

TRANSITION METAL COMPLEXES WITH LIGAND CONTAINING THIOAMIDE MOIETY: SYNTHESIS, CHARACTERIZATION AND ANTIBACTERIAL ACTIVITIES

AURORA REISS* AND MIHAELA MUREȘEANU

Department of Chemistry, Faculty of Sciences, University of Craiova, 1071 Calea București, 200478 Craiova, Romania

(Received: March 16, 2012 - Accepted: August 7, 2012)

ABSTRACT

A new series of transition metal complexes of Fe(II), Co(II), Ni(II), Cu(II) and Zn(II) with the ligand 3-thionicotinoylaminodibenzofuran (L) were synthesized. The complexes were characterized by elemental analyses, metal content, spectroscopic methods (IR, UV-vis, NMR and EPR), conductivity and susceptibility measurements and by thermal studies. A quantum-mechanical interpretation of the electronic transitions for the free and coordinated ligand in the Ni(II) complex was performed using EHT-MO approach in order to get more information about the atoms involved in coordination to the metallic ion. According to all this information, we propose an octahedral geometry for Fe(II) and Co(II) complexes, a square-planar geometry for Ni(II) and Cu(II) complexes and a tetrahedral geometry for Zn(II) complex. The antibacterial activity of the ligand and its complexes was studied against selected bacteria *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*. It was found that all the complexes are antimicrobially active and show higher activity than the free ligand.

Key words: thioamide moiety, metal complexes, antibacterial activity.

INTRODUCTION

The chemistry of thioamides and their derivatives continues to be of interest due to their interesting structural features and also due to their biological importance. Thioamide (rarely named thionamide) is a functional group with the general structure R-CS-NR'R²(H), where R, R¹, R² are organic groups. Several researchers have used this group in the synthesis of different heterocyclic compounds such as triazoles, thiadiazoles, quinazolines, benzothiazines, benzodiazocines, benzotriazocines, benzothiadiazocines, etc.¹⁻⁵. Because of their versatile properties, thioamides are used in rubber vulcanization as accelerators, as inhibitors of metal corrosion, and in electroplating industries as polyolefin stabilizers⁶⁻¹⁰. The thioamide derivatives have shown significant activities such as antituberculosis drug, antitumor activity, anthelmintic activity, thyrotoxic activity; central nervous system depressant etc.¹¹⁻¹⁷. A platinum-pyridine thione complex has been patented for clinical use in cancer treatment¹⁸. Fungicidal, insecticidal, and acaricidal activities have also been reported for these compounds¹⁹.

All these facts motivate our interest in the complex compounds with these heterocyclic ligands. Here we report the synthesis, characterization and antibacterial activities of Fe(II), Co(II), Ni(II), Cu(II) and Zn(II) with the thioamide 3-thionicotinoylaminodibenzofuran (L)²⁰⁻²², which is a continuation of our work in this field.

The structure of the thioamide 3-thionicotinoylaminodibenzofuran (L) and the atom numbering scheme are given in Fig. 1.

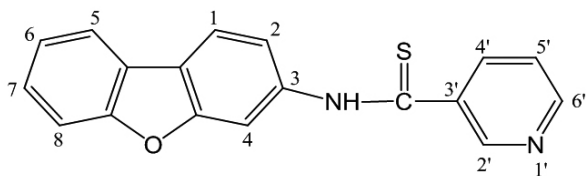


Fig. 1. The structure of the ligand (L) and the atom numbering scheme

The thioamide and its new complexes were tested for antibacterial activity against pathogenic bacteria species, such as *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

EXPERIMENTAL

Materials and Methods

All the chemicals used were of analytical grade and were procured from Sigma-Aldrich and Fluka. Metal salts were purchased from Merck. All the employed solvents were of standard spectroscopic grade.

The IR spectra were recorded on a Perkin Elmer 157 instrument in anhydrous KBr pellets in the range 400-4000 cm⁻¹. A Unicam UV2-300 spectrometer was used to obtain electronic spectra in DMF solutions. The molar conductivities were determined by using OK-102 (Hungary) conductivity meter. The

magnetic susceptibility measurement was made on a Faraday balance at room temperature. The metal contents of the complexes were determined by atomic absorption technique using Varian-AA775 spectrophotometer. C, H and N were analysed using M.L.W. microelementary CHN analyser. Sulphur content was determined with Leco CS-300 analyser. The ¹H and ¹³C NMR spectra were recorded on a Varian Gemini 300BB. Thermogravimetric analysis was carried out in a Netzsch TG 209C thermobalance with a heating rate of 10°C. EPR spectrum was registered in powder at room temperature using an Art-5-IFA Bucharest spectrometer, that operates in X band, the modulation of magnetic field being 100 kHz and Mn²⁺ was used as an internal standard.

Synthesis of the ligand 3-thionicotinoylaminodibenzofuran (L)

The ligand was prepared according to literature²³ as follows: 3-aminodibenzofuran and nicotinic acid react in chlorobenzene in a 1:1 molar ratio in the presence of an excess of phosphorus oxitrichloride when the corresponding amide is formed (m.p. 217 °C). The synthesized amide was recrystallized from alcohol, then it was solubilized in anhydrous xylene and it reacted with phosphorus pentasulfide. The thioamide, 3-thionicotinoylaminodibenzofuran, was obtained (m.p. 198 °C) and it was recrystallized from toluene. The ligand purity was verified by TLC.

Synthesis of the complexes

The metal complexes were prepared by the same general method: ethanolic solutions of 3-thionicotinoylaminodibenzofuran and metal chloride were mixed in 2:1 molar ratio and refluxed for 4-6 h. Because of the poor solubility of the thioamide it was necessary to use a large volume of solvent, heating and stirring until the reaction was complete. The volume of solution was reduced to one third by slow evaporation when a coloured precipitate was formed. It was filtered, washed with ethanol and diethyl ether and dried under reduced pressure.

Antibacterial tests

The thioamide and its complexes were tested for *in vitro* antibacterial activity using the diffusion method against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*^{33,34}. The diffusion method is simple but it is routinely used in hospital laboratories; it requires commercial disks, the medium used is Mueller-Hinton Agar with 2% of glucose; the diameter of inhibition zone is visually read at 24 h after incubation at 37°C. The antibacterial activity was estimated on the basis of the size of inhibition zone formed around the paper disks on the seeded agar plates.

RESULTS AND DISCUSSION

The complexes obtained are microcrystalline variously coloured powders, whose melting points are higher than that of the free ligand. They are air-stable, insoluble in common organic solvents but soluble in dimethylformamide (DMF). The results of elemental analysis (C, H, N and S) and the metal contents along with molecular formulae and melting points of the thioamide and its complexes are presented in Table 1. The molar electric conductivities showed that Fe(II), Co(II) and Ni(II) complexes are non-electrolytes while Cu(II) and Zn(II) complexes are electrolytes.

Table 1. Analytical and physical data for the ligand and its Fe(II), Co(II), Ni(II), Cu(II) and Zn(II) complexes

Compl.	Colour (yield %)	Mp (°C)	Analysis found (calcd.)					λ_{M}^{*} ($\Omega^{-1}cm^{-1}mol^{-1}$)
			C	H	N	S	M	
Ligand (L)	yellow 82	198	74.98 (75.00)	4.08 (4.16)	9.70 (9.72)	11.08 (11.11)	-	-
[FeL ₂ Cl ₂]	brown 85	215	61.06 (61.46)	3.39 (3.41)	7.92 (7.96)	9.05 (9.10)	7.89 (7.94)	14.05
[CoL ₂ Cl ₂]	brown 75	210	61.09 (61.19)	3.30 (3.39)	7.89 (7.93)	9.03 (9.06)	8.31 (8.34)	10.09
[NiL ₂]Cl ₂	red brown 85	195	61.19 (61.21)	3.38 (3.40)	7.91 (7.93)	9.04 (9.06)	8.30 (8.31)	15.71
[CuL ₂]Cl ₂	brown 70	198	60.74 (60.79)	3.35 (3.37)	7.85 (7.88)	8.98 (9.00)	8.92 (8.94)	117.65
[ZnL ₂]Cl ₂	light yellow 66	190	60.63 (60.64)	3.34 (3.36)	7.84 (7.86)	8.90 (8.98)	9.07 (9.17)	122.78

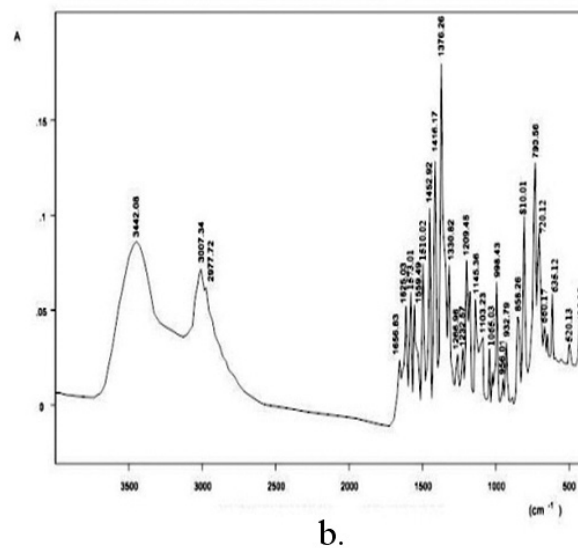
* in 10⁻³ DMF solutions at room temperature

IR spectra

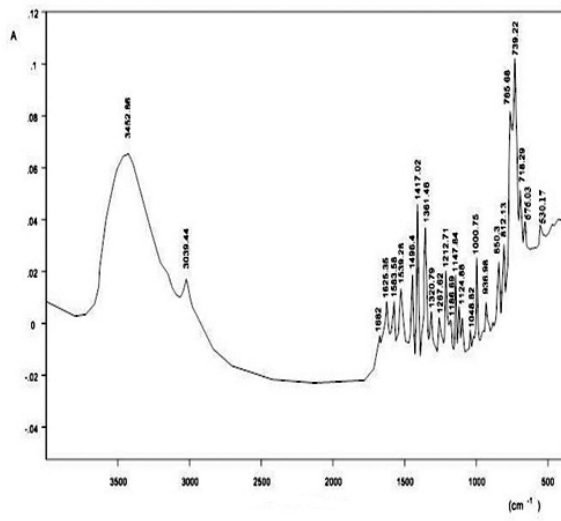
The IR spectra of the thioamide (L) and its complexes are presented in Fig. 2.

The IR spectra data of the complexes were compared with those of the free ligand in order to determine the donor atoms that may be involved in coordination and the results are listed in Table 2.

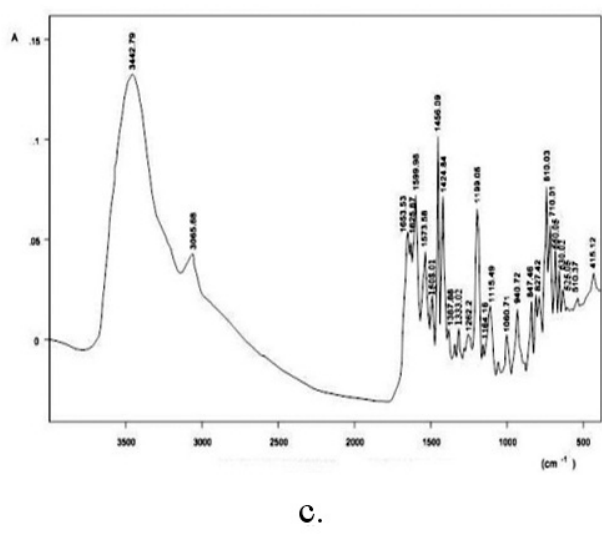
In literature it is stated that thioamide forms a complex vibrational group with four characteristic bands in the 1600 - 600 cm⁻¹ domain^{24,25}. In the spectrum of the free ligand the band at 3452 cm⁻¹ characteristic for ν_{NH} and at 1583 cm⁻¹ assigned to δ_{NH} appear in the spectra of the complexes at lower frequencies. These changes suggest that the nitrogen atom of the -NH- group is involved in the coordination of the ligand to the metallic ion. Changes of the ligand spectrum upon coordination involve a significant perturbation of the characteristic four bands. So, the thioamide I, II and III bands are displaced towards higher frequencies in the complexes spectra and this suggests that nitrogen and sulphur atoms of the thioamide group are involved in coordination. The thioamide IV band is converted from its clearly resolved components in the uncoordinated ligand into a peak with associated shoulders in the complexes. Modest shifts (± 10 cm⁻¹) together with band-splitting also occur with $\delta(C-S)$ (676 cm⁻¹) and $\pi(C-S)$ (530 cm⁻¹). In this case, the general indication is one of a significant perturbation in the thione region (800 - 500 cm⁻¹), thus confirming that the sulphur atom participates in bonding²⁶. The new bands at 430 - 415 cm⁻¹ in the spectra of the metal complexes were assigned to ν_{M-N} stretching vibrations²⁷. Therefore, it is concluded that 3-thionicotinoylaminodibenzofuran behaves as a bidentate ligand in all the complexes and that the coordination takes place at the sulphur and nitrogen atoms of the thioamide group.



b.



a.



c.

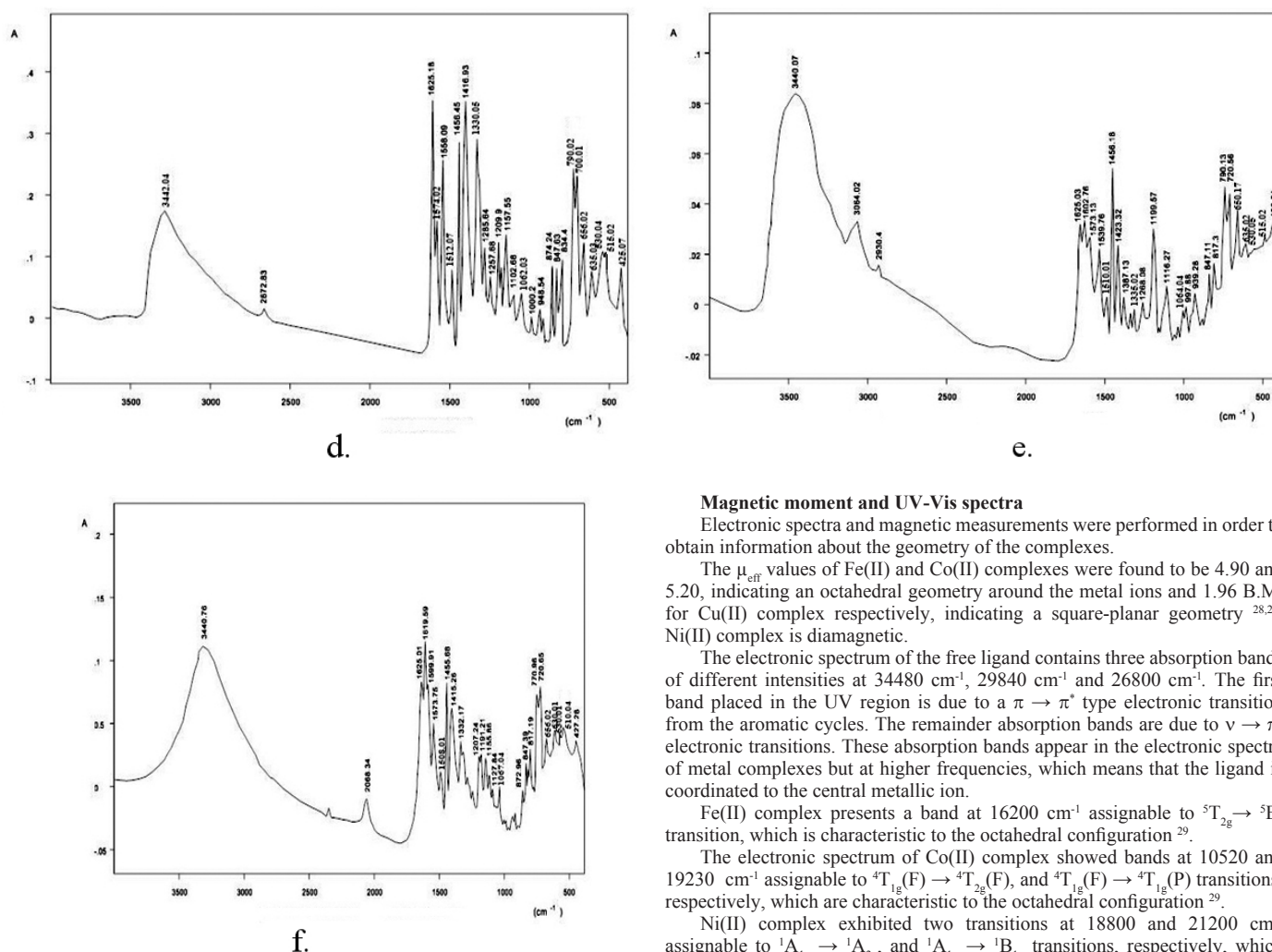


Fig. 2. IR spectra of the ligand (a) and its complexes: [FeL₂Cl₂] (b); [CoL₂Cl₂] (c); [NiL₂Cl₂] (d); [CuL₂Cl₂] (e); [ZnL₂Cl₂] (f).

Table 2. IR data (4000 - 400 cm⁻¹) of the thioamide (L) and its complexes

L	[FeL ₂ Cl ₂]	[CoL ₂ Cl ₂]	[NiL ₂ Cl ₂]	[CuL ₂ Cl ₂]	[ZnL ₂ Cl ₂]	Assignments
3452	3442	3442	3442	3440	3440	ν_{NH}
1625	1625	1625	1625	1625	1625	$\nu_{\text{C=N py}}$
1583	1572	1573	1574	1573	1573	δ_{NH}
1496	1510	1508	1512	1510	1508	Thioamide I $\nu(\text{C-N})+\delta(\text{C-H})$
1320	1330	1333	1330	1335	1332	Thioamide II $\nu(\text{C-N})+\delta(\text{CH})+\nu(\text{C=S})$
1048	1065	1060	1062	1064	1067	Thioamide III $\nu(\text{C-N})+\nu(\text{C=S})$
785	810 720	810 710	790 700	790 720	770 720	Thioamide IV $\nu_s(\text{C-S})+\nu_{as}(\text{C=S})$
676	660 635	660 630	656 635	650 635	656 630	$\delta(\text{C-S})$
530	515 520	510 525	515 530	515 530	510 530	$\pi(\text{C-S})$
-	425	415	425	430	427	M-N

Magnetic moment and UV-Vis spectra

Electronic spectra and magnetic measurements were performed in order to obtain information about the geometry of the complexes.

The μ_{eff} values of Fe(II) and Co(II) complexes were found to be 4.90 and 5.20, indicating an octahedral geometry around the metal ions and 1.96 B.M. for Cu(II) complex respectively, indicating a square-planar geometry^{28,29}. Ni(II) complex is diamagnetic.

The electronic spectrum of the free ligand contains three absorption bands of different intensities at 34480 cm⁻¹, 29840 cm⁻¹ and 26800 cm⁻¹. The first band placed in the UV region is due to a $\pi \rightarrow \pi^*$ type electronic transition from the aromatic cycles. The remainder absorption bands are due to $\nu \rightarrow \pi^*$ electronic transitions. These absorption bands appear in the electronic spectra of metal complexes but at higher frequencies, which means that the ligand is coordinated to the central metallic ion.

Fe(II) complex presents a band at 16200 cm⁻¹ assignable to ${}^5T_{2g} \rightarrow {}^5E_g$ transition, which is characteristic to the octahedral configuration²⁹.

The electronic spectrum of Co(II) complex showed bands at 10520 and 19230 cm⁻¹ assignable to ${}^4T_{1g}(\text{F}) \rightarrow {}^4T_{2g}(\text{F})$ and ${}^4T_{1g}(\text{F}) \rightarrow {}^4T_{1g}(\text{P})$ transitions, respectively, which are characteristic to the octahedral configuration²⁹.

Ni(II) complex exhibited two transitions at 18800 and 21200 cm⁻¹ assignable to ${}^1A_{1g} \rightarrow {}^1A_{2g}$ and ${}^1A_{1g} \rightarrow {}^1B_{1g}$ transitions, respectively, which correspond to a square-planar geometry²⁹.

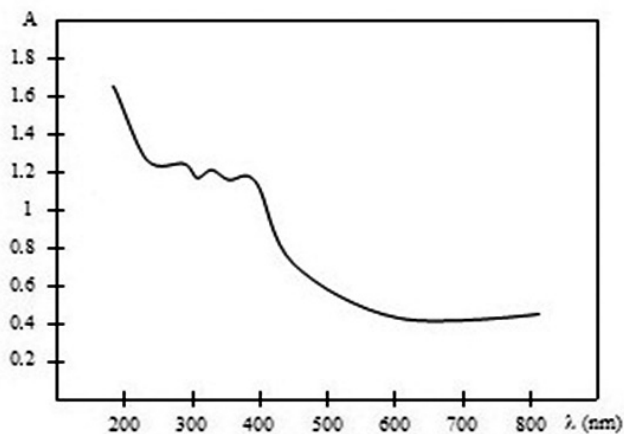
The UV-vis spectrum of Cu(II) complex displays a broad band at 18691 cm⁻¹ attributable to ${}^2B_{1g} \rightarrow {}^2A_{1g}$ transition, which favours the square-planar geometry around the central metallic ion²⁹.

Zn(II) complex presents no absorption band in the visible domain. This is in agreement with the electronic structure of the central metallic ion with a d^{10} electronic configuration, for which the crystal field theory does not predict the presence of absorption bands in the visible domain. The absorption bands, which appear in the UV domain, are considered to be characteristic to the ligand. The assignment of $n \rightarrow \pi^*$ and $\pi \rightarrow \pi^*$ transitions due to the C=S bond was made based on Sandstrom's investigations³⁰. On the basis of analytical, conductance and infrared spectral data, a tetrahedral geometry is proposed for Zn(II) complex.

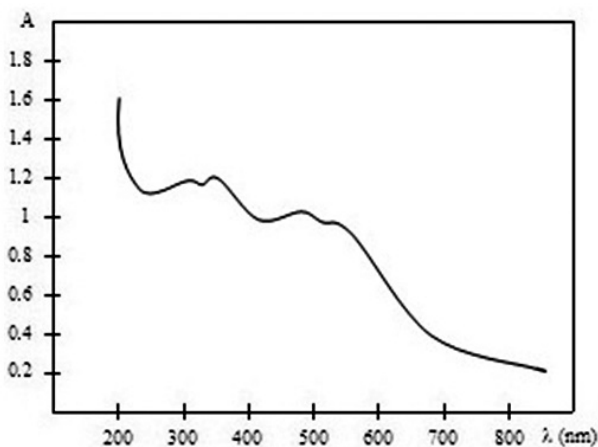
A quantum-mechanical study of the electronic spectra of the free and coordinated ligand

The structural formulae of the free and coordinated ligand were modeled on the computer and their molecular geometry was optimized using the Molecular Mechanics approach (MM⁺), the cartesian coordinates of the atoms being used to perform EHT calculations.

The electronic spectrum of the free ligand presented in Fig. 3(a) contains three absorption bands of different intensities at 34480 cm^{-1} (290 nm), 29840 cm^{-1} (335 nm) and 26800 cm^{-1} (373 nm). The first and very intense maximum absorption is due to a $\pi \rightarrow \pi^*$ type electronic transition from the aromatic cycles. The remainder absorption bands are due to $\nu \rightarrow \pi^*$ electronic transitions.



a.



b.

Fig. 3. Electronic spectra of the ligand (a) and Ni(II) complex (b).

The EHT calculations, which estimate molecular levels and their wave functions (molecular orbitals), were made for the assignment of $n \rightarrow \pi^*$ electronic transitions. The numbering of the energy levels and of the molecular wave functions was given by the ICONC program.³¹

The molecular wave functions presented below, which are associated to the electronic levels occupied by the duplicate electrons, contain mixing coefficients of the atomic orbitals belonging to the atoms with considerable values:

$$\begin{aligned} \Psi_{50} &\approx \alpha - 0.6802 O_{2pz} & E_{50} &= - 11.95 \text{ eV} \\ \Psi_{52} &\approx \alpha - 0.7793 O_{2px} & E_{52} &= - 12.46 \text{ eV} \\ \Psi_{47} &\approx \alpha - 0.9109 S_{2py} & E_{47} &= - 11.19 \text{ eV} \\ \Psi_{48} &\approx \alpha - 0.2502 N_{2px} + 0.3829 N_{2pz} & E_{48} &= - 11.78 \text{ eV} \\ \Psi_{49} &\approx \alpha - 0.2502 N(1)_{2px} + 0.3829 N(1)_{2pz} & E_{49} &= - 10.08 \text{ eV} \end{aligned}$$

The possible transitions from these electronic levels having electronic density localized on the oxygen, sulphur and nitrogen heteroatoms were analysed with the special EDIT software from the ICONC-EDIT software package. The x, y, z components of the power of the oscillator, which is a measurement of the electronic transition intensity, were calculated with the same software. The electronic transitions in which the heteroatoms are involved and the x, y, z components of the power of the oscillator are presented in Table 3.

The EHT calculations were performed for the electronic spectrum of the Ni(II) complex in order to analyze how $\nu \rightarrow \pi^*$ electronic transitions are affected when the heteroatoms are coordinated to the metallic ion. The electronic spectrum of Ni(II) complex (Fig. 3(b)) presents four absorption bands at 32200 cm^{-1} (310 nm) and 28500 cm^{-1} (350 nm), 21200 cm^{-1} (471 nm) and 18800 cm^{-1} (531 nm). The first two absorption bands are assigned to $\nu \rightarrow \pi^*$ electronic transitions and the remainder absorption bands are due to $\delta \rightarrow \delta$ electronic transitions. The quantum-molecular calculations and the chemical modelling were made in the same way as for the free ligand. Molecular wave functions, which contain mixing coefficients with considerable values of the heteroatoms, are presented below:

$$\begin{aligned} \Psi_{54} &\approx \alpha - 0.4712 O_{2px} - 0.4360 O_{2pz} & E_{54} &= - 11.94 \text{ eV} \\ \Psi_{55} &\approx \alpha - 0.266 S_{2py} - 0.2402 S_{2pz} & E_{55} &= - 11.76 \text{ eV} \\ \Psi_{43} &\approx 0.4150 N_{2px} & E_{43} &= - 11.54 \text{ eV} \\ \Psi_{45} &\approx 0.4150 N(1)_{2px} & E_{45} &= - 10.02 \text{ eV} \end{aligned}$$

The electronic transitions, in which the heteroatoms are involved, were analyzed using EDIT program and the results are presented in Table 3 together with x, y, z components of the power of the oscillator. By comparing $n(S) \rightarrow \pi^*$ and $n(N) \rightarrow \pi^*$ transitions in the electronic spectra of the free and coordinated ligand, it may be noticed that these transitions shift towards higher wavenumbers. Also, the x, y, z components of the power of the oscillator, which correspond to $n(S) \rightarrow \pi^*$ and $n(N) \rightarrow \pi^*$ transitions in the coordinated ligand, are more intense than in the free ligand. These changes indicate that the sulphur and nitrogen atoms of the thioamide group are coordinated to the metallic ion. Indeed, by coordination, the orbitals of the donor atom participate in the formation of molecular bonding levels, which have lower energy than their energies in the free ligand. This explains the change of place of the transitions towards higher wavenumbers.

EPR and NMR spectra

The EPR spectrum of [CuL₂]Cl₂ complex, which is given in Fig. 4, is intense and anisotropic, with parameters: $g_{||} = 2.2402$ and $g_{\perp} = 2.0702$. Such spectrum ($g_{||} > g_{\perp} > 2$) is consistent with a square-planar stereochemistry and with the unpaired electron, which lies in the $d_{x^2-y^2}$.³²

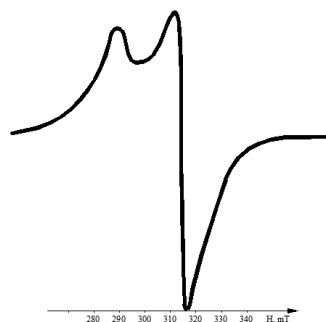
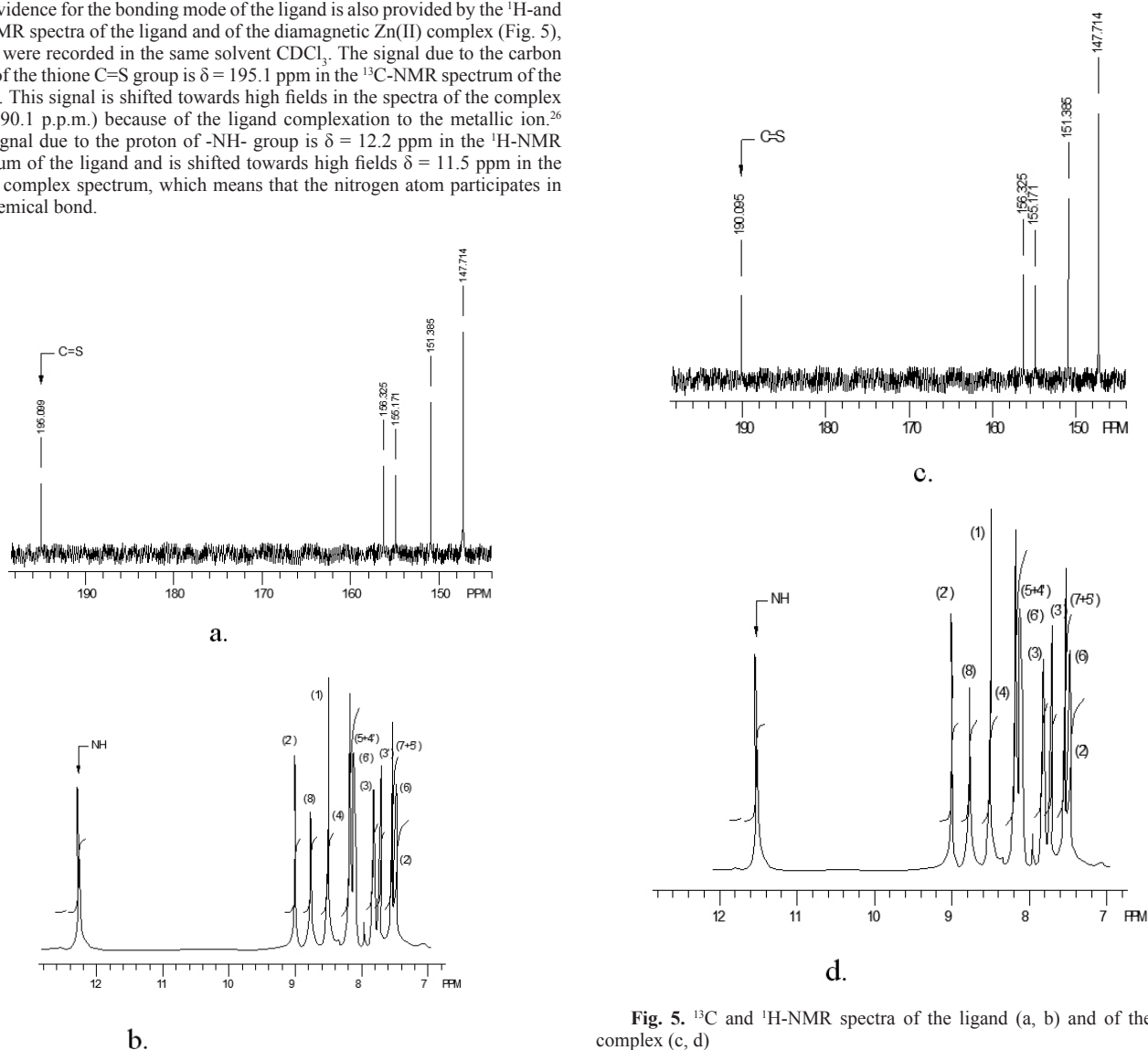


Fig. 4. EPR spectrum for the cooper complex.

Table 3. The calculated and experimental $n \rightarrow \pi^*$ electronic transitions and the power of the oscillator for the free and coordinated ligand.

Assignment	Electronic transitions	ν_{calcd} (cm ⁻¹)	The power of the oscillator			ν_{exp} (cm ⁻¹)
			x	y	z	
free ligand						
n(S) \rightarrow π^*	$\Psi_{48} \rightarrow \Psi_{47}$	29900	0.04058	0.01960	0.02155	29840
n(N) \rightarrow π^*	$\Psi_{49} \rightarrow \Psi_{47}$	27600	0.02068	0.02029	0.07645	26800
n(N1') \rightarrow π^*	$\Psi_{49} \rightarrow \Psi_{45}$	23787	0.00998	0.00026	0.00153	-
n(O) \rightarrow π^*	$\Psi_{50} \rightarrow \Psi_{44}$	29490	0.00800	0.00474	0.00089	-
coordinated ligand						
n(S) \rightarrow π^*	$\Psi_{54} \rightarrow \Psi_{51}$	31500	0.26694	0.02249	0.15023	32200
n(N) \rightarrow π^*	$\Psi_{43} \rightarrow \Psi_{47}$	27800	0.02888	0.23221	0.09704	28500
n(N1') \rightarrow π^*	$\Psi_{45} \rightarrow \Psi_{49}$	21750	0.00080	0.00021	0.05704	-
n(O) \rightarrow π^*	$\Psi_{55} \rightarrow \Psi_{48}$	24004	0.00165	0.00073	0.05030	-

Evidence for the bonding mode of the ligand is also provided by the ¹H- and ¹³C-NMR spectra of the ligand and of the diamagnetic Zn(II) complex (Fig. 5), which were recorded in the same solvent CDCl₃. The signal due to the carbon atom of the thione C=S group is $\delta = 195.1$ ppm in the ¹³C-NMR spectrum of the ligand. This signal is shifted towards high fields in the spectra of the complex ($\delta = 190.1$ p.p.m.) because of the ligand complexation to the metallic ion.²⁶ The signal due to the proton of -NH- group is $\delta = 12.2$ ppm in the ¹H-NMR spectrum of the ligand and is shifted towards high fields $\delta = 11.5$ ppm in the Zn(II) complex spectrum, which means that the nitrogen atom participates in the chemical bond.

**Fig. 5.** ¹³C and ¹H-NMR spectra of the ligand (a, b) and of the Zn(II) complex (c, d)

Thermogravimetric analyses

Thermogravimetric analysis was performed for the Co(II), Ni(II) and Cu(II) complexes. The thermograms of these complexes show nearly the same pattern. The thermal decomposition of the complexes occurs in two different steps. The first one, between 210 - 450 °C, indicates a decomposition of one molecule of organic ligand; the second one, between 450 - 870 °C, corresponds to some decomposition complex processes of the other ligand molecule and oxidation of the remaining compounds. The chemical analysis of the black final residue did not indicate the presence of carbon, nitrogen, sulphur or hydrogen in its composition; it corresponds to the metallic oxides Co_3O_4 , NiO and CuO, respectively.

The thermal stability of the complexes was deduced in the order Ni(II) > Co(II) > Cu(II), based on the values of the initial decomposition temperatures.

On the basis of the above observations, the structures for the complexes may be proposed as follows: an octahedral geometry for Fe(II) and Co(II) complexes, a square-planar for Ni(II) and Cu(II) complexes and a tetrahedral geometry for Zn(II) complex. The metal complex structures are given in Fig. 6.

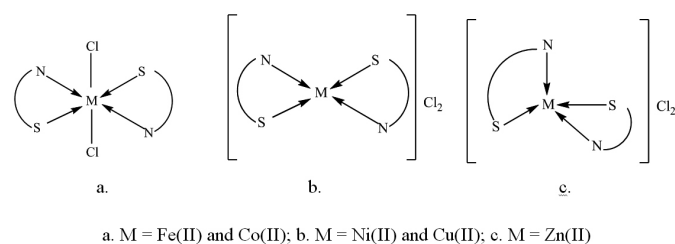


Fig. 6. Structural formulae of the metal complexes

Antibacterial activity

The ligand and its metal complexes were screened for their antibacterial activity and the results are presented in Fig. 7.

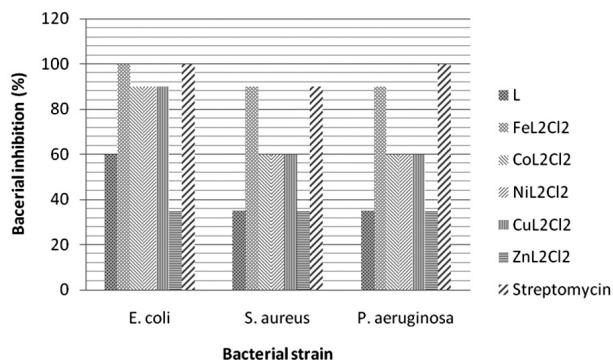


Fig. 7. Biological activity of the thioamide and its complexes

Comparing the biological activity of the thioamide and its metal complexes with the standard (streptomycin), the following results were obtained: the biological activity of the thioamide was less than that of streptomycin; the biological activity of the metal complexes was higher than that of the free ligand and the biological activity of the Fe(II) complex was equal to that of standard, while the biological activity of the other metal complexes was less than that of the standard; the biological activity of the complexes follows the order: Fe(II) > Co(II) = Ni(II) = Cu(II) > Zn(II). Furthermore, the data show that *E. coli* was inhibited to the greatest degree by the Fe(II) complex, followed by the Co(II), Ni(II), Cu(II) and Zn(II) complexes.

A possible explanation for the increased activity upon chelation is that in the chelated complex, the positive charge of the metal ion is partially shared with the donor atoms of the ligand and a π -electron delocalization occurs over the whole chelate ring, increasing in this way the lipophilic character of the metal chelate and favouring its permeation through the lipid layers of the bacterial membranes and blocking the metal binding sites in the enzymes or microorganism.³⁵ Other factors such as solubility, conductivity and dipole moment (influenced by the presence of metal ions) may also be the possible reasons for increasing this activity.

CONCLUSIONS

In this paper, some new metallic complexes with a thioamide ligand 3-thionicotinoylaminodibenzofuran were prepared and characterized. The complexes have the following molecular formulae: $[\text{ML}_2\text{Cl}_2]$ where M = Fe(II) and Co(II); $[\text{ML}_2]\text{Cl}_2$ where M = Ni(II), Cu(II) and Zn(II). Electronic spectra and magnetic measurements gave information about the geometry of the complexes: Fe(II) and Co(II) complexes have octahedral geometry, Ni(II) and Cu(II) complex have a square-planar geometry, while Zn(II) complex has a tetrahedral geometry. The biological activity of all the complexes is higher than that of the free thioamide ligand and follow the order: Fe(II) > Co(II) = Ni(II) = Cu(II) > Zn(II). This means that the metal chelation significantly affects the antimicrobial behaviour of the organic ligand. The metal complexes prepared with 3-thionicotinoylaminodibenzofuran could reasonably be used for the treatment of some common diseases caused by *E. coli*.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the *Filantropia* Clinic Hospital, Clinical Laboratory, Craiova, Romania, for performing the antibacterial studies.

REFERENCES

- P. Wipf, V. Venkatraman, *J. Org. Chem.* **61**, 8004, (1996).
- O. A. Attanasi, S. Berretta, L. D. Crescentini, G. Favi, F. Filippone, G. Giorgi, S. Lillini, F. Mantellini, *Tetrahedron Lett.* **48**, 2449, (2007).
- S. P. McManus, K.Y. Lee, C. U. Pittman, *J. Org. Chem.* **39**, 3041, (1974).
- T. S. Jagodziński, *T.S. Chem. Rev.* **103**, 197, (2003).
- H. Prokopcová, C. O. Kappe, *J. Org. Chem.* **72**, 4440, (2007).
- S. Yadav, O. P. Pandey, S. K. Sengupta, *Transition Metal Chemistry* **20**(2), 107, (1995).
- R. M. Oik, B. Oik, W. Dietzsch, R. Kirmse, E. Hoyer, *Coordination Chemistry Reviews* **117**, 99, (1992).
- P. J. Blower, J. R. Dilworth, *Coordination Chemistry Reviews* **76**, 121, (1987).
- K. A. Petrov, L. N. Andreev, *Usp. Khim.* **38**, 41, (1969).
- T. A. Vannelli, A. Dykman, P. R. O. de Montellano, *J. Biol. Chem.* **277**, 12824, (2002).
- X. Hanouille, J. M. Wieruszkeski, P. Rousselot-Pailley, I. Landrieu, A. R. Baulard, G. Lippens, *Biochem. Biophys. Res. Commun.* **331**, 452, (2005).
- C. Vilchère, T. R. Weisbrod, B. Chen, L. Kremer, M. H. Hazbón, F. Wang, D. Alland, J. C. Sacchetti, W. R. Jacobs, Jr., *Antimicrob. Agents Chemother.* **49**, 708, (2005).
- K. L. Yu, A. F. Torri, G. Luo, C. Cianci, K. Grant-Young, S. Danetz, L. Tiley, M. Krystal, N. A. Meanwell, *Bioorg. Med. Chem. Lett.* **12**, 3379, (2002).
- Y. Hitotsuyanagi, T. Hasuda, Y. Matsumoto, K. Yamaguchi, H. Itokawa, K. Takeya, *Chem. Commun.* 1633, (2000).
- Y. Nakagawa, K. Irie, H. Ohgashi, H. Hayashi, P. A. Wender, *Bioorg. Med. Chem. Lett.* **10**, 2087, (2000).
- M. P. Wentland, X. Sun, Y. Bu, R. Lou, D. J. Cohen, J. M. Bidlack, *Bioorg. Med. Chem. Lett.* **15**, 2547, (2005).
- Q. L. Wei, S. S. Zhang, J. Gao, W. H. Li, L. Z. Xu, G. Z. Yu, *Bioorg. Med. Chem.* **14**, 7146, (2006).
- E. S. Raper, *Coord. Chem. Rev.* **153**, 199, (1996).
- S. Sinha, A. K. Srivastava, C. M. Tripathi, O. P. Pandey, S. K. Sengupta, *Bioinorg. Chem. Appl.* 87918, (2007).
- A. Kriza, A. Reiss, V. Mureşan, S. Florea, *J. Indian. Chem. Soc.* **76**(8), 406, (1999).
- A. Reiss, S. Florea, W. D. Rudolf, *Polish J. Chem.* **74**, 589, (2000).
- A. Kriza, A. Reiss, N. Stanica, *Rev. Roum. de Chimie* **46**(5), 503, (2001).
- S. Florea, *Rev. Roum. Chim.*, **39**, 1138, (1994).
- K. A. Jensen, P. H. Nielsen, *Acta Chem. Scand.* **20**, 597, (1996).
- H. O. Desseyn, M. A. Herman, *Spectrochim. Acta* **23A**, 2457, (1967).
- E. S. Raper, *Coord. Chem. Rev.* **61**, 115, (1985).
- K. Nakamoto *Infrared spectra of inorganic and coordination compound*, Elsevier, New York, 1986.
- B. P. Figgins *Introduction to Ligand Fields*, Wiley-J, New York, 1976.
- A. B. P. Lever *Inorganic Electronic Spectra*, Elsevier, New York, 1984.
- J. Sandstrom, *J. Acta Chem. Scand.* **16**, 1916, (1962).
- G. Calzaferri, M. Brände, *QPCE Bulletin* **12**, 73, (1992).
- B. J. Hathaway, D. E. Billing, *Coord. Chem. Rev.* **5**, 143, (1970).
- E. Duca, M. Duca *Microbiologie medicală*, Ed. Did. și Ped. Buc., 1979.
- V. Zotta *Chimie farmaceutică*, Ed. Medicală, București, 1985.
- Z. H. Chohan, S. Kausar, *Metal- Based Drugs* **7**(1), 17, (2000).