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Note

DETERMINATION OF THERMODYNAMIC PARAMETERS AND STABILITY CONSTANTS OF COMPLEXES OF BIOLOGICALLY ACTIVE *o*-VANILLINTHIOSEMICARBAZONE WITH BIVALENT METAL IONS

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ABSTRACT

Thermodynamic parameters (ΔG, ΔH and ΔS) and stability constants for the formation of complexes of biologically active *o*-vanillinthiosemicarbazone (OVTSC) with Mn(II), Pb(II), Cd(II), Zn(II), Fe(II), Co(II), Ni(II) and Cu(II) have been determined potentiometrically in 50% (v/v) aqueous dioxan at constant ionic strength (0.1 M $NaClO_4$) and at 35 ± 0.1° C. The formation of the complexes has been found to be entropically favoured.

INTRODUCTION

Thiosemicarbazones have wide analytical [1–3] applications and have great chelating power towards traces of metal ions in biological systems. Lambrou [4] has reported that the semi- and thiosemicarbazone derivatives of *o*-vanillin are potential fungistatic and tuberculostatic agents. In the planning and selection of a chelate process for a specific purpose, knowledge of the stability constants is of vital importance. The present study has been undertaken to determine the thermodynamic parameters ΔG, ΔH and ΔS, and the stability constants of complexes of bivalent metal ions with biologically active *o*-vanillinthiosemicarbazone.

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EXPERIMENTAL

Instrumental

A digital pH meter (model PHM83) Radiometer Copenhagen with a single glass–calomel electrode assembly was used for the pH measurements.

Chemicals and reagents

o-Vanillinthiosemicarbazone (OVTSC) was prepared by condensing equimolar quantities of thiosemicarbazide and *o*-vanillin in the presence of a few drops of glacial acetic acid. The purity of the OVTSC was checked by IR and ^{1}H NMR spectroscopy, elemental analysis and thin layer chromatography; its melting point is 207–209 °C. All metal ion solutions were prepared from their corresponding sulphates or nitrates (A.R., B.D.H.) in double distilled water and were standardized using conventional methods. $NaClO_4$ (Fluka) was used to maintain the constant ionic strength. Tetramethyl ammonium hydroxide (TMAH) (Merck) (0.04 M) in 50% aqueous dioxan was used as titrant. The ligand solution was prepared in 100% dioxan which was purified according to the procedure described by Weissberger et al. [5]. The titrations were carried out in a nitrogenous atmosphere (N_2 purity $\simeq$ 99.9%) which was saturated with 50% (v/v) aqueous dioxan before passing through the reaction mixture.

Potentiometric titrations

The method of Bjerrum and Calvin, as modified by Irving and Rossotti [6,7] was used to determine $\bar{n}$ and pL values. The experimental procedure involves the potentiometric titrations of the following solutions against 0.04 M TMAH in 50% (v/v) dioxan–water. (1) $HClO_4$ (2.0×10^{-3} M); (2) $HClO_4$ (2.0×10^{-3} M) + OVTSC (5.0×10^{-3} M); and (3) $HClO_4$ (2.0×10^{-3} M) + OVTSC (5.0×10^{-3} M) + M^{2+} (2.5×10^{-4} M).

In order to evaluate the thermodynamic parameters such as ΔG, ΔH and ΔS, the titrations were repeated at various temperatures (15, 25, 35 and 45 $\pm$ 0.1 °C) at constant ionic strength (0.1 M $NaClO_4$). The experimental temperature was kept constant to within $\pm$0.1 °C by using a Julabo F20 (West Germany) thermostat which also has a low temperature facility. The pH values in aqueous organic mixtures were corrected using the method of Van Uitert and Hass [8], and volume correction was also applied according to the method of Rao and Mathur [9].

The parameters, $\bar{n}_H$, the average number of protons bound per free ligand ion, $\bar{n}$, the average number of ligand molecules bound per metal ion, and pL, the free ligand exponent, were evaluated by the expressions described by Irving and Rossotti [6,7]. Using these parameters, the pK_a values of the ligand and the stability constants of its complexes were calculated. The stability constants were computed on a Hewlett–Packard 9050 FORTRAN 77 computer using a weighted least-squares program based on that of Sullivan et al. [10]. The weighted least-squares treatment determines that set of β_n values which make the function

$$U\left\{U = \sum_{n=0}^{N} (y - x - nz)\beta_n x^n\right\}$$

nearest to zero, by minimizing

$$S\left\{S = \sum_{i=1}^{I} U^2(x_i y_i z_i)\right\}$$

with respect to variation in β_n.

$S_{\min}$ has the same statistical distribution as χ^2 with K degrees of freedom and with weights defined by Rydberg and Sullivan [11]. $S_{\min}$ can be equated with χ^2.

RESULTS AND DISCUSSIONS

The order of stability constants of the metal complexes of biologically active OVTSC was found to be Mn(II) < Pb(II) < Cd(II) < Zn(II) < Fe(II) < Co(II) < Ni(II) < Cu(II). This order is in good agreement with the order observed by Mellor and Maley [12] and by Irving and Williams [13,14].

In all cases, except Mn(II) and Cd(II), log K_1 and log K_2 values were obtained and reported. In the case of Mn(II) and Cd(II) the 1 : 1 complexes initially formed were extensively hydrolysed later on. In all cases, it was observed that log $K_1 >$ log K_2. The values of the stability constants listed in Table 1 reveal that the stability constants decrease with increasing temperature as do the pK_a values of OVTSC.

The thermodynamic parameters (ΔG, ΔH, and ΔS) were calculated using the following relationships

$$\Delta G = -RT \ln K$$

$$\mathrm{d} \log K/\mathrm{d}(1/T) = \Delta H/2.303R$$

$$\Delta S = (\Delta H - \Delta G)/T$$

The overall free energy change, and the enthalpy and entropy changes at 35 ± 0.1°C are reported in Table 1. These results indicate that ΔG and ΔH are negative which shows that the complex formation reactions are favourable at ordinary temperatures. ΔS in all cases was found to be positive which indicates that complex formation is entropically favoured.

TABLE 1

Stability constants of complexes of bivalent metals with OVTSC at $\mu = 0.1$ M $NaClO_4$ at different temperatures and their thermodynamic parameters at $\mu = 0.1$ M $NaClO_4$ and $35 \pm 0.1°$ C

System	Stability constant	Temperature (°C)				$-\Delta G$ (kcal mol^{-1})	$-\Delta H$ (kcal mol^{-1})	ΔS (kcal K^{-1} mol^{-1})
		15	25	35	45			
OVTSC	$\log K_1^H$	10.21	10.04	9.89	9.69	–	–	–
Mn–OVTSC	$\log K_1$	5.36	5.28	5.06	4.12	7.12	6.50	0.00201
	$\log K_2$	–	–	–	–	–	–	–
	S_{min}	0.01452	0.01676	0.00146	0.01556	–	–	–
Pb–OVTSC	$\log K_1$	7.10	6.83	6.72	6.53	9.46	8.45	0.00327
	$\log K_2$	6.13	6.34	6.03	5.90	–	–	–
	S_{min}	0.00872	0.00669	0.00180	0.00487	–	–	–
Cd–OVTSC	$\log K_1$	7.34	7.07	6.99	6.79	9.84	7.80	0.00662
	$\log K_2$	–	–	–	–	–	–	–
	S_{min}	0.01464	0.00541	0.02558	0.00298	–	–	–
Zn–OVTSC	$\log K_1$	7.47	7.42	7.28	7.11	10.25	6.77	0.01146
	$\log K_2$	6.50	6.62	6.28	6.16	–	–	–
	S_{min}	0.00669	0.00648	0.00462	0.00249	–	–	–
Fe–OVTSC	$\log K_1$	8.15	7.99	7.84	7.69	11.04	6.07	0.01613
	$\log K_2$	5.68	6.97	6.37	6.12	–	–	–
	S_{min}	0.01260	0.00258	0.00423	0.00737	–	–	–
Co–OVTSC	$\log K_1$	8.47	8.02	7.94	7.86	11.18	6.93	0.01379
	$\log K_2$	6.54	7.57	6.78	6.39	–	–	–
	S_{min}	0.02980	0.01338	0.01070	0.01092	–	–	–
Ni–OVTSC	$\log K_1$	8.65	8.48	8.37	8.11	11.79	8.02	0.01224
	$\log K_2$	7.50	7.62	7.59	7.59	–	–	–
	S_{min}	0.00035	0.00987	0.00455	0.00972	–	–	–
Cu–OVTSC	$\log K_1$	9.83	9.44	9.36	9.03	13.18	10.84	0.00759
	$\log K_2$	8.22	8.13	8.01	8.02	–	–	–
	S_{min}	0.00336	0.00241	0.01129	0.03303	–	–	–

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