73. Photoisomerization of 2*H*,6*H*-Thiin-3-one 1-Oxides to 3*H*,7*H*-[1,2]Oxathiepin-4-ones

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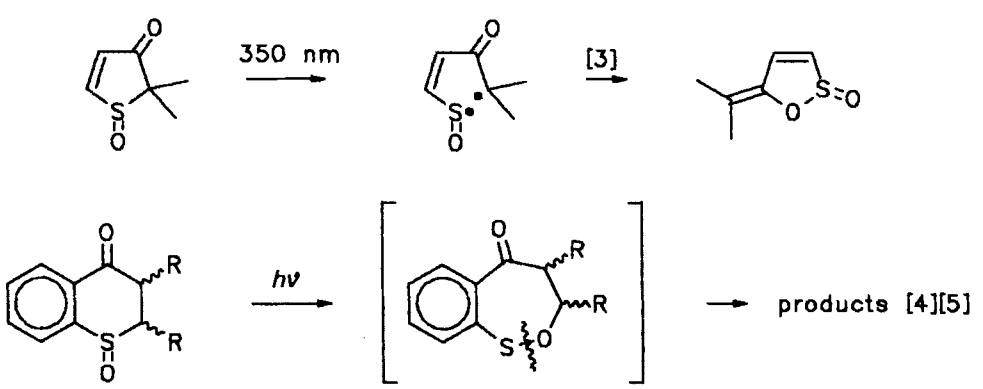
(22.II.93)

Oxidation of 2*H*,6*H*-thiin-3-ones **1a–c** with 3-chloroperbenzoic acid affords the corresponding 1-oxides **2a–c**. On irradiation (350 nm) in either benzene or MeCN, these cyclic sulfoxides **2** isomerize to 3*H*,7*H*-1,2-oxathiepin-4-ones **3**. The tetramethyl derivative **3a** is isolated by flash chromatography at −10°, but, at higher temperatures, it undergoes ring contraction and H_2O elimination to give 4,4-dimethyl-2-(2-methylprop-2-enylidene)thietan-3-one (**4**). Dimethyloxathiepinones **3b** and **3c** undergo ring contraction in MeOH to afford 1-(4-methylthiophen-2-yl)ethanone (**5**) and two diastereoisomeric 4,4-dimethyl-2-methoxy-2-(1-methoxyethyl)thietan-3-ones (**6** and **7**, respectively).

Introduction. – On irradiation, cyclic sulfoxides usually undergo C–S bond homolysis (α-cleavage) to a sulfinyl-alkyl biradical [1] [2]. These intermediates then react *via* different recombination processes, depending both on the ring size of the sulfoxide precursor and on its substitution pattern. Thus, the five-membered 2,2-dimethyl-3(2*H*)-thiophenone 1-oxide is converted (350 nm) quantitatively to 5-isopropylidene-1,2-oxathiol 1-oxide [3], while six-membered benzo[*b*]thiopyran-4-one 1-oxides afford mixtures of ring-contracted deoxygenated products [4] [5], albeit in low yields. Ring-expanded cyclic sulfenates have been proposed as intermediates in these latter reactions, and their instability attributed to rapid subsequent S–O bond homolysis (*Scheme 1*).

Scheme 1

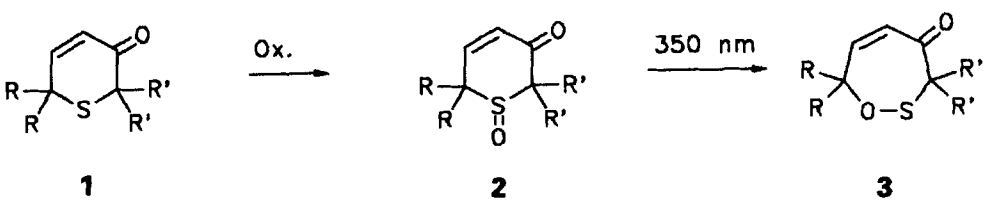


We have recently published results [6] on the photoisomerization of 2*H*,6*H*-thiin-3-ones **1**. We have now prepared the corresponding six-membered sulfoxides **2** by oxidation

of **1** with 3-chloroperbenzoic acid and report here, that *a*) on irradiation (350 nm) in either MeCN or benzene, these monocyclic sulfoxides isomerize to seven-membered cyclic sulfenates **3**, and that *b*) these oxathiepinones **3** react thermally – most probably *via* a [2,3]-sigmatropic rearrangement to intermediate thietan-3-one 1-oxides and a subsequent *Pummerer* reaction – to afford either a thietan-3-one or a 2-acylthiophene.

Results. – Monitoring an irradiated (350 nm) solution of **2a** ($5 \cdot 10^{-2}$ M) in either CD_3CN or C_6D_6 at 20° by ^{1}H-NMR indicates the formation of one new product **3a** in 54% yield. Similarly, **2b** and **2c** are converted exclusively to **3b** and **3c** in 67 and 45% yield, respectively (*Scheme 2*).

Scheme 2



1 **2** **3**

Warming up (40–60°) the CD_3CN solution containing **3a** leads to the disappearance of **3a** and the formation of one new product **4**. Flash chromatography at −10° after preparative irradiation of **2a** in acetonitrile allows the purification and isolation of **3a** in 48% yield. Attempts to isolate pure **3b** or **3c** by the same method failed. A comparison of the spectral data of **2** and **3** shows *a*) a shift to higher field and an increase in the vicinal coupling constants for the signals of the olefinic protons (δ = 6.6 and 6.1 ppm, J = 11.4 Hz for **2**, and δ = 5.9 and 5.8 ppm, J = 13.7 Hz for **3**); *b*) a shift to lower field for the C=O C-atom (δ = 192 ppm for **2** and 202 ppm for **3**); *c*) very similar mass spectra (with identical M^+ peaks) for both **2** and **3**. From these facts and from the additional spectroscopic data of **3** (*cf.* the *Table*), it becomes evident that compounds **3** are seven-membered cyclic sulfenates.

Table. *Spectroscopic Data of 1,2-Oxathiepin-4-ones* **3**

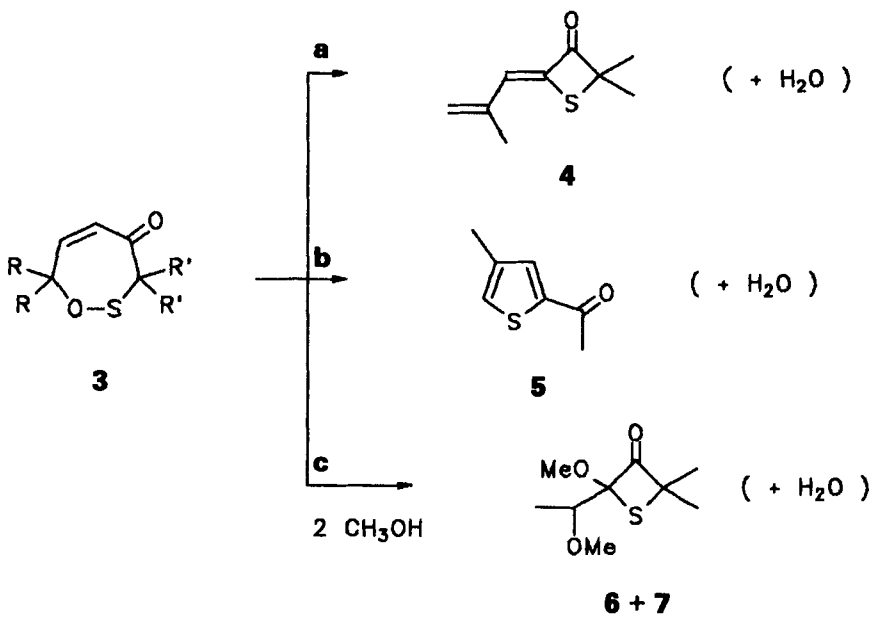
	3a	**3b**	**3c**
IR (neat)	1666, 1055	[a])	1664, 1050
^{1}H-NMR[b]) (CD_3CN)	5.99, 5.81 (*AB*, *J* = 13.7); 1.62 (*s*, 3H); 1.40 (*s*, 6H); 1.12 (*s*, 3H)	6.07, 5.82 (*AB*, *J* = 13.6); 3.96 (*s*, 2H); 1.41 (*s*, 6H)	6.17 (*dt*, *J* = 13.8, 2.9); 6.02 (*dt*, *J* = 13.8, 2.1); 4.64 (*dd*, *J* = 2.9, 2.1, 2H); 1.38 (*s*, 6H)
^{13}C-NMR[b]) (CD_3CN)	204.5 (*s*); 145.6 (*d*); 125.2 (*d*); 85.6 (*s*); 59.9 (*s*); 28.5, 25.2, 24.7, 18.7 (4*q*)	201.1 (*s*); 148.4 (*d*); 126.3 (*d*); 88.3 (*s*); 52.8 (*t*); 27.7 (*q*)	203.9 (*s*); 139.6 (*d*); 128.9 (*d*); 78.1 (*t*); 60.7 (*s*); 22.1 (*q*)
MS	186 (0.1, M^+), *123*	[a])	158 (7, M^+), *68*

[a]) Not measured due to the lack of purity.

[b]) Recorded at −40° because of line broadening of the Me signals due to slow conformational inversion at room temperature.

On warming up the MeCN solution after irradiation, **3b** is also converted to a new product **5**. Better yields of **5** (32% isolated yield) are obtained, if either MeOH is added to the solution of **3b**, or when the irradiation of **2b** is performed in this solvent. Similarly, **3c** decomposes in MeCN solution on warming, but no new defined products could be detected. Again, if MeOH is either added to the solution containing **3c** before warming up, or the irradidation of **2c** is performed in this solvent, two new (diastereoisomeric) products **6** and **7** can be isolated in 7 and 10% yield, respectively. The structures of the rearranged products **4**–**7** (*Scheme 3*) become evident from their spectra (*cf. Exper. Part*). In addition, 1-(4-methylthiophen-2-yl)ethanone (**5**) was independently synthesized from 3-methylthiophene *via* a bromination/acetylation/reductive debromination sequence [7].

Scheme 3

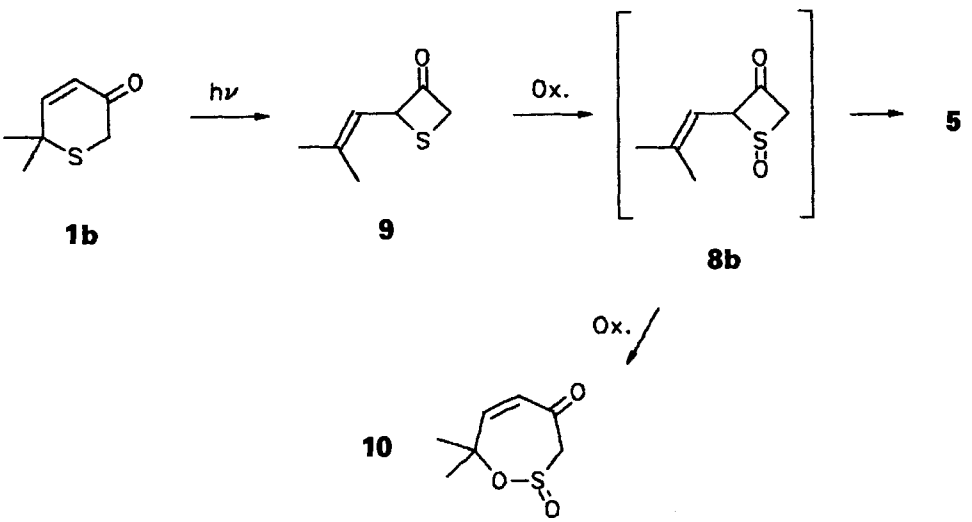


Discussion. – The isolation of **3a** – and the spectroscopic evidence for **3b** and **3c** in solution – represent the first examples of fully characterized light-induced ring enlargement of six-membered cyclic sulfoxides to oxathiepin derivatives. Up to now, such seven-membered cyclic sulfenates had been either simply proposed as plausible intermediates [4] [5] in photorearrangements of cyclic sulfoxides, or their intermediacy suggested on the basis of rather meagre spectroscopic evidence [8].

Even more interesting is the selective (thermal) rearrangement of the oxathiepinones **3** to either four- or five-membered sulfur heterocycles. Then clean conversion of **3a** to **4** (as monitored by ^{1}H-NMR) has to proceed either directly – which is highly improbable – or *via* a rather short lived unstable intermediate. In this context, allylic sulfenates are known to easily undergo [2,3]-sigmatropic rearrangement to sulfoxides [9] and, therefore, thietan-3-one 1-oxides **8** represent very likely intermediates in the conversion of **3a**, **3b**, and **3c** to **4**, **5**, and **6** + **7**, respectively. Indeed, if 2-(2-methylprop-1-enyl)thietan-3-one (**9**),

obtained by irradiation of **1b** [6], is treated with 3-chloroperbenzoic acid in CH_2Cl_2, acetylthiophene **5** is formed in 11% yield, the main product **10** turning out to be a seven-membered cyclic sulfinate, as deduced from its spectroscopic data in part very similar to that of **3b**. Oxathiepinone 2-oxide **10** probably arises from an intermediate thietan-3-one 1,1-dioxide, again *via* a [2,3]-sigmatropic rearrangement (*Scheme 4*). Precedents for ring enlargement of four-membered cyclic sulfones to sulfinates occurring at low temperature are found in the literature [10] [11].

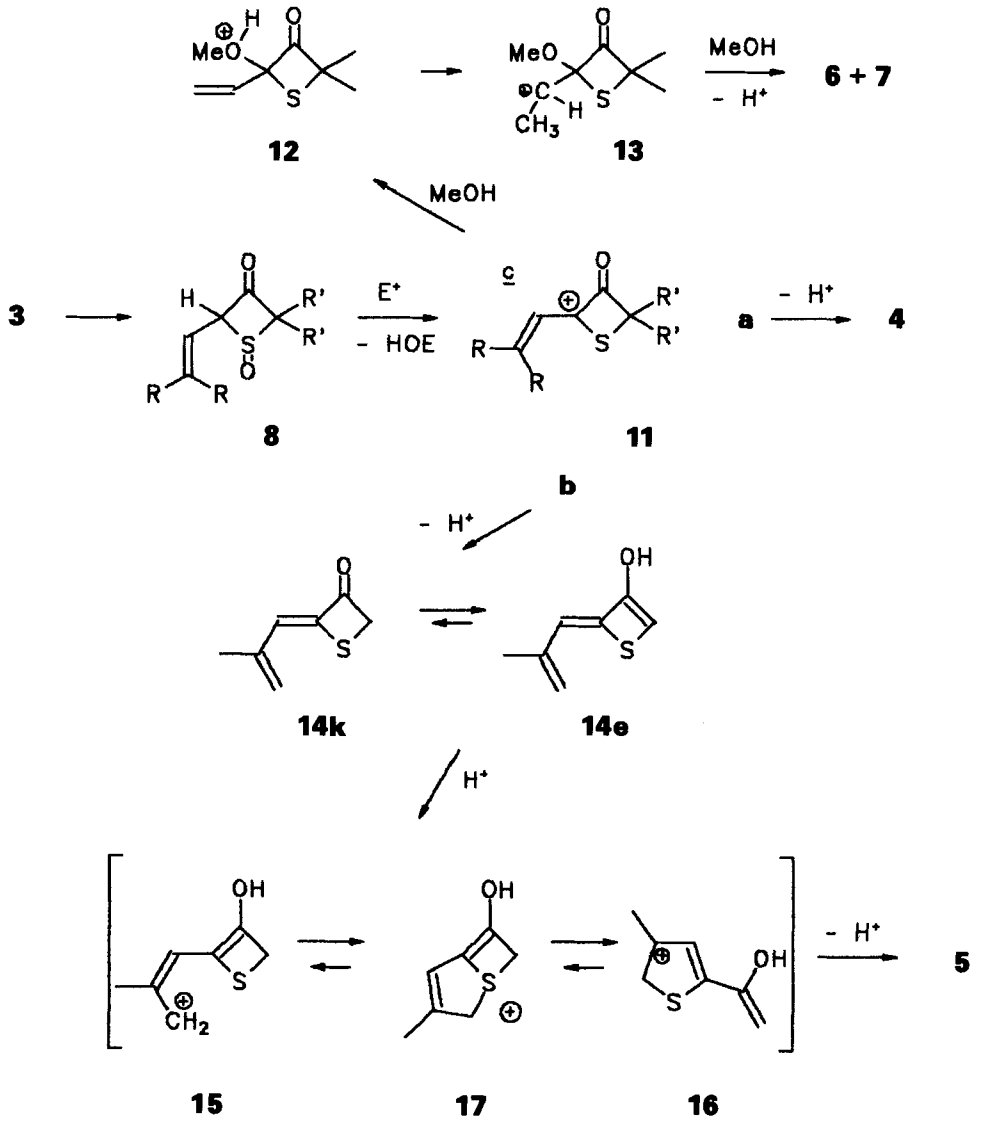
Scheme 4



Considering thietan-3-one 1-oxides **8** as intermediates in the conversion of sulfenates **3** to the isolated products **4**–**7**, the open questions remaining are: *a*) how do these rearrangements **3a**→**4** (in MeCN), **3b**→**5** (better in MeOH than in MeCN), and **3c**→**6** + **7** (only in MeOH) proceed, and *b*) why do **3a** and **3c** rearrange to thietanones, while **3b** rearranges to a thiophene? The mechanistic sequence summarized in *Scheme 5* gives reasonable answers to these questions.

Most probably, the second common intermediate to all products observed is the α-sulfur substituted carbocation **11** formed from **8** *via* a *Pummerer* reaction [12]. The formation of **4** from **8a** *via* **11a** thus corresponds to a α-sulfinyl-ketone→α-oxovinyl sulfide rearrangement [13]. Similarly, cation **11c** is trapped by MeOH to give **12** which isomerizes to **13**. This species adds a (second) molecule of MeOH to give *meso*- and *rac*-dimethoxy adducts **6** and **7**. In contrast to **8a** and **8c** (R′ = CH_3), which rearrange to final products of the same ring size, **8b** (R′ = H) affords thiophene **5**. A plausible sequence involving the required ring enlargement is based on the selective C-protonation of enol **14e** to give the (delocalized) pentadienyl cation **15**, which then undergoes valence isomerization to the (new) pentadienyl cation **16** *via* the bicyclic bridgehead sulfenium ion **17**. The better yields of **5** in MeOH as compared to MeCN and the incorporation of 1–2 D-atoms on the acetyl CH_3 group of **5** on irradiation of **2b** in CD_3OD support the assumption of such enolic intermediates.

Scheme 5



Financial support of this work by the *Deutsche Forschungsgemeinschaft* and the *Fonds der Chemischen Industrie* is gratefully acknowledged. Thanks are also due to Dr. *V. Sinnwell* for measuring the low-temperature NMR spectra.

Experimental Part

General. Photolyses: *Rayonet RPR-100* photoreactor equipped with 350-nm lamps. GC: 30-m *SE 30* capillary column. UV Spectra (MeCN): in nm ($\log\varepsilon$). IR Spectra (neat): in cm^{-1}. ^1H- and ^{13}C-NMR Spectra: at 400 and 100.63 MHz, resp., chemical shifts in ppm rel. to TMS (= 0 ppm), coupling constants J in Hz. MS: at 70 eV; in m/z (rel. intensity in %).

Preparation of Thiinone 1-Oxides **2**. To a soln. of 20 mmol of **1** in 50 ml of CH_2Cl_2 at −10° are added 3.50 g (20 mmol) of 3-chloroperbenzoic acid, and the mixture is then stirred 16 h at r.t. After filtration from the precipitated 3-chlorobenzoic acid, the filtrate is evaporated and the residue purified by chromatography on SiO_2.

*2,2,6,6-Tetramethyl-2*H,*6*H-*thiin-3-one 1-Oxide* (**2a**). CH_2Cl_2/MeOH 97:3, 35%, oil. UV: 354 (2.01), 275 (2.33), 219 (3.91). IR: 1675, 1052. ^1H-NMR ($CDCl_3$): 6.50, 6.01 (*2d*, J = 11.7, 2H); 1.56, 1.54, 1.51, 1.50 (*3s*, CH_3). ^{13}C-NMR ($CDCl_3$): 196.3 (*s*); 147.6 (*d*); 125.5 (*d*); 62.4 (*s*); 53.2 (*s*); 26.4, 22.6, 22.1, 19.1 (*4q*, CH_3). MS: 186 (1, M^+), *123*.

*6,6-Dimethyl-2*H,*6*H-*thiin-3-one 1-Oxide* (**2b**). Et_2O, 68%, oil. UV: 350 (2.00), 265 (2.40), 222 (3.81). IR: 1685, 1051. ^1H-NMR ($CDCl_3$): 6.60, 6.10 (*2d*, J = 11.3, 2H); 3.88, 3.68 (*AB*, J = 15.6, 2H); 1.57 (*s*, 6H). ^{13}C-NMR ($CDCl_3$): 188.2 (*s*); 149.9 (*d*); 128.4 (*d*), 53.2 (*t*); 52.9 (*s*); 24.2, 20.8 (*2q*, CH_3). MS: 158 (6, M^+), *95*.

*2,2-Dimethyl-2*H,*6*H-*thiin-3-one 1-Oxide* (**2c**). Acetone/hexane 2:1, 96%, oil. UV: 342 (2.0), 267 (2.39), 230 (3.71). IR: 1680, 1052. ^1H-NMR ($CDCl_3$): 6.66 (*ddd*, J = 4.0, 5.5, 11.2); 6.21 (*ddd*, J = 1.5, 2.5, 11.2); 3.83 (*ddd*, J = 1.5, 5.5, 17.5); 3.61 (*ddd*, J = 2.5, 4.0, 17.5); 1.53, 1.50 (*2s*, CH_3). ^{13}C-NMR ($CDCl_3$): 195.6 (*s*); 134.7 (*d*); 130.0 (*d*); 62.7 (*s*); 43.7 (*t*); 19.3, 16.1 (*2q*, CH_3). MS: 158 (3, M^+), *68*.

Photochemical Conversion **2**→**3** *in MeCN*. An Ar degassed soln. of 0.2 mmol of **2** in 0.5 ml of CD_3CN containing 5 mg of CH_3CN as internal standard is irradiated in a quartz NMR tube at 20° and monitored by ^1H-NMR. After 5 h, the composition is as follows: **2a** < 5%, **3a** 54%; **2b** 25%, **3b** 67%; **2c** < 5%, **3c** 45%. After recording the ^1H- and ^{13}C-NMR spectra and evaporation of the solvent, the crude residue is further analyzed by IR and MS (**3a** and **3c**). Flash chromatography at −10° (SiO_2, 2-chloropropane) allows the purification of *3,3,7,7-tetramethyl-3*H,*7*H-*[1,2]oxathiepin-4-one* (**3a**), 46%, oil. Under the same conditions, *3,3-dimethyl-3*H,*7*H-*[1,2]oxathiepin-4-one* (**3b**), and *7,7-dimethyl-3*H,*7*H-*[1,2]oxathiepin-4-one* (**3c**) are obtained contaminated with 10–15% of **2** (for spectroscopic data of **3a**–**c**, *cf.* the *Table*).

Preparative Irradiation of **2a** *in MeCN*. An Ar-degassed soln. of 94 mg (0.5 mmol) of **2a** in 8 ml of CH_3CN is irradiated without external cooling (T = 45°) for 3 h. Evaporation of the solvent and chromatography of the residue (SiO_2, 2-chloropropane) affords 43 mg (50%) of *4,4-dimethyl-2-(2-methylprop-2-enylidene)thietan-3-one* (**4**) as a colourless oil. IR: 1755, 1608, 1588. ^1H-NMR ($CDCl_3$): 6.87 (*d*, J = 0.7); 5.31 (*m*, 1H); 5.22 (*m*, 1H); 1.94 (*dd*, J = 0.7, 1.0, 3H); 1.69 (*s*, 6H). ^{13}C-NMR ($CDCl_3$): 196.5 (*s*); 141.0 (*s*); 125.4 (*ds*); 122.6 (*t*); 78.2 (s); 29.7 (*q*); 25.6 (*q*); 20.6 (*q*). MS: 168 (9, M^+), *153*.

Preparative Irradiation of **2b** *in MeOH*. An Ar-degassed soln. of 84 mg (5 mmol) of **2b** in 8 ml of MeOH is irradiated for 8 h. After evaporation of the solvent, the residue is purified by chromatography (SiO_2, CH_2Cl_2) to afford 23 mg (33%) of *1-(4-methylthiophen-2-yl)ethanone* (**5**) as a colourless liquid. IR: 1662. ^1H-NMR ($CDCl_3$): 7.50 (*m*, 1H); 7.23 (*m*, 1H); 2.53 (*s*, 3H); 2.29 (*m*, 3H). ^{13}C-NMR ($CDCl_3$): 190.6 (*s*); 144.1 (*s*); 138.8 (*s*); 134.4 (*d*); 129.5 (*d*); 26.7 (*q*); 15.5 (*q*). MS: 140 (41, M^+), *125*.

Preparative Irradiation of **2c** *in MeOH*. An Ar-degassed soln. of 84 mg (5 mmol) of **2c** in 8 ml of MeOH is irradiated for 18 h. After evaporation of the solvent and chromatography (SiO_2, CH_2Cl_2) one obtains first (tentative stereochemical assignment) 7 mg (7%) of meso-*4,4-dimethyl-2-methoxy-2-(1-methoxyethyl)thietan-3-one* (**6**) as colourless oil. IR: 1769, 1455. ^1H-NMR ($CDCl_3$): 3.68 (*q*, J = 6.0); 3.44 (*s*, 3H); 3.35 (*s*, 3H); 1.62 (*s*, 3H); 1.60 (*s*, 3H); 1.22 (*d*, J = 6.0, 3H). ^{13}C-NMR ($CDCl_3$): 207.5 (*s*); 115.2 (*s*); 79.0 (*d*); 68.1 (*s*); 57.2 (*q*); 53.6 (*q*); 26.5, 25.5, 14.5 (*3q*, CH_3). CI-MS: 173 (11, $[MH - MeOH]^+$), *145*.

The second fraction consists of 11 mg (11%) of rac-*4,4-dimethyl-2-methoxy-2-(1-methoxyethyl)thietan-3-one* (**7**) as colourless oil. IR: 1769, 1456. ^1H-NMR ($CDCl_3$): 3.74 (*q*, J = 6.4); 3.45 (*s*, 3H); 3.43 (*s*, 3H); 1.64 (*s*, 3H); 1.59 (*s*, 3H); 1.33 (*d*, J = 6.4, 3H). ^{13}C-NMR ($CDCl_3$): 204.1 (*s*); 113.8 (*s*); 81.7 (*d*); 67.1 (*s*); 57.9 (*q*); 53.6 (*q*); 26.6, 26.1, 14.5 (*3q*, CH_3). CI-MS: 173 (11, $[MH - MeOH]^+$), *145*.

REFERENCES

[1] I. W. J. Still, in 'Organic Sulfur Chemistry', Eds. F. Bernardi, I. G. Csizmadia, and A. Mangini, Elsevier, Lausanne, 1985, p. 606.
[2] I. W. J. Still, in 'The Chemistry of Sulphoxides and Sulphones', Eds. S. Patai, Z. Rappoport, and C. J. M. Stirling, Wiley, New York, 1988, p. 873.
[3] R. Kowalewski, P. Margaretha, *Angew. Chem.* **1988,** *100*, 1437.
[4] I. W. Still, P. C. Arora, M. S. Chauhan, M. H. Kwan, M. T. Thomas, *Can. J. Chem.* **1976,** *54*, 455.
[5] I. W. J. Still, P. C. Arora, S. K. Hasan, G. W. Kutney, L. Y. T. Lo, K. Turnbull, *Can. J. Chem.* **1981,** *59*, 199.
[6] E. Er, P. Margaretha, *Helv. Chim. Acta* **1992,** *75*, 2265.
[7] H. D. Hartough, *J. Am. Chem. Soc.* **1951,** *73*, 4033.
[8] A. G. Schulz, R. H. Schlessinger, *Tetrahedron Lett.* **1973,** 3605.
[9] S. Braverman, in 'The Chemistry of Sulphenic Acids', Ed. S. Patai, Wiley, New York, 1990, p. 311.
[10] M. Christl, E. Brun, F. Lanzendörfer, *J. Am. Chem. Soc.* **1984,** *106*, 373.
[11] U. Burger, C. Gmünder, S. Schmidlin, G. Bernardinelli, *Helv. Chim. Acta* **1990,** *73*, 1724.
[12] O. De Lucchi, U. Miotti, G. Modena, *Org. React.* **1991,** *40*, 157.
[13] H. L. Monteiro, A. L. Gemal, *Synthesis* **1975,** 437.