# The Oxidation of a Selenium-bridged Bisquinoline Using
## m-Chloroperbenzoic Acid

### Werner Löwe* and Robert Schmidt

Institut für Pharmazie, Freie Universität Berlin,
Königin-Luise-Str. 2+4, D-14195 Berlin, Germany

### Peter Luger

Institut für Kristallographie, Freie Universität Berlin,
Takustr. 6, D-14195 Berlin, Germany
Received August 30, 1993
Revised June 7, 1994

The oxidation of compound **1** with m-chloroperbenzoic acid resulting in selenoxide **2**, seleninate **4** and selenite **6** is reported here.

The oxidation of selenides can lead to the formation of various products. Selenoxides [1-3] and selenones [3-5] are described in the literature as their primary oxidation products.

We investigated the oxidation of a selenium-bridged bisquinoline **1** Lit [6] in the presence of an excess of m-chloroperbenzoic acid (m-CPBA), as we shall describe in the following. The stated oxidation leads to the side-by-side formation of three products, namely the compounds **2**, **4** and **6**, which were separated by means of flash chromatography (Scheme I). Compound **2** comprises the 3,3' bis(4-chloroquinolyl)selenoxide, which arises from selenide **1** by means of direct oxidation. The fact that the compound **2** has an H-2 singlet at 9.18 ppm in the $^1$H-nmr spectrum demonstrates clear down-field shift as compared with the H-2 proton at 8.76 ppm in the compound **1**. An increase in molar mass (m/z = 16) was additionally observed in the mass spectrum. Another significant observation is the characteristically isotopic pattern of the mole peak, which is attributable to the large number of selenium and chlorine isotopes.

The structure of **2** was confirmed by a single X-ray analysis (Figure 1). In the crystal the molecular geometry is characterized by an anti-orientation of both C-Cl bonds with respect to the Se=O bond. Bond lengths, bond angles and atomic coordinates of compound **2** are given in Tables 1-3.

In the mass spectrum, the molar mass of the compound **4** was increased by a factor of m/z = 32 as compared with the educt **1**. This suggests the selenone **3** could have been formed. However, the $^1$H-nmr spectrum demonstrates no evidence of downfield shift of the H-2 proton as compared with that of the selenoxide **2**. Instead, two different H-2 singlet signals occur at 8.72 and 9.11 ppm, which leads us to conclude that the molecular structure is asymmetrical. This structure is suggestive of a seleninate **4**. Furthermore, the $^1$H-nmr spectrum also demonstrates that,
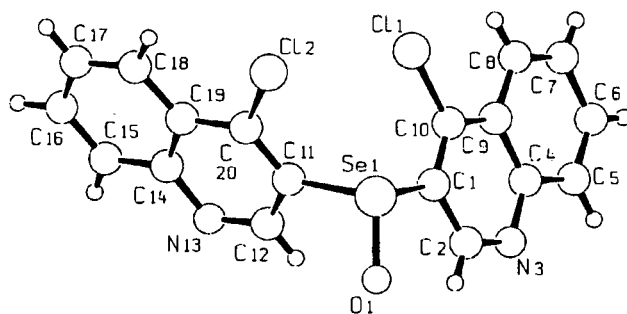


Figure 1. Molecular structure of **2** as obtained from X-ray analysis showing also the numbering scheme used. Drawing generated with SCHAKAL [11].

due to the occurrence of ethyl protons and due to the integral relationship, two molecules of seleninate **4** are bound to a molecule of ethanol. These findings were confirmed in elemental analyses. The ethanol was added during the course of the reprocessing of the reaction mixture.

Table 1
Bond Lengths (Å) of 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C - 1 | C - 2 | 1.405 | (4) | C - 1 | C -10 | 1.362 | (4) |
| C - 1 | Se- 1 | 1.957 | (2) | C - 2 | N - 3 | 1.308 | (3) |
| N - 3 | C - 4 | 1.375 | (4) | C - 4 | C - 5 | 1.411 | (4) |
| C - 4 | C - 9 | 1.423 | (4) | C - 5 | C - 6 | 1.348 | (5) |
| C - 6 | C - 7 | 1.408 | (5) | C - 7 | C - 8 | 1.353 | (4) |
| C - 8 | C - 9 | 1.413 | (4) | C - 9 | C -10 | 1.412 | (3) |
| C -10 | Cl- 1 | 1.731 | (3) | Se- 1 | O - 1 | 1.648 | (2) |
| Se- 1 | C -11 | 1.942 | (3) | C -11 | C -12 | 1.411 | (4) |
| C -11 | C -20 | 1.369 | (3) | C -12 | N -13 | 1.310 | (4) |
| N -13 | C -14 | 1.375 | (3) | C -14 | C -15 | 1.408 | (4) |
| C -14 | C -19 | 1.423 | (4) | C -15 | C -16 | 1.365 | (4) |
| C -16 | C -17 | 1.389 | (6) | C -17 | C -18 | 1.360 | (5) |
| C -18 | C -19 | 1.409 | (4) | C -19 | C -20 | 1.420 | (4) |
| C -20 | Cl- 2 | 1.734 | (3) | | | | |

The most recent studies show that selenium has a high affinity for oxygen [7]. This suggests that the compound **4**

## Table 2

### Bond Angles (deg) of 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C - 2 | C - 1 | C -10 | 118.6 (2) | C - 2 | C - 1 | Se- 1 | 117.1 (2) |
| C -10 | C - 1 | Se- 1 | 124.0 (2) | C - 1 | C - 2 | N - 3 | 124.1 (3) |
| C - 2 | N - 3 | C - 4 | 117.6 (2) | N - 3 | C - 4 | C - 5 | 118.2 (2) |
| N - 3 | C - 4 | C - 9 | 123.0 (2) | C - 5 | C - 4 | C - 9 | 118.8 (3) |
| C - 4 | C - 5 | C - 6 | 120.3 (3) | C - 5 | C - 6 | C - 7 | 121.2 (3) |
| C - 6 | C - 7 | C - 8 | 120.2 (3) | C - 7 | C - 8 | C - 9 | 120.5 (3) |
| C - 4 | C - 9 | C - 8 | 118.9 (2) | C - 4 | C - 9 | C -10 | 116.0 (2) |
| C - 8 | C - 9 | C -10 | 125.0 (2) | C - 1 | C -10 | C - 9 | 120.7 (2) |
| C - 1 | C -10 | Cl- 1 | 119.3 (2) | C - 9 | C -10 | Cl- 1 | 120.1 (2) |
| C - 1 | Se- 1 | O - 1 | 100.8 (1) | C - 1 | Se- 1 | C -11 | 95.7 (1) |
| O - 1 | Se- 1 | C -11 | 103.4 (1) | Se- 1 | C -11 | C -12 | 118.8 (2) |
| Se- 1 | C -11 | C -20 | 122.3 (2) | C -12 | C -11 | C -20 | 118.8 (3) |
| C -11 | C -12 | N -13 | 124.6 (2) | C -12 | N -13 | C -14 | 116.8 (3) |
| N -13 | C -14 | C -15 | 117.9 (3) | N -13 | C -14 | C -19 | 123.6 (3) |
| C -15 | C -14 | C -19 | 118.6 (3) | C -14 | C -15 | C -16 | 120.6 (3) |
| C -15 | C -16 | C -17 | 120.4 (3) | C -16 | C -17 | C -18 | 121.1 (3) |
| C -17 | C -18 | C -19 | 120.2 (3) | C -14 | C -19 | C -18 | 119.1 (3) |
| C -14 | C -19 | C -20 | 116.4 (2) | C -18 | C -19 | C -20 | 124.5 (3) |
| C -11 | C -20 | C -19 | 119.7 (3) | C -11 | C -20 | Cl- 2 | 120.7 (2) |
| C -19 | C -20 | Cl- 2 | 119.5 (2) | | | | |

## Table 3

Atomic Coordinates (x $10^4$) and Equivalent Isotropic Displacement Coefficients ($\text{Å}^2$ x $10^3$) of compound 2. U(eq) is defined as one third of the trace of the orthogonalized $U_{ij}$ tensor

| Atom | x | | y | | z | | U(eq) | |
|---|---|---|---|---|---|---|---|---|
| C - 1 | 4359 | (2) | 10842 | (3) | 3315 | (3) | 31.2 | (8) |
| C - 2 | 5087 | (2) | 10128 | (4) | 2004 | (4) | 37.5 | (9) |
| N - 3 | 5892 | (2) | 10920 | (3) | 797 | (3) | 40.3 | (8) |
| C - 4 | 6025 | (2) | 12557 | (3) | 814 | (3) | 35.1 | (9) |
| C - 5 | 6902 | (2) | 13414 | (4) | -455 | (4) | 47 | (1) |
| C - 6 | 7079 | (3) | 15006 | (4) | -460 | (4) | 50 | (1) |
| C - 7 | 6396 | (2) | 15857 | (4) | 779 | (4) | 47 | (1) |
| C - 8 | 5542 | (2) | 15082 | (4) | 2008 | (4) | 41 | (1) |
| C - 9 | 5334 | (2) | 13406 | (3) | 2078 | (3) | 31.9 | (8) |
| C -10 | 4492 | (2) | 12458 | (3) | 3350 | (3) | 32.6 | (8) |
| Cl- 1 | 3623.3 | (5) | 13338.5 | (9) | 4994 | (1) | 45.3 | (2) |
| Se- 1 | 3285.5 | (2) | 9355.0 | (4) | 5119.0 | (4) | 35.03 | (9) |
| O - 1 | 3516 | (2) | 7641 | (2) | 4333 | (3) | 48.7 | (7) |
| C -11 | 2115 | (2) | 10577 | (3) | 4223 | (3) | 32.1 | (8) |
| C -12 | 2104 | (2) | 10640 | (3) | 2445 | (4) | 36.1 | (9) |
| N -13 | 1350 | (2) | 11386 | (3) | 1701 | (3) | 39.8 | (8) |
| C -14 | 515 | (2) | 12152 | (3) | 2748 | (4) | 36.3 | (9) |
| C -15 | -291 | (2) | 13005 | (4) | 1959 | (5) | 50 | (1) |
| C -16 | -1143 | (3) | 13783 | (4) | 2933 | (5) | 58 | (1) |
| C -17 | -1227 | (2) | 13747 | (4) | 4719 | (5) | 55 | (1) |
| C -18 | -465 | (2) | 12950 | (4) | 5534 | (4) | 44 | (1) |
| C -19 | 431 | (2) | 12147 | (3) | 4568 | (4) | 35.4 | (9) |
| C -20 | 1275 | (2) | 11303 | (3) | 5288 | (3) | 33.9 | (8) |
| Cl- 2 | 1234.6 | (6) | 11222 | (1) | 7500.4 | (9) | 49.2 | (3) |
| H - 2 | 4990 | (2) | 9050 | (3) | 2000 | (3) | 39 | (8) |
| H - 5 | 7360 | (2) | 12840 | (3) | -1260 | (4) | 41 | (8) |
| H - 6 | 7660 | (2) | 15530 | (4) | -1210 | (4) | 51 | (9) |
| H - 7 | 6550 | (2) | 16870 | (4) | 740 | (4) | 51 | (9) |
| H - 8 | 5090 | (2) | 15600 | (3) | 2760 | (3) | 36 | (8) |
| H -12 | 2650 | (2) | 10120 | (3) | 1780 | (4) | 45 | (8) |
| H -15 | -250 | (2) | 12900 | (4) | 830 | (4) | 60 | (1) |
| H -16 | -1740 | (2) | 14380 | (4) | 2350 | (4) | 70 | (1) |
| H -17 | -1820 | (2) | 14260 | (4) | 5420 | (4) | 60 | (1) |
| H -18 | -460 | (2) | 12880 | (3) | 6740 | (4) | 43 | (8) |

probably occurs as a complex compound, the structure of which might better be described by the formula 7.

A similar rearrangement of selenones to seleninates was also described by Moch *et al.*, who studied the Diels-Alder reactions of butane-1,3-dienes and selenium dioxide [8]. Contrary to the assumptions of Becker and Strating [9], cyclic seleninates arise instead of cyclic selenones. Reich also observed a comparable rearrangement of methyl phenyl selenone into methyl phenylseleninate [10]. In these cases, the selenium atom is converted from an energy-rich hexavalent state to a less energy-rich tetravalent state.

The third product that we isolated was the 3,3'-bis(4-chloroquinolyl)-selenite 6. This is evidenced by the H-2 singlet signa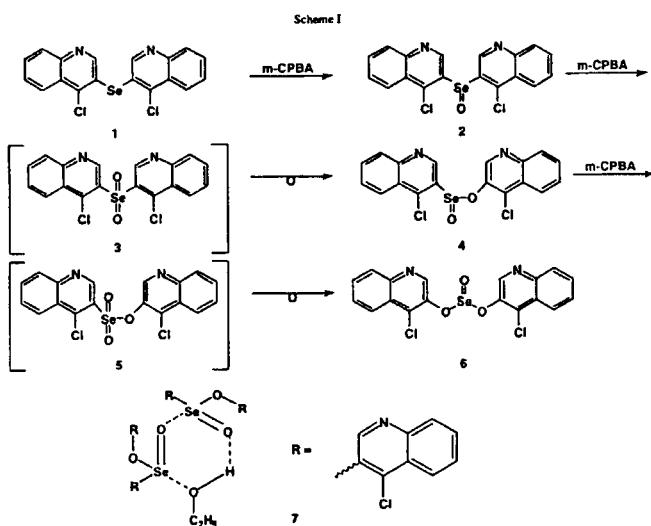l at 8.68 ppm in the $^1$H-nmr spectrum, which is indicative of a symmetrical molecular structure. The mole peak at m/z = 453 (+FAB), in addition to the characteristically isotopic pattern and the results of elemental analysis, confirm the structure 6. In this case, also, the unstable hexavalent ester 5 could first have arisen from the seleninic acid ester 4 by means of oxidation. The ester 5 then stabilizes after further rearrangement into the tetravalent selenite 6 form.

## EXPERIMENTAL

General Methods.

Melting points were determined on a Linström apparatus and are uncorrected. The ir spectra were recorded on a Perkin-Elmer 297 spectrometer. The $^1$H-nmr spectra were recorded on a Bruker AC 300 spectrometer. Mass spectra were obtained on a Finnegan MAT Bremen CH-7A spectrometer and Finnigan MAT Bremen CH-5 DF. Elemental analyses were performed by the Institute für Pharmazie Analytical Service Laboratory.



Scheme I

General Procedure for the Preparation of the Compounds **2**, **4** and **6**.

To a solution of **1** [6] (300 mg, 0.74 mmole) in dioxane (18 ml) was added *m*-CPBA (300 mg, 1.72 mmoles) in chloroform (18 ml) and the whole mixture was stirred at room temperature for 18 hours. The reaction mixture was evaporated to dryness *in vacuo*. After the residue was dissolved in ethanol (10 ml) under heating, the solution was filtered and flash column chromatographed on silica gel (Merck, Kieselgel 60, 230-400 mesh) using chloroform-ethanol (1:4) as an eluant to give **2** (120 mg, 39%, $R_f$ = 0.58), **4** (110 mg, 32%, $R_f$ = 0.50) and **6** (15 mg, 5%, $R_f$ = 0.38).

### 3,3'-Di-(4-chloroquinolyl)selenoxide (2).

This compound was obtained analytically pure as pale yellow crystals, mp 162°; ir (potassium bromide): 3050, 1610, 1560, 1485, 1335 cm⁻¹; ¹H-nmr (DMSO-d₆): δ 7.85 (t, 2H, J = 7.7 Hz, 2 H-7), 7.98 (t, 2H, J = 7.6 Hz, 2 H-6), 8.16 (d, 2H, J = 8.4 Hz, 2 H-8), 8.25 (d, 2H, J = 8.3 Hz, 2 H-5), 9.18 (s, 2H, 2 H-2); ms:+FAB m/z 421 ($^{35}$Cl, $^{80}$Se, MH⁺).

*Anal.* Calcd. for $C_{18}H_{10}Cl_2N_2OSe$: C, 51.44; H, 2.40; N, 6.66. Found: C, 51.43; H, 2.45; N, 6.62.

### 3'-(4'-Chloroquinolyl) 3-(4-chloroquinolyl)seleninate (4).

This compound was obtained analytically pure as pale yellow crystals, mp 155-157°; ir (potassium bromide): 3049, 1645, 1609, 1557, 1480, 1330 cm⁻¹; ¹H-nmr (DMSO-d₆): δ 1.06 (t, 3/2 H, J = 7.0 Hz, CH₃), 3.35 (s, br, 1/2 H, OH, exchangeable), 3.44 (q, 2/2 H, J = 7.0 Hz, CH₂), 7.84-8.01 (m, 4H, H-6, H-6´, H-7, H-7´), 8.14 (d, 1H, J = 8.3 Hz, H-8), 8.19 (d, 1H, J = 7.9 Hz, H-8´), 8.26 (d, 1H, J = 7.8 Hz, H-5), 8.58 (d, 1H, J = 8.1 Hz, H-5´), 8.72 (s, 1H, H-2´), 9.11 (s, 1H, H-2); ms: +FAB m/z 437 ($^{35}$Cl, $^{80}$Se, MH⁺).

*Anal.* Calcd. for $C_{18}H_{10}Cl_2N_2O_2Se\cdot1/2\ C_2H_6O$: C, 49.69; H, 2.85; N, 6.10. Found: C, 49.39; H, 2.71; N, 6.16.

### 3,3'-Di-(4-chloroquinolyl)selenite (6).

This compound was obtained analytically pure as pale yellow powder, mp 180-182°; ir (potassium bromide): 3070, 1645, 1610, 1570, 1490, 1330 cm⁻¹; ¹H-nmr (DMSO-d₆): δ 7.94-8.02 (m, 4H, 2 H-6, 2 H-7), 8.27 (d, 2H, J = 7.8 Hz, 2 H-8), 8.67 (d, 2H, J = 8.10 Hz, 2 H-5), 8.68 (s, 2H, 2 H-2); ms: +FAB m/z 453 ($^{35}$Cl, $^{80}$Se, MH⁺).

*Anal.* Calcd. for $C_{18}H_{10}Cl_2N_2O_3Se$: C, 47.81; H, 2.23; N, 6.19. Found: C, 47.38; H, 2.20; N, 6.13.

### Single Crystal X-ray Analysis of 2.

Crystals of $C_{18}H_{10}Cl_2N_2OSe$ were grown from chloroform/ethanol. Precise lattice parameters (from 80 high-order reflections with 25° ≤ 2θ ≤ 35°) and three-dimensional intensity data were measured on a Siemens diffractometer (AED) using Nb-filtered MoKα-radiation (λ = 0.71069 Å). A single crystal with approximate dimensions 0.45 x 0.35 x 0.30 mm was used to collect the intensity data of 3210 reflections of one hemisphere (2θ ≤ 52°, ± h, k, ± 1) by using the ω-2θ scan technique. No significant intensity variations monitored *via* three check reflections were observed. Merging gave 2991 unique reflections ($R_{int}$ = 0.8%, $R_\sigma$ = 1.8%) of which 289 reflections with $F_0 < 2\sigma$ ($F_0$) were considered unobserved.

Crystal Data.

Molecular formula $C_{18}H_{10}Cl_2N_2OSe$ ($M_r$ = 420.16), space group, triclinic P $\bar{1}$; unit cell, a = 13.368 (2), b = 8.146 (1), c = 7.987 (1) Å, α = 72.98 (2), β = 72.64 (2), γ = 82.07 (2)°, V = 792.6 Å³, Z = 2, $\rho_x$ = 1.761 g·cm⁻³, μ (MoKα) = 28.89 cm⁻¹. Phase determination was made with direct methods (program SHELXS 86 [12]); refinement was done with the corresponding least squares programs of the XTAL program system (version 2.2, 1987 [13]). All hydrogens were located from difference syntheses. A $1/\sigma^2$ ($F_0$) weighting scheme was used; σ ($F_0$) was from counting statistics. No significant peaks or holes were seen in a final difference Fourier map. After convergence R-values of R = 2.4% and $R_w$ = 2.5% were obtained. Supplementary material available: X-ray data including atomic coordinates with anisotropic displacement parameters, bond distances and angles and a list of observed and calculated structure factors.

## REFERENCES AND NOTES

[1]    H. Rheinboldt and E. Giesbrecht, *J. Am. Chem. Soc.*, **69**, 645 (1947).

[2]    W. R. Gaythwaite, J. Kenyon and H. Phillips, *J. Chem. Soc.*, 2280 (1928).

[3]    E. S. Gould and J. D. Mc Cullough, *J. Am. Chem. Soc.*, **73**, 3196 (1951).

[4]    W. Dilthey, L. Neuhaus, E. Reis and W. Schommer, *J. Prakt. Chem.*, **124**, 119 (1930).

[5]    R. Lesser and R. Weiss, *Chem. Ber.*, **46**, 2651 (1913).

[6]    W. Löwe and R. Schmidt, *J. Heterocyclic. Chem.*, in press.

[7]    D. H. R. Barton, M. B. Hall, Z. Lin, S. I. Parekh and J. Reibenspies, *J. Am. Chem. Soc.*, **115**, 5056, (1993).

[8]    W. L. Mock and J. H. Mc Causland, *Tetrahedron Letters*, 391 (1968).

[9]    H. J. Backer and R. L. Strating, *Rec. Trav. Chim.*, **53**, 1113 (1934).

[10]    H. J. Reich, Proc. Int. Symp. Uses Selenium Tellurium and Tellurium, Birmingham, 1983.

[11]    E. Keller, SCHAKAL 86, Program for the Graphic representation of Molecular and Crystallographic Models, University of Freiburg, Germany, 1988.

[12]    G. M. Sheldrick. In Crystallographic Computing 3, G. M. Sheldrick, C. Krüger and R. Goddard, eds, Oxford University Press, Oxford 1985, pp 175-198.

[13]    J. M. Stewart and S. R. Hall, eds, XTAL Program System 2.2, User's Manual, Universities of Western Australia and Maryland, 1987.