

Supporting Information (7 pages)

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An α,α' -Dioxothione in the Reaction of Ninhydrin with Potassium Thiothiosulfate and its [4+2] Cycloaddition with *trans*-Cyclooctene

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Experimental Section

General. Thermolyses were carried out in sealed (rubber stopper, Parafilm) NMR tubes by heating in an oil bath. ^1H - and ^{13}C -NMR spectra were recorded in CDCl_3 , CD_3CN , d_6 -DMSO or d_6 -acetone on a Bruker AC 200, Bruker Avance 400 or DMX 600 (^1H : 200 MHz, 400 MHz or 600 MHz; ^{13}C : 50 MHz, 100 MHz or 151 MHz) spectrometer, with CHCl_3 , CH_3CN , $(\text{CH}_3)_2\text{SO}$ or $(\text{CH}_3)_2\text{CO}$ as reference standards. The products were identified by comparison with the isolated or authentic materials. For quantitative NMR analysis, dimethyl isophthalate was used as internal standard. IR spectra were recorded on a FT-IR Perkin Elmer 1600 spectrophotometer. Mass spectra were recorded on a Finnigan MAT90 mass spectrometer. TLC analysis was conducted on precoated silica-gel foils Polygram SIL G/UV254 (40 \times 80 mm) from Machery and Nagel. Spots were visualized by UV light. Chromatography was performed on a Harrison Research Chromatotron (model 7924 T), equipped with a 4-mm or 2 mm plate of Merck 60 PF₂₅₄ silica gel.

Materials. Ninhydrin (**1a**), Lawesson reagent (Fluka) and potassium thiotosylate (**2**) (Sigma) were commercially available and were used without further purification. 1,2,3-Indanetrione (**1b**) was prepared from ninhydrin (**1a**) by azeotropic distillation with chlorobenzene.⁸ *trans*-Cyclooctene (**3a**) was synthesized by photosensitized isomerization of *cis*-cyclooctene, purified by extraction with AgNO₃ solution⁹ and stored under argon gas at -20 °C. Sodium tosylate was prepared by stirring *p*-toluenesulfonic acid with sodium ethanolate in methanol. Deuterated solvents were used without purification, the other solvents were cleaned up by standard procedures.

General Procedure for the Thermolysis of Ninhydrin (1a) or its 1,2,3-Indanetrione (1b) with Potassium Thiotosylate in the Presence of *trans*-Cyclooctene (3a). A NMR tube was charged with a solution of 0.14 to 0.15 mmol of ninhydrin (**1a**) or its 1,2,3-indanetrione (**1b**) and 2.6 to 4.0 equiv of *trans*-cyclooctene (**3a**) in 1.0 mL of the respective deuterated solvent. Dimethyl isophthalate (ca. 0.07 mmol) was added as internal standard and the ¹H-NMR spectra were recorded for the quantitative determination of the starting materials. Subsequently, 1 to 4 equiv of potassium thiotosylate (**2**) were added to the solution and the NMR tube was shaken vigorously for ca. 20 sec. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C. After heating for up to 23 h, the mixture was submitted to quantitative ¹H-NMR analysis to determine the extent of conversion and the product distribution against the internal standard. In the case of CD₃CN and d₆-acetone solutions, the colorless precipitation was removed by centrifugation prior to NMR analysis. The results are given in Table 1.

***trans*-2,3-[1',2',3',4',5',6'-Hexahydrocycloocta]-2,3-dihydro-indeno[1,2-*b*][1,4]oxathiin-9-one (6).** Samples of 200 mg (1.25 mmol) of 1,2,3-indanetrione (**1b**) and 517 μL (413 mg, 3.75 mmol) of *trans*-cyclooctene (**3a**) were dissolved in 10 mL of acetonitrile. Subsequently,

283 mg (1.25 mmol) of potassium thiotosylate (**2**) were added, and the resulting mixture was heated to 60 °C for 2 h. The colorless precipitation was removed by centrifugation and the solvent was evaporated at 30 °C/15 mbar. Chromatography on a 4-mm Chromatotron plate, followed by recrystallization, afforded 154 mg (0.538 mmol, 43%) of 1,4-oxathiin **6** as a deep red solid, mp 78-80°C (from hexane); R_f (1:1 petroleum ether/CH₂Cl₂) = 0.34; IR (KBr) 2913, 2846, 1691, 1605, 1568, 1464, 1450, 1396, 1347, 1323, 1282, 1132, 1071, 931; MS (EI, 70 eV) 286 (59, M⁺), 178 (100), 176 (9), 132 (10), 109 (21), 76 (8), 67 (31), 55 (7), 41 (9), 39 (4); ¹H NMR (CDCl₃, 600 MHz) δ 1.40-1.93 (m, 9 H); 1.95-2.02 (m, 1 H), 2.08-2.16 (m, 1 H), 2.21-2.29 (m, 1 H), 3.23 (ddd, $J = 8.7, 7.2, 2.6$ Hz, 1 H), 4.41 (ddd, $J = 8.7, 6.8, 2.2$ Hz, 1 H), 7.00 (d, $J = 7.0$ Hz, 1 H), 7.16 (dd, $J = 7.1, 7.1$ Hz, 1 H), 7.25 (dd, $J = 7.1, 7.1$ Hz, 1 H), 7.33 (d, $J = 7.1$ Hz, 1 H); ¹³C NMR (CDCl₃, 151 MHz) δ 23.8 (t), 25.1 (t), 26.1 (t), 26.2 (t), 28.6 (t), 30.9 (t), 41.7 (d), 85.1 (d), 104.3 (s), 116.5 (d), 121.1 (d), 128.8 (d), 132.2 (d), 132.8 (s), 139.3 (d), 168.0 (s), 190.0 (s); Anal. Calcd for C₁₇H₁₈O₂S (286.4): C, 71.30; H, 6.34; S, 11.17. Found: C, 71.13; H, 6.50; S, 10.97. The resonances were assigned by 2D spectroscopy (HH-COSY and HMBC).

Reaction of 1,2,3-Indanetrione (1b) with Potassium Thiotosylate (2) in the Presence of *trans*-Cyclooctene and Sodium Tosylate. A NMR tube was charged with a solution of 19.2 mg (0.120 mmol) of 1,2,3-indanetrione (**1b**) and 50 μL (40.0 mg, 0.360 mmol) of *trans*-cyclooctene (**3a**) in 1.0 mL of d₆-DMSO. Subsequently, 54.3 mg (0.240 mmol) of potassium thiotosylate (**2**) and 46.6 mg (0.240 mmol) of sodium tosylate were added at the same time and the NMR tube was shaken vigorously for ca. 20 sec. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C, and after heating for 23 h, the solution was submitted to ¹H-NMR analysis. 1,2,3-Indanetrione (**1b**) was converted to unidentified products (ca. 23%), but 1,4-oxathiin **6** nor thiirane **3b** were detected.

Reaction of 1,2,3-Indanetrione (1b) with Potassium Thiotosylate (2) in the Presence of 2,3-Dimethylbutadiene. A NMR tube was charged with a solution of 26.8 mg (0.167 mmol) of 1,2,3-indanetrione (**1b**) and 57 μ L (41.4 mg, 0.504 mmol) of 2,3-dimethylbutadiene (**4**) in 1.0 mL of CD₃CN. Subsequently, 37.8 mg (0.167 mmol) of potassium thiotosylate (**2**) were added and the NMR tube was shaken vigorously for ca. 20 sec. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C, and after heating for 5 h, the colorless precipitation was removed by centrifugation and the resulting clear solution was submitted to ¹H-NMR analysis. A 48:52 mixture of dihydrothiopyran **7**^{2c} and dihydropyran **8**⁷ was observed, no other products were detected.

Reaction of 1,2,3-Indanetrione (1b) with Lawesson Reagent in the Presence of *trans*-Cyclooctene (3a) or 2,3-Dimethylbutadiene (4). A 25-mL flask was charged with 0.630 g (1.56 mmol) of Lawesson's reagent and 0.502 g (3.14 mmol) 1,2,4-indanetrione (**1b**) in 12 mL of a 1:1 mixture of benzene/toluene under argon gas atmosphere. The mixture was placed into an oil bath (100 °C), and after 5 min, the color of the mixture changed from purple to brownish-red. Subsequently, 1230 μ L (990 mg, 9.00 mmol) of *trans*-cyclooctene (**3a**) or 1017 μ L (739 mg, 9.00 mmol) of 2,3-dimethylbutadiene (**4**) were added. and after heating for another 5 min, the mixture was allowed to cool to room temperature (ca. 20 °C) and the solvent was evaporated (40 °C/15 mbar). The remaining oil was dissolved in CDCl₃ and a ¹H-NMR spectrum was recorded. With *trans*-cyclooctene (**3a**), the 1,4-oxathiin **6** was detected as the major product together with various unidentified side products. In the reaction with 2,3-dimethylbutadiene (**4**), a 82:18 mixture of dihydrothiopyran **7**^{2c} and dihydropyran **8**⁷ was formed as the major products, together with various unidentified side products.

Thermolysis of Thiirane 3b in the Presence of Potassium Thiotosylate (2). A NMR tube was charged with a solution of 13.3 mg (0.0935 mmol) of thiirane **3b** and 21.1 mg

(0.0935 mmol) of potassium thiotosylate (**2**) in 1.0 mL of CD₃CN. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C, and after heating for 5 h, the solution was submitted to ¹H-NMR. The conversion of **3b** was < 5%.

Thermolysis of *trans*-Cyclooctene (3a**) in the Presence of Potassium Thiotosylate (**2**).** A NMR tube was charged with a solution of 61 μL (48.8 mg, 0.440 mmol) of *trans*-cyclooctene (**3a**) and 49.8 mg (0.220 mmol) of potassium thiotosylate (**2**) in 1.0 mL of CD₃CN. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C, and after heating for 5 h, the solution was submitted to ¹H-NMR analysis. The thiirane **3b** was not detected (mass balance of olefin was 90%).

Thermolysis of 1,2,3-Indanetrione (1b**) with Potassium Thiotosylate (**2**) and Subsequent Addition of *trans*-Cyclooctene (**3a**).** A NMR tube was charged with a solution of 23.3 mg (0.146 mmol) of 1,2,3-indanetrione (**1b**) and 32.9 mg (0.146 mmol) of potassium thiotosylate (**2**) in 1.0 mL of CD₃CN. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath at 60 °C, and after heating for 5 h, 60 μL (48.0 mg, 0.436 mmol) of *trans*-cyclooctene (**3a**) were added; the mixture was heated at 60 °C for another 2 h. The colorless precipitation was removed by centrifugation and the solution was submitted to ¹H-NMR analysis. The thiirane **3b** was not detected (mass balance of olefin was 91%).

Reaction of 1,2,3-Indanetrione (1b**) 1-Methoxycyclooctene (**9**).** A NMR tube was charged with a solution of 30.1 mg (0.188 mmol) of 1,2,3-indanetrione (**1b**) in 1.0 mL of CD₃CN and 99 μL (79.2 mg, 0.564 mmol) of 1-methoxycyclooctene (**9**) were added. The sealed tube (rubber stopper, Parafilm) was placed into an oil bath and heated at 60 °C for 3 h. Subsequently, the colorless solution was submitted to ¹H-NMR analysis and the ene product **10** was observed in 51% yield. Chromatography on a 2-mm Chromatotron plate, followed by

recrystallization, afforded 25.4 mg (0.0846 mmol, 45%) of the ene product **10** as colorless needles, mp 160-162°C (from petroleum ether); R_f (2:1 petroleum ether/diethyl ether) = 0.30; IR (KBr) 3380, 2960, 1760, 1715, 1610, 1475, 1385, 1270, 1190, 1060, 955. MS (EI, 70 eV) 300 (10, M^+), 139 (15), 125 (19), 112 (100), 107 (10), 104 (24), 97 (25), 85 (20), 79 (28), 76 (17), 72 (12), 67 (17), 55 (14), 41 (21); 1H NMR ($CDCl_3$, 400 MHz) δ 1.05-2.10 (m, 10 H); 2.68 (s, 3 H), 3.36 (dd, $J = 4.3, 12.4$ Hz, 1 H), 4.12 (s, 1 H), 4.47 (t, $J = 8.2$ Hz, 1 H), 7.80-8.00 (m, 4 H); ^{13}C NMR ($CDCl_3$, 151 MHz) δ 26.3 (t), 26.4 (t), 27.8 (2xt), 32.6 (t), 46.5 (d), 53.8 (q), 77.0 (s), 99.5 (d), 124.1 (d), 124.4 (d), 136.7 (d), 137.8 (d), 140.7 (s), 143.9 (s), 155.5 (s), 200.4 (s), 202.3 (s); Anal. Calcd for $C_{18}H_{20}O_4$ (300.3): C, 71.98; H, 6.71. Found: C, 72.05; H, 6.62. The resonances were assigned by 2D spectroscopy (CH-COSY).

Additional References

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- ⁹ Inoue, Y.; Tsuneishi, H.; Hakushi, T.; Tai, A. In *Photochemical Key Steps in Organic Synthesis, An Experimental Course Book*, Mattay, J.; Griesbeck, A., Eds.; VCH: Weinheim, 1994, p 207.

Structure Matrix

