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A study of novel cobalt(II) octaazamacrocyclic complexes with aminocarboxylates or their derivatives

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Abstract: Four new air-stable mixed-ligand Co(II) complexes having the general formula $[Co_2(Y)tpmc]Z_3 \cdot q(H_2O/CH_3CN)$ (HY = *N*-methylglycine/*N*,*N*-dimethylglycine, $Z = BF_4^-$, $qH_2O = 4$ or 3; HY = *S*-norvaline/*S*-valine $Z = ClO_4^-$, $qCH_3CN = 0.5$; $qH_2O = 0.5$; tpmc = *N*,*N*',*N*'',*N*'''-tetrakis(2-pyridylmethyl)-1,4,8,11-tetraazacyclotetradecane) were prepared. The composition, some physical and chemical properties and their tentative geometries were evaluated based on elemental analysis (C, H, N), conductometric and magnetic measurements, spectroscopic data (UV/Vis, IR) and cyclic voltammetry. The data were compared with earlier described analogous complexes containing the macrocyclic ligand and aliphatic aminocarboxylates. It is assumed that all complexes are binuclear with an *exo* coordination mode of the octaazamacrocyclic pendant ligand in the boat conformation. In addition, two $–N–(CH_2)_2–N–$ portions of the cyclam ring within the tpmc ligand and Co(II) ions in the high-spin state are most probably bridged *via* oxygen atoms from the anion of the aminocarboxylate/derivatives, whereas nitrogen atoms rest uncoordinated. In all cases, a combined chelate-bridged coordination is proposed as the most probable. The complexes were electrochemically stable in the potential range –1.0 to 1.0 V. They were also preliminary assayed toward some microorganisms together with the ligands, starting simple salts and solvents as test substances. In some cases, certain antimicrobial activity of the complexes was detected.

Keywords: cobalt(II) complexes; pendant octaazamacrocycle; aminocarboxylates and derivatives.

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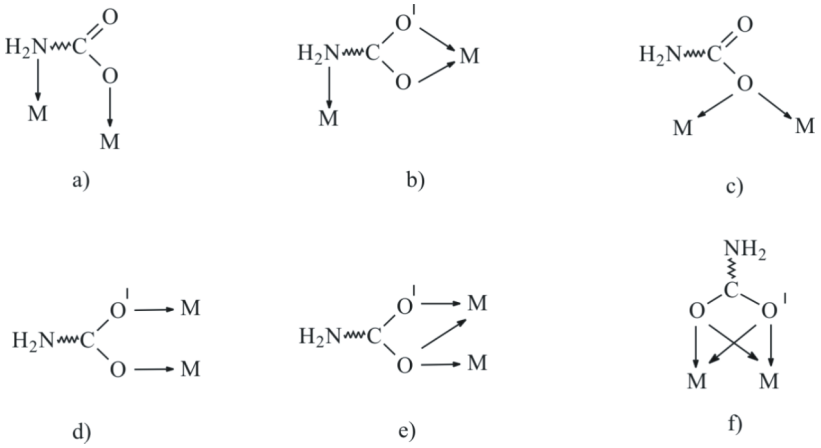
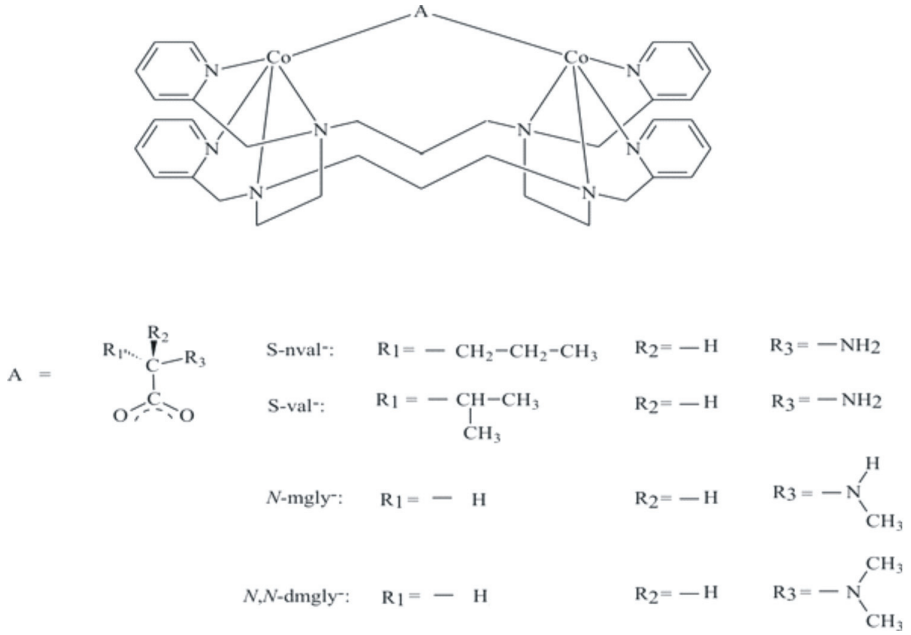
INTRODUCTION

The field of investigation concerning azamacrocyclic and/or aminocarboxylic transition metal complexes is widely explored[1–5] with regard to their properties: some of them are models for the active centres of metalloenzymes, are potentially bioactive and could be used as drugs, catalysts or represent new materials with specific electrical and magnetic properties.[6,7] In most hitherto described complexes, aminocarboxylato ligands are bonded in one of many modes *via N*: as *N*-monodentate; *N*,*O*-bonded as chelate in mononuclear complexes or as a bridging ligand between two metallic centres (Scheme 1a); *N*,*O*,*O*'-mode (Scheme 1b). In some binuclear complexes, one or both oxygens are included in the coordination, with the $-NH_2$ group resting uncoordinated: unsymmetrically (Scheme 1c), symmetrically (Scheme 1d) or in a combined chelate-bridged manner (Schemes 1e and 1f).[1,4] Depending on the reaction conditions, the nature of the central metal ion, pH, the presence of other ligands, steric hindrance *etc.*, one of the mentioned coordination modes is favoured. In addition, for such complexes some biological activity is expected or found. In previous papers, the synthesis and study of a series of cationic binuclear high-spin Co(II) complexes containing besides a pendant octaazamacrocycle *N*,*N*',*N*'',*N*'''-tetrakis(2-pyridylmethyl)-1,4,8,11-tetraazacyclotetradecane (tpmc), a coordinated aminocarboxylate with an aliphatic side chain, were described.[8,9] The proposed general formula was $[Co_2(A)tpmc](ClO_4)_3$, where HA = glycine/*S*-alanine/*S*-α-aminobutyric/α-aminoisobutyric acid or β-aminobutyric/isobutyric acid. Different amounts of crystal solvents (H_2O/CH_3CN) were present in some of them. μ-*O*,*O*'-Bonding of the aminocarboxylato ligands was proposed, while tpmc adopted a boat conformation and the *exo* coordination mode (Schemes 1d and 2, where A is the corresponding anion of the mentioned aminocarboxylates).



Scheme 1. Selected possible coordination modes of aminocarboxylates in binuclear complexes.



Scheme 2. Boat conformation in the complex cation of $[Co_2(A)tpmc](ClO_4)_3$; A = bridged monoanion of aminocarboxylates/derivatives (*S*-norvaline/*S*-valine/ /*N*-methylglycine/*N*,*N*-dimethylglycine).

The objective of this study was the preparation and study of Co(II)-tpmc complexes with *N*-derivatives of glycine (*N*-methyl/*N*,*N*-dimethylglycine), and amino acids of longer aliphatic side chain (*S*-norvaline/*S*-valine). In addition, an attempt was made to reduce $[Co_2(OH)tpmc](ClO_4)_3$ complex formation,[10] which is always present as an impurity which drastically decreases the yield of the target mixed-ligand complexes. Some of their physical and chemical properties were investigated. Finally, the results were compared mutually and with already published data with the aim of proposing the most probable mode of ligand(s) coordination.

EXPERIMENTAL

Preparation and optimization of the reaction conditions

CAUTION! Perchlorate metal salts with organic ligands are potentially explosive and should be handled with extreme caution although in this work such properties were not observed! Always prepare a small amount of the complex and do not heat more than a few crystals in the solid state! Cobalt tetrafluoroborate hexahydrate is a corrosive substance not yet fully tested!

The ligand tpmc[11] and $Co(ClO_4)_2 \cdot 6H_2O$[12] were prepared and purified as described in the literature. The other chemicals as *p.a.* commercial products were provided by Merck, Germany; *S*-valine, cyclam and 2-picolyl chloride hydrochloride by Aldrich, USA, *S*-norvaline by Fluka, Switzerland; $Co(BF_4)_2 \cdot H_2O$ by Acros Organics, USA.

[Co_2(Y)tpmc](BF_4)$_3$·qH_2O (HY = N-*methylglycine,* N,N-*dimethylglycine, abbreviated below as* N-*mgly/*N,N-*dmgly;* q = *4 (**A**) or 3 (**B**))*

General procedure. $Co(BF_4)_2·6H_2O$ (0.170 g, 0.500 mmol) and *N*-methyglycine/*N,N*-dimethylglycine (0.0334g/0.0387g, 0.375 mmol) (previously neutralized to pH 6.0 with NaOH, c = 0.10 mol/dm^3, checked with indicator strips) were dissolved in a minimum amount of CH_3OH and refluxed on a water bath (80 °C) for 30 min with stirring. After that, a suspension of tpmc (0.141 g, 0.250 mmol) in CH_3OH was added. The reaction mixture was continuously stirred and heated for the following 2 h, concentrated to 1/4 of its initial volume and left in a refrigerator overnight. The purple microcrystalline product was separated by suction, dried at room temperature, powdered, washed properly with small portions of cold water, and the procedure was repeated until a pure product was obtained (checked using a microscope).

*[Co_2(*N-*mgly)tpmc](BF_4)$_3$·4H_2O (**A**)*. Yield: 78 % (0.215 g). Anal. Calcd. for $C_{37}H_{59}O_6N_9B_3Co_2F_{12}$ (FW = 1103): C, 40.28; H, 5.30; N, 11.42. Found: C, 39.94; H, 5.33; N, 11.41.

*[Co_2(*N,N-*dmgly)tpmc](BF_4)$_3$·3H_2O (**B**)*. Yield: 75 % (0.206 g). Anal. Calcd. for $C_{38}H_{59}O_5N_9B_3Co_2F_{12}$ (FW = 1099): C, 41.52; H, 5.31; N, 11.46. Found: C, 41.30; H, 5.25; N, 11.50.

*[Co_2(*S-*nval)tpmc](ClO_4)$_3$·0.5CH_3CN (*S-*nvalH* = S-*norvaline) (**C**)*. To a suspension of tpmc (0.141 g; 0.250 mmol) in 5 cm^3 of CH_3CN, a solution of $Co(ClO_4)_2·6H_2O$ (0.176 g; 0.500 mmol) in 4.0 cm^3 of deionised H_2O was added. The mixture was stirred for 10 min, when a saturated aqueous solution of *S*-norvaline (0.0440 g; 0.375 mmol) (previously neutralized with 0.10 mol/dm^3 aqueous NaOH to pH 6.2, checked with indicator strips) was slowly added dropwise. The reaction mixture of intensive purple colour was refluxed on a water bath (80 °C) for 2 h with continuous stirring. The purple precipitate separated by suction was slightly contaminated with violet $[Co_2(OH)tpmc](ClO_4)_3$.[10] The product was recrystallized several times from a mixture of CH_3CN:H_2O (5:1, v/v), washed with cold CH_3CN and deionised water to give pure purple microcrystals, which were dried and kept in a desiccator over anhydrous $CaCl_2$. Yield: 42 % (0.117 g); Anal. Calcd. for $C_{40}H_{55.5}O_{14}N_{9.5}Cl_3Co_2$ (FW = 1117.70): C, 42.98; H, 5.00; N, 11.90. Found: C, 43.14; H, 5.29; N, 11.54.

*[Co_2(*S-*val)tpmc](ClO_4)$_3$·0.5H_2O (*S-*valH* = S-*valine) (**D**)*. The procedure and colour of complex **D** was like for complex **C** with *S*-norvaline, except for using *S*-valine (0.0440 g, 0.375 mmol) and neutralization to pH 6.0. Yield: 46% (0.129 g); Anal. Calcd. for $C_{39}H_{57}O_{15.5}N_9Cl_3Co_2$ (FW = 1124.20): C, 41.67; H, 5.11; N, 11.21. Found: C, 41.68; H, 5.27; N, 11.68.

The complexes **A**–**D** are well soluble in CH_3CN, sparingly in DMSO and DMF, and insoluble in CH_3OH, C_2H_5OH and cold water. The complexes did not melt or decompose up to 250 °C (checked with a hot plate equipped with a microscope).

Analytical methods and applied instruments

Elemental analyses were performed by standard methods in the Centre for Instrumental Analyses, ICTM in Belgrade.

Electronic absorption spectra of complex in CH_3CN solution (c = 1.0×10^{-3} mol/dm^3) were recorded on a GBC UV/Vis spectrophotometer Cintra 20. IR spectra were recorded on a NICOLET 6700 FTIR (ATR technique) in the range 400–4000 cm^{-1}.

Molar conductivities were measured on an HI 8820N conductometer, Hanna Instruments at 20±2 °C in CH_3CN (c = 1.0×10^{-3} mol/dm^3).

Optical rotation measurements for the complexes **C** and **D** in CH_3CN were measured at 589 nm and ambient temperature (20±2 °C) using a tube of 1 dm on a Polarimeter AUTOPOL IV automatic, Rudolf Research Analytical (c = 9.8×10^{-3} mol/dm^3 for complex **C** and 1.2×10^{-3} mol/dm^3 for complex **D**).

Magnetic susceptibilities were measured on MSB-MKI magnetic balance, Sherwood Scientific Ltd., England, at room temperature (23±2 °C). For all complexes, the data were corrected for diamagnetism using Pascal's constants.[13]

Cyclic voltammetry (CV) measurements for complexes **A**–**D** were performed using METHROME 797 VC Compurtrace electronic equipment in a standard three-electrode cell with a Pt disc as the working, standard Ag/AgCl as the reference electrode and Pt as the auxiliary electrode. The measurements were first performed in 10 cm^3 of CH_3CN as the electrolyte, and then in the same volume of complex solution (c = 1.0×10^{-4} mol/dm^3). CV was performed at sweep rates of 50, 100 and 200 mV/s within the potential range from –1.0 to 1.0 V *vs.* Ag/AgCl. To remove O_2 from the system, N_2 was continuously bubbled before each experiment. All measurements were done at room temperature (20±2 °C).

Antimicrobial test

For the determination of antimicrobial activity of the complexes, cultures of the following six microorganisms were used. Gram(+) bacteria: *Micrococcus lysodeikticus* ATCC 4698, *Staphylococcus aureus* ATCC 25923, *Bacillus subtilis* ATCC 6633 and *Bacillus cereus*; Gram(–) bacterium: *Escherichia coli* ATCC 25922; yeast: *Candida albicans* ATCC 24433 and mould: *Aspergillus niger* ATCC 12066. The bacteria were cultivated on Mueller–Hinton agar and the fungi on Sabouraud dextrose agar. Inoculation was performed by mixing 0.10 mL of the microorganism suspension in physiological solution (0.80 g/L NaCl) with 20 mL of cold molten medium.[14] Holes (Ø 0.8 cm) were formed in the inoculated agar plates and 100 μL of the tested complexes (1.0 mg/mL in DMSO) were separately introduced into the holes. Apart from the complexes **A**–**D**, tpmc, amino acids/derivatives, $Co(ClO_4)_2\cdot6H_2O$ and $Co(BF_4)_2\cdot6H_2O$ were tested. The incubation temperature was 37 °C for the bacteria and 28 °C for the fungi. The zones of inhibition were measured after 24 h for the bacteria and 48 h for the fungi if microbiological activity was detected.

RESULTS AND DISCUSSION

The reaction conditions for the preparation of the mixed-ligand complexes were carefully adjusted. At ambient temperature, usually used for Co(II) complexes, the yield was very low (less than 1 %) even if the reaction time was several days. Nevertheless, pure products were thus isolated. At elevated temperatures, the yield was much better but side-products in saturated solutions and decomposition in dilute ones are possible. In both cases, the very stable violet side--product $[Co_2(OH)tpmc](ClO_4)_3$ was formed. In this work, its formation was maximally avoided by careful control of the pH to which the aminocarboxylates were previously neutralized, taking into account that tpmc itself is a weak base. In addition, CH_3CN was replaced as the solvent by CH_3OH in the procedure for *N*-methyl derivatives of glycine.

All attempts to prepare Co(II)tpmc complexes of *N*-methyl/*N,N*-dimethylglycinate ligands as ClO_4^- salts from various solvents failed, due to the formation of an oily product which was difficult to purify by ordinary methods (fraction crystallization, chromatographically, by adding infusorial earth, by changing solvents, *etc.*). Instead of ClO_4^-, BF_4^- was used as the counter ion and CH_3OH as the solvent. Under these conditions, $Co(BF_4)_2\cdot6H_2O$, tpmc and neutralized *N*--methyl/*N*,*N*-dimethylglycine in a molar ratio 2:1:1.5 gave purple microcrystal-

line products by direct syntheses. It was very important to neutralize the *N*-alkyl derivatives of the aminocarboxylates to pH equal to their pK_a±1, taking into account that tpmc itself is a weak base and the formation of the unavoidable hydroxo complex could be favoured when the solutions were slightly alkaline. The presence of H_2O during synthesis should also be minimized to suppress hydrolysis of BF_4^-. On the other hand, the preparation of analogous complex with glycine as BF_4^- salt also failed, for the above given reasons.

The complexes with *S*-norvaline/*S*-valine were isolated using a similar procedure as for the already published analogous complexes, but pH of the neutralized amino acids was lower (about pK_a±1).

All the complexes were unexpectedly air-stable. However, stable single crystal(s) suitable for X-ray analysis could not be grown. Even if regular size and shiny crystals were isolated, they decompose on prolonged standing in an open atmosphere by losing crystal solvent(s). It can be seen from the Experimental and Table I that elemental analyses and conductivity measurements suggested binuclear and cationic nature for all the newly synthesized complexes, being consistent with the same general formula as for the previously prepared analogous complexes. The values of the molar electrical conductivities in their 1.0×10^{-3} mol/dm^3 CH_3CN solutions at room temperature laid in the range 340–366 S cm^2 mol^{-1} (Table I), corresponding to a 1:3 electrolyte type (the literature range is 340–420 S cm^2 mol^{-1}).[15]

TABLE I. Vis spectral, magnetic and molar conductivity data in a CH_3CN complex solution ($c = 1.0\times10^{-3}$ mol dm^{-3}) at room temperature

Complex[a]	λ / nm (ε / dm^3 mol^{-1} cm^{-1})			Λ_M S cm^2 mol^{-1}	μ_{eff}(per Co) μ_B
$[Co_2(OH)tpmc](ClO_4)_3$[b]	489 (60)	–	574 (80)	–	4.46
$[Co_2(gly)tpmc](ClO_4)_3$[c]	458 (80)	511 (96)	548 (79) *sh*[d]	–	4.70
$[Co_2(N\text{-mgly})tpmc](BF_4)_3\cdot4H_2O$	455 (30)	508 (53)	544 (35) *sh*	360	4.75
$[Co_2(N,N\text{-dmgly})tpmc](BF_4)_3\cdot3H_2O$	487 (38)	510 (42)	546 (28) *sh*	366	4.70
$[Co_2(S\text{-nval})tpmc](ClO_4)_3\cdot0.5\ CH_3CN$	458 (42)	514 (57)	555 (44) *sh*	355	4.65
$[Co_2(S\text{-val})tpmc](ClO_4)_3\cdot0.5\ H_2O$	456 (50)	512 (66)	552 (47) *sh*	340	4.63

[a]glyH = glycine, *N*-mglyH = *N*-methylglycine, *N*,*N*-dmglyH = *N*,*N*-dimethylglycine, *S*-nvalH = *S*-norvaline, *S*-valH = *S*-valine; [b]data taken from ref. 10; [c]data taken from ref. 9; [d]shoulder

Cobalt(II) complexes are coloured due to d-d transitions. All the complexes described in this paper had an intensive purple colour. The UV/Vis data and μ_{eff}/Co(II) at room temperature (Table I) for all complexes are in agreement with the high-spin state of Co(II).[16,13b] The complexes containing *N*-methyl substituted derivatives of glycine, **A** and **B** (Table I) have two absorption maxima and one shoulder in the range 487–546 nm and molar extinction coefficients (ε) values of 28–53 dm^3 cm^{-1} mol^{-1}. They were comparable with the corresponding glycinato complexes in spite of the fact that the counter anion was not the same

(BF_4^- instead of ClO_4^-). The intensities of the bands were lower than those found for the corresponding analogous glycinato complexes. It is known that pentacoordinated Co(II) complexes, owing to their lower symmetry, have higher ε values than hexacoordinated ones in the case of the same chromophore.[16] The more pronounced bathochromic shift of the first absorption maxima by about 30 nm in the spectrum of the *N*,*N*-dimethylglycinato analogue could be ascribed to a possible exchange of this ligand with OH^- (Table I). However, the absence of an absorption maximum at 574 nm and the appearance of a maximum at 510 nm, as well as the lower intensities, might suggest a higher degree of symmetry. Thus, it is supposed that in complexes **A** and **B** containing *N*-methylglycinato/*N*,*N*-dimethylglycinato anions, the Co(II) is hexacoordinated (Scheme 1e or 1f).

The Vis spectra of the complexes **C** and **D** with *S*-norvalinato/*S*-valinato ligands are of similar shape and corresponding band positions. They are also similar to those containing amino acids of the preceding members of the homologous series (glycine/*S*-alanine/*S*-α-aminobutyric/α-aminoisobutyric acid), although of lower intensities, but this trend on enlarging the side hydrocarbon chain had already been observed. In addition, for complex **D**, with a branched aminocarboxylato side chain, the values of ε were higher than those for complex **C**, having the isomeric normal side chain ligand. The same was observed earlier for complexes with isomeric *S*-α-aminobutyrato/α-aminoisobutyrato ligands.[8,9]

In UV part of the electronic spectra, very intense multiple bands ascribed to CT appeared in the 230–300 nm range (ε was in the range 5000–5500 $dm^3\ mol^{-1}\ cm^{-1}$ for the *N*-methylglycinato/*N*,*N*-dimethylglycinato complexes and 3750––3900 $dm^3\ mol^{-1}\ cm^{-1}$ for the *S*-norvalinato/*S*-valinato complexes).

The origin of the optical activity of the complexes $[Co_2(A)tpmc](ClO_4)_3$ where HA = *S*-alanine/*S*-α-aminobutyric acid was earlier ascribed to the "vicinal effect", *i.e.*, to the optical activity of A^- alone.[9] Namely, the values of $[M]_{589}^{20}$ for the *S*-alaninato/*S*-α-aminobutyrato complex were +167.7 and +125.5°. The calculated $[M]_{589}^{20}$ values for complexes **C** and **D** (containing *S*-norvalinato/*S*-valinato ligand) were +279.4 and +459.7°, respectively. This strongly suggests an enhanced conformational and configurational contribution to the overall asymmetry of these complexes. Complex **D**, containing a branched side chain and thus larger steric hindrance, has a substantially higher molecular rotation value than its analogue with the isomeric normal side chain ligand (complex **C**).

In the IR spectra of the complexes, there are some characteristic bands:[17] a broad multiple band around 3600 (for complex **A**) or 3580 cm^{-1}(for complexes **B** and **D**), arising from ν(O–H) of crystal water; at 3244 cm^{-1} of ν(NH) for the secondary amino group excluded from coordination (complex **A**), a doublet at 3310 and 3277 cm^{-1} belonging to the primary non-coordinated amino group in the spectra of **C** and **D**; a sharp strong band at 1603–1609 cm^{-1} from the skeletal stretching valence vibration of the tpmc pyridine included in coordination (in the

spectra of all complexes); a very strong broad band at about 1070 cm^{-1} from $\nu(ClO_4^-)$ and a medium sharp band around 631 cm^{-1} from $\delta(ClO_4^-)$ for complexes **C** and **D**, and around 1020–1030 cm^{-1} of $\nu(BF_4^-)$ for complexes **A** and **B**. Sharp weak bands in the spectra of all complexes assigned to ν(Co–N) appeared in the range 475–485 cm^{-1} and ν(Co–O) in the range 412–420 cm^{-1}. Additionally, in the region of 1560–1392 cm^{-1}, asymmetrical (ν_a) and symmetrical (ν_s) valence vibrations of the OCO group of weak to strong intensities were observed (Table II). The observed changes of the $\Delta\nu = \nu_a - \nu_s$ values for the complexes compared with those found for their corresponding sodium salts[18] showed that the aminocaroxylato/derivatives ligand are coordinated using both oxygen atoms. Moreover, the $\Delta\nu$ values in all cases were significantly lower than in the spectra of the respective free ligand. It is obvious that the $\Delta\nu$ values decrease in the following order: *S*-ala^{-9} > gly^{-9} > *α*-aibu^{-8} > *S*-abu^{-9} > *S*-val^{-}/*S*-nval^{-}. Such an order suggests the formation of weaker Co–O bonds in the complexes **C** and **D** containing the longest chains than those predicted for the other aminocarboxylates from the same homologous series[8,9] As for the *N*-methyl derivatives of glycine, the strength of the Co–O bond parallels the decrease in $\Delta\nu$ in the order: gly^{-9} > *N*-mgly > *N*,*N*-dmgly, which could be explained by the steric hindrance produced by the introduction of voluminous $-CH_3$ group(s) on the nitrogen atom instead of the smaller H atom(s). In addition, the formation of stronger H-bonds within complexes **A** and **B** containing BF_4^- than in the glycinato complexes hav-

TABLE II. Selected IR spectral data of OCO^- (asymmetrical, ν_a, symmetrical valence vibrations, ν_s, and $\Delta\nu$ values in cm^{-1}) for uncoordinated alkaline salts and the corresponding aminocarboxylates/derivatives in the complexes

Compound[a]	ν_a	ν_s	$\Delta\nu$
Na-gly	1595 *s*[c]	1399 *s*	196
$[Co_2(gly)tpmc](ClO_4)_3$[b]	1580 *m*	1365 *m*	215
Na-*N*-mgly	1580 *m*	1391 *m*	190
$[Co_2(N\text{-mgly})tpmc](BF_4)_3\cdot H_2O$	1585 *sh*, *m*	1481 *w*, 1446 *m*, 1392 *m*, 1439[e]	146
Na-*N*,*N*-dmgly	1593 *vs*	1375 *vs*	218
$[Co_2(N,N\text{-dmgly})tpmc](BF_4)_3\cdot 3H_2O$	1573 *sh*, *m*	1481 *w*, 1443 *m*, 1405 *m*, 1443[e]	130
Na-*S*-ala	1595 *s*	1406 *s*	189
$[Co_2(S\text{-ala})tpmc](ClO_4)_3\cdot H_2O$[d]	1575 *m*	1350 *w*	225
K-*S*-abu	1587 *s*	1408 *s*	179
$[Co_2(S\text{-abu})tpmc](ClO_4)_3\cdot H_2O$[d]	1575 *m*	1390 *m*	185
K-*α*-aibu	1577 *s*	1416 *vs*	161
$[Co_2(\alpha\text{-aibu})tpmc](ClO_4)_3$[d]	1555 *s*	1361 *w*	194
Na-*S*-nval	1569 *vs*	1410 *s*	159
$[Co_2(S\text{-nval})tpmc](ClO_4)_3\cdot 0.5CH_3CN$	1560 *m*	1483 *w*, 1442 *m*, 1462[e]	99
Na-*S*-val	1549 *vs*	1395*s*	154
$[Co_2(S\text{-val})tpmc](ClO_4)_3\cdot 0.5H_2O$	1560 *m*	1482 *w*, 1467 *w*, 1441 *m*, 1463[e]	97

[a]abbreviations as in Table I; [b]data taken from ref. 9 and [c]from ref. 8; [d]*m* = medium; *s* = strong; *vs* = very strong; *w* = weak; [e]calculated as the average value of two or three bands

ing ClO_4^- are to be expected. Similar shifts of ν(OCO) were already observed for some bulky dicarboxylato ligands in the Co(II)tpmc moiety,[19,20] for which hexacoordination was proposed or confirmed by X-ray analysis. Hence, it is proposed that in the complexes **A**–**D**, the anions of *N*-methyl derivatives/aminocarboxylates are coordinated through OCO in a combined chelate-bridged manner (Scheme 1e or 1f). The participation of the amino nitrogen is excluded in all cases, although it can form H-bonds with the counter ions or crystal solvents molecules. The strength of the Co–O bonds in the above-described complexes is the consequence of various factors, such as: steric repulsions between the alkyl groups from the aminocarboxylates/derivatives and the pyridyl groups from tpmc; changes of the inductive effects of the introduced $–CH_2–$/$–CH_3$ groups and their positions; the size of the alkyl group in relation to the size of the macrocyclic cavity; non-covalent interactions; *etc*. It is difficult to determine the contribution of each of them, as they are all responsible for the overall structure.

The electrochemical behaviour of the complexes **A**–**D** was studied by cyclic voltammetry. The absence of any peaks on all voltammograms under the investigated conditions suggests electrochemical stability of the complexes. This fact gives the possibility of their use as catalysts. A previous electrochemical study of some congeneric complexes with *α*-amino acids showed that complexes with a gly$^-$/*S*-ala$^-$ ligand undergo a two-step reversible electrochemical oxidation and are destroyed at a potential of 0.60 V, which was ascribed to ligand oxidation. The complex containing *α*-aibu$^-$ exhibited another type of electrochemical behaviour. It adsorbed on the electrode surface without charge transfer. A similar stability was observed for Co(II)-tpmc complexes containing some of the dicarboxylates.[20,21]

The results of the antimicrobial tests are presented in Table III. It is obvious that the complexes showed moderate antibacterial and antifungal activity. Furthermore, the complexes **A** and **D** are active against all tested microorganisms, while the solvent and ligands were inactive under the same conditions.

TABLE III. Antimicrobial activity of the prepared complexes

Microorganism	Zone diameter, mm			
	Compound[a]			
	A	**B**	**C**	**D**
Bacillus cereus (Gram(+) bacterium)	22	26	16	18
Micrococcus lysodeikticus ATCC 4698 (Gram(+) bacterium)	25	20	–[b]	20
Bacillus subtilis ATCC 6633 (Gram(+) bacterium)	16	–	–	18
Staphylococcus aureus ATCC 25923 (Gram(+) bacterium)	20	–	–	15
Escherichia coli ATCC 25922 (Gram(–) bacterium)	16	19	16	17
Aspergillus niger ATCC12066 (mold)	20[c]	15[c]	16[c]	18[c]
Candida albicans ATCC 24433 (fungus)	15	17	16	16

[a]Abbreviations as in Table I; [b]activity was not found; [c]fungistatic activity

CONCLUSIONS

Four novel Co(II) complexes with the pendant octaazamacrocyclic ligand *N*,*N*',*N*'',*N*'''-tetrakis(2-pyridylmethyl)-1,4,8,11-tetraazacyclotetradecane (tpmc) and *N*-methylglycine/*N*,*N*-dimethylglycine/*S*-norvaline/*S*-valine anions were prepared in good yields. They were characterized by some physical properties and by valuable methods and techniques (elemental analyses, molar electrical conductivity, spectroscopic data, magnetic measurements, cyclic voltammetry) and compared with already described analogous Co(II) complexes.

All complexes are binuclear with an *exo* coordination mode of tpmc in the boat conformation. The Co(II) ions are coordinated to the four nitrogen atoms of tpmc and bridged *via* oxygen atoms from the aminocarboxylate/derivatives, while the nitrogen atoms are uncoordinated. In all complexes, a combined chelate--bridged mode with hexacoordinated cobalt atom is suggested as the most probable. The complexes are electrochemically stable and showed some antimicrobial activity.

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ИЗВОД

ПРОУЧАВАЊЕ НОВИХ КОМПЛЕКСА КОБАЛТА(II) СА ОКТААЗАМАКРОЦИКЛОМ И АМИНОКАРБОКСИЛАТИМА ИЛИ ЊИХОВИМ ДЕРИВАТИМА

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Добијена су четири нова мешовито-лигандна комплекса Co(II), стабилна на ваздуху, опште формуле $[Co_2(Y)tpmc]Z_3 \cdot q(H_2O/CH_3CN)$ (HY = *N*-метилглицин/*N*,*N*-диметилглицин, $Z = BF_4^-$, $qH_2O = 4$ или 3); HY = *S*-норвалин/*S*-валин, $Z = ClO_4^-$, $qCH_3CN = 0{,}5$; $qH_2O = 0{,}5$; tpmc = *N*,*N*',*N*'',*N*'''-тетракис(2-пиридилметил)-1,4,8,11-тетраазациклотетрадекан). Састав, нека физичка и хемијска својства и њихове приближне геометрије су изведене на основу елементалне анализе (C, H, N), кондуктометријских и магнетних мерења, спектроскопских података (UV/Vis, IR) односно цикличне волтаметрије. Подаци су упоређени са раније описаним аналогим комплексима који садрже макроциклични лиганд и алифатичне аминокарбоксилате. Претпостављено је да су сви комплекси динуклеарни са егзо координацијом пендантног октаазамакроцикла у конформацији лађе. Поред два –N–$(CH_2)_2$–N– дела цикламовог прстена унутар tpmc-а, јони високо-спинског Co(II) су највероватније премошћени ангажовањем кисеоникових атома са анјона аминокарбоксилата/деривата, док атоми азота остају некоординовани. За све комплексе предложен је комбиновани хелатно-мостовни начин везивања. Комплекси су били електрохемијски стабилни у опсегу потенцијала –1,0 до 1,0 V. Они су прелиминарно тести-

рани на микроорганизме заједно са лигандима, полазним простим солима и растварачима као тест супстанцама. У неким случајевима је нађена извесна антимикробна активност комплекса.

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