

## Potentiometric investigation of Schiff base equilibria involving salicylaldehyde and tridentate $\alpha$ -aminoacids with Cu(II), Ni(II) and Zn(II) in aqueous medium

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**Abstract.** Potentiometric determination of equilibrium constants and species distribution of Schiff base complexes, in aqueous solution, involving salicylaldehyde (A) and tridentate  $\alpha$ -amino acids (B) (L-threonine, L-glutamine and L-glutamic acid) with metal ions Cu(II), Ni(II) and Zn(II) (M) indicates preference for the formation of Schiff base complexes rather than the ligands binding as such to the metal ions. Binary stability constants follow the Irving–Williams order: Cu(II) > Ni(II) > Zn(II). The influence of additional coordination sites such as –OH, –CONH<sub>2</sub> and –COOH in the formation of ternary complexes is also discussed.

**Keywords.** Potentiometry; stability constants; Schiff bases; L-threonine; L-glutamine; L-glutamic acid.

### 1. Introduction

Potentiometric studies have been employed as a tool to unravel the mechanism of formation of Schiff bases and their metal complexes and mixed ligand complexes in solution (Leussing and Huq 1966; Leussing and Leach 1971; Motekaitis *et al* 1984; Ngwenya 1991; Venkata Ramana Reddy and Rama Reddy 1995). The importance of the determination of the equilibrium constants of Schiff base complexes in the investigation, in understanding complicated biological reactions like transamination, racemisation and decarboxylation etc., is well documented (Snell *et al* 1963; Siegel 1978). However, there is no quantitative information available on the stabilities of Schiff base complexes in aqueous medium. Thus, the current investigation is oriented towards the determination of Schiff base complex equilibria between salicylaldehyde and L-threonine (Thr), L-glutamine (Gln) or L-glutamic acid (Glu) in the presence of metal ions like copper(II), nickel(II) and zinc(II).

### 2. Experimental

Nitrates of copper(II), nickel(II) and zinc(II), salicylaldehyde and amino acids in this study were of AnalaR grade. Dissociation constants of ligands used in this study were determined by a standard procedure (Albert and Serjeant 1971). The formation

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constants of protonated and deprotonated Schiff bases were determined by reported methods (Motekaitis and Martell 1988). In all the experiments, the solutions were prepared with double distilled water and the titrations performed under nitrogen atmosphere at a temperature of  $27 \pm 0.1^\circ\text{C}$ . The ionic strength of the test solutions was maintained at 0.1 using  $\text{KNO}_3$  throughout the investigation.

Since equilibrium in a ternary system is established very slowly with all metal ions, a batchwise titration procedure was employed. It involves titration of solution containing metal ion ( $3 \times 10^{-3} \text{ M}$ ), salicylaldehyde ( $3 \times 10^{-3} \text{ M}$ ), and potassium nitrate, in several bottles of 50 ml capacity, with standard 0.1 M potassium salt of amino acid solution. With each metal ion, two successive experiments were carried out at metal-salicylaldehyde ratios of 1:1 and 1:2. The test solutions were stoppered and equilibrated for a period of 24 h. The equilibrium pH value was then measured for each test solution. The data obtained were utilised for the computation of stability constants.

### 2.1 Computation

The mass balance equation for the system was set up as follows:

$$\begin{aligned} M_t &= M + MA + MA_2 + MB + MB_2 + MB_3 + MAB + MA_2B + MAB_2 + MA_2B_2, \\ A_t &= HA + A + MA + 2[MA_2] + MAB + 2MA_2B + MAB_2 + 2[MA_2B_2] + HAB + AB, \\ B_t &= H_3B + HB + B + MB + MB_2 + MAB + 2MBA_2 + 2MA_2B_2 + HAB + AB, \\ H_t &= 2[H_2B] + HB + HA + HAB + H + OH, \end{aligned}$$

where M = metal ion, A = salicylaldehyde, B = aminoacid and H = hydrogen ion.

Total concentrations on the left-hand side are known. Equilibrium was evoked by replacing the terms for the associated species on the right-hand side by their formation constants. Though the binary stability constants were obtained separately, the only unknowns are the ternary stability constants and these were obtained by the curve-fitting procedure.

## 3. Results and discussion

### 3.1 Binary complexes

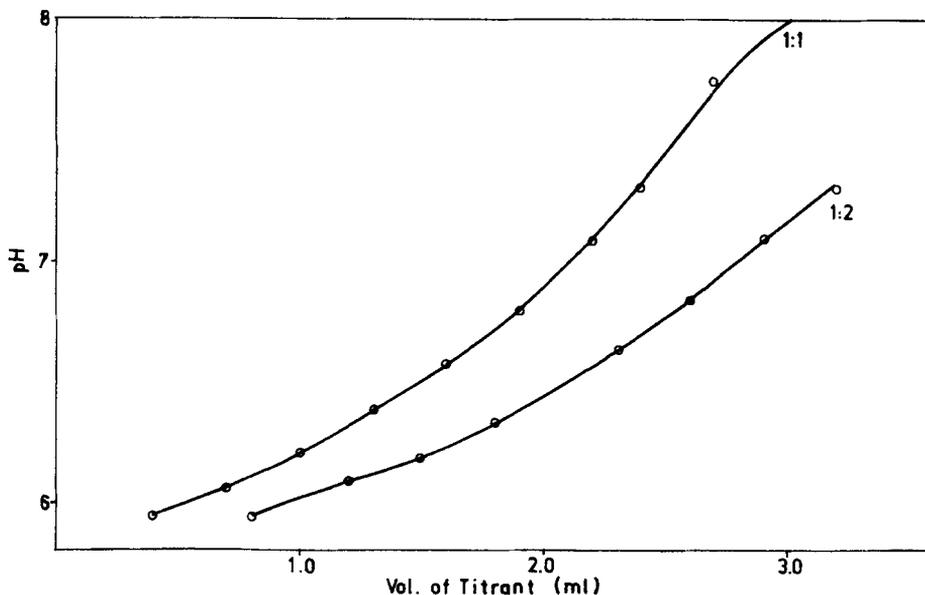
Study of the complexation of salicylaldehyde (A) and the tridentate aminoacids (B), L-threonine, L-glutamine and L-glutamic acid with Cu(II), Ni(II) and Zn(II) indicates that in the Cu(II)-salicylaldehyde system the values of both MA and  $MA_2$  species could be determined easily because of the presence of both species in appreciable concentrations. In the case of Zn(II), the plot of  $n$  vs  $pL$  was found to be a straight line parallel to the horizontal axis indicating the absence of  $MA_2$  species. The binary stability constants determined in the present study (table 1) are in good agreement with previously reported values (Sillen and Martell 1971).

### 3.2 Ternary complexes

3.2a *N-Salicylidene-1-threoninate complexes*: N-Salicylidene-1-threoninate is a potentially tetradentate Schiff base with phenolic hydroxyl, imino, carboxyl and alcoholic hydroxyl groups as possible coordination sites. The binary threoninate complexes of Cu(II), Ni(II) and Zn(II) exhibit only bidentate coordination involving the amino and carboxyl groups. The possibility of simultaneous coordination of all the three groups, in Cu(II) complexes has been ruled out from polarographic studies on the basis of

**Table 1.** Binary stability constants of Cu(II), Ni(II) and Zn(II) with salicylaldehyde and aminoacids.

Ligands	Zinc		Nickel		Zinc	
	$K_1$	$K_2$	$K_1$	$K_2$	$K_1$	$K_2$
Sal	5.50	9.78	3.80	6.45	2.93	—
Thr	7.96	14.39	5.42	9.76	4.72	8.50
Gln	7.74	14.20	5.17	9.45	4.55	8.35
Glu	8.75	15.30	6.10	10.80	5.10	9.4

**Figure 1.** N-Salicylidene-1-threoninate nickel(II) system: pH titration curves.

geometrical consideration. Coordination of the hydroxyl group has however been indicated at pH 10.0 in the case of Cu(II). It is of interest to know the relative coordinating abilities of these groups towards metal ions. In the evaluation of the stability constant of MAB, if MAB is considered a ternary complex, the theoretical pH values do not coincide with the experimental pH values. The role of metal ions as templates as well as “match-maker” in fusing the ligands to produce Schiff bases has already been proved in this area. If MAB is considered a ternary species rather than a binary species, the existence of  $MA_2B_2$  in this study, requiring metals with 8-coordination capability, would violate the hitherto cherished concepts of complexation of transition metal ions. So, MAB is a metal complex with one Schiff base ligand and  $MA_2B_2 = M(AB)_2$  is a metal complex with two Schiff base ligands. This revolutionary finding has been already made by Leussing, the pioneer of this study. The experimental pH titration curves along with the computed points are illustrated in figure 1. The complexation of Ni(II) starts at pH 5.8 in this system. The existence of all the three ternary species, MAB,  $MAB_2$  and  $MA_2B_2$ , is indicated by the absence of a clearly

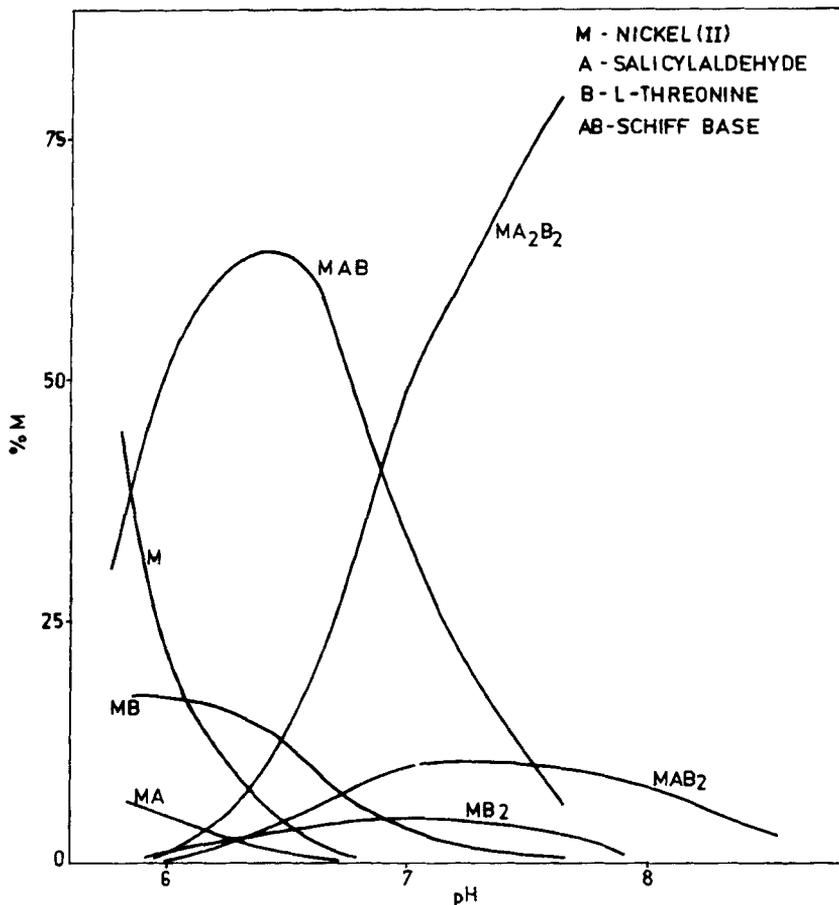


Figure 2. Species distribution as a function of pH (M:A-1:2).

defined neutralization region and confirmed by the curve fitting processes. The preferred formation of the ternary species over the binary species is brought out by considering the stepwise formation of the various species. The relative concentrations of the various species as a function of pH are shown in figure 2. The Schiff base species MBA and  $MA_2B_2$  formed in the N-salicylidene-1-threoninate zinc(II) system with overall formation constants of 9.30 and 15.20 log units. Preference for the formation of Schiff base complexes is quite obvious from the magnitude of the stability constants. However, the formation constants of MAB species of N-salicylidene-1-threoninate systems of nickel(II) and zinc(II) are identical with the values of the corresponding species in N-salicylidene- $\alpha$ -aminoacid systems (Rengaraj *et al* 1991). Apparently, N-salicylidene-1-threoninate also functions as a tridentate ligand, coordinating through the carboxyl, amino and phenolic hydroxyl groups without involving the alcoholic hydroxyl group of the threoninate moiety in coordination. However, the  $\log K_{MAB}$  values for copper(II) systems show a difference, the value being higher by about 0.3 log units for N-salicylidene-1-threoninate copper(II). Though the difference is not much the higher value is probably due to the involvement of the hydroxyl group in its

nonionised form in coordination. While the stabilities of MAB complexes do not require any special comments, the case with the  $MA_2B_2$  species is different. Between N-salicylidene- $\alpha$ -aminoacid systems and N-salicylidene-1-threoninate systems of nickel(II), and zinc(II), the magnitude of the difference in stability constants is of the order of 1.4 log units in nickel(II) systems and in the case of zinc(II) complexes of about one log unit. This additional stability cannot be attributed to the possible additional coordination of the hydroxyl group of the threoninate moiety because the overall coordination number would exceed six. However, a structure involving the coordination of the phenolic hydroxyl, imino and alcoholic hydroxyl groups can be envisaged by excluding the carboxyl group but retaining an overall coordination number of six. Such a change in the coordination site has been proposed in the case of the copper(II) threoninate system at pH 10.0. But this assumption does not help in assigning a reasonable structure, since the hydroxyl group can coordinate with either ionised or nonionised form. Though the pH range in the present study is well below  $pK_{OH}$  which is equal to 11.20; so that the  $-OH$  is not deprotonated, it is possible that deprotonation may occur at pH lower than the  $pK_{OH}$  due to the exigencies of stable complex formation. Hence it is not possible to indicate whether the  $-OH$  is coordinated in ionised or nonionised form. But the possibility of  $-OH$  coordination, displacing the  $-COOH$  group, may be visualised due to the following factors. The  $-OH$  group is softer than the  $-COOH$  at higher pH conditions and  $3d$  metals are known to prefer soft bases particularly at higher pH conditions.

**3.2b N-salicylidene-1-glutamate complexes:** N-salicylidene-1-glutamate is a tetradentate Schiff base with carboxyl amide, imino and phenolic hydroxyl groups as the potential donor sites. In binary aminoacid complexes, glutamine functions only as bidentate ligand coordinating through the carboxyl and amino groups. In a few mixed ligand complexes involving aminoacids, tridentate coordination of glutamine has been reported. The stability constants of the species, considered for computation of the theoretical curves of MAB,  $MAB_2$ , and  $MA_2B_2$  of the N-salicylidene-1-glutamate nickel(II) system, were found to be 10.15, 13.95 and 17.45 respectively. These values are similar to those of the corresponding species in N-salicylidene- $\alpha$ -aminoacid systems, indicating a similarity in the nature of coordination sites. Apparently the amide group of the glutamate is not involved in coordination. The distribution of species as a function of pH is shown in figures 3 and 4 for 1:1 and 1:2 metal:sal systems. The ternary species predominate over the binary species in general but as pH increases the concentrations of the binary glutamate species seem to increase, when the metal to salicylaldehyde ratio is equimolar. On increasing the concentration of salicylaldehyde, the Schiff base species predominate over the binary species (figure 4). The concentrations of binary glutamate complexes are comparable to those of the Schiff base species and, in general, the binary glutamate species are also equally favoured. It is possible that the long side chain in the glutamate moiety in some way renders the formation of the Schiff base species difficult due to steric considerations. The stability constant of N-salicylidene-1-glutamate copper(II) is found to be 15.50 log units, about 0.6 log units greater than that of the corresponding N-salicylidene- $\alpha$ -aminoacid complex, suggesting the involvement of the amide group of the glutamate moiety in coordination. In the case of zinc(II) systems, the species MAB and  $MA_2B_2$  were found to exist and the stability constant of the species were computed as 9.40 and 15.15 log units, respectively. These values are comparable to the values of the corresponding species in N-salicylidene- $\alpha$ -amino acid systems and are indicative of tridentate

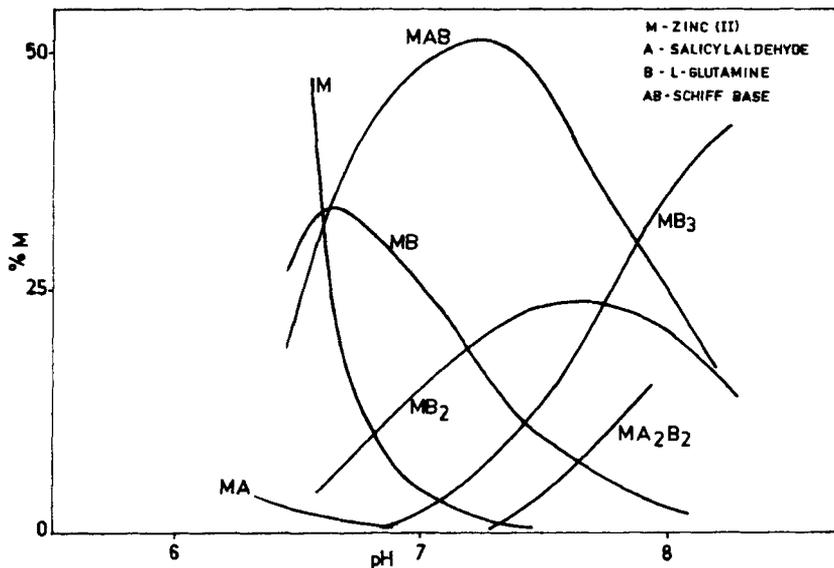


Figure 3. Species distribution as a function of pH (M:A-1:1).

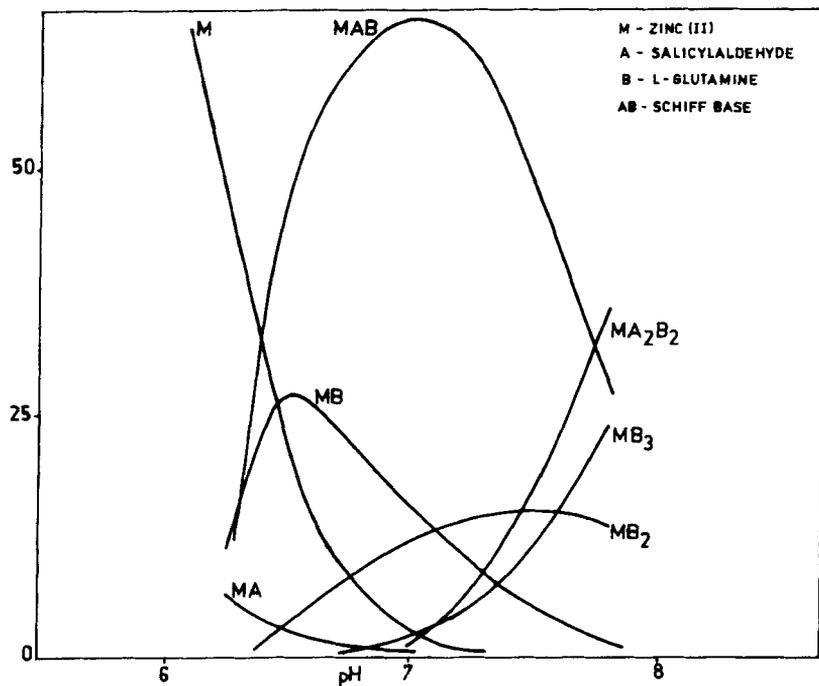


Figure 4. Species distribution as a function of pH (M:A-1:2).

coordination of the Schiff base. From the species distribution, it is obvious that the behaviour of various species is similar to that in N-salicylidene-1-glutaminato nickel(II) system with the concentrations of binary species being comparable to that of Schiff base species.

**Table 2.** Stability constants of Schiff base complexes.

Ligands	Copper				Nickel				Zinc		
	$K_{11}$	$K_{12}$	$K_{22}$	$K_{11}-K_{11}^*$	$K_{11}$	$K_{12}$	$K_{22}$	$K_{11}-K_{11}^*$	$K_{11}$	$K_{22}$	$K_{11}-K_{11}^*$
Sal-Thr	15.55	—	—	3.62	10.35	14.05	18.50	2.21	9.30	15.20	2.59
Sal-Gln	15.50	—	—	3.54	10.15	13.95	17.45	2.07	9.40	15.15	2.67
Sal-Glu	16.10	—	—	4.05	10.50	14.10	17.55	2.00	9.55	15.35	2.32

3.2c *N-Salicylidene-1-glutamate complexes*: The tetradentate Schiff base obtained by the fusion of salicylaldehyde and glutamic acid possesses a phenolic hydroxyl, an imino and the carboxyl groups as donor sites. Glutamate by itself functions as a tridentate ligand in binary systems. The stability constants  $K_{11}$ ,  $K_{12}$ , and  $K_{22}$  of MAB,  $MAB_2$ , and  $MA_2B_2$  species respectively of *N*-salicylidene-1-glutamate nickel(II) system (table 2) are comparable to the corresponding values of *N*-salicylidene- $\alpha$ -aminoacid systems. This clearly shows that the Schiff base *N*-salicylidene-1-glutamate functions only as tridentate ligand. Apparently one of the carboxyl groups is not involved in coordination. It is interesting to note the effect of pH on the relative concentrations of the various species which is illustrated in figure 5. The Schiff base species are formed only to a small extent and the predominant species is the binary glutamate  $MB_2$ , which increases in its concentration with the increase in pH having a maximum of 80% at pH 8.0. This clearly indicates that though the Schiff base species have higher stability constants than the binary glutamate species, the magnitude of stability constant is not the deciding factor in determining the relative concentrations of the species. The higher preference for the formation of binary glutamate species may be attributed to the favourable conformation about the amino nitrogen which possibly directs the carboxyl group towards the metal ion with much less steric strain than the unsaturated imino nitrogen in the Schiff base. *N*-salicylidene-1-glutamate zinc(II) also shows behaviour similar to that of the corresponding nickel(II) system. Stability constant values are given in table 2. The species distribution diagram indicates that the Schiff base complex is the predominant one followed by considerable concentration of the binary glutamate species  $MB_2$ . Zinc(II) seems to favour the formation of Schiff base complexes in contrast to nickel(II) which prefers binary glutamate complexes.

#### 4. Conclusions

Among the Schiff base complexes derived from potentially tridentate aminoacids in the present investigation, the effect of additional coordination sites such as  $-OH$  in 1-threonine,  $-CONH_2$  in 1-glutamine and  $-COOH$  in 1-glutamic acid systems has been investigated. In the case of binary threoninate complexes, it has been found that the  $-OH$  group, in spite of its proximity to the other coordinating sites, is not involved in coordination possibly due to steric constraints. Thus threonine effectively functions as a bidentate ligand coordinating through the amino and carboxyl groups only. The same feature has been observed in the Schiff base complexes of nickel(II), copper(II) and zinc(II). Glutamine also behaves as a bidentate ligand in its binary complexes with

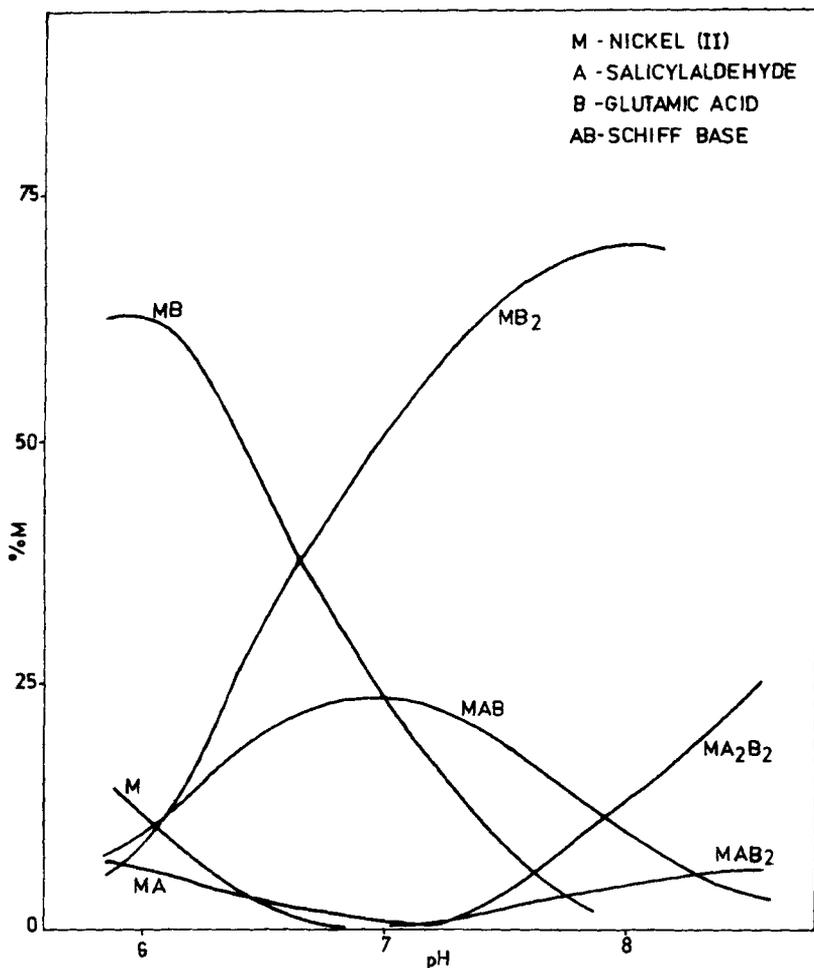


Figure 5. Species distribution as a function of pH (M:A-1:2).

nickel(II), copper(II) and zinc(II), and in its Schiff base complexes. Glutamic acid with two terminal carboxyl groups and  $\alpha$ -amino group functions essentially as a tridentate ligand. The tridentate behaviour of N-salicylidene-1-glutamate in its complexes is clearly reflected in the higher values of stability constants. The preference exhibited in the formation of Schiff base complexes over simple mixed ligand complexes similar to the systems discussed in our previous publication (Rengaraj *et al* 1991) is clearly brought out by considering the stepwise formation constants. The overall formation constants of the mixed ligand complexes  $K_{11}^*$  can be derived from binary stability constants,

$$K_{11}^* = K_{10} \cdot K_{02} \quad \text{or} \quad K_{01} \cdot K_{20}.$$

The difference in the overall formation constant of Schiff base complex species  $K_{11}$  and mixed ligand complex species  $K_{11}^*$  is the proof for the favoured nature of Schiff base species. The  $K_{11} - K_{11}^*$  values for the systems investigated in the present study ranging

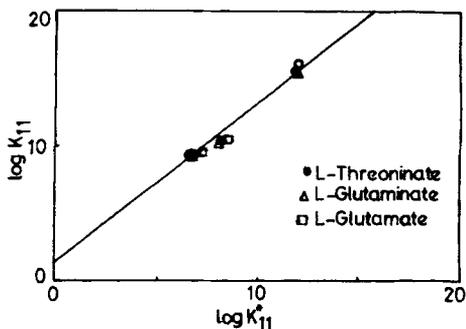


Figure 6. Plot of  $\log K_{11}$  vs  $\log K_{11}^*$ .

from 2.0 to 4.0 log units indicate the preference for the formation of Schiff base complex. The plot of  $\log K_{11}^*$  vs  $\log K_{11}$  (figure 6) was found to be a straight line, with a slope of unity and an intercept equal to two, irrespective of the metal or Schiff bases involved. This observation confirms that the enhanced stability of the Schiff base complex species is mainly due to the entropy factor rather than to mere interligand attractive forces.

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