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Synthesis, spectroscopic thermal and biological activity studies on azo-containing Schiff base dye and its Cobalt(II), Chromium(III) and Strontium(II) complexes

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ABSTRACT

Schiff base ligand is prepared by condensation of *o*-amino benzoic acid with 5-phenyl azo-salicyladehyde. The characterization of the ligand is based on elemental analysis, mass spectra and IR spectra. The novel Co(II), Cr(III) and Sr(II) metal complexes are reported and characterized by physico-chemical, spectroscopic methods based on elemental analyses, IR, magnetic moment, and thermal analysis (TGA). The molar conductance data reveals that all the complexes are non-electrolytes. The activation thermodynamic parameters, such as ΔE^* , ΔH^* , ΔS^* and ΔG^* are calculated from the DTA curves using Coats–Redfern method. Optical absorption measurements show that the fundamental absorption edge obeys Tauc's relation for the allowed non-direct transition. Optical band gap (E_g) values equal 2.4, 2.38 and 1.5 eV for Co(II), Cr(III) and Sr(II) metal complexes respectively. The synthesized ligand and its metal complexes were screened for their biological activity against bacterial species, two Gram positive bacteria (*Bacillus subtillis* and *Staphylococcus aureus*) and two Gram negative bacteria (*Escherichia coli* and *Pseudomonas aereuguinosa*).

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1. Introduction

Salen type ligands, one of the oldest classes of ligands in coordination chemistry, have been used extensively to complex transition and main group metals [1]. Schiff base complexes containing different metal ions such as Ni and Cu have been studied in great details for their various crystallographic features, structure-redox relationships and enzymatic reactions, mesogenic characteristics and catalysis properties [2-6]. Transition metal complexes of Schiff bases are of paramount scientific interest, due to their multiple uses as biomimetic systems of enzymes involved in the transport, storage and activation of dioxygen [7–11]. CuN₂O₂ coordination is very common in copper chemistry and the redox behavior of a wide series of mononuclear copper(II) Schiff base complexes was reviewed some years ago in relation to their structural changes [12]. Mn complex of Schiff bases have been used as metal cofactors for the elaboration of artificial metalloenzymes used as new biocatalysts for selective oxidation reactions [13,14].

On the other hand, Azo compounds are important due to their applications in dyes, pigments and functional materials. For example, azo-containing photochromic organic compounds especially with liquid crystalline character and azo-conjugated metal complexes have been attracting much attention recently because of their possible applications in the area of photon-mode high density

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information storage, photo-switching devices and optical computing [15–18]. Azo groups are relatively robust and chemically stable, and therefore they prompted extensive studies of azobenzenebased structures as dyes and colorants. Furthermore, the light-induced interconversion allows systems incorporating azo group to be used as photo switches, effecting rapid and reversible control over a variety of chemical, mechanical, electronic and optical properties. Because of the good thermal stability of azo compounds, one of the most important applications of azo compounds is in the optical data storage [15,19]. In this work new efficient route for the synthesis of Schiff base ligand and its metal complexes has been studied. The thermal decomposition of its complexes is also used to infer the structure and the different thermodynamic activation parameters are calculated. The biological activity of this ligand and its metal complexes are evaluated. Optical absorption measurements have been made on Co(II), Cr(III) and Sr(II) metal complexes. Optical absorption measurements are used to obtain the band structure and the energy gap of a material, because the analvsis of the optical absorption spectra is one of the most productive tools for understanding and developing the energy band diagram of both crystalline and amorphous materials.

2. Experimental

All the used chemicals are of the analytical reagent grade (AR), and of highest purity available. CoCl₂·4H₂O, CrCl₃·6H₂O, SrCl₂·6H₂O



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and other chemicals were purchased from Fluka and Merck companies.

2.1. Synthesis of ligand and its metal complexes

2.1.1. Synthesis of the Schiff base ligand

The Schiff base ligand was synthesized according to the known condensation method [20]. The methanol solution (50 ml) of *o*-amino benzoic acid (6.85 g, 50 mmol) was mixed with a solution of 5-phenyl azo-salicyladehyde (11.3 g, 50 mmol). The mixture was refluxed and stirred magnetically for 2 h at 80 °C on a hot plate. After cooling, the solution of the Schiff base was filtered, and the solid was washed several times with methanol. All organic impurities were then extracted by washing with small portions of diethyl ether. The ligand was dried under vacuum, and was recrystallized several times from ethyl alcohol. The purity of ligand was evaluated by thin layer chromatography. Elemental analysis CHN, IR, UV–vis, and mass spectra [20] confirm the composition of the ligand.

2.1.2. Synthesis of metal complexes

All complexes were synthesized by adding of the appropriate metal salts (1.0 mmol, in 20 ml ethyl alcohol–water (1:1) to a hot solution of the ligand (1.0 mmol, in 30 ml ethyl alcohol (95%)) and few drops of triethylamine. The resulting solutions were stirred and heated on a hot plate at 70 °C for 30 min. The volume of the obtained solution was reduced to one-half by evaporation. One day later, the colored solid of the complexes formed was filtered, the solids washed with ethanol and diethyl ether, and finally dried under vacuum. The synthesized complexes were re-crystallized from ethanol–water (1:1). The purity of all complexes was evaluated by thin layer chromatography. All complexes were prepared by the same method and isolated as powdered material. Elemental analysis (C, H and N), IR, UV–vis, and thermogravimetric analyses confirm the composition of the complexes.

2.2. Analysis

Elemental analyses (C, H and N) were performed using a Perkin-Elmer CHN 2400 elemental analyzer. The content of metal ions was calculated gravimetrically as metal oxides. Molar conductance measurements of the ligand and its complexes with 1.0×10^{-3} mol/l in DMSO were carried out using Jenway 4010 conductivity meter. Magnetic measurements were carried out on a Sherwood Scientific magnetic balance using Gouy method. Electron impact mass spectra were recorded on a Jeol, JMS, DX-303 mass spectrometer. The UV/ vis spectra were obtained in DMF solution $(1.0 \times 10^{-3} \text{ M})$ for the ligand and its metal complexes with a Jenway 6405 spectrophotometer using 1 cm quartz cell, in the range 200-600 nm. IR spectra (4000–400 cm⁻¹) were recorded as KBr pellets on Bruker FT-IR spectrophotometer. A double beam (Jasco V-630) spectrophotometer was used to measure the absorption spectra for Co(II), Cr(III) and Sr(II) metal complexes (using DMF at 25 °C) in the spectral range of wavelength from 400 to 2500 nm. Thermogravimetric analyses (TG/ DTG) were carried out in the temperature range from 25 to 800 °C in a steam of nitrogen atmosphere using Shimadzu TGA 50H thermal analysis. The experimental conditions were: platinum crucible, nitrogen atmosphere with a 30 ml/min flow rate and a heating rate 10 °C/min.

2.3. Microbiological investigations

For these investigations the filter paper disc method was applied according to Gupta et al. [21]. The investigated isolates of bacteria were seeded in tubes with nutrient broth (NB). The seeded NB (1 cm³) was homogenized in the tubes with 9 cm³ of melted

(45 °C) nutrient agar (NA). The homogeneous suspensions were poured into Petri dishes. The discs of filter paper (diameter 4 mm) were ranged on the cool medium. After cooling on the formed solid medium, 2×10^{-5} dm³ of the investigated compounds were applied using a micropipette. After incubation for 24 h in a thermostat at 25–27 °C, the inhibition (sterile) zone diameters (including disc) were measured and expressed in mm. An inhibition zone diameter over 7 mm indicates that the tested compound is active against the bacteria under investigation. The antibacterial activities of the investigated compounds were tested against *Escherichia coli and Pseudomonas aeruginosa* as Gram negative, *Bacillus subtilis* and *Staphylococcus aureus* as Gram positive. The concentration of each solution was 1.0×10^{-3} mol dm³. Commercial DMSO was employed to dissolve the tested samples.

3. Results and discussions

Tridentate complexes were obtained upon reaction between metal ions and (H_2L) ligand at 1:1 M ratio. The synthesized Schiff base ligand and its complexes are very stable at room temperature in the solid state. The ligand is insoluble in common organic solvents on cold. The ligand and its metal complexes are generally soluble in hot DMF and DMSO. The yields, melting/decomposition points, elemental analyses, magnetic measurements, and molar conductance of H_2L and its metal complexes are presented in Table 1. The analytical data are in a good agreement with the proposed stoichiometry of the complexes.

The metal-to-ligand ratio in the Co(II), Cr(III) and Sr(II) complexes was found to be 1:1. The ligand decomposed at temperatures higher than 250 °C, while all complexes decomposed at temperatures higher than 300 °C. The ligand and their metal complexes have dye character due to the high molar extinction constant. Elemental analyses are in good agreement with the proposed formula.

3.1. Molar conductivity of metal chelates

The metal complexes discussed herein were dissolved in DMF and the molar conductivities of their 10^{-3} M solutions at room temperature were measured to establish the charge of the metal complexes. The range of conductance values listed in Table 1 indicates that all the metal complexes have non-electrolyte nature [22].

These results are confirmed by the chemical analysis (elemental analysis data) because Cl⁻ ions are not precipitated by addition of AgNO₃ solution. This test matches well CHN data. All complexes did not have electrolytic properties. This fact elucidated that the Cl⁻ ions are absent. Also the molar conductance values indicate that the anions may be absent or exhibits inside the coordination sphere as in [Cr(L)·(2H₂O)Cl]·H₂O complex, the chloride ion was detected inside the coordination sphere of the complex by the degradation of the complex using nitric acid and titrated against AgNO₃.

3.2. UV-vis spectra and magnetic moments

The UV–vis spectra of the ligand and its metal complexes are recorded in DMF solution in the wavelength range 200–800 nm. The electronic spectrum of the Co(II) complex, exhibits an intense band at 684 nm assignable to the ${}^{4}A_{2} \rightarrow {}^{4}T_{1}(P)$ transition, indicating tetrahedral geometry for this complex. Also the magnetic moment of 4.25 BM is a further indication for the tetrahedral geometry.

The electronic spectrum of the dark brown Cr(III) complex exhibits weak broad bands at 398 and 576 nm, which have been assigned to ${}^{4}T_{1g}(F) \leftarrow {}^{4}A_{2g}(F)$ and ${}^{4}T_{2g}(F) \leftarrow {}^{4}A_{2g}(F)$ transitions,

Table 1		
Elemental analyses and	physical data of H_2L ligand and its Co(II), Cr(II) and Sr(II) complexes.	
Compound	Calc./(found) (%)	

Compound	Calc./(found)	Calc./(found) (%)					$\Lambda (m \Omega^{-1} mol^{-1} cm^2)$
	M. wt	С	Н	Ν	Μ		
H ₂ L C ₂₀ H ₁₄ N ₃ O ₃	344.34	69.76 (69.44)	4.10 (4.34)	12.20 (12.54)	-	-	-
$[Co(L) \cdot H_2O] \cdot 2H_2O$ $C_{20}H_{18}N_3O_6$ Co	455.31	52.76 (52.41)	3.98 (4.11)	9.23 (9.52)	12.94 (13.25)	4.25	16
$[Cr(L) \cdot (2H_2O)Cl] \cdot H_2O$ $C_{20}H_{20}N_3O_7CrCl$	501.84	47.87 (47.68)	4.02 (4.21)	8.37 (8.12)	10.36 (10.64)	3.89	23
$[Sr(L)(H_2O)]\cdot 2H_2O$ $C_{20}H_{18}N_3O_6\cdot Sr$	483.99	49.63 (49.15)	3.75 (3.38)	8.68 (8.82)	18.10 (19.0)	-	16

respectively, with charge transfer bands. The magnetic behavior of octahedral Cr(III) is independent of the field strength of the ligand. The Cr(III) complex has the value of 3.89 BM. Thus, the ligand field bands and magnetic moment value support an octahedral geometry around the metal ion in Cr(III) complex.

3.3. IR spectra and mode of bonding

The IR spectral bands of the ligand and its complexes are listed in Table 2. The assignments for most of the major peaks are shown in Fig. 1. The functional groups of the Schiff base ligand and the metal complexes have been detected by infrared spectra.

A comparison of the infrared spectra of the ligand and the respective complexes reveals the absence of absorption bands associated with the stretching OH of the phenolic group, indicating the loss of phenolic proton on complexation, forming metal–oxygen bond. This was further supported by the decrease in (C–O) frequency by *ca.* ~30 m⁻¹ [23]. On the other hand the absorption bands associated with the stretching OH of the carboxylic group disappear in IR spectra of complexes, indicating the loss of proton of carboxylic group, forming metal–oxygen bonds. When the carboxylic acid group in the ligand is converted to carboxylate, the bands assigned to asymmetric vibrations $v_{\rm as}(\rm OCO)$ at 1539–1556 cm⁻¹ and the bands of symmetric vibrations $v_{\rm s}(\rm OCO)$ at 1387–1404 cm⁻¹ appear.

The band at $\sim 1620 \text{ cm}^{-1}$ was assigned to the stretching vibration of the (C=N) group of the ligand H₂L. This band is shifted in the complexes toward lower wave numbers by *ca*. $\sim 20 \text{ cm}^{-1}$ because of the coordination of the nitrogen atom to the metal ion. This fact can be explained by the withdrawing of electrons from nitrogen atom to the metal ion due to coordination process.

The infrared spectra of the complexes exhibited broad band at $3423-3437 \text{ cm}^{-1}$ that are attributed to OH of the crystal water molecules, while the IR bands of $v(H_2O)$ of coordinated water appeared at $834-842 \text{ cm}^{-1}$, indicating the binding of water molecules to the metal ions. In the far IR spectra of all the complexes, the non-ligand bands observed at 518-530, $427-437 \text{ cm}^{-1}$ regions can be assigned to v(M-O), v(M-N), respectively [24]. Therefore, the IR spectra reveal that H₂L coordinated to the metal ions via phenolic oxygen, carboxylic oxygen and azomethine nitrogen atom as tridentate.

3.4. Thermal analyses (TG and DTG)

The thermal analysis was realized using a Shimadzu TGA 50H instrument using 6.235, 2.887, 3.460 and 11.672 mg samples for



Fig. 1. IR spectra of the H₂L ligand and its metal complexes.

Table 2

Infrared spectral data of H_2L ligand and its Co(II), Cr(II) and Sr(II) complexes (cm⁻¹).

Compounds	v(OH) hydrated	v(OH) coord.	v(C==N)	v(OH)	v(OH)	v(C—O) phenolic	v(N=N)	v _{as} (OCO) COO ⁻	v _s (OCO) COO ⁻
	(br)	(m)	(s)	carboxylic	phenolic	(m)	(m)	(m)	(m)
$\begin{array}{l} H_2L\\ [Co(L)\cdot H_2O]\cdot 2H_2O\\ [Cr(L)\cdot (2H_2O)CI]\cdot H_2O\\ [Sr(L)\cdot H_2O]\cdot 2H_2O\end{array}$	- 3424 3435 3437	- 834 841 842	1620 1601 1598 1603	3422 - - -	3354 (br) - -	1279 1251 1255 1254	1604 1596 1597 1590	- 1544 1556 1539	- 1397 1404 1387

br = Broad; s = strong; w = week; m = medium.

H₂L, [Co(L)·H₂O]·2H₂O, [Cr(L)·3H₂O]·H₂O, [Sr(L)·H₂O]·2H₂O complexes, respectively. The heating rate within the temperature range from 25 °C to 800 °C is 10 °C/min. The TG and DTG curves are rep-

Table 3

resented in Fig. 2. The weight losses for each chelate were calculated for the corresponding temperature ranges and are shown in Table 3. The metal percentages calculated from the metal oxide



Fig. 2. TGA diagrams of H₂L ligand and its metal complexes.

Complexes	Temperature range (°C)	DTG peak (°C)	TG weight loss% calc./found	Assignments
H ₂ L	25-390	300	39.20(39.61)	C7H4O2N
	390-600	500	60.80(60.39)	$C_{13}H_{10}ON_2$
$[Co(L) \cdot H_2O] \cdot 2H_2O$	25-140	75	7.90(7.51)	2H ₂ O
	140-600	505	3.95(4.12)	H ₂ O
	600-		56.75(56.50)	Organic moiety
			31.40(31.87)	$1/2Co_2O_3 + 5C$
$[Cr(L)\cdot(2H_2O)Cl]\cdot H_2O$	25-140	80	3.58(3.27)	H ₂ O
	140-350	180	14.24(14.63)	$2H_2O + Cl$
	350-600	525	55.09(54.01)	Organic moiety
	600-		27.09(28.00)	$1/2Cr_2O_3 + 5C$
$[Sr(L) \cdot H_2O] \cdot 2H_2O$	25-140	80	3.71(3.57)	2H ₂ O
	140-220	150	7.43(7.49)	H ₂ O
	220-600	430	67.46(67.11)	Organic moiety
	600-		21.40(21.83)	SrO



Scheme 1. The proposed structures of metal complexes.

residues were compared with those determined by the analytical metal content determination [25]. The hydrated water molecules are associated with the complex formation and found outside the coordination sphere formed around the central metal ion. The dehydration of this type of water takes place in the temperature range 25–150 °C, the weight loss corresponds to one or two water molecules. On the other hand, the coordinated water molecules are eliminated at higher temperatures than the water molecules of hydration. The water of coordination is usually eliminated [30] in the temperature range 120-250 °C. The organic part of the complexes may decompose in one or more steps with the possibility of the formation of one or two intermediates. These intermediates may include the metal ion with a part of the Schiff base complexes. These intermediates may finally decompose to stable metal oxides. The decomposition of all complexes ended with the stoichiometric oxide formation and carbon residue. The metal content percentages of the complexes are thus calculated and compared with those obtained from the metal content analytical determination [26]. The average metal percentages were found to be in good agreement with those calculated from the tentative formulae based on the elemental analyses. The initial decomposition and

inflection temperatures have been used as an indication on the thermal stability of complexes [27].

The proposed structures of the synthesized complexes which are presented in Scheme 1 are consistent with each other in term of chemical, spectroscopic data and thermal analysis.

3.5. Kinetic studies

Coats–Redfern [28] is the method mentioned in the literature related to decomposition kinetics studies; this method is applied in this study. From the TG curves, the activation energy, *E*, pre-exponential factor, *A*, entropies, ΔS , enthalpy, ΔH , and Gibbs free energy, ΔG , were calculated by Coats–Redfern method; where

$$\Delta H = E - RT$$
 and $\Delta G = \Delta H - T\Delta S$

The linearization curves of Coats–Redfern method is shown in Fig. 3. Kinetic parameters are calculated by employing the Coats–Redfern equations, are summarized in Table 4. The Coats–Redfern equation [28] may be written in the form:

$$\log\left[\frac{(w_f/(w_f - w))}{T^2}\right] = \log\left[\frac{AR}{\theta Ea}\left(1 - \frac{2RT}{Ea}\right)\right] - \frac{Ea}{2.303RT}$$
(1)



Fig. 3. Coats-Redfern (CR) of third step of the H₂L ligand and its metal complexes.

Table 4

Thermodynamic data of the thermal decomposition of H₂L ligand and its Co(II), Cr(II) and Sr(II) complexes.

	Complex	Parameter						
		E (J mol ⁻¹)	A (s ⁻¹)	ΔS (J mol ⁻¹ K ⁻¹)	ΔH (J mol ⁻¹)	$\Delta G (J \text{ mol}^{-1})$		
-	H ₂ L [Co(L)·H ₂ O]·2H ₂ O [Cr(L)·(2H ₂ O)CI]·H ₂ O [Sr(L)·H ₂ O]·2H ₂ O	120 92.8 372 179	$\begin{array}{c} 1.60 \times 10^{6} \\ 43.3 \\ 1.14 \times 10^{28} \\ 2.34 \times 10^{6} \end{array}$	-131 -220 287 -131	$\begin{array}{c} -4.25\times 10^{3}\\ -5.06\times 10^{3}\\ -4.56\times 10^{3}\\ -6.25\times 10^{3} \end{array}$	$\begin{array}{c} 6.45\times 10^4 \\ 1.31\times 10^5 \\ -1.75\times 10^5 \\ 9.47\times 10^4 \end{array}$	0.99401 0.99407 0.99650 0.99681	

where W_f is the mass loss at the completion of the reaction, W the mass loss up to temperature $T(W_r = W_f - W)$, R the gas constant, Ea the activation energy in J mol⁻¹ and θ is the heating rate. Since 1–2 $RT/Ea \sim = 1$, a plot of the left-hand side of the above equation against 1/T was constructed (Fig. 3) and E^* was calculated from the slope and A (Arrhenius constant) was found from the intercept. The activation entropy S^* , the activation enthalpy H^* and the free energy of activation G^* were calculated using the following equations:

$$S^* = 2.303 \left(\log \frac{Ah}{KT} \right) R, \quad H^* = E^* - RT, \quad G^* = H^* - T_S S^*$$
 (2)

where *K* and *h* are the Boltzman's and Plank's constants, respectively. The calculated values of ΔE^* , ΔS^* , ΔH^* and ΔG^* for the dehydration and the decomposition steps are given in Table 4. The activation energies of the decomposition were found to be in the range 134–208 J mol⁻¹.

According to the kinetic data obtained from DTG curves, the negative values of activation entropies ΔS^* indicate a more ordered activated complex than the reactants and/or the reactions are slow [29].

3.6. Optical band gap

The absorption spectra for Co(II), Cr(III) and Sr(II) complexes, recorded using DMF at 25 $^{\circ}$ C, are shown in Fig. 4. The absorption



Fig. 4. The optical absorption spectra of the H₂L ligand and its metal complexes.



Fig. 5. The dependence of $(\alpha hv)^{1/2}$ on photon energy (hv) of the H₂L ligand and its metal complexes from which the optical band gap (E_g) is estimated (Tauc extrapolation).

Table 5

0

Antibacterial activity data of H_2L ligand and its Co(II), Cr(II) and Sr(II) complexes inhibition zone (mm).

Compound	Bacillus	Staphylococcus	Escherichia	Pseudomonas
	subtilis G⁺	aureus G⁺	coli G [–]	aeruginosa G ⁻
$\begin{array}{l} H_2L \\ [Co(L) \cdot H_2O] \cdot 2H_2O \\ [Cr(L) \cdot (2H_2O)Cl] \cdot H_2O \\ [Sr(L) \cdot H_2O] \cdot 2H_2O \end{array}$	20	17	19	16
	22	20	22	18
	24	22	24	22
	20	20	16	21

Key to interpretation: less than 10 mm = inactive, 10–15 mm = weakly active, 15–20 mm = moderately active; more than 20 mm = highly active.

coefficient (α) can be calculated from the optical absorption spectra using the relation:

$$t = 1/d\ln A \tag{3}$$

where d is the width of the cell. According to Tauc's relation [30,31] for allowed non-direct transitions, the photon energy dependence of the absorption coefficient can be described by:

$$(\alpha h v)^{1/2} = B(h v - E_g) \tag{4}$$

where *B* is a parameter that depends on the transition probability and *E*_g is the optical energy gap. Fig. 5 shows the absorption coefficient in the form of $(\alpha hv)^{1/2}$ versus hv for the Co(II), Cr(III) and Sr(II) complexes. The intercepts of the straight lines with the photon energy axis yield values of the optical band gap.

From Fig. 5, it is clear that the values of E_g equal 2.4, 2.38 and 1.5 eV for Co(II), Cr(III) and Sr(II) metal complexes respectively. There is no trend between the atomic numbers of the central atoms and E_g values. However, it is clear that E_g depends on the stereo-chemistry of the complexes. The band gap values reveal that these complexes are semi-conductors. Also, the values of E_g are in the range reported for the high efficient photovoltaic materials. So, the present compounds could be considered potential materials for harvesting solar radiation in solar cell applications [32].

3.7. Microbiological investigation

The biological activity of H_2L ligand and its metal complexes were tested against bacteria; we used more than one test organism to increase the chance of detecting antibiotic principles in tested materials. The organisms used in the present investigations included two Gram positive bacteria (*Bacillus subtillis* and *Staphylococcus aureus*) and two Gram negative bacteria (*Escherichia coli* and *Pseudomonas aereuguinosa*). The results of the bactericidal screening of the synthesized compounds are recorded in Table 5. An influence of the central ion of the complexes in the antibacterial activity against the tested Gram positive and Gram negative organisms show that the complexes have an enhanced activity compared to the ligand itself.

4. Conclusion

The coordination ability of 5-phenyl azo-salicyladehyde has been proved in complexation reaction with Co(II), Cr(III) and Sr(II) ions. The elemental analysis and (TGA) confirmed the compositions of the compounds. IR, UV–vis spectra and magnetic measurements of the ligand and its metal complexes confirmed the suggested coordination of the ligand through phenolic oxygen, oxygen of OH carboxylic group and nitrogen of the azomethine group as tridentate. Under experimental conditions employed, only 1:1 (M:L) complexes have been found. Allowed non-direct electronic transitions are mainly responsible for the photon absorption in the investigated complexes.

References

- [1] E.J. Cambel, S.T. Nguyen, Tetrahedron Lett. 42 (2001) 1221.
- [2] A.J. Stemmler, C.T. Burrows, J. Am. Chem. Soc. 121 (1999) 6956.
- [3] I.C. Santos, M. Vilas-Boas, M.F.M. Piedade, C. Freire, M.T. Durate, B. Castro, Polyhedron 19 (2000) 655.
- [4] I. Aiello, M. Ghedini, F. Neve, D. Pucci, Chem. Mater. 9 (1997) 2107.
- [5] R. Klement, F. Stock, H. Elias, H. Paulus, M. Valko, M. Mazur, Polyhedron 18 (1999) 3617.
- [6] R.I. Kureshy, N.H. Khan, S.H.R. Abdi, S.I. Patel, P. Iyer, E. Suresh, P. Dastidar, J. Mol. Catal. A: Chem. 160 (2000) 217.
- [7] A. Pui, J. Pierre Mahy, Polyhedron 26 (2007) 3143–3152.
 [8] T. Ueno, N. Yokoi, M. Unno, T. Matsui, Y. Tokita, M. Yamada, M. Ikeda-Saiti, H. Nakajima, Y. Watanabe, PNAS 103 (2006) 9416.
- [9] K.P. Bryliakov, E.P. Talsi, Angew. Chem. Int. Ed. 43 (2004) 5282.
- [10] L. Dyers Jr., S.Y. Que, D. Van Derveer, X.R. Bu, Inorg. Chim. Acta 359 (2006) 197.
- [11] P.A. Vigato, S. Tamburini, Coord. Chem. Rev. 248 (2004) 1717.
 [12] I. Bernal, I. Bernal, Stereochemical Control, Bonding and Steric Rearrangements, Elsevier, Amsterdam, 1990 (Chapter 3).
- [13] J.R. Carey, S.K. Ma, T.D. Pfister, D.K. Garner, H.K. Kim, J.A. Abramite, Z. Wang, Z. Guo, Y. Lu, J. Am. Chem. Soc. 126 (2004) 10812.
- [14] T. Ueno, M. Ohashi, K. Kono, A. Suzuki, T. Yamane, Y. Watanabe, Inorg. Chem. 43 (2004) 2852.
- [15] H. Nishihara, Bull. Chem. Soc. Jpn. 77 (2004) 407.

- [16] C. Joachim, J.K. Gimzewski, A. Aviram, Nature 408 (2000) 541.
- [17] H. Nishihara, M. Kurashina, M. Murata, Macromol. Symp. 27 (2003) 196.
- [18] M. Kurashina, M. Murata, T. Watanabe, H. Nishihara, J. Am. Chem. Soc. 125 (2003) 12420.
- [19] H. El Halabieh Rolla, O. Mermut, B. Christopher, J. Pure Appl. Chem. 76 (2004) 1445.
- [20] M.S. Refat, I.M. El-Deen, H.K. Ibrahim, S. El-Ghool, Spectrochim. Acta Part A 65 (2006) 1208-1220.
- [21] R. Gupta, R.K. Saxena, P. Chatarvedi, J.S. Virdi, J. Appl. Bacteriol. 78 (1995) 378.
- [22] A. Golcu, M. Tumer, H. Demirelli, R.A. Wheatley, Inorg. Chim. Acta 358 (2005) 1785
- [23] J.R. Ferraro, Low Frequency Vibrations of Inorganic and Coordination Compounds, first ed., Plenum Press, New York, 1971. p. 168.
- [24] P. Venkateswara Rao, N. Rama Rao, M.C. Ganorkar, Indian J. Chem. 27A (1988) 160.
- [25] A.M.G. Macdonald, P. Sirichanya, Microchem. J. 14 (1969) 199.
- [26] N.T. Abdel-Ghani, O.E. Sherif, Thermochim. Acta 156 (1989) 69.
- [27] M. Nath, P. Arora, Synth. React. Inorg. Metal. Org. Chem. 23 (1993) 1523.
- [28] A.W. Coats, J.P. Redfern, Nature 68 (1964) 201.
- [29] A.A. Frost, R.G. Pearson, Kinetics and Mechanism, Wiley, New York, 1961.
- [30] E.A. Davis, N.F. Mott, Philos. Mag. 22 (1970) 903.
- [31] H. Fritzsche, Philos. Mag. B 68 (1993) 561.
- [32] H.J. Snaith, L. Schmidt-Mende, Adv. Mater. 19 (2007) 3187-3200.