SUPPORTING INFORMATION

Title: A Study of the Equilibrium and Kinetics of Urea Binding by a Biomimetic Dinickel(I) Complex
Author(s): Sergey V. Kryatov, Elena V. Rybak-Akimova,* Franc Meyer,* Hans Pritzkow
Ref. No.: I02584
Figure S1. Spectrophotometric titration of complex 1 (1.8 mM solution) with water in anhydrous acetonitrile.
Figure S2. Spectrophotometric titration of the 1.8 mM solution of complex 4 with urea in anhydrous methanol: (a) UV-Vis spectra; (b) differential UV-Vis spectra.
Figure S3. UV/vis spectra of the [LNi$_2$(OR)(ROH)]$^{2+}$ complexes (R = H, Me) in methanol (obtained from the spectrophotometric titration of complex 4 with water).
Figure S4. Pseudo-first order rate constants of the reaction between complex 1 and urea vs water concentration in the series with constant urea concentration. Lines represent the fits with kinetic equation (6).
Figure S5. Auxiliary plots used to establish empiric kinetic equation S1:

i) linear fits of $k_{\text{obs}}^{-1}$ vs $[\text{H}_2\text{O}]$;

ii) slopes of the linear fits vs $[\text{urea}]^{-2}$;

iii) intercepts of the linear fits vs $[\text{urea}]^{-1}$. 
Table S1. Pseudo-first order rate constants of the reaction between 1 and urea in acetone at 25°C under different concentrations of urea and water; the values of $k_{\text{fit}}$, steady-state yield of intermediate 1a, and shares of the mono- and bis-urea pathways were calculated from Equation (6); the final equilibrium yield of complex 2 was calculated from Equation (1).

<table>
<thead>
<tr>
<th>[H$_2$O], M</th>
<th>[urea], M</th>
<th>$k_{\text{obs}}$, s$^{-1}$</th>
<th>$k_{\text{fit}}$, s$^{-1}$</th>
<th>Share of mono-urea pathway</th>
<th>Share of bis-urea pathway</th>
<th>Steady-state yield of 1a</th>
<th>Final yield of 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.010</td>
<td>0.0080</td>
<td>1.02</td>
<td>1.04</td>
<td>0.07</td>
<td>0.93</td>
<td>0.19</td>
<td>0.997</td>
</tr>
<tr>
<td>0.010</td>
<td>0.0100</td>
<td>1.55</td>
<td>1.53</td>
<td>0.06</td>
<td>0.94</td>
<td>0.22</td>
<td>0.998</td>
</tr>
<tr>
<td>0.010</td>
<td>0.01375</td>
<td>2.6</td>
<td>2.63</td>
<td>0.04</td>
<td>0.96</td>
<td>0.28</td>
<td>0.998</td>
</tr>
<tr>
<td>0.010</td>
<td>0.0200</td>
<td>4.8</td>
<td>4.86</td>
<td>0.03</td>
<td>0.97</td>
<td>0.36</td>
<td>0.999</td>
</tr>
<tr>
<td>0.010</td>
<td>0.0275</td>
<td>7.8</td>
<td>8.02</td>
<td>0.02</td>
<td>0.98</td>
<td>0.44</td>
<td>0.999</td>
</tr>
<tr>
<td>0.015</td>
<td>0.0275</td>
<td>6.5</td>
<td>6.26</td>
<td>0.02</td>
<td>0.98</td>
<td>0.34</td>
<td>0.998</td>
</tr>
<tr>
<td>0.020</td>
<td>0.0080</td>
<td>0.58</td>
<td>0.57</td>
<td>0.07</td>
<td>0.93</td>
<td>0.10</td>
<td>0.988</td>
</tr>
<tr>
<td>0.020</td>
<td>0.0100</td>
<td>0.84</td>
<td>0.86</td>
<td>0.06</td>
<td>0.94</td>
<td>0.13</td>
<td>0.991</td>
</tr>
<tr>
<td>0.020</td>
<td>0.01375</td>
<td>1.5</td>
<td>1.53</td>
<td>0.04</td>
<td>0.96</td>
<td>0.16</td>
<td>0.993</td>
</tr>
<tr>
<td>0.020</td>
<td>0.0200</td>
<td>3.2</td>
<td>2.97</td>
<td>0.03</td>
<td>0.97</td>
<td>0.22</td>
<td>0.995</td>
</tr>
<tr>
<td>0.020</td>
<td>0.0275</td>
<td>5.2</td>
<td>5.14</td>
<td>0.02</td>
<td>0.98</td>
<td>0.28</td>
<td>0.997</td>
</tr>
<tr>
<td>0.030</td>
<td>0.0200</td>
<td>2.1</td>
<td>2.14</td>
<td>0.03</td>
<td>0.97</td>
<td>0.16</td>
<td>0.990</td>
</tr>
<tr>
<td>0.030</td>
<td>0.0275</td>
<td>3.8</td>
<td>3.78</td>
<td>0.02</td>
<td>0.98</td>
<td>0.21</td>
<td>0.992</td>
</tr>
<tr>
<td>0.040</td>
<td>0.0080</td>
<td>0.32</td>
<td>0.30</td>
<td>0.07</td>
<td>0.93</td>
<td>0.05</td>
<td>0.953</td>
</tr>
<tr>
<td>0.040</td>
<td>0.0100</td>
<td>0.44</td>
<td>0.46</td>
<td>0.06</td>
<td>0.94</td>
<td>0.07</td>
<td>0.964</td>
</tr>
<tr>
<td>0.040</td>
<td>0.01375</td>
<td>0.81</td>
<td>0.83</td>
<td>0.04</td>
<td>0.96</td>
<td>0.09</td>
<td>0.973</td>
</tr>
<tr>
<td>0.040</td>
<td>0.0200</td>
<td>1.74</td>
<td>1.67</td>
<td>0.03</td>
<td>0.97</td>
<td>0.13</td>
<td>0.982</td>
</tr>
<tr>
<td>0.040</td>
<td>0.0275</td>
<td>2.85</td>
<td>2.99</td>
<td>0.02</td>
<td>0.98</td>
<td>0.16</td>
<td>0.987</td>
</tr>
<tr>
<td>0.060</td>
<td>0.0200</td>
<td>1.2</td>
<td>1.16</td>
<td>0.03</td>
<td>0.97</td>
<td>0.09</td>
<td>0.960</td>
</tr>
<tr>
<td>0.060</td>
<td>0.0275</td>
<td>2.2</td>
<td>2.11</td>
<td>0.02</td>
<td>0.98</td>
<td>0.12</td>
<td>0.970</td>
</tr>
<tr>
<td>0.085</td>
<td>0.0200</td>
<td>0.89</td>
<td>0.84</td>
<td>0.03</td>
<td>0.97</td>
<td>0.06</td>
<td>0.931</td>
</tr>
<tr>
<td>0.085</td>
<td>0.0275</td>
<td>1.55</td>
<td>1.54</td>
<td>0.02</td>
<td>0.98</td>
<td>0.08</td>
<td>0.949</td>
</tr>
<tr>
<td>0.100</td>
<td>0.0275</td>
<td>1.41</td>
<td>1.33</td>
<td>0.02</td>
<td>0.98</td>
<td>0.07</td>
<td>0.922</td>
</tr>
</tbody>
</table>
Table S2. Model kinetic equation used to fit the experimental data obtained for reaction (1).

| Kinetic equation | Best fit parameters | Average relative deviation of the best fit from experimental data, \{
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{obs} = \frac{[\text{urea}]^2}{a'[\text{H}_2\text{O}] + b' [\text{urea}]}$ (S1) or</td>
<td>$a' = (k''K'')^{-1}$ \hspace{1cm} $b' = (k''K'')^{-1}$</td>
<td>0.029</td>
</tr>
<tr>
<td>$k_{obs} = \frac{k''K'[\text{urea}]^2}{[\text{H}_2\text{O}] + K'[\text{urea}]}$ (S2)</td>
<td>$K' = 0.30$ \hspace{1cm} $k''K'' = 645 \text{ M}^{-1}\text{s}^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$k_{obs} = \frac{k'[\text{urea}] + k''K'[\text{urea}]^2}{[\text{H}_2\text{O}] + K'[\text{urea}]}$ (S3)</td>
<td>$k' = 0.39 \text{ s}^{-1}$ \hspace{1cm} $K' = 0.29$ \hspace{1cm} $k''K'' = 650 \text{ M}^{-1}\text{s}^{-1}$</td>
<td>0.027</td>
</tr>
<tr>
<td>$k_{obs} = \frac{kK[\text{urea}]}{[\text{H}_2\text{O}]+K[\text{urea}]}$ (S4)</td>
<td>$k = 15.6 \text{ s}^{-1}$ \hspace{1cm} $K = 0.15$</td>
<td>0.36</td>
</tr>
<tr>
<td>$k_{obs} = \frac{kK[\text{urea}]^2}{[\text{H}_2\text{O}]+K[\text{urea}]^2}$ (S5)</td>
<td>$k = 17.8 \text{ s}^{-1}$ \hspace{1cm} $K = 10.2 \text{ M}^{-1}$</td>
<td>0.064</td>
</tr>
<tr>
<td>$k_{obs} = \frac{kK'[\text{urea}]^2}{[\text{H}_2\text{O}]+K'[\text{urea}][\text{urea}]}$ (S6)</td>
<td>$k'K'' = 0.57 \text{ M}^{-1}\text{s}^{-1}$ \hspace{1cm} $K' = 302 \text{ M}^{-1}$</td>
<td>0.044</td>
</tr>
<tr>
<td>$k_{obs} = \frac{k'[\text{H}_2\text{O}][\text{urea}]+k''K'[\text{urea}]^2}{[\text{H}_2\text{O}]}$ (S7)</td>
<td>$k'K' = 16.5 \text{ M}^{-1}\text{s}^{-1}$ \hspace{1cm} $k'K'' = 124 \text{ M}^{-1}\text{s}^{-1}$</td>
<td>0.069</td>
</tr>
<tr>
<td>$k_{obs} = \frac{kK[\text{urea}]^2}{[\text{H}_2\text{O}]}$ (S8)</td>
<td>$kK = 152 \text{ M}^{-1}\text{s}^{-1}$</td>
<td>0.125</td>
</tr>
<tr>
<td>$k_{obs} = \frac{k''K'[\text{urea}]^2}{[\text{H}_2\text{O}]+K'[\text{urea}]+K'K'[\text{urea}]^2}$ (S9)</td>
<td>$k'' = 76 \text{ s}^{-1}$ \hspace{1cm} $K' = 0.236$ \hspace{1cm} $K'' = 10.8 \text{ M}^{-1}$</td>
<td>0.0285</td>
</tr>
<tr>
<td>$k_{obs} = \frac{k'K'[\text{urea}]+kK'K''[\text{urea}]^2}{[\text{H}_2\text{O}]+K'[\text{urea}]+K'K''[\text{urea}]^2}$ (S10)</td>
<td>$k' = 0.42 \text{ s}^{-1}$ \hspace{1cm} $k'' = -237 \text{ s}^{-1}$ \hspace{1cm} $K' = 0.30$ \hspace{1cm} $K'' = -2.55 \text{ M}^{-1}$</td>
<td>0.0265</td>
</tr>
</tbody>
</table>
Derivation of kinetic equation (6).

Experimental kinetic data on the reaction of 1 with urea in acetone in the presence of controlled amounts of water were plotted in Lineweaver-Burk-like coordinates (k_{obs}^{-1} versus [H_{2}O]^{-1} at constant [urea]). These graphs are a family of straight lines described by expressions k_{obs}^{-1} = a[H_{2}O] + b, with parameters a and b depending on the concentration of urea as a = a' [urea]^{-2} and b = b' [urea]^{-1} (Figure S4). Therefore, the simplest empirical function of k_{obs} versus [H_{2}O] and [urea] should have the following form:

\[ k_{obs} = \frac{[\text{urea}]^2}{a'[H_{2}O] + b'[\text{urea}]} \quad (S1) \]

Scheme S1 and Equation (S2) represent a mechanistic rationalization of Equation (S1), if a' = (k''K'K'')^{-1} and b' = (k''K'')^{-1}.

\[ k_{obs} = \frac{k''K'K''[\text{urea}]^2}{[H_{2}O] + K'[\text{urea}]} \quad (S2) \]

Scheme S1 assumes the formation of two intermediate urea complexes, [LNi_{2}(OH)(urea)]^{2+} (1a) and [LNi_{2}(OR)(urea)]^{2+} (1b) in a fast preequilibrium with the starting complex 1, such that [1b] << [1] + [1a]. It also implies that only intermediate 1b is reactive, while 1a is just a preequilibrium “sink”, and the role of the first urea molecule is phenomenological. However, the kinetic data obtained in methanol suggested that the mono-urea species might also be reactive. The addition of a first-order [urea] term to the nominator of Equation (S2) gave Equation (S3), which is given in the main text as Equation (6):

\[ k_{obs} = \frac{k'K'[\text{urea}] + k''K'K''[\text{urea}]^2}{[H_{2}O] + K'[\text{urea}]} \quad (S3) \]

Equation (S3) gave a somewhat better fit of the experimental kinetic data and a more plausible mechanistic interpretation with reasonable values of parameters. Several other kinetic models were tried, but they gave much worse fits or unreasonable values of fit parameters (Table S2).

The overall transformation of 1 into 2 is almost irreversible under the concentration conditions employed in this study. The yield of complex 2 is over 95% (see Table S1). Therefore, the overall reaction and its the rate-limiting step can indeed be assumed irreversible.
Scheme S1. A simple mechanism accounting for the kinetic data on the reaction of 1 with urea in acetone, which assumes that only intermediate 1b is reactive (see page S8 for explanation).
**Scheme S2.** An alternative mechanistic scheme explaining the role of a second urea molecule in the formation of complex 2. In this picture, urea is bound to the [LNi₂(OR)(urea)]²⁺ species by hydrogen bonds and acts as proton 'shuttle'. The formation of complex 4b' in methanol accounts for the higher input of the mono-urea pathway in methanol compared to that in acetone.