

Available online at www.sciencedirect.com



SPECTROCHIMICA ACTA PART A

Spectrochimica Acta Part A 62 (2005) 1089-1094

www.elsevier.com/locate/saa

Spectroscopic and biological studies on newly synthesized nickel(II) complexes of semicarbazones and thiosemicarbazones

Sulekh Chandra*, Lokesh Kumar Gupta

Department of Chemistry, Zakir Husain College, University of Delhi, J.L. Nehru Marg, New Delhi 110002, India

Received 10 February 2005; accepted 6 April 2005

Abstract

Nickel(II) complexes, having the general composition Ni(L)₂X₂, have been synthesized [where L: isopropyl methyl ketone semicarbazone (LLA), isopropyl methyl ketone thiosemicarbazone (LLB), 4-aminoacetophenone semicarbazone (LLC) and 4-aminoacetophenone thiosemicarbazone (LLD) and $X = CI^-$, $1/2SO_4^{2-}$]. All the Ni(II) complexes reported here have been characterized by elemental analyses, magnetic moments, IR, electronic and mass spectral studies. All the complexes were found to have magnetic moments corresponding to two unpaired electrons. The possible geometries of the complexes were assigned on the basis of electronic and infrared spectral studies. Newly synthesized ligand and its nickel(II) complexes have been screened against different bacterial and fungal growth. © 2005 Elsevier B.V. All rights reserved.

Keywords: Semicarbazones; Thiosemicarbazones; Nickel(II); Spectroscopic and biological screening

1. Introduction

Metal complexes of semicarbazones and thiosemicarbazones were found to have pronounced carcinostatic properties against a wide range of transplanted neoplasia [1-4], while the oxygen derivatives (semicarbazones) were found to be inactive carcinostatic agents. Such differences in antitumour activity can be co-related to the different chelating properties of the semicarbazones. In a series of recent papers [5–9], the synthetic and structural aspects of a number of transition metal complexes of NS and NO donor systems have been described. Nickel is one of the most toxic metal among transition metals. It shows the toxicity even in low doses to both plants and animals [10,11]. Excess nasal and lung cancers are known to be associated with the refining of nickel. Epimediological data and animal study confirm that crystalline nickel compounds are carcinogenic, while amorphous nickel compounds are weak or non-carcinogenic. Nickel is also involved in transport of metal in eukaryotic algae. It is

found that nickel transport involves ATP-dependant Mg(II) transport system and nickel toxicity can be prevented by increasing the concentration of Mg(II) relative to Ni(II).

In this paper, we report the synthesis and spectroscopic characterization of nickel(II) complexes with ligands isopropyl methyl ketone semicarbazone (LLA), isopropyl methyl ketone thiosemicarbazone (LLB), 4-aminoacetophenone semicarbazone (LLC) and 4-aminoacetophenone thiosemicarbazone (LLD) (Fig. 1).

2. Experimental

All the chemicals used were of AnalaR grade, and procured from Sigma–Aldrich and Fluka. Metal salts were purchased from E. Merck and were used as received.

2.1. Preparation of ligands

All the ligands were prepared by the methods reported earlier [12] by coupling of semicarbazide hydrochloride and thiosemicarbazide, respectively, with isopropyl methyl ketone and 4-aminoacetophenone.

^{*} Corresponding author. Tel.: +91 11 229 112 67; fax: +91 11 232 159 06. *E-mail addresses:* schandra_00@yahoo.com (S. Chandra), lokesh_kg@rediffmail.com (L.K. Gupta).

^{1386-1425/\$ –} see front matter @ 2005 Elsevier B.V. All rights reserved. doi:10.1016/j.saa.2005.04.005



Fig. 1. Structure of the ligands.

2.2. Preparation of complexes

A general method has been adopted for the synthesis of the complexes. A hot (\sim 75 °C) aqueous ethanolic solution (20 mL, 1:1, v/v) of the hydrated metal salts (0.05 mol) and a hot ethanolic solution (20 mL) of the respective ligand (0.1 mol) were mixed with constant stirring. The mixture was refluxed for about 5 h at a temperature of \sim 80 °C. On cooling the contents to a temperature of \sim 5 °C, the complexes were separated out. They were filtered, washed with 50% ethanol and dried over P₄O₁₀ under vacuum.

2.3. Physical measurements

C, H and N were analyzed on a Carlo-Erba 1106 elemental analyzer. The nitrogen content of the complexes was determined using Kjeldahl's method. The nickel content in the complexes was determined gravimetrically as nickeldmg [13]. Molar conductances were measured on an Elico (CM82T) conductivity bridge. Magnetic susceptibility was measured at room temperature on a Gouy balance using CuSO₄·5H₂O as a callibrant. Electron impact mass spectra were recorded on a Jeol, JMS, DX-303 mass spectrometer. ¹H NMR spectra were recorded on Hitachi FT-NMR model R-600 spectrometer using CDCl₃ as solvent. Chemical shifts are given in ppm relative to tetramethylsilane. IR spectra (KBr) were recorded on a FTIR Spectrum BX-II spectrophotometer. The electronic spectra were recorded in DMSO on Shimadzu UV mini-1240 spectrophotometer.

3. Results and discussion

Molar conductance measurement for these complexes was determined in nitrobenzene. All the complexes were found to be non-electrolytes [14] (Table 1). Thus, on the basis of the above data [Ni(L)₂X₂] [where L: LLA, LLB, LLC and LLD, $X = Cl^-$ and $1/2SO_4^{2-}$] formula, reported in Table 2, may be suggested for the nickel complexes.

3.1. Infrared spectra of the ligands

Infrared spectra of the ligands show bands in the region ~1636 and 1588 cm⁻¹, which may be assigned to the symmetric or asymmetric [ν (C=N)] vibrations. Strong bands in the region ~791–813 cm⁻¹ in thiosemicarbazones and ~1688–1712 cm⁻¹ in semicarbazones are due to the [ν (C=S)] and [ν (C=O)] groups, respectively. On complex formation, these bands shifted toward lower frequency as compared to metal free ligand, which indicates that the coordination takes place through the nitrogen, oxygen and sulphur atoms of (C=N), (C=O) and (C=S) groups, respectively. Thus, it has been concluded that the semicarbazones and thiosemicarbazones act as bidentate chelating agent.

3.2. ¹H NMR spectra of the ligands

¹H NMR spectra of the ligands in DMSO show the signals [15] as follows (chemical shift in ppm):

Ligand (*LLA*): $\delta 1.82$ ppm (t) (3H, H₃C–C–), $\delta 8.58$ ppm (s) (1H, HN–CO), $\delta 3.45$ ppm (d) (2H, H₂N–CO), $\delta 1.18$ (t), $\delta 2.48$ (sextet), $\delta 4.41$ ppm (d) (C₃H₇–C). *Ligand* (*LLB*): $\delta 1.84$ ppm (t) (3H, H₃C–C–), $\delta 8.65$ ppm (s) (1H, HN–CS), $\delta 3.59$ ppm (d) (2H, H₂N–CS), $\delta 1.15$ (t), $\delta 2.50$ (sextet), $\delta 4.44$ ppm (d) (C₃H₇–C). *Ligand* (*LLC*): $\delta 1.80$ ppm (t) (3H, H₃C–C–), $\delta 8.57$ ppm (s) (1H, HN–CO), $\delta 3.45$ ppm (d) (2H, H₂N–CO), $\delta 7.11$ ppm

(m) $(4H, -Ph-), \delta 3.80 \text{ ppm}$ (d) $(2H, -Ph-NH_2).$

Table 1

Molecular conductance, magnetic moment and electronic spectral data of the complexes

Complexes	Molar conductance ^a ($\Omega^{-1} \operatorname{cm}^2 \operatorname{mol}^{-1}$)	μ_{eff} (B.M.)	$\lambda_{\rm max} \ ({\rm cm}^{-1}), \varepsilon \ ({\rm L} {\rm mol}^{-1} {\rm cm}^{-1})$
[Ni(LLA) ₂ Cl ₂]	4	2.93	10270 (32), 15610 (59), 24864 (122)
[Ni(LLA) ₂ SO ₄]	6	3.07	7072 (28), 10408 (45), 17018 (99)
[Ni(LLB) ₂ Cl ₂]	5	2.95	10538 (34), 15872 (62), 24958 (122)
[Ni(LLB) ₂ SO ₄]	3	3.05	7195 (29), 10256 (44), 18662 (100)
[Ni(LLC) ₂ Cl ₂]	4	2.98	10456 (37), 15578 (65), 25109 (125)
[Ni(LLC) ₂ SO ₄]	2	3.14	7246 (28), 10474 (47), 17846 (100)
[Ni(LLD) ₂ Cl ₂]	5	2.97	10754 (35), 16966 (63), 25006 (124)
[Ni(LLD) ₂ SO ₄]	1	3.12	7184 (30), 10337 (46), 18324 (101)

^a Error limit, ±3%.

Molar conductance and elemental anal	yses data of the complexes							
Complex	Atomic mass ^a , found (calculated)	Colour	mp ^b (°C)	Yield (%)	Elemental analys	es data (%), found (calculated)	
					Ni	C	Н	N
(LLA), C ₆ H ₁₃ N ₃ O	144 (143)	Off white	229	68	I	50.32 (50.35)	9.21 (9.09)	29.22 (29.37)
(LLB), C ₆ H ₁₃ N ₃ S	161 (159)	Dirty white	220	78	I	45.17 (45.28)	8.03 (8.18)	26.57 (26.41)
$(LLC), C_9H_{12}N_4O$	192 (192)	Cream	204	70	I	56.38 (56.25)	6.36 (6.25)	29.03 (29.17)
(LLD), C ₉ H ₁₂ N ₄ S	209 (208)	Off white	210	73	I	52.01 (51.92)	5.92 (5.77)	26.83 (26.92)
Ni(LLA) ₂ Cl ₂], NiC ₁₂ H ₂₆ N ₆ O ₂ Cl ₂	(416)	Mehandi green	264	65	14.05 (14.18)	34.50 (34.62)	6.17 (6.25)	20.11 (20.19)
Ni(LLA) ₂ SO ₄], NiC ₁₂ H ₂₆ N ₆ O ₆ S	(441)	Greenish blue	271	63	13.31 (13.38)	32.52 (32.65)	5.83 (5.90)	18.98 (19.05)
Ni(LLB) ₂ Cl ₂], NiC ₁₂ H ₂₆ N ₆ S ₂ Cl ₂	(448)	Bluish green	244	68	13.02 (13.17)	32.02 (32.14)	5.71 5.80)	18.67 (18.75)
Ni(LLB) ₂ SO ₄], NiC ₁₂ H ₂₆ N ₆ O ₄ S ₃	(473)	Algae green	258	60	12.55 (12.47)	30.49 (30.44)	5.41 (5.50)	17.91 (17.76)
Ni(LLC) ₂ Cl ₂], NiC ₁₈ H ₂₄ N ₈ O ₂ Cl ₂	(514)	Blue	239	70	11.57 (11.48)	41.91 (42.02)	4.58 (4.67)	21.70 (21.79)
[Ni(LLC) ₂ SO ₄], NiC ₁₈ H ₂₄ N ₈ O ₆ S	(539)	Mehandi green	236	72	11.02 (10.95)	40.00 (40.07)	4.39 (4.45)	20.94 (20.78)
Ni(LLD) ₂ Cl ₂], NiC ₁₈ H ₂₄ N ₈ S ₂ Cl ₂	(546)	Blue	257	69	10.92 (10.81)	39.37 (39.56)	4.47 (4.40)	20.41 (20.51)
Ni(LLD) ₂ SO ₄], NiC ₁₈ H ₂₄ N ₈ O ₄ S ₃	(571)	Pale green	248	64	10.25 (10.33)	37.92 (37.83)	4.29 (4.20)	19.50 (19.61)
^a In amu.								

Table 2

Ligand (*LLD*): δ 1.78 ppm (t) (3H, H₃C–C–), δ 8.63 ppm (s) (1H, HN–CS), δ 3.55 ppm (d) (2H, H₂N–CS), δ 7.10 ppm (m) (4H, –Ph–), δ 3.86 ppm (d) (2H, –Ph–NH₂).

3.3. Electron impact mass spectra of the ligands

EI mass spectra of the ligands (Fig. 2) confirm the proposed formula by showing the following peaks:

Ligand (*LLA*): Appearance of final peak at 144 amu ($C_6H_{13}N_3O$, calculated atomic mass 143 amu) and other peaks at 15, 43, 78, 99 and 127 amu may be due to different fragments. The intensity of these peaks gives an idea of the stability of these fragments.

Ligand (LLB): Under the EI mass spectral study, it gives a final peak at 158 amu which confirms the proposed formula ($C_6H_{13}N_3S$, calculated atomic mass 159 amu) and other peaks at 15, 44, 60, 77, 89, 127 and 143 amu may be attributed to different fragments.

Ligand (LLC): The presence of EI mass spectral peak at 193 amu confirms the proposed formula ($C_9H_{12}N_4O$ calculated atomic mass 192 amu). A set of peaks observed in the range 16, 44, 59, 77, 92, 104, 119 and 134 amu is assigned to various fragments.

Ligand (LLD): Presence of a peak at 208 amu supports the proposed formula ($C_9H_{12}N_4S$, calculated atomic mass 208 amu). The peaks due to the various fragments appear at 15, 60, 78, 92, 105, 134, 192 and 208 amu.

3.4. Chloro complexes [Ni(L)₂Cl₂]

Room temperature magnetic moments of the nickel(II) chloride complexes lie in the range 2.93–2.98 B.M. These values are in tune with a high spin configuration.

The electronic spectra of the complexes display three absorption bands in the range 10,270–10,754 cm⁻¹ ($\varepsilon = 32-37 \text{ L} \text{ mol}^{-1} \text{ cm}^{-1}$), 15,578–16,966 cm⁻¹ ($\varepsilon = 59-65 \text{ L} \text{ mol}^{-1} \text{ cm}^{-1}$) and 24,869–25,109 cm⁻¹ ($\varepsilon = 122-125 \text{ L} \text{ mol}^{-1} \text{ cm}^{-1}$). The ground state of Ni(II) in an octahedral coordination is ${}^{3}\text{A}_{2g}$. Thus, these bands may be assigned to the three spin allowed transitions [16–18]: ${}^{3}\text{A}_{2g}(F) \rightarrow {}^{3}\text{T}_{2g}$ (F) (ν_1), ${}^{3}\text{A}_{2g}(F) \rightarrow {}^{3}\text{T}_{1g}$ (F) (ν_2) and ${}^{3}\text{A}_{2g}(F) \rightarrow {}^{3}\text{T}_{1g}$ (P) (ν_3), respectively. The positions of bands indicate that the complexes have six-coordinated octahedral geometry.

3.5. Sulphato complexes [Ni(L)₂]SO₄

Decomposition temperature.

Room temperature magnetic moments of the nickel(II) sulphate complexes lie in the range 3.05–3.14 B.M. These values are in tune with a high spin configuration.

The infrared spectra of the sulphate complexes (Fig. 3) show two bands ν_3 and ν_1 in the range 1137–1106 and 984 cm⁻¹, respectively [19]. This suggests that the sulphate group coordinates to the metal as unidentate. Thus, a five-coordinate geometry may be assigned to these complexes. The electronic spectra of the complexes



Fig. 2. Electron impact mass spectra of the ligands.

show bands at 7072–7246 cm⁻¹ ($\varepsilon = 28-30 \text{ L mol}^{-1} \text{ cm}^{-1}$) (ν_1), 10,256–10,474 cm⁻¹ ($\varepsilon = 44-47 \text{ L mol}^{-1} \text{ cm}^{-1}$) (ν_2) and 17,018–18,662 cm⁻¹ ($\varepsilon = 99$ –101 L mol⁻¹ cm⁻¹) (ν_3) [20,21], which may be assigned to the transitions



Fig. 3. IR spectral peaks of the coordinated sulphate group.



Fig. 4. Suggested structures of the complexes: (a) chloro complexes of semicarbazone; (b) chloro complexes of thiosemicarbazone; (c) sulphato complexes of semicarbazones; (d) sulphato complexes of thiosemicarbazone. $R = C_3H_7$ and H_2N –Ph.

 ${}^{3}B_{1}(F) \rightarrow {}^{3}E(F)$ and ${}^{3}B_{1}(F) \rightarrow {}^{3}A_{2}(P)$, characteristic to fivecoordinate square pyramidal geometry [22] (Fig. 4).

4. Ligand field parameters

Various ligand field parameters were calculated and listed in Table 3. The values of Dq have been calculated from transition energy ratio diagram [18]. Our results are in agreement with those reported earlier [23]. The Nephelauxetic parameter β was readily obtained by using the relation $\beta = B(\text{complex})/B(\text{free ion})$, where B(free ion) for Ni(II) is 1041 cm⁻¹ [21]. The values of β lie in the range 0.62–0.64. These values indicate the covalent character in metal ligand ' σ ' bond.

Table

 Table 3

 Ligand field parameters of the complexes

Complexes	Dq (cm ⁻)	$B (\mathrm{cm}^{-1})$	β	LFSE (kJ mol ⁻¹)	v_2/v_1
[Ni(LLA)2Cl2]	1027	642	0.62	147.24	1.52
[Ni(LLA)2SO4]	707	_	-	101.36	1.47
[Ni(LLB)2Cl2]	1054	659	0.63	151.11	1.51
[Ni(LLB) ₂ SO ₄]	719	_	_	103.08	1.42
[Ni(LLC) ₂ Cl ₂]	1046	654	0.63	149.96	1.49
[Ni(LLC) ₂ SO ₄]	725	_	_	103.94	1.44
[Ni(LLD)2Cl2]	1075	672	0.64	154.12	1.58
[Ni(LLD) ₂ SO ₄]	718	-	_	102.94	1.44

5. Biological activities

The newly synthesized Ni(II) complexes have been screened against a number of bacteria and plant pathogenic fungi [24,25].

5.1. Antibacterial screening

The antibacterial activities of the purified metal complexes were determined at different concentrations (100 and 30 µg/disc) against a series of Gram-positive and Gramnegative pathogenic bacteria by using disc diffusion technique and were compared with the results obtained with the results obtained with standard antibiotic, Kanamycin (K: $30 \,\mu g/disc$). The results are shown in the Table 4. It was found that the metal complexes were active against all of the test bacteria but the metal complexes (C₄ and C₈) exhibited moderate to strong activity against the test pathogenic bacteria. The antibacterial activities of the eight metal complexes (C_1-C_8) against 14 pathogenic bacteria are presented in Table 4. It was found that the metal complexes C₄ and C₈ were most effective against all pathogenic bacteria. The zones of inhibition of the complexes were approximately same as standard Kanamycin. But the individual activity of the complexes C1 and C2 was moderate against all pathogenic bacteria and on comparison with the results of zones of inhibition with standard Kanamycin, these activities were much lower than those of standard Kanamycin. On the other hand, the remaining complexes such as C₃ and C₅ were less active against all pathogenic bacteria. On comparison with the results of zones of inhibition with standard Kanamycin, these activities were approximately zero.

5.2. Antifungal screening

The antifungal activity of the complexes was checked, by the disc diffusion technique for the 11 pathogenic fungi as test organisms in vitro. The antifungal activities of the complexes against 10 pathogenic fungi are presented in Table 5. The complexes C_4 , C_6 and C_8 were moderate active against all pathogenic fungi and much lower than those of standard fungicide, Nistatin. Remaining all the complexes were found

Antibacterial activities of th	le comp.	lexes and sta	andard K [£]	mamycin													
Test organisms	C ₁ di ² zones inhibi	ameter of of tion (mm)	C ₂ diar zones c inhibiti	neter of of on (mm)	C ₃ dia zones (inhibiti	meter of of ion (mm)	C ₄ diam zones of inhibition	eter of n (mm)	C ₅ dian zones o inhibitic	neter of f on (mm)	C ₆ dian zones of inhibitic	ieter of f in (mm)	C ₇ diam zones of inhibitio	eter of n (mm)	C ₈ diam zones of inhibitio	eter of n (mm)	Kanamycin diameter of zones of inhibition (mm)
	100 µ	g 30 µg	100 µg	30 µg	100 µg	; 30 µg	100 µg	30 µg	100 µg	30 µg	$100\mu g$	30 µg	100 µg	30 µg	100 µg	30 µg	
Shigella dysenteriae	14	~	10	6	6	-	20	12	7	2	11	6	13	6	20	12	20
Shigella boydii	11	9	11	5	8	0	21	6	8	1	10	5	14	7	21	11	24
Shigella flexneri	16	5	12	8	10	3	23	11	7	3	6	3	10	8	19	10	28
Escherichia coli	11	6	10	L	11	2	23	12	9	0	12	4	12	5	22	6	20
Pseudomonas aeruginosa	11	4	13	9	10	0	24	10	6	1	10	3	6	9	23	13	20
Klebsiella species	12	9	11	4	8	1	25	6	8	1	11	5	11	7	21	14	21
Salmonella typhi	11	9	12	7	11	c,	21	11	5	2	12	9	12	5	24	15	19
Shigella sonnei	14	8	10	8	13	2	26	10	7	0	10	2	11	4	26	12	23
Shigella shiga	13	7	14	5	6	1	24	13	6	2	6	4	10	9	25	11	26
Bacillus megaterium	16	4	12	6	10	0	28	11	8	3	8	1	13	5	22	10	25
Sarcina lutea	12	9	15	4	12	1	22	10	8	0	11	5	14	3	23	13	23
Streptococcus haemolyticus	10	6	12	7	8	2	25	12	6	1	10	4	11	5	25	14	18
Sacillus subtilis	16	5	10	9	12	4	26	9	7	5	6	3	12	4	20	12	24
Staphylococcus aureus	28	8	11	5	13	0	26	11	9	0	10	2	11	3	22	10	22
C_1 : [Ni(LLA), C_1]: C_2 : [N]	(TLA)	SOAL: C2: IV	Ni(LLB)	Chl: CA: IN	Hi(LLB)	3OAl: Cs: I	'Ni(LLC),	Cl ₂ 1: C ₆ :	INICLLC	D ₂ SO ₄ 1: C ₇	: INi(LLI	D),CI,1: C ₈	INICLE	D),SOAL			

U	1	5							
Test organisms	C_1^{a}	$C_2{}^a$	C ₃ ^a	$C_4{}^a$	C ₅ ^a	$C_6{}^a$	$C_7{}^a$	$C_8{}^a$	Nystatin ^b
Achlya bisexualis	8	15	20	10	10	7	10	10	18
Saprolegnia monoeca	8	7	25	15	11	25	9	12	15
Albugo bliti	9	20	10	10	9	9	8	11	8
Ustilago avenae	8	20	15	8	12	20	11	9	20
Morchella conica	7	16	12	10	10	8	10	10	12
Peziza vesiculosa	6	21	18	7	11	13	8	11	30
Peziza pustulata	0	20	25	7	9	15	12	12	20
Aspergilus niger	11	20	35	10	12	14	9	10	16
Aspergilus flavus	9	10	9	8	10	20	10	9	22
Candida albicans	8	14	18	11	11	15	8	10	30

 Table 5

 Antifungal activities of the complexes and standard Nystatin

^a C₁: [Ni(LLA)₂Cl₂]; C₂: [Ni(LLA)₂SO₄]; C₃: [Ni(LLB)₂Cl₂]; C₄: [Ni(LLB)₂SO₄]; C₅: [Ni(LLC)₂Cl₂]; C₆: [Ni(LLC)₂SO₄]; C₇: [Ni(LLD)₂Cl₂]; C₈: [Ni(LLD)₂SO₄].

^b 200 μg/disc.

to possess less activity against pathogenic fungi under study, as compared with standard drug Nistatin.

Acknowledgements

The authors are thankful to the University Grant Commission, New Delhi, for financial assistance and the Principal, Zakir Husain College, for providing research facilities. We also express our sincere thanks to Dr. Mordhwaj ACBR, University of Delhi, for recording IR spectra.

References

- [1] M.J.M. Campbell, Coord. Chem. Rev. 15 (1975) 279.
- [2] M.A. Ali, S.E. Livingston, Coord. Chem. Rev. 13 (1974) 101.
- [3] N.K. Singh, A. Srivastava, Trans. Met. Chem. 25 (2000) 133.
- [4] J.P. Scovill, D.L. Klayman, C.F. Franchino, J. Med. Chem. 25 (1982) 1261.
- [5] C.F. Bell, K.A.K. Lott, N. Hearn, Polyhedron 6 (1987) 39.
- [6] A.G. Bingham, H. Boegge, A. Mueller, E.W. Ainscough, A.M. Brodie, J. Chem. Soc. Dalton Trans. (1987) 493.
- S. Chandra, L.K. Gupta, Spectrochim. Acta-A 60 (2004) 3079;
 D.X. West, S.L. Dietrich, I. Thientanavanich, C.A. Brown, Trans. Met. Chem. 19 (1994) 195.
- [8] S. Chandra, L.K. Gupta, Spectrochim. Acta-A 60 (2004) 1751;
 J.K. Swearingen, D.X. West, Trans. Met. Chem. 25 (2000) 241.

- [9] S. Chandra, L.K. Gupta, Spectrochim. Acta-A 60 (2004) 2767;
- D.X. West, A.A. Nassar, M.I. Ayad, F.A. El-Saied, Trans. Met. Chem. 24 (1999) 617.
- [10] J.K. Swearingen, D.X. West, Trans. Met. Chem. 26 (2001) 252.
- [11] J.M. Wood, in: H. Sigel (Ed.), Microbial Strategies in Resistance to Metal Ion Toxicity Metal Ions in Biology, Marcel Dekker, New York, 1984.
- [12] S. Talwar, U. Bansal, S. Chandra, R. Singh, P. Veeraswamy, Synth. React. Inorg. Met.-Org. Chem. 21 (1991) 131.
- [13] A.I. Vogel, Textbook of Quantitative Inorganic Analysis, fourth ed., ELBS and Longman, 1978.
- [14] W.G. Geary, Coord. Chem. Rev. 7 (1971) 81.
- [15] P.S. Kalsi, Spectroscopy of Organic Compounds, fourth ed., New Age International (P) Ltd., New Delhi, 1999.
- [16] S. Chandra, L.K. Gupta, Spectrochim. Acta-A 60 (2004) 1563;
 N.K. Singh, S.B. Singh, Trans. Met. Chem. 26 (2001) 487.
- [17] F. Athar, F. Arjmand, S. Tabassum, Trans. Met. Chem. 26 (2001) 426.
- [18] A.B.P. Lever, Crystal Field Spectra. Inorganic Electronic Spectroscopy, first ed., Elsevier, Amsterdam, 1968.
- [19] K. Nakamoto, Infrared Spectra of Inorganic and Coordination Compounds, Wiley/Interscience, New York, 1970.
- [20] S. Chandra, K. Gupta, S. Sharma, Synth. React. Inorg. Met.-Org. Chem. 31 (2001) 1205.
- [21] S. Chandra, K. Gupta, Trans. Met. Chem. 27 (2002) 329.
- [22] S. Chandra, L.K. Gupta, D. Jain, Spectrochim. Acta-A 60 (2004) 2411.
- [23] S. Chandra, K. Gupta, Trans. Met. Chem. 27 (2002) 196.
- [24] N.K. Singh, S.K. Kushawaha, Trans. Met. Chem. 26 (2001) 140.
- [25] S. Chandra, L.K. Gupta, Spectrochim. Acta-A 61 (2005) 269;
 W.G. Hanna, M.M. Moawad, Trans. Met. Chem. 26 (2001) 644.