Complexation of a Catecholamine with Zinc (II) in Media with Different Dielectric Constants

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Abstract:

The complexation of zinc (II) with dopamine has been investigated by spectrophotometric measurements in mixed solvent system at an ionic strength of 0.2 mol*dm⁻³ sodium chloride, employed (25± 0.1 °C) at pH ranges of ~6 to ~7 with a high ratio of ligand to metal.

Keywords: Zinc (II), Catecholamine, Complexation, Mixed solvent.

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1. INTRODUCTION

Dopamine can be supplied as a medication that acts on the sympathetic nervous system, producing effects such as increased heart rate and blood pressure [1-3]. However, since dopamine cannot cross the blood-brain barrier, dopamine given as a drug does not directly affect the central nervous system. To increase the amount of dopamine in the brains of patients with diseases such as Parkinson's disease [4-6] and Dopa-Responsive Dystonia, L-DOPA (levodopa), which is the precursor of dopamine, can be given because it can cross the blood-brain barrier. As a member of the catecholamine [7] family, dopamine is a precursor to epinephrine (adrenaline) and then norepinephrine in the biosynthetic pathways for these neurotransmitters. Neurotransmitters are frequently organic bases, which form adducts with systems of electron acceptors as metal ions, proteins and components of protein by direct or indirect interactions. For example operation of neurotransmitters are distorted if they react with heavy metals such as Pb, Hg or lanthanides that frequently act as hard acids. The coordination chemistry of these compounds is complicated by their ability to act as ambidentate or bridging ligands [8,9]

An important finding is the demonstration that alcohol can affect the function of specific neurotransmitter [10]. Specifically, alcohol can act as a depressant by increasing inhibitory neurotransmission, by decreasing excitatory neurotransmission or through a combination of both. Alcohol has been shown to activate dopamine systems in certain areas of the brain. Through an interaction with glutamate receptors [11]. Interestingly endogenous opiate systems could cause the decrease in the acting of dopamine systems that occurs during alcohol with drawal. In this paper we evaluate the stability constants and thermodynamic parameters for Zn\(^{2+}\) binding to dopamine in cosolvent systems of ethanol and water using a combination of potentiometric and spectrophotometric methods [12-14].

2. EXPERIMENTAL

Reagent: Dopamine, Zinc nitrats, ethanol, sodium dihydrogen phosphate, disodium hydrogen phosphate and sodium chloride were supplied from Merck Chemical Company.
Table 1. Average values of log $K_{Zn(HL)^2}$ and log $K^{H}_{Zn(HL)^2}$ and protonation dopamine with standard deviations (0.01), in ($x$) water + (1-$x$) ethanol at different temperatures and $I=0.2$ mol*dm$^{-3}$

<table>
<thead>
<tr>
<th>$x$ (molar fraction)</th>
<th>log $K_{Zn(HL)^2}$</th>
<th>log $K^{H}_{Zn(HL)^2}$</th>
<th>log $k_{1a}$</th>
<th>log $k_{3a}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>52.14</td>
<td>8.96</td>
<td>8.89</td>
<td>13.10</td>
</tr>
<tr>
<td>0.979</td>
<td>52.65</td>
<td>9.37</td>
<td>8.94</td>
<td>13.10</td>
</tr>
<tr>
<td>0.955</td>
<td>52.89</td>
<td>9.49</td>
<td>8.99</td>
<td>13.11</td>
</tr>
<tr>
<td>0.930</td>
<td>53.57</td>
<td>10.07</td>
<td>9.03</td>
<td>13.12</td>
</tr>
</tbody>
</table>

Measurements: All measurements were carried out at $25 \pm 0.1$ °C and at an ionic strength of 0.2 mol*dm$^{-3}$ which was controlled with sodium chloride. The ligand concentrations were 1.2 m mol*dm$^{-3}$ and Zn$^{2+}$ concentrations were 0.4, 0.6, 1.2 m mol*dm$^{-3}$ with ligand to Zn$^{2+}$ molar ratios of 3, 2 and 1. The pHs of the solutions were controlled with phosphate buffers.

A Horiba D-14 pH meter was employed for pH measurements. The hydrogen ion concentrations were measured using an Ingold UO3234 glass electrode and an Ingold UO3236 calomel electrode. It is essential that the system be calibrated routinely for various solvent mixtures of known hydrogen-ion concentration [15-19].

Spectrophotometric measurements were conducted using an UV-VIS Shimadzu 2101 spectrophotometer equipped with a Acermate 486 SX/25D computer and thermostatically matched 10-mm quartz cells.

3. RESULTS AND DISCUSSION

Protonation equilibria of the ligand. The protonation constants for a 1mmol*dm$^{-3}$ concentration ligand in water and in mixed solvent systems of ethanol and water were obtained from potentiometric titrations with NaOH 0.1 mol*dm$^{-3}$ and employing a
computer-programmed nonlinear least-squares method. Values of the constants obtained are listed in Table 1 and agree with those obtained from the literature (pK\textsubscript{a1} = 8.89 , pK\textsubscript{a2} = 10.41 , pK\textsubscript{a3} = 13.1 in 25 °C) [20-22]. We assume that deprotonation occurs in the following order with increasing pH: the paraphenolic group, the ammonium group and then the second OH group for dopamine.

The following equilibria are considered:

\[
\begin{align*}
\text{H}^+ + \text{L}^- & \rightleftharpoons \text{HL}^- & (1) \\
\text{H}^+ + \text{HL}^- & \rightleftharpoons \text{H}_2\text{L} & (2) \\
\text{H}^+ + \text{H}_2\text{L} & \rightleftharpoons \text{H}_3\text{L}^+ & (3)
\end{align*}
\]

The protonation constants are \( K_1a, K_2a, K_3a \).

**Complexation Zn(II) with dopamine.** Complexation equilibria of a Zn(II) ion with dopamine have been studied by employing a technique based on the relationship of absorbance as a function of pH, \( A = f(pH) \). Absorbance measurements were made for solutions containing Zn (II) and dopamine with different molar ratios in pH of ~6 and ~7 in different solvent systems.

Considering that absorbance is a function of pH, the values of the molar absorptivities of Zn (II), \( \varepsilon_0 \), (and for dopamine, \( \varepsilon_1 \)) at different wavelengths and various dielectric constants are obtained. In order to determine \( \varepsilon_1 \) and \( \varepsilon_0 \), solutions was prepared by the similar method and conditions, but in the absence of metal and ligand ions as described, respectively.

In order to determine \( \varepsilon_2 \), the formation constant of complex can be expressed as follows:

\[
\text{Zn(HL)}^+ + 2\text{H}^+ \rightleftharpoons \text{Zn}^{2+} + \text{H}_3\text{L}^+ 
\]

\[
K^H_{\text{Zn(HL)}^+} = \frac{[\text{Zn(HL)}^+][\text{H}^+]^2}{[\text{Zn}^{2+}][\text{H}_3\text{L}^+]} 
\]
The absorbance at a wavelength is given by:

$$A = \varepsilon_0 \left[ Zn^{2+} \right] + \varepsilon_1 \left[ H_3L^+ \right] + \varepsilon_2 \left[ Zn(HL)^+ \right]$$  \hspace{1cm} (6)

Where $\varepsilon_0$, $\varepsilon_1$, $\varepsilon_2$ are the molar absorptivities of the Zn (II) ion and dopamine and complex, respectively.

Thus, considering material balance, the equilibrium constant for the formation reaction of complex can be expressed as follows:

$$A + \varepsilon_1 C_{Zn^{2+}} + \varepsilon_0 \left( C_{H_3L^+} / C_{Zn^{2+}} \right) = \varepsilon_2 + \frac{(\varepsilon_0 + \varepsilon_1 - \varepsilon_2)\left( -A + \varepsilon_1 C_{H_3L^+} + \varepsilon_0 C_{Zn^{2+}} \right)[H^+]^n}{C_{Zn^{2+}} \left( A - \varepsilon_0 C_{Zn^{2+}} - \varepsilon_2 C_{H_3L^+} + \varepsilon_0 C_{H_3L^+} \right) K_{Zn(HL)^+}^H}$$ \hspace{1cm} (7)

The values of $K_{Zn(HL)^+}^H$ were determined from the intercept of the straight line plots of $A + \varepsilon_1 C_{Zn^{2+}} + \varepsilon_0 \left( C_{H_3L^+} / C_{Zn^{2+}} \right)$ (Y) against $(-A + \varepsilon_1 C_{H_3L^+} + \varepsilon_0 C_{Zn^{2+}})[H^+]^n / C_{Zn^{2+}}$ (X). The intercept of linear fit yields $\varepsilon_2$.

In the equilibrium reaction of complex formation is:

$$Zn(HL)_2 + 2H^+ \rightleftharpoons Zn(HL)^+ + H_3L^+$$ \hspace{1cm} (8)

The formation constant of the complex can be expressed as follows:

$$K_{Zn(HL)_2}^H = \left[ Zn(HL)_2 \right][H^+]^2 / \left[ Zn(HL)^+ \right][H_3L^+]$$ \hspace{1cm} (9)

The absorbance at a wavelength is given by:
\[ A = \varepsilon_0 [Zn^{2+}] + \varepsilon_1 [H_3L^+] + \varepsilon_2 [Zn(HL)^+] + \varepsilon_3 [Zn(HL)_2] \]  
(10)

\[ Zn^{2+} \approx 0 \]  
(11)

\[ A = \varepsilon_1 [H_3L^+] + \varepsilon_2 [Zn(HL)^+] + \varepsilon_3 [Zn(HL)_2] \]  
(12)

Where \( \varepsilon_0 \), \( \varepsilon_1 \), \( \varepsilon_2 \) and \( \varepsilon_3 \) are the molar absorptivities of the Zn(II) ion, dopamine and their complexes.

For the molar balance of zinc and dopamine:

\[ [Zn^{2+}] = [Zn(HL)^+] + [Zn(HL)_2] \]  
(13)

\[ [H_3L^+] = C_{H_3L^+} + [Zn(HL)^+] + 2 [Zn(HL)_2] \]  
(14)

Where \( C_{Zn^{2+}} \) and \( C_{H_3L^+} \) are the total concentrations of \( Zn^{2+} \) and dopamine. Thus, the equilibrium constant for formation the complex can be expressed as follows:

\[
\left(-A + \varepsilon_1 C_{H_3L^+} - 2 \varepsilon_1 C_{Zn^{2+}}\right)/C_{Zn^{2+}} \\
= -\varepsilon_3 + \frac{\left(\varepsilon_3 - \varepsilon_2 - \varepsilon_1\right) \left[A - \varepsilon_1 C_{H_3L^+} + \varepsilon_1 C_{Zn^{2+}} - \varepsilon_2 C_{Zn^{2+}}\right] [H^+]^2}{K_{Zn(HL)_2} \left(\varepsilon_3 C_{H_3L^+} - \varepsilon_2 C_{H_3L^+} + A - \varepsilon_3 C_{Zn^{2+}} + 2 \varepsilon_2 C_{Zn^{2+}}\right) C_{Zn^{2+}}} 
\]

(15)

Considering that \( A \) is a function of pH, the values of molar absorptivities, are obtained. The values of \( K_{Zn(HL)_2} \) were determined from the intercept of the straight line plots of \(-A + \varepsilon_1 C_{H_3L^+} - 2 \varepsilon_1 C_{Zn^{2+}}\) (Y) against \( A - \varepsilon_1 C_{H_3L^+} + \varepsilon_1 C_{Zn^{2+}} - \varepsilon_2 C_{Zn^{2+}} [H^+]^2 / C_{Zn^{2+}}\) (X) and are shown in Table 1. The intercept of the lines yields \( \varepsilon_3 \).

4. REFERENCES


