Bioactive L-amino acids are used in medicine for treatment of diseases associated with metabolic disorders. α-Amino acids form stable five-member chelate complexes with transition metal ions; this complexation has found an application in selective complexing agents based on aminocarbon acids. Complexation plays an essential role in maintaining the metal–ligand balance in living organisms. In biological systems, free d-metal ions are almost completely absent, since they are present in the form of coordination compounds, such as metalloporphyrins. Copper is one of the components of several functional proteins involved in redox processes. α-L-alanine belongs to the group of proteinogenic amino acids.

This study focuses on the formation of Cu(II) complexes with α-L-alanine, acidic dissociation of alanine and the influence of solvation on these processes. The acid–base interaction constant and the alanine complexation constants in water–formamide solvents were obtained from potentiometric measurements. Earlier obtained thermochemical data on the Cu(NO₃)₂–water–formamide system was considered for the process of Cu(NO₃)₂ transfer from water to an aqueous solution of alanine using the earlier determined K_stab and thermochemical data.

EXPERIMENTAL

All the reagents used in this study were of pure or chemically pure grade. Formamide (FA) was purified by double fractional distillation under vacuum. According to the recommendations of [1], the excess acidity formamide was neutralized with alkali in the presence of bromothymol blue indicator immediately prior to distillation.

The following electrochemical chain, consisting of Ag/AgCl and a glass pH electrode, was used to study the equilibrium of the chemical reactions:

\[
\text{Glass el.} \vert \text{NaClO}_4(c = 0.1 M), \text{HAla}_2(c_1), \text{Cu(NO}_3)_2(c_2), \text{X}_{\text{FA mol.fr}} || \text{X}_{\text{FA mol.fr}}, \text{KCl}_{\text{sat}} \vert \text{AgCl, Ag.}
\]

The inner filling solution of the reference electrode had a solvent identical to that of the examined solution. The electrical contact between the investigated solution and the reference electrode was carried out via a ground glass joint that stabilized the liquid junction potential of the connection. Calibration of the electrode system and calculation of \( \log K_{\text{eq}} \) were performed as described in [2].

The measuring cell solution contained 0.05 mol/l α-L-alanine, 0.02–0.04 mol/l of copper nitrate, \( 5 \times 10^{-3} \) mol/l HClO₄, NaClO₄ (background electrolyte), and water–formamide solvent. The aqueous solution NaOH (5.013 mol/l) was used a titrant, which was added by weight using a syringe. In the course of determining the complexation constants, the metal : ligand ratio varied, depending on the experiment, from 1:1.3 to 1:2.5. The dissociation constant of alanine was found in separate experiments. For each solvent, titration was done three to five times. The accuracy in determining \( \log K \) in each individual titration was assessed by statistical data treatment of 10–20 measurements.

DISCUSSION OF RESULTS

Alanine, like other amino acids in the crystalline state and in an aqueous solution, exists in the form of
a zwitter ion and has the properties of an amphoteric compound:

\[
\text{CH}_3\text{CH}((\text{NH}_3)\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}((\text{NH}_3)\text{COO}^- \rightleftharpoons \text{H}^+ = \text{CH}_3\text{CH}((\text{NH}_3)\text{COO}^-. (1)
\]

The anion \(\text{CH}_3\text{CH}((\text{NH}_3)\text{COO}^-\) forms \(1 : 1\) and \(1 : 2\) chelate complexes with copper (II) ions, and it is believed that the bis–complex has a square plane structure typical of copper(II) coordination compounds. The possibility a nonchelate complex forming with protonated alanine could not be completely excluded, but it does not seem very probable since the bonding present (in solution with alanine solution pH; however, acidity reduces the yield of the complex. While about 15% of the added copper present (in solution with \(c_{\text{Ala}}^\circ = 0.05\) mol/l) is bound in the form of the monocomplex \([\text{CuAla}]^+\), the fraction of \([\text{CuAla}_2]\) complex is negligibly small. This was also confirmed by the calculation of the particle distribution in the equilibrium process, performed with the RRSU program [12].

\[
\text{Cu}^{2+} + \text{Ala}^- \rightleftharpoons [\text{CuAla}]^+, \quad (3)
\]

\[
\text{Cu}^{2+} + 2\text{Ala}^- \rightleftharpoons [\text{CuAla}_2], \quad (4)
\]

\[
\text{HL} \rightleftharpoons [\text{CuAla}^+] + \text{H}^+. \quad (2)
\]

The authors of [13] demonstrated that the enthalpies of the transfer of copper nitrate (II) in water–FA is significantly altered in the presence of a small concentration (~0.05 mol/l) of dissolved alanine; notably, the transfer of \(\text{Cu(NO}_3)_2\) from water to water–FA mixtures becomes less exothermic. Let us consider the factors affecting the heat balance of \(\text{Cu(NO}_3)_2\) transfers in a water–FA system containing alanine.

In an aqueous solution, dissociation of alanine is an endothermic process \(\Delta_{\text{diss}}H^\circ = 45 \text{ kJ/mol} [5]\) and formation of \([\text{CuL}]^+\) complex is an exothermic one \(\Delta_{\text{comp}}H^\circ = -22.2 \text{ kJ/mol} [4]\). The equation relating the enthalpy of dilution of the concentrated solution of \(\text{Cu(NO}_3)_2\) in a solvent and in an alanine solution \(\Delta_{\text{dil}}H_1^\circ\) and \(\Delta_{\text{dil}}H_2^\circ\) looks as follows:

\[
\Delta_{\text{dil}}H_2^\circ = \Delta_{\text{dil}}H_1^\circ + \frac{c_{\text{CuNO}_3}}{c_{\text{Cu(NO}_3)_2}} \left(\Delta_{\text{comp}}H^\circ + \Delta_{\text{diss}}H^\circ\right). \quad (6)
\]