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cis- and *trans*-*N*-(Benzylsulfinyl)hexahydrobenzoxazolidin-2-ones as novel chiral sulfinyl transfer reagents

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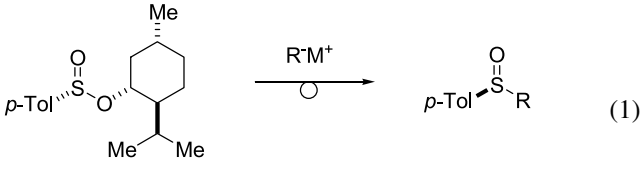
Abstract—The synthesis of *N*-benzylsulfinyl derivatives **5a–d** from both pairs of enantiomeric hexahydrobenzoxazolidin-2-ones **4a–d** is reported. The use of **5a–d** as effective chiral sulfinylating reagents in the preparation of enantiopure sulfoxides (e.e.>98%) is also reported.

1. Introduction

The interest in tricoordinated sulfur compounds in general, and sulfoxides in particular, has increased exponentially in the past two decades as consequence of the enormous potential of the chiral sulfinyl group as auxiliary in asymmetric synthesis.[1] Accordingly, the search for efficient and general methods in the preparation of chiral enantiopure sulfoxides continues to be a matter of great importance.

Salient methods for the preparation of non-racemic chiral sulfoxides can be divided into three classes: (1) kinetic resolution (either chemical[2a] or enzymatic[2b,c]) of racemic sulfoxides, (2) asymmetric oxidation of prochiral sulfides; especially with Sharpless reagent,[3a] with chiral oxaziridines,[3b] or in the presence of Noyori's BINOL ligand,[3c] and (3) stereospecific sufinylation of organometallic nucleophiles with chiral sulfinyl transfer reagents.[4–6]

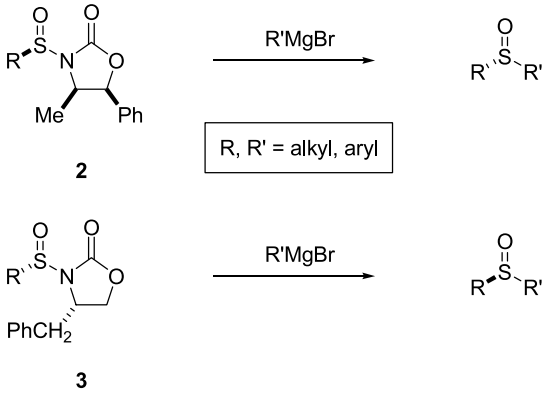
Special mention deserves the early (and still frequently used) Andersen method,[4a,b] which utilizes (*S*)-menthyl *p*-toluensulfinate (**1**) in the transfer of a chiral *p*-toluensulfinyl moiety to various types of nucleophilic organometallics with very high enantioselectivity (Eq. 1).



(1)

1

While the Andersen method (Eq. 1) is restricted to the synthesis of aryl-alkyl or diaryl sulfoxides, Evans et al.[6] reported in 1992 a new class of chiral sulfinyl transfer reagents, *N*-sulfinyloxazolidinones **2** and **3** (R = alkyl, aryl; Scheme 1). These sulfinylating agents were shown to react with Grignard reagents with inversion of configuration at the sulfur center to afford the derived chiral sulfoxides in high yields and enantioselectivities[6] (Scheme 1).



2

3

Scheme 1.

Keywords: Oxazolidinones; Sulfoxides; Sulfinyl transfer; Diastereoselective reactions; Enantioselective synthesis.

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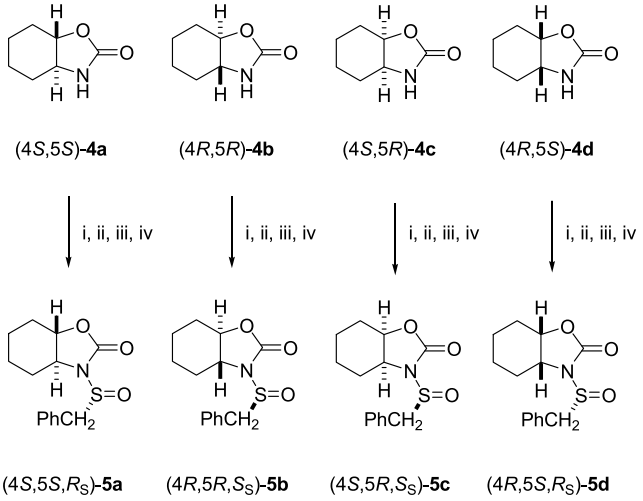
Recently, we reported a convenient procedure for the preparation of both pairs of enantiomeric hexahydrobenzoxazolidin-2-ones **4a–d** from inexpensive cyclohexene oxide and (*S*)-α-phenylethylamine.[7,8] We now report the use of *N*-benzylsulfinyl derivatives **5a–d** as effective chiral sulfinylating reagents in the preparation of enantiopure sulfoxides (Scheme 2).



Scheme 2. Conditions: i, *n*-BuLi, THF, 0 °C, 30 min. ii, $BnSSO_2Bn$, THF, −78 °C. iii, $NaIO_4$, $MeOH/H_2O$, 30–42 h, 0 °C. iv, Fractional recrystallization or preparative TLC.

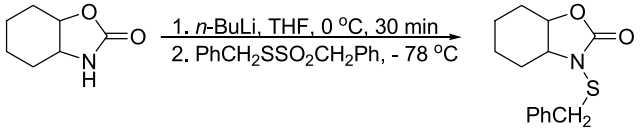
2. Results and discussion

2.1. Synthesis of *N*-(benzylsulfinyl)oxazolidinones 5a–d

The reaction of the lithiated oxazolidinones **4**-Li (obtained by treatment of **4a–d** with *n*-butyllithium at 0 °C)[9] with benzylthiosulfonate ester $PhCH_2SSO_2CH_2Ph$ proceeded in excellent yields to give crystalline products **6a–d** (Table 1).

Oxidation of *N*-sulfides **6a–b** to the desired *N*-sulfoxides **5a–b** was first attempted with *m*-chloroperoxybenzoic acid (*m*-CPBA), according to the conditions reported by Evans et al.[6] for the preparation of *N*-sulfinyloxazolidinones **3**. However, a ca. 1:1 mixture of diastereoisomeric sulfoxides **5** and *N*-sulfonyloxazolidinone **7** was produced under this condition (entry 1 in Table 2). Improved ratios of the *N*-sulfinyloxazolidinones **5** were obtained by the use of

Table 1. *N*-Thiobenzylation of hexahydrobenzoxazolidin-2-ones **4a–d** with benzylthiosulfonate ester

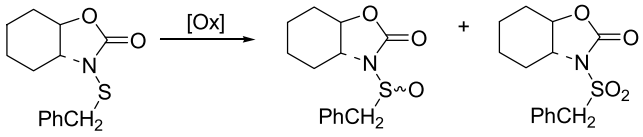


4a-d **6a-d**

Oxazolidinone	Product	Yield[a] (%)	Mp (°C)	$[\alpha]_D^{20b}$
(4*S*,5*S*)-**4a**	**6a**	91	102–103	−100.1
(4*R*,5*R*)-**4b**	**6b**	92	104–105	+98.1
(4*S*,5*R*)-**4c**	**6c**	90	50–51	−128.1
(4*R*,5*S*)-**4d**	**6d**	90	50–51	+131.1

[a] After purification by column chromatography.
[b] In $CHCl_3$, concentrations in Section 3.

Table 2. Oxidation of *N*-(thiobenzyl)oxazolidinones **6a** and **6b** with *m*-CPBA and $NaIO_4$



6a or **6b** **5** (mixture of diastereoisomers) **7**

Entry	[Ox] (equiv)	Time (h)	Temperature (°C)	Yield (%)	Product ratio[a] **5**:**7**
1	*m*-CPBA (1.5)	24	−20	66	50:50
2	*m*-CPBA (1.0)	3	−25	40	75:25
3	*m*-CPBA (1.0)	1.5	10	73	92:8
4	$NaIO_4$ (2.0)	48	25	70	98:2
5	$NaIO_4$ (3.0)	42	25	92	98:2

[a] Determined by ^1H NMR spectroscopy in the crude product.

1.0 equiv of *m*-CPBA (instead of 1.5 equiv; entries 2 and 3 in Table 2). Clearly, the use of a single equivalent of *m*-CPBA oxidant minimizes formation of the *N*-sulfonyl derivative **7**. Furthermore, faster reaction at 10 °C instead of −25 °C provided a better **5**:**7** ratio. Nevertheless, best results were observed with $NaIO_4$ as oxidant[10] (3.0 equiv, entry 5 in Table 2).

Once the optimum condition for the oxidation of *N*-sulfides **6** had been established, we proceeded to determine the diastereomeric ratios in the mixtures of sulfoxides **5**. The reaction of *N*-(thiobenzyl)hexahydrobenzoxazolidinone *trans*-(4*S*,5*S*)-**6a** in methanol with an aqueous solution of $NaIO_4$ at 0 °C afforded a 6:1 mixture of the expected diastereoisomeric *N*-sulfoxides. The major product was purified by fractional crystallization from methylene chloride–petroleum ether (5:95) (entry 1 in Table 3).

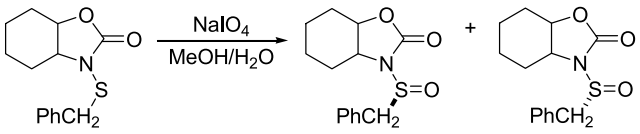
As expected, oxidation of *N*-sulfide *trans*-(4*R*,5*R*)-**6b** under the same conditions gave the enantiomeric sulfoxides in a similar 6:1 ratio (entry 2 in Table 3).

In contrast with the high diastereoselectivity observed in the oxidation of *trans*-*N*-(thiobenzyl)oxazolidinones **6a** and **6b**, the oxidation of *cis* congeners **6c** and **6d** proceeded with low, 1.6:1, diastereoselectivity (entries 3 and 4 in Table 3). Nevertheless, the major products **5c** and **5d** were easily purified by preparative TLC (petroleum ether–ethyl acetate, 2:1, eluent).

The absolute configuration at sulfur in sulfoxide (4*S*,5*S*,R_S)-**5a** was assigned by X-ray diffraction analysis from a suitable crystal of the major product from oxidation of sulfide (4*S*,5*S*)-**6a** (Fig. 1). Since the major diastereoisomeric sulfoxide product derived from enantiomeric (4*R*,5*R*)-**6b** presented same physical and spectroscopic properties but opposite sign of the optical rotation, its absolute configuration was assigned as (4*R*,5*R*,S_S)-**5b**.

The absolute configuration at the stereogenic sulfur in sulfoxide (4*R*,5*S*,R_S)-**5d** was similarly obtained by X-ray diffraction analysis from a suitable crystal (Fig. 2). Again, the major product from oxidation of (4*S*,5*R*)-**6c** was safely assigned as (4*S*,5*R*,S_S)-**5c** since it exhibited identical

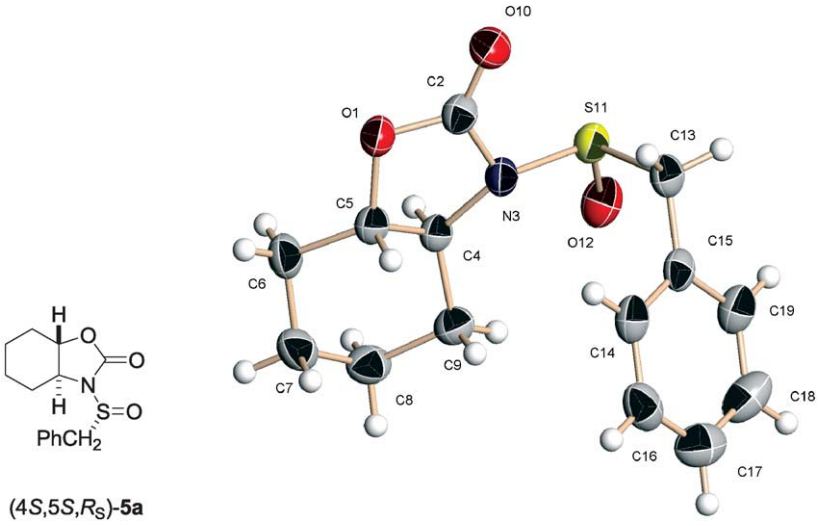
Table 3. Diastereoselectivity of the oxidation of *N*-(thiobenzyl)hexahydrobenzoxazolidinones **6** with $NaIO_4$



6 **5**

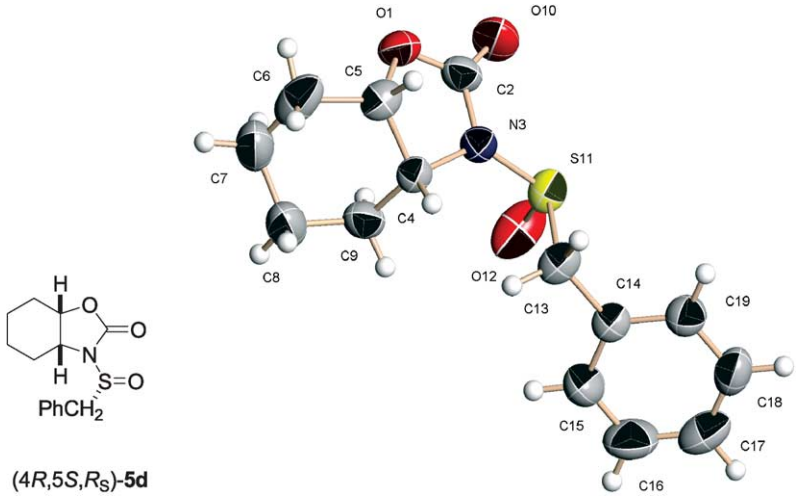
Entry	Substrate	Major product[a]	d.r. (R_S:S_S)	Yield[b] (%)	Mp[c] (°C)	$[\alpha]_D$[d]
1	(4*S*,5*S*)-**6a**	(4*S*,5*S*,R_S)-**5a**	6:1	90(50)	105–106	−30.6
2	(4*R*,5*R*)-**6b**	(4*R*,5*R*,S_S)-**5b**	1:6	90(55)	102–103	+32.0
3	(4*S*,5*R*)-**6c**	(4*S*,5*R*,S_S)-**5c**	1:1.6	80(46)	98–99	+185.3
4	(4*R*,5*S*)-**6d**	(4*R*,5*S*,R_S)-**5d**	1.6:1	80(43)	96–97	−184.1

[a] The configuration at sulfur was assigned by X-ray diffraction crystallography.
[b] Of the diastereoisomeric mixture (of the purified major isomer).
[c] Of the major product.
[d] In $CHCl_3$ concentrations in Section 3.



(4*S*,5*S*,R_S)-**5a**

Figure 1. Structure and solid-state conformation of (4*S*,5*S*,R_S)-*N*-(benzylsulfinyl)hexahydrobenzoxazolidin-2-one **5a**.[11]



(4*R*,5*S*,R_S)-**5d**

Figure 2. Structure and solid state conformation of (4*R*,5*S*,R_S)-*N*-(benzylsulfinyl)hexahydrobenzoxazolidin-2-one **5d**.[11]

melting points and NMR spectra, but an opposite sign in its optical rotation, upon comparison with (4*R*,5*S*,R_S)-**5d**.

2.2. Molecular modeling of the preferred conformations adopted by *N*-sulfides 6

The contrasting behavior of *cis*- and *trans*-*N*-(thiobenzyl)-hexahydrobenzoxazolidin-2-ones **6** can be understood with consideration of their most likely reactive conformations during oxidation, as predicted by HF/6-31G(d,p) ab initio calculations.

Indeed, the structure of lowest energy for *N*-sulfide **6b** (Fig. 3) clearly shows that steric hindrance should inhibit approach by the oxidant agent on the pro-(*R*) sulfur lone pair. As a consequence, the preferred pathway for oxidation involves the pro-(*S*) lone pair at sulfur, leading to formation of *S*-configurated *N*-sulfoxide (4*R*,5*R*,S_S)-**5b** as experimentally observed (entry 2 in Table 3).

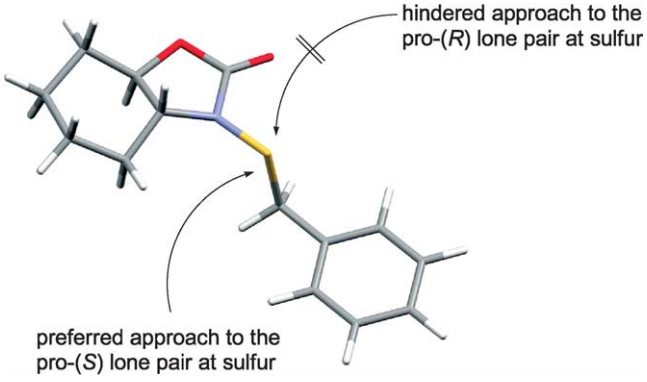


Figure 3. Lowest-energy structure calculated at HF/6-31G(d,p) ab initio level for (4*R*,5*R*)-**6b**.

Furthermore, the calculated electrostatic potential for the lowest-energy conformation of (4*R*,5*R*)-**6b** [DFT calculations[12,13] at the B3LYP/6-31G(d,p) level] shows increased electron density at the sulfur pro-(*S*) lone pair, which is in line with the experimentally observed S_S major sulfoxide product.

Along similar lines of thought, the optimized [HF/6-31G(d,p) level] structure for *cis*-*N*-(thiobenzyl)hexahydrobenzoxazolidin-2-one (4*R*,5*S*)-**6d** (Fig. 4) shows that both lone pairs at sulfur are accessible for approach by the oxidizing agent.

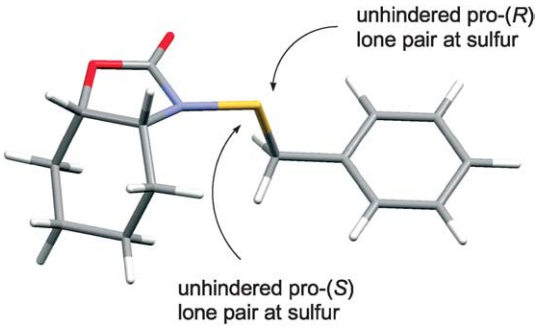


Figure 4. Lowest-energy structure calculated at the HF/6-31G(d,p) ab initio level for (4*R*,5*S*)-**6d**.

This observation is in line with the low selectivity found in the oxidation reaction (entries 3 and 4 in Table 3).

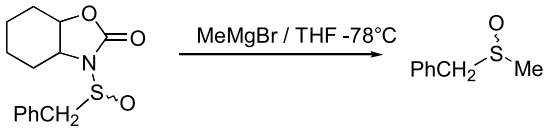
Finally, the calculated electrostatic potential for the lowest-energy conformation of (4*R*,5*S*)-**6d** [DFT calculations[12,13] at the B3LYP/6-31G(d,p) level] show similar electron density at both diastereotopic[14] sulfur lone pairs, which is in line with the observed comparable ratios of diastereoisomeric ratios of *N*-sulfoxide derivatives (entries 3 and 4 in Table 3).

2.3. Enantioselective chiral sulfinyl transfer reactions

To determine the ability of the *N*-benzylsulfinyl derivatives **5a–d** as effective chiral sulfinylating reagents in the preparation of enantiopure sulfoxides, the reaction with the Grignard reagent methylmagnesium bromide was carried out. It is known[6] that transfer of the sulfinyl group proceeds with inversion of configuration at sulfur.

To a solution of *N*-benzylsulfinyl derivatives **5a–d** in THF at −78 °C was added MeMgBr affording the chiral benzyl methyl sulfoxides **8a**,**b**. These sulfoxides and the recovered chiral auxiliary were purified by preparative TLC. Sulfoxides **8a**,**b** were obtained as white solids in 70–75% yield (Table 4). The assignment of configuration of the known benzyl methyl sulfoxides was achieved by chiral HPLC and optical rotation, respectively. The enantioselectivity measured was higher than 98% (Table 4) confirming the potential of *N*-sulfinyl derivatives **5** as effective sulfinylating agents in the preparation of enantiopure sulfoxides.

Table 4. *N*-Benzylsulfinyl derivatives **5a–d** as effective chiral sulfinylating reagents in the preparation of enantiopure sulfoxides **8a**,**b**



5a-d **8a,b**

Entry	Substrate	Yield (%)	$[\alpha]_D$[a]	Config.[b]	e.e. (%)[c]
1	(4*S*,5*S*,R_S)-**5a**	70	+51.1 (*c* 1.1)	(R_S)-**8a**	>98
2	(4*R*,5*R*,S_S)-**5b**	70	−49.1 (*c* 0.9)	(S_S)-**8b**	>98
3	(4*S*,5*R*,S_S)-**5c**	75	−49.3 (*c* 1.0)	(S_S)-**8b**	>98
4	(4*R*,5*S*,R_S)-**5d**	75	+50.1 (*c* 0.9)	(R_S)-**8a**	>99

[a] In $CHCl_3$.
[b] Assigned by comparison with the literature $[\alpha]_D = -55.0$ (*c* 0.9, $CHCl_3$) for (S_S)-benzyl methyl sulfoxide.[6,15]
[c] Determined by HPLC.

3. Experimental

3.1. General methods

All manipulations of organometallic compounds were carried out under an inert argon atmosphere. NMR spectra were obtained on a Jeol 400 MHz Fourier transform spectrometer. ^1H and ^{13}C NMR spectra were referenced to tetramethylsilane.

3.2. General procedure for the preparation of *trans*- and *cis*-*N*-(thiobenzyl)hexahydrobenzoxazolidin-2-one, 6a–d

To a solution of hexahydrobenzoxazolidin-2-ones **4a**–**d**[7] (0.2 g, 1.42 mmol) in THF (10 mL) was slowly added at 0 °C *n*-BuLi (0.98 mL, 1.56 mmol, 1.6 M in hexanes). The resulting mixture was stirred for 30 min at 0 °C, after which was cooled at −78 °C. The lithiated oxazolidinones **4**-Li were treated with commercially available (*S*)-benzyl phenyl-methanethiosulfonate (0.48 g, 1.70 mmol) in THF (2 mL). The resulting solution was stirred for 3 h, allowed to warm to rt, quenched with saturated aqueous NH_4Cl, extracted with 3×25 mL portions of dichloromethane, and the combined organic phases dried with sodium sulfate. The solvent was then removed under reduced pressure. The pale yellow solid obtained (0.36 g) was purified by column chromatography on silica gel (petroleum ether–EtOAc, 50:50, as eluent) to yield **6a**–**d**.

3.2.1. *trans*-(4*S*,5*S*)-*N*-(Thiobenzyl)hexahydrobenzoxazolidinone 6a. Mp 102–103 °C; 0.34 g (91% yield), $[\alpha]_D^{20}=-100.1$ (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz) $\delta=0.90$ (m, 2H), 1.30 (m, 2H), 1.75 (m, 3H), 2.09 (m, 1H), 2.48 (td, $^3J=3.8$, 11.2 Hz, 1H), 3.61 (td, $^3J=3.8$, 11.2 Hz, 1H), 3.81 (d, $^3J=12.8$ Hz, 1H), 4.19 (d, $^3J=12.8$ Hz, 1H), 7.32 (m, 5H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) $\delta=23.3$, 23.8, 27.5, 28.5, 41.5, 66.2, 82.4, 127.6, 128.6, 129.5, 136.3, 159.5; IR (film) 3865, 3741, 3618, 3564, 2993, 2361, 1767, 1651, 1512, 1458, 1381, 1242, 1057 cm^{-1}; $C_{14}H_{17}NO_2S$ (263.36) calcd: 63.79% C, 6.45% H, 5.31% N; found: 63.63% C, 6.51% H, 5.34% N.

3.2.2. *trans*-(4*R*,5*R*)-*N*-(Thiobenzyl)hexahydrobenzoxazolidinone 6b. Mp 104–105 °C; 0.35 g (92% yield), $[\alpha]_D^{20}=+98.1$ (*c* 0.9, $CHCl_3$). ^1H and ^{13}C NMR spectra identical with those for **6a**.

3.2.3. *cis*-(4*R*,5*S*)-*N*-(Thiobenzyl)hexahydrobenzoxazolidinone 6d. Mp 50–51 °C; 0.34 g (90% yield), $[\alpha]_D^{20}=+131.1$ (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz) $\delta=1.29$ (m, 2H), 1.45 (m, 2H), 1.65 (m, 4H), 3.10 (c, $^3J=5.6$, 12.1 Hz, 1H), 3.80 (d, $^3J=12.8$ Hz, 1H), 4.15 (d, $^3J=12.4$ Hz, 1H), 4.32 (c, $^3J=5.8$, 12.1 Hz, 1H), 7.30 (m, 5H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) $\delta=19.1$, 19.6, 25.7, 26.8, 41.8, 58.2, 74.4, 127.6, 128.6, 129.4, 135.6, 159.1; IR (film) 3865, 3741, 3618, 2993, 1759, 1512, 1381, 1242, 1057 cm^{-1}; HRMS-ES+*m*/*z* found 264.1068 $[(M+H)^+]$; calcd 264.1058 for $C_{14}H_{17}NO_2S+H^+$].

3.2.4. *cis*-(4*S*,5*R*)-*N*-(Thiobenzyl)hexahydrobenzoxazolidinone 6c. Mp 50–51 °C; 0.34 g (90% yield), $[\alpha]_D^{20}=-128.1$ (*c* 1.1, $CHCl_3$). ^1H and ^{13}C NMR spectra identical with those for **6d**.

3.3. General procedure for the preparation of *trans*- and *cis*-*N*-(benzylsulfinyl)hexahydrobenzoxazolidin-2-one, 5a–d

To a solution of *N*-(thiobenzyl)hexahydrobenzoxazolidin-2-one **6a**–**d** (0.31 g, 1.2 mmol) in MeOH (12 mL) was added $NaIO_4$ (0.77 g, 3.7 mmol) in H_2O (6 mL). The reaction mixture was stirred for 42 h at rt. The white solid formed was filtered, and the MeOH was removed under reduced pressure. The aqueous phase was extracted with 3×25 mL portions of dichloromethane, and the combined organic phase was dried with sodium sulfate. The solvent was removed under reduced pressure. The solid obtained from **6a**,**b** (0.30 g) was purified by fractional recrystallization from dichloromethane–petroleum ether (95:5) to yield the major diastereoisomers **5a**,**b** as white crystals. The solid obtained from **6c**,**d** (0.27 g) was purified by preparative TLC on silica gel (hexanes–EtOAc, 67:33, as eluent) to yield the major diastereoisomer **5c**,**d** as white crystals.

3.3.1. (4*S*,5*S*,R_S)-*trans*-*N*-(Benzylsulfinyl)hexahydrobenzoxazolidin-2-one, 5a. Mp 105–106 °C; 0.17 g (50% yield), $[\alpha]_D^{20}=-30.6$ (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz) $\delta=1.3$–1.6 (m, 8H), 1.8–2.0 (m, 4H), 2.23 (m, 1H), 2.43 (m, 1H), 3.55 (dt, 1H, $^3J=3.6$, 11.6 Hz), 3.96 (dt, 1H, $^3J=3.6$, 11.2 Hz), 4.28 (dd, 2H, $^2J=13.0$ Hz), 7.2–7.4 (m, 5H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) $\delta=23.3$, 23.7, 28.7, 29.4, 61.0, 62.0, 81.8, 128.9, 129.9, 130.2, 158.0; IR (film) 3061, 2962, 2922, 2858, 1755, 1732, 1454, 1392, 1302, 1217, 1163, 1136, 1099, 1032, 762, 698 cm^{-1}; HRMS-ES+*m*/*z* found 302.0828 $[(M+Na)^+]$; calcd 302.0827 for $C_{14}H_{17}NO_3S+Na^+$].

3.3.2. (4*R*,5*R*,S_S)-*trans*-*N*-(Benzylsulfinyl)hexahydrobenzoxazolidin-2-one, 5b. Mp 102–103 °C; 0.18 g (55% yield), $[\alpha]_D^{20}=+32.0$ (*c* 0.9, $CHCl_3$). ^1H and ^{13}C NMR spectra identical with those for **5a**.

3.3.3. (4*S*,5*R*,S_S)-*cis*-*N*-(Benzylsulfinyl)hexahydrobenzoxazolidin-2-one, 5c. Mp 98–99 °C; 0.15 g (46% yield), $[\alpha]_D^{20}=+185.3$ (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz) $\delta=0.92$ (m, 1H), 1.10 (m, 1H), 1.34 (m, 2H), 1.55 (m, 2H), 1.75 (m, 2H), 4.14 (c, 1H, $^3J=12.0$, 6.4 Hz), 4.34 (d, 1H, $^2J=12.8$ Hz), 4.44 (c, 1H, $^3J=11.6$, 5.6 Hz), 4.90 (d, 1H, $^2J=12.8$ Hz), 7.38 (m, 5H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) $\delta=19.1$, 19.3, 26.9, 27.5, 55.5, 59.0, 75.0, 128.4, 128.7, 128.8, 129.8, 154.8; IR (film) 1755, 1217 cm^{-1}; HRMS-ES+*m*/*z* found 302.0841 $[(M+Na)^+]$; calcd 302.0827 for $C_{14}H_{17}NO_3S+Na^+$].

3.3.4. (4*R*,5*S*,R_S)-*cis*-*N*-(Benzylsulfinyl)hexahydrobenzoxazolidin-2-one, 5d. Mp 96–97 °C; 0.14 g (43% yield), $[\alpha]_D^{20}=-184.1$ (*c* 1.0, $CHCl_3$). ^1H and ^{13}C NMR spectra identical with those for **5c**.

3.4. Preparation of (S_S) and (R_S)-benzyl methyl sulfoxides 8a,b

To a previously cooled solution at −78 °C of *N*-(benzylsulfinyl) hexahydrobenzoxazolidin-2-one **5a**–**d** (0.04 g, 0.143 mmol) in THF (10 mL) was added dropwise MeMgBr (1.4 M, in toluene–THF 75:25, 0.20 mL, 0.28 mmol). The reaction was quenched with saturated aqueous NH_4Cl (1 mL). The solvent was removed under reduced pressure, extracted with 3×25 mL portions of ethyl acetate, and the combined organic phase was dried with sodium sulfate. The solvent was then removed under reduced pressure. The product and the chiral auxiliary were purified by preparative TLC (petroleum ether–EtOAc, 33:67, as eluent). The recovered chiral auxiliary afforded 18 mg (90%).

3.5. Conditions for the analysis and assignment of configuration of the chiral sulfoxides 8a,b

Chiral HPLC: Chiralcel OD column 254 nm UV detector, diameter 0.46 cm, length 25 cm, 1.0 mL/min. Hexanes–*i*-PrOH, 90:10.

Specific rotations of the chiral sulfoxides were measured and compared with those reported on the literature to assign the configuration.[6,15]

3.5.1. (R_S)-Benzyl methyl sulfoxide 8a. The sulfoxide was obtained as a white solid (0.016 g, 75.0% yield); e.e.>98%; t_R=35.4 min, $[\alpha]_D^{20}=+50.1$ (*c* 1.0, $CHCl_3$).

3.5.2. (S_S)-Benzyl methyl sulfoxide 8b. The sulfoxide was obtained as a white solid (0.016 g, 75.0% yield); e.e.>98%; t_R=38.4 min, $[\alpha]_D^{20}=-49.3$ (*c* 1.1, $CHCl_3$). [Lit.[15] $[\alpha]_D^{20}=-55.0$ (*c* 0.9, $CHCl_3$)].

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11. Crystal data for (4*S*,5*S*,R_S)-**5a**: $C_{14}H_{17}N_1O_3S_1$, molecular weight=279.35, monoclinic *P* 21, *a*=9.5214(7) Å, *b*=5.6279(5) Å, *c*=12.8734(11) Å, α=90.0°, β=104.386(3)°, γ=90.0°, *V*=668.20(10) Å^3, crystal size: 0.32×0.20×0.15 mm, *R*1=0.0444 (wR2=0.0980); for (4*R*,5*S*,R_S)-**5d**: $C_{14}H_{17}N_1O_3S_1$, molecular weight=279.35, orthorhombic *P* 21 21 21, *a*=6.9022(2) Å, *b*=9.3434(3) Å, *c*=22.0288(8) Å, α=90.0°, β=90.0°, γ=90.0, *V*=668.20(10) Å^3, crystal size: 0.20×0.15×0.12 mm, *R*1=0.0469 (wR2=0.0840). Atomic coordinates for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 IEZ, UK. (Fax: +44 1223 336 036; e-mail: deposit@ccdc.cam.ac.uk; deposition number: CCDC 248001, CCDC 248002).
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