Electroreduction of Organic Compounds. 4.* Electrochemical Reduction of Mono- and Bis-dithiobenzoate Esters in the Presence of Bi- or Monofunctional Electrophiles

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Co-electroreduction of methyl dithiobenzoate (1a) and 1,3-dimesoxypropane (5) in acetonitrile yields the tetrahydrodithiepine 6, whereas the thirane 9 is formed from trimethylene-1,3-bis-dithiobenzoate (7a) and methyl iodide. The bis-thioacetals 8 are obtained, if 7a and its homologue 7b are electrolyzed together with methyl iodide; the heterocyclic bis-thioacetal 10 is formed from 7c as a mixture of the meso- and d,l-diastereomers in acetonitrile.

\[
\begin{align*}
\text{ArC} & \rightarrow \text{SR}^1 + R^2X & \text{ArCH} & \rightarrow \text{SR}^1 \\
\text{S} & \quad 1 & \quad \text{SR}^2 & \quad 2 \\
\text{SCH}_3 & \quad \text{PhC} & \rightarrow \text{CH}_3 & \quad \text{SCH}_3 \\
\text{1} & \quad \text{3} & \quad \text{2} & \quad \text{3}
\end{align*}
\]

Alkyl dithiobenzoates (1) are easily electroreduced in the presence of alkylating agents according to eqn. (1). Under various conditions thioacetals (2) are formed as main products in reasonable yields,\textsuperscript{1,2} whereas C-alkylation occurs only in dry DMF at a Pt-cathode yielding acethophenone thioacetal (3).\textsuperscript{3}

On the other hand, the stilbene derivatives 4 which are formed as minor by-products in the presence of alkyl iodides \textsuperscript{1,2} are obtained in good yields, if the latter are absent \textsuperscript{4} (eqn. (2)).

Stimulated by the work of C. Degrand and coworkers,\textsuperscript{5} who established the cyclization shown in eqn. (3) as an interesting type of electroorganic reaction, we became interested in the products – possibly heterocycles – that could be formed, if bifunctional electrophiles and bis-dithioesters were used in the electrolyses.

\[
\begin{align*}
2 \text{ArC} & \rightarrow \text{SR}^1 + \frac{\text{4e}^- + \text{4H}^+}{- \text{2H}_2\text{S}} & \text{Ar} & \rightarrow \text{C} \quad \text{SR}^1 \\
\text{S} & \quad \text{4} & \quad \text{4} & \quad \text{4}
\end{align*}
\]

\[
\begin{align*}
\text{A} & \rightarrow \text{B} \\
\text{X} & \rightarrow (\text{CH}_2)_n \text{X} & \frac{\text{2e}^-}{- \text{2X}^-} & \rightarrow (\text{A} \rightarrow \text{B}) \\
\text{X} & \rightarrow (\text{CH}_2)_n \text{X} & \quad (\text{CH}_2)_n
\end{align*}
\]

ELECTROLYSES

Methyl dithiobenzoate and bis-electrophiles. Electroreduction of methyl dithiobenzoate (1a) in dry acetonitrile in the presence of 1,3-dimesyl-oxypropane (5) yielded 30% of a pale yellow crystalline compound, which could easily be isolated from the catholyte by extraction with light petroleum. Elemental analyses and spectroscopic data (cf. Experimental) were consistent with the structure of dithiepine 6. This could be further confirmed by independent synthesis from benzoin and propane-1,3-dithiol (eqn. (4)).
No electrolysis products could be identified when 1,2-dichloroethane, 1,3-dichloropropane or 1,4-dichlorobutane were used as bifunctional electrophiles. Especially the formation of the allyl thiaoacetal 2a which could have been formed during co-electroreduction of 1a with 1,3-dichloropropane by elimination of hydrogen chloride, was excluded. [Co-electroreduction of thiobenzomorpholide with 1,3-dichloropropane yields the S-allyl-S,N-acetal PhCH(NR₂)SCH₂CH=CH₂].6 

2a was easily obtained if 1a and allyl chloride were electroreduced (eqn. (5)).

**Bis-dithiobenzozate esters.** The bis-dithiobenzozates 7 were electrolysed in the presence of methyl iodide using the protic solvent methanol.

As one would expect, the bis-thiaoacetals 8 were formed (eqn. (6)). These compounds were accompanied by a variety of lesser interest by-products (cf. Experimental). The isolation and purification of the oily and non-distillable liquids were difficult and the yields were low. The structures of 8a and 8b were established by NMR spectroscopy.

When, on the other hand, 7a and methyl iodide were electroreduced in dry acetonitrile, no thiaoacetal could be identified. Preparative layer chromatography of the product mixture on silica gel yielded the thiirane 9 (28 %) as a colourless crystalline compound (eqn. (7)).

Quite a different result was obtained, when ethylene bis-dithiobenzozate (7c) was electroreduced in dry acetonitrile in the presence of methyl iodide. The six-membered cyclic bis-thiaoacetal 10 was formed (74 %) as a 1:1-mixture of the two possible diastereomers 10a and 10b (eqn. (8)). Separation of 10a and 10b was easily and completely accomplished by preparative layer chromatography. We were able to assign the two configurations unequivocally by high-resolution ¹H NMR spectroscopy. The four methylene protons in 10a are non-equivalent. Therefore a complex multiplet results even at 400 MHz. On the other hand, 10b exhibits a twofold axis of symmetry, and the methylene signal appears as an AA′XX′-system with a diastel coupling $J_{AA} = 12.2$ Hz, a diequatorial coupling $J_{XX} = 4.2$ Hz, a geminal coupling $J_{AX} = -15.5$ Hz and an axial-equatorial coupling $J_{AX} = 1.3$ Hz.

DISCUSSION

The seven-membered heterocycle 6, obtained from 1a is not the expected product. According to eqn. (3) the thiolane 11 should have been formed but C-alkylation failed to take place. Obviously cyclization, which should be favoured by entropy effects, does not even overcome competing reactions that lead to products without attack of the electrophile on the central carbon atom.

On the other hand, C-C-coupling reactions between two thiocarbonyl carbon atoms do occur during electroreduction of the dithiobenzoate esters. Even though the electrochemical mechanism has not really been studied, some considerations about the course of the reactions will be given.

Primarily the radical anions of the dithioesters which are moderately persistent are formed at the applied potentials by a one-electron step. The data of Table 1 show that the electron transfer is not reversible in the case of the bis-dithiobenzoates 7a and 7c. Apparently fast irreversible steps are involved. Ethylene dithiobenzoate (7c) is easier reduced than 1a which probably results from the electron-withdrawing effect of the second thiobenzoylthio group in the β-position. A second wave due to formation of a diacid or bis-radical anion 12 is well separated in the polarogram of 7a and 7c. Nevertheless, the two-electron reduction product can be present in a small equilibrium concentration and may play a significant role in the overall reaction. The reduction potentials are shifted in the positive direction in the protic solvent methanol. Trimethylene dimesylate (5) as a model electrophile is reduced at a far more negative potential, so that its reduction can be excluded as the primary step and even its electrocatalytic reduction is unlikely.

Formation of the open-chain thioacetals 8 from the radical anions by protonation, further reduction and alkylation is rather straightforward. However, our data do not allow one to decide which step of this sequence is the first one or whether steps occur more or less simultaneously. The formation of the heterocyclic thioacetal 10 is explained quite similarly. Initially 7c is reduced to the bis-radical anion 12 which can first undergo radical dimerization and then alkylation (eqn. (9)).

This assumption is supported by the fact that the first cyclovoltammetric peak of 7c is not even reversible in the absence of methyl iodide and is not significantly shifted on addition of a large excess of methyl iodide (ΔE=+30 mV at molar ratios up to 200:1). However, the second possibility, first methylation and then dimerization of the neutral biradical (eqn. (9)), cannot be completely excluded.

The occurrence of the thirane 9 as a precursor of 4 during electroreduction of 1a has been presumed. Its formation from a carbene 13 or the corresponding carbene 14 and 1a (eqn. (10)) seems reasonable and is in accordance with

<table>
<thead>
<tr>
<th>Comp</th>
<th>$E_{1/2}$</th>
<th>$E_{3/2}$</th>
<th>$E_{1/2} - E_{3/2}$</th>
<th>$i_{pa}$</th>
<th>$i_{pc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>-1.26</td>
<td>-1.32</td>
<td>52</td>
<td>-1.91</td>
<td>0.86</td>
</tr>
<tr>
<td>7a</td>
<td>-1.09</td>
<td>-1.31</td>
<td>127</td>
<td>-2.02</td>
<td>0.55</td>
</tr>
<tr>
<td>7b</td>
<td>-1.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7c</td>
<td>-1.15</td>
<td>58</td>
<td>-1.52 &lt;0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-1.96</td>
<td>150</td>
<td></td>
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</tr>
</tbody>
</table>

*a* In methanol, V vs. s.c.e. *b* In acetonitrile, V vs. s.c.e. *c* In acetonitrile, mV. *d* In acetonitrile at a sweep rate of 200 mVs⁻¹.

Seebach’s results on the behaviour of (RS)_2C-radicals, -anions (carbenoids), and carbenes of the type (RS)_2C. The formation of 9 and 7a which again shows no significant dependence of the cyclovoltammetric peak potential on the methyl iodide concentration needs, however, a special explanation. Loss of the trimethylene chain can take place by a Hofmann-type elimination from an intermediate 15 which is formed similarly to 9 from 7a and 13 (eqn. (11)) or after initial dimerization and thiirane formation.

Finally, the formation of 6 which is a cyclic analogue of 4 should take place by dimerization of a carbene or reaction of the corresponding carbenoid according to eqn (12).

EXPERIMENTAL


The electrochemical equipment has been described elsewhere. All potentials are referred to the aqueous SCE. Electrolyses in methanol were performed in a simple beaker-type cell, shown in Fig. 1. Preparation of the cellulose diaphragm: 50 g fine copper wire were put into 1 l conc. aqueous ammonia, and air was passed through for 20 h. 30 g of cotton wool were dissolved with shaking in the deep blue tetramine-copper-hydroxide solution. Soxhlet thimbles were impregnated with the obtained cellulose solution, dried first at room temperature (8 h), then at 120 °C (3 h). The thimbles were treated with dilute hydrochloric acid (20 ml conc. HCl/1 water) for 3 h at 40–60 °C, then twice rinsed with warm water in the same way and again dried at 120 °C (3 h). This impregnation was repeated a few times. Finally the colourless diaphragms had a permeability of 2–3 ml/min, when they were half-filled with methanol.

Materials. Methanol, tetraethylammonium bromide, methyl iodide, allyl chloride, 1,2-dichloroethane, 1,3-dichloropropane, 1,4-dichlorobutane, ethane-1,2-dithiole, propane-1,3-dithiole, butane-1,4-dithiole and benzoin are commercially available and were used as received.

1,3-Dimesyloxypropylene (5)\textsuperscript{11} and tetra-n-propylammonium perchlorate\textsuperscript{12} were prepared according to literature procedures. Acetonitrile was purified as described earlier.\textsuperscript{9}

Methyl dithiobenzoate (1a). 4.6 g (0.2 mol) of sodium were dissolved in 100 ml dry methanol. 6.4 g (0.2 mol) of sulfur and 12.6 g (0.1 mol) of benzyl chloride were added. The mixture was stirred at 70 °C for 4 h and then evaporated in vacuo. The residue was dissolved in 100 ml water and extracted with chloroform to remove unpolar material. 12.6 g (0.1 mol) of dimethyl sulfate were added dropwise to the aqueous solution of the sodium dithiobenzoate at room temperature. After 1 h of stirring the product was extracted with light petroleum, washed with water, dried
over sodium sulfate and after removal of the solvent distilled.

Yield 8.4 g (50 %), red oil. B. p. 125–127.5 °C/0.53 kPa; lit. 13 b p. 118 °C/0.4 kPa.

Ethylene-1,2-bis(dithiobenzolate) (7c). 5.3 g (25 mmol) of carboxymethyl dithiobenzate 14 and 2 g sodium hydroxide were dissolved in 50 ml water. After addition of 1.2 g (12.5 mmol) of ethane-1,2-dithiole the mixture was stirred under N₂ for 1 h at room temperature. The red crystals of 7c, which separated from the solution, were filtered off and recrystallized from ether.

Yield 2.3 g (55 %), m. p. 103–105 °C. Anal. C₁₅H₁₄S₄: C, H, S. ¹H NMR (60 MHz, CDCl₃): δ 3.75 (4H, s), 7.43 (6H, m), 7.93 (4H, m). IR (KBr): 1265 (ss) cm⁻¹ (C=S).

Trimethylene-1,3-bis(dithiobenzolate). (7a) was obtained as a red oil analogously to 7c from 15.3 g (75 mmol) of carboxymethyl dithiobenzate and 4.1 g (37.5 mmol) of propane-1,3-dithiole. 7c was purified by column chromatography on silica gel with light petroleum (60–70 °C)/ethyl acetate 9:1 as eluant.

Yield 9.0 g (79 %). Anal. C₁₉H₁₈S₄: C, H, S. ¹H NMR (60 MHz, CDCl₃): δ 2.12 (2H, q), 3.45 (4H, t), 7.35 (6H, m), 8.00 (4H, m). IR (film): 1230 (ss) cm⁻¹ (C=S).

Tetramethylene-1,4-bis(dithiobenzolate). (7b) was obtained analogously to 7c from 15.3 g (75 mmol) of carboxymethyl dithiobenzate and 4.6 g (37.5 mmol) of butane-1,4-dithiole. 7b was purified by recrystallization from methanol/chloroform.

Yield 7.4 g (62 %), red crystals, m. p. 64–65 °C. Anal. C₂₁H₂₀S₄: C, H, S. ¹H NMR (60 MHz, CDCl₃): δ 1.98 (4H, m), 3.50 (4H, m), 7.49 (6H, m), 8.09 (4H, m). IR (KBr): 1215 (ss) cm⁻¹ (C=S).

2,3-Diphenyl-4,5,6,7-tetrahydro-1,4-dithiepin (6). 3.6 g (17 mmol) benzoin are dissolved in 100 ml acetic acid. 4 ml of water and 4.7 g (43 mmol) of propane-1,3-dithiole are added. The solution is saturated with gaseous hydrogen chloride at 0 °C (1 h). The product precipitates from the mixture. It is filtered with suction, washed with water, dried over potassium hydroxide in a desiccator and recrystallized from light petroleum (60–70 °C).

Yield 2.7 g (54 %), yellowish leaflets, m. p. 142 °C. Anal. C₁₉H₁₆S₂: C, H, S. ¹H NMR (60 MHz, CDCl₃): δ 2.15 (2H, q, J=6 Hz), 3.72 (4H, t, J=6 Hz), 7.1 (10H, m). IR (KBr): 1520 (cm⁻¹) (C=S).

Electroreductions in acetonitrile. ² 1.2 g (7 mmol) 1a and 1.6 g (21 mmol) allyl chloride were reduced at −1.4 V, n=1.75 F mol⁻¹. Allylthio-methylthio-phenylmethane (2a) was isolated.

Yield 0.6 g (40 %), NMR-spectroscopically:

Electroreduction of Dithienzoate Esters 523

63 %), red oil, b. p. 110–120 °C/2.5 kPa. Anal. C₁₅H₁₄S₄: C, H, S. ¹H NMR (60 MHz, CDCl₃): δ 1.93 (3H, s), 3.03 (2H, m), 4.53 (1H, s), 4.6–5.9 (3H, m), 6.8–7.2 (5H, m). IR (film): 1615 (s) cm⁻¹ (C=C).

1.2 (7 mmol) 1a and 4.1 g (18 mmol) 5 were reduced at −1.4 V, n=1.7 F mol⁻¹. 6 was isolated by rapid column chromatography on silica gel with CCl₄.

Yield 0.3 g (15 %) yellowish leaflets, m. p. 141–143 °C (ether). Anal. C₁₅H₁₆S₆: C, H, S. MS [IP 70 eV; m/e (% rel. int.):] 284 (100, M⁺), 210 (60, 9), 178 (70, Ph⁻=C⁻Ph), 121 (59, Ph−=CS), 106 (57, C₆H₄S₂). ¹H NMR and IR: identical with δ from benzoin. ¹³C NMR (20.15 MHz, CDCl₃): 29.0 (CH₂), 32.4 (CH₂S), 127.0 (C−C), 127.6, 131.0, 131.6, 142.2 (Ar).

1.0 g (3 mmol) 7a and 1.27 g (9 mmol) methyl iodide were reduced at −1.55 V, n=3.1 F mol⁻¹. 2,3-Bis(methylthio)-2,3-diphenylthrorran (9) was isolated by preparative layer chromatography on silica gel with CCl₄ (3 elutions).

Yield 0.25 g (28 %), colourless crystals, m. p. 150–152 °C (light petroleum). Anal. Found: C 61.79; H 6.35; S 30.40. Calc. for C₈₀H₁₄₂S₄: C 63.11; H 5.30; S 31.59; decomposition occurs during recrystallization. MS [IP 70 eV; m/e (% rel. int.):] 272 (2, M⁺−S), 195 (96, M−C₆H₄S), 121 (100, Ph−=CS), 77 (26, C₆H₄). ¹H NMR (270 MHz, CDCl₃): δ 1.69 (6H, s), 1.77 (6H, s), 7.1–7.4 (2OH, m); E—Z—9 are obtained as a mixture. IR: No C=C—band occurring.

1.0 g (3 mmol) 7c and 1.27 g (9 mmol) methyl iodide were reduced at −1.55 V, n=3.3 F mol⁻¹. 0.75 g of 10 crystallizes from the light petroleum extract on standing at 4 °C for several days. NMR-yield: 74 %. Chromatography on silica gel plates (Merck) with CCl₄ (3 elutions) and subsequent recrystallization gave equal amounts of meso-(R,S)-2,3-bis(methylthio)-2,3-diphenyl-1,4-dithiane (10a) Colourless crystals, m. p. 164–166 °C (light petroleum). Anal. C₈₀H₁₄₂S₄: C, H, S. ¹H NMR (400 MHz, CDCl₃): 1.74 (6H, s), 3.28 (2H, m), 3.56 (2H, m), 7.2 (10H, m), and d,1-(R, R,S,S)-2,3-bis(methylthio)-2,3-diphenyl-1,4-dithiane (10b) Colourless crystals m. p. 214–216 °C (light petroleum). Anal. C₈₁H₁₄₂S₄: C, H, S. ¹H NMR (400 MHz, CDCl₃): δ 1.71 (6H, s), 2.84 (2H, νs), 3.92 (2H, νs) [ν_s=12.2 Hz, ν_s=J=AX=−15.5 Hz, ν_s=J=AX=1.3 Hz, ν_s=J=XX=4.2 Hz], 7.15 (10H, m).

Electroreductions in methanol. The Pb-cathode was polished and rinsed with methanol before use. 650 ml of a 0.2 molar solution of tetraethylammonium bromide in methanol were filled into the cathodic compartment of the cell (Fig. 1). After 30 min waiting for compensation of the
on silica gel with $\text{CCl}_4/\text{CH}_2\text{Cl}_2$ (1:1) gave a small amount of the main product, which was not analytically pure, exhibited the expected NMR spectrum of $2,4,8,10$-tetraethyl-3,9-diphenylundecane (8a) (yellow liquid).

$^1$H NMR (60 MHz, $\text{CCl}_4$): $\delta$ 1.89 (6H, s), 1.6–3.8 (6H, m), 4.70 (2H, s), 7.3 (6H, m), 7.95 (4H, m).

Methyl benzoate, O-methyl thiobenzoate and benzaldehyde were detected as by-products by their characteristic NMR signals.

6 g (16.6 mmol) 7b and 5.6 g (39.7 mmol) methyl iodide were reduced at $-1.2$ V, $n=7.5$ F mol$^{-1}$. 4.76 g yellow oil were obtained. Column chromatography on silica gel with light petroleum/CH$_2$Cl$_2$ (4:1) gave $2,4,9,11$-tetraethyl-3,10-diphenylundecane (8b).

Yield 26% (by NMR), yellow liquid. Anal. Found: C 61.20; H 6.71; S 31.37. Calc. for C$_{20}$H$_{30}$S$_4$: C 60.86; H 6.64; S 32.50. MS [IP 70 eV; m/e (% rel. int.):] 137 (25, PhCH(SCH$_3$)), 136 (34), 135 (12), 122 (5, PhCHS), 121 (31, PhCS). $^1$H NMR (60 MHz, $\text{CCl}_4$): $\delta$ 1.63 (4H, m), 2.00 (6H, s), 2.43 (4H, m), 4.82 (2H, s), 7.3 (10H, m).

Methyl benzoate, O-methyl thiobenzoate, benzaldehyde and dibenzylsulfide were detected as by-products by their characteristic NMR signals.

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**REFERENCES**


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