A Potentiometric Study on Chemical Speciation of Binary Complexes of Biologically Essential Metal Ions with Glycylglycine in CTAB-Water Mixtures

Sowbhagya Lakshmi Matcha[a*] and Nagakrishna Taidala[b]

[a]Deparment of Chemistry, Jawaharlal Nehru Technological University-Gurajada, Vizianagaram, India-535003.

[b]Deparment of Physics, M.R.A.G.R. Government Polytechnic College, Vizianagaram, India-535002.

*Corresponding Author E-mail: sowbhagya.che@jntukucev.ac.in

Abstract

In the current work, the binary metal ligand complexes generated between essential metal ions and glycylglycine in a (0.0-2.5% v/v) CTAB-water mixture have been examined. In order to gather the data for this experiment, a pH metre was utilised. The temperature was held at 303.0 K, and the medium's ionic strength was kept at 0.16 mol L-1. Numerous metal ligand complexes have been created and investigated by the computer model MINIQUAD75. Titrimetric data is statistically analysed, and using statistical criteria like R-factor, Standard deviation, and U-Correction, among others, the best-fit chemical model is chosen. The stability constants of binary metal ligand complexes produced with regard to the mole fraction of the CTAB were found to be significantly affected by electrostatic and non-electrostatic forces in this experiment.

Keywords: Formation constants, Binary metal ligand complexes, Glycylglycine, CTAB, pH.

1. Introduction

For solution chemists, biochemists, and chemists in general, stability constants are well-known tools that assist them assess the characteristics of metal-ligand reactions in water and biological systems. According to Thomas et al. (2000), they have significant therapeutic implications for measuring the metal ligand selectivity in terms of the relative strength of metal-ligand connections. As antibacterial (Patel et al. 2004), antiviral (Fairlamb et al. 1989 and Balcarova et al. 1998), antiviral (Fairlamb et al. 1998), and anti-cancer (Lafemina et al. 1992 and Moore et al. 1995) medications, metal coordination complexes have been widely used in therapeutic applications. Industry makes use of transition metal ion chelate complexes to purify amino acids on a massive scale as well as a variety of drugs and drug precursors with an amino carboxylic acid component (Rixe et al. 1996 and Bakhtiar et al. 1999).

One of the newest fields of research in the globe, chemical speciation discusses the toxicity, bioavailability, and stability constants of metals and their complexes. The word "chemical species" refers to an element's chemical makeup or molecular structure. The distribution of an element in specific chemical species within a system is referred to as speciation. The author(s) has been studied the protonation constants of glycylglycine in different medium like SLS-water, CTAB-water and TX100-water mixtures and the protonation constant values are also reported (Dhanalakshmi et al. 2014, Seetharam et al. 2016 and Seetharam et al. 2020), along with this the author(s) also studied the chemical speciation of Ca(II), Zn(II) and Mn(II) metal ions with glycylglycine in TX100-water mixtures, and the results were reported (Seetharam et al. 2016). The inorganic form of some essential metal ions like Cobalt is vital for human body, the excess or deficiency of which causes adverse effects (Balakrishna et al. 2021 and Balakrishna et al. 2020). The main aim of the present electrometric investigation is understanding type of species formed and their stability constants and also to present how the stability constants are affected by changing the concentration of acid, base, ligand and metal ions. In the present study the author has studied the stability constants of Ca (II), Mg (II), and Zn (II) binary metal ligand complexes in CTAB-water medium. This investigation has been carried out by using pH meter. The obtained data is very useful in understanding the biological activity of the type of complexes formed (Seetharam et al. 2017 and Ramanaiah et al. 2014).

Experimental

By dissolving the pure chemical component in distilled water and adding a small amount of 0.05 mol L-1 hydrochloric acid, which boosts glycylglycine's solubility, glycylglycine solution with 0.05 mol L-1 concentration was created. The sodium hydroxide pellets are dissolved in distilled water to create a sodium hydroxide solution with a concentration of 0.4 mol L-1. The titrand solution, which is created with a 2.0 mol L-1 concentration by dissolving the drug in distilled water, uses sodium chloride to maintain ion strength. Metal ion solutions of Ca(II), Mg(II), and Zn(II) chloride were created by dissolving the components in distilled water to a concentration of 0.05 mol L-1. By dissolving in distilled water, hydrochloric acid solution with a concentration of 0.2 mol L-1 is created. CTAB is utilised directly from the manufacturer, without being further purified. Glycylglycine is purchased from Qualigens in India, and sodium chyloride is purchased from Himedia in India. All solutions are made with triple-distilled water, which is also used to clean glassware equipment. Sodium hydroxide, metal ion solutions, and hydrochloric acid were all standardised using accepted techniques. Any errors in the concentration determination are evaluated using the analysis of variance of one way classification (Seetharam et al., 2021). To evaluate the strengths of acids and bases, the widely utilised Gran plot approach is employed (Ramanaiah et al. 2019, and Gran 1952).

Procedure

Titration between acid and alkali is the first step in the process of figuring out the stability constants of metal ligand complexes. This will assist determine whether equilibrium has been reached. In order to maintain the electrode in an equilibrium state when using this approach, CTAB-water solution must be maintained. For every titration against 0.4 mol L-1 of sodium hydroxide, 1 mmol of mineral acid must be introduced to the titrand using the same method of maintaining the electrode in CTAB-water mixtures. By changing the metal-to-ligand ratios (1:2.5, 1:3.75, and 1:5), titrations are performed. Additional experimental information is provided elsewhere (Gran 1988).

Table 1: Total initial concentrations of ingredients (in mmol) for metal - ligand titrations in CTAB-water mixtures. [NaOH] = 0.4 mol dm^{-3}; V_0 = 50 cm^3; Temperature = 303 K; Mineral acid = 1.0 mmol; μ = 0.16 mol dm^{-3}.

% w/v CTAB	Titration curves	TM0			TL0	TL0/TM0
		Ca(II)	Mg(II)	Zn(II)	GG	
0.0	3	0.10031	0.10019	0.10012	0.2488 0.3767 0.4990	2.50 3.75 5.00
0.5	3	0.10031	0.10019	0.10012	0.2445 0.3668 0.4891	2.50 3.75 5.00
1.0	3	0.10031	0.10019	0.10012	0.2499 0.3748 0.4998	2.50 3.75 5.00
1.5	3	0.10031	0.10019	0.10012	0.2500 0.3750 0.5001	2.50 3.75 5.00
2.0	3	0.10031	0.10019	0.10012	0.2493 0.3739 0.4986	2.50 3.75 5.00
2.5	3	0.10031	0.10019	0.10012	0.2494 0.3741 0.4988	2.50 3.75 5.00

2. Modeling Strategy

In our study, the correction factor is calculated using SCPHD, a computer programme [Seetharam et al. 2023 and Balakrishna et al. 2017]. The stability constants of binary complexes are calculated using a computer programme called MINIQUAD75 to simulate the data from pH metric titrations [Seetharam et al. 2021]. The correction factor and protonation constants of glycylglycine must be fixed in order to refine the stability constants of the metal ligand complexes. The stability constants of binary metal ligand complexes will fluctuate when the mole fraction of the CTAB-water medium increases; this may be caused by interactions between the solute and the solvent. Electrostatically, the effects of solute-solvent and solute-solute interactions were studied.

3. RESULTS AND DISCUSSION

The prominent statistical parameters, including complex species, overall formation constants and stoichiometry were implemented to achieve best-fit models. Table 2 displays the statistical data and weak standard deviation values were appeared in this model which signifies the precision of the stability constants (Grans 1976, R and Seetharam et al. 2023).

4. Residual Analysis

The residuals in least squares data analysis are predicted to have a Gaussian or normal distribution. In order to test the residuals' normal distribution and confirm the randomness of the mistakes, the residuals are examined for this. Such tests include 2, Skewness, Kurtosis, and R-factor. The models found in the current study are approved because the χ^2 values are lower than the values shown in the Table 2. Based on the kurtosis values, the residuals in this study display a leptokurtic pattern. For Ca (II), Mg (II), and Zn (II), the skewness values obtained in the current study range from -0.07 to 0.16, -0.90 to 0.14, and -0.07 to 0.33, respectively. The table 2 below shows the values for Ucorr, χ^2, Skewness, Kurtosis, and R-factor.

Table 2: Parameters of best fit chemical models of M(II) – Glycylglycine complexes in CTAB-water medium

% w/v CTAB	log β_{mlh} (SD) ML_2	ML_2H	ML_2H_2	pH-Range	NP	$U_{corr} \times 10^8$	χ^2	Skew-ness	Kurt-osis	R-factor
				Ca(II)						
0.0	4.80(38)	14.80(22)	22.85(27)	3.0-10.1	28	16.76	0.80	0.16	3.32	0.0280
0.5	5.12(26)	15.17(36)	22.95(35)	3.0-10.1	22	26.07	29.07	0.09	4.52	0.0377
1.0	5.98 (29)	15.68(35)	23.18(24)	3.0-10.8	26	13.13	46.33	0.09	11.28	0.0238
1.5	5.86(20)	15.94(36)	24.01(33)	3.2-11.1	22	11.46	40.81	0.08	5.33	0.0303
2.0	7.99(14)	15.89(19)	23.40(12)	2.9-8.2	41	4.62	16.51	-0.07	3.10	0.0172
2.5	7.37(24)	15.15(28)	23.39(20)	2.9-8.2	27	9.23	13.91	0.01	4.22	0.0223
				Mg(II)						
0.0	6.97(28)	16.32(25)	23.68(19)	2.2-10.3	73	21.14	56.98	0.14	4.37	0.0343
0.5	7.07(27)	14.88(31)	22.49(24)	2.7-10.3	49	26.84	30.47	-0.55	5.38	0.0314
1.0	6.74(14)	15.68(19)	22.99(09)	2.8-10.5	48	7.68	4.89	0.07	3.21	0.0197
1.5	7.26(28)	15.20(29)	22.71(26)	2.5-10.5	40	15.01	35.07	-0.90	6.43	0.0356
2.0	6.71(26)	15.96(30)	23.02(17)	2.9-8.2	42	13.31	6.57	-0.15	3.17	0.0279
2.5	6.82(28)	15.15(42)	22.73(35)	3.1-10.0	23	14.13	9.72	0.07	4.39	0.0420
				Zn(II)						
0.0	7.46(30)	14.76(35)	21.76(40)	2.5-8.1	56	13.94	32.67	0.33	4.55	0.0305
0.5	7.52 (44)	14.82(40)	21.90(33)	2.6-8.1	56	8.87	6.86	0.20	3.14	0.0235
1.0	8.29(27)	15.36(47)	22.11(27)	2.7-7.2	37	15.17	39.56	-0.07	7.75	0.0321
1.5	8.57(20)	15.41(36)	22.62(16)	2.8-8.2	52	16.51	17.95	0.19	3.18	0.0323
2.0	8.73(20)	15.68(28)	22.53(17)	1.9 - 7.1	29	13.37	9.64	0.14	3.33	0.0192

2.5	8.41(35)	14.89(40)	22.18(36)	2.8 - 7.5	30	11.57	6.18	-0.05	3.64	0.0349

U_{corr} = U/(NP-m)X10^8, where m = number of species; NP=Number of experimental points; SD=Standard deviation.

5. Consequences of Best-Fit Model Errors

Table 3 below shows the impact of various concentrations of alkali, acid, metal, ligand, volume, and log F values on the stability constants of binary metal ligand complexes. The insufficiency of the model is indicated by the high standard deviation values of stability constants, which will clearly demonstrate the influence of alkali, metal, acid, volume, ligand and F values.

Table 3: Effect of errors in influential parameters on the stability constants of Zn(II) Glycylglycine complexes in 0.5% v/v CTAB – water medium.

Ingredient	% Error	Log β_{mlh}(SD)		
		111	120	121
Acid	0	7.46(30)	14.76(35)	21.76(40)
	-5	Rejected	14.32(50)	21.79(60)
	-2	7.55(41)	14.85(40)	22.07(77)
	+2	7.52(51)	14.58(42)	Rejected
	+5	7.77(62)	14.99(64)	Rejected
Alkali	-5	7.52(45)	14.87(72)	Rejected
	-2	7.50(44)	14.42(35)	21.83(47)
	+2	7.51(41)	14.78(33)	21.77(30)
	+5	Rejected	Rejected	Rejected
Ligand	-5	7.56 (44)	14.66(32)	21.80(29)
	-2	7.48(34)	14.57(26)	21.74(30)
	+2	7.45(32)	14.68(35)	21.82(35)
	+5	7.45(36)	14.56(36)	21.83(52)
Metal	-5	7.39(22)	14.80(29)	21.66(25)
	-2	7.42(20)	14.79(20)	21.65(26)
	+2	7.47(12)	14.78(31)	21.62(25)
	+5	7.50(21)	14.73(30)	21.66(30)
Volume	-5	7.43(21)	14.78(29)	21.75(21)
	-2	7.37(17)	14.75(28)	21.70(23)
	+2	7.44(18)	14.65(28)	21.77(29)
	+5	7.45(17)	14.66(39)	21.62(30)
Log F	-5	7.45(20)	14.81(26)	21.70(27)
	-2	7.43(22)	14.80(26)	21.76(26)
	+2	7.40(20)	14.79(27)	21.71(26)
	+5	7.41(22)	14.76(25)	21.66(27)

6. Effect of Surfactant

Due to the nature of the solute and solvent, electrostatic and non-electrostatic forces may dominate one another and must be taken into account (Feakin et al. 1983). The quantity of micelles increases as surfactant concentration rises (Bunton et al. 1979). The dielectric constant of the medium has a direct impact on the protonation-deprotonation equilibria (Chaimovichet al. 2014 and Bunton et al. 1980). Born et al. 1920 said that the dielectric constant of the medium is proportional to the energy of electrostatic interaction. The fluctuation in the log values of the CTAB-water mixes with Glycylglycine binary metal ligand complexes with respect to the mole fraction is shown in Figure 1. There is a linear trend in the logβ values with respective to mole fraction indicates the interaction between metal and ligand, which is electrostatic in nature.

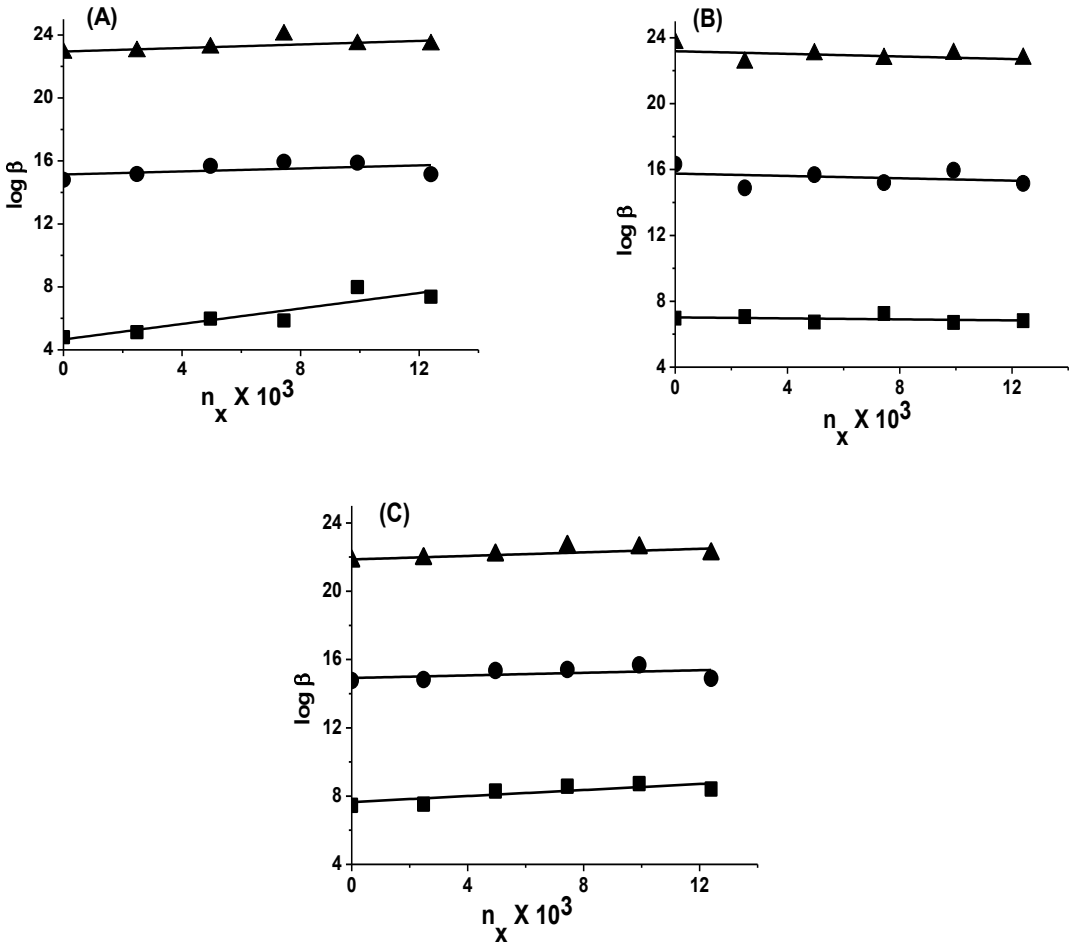


Fig. 1: Variation of stability constants of GG complexes of (A) Ca(II), (B) Mg(II) and (C) Zn(II);(■)logβ_{ML_2} ; (●)logβ_{ML_2H} ;(▲)log$\beta_{ML_2H_2}$.

7. Distribution Diagrams

GG has one associable (amino) and one dissociable (carboxylate) proton. LH^{2+}, LH+, and L-, which have pH ranges of 1.8 to 3.0, 3.0 to 10.0, and 8.0 to 10.0, respectively, are the three distinct forms of GG. These data allow for a prediction of the likely binary metal-ligand species in various systems, which MINIQUAD75 then confirms.

The current analysis shows that Ca(II), Mg(II), and Zn(II) all have ML_2H_2, ML_2H, and ML_2.The fact that Ca(II), Mg(II), and Zn(II) may produce ML_2H_2 suggests that the side chain amino group is still protonated in their presence. Among all the binary complexes, the ML_2 species predominates at higher pH levels while ML_2H_2 predominates at lower pH levels. The strong complexing character of glycylglycine is indicated by the low concentration of free metal ions (FM). The following equilibria demonstrate how distinct binary complex species develop. Figures (4.9-4.11) display some typical distribution diagrams for SLS-, TX100-, and CTAB-water media. When observed in Equilibrium (4), ML_2H_2 is produced when the concentration of the free metal ion and LH^{2+} decreases. Equilibria (7) and (8) are suggested for the creation of ML_2H, however ML_2H is more likely to occur in equilibria (8) than in equilibria (7) since it does so with a decreasing concentration of MLH. Equilibria (9) and (10) both describe possible pathways for the formation of ML_2H, but (10) is more appropriate because, during this process, the concentration of ML decreases and the percentage of ML_2 increases as the concentration of ML and ML_2H are decrease at the same pH range. The following equilibria illustrate how different GG complex species form:

$$M(II) + LH_2^{+} \rightleftharpoons MLH^{2+} + H^{+} \quad (1)$$

$$MLH^{2+} \rightleftharpoons ML^{+} + H^{+} \quad (2)$$

$$M(II) + LH_2^{+} \rightleftharpoons ML^{+} + 2H^{+} \quad (3)$$

$$M(II) + 2LH_2^{+} \rightleftharpoons ML_2H_2^{2+} + 2H^{+} \quad (4)$$

$$MLH^{2+} + LH_2^{+} \rightleftharpoons ML_2H_2^{2+} + H^{+} \quad (5)$$

$$ML_2H_2^{2+} \rightleftharpoons ML_2H^{+} + H^{+} \quad (6)$$

$$M(II) + 2LH_2^{+} \rightleftharpoons ML_2H^{+} + 3H^{+} \quad (7)$$

$$MLH^{2+} + LH \rightleftharpoons ML_2H^{+} + H^{+} \quad (8)$$

$$ML^{+} + LH_2^{+} \rightleftharpoons ML_2H^{+} + H^{+} \quad (9)$$

$$ML_2H^{+} \rightleftharpoons ML_2 + H^{+} \quad (10)$$

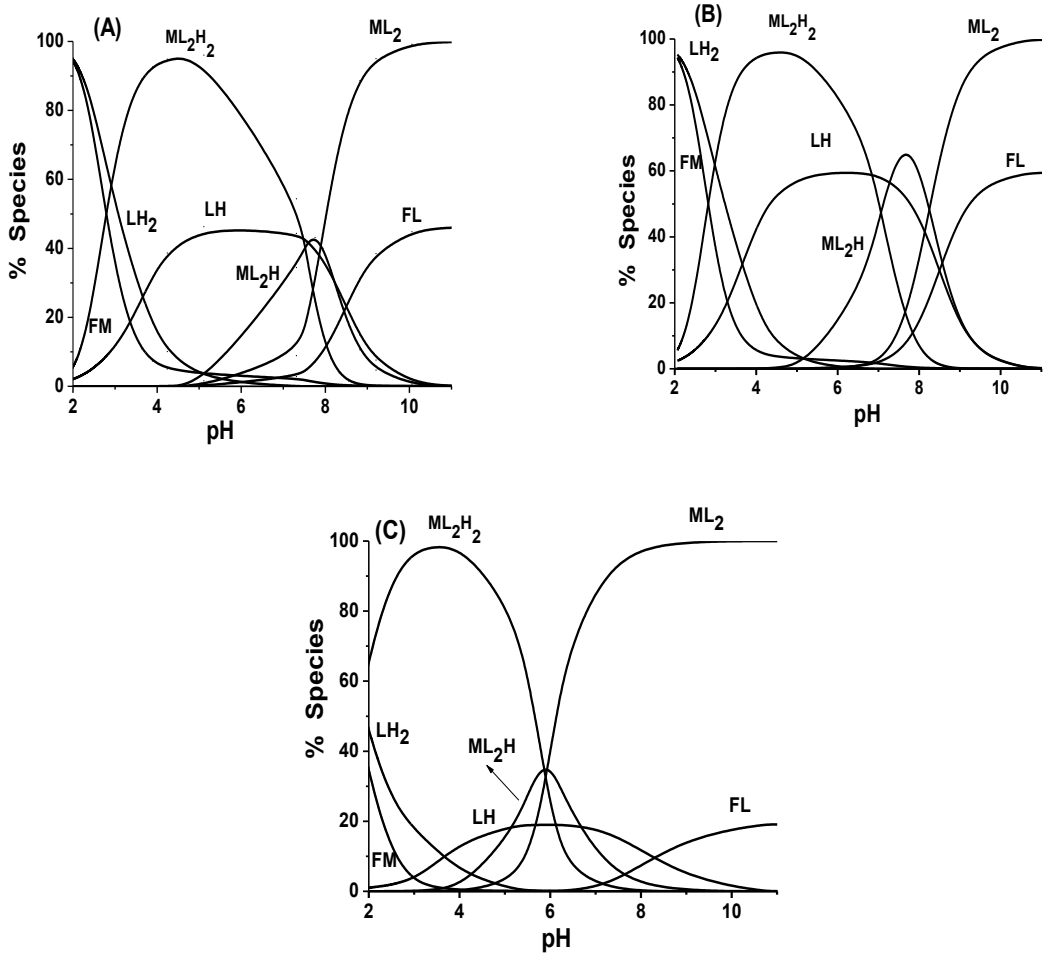


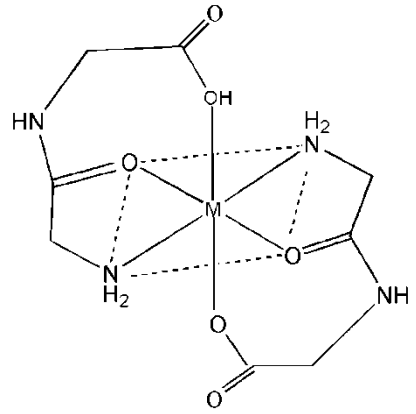
Fig. 2: Distribution diagrams of GG complexes in 2.0 % w/v CTAB-water medium. (A) Ca(II) (B) Mg(II) and (C) Zn(II)

8. Structures of Complexes

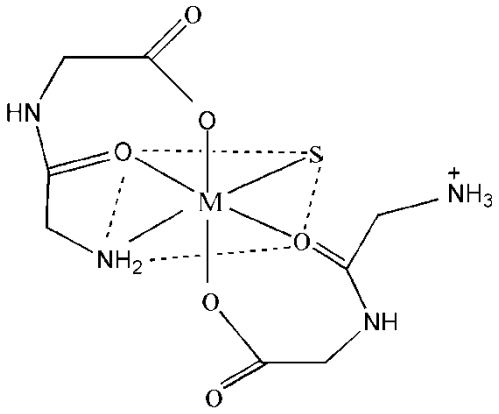
The structures of complicated organisms cannot be clarified or verified using pH metres, but they can be hypothesised based on descriptions in the literature and chemical understanding. For the M(II)-GG system of the metals Ca, Mg, and Zn, both mono- and bis-glycylglycine complexes have been discovered. The carboxyl group's oxygen serves as the first

donor, and the GG's amine nitrogen atom serves as the second donor site. The amide group's oxygen or nitrogen might alternatively serve as GG's third donor site. A five-membered ring is created as a result of the extra chelation. According to the Soft and Hard Acid and Bases (SHAB) principle, the harder carboxylate or amide oxygen site is preferred by Ca(II), Mg(II), and Zn(II) due to their very soft natures. Probst and Rodes (Probst et al. 1984) observed that below pH 8.0, the terminal carboxyl group and terminal amino group are simultaneously coordinated to cadmium ion and the amide might also be simultaneously coordinated through carbonyl oxygen atom resulting in a five-membered chelate ring, which is proved from the X-ray diffraction analysis of GG complexes of cadmium ion (Takayama et al. 1996) and mercury ion (Corbeil et al. 1986).

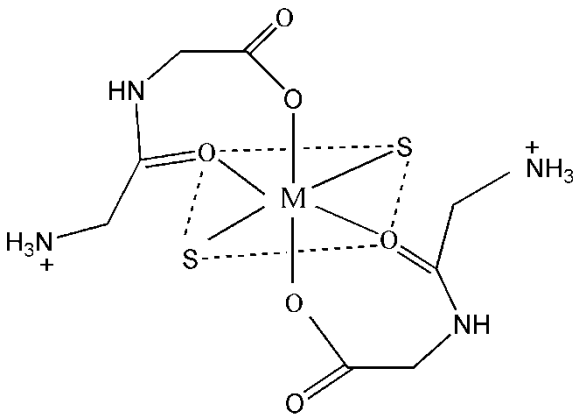
Octahedral structures are proposed to the complexes of Ca(II), Mg(II) and Zn(II). Amine nitrogen atoms can associate with hydrogen ions in the lower pH ranges. Hence, there is often significant competition between hydrogen and metal ion for this second donor site. This situation results in the simultaneous existence of equilibria producing protonated and un protonated complexes. The possible structures for the species of M(II)-GG complexes are given in Fig. 3.



ML_2



ML_2H



ML_2H_2

Fig. 3: GG-M(II) metal ligand complexes, S is solvent or water.

9. Conclusion

Complexes between glycylglycine and Ca(II), Mg(II), and Zn(II) are formed. The complexes are described below; they develop in the pH range of 2.0 to 10.0. The linear fluctuation of stability constants as a function of the medium's dielectric constant shows that electrostatic forces predominate over non-electrostatic forces. In the current study, the complexes produced between the metal and ligand are designated as ML_2, ML_2H, and ML_2H_2. The statistical parameters acquired in the current investigation show that the current model fits the data the best. The concentration of alkali has a significant impact on the stability constants of metal ligand complexes, whereas log F values have very little of an impact. This is denoted by the order alkali > acid > ligand. > metal > total volume >LogF

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