

# Synthesis, Characterization and Antibacterial Activity of Co(II) and Cu(II) Complexes of N,N'-bis-(salicylidene)-o-tolidine

IONELA ALAN<sup>1</sup>, ANGELA KRIZA<sup>1</sup>, NICOLAE STANICA<sup>2</sup>, CONSTANTIN DRAGHICI<sup>3</sup>, GABRIELA LAURA ALMAJAN<sup>4\*</sup>

<sup>1</sup> University of Bucharest, Faculty of Chemistry, Inorganic Chemistry Department, Dumbrava Rosie Street 23, 020462 Bucharest, Romania

<sup>2</sup> Romanian Academy, Ilie Murgulescu Physical Chemistry Institute, 202 Splaiul Independentei, 77208, Bucharest, Romania

<sup>3</sup> Romanian Academy, C.D. Nenitescu Organic Chemistry Center, 202B Splaiul Independentei, 060023 Bucharest, Romania

<sup>4</sup> University of Medicine and Pharmacy, Faculty of Pharmacy, Organic Chemistry Department, 6 Traian Vuia Str., 020956 Bucharest, Romania

*Co(II) and Cu(II) complexes of Schiff base N,N'-bis-(salicylidene)-o-tolidine (OTSA) are reported and characterized based on elemental analyses, IR, EPR, solid reflectance, magnetic moment, molar conductance and cyclic voltammogram. Their low electrical conductance values indicate that all the complexes are non-electrolytes. The obtained spectral data suggest that Co(II) complexes have distorted octahedral geometry and Cu(II) complexes have pseudo-tetrahedral, distorted octahedral and square-planar geometry, depending on the copper salt and the molar ratio ligand: copper ion used. In all complexes, OTSA acts as binegative tetradentate, around the metallic ion, while in **3** and **6** acts as mononegative bidentate. The synthesized compounds have been tested against Staphylococcus aureus ATCC 25923; Enterococcus faecalis ATCC 29212, Escherichia coli ATCC 25922; Pseudomonas aeruginosa ATCC 27853. A comparative study of the MIC values indicates that the tetracoordinated complexes have better action than the hexacoordinated compounds and the Cu(II) complexes are more active than Co(II) complexes.*

**Keywords:** Schiff base, Co(II), Cu(II) complexes, antibacterial activity

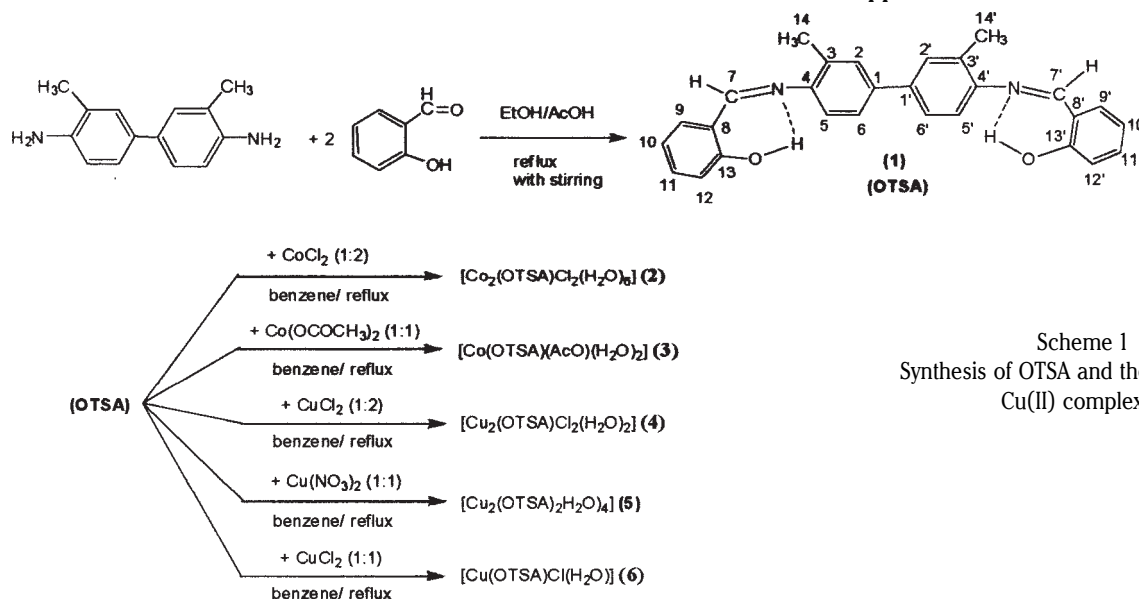
The coordination chemistry of Schiff bases derived from the reaction of salicylaldehyde and diamines has been the subject of many studies and a number of them are used as oxygen carriers to mimic complicated biological systems [1-5]. Schiff bases ligands have an affinity for transitional metals such as Cu, Co, Ni, Zn, Mn, Fe. Some of these complexes have been studied in great deal for their various structures, steric effects and their coordination chemistry [6,7].

Schiff bases derived from aromatic substituted diamines and salicylaldehyde are usually tetradentate with N<sub>2</sub>O<sub>2</sub> donor set, but they can also act in a neutral or monobasic bidentate manner [8]. In view of this and in continuation of

our studies of Schiff bases complexes [9,10], this paper described the synthesis and characterization of Cu(II) and Co(II) complexes obtained by reaction of N,N'-bis-(salicylidene)-o-tolidine (OTSA) with various metal salts (Scheme 1). These studies have been mainly directed toward identifying the group directly attached to the metal site and establishing the structure of the coordination compounds thus formed. More, these complexes were also tested for their antibacterial activity comparatively with that of the free ligand.

## Experimental part

The melting points were determined with Stuart Scientific SMP3 apparatus and are uncorrected. The content



Scheme 1  
Synthesis of OTSA and their Co(II) and Cu(II) complexes

\* email: laura.almajan@gmail.com ; Tel.: +40 741 095490

of metallic ions was determined by atomic absorption spectroscopy with Varian-A240 spectrometer; C, H, and N were done with ECS-40-10-Costeh microdosimeter, after drying the compounds at 105°C. The molar conductivity was determined in DMF (10<sup>-3</sup> M), at room temperature, using Consort C533 conductometer. Electronic spectra were recorded by the diffuse-reflectance technique, using MgO as diluting matrix, on a JASCO UV-VIS 540 spectrophotometer. IR spectra were recorded with Fourier FTS-135 BioRad spectrophotometer in the 4000–400 cm<sup>-1</sup> region using KBr pellets and with Escalibur FT-IR/ATR in the 400–150 cm<sup>-1</sup> region. Cyclic voltammetry was performed using a UNISCAN PG 580 or Voltalab 80 system. The NMR spectra were registered on a Varian Gemini 300 BB spectrometer working at 300 MHz for <sup>1</sup>H and 75 MHz for <sup>13</sup>C in DMSO-d<sub>6</sub>. All chemical shifts are reported in δ (ppm) using TMS as an internal standard. The mass spectra of ligand was registered with a triple quadrupole mass spectrometer Varian 1200 L/MS/MS coupled with a high performance liquid chromatograph with Varian ProStar 240 pump and a Varian ProStar 410 automatic injector. For the obtainment of ions was used an electrospray interface (ESI). The solvent used was DMSO the mobile phase was 30% water and 70% methanol. The required chemicals were purchased from Merck and Sigma-Aldrich and all manipulations were performed using materials as received.

#### Synthesis of *N, N'*-bis-(salicylidene)-*o*-tolidine (1) (OTSA) [11]

*o*-Tolidine (2.5g; 11.8 mmol) is dissolved in hot ethanol (50 cm<sup>3</sup>). Then add 2-3 drops of glacial acetic acid and salicylaldehyde (2.875g; 23.6 mmol). The obtained reaction mixture, intense yellow colored, was refluxed with boiling for 4 h, under constant stirring. After cooling, orange crystals were collected by filtration and recrystallized from benzene.

89% yield; m.p. = 204°C (lit. 200°C); Anal. Calc. (%) for C<sub>28</sub>H<sub>24</sub>N<sub>2</sub>O<sub>2</sub> (420.50 g/mol): C-79.98; H-5.75; N-6.66; Exp.: C-79.91; H-5.70; N-6.60; IR (KBr, cm<sup>-1</sup>): 3455m (OH), 3056m (CH<sub>ar</sub>), 2969m, 2917w (CH<sub>2</sub>), 2718w (NH...O), 1617s (C=N), 1565s, 1483m (C=C<sub>ar</sub>); ESI-MS, *m/z* (%): 420.18 (33); 180.90 (100); 120.09 (25); <sup>1</sup>H-RMN (DMSO-d<sub>6</sub>, δ, ppm): 13.38 (s; 2H; OH); 8.97 (s; 2H; H-7,7'); 7.68 (m; 6H; H-2,2',5,5',6,6'); 7.44 (m; 6H; H-9,9',11,11',12,12'); 6.99 (bd; *J*=7.7 Hz; 2H; H-10,10'); 2.42 (s; 2H; H-14,14'); <sup>13</sup>C-RMN (DMSO-d<sub>6</sub>, δ, ppm): 162.72 (C-7,7'); 160.49 (C-13,13'); 146.05 (C-4,4'); 137.86 (C-1,1'); 133.30 (C-12,12'); 132.62 (C-2,2'); 132.50 (C-3,3'); 128.59 (C-6,6'); 125.16 (C-5,5'); 119.48 (C-13,13'); 119.13 (C-10,10'); 118.52 (C-11,11'); 116.61 (C-12,12'); 17.97 (C-14,14').

#### Synthesis of complexes

We prepared the complexes with CoCl<sub>2</sub>, Co(OCOCH<sub>3</sub>)<sub>2</sub>·xH<sub>2</sub>O, CuCl<sub>2</sub>, Cu(NO<sub>3</sub>)<sub>2</sub>. The ethanolic solution of metallic ion (1 mmol salt/5 mL ethanol) was mixed with stirring with a hot clear solution of OTSA in benzene (2 mmol OTSA/20 mL benzene) in molar ratio M:L= 1:1 for (3), (5), (6) and 1:2 for (2) and (4). After refluxing the contents, colored complex were separated out in each case. They were filtered, washed successively with hot ethanol, cold ethanol, hot benzene and diethyl ether and finally dried under vacuum.

Co(II) and Cu(II) complexes were found to be air stable and insoluble in water, alcohol, but soluble in DMSO and DMF. The analytical data of the complexes together with some physical properties are summarized in table 1. The molar conductivity values (DMF, 10<sup>-3</sup> M) indicate that these complexes are non-electrolytes.

#### Antibacterial activity

The synthesized compounds were tested for their in vitro antimicrobial activity against the Gram-positive bacteria (*Staphylococcus aureus* ATCC 25923; *Enterococcus faecalis* ATCC 29212), Gram-negative bacteria (*Escherichia coli* ATCC 25922; *Pseudomonas aeruginosa* ATCC 27853) by using the broth dilution method [12,13] for determination of MIC. Streptomycin was used as control drug. The materials used were 96-well plates, suspensions of microorganism (0.5 McFarland), Muller–Hinton broth (Merck), solutions of the substances to be tested (2048 µg/mL in DMSO). The following concentrations of the substances to be tested were obtained in the 96-well plates: 1024, 512, 256, 128, 64, 32, 16, 8, 4, 2 µg/mL. After incubation at 37°C for 18–24 h, the MIC for each tested substance was determined by macroscopic observation of microbial growth. It corresponds to the well with the lowest concentration of the tested substance where microbial growth was clearly inhibited.

#### Results and discussion

##### IR spectra

The characteristic bands in the IR spectra of the ligand and its metal complexes are listed in table 2. The shift of νC=N to lower frequency in all IR spectra of the complexes indicating that the azomethine nitrogen atom coordinates to the metal ion. This result is in accordance with the expectation that N-coordination to a metal ion having filled π-orbital should result in a shift towards the lower energy region in the νC=N [14]. The broad band that appeared in the IR spectrum of OTSA at 2718 cm<sup>-1</sup> is assigned to the

Table 1  
ANALYTICAL AND PHYSICAL CHARACTERIZATION OF THE TITLE COMPOUNDS

No.	Compound	Molecular formula	Melting point (°C)	Color	Elemental analysis <sup>*</sup>				Λ (ohm <sup>-1</sup> .cm <sup>2</sup> .mol <sup>-1</sup> )
					Calc.(exp)				
					C	H	N	M	
2	[Co <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>6</sub> ]	C <sub>28</sub> H <sub>34</sub> Cl <sub>2</sub> Co <sub>2</sub> N <sub>2</sub> O <sub>8</sub>	335	reddish brown	47,01 (46,91)	4,79 (4,63)	3,92 (3,84)	16,48 (16,35)	25,9
3	[Co(OTSA)(AcO)(H <sub>2</sub> O) <sub>2</sub> ]	C <sub>30</sub> H <sub>32</sub> CoN <sub>2</sub> O <sub>6</sub>	330	red	62,61 (62,54)	5,60 (5,51)	4,87 (4,75)	10,24 (10,12)	46,8
4	[Cu <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>2</sub> ]	C <sub>28</sub> H <sub>24</sub> Cl <sub>2</sub> Cu <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	230	dark green	51,70 (51,59)	3,72 (3,63)	4,31 (4,22)	19,54 (19,51)	29,8
5	[Cu <sub>2</sub> (OTSA) <sub>2</sub> (H <sub>2</sub> O) <sub>4</sub> ]	C <sub>56</sub> H <sub>52</sub> Cu <sub>2</sub> N <sub>2</sub> O <sub>8</sub>	335	green	64,91 (64,86)	5,06 (4,95)	5,41 (5,36)	12,27 (12,14)	43,5
6	[Cu(OTSA)Cl(H <sub>2</sub> O)]	C <sub>28</sub> H <sub>23</sub> ClCuN <sub>2</sub> O <sub>3</sub>	300	green	62,92 (62,80)	4,34 (4,25)	5,24 (5,09)	11,89 (11,72)	23,8

\* Elemental analysis value limit = ± 0.4% of the theoretical value

**Table 2**  
INFRARED ABSORPTION FREQUENCIES (CM<sup>-1</sup>) OF THE NEW OBTAINED COMPLEXES

No	Compound	$\nu$ OH, H <sub>2</sub> O	$\nu$ NH...O	$\nu$ C=N	$\nu$ acetate	$\nu$ C-O	$\delta$ H <sub>2</sub> O	$\nu$ M-O, M-N M-Cl
1	OTSA	3455	2718	1617	-	1368	-	-
2	[Co <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>6</sub> ]	3471	-	1610	-	1354	888 763	521 453 222
3	[Co(OTSA)(AcO)(H <sub>2</sub> O) <sub>2</sub> ]	3405	2759	1601	1516 1433	1316	868 773	507 451
4	[Cu <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>2</sub> ]	3461	-	1601	-	1275	878 778	520 485 244
5	[Cu <sub>2</sub> (OTSA) <sub>2</sub> (H <sub>2</sub> O) <sub>4</sub> ]	3424	-	1605	-	1275	871 784	584 488
6	[Cu(OTSA)Cl(H <sub>2</sub> O)]	3438	2728	1611	-	1269	880 766	527 460 250

stretching vibration of the intramolecular hydrogen bonded OH in the molecule [15]. This band disappears in all complexes (except **3** and **6**). Better than that the new band in the 1269-1381 cm<sup>-1</sup> region, which is attributed to the valence vibration of C-O bond, confirmed the deprotonation of phenolic OH group of the ligand and complexation to the metal ion by this group [15]. These results suggest the bidentate behaviour for OTSA. For compounds **3** and **6**, the presence of characteristic bands of intramolecular hydrogen bonded at 2759 and 2728 cm<sup>-1</sup>, confirms in these case, that the ligand behaves mononegative bidentate [16,17]. The coordinated bidentate acetate ion in the Co(II) acetate complex **3** is confirmed by the existence of two bands at 1516 and 1433 cm<sup>-1</sup> assigned to  $\nu$  asymmetric and  $\nu$  symmetric acetate. The difference between the two frequencies is less than 100 cm<sup>-1</sup>, value which confirm the presence of bidentate mononegative acetate [16,17]. All compounds exhibit a broad and relatively intense band around 3400 cm<sup>-1</sup> which indicates the presence of water molecules. This band corresponds to the (O-H) stretching vibration. For all the complexes, this band is accompanied by two new bands in the 700-800 cm<sup>-1</sup> range, assigned to the rocking and wagging modes of (O-H) group [16,18]. This suggests that the water molecules are indeed coordinated. Additionally, all spectra of **2-6** exhibit two bands which are not found in the free ligand spectrum. These bands appear at lower frequencies, in the 400-500 cm<sup>-1</sup> range, have medium intensity and correspond to the stretching vibration of the new M-N and M-O bonds [16, 19,20].

#### Electronic spectra and magnetic studies

The nature of the ligand field around metal ion and the geometry of the metal complexes have been deduced from the electronic spectra and magnetic moment data of the complexes (table 3). Cobalt(II) complexes **2** and **3** exhibit a typical electronic spectrum for octahedral species in the solid state [21,22]. Two main bands are observed at 14,684, 15,890 cm<sup>-1</sup> and 17,761, 18,790 cm<sup>-1</sup> respectively, which are assigned to <sup>4</sup>A<sub>2g</sub>(F) ← <sup>4</sup>T<sub>1g</sub>(F) ( $\nu_2$ ) and <sup>4</sup>T<sub>1g</sub>(P) ← <sup>4</sup>T<sub>1g</sub>(F) ( $\nu_3$ ) transitions. The band  $\nu_1$ , due the transition <sup>4</sup>T<sub>1g</sub>(F) ← <sup>4</sup>T<sub>2g</sub>(F) which is usually under 10,000 cm<sup>-1</sup>, as ligand field parameters, 10Dq, B and  $\beta$  were calculated using the following equations:

$$10Dq = 1/3 (2\nu_2 - \nu_3) + 5B$$

$$B = 1/510 [7(\nu_3 - 2\nu_2) \pm 3 \{81\nu_3^2 - 16(\nu_2 - \nu_3)\}^{1/2}]$$

$$10Dq = (\nu_2 - \nu_1)$$

The calculated values of the ligand field parameters 10Dq = 7839 cm<sup>-1</sup>, B = 794 cm<sup>-1</sup> for **2** and 10Dq = 8416 cm<sup>-1</sup>, B = 817 cm<sup>-1</sup> for **3** are in good agreement with the predicted values for octahedral complexes of Co(II) [23]. The nephelauxetic ratio  $\beta = B/B_0 = 0.82$  for the complex **2** and 0.84 for complex **3** suggesting an ionic character of cobalt(II)-ligand bonds [24]. The room temperature magnetic moment values, 4.8-5.8 B.M., demonstrate that the Co(II) complexes are paramagnetic and have a high-spin octahedral configuration with <sup>4</sup>T<sub>1g</sub>(F) ground state [25].

In the electronic spectra of complex **4**, the bands which were observed at 13.605 and 11.574 cm<sup>-1</sup>, due to d<sub>xy</sub> → d<sub>z<sup>2</sup></sub>, d<sup>2</sup> → d<sup>2</sup> and d<sub>xy</sub> → d<sub>xz,yz</sub> transitions, suggesting a pseudo-tetrahedral configuration around the central metal ion [21]. The complex was found paramagnetic with magnetic moments 2.43 BM, which is normal for Cu(II) with pseudo-tetrahedral stereochemistry.

The electronic spectra for **5** exhibits three bands observed at 11.590, 14.025 and 16,077 cm<sup>-1</sup> which may be assigned to d<sub>x<sup>2</sup>-y<sup>2</sup></sub> → d<sub>z<sup>2</sup></sub>, d<sub>x<sup>2</sup>-y<sup>2</sup></sub> → d<sub>xy</sub> and d<sub>x<sup>2</sup>-y<sup>2</sup></sub> → d<sub>xz,yz</sub> transitions, due to the octahedral (D<sub>4h</sub>) geometry around Cu(II) [21]. For this complex  $\mu_{\text{eff}} = 1.28\text{BM} < 2\text{BM}$  suggests an antiferromagnetic interaction in the dinuclear compound [26].

The solid state reflectance spectra of the complex **6** exhibit two well separated d-d bands at 18.452 and 15.923 cm<sup>-1</sup>, which are attributed to d<sub>x<sup>2</sup>-y<sup>2</sup></sub> → d<sub>xz,yz</sub> and d<sub>x<sup>2</sup>-y<sup>2</sup></sub> → d<sub>xy</sub> transition and are typical of Cu(II) present in a square-planar coordination geometry [24].

#### EPR spectra

The tensor value {g} of copper complexes obtained from EPR spectra recorded on powder at room temperature confirms the conclusions concerning the geometry of metallic ion. In pseudo-tetrahedral complex **4** the unpaired electron lies in the d<sub>xy</sub> orbital giving <sup>2</sup>B<sub>1</sub> as ground state. The g values obtained in these cases (g<sub>||</sub> = 2.217, g<sub>⊥</sub> = 2.052) and G = 4.05 indicate an increase of the covalent nature of the bonding between the metal ion and the ligand molecule [21,28]. In square-planar complex **6**, the unpaired electron lies in the d<sub>x<sup>2</sup>-y<sup>2</sup></sub> orbital giving <sup>2</sup>B<sub>1g</sub> as ground state, with g<sub>||</sub> > g<sub>⊥</sub> > 2.0053 (2.127 > 2.050). The exchange interaction is considerable in solid state and the local tetragonal axes are misaligned [25-27]. The room temperature EPR spectra

**Table 3**  
ELECTRONIC SPECTRAL DATA OF THE SYNTHESIZED COMPOUNDS

No	Compound	Intraligand transition (cm <sup>-1</sup> )	Charge-transfer transition (cm <sup>-1</sup> )	d-d transition (cm <sup>-1</sup> )			10Dq (cm <sup>-1</sup> )	B (cm <sup>-1</sup> )	β (cm <sup>-1</sup> )	Geom	ν <sub>2</sub> /ν <sub>1</sub>	μ (BM)
				<sup>4</sup> T <sub>1g</sub> (F) → <sup>4</sup> T <sub>1g</sub> (F) (calc.) (ν <sub>1</sub> )	<sup>2</sup> T <sub>1g</sub> (F) → <sup>4</sup> T <sub>1g</sub> (P) (ν <sub>2</sub> )	<sup>4</sup> T <sub>1g</sub> (F) → <sup>4</sup> A <sub>2g</sub> (F) (ν <sub>3</sub> )						
1	OTSA	29239 23364 20525										
2	Co <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>6</sub>	28248 23419	20202	6809	14684	17761	7839	794	0,82	Dist. Oh high-spin	2.15	4.8
3	Co(OTSA)(AcO)(H <sub>2</sub> O) <sub>2</sub>	26809 22624	-	7475	15890	18790	8415	817	0,84	Dist. Oh high-spin	2.12	5.8
No	Compound	Intraligand transition (cm <sup>-1</sup> )	Charge-transfer transition (cm <sup>-1</sup> )	d-d transition (cm <sup>-1</sup> )			Geometry	μ (BM)				
				d <sub>xy</sub> → d <sub>xy</sub>	d <sub>xy</sub> → d <sub>x<sup>2</sup>-y<sup>2</sup></sub> , d <sub>z<sup>2</sup>-y<sup>2</sup></sub>	d <sub>z<sup>2</sup>-y<sup>2</sup></sub> → d <sub>z<sup>2</sup>-y<sup>2</sup></sub>						
4	Cu <sub>2</sub> (OTSA)Cl <sub>2</sub> (H <sub>2</sub> O) <sub>2</sub>	27472 22624 19723	19193	11574	13605	Pseudo-tetrahedral	2.43					
				d-d transition (cm <sup>-1</sup> )								
				d <sub>z<sup>2</sup>-y<sup>2</sup></sub> → d <sub>xy</sub>	d <sub>x<sup>2</sup>-y<sup>2</sup></sub> → d <sub>xy</sub>	d <sub>x<sup>2</sup>-y<sup>2</sup></sub> → d <sub>z<sup>2</sup>-y<sup>2</sup></sub>						
5	Cu <sub>2</sub> (OTSA) <sub>2</sub> (H <sub>2</sub> O) <sub>4</sub>	28571 23201	20243	16077	14025	11520	Distorted-octahedral	1.28				
6	Cu(OTSA)Cl(H <sub>2</sub> O)	21752 21231	-	18450	15923	-	Square-planar	1.76				

of Cu(II) complex **5** exhibits an isotopic signal with  $g_{\text{iso}} = 2.080$  which confirms the octahedral geometry for metallic ion [30,31].

#### Cyclic voltammetry

Determinations were made in DMSO, in an electrolytic cell with three electrodes: working electrode (platinum electrode with a diameter of 3 mm), reference electrode (Ag/AgCl, 3M KCl) and auxiliary electrode (platinum wire), using *n*-butylamoni perchlorate as supporting electrolyte. In the case of [Cu<sub>2</sub>(OTSA)Cl<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>] complex **4**, the one electron reduction peak, which is attributed to the Cu(II)/Cu(I) couple, occurs at  $E_p_c = 0.23$  V, with an associated re-oxidation peak in the reverse scan at  $E_p_a = 0.47$  V. The difference between cathodic and anodic peak potentials for Cu(II) complex ( $\Delta E_p$ ) is 0.24 V, has a value which indicates that redox process involves a high energy. This requires a high stability of this complex [32]. Also,  $\Delta E_p$  value indicated that the electrode process is controlled by diffusion and has a quasi-reversible character. This behavior may suggest that both the Cu(II) and Cu(I) forms appear in a similar planar configuration, so the electron transfer does not require larger reorganization of the complex and

this is in good agreement with the spectroscopic results [33].

For the complex **5**, [Cu<sub>2</sub>(OTSA)<sub>2</sub>(H<sub>2</sub>O)<sub>4</sub>], there are three peaks. The cathodic peak 1 and anodic peak 3 consist of a pair of redox peaks, which can be attributed to Cu<sup>2+</sup> → Cu<sup>+</sup>, exhibiting a quasi-reversible process [34,35]. The potential for the pair of redox peaks is as follows:  $E_p_a = 0.479$  V,  $E_p_c = 0.355$  V, the half-wave potential is located at  $E_{1/2} = 0.417$  V, the difference between the peaks is  $\Delta E_p = 0.124$  V, and the peak current ratio  $I_p_a/I_p_c = 0.84$ . Another cathodic peak 2 is a single one, attributed to Cu<sup>+</sup> → Cu<sup>0</sup> exhibiting an irreversible process [31,32], while  $E_p_c = 0.003$  V and  $I_p_c = 0.46$  μA.

The cyclic voltammogram of the complex **6**, [Cu(OTSA)Cl(H<sub>2</sub>O)], obtained in DMSO solution at room temperature, shows a redox process corresponding to the copper(II)/copper(I) couple at  $E_p_a = +0.40$  V and the associated cathodic peak at  $E_p_c = +0.13$  V. This couple is found to be quasi-reversible as the peak separation between the anodic and cathodic potential. Value  $\Delta E_p = 0.24$  V indicates that redox process involves a high energy and proves the high stability of this complex [36,37].

Thus, based on these analytical and physico-chemical data, the proposed structures for the complexes are shown in figure 1.

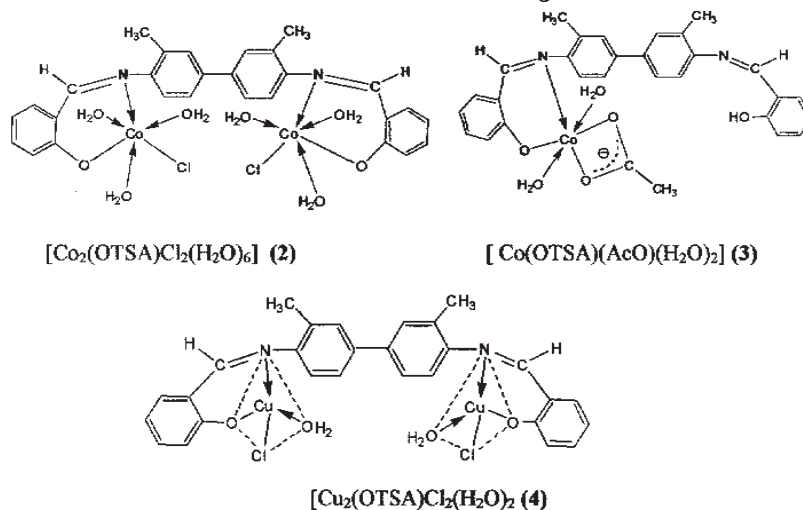


Fig. 1

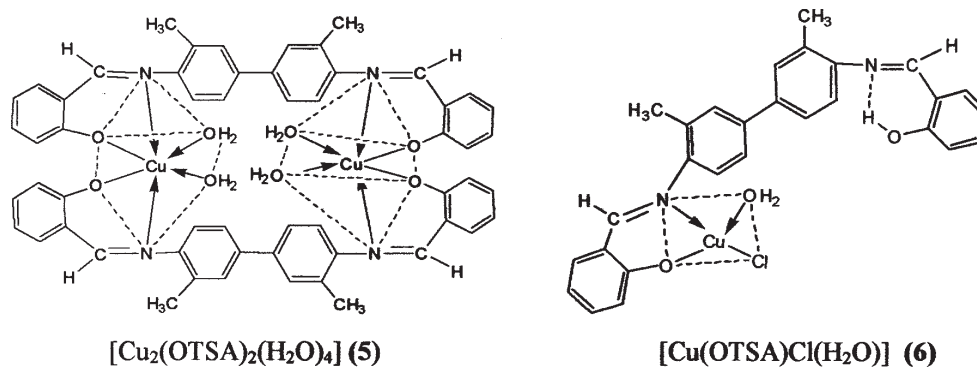


Fig. 1 (cont)

**Table 4**  
ANTIBACTERIAL ACTIVITIES OF LIGAND OTSA AND ITS CO(II), CU(II) COMPLEXES (MIC,  $\mu\text{g}/\text{mL}$ )

Compound	Gram-positive bacteria <sup>a</sup>		Gram-negative bacteria <sup>b</sup>	
	<i>Sa</i>	<i>Ef</i>	<i>Ec</i>	<i>Pa</i>
OTSA (1)	256	512	128	256
$[\text{Co}_2(\text{OTSA})\text{Cl}_2(\text{H}_2\text{O})_6]$ (2)	256	128	256	512
$[\text{Co}(\text{OTSA})(\text{AcO})(\text{H}_2\text{O})_2]$ (3)	512	128	128	256
$[\text{Cu}_2(\text{OTSA})\text{Cl}_2(\text{H}_2\text{O})_2]$ (4)	8	32	16	16
$[\text{Cu}_2(\text{OTSA})_2(\text{H}_2\text{O})_4]$ (5)	64	128	128	256
$[\text{Cu}(\text{OTSA})\text{Cl}(\text{H}_2\text{O})]$ (6)	16	64	64	32
Streptomycin	4	8	8	16

<sup>a</sup> *Sa* = *Staphylococcus aureus* ATCC 25923; *Ef* = *Enterococcus faecalis* ATCC 29212

<sup>b</sup> *Ec* = *Escherichia coli* ATCC 25922; *Pa* = *Pseudomonas aeruginosa* ATCC 27853

#### Antibacterial activity

All the synthesized compounds were screened for their antibacterial activity. All the tested complexes possessed variable antibacterial activity against both Gram-positive (*S. aureus*, *E. faecalis*) and Gram-negative (*E. Coli*, *P. aeruginosa*) bacteria. To compare the antibacterial activities shown by the synthesized complexes, standard drug namely Streptomycin was used (table 4).

By careful study of the obtained results, we can see that the ligand has a weak action on all the tested microorganisms. The activity of OTSA becomes more pronounced when coordinated to the metal ions. All metal ions have varying antibacterial influence on bacterial species. The action of the tested complexes on Gram-positive bacteria is better than that on Gram-negative bacteria. The antibacterial activity of the complexes is governed by the following factors: the chelate effect of the ligand; the nature of the donor atoms; the total charge on the complex ion; the nature of the metal ions and the geometrical structure of the complex. Since all the complexes have the same donating atoms (N, O), containing metals with the same oxidation state ( $M^{2+}$ ), which form 5-membered chelating rings with ligand, therefore the more effective factors that influence the antibacterial activity are the geometrical shape and the nature of the central atoms.

The tetracoordinated complexes have better action than the hexacoordinated compounds and the Cu(II) complexes are more active than Co(II) complexes. Co(II) complexes inhibit the growth of *E. faecalis* more than OTSA, but they have no significant effect on other studied microorganisms. The most active is pseudo-tetrahedral complex  $[\text{Cu}_2(\text{OTSA})\text{Cl}_2(\text{H}_2\text{O})_2]$  **4** which presents a very good inhibitory action against all the tested bacterial species,

probably due the presence of two chlorine atoms and especially due the presence of two copper ions (MIC = 8-32  $\mu\text{g}/\text{mL}$ ). The antibacterial activity of the square-planar Cu(II) complex **6** is slightly weaker than **4** (MIC = 16-64  $\mu\text{g}/\text{mL}$ ), probably due to the presence only of a single copper ion. The present investigations of antibacterial screening data revealed that all of the newly synthesized compounds exhibited poor activity compared to that of the control drug. Because the MIC values are not spectacular, no statistical calculations were made.

#### Conclusions

The coordination ability of N,N'-bis-(salicylidene)-*o*-tolidine OTSA has been proved in complexation reaction with Co(II) and Cu(II) ions. The analytical and physico-chemical analyses confirmed the composition and the structure of the newly obtained complex combinations and lead to the conclusion that the  $\text{Cu}^{2+}$  ion takes different geometries depending on the nature of used metallic salts. In all complexes, OTSA acts as binegative tetradentate, around the metallic ion, while in **3** and **6** acts as mononegative bidentate.

The biological activity data given for the compounds presented in this paper allowed us to state that the metal complexes generally have a better activity than the free ligands and the structure of the tested compounds seemed to be the principal factor influencing the antibacterial activity. The tetracoordinated complexes have better action than the hexacoordinated compounds and the Cu(II) complexes are more active than Co(II) complexes. The most active is pseudo-tetrahedral complex  $[\text{Cu}_2(\text{OTSA})\text{Cl}_2(\text{H}_2\text{O})_2]$  **4** which presents a very good inhibitory action against all the tested bacterial species.

## References

1. GAKIAS, S., RIX, C., FOWLESS, A., HOBDA, M., *Inorg. Chim. Acta*, **359** 2006 p.2291
2. HAMNRYNDAM, E., BAYIR, A.Z., BEKAROGLU, Ö., *Monatsh. Chem.* **131** 2000 p.175
3. DEMIRHAN, N., ERDEN, I., AVCIATA, U., *Synth. React.Inorg. Met.-Org. Chem.* **32** 2002 p.1567
4. KARAO LAN, G.K., AVCIATA, U., GÖL, A., *Indian J. Chem.* **46A** 2007 p. 1273
5. HOSSAIN, M.E., ALAM, M.N., BUGUN, J., AKBAR, A.M., NAZIMUDDIN, M., SMITH, F.E., HYNS, R.C., *Inorg. Chim. Acta* **249** 1996 P. 207
6. KHANDAR, A.A., NEJATI, K. Nejadi, *Polyhedron* **19** 2000 p.607
7. NATHAN, L., KOEHNE, J.E., GILMORE, J.M., HANNIBAL, K.A., DEWHIRST, W.E., *Polyhedron* **22** 2003 p.887
8. ALI, M.A., AYMAN, H.A., TAREK, A.M., BASSEM, H.M., *Trans. Met. Chem.* **32** 2007 p. 461
9. KRIZA, A., IGNAT, I., OPREA, O., STANICA, N., *Rev. Chim. (Bucharest)* **61**, no. 8, 2010 p. 733
10. KRIZA, A., DIANU, M., STANICA, N., DRAGHICI, C., POPOIU, M., *Rev. Chim. (Bucharest)*, **60**, no. 6, 2009 p. 555
11. ALI, M.A., AYMAN, H.A., TAREK, A.M., BASSEM, H.M., *J. Appl.Sci. Res.* **3** 2007 p. 109
12. YAKAMOTO, M., HORI, T., WATANABE, I., TSUTSUI, H., IKEDA, S., OTHAKA, H., *Chem. Pharm. Bull.* **46** 1998 p. 1317
13. ZGODA, J.R., PORTER, J.R., *Pharm. Biol.* **39** 2001 p. 221
14. BUTCHER, R.J., JOSINSKI, J., MOCKLER, G.M., SINN, E., *J. Chem. Soc.* 1976 p. 1099
15. SOCRATES, G., *Infrared and Raman characteristic group frequencies – Tables and Charts*, 3rd, Ed., John Wiles & Sons, West Sussex, 2004, p. 94, p. 96
16. NAKAMOTO, K., *Infrared and Raman spectra of inorganic coordination compounds, Part B – Application in coordination, organometallic and bioinorganic chemistry*, John Wiley & Sons, New Jersey, 2009
17. SRINISAVAN, R., SOUGANDI, I., VEDEVAN, K., VENKASTAN, R., BABU, V., RAO, P.S., *Polyhedron*, **23** 2004 p. 1115
18. SHUKLA, P.R., SINGH, V. K., JAISWAL, A. M., *J. Indian Chem. Soc.*, **60** 1983 p. 321
19. SREEKANTH, A., SIVAKUMAS, S., KURUM, M.R.P., *J. Mol Struct.* **655** 2003 p. 47
20. KOVALA-DEMERTZI, D., GALANI, A., KORKOUMELIS, N., MILLER, J.R., DEMERTZIS, A., *Polyhedron* **26** 2007 p. 2871
21. LEVER, A.B.P., *Inorganic Electronic Spectroscopy*, 2nd ed. Elsevier, Amsterdam, 1984
22. DANIEL, V.P., MUKURAN, B., KUMARI, B.S., MIHANAN, K., *Spectrochim. Acta Part A* **70**, 2008 p. 403
23. VINUELAS-ZAHINOS, E., MALDONADO-ROGADO, M.A., LUNA-GILES, F., BARROS-GARCIA, F.J., *Polyhedron* **27** 2008 p. 879
24. BERNALTE-GARCIA, A., GARCIA-BARROS, F.J., HIGES-RONALDO, F.J., LUNA-GILES, F., PACHECO-RODRIGUEZ, M.M., VINUELAS-ZAHINOS, E., *Bioinorg. Chem. Appl.* **2** 2004 p. 307
25. EL-SHERIF, A.A., *Inorg. Chim. Acta* **362** 2009 p. 4991
26. PARMAR, S., KUMAR, Y., *Chem. Pharm. Bull.* **57** 2009 p. 603
27. RICHARDSON, F.J., PAYNE, C.N., *Inorg. Chem.* **17** 1978 p. 2111
28. RAY, R. K., URBACH, F.L., *Inorg. Chim. Acta*, **173** 1990 p. 207
29. JEYASUBRAM, K., SAMATH, S.A., THAMBIDURAI, S., MURUGESAN, R., RAMALIGNAN, S.K., *Transition Met. Chem.*, **20** 1995 p. 76
30. HATHWAY, B.J., TOMLINSON, A.A.G., *Coord. Chem. Rev.* **5** 1970 p. 1
31. EL-METWALLY, N.M., GABOR, I.M., ABOU-HUSSEN, A.A., *Transition Met. Chem.* **31** 2006 p. 71
32. REID, G., SCHREIBER, I., *Chem. Soc. Rev.*, **19** 1990 p. 239
33. BARD, A.J., ZALDAN, L.R., *Electrochemical Methods: Fundamentals and Applications*, 2nd Ed, New York, 2001
34. YE, B. X., XU, Y., WANG, F., FU, Y., SONG, M.P., *Inorg. Chem. Commun.* **8** 2005 p. 44
35. VAZQUEZ-ARENAS, J., LAZARO, I., CRUZ, R., *Electrochimica Acta* **2** 2007 p. 6106
36. RAMAN, N., MUTHURAJ, V., RAVICHANDRAN, S., KULANDAISAMY, A., *Proc. Indian Acad. Sci. (Chem. Sci.)* **115** 2003 p. 161
37. SHYAMALA, A., CHAKRAVARTY, A.R., *Polyhedron* **12** 1993 p. 1545

Manuscript received: 31.01.2011