Extraction of copper(II) and nickel(II) by nopinoquinone dioxime

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EXTRACTION OF COPPER(II) AND NICKEL(II) 
BY NOPINOQUINONE DIOXIME

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Abstract—In the research for a selective extractant for nickel a strained dioxime, \( \beta \)-nopinoquinone dioxime, has been studied in its extraction properties for copper(II) and nickel(II). Spectroscopic investigations (ESR and NMR) showed that both copper and nickel are extracted as a N,N-coordinated chelate. The extraction studies showed that the use of strained instead of aliphatic dioximes makes the extraction more convenient because of the higher extraction rate, but the selectivity for nickel above copper disappears.

\( \delta \)-nopinoquinone dioxime is easily converted into its furazan by treatment with 1N NaOH. This furazan is a rather weak ligand without significant extraction capacities.

Vicinal dioximate ligands usually form stable N,N-chelated complexes containing a conjugated N = C–C = N system (Fig. 1a).

In previous work\(^1\) it became clear that camphorquinone dioxime cannot form a stable N,N-coordinated chelate with copper and nickel. The rigid bicyclic skeleton is responsible for a larger N–N distance than in aliphatic \( \alpha \)-dioximes and makes the N,O-coordination, with a six-membered ring metal–N = C–C = N–O– more attractive (Fig. 1b).

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![Diagram](Image)

**Fig. 1.** (a) The N,N-coordinated bis(dimethylglyoximato)nickel(II) chelate. (b) The N,O-coordinated bis(camphorquinonedioximato) copper(II) chelate.
The extraction experiments were carried out in a three stoppered flask with a stirring device and continuous pH measurements. The starting volumes of water and organic solvent were both 250 cm³. Stirring was stopped when no further change of the pH was noticed, indicating that equilibrium was reached. For analysis equally small volumes of water layer and organic layer were withdrawn from the system. To measure the distribution coefficient as a function of pH thereafter a small quantity of 4N acid or base was added, and the process of stirring until equilibrium and withdrawal of small portions of the aqueous and organic solutions was repeated at a different pH. Care was taken to keep the volumes of the aqueous and organic solutions equal. Although in this procedure the electrolyte concentration does not stay constant we preferred this method because it is convenient to execute and because in a separate experiment it was shown that in the applied concentration range the influence of the electrolyte concentration was negligible. Pentanol was used as organic solvent and as inorganic salt we used metal nitrate. We used NaOH as base and HNO₃ as acid.

SYNTHESIS

**β-Nopinoquinonedioxime**

Nopinoone (6,6-dimethylbicyclo[3.1.1]heptane-2-one) was prepared by ozonolysis of β-pinene (J. T. Baker chemicals B. V. Deventer, Baker grade) according to a published method.² The decrease in intensity of the sharp C–H band of alkenes at 3070 cm⁻¹ in the IR spectrum was a useful indication how much pinene was converted. Following the conventional method³ using n-butyl nitrite, isonitrosonopinone was obtained in 30% yield from nopinoone. Following the procedures of Nakamura⁴, crude isonitrosonopinone (0.18 mol) dissolved in 50 cm³ ethanol was treated with an aqueous solution of NH₂OH.HCl (0.48 mol) and NaOAc (0.51 mol) at 90°C for 3 days. A solid white inorganic product precipitated. The mother liquid was concentrated in vacuo to 50% of the original volume and filtered. Further concentration, removing ethanol completely gave the crude β-isomer. Extraction with boiling ethyl acetate removed the δ-isomer completely and gave the pure β-H₂NQD. Found: C,59.3; H,7.9; N,15.5. Calc.: C,59.3; H,7.7; N,15.4%. IR: OH stretching vibrations at 3360 and 3180 cm⁻¹ C = N absorptions at 1585 and 1615 cm⁻¹. These values are in perfect agreement with Nakamura.⁵ 'H NMR (DMSO-d₆): δ0.74 (8, 3H), 1.03 (s, 3H), 2.05 (m, c, 1H), 2.41 (r, 1H), 2.64 (d, lH), 3.41 (t, 1H), 10.74 (s, 1H), 11.18 (s, 1H) confirms the β structure.⁴

**The furazan of nopinoquinone dioxime (Fig. 3)**

The yellow oil, which was obtained in the above synthesis by the evaporation of the ethylacetate from the extract, was treated with 1N NaOH and extracted with ether. The ether layer was dried and evaporated. A yellow pleasantly smelling oil was obtained. After distillation a white powder was produced with a melting point of 30°C. IR: 1510 cm⁻¹ (furazan) 1550 and 1615 cm⁻¹ (C = N); no OH stretchings present. Found: C,65.5; H,7.3; N,16.9%. Calc. for C₇H₁₇N₂O: C,65.8; H,7.3; N,17.1%. 'H NMR (DMSO-d₆): see Fig. 4.

**Bis(β-nopinoquinonedioximato)nickel(II)**

Ni(β-HNQD)₂ was synthesized by the reaction of β-nopinoquinone dioxime and NiCl₂.6H₂O in ethanol with NaOH in a minimum amount of water. After stirring for two hours water was added and the orange–red chelate precipitated. The chelate was washed with water and dried at 50°C in the presence of silica.

IR: No absorption in the 3100–3600 cm⁻¹ region. 1585 and 1560 cm⁻¹ (shoulder) (C=N) Found: C,51.9; H,6.26; N,13.51. Calc. for NiC₁₈H₂₀N₄O₄: C,51.35; H,6.25; N,13.31%.

**Experimental**

'¹H NMR spectra were obtained at room temperature on a 60 MHz Varian EM 360A spectrometer, while ESR measurements were done with a Varian El5 spectrometer at room temperature and UV-visible spectra were obtained on a Unicam SP.800D. Aqueous metal ion concentrations were measured with the Perkin–Elmer 300 Atomic Absorption Spectrophotometer.

The extraction experiments were carried out in a three stoppered flask with a stirring device and continuous pH measurements. The starting volumes of water and organic solvent were both 250 cm³. Stirring was stopped when no further change of the pH was noticed, indicating that equilibrium was reached. For analysis equally small volumes of water layer and organic layer were withdrawn from the system. To measure the distribution coefficient as a function of pH thereafter a small quantity of 4N acid or base was added, and the process of stirring until equilibrium and withdrawal of small portions of the aqueous and organic solutions was repeated at a different pH. Care was taken to keep the volumes of the aqueous and organic solutions equal. Although in this procedure the electrolyte concentration does not stay constant we preferred this method because it is convenient to execute and because in a separate experiment it was shown that in the applied concentration range the influence of the electrolyte concentration was negligible. Pentanol was used as organic solvent and as inorganic salt we used metal nitrate. We used NaOH as base and HNO₃ as acid.
TREATMENT OF EXTRACTION DATA

The extraction is expected to follow eqn (1):

\[ \text{Me}^{2+} + 2\text{H}_2\text{NQD} \rightleftharpoons \text{Me(HNQD)}_2 + 2\text{H}^+ \]  

(1)

where Me\(^{2+}\) represents the aquo metal ion, Me-(HNQD)\(_2\) the extractable complex and bars indicate the organic layer. The equilibrium constant \(K_E\) and the distribution coefficient \(D\) are defined as:

\[ K_E = \frac{[\text{Me(HNQD)}_2][\text{H}^+]^2}{[\text{Me}^{2+}][\text{H}_2\text{NQD}]^2} \]  

(2)

\[ D = \frac{[\text{Me(HNQD)}_2]}{[\text{Me}^{2+}]} \]  

(3)

Combination of (2) and (3) gives

\[ \log D = \log K_E + 2\text{pH} + 2\log[\text{H}_2\text{NQD}] \]  

(4)

When taking a large excess \(\text{H}_2\text{NQD}\), so that \(\text{H}_2\text{NQD}\) is constant, it follows that

\[ \frac{\partial \log D}{\partial \text{pH}} \bigg|_{\text{H}_2\text{NQD}} = 2. \]  

(5)

Introducing \(\text{pH}_{1/2}\) as the pH value at which 50% of the metal is extracted (\(\log D = 0\)) eqn (4) leads to:

\[ \log K_E = -2 \log[\text{H}_2\text{NQD}] - 2\text{pH}_{1/2} \]  

(6)

Finally the value of \(\text{pH}_{1/2}\) at 1.0 M equilibrium concentration of extractant in the organic phase, denoted by \((\text{pH}_{1/2})_{1.0}\), can be obtained from eqn (6) as

\[ (\text{pH}_{1/2})_{1.0} = -\frac{\log K_E}{2}. \]  

(7)

Figure 5 shows the results for the extraction of Cu\(^{2+}\) and Ni\(^{2+}\) with an excess of \(\beta\)-\(\text{H}_2\text{NQD}\). The \(\text{pH}_{1/2}\) value of 1.85 for Cu\(^{2+}\) corresponds with
Fig. 5. Log D as a function of pH for the extraction of Cu(II) (X) and Ni(II) (O) by nopinoquinone dioxime. Concentration of $\beta$-H$_2$NQD is pentanol 0.025 M. Initial metal nitrate concentration 0.001 M.

$$(pH^3)_{1.0} = 0.25.$$ For Ni$^{2+}$ these values are somewhat higher: $pH^2 = 2.88$ and $(pH^3)_{1.0} = 1.28$. For the nickel extraction equilibrium was reached within ten minutes.

The slopes of the log D – pH curves are 1.75 for copper and 2.22 for nickel, both values deviate from the theoretically expected value of 2 for a metal:ligand ratio of 1:2. No change in the extraction behaviour of $\beta$ - H$_2$NQD could be observed after 2 days of contact.

To find out if copper only forms a 1:2 chelate with $\beta$-H$_2$NQD an experiment was done with equimolar amounts of copper and $\beta$-H$_2$NQD (Fig. 6). Maximum copper extraction was 50%, in excellent agreement with the formation of Cu: $\beta$-H$_2$NQD = 1:2. The shape of the UV/visible spectrum of the pentanol solution with the extracted chelate did not change during this experiment. The spectrum showed two maxima below 37.500 cm$^{-1}$, one at 35.700 cm$^{-1}$ ($\epsilon = 9000$) and

Fig. 6. % Copper extraction as a function of pH for the extraction of Cu(II) by $\beta$ - nopinoquinone dioxime. The initial concentration of $\beta$-H$_2$NQD in pentanol and the initial copper concentration in water are both 0.002 M.
Extraction of copper(I1) and nickel(I1) by nopinoquinone dioxime

Fig. 7. ESR spectrum of the copper chelate formed during the extraction of Cu²⁺ by β-H₂NQD in chloroform at room temperature.

The other at 27,000 cm⁻¹ (e = 2300). The elemental analysis from the isolated chelate is: C, 48.61; H, 6.32; N, 11.29; Cu, 12.98; O, 20.8%. This leads to a chelate with formula Cu₂H₃N₂O₆ indicating that the chelate has two additional water molecules and also that some pentanol is retained. The expected elemental analysis for Cu(HNQD)₂⋅2H₂O containing 62% pentanol (C₃H₇OH) is: C, 48.19; H, 6.96; N, 11.34; Cu, 12.88; O, 20.63%. The ESR spectrum of the chelate in CHCl₃ is presented in Fig. 7.

The nickel H₂NQD chelate isolated from the extraction was examined by NMR (Fig. 8). The elemental analysis gave: C, 54.4; H, 7.0; N, 12.6; Ni, 11.7% which was different from the expected for Ni(HNQD)₂: C, 51.3; H, 6.2; N, 13.3; Ni, 13.9%. The IR spectrum was almost identical with that from the synthesized Ni(β-HNQD)₂. Only one extra absorption appeared at 3400 cm⁻¹, probably due to the OH from pentanol that was not completely removed at 60°C.

The furazan of nopinoquinone dioxime did not have any extraction capacities at all.

DISCUSSION

Extraction

If we compare the extraction results of β-H₂NQD with those of β-H₂CQD clearly a lowering of the (pHf) value for both copper and nickel is observed (Table 1). This lowering cannot completely be explained by the fact that different solvents are used. In previous work it was proven that β-H₂CQD isomerizes to δ-H₂CQD and that this is coupled with a lowering of the pHf value. So pHf(β-H₂CQD) > pHf(δ-H₂CQD). In Table 1 it is observed that the pHf value of δ-H₂CQD is larger than that of β-H₂NQD in pentanol. The conclusion can be drawn that the pHf value of β-H₂NQD is smaller than that of β-H₂CQD. Another difference between β-H₂NQD and β-H₂CQD is that with the former compound no change in the extraction behaviour is seen after a contact time of two days. Isomerization of β-H₂NQD is therefore very unlikely. To confirm this the isolated copper chelate was investigated with ESR spectroscopy and the isolated nickel chelate was examined with NMR spectroscopy.

The structure of the copper H₂NQD chelate

Figure 6 shows that copper forms a 1:2 chelate with β-H₂NQD under extraction conditions. From the elemental analysis of the extracted Cu(β-HNQD)₂ it became clear that the chelate is extracted with two additional water molecules. It
Fig. 8. 60 MHz $^1$H spectrum of the nickel chelate formed during the extraction of Ni$^{2+}$ by $\beta$-H$_2$NQD in benzene at room temperature.

Table 1. Extraction of copper(I1) and nickel(I1) by some vic-dioximes

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solvent</th>
<th>($\mu$H)$_{Cu}$</th>
<th>($\mu$H)$_{Ni}$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$-H$_2$CQD*</td>
<td>pentanol</td>
<td>+1.48</td>
<td>+3.43</td>
<td>(1)</td>
</tr>
<tr>
<td>$\beta$-H$_2$CQD*</td>
<td>t.b.p.</td>
<td>+2.61</td>
<td>+4.73</td>
<td>(1)</td>
</tr>
<tr>
<td>$\delta$-H$_2$CQD</td>
<td>pentanol</td>
<td>+1.15</td>
<td>+3.60</td>
<td>(1)</td>
</tr>
<tr>
<td>$\delta$-H$_2$NQD</td>
<td>pentanol</td>
<td>+0.25</td>
<td>+1.28</td>
<td>this study</td>
</tr>
<tr>
<td>C$<em>5$H$</em>{11}$-C(NOH)-C(NOH)-C$<em>5$H$</em>{11}$</td>
<td>toluene</td>
<td>+0.62</td>
<td>-0.42</td>
<td>(6)</td>
</tr>
<tr>
<td>C$<em>7$H$</em>{15}$-C(NOH)-C(NOH)-C$<em>7$H$</em>{15}$</td>
<td>toluene</td>
<td>+0.54</td>
<td>-0.36</td>
<td>(6)</td>
</tr>
</tbody>
</table>

*Isomerization occurs to $\delta$-H$_2$CQD under extraction conditions.
is reasonable to expect that these two water molecules are weakly bound in the axial position of a distorted octahedron. Cu** is a d⁹ system with one unpaired electron which will be located in the d(x² − y²) orbital to minimize the electronic repulsion of the other electrons with the ligand electrons. The ESR spectrum (Fig. 7) shows four main lines which are due to copper (⁶⁵Cu, ⁶³Cu: I = 3/2) and extra lines superimposed on it due to nitrogen (¹⁴N: I = 1) superhyperfine interaction. If copper forms a CuN₄ species then the d(x² − y²) orbital will have overlap with 4N's which results in a superhyperfine structure with nine equidistant lines with an intensity ratio of 1:4:10:16; 19:16:10:4:1. If on the other hand copper forms a CuN₂O₂ chromophore, only 2 N's are coupled to copper, and given the fact that O does not have a magnetic moment, five equidistant lines with an intensity ratio of 1:2:3:2:1 are expected. In Fig. 7 it is hard to see how many lines are superimposed on one copper line because there is some overlap between the two copper lines on which nitrogen superhyperfine splitting is noticeable. In contrast with the spectrum of Cu(δ-HCQD)₂ (Ref. 1 Fig. 9) there are now no equidistant extra lines with strange intensities due to ⁶⁵Cu, visible on the high field side of the spectrum. This can be explained in two days. Firstly, the Cu(δ-HCQD)₂ spectrum has more narrow lines as deduced from the fact that the nitrogen superhyperfine splitting is clearly visible on the second low-field copper line. Furthermore, the ⁶⁵Cu splitting is smaller in Cu(β-HNQD)₂; 77.5 G instead of 90.5 G. The splitting of ⁶⁵Cu can now be calculated from the difference in magnetic moment (0.70904 × 10⁻⁴ for ⁶⁵Cu vs 0.75958 × 10⁻⁴ rad sec⁻¹ G⁻¹ for ⁶³Cu). The expected separation between ⁶⁵Cu and ⁶³Cu on the high field side of the ESR spectrum is 3/2. ((0.75958/0.70904) − 1) × 77.5 = 8.3 G instead of the 9.6 G for Cu(δ-HCQD)₂. In Fig. 9 the two high-field lines of copper are seen, and the nitrogen superhyperfine lines are numbered. The intensities cannot be measured exactly, because of the superposition on the copper lines. The rough values can be obtained by taking the so-called up–down distance, but these values are too low if the copper line goes up and too high if the copper line goes down.

Table 2 shows that the intensities are in reasonably good correlation with a CuN₄ chromophore, especially the lines 8–13 where no overlap occurs with the other nitrogen superhyperfine splitting. The CuN₂O₂ chromophore can be rejected because the lines 1, 12 and 13 cannot be explained. Furthermore the calculated intensities of the lines 7, 8, 10 and 11 deviate from the observed intensities. It is concluded from the ESR spectrum that Cu(β-HNQD)₂ has N,N-coordination.

The structure of the nickel H₂NQD chelate

The elemental analysis of Ni(β-HNQD)₂ from extraction deviates from the expected values, while the synthesized Ni(β-HNQD)₂ had a very good elemental analysis. Nevertheless the IR spectra of these two species are identical, except for an extra absorption of the extracted chelate at 3400 cm⁻¹, probably due to the OH group of pentanol that was not completely removed at 60°C. That is why the C and H percentages are raised and as a consequence the N and Ni percentages are lowered. No additional water molecules were found by the elemental analysis. This makes a square planar structure the most probable configuration as is often seen for Ni²⁺ d⁸ systems. This system will
Table 2. Up-down values of the nitrogen superhyperfine splittings of Fig. 9 and the expected values for CuN₄ and CuN₂O₂ chromophores

<table>
<thead>
<tr>
<th>line number</th>
<th>up-down value CuN₄ expectation</th>
<th>CuN₂O₂ expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>4.4</td>
<td>5.8</td>
</tr>
<tr>
<td>3</td>
<td>9.1</td>
<td>9.3</td>
</tr>
<tr>
<td>4</td>
<td>11.1</td>
<td>11.1</td>
</tr>
<tr>
<td>5</td>
<td>8.4</td>
<td>9.3/1.0*</td>
</tr>
<tr>
<td>6</td>
<td>4.4</td>
<td>5.8/4.1*</td>
</tr>
<tr>
<td>7</td>
<td>8.1</td>
<td>2.3/10.3*</td>
</tr>
<tr>
<td>8</td>
<td>15.2</td>
<td>0.6/16.4*</td>
</tr>
<tr>
<td>9</td>
<td>19.5</td>
<td>19.5</td>
</tr>
<tr>
<td>10</td>
<td>15.7</td>
<td>16.4</td>
</tr>
<tr>
<td>11</td>
<td>9.6</td>
<td>10.3</td>
</tr>
<tr>
<td>12</td>
<td>3.2</td>
<td>4.1</td>
</tr>
<tr>
<td>13</td>
<td>0.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*The superhyperfine splitting of the two copper lines are overlapping in this region.

Table 3. 'H NMR spectra of β- and δ-nopinoquinone dioxime and their nickel(II) chelates

<table>
<thead>
<tr>
<th>compound</th>
<th>C⁹H₃ C₈H₃ Hf He Hd Hb,c Ha OH</th>
<th>solvent</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni(δ-HNQD)₂</td>
<td>0.80 1.35 1.21 2.16 2.60 2.82</td>
<td>11.16</td>
<td>CDCl₃</td>
</tr>
<tr>
<td>Ni(β-HNQD)₂</td>
<td>0.56 0.94 1.17 1.52 2.20 2.45 3.29</td>
<td>17.90</td>
<td>C₆D₆</td>
</tr>
<tr>
<td>Ni(δ-HNQD)₂</td>
<td>0.63 0.94 0.86 1.52 2.09 2.38 3.29</td>
<td>18.14</td>
<td></td>
</tr>
<tr>
<td>β-H₂NQD</td>
<td>0.74 1.30 1.07 2.05 2.48-2.74 3.47 11.09/10.72</td>
<td>DMDO-d₆</td>
<td></td>
</tr>
<tr>
<td>δ-H₂NQD</td>
<td>0.74 1.31 1.20 2.10 2.44- -2.78 12.30/12.08</td>
<td>DMSO-d₆</td>
<td></td>
</tr>
<tr>
<td>β-H₂NQD</td>
<td>0.74 1.30 1.03 2.05 2.40-2.80 3.41 11.18/10.74</td>
<td>DMSO-d₆</td>
<td></td>
</tr>
</tbody>
</table>

*The chemical shifts of these protons could not be determined because of the presence of some pentanol.

The chemical shifts are given in ppm from SiMe₄.

Daniel and Pavia⁷,⁸ have studied in detail the effect of the oxime group on the chemical shift of the neighbouring proton. If the oxime group is anti, as is the case in Ni(β-HNQD)₂, the chemical...
shift of Ha will move to higher field. The origin of this effect is not known with certainty. Phillips explains the shift by the interaction of the hydroxyl group with the Ha proton. Saito suggests interference of the free electron pair with the Ha proton. Saito suggests interference of the free electron pair with the syn structure. The observed δ of 3.28 for the extracted Ni(β-HNQD)₂ proves that the neighbouring oxime group has the anti configuration. Furthermore, the observed δ of 17.87 of the OH group is in very good agreement with the Ni(β-HNQD)₂ compound synthesized by Nakamura.

In N,O-coordination another kind of hydrogen bridging occurs (see Fig. 1) and this leads to a different chemical shift, such as Ni(δ-HNQD)₆: δ = 11.16, Ni(α-HCQD)₆: δ = 11.07° and Ni(δ-HCQD)₆: δ = 10.80°. The conclusion drawn from this NMR study is that the extracted nickel chelate indeed has N,N-coordination. The spectrum gives some extra lines in the δ = 1.4 region because of the presence of some pentanol. From the NMR integral the quantity of pentanol is calculated to be about 6%, which is in good agreement with that estimated by elemental analysis.

The influence of the N-N distance

The fact that both Cu²⁺ and Ni²⁺ form N,N-bonding chelates with β-H₂NQD confirms the theory that the N-N distance is an important factor in the chelation. Camphorquinone dioxime H₂CQD₆, an analogous molecule with a N-N distance of about 3.0 Å instead of the 2.8 Å of H₂NQD, cannot form stable N,N-coordinated chelates. From the fact that copper and nickel have smaller pH value with β-H₂NQD than with δ-H₂CQD (see Table 1) the conclusion may be drawn that Ni,N-coordinated chelates are thermodynamically more stable, but that with H₂CQD the critical boundary for the N-N distance is passed.

Comparing β-H₂NQD with the unstrained aliphatic dioximes in Table 1 it is remarkable that the order of stability for copper and nickel is reversed. For copper it does not seem to matter that the Cu-N distance is enlarged and even a slight decrease of the pH value can be observed. For nickel the N-N distance is coupled with a striking difference in the pH value. Furthermore, the nickel extraction rate is raised enormously. Equilibrium is reached within 10 min using β-H₂NQD as extractant instead of several days, when using unstrained aliphatic dioximes. To understand this difference the crystal structure of some known copper and nickel dioxime chelates have to be discussed. If we compare the results of the crystal structure analysis of bis(methylglyoximato)nickel(II) of Bowers et al. with the crystal structure analysis of bis(dimethylglyoximato)copper(II) from Vaciago and Zambonelli there are some clear differences. Nickel forms a square planar structure with a nickel to nitrogen distance of 1.86 Å and a dioxime N-N distance of 2.42 Å, while copper is five coordinated in a square-pyramidal configuration with a copper to nitrogen distance of 1.95 Å and a dioxime N-N distance of 2.52 Å. Shannon has calculated the ionic radii for different kinds of configurations. The values for copper(II) are 0.57 Å for a four coordinated square complex, 0.65 Å for a five coordinated complex and 0.73 Å for a six coordinated complex. For nickel(II) these values are 0.49 Å for a four coordinated square complex, 0.63 Å for a five coordinated complex and 0.69 Å for a six coordinated complex. The difference between the copper and nickel radius in the structure analysis of the glyoxime chelate, however, is 0.09 Å. In the unstrained glyoxime chelate the N-N distance will be determined by the metal ion radius. That elucidates the difference in N-N distance between the two complexes in the crystal structure. In the β-H₂NQD complex the N-N distance is determined by the strained carbon skeleton to be about 2.8 Å. This is far from the ideal N-N distance for a NiN₄ chromophore which is 2.426, so the chelate will be destabilized and the pH value will rise. For Cu(β-HNQD)₂ elemental analysis shows that there are two additional water molecules associated to the chelate. It is not unlikely that these water molecules are located in the axial position of octahedral copper (d(2)) so that a (distorted) octahedral configuration exists. The six coordinated copper has according to Shannon a much greater ionic radius than the four coordinated nickel: 0.73 Å vs 0.49 Å. Furthermore the copper coordination sphere possesses some plasticity i.e. the stronger the axial ligands are bonded, the weaker the equatorial ligands are bonded (which means in this case the larger the Cu-N distance). So less destabilization is to be expected for copper.

Good kinetics of nickel(II) extraction are to be expected whenever substitution of water takes place within an octahedral paramagnetic complex, which is directly followed by the elimination of the surplus monodentate ligands to a square planar diamagnetic complex. No octahedral complexes of the type Ni(H₂O)₂ (LL)₂ are formed by unstrained aliphatic dioximes. The weakening of the ligand by enlargement of the N-N distance makes it energetically more favourable to form this kind of paramagnetic octahedral intermediate. This could explain why β-H₂NQD has such good kinetics relative to unstrained aliphatic dioximes.
Table 4. The chemical shifts in ppm and the coupling constants in cps from the furazan of nopinoquinone dioxime. NMR spectrum see Fig. 7. Proton numbering see Fig. 10.

<table>
<thead>
<tr>
<th>Proton</th>
<th>Chemical Shift (ppm)</th>
<th>Multiplicity</th>
<th>Coupling Constants (cps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα</td>
<td>3.20</td>
<td>triplet</td>
<td>(2J(\text{He}, \text{Hf}) = 10.5)</td>
</tr>
<tr>
<td>Hβ, C</td>
<td>3.04</td>
<td>doublet</td>
<td>(3J(\text{He}, \text{He}) = 5.0)</td>
</tr>
<tr>
<td>Hδ</td>
<td>2.35</td>
<td>multiplet</td>
<td>(3J(\text{Hα}, \text{Hf}) = 0)</td>
</tr>
<tr>
<td>Hε</td>
<td>2.87</td>
<td>doublet</td>
<td>(3J(\text{Hδ}, \text{He}) = 5.0)</td>
</tr>
<tr>
<td>Hf</td>
<td>1.27</td>
<td>multiplet</td>
<td>(3J(\text{Hδ}, \text{Hf}) = 0)</td>
</tr>
<tr>
<td>C₉H₃</td>
<td>0.58</td>
<td>singlet</td>
<td>(3J(\text{Hδ}, \text{Hβ, C}) = 2.5)</td>
</tr>
<tr>
<td>C₈H₃</td>
<td>1.42</td>
<td>singlet</td>
<td>(4J(\text{Hα}, \text{Hδ}) = 5.0)</td>
</tr>
</tbody>
</table>

The furazan of nopinoquinone dioxime

The yellow oil which was obtained in the synthesis of \(\beta\)-\(H\),\(N\)QD by evaporation of ethylacetate probably consists for the major part of \(\delta\)-\(H\),\(N\)QD. To remove the impurities the oil was treated with 1N NaOH and extracted with ether. Acidifying of the water layer did not give much product, but evaporation of the ether layer gave a compound that is probably the dehydrated form of nopinoquinone dioxime. Wolff\(^6\) made such a furazan—also called 1,2,5-oxadiazole—by refluxing dimethylglyoxime with sodium hydroxide in water. This compound had a low melting point—7°C and a sweet smell. Also other furazans could be synthesized from dioximes. Behr\(^7\) found that especially the amphi forms (\(\delta\)-\(H\),\(N\)QD is amphi) are most easily dehydrated. To prove whether the compound really is the furazan the NMR spectrum (Fig. 4) was studied in detail. The compound gave a very clear spectrum. Chemical Shifts and coupling constants are given in Table 4. Because furazan is a six electron system, 4\(\pi\) electrons from the two CN double bonds and two from the oxygen, the five membered ring is aromatic. The field of this aromatic ring causes a deshielding effect for the protons on the pinene skeleton. Comparing the chemical shifts of \(\beta\)-\(H\),\(N\)QD with those of the furazan it is notable that almost all chemical shifts are shifted downfield. This confirms the aromatic character of the furazan ring. The chemical shift of Hα is somewhat smaller, which was to be expected because in the furazan no anti \(\text{OH}\) group exists. The chemical shift of \(\text{C}₉\text{H}_₃\) is changed in the opposite direction because the methyl group is placed partly above the aromatic ring where lines of the induced field are opposite to the applied field.

It is known that theoretical treatments of the magnitude of coupling constants such as the Karplus\(^8\) equation (vicinal couplings) must be treated with reserve.\(^9\) Nevertheless the use of the equation of Karplus:

\[
3J(H, H) = 4.22 \cdot 0.5 \cos \phi + 4.5 \cos 2\phi
\]

in which \(\phi\) is the dihedral angle between the two H's, gives dihedral angles which are in good agreement with the scale model made from the furazan of nopinoquinone dioxime. \(3J(\text{Hα}, \text{Hε}) = 5.0\) cps leads to an angle of 37° between Hα and Hε. The expected angle between Hα and Hf now is 120° - 37° = 83°. A dihedral angle of 83° leads to a coupling constant \(3J(\text{Hα}, \text{Hf}) = -0.21\) cps, a coupling that will not be observed. The same holds for \(3J(\text{Hδ}, \text{Hf})\). The coupling constants are almost equal to the values found by Abraham\(^\text{m2}\) for some other pinane derivatives. The long-range coupling \(3J(\text{Hα}, \text{Hδ})\) is remarkable but not unknown in bicyclic molecules.\(^\text{m21}\) Meinwald\(^\text{m21}\) explained this long-range interaction by assuming a fairly extensive overlap between the small lobes of the orbitals directed 180° away from the direction of the CH bonds, which are pointed towards each other. This explanation appears reasonable when a scale model is examined. This proves that the pinane skeleton is still preserved. Elemental analysis also leaves no doubt on the compound being the furazan of nopinoquinone dioxime.

The furazan of nopinoquinone dioxime shows no extraction capacities at all. The main reason for this is that there is no acidic H atom present. Also no hydrogen bridge stabilization of the complex can occur. Furthermore the bidentate character of the ligand is lost. Driessen\(^\text{m22}\) did make some metal furazan complexes with SbCl\(_6^-\) as anion. All the complexes decomposed when in contact with water which means that furazan is a rather weak ligand.

The aromaticity of the furazan ring makes the molecule very stable. It is therefore not possible to convert the furazan into \(\beta\)- or \(\delta\)-\(H\),\(N\)QD.

REFERENCES

Extraction of copper(II) and nickel(II) by nopinoquinone dioxime