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46. Zenzo Tamura and Motoichi Miyazaki: Metal Complexes of D-Glucosamine and its Derivatives. IV.*[1] Determinations of Stability and Equilibrium Constants of Metal Complexes of D-Glucosamine by pH Titration Method.*[2]

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Many investigations on the non-metal or metal complexes of sugar and sugar like compounds by pH titration method were made by several workers.

Deutsch, *et al.*[1] studied the complex formation between boric acid and mannitol and found that these compounds formed strong complexes in solution. Pecsock, *et al.*[2] demonstrated that gluconic acid had a strong chelating ability with several metal ions in alkaline solution and they determined the stability constants of copper, iron, and lead complexes of gluconic acid. Sawyer, *et al.*[3] and Tabe, *et al.*[4] had also studied the metal complex formation with gluconic acid.

Recently, Juvet[5] investigated the complex formation of N-methyl glucamine, one of the sequestering agents similar to gluconic acid, with lead ion.

However, any information has never reported on the metal complexes of D-glucosamine and its derivatives by pH titration method.

This report deals with pH titrations designed with a view to obtain informations on the complex formations between metal ions and D-glucosamine (I). Prior to the pH titrations, ability of the complex formation was examined with I by measuring the magnitude of pH depression which would be caused by the displacement of a metal ion for protons during complex formation.

The pH titrations of I were carried out in the presence of nine metal ions such as cupric, lead, zinc, nickelous, cadmium, cobaltous, manganous, calcium, and magnesium ion respectively, and the calculations based upon the titration data were attempted to obtain stability constants of the complexes. The applicability of Bjerrum's method[6] to the I-metal complex system was examined, and it was found that the method could be employed to the calculation of the constants. However, the stability constants of calcium and magnesium complexes could not be obtained under these experimental conditions.

Furthermore, the hydrolysis constants were determined on the complexes of seven metal ions except calcium and magnesium ion and the copper complex was found to be the most hydrolysable complex among them. In addition to the hydrolysis, dimerization reaction was perceived in the case of copper complex in a 1:1 ratio of I to cupric ion during the titration procedure.

Experimental

Materials and Solutions——D-Glucosamine hydrochloride was the same preparation as described in a

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*[1] Part III. Z. Tamura, M. Miyazaki, T. Suzuki: This Bulletin, **13**, 330 (1965).

*[2] Presented before the Monthly Meeting for the Pharmaceutical Society of Japan, Tokyo, September, 1963.

*[3] Hongo, Tokyo (田村善蔵, 宮崎元一).

1) A. Deutsch, S. Osoling: J. Am. Chem. Soc., **71**, 1637 (1949).
2) R. L. Pecsok, R. S. Juvet: J. Am. Chem. Soc., **77**, 202 (1955); R. L. Pecsok, J. Sandera: *Ibid.*, **77**, 1489 (1955); R. L. Pecsok, R. S. Juvet: *Ibid.*, **78**, 3967 (1956).
3) D. T. Sawyer, R. S. George, J. B. Bagger: J. Am. Chem. Soc., **81**, 5893 (1959).
4) H. Tabe, K. Okamoto: Yakugaku Zasshi, **78**, 951 (1958).
5) R. S. Juvet: J. Am. Chem. Soc., **81**, 1796 (1959).
6) J. Bjerrum: "Metal Ammine Formation in Aqueous Solutions," (1941), Hasse & Son, Copenhagen.

previous report.7) $Cu(NO_3)_2$, $Pb(NO_3)_2$, $Zn(NO_3)_2$, $Ni(NO_3)_2$, $Cd(NO_3)_2$, $Co(NO_3)_2$, $Mn(NO_3)_2$, $Ca(NO_3)_2$ and $Mg(NO_3)_2$ of analytical grade were used for the stock solutions at a concentration of $10^{-2}M$ each. These stock solutions were standardized by EDTA titration with metal indicators respectively.

Apparatus and Procedure——The apparatus and the equipments for the pH titrations were as same as those used for the pKa determination of I. The experimental method used in the pH titration was similar to that described in the pKa determination of I which was also mentioned in the preceding report.7)

The temperature was 30±0.5°, and the ionic strength was kept nearly at 0.1 with KNO_3. As to the sample solutions for pH titrations, the order of the concentrations of both I and a metal ion was chosen in the range between $10^{-4}M$ and $10^{-3}M$ with a various ratio of I to a metal ion.

Treatments of Data of pH Titrations——The calculation method for the stability constants of the metal complexes is based mainly on Bjerrum's method, assuming that I behaves as mono basic acid and plays a role for the mono dentate ligand in the complex formation with a metal ion.

According to the treatment of Bjerrum's, following equations will be obtained.

In the formation of a complex having a 1:1 ratio of I to a metal ion, assuming that the reaction as shown in equation (1) will take place,

$$G+M \overset{K_1}{\rightleftharpoons} GM \qquad (1)$$

where, G, M and GM stand for I, metal ion and I-metal complex (1:1), respectively, and K_1 is the formation constant of GM.

Therefore, the formation function of the above reaction is given by the equation (2).

$$\bar{n}+(\bar{n}-1)K_1[G]=0 \qquad (2)$$

and the equation (2) can be rewritten to obtain the equation (3)

$$\bar{n}=(1-\bar{n})K_1[G] \qquad (3)$$

here, $\bar{n}$ means a ratio of the concentration of complex-bound ligand to the total concentration of metal ion. [ ] denotes the concentration of each species in terms of molarity, *M*. The electric charge of each ionic species is omitted so as to simplify the equations.

If $\bar{n}$ is plotted against $(1-\bar{n})[G]$, there will be found a linear relation between them and the slope of the line indicates directly the K_1 of the reaction defined by the equation (1).

When the two species of complexes such as 1:1 and 2:1 compounds will be formed succesively in the complex formation, the second reaction and the formation function can be given by the following equations (4) and (5), respectively.

$$GM+G \overset{K_2}{\rightleftharpoons} G_2M \qquad (4)$$

$$\bar{n}+(\bar{n}-1)K_1[G]+(\bar{n}-2)K_1K_2[G]^2=0 \qquad (5)$$

equation (5) is rearranged to obtain the equation (6)

$$\frac{\bar{n}}{(\bar{n}-1)[G]}=\frac{(2-\bar{n})[G]}{(\bar{n}-1)}K_1K_2-K_1 \qquad (6)$$

Hence, a linear relation will be observed between $\bar{n}/(\bar{n}-1)[G]$ and $(2-\bar{n})[G]/(\bar{n}-1)$, if $\bar{n}/(\bar{n}-1)[G]$ is plotted against $(2-\bar{n})[G]/(\bar{n}-1)$. The slope of the line obtained indicates the K_1K_2 of the reaction which is shown by the equation (1) and (4).

Calculations of Hydrolysis Constants of the I-metal Complexes8)——Assuming that the hydrolysis reaction of a metal complex of I is carried out after the following equations (7) and (8),

$$GM+H_2O \overset{K_{GM(OH)}}{\rightleftharpoons} GM(OH)+H^+ \qquad (7)$$

$$GM(OH)+H_2O \overset{K_{GM(OH)_2}}{\rightleftharpoons} GM(OH)_2+H^+ \qquad (8)$$

then, the hydrolysis constants $K_{GM(OH)}$ and $K_{GM(OH)_2}$ are given by equations (9) and (10).

$$K_{GM(OH)}=\frac{[GM(OH)][H^+]}{[GM]} \qquad (9)$$

$$K_{GM(OH)_2}=\frac{[GM(OH)_2][H^+]}{[GM(OH)]} \qquad (10)$$

If T_{OH} is defined to represent the concentration of hydroxide added to the solution of GM complex, it may be expressed by the equation (11) assuming that the concentration of hydroxide will be so small at the early stage of the titration that $GM(OH)_2$ may be neglected.

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7) Z. Tamura, M. Miyazaki, T. Suzuki: This Bulletin, **13**, 330 (1965).

8) M. Ishidate, A. Hanaki: Yakugaku Zasshi, **77**, 634 (1957).

Therefore, T_{OH} can be written as follows

$$T_{OH}=[GM(OH)]+[OH^-]-[H^+] \qquad (11)$$

and, the total concentration of ligand in solution, T_I can be also given by the equation (12)

$$T_I=[G]+[GM]+[GM(OH)] \qquad (12)$$

If the dissociation of the complex into respective component in such a manner as $GM \rightleftharpoons G+M$ is negligibly small, then, the concentration of the free ligand [G] can be reasonably neglected. Thus, the equation (13) will be obtained from the equation (12).

$$T_I=[GM]+[GM(OH)] \qquad (13)$$

Combining the equations (11) and (13), the equation (14) can be obtained

$$[GM]=T_I-T_{OH}+[OH^-]-[H^+] \qquad (14)$$

and also the equation (15) is derived by displacing the equation (14) with the equation (13)

$$[GM(OH)]=T_{OH}-[OH^-]+[H^+] \qquad (15)$$

Finally, $K_{GM(OH)}$ can be obtained from the combination of the equations (9), (14) and (15)

$$K_{GM(OH)}=\frac{\{T_{OH}-[OH^-]+[H^+]\}[H^+]}{T_I-T_{OH}+[OH^-]-[H^+]} \qquad (16)$$

The Analysis of the Dimerization of I-copper Complex——This treatment was made by the method of Martell, *et al.*,[9] which was also useful for the mathematical treatment of the copper complex of I.

Results and Discussion

The Proof of the Complex Formation between Metal Ions and I

The probability of the complex formation between metal ions and I was examined

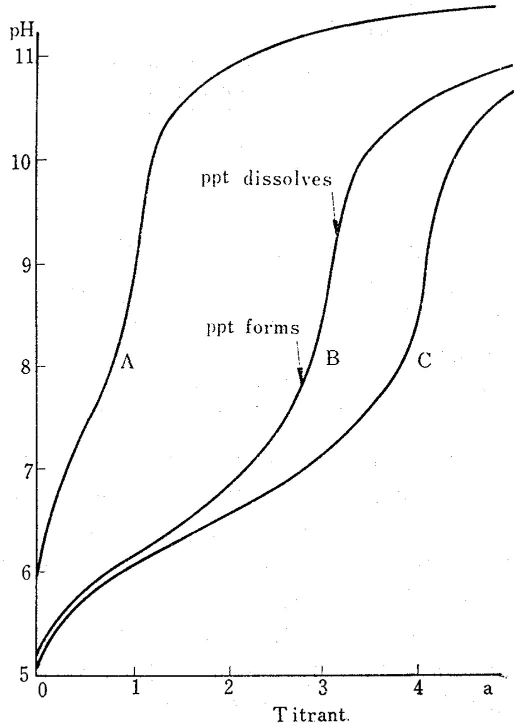

Fig. 1-a. Titration Curves of D-Glucosamine (I) in the Presence of Cupric Ion

A : (I) (hydrochloride) $1.0\times10^{-3}M$
B : I—Cu=1:1, I concentration $1.028\times10^{-3}M$
C : I—Cu=2:1, I concentration $2.056\times10^{-3}M$
titrant : $0.1M$ NaOH
The symbol, a, means the mole of hydroxide added per mole of I or ligand present.

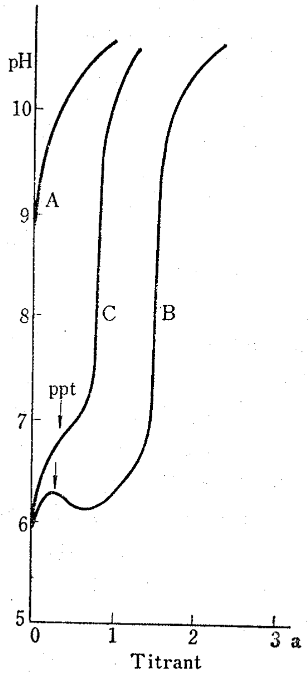

Fig. 1-b. Titration Curves of D-Glucose in the Presence of Cupric Ion

A : ligand $1.03\times10^{-3}M$
B : ligand—Cu=1:1
C : ligand—Cu=2:1

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9) R.C. Courtney, R.L. Gustafson, S. Chaberek, A.E. Martell : J. Am. Chem. Soc., 81, 519 (1959).

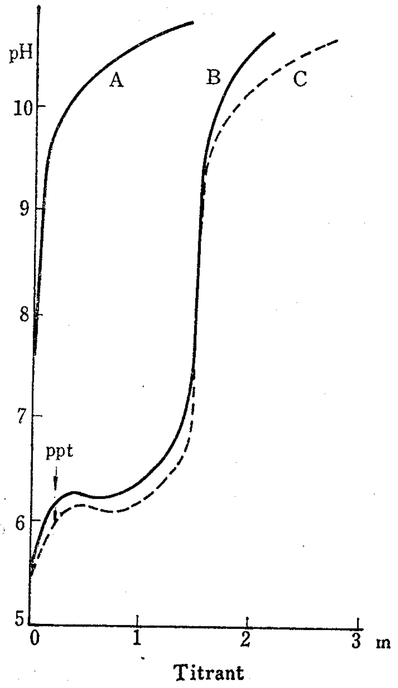


Fig. 1-c. Titration Curves of Ethyleneglycol in the Presence of Cupric Ion

A : ligand $5.14 \times 10^{-3} M$
B : ligand—Cu=2:1
C : ligand—Cu=5:1
The symbol, m, means the mole of hydroxide added per mole of metal ion.

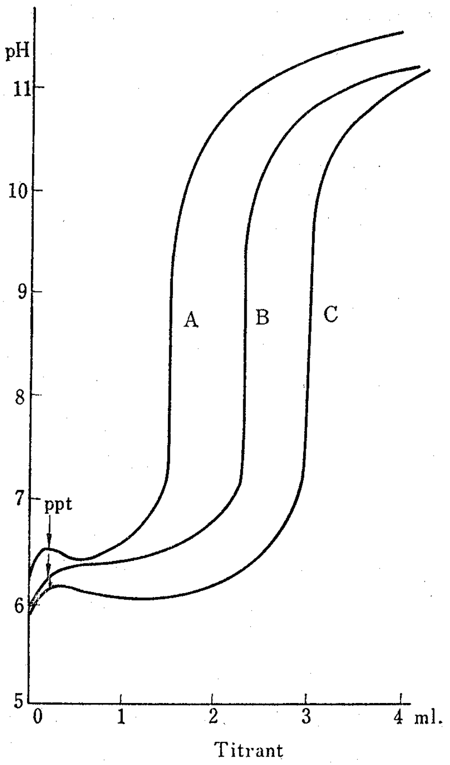


Fig. 1-d. Titration Curves of Cupric Ion

A : cupric ion $1.0 \times 10^{-3} M$
B : cupric ion $1.5 \times 10^{-3} M$
C : cupric ion $2.0 \times 10^{-3} M$

prior to the pH titrations. From the results of the preliminary experiments, cupric ion was chosen for a metal ion in the experiment since cupric ion is considered to form the strongest complex with I among nine metal ions used. One of the methods employed in general to examine complex formation is a measurement of magnitude of pH depression which is caused by displacing a metal ion with a proton of the ligand during the complex formation between metal ion and ligands.

Therefore, the magnitude of the pH depression in the complex formation between cupric ion and I was measured. In addition to I, D-glucose and ethyleneglycol were also measured as ligands since they have OH groups in their structure and in order to determine the possibility of complex formation of OH group with metal ions under the experimental conditions. The results are given in Fig. 1.

I was found to show the strongest pH depression among those of three ligands, and therefore to have a fairly strong ability of complex formation with cupric ion. Ethyleneglycol was found to have scarcely forming ability and there was hardly pH depression. As to D-glucose, a slight pH depression was found at an initial stage of the titration.

Furthermore, in the cases of both ethyleneglycol and D-glucose, it was observed that either cupric hydroxide or hydrolysis product was precipitated when pH of the solution was increased by an addition of base.

In the titration of I in the presence of cupric ion, the precipitate was formed only at a 1:1 ratio of I to cupric ion, but it disappeared in the strong alkaline pH region of the solution.

Considering from the experimental data mentioned above, it may be inferred that I has a stronger complex forming ability than the other two compounds and the ability of complex formation by OH groups seems to be quite small or negligible in magnitude.

The pH Titrations of I in the Presence of Nine Metal Ions respectively

The titrations of the complex formations of I and nine metal ions respectively were carried out. The results are illustrated in Figs. 2, 3, and 4.

It is clearly seen that cupric ion forms the strongest complex with I among the ions, considering from the magnitude of the pH depression.

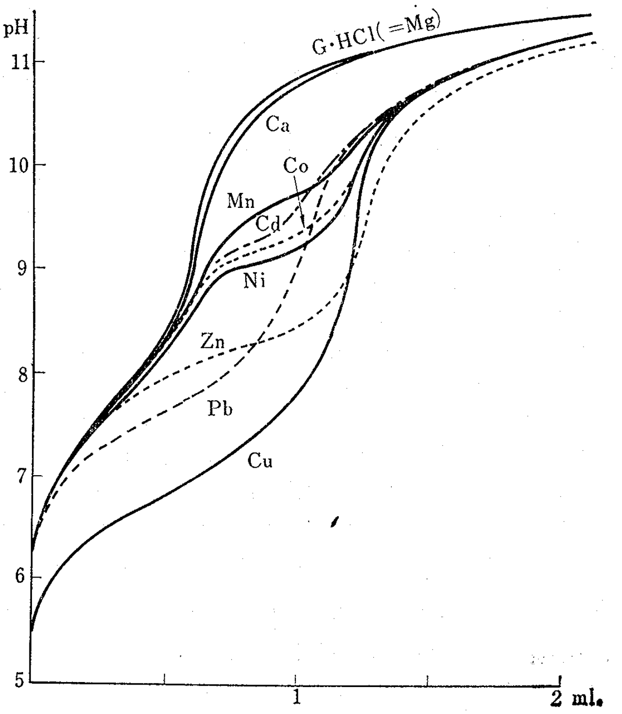


Fig. 2. Titration Curves of D-Glucosamine (I) in the Presence of Respective Metal Ions

molar ratio of I to metal ion=2:1
I concentration: $1.117\times10^{-3}M$
metal ion: $5.585\times10^{-4}M$
temp.: 30±0.5°, $\mu=0.1(KNO_3)$
titrant: $0.1M$ NaOH

I-copper Complex

In the titration curve of I to cupric ion 1:1 as shown in Fig. 1-a, there is an inflection point at a=1, when only I is titrated with the base and this inflection point shifts to a=3 in the presence of equimolar concentration of cupric ion. The symbol, a, means the mole of hydroxide added per mole of I present. Therefore, it is considered that the complex formation requires two moles of base per mole of I in this case. The color of the sample solution turns from bluish green to deep blue according to the increase of pH of the solution.

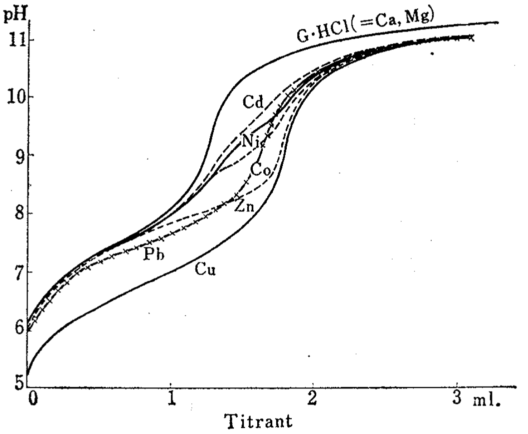


Fig. 3. Titration Curves of D-Glucosamine (I) in the Presence of Respective Metal Ions

molar ratio of I to metal ion=5:1
I concentration: $2.793\times10^{-3}M$
metal ion: $5.585\times10^{-4}M$
tem.: 30±0.5°, $\mu=0.1(KNO_3)$
titrant: $0.1M$ NaOH

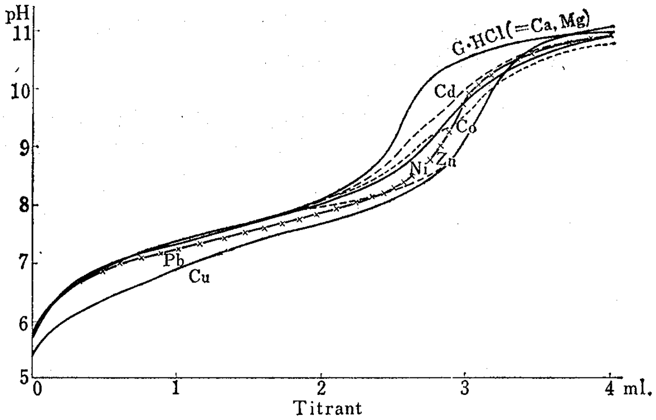


Fig. 4. Titration Curves of D-Glucosamine (I) in the Presence of Respective Metal Ions

molar ratio of I to metal ion=10:1
I concentration: $5.585\times10^{-3}M$
metal ion: $5.585\times10^{-4}M$
temp.: 30±0.5°, $\mu=0.1(KNO_3)$
titrant: $0.1M$ NaOH

At about a pH between 8 and 9, an insoluble precipitate was produced and it redissolved in more alkaline pH region nearly from 10 to 11 during the titration.

In the titration curve of I to cupric ion of 2:1 ratio, the inflection point moves further to a=4. Since two moles of I also requires two moles of the base for neutralization, hereagain, the complex formation requires two moles of the base. However, in the titration of 2:1 system, there was no precipitation throughout any range of pH during the titration and the insoluble solid was not observed.

Moreover, when the concentration of I is increased further over 2:1 ratio of I to cupric ion, the shape of the titration curves was in resemblance to that of 2:1 titration curve as is seen in Figs. 3 and 4.

The different behaviors among the systems of 1:1 and 2:1 ratio and in the presence of excess of I, suggest that it may be available to consider every mechanism of complex formations would not be the same. As it will be reported later the existence of mono hydroxo complex may be considered in alkaline regions besides the normal 1:1 complex in the solution of a ratio of I to cupric ion 1:1, and a dimerization of copper complex may be also considered. In further alkaline pH region, these hydroxo complex or dimeric complex will be subjected to the hydrolysis effected by hydroxide ion, and finally cupric oxide or other hydrolysis product may be precipitated because these complexes have relativaly low stability constants as will be shown later.

The Titration of I in the Presence of the other Eight Sorts of Metal Ions

Every titration of I in the presence of eight kinds of metal ions was carried out under as same experimental conditions as was in the case of cupric ion. The results are shown in Figs. 2, 3, and 4.

To compare a relative degree of these complex formation, the titration curve of I with cupric ion is also given together. Considering from the magnitude of pH depression, it is clearly seen that the degrees of the complex formation of these complexes are in the tendency to increase in the order, $Cu > Pb > Zn > Ni \fallingdotseq Co \fallingdotseq Cd \fallingdotseq Mn \gg Ca$, Mg.

However, in the case of magnesium and calcium, the pH depressions were hardly observed. Moreover, the precipitation of a metallic hydroxide or the hydrolysis product was deposited during the pH titration even though relatively an excess amount of I less than that of a metal ion was present in the solution. Respective pH values at which the precipitation occurred initially are given in Table I.

Table I. Appearance of Precipitation during the Titration of D-Glucosamine (I) in the Presence of Respective Metal Ions

Metal ion	Ratio of I to metal ion			
	1 : 1	2 : 1	5 : 1	10 : 1
Cu^{2+}	+	—	—	—
Pb^{2+}		±	±	±8.0
Zn^{2+}	+8.3	+8.0	+8.7	+7.8
Co^{2+}		+9.0	+9.5	+8.7
Cd^{2+}		+	+	±9.1
Ni^{2+}		+9.0	+9.6	—
Mn^{2+}		+9.2		
Ca^{2+}	—	—	—	—
Mg^{2+}	—	—	—	—

The value indicates the pH at which precipitation occurs initially.

These facts suggest that these metal complexes of I would be considerably weak in stability, and they might be easily hydrolysable.

The magnitude of pH depression of these complexes are relatively smaller than that of I with cupric ion and therefore it may be deduced that I has the most stable complexing ability with cupric ion among these nine metal ions.

The Determinations of Stability Constants

The results of the examination on the applicability of Bjerrum's method to I-metal complexes are shown in Figs. 5-a and 5-b.

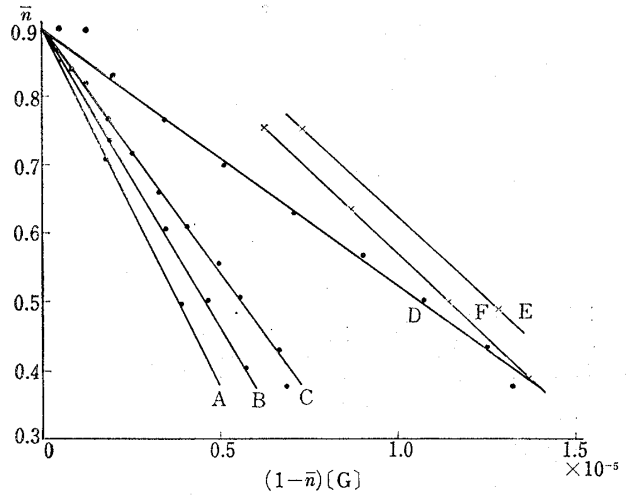


Fig. 5-a. Relation between $\bar{n}$ and $(1-\bar{n})[G]$

I : Cu=1:1 I : Cu=2:1

concentration

A : I $5.14\times10^{-4}M$ E : I $2.056\times10^{-3}M$
B : I $1.028\times10^{-3}M$ F : I $4.112\times10^{-3}M$
C : I $2.056\times10^{-3}M$
D : I $4.112\times10^{-3}M$

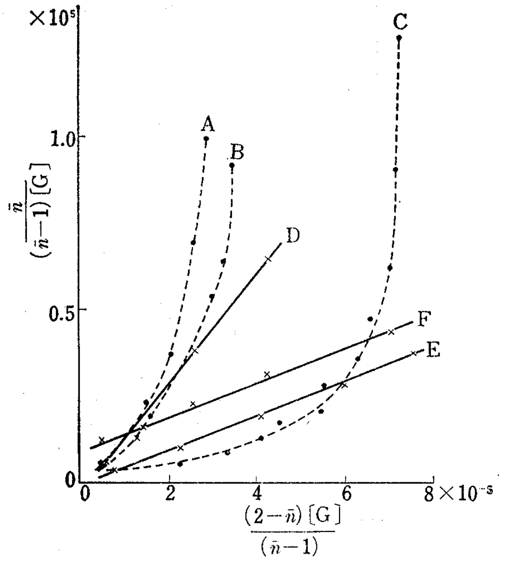


Fig. 5-b. Relation between $\frac{\bar{n}}{(\bar{n}-1)[G]}$ and $\frac{(2-\bar{n})[G]}{(\bar{n}-1)}$

I : Cu=1:1 I : Cu=2:1

concentration

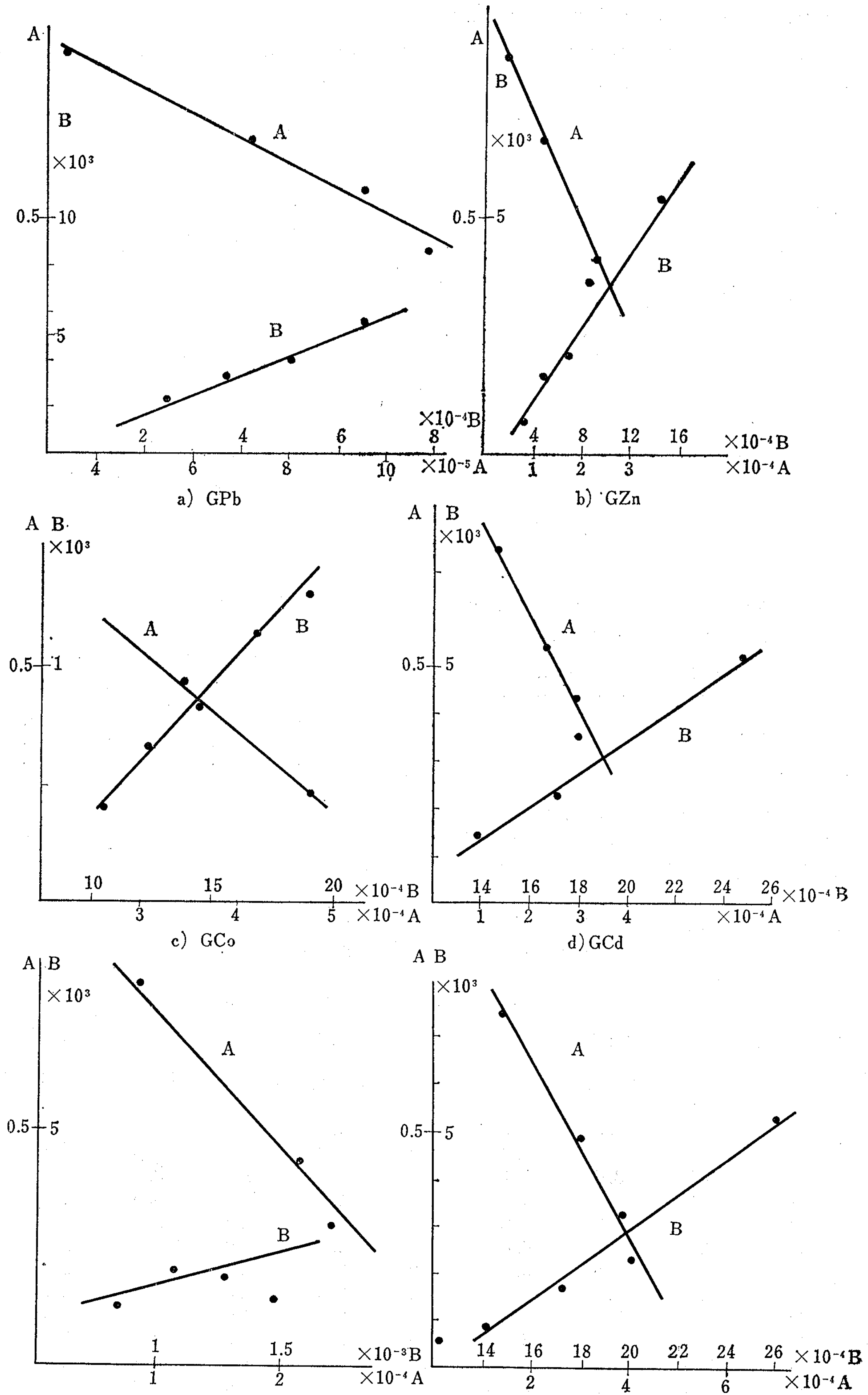
A : I $1.028\times10^{-3}M$ D : I $1.028\times10^{-3}M$
B : I $2.056\times10^{-3}M$ E : I $2.056\times10^{-3}M$
C : I $4.112\times10^{-3}M$ F : I $4.112\times10^{-3}M$

As to the I-copper complex, linear relationships can be seen between $\bar{n}$ and $(1-\bar{n})$ [G] as shown in Fig. 5-a in the complex formation of I to cupric ion having a ratio of 1:1 and 2:1, respectively.

TABLE II. Stability Constants of Seven Metal Complexes of D-Glucosamine (I)
$C_M=5.585\times10^{-4}M$, 30±0.5°, $\mu=0.1$ (KNO_3)

Metal ion		Ratio of I to metal ion								
		2 : 1			5 : 1			10 : 1		
		log K_1	log K_2	log K_1K_2	log K_1	log K_2	log K_1K_2	log K_1	log K_2	log K_1K_2
Cu^{2+}	D	4.8	4.9	9.7	4.2	4.1	8.3	4.0	3.6	7.6
	G	—	—	9.3	4.0	3.8	7.8	4.4	3.1	7.5
Pb^{2+}	D	3.5	3.6	7.1	3.6	2.9	6.5	3.2	2.8	6.0
	G	3.3	3.3	6.6	3.5	1.9	5.4	3.0	2.4	5.4
Zn^{2+}	D	3.3	3.3	6.6	3.3	2.9	6.2	2.9	2.0	4.9
	G	3.3	3.3	6.6	2.6	2.3	4.9	2.7	2.0	4.7
Co^{2+}	D	2.8	2.8	5.6	3.2	2.2	5.4	3.1	2.2	5.3
	G	2.6	3.4	6.0	3.0	3.0	6.0	2.7	2.9	5.6
Cd^{2+}	D	3.1	3.1	6.2	3.2	2.8	6.0	2.7	3.1	5.8
	G	3.0	2.5	5.5	3.0	2.7	5.7	2.5	3.1	5.6
Ni^{2+}	D	3.3	2.6	5.9	2.9	2.8	5.7	3.1	2.5	5.6
	G	3.2	2.7	5.9	3.2	2.8	6.0	3.0	2.6	5.6
Mn^{2+}	D	3.0	3.0	6.0	—	—	—	—	—	—
	G	2.9	2.7	5.6	—	—	—	—	—	—

D : Direct calculation G : Graphical solution



a) GPb

b) GZn

c) GCo

d) GCd

e) GNi

f) GMn

Fig. 6. Relation between $\bar{n}$ and $(1-\bar{n})[G]$····A and Relation between $\frac{\bar{n}}{(\bar{n}-1)[G]}$ and $\frac{(2-\bar{n})[G]}{(\bar{n}-1)}$····B

I : M=2:1, I concn. $1.117\times10^{-8}M$

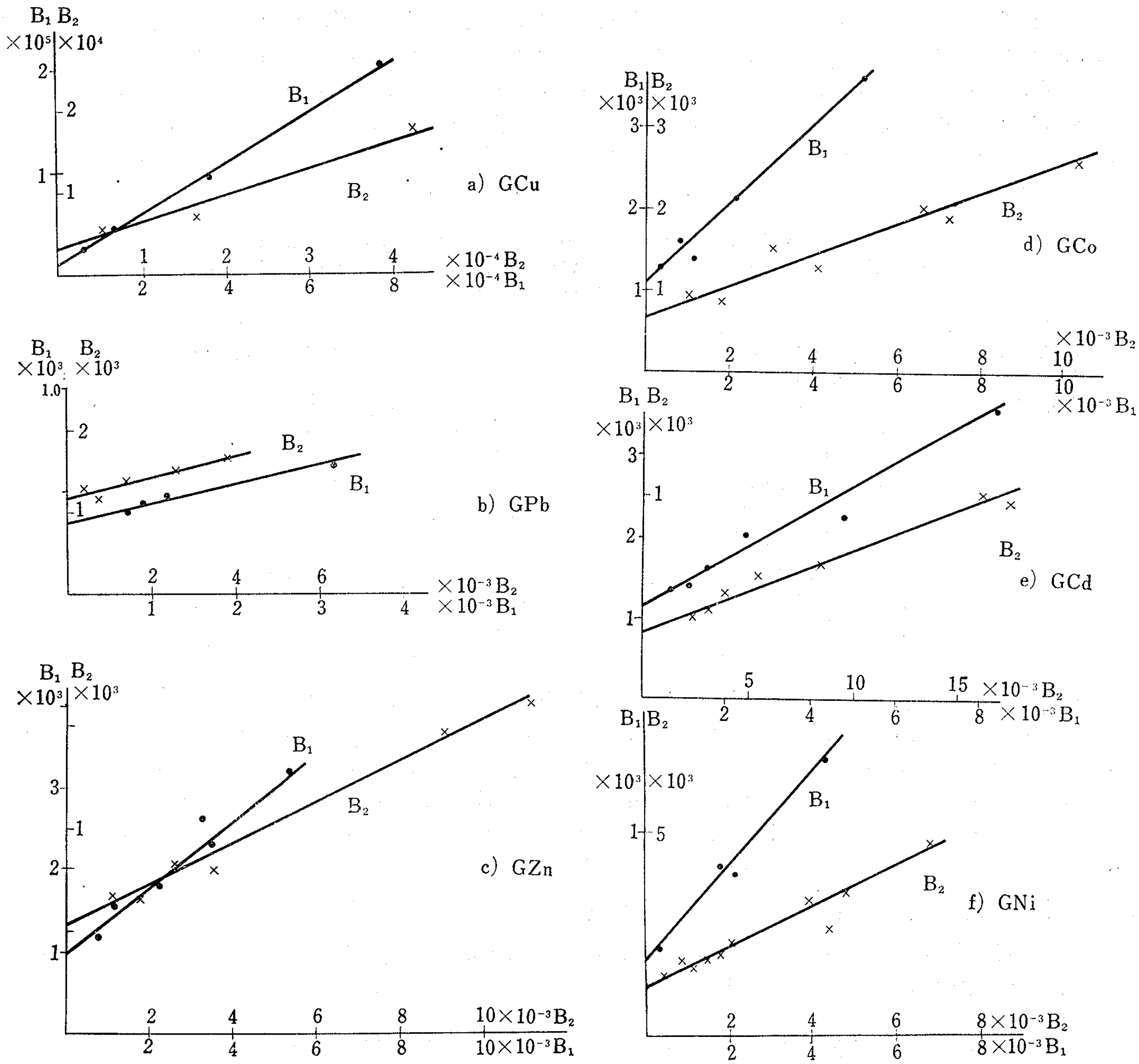


Fig. 7. Relation between $\frac{\bar{n}}{(\bar{n}-1)[G]}$ and $\frac{(2-\bar{n})[G]}{(\bar{n}-1)}$

B_1 (I): M=5:1, B_2 (I): M=10:1 M^{2+} concn. $5.585\times10^{-4}M$

Furthermore, the linear relations are found similar between $\bar{n}/(\bar{n}-1)[G]$ and $(2-\bar{n})[G]/(\bar{n}-1)$ in the complex formation in a 2:1 ratio of I to cupric ion, while the curves are obtained in the case of 1:1 as are seen in Fig. 5-b.

The similar relationships are established for the other metal complexes of I as given in Figs. 6 and 7 in such a various ratio of I to metal ions as 2:1, 5:1, and 10:1.

Consequently, stability constants, log K_1 and log K_2 were calculated according to Bjerrum's method from the titration data, and also obtained from the slopes of these straight lines. They are shown in Table II.

Therefore, 1:1 and 2:1 complexes were formed in the following cases of having the ratio of I to a metal ion in 1:1, 2:1, 5:1, and 10:1 respectively, but only 1:1 complex was present in the system of I to a metal ion 1:1.

The magnitudes of the values obtained for log K_1 and log K_2 of these metal complexes are almost the same degree to those of corresponding metal ammine complexes. The copper complex of I is the most stable and it has the largest values of stability constants among these metal complexes of I. This may belong to the same case also in cupra-ammonium complex.

From Table II, it is clearly seen that the values of stability constants are inclined to decrease slightly in its magnitude according to the increasing concentration of I. These phenomena are especially obvious with copper, lead, and zinc complexes of I, and further investigations were carried on the properties of copper complex so as to study the effect at various concentrations of I and cupric ion to the stability constants. The results are shown in Table III.

TABLE III. The Effect of Varying Concentration of D-Glucosamine (I) on the First and Second Stability Constants of I-copper Complexes
temp.: 30±0.5°, $\mu=0.1$ (KNO_3)

Ratio of I to cupric ion	Cupric ion concentration (M)	Stability constant		
		$\log K_1$	$\log K_2$	$\log K_1K_2$
1 : 1	5.14×10^{-4}	5.1		
	1.028×10^{-3}	5.0		
	2.056×10^{-3}	5.0		
	4.112×10^{-3}	4.7		
2 : 1	5.14×10^{-4}	4.8	4.9	9.7
	1.028×10^{-3}	4.6	4.7	9.3
	2.056×10^{-3}	4.7	4.3	9.0

Under the conditions examined, the same decreasing tendency was observed with the stability constants of copper complex. One of the reasons in these phenomena may be explained that the values of the stability constants obtained are the concentration constants and not the one thermodynamically determined, therefore, they would be partially subjected to the influence at various concentrations of ligand, ionic species, complex species and so forth present in the solution.

The Determinations of Hydrolysis Constants

The hydrolysis constants of seven metal complexes of I were calculated after the equation (16) according to the titration data and are given in Table IV as their $pK_{G_2M(OH)}$.

TABLE IV. Hydrolysis Constants of Seven Metal Complexes of D-Glucosamine (I)
I to metal ion 2:1, temp.: 30±0.5° I concn. $1.028 \times 10^{-3} M$, $\mu=0.1$ (KNO_3)

Metal ion	$pK_{G_2M(OH)}$	Metal ion	$pK_{G_2M(OH)}$
Cu^{2+}	7.3	Cd^{2+}	9.1
Pb^{2+}	7.9	Ni^{2+}	9.0
Zn^{2+}	8.1	Mn^{2+}	9.2
Co^{2+}	9.2		

Susceptibility to hydrolysis of the metal complexes is found to be in the following order of $Cu > Pb > Zn > Co \fallingdotseq Cd \fallingdotseq Ni \fallingdotseq Mn$.

Copper complex is found to be the most hydrolysable among these complexes of I.

These hydrolysis constants of metal complexes of I are perceived to be independent from the variety of ligand concentration and they are kept relatively constant within experimental errors under experimental conditions.

Dimerization of Copper Complex

The treatment of Martell's method was applied to the copper complex.

The titration curves of the systems are shown in Fig. 8. As is seen in Fig. 9, a linear relationship is found between $[G\ Cu]/[H^+]$ and $T_{OH}+[H^+]-[OH^-]/[G\ Cu]/[H^+]$ as defined by Martell in the case of 1:1 system cupric complex.

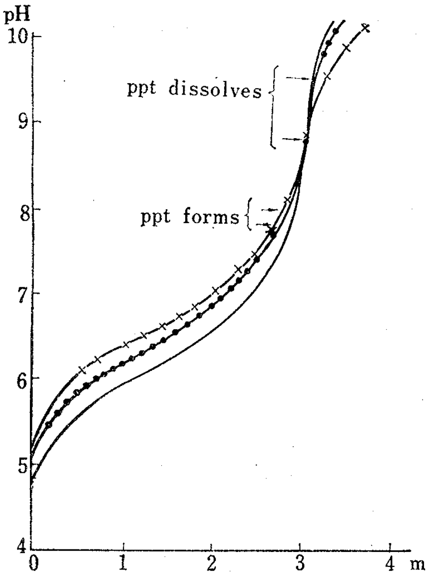


Fig. 8. Titration Curves of 1:1 D-Glucosamine (I)-copper Complex Systems

concentrations :
×——× $5.14\times10^{-4}M$
•——• $1.028\times10^{-3}M$
——— $2.056\times10^{-3}M$
m : moles of base added per mole of 1:1 complex

In the 2:1 system, no definite linear relation is observed, so it may be inferred that dimerization of copper complex would be present only in the 1:1 system.

Four equilibrium constants calculated by this method are shown in Table V, and the hydrolysis constants obtained here are fairly coincided well with those values given in Table IV.

A tendency of dimerization of complexes could not be observed on the other metal complexes.

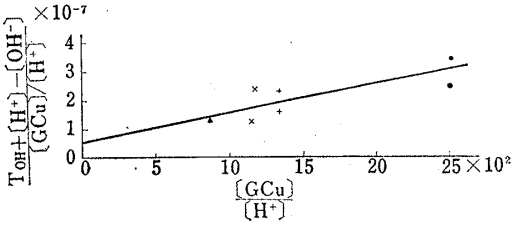


Fig. 9. Relation between $\frac{T_{OH}+[H^+]-[OH^-]}{[GCu]/[H^+]}$ and $\frac{[GCu]}{[H^+]}$ which was found in 1:1 D-Glucosamine (I)-copper Complex Systems

concentrations :
▲ $5.14\times10^{-4}M$ + $2.056\times10^{-3}M$
× $1.028\times10^{-3}M$ ● $4.112\times10^{-3}M$

Table V. Equilibrium Constants of Copper Complexes of D-Glucosamine (I) 30±0.5°, $\mu=0.1$ (KNO_3)

$pK_{GCu(OH)}$	7.3	$\log K_D$	4.2
$pK_{(GCu(OH))_2}$	10.3	$pK_{G_2Cu(OH)}$	7

The Possible Path Way of Complex Formation of Metal Complexes

Considering from the experimental data already described, such metal complex formations are supposed to be complicated for these metal complexes. As to the role

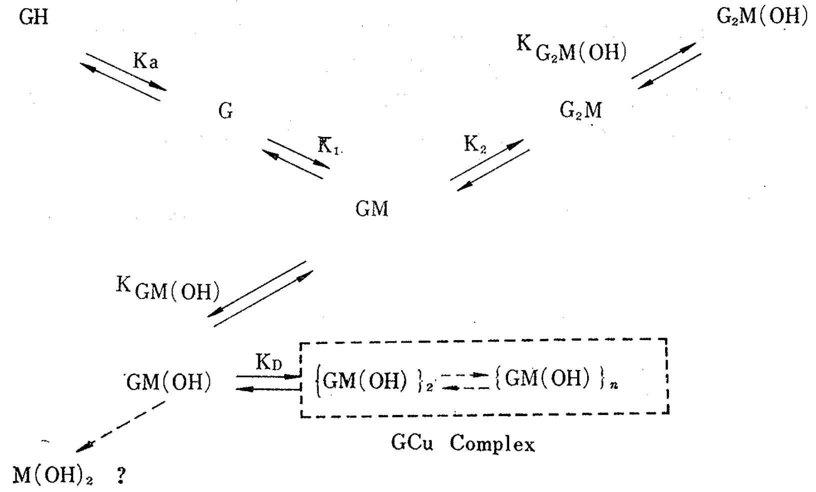


Chart 1.

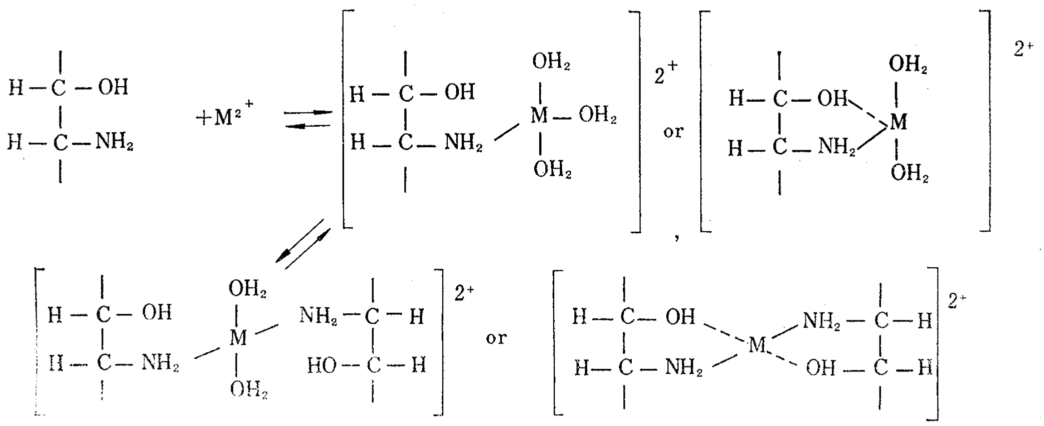


Chart 2.

of OH groups of glucosamine molecules in complex formation, an elucidation of their ability is very difficult at present, however, a contribution of OH groups to the complex formation would be negligibly small comparing with that of amino group of I under the experimental conditions.

Therefore, a tentative assumption on the path way of the formation of metal complexes in solutions as well as the possible structures would be suggested as shown in Chart 1 and Chart 2, respectively.

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Summary

Stability constants and equilibrium constants of seven metal complexes of D-glucosamine (I) with Cu, Pb, Zn, Co, Cd, Ni, and Mn were determined by pH titration method. The possibility of complex formation of I with metal ions were examined and Bjerrum's method for calculations of stability constants was also studied, and was found to be applicable to these metal complexes. Complexes having a 1:1 and 2:1 of I to a metal ion were formed in the solution and their stability constants were calculated. Copper complexes were found to be the most stable compound and had the largest log K_1 and log K_2 values among these metal complexes. From the results of hydrolysis constants calculated of these complexes, the copper complex was found to be most susceptible to hydrolysis. Further study showed that the dimerization of complex occurred only in the case of the copper complex.

Consequently, the formation path way and the possible structures for these metal complexes were proposed based upon the experimental data.

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