Determination of Formation Constant and Study of Thermodynamic parameters of transition metal complexes with Pyrazoline derivatives as ligand

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Abstract

Trisubstituted Pyrazolines were prepared. Metal ligand stability constant of complex compounds of Co(II), Ni(II), Cu(II), Zn (II) & Cd (II) were determined by Calvin – Bjerrum pH metric titration technique modified by Irving & Rossotti at two temperatures ie. 303 K & 308 K in water : dioxane mixture in 1:1 ratio by volume. Ionic strength of the solution was kept constant ($\mu = 0.1$ M) using $NaNO_3$ solution. The values of stepwise stability constant log K_1 & log K_2 were calculated by half integral method and was further verified by mid point calculation method and linear plot method.

The observed stability constant value are in the order Cd(II) < Zn (II) < Co(II) < Ni (II) < Cu (II). This result is in conformity with the Irving – Williams natural order of stability. The values of ΔG^0 and ΔH^0 for all the metal chelates were found to be negative indicating that the chelate formation is a spontaneous process.

Key words: Transition metals, complex compounds pyrazoline derivatives, pH metric titration, Irving – Rossotti, Thermodynamic Parameters, Proton – Ligand stability constant, Metal – ligand stability constant.

Introduction

Pyrazoline derivatives are frequently used as chemotherapeutic agents. Antipyretics, analgesics etc contain pyrazoline nucleus. These chemicals exhibit antibacterial[1-2], antiinflamatory[3], hypoglycemic[4], antitumour[5] immunosuppressive[6] and antidepresent agents[7].

It has been observed that many drugs after complexation with metals exhibit modified toxicological and pharmacological properties.

Complexes have been found to be more effective than their free organic moiety[8-10]. This is why now a days chelation therapy is more important than chemo therapy[11]. Due to diverse biological properties a series of novel complexes of pyrazoline derivatives have been synthesized in recent years. Literature survey reveals that a little is known about its stability in solution although solution of complexes play vital role in biological systems. Therefore this title project has been undertaken for inves-tigation.

Experimental

All the chemicals used in this experiment was of Analar grade supplied by E. Merck. Solutions were prepared in doubly distilled CO_2 free water. The solutions were kept in polythene bottle. Metals were used in the form of nitrate salt. All the metals were estimated by EDTA titration method and Gravimetric method[12-21], using α − nitro so β − naphthol for Co, Dimethyl glyoxime for nickel, α − Benzoinoxime for copper, diammonium hydrogen phosphate for Zn and β − naphtha-quinoline for Cd.

Ligand was synthesized by condensation of chalcones with isonicotinic hydrazine in glacial acetic acid by reported method[22]. Calvin – Bjerrum pH metric titration of acid, acid + ligand and acid + ligand with metal ions Co(II), Ni (II), Cu (II), Zn (II) and Cd(II) were carried out at two temperatures ie 303 K and 308 K. Water dioxane ratio was kept 1:1. Titration were carried out at constant ionic strength of 0.1M $NaNO_3$ in inert atmosphere of nitrogen using standard 0.5 (N) NaOH solution. During the titration the changes in colour and appearance of turbidity at particular pH value were recorded simultaneously.

Result and Discussion

Titration reading of the three titrations at two temperatures are given in table 1.1 graph 1.1 at 303 K and table 1.2 and graph 1.2 at 308 K

The value of n_A^-, $\overline{n}$ and P^L were calculated using standard expressions

$$\overline{n}_A = 1 + \frac{V_1 - V_2}{V_0 + V_1} \times \frac{N_0 + E_0}{T_L}$$

$$\overline{n} = \left(\frac{V_3 - V_2}{V_0 + V_1} \right) \times \frac{N + E}{T_M} \times \frac{1}{\overline{n}_A}$$

$$P^L = \log \frac{\sum P^{B_n H} \dfrac{1}{(anti \ \log B)^n} (V_0 + V_3)}{T_L . T_M . \overline{n} . V_0}$$

The ligand titration curve is above the acid titration curve showing the basic nature of ligand. It is well separated from the acid titration curve at pH 9.5 (Temp 303 K) and pH = 8.9 (Temp. 308 K). The ligand curves run parallel to the acid titration curve indicating the smooth dissociation of the ligand. The value n_A^- at various pH reading [B] was calculated from the acid and ligand titration curves. The formation curve obtained from the plot of n_A^- vs [B] extends from 1.80 to 0.1268. The dissociation of ligand may be represented as

HL $\rightleftharpoons$ H$^+$ + L$^-$
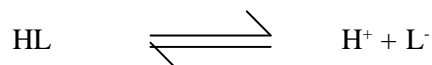
The value of proton ligand stability constant was calculated by half integral method and it was further corroborated by linear plot method. (Log n_A^- /1- n_A^-) vs [B] and log

Table 1.1

The pH titration reading of acid, acid + ligand $(1 - M_1 TDPM)$ and acid + ligand $(1 - M_1 TDPM)$ + Metal ions $N^0 = 0.5$, $E^0 = 0.02$ M, $V^0 = 50.00$ mL,

$T_{cl}^0 = 5 \times 10^{-3}$ M, $T_{CM}^0 = 1 \times 10^{-3}$ M, $\mu^0 = 0.1M$,

T = 303K.

Solvent = Dioxane : Water – 1:1 (v/v)

Vol. of alkali added	Acid	Acid + Ligand	Acid + Ligand + Metal ions				
			Co^{2+}	Ni^{2+}	Cu^{2+}	Zn^{2+}	Cd^{2+}
0.2	1.8	1.8	1.8	1.8	1.8	1.8	1.8
0.4	1.92	1.93	1.94	1.94	1.94	1.94	1.94
0.6	2.15	2.4	2.46	2.34	2.4	2.5	2.6
0.8	2.22	2.64	2.69	2.54	2.55	2.6	2.62
1	2.24	2.69	2.73	2.69	2.7	2.68	2.72
1.2	2.39	3.14	3.15	3.2	3.28	3.3	3.41
1.8	2.58	3.6	3.62	3.65	3.46	3.54	3.8
1.82	2.74	3.82	3.75	3.8	3.88	3.71	4
1.84	2.86	3.95	3.9	3.98	4.12	3.89	4.2
1.86	3.09	4.09	4.12	4.12	4.2	4.1	4.3
1.88	3.14	4.32	4.27	4.26	4.24	4.18	4.38
1.9	3.2	4.61	4.39	4.32	4.43	4.48	4.52
1.92	3.46	4.66	4.56	4.46	4.62	4.63	4.72
1.94	4.55	4.71	4.61	4.64	4.76	4.83	4.9
1.96	8.1	6.05	5.14	4.75	4.91	4.95	5.03
1.98	10.31	6.55	5.36	5.12	5.14	5022	5.26
2	11.08	9.35	5.75	5.28	5.72	6.59	6.7
2.25	11.58	9.95	6.28	6.1	6.49	7.4	7.61
2.4	11.79	10.45	7.62	6.68	7.6	8.28	7.95
2.65	12.15	10.81	8.68	8.4	7.72	9.95	8.15
2.8	12.22	11.08	8.89	9.02	7.86	9.85	8.55
2.9	12.32	11.23	9.06	9.46	7.95	9.98	8.65
3	12.41	11.43	9.25	9.66	8	10.08	8.8

$(2 - \bar{n}_A / \bar{n}_A - 1)$ vs [B]. The value of $pK_1^H = 10.66$ and $pK_2^H = 3.11$ were recorded. The complex titration curve crossed the ligand titration curve at pH = 6.0 for Co(II) & Cu(II), pH = 5.2 for Ni (II), pH= 6.6 for Zn(II) and 6.3 for Cd(II) indicating the start of complex formation.

In the case of Co(II) metal titration curves didn't join up and run parallel to the ligand titration curve indicating liberation of

Table 1.2

The pH titration reading of acid, acid + ligand (1 – M$_l$TDPM) and acid + ligand (1 – M$_l$TDPM) + Metal ions N^0 = 0.5, E^0 = 0.02 M, V^0 = 50.00 mL,

T$_{cl}^0$ = 5 x 10^{-3} M, T$_{CM}^0$ = 1 x 10^{-3} M, $\mu^0 = 0.1M$,

T = 303±1K.

Solvent = Dioxane : Water – 1:1 (v/v)

Vol. of alkali added	Acid	Acid + Ligand	Acid + Ligand + Metal ions				
			Co^{2+}	Ni^{2+}	Cu^{2+}	Zn^{2+}	Cd^{2+}
0.2	1.8	1.8	1.8	1.8	1.8	1.8	1.8
0.4	1.92	1.93	1.94	1.94	1.94	1.94	1.94
0.6	2.15	2.4	2.46	2.34	2.4	2.5	2.6
0.8	2.22	2.64	2.69	2.54	2.55	2.6	2.62
1	2.24	2.69	2.73	2.69	2.7	2.68	2.72
1.2	2.39	3.14	3.15	3.2	3.28	3.3	3.41
1.8	2.58	3.6	3.62	3.65	3.46	3.54	3.8
1.82	2.74	3.82	3.75	3.8	3.88	3.71	4
1.84	2.86	3.95	3.9	3.98	4.12	3.89	4.2
1.86	3.09	4.09	4.12	4.12	4.2	4.1	4.3
1.88	3.14	4.32	4.27	4.26	4.24	4.18	4.38
1.9	3.2	4.61	4.39	4.32	4.43	4.48	4.52
1.92	3.46	4.66	4.56	4.46	4.62	4.63	4.72
1.94	4.55	4.71	4.61	4.64	4.76	4.83	4.9
1.96	8.1	6.05	5.14	4.75	4.91	4.95	5.03
1.98	10.31	6.55	5.36	5.12	5.14	5022	5.26
2	11.08	9.35	5.75	5.28	5.72	6.59	6.7
2.25	11.58	9.95	6.28	6.1	6.49	7.4	7.61
2.4	11.79	10.45	7.62	6.68	7.6	8.28	7.95
2.65	12.15	10.81	8.68	8.4	7.72	9.55	8.15
2.8	12.22	11.08	8.89	9.02	7.86	9.85	8.55
2.9	12.32	11.23	9.06	9.46	7.95	9.98	8.65
3	12.41	11.43	9.25	9.66	8	10.08	8.8

extra proton due to hydrolysis of metal ions. Precipitation was observed proton due to hydrolysis of metal ions. Precipitation was observed at pH 6.0. Hence in order to preclude error due to hydrolysis in the calculation of $\overline{n}$ only the lower pH region of titration curves were used.

In case of all other meals i.e. Ni(II), Cu(II), Zn(II) & Cd (II). The curve increases regularly up to pH = 5.2, indicating constant rate of release of proton and then complex

titration curve diverse indicating quick but incomplete dissociation of ligand. No turbidity appears, it means hydrolysis does not take place.

The value of $\overline{n}$ extended between 0.0951 – 1.88 for Co(II), 0.780 – 1.89 for Ni(II), 0.0902 – 1.892 for Zn(II), 0.0901 – 1.89 for Cu(II) and 0.0945 – 1.824 for Cd(II) at 303 K. At 308 K the value of $\overline{n}$ extended from 0.0952 – 1.7095 for Co(II), 0.0786 – 1.8653 for NI(II) , 0.0902 – 1.7089 for Cu(II) 0.0902 to 1.8072 for Zn (II) & 0.945 – 1.7098 for Cd(II). All these values indicate formation of ML_1 and ML_2 type of complexes. From the

formation curve of $\overline{n}$ vs PL the values of log K_1 and log K_2 of complex were calculated by half integral method which was further verified by mid point calculation method and straight line plot method. The values are given in table 1.3 and 1.4.

The values of protonation constant and stepwise stability constant obtained from different computational methods at temperature 303 K and 308 K are summarized in table 1.3 the different computational methods are (a) Half integral method (b) Mid point slope calculation method and (c) straight line plot method.

Table 1.3

Values of protonation constant of lingand and step wise stability constant of complexes of Co(II), Ni(II), Cu(II), Zn(II) & Cd (II) with ligand M_1TDPM at temperatures 303 K and 308 K.

SYSTEM		Temperature - 303 ± 1 K		Temperature - 308 ± 1 K	
		log K_1	log K_2	log K_1	log K_2
M_1TDPM	a	10.6615	3.114	10.662	3.1144
	b	10.6614	3.1139	10.6616	3.1142
	c	10.6616	3.1141	10.6609	3.1134
Co(II) M_1TDPM	a	6.24	5.36	6.27	5.48
	b	6.38	5.46	6.26	5.64
	c	6.36	5.38	6.37	5.63
Ni(II) M_1TDPM	a	7.23	6.05	7.05	5.89
	b	7.25	6.22	7.16	6.17
	c	6.37	5.43	6.42	5.28
Cu(II) M_1TDPM	a	7.18	6.24	7.19	5.43
	b	7.36	6.36	7.21	5.51
	c	7.29	6.18	7.16	5.49
Zn(II) M_1TDPM	a	6.17	5.3	6.17	6.07
	b	6.32	5.46	6.24	6.05
	c	6.36	5.38	5.93	5.08
Cd(II) M_1TDPM	a	6.35	5.38	6.14	5.27
	b	6.18	5.3	6.04	5.29
	c	6.33	5.42	6.16	5.44

The most representative values of log K_1, log K_2 and log β are given in table 1.4.

Table 1.4

Log of step wise and overall stability constants of complex compounds of various metals at 303K and 308K temperatures respectively.

Ligand M₁TDPM

$\mu^0 = 0.1 M$

System	Temperature - 303 ± 1 K			Temperature - 308 ± 1 K		
	log K1	log K2	log β	log K1	log K2	log β
M1TDPM	10.66	3.114	13.7755	10.6615	3.114	13.7755
Co(II) M₁TDPM	6.33	5.38	11.71	6.3	5.58	11.88
Ni(II) M₁TDPM	6.95	5.9	12.85	6.87666667	5.78	12.656666
Cu(II) M₁TDPM	7.28	6.26	13.54	7.19	5.48	12.66
Zn(II) M₁TDPM	6.28	5.4	11.68	6.11	5.73	11.85
Cd(II) M₁TDPM	6.29	5.37	11.65	6.11	5.33	11.45

The standard free energy change ΔG^0 were calculated by the Gibb's – Helmholtz equation =-2.303 RT $\log_{10}$K, standard enthalpy change (ΔH^0) were calculated by the integrated Vant – Hoff's equation

$$\log \frac{k_2}{k_1} = \frac{\Delta H}{2.303 R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$ and standard

entropy change (ΔS^0) of the chelation process were calculated using thermodynamic equations[23-25] $\Delta G^0 = \Delta H^0 - T\Delta S$ and recorded in table 1.5.

Table 1.5

	Temperature - 303 ± 1 K			Temperature - 308 ± 1 K				
	ΔG₁ k.cal	Δ G₂ k.cal	Δ S₁ k.cal	Δ G₁ k.cal	Δ G₂ k.cal	Δ S₂ k.cal	Δ H₁ k.cal	Δ H₂ k.cal
Co(II)	-8.75	-7.42	18.5	-8.84	-7.4	13.6	-3.5	-3.28
Ni(II)	-9.68	-8.24	19.4	-9.9	-8.34	13.9	-4.3	-4.23
Cu(II)	-9.75	-8.42	19.5	-10.18	-8.6	15.4	-4.1	-4.3
Zn(II)	-8.5	-7.26	16.18	-8.62	-7.36	13.55	-4.1	-3.26
Cd(II)	-8.43	-7.23	14.1	-8.56	-7.35	13.4	-3.7	-3.28

The stability constants of metal show the sequence Cu(II)> Ni(II) > Co(II) > Zn (II) > Cd (II). This is in accordance with Irving-William natural order of stability. The same order has been observed by several workers[4-13]. The negative values of ΔG^0 with increase in temperature for metal ion chelates show that chelate formation is a spontaneous process. Metal ligand formation curve for all the metal ions show that function $\overline{n}$ has attained its maximum value not beyond 2 which indicate formation of ML_2 type chelates. The value of first stepwise stability constant log K_1 of Cu(II) is relatively higher than that of other metal ions.

It indicates that Cu(II) chelates are relatively more stable. The higher stability of Cu(II) chelates might be due to its square planar configuration commonly observed for Cu(II) chelates[22-37].

The difference between the successive stepwise stability constant is large which suggests that the formation of ML_1 & ML_2 chelates take place independently[3,7-25].

The order of stability constant of the chelates of bivalent transition metal ions of the first series are usually in natural order a theoretical justification of the order of stability constants follows from the consideration of the reciprocal of the ionic radii and second ionization enthalpy of metal concerned. The stepwise enthalpy changes ΔH_1 & ΔH_2 in all the metal ions are equal within the error limit. This is in general agreement with the result reported in the literature[36] and also in agreement with thermo chemical cycle of Yatsimirskii and Grinberg[37].

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