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THE STABILITY AND THERMODYNAMIC FUNCTIONS OF 4-AMINO-1,6-DIHYDRO-1-METHYL-2-METHYLTHIO-5-NITROSO-6-OXO-PYRIMIDINE COMPLEXES WITH Zn(II), Cd(II) AND Hg(II)

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ABSTRACT

The stability constants of the complexes formed by 4-amino-1,6-dihydro-1-methyl-2-methylthio-5-nitroso-6-oxo-pyrimidine with Zn(II), Cd(II) and Hg(II) ions, in aqueous media at different ionic strengths and temperatures, have been calculated by Bjerrum's method.

From the data obtained, the thermodynamic functions of complexation processes are reported.

INTRODUCTION

The study of interactions between metal ions and pyrimidine derivatives has aroused a growing interest due, fundamentally, to the chemotherapeutic effects that some of these complexes have shown [1–4]. For these reasons, and in view of the importance of Zn(II) in most of the biological processes involving enzymatic reactions [5,6] and the involvement of mercury in poisoning resulting in increased excretion of copper and zinc [7], it was thought desirable to study the complexes of zinc(II), cadmium(II) and mercury (II) with some pyrimidine derivatives. In a previous work [8], the influence of the ionic strength of the medium on the stability constants of Zn(II), Cd(II) and Hg(II) complexes with 6-amino-5-nitroso-uracil derivatives was studied. This work reports the study of interactions between zinc group metal ions and 4-amino-1,6-dihydro-1-methyl-2-methylthio-5-nitroso-6-oxo-pyrimidine (LH).

EXPERIMENTAL

All the chemicals used in this work were analytical reagent grade. The solutions were prepared in double-distilled carbon dioxide-free water. A

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solution of LH (4×10^{-4} M) was prepared by direct weighing from a pure sample which was synthesized according to previously reported methods [9]. Solutions of zinc, cadmium and mercury chlorides were prepared and standardised. Suitable volumes of these solutions were diluted to 5×10^{-3} M. A standardised solution of potassium chloride (1 M) was used to maintain the required ionic strength. A solution of carbonate-free potassium hydroxide (0.01 M) was prepared and standardised.

Apparatus

A Radiometer TTT-60 pH-meter, fitted with glass and calomel electrodes, was used for recording pH.

Bjerrum's method [10] was employed in this study. In each case, a solution (initial volume 25 ml) in which $[M^{2+}] = 10^{-4}$ M and $[LH] = 2 \times 10^{-4}$ M was titrated against a standard alkali (0.01 M KOH) after adjusting its ionic strength and temperature in a thermostat bath.

According to the Bjerrum's method [10], the ratio of metal to ligand concentration was kept at 1 : 2 in order to calculate the corresponding K_1 and K_2 values.

RESULTS AND DISCUSSION

The values of $\bar{n}$ and pL were calculated from the pH titration curves following Bjerrum's method [10]. The previously reported [11] values of the ionization constants of LH, were used here. The formation curves between $\bar{n}$ and pL were plotted, and, by interpolation at $\bar{n} = 0.5$ and 1.5, the corresponding log K_1 and log K_2 values were obtained for each metal–ligand complex. These values, at different temperatures and ionic strengths, are given in Table 1.

In this table, it is evident that the stability constant values are similar to those found for Zn(II), Cd(II) and Hg(II) complexes with other analogous 4-amino-5-nitroso-pyrimidine derivatives [8], di-(*o*-, *m*-, *p*-)tolylthiovioluric acids [12–14], and uracil, thymine and cytosine [15–18].

In all cases, the stability constant values decrease with increasing ionic strength of the medium. This is in agreement with the observation recorded by Debye [19], and can be justified by the decreased tendency of the metal ion to interact with the ligand, since the negatively charged atmosphere around the cation is denser in salt solutions, thus screening the interactions of the metal ions with the ligands, and hampering the complexation process. On the other hand, we have observed that the values of log K are unaffected by the temperature of the medium.

In order to obtain the corresponding thermodynamic stability constants, log K_1 and log K_2 have been plotted vs. $\sqrt{I}$ (Fig. 1). This figure shows that,

TABLE 1

Stability constants of 4-amino-1,6-dihydro-1-methyl-2-methylthio-5-nitroso-6-oxo-pyrimidine complexes with Zn(II), Cd(II) and Hg(II) at different temperatures and ionic strengths

Metal ion	I (mol l^{-1})	T (°C)	log K_1	log K_2	log β_2
Zn(II)	0.01	25	6.27	5.85	12.12
	0.02	25	5.85	5.70	11.55
	0.06	25	5.73	5.59	11.32
	0.10	25	5.54	5.50	11.04
	0.10	30	6.20	5.64	11.84
	0.10	40	5.89	5.52	11.41
	0.10	50	5.48	5.40	10.88
	0.20	25	5.40	5.39	10.79
Cd(II)	0.01	25	4.83	4.48	9.31
	0.02	25	4.05	4.43	8.48
	0.06	25	3.85	3.66	7.51
	0.10	25	3.96	3.70	7.66
	0.10	30	3.88	3.67	7.55
	0.10	40	4.01	3.72	7.73
	0.10	50	4.02	3.76	7.78
	0.20	25	3.91	3.65	7.56
Hg(II)	0.01	25	6.63	6.30	12.93
	0.02	25	6.45	6.08	12.53
	0.06	25	5.94	5.55	11.49
	0.10	25	5.76	5.31	11.07
	0.10	30	5.76	5.31	11.07
	0.10	40	5.55	5.18	10.73
	0.10	50	5.38	5.04	10.42
	0.20	25	5.58	4.98	10.56

all cases, these plots define straight lines, from which, by extrapolation to zero ionic strength, the values of the thermodynamic stability constants can be obtained. These data are tabulated in Table 2. In this table, the corre-

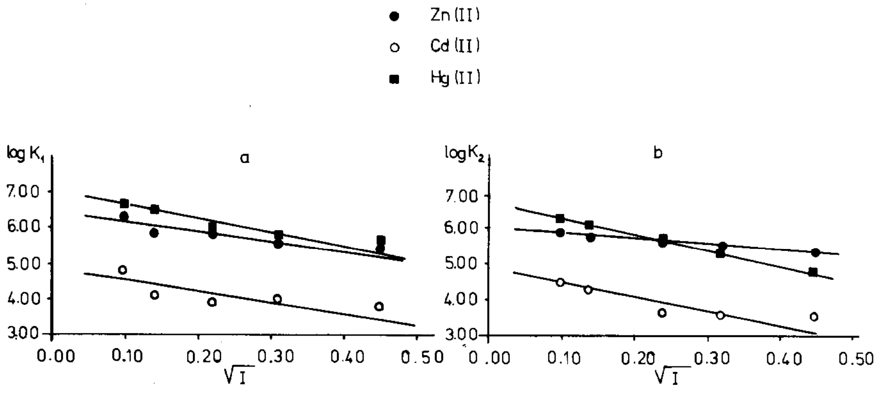

Fig. 1. Plots of (a) log K_1 and (b) log K_2 vs. $\sqrt{I}$ for metal–LH complexes at 25 °C.

TABLE 2

Thermodynamic stability constants and free energy (kJ mol^{-1}) of metal ion–LH complexes at 25 °C

Metal ion	$\log K_1$	$\log K_2$	$\log \beta_2$	$-\Delta G_1$	$-\Delta G_2$	$-\Delta G$
Zn(II)	6.41	5.95	12.36	36.6	33.9	70.5
Cd(II)	4.83	4.90	9.73	27.6	28.0	55.6
Hg(II)	7.01	6.73	13.74	40.0	38.4	78.4

sponding values of free energy (ΔG) for the complexation processes are also included, calculated by the relation

$$\Delta G = -2.303RT \log K$$

The stability constants are in the order Hg(II) > Zn(II) > Cd(II). This may be explained on the basis of the corresponding ionization potential values, since this property increases in the same way. It is, therefore, logical to assume that the metal ion with a higher ionization potential would form more stable complexes due to it higher tendency to accept the ligand's electrons. This is also supported by the empirical Van Panthaleon's relation [20].

Likewise, we have calculated the corresponding enthalpy and entropy changes for each complexation process by plotting $\log K$ vs. $1/T$ (Fig. 2) and using the following relation

$$\log K = -\frac{\Delta H}{2.303RT} + \frac{\Delta S}{2.303R}$$

These values are listed in Table 3. The enthalpy values for Zn(II) and Hg(II) complexation processes are negative, which indicates that these reactions are

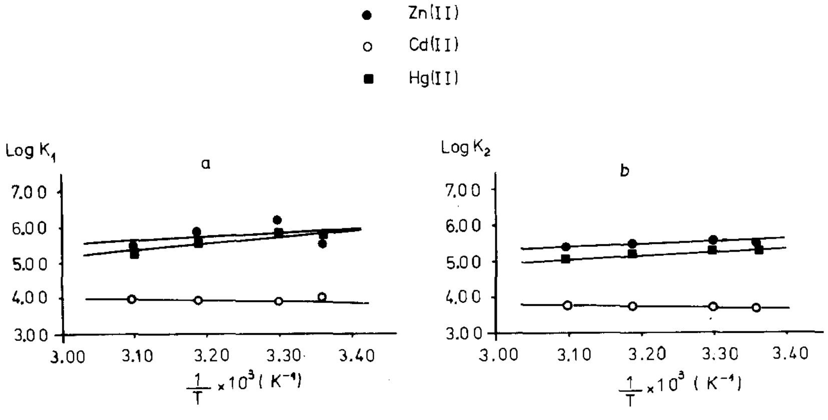

Fig. 2. Plots of (a) $\log K_1$ and (b) $\log K_2$ vs. $1/T$ for metal–LH complexes at 0.1 M ionic strength.

TABLE 3

Enthalpy (kJ mol^{-1}) and entropy changes (J mol^{-1} K^{-1}) of metal–LH complexes at 0.1 M ionic strength

Metal ion	ΔH_1	ΔH_2	ΔH	ΔS_1	ΔS_2	ΔS
Zn(II)	−15.7	−10.3	−26.0	59.7	72.2	131.9
Cd(II)	7.5	5.3	12.8	100.1	88.3	188.4
Hg(II)	−29.7	−20.7	−50.4	11.3	32.7	44.0

exothermic. On the contrary, the corresponding ΔH values for Cd(II) are positive.

The entropy values for all complexes are positive, which may be due to the increased disorder by the desolvation processes of metal ions and ligands, which are much greater than the increase in the order taking place in the complexation reactions.

This suggests that only in the case of Cd(II) is the enthalpy unfavourable for the formation of complexes with LH, while the entropy is favourable. In the case of Hg(II) and Zn(II), both the enthalpy and entropy are favourable for complexation.

This study shows that, at 25 °C, the formation of complexes between LH and zinc group metal ions, in aqueous solution, is a spontaneous process. The stabilities are in the order Hg(II) > Zn(II) > Cd(II), they decrease with the increasing ionic strength of the medium, and are practically unaffected by the temperature.

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