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X-Ray Crystallography and Biological Studies of Iron(II), Cobalt(II) and Nickel (II) Complexes Derived from Bidentate Schiff Bases

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The aldehydes, salicylaldehyde and 5-nitrosalicylaldehyde were treated with *o*-phenylenediamine for the synthesis of Schiff base. The ligands, thus formed were used to synthesize Fe(II), Co(II) and Ni(II) complexes. Elemental analysis, molar conductivity, magnetic susceptibility, IR absorption spectra, thermogravimetric analysis characterized the ligand and the metal complexes. The elemental analysis reveals the metal : ligand stoichiometry for Ni(II) and Co(II) complexes are 1 : 1, while that of Fe(II) complex is also 1 : 1 with two water molecules. The XRD data can be indexed to monoclinic system for Ni(II) and Co(II) complexes, while orthorhombic system for Fe(II) complexes. The ligand and the metal complexes were also studied for their antibacterial and antifungal activity.

Key Words: X-ray crystallography, Fe(II), Co(II), Ni(II) complexes, Biological activity.

INTRODUCTION

Literature[1–4] survey on transition metal complexes with Schiff bases revealed that major contribution of the study is based on the aromatic carbonyls and aliphatic diamines. However, aromatic diamines are not used much for the preparation of corresponding ligands and their transition metal complexes. Synthesis of the Co(II) complex of the Schiff base derived from diamine and salicylaldehyde was initally done by Bigotto *et al.*[5] to study the extended model systems for vitamin B_{12}. Later some Co(II) complexes were characterized as the oxygen carriers[6]. Despite the fact that synthesis work on *o*-phenylenediamine and salicylaldehyde with some transition metal has been studied, but no attempt has been made to elucidate the structure of the Fe(II), Co(II) and Ni(II) complexes with the help of X-ray, TGA, magnetic susceptibility, UV, IR, NMR studies.

In the past, we have concluded lattice parameter of Pd(II) and oxovanadium complexes and are reported in literature[7, 8]. In the present paper, an attempt is made to synthesize Fe(II), Co(II) and Ni(II) complexes of ligands derived from salicylaldehyde and 5-nitrosalicylaldehyde with *o*-phenylenediamine and investigate their crystal structure and biological studies.

EXPERIMENTAL

All the chemicals, solvents and reagents used were of LR grade. The ligand L_1 [N,N′-bis-(2-hydroxy benzylidene)-1,2-benzenediamine] and ligand L_2 [N,N′-bis-(2-hydroxy-5-nitrobenzylidene)-1,2-benzenediamine] were synthesized by treating salicylaldehyde and 5-nitrosalicylaldehyde with *o*-phenylenediamine respectively. The precipitate obtained was washed with methanol and dried in an oven at 60°C. The Schiff base was recrystallized using methanol.

The metal complexes were synthesized by using ethanolic solution of the ligand with aqueous metal solution; the complexes obtained were filtered, washed with a methanolic solution and dried in an oven at 60°C. The elemental analysis was carried out by reported methods[9] (Table-1). The complexes were examined for solubility using various polar and non-polar solvents. Molar conductivity of ligand and metal complexes was recorded using 5×10^{-3} M solution in nitrobenzene on Toshniwal conductivity meter. The electronic absorption spectra of complexes were recorded in the UV-Visible region using tetrahydrofuran as solvent on UV-Visible 2100 spectrophotometer supplied by M/s Shimadzu Corporation while IR spectra were recorded on FTIR-4200 supplied by M/s Shimadzu Corporation using KBr pellets. The magnetic susceptibility measurements were made on Gouy's balance. The NMR spectra for the ligand and the metal complexes were recorded on VXR-300S Varian spectrophotometer. TGA-DTA analysis was carried out for the metal complexes on STA-92 Setaram TG-DTA Instrument. The X-ray diffractogram was recorded on XRD diffracto-

TABLE-1
ANALYTICAL DATA OF LIGANDS AND METAL COMPLEXES

Complexes (Colour)	M (%)	Molar cond. $\times 10^{-3}$ siemens	Magnetic moment (B.M.)	Charge transfer bands (cm^{-1})	ν(—OH) (cm^{-1})	ν(>C═N) (cm^{-1})	D_{cal} (g/cm^3)	Temp range (°C)
L_1 ($C_{20}H_{16}N_2O_2$) (Orange)	—	3.76	—	—	3050 (s)	1620 (s)	—	—
L_1 ($C_{20}H_{14}N_4O_6$) (Yellow)	—	4.85	—	—	3100 (s)	1630 (s)	—	—
$FeL_1 \cdot 2H_2O$ (Brown)	15.48 (15.76)	12.08	0.98	24937	3010 (w)	1610 (s)	1.1644	(i) 50–150 (ii) 150–350 (iii) 350–800
$FeL_2 \cdot 2H_2O$ (Brown)	12.55 (11.26)	10.43	0.87	24420	3050 (w)	1610 (s)	1.4217	(i) 50–150 (ii) 150–350 (iii) 350–800
CoL_1 (Brown)	15.93 (15.80)	10.20	3.01	25575	—	1610 (s)	1.3614	(i) 100–400 (ii) 400–650
CoL_2 (Red)	12.95 (12.67)	9.16	3.38	26041	—	1610 (s)	0.9081	(i) 100–350 (ii) 350–700
NiL_1 (Brick red)	16.25 (15.75)	11.64	0.98	21739	—	1610 (s)	1.0440	(i) 100–450 (ii) 450–550
NiL_2 (Red)	12.55 (12.63)	9.68	1.20	21505	—	1615 (s)	1.3640	(i) 100–400 (ii) 400–550

gram 6000 using CuK_α radiation (CuK_α = 1.5418 Å). The X-ray diffractograms were scanned in the 2θ range of 10–60°C.

RESULTS AND DISCUSSION

The results of all the above experimental findings are summarized in Table-1. The ligands L_1 and L_2 are yellow in colour having melting point 152 and 197°C respectively. The Fe(II), Co(II) and Ni(II) complexes derived from this Schiff base vary in their colour. The elemental analysis of Fe(II) complexes suggests metal : ligand stoichiometry as 1 : 1 with two water molecules, while that of Co(II) and Ni(II) complexes is also 1 : 1. This can be indicated by close agreement with the analytical data and theoretical molecular formula. The metal complexes are soluble in nitrobenzene and DMSO. The molar conductance value suggests that these complexes are non-electrolytic in nature.

The prominent features in the spectrum of the ligands are sharp and strong absorption bands at around 3100–3050 and 1620 cm^{-1}, characteristic of ν(—OH) and ν(>C═N) respectively. However, the weak bands of ν(—OH) are seen in the Fe(II) complexes at 3050–3010 cm^{-1} suggesting the presence of water molecule. Thus absence of strong band of ν(—OH) in the Fe(II) complexes indicates the involvement of —OH group in bond formation. Similarly, a shift in absorption band from 1620 cm^{-1} to lower frequency suggests the involvement of azomethine nitrogen in the coordination of the metal ion. Sreenivasulu and Reddy[10] reported similar assignments to band appearing at around 1600 cm^{-1} in the Schiff base complexes. Critical examination of the spectra of ligands and their metal complexes in the far infrared region shows appearance of few but definite absorption bands. These new bands may be assigned to ν(M—N) and ν(M—O) stretching vibrations in the region 550–540 cm^{-1} and 480–440 cm^{-1} respectively. The infrared spectra of the ligands do not show any absorption in these regions. Nakamoto[11] has reported assignments of ν(M—N) and ν(M—O) in the same range.

The electronic absorption spectra of metal complexes display various *d-d* transitions and charge transfer transitions in the UV-Vis region. Fe(II) complexes are brown in colour and exhibit a subnormal magnetic moment of 0.98 and 0.87 B.M. for $FeL_1 \cdot 2H_2O$ and $FeL_2 \cdot 2H_2O$ complexes respectively. The band pointed at 24937 cm^{-1} and 24420 cm^{-1} in the spectrum of $FeL_1 \cdot 2H_2O$ and $FeL_2 \cdot 2H_2O$ may be assigned to charge transfer transitions. On the colour, magnetic susceptibility data and spectral properties, low spin octahedral geometry can be assigned for Fe(II) complexes. Co(II) complexes of ligands L_1 and L_2 are red and brown in colour and exhibit a magnetic moment of 3.01 and 3.38 B.M. respectively. The Co(II) complexes exhibit bands at 25575 and 26041 cm^{-1} for CoL_1 and CoL_2 respectively, which can be assigned to charge transfer bands. Rai *et al.*[12] also observed high frequency band at 26100 cm^{-1}, which can be assigned to charge transfer transitions. Based on the above data, Co(II) complexes may be considered as crystals with distorted octahedral geometry. Ni(II) complexes of ligands L_1 and L_2 are brick red in colour and exhibit subnormal magnetic moments of 0.96 and 1.21 B.M. respectively. The absorption spectrum of NiL_1 complexes shows an absorption band at 21739, 26350 and 32258 cm^{-1}, while NiL_2 complexes show an absorption band at 21505, 28169 and 36363 cm^{-1}. The band appearing at 21739 and 21505 may be assigned to charge transfer bands. On the basis of magnetic susceptibility and electronic spectral data Ni(II) complexes may be assigned tetrahedral geometry. Dickson and Long[13] have interpreted such observations in favour of tetrahedral Ni(II) complexes.

The proton NMR of Fe(II), Co(II) and Ni(II) complexes were recorded using TMS as a reference in DMSO solvent. Spectra of ligands show multiple signals in the range of 6.94–7.67 ppm, which are characteristic signals for aromatic ring protons. The signals were integrated for 12 protons. The corresponding metal chelates also show a similar multiple signal with δ value in the range of 6.40–9.75 ppm. Similarly, signals at 8.92 and 12.96 ppm were assigned to $>CH{=}N$ and phenolic OH group respectively. The spectra of Ni(II) and Co(II) complexes do not show any proton signal corresponding to a phenolic OH. But the spectrum of FeL_1 and FeL_2 does show a signal at 12.97 and 10.26 ppm, which is due to the coordinated water molecule in the complexes. Thus, the PMR of metal complexes suggests that phenolic oxygen participates in coordination after complete deprotonation of phenolic group. The assignments to the aromatic proton and phenolic proton were supported by literature[14].

The thermal behaviour of the metal complexes was studied by recording thermogravimetric plot (Fig. 1). It can be seen that for Fe(II) complexes decomposition begins at 300–350°C and is completely decomposed at 800°C. The sudden weight loss at around 150°C is attributed to water molecules coordinated with Fe(II) complexes. In case of Co(II) and Ni(II) complexes decomposition begins at 450°C whereby Co(II) complexes are completely decomposed at 700°C while Ni(II) complexes are decomposed at 550°C. The percentage loss at decomposition temperature is in agreement with the calculated values. After decomposition metal oxide remains as residue.

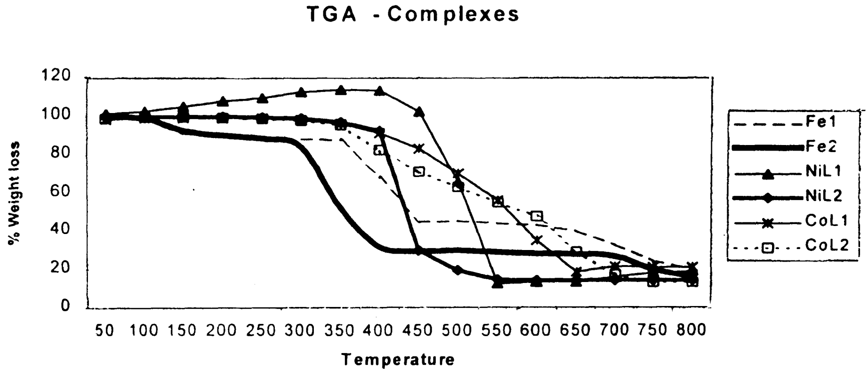

Fig. 1. TGA curves for the metal complexes

In X-ray diffractogram of the complexes, major refluxes were measured and corresponding 'd' values were obtained using Bragg's equation. The independent indexing of major refluxes was carried out using least square method. The Miller indices h, k, l were calculated and refined by using Back-cal program on computer. The complexes were successfully indexed to orthorhombic crystal system with Z = 4 for Fe(II) complexes, Co(II) and Ni(II) complexes exhibited monoclinic crystal system with Z = 4 for CoL_1 and Z = 2 for CoL_2 complexes and Z = 4 for Ni(II) complexes. Similar observations are reported in the literature[15, 16].

The lattice parameters along with 'd' values are summarized in Tables 2–7. The correctness of these values was confirmed by comparing the observed density with that calculated from the X-ray diffractogram. It may be concluded that Fe(II) complexes are low spin octahedral complexes, which crystallize in orthorhombic system with space group $\mathbf{P_{222}}$. Co(II) complexes have distorted octahedral geometry which crystallize in monoclinic system with space group $\mathbf{P_{2/m}}$ for CoL_1 complex and $\mathbf{P_m}$ for CoL_2 complex. Ni(II) complexes are tetrahedral complexes, which crystallize in monoclinic system with space group $\mathbf{P_{2/m}}$. The space groups were assigned to the complexes as specified in the literature[17, 18].

TABLE-2

CELL DATA AND CRYSTAL LATTICE PARAMETERS FOR FeL_1

a (Å) = 9.9689 ± 0.0198
b (Å) = 17.2443 ± 0.1110
c (Å) = 13.4616 ± .03273
Std. Deviation = 0.58%
α = 90°
β = 90°
γ = 90°

Volume $(Å)^3$ = 2314.1740
D_{cal} (g/cm^3) = 1.1644
D_{obs} (g/cm^3) = 1.2086
% Porosity = 2.25%
Z = 4
Crystal system = orthorhombic
Space group = $P_{222} - D_{1/2}$

I/I_0	D_{obs}	D_{cal}	h	k	l
51	5.8761	5.8689	1	2	1
39	4.0931	4.0918	1	0	3
100	3.3335	3.3229	3	0	0
41	3.0085	3.0085	3	2	1
37	2.9801	2.9801	3	0	2
23	1.9291	1.9291	2	3	6
23	1.7665	1.7665	3	3	6

The literature survey of the antimicrobial activity of Schiff bases is well known for their pronounced biological activity[19, 20] and their metal complexes have shown that many of them are useful as bactericides and fungicides against various bacteria and fungi. These compounds were screened against various pathogenic microorganisms, *viz.*, *Staphylococcus aures* 209P, *E. coli* ESS 2231, *Aspergillus fumigatus, Candida albicans, Candida albicans* ATCC 10231, *Candida krusei* GO3 and *Candida glabratea* HO5. The screening was performed by using solutions of the compounds prepared in 10% DMSO in methanol. The concentrations of the compounds employed for the screening were 250 μg/mL (50 μL per well/disc). The standard agar well diffusion assay method[21] was used for the screening. The control used for the screening was flucanozole.

TABLE-3
CELL DATA AND CRYSTAL LATTICE PARMETERS FOR CoL$_1$

a (Å) = 8.6065 ± 0.0117
b (Å) = 20.2815 ± 0.0836
c (Å) = 10.61436 ± 0.0389
Std. deviation = 0.44%
$\alpha = 90°$
$\beta = 100.99°$
$\gamma = 90°$

Volume (Å)^3 = 1818.79
D$_{cal}$ (g/cm^3) = 1.3614
D$_{obs}$ (g/cm^3) = 1.2784
% Porosity = 6.49%
Z = 4
Crystal system = monoclinic
Space group = $P_{2/m} - C_{1/2h}$

I/I$_0$	D$_{obs}$	D$_{cal}$	h	k	l
38.41	7.8070	7.7990	1	1	0
100.00	4.9418	4.9527	1	3	1
66.73	4.2101	4.2038	2	0	1
97.20	3.7906	3.8004	1	2	–2
25.71	3.5140	3.5051	1	3	–2
43.82	2.6426	2.6382	0	5	3
41.98	2.3113	2.3113	3	4	–1
36.68	2.2983	2.3007	3	0	–2
27.16	1.9688	1.9707	4	1	3

TABLE-4
CELL DATA AND CRYSTAL LATTICE PARMETERS FOR NiL$_1$

a (Å) = 8.9938 ± 0.0195
b (Å) = 20.5700 ± 0.0955
c (Å) = 13.2995 ± 0.0510
Std. deviation = 0.83%
$\alpha = 90°$
$\beta = 105.68°$
$\gamma = 90°$

Volume (Å)^3 = 2369.0240
D$_{cal}$ (g/cm^3) = 1.044
D$_{obs}$ (g/cm^3) = 1.2926
% Porosity = 19.23%
Z = 4
Crystal system = monoclinic
Space group = $P_{2/m} - C_{1/2h}$

I/I$_0$	D$_{obs}$	D$_{cal}$	h	k	l
4.03	8.6527	8.6597	1	0	0
100.00	8.2886	8.2868	1	0	1
6.08	5.9808	5.9776	1	0	2
0.60	5.4419	5.4355	1	2	2
4.83	5.2668	5.2828	1	3	1
1.01	4.6599	4.6796	0	3	2
7.74	4.1568	4.1434	2	0	2
4.03	4.0352	4.0352	1	4	–1

TABLE-5
CELL DATA AND CRYSTAL LATTICE PARAMETERS FOR FeL_2

a (Å) = 9.9958 ± 0.02580
b (Å) = 17.2976 ± 0.06856
c (Å) = 13.3878 ± 0.05717
Std. deviation = 1.0%
$\alpha = 90°$
$\beta = 90°$
$\gamma = 90°$

Volume (Å)^3 = 2315.6810
D_{cal} (g/cm^3) = 1.4217
D_{obs} (g/cm^3) = 1.3841
% Porosity = 2.71%
Z = 4
Crystal system = orthorhombic
Space group = $P_{222} - D_{1/2}$

I/I_0	D_{obs}	D_{cal}	h	k	l
14	6.2695	6.2427	0	1	2
24	5.8761	5.8773	1	2	−1
100	5.0026	4.9997	2	0	0
26	3.5915	3.6348	2	2	−2
29	3.2020	3.1793	3	1	1
14	2.1749	2.1794	2	6	−3
14	2.0913	2.0875	1	8	1
17	1.9250	1.9281	5	2	1
14	1.6729	1.6737	0	5	7
14	1.5159	1.5139	4	9	−1
14	1.5014	1.5014	6	5	0
14	1.4761	1.4750	5	6	4

TABLE-6
CELL DATA AND CRYSTAL LATTICE PARAMETERS FOR CoL_2

a (Å) = 8.3018 ± 0.0335
b (Å) = 20.9121 ± 0.1065
c (Å) = 10.3225 ± 0.0501
Std. deviation = 0.99%
$\alpha = 90°$
$\beta = 102.85°$
$\gamma = 90°$

Volume (Å)^3 = 1699.7630
D_{cal} (g/cm^3) = 0.9081
D_{obs} (g/cm^3) = 1.2334
% Porosity = 26.37%
Z = 2
Crystal system = monoclinic
Space group = $P_m - C_{1/s}$

I/I_0	D_{obs}	D_{cal}	h	k	l
52.16	6.0809	6.0316	1	2	1
44.44	4.9052	4.9137	1	0	2
100.00	3.5339	3.5560	2	3	1
60.49	3.2753	3.2674	2	1	−1
46.95	2.9982	2.9965	2	1	3
100.00	2.0785	2.0774	1	8	3
66.39	2.0699	2.0740	1	6	4
35.12	1.9642	1.9665	2	9	2
35.12	1.5347	1.5362	5	3	0

TABLE-7
CELL DATA AND CRYSTAL LATTICE PARAMETERS FOR NiL_2

a (Å) = 8.5098 ± 0.0141
b (Å) = 20.4441 ± 0.0404
c (Å) = 13.7105 ± 0.0354
Std. deviation = 0.43%
$\alpha = 90°$
$\beta = 108.52°$
$\gamma = 90°$

Volume $(Å)^3$ = 2262.2790
D_{cal} (g/cm^3) = 1.3640
D_{obs} (g/cm^3) = 1.3339
% Porosity = 2.25%
Z = 4
Crystal system = monoclinic
Space group = $P_{2/m} - C_{1/2h}$

I/I_0	D_{obs}	D_{cal}	h	k	l
100.00	8.1290	8.1047	1	0	1
27.59	6.3455	6.3507	1	2	1
45.80	5.1129	5.1110	0	4	0
29.75	4.3488	4.3500	1	1	3
24.50	4.0407	4.0523	2	0	2
94.03	3.3739	3.3719	2	2	3
29.75	3.0265	3.0257	2	0	–2
25.51	2.9141	2.9150	2	4	–1

The results of the screening are presented in Table-8. Two different types of bacteria, *viz.*, *Staphylococcus aureus* 209P and *E. coli* ESS 2231 were used for determining the activity of ligands and metal complexes. It was seen that ligand L_1 and its iron complex, *i.e.*, FeL_1 were active to *Staphylococcus aureus* 209P and *E. coli* ESS 2231, whereas ligand L_2 is active only to *E. coli* ESS 2231 type of bacteria but its cobalt and iron complexes were active to both types of bacteria.

TABLE-8
ANTIMICROBIAL IN VITRO TESTING OF LIGAND AND METAL COMPLEXES

Sr. No.	Sample code	*Staph. aureus* 209 p	*E. coli* ESS 2231	*Aspergillus fumigatus*	*Candida albicans*	*Candida albicans* ATCC 10231	*Candida krusei* GO3	*Candida glabrata* HO5
1.	L_1	10	16	—	—	—	—	—
2.	L_2	sl	11	—	17	—	—	—
3.	CoL_1	—	—	15	20	24	22	11
4.	CoL_2	11	13	—	—	18	—	—
5.	FeL_1	12	16	—	—	18	—	—
6.	FeL_2	sl	10	—	—	14	—	—
7.	NiL_1	—	—	—	—	—	—	—
8.	NiL_2	—	—	—	—	—	—	—
9.	Fluconazole 0.5 mg/mL	—	—	—	29h	25h	19	15
10.	10% DMSO in methanol	—	—	—	—	—	—	—

Five types of fungus, namely *Aspergillus fumigatus, Candida albicans, Candida albicans* ATCC 10231, *Candida krusei* GO3, *Candida glabrata* HO5 were used to determine the antifungal activity. It was seen that only ligand L_2 was active against *Candida albicans.* Cobalt complex of ligand L_1 was active towards all types of fungi. Co(II) complex of ligand L_1 was active to all type of fungi, while iron complex of ligands L_1, L_2 and cobalt complexes of ligand L_2 are also good antifungal agents. Nickel complexes of both the ligands were found to be inactive towards bacteria as well as fungus.

Conclusively, these coloured Fe(II), Co(II) and Ni(II) complexes are thermally stable as indicated by TGA. Orthorhombic system is assigned to Fe(II) complexes and monoclinic system assigned to Co(II) and Ni(II) complexes. All the complexes showed slight decrease in bacterial activity after complexation. The activity of some complexes seems to be positive as compared to ligands, when tested for antifungal activity. Ligands did not show any activity toward fungus. It can be clearly depicted from the results that all the complexes except Ni(II) were active toward *Candida albicans* ATCC 10231. The use of Fe(II) and Co(II) complexes as strong antifungal agents is recommended.

REFERENCES

1. R.H. Holm, G.W. Everett and A. Chakravorthy, *Prog. Inorg. Chem.*, **7**, 83 (1966).
2. M. Calligaris, G. Nardin and L. Ranadacio, *Coord. Chem. Rev.*, **7**, 385 (1972).
3. D.J. Hodgson, *Prog. Inorg. Chem.*, **79,** 173 (1975).
4. R.D. Jones, D.A. Summerville and F. Basalo, *Chem. Rev.*, **79**, 13 (1979).
5. A. Bigotto, G. Costa, G. Mestorani, G. Pellizer, A. Pexeddu, E. Reisehenhofer, L. Stefani, and G. Tauzher, *Inorg. Chim. Acta Rev.*, 41 (1970).
6. D. Chen, A.E. Martell and Y. Sun, *Inorg. Chem.*, **28**, 2647 (1990).
7. V.P. Vengurlekar and B.H. Mehta, *Asian J. Chem.*, **13,** 939 (2000).
8. P.M. Prabhu and B.H. Mehta, *Orient J. Chem.*, **13,** 297 (1997).
9. A. Steyermerk, Qualitative Organic Microanalysis, 2nd Edn., Academic Press, New York (1961).
10. Y. Sreenivasulu and K.H. Reddy, *J. Indian Chem. Soc.*, **70**, 1 (1993).
11. K. Nakamoto, Infrared Spectra of Inorganic and Coordination Compounds, 1st Edn., John Wiley, New York (1963).
12. B.K. Rai, K. Sharma and A.K. Singh, *Asian. J. Chem.*, **14**, 1556 (2002).
13. R.C. Dickson and C.J. Long, *Inorg. Chem.*, **13,** 262 (1974).
14. R.M. Silverstine, G.C. Bassler and T.C. Morill, Spectroscopic Identification of Organic Compounds, 5th Edn., John Wiley & Sons, New York (1991).
15. E. Frasson and C. Panattoni, *Acta Crystallogr.*, **13,** 893 (1960).
16. S. Bruckner, M. Calligaris, G. Nardin and L. Randaceio, *Acta Crystallogr.*, **25B**, 1671 (1989).
17. Y. Elerman, M. Kabak and A. Elmali, *Anal. Sci.*, **19**, 331 (2003).
18. F.M. Norman, Henry and Kathleen Lonsdale, International Tables for X-Ray Crystallography, 3rd Edn. (1969).
19. E.M. Hodnett and W.J. Dunn, *J. Med. Chem.*, **13**, 768 (1970).
20. S.S. Tiwari, S.M.I. Husain and G.C. Srivastava, *J. Indian Chem. Soc.*, **58,** 214 (1981).
21. A.L. Barry, Antibiotics in Laboratory Medicine (Lorian, 5th Edn.); Williams & Wilkins, Baltimore, 3rd Edn., Chapter 1, pp. 1–16 (1991).

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