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Specific properties of 3d-metal complexes with optical isomers of complexones derived from dicarboxylic amino acids

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Methods for the synthesis of optical isomers of monoamine complexones derived from dicarboxylic amino acids and their complexes with 3d-metals are considered. The physicochemical properties of the compounds in question were studied and a number of specific properties of the complexes were revealed. An approach was proposed to the study of quantitative relationships between the chemical composition, structure, and properties of chemical substances.

Key words: complexones derived from dicarboxylic amino acids; L-*N*-(carboxymethyl)aspartic acid; D-*N*-(carboxymethyl)aspartic acid; L-*N*-(carboxymethyl)glutamic acid, complexes with 3d-metals.

Optically active compounds are of interest to chemists and pharmacists since their discovery, *i.e.*, more than a century.[1] The most complicated and intriguing problem is why do optical isomers exhibit different types of biological and pharmacological activity?[2] Indeed, different optical isomers of the same chemical compounds influence living organisms in different manner. Usually, the highest biological activity is associated with L-isomers, whereas many drugs represent mixtures of two isomers acting differently. For instance, even the physical properties of amino acids can be different. Examples are provided by aspartic acid (H_2Z^1) and glutamic acid (H_2Z^2) that were used in this work to synthesize new complexones. Indeed, L-H_2Z^1 has a slightly bitter taste, whereas D-H_2Z^1 has no taste. As to H_2Z^2, its D-isomer has a characteristic meaty taste and is widely used as flavoring additive[3] in contrast to the L-isomer.

Optical isomers also exhibit different chemical properties. In particular, they differ from each other in the sense of optical rotation and in the dissociation constants that change with increasing the number of carbon atoms in organic compounds.[4]

The synthesis and physicochemical properties of transition-metal complexes with various carboxylic acid derivatives are of interest for specialists in complexation studies. Specific properties and application fields of 3d-metal complexes with hydroxyaromatic acids[5] and phloroglucinol carboxylic acid[6] have been well studied, as well as the synthesis and properties of complexes of biologically active carboxylic acid derivatives (including succinic acid ones).[7]

Earlier,[8] we synthesized *N*-(carboxymethyl)aspartic acid (H_3Z^3) and studied its acid-base properties. This work has been carried out in a continuation of research into the physicochemical properties of biologically active dicarboxylic amino acids including *N*-(carboxymethyl)glutamic acid (H_3Z^4) and its L-isomer (L-H_3Z^4), as well as the L- and D-isomers of H_3Z^3. The complexones were synthesized by the reactions of aspartic or glutamic acid with chloroacetic acid, respectively. We studied the acid-base properties of the new complexones, their complexation with 3d metals (nickel, copper and zinc), certain specific properties of the complexes synthesized, and evaluated the thermal and chemical stabilities of the complexes.

Experimental

Reactants. The following commercially available reactants were used: KNO_3 ("chemically pure" grade, GOST 4217-77, Belkali—Migao LLC, Belarus), NaOH (fixanal, OOO Uralhiminvest, Russia), sulfaminic acid (CAS: 5329-14-6, Sigma-Aldrich, USA), KBr (CAS: 7758-02-3, Sigma-Aldrich, USA), L-aspartic acid ("analytically pure" grade, Reanal Laboratory Chemicals Ltd., Hungary), D-aspartic acid ("analytically pure" grade, Reanal Laboratory Chemicals Ltd., Hungary), L-glutamic acid ("analytically pure" grade, Reanal Laboratory Chemicals Ltd., Hungary), chloroacetic acid (CAS: 79-11-8, Alfa Aesar, United Kingdom), HCl ("chemically pure" grade, AO "Baza No. 1 Khimreaktivov", Russia), EtOH (95%, OOO "Konstanta-Farm M", Russia), $NiNO_3 \cdot 6H_2O$ ("chemically pure" grade, AO "Uralchem", Russia), $Cu(NO_3)_2 \cdot 3H_2O$ ("chemically pure" grade, AO "Uralchem", Russia), and $Zn(NO_3)_2 \cdot 6H_2O$ ("chemically pure" grade, AO "Uralchem", Russia).

Analytical methods. The protolytic equilibria in complexone solutions were studied by potentiometric titration[8] at an ionic strength of 0.1 mol L^{-1} (with a KNO_3 solution as a background electrolyte). The individual monoamine complexones L-H_3Z^3,

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D-H_3Z^3, and L-H_3Z^4 were prepared for titration by mixing a corresponding complexone solution (1 mL, a concentration of $5 \cdot 10^{-2}$ mol L^{-1}), KNO_3 (5 mL, an initial concentration of 1 mol L^{-1}), and a necessary amount of bidistilled water until a total volume of 50 mL. The copper, zinc and nickel complexes were titrated with mixtures (total volume 50 mL) composed of a complexone solution (1 mL, a concentration of $5 \cdot 10^{-2}$ mol L^{-1}), a corresponding metal nitrate solution (1 mL, a concentration of $5 \cdot 10^{-2}$ mol L^{-1}), KNO_3 (5 mL, an initial concentration of 1 mol L^{-1}), and bidistilled water. The resulting solutions were placed into a thermostatted (25±0.1 °C) potentiometric cell for titration in nitrogen atmosphere using a 0.05 *M* aqueous NaOH solution prepared from the fixanal diluted two-fold with bidistilled water. The concentration of the alkali was determined by pH-potentiometric titration using an accurately weighed sample of sulfaminic acid. The NaOH solution was stored in a Compoplast-300 disposable sterile polymeric container for blood components. The equilibrium concentration of hydrogen ions was determined using a HI 2210 microprocessor laboratory pH-meter (Hanna instruments, Italy) with a HI-1131B combination refillable glass pH-electrode. The step ionization constants of the complexones and the stability constants of the metal complexes were calculated using the DALSFEK program**[10]** which utilizes the nonlinear least-squares method. Thermogravimetric studies of all complexes were carried out on a STA 449F differential scanning calorimeter (NETZSCH, Germany) using nearly 10-mg weighed samples. Heating to 500 °C was performed at a rate of 10 °C min^{-1}. Samples of protonated complexes of L-H_3Z^3, D-H_3Z^3, and L-H_3Z^4 with Ni^{II}, Cu^{II}, and Zn^{II} were prepared as KBr pellets. Their IR spectra were recorded on an FSM 1202 FT IR spectrometer (Infraspek Ltd., Russia) in the wavenumber range of 4000—450 cm^{-1}. Two spectral regions, *viz.*, 3600—2500 and 1800—800 cm^{-1}, were analyzed. The absorption bands corresponding to vibrations of O—H, N—H, C=O, C—O, and C—N groups and thus representing the main source of information on the complexes under study appear just in these regions.

Synthesis of L-H_3Z^3, D-H_3Z^3, and L-H_3Z^4 (general procedure). Weighed samples of the corresponding amino acid (L-H_2Z^1, D-H_2Z^1, L-H_2Z^2) and chloroacetic acid were mixed in a 200-mL volumetric flask and then a necessary amount of bidistilled water was added until a total volume of 200 mL. The suspension thus prepared was transferred to a 500-mL heat-resistant flat-bottom flask and alkalinized by adding sodium hydroxide until pH ~10. The flask containing the reaction mixture was attached to a reflux condenser and heated on a boiling water bath for 10 h. Then, the reaction mixture was cooled to ambient temperature (25 °C) and acidified with HCl until pH ~2.0—2.5 and then cooled again to 4—6 °C to initiate precipitation of the corresponding complexone. The precipitate was filtered off on a Büchner funnel, washed repeatedly with EtOH, and dried at 50—60 °C in air stream. The complexone thus synthesized was used without additional purification.

D-*N*-(Carboxymethyl)aspartic acid (D-H_3Z^3) was synthesized by mixing accurately weighed samples of D-H_2Z^1 (6.65 g, 0.05 mol) and chloroacetic acid (5.2 g, 0.055 mol). White crystals poorly soluble in water. The yield was 55%, m.p. 260 °C. Found (%): C, 37.881; H, 4.725; N, 7.298. $C_6H_9NO_6$. Calculated (%): C, 37.696; H, 4.712; N, 7.329. IR, ν/cm^{-1}: 3493 (O—H_{free}), 3003 (O—H_{bound}), 3408 (N—H), 2658 (N—H^+), 1690 (C=O), 1643 (C—O_{as}), 1423 (C—O_s), 1153 (C—N_{as}), 899 (C—N_s).

L-*N*-(Carboxymethyl)aspartic acid (L-H_3Z^3) was synthesized by mixing accurately weighed samples of L-H_2Z^1 (6.65 g, 0.05 mol) and chloroacetic acid (5.2 g, 0.055 mol). White crystals are poorly soluble in water and insoluble in nonpolar organic solvents. The yield was 58%, m.p. 260 °C. Found (%): C, 37.671; H, 4.719; N, 7.348. $C_6H_9NO_6$. Calculated (%): C, 37.696; H, 4.712; N, 7.329. IR, ν/cm^{-1}: 3598 (O—H_{free}), 3000 (O—H_{bound}), 3437 (N—H), 2477 (N—H^+), 1710 (C=O), 1638 (C—O_{as}), 1398 (C—O_s), 1082 (C—N_{as}), 890 (C—N_s).

L-*N*-(Carboxymethyl)glutamic acid (L-H_3Z^4) was synthesized by mixing accurately weighed samples of L-H_2Z^2 (7.36 g, 0.05 mol) and chloroacetic acid (5.67 g, 0.06 mol). White crystals are poorly soluble in water and insoluble in nonpolar organic solvents. The yield was 63%, m.p. 266 °C. Found (%): C, 43.854; H, 5.948; N, 7.335. $C_8H_{13}NO_6$. Calculated (%): C, 43.836; H, 5.936; N, 7.329. IR, ν/cm^{-1}: 3058 (O—$H_{bound.}$), 3432 (N—H), 2663 (N—H^+), 1660 (C—O_{as}), 1423 (C—O_s), 1130 (C—N_{as}), 808 (C—N_s).

Synthesis of the nickel, copper, and zinc complexes with dicarboxylic amino acid derivatives (general procedure). In a 100-mL conical flask, a weighed sample of the corresponding metal salt (0.0025 mol) was dissolved in distilled water (15 mL). The solution thus prepared was heated to 85 °C under continuous stirring and a 0.1 N aqueous NaOH solution (50 mL) was added portionwise in 10-mL portions. The 3d-metal hydroxide solution thus obtained was settled for 1.5 h and then the liquid was decanted. The residue was washed with warm distilled water (50 mL), the solution was settled again, and the wash liquid was decanted (this procedure was repeated three times). An accurately weighed sample of a complexone (0.0025 mol) was pounded in a mortar, dissolved in warm distilled water (10 mL), and this solution was added to the metal hydroxide solution. The suspension thus prepared was heated for 5 min at 55 °C until complete dissolution of the precipitate. The metal complex solution thus formed was transferred to a 25-mL porcelain bowl,

Table 1. IR spectra of 3d-metal complexes

Complex	IR spectrum
Ni(L-HZ^3)	2940 (O—H_{bound}), 3284 (N—H), 1587 (C—O_{as}), 1404 (C—O_s), 1118 (C—N_{as}), 839 (C—N_s)
Cu(L-HZ^3)	2935 (O—H_{bound}), 3180 (N—H), 1605 (C—O_{as}), 1379 (C—O_s), 1134 (C—N_{as}), 979 (C—N_s)
Zn(L-HZ^3)	2938 (O—H_{bound}), 3271 (N—H), 1602 (C—O_{as}), 1407 (C—O_s), 1088 (C—N_{as}), 908 (C—N_s)
Ni(D-HZ^3)	2938 (O—H_{bound}), 3281 (N—H), 1593 (C—O_{as}), 1412 (C—O_s), 1096 (C—N_{as}), 906 (C—N_s)
Cu(D-HZ^3)	3500 (O—H_{free}), 2933 (O—H_{bound}), 3264 (N—H), 1615 (C—O_{as}), 1408 (C—O_s), 1098 (C—N_{as}), 905 (C—N_s)
Zn(D-HZ^3)	3506 (O—H_{free}), 2930 (O—H_{bound}), 3268 (N—H), 1613 (C—O_{as}), 1409 (C—O_s), 1125 (C—N_{as}), 937 (C—N_s)
Ni(L-HZ^4)	2930 (O—H_{bound}), 3413 (N—H), 2425 (N—H^+), 1600 (C—O_{as}), 1370 (C—O_s), 1080 (C—N_{as}), 640 (C—N_s)
Cu(L-HZ^4)	2933 (O—H_{bound}), 3432 (N—H), 1628 (C—O_{as}), 1388 (C—O_s), 1129 (C—N_{as}), 785 (C—N_s)
Zn(L-HZ^4)	3500 (O—H_{free}), 2925 (O—H_{bound}), 3333 (N—H), 1590 (C—O_{as}), 1408 (C—O_s), 1103 (C—N_{as}), 745 (C—N_s)

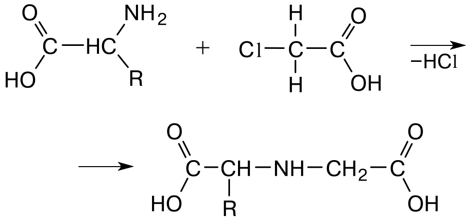
placed in a loss-on-drying oven pre-heated to 55 °C, and kept for 3—4 h at a specified temperature until complete crystallization. The solidified crystalline product was pounded with a porcelain pestle, EtOH (10 mL) was added, and the mixture was kept in the loss-on-drying oven until complete evaporation of the alcohol. The complexes were stored in a sealed desiccator in the dark.

The IR spectra of the complexes are listed in Table 1.

Results and Discussion

Scheme 1 presents the reaction between dicarboxylic amino acids and chloroacetic acid affording corresponding monoamine complexones. A similar reaction with bromoacetic acid was used in our previous study.[9]

Scheme 1



Conditions: pH = 10, t = 10 h, T = 100 °C.

Since the haloacetic acid is hydrolyzed during the reaction, it is taken in 1.5—2-fold excess and introduced into the reaction medium by small portions. This procedure was used to synthesize the complexones L-H_3Z^4 (Scheme 1, R = $CH_2C(O)OH$), L-H_3Z^3 and D-H_3Z^3 (Scheme 1, R = C(O)OH). In all cases the alkaline medium was maintained using NaOH, while acidification of the solutions after the synthesis to convert the complexones to the acid form was achieved using HCl.

The step dissociation constants of the complexones were determined from the results of separate titrations at an ionic strength of 0.1 mol L^{-1} produced by KNO_3 to make the results of our experiments comparable with relevant published data.[11—13] The neutralization curves of the complexones synthesized in this work are presented in Fig. 1 (the reproducibility was ±0.05 pH units).

The logarithms of the dissociation constants of the starting amino acids and of the optical isomers of the monoamine complexones we have synthesized are listed in Table 2 which also includes the dissociation constants of certain complexones determined at different ionic strength.[11—26] This is done to confirm the correctness of our conclusions about the changes in the basicity of the nitrogen atoms in the complexones studied.

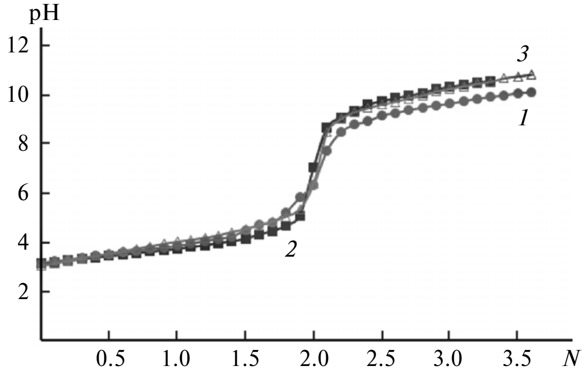


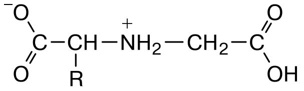
Fig. 1. Neutralization curves of monoamine complexones L-H_3Z^3 (*1*), D-H_3Z^3 (*2*), L-H_3Z^4 (*3*) obtained using a NaOH solution at 25 °C. Here and in Fig. 2 $C = 5 \cdot 10^{-2}$ mol L^{-1}, $I = 0.1$ mol L^{-1} (KNO_3), N is the number of NaOH moles added during titration calculated per mole of complexone present in solution.

Table 2. Logarithms of dissociation constants of the starting amino acids and monoamine complexones at 25 °C

Complexone	pk_1	pk_2	pk_3
	I = 0 mol L^{-1}		
H_3Z^3	2.95[11]	4.31[11]	10.33[11]
L-H_3Z^3	2.81±0.02	3.83±0.05	10.05±0.01
D-H_3Z^3	2.05±0.03	4.31±0.04	9.62±0.06
L-H_3Z^4	2.67±0.02	3.87±0.01	9.60±0.04
	I = 0.1 mol L^{-1}		
H_3Z^3	2.58[12], 2.44[13]	3.87[12], 3.80[13]	9.67[12], 9.82[13]
L-H_3Z^3	2.79±0.04	3.80±0.07	10.06±0.03
D-H_3Z^3	2.04±0.06	4.32±0.07	9.63±0.02
H_2Z^1	1.99[14,15], 2.09[16—21], 1.91[22]	3.90[14,15], 3.86[16—21], 3.63[24]	10.00[14,15], 9.82[16—21], 9.47[24]
L-H_2Z^1	1.88±0.07	2.90±0.08	10.04±0.03
D-H_2Z^1	1.82±0.06	4.94±0.03	9.27±0.05
H_3Z^4	2.49[23]	4.16[23]	9.28[23]
L-H_3Z^4	2.67±0.05	3.86±0.01	9.59±0.06
H_2Z^2	2.19[3,21,24], 2.10[15,25], 2.30[14]	4.25[3,21,24], 4.07[15,25], 4.51[14]	9.67[3,21,24], 9.47[15,25], 9.95[14]
L-H_2Z^2	2.00±0.05	3.31±0.06	10.21±0.04
	I = 0.5 mol L^{-1}		
H_3Z^3	2.65[12]	3.85[12]	9.47[12]
L-H_3Z^3	2.78±0.07	3.76±0.05	9.86±0.01
D-H_3Z^3	2.01±0.05	4.07±0.04	9.48±0.02
L-H_2Z^1	1.86±0.07	2.86±0.04	10.01±0.05
D-H_2Z^1	1.80±0.02	4.83±0.06	9.18±0.08
L-H_3Z^4	2.63±0.04	3.79±0.05	9.57±0.02
	I = 1.0 mol L^{-1}		
H_3Z^3	2.58[26], 2.49[26]	3.75[26], 3.88[26]	9.38[26], 9.74[26]
L-H_3Z^3	2.72±0.05	3.63±0.04	9.84±0.06
D-H_3Z^3	1.97±0.03	4.01±0.04	9.45±0.01
L-H_2Z^1	1.82±0.07	2.80±0.06	9.99±0.03
D-H_2Z^1	1.76±0.08	4.79±0.05	9.14±0.01
L-H_3Z^4	2.61±0.06	3.72±0.02	9.54±0.05

Like racemic H_3Z^3 or H_3Z^4, individual optical isomers should be treated as environmentally safe complexones since they contain rapidly photodegradable structural fragments. This feature of dicarboxylic amino acid derivatives has been well documented.[27—31]

It is of interest to establish the mechanism of formation of the zwitter-ion and the order of protonation of the acid groups in the molecules of the optical isomers of the complexones synthesized in this work. The α-carboxyl group of the dicarboxylic amino acid should exhibit the highest acidity.[32] The dissociation constants of succinic acid[33] (pk_1 = 4.16 and pk_2 = 5.61) whose fragment is a constituent of H_3Z^3, glutaric acid[34] (pk_1 = 4.34 and pk_2 = 5.27) whose fragment is a constituent of H_3Z^4, and acetic acid[35] (pk = 4.76) suggest that the α-carboxyl protons of the succinic and glutaric acid residues are characterized by higher acidity, which is responsible for proton abstraction during the formation of the zwitter-ionic structure shown below.


$^-OOC-CH(R)-\overset{+}{N}H_2-CH_2-COOH$

From the data in Table 2 it follows that the pk_n values (n is the basicity of the complexone H_nZ) differ from the corresponding previous values by a few units; therefore, the complexones under study have similar structures in aqueous solutions.

Our study of dissociation of the optical isomers of the complexones H_2Z^1 and H_3Z^3 showed (see Table 2) that the D- and L-isomers are characterized by different basicity of the nitrogen donor atoms. Indeed, the pk_3 value of L-H_3Z^3 is 0.43 higher than that of D-H_3Z^3 while the pk_3 value of L-H_2Z^1 is 0.77 higher than that of D-H_2Z^1.

The pH-potentiometric titration curves of the complexones L-H_3Z^3, D-H_3Z^3, and L-H_3Z^4 in the presence of Ni^{2+}, Cu^{2+}, and Zn^{2+} ions are presented in Fig. 2.

The logarithms of the stability constants of the metal complexes calculated using the DALSFEK program and those of the complexes of the same metals with racemic complexones are listed in Table 3.

The addition of an acetate group to H_2Z^1 and H_2Z^2 (all forms of H_3Z^3 and H_3Z^4) makes the 3d-metal complexes more stable (see Table 3). A gradual increase in stability of the complexes by 1.5—2 orders of magnitude is with certainty determined by an increase in the denticity of the compounds studied (*cf.* the stability of the copper complexes with the L-H_3Z^3 and D-H_3Z^3 isomers).

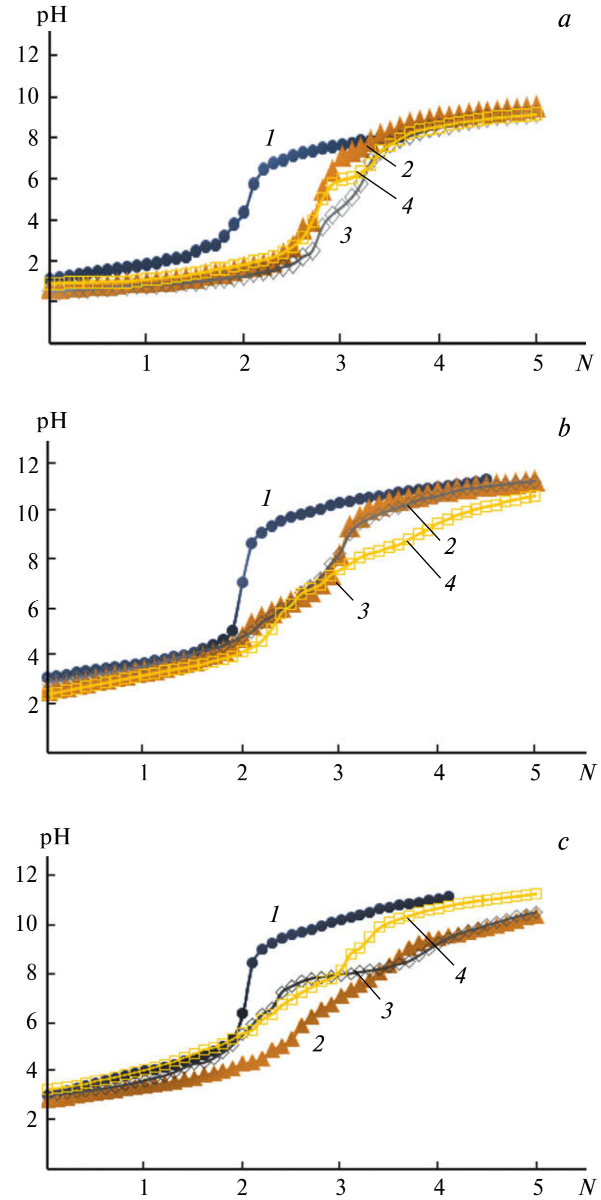


Fig. 2. Titration curves of the starting complexones L-H_3Z^3 (*a*), D-H_3Z^3 (*b*), L-H_3Z^4 (*c*) using a NaOH solution in the absence (*1*) and in the presence of Ni^{2+} (*2*), Cu^{2+} (*3*), and Zn^{2+} ions (*4*).

Changes in the stability of the 3d-metal complexes in question agree with the decrease in the atomic radius in the Irving—Williams series, *viz.*, $Cu^{2+} > Zn^{2+}$, Ni^{2+} and can be explained by stabilization of the complexes in the field produced by the nitrogen- and oxygen-containing ligands compared to aqua ions. Table 4 presents the results of thermogravimetric study of crystal hydrates of the metal complexes with the optical isomers of H_3Z^3 and H_3Z^4. It follows that dehydration of the crystal hydrates proceeds in one step and thus it is impossible to determine the coordination number of the metal (separation into inner-sphere and outer-sphere water).[44—46]

Among the metal complexes studied, the copper complexes demonstrated the lowest thermal stability while the nickel ones appeared to be the most thermally stable. A better illustration is provided by the two-step dehydration of the zinc and copper complexes with D-H_3Z^3 containing two water molecules each. One water molecule eliminates at higher temperature; consequently, it forms a stronger bond, which is usually typical of inner-sphere molecules. Therefore, we concluded that the second step of dehydration of these complexes involves elimination of

Table 3. Logarithms of stability constants of 3d-metal complexes with the amino acid ligands (t = 25 °C, I = 0.1 mol L^{-1})

Complex*	Complex-forming ion		
	Ni^{2+}	Cu^{2+}	Zn^{2+}
MZ^1	7.02[36], 7.35[37], 7.16[38]	8.81[36], 8.57[38]	6.40[36], 11.2[37], 5.84[38]
M(L-Z^3)	10.49±0.03	12.63±0.04	9.09±0.08
M(D-Z^3)	9.96±0.05	11.09±0.02	8.52±0.09
MZ^3	10.25[11]	10.98[35], 12.80[24]	8.60[11]
MZ^2	6.54[36], 6.46[38], 5.60[39]	8.08[36], 7.87[39]	4.87[36], 4.59[39]
M(L-Z^4)	9.11±0.03	10.77±0.05	7.35±0.07
$MZ^1{}_2$	12.75[33]	—	—
M(L-Z^3)$_2$	16.11±0.2	16.78±0.04	12.34±0.05
M(D-Z^3)$_2$	14.96±0.1	15.44±0.05	11.29±0.06
$MZ^3{}_2$	15.20[40]	15.82[41], 19.58[42]	11.65[11]
$MZ^2{}_2$	10.34[37]	—	—
M(L-Z^4)$_2$	14.19±0.05	14.85±0.05	10.21±0.05
M(L-HZ^3)	15.09±0.04	16.69±0.02	12.29±0.03
M(D-HZ^3)	13.62±0.03	14.97±0.06	13.64±0.05
MHZ^3	14.26[24]	15.07[41], 20.45[42]	12.77[11]
MHZ^2	—	21.15[43]	—
M(L-HZ^4)	12.70±0.05	13.21±0.05	11.59±0.05

* The anion charges are omitted.

inner-sphere water. Assuming that the coordination number of Zn(II) and Cu(II) in the complexes is four, D-H_3Z^3 is a tridentate ligand in the complexes with these metals.

The IR spectra of all compounds studied exhibit the stretching vibration bands of secondary amino groups in the range of 3450—3200 cm^{-1} and weak bands corresponding to bound OH groups in the range of 3000—2500 cm^{-1}. The absence of the $NH_2{}^+$ absorption bands in the range of 3000—2250 cm^{-1} in the IR spectra of the complexes with 3d-metals suggests that the α-carboxyl proton is not localized on the amino group. It follows that the structures of all the complexes under study are different from zwitter-ionic one. Indeed, the metal atom replaces the carboxyl hydrogen atoms and forms a coordination bond with the nitrogen atom (formation of soluble intra-complex salts), which is confirmed by the observation of absorption bands in the range of 1714—1724 cm^{-1} corresponding to nonionized —CH_2—COOH moiety in the IR spectra of the free complexone isomers.

Table 4. Thermal properties of metal complexes with the optical isomers of complexones

Complex	T_1/°C		n	T_2/°C
Cu(L-HZ^3)·H_2O	77.9	—	1	>215
[Cu(D-HZ^3)·H_2O]·H_2O	104.3 (I)	142.0 (II)	1+1	>205
Cu(L-HZ^4)·H_2O	57.9	—	1	>205
Zn(L-HZ^3)·$2H_2O$	90.7	—	1	>275
[Zn(D-HZ^3)·H_2O]·H_2O	75.6 (I)	168.6 (II)	1+1	>260
Zn(L-HZ^4)·$2H_2O$	104.9	—	2	>260
Ni(L-HZ^3)·$2H_2O$	84.8	—	2	>270
Ni(D-HZ^3)·$2H_2O$	99.3	—	2	>330
Ni(L-HZ^4)·$2H_2O$	97.8	—	2	>315

Note. T_1 is the dehydration temperature (dehydration stage is given in parentheses), T_2 is the decomposition temperature, and n is the number of moles of water lost.

The spectra of the Cu(II) and Zn(II) complexes with D-H_3Z^3 exhibit an absorption band corresponding to free OH group. It follows that (i) this group is not coordinated to metal ions and (ii) coordination involves the amino nitrogen atom and two α-carboxylate groups. Thus, D-H_3Z^3 is a tridentate ligand in these complexes.

The IR spectra of the Zn(II) and Cu(II) complexes with L-H_3Z^3 and L-H_3Z^4 and of the Ni(II) complexes with L-H_3Z^4, L-H_3Z^3, and D-H_3Z^3 show no absorption band corresponding to free OH group. Therefore, the hydroxyl group is coordinated to the metal ions. Thus, the isomers in question are tetradentate ligands in these complexes, *i.e.*, all the three carboxylate groups and the amino nitrogen atom are involved in coordination.

An analysis of the IR spectra of the optical isomers of *N*-(carboxymethyl)aspartic and *N*-(carboxymethyl)glutamic acids, which exhibit an amine "fingerprint" band in the wavenumber range of 3000—2250 cm^{-1},[47—49] confirmed the formation of the zwitter-ionic structure. The structure of the 3d-metal complexes is different from the zwitter-ionic one, since the metal atom replaces the carboxyl hydrogen atoms and is coordinated to the nitrogen atom.

The results obtained made it possible to propose possible structures of the title compounds (Fig. 3).

Summing up, we studied the physicochemical properties of the complexones synthesized, calculated the concentration and thermodynamic dissociation constants of their optical isomers, and determined the stability constants of the metal complexes. We have shown that the

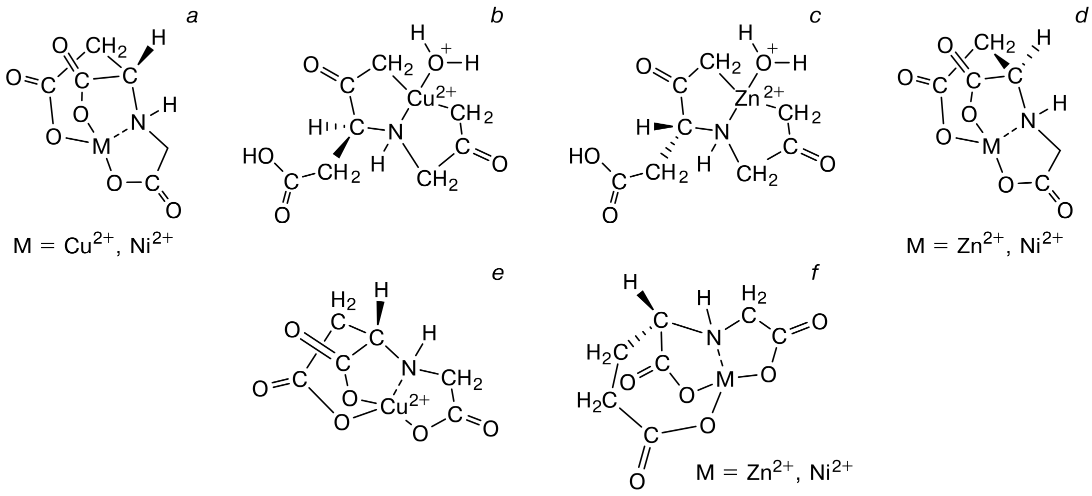


Fig. 3. Possible structures of the Cu(II) and Ni(II) complexes with L-H_3Z^3 (*a*), Cu(II) complex with D-H_3Z^3 (*b*), Zn(II) complex with D-H_3Z^3 (*c*), Zn(II) complex with L-H_3Z^3 and Ni(II) complex with D-H_3Z^3 (*d*), as well as the Cu^{2+} (*e*) and Zn^{2+}, Ni^{2+} complexes with L-H_3Z^4 (*f*).

complexones have a betaine structure not only in aqueous solutions, but also in the solid phase, whereas the metal complexes have different structures. Recently, unique properties of the optical isomers of *N*-(carboxymethyl)-aspartic acid have found a practical application in the design of chemical indicators supported on solid substrates for express control of the content of nitrates in food products.[50]

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