Cathodic Reduction of 1-Nitroalkenes\textsuperscript{1)} to Oximes and Primary Amines

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1-Nitroalkenes are reduced in high yields at \(-0.3\) to \(-0.5\) V (vs. SCE) at a mercury or graphite cathode to oximes. At higher cathodic reduction potentials \((-1.1\) V) primary amines are selectively obtained in fair yields. Nitroalkadienes are selectively reduced at the double bond conjugated with the nitro group to either the oxime or amine.

The double bond of 1-nitroalkenes can react as a Michael acceptor in Michael additions\textsuperscript{2,9} or as a dienophile in Diels-Alder reactions\textsuperscript{\textsuperscript{4}-\textsuperscript{6}}. The nitro group has been reduced both chemically and electrochemically. 1-Nitroalkenes with aromatic or heterocyclic substituents at C-2 afford upon treatment with iron/hydrochloric acid/sodium hypophosphite/Raney nickel\textsuperscript{1,4}, chromium(II)chloride, 3% hydrochloric acid\textsuperscript{6}, or lithium tris-sec-butylhydridoborate and subsequent acidic workup\textsuperscript{6d} ketones or aldehydes in \(35\) – \(92\)\% yield. The corresponding oximes are obtained by reduction with sodium hypophosphite/palladium-charcoal\textsuperscript{16}, chromium(II) chloride\textsuperscript{6e}, sodium stannite\textsuperscript{6c}, tin(II)chloride\textsuperscript{6d}, lead\textsuperscript{6e} or hydrogen palladium on charcoal.\textsuperscript{11b} 2-Aryl-substituted 1-nitroalkenes have been electrochemically reduced selectively to either ketones or oximes at the lead cathode\textsuperscript{5g} or, more unselectively, to mixtures of oximes and ketones at the platinum cathode\textsuperscript{7b}, and to nitriles\textsuperscript{5b}.

\section*{Results}

The 1-nitro-2-arylalkenes \textbf{3} are prepared by condensation of aldehydes \textbf{1} with nitroalkanes \textbf{2}\textsuperscript{5a,b} (eq. 1). They exhibit reduction potentials between \(-0.17\) and \(-0.33\) V vs. SCE (Table 1). A second more cathodic reduction potential appears at \(-1.1\) V (for \textbf{3a}), which can be attributed to the reduction of the oxime \textbf{4} to the amine \textbf{14}, as the oxime \textbf{4a} shows a reduction potential at \(-1.02\) V.

The reduction of \textbf{3} at a mercury pool cathode in a divided cell in \(0.1\) M \(\text{H}_2\text{SO}_4\) in 2-propanol/water(3:2, v/v) affords oximes \textbf{4} (eq. 1, Table 2). Compound \textbf{3} is probably first reduced to the 1-nitrosoalkene \textbf{5} and this subsequently to the 1-(hydroxylamino)alkene \textbf{6}, which tautomerizes to \textbf{4} (eq. 2).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
1-Nitroalkene & \textbf{3b} & \textbf{3a} & \textbf{3e} & \textbf{3d} & \textbf{3c} \\
\hline
\(-E_{\text{pc}},\text{V}(\text{SCE})\) & 0.17 & 0.19 & 0.30 & 0.315 & 0.33 \\
\hline
1-Nitroalkene & \textbf{12a} & \textbf{12b} & & & \\
\hline
\(-E_{\text{pc}},\text{V}(\text{SCE})\) & 0.375 & 0.458 & & & \\
\hline
\end{tabular}
\caption{Reduction potentials of different 1-nitroalkenes}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textbf{3} & \textbf{4} & \text{Yield (\%)} \\
\hline
\textbf{a} & \textbf{a} & 85 \\
\textbf{b} & \textbf{b} & 85 (76 [44])\textsuperscript{b1} \\
\textbf{c} & \textbf{c} & 91 (85 [77])\textsuperscript{b1} \\
\textbf{d} & \textbf{d} & 92 \\
\textbf{e} & \textbf{e} & 91\textsuperscript{c} \\
\hline
\end{tabular}
\caption{Cathodic reduction of 1-nitroalkenes \textbf{3} to oximes \textbf{4}}
\end{table}

\textsuperscript{a} Isolated yield, purity \(>98\)% determined by GLC, current yield corresponds to \(95\) – \(100\)% of isolated yield. \textsuperscript{b} Reduction at a graphite cathode, otherwise the conditions are identical to those at the mercury cathode; numbers in brackets: current yield at graphite cathode. \textsuperscript{c} Contains \(4\)% 1-isopropoxy-1-(4-methoxyphenyl)acetone oxime determined by GLC.

The intermediate formation of \textbf{5} is supported by the formation of side product \textbf{7}, an adduct of 2-propanol to \textbf{5}. Its formation may be suppressed to as little as \(4\)% by increasing the current density, that means by decreasing the lifetime of 2-propanol.\textsuperscript{14d}}
The oxime 4 hydrolyzes to a small extent to the corresponding ketone in the course of the electrolysis. Therefore, the electrolyte is treated with hydroxylammonium chloride before workup to reconvert the ketone into the oxime. Similarly the commercially available 1-nitro-1-cyclohexene (8) is reduced to the oxime 9 in 87% yield (eq. 3). The reductions can be performed also at an untoxic graphite cathode in slightly lower yields (Table 2) and decreased current yields due to a higher hydrogen evolution.

To demonstrate the chemoselective reduction of the double bond conjugated with the nitro group the nitroalkadienes 12 are prepared by addition of the nitroalkane 11 to the aldehyde 10 and subsequent acylation as described in ref. 10. Elimination of acetic acid (11) followed by column chromatography affords 12 (eq. 4, Table 3).

Compound 12 is reduced in a divided cell at a mercury pool cathode in 0.1 M H2SO4, 2-isopropanol/water (3:2, v/v) at controlled potential (−0.5 V for 12a, −0.55 V for 12b). After consumption of 4.27 (12a) or 4.02 F/mol (12b) the electrolyte is treated with hydroxylammonium chloride to reconvert partially hydrolyzed oximes. After workup 13 is obtained (Table 3, eq. 5).

The chemoselectivity of this reduction has been demonstrated by the conversion of nitroalkadienide 12a (eq. 7) into 15, the unconjugated double bond being unaffected.

In conclusion, the present work demonstrates that 1-nitroalkenes may be converted into oximes electrochemically in high yield. The scope and selectivity of this process are larger than in earlier cathodic reductions of 1-nitroalkenes. Furthermore, mercury as cathode material can be replaced by graphite as shown in two cases with nearly the same product yield and a somewhat lower current yield, due to higher competing hydrogen evolution. At higher negative reduction potentials the 1-nitroalkenes are reduced to the corresponding amines. Here the conversion is incomplete and the yield of amine is only fair, due to an increasing hydrogen evolution in the course of the electrolysis. The chemoselectivity has been demonstrated by the reduction of nitroalkadienes to the oximes or amines, whereby only the conjugated double bond is reduced whilst the other remains unaffected.

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### Table 3. Preparation of nitroalkadienes 12 and their reduction to 13

<table>
<thead>
<tr>
<th>Preparation of 12</th>
<th>Yield (%)</th>
<th>Reduction of 12 to 13</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>76</td>
<td>a</td>
<td>88</td>
</tr>
<tr>
<td>b</td>
<td>62</td>
<td>b</td>
<td>93</td>
</tr>
</tbody>
</table>

* Isolated yield, purity >98% by GLC, current yield corresponds to 95−100% of isolated yield.

The reduction of 3 to the corresponding amines 14 is not complete due to an increasingly competing hydrogen evolution at the cathode with the progress of the electrolysis. This seems to be ascribed to the presence of hydroxylamine originating from the hydrolysis of the intermediate oxime, which decreases the hydrogen overvoltage at the cathode. This leads to recovered 3, the formation of 4 and the corresponding ketone as well as only fair yields of the amine 14 (eq. 6, Table 4).

### Table 4. Reduction of 1-nitroalkenes 3 to primary alkylamines 14

<table>
<thead>
<tr>
<th>1-Nitroalkene</th>
<th>Alkylamine</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>14a</td>
<td>66</td>
</tr>
<tr>
<td>3c</td>
<td>14c</td>
<td>60</td>
</tr>
</tbody>
</table>

* Reduction in a divided cell at a Hg-pool cathode at 10 to 15°C in 0.3 M H2SO4 in 2-propanol/water (2:1, v/v).

The chemoselectivity of this reduction has been demonstrated by the conversion of nitroalkadiene 12a (eq. 7) into 15, the unconjugated double bond being unaffected.

In conclusion, the present work demonstrates that 1-nitroalkenes may be converted into oximes electrochemically in high yield. The scope and selectivity of this process are larger than in earlier cathodic reductions of 1-nitroalkenes. Furthermore, mercury as cathode material can be replaced by graphite as shown in two cases with nearly the same product yield and a somewhat lower current yield, due to higher competing hydrogen evolution. At higher negative reduction potentials the 1-nitroalkenes are reduced to the corresponding amines. Here the conversion is incomplete and the yield of amine is only fair, due to an increasing hydrogen evolution in the course of the electrolysis. The chemoselectivity has been demonstrated by the reduction of nitroalkadienes to the oximes or amines, whereby only the conjugated double bond is reduced whilst the other remains unaffected.

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### Experimental

Melting points (uncorrected): Kofler hot-stage. – Refractive indices: Zeiss refractometer. – IR: Perkin-Elmer 421, Shimadzu IR-408. – 1H, 13C NMR: Bruker WM 300, TMS for 1H and CDCl3 for 13C NMR as internal standard. – MS: Varian MAT CH7A, data system SS 200, 70 eV. – Elementary analyses: Mikroanalytisches Laboratorium M. Beller, Göttingen. – GLC: Shimadzu GC-14A with integrator C-R3A, quartz capillary column 0.32 mm x 50 m, 0.25 μm SE 54 (Macherey & Nagel). – Flash
chromatography\textsuperscript{13}: Silica gel 60 (Merck). – HPLC: Knauer 64 system, Knauer 51.78 differential refractometer, 250 mm × 8 mm Nucleosil 100-3 column (Knauer). – Electrolysis: Divided standard beaker-type cell (150 ml), cathode: mercury pool (19.5 mm), reference electrode: SCE, Luggin capillary, diaphragm: glass frit (G4), current source: Wenking HP 88 (Bank Elektronik).

Compounds 3a–e were prepared according to known procedures\textsuperscript{24,29}. Commercially available samples (Alrich) of 1-nitro-1-cyclohexene (8), 1,2,3,6-tetrahydrobenzaldehyde (10), and nitroalkanes 11a,b were redistilled prior to use.

(E)-1-(3-Cyclohexen-1-yl)-2-nitro-1-propene (12a): To a stirred solution of 5.35 g (50 mmol) of aldehyde 10 and 6.10 g (100 mmol) of nitromethane (11a) in 50 ml of 2-propanol was added 0.18 g (18 mmol) of potassium fluoride. After 20 h at room temp. the solvent was evaporated at aspirator pressure. The crude nitro alcohol was dissolved in 90 ml of ether followed by addition of 6.70 g (65 mmol) of silica gel 60 (Merck). The solution was stirred at room temp. for 20 h the ether was evaporated and re-washed with water. After drying (magnesium sulfate) the solvent was removed by evaporation and re-distilled prior to use.

Phenylacetaldehyde Oxime (4a)\textsuperscript{6b}: IR (KBr): \( \tilde{\nu} = 3550, 3400 \text{ cm}^{-1} \) (OH), 1630 (C = N). – H NMR (CDCl\textsubscript{3}): \( \delta = 1.04 \) to 1.17 (4H, aromatic CH\textsubscript{2}), 5.00 (2H, E-CH\textsubscript{2}CH=N), 7.24–7.36 (4H, 2H, aromatic H). – MS: \( m/z (\%) = 199 (1) [M^+] \), 133 (94) [M^+ - 18], 119 (42) [M^+ - 31], 91 (100), 75 (65), 65 (35), 57 (17), 43 (16).

C\textsubscript{6}H\textsubscript{5}CH\textsubscript{2}NO (199) (153.2)
Calcd. C 74.34 H 6.12 N 13.97
Found C 74.53 H 6.02 N 13.92

1-Phenyl-2-butanone Oxime (4d)\textsuperscript{6c}: IR (film): \( \tilde{\nu} = 3500 \text{ to } 3000 \text{ cm}^{-1} \) (OH), 1650 (C = O). – H NMR (CDCl\textsubscript{3}): \( \delta = 1.00 \) to 1.06 (4H, aromatic CH\textsubscript{2}), 5.22–5.38 (2H, E-CH\textsubscript{2}CH=CH\textsubscript{3}), 2.13–2.32 (2H, CH\textsubscript{2}CH=CH\textsubscript{3}), 1.95–2.15 (2H, aromatic CH\textsubscript{2}ECH). – MS: \( m/z (\%) = 166 (5) [M^+] \), 139 (100), 123 (65), 107 (41), 91 (100), 75 (37), 57 (24), 41 (16).

C\textsubscript{7}H\textsubscript{8}NO (166) (153.2)
Calcd. C 74.34 H 6.12 N 13.97
Found C 74.53 H 6.02 N 13.92

Cyclohexanone Oxime (9): M. p. 88–90 °C (ref.\textsuperscript{6d} 90 °C).
6.79, 7.46 (2 t, J = 5.5, 6.5 Hz, 2H, Z-, E-CH=CH=N). − MS: m/z (%)
= 139 (5), [M]+, 81 (40), 80 (77), 79 (55), 77 (55), 59 (100).

C_{2}H_{7}NO (132.2)
CaOd. C 69.03 H 9.41 N 10.06
Found C 69.11 H 9.39 N 10.01

3-Cyclohexen-1-ylacetoxime (13b) IR (film): ν = 3400 to
3200 cm⁻¹ (OH). 1660 (C=O). − 1H NMR (CDCl₃): δ = 1.15-1.6-2.1 (2 m, 7H, ring H), 1.86, 1.87 (2 s, 3H, E-, Z-
CH₃), 2.12, 2.34 (2 d, J = 7.3 Hz, 2H, Z-, E-CH₂C=CH₂=N), 5.56-5.72
(m, 2H, HC=CH). − 13C NMR (CDCl₃): δ = 36.2, 36.4 (13.5, 20.5 (2 q, E-
-, Z-CH₃), 24.85, 25.02, 28.84, 28.83, 31.42, 31.67 (6 t, E, Z-
CH₂CH=CHCH₂CH₃), 30.95, 31.00 (2 d, E, Z-CH₃), 35.29, 42.34
(2 t, Z, E-CH₂CH₂C=CH₃), 125.99, 126.07, 126.68, 126.79 (4 d, E-, Z-
HC=CH), 157.38, 157.68 (2 s, E, Z-CH₂C=CH₂=N). − MS: m/z (%) = 153
(9) [M]+, 79 (44), 74 (52), 73 (100), 42 (26), 41 (39).

C_{3}H_{5}NO (153.2)
CaOd. C 70.55 H 8.97 N 9.14
Found C 70.70 H 9.97 N 9.02

1-Isopropyl-1-(4-methoxyphenyl)acetoxime (7e)⁶⁰: 
Electrolysis of 3e afforded a mixture of 4e and 7e (96-4, GLC).
Side product 7e was separated by HPLC [petroleum ether/ether (1:1)].
Yield: 0.017 g (2.5%). − 1H NMR (CDCl₃): δ = 1.20, 1.23 (2 t, J = 6.06 Hz, diastereotopic CH₃), 1.75 (s, 3H, N=CCH₃), 3.62-3.75 [m, 1H, O=CHCH₂CH₃], 3.82 (s, 3H, OCH₃), 5.01 (s, 1H,
CH=CH₂), 6.85-6.93, 7.29-7.38 (2 m, 4H, aromatic H). − MS: m/z (%) = 237 (10) [M]+, 179 (34), 137 (100), 77 (15), 43 (20), 41 (24).

General Procedure for the Reduction of the 1-Nitroalkenes to the 
Amines: The cathodic compartment was charged with 70 ml of 0.3 M sulfuric acid in
2-propanol (2:1, v/v), subsequently by 6 mmol of the I-nitro olefin. After introducing the anodic chamber,
0.3 M sulfuric acid in 2-propanol/Jwater (2:1, v/v), subsequently by
ether. To the remaining aqueous phase 2 M NaOH was added
orated at reduced prcssure and the residue extracted twice with
of ether. The combined ethereal extracts were dried (MgSO₄) and
of Fe/S. The cathodic compartment was charged with 70 ml of
the Reduction 

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[116/91]