1,3-Oxathiolanes from the Reaction of Aromatic and Enolized Thioketones with Monosubstituted Oxiranes

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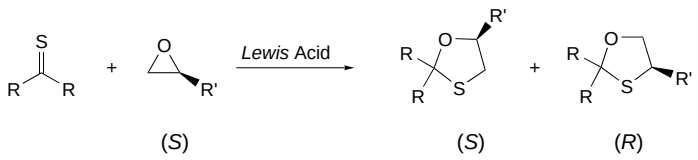
The reactions of 4,4′-dimethoxythiobenzophenone (**1**) with (*S*)-2-methyloxirane ((*S*)-**2**) and (*R*)-2-phenyloxirane ((*R*)-**6**) in the presence of a *Lewis* acid such as $BF_3 \cdot Et_2O$, $ZnCl_2$, or SiO_2 in dry CH_2Cl_2 led to the corresponding 1:1 adducts, *i.e.*, 1,3-oxathiolanes (*S*)-**3** with Me at C(5), and (*S*)-**7** and (*R*)-**8** with Ph at C(4) and C(5), respectively. A 1:2 adduct, 1,3,6-dioxathiocane (4*S*,8*S*)-**4** and 1,3-dioxolane (*S*)-**9**, respectively, were formed as minor products (*Schemes 3* and *5*, *Tables 1* and *2*). Treatment of the 1:1 adduct (*S*)-**3** with (*S*)-**2** and $BF_3 \cdot Et_2O$ gave the 1:2 adduct (4*S*,8*S*)-**4** (*Scheme 4*). In the case of the enolized thioketone 1,3-diphenylprop-1-ene-2-thiol (**10**) with (*S*)-**2** and (*R*)-**6** in the presence of SiO_2, the enesulfanyl alcohols (1′*Z*,2*S*)-**11** and (1′*E*,2*S*)-**11**, and (1′*Z*,2*S*)-**13**, (1′*E*,2*S*)-**13**, (1′*Z*,1*R*)-**15**, and (1′*E*,1*R*)-**15**, respectively, as well as a 1,3-oxathiolane (*S*)-**14** were formed (*Schemes 6* and *8*). In the presence of HCl, the enesulfanyl alcohols (1′*Z*,2*S*)-**11**, (1′*Z*,2*S*)-**13**, (1′*E*,2*S*)-**13**, (1′*Z*,1*R*)-**15**, and (1′*E*,1*R*)-**15** cyclize to give the corresponding 1,3-oxathiolanes (*S*)-**12**, (*S*)-**14**, and (*R*)-**16**, respectively (*Schemes 7*, *9*, and *10*). The structures of (1′*E*,2*S*)-**11**, (*S*)-**12**, and (*S*)-**14** were confirmed by X-ray crystallography (*Figs. 1–3*). These results show that 1,3-oxathiolanes can be prepared directly *via* the *Lewis* acid-catalyzed reactions of oxiranes with non-enolizable thioketones, and also in two steps with enolized thioketones. The nucleophilic attack of the thiocarbonyl or enesulfanyl S-atom at the *Lewis* acid-complexed oxirane ring proceeds with high regio- and stereoselectivity *via* an S_N2-type mechanism.

1. Introduction. – Recent studies have shown that 1,3-oxathiolanes are easily prepared *via* the *Lewis* acid-catalyzed reaction of oxiranes with thioketones. The mechanism of this reaction has been investigated intensively [1–6]. The results reported so far indicate that the formation of 1,3-oxathiolanes in the case of non-enolizable thiocarbonyl compounds proceeds with high regio- and stereoselectivity *via* an S_N2-type mechanism (*Scheme 1*). With alkyl-substituted oxiranes, the nucleophilic attack occurs at C(3) and leads to the product with retention of configuration, whereas phenyloxirane is attacked mainly at C(2) under inversion of the configuration.

Scheme 1



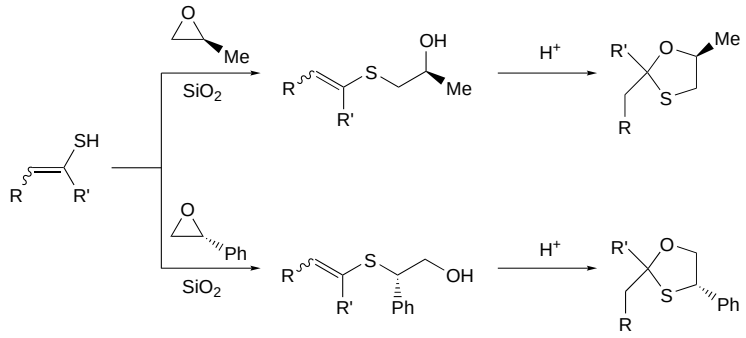
Enolizable thioketones exist predominantly in the enethiol form [7][8], and in extreme cases, *e.g.* dibenzyl thioketone, only the enethiol form can be detected [9].

[1]) Part III of the projected Ph.D. thesis of *C. F.*, University of Zurich. Part I: [1], Part II: [2].

These enethiols undergo different reactions with oxiranes, yielding enesulfanyl alcohols, but not 1,3-oxathiolanes [10].

The *Lewis* acid-catalyzed reaction of (1*R*,4*R*)-thiocamphor, an enolizable thioketone, with oxiranes gave the expected enesulfanyl alcohols, as well as the spirocyclic 1,3-oxathiolanes, with high regio- and stereoselectivity in good yields. Surprisingly, the enesulfanyl alcohols cyclized smoothly to 1,3-oxathiolanes in the presence of traces of HCl [2]. On the basis of the results described above, the preparation of 1,3-oxathiolanes *via* the *Lewis* acid-catalyzed reactions of open chain enethiols with oxiranes can be performed in two steps (*Scheme 2*).

Scheme 2



The objective of the present study was to gain more insight into the regio- and stereoselectivity of the ring-opening of optically active oxiranes by thioketones, in particular, to establish the scope and limitation of the formation of 1,3-oxathiolanes. Reactions of 4,4′-dimethoxythiobenzophenone (**1**) and 1,3-diphenylprop-1-ene-2-thiol (**10**), the enethiol of dibenzyl thioketone, with optically active oxiranes were carried out. In the present paper, the results of the reactions of **1** and **10** with (*S*)-2-methyloxirane ((*S*)-**2**) and (*R*)-2-phenyloxirane ((*R*)-**6**) are described.

2. Results. – 2.1. *Reaction of 4,4′-Dimethoxythiobenzophenone* (**1**) *with (*S*)- and (*R*)-2-Methyloxirane* ((*S*)-**2** and (*R*)-**2**). The reaction of **1** with (*S*)-**2** was carried out in dry CH_2Cl_2 at $-30°$ under an N_2 atmosphere in the presence of $ZnCl_2$. After 2 h 20 min, the dark blue solution turned to light yellow, and the reaction was quenched with H_2O. Chromatographic separation gave the 1:1 adduct (*S*)-**3** and the 1:2 adduct (4*S*,8*S*)-**4**, as well as 4,4′-dimethoxybenzophenone (**5**) in 47, 7, and 35% yield, respectively. The reaction of **1** with (*R*)-**2** under the same conditions for 2 h 45 min led to (*R*)-**3**, (4*R*,8*R*)-**4**, and **5** in 47, 5, and 37% yield, respectively. Treatment of a mixture of **1** and (*S*)-**2** in dry CH_2Cl_2 at room temperature for 8 h with silica gel led to (*S*)-**3**, (4*S*,8*S*)-**4**, and **5** in 67, 3, and 18% yield, respectively (*Scheme 3* and *Table 1*).

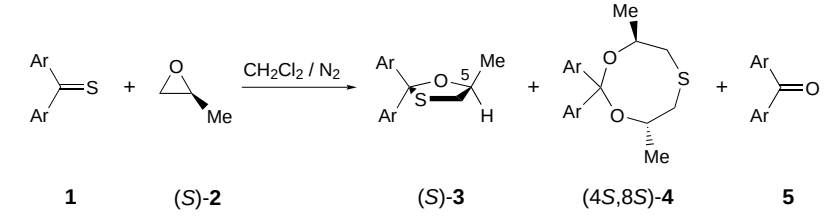
The structures of (*S*)-**3** and (4*S*,8*S*)-**4** were assigned on the basis of their ^{1}H- and ^{13}C-NMR spectra, and by comparison of these spectra with those described in [6]. The

Table 1. *$ZnCl_2$- and SiO_2-Catalyzed Reaction of* **1** *with* (S)-**2** *and* (R)-**2** *in CH_2Cl_2*

	Temp.	Reaction time	Yield [%], specific rotation ($[\alpha]_D^{23}$, $c = 1$, in THF), and enantiomeric excess (ee) of products (HPLC)		
			(*S*)-**3**	(4*S*,8*S*)-**4**	**5**
$ZnCl_2$, (*S*)-**2**	$-30°$	2 h 20 min	47, -22.6, 98% ee	7, -254.8[a]), >99% ee	35
SiO_2, (*S*)-**2**	r.t.	8 h	67, -22.2, 97% ee	3, -162.1, >99% ee	18
			(*R*)-**3**	(4*R*,8*R*)-**4**	**5**
$ZnCl_2$, (*R*)-**2**	$-30°$	2 h 45 min	47, $+23.8$, 98% ee	5, $+255.7$[a]), >99% ee	37

[a]) $c = 1$, in CH_2Cl_2.

Scheme 3



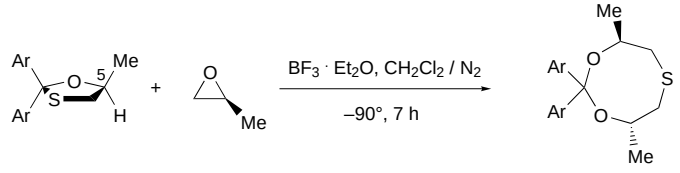
1 (*S*)-**2** (*S*)-**3** (4*S*,8*S*)-**4** **5**

Ar = 4-MeOC$_6$H$_4$

enantiomeric excess (ee) of the products was determined by analytical HPLC (*Chiralcel OD-H*, hexane/i-PrOH 1000:1)[2]).

2.2. *Reaction of* (*S*)-**3** *with* (*S*)-**2**. To explain the formation of the 1:2 adduct (4*S*,8*S*)-**4**, the 1:1 adduct (*S*)-**3** was reacted with (*S*)-**2** at $-90°$ for 7 h in the presence of $BF_3 \cdot Et_2O$ (*cf.* [6]). After chromatographic separation, the expected 1:2 *trans*-adduct (4*S*,8*S*)-**4** was obtained in 3% yield. The starting material (*S*)-**3** was recovered in 30% yield (*Scheme 4*).

Scheme 4



(*S*)-**3** (*S*)-**2** (4*S*,8*S*)-**4**

Ar = 4-MeOC$_6$H$_4$ 3% (> 99% ee)

[2]) The absolute configurations have been assigned based on the knowledge that ring opening of 2-methyloxirane (**2**) occurs *via* nucleophilic attack at C(3) and cleavage of the O–C(3) bond under retention of the configuration at C(2) (see *Sect. 2.4* and [2]).

In an analogous reaction of (*R*)-**3** with (*S*)-**2** under the same conditions, no 1:2 adduct was formed, but most of (*R*)-**3** decomposed to **5**; only 11% of (*R*)-**3** were recovered.

2.3. *Reaction of 4,4′-Dimethoxythiobenzophenone* (**1**) *with (*R*)- and (*S*)-2-Phenyloxirane* ((*R*)- **6** and (*S*)-**6**). To a solution of **1** and 0.6 equiv. of $BF_3 \cdot Et_2O$ in dry CH_2Cl_2 at $-80°$ under N_2, 3 equiv. of (*S*)-**6** were added dropwise. The violet color of the solution changed rapidly to light yellow. After 5 min, the reaction was quenched by addition of H_2O, and chromatographic workup gave (*R*)-**7**, (*R*)-**9**, and **5** in 41, 9, and 45% yield, respectively. Similarly, in the presence of $ZnCl_2$ at $-30°$ (2 h 50 min), the reaction of **1** with (*R*)-**6** led to (*S*)-**7** in 60% yield. The SiO_2-catalyzed reaction of **1** with (*R*)-**6** at room temperature for 1 h 40 min gave (*S*)-**7** in 77% yield, as well as an unexpected isomer (*R*)-**8** in 2% yield. In addition, **5** was isolated in 19% yield (*Scheme 5* and *Table 2*).

Scheme 5

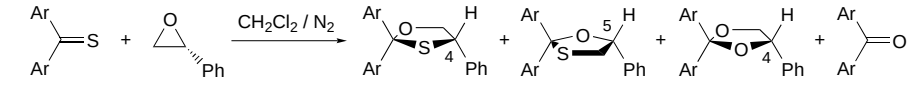


Table 2. Lewis *Acid-Catalyzed Reaction of* **1** *with (*S*)-***6*** and (*R*)-***6*** in CH_2Cl_2*

	Temp.	Reaction time	Yield [%], specific rotation ($[\alpha]_D^{23}$, $c = 1$, in THF), and enantiomeric excess (ee) of products (HPLC)			
			(*R*)-**7**	(*S*)-**8**	(*R*)-**9**	**5**
$BF_3 \cdot Et_2O$, (*S*)-**6**	$-80°$	5 min	41, +11.4, 94% ee	–	9, −7.8	45
			(*S*)-**7**	(*R*)-**8**	(*S*)-**9**	**5**
$ZnCl_2$, (*R*)-**6**	$-30°$	2 h 50 min	60, −10.2, 88% ee	–	–	–
SiO_2, (*R*)-**6**	r.t.	1 h 40 min	77, −11.8, 94% ee	2, −79.4, 92% ee	–	19

The structures of (*R*)- and (*S*)-**7**, (*R*)-**8**, and (*R*)-**9** were assigned on the basis of ^{1}H- and ^{13}C-NMR spectra, and by comparison of these spectra with those described in [6]. The ee of the products was determined by analytical HPLC (*Chiralcel OD-H*, hexane/i-PrOH 250:1)[3]).

2.4. *Reaction of 1,3-Diphenylprop-1-ene-2-thiol* (**10**) *with (*S*)-2-Methyloxirane* ((*S*)-**2**). The reaction of **10** with (*S*)-**2** was carried out in dry CH_2Cl_2 at room temperature under an N_2 atmosphere in the presence of SiO_2. After 4 d, filtration and the usual workup, CC, and MPLC gave two isomeric products (1′*Z*,2*S*)-**11** and (1′*E*,2*S*)-**11** in 46 and 10% yield, repectively (*Scheme 6*). The ee of the isomers was determined by HPLC.

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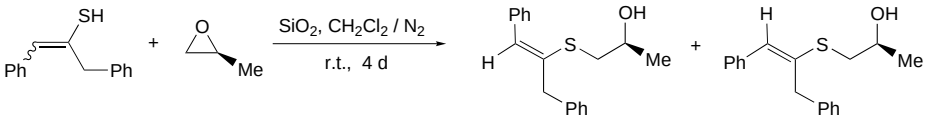
[3]) The absolute configurations have been assigned based on the knowledge that ring opening of 2-phenyloxirane (**6**) takes place *via* nucleophilic attack at C(2) and cleavage of the O–C(2) bond under inversion of the configuration at C(2) (see *Sect. 2.6* and [2]).

Scheme 6



10 ((*Z*)/(*E*) 3:1) (*S*)-**2** (1′*Z*,2*S*)-**11** 46% (98% ee) (1′*E*,2*S*)-**11** 10% (89% ee)

The structures of (1′*Z*,2*S*)-**11** and (1′*E*,2*S*)-**11** were assigned on the basis of the elemental analyses, IR, 1D-NOESY, ^{1}H- and ^{13}C-NMR, and mass spectra, and that of (1′*E*,2*S*)-**11** was confirmed by X-ray crystallography (*Fig. 1*). The IR spectra of (1′*Z*,2*S*)-**11** and (1′*E*,2*S*)-**11** showed typical broad absorptions for the OH group at 3396 and 3480 cm^{-1}, respectively, which indicate that the two isomers are not cyclic 1,3-oxathiolanes, but open-chain alcohols. The 1D-NOESY spectrum of (1′*Z*,2*S*)-**11**, on irradiation of H–C(2′) at 6.7 ppm, showed NOE signals for $PhCH_2$ at 3.88 ppm and for 2 arom. H (Ph–C(2′)) at 7.35 ppm, and irradiation of $PhCH_2$ at 3.8 ppm led to NOE signals for H–C(2′) at 6.69 ppm, 2 H–C(1) at 2.76 and 2.47 ppm, and 2 arom. H of $PhCH_2$ at 7.32 ppm. The formation of (1′*Z*,2*S*)-**11** proceeded with retention of the configuration at C(2) because the nucleophilic attack of the enesulfanyl S-atom took place at C(3) of (*S*)-**2**. Therefore, the analyses mentioned above indicate that (1′*Z*,2*S*)-**11** should have the (*Z*,*S*)-configuration.

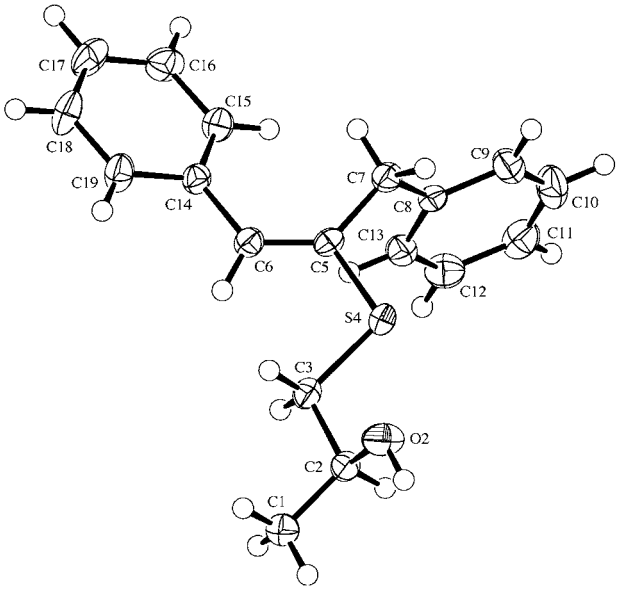
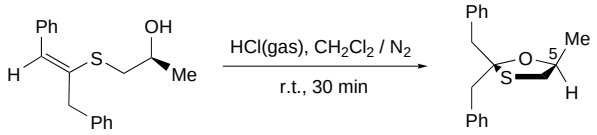


Fig. 1. *ORTEP Plot* [11] *of the molecular structure of (1′*E,2S*)*-**11** (arbitrary numbering of the atoms; displacement ellipsoids with 50% probability)

Similarly, the 1D-NOESY spectrum of (1′*E*,2*S*)-**11**, on irradiation of H–C(2′) at 6.7 ppm, led to NOE signals for 2 arom. H (Ph–C(2′)) at 7.22 ppm, and for 2 H–C(1) at 2.96 and 2.70 ppm, respectively, and irradiation of $PhCH_2$ at 3.8 ppm showed no NOE signal for H–C(2′). In analogy to (1′*Z*,2*S*)-**11**, (1′*E*,2*S*)-**11** has been formed with retention of the configuration at C(2). Therefore, (1′*E*,2*S*)-**11** has the (*E*,*S*)-configuration, which was then confirmed by X-ray crystallography (*Fig. 1*). The absolute configuration of the molecule has been confidently determined independently by the diffraction experiment. The compound has the expected (2*S*)-configuration, and the ethylene group is (*E*)-configured. The OH group forms an intermolecular H-bond with the OH O-atom of an adjacent molecule, thereby linking the molecules into extended one-dimensional chains, which run parallel to the *y*-axis and have a graph set motif [12] of C(3).

2.5. *Cyclization of* (1′*Z*,2*S*)-**11** *to 1,3-Oxathiolane (*S*)*-**12**. A solution of (1′*Z*,2*S*)-**11** in dry CH_2Cl_2 was treated with HCl gas at room temperature for 30 min. After chromatographic workup, (*S*)-**12** was obtained in 88% yield (*Scheme 7*). The ee was determined by HPLC.

Scheme 7



(1′*Z*,2*S*)-**11** (*S*)-**12**

88% (98% ee)

The structure of (*S*)-**12** was deduced from the elemental analysis, ^{1}H- and ^{13}C-NMR, and mass spectra, and was then confirmed by X-ray crystallography (*Fig. 2*). In the crystal structure, there are two symmetry-independent molecules in the asymmetric unit. Both are of the same enantiomer and have very similar conformations, although there are slight differences in the puckering of the five-membered ring. In both molecules, the five-membered ring has a half-chair conformation distorted towards an envelope conformation, but the atom that is closest to being the envelop flap is different in each molecule, being C(4) in molecule A and C(5) in molecule B. In molecule A, the deviation of atoms C(4) and C(5) from the plane defined by S(1), C(2), and C(3) is −0.459(1) and 0.179(2) Å, respectively. In molecule B, the corresponding deviations are 0.214(2) and −0.457(2) Å for C(24) and C(25), respectively. The absolute configuration of the molecule has been determined independently by the diffraction experiment. The compound has the expected (*S*)-configuration.

2.6. *Reaction of 1,3-Diphenylprop-1-ene-2-thiol* (**10**) *with (*R*)-2-Phenyloxirane* ((*R*)-**6**). The reaction of **10** with (*R*)-**6** in dry CH_2Cl_2 at room temperature for 10 d under an N_2 atmosphere in the presence of SiO_2 gave four open chain products, (1′*Z*,2*S*)-**13**, (1′*E*,2*S*)-**13**, (1′*Z*,1*R*)-**15**, and (1′*E*,1*R*)-**15**, and one 1,3-oxathiolane (*S*)-**14** in 22, 9, 2, 1, and 1% yield, repectively. In addition, **10** was recovered in 40% yield (*Scheme 8*). The ee values were determined by HPLC. They show that the reaction

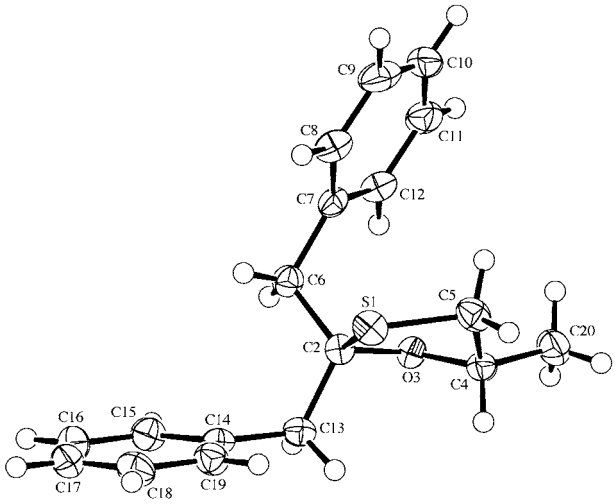
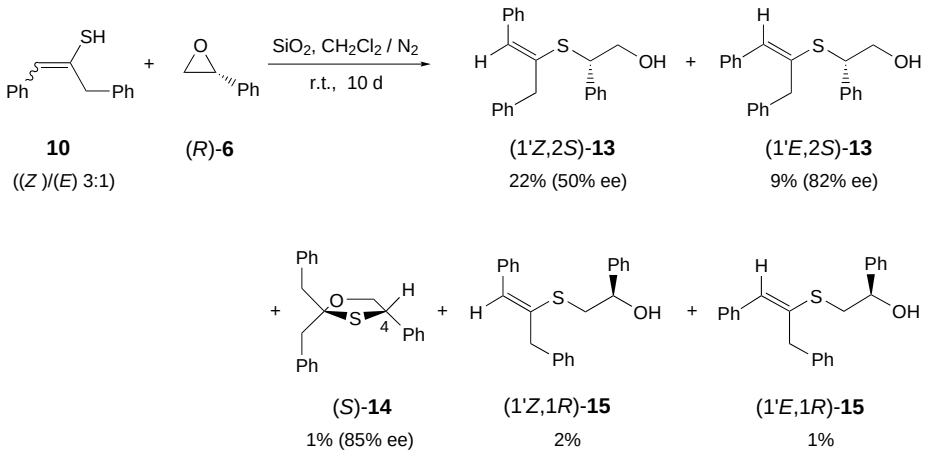


Fig. 2. *ORTEP Plot* [11] *of the molecular structure of one of the two symmetry-independent molecules of* (S)-**12** (arbitrary numbering of the atoms; displacement ellipsoids with 50% probability)

took place with partial racemization. For example, in the case of the main product (1′*Z*,2*S*)-**13** with 50% ee, the reaction occurred with a stereoselectivity of only 75%.

Scheme 8



The structures of the products were assigned on the basis of their elemental analyses, IR, 1D-NOESY, ^{1}H- and ^{13}C-NMR, and mass spectra, and that of (*S*)-**14** was confirmed by X-ray crystallography (*Fig. 3*). In the crystal structure, there are two symmetry-independent molecules in the asymmetric unit. Both are of the same enantiomer and have very similar conformations. The absolute configuration of the molecule has been determined independently by the diffraction experiment. The compound has the expected (*S*)-configuration. The five-membered ring in molecule B

has an envelope conformation, with C(35) being the envelope flap and with a deviation of 0.577(2) Å from the plane defined by the other four ring atoms. The five-membered ring in molecule A has a similar conformation, although it is distorted slightly towards a half-chair conformation twisted on C(4)–C(5) with C(4) and C(5) being 0.164(2) and −0.445(2) Å, respectively, from the plane defined by the other three ring atoms.

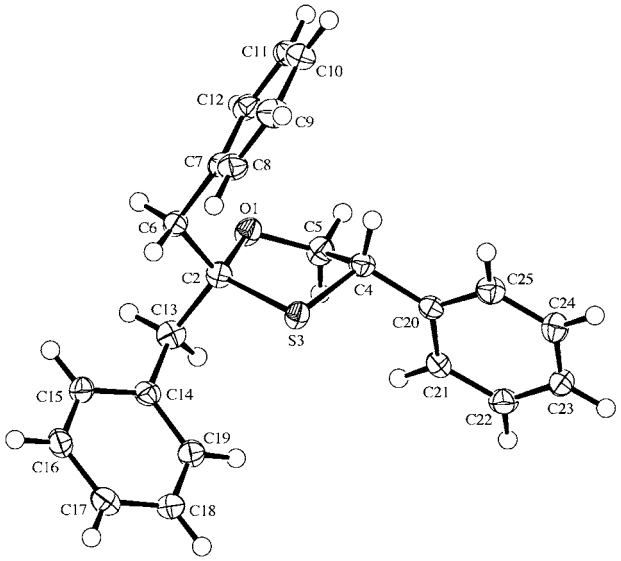


Fig. 3. *ORTEP Plot* [11] *of the molecular structure of one of the two symmetry-independent molecules of* (S)-**14** (arbitrary numbering of the atoms; displacement ellipsoids with 50% probability)

The IR spectra of (1′*Z*,2*S*)-**13**, (1′*E*,2*S*)-**13**, (1′*Z*,1*R*)-**15**, and (1′*E*,1*R*)-**15** showed typical broad absorptions for the OH group at 3407, 3403, 3406, and 3376 cm^{-1}, respectively. The 1D-NOESY spectrum of (1′*Z*,2*S*)-**13**, on irradiation of H–C(2′) at 6.6 ppm, showed NOE signals for $PhCH_2$ at 3.67 ppm, 2 arom. H (Ph–C(2′)) at 7.51 ppm, and 2 arom. H of $PhCH_2$ at 7.15 ppm. The formation of (1′*Z*,2*S*)-**13** proceeded mainly (75% selectivity) with inversion of configuration at C(2). Therefore, the nucleophilic attack of the enesulfanyl S-atom at C(2) of (*R*)-**6** occurs preferentially *via* an S_N2-type process. The analyses mentioned above indicate that (1′*Z*,2*S*)-**13** has the (*Z*,*S*)-configuration[4]).

An analogous 1D-NOESY experiment led to the conclusion that (1′*E*,2*S*)-**13** has the (*E*,*S*)-configuration.

Similarly, the 1D-NOESY spectrum of (1′*Z*,1*R*)-**15**, on irradiation of H–C(2′) at 6.76 ppm, showed NOE signals for $PhCH_2$ at 3.82–3.75 ppm, and 2 arom. H (Ph–C(2′)) at 7.56 ppm. The formation of (1′*Z*,1*R*)-**15** should have proceeded with retention of configuration at C(2) because the nucleophilic attack of the enesulfanyl S-atom took place at C(3) of (*R*)-**6**. For this reason, (1′*Z*,1*R*)-**15** should have the (*Z*,*R*)-

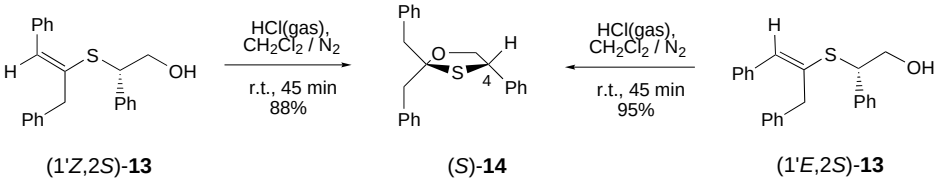
[4]) The absolute configuration at C(2) of the major enantiomer of (1′*Z*,2*S*)-**13** follows from the cyclization to (*S*)-**14** (see *Sect. 2.7*).

configuration. The analogous experiments with (1′*E*,1*R*)-**15** indicated that it has the (*E*,*R*)-configuration.

2.7. *Cyclization of (1′*Z*,2*S*)-***13*** and (1′*E*,2*S*)-***13*** to 1,3-Oxathiolane* (S)-**14**. Treatment of a solution of (1′*Z*,2*S*)-**13** in dry CH_2Cl_2 with HCl gas at room temperature for 45 min yielded 88% of (*S*)-**14** with 59% ee (HPLC). Furthermore, treatment of (1′*Z*,2*S*)-**13** with SiO_2 in CH_2Cl_2 at room temperature for 12 d gave 9% of (*S*)-**14**, and (1′*Z*,2*S*)-**13** was recovered in 58% yield.

An analogous treatment of (1′*E*,2*S*)-**13** with HCl under the conditions mentioned above gave (*S*)-**14** in 95% yield with 67% ee (HPLC) (*Scheme 9*).

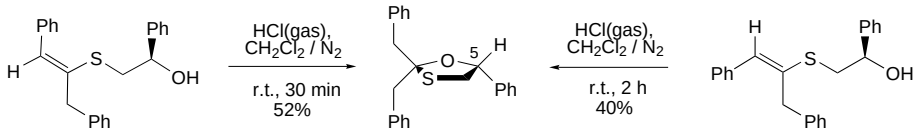
Scheme 9



(1′*Z*,2*S*)-**13** (*S*)-**14** (1′*E*,2*S*)-**13**

2.8. *Cyclization of (1′*Z*,1*R*)-***15*** and (1′*E*,1*R*)-***15*** to 1,3-Oxathiolane (*R*)-**16**.* A solution of (1′*Z*,1*R*)-**15** in dry CH_2Cl_2 at room temperature was treated for 30 min with HCl gas. After usual workup, TLC yielded 52% of (*R*)-**16**. An analogous reaction with (1′*E*,1*R*)-**15** for 2 h gave (*R*)-**16** in 40% yield (*Scheme 10*). In both cases, the ee value was determined by HPLC to be 90%.

Scheme 10



(1′*Z*,1*R*)-**15** (*R*)-**16** 90% ee (1′*E*,1*R*)-**15**

3. Discussion and Conclusions. – The results presented show that 1,3-oxathiolanes can be prepared not only by the *Lewis* acid-catalyzed reactions of oxiranes with non-enolizable thioketones, but with enolized thioketones as well. For example, the aromatic thioketone **1** reacts with the optically active monosubstituted oxiranes (*S*)-**2** and (*R*)-**6** in the presence of a *Lewis* acid to yield 1,3-oxathiolanes with high regio- and stereoselectivity. The weaker the *Lewis* acid, the higher the yield of the 1,3-oxathiolane (*Schemes 3* and *5*, and *Tables 1* and *2*). However, in the case of the enolized thioketone **10**, the analogous reactions yielded mainly the open-chain enesulfanyl alcohols, which, in turn, in the presence of HCl, easily cyclized to give 1,3-oxathiolanes, again with high regio- and stereoselectivity in most cases.

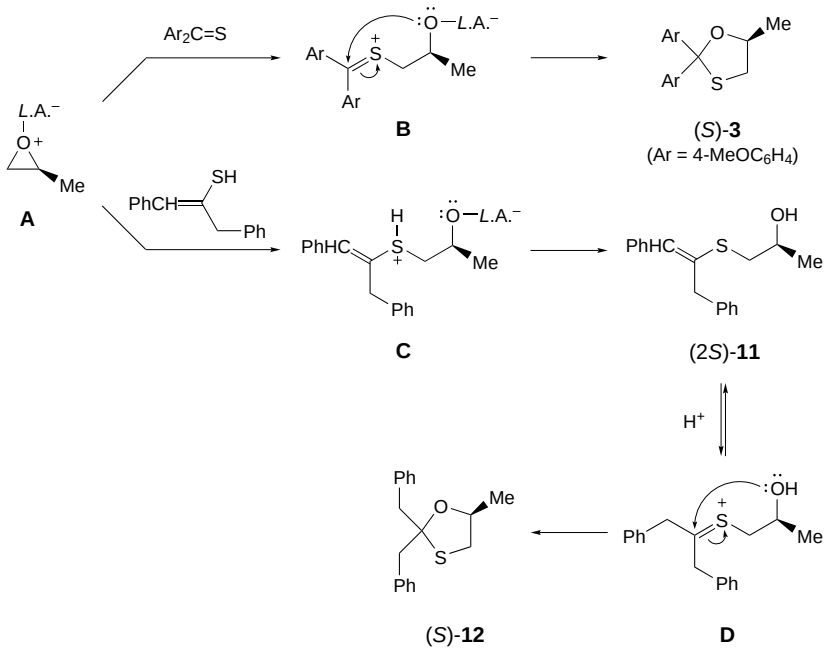
We assume that the reactions proceed *via* an S_N2-type mechanism, whereby the nucleophilic thiocarbonyl or enesulfanyl S-atom favorably attacks the C(3)-atom

(O–C(3) cleavage) of the activated (*S*)-2-methyloxirane ((*S*)-**2**) with retention of configuration, but, in the case of (*R*)-2-phenyloxirane ((*R*)-**6**), the preferred attack took place at the C(2)-atom (O–C(2) cleavage) mainly with inversion of configuration.

In the presence of SiO_2, the aromatic thioketone **1** is more reactive than the enethiol **10**. On the other hand, **10** is more stable than **1**, as **10** was partially recovered even when the reaction was performed at room temperature for 10 d, while no trace of **1** could be detected after 1 h 40 min at room temperature.

The reaction mechanisms for the 'direct' and 'indirect' formation of 1,3-oxathiolanes are depicted in *Scheme 11*. In the case of non-enolizable thioketones, the reaction with the complexed oxirane **A** leads to the unstable thiocarbonylium ion **B**, which undergoes *in situ* ring closure to give 1,3-oxathiolanes of type (*S*)-**3** (*Scheme 11*). On the other hand, enolized thioketones and **A** form sulfonium ions **C**, which can be stabilized by a H-transfer to give the hydroxy sulfides **11**. In the presence of a strong acid such as HCl, the enethiol group is protonated to give thiocarbonylium ion **D**, which cyclizes to (*S*)-**12**.

Scheme 11



It is worth mentioning that the control experiments showed that (*S*)-**2** reacts only with (*S*)-**3**, leading to the 1:2 *trans*-adduct (4*S*,8*S*)-**4** (*Scheme 4*), but does not react with (*R*)-**3**. No 1:2 *cis*-adduct (4*R*,8*S*)-**4** was obtained from the reaction of (*R*)-**3** with (*S*)-**2**. These results confirm the assumption presented in [6].

We thank the analytical services of our institute for NMR and mass spectra, and elemental analyses, Miss *J. Cavegn* for her assistance with the determination of the crystal structures, and the *Swiss National Science Foundation* and *F. Hoffmann-La Roche AG*, Basel, for financial support.

Experimental Part

1. *General.* See [13]. Optical rotations: *Perkin-Elmer 241* polarimeter ($c = 1$, in THF). IR Spectra: film or KBr, cm^{-1}. NMR Spectra: at 300 (^1H) and 75.5 MHz (^{13}C) in $CDCl_3$. Enantiomeric excesses were determined by anal. HPLC on a *Chiralcel OD-H* column.

2. *General Procedures for the Reactions of 4,4′-Dimethoxythiobenzophenone* (**1**) *and 1,3-Diphenylprop-1-enethiol* **10** *with Methyl- and Phenyloxiranes* **2** *and* **6**. *Procedure 1:* To the soln. of **1** (*ca.* 1 mmol) in dry CH_2Cl_2 (10–15 ml) under N_2, 0.5 equiv. of $BF_3 \cdot Et_2O$ or $ZnCl_2$ was added at $-80°$ or $-30°$. In general, this led to a more or less pronounced change in the color of the soln. After stirring the mixture for 15 min at the selected temp., *ca.* 2 equiv. of (*S*)-**2** or (*R*)-**6** were added dropwise, whereby the color of the soln. changed again rapidly in most cases. Then, the reaction was quenched by addition of H_2O, and the mixture was washed with sat. aq. NaCl soln. (3×). The combined org. layers were dried ($MgSO_4$) and evaporated *i.v.* The products were separated by chromatography (SiO_2; hexane/Et_2O or hexane/CH_2Cl_2; CC or prep. TLC (PLC)).

Procedure 2: To the soln. of **1** or **10** (*ca.* 1 mmol), and **2** or **6** (*ca.* 2 mmol) in dry CH_2Cl_2 (10–15 ml) under N_2, 4.5 g of silica gel (SiO_2) were added at r.t. After stirring the suspension for 2 h–10 d at r.t., the mixture was filtered, and the residue was washed with CH_2Cl_2 (4×). Then, the combined filtrate was evaporated *i.v.*, and the products were separated as described above.

3. *Reactions of* **1**. 3.1. *With (*S*)- and (*R*)-2-Methyloxirane* ((*S*)-**2** and (*R*)-**2**, resp.; see [6]). Reaction of **1** (258 mg, 1 mmol) with (*S*)-**2** (290 mg, 5 mmol) and 1.2 mmol of $ZnCl_2$ (or 4.5 g of SiO_2) at $-30°$ (or r.t.), 2 h 20 min (or 8 h), and CC (hexane/Et_2O 10:1) yielded *(*S*)-2,2-bis(4-methoxyphenyl)-5-methyl-1,3-oxathiolane* ((*S*)-**3**), *(4*S*,8*S*)-2,2-bis(4-methoxyphenyl)-4,8-dimethyl-1,3,6-dioxathiocane* ((4*S*,8*S*)-**4**), and *4,4′-dimethoxybenzophenone* (**5**) (*Scheme 3* and *Table 1*; for spectroscopic characterization of the products, see [6]).

The analogous reaction with (*R*)-**2**, $ZnCl_2$, $-30°$, 2 h 45 min gave the enantiomeric products (*R*)-**3** and (4*R*,8*R*)-**4** together with **5** (*Table 1*).

3.2. *Reaction of (*S*)-3 with (*S*)-2.* Treatment of (*S*)-**3** (138 mg, 0.44 mmol) with (*S*)-**2** (511 mg, 8.8 mmol) in the presence of 0.39 mmol of $BF_3 \cdot Et_2O$ at $-90°$, 7 h and CC (hexane/Et_2O 10:1), yielded 4 mg (3%) of (4*S*,8*S*)-**4** with *ca.* 100% ee. In addition, 41 mg (30%) of (*S*)-**3** were recovered.

An analogous reaction of (*R*)-**3** (167 mg, 0.53 mmol) with (*S*)-**2** (145 mg, 2.5 mmol) in the presence of 0.55 mmol of $BF_3 \cdot Et_2O$ at $-90°$, 1 h 25 min, did not give the expected *cis*-product (4*R*,8*S*)-**4**; most of (*R*)-**3** decomposed to **5**. Only 19 mg (11%) of (*R*)-**3** were recovered.

3.3. *With (*R*)- and (*S*)-2-Phenyloxirane* ((*R*)-**6** and (*S*)-**6**, resp.). Reaction of **1** (258 mg, 1 mmol) with (*R*)-**6** (360 mg, 3 mmol) and 1.0 mmol of $ZnCl_2$ (or 4.5 g of SiO_2), at $-30°$ (r.t.), and CC (hexane/Et_2O 10:1 and C_6H_6/hexane 4:1) yielded *(*S*)-2,2-bis(4-methoxyphenyl)-4-phenyl-1,3-oxathiolane* ((*S*)-**7**), *(*R*)-2,2-bis(4-methoxyphenyl)-5-phenyl-1,3-oxathiolane* ((*R*)-**8**), *(*S*)-2,2-bis(4-methoxyphenyl)-4-phenyl-1,3-dioxolane* ((*S*)-**9**), and **5** (*Scheme 5* and *Table 2*; for spectroscopic characterization, see [6]).

*Data of (*R*)-8*: Colorless oil. $[\alpha]_D^{23} = -79.4$ (92% ee). IR (film): 3065*w*, 3035*w*, 3002*w*, 2954*w*, 2933*m*, 2907*w*, 2836*m*, 1608*s*, 1583*m*, 1509*s*, 1463*m*, 1456*m*, 1441*m*, 1414*w*, 1303*s*, 1251*s*, 1172*s*, 1114*w*, 1035*s*, 1007*m*, 910*m*, 828*s*, 735*m*, 699*s*. ^{1}H-NMR: 7.58–7.45 (*AA′* of *AA′BB′*, $J = 8.9$, 2 arom. H); 7.48 (*m*, 2 arom. H); 7.39–7.30 (*m*, 5 arom. H); 6.86 (*BB′* of *AA′BB′*, $J = 8.9$, 2 arom. H); 6.80 (*BB′* of *AA′BB′*, $J = 9.0$, 2 arom. H); 5.04 (*dd*, $J = 9.1$, 5.9, H–C(5)); 3.80, 3.76 (2*s*, 2 MeO); 3.42 (*dd*, $J = 10.2$, 5.9, 1 H–C(4)); 3.25 (*dd*, $J = 10.2$, 9.1, 1 H–C(4)). ^{13}C-NMR: 159.1, 159.0 (2*s*, 2 arom. C); 139.7, 137.2, 137.0 (3*s*, 3 arom. C); 128.7, 128.6, 128.2, 127.9, 126.3 (5*d*, 9 arom. CH); 113.4, 113.3 (2*d*, 4 arom. CH); 98.6 (*s*, C(2)); 83.3 (*d*, C(5)); 55.3 (2*q*, 2 MeO); 42.2 (*t*, C(4)). ESI-MS (MeOH/CH_2Cl_2): 401 (10, $[M + Na]^+$), 379 (31, $[M + H]^+$), 333 (100), 307 (47), 243 (58), 112 (37). Anal. calc. for $C_{23}H_{22}O_3S$ (378.49): C 72.99, H 5.86, S 8.47; found: C 72.84, H 6.09, S 8.39.

4. *Reactions of* **10**. 4.1. *With (*S*)-2-Methyloxirane* ((*S*)-**2**). Reaction of **10** (226 mg, 1 mmol) with (*S*)-**2** (116 mg, 2 mmol) and 4.5 g of SiO_2 at r.t., 4 d, and CC (hexane/Et_2O 2:1) yielded 181 mg (64%) of *(Z/E,2S)-1-[(1′-benzyl-2′-phenylethenyl)sulfanyl]propan-2-ol* ((*Z/E*,2*S*)-**11**). Separation of the two isomers by MPLC (hexane/Et_2O 3:1) gave 132 mg (46%) of (1′*Z*,2*S*)-**11** and 27 mg (10%) of (1′*E*,2*S*)-**11** (*Scheme 6*).

*Data of (1′*Z*,2*S*)-11*: Colorless crystals. M.p. 36.0–37.2°. $[\alpha]_D^{22} = +13.6$ (98% ee). IR (film): 3396*m* (br., OH), 3083*w*, 3060*m*, 3026*m*, 2971*m*, 2927*m*, 1599*m*, 1573*w*, 1493*s*, 1453*s*, 1445*m*, 1373*w*, 1266*w*, 1184*w*, 1124*m*, 1109*m*, 1074*m*, 1031*m*, 935*m*, 751*s*, 697*s*. ^{1}H-NMR (600 MHz, $CDCl_3$): 7.53 (*d*, $J = 7.5$, 2 arom. H); 7.35–7.30 (*m*, 6 arom. H); 7.27–7.22 (*m*, 2 arom. H); 6.69 (*s*, H–C(2′)); 3.80–3.73 (*m*, PhCH_2); 3.63–3.60 (*m*, H–C(2)); 2.76 (*dd*, $J = 13.7$, 3.6, 1 H–C(1)); 2.47 (*dd*, $J = 13.7$, 8.5, 1 H–C(1)); 2.03 (*d*, $J = 3.0$, OH); 1.09 (*d*, $J = 6.3$, Me). ^{13}C-NMR: 138.6, 136.5 (2*s*, 2 arom. C); 134.4 (*s*, C(1′)); 132.4 (*d*, C(2′)); 129.2, 128.8, 128.6, 128.1, 127.2, 126.7 (6*d*, 10 arom. CH); 66.3 (*d*, C(2)); 44.8 (*t*, Ph*C*H$_2$); 40.7 (*t*, C(1)); 21.7 (*q*, Me). CI-MS (NH_3): 302 (36, $[M + NH_4]^+$),

286 (20), 285 (100, $[M+H]^+$), 268 (8), 267 (40, $[M-H_2O+H]^+$), 228 (20). Anal. calc. for $C_{18}H_{20}OS$ (284.42): C 76.01, H 7.09, S 11.27; found: C 75.94, H 6.96, S 11.07.

*Data of (1′*E*,2*S*)*-**11**: Colorless crystals. M.p. 67.5 – 70.8°. $[\alpha]_D^{22} = +2.6$ (89% ee). IR (KBr): 3480*s* (br., OH), 3079*w*, 3057*w*, 3025*w*, 2973*m*, 2920*s*, 2854*m*, 1611*s*, 1599*m*, 1573*w*, 1495*s*, 1487*s*, 1452*s*, 1424*s*, 1398*m*, 1367*m*, 1342*m*, 1316*m*, 1285*m*, 1261*w*, 1248*w*, 1222*w*, 1192*w*, 1182*w*, 1156*w*, 1123*s*, 1080*m*, 1046*s*, 1032*s*, 944*m*, 853*m*, 766*m*, 743*m*, 717*s*, 695*s*. ^{1}H-NMR (600 MHz, $CDCl_3$): 7.33 – 7.21 (*m*, 10 arom. H); 6.73 (*s*, H–C(2′)); 3.94 (br. *s*, H–C(2)); 3.91 – 3.81 (*m*, PhCH_2); 2.96 (*dd*, *J* = 13.6, 3.7, 1 H–C(1)); 2.70 (*dd*, *J* = 13.6, 8.5, 1 H–C(1)); 2.23 (br. *s*, OH); 1.26 (*d*, *J* = 6.3, Me). ^{13}C-NMR: 138.4, 136.8 (2*s*, 2 arom. C); 135.9 (*s*, C(1′)); 128.6, 128.5, 128.4, 128.2 (4*d*, 8 arom. CH); 128.1 (*d*, C(2′)); 126.9, 126.5 (2*d*, 2 arom. CH); 65.7 (*d*, C(2)); 41.0 (*t*, C(1)); 38.1 (*t*, PhCH$_2$); 22.1 (*q*, Me). CI-MS (NH_3): 302 (30, $[M+NH_4]^+$), 286 (21), 285 (100, $[M+H]^+$), 267 (32, $[M-H_2O+H]^+$), 228 (15). Anal. calc. for $C_{18}H_{20}OS$ (284.42): C 76.01, H 7.09, S 11.27; found: C 76.04, H 7.13, S 11.34.

Crystals of (1′*E*,2*S*)-**11** suitable for X-ray crystal-structure analysis were grown from Et_2O/hexane.

4.2. *Cyclization of* (*1′*Z*,2*S*)*-**11** *to* (S)*-2,2-Dibenzyl-5-methyl-1,3-oxathiolane* ((*S*)-**12**). Treatment of (1′*Z*,2*S*)-**11** (80 mg, 0.35 mmol) in CH_2Cl_2 (10 ml) with HCl gas at r.t., 30 min, and CC (hexane/Et_2O 20 : 1) yielded 70 mg (88%) of (*S*)-**12** (*Scheme 7*). Colorless crystals. M.p. 66.7 – 67.9°. $[\alpha]_D^{22} = -14.3$ (98% ee). IR (KBr): 3082*w*, 3058*w*, 3027*m*, 2985*m*, 2945*m*, 2925*m*, 2886*m*, 2847*w*, 1600*w*, 1493*s*, 1452*s*, 1440*m*, 1430*m*, 1379*m*, 1349*w*, 1337*w*, 1313*w*, 1235*m*, 1222*m*, 1165*m*, 1135*m*, 1088*s*, 1078*s*, 1062*s*, 1030*w*, 1017*m*, 991*m*, 950*m*, 809*m*, 755*s*, 700*vs*, 636*m*, 608*m*. ^{1}H-NMR: 7.35 – 7.18 (*m*, 10 arom. H); 4.06 – 3.95 (*m*, H–C(5)); 3.24 – 2.90 (*m*, 2 PhCH_2); 2.56 (*dd*, *J* = 10.3, 4.1, 1 H–C(4)); 1.80 (*dd*, *J* = 10.2, 9.8, 1 H–C(4)); 1.18 (*d*, *J* = 6.0, Me). ^{13}C-NMR: 137.1, 137.0 (2*s*, 2 arom. C); 131.6, 131.0, 127.9, 127.3 (4*d*, 8 arom. CH); 126.5, 126.3 (2*d*, 2 arom. CH); 97.1 (*s*, C(2)); 79.7 (*d*, C(5)); 49.0, 47.7 (2*t*, 2 PhCH$_2$); 40.3 (*t*, C(4)); 18.9 (*q*, Me). CI-MS (NH_3): 302 (4, $[M+NH_4]^+$), 285 (4, $[M+H]^+$), 229 (17), 228 (100), 193 (9). Anal. calc. for $C_{18}H_{20}OS$ (284.42): C 76.01, H 7.09, S 11.27; found: C 75.97, H 7.26, S 11.05.

Crystals of (*S*)-**12** suitable for X-ray crystal-structure analysis were grown from Et_2O/MeOH.

4.3. *With* (R)*-2-Phenyloxirane* ((*R*)-**6**). Reaction of **10** (452 mg, 2 mmol) with (*R*)-**6** (360 mg, 3 mmol) and 4.8 g of SiO_2 at r.t., 10 d, and CC and MPLC (hexane/CH_2Cl_2 15 : 1, hexane/Et_2O 3 : 1) yielded 150 mg (22%) of *(1′*Z*,2*S*)-2-[(1′-benzyl-2′-phenylethenyl)sulfanyl]-2-phenylethanol* ((1′*Z*,2*S*)-**13**), 60 mg (9%) of *(1′*E*,2*S*)-2-[(1′-benzyl-2′-phenylethenyl)sulfanyl]-2-phenylethanol* ((1′*E*,2*S*)-**13**), 5 mg (1%) of *(*S*)-2,2-dibenzyl-4-phenyl-1,3-oxathiolane* ((*S*)-**14**), 14 mg (2%) of *(1′*Z*,1*R*)-2-[(1′-benzyl-2′-phenylethenyl)sulfanyl]-1-phenylethanol* ((1′*Z*,1*R*)-**15**), and 9 mg (1%) of *(1′*E*,1*R*)-2-[(1′-benzyl-2′-phenylethenyl)sulfanyl]-1-phenylethanol* ((1′*E*,1*R*)-**15**). In additon, **10** was recovered in 40% yield (*Scheme 8*).

*Data of (1′*Z*,2*S*)*-**13**: Colorless oil. $[\alpha]_D^{22} = -2.6$ (50% ee). IR (film): 3407*m* (br., OH), 3080*w*, 3060*m*, 3027*m*, 2927*m*, 2868*w*, 1600*m*, 1492*s*, 1453*s*, 1383*w*, 1181*w*, 1075*m*, 1054*s*, 1030*s*, 751*s*, 697*vs*. ^{1}H-NMR: 7.52 – 7.49 (*m*, 2 arom. H); 7.35 – 7.15 (*m*, 13 arom. H); 6.64 (*s*, H–C(2′)); 4.19 (*t*, *J* = 6.6, H–C(2)); 3.75 – 3.67 (*m*, 2 H–C(1), PhCH_2); 1.66 (*t*, *J* = 6.7, OH). ^{13}C-NMR: 138.9, 138.6, 136.5 (3*s*, 3 arom. C); 134.4 (*s*, C(1′)); 133.4 (*d*, C(2′)); 129.3, 129.0, 128.6, 128.5, 128.1, 128.0 (6*d*, 12 arom. CH); 127.7, 127.2, 126.7 (3*d*, 3 arom. CH); 66.0 (*t*, C(1)); 52.4 (*d*, C(2)); 45.5 (*t*, PhCH$_2$). CI-MS (NH_3): 365 (15), 364 (57, $[M+NH_4]^+$), 349 (8), 348 (26), 347 (100, $[M+H]^+$), 346 (12, $[M-H_2O+NH_4]^+$), 330 (11), 329 (50, $[M-H_2O+H]^+$), 313 (12), 228 (21), 227 (14). Anal. calc. for $C_{23}H_{22}OS$ (346.49): C 79.73, H 6.40, S 9.25; found: C 79.54, H 6.47, S 9.21.

*Data of (1′*E*,2*S*)*-**13**: Colorless oil. $[\alpha]_D^{22} = +126.2$ (82% ee). IR (film): 3403*m* (br., OH), 3080*w*, 3060*m*, 3027*m*, 2927*m*, 2868*w*, 1601*m*, 1573*w*, 1494*s*, 1452*s*, 1384*w*, 1285*w*, 1182*w*, 1076*m*, 1051*s*, 1030*m*, 746*s*, 698*vs*. ^{1}H-NMR: 7.34 – 7.13 (*m*, 15 arom. H); 6.80 (*s*, H–C(2′)); 4.29 (*t*, *J* = 6.8, H–C(2)); 3.89 (*t*, *J* = 6.7, 2 H–C(1)); 3.79 (*s*, PhCH_2); 1.84 (*t*, *J* = 6.7, OH). ^{13}C-NMR: 138.9, 138.3, 136.7 (3*s*, 3 arom. C); 135.2 (*s*, C(1′)); 131.9 (*d*, C(2′)); 129.3, 128.7, 128.6, 128.5, 128.4, 128.2 (6*d*, 12 arom. CH); 127.8, 127.1, 126.5 (3*d*, 3 arom. CH); 65.8 (*t*, C(1)); 53.6 (*d*, C(2)); 38.5 (*t*, PhCH$_2$). CI-MS (NH_3): 365 (9), 364 (32, $[M+NH_4]^+$), 349 (8), 348 (27), 347 (100, $[M+H]^+$), 346 (8, $[M-H_2O+NH_4]^+$), 330 (14), 329 (52, $[M-H_2O+H]^+$), 313 (6), 228 (13), 227 (8). Anal. calc. for $C_{23}H_{22}OS$ (346.49): C 79.73, H 6.40, S 9.25; found: C 79.53, H 6.52, S 9.25.

Data of (S)*-**14**: Colorless crystals. M.p. 90.0 – 93.6°. $[\alpha]_D^{22} = -23.9$ (85% ee). IR (KBr): 3085*w*, 3062*m*, 3030*s*, 2943*m*, 2916*m*, 2871*w*, 1602*m*, 1584*w*, 1494*s*, 1453*s*, 1435*m*, 1324*w*, 1275*w*, 1230*m*, 1209*w*, 1156*w*, 1093*s*, 1081*s*, 1031*m*, 991*m*, 753*s*, 699v*s*, 646*m*. ^{1}H-NMR: 7.39 – 7.03 (*m*, 15 arom. H); 4.19 (*dd*, *J* = 9.1, 5.8, H–C(4)); 3.96 (*dd*, *J* = 8.5, 5.8, 1 H–C(5)); 3.71 (*dd*, *J* = 9.0, 8.6, 1 H–C(5)); 3.33 – 3.24 (*m*, PhCH_2); 3.19 – 3.07 (*m*, PhCH_2). ^{13}C-NMR: 137.6, 137.0, 136.8 (3*s*, 3 arom. C); 131.34, 131.30 (2*d*, 4 arom. CH); 128.4, 127.93, 127.89, 127.7 (4*d*, 8 arom. CH); 127.5, 126.7, 126.5 (3*d*, 3 arom. CH); 99.3 (*s*, C(2)); 77.8 (*t*, C(5)); 54.3 (*d*, C(4)); 47.9, 47.8 (2*t*, 2 PhCH$_2$). CI-MS (NH_3): 364 (7, $[M+NH_4]^+$), 347 (6, $[M+H]^+$), 313 (11), 286 (7), 255 (6), 229(34), 228 (100). Anal. calc. for $C_{23}H_{22}OS$ (346.49): C 79.73, H 6.40, S 9.25; found: C 79.70, H 6.18, S 9.12.

Crystals of (*S*)-**14** suitable for X-ray crystal-structure analysis were grown from Et_2O/MeOH.

Data of (1′Z,1R)-**15**: Colorless oil. $[\alpha]_D^{22} = +13.0$. IR (film): 3406*m* (br., OH), 3084*w*, 3061*m*, 3027*m*, 2925*m*, 1600*m*, 1493*s*, 1453*s*, 1193*w*, 1079*w*, 1056*m*, 1029*m*, 751*s*, 698vs. ^{1}H-NMR (600 MHz, $CDCl_3$): 7.56 (*d*, *J* = 7.7, 2 arom. H); 7.36–7.22 (*m*, 11 arom. H); 7.16–7.15 (*m*, 2 arom. H); 6.76 (*s*, H–C(2′)); 4.48 (*dd*, *J* = 9.3, 2.2, H–C(1)); 3.82–3.75 (*m*, PhCH_2); 2.99 (*dd*, *J* = 13.9, 3.3, 1 H–C(2)); 2.70 (*dd*, *J* = 13.9, 9.5, 1 H–C(2)); 2.41 (*s*, OH). ^{13}C-NMR (150.9 MHz, $CDCl_3$): 142.1, 138.6, 136.4 (3*s*, 3 arom. C); 134.0 (*s*, C(1′)); 132.9 (*d*, C(2′)); 129.3, 128.9, 128.6, 128.4, 128.2 (5*d*, 10 arom. CH); 127.8, 127.3, 126.8 (3*d*, 3 arom. CH); 125.7 (*d*, 2 arom. CH); 72.1 (*d*, C(1)); 45.0 (*t*, PhCH$_2$); 41.2 (*t*, C(2)). CI-MS (NH_3): 364 (11, $[M + NH_4]^+$), 346 (11, $[M - H_2O + NH_4]^+$), 331 (8), 330 (26), 329 (100, $[M - H_2O + H]^+$), 244 (7), 228 (32), 227 (14), 170 (7).

Data of (1′E,1R)-**15**: Colorless oil. $[\alpha]_D^{22} = +16.4$. IR (film): 3376*s* (br., OH), 3083*w*, 3061*m*, 3028*m*, 2954*m*, 2925*m*, 1601*m*, 1573*w*, 1494*s*, 1453*s*, 1431*w*, 1287*w*, 1196*w*, 1077*m*, 1054*s*, 1029*s*, 918*m*, 749*s*, 698vs. ^{1}H-NMR (600 MHz, $CDCl_3$): 7.37–7.22 (*m*, 15 arom. H); 6.80 (*s*, H–C(2′)); 4.81 (*dd*, *J* = 9.4, 3.4, H–C(1)); 3.93–3.83 (*m*, PhCH_2); 3.18 (*dd*, *J* = 13.9, 3.4, 1 H–C(2)); 2.93 (*dd*, *J* = 13.8, 9.4, 1 H–C(2)); 2.65 (br. *s*, OH). ^{13}C-NMR (150.9 MHz, $CDCl_3$): 142.3, 138.3, 136.7 (3*s*, 3 arom. C); 135.5 (*s*, C(1′)); 128.7 (*d*, C(2′)); 128.62, 128.57, 128.50, 128.47, 128.2 (5*d*, 10 arom. CH); 128.0, 127.0, 126.6 (3*d*, 3 arom. CH); 125.8 (*d*, 2 arom. CH); 71.7 (*d*, C(1)); 44.4 (*t*, C(2)); 38.1 (*t*, PhCH$_2$). CI-MS (NH_3): 364 (15, $[M + NH_4]^+$), 363 (15), 346 (9, $[M - H_2O + NH_4]^+$), 331 (8), 330 (26), 329 (100, $[M - H_2O + H]^+$), 295 (6), 228 (13), 178 (6).

4.4. *Cyclization of (1′Z,2S)*-**13** *or (1′E,2S)*-**13** *to (S)*-**14**. Treatment of (1′*Z*,2*S*)-**13** (24 mg, 0.07 mmol) in CH_2Cl_2 (15 ml) with HCl gas at r.t., 45 min, and TLC (hexane/CH_2Cl_2 1:2) yielded 21 mg (88%) of (*S*)-**14**. Similarly, treatment of (1′*Z*,2*S*)-**13** (45 mg, 0.13 mmol) in CH_2Cl_2 (7 ml) with 2.4 g of SiO_2 at r.t., 12 d, and TLC (hexane/CH_2Cl_2 1:1) gave 4 mg (9%) of (*S*)-**14**. Compound (1′*Z*,2*S*)-**13** was recovered in 58% yield (26 mg, 66% ee).

An analogous treatment of (1′*E*,2*S*)-**13** (22 mg, 0.06 mmol) in CH_2Cl_2 (15 ml) with HCl gas at r.t., 45 min, and TLC (hexane/CH_2Cl_2 1:2) yielded 21 mg (95%) of (*S*)-**14**.

4.5. *Cyclization of (1′Z,1R)*-**15** *or (1′E,1R)*-**15** *to (R)-2,2-Dibenzyl-5-phenyl-1,3-oxathiolane* ((*R*)-**16**). Treatment of (1′*Z*,1*R*)-**15** (11.5 mg, 0.03 mmol) in CH_2Cl_2 (15 ml) with HCl gas at r.t., 30 min, and TLC (hexane/CH_2Cl_2 1:1) yielded 6 mg (52%) of (*R*)-**16**.

An analogous treatment of (1′*E*,1*R*)-**15** (5 mg, 0.01 mmol) in CH_2Cl_2 (15 ml) with HCl gas at r.t., 2 h, and TLC (hexane/CH_2Cl_2 4:1) yielded 2 mg (40%) of (*R*)-**16** (*Scheme 10*).

Data of (R)-**16**: Colorless crystals. M.p. 86.5–94.0°. $[\alpha]_D^{22} = +6.1$ (90% ee). IR (KBr): 3087*w*, 3061*w*, 3029*m*, 2951*w*, 2938*w*, 2920*m*, 2860*m*, 2843*w*, 1602*w*, 1491*m*, 1450*m*, 1441*w*, 1428*w*, 1343*w*, 1327*w*, 1308*w*, 1237*m*, 1206*m*, 1143*m*, 1096*s*, 1071*s*, 1041*m*, 1031*w*, 853*m*, 754*s*, 739*s*, 702vs, 696vs, 608*m*. ^{1}H-NMR: 7.40–7.13 (*m*, 15 arom. H); 4.76 (*dd*, *J* = 10.4, 4.3, H–C(5)); 3.34–3.06 (*m*, 2 PhCH_2); 2.90 (*dd*, *J* = 10.5, 4.3, 1 H–C(4)); 2.33 (*t*, *J* = 10.4, 1 H–C(4)). ^{13}C-NMR: 138.7, 136.8, 136.7 (3*s*, 3 arom. C); 131.7, 131.1 (2*d*, 4 arom. CH); 128.4, 128.2, 128.0, 127.5, 126.7, 126.6, 126.1 (7*d*, 11 arom. CH); 96.8 (*s*, C(2)); 84.9 (*d*, C(5)); 49.0, 47.6 (2*t*, 2 PhCH$_2$); 40.7 (*t*, C(4)). CI-MS (NH_3): 365 (8), 364 (32, $[M + NH_4]^+$), 229 (17), 228 (100). Anal. calc. for $C_{23}H_{22}OS$ (346.49): C 79.73, H 6.40, S 9.25; found: C 79.65, H 6.68, S 9.15.

6. *X-Ray Crystal-Structure Determination of (1′E,2S)*-**11**, (S)-**12**, *and (S)*-**14** (*Table 3* and *Figs. 1–3*[5]). All measurements were performed on a *Nonius KappaCCD* diffractometer [14] with graphite-monochromated MoK_α radiation (λ 0.71073 Å) and an *Oxford Cryosystems Cryostream 700* cooler. The data collection and refinement parameters are given in *Table 3*, and views of the molecules are shown in *Figs. 1–3*. Data reductions were performed with *HKL Denzo* and *Scalepack* [15]. The intensities were corrected for *Lorentz* and polarization effects, and, in the case of (*S*)-**12**, an absorption correction based on the multi-scan method [16] was applied. The structures were solved by direct methods with SIR92 [17], which revealed the positions of all non-H-atoms. In the case of (*S*)-**12** and (*S*)-**14**, there were two symmetry-independent molecules in the asymmetric unit. The atomic coordinates of the two molecules were tested carefully for a relationship from a higher symmetry space group with the program PLATON [18], but none could be found. The non-H-atoms were refined anisotropically. For (1′*E*,2*S*)-**11**, the OH H-atom was placed in the position indicated by a difference-electron-density map, and its position was allowed to refine together with an isotropic displacement parameter. All remaining H-atoms, and all the H-atoms of (*S*)-**12** and (*S*)-**14** were fixed in geometrically calculated positions (d(C–H) = 0.95 Å) and each was assigned a fixed isotropic displacement parameter with a value equal

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[5]) CCDC-207086–207088 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html (or from the *Cambridge Crystallographic Data Centre*, 12 Union Road, Cambridge CB21EZ, UK (fax: +44-(0)1223-336033; e-mail: deposit@ccdc.cam.ac.uk)).

to $1.2U_{eq}$ of its parent C-atom. Refinements of the structures were carried out on F using full-matrix least-squares procedures, which minimized the function $\Sigma w(|F_o|-|F_c|)^2$. A correction for secondary extinction was applied in the case of (*S*)-**12** and (*S*)-**14**. In (1′*E*,2*S*)-**11**, (*S*)-**12**, and (*S*)-**14**, four, eight, and eight reflections, respectively, whose intensities were considered to be extreme outliers, were omitted from the final refinement. Refinements of the absolute structure parameter [19] yielded values of $-0.03(5)$, $-0.01(3)$, and $0.02(3)$ for (1′*E*,2*S*)-**11**, (*S*)-**12**, and (*S*)-**14**, respectively, which confidently confirm that the refined coordinates represent the true enantiomorph in each case. Neutral atom scattering factors for non-H-atoms were taken from [20a], and the scattering factors for H-atoms were taken from [21]. Anomalous dispersion effects were included in F_c [22]; the values for f' and f'' were those of [20b]. The values of the mass attenuation coefficients are those of [20c]. All calculations were performed with the *teXsan* crystallographic software package [23].

Table 3. *Crystallographic Data of Compounds* (*1′*E,2S)-**11**, (S)-**12**, *and* (S)-**14**

	(1′*E*,2*S*)-**11**	(*S*)-**12**	(*S*)-**14**
Crystallized from	Et_2O/hexane	Et_2O/MeOH	Et_2O/MeOH
Empirical formula	$C_{18}H_{20}OS$	$C_{18}H_{20}OS$	$C_{23}H_{22}OS$
Formula weight [g mol^{-1}]	284.42	284.42	346.49
Crystal color, habit	colorless, needle	colorless, needle	colorless, needle
Crystal dimensions [mm]	$0.10 \times 0.10 \times 0.30$	$0.05 \times 0.12 \times 0.32$	$0.07 \times 0.17 \times 0.22$
Temp. [K]	160(1)	160(1)	160(1)
Crystal system	monoclinic	monoclinic	monoclinic
Space group	$P2_1$	$P2_1$	$P2_1$
Z	2	4	4
Reflections for cell determination	2474	25173	4295
2θ range for cell determination [°]	4–60	2–60	4–55
Unit cell parameters a [Å]	8.3752(2)	15.0307(2)	9.5943(1)
b [Å]	5.3164(1)	5.8975(1)	19.5143(1)
c [Å]	17.5394(5)	17.1689(2)	9.7674(1)
β [°]	99.953(1)	91.9977(6)	96.0664(3)
V [Å^3]	769.20(3)	1520.99(4)	1818.47(3)
D_X [g cm^{-3}]	1.228	1.242	1.265
μ (MoK_α) [mm^{-1}]	0.204	0.206	0.185
$2\theta_{(max)}$ [°]	60	60	55
Total reflections measured	22113	44192	43766
Symmetry independent reflections	4484	8726	8302
Reflections used [$I > 2\sigma(I)$]	3532	7178	7387
Parameters refined	185	361	451
Final R	0.0427	0.0389	0.0344
wR	0.0409	0.0330	0.0311
Weights: p in $w=[\sigma^2(F_o)+(pF_o)^2]^{-1}$	0.015	0.005	0.005
Goodness-of-fit	1.359	1.594	1.661
Secondary extinction coefficient	–	$1.8(2) \times 10^{-6}$	$1.6(2) \times 10^{-6}$
Final Δ_{max}/σ	0.0007	0.001	0.0004
$\Delta\rho$ (max; min) [e Å^{-3}]	0.22; −0.28	0.34; −0.17	0.20; −0.19

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