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Implication of Metal Complexes in Biology and Medicine: The System Aluminum (III)/Chromium (III)/Iron (III) – Homoserine

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ABSTRACT

Metal ions are fundamental elements for the maintenance of life spans of humans, animals and plants. In coordinatton compounds studies, knowledge of the stability constants of complexes is necessary for preliminary quantitative treatment. Aluminum prefers oxygen doner groups for complexation. The stability of complexes in the biological system depends on pH, which is blood plasma is 7.4. Chromium is very adaptable metal and it can form copious species with variable oxidation numbers from (-VI) to (+VI). Iron is a component of heme and chlorophyll and serves as micronutrients of plants and animals. Ferric ion from industrial effluent has the potential to poison animals and plants. The present technique involving the use of paper electrophoresis is described for the study of equilibria in binary complexes system in solution. The method is based on the movement of a spot of a metal ion in an electric field at various pH's of background electrolyte. A graph of pH versus mobility was used to obtain information in the binary complexes and to calculate its stability constants. Using this method, the stability constants of binary complexes, metal (III) – homoserine have been determined to be (8.15 ± 0.03, 6.66 ± 0.08); (8.49 ± 0.01, 7.00 ± 0.05); and (8.79 ± 0.01, 7.43 ± 0.03) (logarithm stability constant values) for aluminum (III), chromium (III), and iron (III) complexes, respectively, at ionic strength 0.1Mol/L and a temperature of 35 °C.

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Introduction

For a mononuclear binary complex, if a central atom (central group) M (the metal) and a ligand L have been defined, then in the following expressions Kn is the stepwise formation constant, and ßn is the cumulative formation constant for the complex MLn. they can both be referred to as stability constants (stepwise and cumulative) [1].

$$K_n = K\ (ML_{n-1} + L = ML_n)$$
$$\beta_n = K\ (M + {}_nL = ML_n)$$

Metal complexes play an important role in various biological systems; hence the formation, stability and reactivity of these complexes have been an active field of research [2-4]. Iron is an essential metal without which life cannot sustain, chromium is a beneficial metal which are helpful for healthy life. Aluminum is indifferent metal toxic at a very high level. Essential and beneficial metals are also toxic metals are also toxic at high concentration and their deficiency leads to disease conditions. Average chromium and iron of healthy human body (weight 70 Kg), with plasma concentration and recommended daily allowance for man are (0.006g, 0.05 µM, 0.1 mg) and (5.0g, 20 µM, 10-20 mg), respectively. Aluminum is neither essential nor beneficial. Adult humans bear 60 mg Aluminum, most of it in lungs from inhalation. Following absorption, the highest concentration occurs in the brain. Impaired kidney function reduces body's ability to clear Al^{3+} and may cause $PO4^{3-}$ depletion through formation of insoluble Al PO4 [5]. Ganrat has discussed some specific diseases caused by accumulation of aluminum (III) ion in brain tissues [6]. He has also discussed proposed metabolic pictures in the mind. The interactions specifically for oxidative stress, process owed to the presence of aluminum ion (Al^{3+}), which cause variations in lipidic metabolism has been investigated by Pup et al. [7]. Reyes – Loaiza et al. has presented laser – induced graphene electrochemical sensor for quantitative detection of phytotoxic aluminum ions (Al^{3+}) in soils extracts [8]. Aluminum in its Al^{3+} form is a metal that inhibits plant growth, especially in acidic soils (pH<5.5). A brief valuation of the biological significance of the latest macrocyclic complexes of chromium metal with highlighting the synthesis of these complexes and their applications as antimicrobial agents has been investigated by Gurjar et al. [9]. Dwivedi et al. aimed to present a review of presence of Cr (III), Cr (VI) ions and their compounds in soil, plant, animal and human and their impact on the environment [10]. The process of sorption of chromium (III) ions with a stationary sorbent layer of bentonite clays was investigated by Soloviy et al. [11]. Dworzariski et al. has determined how a high – fat diet supplemented with various forms of chromium affects hematological and immune parameters of the blood of rats [12]. A review on chromium uptake, translocation and accumulation in plants has been discussed by Abdullah et al.[13]. It also provides a model to unravel the complexities of the Cr- plant interaction utilizing system biology and integrated OMICS approach. Kulaszynska et al. has reported a review to systematize the available data on the role of iron in the function of the nervous system, especially in the brain [14].

This review summarizes recent reviews on iron metabolism and its regulatory mechanisms in humans, including the essential action of hepcidin. Pharmacological tests including antibacterial, antifungal, antioxidant and antitumor on iron (II) and zinc (II) metal alkaloid complexes were studied by Naureen et al.[15]. Kontoghiorghes has discussed iron load toxicity in medicine from molecular and cellular aspects to clinical implications [16]. The synthetic methods and pharmacological potentials of iron – imine complexes having in vitro activity to significant clinical performance from 2016 to present has been described by Anane et al.[17].

The trivalent aluminum, chromium and iron have several applications in biological systems and are toxic at higher concentrations [18-22]. Homoserine (also called isothreonine) is an ∝ - amino acid with the chemical formula HO_2 CCH (NH_2) CH_2 CH_2OH. L- homoserine is not one of the common amino acids encoded by DNA. It differs from the proteinogenic amino acid serine by insertion of an of an addition – CH_2 – unit into the backbone. Homoserine is used by plants and bacteria to make methionine, threonine and isoleucine. Homoserine is a naturally occurring amino acid which do not occur in protein. It is formed by reduction of aspartic acid via the intermediary of aspartate semialdehyde. Homoserine has several significances in biological systems [23-27]. Kiso has done comprehensive study on paper electrophoretic migration of metal complexes [28]. The paper electrophoretic technique usually suffers from a few defects. Temperature during electrophoresis, capillary flow on paper, electro – osmosis and adsorption affect the mobility of charged moieties [29]. The present technique is free from all these destroying factors and very convenient in use. It results in fair agreement with accepted literature values.

Publications from our laboratory described a new method for the study of metal complexes [30-34]. A search of literature indicated few reports on Al (III) / Cr (III)/ Fe (III) – homoserine complexes. In view of this, attempts were made to establish the optimum condition for metal (III) – homoserine complex formation. In addition, the present paper describes a Paper Ionophoretic method for the determination of the nature and stability constants of Al (III) / Cr (III) / Fe (III) – homoserine binary complexes.

Experimental

Apparatus

A Systronic (Naroda, India) Model 604 electrophoretic system was used. The apparatus consisted of a poly (vinyl chloride) PVC moulded double tank vessel. In our laboratory a significant change in the instrument has been made. Two hollow rectangular iron plates each weighing one kg. and covered with thin polythene sheets have been used through which thermostated water circulated for controlling the temperature. The tanks are closed with a transparent PVC moulded lid. The whole assembly is tight to prevent moisture changes, which might upset the equilibria in the paper strip. The assembly design thus keeps to a minimum the disturbing effects of evaporation from unwanted liquid flow in the paper strip. Each electrolyte tank contains a separate electrode chamber in which Pt-wire anode and cathode are placed, respectively. Applied voltage was from a stabilized source. Paper electrophoresis equipment model 604 and electrophoresis assembly covered by thin polythene sheet is shown in Figure 1. Paper electrophoresis model 604 and lower metallic plate showing sandwiched paper strips is shown in Figure 2.

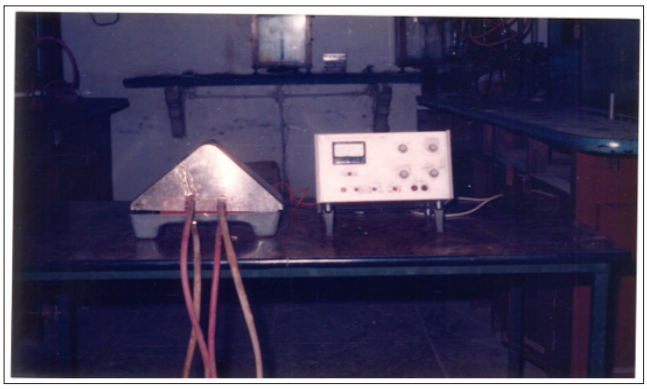


Figure 1: Paper Electrophoresis Equipment Model 604 and Electrophoresis Assembly Covered by Thin Polythine Sheet

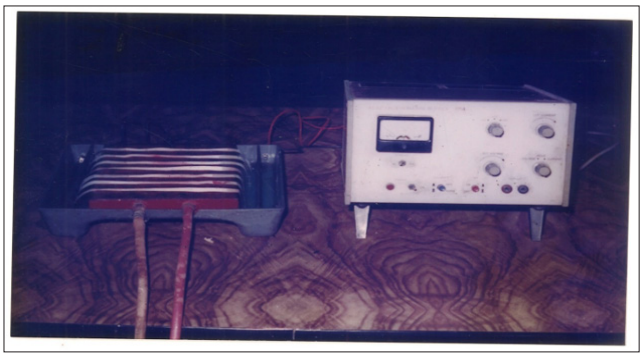


Figure 2: Paper Electrophoresis Equipment Model 604 and Lower Metallic Plate Showing Sandwiched Paper Strips

Whatman No. 1 filter paper for chromatography was used for the purpose of electrophoresis. Elico (Hyderabad, India), Model L_{1-10} pH meter using a glass and calomel electrodes assembly working on 220 V/50 Hz established a. c. mains, was used for the pH measurement. pH meter was calibrated with buffer solution of pH 7.0. Figure 3 shows thermostat 35 ^{0}C water supply in upper and lower metallic plates. The scheme for paper electrophoresis set-up is shown in Figure 4.

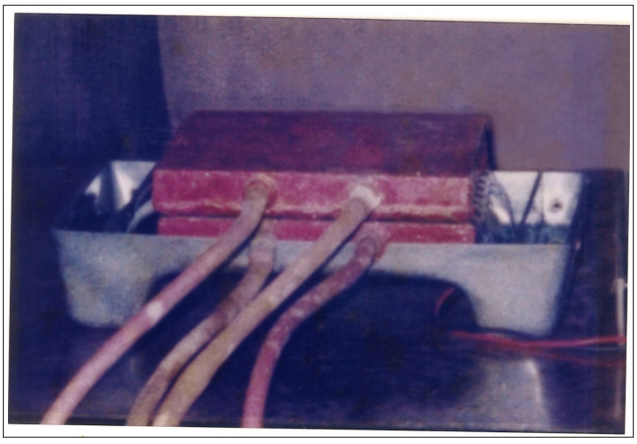


Figure 3: Thermostat 35 ^{0}C Water Supply in Upper and Lower Metallic Plates

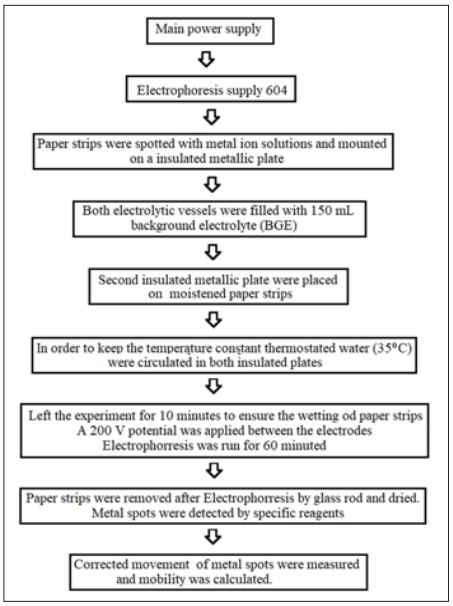


Figure 4: The Scheme for Paper Electrophoresis Set-Up

Preparation of Metal Solution

Aluminum (III), chromium (III) and iron (III) perchlorate solutions were prepared by preliminary precipitation of metal carbonates from a 0.1 Mol L^{-1} solution of aluminum (III), chromium (III) and iron (III) sulphate with the solution of sodium carbonate (chemically pure grade BDH, Poole, UK).

The precipitates were washed with boiling water and treated with measured amounts of 1 % perchloric acid. They were heated and filtered. The metal contents of the filtrates were determined, and the final concentration was kept at 0.005 Mol L^{-1} [35,36].

Sodium Hydroxide Solution

Carbon dioxide free sodium hydroxide solution was prepared by dissolving 500 gms of sodium hydroxide in 500 mL of water in a flask. The flask was left overnight. The clear supernatant liquid was filtered rapidly using a high vacuum pump. A suitable volume of the filtrate was diluted, and the concentration determined by titrating against a standard oxalic acid solution. A solution (2.0 Mol L^{-1}) was obtained by suitable dilution. The concentration of stock solution was checked from time to time.

Detecting Reagents for Metal Ions and Glucose

Metal spots were detected on the paper using an aluminon solution (BDH, England) for Al^{3+}, 0.5 % solution of potassium ferrocyanide (BDH) for Fe^{3+} and 0.1 %, solution of 1 – (2 – pyridylazo) – 2 – napthol (PAN) (Merck, Darmstadt, Germany) in ethanol for Cr^{3+}. A 0.005 Mol L^{-1} glucose (BDH, Analytical Reagent grade) solutions were prepared in water and used as an electron - osmotic indicator for the correction due to electro – osmosis. A saturated aqueous solution (0.9 ml) of silver nitrate was diluted with acetone to 20 ml. Glucose was detected by spraying with this silver nitrate solution and then with 2 % ethanolic solution of sodium hydroxide, when a black spot was formed.

Background Electrolyte

The background electrolytes used in the study of binary complexes were 0.1 Mol L^{-1} perchloric acid and 0.01 Mol L^{-1} homoserine. The system was maintained at various pH by the addition of sodium hydroxide. Stock solution of 5.0 Mol L^{-1} perchloric acid (SDS, Analytical Reagent grade), 2.0 Mol L^{-1} sodium hydroxide (Analytical Reagent grade) and 0.5 Mol L^{-1}homoserine was prepared. Each solution was standardized using the appropriate method.

Procedure

Whatman No.1 filter paper chromatography was used for the purpose of electrophoresis. For recording observation of particular metal ion, two strips were spotted with the metal ion solution along with additional two spotted with glucose using 1.0 µL pipette and mounted on insulated plate. Each of the two-electrolyte vessels were filled with 150 mL of background electrolyte containing 0.1 Mol L^{-1} perchloric acid and 0.01 Mol L^{-1} homoserine. The paper became moistened with the background electrolyte solutions due to diffusion. The second insulated plate was placed on paper strips and then thermostated water (35º C) was circulated in the plates to keep the temperature constant. The lid was then placed on the instrument to make it airtight. It was left for 10 minutes to insure wetting the strips. Subsequently a direct 200 Volts potential was applied between the electrodes. Electrophoresis was carried for 60 minutes after which these strips were removed from the tank and dried. The metal ion and glucose spots were detected by specific reagents. The leading and tailing edge were measured from the marked centre point and the mean were taken. The distance moved by glucose as subtracted (in case of migration toward anode) to obtain correct path length. Migration towards anode and cathode were designated by negative and positive signs respectively.

Electrophoretic observations on metal ions were recorded at various pH values of the background electrolyte obtained by adding sodium hydroxide solution. The ionic strength being maintained at 0.1 Mol L^{-1}. The observed mobility of migrants was calculated by using the formula.

$$U = \frac{d}{x \cdot t}$$

after applying the correction factor the observed mobility is given as

$$U = \frac{d \pm d_G}{x \cdot t}$$

where U = mobility of metal ion / complex ion, d = mean of duplicate distance travelled by metal ion / complex ion; d_G = mean duplicate distance travelled by glucose spot; x = field strength; t = time for electrophoresis. The mobility of metal / complex ion spots on the paper strips were thus calculated and are reported with different pH values (Figure 5).

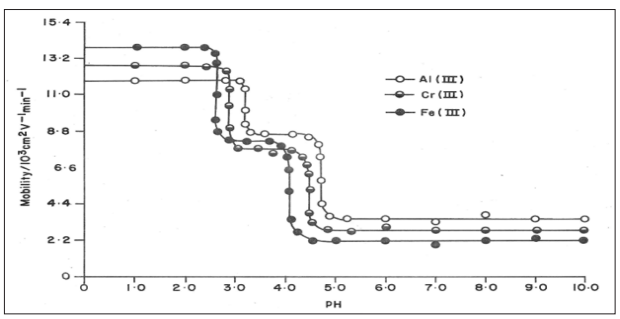


Figure 5: Mobility Curve for Metal (III)- Homoserine Systems. —●— = Al (III) -Homoserine = Cr (III) - Homoserine —●— = Fe III)- Homoserine. pH's Were Maintained by Addition of Sodium Hydroxide. The Paper Strips Were Spotted with 0.1 uL of Sample Solutions and Glucose (for making osmotic corrections)

The protonation constants of pure homoserine were determined by the same paper electrophoresis technique. The two paper strips were spotted with pure homoserine along with two glucoses using 0.1 Mol L^{-1} perchloric acid only in a background electrolyte. The electrophoresis was carried out for 60 minutes for metal ions. The electrophoresis speed was calculated. The speed of metal ion / homoserine spots is reported with pH values. The individual speeds of duplicate spots were found to be equal.

Results

Literature reveals that an ionic species of amino acids are sole coordinating species in complex formation with metal ion [37,38]. Hence, a metal ion spot on the strip shows a variation in composition of different ionic species of amino acids in background electrolyte. So, the mobility of metal ion spot would depend upon the pH of the background electrolyte.

The plot of overall electrophoretic mobility of metal spot against pH is shown in Figure 5. The first plateau in the beginning corresponds to a region in which metal ions are uncomplexed. It is obvious that protonated ionic species of homoserine, which exist in low pH ranges are non – complex [CH_2 (OH) CH_2 CH (NH_3^+) COOH]. Figure 5 reveals that the second plateau lies in a positive region indicating the cationic nature of 1:1 metal complex. Aluminum (III), chromium (III) and iron (III), metal ions form their first complex movements towards negative electrode. Hence, one homoserine anionic species [CH_2 (OH) CH_2 CH (NH_2) COO-] must have combined with aluminum (III), chromium (III) and iron (III), to give 1:1, [Al {CH_2 (OH) CH_2 CH (NH_2) COO}]$^{2+}$; [Cr {CH_2 (OH) CH_2 CH (NH_2) COO}]$^{2+}$ and [Fe {CH_2 (OH) CH_2 CH (NH_2) COO}]$^{2+}$ complex cations, respectively.

The third plateau in each case is still in a positive region of mobility curve showing further cationic nature of metal ligand complex. Hence, two anionic species of homoserine [CH_2 (OH) CH_2 CH (NH_2) COO-] must have combined with metal ions to give 1:2, [Al {CH_2 (OH) CH_2 CH (NH_2) COO}$_2$}] +;[Cr {CH_2 (OH) CH_2 CH (NH_2) COO}$_2$]$^+$ and [Fe {CH_2 (OH) CH_2 CH (NH_2) COO}$_2$] +, complex cations respectively. Further increase of pH has no effect on the mobility of metal ions, which indicates no further interaction between metal ions and ligands.

In general, the complexation of metal ions with homoserine anion [L^-] may be represented as:

$$M^{3+} + L^- \underset{}{\overset{K_1}{\rightleftharpoons}} ML^{2+} \quad (1)$$

$$ML^{2+} + L^- \underset{}{\overset{K_2}{\rightleftharpoons}} ML_2^{+} \quad (2)$$

Where M^{3+} is Al^{3+}, Cr^{3+} and Fe^{3+} metal cations; [L^-] is the homoserine anion; K_1 and K_2 are first and second stability constants, respectively. ML^{2+} and ML_2^+ are 1:1 and 1:2 metal complexes, respectively.

The metal spot on the paper is thus a combination of uncomplexed metal ions, 1:1 and 1:2 metal complexes. The spot moving under the influence of electric field and the overall mobility U is given by equation [39].

$$U = \frac{U_{0.0}\cdot\beta_{0.0} + U_{1.0}\cdot\beta_{1.0}[L] + U_{2.0}\cdot\beta_{2.0}[L]^2 + \cdots + U_{1.1}\cdot\beta_{1.1}[HL] + U_{2.1}\cdot\beta_{2.1}[HL]^2 + \cdots + U_{2,1}\cdot\beta_{2,1}[H_2L] + U_{2,2}\cdot\beta_{2,2}[H_2L]^2 + \cdots}{\beta_{0.0} + \beta_{1.0}[L] + \beta_{2.0}[L]^2 + \beta_{1.1}[HL] + \beta_{2,1}[HL]^2 + \beta_{2.1}[H_2L] + \beta_{2,2}[H_2L]^2 + \cdots} \quad (3)$$

wherein $U_{0,0}$ is the speed of uncomplexed metal ions, $U_{1,0}$ is the speed of complex formed by the combination of one unprotonated anionic ligand with metal ion and Ux.p. is the speed of the metal complex formed by the combination of X anions containing p, protons, each β^1s are the overall stability constant of the different metal complexes formed in the interaction. On taking into consideration the different equilibrium above equation transformed into following useful form.

$$U = \frac{u_0 + u_1 K_1 [L^-] + u_2 K_1 K_2 [L^-]^2}{1 + K_1 [L^-] + K_1 K_2 [L^-]^2} \quad (4)$$

Wherein $u_{0,}$ u_1 and u_2 are mobilities of uncomplexed metal ion, 1:1 metal complex and 1:2 metal complex, respectively.

The protonation constant of pure homoserine (k_{a1} = 2.47; k_{a2} = 9.28) was determined by the same paper electrophoretic technique. The mode of deprotonation of homoserine can be given as:

[CH_2 (OH) CH_2 CH (NH_3^+) COOH]

$-H^+ \Updownarrow k_1$

[CH_2 (OH) CH_2 CH (NH_3^+) COO^-]

$-H^+ \Updownarrow k_2$

[CH_2 (OH) CH_2 CH (NH_2) COO^-]

For calculating the first stability constant, K_1, the region between the first and second plateau is relevant. The overall mobility U will be equal to the arithmetic means of mobility of the uncomplexed metal ion, u_0 and that of first complex u_1 at a pH where

$$K_1 = 1 / [CH_2 (OH) CH_2 CH (NH_2) COO^-].$$

Using the dissociation constants of pure homoserine, the concentration of homoserine anion [L^-] is determined for the pH, from which K_1 can be calculated. The concentration of chelating homoserine anion, [L^-], is calculated with the help of equation (5) below

$$[L^-] = \frac{[L_T]}{1 + [H]/k_2 + [H]^2/k_1 k_2} \quad (5)$$

where [L_T] is the total concentration of ligand homoserine (0.01 / Mol L^{-1}). k_1 and k_2 of 1:2 is the first and second dissociation constants of pure homoserine, respectively. The second stability constant K_2 of second complex can be calculated by taking into consideration the region between the second and third plateau of mobility curve, the calculated values of K_1 and K_2 are given in Table 1.

Table 1: Stability Constants of Binary Complexes of Al (III), Cr (III) and Fe (III) with Homoserine

Metal ions	Complexes	Stability constants	Stability constants values
Aluminum (III)	ML^{2+}	K_1	8.15 ± 0.03
	ML_{2+}	K_2	6.66 ± 0.08
Chromium (III)	ML^{2+}	K_1	8.49 ± 0.01
	ML_{2+}	K_2	7.00 ± 0.05
Iron (III)	ML^{2+}	K_1	8.79 ± 0.01
	ML_{2+}	K_2	7.43 ± 0.03

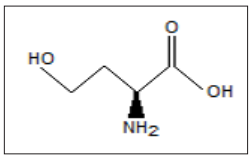
Ionic strength = 0.1 M; temperature = 35 ^{0}C; M = metal cation; L = Ligand (homoserine); homoserine anion = [CH_2 (OH) CH_2 CH (NH_2) COO-].

Discussion

It is observed from Table 1 that first and second stability constants of aluminum (III), chromium (III), and iron (III) complexes with homoserine follow the order:

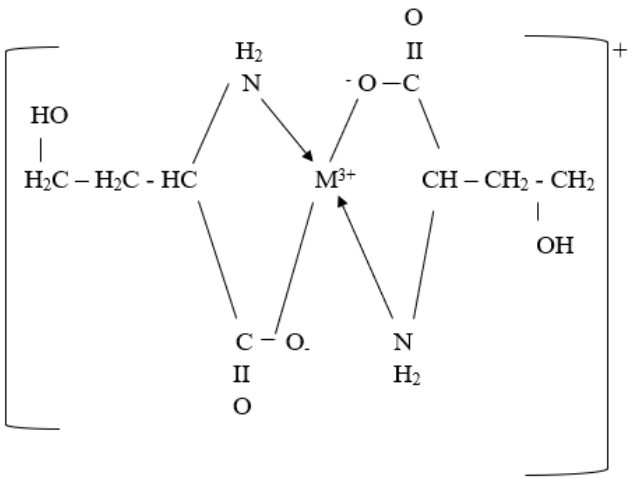
$$\log K_1 > \log K_2$$

The corresponding second stability constant values are found to be lower for all complexes formed. It is therefore inferred that coordinating tendency of a ligand decreases with the higher state of aggregation [40,41]. It is also observed from Table 1 that stability constants of aluminum (III), chromium (III), and iron (III) metal ions with homoserine follow the order: iron (III) > chromium (III) > aluminum (III). The high stability constant values of iron (III) – homoserine complex indicate strong bonding between iron (III) cation and homoserine anion, while the low stability constant values of aluminum (III) – cation and homoserine anion. The stability of iron (III) complexes may be ascribed to the greater affinity to iron (III) cation for the oxygen donor ligands. The stability of metal complexes may be dependent on electronic configuration of central metal cation, because ligand anion is the same in each case. The molecular structure of homoserine is as follows:



The stability constants of metal complexes can be very easily calculated by this technique; therefore, the present method has significant advantages over other methods (viz: polarographic, potentiometric, solubility etc.) reported in chemical literature for the determination of stability constants of metal complexes.

According to standard deviation (statistics) the precision of the method is limited to that of paper electrophoresis, and uncertainty in the result is ± 5 %. Hence, it cannot immediately replace the most reliable methods, even though it is a new approach deserving further development. The proposed structure for metal (III) – homoserine, ML_2^+, binary complexes may be given as follow:



In general, the calculation of first (K_1) and second (K_2) stepwise stability constants of binary metal complexes can be explained in the following steps.

$$M + L \underset{}{\overset{K_1}{\rightleftharpoons}} ML$$

$$K_1 = \frac{[ML]}{[M]\,[L]}$$

$$[ML] = K_1\,[M]\,[L]$$

$$ML + L \underset{}{\overset{K_2}{\rightleftharpoons}} ML_2$$

$$K_2 = \frac{[ML_2]}{[M]\,[L]}$$

$$[ML_2] = K_2\,[ML]\,[L]$$

$$U = \sum u_i f_i$$

Where M = metal cation; L = Ligand anionic species K_1 and K_2 are first and second stability constants, respectively.

$$U = u_M f_M + u_{ML} f_{ML} + u_{ML2} f_{ML2}$$

$$\text{Mole fraction} = \frac{\text{Number of moles}}{\text{Total mole}}$$

$$\text{Total mole} = [M] + [ML] + [ML_2]$$
$$= [M] + K_1 [M] [L] + K_2 [ML] [L]$$
$$= [M] + K_1 [M] [L] + K_1 K_2 [M] [L]^2$$
$$= [M] [1 + K_1 [L] + K_1 K_2 [L]^2]$$

On considering $[1 + K_1 [L] + K_1 K_2 [L]^2] = J = MJ$

$$f_M = \frac{[M]}{[M]J} = \frac{1}{J}$$

Where U = overall mobility; u = mobility of particular species; f = mole fraction of particular species.

$$f_{ML} = \frac{K_1 [M] [L]}{[M] J} = \frac{K_1 [L]}{J}$$

$$f_{ML2} = \frac{K_1 K_2 [M] [L]^2}{[M] J} = \frac{K_1 K_2 [L]^2}{J}$$

$$U = \frac{u_M}{J} \frac{1 + u_{ML} K_1 [L]}{J} + u_{ML2} \frac{K_1 K_2 [L]^2}{J}$$

$$U = \frac{u_M + u_{ML} K_1 [L] + u_{ML2} K_1 K_2 [L]^2}{J}$$

On putting the value of J in above equation

$$U_X = \frac{U_M + u_{ML} K_1 [L] + u_{ML2} K_1 K_2 [L]^2}{1 + K_1 [L] + K_1 K_2 [L]^2}$$

For the calculation of first stability constant ("K_1"), first and second plateau is calculated then

$$U = \frac{U_M + u_{ML2} K_1 [L]}{1 + K_1 [L]}$$

when $K_1 [L] = 1$

then $K_1 = \frac{1}{[L]}$

$$U = \frac{u_M + u_{ML}}{2} \quad \text{(half mobility)}$$

Therefore, first stability constant "K_1" = 1/ [L]. [L] is concentration of ligating species at half of the mobility of first and second plateaus of mobility curve.

For the calculation of second stability constant, ("K_2"), second and third plateau is considered then

Therefore, second stability constant "K_2" = 1/ [L]. [L] is the concentration of ligating species at half of the mobilities of second and third plateaus of mobility curve.

Conclusions

The following conclusions can be drawn from the present studies

- The present paper ionophoretic technique is very helpful in finding whether complex systems are formed or not, if formed its stability constant can also be determined.
- Aluminum (III), chromium (III) and iron (III) are significant for biological systems as such they are toxic, the homoserine may be used to reduce the level of these metal ions in the biological systems.
- The stability constants of metal (III) complexes with homoserine follows the order iron (III) > chromium (III) > aluminum (III).
- Stability constants of metal complexes can be very easily calculated by this technique, therefore present paper electrophoretic technique has significant advantages over the other methods (viz. potentiometry, solubility etc.) reported in chemical literature for the determination of stability constants of metal complexes.
- Biologically important aluminum (III), chromium (III) and iron (III) metal ions complexes with amino acid homoserine can be prepared on large scale at a particular pH of background electrolyte.
- Future work is to prepare aluminum (III), chromium (III) and iron (III)) - homoserine complexes at an optimum condition mentioned in this paper, characterize them and study their possible medical applications.

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