Polyhedron 61 (2013) 87-93

Contents lists available at SciVerse ScienceDirect

Polyhedron

journal homepage: www.elsevier.com/locate/poly

Magnetism of novel Schiff-base copper(II) complexes derived from aminoacids



Department of Chemistry, FPV, University of SS Cyril and Methodius, Nám. J. Herdu 2, 917 01 Trnava, Slovakia

ARTICLE INFO

Article history: Received 29 April 2013 Accepted 23 May 2013 Available online 1 June 2013

Keywords: Aminoacids Schiff base Cu(II) complex Magnetism Magnetic ordering

1. Introduction

Copper(II) complexes with Schiff base ligands derived from amino acids and salicylaldehyde have been reported in the literature for a long time [1]. The distorted square-pyramidal geometry around Cu(II) ion gives Schiff base copper(II) chelates potential to act as valuable non-enzymatic models for more complicated copper metalloproteins, such as Cu,Zn-superoxide dismutase [2-4] and catechol oxidase [5,6]. The number of reported mononuclear copper(II) N-salicylidene aminoacidates [7-12] is superior to those with higher nuclearities [13,14]. This is due to the fact that the majority of ligands are produced by condensation reaction of salicylaldehyde and α -amino acid exhibiting tridentate coordination mode around the metal centre with the most stable five-membered chelate ring. Such arrangement prefers formation of mononuclear copper(II) complexes with one Schiff base ligand and two aqua ligands adopting square-pyramidal geometry [10–12]. The employment of β -aminoacids in the synthesis of N-salicylideneaminoacidato Schiff base ligand offers the possibility of construction of extended networks of higher nuclearity [13] where the six-membered chelate ring is incorporated. Moreover, different coordination behaviour of the carboxylato functional group in a simple β -aminoacids (e.g. β -alanine, β -amino-iso-butyric acid) and sulfonato functional group for example in taurine as a part of Schiff base ligand can be observed [14]. Recently, we reported the structure of copper(II) N-salicylidene-aminoacidate containing

ABSTRACT

Magnetic properties of five copper(II) complexes of the formula $[CuL^3(H_2O)_2]$ or $[CuL^4(H_2O)]$ were investigated. These contain a Schiff-base L derived from salicylaldehyde and aminoacids. The ligand L is represented by four bonding isomers (1 through 4) and it is either tridentate (L^3) or tetradentate (L^4) . The fifth ligand contains sulfonato group instead of the carboxyl one. Structurally, two complexes are monomers (1 and 4), one is a dimer (5), and two are polymers (2 and 3). Their magnetic behaviour is more complex: 1 behaves as an antiferromagnetic Heisenberg diad, 2 and 4 are ferromagnetic chains, 3 is a combined ferromagnetic/antiferromagnetic ladder (ribbon), and 5 exhibits a complex 3D-ordering with unusual temperature evolution of the effective magnetic moment.

© 2013 Elsevier Ltd. All rights reserved.

 γ -aminobutyric acid which causes coordination via the unique seven-membered ring [15]. Extensive investigations on modelling of active sites of native copper oxidases by copper(II) chelates derived from Schiff base ligands containing amino acids over past decades provided clear insights into the relationship between the structural features and the catalytic activity (superoxide scavenging activity, catechol-oxidase like activity, ascorbic-oxidase like activity) of these complexes [7–21]. Despite of this plethora publications on the structure–activity relationship, studies concerning their magnetostructural correlations are rather rare [13,22]. As an extension of such work, we have chosen five copper(II) *N*-salicylidene-aminoacidates **1–5** (Fig. 1) with different coordination modes in order to obtain detailed information about the magnetic exchange mechanism and to identify factors that influence their magnetic properties.

2. Experimental

2.1. Materials

All chemicals were of reagent grade, obtained from commercial sources, and used without further purification. All solvents were dried and distilled by standard methods prior to use. Spectroscopic grade solvents were used for spectral measurements.

2.2. Physical measurements

IR spectra were measured as KBr pellets (Schimadzu, Impact 400) in the $4000-400 \text{ cm}^{-1}$ region. Electronic spectra of DMSO





POLYHEDRON

^{*} Corresponding author. Tel.: +421 33 5921408; fax: +421 33 5921 403.

E-mail addresses: zita.tokarova@ucm.sk, zita.puterova@gmail.com (Z. Puterová-Tokárová).

^{0277-5387/\$ -} see front matter @ 2013 Elsevier Ltd. All rights reserved. http://dx.doi.org/10.1016/j.poly.2013.05.045



Fig. 1. Sketch of complexes under study. Red (bold) atoms are from the neighbouring units. (Colour online.)

solutions of compounds ($c = 4 \times 10^{-3} \text{ mol dm}^{-3}$) were measured in the 200–800 nm region (Schimadzu, UV-160). Elemental analysis was performed by FlashEA 1112 (ThermoFinnigan). Content of copper was determined by electrolysis (Pt-cathode, U = 2 V, I = 2-3 A) after mineralization of the complexes in conc. H₂SO₄.

A SQUID magnetometer (MPMS-XL7, Quantum Design) has been used for magnetic data using the RSO mode of detection. The susceptibility taken at B = 0.1 T between T = 2-300 K has been corrected for the underlying diamagnetism and converted to the effective magnetic moment. The magnetization has been measured at two temperatures: T = 2.0 and 4.6 K.

2.3. Synthesis

2.3.1. Ligands – general procedure

The Schiff-condensation of salicylaldehyde with the corresponding amino acid at a ratio 1:1 in water-alcohol solution for 3 h at room temperature resulted to the tridentate ligands: H_2SAIB , H_2SGABA , H_2SBAIB , H_2SBAB , $H_2STaurine$. Ligands were subsequently used without further purification.

2.3.2. Complexes – general procedure

To a water/ethanol solution (1:1, 60 cm³) of appropriate Schiff base ligand (10 mmol), an aqueous solution of copper acetate dihydrate (10 mmol in 60 cm³ of water) was added and stirred for 1 h at 50 °C accompanied by a colour change to dark green. The resultant reaction mixture was filtered off and the filtrate was left to crystallise spontaneously for several days at room temperature. Final complexes were separated and washed with cold ethanol.

2.3.3. Compound $1 - [Cu(SAIB) (H_2O)_2]$

Anal. Calc. for C₁₁H₁₅CuNO₅ (304.78 g mol⁻¹): C, 43.35; H, 4.96; N, 4.60; Cu, 20.85. Found: C, 45.69; H, 4.52; N, 4.88; Cu, 20.19%. IR(KBr) v = 3446 (OH, coord. water), 3290, 2984, 1636 (C=N), 1541 (COO⁻_{as}.), 1340 (COO⁻_{sym}), 1206, 755, 549, 442 cm⁻¹. UV-Vis (DMSO, c = 4 × 10⁻³ mol dm⁻³) λ_{max} = 658 (log ε = 1.65), 353 (log ε = 2.39), 264 nm.

2.3.4. Compound $2 - [Cu(SGABA)(H_2O)]$

Anal. Calc. for C₁₁H₁₃CuNO₄ (286.76 g mol⁻¹): C, 46.07; H, 4.57; N, 4.88; Cu, 22.16. Found: C, 46.37; H, 4.45; N, 4.70; Cu, 22.54%. IR(KBr) ν = 3442 (OH, coord. water), 3030, 2917, 1635 (C=N), 1540 (COO⁻_{as}.), 1352 (COO⁻_{sym}), 1210, 752, 557, 459, 415 cm⁻¹. UV–Vis (DMSO, c = 4 × 10⁻³ mol dm⁻³) λ_{max} = 682 (log ε = 1.48), 352 (log ε = 2.60), 282 nm.

2.3.5. Compound $\mathbf{3} - [Cu(DL-SBAIB)(H_2O)] \cdot H_2O$

Anal. Calc. for C₁₁H₁₅CuNO₆ (320.78 g·mol⁻¹): C, 41.19; H, 4.71; N, 4.37; Cu, 19.81. Found: C, 40.90; H, 4.50; N, 4.76; Cu, 20.11%. IR(KBr) v = 3444 (OH, coord. water), 3042, 2959, 1627 (C=N), 1540 (COO⁻_{as}.), 1350 (COO⁻_{sym}), 1205, 769, 606, 470, 410 cm⁻¹. UV–Vis (DMSO, $c = 4 \times 10^{-3}$ mol dm⁻³) $\lambda_{max} = 667$ (log $\varepsilon = 1.28$), 352 (log $\varepsilon = 2.48$) nm.

2.3.6. Compound $\mathbf{4}$ – Cu(DL-SBAB)(H₂O)₂

Anal. Calc. for C₁₁H₁₅CuNO₆ (320.78 g·mol⁻¹): C, 41.19; H, 4.71; N, 4.37; Cu, 19.81. Found: C, 41.52; H, 4.76; N, 4.70; Cu, 20.20%. IR(KBr) v = 3453 (OH, coord. water), 3050, 2974, 1638 (C=N), 1529 (COO⁻_{as}.), 1344 (COO⁻_{sym}), 1211, 753, 564, 454, 412 cm⁻¹. UV–Vis (DMSO, $c = 4 \times 10^{-3}$ mol dm⁻³) $\lambda_{max} = 670$ (log $\varepsilon = 1.32$), 352 (log $\varepsilon = 2.54$) nm.

2.3.7. Compound 5 – $[Cu(STaurine)(H_2O)] \cdot H_2O$

Anal. Calc. for $C_{18}H_{26}Cu_2N_2O_{12}S_2$ (653.63 g·mol⁻¹): C, 33.10; H, 4.00; N, 4.30; S, 10.00; Cu, 20.00. Found: C, 32.99; H, 3.87; N, 4.28; S, 10.20; Cu, 20.34%. IR(KBr) ν = 3418 (OH, coord. water), 1628 (C=N), 1285 (SOO⁻_{as}.), 1246 (phenolic O⁻), 1177 (SOO⁻_{sym}), 755, 618, 415 cm⁻¹. UV–Vis (DMSO, c = 4 × 10⁻³ mol dm⁻³) λ_{max} 716 (log ε = 1.44), 358 (log ε = 2.40) nm.

3. Results and discussion

3.1. Synthesis of complexes

All the complexes were synthesized by two step procedure as we had previously described elsewhere [15]. First, by condensation of salicylaldehyde and appropriate amino acid in water–ethanol (1:1) solution Schiff base ligands were formed *in situ*. In the next step, the coordination was performed by the reaction of copper(II) acetate dihydrate with Schiff base ligand leading to final copper(II) complexes **1–5** (Fig. 1) in 62–67% yields.

3.2. IR and electronic spectra of the complexes

The electronic spectral data recorded in DMSO ($c = 4 \cdot 10^{-3}$ mol dm^{-3}) of compounds **1–5** exhibit a similar absorptions, displaying a d-d transitions in the range 658-716 nm corresponding to the square-pyramidal arrangement of {CuNO₄} chromophore. Absorption bands at 350-360 nm are attributed to the ligand-to-metal charge transfer (CT) transitions. IR spectra of all complexes display strong band at 1628–1638 cm⁻¹ characteristic for the stretching frequencies of (C=N) group. The asymmetric vibration of the coordinated carboxylato group [v (COO⁻_{as.})] in complexes **1–4** are observed at 1529–1540 cm⁻¹ region, and a band within the region 1340–1350 cm⁻¹ is assigned to symmetric vibration of carboxylato group [v (COO⁻_{symm})] [15]. The frequencies characteristics of the (S-O) stretching modes in compound 5 are observed at 1285 and 1177 cm⁻¹, respectively [14]. The band around 1200–1250 cm⁻¹ can be assigned to (C–O) vibrations of the phenolic group in all complexes.

3.3. Description of the structures 1-3 and 5

The crystal structures of complexes $[Cu(SAIB)(H_2O)_2]$ (1), $[Cu(SGABA)(H_2O)]$ (2), $[Cu(DL-SBAIB)(H_2O)] \cdot H_2O$ (3), and [Cu(STa $urine)(H_2O)] \cdot H_2O$ (5) were already described elsewhere [14,15]. The coordination polyhedron around each copper(II) centre of all complexes 1-3, 5 is best described as a slightly distorted tetragonal pyramid as confirmed by the structural parameter τ [23]; 1: $\tau^1 = 0.1939$, $\tau^2 = 0.0898$; **2**: $\tau = 0.0740$; **3**: $\tau = 0.0352$; **5**: τ = 0.0402. The crystal structure of [Cu(SAIB)(H₂O)₂] (**1**) is formed by single molecules with five-membered metallocycle ring coordinated with cooper(II) ion. The studied crystal was non-merohedrally twinned with a ratio of twin components 0.52:0.48. The ligand connectivity in the compound $\mathbf{3} - [Cu(DL-SBAIB)(H_2O)] \cdot H_2O$ is very similar to that found in 1 except that the DL-H₂SBAIB dianion forms a six-membered ring. The {CuNO₄} chromophore is in **1** and **3** coordinated by two oxygen atoms from the phenolic group (1:Cu1-O1, and Cu21-O21; 3: Cu1-O1) and carboxylato group (1:Cu1-O2 and Cu21-O22; 3: Cu1-O2) and one nitrogen atom from imine group (1: Cu1-N1and Cu21-N21; 3: Cu1-N1) of L and two oxygen atoms of water, one in equatorial position (1: Cu1-O4 and Cu21-O24: **3**:Cu1-O4) and one in axial position (**1**: Cu1-O5 and Cu21-O25: 3: Cu1-O5). The crystal structure of compound $2 - [Cu(SGABA)(H_2O)]$ is formed by dimers in which carboxyl oxygen O3 is bonded in a bidentate manner to one copper(II) ion in the equatorial plane and axially to the adjacent molecule. Coordination via γ -amino-butyric acid chain of the H₂₋ SGABA ligand causes the formation of unusual seven-membered ring. The coordination polyhedron is in basal plane completed with phenolic oxygen (Cu1-O1), carboxylato oxygen (Cu1-O2), imino nitrogen (Cu1-N1) and carboxyl oxygen (Cu1-O3) from the neighbouring molecule. Water oxygen (Cu1-O5) is bonded axially. Compound 5 is a centrosymmetric dimer. At each copper centre, the basal plane of the square pyramid is occupied by three oxygen atoms, one each from the phenolato group (Cu1-O1), sulfonato group (Cu1-O2), aqua ligand (Cu1-O5), and nitrogen (Cu1-N1) from imine group. The apical sites of copper(II) ion are occupied by the oxygen atoms (Cu1-O3) of the sulfonato group from the neighbouring molecule [14].

3.4. Magnetic properties

The complex **1** consists of mononuclear units ($C_{11}H_{15}CuNO_5$, $M_r = 304.78$) for which a simple Curie–Weiss law is expected to be obeyed. However, the magnetic susceptibility on cooling passes through a maximum and then it turns to the zero (Fig. 2). This is a fingerprint of an exchange coupling of the antiferromagnetic nature. The inspection to the crystal structure shows that, indeed, a formation of dimers held by the π – π stacking of the benzene rings is evident (Fig. 3). Thus the magnetic data have been fitted using a

model of the $[S_1, S_2] = [1/2, 1/2]$ diad. The susceptibility and magnetization data sets have been treated simultaneously, by minimizing a functional $F = R(\chi) \times R(M)$ that accounts for relative errors of the susceptibility and magnetization. The minor corrections account for some temperature independent magnetism (χ_{TIM}), molecular-field correction (*zj*), and eventually a presence of a monomeric paramagnetic impurity (x_{Pl}). The conventional spin-Hamiltonian

$$\hat{H} = -J(S_1 \cdot S_2)\hbar^{-2} + \mu_{\rm B}B_z g_{\rm iso}(\hat{S}_{1z} + \hat{S}_{2z}) \tag{1}$$

gave the following set of magnetic parameters: $J/hc = -18.9 \text{ cm}^{-1}$, $g_{iso} = 2.148$, $\chi_{TIM} = -5.0 \times 10^{-9} \text{ m}^3 \text{ mol}^{-1}$, $x_{PI} = 0.0039$; discrepancy factor $R(\chi) = 0.020$ and R(M) = 0.033.

The compound **2** differs from **1** in the feature that the carboxylato oxygen atom bears a bridging function; this causes a formation of dinuclear units ($C_{22}H_{14}Cu_2N_2O_8$, $M_r = 561.43$) that form a zigzag chain structure (Fig. 4). The magnetic behaviour is completely different: the effective magnetic moment on cooling rises progressively showing that a ferromagnetic exchange interaction applies (Fig. 5). The magnetic data were fitted by a model of a finite Heisenberg ring: *cyclo*-[S = 1/2]. Eight members have been chosen and the data fitting gave: $J/hc = +7.1 \text{ cm}^{-1}$, $g_{iso} = 2.156$, $\chi_{TIM} = -7.5 \times 10^{-9} \text{ m}^3 \text{ mol}^{-1}$; $R(\chi) = 0.016$, R(M) = 0.0091.

The compound **4** shows analogous magnetic properties to **2** (Fig. 6); the same model has been applied for the data fitting (dinuclear formula unit $C_{22}H_{26}Cu_2N_2O_8$, $M_r = 573.54$). To this end: $J/hc = +3.83 \text{ cm}^{-1}$, $g_{iso} = 2.142$, $\chi_{TIM} \sim 0$, $zj/hc = -0.0023 \text{ cm}^{-1}$; $R(\chi) = 0.014$, R(M) = 0.022.

The compound **3** is formed of mononuclear neutral complexes (formula unit $C_{11}H_{15}$ CuNO₆, M_r = 320.78) for which a behaviour like a Curie paramagnet enriched is expected. However, an exchange interaction of the ferromagnetic nature is evident from the temperature dependence of the effective magnetic moment (Fig. 7). An inspection to the crystal packing shows that there exists a hydrogen-bond rich channel among mononuclear units (Fig. 8).

Two models of magnetic interactions can be applied. The former considers a ferromagnetic coupling between a pair of $[S_1, S_2] = [1/2, 1/2]$ centres. This could explain a drop of the effective magnetic moment at low temperature as a consequence of the (positive) zero-field splitting for the S = 1 ground state. However, this model does not work properly.

The second model mimics a dinuclear ribbon-type structure through an octanuclear fragment (a doubled tetranuclear ring, a ladder with four stacks) where two *J*-constants occur: J_1 – ferro-



Fig. 2. Magnetic functions for 1: left – temperature dependence of the effective magnetic moment per formula unit, right – field dependence of the magnetization. Lines – fitted.



Fig. 3. Expanded short contacts in 1 evidencing formation of dimers held by π - π stacking. Hydrogen atoms are omitted for clarity.



Fig. 4. Extended dinuclear motif for 2 showing a zigzag chain-like structure. Hydrogen atoms are omitted for clarity.



Fig. 5. Magnetic functions for 2: left – temperature dependence of the effective magnetic moment per dinuclear formula unit, right – field dependence of the magnetization. Lines – fitted.

magnetic inside legs, J_2 – antiferromagnetic between stacks. To this end: $J_1/hc = +8.13 \text{ cm}^{-1}$, $J_2/hc = -0.98 \text{ cm}^{-1}$, $g_{\rm iso} = 2.264$, $\chi_{\rm TIM} = -4.6 \times 10^{-9} \text{ m}^3 \text{ mol}^{-1}$; $R(\chi) = 0.021$, R(M) = 0.054. Perhaps an extension of the members of the double ring (10, 12, etc.) will improve the reconstruction of the magnetization.

The compound **5** was structurally characterized as a dinuclear complex ($C_{18}H_{26}Cu_2N_2O_{12}S_2$, $M_r = 653.63$). Its magnetic behaviour is surprisingly unusual and complex (Fig. 9); it cannot be interpreted like a diad. Between T = 4 and 70 K the effective magnetic moment adopts a subnormal value and then it rises linearly until



Fig. 6. Magnetic functions for 4: left – temperature dependence of the effective magnetic moment per dinuclear formula unit, right – field dependence of the magnetization. Lines – fitted.



Fig. 7. Magnetic functions for 3: left – temperature dependence of the effective magnetic moment per mononuclear formula unit, right – field dependence of the magnetization. Lines – fitted.



Fig. 8. Mononuclear units and their packing in 3 evidencing a hydrogen-bond rich channel. Hydrogen atoms are omitted for clarity. Short contacts are represented by dotted lines.

the room temperature where it becomes $\mu_{\text{eff}} = 1.32 \,\mu_{\text{B}}$. Also the magnetization shows a subnormal value. The crystal packing of **5** is complex (Fig. 10): the dinuclear units in one direction are held together by π - π stacking (3.56 Å); in the second direction of a

plane they are linked by hydrogen bonds (0...0 = 2.78 Å). These planes are stacked thus forming a 3D-network.

Magnetic data in combination with the key structural factors are summarized in Table 1.



Fig. 9. Magnetic functions for 5: left - temperature dependence of the effective magnetic moment per dinuclear formula unit, right - field dependence of the magnetization.



Fig. 10. Dinuclear units and their packing in 5. Hydrogen atoms are omitted for clarity.

Table 1

Key structural and magnetic characteristics of complexes 1 through 5.

Compound	1 [Cu(SAIB)(H ₂ O) ₂]	2 [Cu(SGABA) (H ₂ O)]	3 Cu(DL-SBAB) $(H_2O)_2$	4 [Cu(DL-SBAIB) (H_2O)]· H_2O	5 [Cu(STaurine) (H ₂ O)]·H ₂ O
Structure	monomer	1D-chain	ladder	n.a.	3D
Packing	π – π stacking		H-bonds		H-bonds, π - π stacking
Magnetism	diad	ferromagnetic 1D-chain	ferromagnetic/antiferromagnetic ladder	ferromagnetic 1D-chain	complex
$J/hc (cm^{-1})$	-18.9	+7.1	+8.1 inside leg	+3.8	n.a.
			-0.98 between stacks		

4. Conclusions

The magnetic data (susceptibility and magnetization) of five Cu(II) complexes containing Schiff base ligands of N-salicylideneaminoacidato type were investigated. The magnetic data for 1 were fitted using the spin Hamiltonian and this complex behaves as an antiferromagnetic Heisenberg diad. The magnetic susceptibility data for 2 and 4 follow the model of a finite Heisenberg ring formed of dinuclear entities with ferromagnetic 1D-chain behaviour. The complex **3** is a combined ferromagnetic/antiferromagnetic ladder with two I constants: one inside the leg and another between stacks. The dinuclear complex 5 with sulfonato group instead of carboxylato as it is in compounds **1–4** exhibits unusual magnetic behaviour and cannot be interpreted like a diad. The different magnetic behaviour of complexes 1-5 is ascribed to a different modes of coordination at the Cu(II) atom: 1 – [Cu(SAIB)(H₂O)₂] is a mononuclear complex forming dimers held by π - π stacking; 2 - $[Cu(SGABA)(H_2O)]$ and **4** – $Cu(DL-SBAB)(H_2O)_2$ are dinuclear complexes forming a zig-zag chain where the carboxylato groups bear a bridging function; $\mathbf{3} - [Cu(DL-SBAIB)(H_2O)] \cdot H_2O$ is a mononuclear complex packed into a hydrogen bond rich channel inside a ladder; **5** – [Cu(STaurine)(H₂O)]·H₂O is formed of dinuclear entities containing sulfonato bridging group packed into a 3D-network via hydrogen bonds. The common feature of all presented copper(II) *N*-salicylidene-aminoacidates **1**–**5** is a distorted square-pyramidal arrangement of the chromophore {CuNO₄}.

Acknowledgments

We gratefully acknowledge the financial support from Slovak grant agencies (VEGA 1/0073/13, APVV-0014-11).

References

- [1] D.E. Metzler, M. Ikawa, E.E. Snell, J. Am. Chem. Soc. 76 (1954) 648.
- [2] Ľ. Bergendi, J. Krätsmár-Šmogrovič, Z. Ďuračková, I. Žitňanová, Free. Radic. Res.
- Commun 12–13 (1991) 195.
- [3] L. Andrezálová, Z. Ďuračková, A. Valent, F. Devínsky, Pharmazie 53 (1998) 338.
 [4] J. Vančo, J. Marek, Z. Trávníček, E. Račanská, J. Muselík, J. Valentová, J. Trace
- Elem, Med. Biochem. 18 (2004) 155.
- [5] C. Yang, M. Vetrichelvan, X. Yang, B. Moubaraki, K.S. Murray, J.J. Vittal, Dalton Trans. (2004) 113.

- [6] B. Sreenivasulu, F. Zhao, S. Gao, J.J. Vittal, Eur. J. Inorg. Chem. (2006) 2656.
- [7] G. Plesch, C. Friebel, O. Švajlenová, J. Krätsmár-Šmogrovič, Polyhedron 14
- (1995) 1185.
 [8] C. Friebel, G. Plesch, V. Kettmann, J. Krätsmár-Šmogrovič, Inorg. Chim. Acta 254 (1997) 443.
- [9] A. Valent, M. Kohútová, O. Švajlenová, D. Hudecová, P. Olejníková, M. Melník, J. Coord. Chem. 57 (2004) 1279.
- [10] V. Langer, D. Gyepesová, E. Scholtzová, P. Mach, M. Kohútová, A. Valent, L. Smrčok, Z. Kristallogr. 219 (2004) 112.
- [11] H.M. Parekh, M.N. Patel, Russ. J. Coord. Chem. 32 (2006) 431.
- [12] J. Lv, T. Liu, S. Cai, X. Wang, L. Liu, Y. Wang, J. Inorg. Biochem. 100 (2006) 1888.
- [13] J. Vančo, J. Marek, Z. Trávníček, E. Račanská, J. Muselík, O. Švajlenová, J. Inorg. Biochem. 102 (2008) 595.
- [14] B. Sreenivasulu, M. Vetrichelvan, F. Zhao, S. Gao, J.J. Vittal, Eur. J. Inorg. Chem. (2005) 4635.

- [15] Z. Puterová, J. Valentová, Z. Bojková, J. Kožíšek, F. Devínsky, Dalton Trans. 40 (2011) 1484.
- [16] D. Jiang, X. Li, L. Liu, G.B. Yagnik, F. Zhou, J. Phys. Chem. B 114 (2010) 4896.
- [17] Á. Kupán, J. Kaizer, G. Speier, M. Giorgi, M. Réglier, F. Pollreiz, J. Inorg. Biochem.
- 103 (2009) 389. [18] A.D. Naik, P.A.N. Reddy, M. Nethaji, A.R. Chakravarty, Inorg. Chim. Acta 349 (2003) 149.
- [19] I. Blain, M. Giorgi, I. DeRiggi, M. Reglier, Eur. J. Inorg. Chem (2001) 205.
- [20] R. Bakshi, M. Rossi, F. Caruso, P. Mathur, Inorg. Chim. Acta 376 (2011) 175.
- [21] Z. Moradi-Shoeili, Z. Amini, D.V. Boghaei, B. Notash, Polyhedron 53 (2013) 76.
- [22] M. Andruh, Chem. Commun. 47 (2011) 3025.
- [23] A.W. Addison, T.N. Rao, J. Reedijk, J. van Rijn, G.C. Veschoor, J. Chem. Soc., Dalton Trans. (1984) 1349.