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Highly stereoselective 1,4-asymmetric reactions of 2-(arylsulfinyl)benzaldehydes and 2-(arylsulfinyl)phenyl ketones

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Abstract—The Grignard reaction of 2-(arylsulfinyl)benzaldehydes and the DIBAL reduction of 2-(arylsulfinyl)phenyl ketones were examined. The sterically bulky (2,4,6-trimethylphenyl)- and (2,4,6-triisopropylphenyl)sulfinyl groups were shown to effect high 1,4-remote asymmetric induction. The optically active 1-phenyl-1-*p*-tolylmethanol could be efficiently prepared by desulfinylation of the Grignard reaction product obtained from chiral [(2,4,6-triisopropylphenyl)sulfinyl]benzaldehyde. © 2001 Elsevier Science Ltd. All rights reserved.

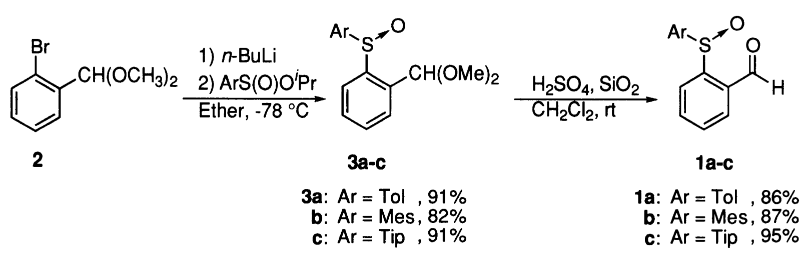
1. Introduction

The carbonyl-face selective reductions[1] and nucleophilic reactions[2] of β-ketosulfoxides provide versatile methods for the synthesis of chiral secondary alcohols. Reduction of β-ketosulfoxides with diisobutylaluminum hydride (DIBAL) proceeds through a six-membered cyclic transition state, and gives the β-hydroxysulfoxides with high diastereoselectivity.[1a–f] On the other hand, nucleophilic addition and reduction of γ-ketosulfoxides[3] would proceed through a seven-membered cyclic transition state, and thus give the alcohols with lower stereoselectivity in comparison with those of β-ketosulfoxides. Nonetheless, we recently reported successful results in DIBAL reduction of acyclic γ-ketosulfoxides having the sterically bulky 2,4,6-triisopropylphenyl substituent on the sulfur.[4] The bulky group on the sulfur such as the 2,4,6-triisopropylphenyl (Tip) group is also efficient to induce high stereoselectivity in nucleophilic reactions of the 1-sulfinyl-2-naphthaldehydes and reduction of 1-(arylsulfinyl)-2-naphthyl ketones,[5] in which the rotational barrier around the C_{naph}–S bond axis was shown to be a key factor for controlling the stereochemistry. On the other hand, phenyl derivatives were expected to show stereochemical features different from those of the naphthalene derivatives, since they obviously have no significant rotational barrier around the C_{Ph}–S bond axis. We now report highly diastereoselective reactions of 2-(arylsulfinyl)benzaldehydes and 2-(arylsulfinyl)phenyl ketones.

2. Results

2.1. The stereoselective Grignard reaction of 2-(arylsulfinyl)benzaldehydes

Scheme 1 summarizes the synthetic route for the preparation of various 2-sulfinylbenzaldehydes **1a–c** for the study of the stereoselectivity in the addition of nucleophiles. Treatment of *p*-toluene-, 2,4,6-trimethylbenzene-, 2,4,6-triisopropylbenzenesulfinates with 2-lithio benzaldehyde dimethyl acetal at −78°C in Et_2O, followed by deprotection upon treatment with silica gel containing a small amount of sulfuric acid in CH_2Cl_2,[6] gave the corresponding 2-(arylsulfinyl)benzaldehydes **1a–c** in high yields.



Scheme 1.

Keywords: asymmetric reaction; chelation; Grignard reactions; reduction; sulfoxides.
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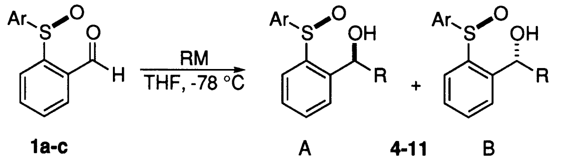
Table 1. Stereoselective reaction of 2-sulfinylbenzaldehydes **1a–c** with Grignard reagents



Entry	Ar	RM	Product	Yield (%)	Ratio A:B
1	Tol	PhMgBr	**4**	94	88:12[a]
2	Tol	MeMgI	**5**	61	67:33[a]
3	Mes	PhMgBr	**6**	97	>98:2[a]
4	Mes	MeMgI	**7**	81	>98:2[a]
5	Tip	PhMgBr	**8**	96	>98:2[a]
6	Tip	PhMgBr[b]	**8**	79	>98:2[a]
7	Tip	MeMgI	**9**	89	>98:2[a]
8	Tip	MeLi	**9**	74	69:31[a,c]
9	Tip	EtMgBr	**10**	76[d]	>98:2[a]
10	Tip	AllylMgBr	**11**	91	51:49[c]
11	Tip	AllylMgBr[b]	**11**	70	65:35[c]
12	Tip	AllylMgBr[e]	**11**	97	82:18[c]

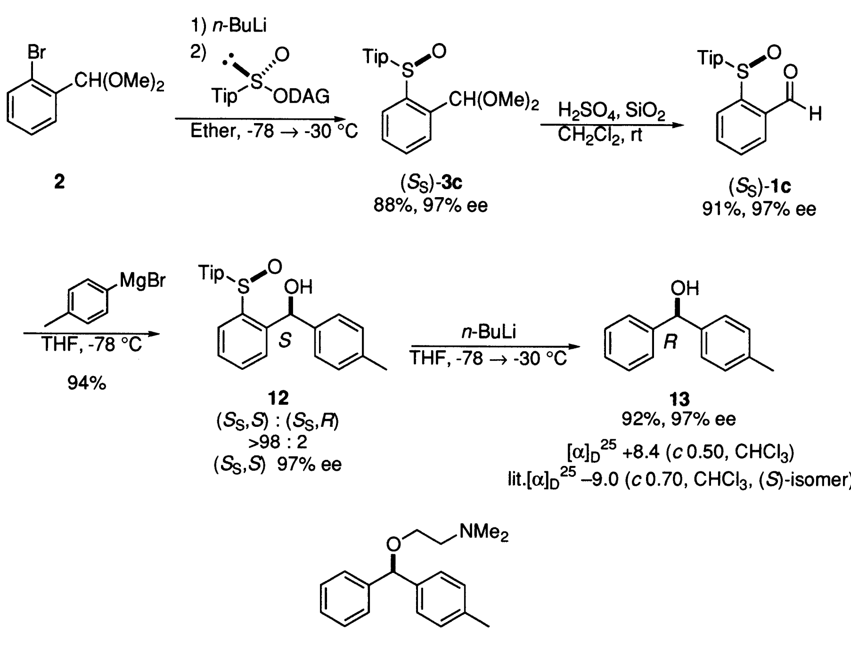
[a] Determined by the ^{1}H NMR spectral analysis.
[b] $Yb(OTf)_3$ (1.1 equiv.) was used.
[c] Determined by the HPLC analysis.
[d] Formation of a small amount of the 2-[(2,4,6-triisopropylphenyl)sulfinyl]phenylmethanol was observed.
[e] $ZnCl_2$ (1.1 equiv.) was used.

The thus-obtained 2-sulfinylbenzaldehydes **1a–c** were treated in THF with 1.5 equiv. of a Grignard reagent to give the sulfinylbenzyl alcohols **4–11**. A variety of Grignard reagents were used and the results are shown in Table 1.

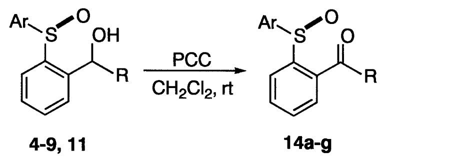
Obviously, the stereoselectivity varied depending upon the ortho substituents of the aryl groups attached to the sulfinyl group. Reactions of 2-[(2,4,6-trimethylphenyl)sulfinyl]- and 2-[(2,4,6-triisopropylphenyl)sulfinyl]benzaldehydes **1b**,**c** with PhMgBr show high stereoselectivity in comparison with 2-(*p*-tolylsulfinyl)benzaldehyde **1a**. Thus, the reaction of **1b**,**c** with PhMgBr, MeMgI or EtMgBr proceeded with high stereoselectivity leading to the exclusive formation of the isomer A of the phenylmethanols **6–10** (entries 3–5, 7 and 9), whereas (*p*-tolylsulfinyl)benzaldehydes **1a** showed only moderate stereoselectivity (entries 1 and 2). The reaction of **1c** with MeLi or allylmagnesium bromide showed only low stereoselectivity (entries 8 and 10), whereas $ZnCl_2$ addition in the reaction of **1c** with allylmagnesium bromide increased the stereoselectivity (entry 12). Use of $Yb(OTf)_3$ did not alter the stereoselectivity (entries 6 and 11).

Having established a highly diastereoselective reaction of **1c**, we examined the preparation of chiral diaryl methanols[7] by using the chiral (*S*)-**1c**. Asymmetric reactions often incur difficulty in the preparation of enantiomerically pure unsymmetrical diarylmethanols, especially methanols having sterically and electronically similar aryl groups.[8] We chose 1-phenyl-1-*p*-tolylmethanol, a precursor of antihistaminic (*R*)-neobenodine,[9] as the most appropriate compound to represent the efficiency of the present synthetic method.

The chiral Tip-sulfinyl acetal (*S*)-**3c** was obtainable with 97% ee from (R_S)-diacetone-D-glucosyl 2,4,6-triisopropylbenzenesulfinate,[10] where the precooled solution of the sulfinate was added to lithiated **2** to minimize racemization of the sulfoxide (Scheme 2). Deacetalization afforded the Tip-sulfinylaldehyde (*S*)-**1c** which was subjected to the Grignard reaction with *p*-tolylmagnesium bromide in THF at −78°C giving exclusively Tip-sulfinylphenylmethanol (S_S,*S*)-**12**. Cleavage of the sulfinyl moiety using *n*-BuLi[11] gave the optically active phenylmethanol (*R*)-**13** with 97% ee. The absolute configuration of **13** was assigned to be *R*by comparison of the specific rotation with the reported value.[12] The stereochemistry of the products **4–11** obtained in the Grignard reaction was tentatively assigned to be the



Scheme 2.



Scheme 3.

same as that of **12**.[13] This reaction provides a convenient method for the preparation of the optically active chiral diarylmethanols via the nucleophilic reaction of the Tip-sulfinylbenzaldehyde **1c** in combination with cleavage of the sulfinyl group.

2.2. Stereoselective reduction of 2-(arylsulfinyl)phenyl ketones

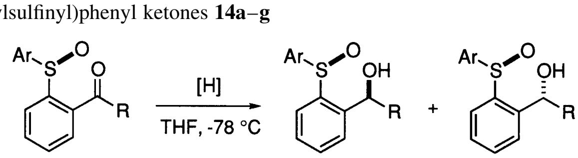
The pyridinium chlorochromate (PCC) oxidation of the 2-(arylsulfinyl)phenylmethanols **4–9**, **11**, prepared in the former reaction, gave the 2-(arylsulfinyl)phenyl ketones **14a–g** (Scheme 3). Reactions of the *p*-tolylsulfinyl, (2,4,6-trimethylphenyl)sulfinyl and [(2,4,6-triisopropylphenyl)-sulfinyl]phenyl ketones **14a–g** with various reducing reagents, without or in the presence of Lewis acids at −78°C in THF, were examined. The results are summarized in Table 2.

Reduction of **14a–f** with $LiAlH_4$ proceeded with low diastereoselectivity irrespective of the bulkiness of the substituent on the sulfur (entries 1, 3, 5, 7, 9 and 16). The diastereoselectivity of the products in the DIBAL reduction depended upon the substituent on the sulfur. The (*p*-tolylsulfinyl)phenyl ketones **14a**,**b** with DIBAL afforded the products with low stereoselectivity (entries 2 and 4), whereas [(2,4,6-trimethylphenyl)sulfinyl]phenyl ketones **14c**,**d**, especially [(2,4,6-triisopropylphenyl)sulfinyl]phenyl ketones **14e–g**, gave alcohols **6–9**, **11** with high stereoselectivity, favoring the isomer B (entries 6, 8, 10, 17 and 18). Reduction of **14e** with other reducing agents such as L-selectride® and Superhydride® gave the product **8** with slightly lower stereoselectivity (entries 11 and 12). Solladié and co-workers have reported that reduction of γ-keto-sulfoxides with DIBAL proceeds with moderate diastereoselectivity without Lewis acids and the stereochemistry of the product was reversed in the presence of $Yb(OTf)_3$.[3c] In the DIBAL reduction of **14e**, the stereoselectivity was lowered in the presence of $Yb(OTf)_3$ or LiBr in THF, but not reversed (entries 13 and 14). On the other hand, $ZnCl_2$ significantly reversed the diastereoselectivity to give **8** in a ratio of 85:15, favoring the isomer A (entry 15). The relative configurations of the alcohols **4–9** and **11** were determined by comparison of the HPLC behavior with those obtained in the previous nucleophilic reactions (Table 1).

3. Discussion

We recently reported highly stereoselective nucleophilic reactions of 1-[(2,4,6-triisopropylphenyl)sulfinyl]-2-naph-

Table 2. Stereoselective reduction of 2-(arylsulfinyl)phenyl ketones **14a–g**



Entry		Substrate		Reducing agent	Product	Yield (%)	Ratio[a] A:B
		Ar	R				
1	**14a**	Tol	Ph	$LiAlH_4$	**4**	80	47:53
2	**14a**	Tol	Ph	DIBAL	**4**	80	15:85
3	**14b**	Tol	Me	$LiAlH_4$	**5**	84	51:49
4	**14b**	Tol	Me	DIBAL	**5**	85	37:63
5	**14c**	Mes	Ph	$LiAlH_4$	**6**	82	21:79
6	**14c**	Mes	Ph	DIBAL	**6**	92	<2:>98
7	**14d**	Mes	Me	$LiAlH_4$	**7**	94	56:44
8	**14d**	Mes	Me	DIBAL	**7**	94	16:84
9	**14e**	Tip	Ph	$LiAlH_4$	**8**	81	35:65
10	**14e**	Tip	Ph	DIBAL	**8**	96	<2:>98
11	**14e**	Tip	Ph	L-selectride®	**8**	86	11:89
12	**14e**	Tip	Ph	Superhydride®	**8**	94	12:88
13	**14e**	Tip	Ph	DIBAL[b]	**8**	88	16:84
14	**14e**	Tip	Ph	DIBAL[c]	**8**	81	19:81
15	**14e**	Tip	Ph	DIBAL[d]	**8**	92	85:15
16	**14f**	Tip	Me	$LiAlH_4$	**9**	97	58:42[e]
17	**14f**	Tip	Me	DIBAL	**9**	96	3:97[e]
18	**14g**	Tip	Allyl	DIBAL	**11**	94	<2:>98

[a] Determined by the ^1H NMR spectral analysis.
[b] Reaction was carried out in the presence of LiBr.
[c] Reaction was carried out in the presence of $Yb(OTf)_3$.
[d] Reaction was carried out in the presence of $ZnCl_2$.
[e] Determined by the HPLC analysis.

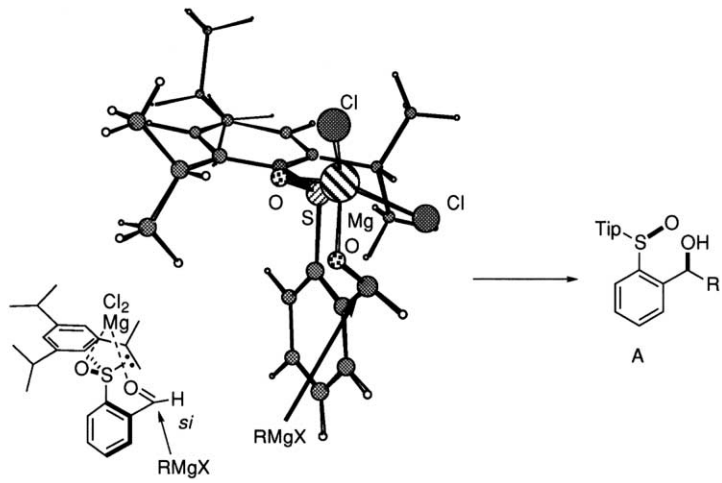


Figure 1. Assumed chelated intermediate for **1c** with $MgCl_2$.

thaldehydes and reduction of 1-[(2,4,6-triisopropylphenyl)-sulfinyl]-2-naphthyl ketones.[5] We demonstrated that the high stereoselectivity obtained in these reactions was due to the restricted C–S axis rotation, controlled by chirality on the sulfur and, consequently, due to complete covering over a carbonyl face by the bulky aryl group. However, neither 2-sulfinylbenzaldehydes **1a–c** nor 2-sulfinylphenyl ketones **14a–f** would have a significant rotational barrier around the C–S axis. The mechanism of the nucleophilic reaction of 2-sulfinylbenzaldehydes **1a–c** and reduction of 2-sulfinyl-phenyl ketones **14a–f** should be different from those expected in the reactions of 1-sulfinyl-2-naphthaldehydes and 2-sulfinylnaphthyl ketones, respectively. Use of $Yb(OTf)_3$ did not change the stereoselectivity in the reaction of 2-sulfinylbenzaldehyde **1c** with Grignard reagents (Table 1, entry 6). These results indicate that the Grignard reaction of **1c** without a Lewis acid proceeds through an intermediate involving chelation of magnesium with the sulfinyl and the carbonyl oxygens. The Grignard reaction of 1-sulfinyl-2-naphthaldehydes without a Lewis acid proceeds through the nonchelated intermediate because of significant steric interaction between the *peri*-H (8) proton and the (triiso-propylphenyl)sulfinyl group in the chelate structure. On the other hand, 2-sulfinylbenzaldehyde **1c** without the *peri*-H (8) readily forms the chelated intermediate.

In order to obtain further information regarding the chelate structure of **1c** with a magnesium salt, the chelated conformers were calculated by the semiempirical MOPAC 93/PM3 method,[14,15] leading to the optimized structure depicted in Fig. 1. One of the faces of the formyl group in this intermediate is efficiently covered with the bulky 2,4,6-triiso-propylphenyl group, and a Grignard reagent approaches from the less hindered side to give the isomer A (Fig. 1).

Low stereoselectivity in the reaction of **1c** with MeLi can be ascribed to the weaker chelating ability of the lithium atom than that of the magnesium atom (Table 1, entry 8).[16,17] Thus, the reaction proceeds through a nonchelated transition state in which both the C_{Ph}–S and C_{Ph}–$C_{C=O}$ bond axes may freely rotate, giving the product **9** with low stereoselectivity. The allylation behavior was peculiar and gave the product **11** with low stereoselectivity although other Grignard reagents gave the products with high stereoselectivity (Table 1, entry 10). It is likely that the reaction also proceeds predominantly via a chelated transition state as in the other Grignard reactions, but there would be another reaction pathway which involves the intramolecular bond formation via the S_E2' mechanism through a six-membered transition state[18] (Fig. 2). Addition of $ZnCl_2$ partially prevents the formation of the chelate with allylmagnesium bromide

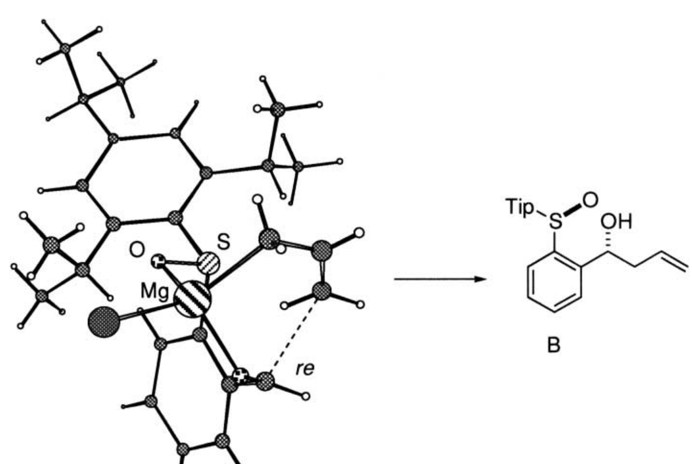
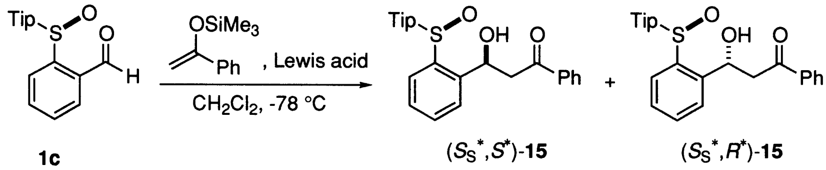


Figure 2. Assumed S_E2' transition state for the reaction of **1c** with allylmagnesium bromide.



Lewis acid	yield (%)	ratio (S_S^*,S^*):(S_S^*,R^*)
$BF_3{\cdot}OEt_2$	84	58 : 42
$TiCl_4$	79	88 : 12

Scheme 4.

and, hence, the intermolecular allylation to give the product **11** with relatively high stereoselectivity favoring the isomer A (entry 12).

We examined the Mukaiyama aldol reaction of the 2-sulfinylbenzaldehyde **1c** with the silyl enol ether derived from acetophenone in order to further clarify the reaction mechanism of the Grignard reaction of **1c** proceeding through the chelated intermediate. The reaction was carried out by stirring a CH_2Cl_2 solution of **1c** and a Lewis acid for 1 h at −78°C, and subsequent addition of the ketene acetals (Scheme 4).

Treatment of **1c** with the silyl enol ether in the presence of 2.0 equiv.of $BF_3{\cdot}OEt_2$ gave the product **15** with low stereoselectivity. The relative configuration of the minor product was determined to be (S_S^*,R^*) by the X-ray crystal structure analysis (Fig. 3).

In order to promote the Mukaiyama aldol reaction, Lewis acids are needed to activate the aldehyde. Actually, $BF_3{\cdot}OEt_2$ enhanced the reactivity of **1c** toward the silyl enol ether but it gave the product **15** with low stereoselectivity. The reaction apparently proceeded through a nonchelated transition state due to the coordination of two BF_3 molecules with the sulfinyl and the carbonyl oxygens. $TiCl_4$ (1.1 equiv.), on the other hand, formed a chelate with the sulfinyl and the carbonyl oxygens, in which a silyl enol ether approached the carbonyl face from the less hindered side avoiding the steric interaction with the 2,4,6-triisopropylphenyl group, giving the aldol product **15** favoring the (S_S^*,S^*)-isomer with higher stereoselectivity than that obtained in the reaction using $BF_3{\cdot}OEt_2$. It should be noted that attack of the silyl enol ether in the $TiCl_4$-chelated 7-membered cyclic intermediate occurred on the same carbonyl face as that in the Grignard reaction of **1c**. These results in the Mukaiyama aldol reaction of **1c** support the Grignard reaction proceeding through the chelated intermediate.

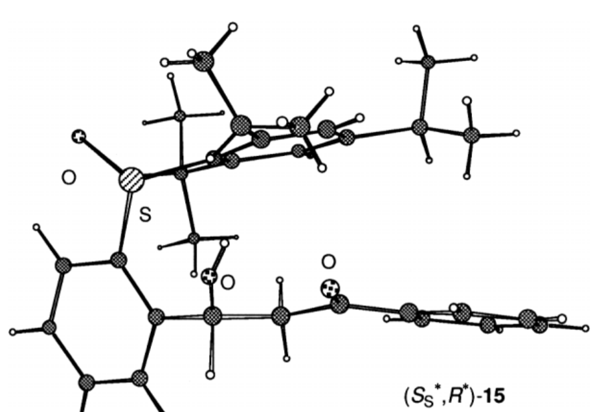


Figure 3. X-Ray crystallography of (S_S^*,S^*)-**15**.

The stereochemical outcome in the reduction of **14** with DIBAL is ascribed to a seven-membered cyclic transition state as shown in Fig. 4.[19] The bulky 2,4,6-triisopropylphenyl group is placed away from the neighboring acyl substituent in a preferred transition state, and intramolecular reduction occurs from the *si* face of the carbonyl to give the isomer B. High stereoselectivity could be achieved through the cyclic transition state fixed preferably by the 2,4,6-triisopropylphenyl group than by the mesityl and *p*-tolyl groups. Addition of $ZnCl_2$ reversed the stereochemistry of the product **8** (Table 2, entry 15), indicating that $ZnCl_2$ would form a chelate in place of DIBAL and reduction occurs from the outside of the chelate.

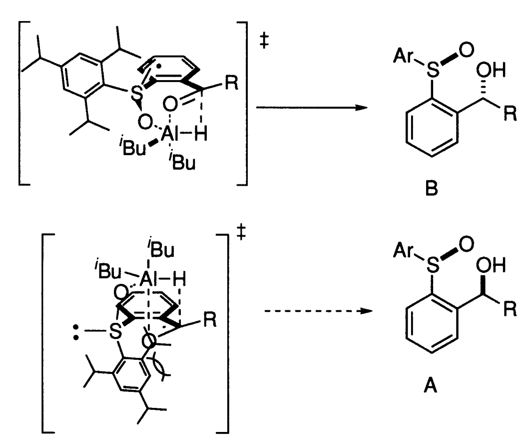


Figure 4. Assumed transition state in reduction of **14** with DIBAL.

4. Conclusion

The Grignard reaction of benzaldehydes and the DIBAL reduction of phenyl ketones bearing the bulky (2,4,6-trimethylphenyl)sulfinyl and (2,4,6-triisopropylphenyl)-sulfinyl groups at the 2-position gave the products with high stereoselectivity through the chelated intermediates.

These reactions provide a convenient and efficient method for the preparation of the optically active benzyl alcohols by removal of the sulfinyl group from the products.

5. Experimental

5.1. Preparation of the sulfoxides

5.1.1. 2-[(2,4,6-Triisopropylphenyl)sulfinyl]benzaldehyde dimethyl acetal (3c). To a solution of 2-bromobenzaldehyde dimethyl acetal (**2**) (110 mg, 0.417 mmol) in Et_2O (0.8 mL) was added *n*-butyllithium (1.56 mol L^{-1} solution in hexane, 0.31 mL, 0.484 mmol) at −78°C and the mixture was stirred for 30 min. A solution of isopropyl 2,4,6-triisopropylbenzenesulfinate (135 mg, 0.434 mmol) in Et_2O (2 mL) was then added. After stirring for 3 h, the reaction was quenched with saturated aqueous NH_4Cl and extracted with CH_2Cl_2. The combined organic extracts were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure to leave a residue which was purified by column chromatography (silica gel 6 g, hexane/ethyl acetate =90:10) to afford **3c** (158 mg, 91%): R_f=0.18 (hexane/ethyl acetate=90:10); ^{1}H NMR δ 0.92 (d, 6H, *J*=6.8 Hz), 1.23 (d, 6H, *J*=6.8 Hz), 1.24 (d, 6H, *J*=6.8 Hz), 2.85 (hep, 1H, *J*=6.8 Hz), 3.13 (s, 3H), 3.17 (s, 3H), 3.80 (hep, 2H, *J*=6.8 Hz), 5.13 (s, 1H), 7.07 (s, 2H), 7.30–7.50 (m, 2H), 7.60–7.70 (m, 1H), 7.75–7.85 (m, 1H); ^{13}C NMR δ 23.8, 23.9, 24.3, 28.8, 34.4, 51.3, 54.0, 98.9, 122.9, 126.0, 127.4, 128.7, 129.6, 136.4, 143.4, 151.6, 153.3; IR (neat) 2980, 1200, 1100, 1060 cm^{-1}; EIMS *m*/*z* (rel. intensity) 402 (M^+, 0.1), 311 (10), 291 (100). Anal. Calcd for $C_{24}H_{34}O_3S$: C, 71.32; H, 8.76; Found: C, 71.32; H 8.76.

5.1.2. 2-(*p*-Tolylsulfinyl)benzaldehyde dimethyl acetal (3a). The reaction was carried out as the preparation of **3c** except using isopropyl *p*-toluenesulfinate (671 mg, 3.64 mmol), **2** (1.0 g, 4.33 mmol) and *n*-butyllithium (1.55 mol L^{-1}, 2.32 mL, 3.60 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=90:10) to afford **3a** (966 mg, 91%). mp 64–65°C; R_f=0.11 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 2.35 (s, 3H), 3.16 (s, 3H), 3.38 (s, 3H), 5.61 (s, 1H), 7.19–7.28 (m, 3H), 7.45–7.65 (m, 4H), 8.00–8.10 (m, 1H); ^{13}C NMR δ 21.3, 52.4, 53.8, 100.4, 125.3, 126.9, 129.7, 129.9, 130.6, 136.1, 141.1, 142.3, 144.1; IR (KBr) 3050, 3000, 1200, 1050 cm^{-1}; EIMS *m*/*z* (rel. intensity) 290 (M^+, 8), 273 (100), 258 (70), 227 (60). Anal. Calcd for $C_{16}H_{18}O_3S$: C, 66.18; H, 6.25; Found: C, 66.19; H, 6.41.

5.1.3. 2-[(2,4,6-Trimethylphenyl)sulfinyl]benzaldehyde dimethyl acetal (3b). The reaction was carried out as the preparation of **3c** except using isopropyl 2,4,6-trimethylbenzenesulfinate (453 mg, 1.99 mmol), **2** (506 mg, 2.19 mmol) and *n*-butyllithium (1.56 mol L^{-1} solution in hexane, 1.40 mL, 2.18 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 6 g, hexane/ethyl acetate=85:15) to afford **3b** (568 mg, 82%): mp 86–87°C; R_f=0.26 (hexane/ethyl acetate=80/20); ^{1}H NMR δ 2.28 (s, 3H), 2.38 (s, 6H), 3.12 (s, 3H), 3.14 (s, 3H), 5.00 (s, 1H), 6.85 (s, 2H), 7.40–7.60 (m, 2H), 7.65–7.70 (m, 1H), 7.80–8.10 (m, 1H); ^{13}C NMR δ 19.5, 21.1, 50.8, 54.1, 99.1, 126.6, 127.5, 127.9, 128.6, 130.6, 135.5, 135.7, 140.4, 141.5, 142.0; I R (KBr) 3030, 1200, 1060 cm^{-1}; EIMS *m*/*z* (rel. intensity) 318 (M^+, 10), 301 (100), 207 (50). Anal. Calcd for $C_{18}H_{22}O_3S$: C, 67.90; H, 6.96; Found: C, 67.81; H, 7.05.

5.1.4. 2-[(2,4,6-Triisopropylphenyl)sulfinyl]benzaldehyde (1c). To a suspension of silica gel (2.0 g) in CH_2Cl_2 (15 mL) was added 20 drops of a 15% sulfuric acid solution and the mixture was stirred for 5 min. Then a solution of **3c** (1.39 g, 3.44 mmol) in CH_2Cl_2 (15 mL) was added. After stirring for 1 h, a small amount of $NaHCO_3$ (300 mg) was added. The mixture was stirred for 5 min, then filtered, and washed with CH_2Cl_2. The filtrate was concentrated under reduced pressure to leave a residue which was purified by column chromatography (silica gel 40 g, hexane/ethyl acetate=95:5) to afford **1c** (1.17 g, 95%): R_f=0.32 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 0.90 (d, 6H, *J*=6.8 Hz), 1.24 (d, 6H, *J*=6.8 Hz), 1.25 (d, 6H, *J*=6.8 Hz), 2.90 (hep, 1H, *J*=6.8 Hz), 3.80 (hep, 2H, *J*=6.8 Hz), 7.06 (s, 2H), 7.55–7.65 (m, 1H), 7.70–7.80 (m, 1H), 7.90–8.00 (m, 2H), 10.2 (s, 1H); ^{13}C NMR δ 23.6, 23.9, 24.4, 29.1, 34.4, 123.3, 126.7, 130.0, 131.3, 133.6, 134.1, 148.7, 151.0, 153.6, 189.4; IR (neat) 2950, 1700, 1200, 1060, 1020 cm^{-1}; EIMS *m*/*z* (rel. intensity) 356 (M^+, 0.2), 339 (20), 291 (100), 265 (50). Anal. Calcd for $C_{22}H_{28}O_2S$: C, 74.12; H, 7.92. Found: C, 73.98; H, 8.05.

5.1.5. 2-(*p*-Tolylsulfinyl)benzaldehyde (1a). The reaction was carried out as the preparation of **1c** except using 15% sulfuric acid (20 drops), SiO_2 (2.0 g) and **3a** (966 mg, 3.33 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=70:30) to afford **1a** (698 mg, 86%): mp 118–119°C; R_f=0.17 (hexane/ethyl acetate=50:50); ^{1}H NMR δ 2.31 (s, 3H), 7.15–7.40 (m, 2H), 7.50–7.70 (m, 3H), 7.80–8.00 (m, 2H), 8.50–8.60 (m, 1H), 10.0 (s, 1H); ^{13}C NMR δ 21.3, 124.0, 124.6, 126.6, 129.7, 130.7, 134.2, 134.9, 141.6, 142.7, 148.2, 190.7; IR (KBr) 3060, 1680, 1060 cm^{-1}; EIMS *m*/*z* (rel. intensity) 244 (M^+, 74), 227 (100), 184 (68). Anal. Calcd for $C_{14}H_{12}O_2S$: C, 68.83; H, 4.95. Found: C, 68.80; H, 4.97.

5.1.6. 2-[(2,4,6-Trimethylphenyl)sulfinyl]benzaldehyde (1b). The reaction was carried out as the preparation of **1c** except using 15% sulfuric acid solution (14 drops), SiO_2 (1.78 g) and **3b** (568 mg, 1.79 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 20 g, hexane/ethyl acetate=85:15) to afford **1b** (422 mg, 87%): R_f=0.25 (hexane/ethyl acetate=50:50); ^{1}H NMR δ 2.23 (s, 3H), 2.39 (s, 6H), 6.81 (s, 2H), 7.60–7.90 (m, 3H), 8.38 (d, 1H, *J*=7.6 Hz), 9.90 (s, 1H); ^{13}C NMR δ 19.7, 21.1, 127.9, 130.1, 130.7, 133.2, 133.6, 136.9, 139.9, 142.1, 146.7, 189.7; IR (KBr) 3120, 1680, 1210, 1060 cm^{-1}; EIMS *m*/*z* (rel. intensity) 272 (M^+, 14), 255 (70), 225 (50), 119 (100). Anal. Calcd for $C_{16}H_{16}O_2S$: C, 70.56; H, 5.92; Found: C, 70.47; H, 6.01.

5.2. Reaction of the 2-sulfinylbenzaldehydes with Grignard reagents

5.2.1. (S_S^*,S^*)-1-Phenyl-1-[2-(2,4,6-triisopropylphenyl)-sulfinyl]phenylmethanol [(S_S^*,S^*)-8]. To a solution of **1c**

(23 mg, 0.064 mmol) in THF (0.5 mL) was added PhMgBr (1.08 mol L^{-1} solution in THF, 0.08 mL, 0.086 mmol) at −78°C and the mixture was stirred for 1 h. Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ethyl acetate=85:15) to afford (S_S*,S*)-**8** (27 mg, 96%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: mp 198–199°C; R_f=0.41 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 1.10 (d, 6H, *J*=6.8 Hz), 1.17 (d, 6H, *J*=6.8 Hz), 1.30 (d, 6H, *J*=6.8 Hz), 2.95 (hep, 1H, *J*=6.8 Hz), 3.63 (hep, 2H, *J*=6.8 Hz), 4.85 (br, 1H), 6.50 (br, 1H), 6.90–7.00 (m, 1H), 7.05–7.40 (m, 10H); ^{13}C NMR δ 23.8, 24.6, 34.5, 71.2, 123.6, 126.9, 127.3, 127.6, 127.9, 128.2, 130.1, 130.8, 141.4, 143.3, 145.3, 151.4, 153.9; IR (KBr) 3320, 2980, 1040 cm^{-1}; EIMS *m/z* (rel. intensity) 434 (M^+, 3), 416 (50), 353 (100), 203 (40). Anal. Calcd for $C_{28}H_{34}O_2S$: C, 77.38; H, 7.88. Found: C, 77.20; H, 8.06.

5.2.2. (R_S*,S*)- and (R_S*,R*)-1-Phenyl-1-[2-(*p*-tolylsulfinyl)phenyl]methanols [(R_S*,S*)-4 and (R_S*,R*)-4]. The reaction was carried out as the preparation of **8** except using **1a** (21 mg, 0.085 mmol) and PhMgBr (1.98 mol L^{-1}, 0.14 mL, 0.277 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 3 g, hexane/CH_2Cl_2/Et_2O=20:50:30) to afford (R_S*,S*)-**4** (22 mg, 85%) and (R_S*,R*)-**4** (2.5 mg, 9%). The diastereomer ratio was determined to be 88:12 by the ^{1}H NMR analysis of the crude product: (R_S*,S*)-**4**: mp 112–113°C; R_f=0.09 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 2.31 (s, 3H), 2.92 (br, 1H), 6.40 (d, 1H, *J*=3.2 Hz), 7.09–7.80 (m, 13H); ^{13}C NMR δ 21.9, 71.2, 125.3, 125.5, 127.4, 127.8, 128.3, 128.8, 129.6, 131.4, 140.8, 141.2, 142.3, 142.5, 142.9; IR (KBr) 3300, 2900, 1180, 1080 cm^{-1}; EIMS *m/z* (rel. intensity) 322 (M^+, 0.2), 304 (100), 227 (30) 213 (49); Anal. Calcd for $C_{20}H_{18}O_2S$: C, 74.50; H, 5.63; Found: C, 74.23; H, 5.91.

5.2.3. (R_S*,S*)- and (R_S*,R*)-1-[2-(*p*-Tolylsulfinyl)phenyl]ethanols [(R_S*,S*)-5 and (R_S*,R*)-5]. The reaction was carried out as the preparation of **8** except using **1a** (60 mg, 0.246 mmol) and MeMgI (0.96 mol L^{-1} solution in THF, 0.38 mL, 0.365 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ethyl acetate=80:20) to afford (R_S*,S*)-**5** (19.2 mg, 30%) and (R_S*,R*)-**5** (19.6 mg, 31%). The diastereomer ratio was determined to be 67:33 by the ^{1}H NMR analysis of the crude product: (R_S*,S*)-**5**: mp 109–110°C; R_f=0.15 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.16 (d, 3H, *J*=6.4 Hz), 2.35 (s, 3H), 3.40 (br, 1H), 5.23 (q, 1H, *J*=6.4 Hz), 7.20–7.86 (m, 8H); ^{13}C NMR δ 21.2, 24.1, 64.6, 123.7, 126.2, 126.5, 128.2, 129.8, 131.2, 140.3, 141.2, 141.8, 144.7; IR (KBr) 3340, 3060, 1190, 1090, 1050 cm^{-1}; EIMS *m/z* (rel. intensity) 260 (M^+, 0.1), 242 (100), 227 (44), 151 (43). Anal. Calcd for $C_{15}H_{16}O_2S$: C, 69.20; H, 6.19; Found: C, 69.06; H, 6.29.

5.2.4. (S_S*,S*)-1-Phenyl-1-[2-(2,4,6-trimethylphenyl)sulfinyl]phenylmethanol [(S_S*,S*)-6]. The reaction was carried out as the preparation of **8** except using **1b** (20.4 mg, 0.075 mmol) and PhMgBr (1.98 mol L^{-1} solution in THF, 0.040 mL, 0.079 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 4 g, hexane/CH_2Cl_2/Et_2O=60:20:20) to afford (S_S*,S*)-**6** (25.6 mg, 97%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: mp 163–164°C; R_f=0.46 (hexane/CH_2Cl_2/Et_2O=20:50:30); ^{1}H NMR δ 2.30 (s, 3H), 2.40 (s, 6H), 4.49 (br, 1H), 6.36 (d, *J*=3.0 Hz, 1H), 6.88 (s, 2H), 7.12–7.35 (m, 9H); ^{13}C NMR δ 19.7, 21.2, 70.9, 125.7, 126.8, 127.2, 127.8, 127.9, 128.1, 129.9, 130.8, 131.0, 133.6, 140.2, 141.1, 142.6, 144.7; IR (KBr) 3300, 2900, 1250, 1050 cm^{-1}; EIMS *m/z* (rel. intensity) 350 (M^+, 0.7), 332 (69), 213 (100). Anal. Calcd for $C_{22}H_{22}O_2S$: C, 75.40; H, 6.33; Found: C, 75.27; H, 6.45.

5.2.5. (S_S*,S*)-1-[2-(2,4,6-Trimethylphenyl)sulfinyl]phenylethanol [(S_S*,S*)-7]. The reaction was carried out as the preparation of **8** except using **1b** (20.2 mg, 0.073 mmol) and MeMgI (0.96 mol L^{-1} solution in THF, 0.090 mL, 0.086 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ethyl acetate=80:20) to afford (S_S*,S*)-**7** (17.3 mg, 81%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis and the HPLC analysis of the crude product: mp 154–155°C; R_f=0.22 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.24 (d, 3H, *J*=6.3 Hz), 2.32 (s, 3H), 2.38 (s, 6H), 3.83 (br, 1H), 5.18 (q, 1H, *J*=6.3 Hz), 6.91–7.69 (m, 6H); ^{13}C NMR δ 19.7, 21.2, 21.6, 65.2, 125.7, 126.9, 127.7, 127.9, 131.9, 131.0, 131.2, 140.3, 142.6, 145.2; IR (KBr) 3340, 2960, 1090, 1060 cm^{-1}; EIMS *m/z* (rel. intensity) 288 (M^+, 0.2), 270 (100), 207 (35), 151 (94), 119 (31). Anal. Calcd for $C_{17}H_{20}O_2S$: C, 70.80; H, 6.99; Found: C, 70.69; H, 7.11.

5.2.6. (S_S*,S*)-1-[2-(2,4,6-Triisopropylphenyl)sulfinyl]phenylethanol [(S_S*,S*)-9]. The reaction was carried out as the preparation of **8** except using **1c** (141 mg, 0.396 mmol) and MeMgI (0.96 mol L^{-1} solution in THF, 0.70 mL, 0.672 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 15 g, hexane/ethyl acetate=85:15) to afford (S_S*,S*)-**9** (132 mg, 89%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: mp 195–196°C; R_f=0.36 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.00 (d, 6H, *J*=6.8 Hz), 1.19 (d, 6H, *J*=6.8 Hz), 1.26 (d, 9H, *J*=6.8 Hz), 2.92 (hep, 1H, *J*=6.8 Hz), 3.61 (hep, 2H, *J*=6.8 Hz), 4.26 (br, 1H), 5.24 (q, 1H, *J*=6.8 Hz), 7.12 (s, 2H), 7.20–7.68 (m, 4H); ^{13}C NMR δ 21.5, 23.7, 24.0, 29.0, 34.3, 64.9, 67.5, 123.4, 125.2, 126.9, 127.4, 130.6, 133.8, 141.7, 145.1, 151.2, 153.8; IR (KBr) 3350, 2970, 1100, 1070 cm^{-1}; EIMS *m/z* (rel. intensity) 372 (M^+, 0.3), 337 (51), 292 (41), 291 (100). Anal. Calcd for $C_{23}H_{32}O_2S$: C, 74.15; H, 8.66; Found: C, 73.98; H, 8.83.

5.2.7. (S_S*,S*)-1-[2-(2,4,6-Triisopropylphenyl)sulfinyl]phenyl-1-propanol [(S_S*,S*)-10]. The reaction was carried out as the preparation of **8** except using **1c** (25.2 mg, 0.071 mmol) and EtMgBr (0.89 mol L^{-1} solution in THF, 0.010 mL, 0.089 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 5 g, hexane/ethyl acetate=95:5) to afford (S_S*,S*)-**10** (17.7 mg, 76%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: mp 134.0–135.2°C; R_f=0.41(hexane/ethyl acetate=60:40); ^{1}H NMR δ 0.89 (t, 3H, *J*=7.2 Hz), 1.01 (d, 6H, *J*=6.8 Hz), 1.20 (d, 6H, *J*=6.8 Hz), 1.27 (d, 6H, *J*=6.8 Hz), 1.78 (dq, 2H, *J*=7.2, 7.2 Hz), 2.92 (hep, 1H, *J*=6.8 Hz), 3.62 (hep, 2H, *J*=6.8 Hz), 3.81 (br, 1H), 4.93 (br, 1H), 7.20–7.50 (m, 6H); ^{13}C NMR δ 10.8, 23.7, 23.9, 24.3, 28.6, 29.4, 29.6, 34.5, 70.7, 123.5, 125.9, 127.5, 127.9, 130.6, 134.0, 142.8, 144.3, 151.2, 153.8; IR (KBr) 3360, 2960, 1460, 1100, 1000 cm^{-1}; EIMS *m*/*z* (rel. intensity) 386 (M^+, 0.2), 351 (31), 292 (31), 291 (100). Anal. Calcd for $C_{24}H_{34}O_2S$: C, 74.57; H, 8.86; Found: C, 74.52; H, 8.90.

5.2.8. (S_S*,S*)-1-[2-(2,4,6-Triisopropylphenyl)sulfinyl]-phenyl-3-buten-1-ol [(S_S*,S*)-11]. The reaction was carried out as the preparation of **8** except using **1c** (22.3 mg, 0.063 mmol) and allylmagnesium bromide (0.89 mol L^{-1} solution in THF, 0.011 mL, 0.098 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 8 g, hexane/ethyl acetate=90:10) to afford (S_S*,S*)-**11** (13.0 mg, 52%) and (S_S*,R*)-**11** (10.3 mg, 40%). The diastereomer ratio was determined to be 51:49 by the HPLC analysis of the crude product: (S_S*,S*)-**11**: mp 172–173°C; R_f=0.21(hexane/ethyl acetate=60:40); ^{1}H NMR δ 0.95 (d, 6H, *J*=6.8 Hz), 1.20 (d, 6H, *J*=6.8 Hz), 1.25 (d, 6H, *J*=6.8 Hz), 1.91–2.05 (ddd, 1H, *J*=7.2, 7.2, 14.3 Hz), 2.24–2.41 (ddd, 1H, *J*=7.2, 7.2, 14.3 Hz), 2.90 (hep, 1H, *J*=6.8 Hz), 3.64 (hep, 2H, *J*=6.8 Hz), 4.00 (br, 1H), 4.90–5.05 (m, 3H), 5.56–5.76 (m, 1H), 7.10 (s, 2H), 7.28–7.64 (m, 4H); ^{13}C NMR δ 23.7, 24.1, 29.2, 34.4, 40.5, 68.5, 117.6, 123.4, 125.6, 127.6, 130.4, 134.7, 142.3, 143.2, 151.2, 153.8; IR (KBr) 3340, 2960, 1060 cm^{-1}; EIMS *m*/*z* (rel. intensity) 398 (M^+, 0.1), 291 (100). Anal. Calcd for $C_{25}H_{34}O_2S$: C, 75.33; H, 8.60; Found: C, 75.26; H, 8.78. HPLC (COSMOSIL hexane/ethyl acetate=80:20, flow rate 0.50 mL min^{-1}) t_R 38.4 (S_S*,R*) and 40.4 (S_S*,S*) min.

5.3. Preparation of the chiral sulfoxides

5.3.1. (*S*)-2-[(2,4,6-Triisopropylphenyl)sulfinyl]benzaldehyde dimethyl acetal [(*S*)-3c]. The reaction was carried out as described in the preparation of racemic-**3c** except using (−)-1,1-diacetone-D-glucosyl 2,4,6-triisopropylbenzenesulfinate (304 mg, 0.595 mmol), 2-bromobenzaldehyde dimethyl acetal (241 mg, 0.472 mmol) and *n*-butyllithium (1.50 mol L^{-1}, 0.30 mL, 0.450 mmol) at −78°C. Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=95:5) to afford (*R*)-**2c** (220 mg, 96%). The enantiomeric excess was determined to be 97% ee by the HPLC analysis using Chiralcel OD–H: $[\alpha]_D^{20}$=−68.3 (*c* 0.436, $CHCl_3$) for 97% ee; HPLC (Chiralcel OD–H, hexane/*i*-PrOH=96:4, flow rate 0.2 mL min^{-1}) t_R 22.1 (*R*), 25.4 (*S*) min.

5.3.2. (*S*)-2-[(2,4,6-Triisopropylphenyl)sulfinyl]benzaldehyde [(*S*)-1c]. The reaction was carried out as described in the preparation of racemic **1c** except using 2 drops of 15% sulfuric acid solution, silica gel (500 mg) and (*S*)-**3c** (128 mg, 0.315 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=90:10) to afford (*S*)-**1c** (102 mg, 91%). The enantiomer excess was determined to be 97% ee by the HPLC analysis using Chiralcel OD–H: $[\alpha]_D^{20}$=−87.4 (*c* 0.464, $CHCl_3$) for 97% ee; HPLC (Chiralcel OD–H, hexane/*i*-PrOH=96:4, flow rate 0.5 mL min^{-1}) t_R 11.2 (*R*), 14.2 (*S*) min.

5.4. Reaction of (*S*)-1c with *p*-tolyl magnesium bromide

5.4.1. (S_S,S)-1-*p*-Tolyl-1-[2-(2,4,6-triisopropylphenyl)sulfinyl]phenylmethanol [(S_S,S)-12]. The reaction was carried out as described in the preparation of **4** except using (*R*)-**1c** (101 mg, 0.283 mmol) and *p*-tolyl magnesium bromide (1.42 mol L^{-1}, 0.30 mL, 0.425 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 10 g, hexane/CH_2Cl_2/Et_2O=80:10:10) to afford (S_S,S)-**12** (120 mg, 94%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product. The enantiomeric excess was determined to be 97% ee by the HPLC analysis using Chiralcel OD–H: mp 200–201°C; $[\alpha]_D^{25}$=−96.8 (*c* 0.27, $CHCl_3$) for 97% ee; R_f=0.16 (hexane/CH_2Cl_2/Et_2O=50:30:20); ^{1}H NMR δ 1.11 (d, 6H, *J*=6.8 Hz), 1.17 (d, 6H, *J*=6.8 Hz), 1.29 (d, 6H, *J*=6.8 Hz), 2.38 (s, 3H), 2.95 (hep, 1H, *J*=6.8 Hz), 3.61 (hep, 2H, *J*=6.8 Hz), 4.69 (d, 1H, *J*=3.8 Hz), 6.52 (d, 1H, *J*=3.8 Hz), 6.92–7.30 (m, 10H); ^{13}C NMR δ 21.1, 23.7, 24.5, 29.4, 34.4, 70.9, 123.5, 125.9, 126.7, 127.5, 128.8, 129.9, 130.7, 133.1, 136.7, 138.4, 143.0, 145.3, 151.3, 153.8; IR (KBr) 3320, 2970, 1040, 1010 cm^{-1}; EIMS *m*/*z* (rel. intensity) 431 (20), 367 (95), 227 (72), 203 (100); Anal. Calcd for $C_{29}H_{36}O_2S$: C, 77.63; H, 8.09; Found: C, 77.34; H, 8.38. HPLC (Chiralcel OD–H, hexane/*i*-PrOH=90:10, flow rate 0.3 mL min^{-1}) t_R 19.0 min (R_S,S), 25.8 min (R_S,R).

5.4.2. Preparation of (*R*)-1-phenyl-1-*p*-tolylmethanol [(*R*)-13]. To a solution of (S_S,S)-**12** (120 mg, 0.267 mmol) in THF (4.0 mL) was added *n*-BuLi (0.89 mL, 1.52 mol L^{-1} in hexane, 1.35 mmol) at −78°C and the mixture was stirred for 10 min. The reaction mixture was then warmed to −30°C and the mixture was stirred for 1 h. Usual workup gave the crude product which was purified by column chromatography (silica gel 7 g, hexane/CH_2Cl_2/Et_2O=80:10:10) to afforded (*R*)-**13** (48.4 mg, 92%): $[\alpha]_D^{20}$=+8.4 (*c* 0.50, $CHCl_3$, 97% ee) lit.[12] $[\alpha]_D^{20}$=−9.0 (*c* 0.77, benzene) for the (*R*)-isomer: R_f=0.58 (hexane/CH_2Cl_2/Et_2O=50/30/20); ^{1}H NMR δ 2.14 (d, 1H, *J*=3.5 Hz), 2.33 (s, 3H), 6.82 (d, 1H, *J*=3.5 Hz), 7.12–7.40 (m, 9H); IR (KBr) 3270, 2920, 1270, 1030 cm^{-1}. HPLC (Daicel Chiralcel OD–H, hexane/*i*-PrOH=97:3, flow rate 0.8 mL min^{-1}) t_R 20.8 (*R*) and 24.6 (*S*) min.

5.5. Preparation of the 2-(arylsulfinyl)phenyl ketones

5.5.1. 2-[(2,4,6-Triisopropylphenyl)sulfinyl]benzophenone (14e). To a solution of PCC (114 mg, 0.53 mmol) in CH_2Cl_2 (1.0 mL) was added a solution of **8** (157 mg, 0.36 mmol) in CH_2Cl_2 (14.0 mL) at room temperature. After stirring for 4 h, Et_2O was added and the supernatant decanted from the black gum. The insoluble residue was thoroughly washed with Et_2O. The ethereal solution was concentrated under reduced pressure to leave a residue which was purified by column chromatography (silica gel 13 g, hexane/ethyl acetate=90:10) to afford **14e** (142 mg, 91%): mp 157–159°C (from hexane/ethyl acetate); R_f=0.29 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 0.87 (d, 6H, *J*=6.8 Hz), 0.95 (d, 3H, *J*=6.8 Hz), 0.96 (d, 3H, *J*=6.8 Hz), 1.18 (d, 6H, *J*=6.8 Hz), 2.58 (hep, 1H, *J*=6.8 Hz), 3.74 (hep, 2H,

J=6.8 Hz), 6.73 (s, 2H), 7.20–7.30 (m, 3H), 7.35–7.50 (m, 4H), 7.60–7.70 (m, 1H), 8.15–8.30 (m, 1H); ^{13}C NMR δ 23.3, 23.5, 23.6, 24.6, 28.5, 33.9, 122.3, 126.4, 127.8, 128.2, 128.8, 129.8, 130.2, 133.0, 135.4, 137.4, 147.5, 151.2, 153.1, 194.8; IR (KBr) 2980, 1660, 1280, 1060 cm^{-1}; EIMS m/z (rel. intensity) 432 (M$^+$, 40), 386 (70), 370 (80), 213 (100). Anal. Calcd for $C_{28}H_{32}O_2S$: C, 77.74; H, 7.46. Found: C, 77.65; H, 7.53.

5.5.2. 2-(*p*-Tolylsulfinyl)benzophenone (14a). The reaction was carried out as the preparation of **14e** except using **4** (129 mg, 0.339 mmol), PCC (175 mg, 0.809 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 15 g, hexane/ethyl acetate=75:25) to afford **14a** (77 mg, 60%): mp 82–83°C; R_f=0.18 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 2.20 (s, 3H), 7.06–7.67 (m, 12H), 8.26–8.30 (m, 1H); ^{13}C NMR δ 21.2, 125.2, 126.0, 128.4, 129.6, 130.1, 130.4, 135.6, 136.7, 141.0, 143.0, 148.5, 195.0; IR (KBr) 2920, 1650, 1078 cm^{-1}; EIMS m/z (rel. intensity) 320 (M$^+$, 7), 213 (100). Anal. Calcd for $C_{20}H_{16}O_2S$: C, 74.97; H, 5.03; Found: C, 74.81; H, 5.22.

5.5.3. 2-(*p*-Tolylsulfinyl)acetophenone (14b). The reaction was carried out as the preparation of **14e** except using **5** (289 mg, 1.11 mmol), PCC (366 mg, 1.70 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=80:20) to afford **14b** (186 mg, 65%): R_f=0.26 (hexane/ethyl acetate=70:30); ^{1}H NMR δ 2.39 (s, 3H), 2.69 (s, 3H), 7.27–7.32 (m, 3H), 7.52–7.70 (m, 2H), 7.80–7.84 (m, 2H), 8.01–8.08 (m, 1H); ^{13}C NMR δ 21.6, 32.0, 125.9, 127.7, 128.1, 129.7, 129.8, 133.2, 138.3, 142.3, 144.4, 203.4; IR (neat) 2890, 1640, 1220, 1040 cm^{-1}; EIMS m/z (rel. intensity) 258 (M$^+$, 100), 167 (89), 152 (32). Anal. Calcd for $C_{15}H_{14}O_2S$: C, 69.74; H, 5.46; Found: C, 69.63; H, 5.57.

5.5.4. 2-[(2,4,6-Trimethylphenyl)sulfinyl]benzophenone (14c). The reaction was carried out as the preparation of **14e** except using **6** (104 mg, 0.296 mmol), PCC (100 mg, 0.466 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=85:15) to afford **14c** (64 mg, 62%): mp 130–131°C; R_f=0.28 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.87 (s, 3H), 2.24 (s, 6H), 6.40 (s, 2H), 7.24–8.31 (m, 9H); ^{13}C NMR δ 19.0, 20.7, 127.3, 127.8, 128.3, 128.5, 129.6, 129.9, 130.2, 133.0, 134.9, 136.3, 136.4, 140.6, 142.1, 145.0, 194.7; IR (KBr) 2950, 1660, 1150, 1070 cm^{-1}; EIMS m/z (rel. intensity) 348 (M$^+$, 21), 330 (42), 225 (100), 105 (32). Anal. Calcd for $C_{22}H_{20}O_2S$: C, 75.83 H, 5.79; Found: C, 75.66; H, 5.95.

5.5.5. 2-[(2,4,6-Trimethylphenyl)sulfinyl]acetophenone (14d). The reaction was carried out as the preparation of **14e** except using **7** (230 mg, 0.80 mmol), PCC (269 mg, 1.25 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 30 g, hexane/ethyl acetate=90:10) to afford **14d** (170 mg, 74%): mp 145–146°C; R_f=0.32 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 2.22 (s, 3H), 2.25 (s, 3H), 2.34 (s, 6H), 6.78 (s, 2H), 7.56–7.79 (m, 3H), 8.48–8.53 (m, 1H); ^{13}C NMR δ 19.7, 20.4, 27.3, 128.3, 129.6, 130.4, 131.9, 135.5, 137.8, 139.8, 141.2, 146.2, 198.4; IR (KBr) 2880, 1680, 1280, 1260, 1020 cm^{-1}; EIMS m/z (rel. intensity) 286 (M$^+$, 6), 225 (100), 151 (59). Anal. Calcd for $C_{17}H_{18}O_2S$: C, 71.30; H, 6.34; Found: C, 71.16; H, 6.48.

5.5.6. 2-[(2,4,6-Triisopropylphenyl)sulfinyl]acetophenone (14f). The reaction was carried out as the preparation of **14e** except using **9** (132 mg, 0.31 mmol), PCC (121 mg, 0.56 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 35 g, hexane/ethyl acetate=90:10) to afford **14f** (80 mg, 62%): mp 115–116°C; R_f=0.44 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 0.84 (d, 6H, J=6.8 Hz), 1.21 (d, 6H, J=6.8 Hz), 1.28 (d, 6H, J=6.8 Hz), 2.03 (s, 3H), 2.86 (hep, 1H, J=6.8 Hz), 3.73 (hep, 2H, J=6.8 Hz), 7.00 (s, 2H), 7.45–7.72 (m, 3H), 8.19–8.24 (m, 1H); ^{13}C NMR δ 23.5, 23.7, 24.5, 28.0, 28.7, 34.3, 122.5, 127.0, 127.8, 127.9, 129.1, 131.2, 135.9, 137.9, 147.1, 151.5, 152.9, 199.9; IR (KBr) 2880, 1710, 1280 cm^{-1}; EIMS m/z (rel. intensity) 370 (M$^+$, 4), 327 (34), 307 (100), 151 (51). Anal. Calcd for $C_{23}H_{30}O_2S$: C, 74.55; H, 8.16; Found: C, 74.37; H, 8.34.

5.5.7. 1-[2-[(2,4,6-Triisopropylphenyl)sulfinyl]phenyl]-3-buten-1-one (14g). The reaction was carried out as the preparation of **14e** except using **11** (101 mg, 0.253 mmol), PCC (124 mg, 0.58 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 25 g, hexane/ethyl acetate=90:10) to afford **14g** (72 mg, 72%): R_f=0.31 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 0.83 (d, 6H, J=6.8 Hz), 1.21 (d, 6H, J=6.8 Hz), 1.28 (d, 6H, J=6.8 Hz), 2.75–2.87 (dd, 1H, J=6.7, 19.6 Hz), 2.88 (hep, 1H, J=6.8 Hz), 3.30–3.42 (dd, 1H, J=6.7, 19.6 Hz), 3.73 (hep, 2H, J=6.8 Hz), 4.81–5.02 (m, 2H), 5.36–5.56 (m, 1H), 7.00 (s, 2H), 7.43–7.72 (m, 3H), 8.21–8.25 (m, 1H); ^{13}C NMR δ 23.6, 23.7, 24.4, 28.7, 34.3, 45.2, 118.9, 122.7, 127.0, 127.8, 129.0, 129.8, 131.2, 135.8, 137.5, 147.4, 151.6, 153.0, 200.0; IR (neat) 2960, 1690, 1210, 1070 cm^{-1}; EIMS m/z (rel. intensity) 396 (M$^+$, 9), 331 (31), 327 (43), 307 (100), 265 (31). Anal. Calcd for $C_{25}H_{32}O_2S$: C, 75.71; H, 8.13; Found: C, 75.61; H, 8.23.

5.6. Reduction of the 2-(arylsulfinyl)phenyl ketones with DIBAL

5.6.1. (S_S*,R*)-1-Phenyl-1-[2-(2,4,6-triisopropylphenyl)-sulfinyl]phenylmethanol [(S_S*,R*)-8]. To a solution of **14e** (22.8 mg, 0.053 mmol) in THF (1.0 mL) was added DIBAL (0.95 mol L^{-1} solution in hexane, 0.08 mL, 0.076 mmol) at −78°C and the mixture was stirred for 1 h. MeOH was then added and the mixture was extracted with CH_2Cl_2. Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ethyl acetate=90:10) to afford (S_S*,R*)-**8** (22.0 mg, 96%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: mp 195–196°C; R_f=0.37 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 0.96 (d, 6H, J=6.8 Hz), 1.09 (d, 6H, J=6.8 Hz), 1.26 (d, 6H, J=6.8 Hz), 2.91 (hep, 1H, J=6.8 Hz), 3.42 (hep, 2H, J=6.8 Hz), 4.82 (d, 1H, J=9.5 Hz), 6.00 (d, 1H, J=9.5 Hz), 7.00–7.10 (m, 1H), 7.10 (s, 2H), 7.20–7.60 (m, 8H); ^{13}C NMR δ 23.6, 24.4, 29.4, 34.4, 75.5, 123.5, 126.2, 126.8, 127.1, 127.8, 130.7, 132.0, 132.8, 142.4, 143.5, 144.5, 151.4, 153.8; IR (KBr) 3450, 2980, 1280, 1080 cm^{-1};

EIMS m/z (rel. intensity) 434 (M^+, 10), 416 (20), 353 (100), 203 (65). Anal. Calcd for $C_{28}H_{34}O_2S$: C, 77.38; H, 7.88. Found: C, 77.40; H, 7.77.

5.6.2. (R_S*,S*)- and (R_S*,R*)-1-Phenyl-1-[2-(*p*-tolylsulfinyl)phenyl]methanols [(R_S*,S*)-4 and (R_S*,R*)-4]. The reaction was carried out as reduction of **14e** except using **14a** (20 mg, 0.066 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.10 mL, 0.095 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 3 g, hexane/ethyl acetate/benzene =50:20:30) to afford (R_S*,S*)-**4** (3.1 mg, 16%) and (R_S*,R*)-**4** (12.8 mg, 64%). The diastereomer ratio was determined to be 15:85 by the ^{1}H NMR analysis of the crude product: (R_S*,R*)-**4**: R_f=0.26 (hexane/ethyl acetate =60:40); ^{1}H NMR δ 2.39 (s, 3H), 3.45 (d, 1H, J=3.8 Hz), 6.24 (d, 1H, J=3.8 Hz), 7.16–7.90 (m, 13H); ^{13}C NMR δ 21.3, 71.0, 125.3, 126.6, 126.7, 127.5, 128.3, 128.6, 129.1, 129.9, 131.7, 141.3, 141.4, 141.8, 143.0; IR (KBr) 3350, 1650, 1080, 1020 cm^{-1}; EIMS m/z (rel. intensity) 322 (M^+, 0.4), 304 (100), 213 (47). Anal. Calcd for $C_{20}H_{18}O_2S$: C, 74.51; H, 5.63; Found: C, 74.32; H, 5.81.

5.6.3. (R_S*,S*)- and (R_S*,R*)-1-[2-(*p*-Tolylsulfinyl)phenyl]ethanols [(R_S*,S*)-5 and (R_S*,R*)-5]. The reaction was carried out as reduction of **14e** except using **14b** (20 mg, 0.078 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.12 mL, 0.114 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ ethyl acetate/benzene=90:10) to afford (R_S*,S*)-**5** (5 mg, 25%) and (R_S*,R*)-**5** (12 mg, 60%). The diastereomer ratio was determined to be 37:63 by the ^{1}H NMR analysis of the crude product: (R_S*,R*)-**5**: R_f=0.23 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.47 (d, 3H, J=6.4 Hz), 2.36 (s, 3H), 3.00 (br, 1H), 5.27 (q, 1H, J=6.4 Hz), 7.21–7.88 (m, 8H); ^{13}C NMR δ 21.3, 23.3, 65.2, 125.4, 126.3, 126.5, 128.4, 130.0, 131.9, 141.3, 141.4, 141.9, 144.3; IR (neat) 3370, 2970, 1190, 1080 cm^{-1}; EIMS m/z (rel. intensity) 260 (M^+, 0.1), 242 (100), 227 (43), 151 (42). Anal. Calcd for $C_{15}H_{16}O_2S$: C, 69.20; H, 6.19; Found: C, 68.97; H, 6.42.

5.6.4. (S_S*,R*)-1-Phenyl-1-[2-(2,4,6-trimethylphenyl)sulfinyl]phenylmethanol [(S_S*,R*)-6]. The reaction was carried out as reduction of **14e** except using **14c** (53 mg, 0.151 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.25 mL, 0.238 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 3 g, hexane/ethyl acetate=85:15) to afford (S_S*,R*)-**6** (48.5 mg, 92%). The diastereomer ratio was determined to be:>98:2 by the ^{1}H NMR analysis of the crude product: mp 148–149°C; R_f=0.36 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.26 (s, 3H), 2.31 (s, 6H), 3.85 (br, 1H), 5.95 (d, 1H, J=3.7 Hz), 6.90 (s, 2H), 7.26–7.48 (m, 9H); ^{13}C NMR δ 19.6, 21.2, 73.9, 126.1, 126.3, 127.2, 128.1, 130.7, 131.1, 134.4, 140.2, 141.4, 142.3, 142.6, 143.5; IR (KBr) 3310, 1600, 1180, 1060 cm^{-1}; EIMS m/z (rel. intensity) 350 (M^+, 0.9), 332 (73), 213 (100). Anal. Calcd for $C_{22}H_{22}O_2S$: C, 75.40; H, 6.33; Found: C, 75.36; H, 6.53.

5.6.5. (S_S*,S*)- and (S_S*,R*)-1-[2-(2,4,6-Trimethylphenyl)-sulfinyl]phenylethanols [(R_S*,S*)-7 and (R_S*,R*)-7]. The reaction was carried out as reduction of **14a** except using **14d** (20.4 mg, 0.071 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.16 mL, 0.152 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 7 g, hexane/ethyl acetate/benzene=40:30:40) to afford (S_S*,S)-**7** (3.2 mg, 16%) and (S_S*,R)-**7** (15.8 mg, 78%). The diastereomer ratio was determined to be 16:84 by the ^{1}H NMR analysis of the crude product: (S_S*,R)-**7**: mp 153 –154°C; R_f=0.32 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.56 (d, 3H, J=6.8 Hz), 2.30 (s, 3H), 2.41 (s, 6H), 3.82 (br, 1H), 4.96 (q, 1H, J=6.8 Hz), 6.90 (s, 2H), 7.30–7.65 (m, 4H); ^{13}C NMR δ 19.5, 21.2, 24.1, 66.8, 126.1, 127.0, 127.7, 130.7, 131.0, 131.2, 140.1, 142.6, 144.1; IR (KBr) 3240, 2340, 1650, 1560, 1540, 1460, 990, 770 cm^{-1}; EIMS m/z (rel. intensity) 288 (M^+, 0.1), 270 (100), 207 (37), 151 (98), 119 (32). Anal. Calcd for $C_{17}H_{20}O_2S$: C, 70.80; H, 6.99; Found: C, 70.69; H, 7.11. HPLC (COSMOSIL hexane/ethyl acetate=60:40, flow rate 0.50 mL min^{-1}) t_R 23.7 (S_S*,R*) and 25.9 (S_S*,S*) min.

5.6.6. (S_S*,R*)-1-[2-(2,4,6-Triisopropylphenyl)sulfinyl]-phenylethanol [(S_S*,R*)-9]. The reaction was carried out as the reduction of **14e** except using **14f** (20.6 mg, 0.056 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.085 mL, 0.081 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 3 g, hexane/ethyl acetate=80:20) to afford (S_S*,R)-**9** (20 mg, 96%). The diastereomer ratio was determined to be 97:3 by the HPLC analysis of the crude product: R_f=0.45 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 1.05 (d, 6H, J=6.8 Hz), 1.18 (d, 6H, J=6.8 Hz), 1.28 (d, 6H, J=6.8 Hz), 1.38 (d, 3H, J=6.3 Hz), 2.93 (hep, 1H, J=6.8 Hz), 3.64 (hep, 2H, J=6.8 Hz), 4.13 (br, 1H), 5.34 (q, 1H, J=6.3 Hz), 7.14 (s, 2H), 7.42–7.68 (m, 4H); ^{13}C NMR δ 23.7, 24.1, 29.1, 34.3, 67.5, 123.5, 125.7, 127.6, 127.8, 130.4, 134.6, 142.3, 144.4, 151.1, 153.7; IR (KBr) 3400, 2950, 1600, 1090, 1060 cm^{-1}; EIMS m/z (rel. intensity) 372 (M^+, 0.3), 337 (98), 292 (79), 291 (100), 253 (35), 203 (53). Anal. Calcd for $C_{23}H_{32}O_2S$: C, 74.15; H, 8.66; Found: C, 74.38; H, 8.77. HPLC (COSMOSIL hexane/ethyl acetate=75:25, flow rate 0.50 mL min^{-1}) t_R 23.5 (S_S*,R*) and 27.0 (S_S*,S*) min.

5.6.7. (S_S*,R*)-1-[2-(2,4,6-Triisopropylphenyl)sulfinyl]-phenyl-3-buten-1-ol [(S_S*,R*)-11]. The reaction was carried out as the reduction of **14e** except using **14g** (20 mg, 0.050 mmol), DIBAL (0.95 mol L^{-1} solution in hexane, 0.080 mL, 0.076 mmol). Usual workup gave the crude product which was purified by column chromatography (silica gel 2 g, hexane/ethyl acetate=90:10) to afford (S_S*,R)-**11** (18.8 mg, 94%). The diastereomer ratio was determined to be >98:2 by the ^{1}H NMR analysis of the crude product: R_f=0.31 (hexane/ethyl acetate=60:40); ^{1}H NMR δ 0.99 (d, 6H, J=6.8 Hz), 1.22 (d, 6H, J=6.8 Hz), 1.26 (d, 6H, J=6.8 Hz), 2.58–2.80 (m, 2H), 2.83 (br, 1H), 2.91 (hep, 1H, J=6.8 Hz), 3.70 (hep, 2H, J=6.8 Hz), 4.83–4.92 (m, 1H), 5.07–5.18 (m, 2H), 5.69–5.89 (m, 1H), 7.12 (s, 2H), 7.30–7.58 (m, 4H); ^{13}C NMR δ 23.6, 24.1, 29.1, 34.3, 42.2, 71.4, 117.9, 123.4, 125.8, 127.8, 128.5, 130.2, 134.4, 142.5, 142.9, 151.1, 153.7; IR (KBr) 3650, 2960, 1600, 1560, 1060 cm^{-1}; EIMS m/z (rel. intensity) 398 (M^+, 0.2), 291 (100). Anal. Calcd for $C_{25}H_{34}O_2S$: C, 75.33; H, 8.60; Found: C, 75.22; H, 8.72. HPLC

(COSMOSIL hexane/ethyl acetate=75:25, flow rate 0.50 mL min^{-1}) t_R 23.5 (S_S^*,R^*) and 27.0 (S_S^*,S^*) min.

5.6.8. (S_S^*,S^*)- and (S_S^*,R^*)-3-Hydroxy-1-phenyl-3-[2-[(2,4,6-triisopropylphenyl)sulfinyl]phenyl]-1-propanones [(S_S^*,S^*)-15 and (S_S^*,R^*)-15]. To a solution of **1c** (38.6 mg, 0.108 mmol) in CH_2Cl_2 (0.5 mL) was added $BF_3{\cdot}OEt_2$ (1.34 mol L^{-1} solution in CH_2Cl_2, 0.16 mL, 0.214 mmol) at −78°C and the mixture was stirred for 1 h. A solution of *O*-trimethylsilyl enol ether of acetophenone (32.0 mg, 0.166 mmol) in CH_2Cl_2 (0.5 mL) was then added. After stirring for 3 h, HCl (1 mol L^{-1}) was added and the mixture was stirred for 15 min. Usual workup gave the crude product which was purified by column chromatography (silica gel 10 g, hexane/ethyl acetate=85:15) to afford (S_S^*,S^*)-**15** (28.4 mg, 55%) and (S_S^*,R^*)-**15** (14.9 mg, 29%). The diastereomer ratio was determined to be 58:42 by the ^{1}H NMR analysis of the crude product. (S_S^*,S^*)-**15**; R_f=0.20 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 1.05 (d, 6H, J=6.9 Hz), 1.16 (d, 6H, J=6.9 Hz), 1.27 (d, 6H, J=6.9 Hz), 2.90 (hep, 1H, J=6.9 Hz), 3.32 (dd, 1H, J=9.0, 17.3 Hz), 3.67 (hep, 2H, J=6.9 Hz), 3.84 (dd, 1H, J=3.4, 17.3 Hz), 4.29 (d, 1H, J=4.3 Hz), 5.72 (ddd, 1H, J=3.4, 4.3, 9.0 Hz), 7.13 (s, 2H), 7.30–7.80 (m, 7H), 7.95–8.05 (m, 2H); ^{13}C NMR δ 23.7, 24.2, 29.2, 34.4, 46.6, 68.0, 123.4, 125.9, 127.8, 128.4, 128.6, 130.7, 133.6, 141.8, 143.0, 151.1, 153.5; IR (neat) 3400, 2980, 1680, 1260, 1060 cm^{-1}; EIMS m/z (rel. intensity) 476 (M^+, 0.2), 290 (100), 256 (95), 105 (98); Anal. Calcd for $C_{30}H_{36}O_3S$: C,75.59; H, 7.61. Found: C, 75.44; H, 7.73. (S_S^*,R^*)-15: R_f=0.11 (hexane/ethyl acetate=80:20); ^{1}H NMR δ 0.83 (d, 6H, J=6.9 Hz), 0.94 (d, 6H, J=6.9 Hz), 1.25 (d, 6H, J=6.9 Hz), 2.15 (dd, 1H, J=3.0, 18.0 Hz), 2.43 (hep, 1H, J=6.9 Hz), 3.05 (dd, 1H, J=9.3, 18.0 Hz), 3.80 (hep, 2H, J=6.9 Hz), 4.15 (d, 1H, J=3.0 Hz), 5.37 (ddd, 1H, J=3.0, 3.0, 9.3 Hz), 6.92 (s, 2H), 7.35–7.85 (m, 9H); ^{13}C NMR δ 23.0, 23.4, 24.6, 29.1, 33.8, 449., 65.7, 123.2, 125.7, 127.2, 128.1, 128.6, 130.4, 133.5, 135.1, 136.3, 140.7, 141.9, 151.2, 153.7; IR (neat) 3450, 2980, 1680, 1630, 1060, 1030, 890 cm^{-1}; EIMS m/z (rel. intensity) 476 (M^+, 0.2), 290 (100), 283 (90), 256 (95); Anal. Calcd for $C_{30}H_{36}O_3S$: C,75.59; H, 7.61. Found: C, 75.43; H, 7.89.

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