frac{1}{K_b}(\varepsilon_a - \varepsilon_f)$$

Hyperchromic and hypochromic effects are the special features of DNA related to its double helix structure. Hypochromism results from DNA contraction in the helix axis as well as from the change in DNA conformation, whereas hyperchromism emerges from the damage of double helix structure [38]. Hypochromism occurs due to intercalation involving strong stacking interactions between the aromatic chromophore of metal complexes and nitrogenous bases of DNA [38]. Conversely, hyperchromism may occur due to the dissociation of ligands accumulated and the breakage of intermolecular hydrogen bonds when the metal complex binds to DNA.

Hypochromism and bathochromic shift in the case of Ni(II) and Co(II) complexes suggest that these complexes bind to DNA through intercalation involving a strong π-stacking interaction between the aromatic chromophore and DNA base pairs.

Antibacterial activity: Metal(II) complexes were screened for their antibacterial activity by using the agar well diffusion method. The inhibition zone diameter was measured in millimetres and the values are summarized in Table-7. The antibacterial activities of the present metal complexes were comparable with those of the standard compound. The synthesized [Co(Bpy)(ATPT)Cl·H_2O] complex inhibits *Klebsiella pneumoniae* bacteria more strongly than any other metal complex. The mixed

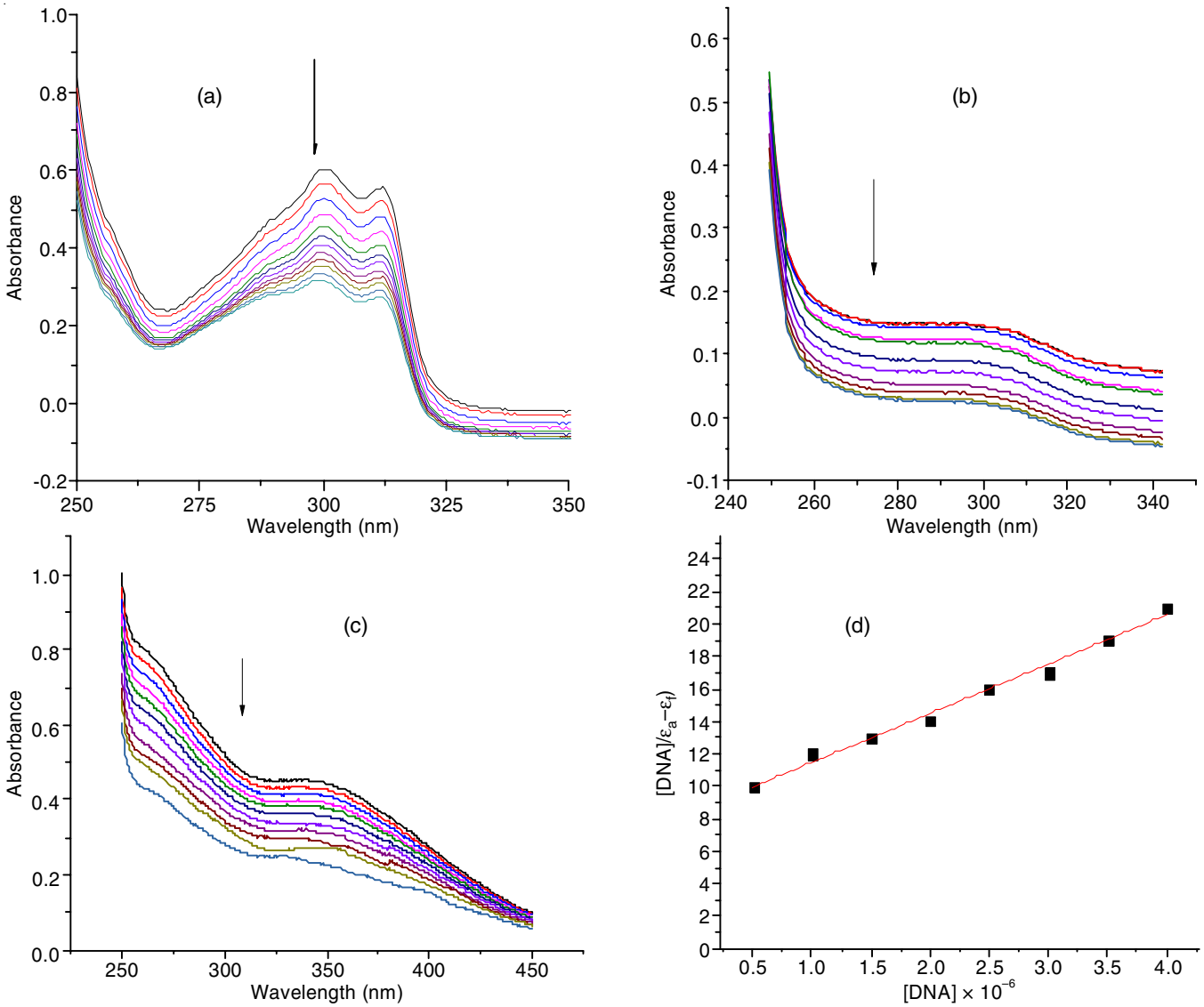


Fig. 5. Absorption spectra of (a) [Cu(Bpy)(ATPT)Cl·H_2O], (b) [Ni(Bpy)(ATPT)Cl·H_2O], (c) [Co(Bpy)(ATPT)Cl·H_2O]. In the absence and in the presence of increasing concentration of CT-DNA; [The top most spectrum is recorded in the absence of CT-DNA and below spectra on addition 20 µL DNA each time], (d) A plot [DNA]/(ε_a-ε_f) *vs.* [DNA] × 10^{-6} is shown

TABLE-6
ELECTRONIC ABSORPTION DATA UPON ADDITION OF CT-DNA TO THE COMPLEX

Complex	λ_{max} (nm)		Δλ	H%	K_b [M^{-1}]
	Free	Bound			
$Cu(Bpy)Cl_2$	300.5	300.0	0.5	38.80	3.50×10^5
$[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$	349.0	350.5	1.5	42.90	5.23×10^5
$Ni(Bpy)Cl_2$	306.0	306.5	0.5	36.60	3.56×10^5
$[Ni(Bpy)(ATPT)Cl{\cdot}H_2O]$	300.0	301.5	1.5	19.72	3.70×10^5
$Co(Bpy)Cl_2$	295.0	296.5	1.5	17.77	3.12×10^5
$[Co(Bpy)(ATPT)Cl{\cdot}H_2O]$	303.0	304.0	1.0	9.52	4.20×10^5

TABLE-7
ANTIBACTERIAL ACTIVITY OF DIFFERENT METAL COMPLEXES AGAINST PATHOGENIC BACTERIAL STRAINS

Sample	Treatment (concen.) (μg/μL)	*E. coli* (Mean ± SE)	*K. pneumoniae* (Mean ± SE)	*S. aureus* (Mean ± SE)	*B. cereus* (Mean ± SE)
S-Ciprofloxacin	5	10.5 ± 0.02	8.98 ± 0.09	10.03 ± 0.03	12.16 ± 0.05
$Cu(Bpy)Cl_2$	100	3.98 ± 0.14	4.17 ± 0.17	3.87 ± 0.18	3.14 ± 0.25
	200	4.37 ± 0.47	3.47 ± 0.47	4.8 ± 0.32	5.45 ± 0.75
	300	5.12 ± 0.8	4.93 ± 0.3	6.97 ± 0.06	6.87 ± 0.36
$[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$	100	3.5 ± 0.36	5.3 ± 0.05	5.6 ± 0.01	5.6 ± 0.24
	200	4.6 ± 0.58	4.6 ± 0.65	5.9 ± 0.05	6.9 ± 0.68
	300	5.3 ± 0.37	5.1 ± 0.67	5.2 ± 0.4	7.1 ± 0.34
$Ni(Bpy)Cl_2$	100	2.4 ± 0.11	2.4 ± 0.17	1.5 ± 0.28	2.87 ± 0.16
	200	2.67 ± 0.09	3.67 ± 0.17	2.34 ± 0.15	1.93 ± 0.26
	300	1.98 ± 0.06	5.33 ± 0.17	3.5 ± 0.63	1.4 ± 0.32
$[Ni(Bpy)(ATPT)Cl{\cdot}H_2O]$	100	2.5 ± 0.52	3.5 ± 0.14	2.6 ± 0.06	3.1 ± 0.01
	200	2.1 ± 0.47	4.6 ± 0.01	2.9 ± 0.08	3.6 ± 0.45
	300	2.6 ± 0.68	6.3 ± 0.09	3.5 ± 0.98	3.9 ± 0.78
$Co(Bpy)Cl_2$	100	1.3 ± 0.15	1.2 ± 0.18	1.53 ± 0.3	1.83 ± 0.01
	200	2.83 ± 0.17	1.93 ± 0.13	1.87 ± 0.87	2.01 ± 0.34
	300	1.5 ± 0.29	2.01 ± 0.15	1.69 ± 0.23	1.57 ± 0.36
$[Co(Bpy)(ATPT)Cl{\cdot}H_2O]$	100	4.5 ± 0.14	3.6 ± 0.03	3.6 ± 0.25	2.1 ± 0.23
	200	4.8 ± 0.80	5.9 ± 0.07	3.9 ± 0.36	2.6 ± 0.65
	300	5.3 ± 0.65	6.5 ± 0.65	4.5 ± 0.65	2.5 ± 0.32

Values are the mean ± SE of inhibition zone in mm.

ligand complexes show a higher activity than the respective parent complexes possibly due to the synergistic interactions of two organic ligands with bacteria.

Conclusion

Mixed ligand transition metal complexes with 2,2′-bipyridyl (Bpy) and 2-acetylthiophene-4-phenyl-3-thiosemicarbazone (ATPT) were synthesized and characterized based on molar conductivity, mass, infrared and electronic spectra. The electrochemical properties of these complexes were investigated by using cyclic voltammetry. The M(II)–M(I) couple in complexes show the quasi-reversible cyclic voltammetric responses. The binding properties of these complexes with CT-DNA were investigated through absorption spectrophotometry. Heteroleptic metal complexes show a high binding affinity towards DNA. It is pertinent to note that the complex, $[Cu(Bpy)(ATPT)Cl{\cdot}H_2O]$, which binds to DNA strongly (K_b value) shows a higher antibacterial activity. Metal complexes were screened for their antibacterial activities against pathogenic bacterial strains by using the agar well diffusion method, which were comparable with ciprofloxacin activity.

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