Efficient Diastereoselective Syntheses of *erythro*- or *threo*-α-Alkyl-*β*-hydroxy Sulfones by Reductions of α-Alkyl-*β*-keto Sulfones with $TiCl_4/BH_3$ or $LiEt_3BH/CeCl_3$, Respectively

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A stereoselective synthesis of *erythro*- and *threo*-α-alkyl-*β*-hydroxy sulfones by reduction of the corresponding α-alkyl-*β*-keto sulfones has been developed. The pivotal role in this methodology is played by the chelating or nonchelating properties of the Lewis acid employed. The strong chelating $TiCl_4$ led to the *erythro* isomer in high diastereomeric excess in noncoordinating solvents (CH_2Cl_2) at −78 °C using BH_3/py as reducing agent, while the nonchelating $CeCl_3$ gave a high excess of the *threo* isomer in coordinating solvents (THF) at the same temperature using lithium triethylborohydride ($LiEt_3BH$) as reducing agent. Moreover, this methodology has been successfully utilized for the synthesis of α-allyl-*β*-hydroxy sulfones, which are useful synthetic intermediates to obtain 2,5-disubstituted tetrahydrofurans by electrophilic cyclization.

Introduction

During the last 20 years, organic sulfur compounds have become increasingly important in organic synthesis. In this field, the benzenesulfonyl group is a versatile and flexible functionality that enjoys increasing popularity as a temporary control element and activating group in organic synthesis.[1−6] In particular, the ready availability of *β*-hydroxy sulfones and their derivatives from condensation on a sulfonyl carbanion with a carbonyl compound makes them attractive as intermediates for the regiospecific synthesis of trans olefins.[7] The formation of mixtures of stereoisomers in such reactions appears quite general, although for applications involving the Julia's elimination, this is of no consequence. More recently, it has found that *β*-hydroxy sulfones are also versatile synthetic intermediates for the synthesis of 2,5-disubstituted tetrahydrofurans.[8−10] These units are found in many natural products, including polyether antibiotics[11] and furanoterpenes.[12] For this reason, the stereoselective synthesis of *erythro*- or *threo*-α-alkyl-*β*-hydroxy sulfones is a challenging problem for synthetic organic chemists. Addition of a metalated sulfone to an aldehyde or ketone has been successfully employed for this purpose.[13,14] A promising alternative solution to this problem is the stereoselective reduction of the corresponding α-alkyl-*β*-keto sulfones. Selective reduction with L-Selectride[15] or sodium borohydride[16] has been reported to give α-alkyl-*β*-hydroxy sulfones of the *threo* configuration. Here, we wish to report an extremely simple and effective alternative procedure for the highly stereoselective synthesis of *erythro*- or *threo*- α-alkyl-*β*-hydroxy sulfones through the reduction of the corresponding *β*-keto sulfones with BH_3·py or lithium triethylborohydride ($LiEt_3BH$) in the presence of $TiCl_4$ or dry $CeCl_3$, respectively. Indeed, the correct choice of hydrides, solvent, and Lewis acid has been the switch for either chelation or nonchelation control in these reactions[17] in order to obtain high diastereomeric excess.

Results and Discussions

A series of α-alkyl-*β*-keto sulfones **1** was submitted to reduction with BH_3·py complex in the presence of $TiCl_4$ or with $LiEt_3BH$ in the presence of $CeCl_3$ as the Lewis acid (Scheme 1).

Reduction in the Presence of Titanium Tetrachloride. Recently, DiMare reported the system BH_3·py as an efficient reducing agent in reduction of ketones promoted by titanium tetrachloride.[18] In fact, the amine

(1) Recent overview: Trost, B. M. *Bull. Chem. Soc. Jpn.* **1988**, *61*, 107.
(2) Magnus, P. D. *Tetrahedron* **1977**, *33*, 2019.
(3) Schank, K. *Methoden der Organischen Chemie (Houben-Weyl)*, 4th ed.; Thieme: Stuttgart, 1985; Vol. E11, p 1129.
(4) Durst, T. In *Comprehensive Organic Chemistry*; Barton, D. H. R., Ollis, W. D., Eds.; Pergamon Press: Oxford, 1979; Vol. 3, pp 171−197.
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(6) Fuchs, P. L.; Breish, T. F. *Chem. Rev.* **1986**, *86*, 903.
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(11) Bartlett, P. A. *Tetrahedron* **1980**, *36*, 46.
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(16) Grossert, J. S.; Dharmaratue, H. R. W.; Cameron, T. S.; Vincent, B. R. *Can. J. Chem.* **1988**, *66*, 2860.
(17) Bartoli, G.; Bosco, M.; Dalpozzo, R.; Marcantoni, E.; Sambri, L. *Chem. Eur. J.* **1997**, *12*, 1941.

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Scheme 1

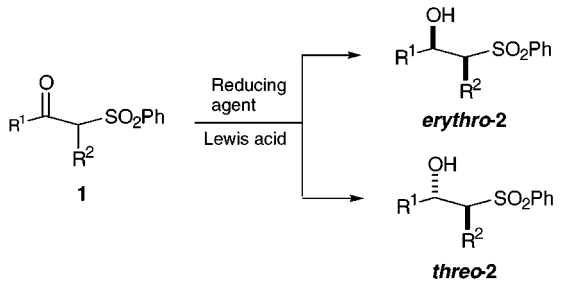


Table 1. Stereoselective Reduction of *β*-Keto Sulfones (1) to *β*-Hydroxy Sulfones with BH_3/Py in the Presence of $TiCl_4$ in CH_2Cl_2 at −78°C

entry	starting material	R^1	R^2	product[a]	erythro/threo[b]	yield[c] (%)
1	**1aa**	Me	Me	**2aa**	87/13	85
2	**1ab**	Me	Et	**2ab**	90/10	90
3	**1ac**	Me	Ph	**2ac**	95/5	94
4	**1ad**	Me	c−C_6H_{11}	**2ad**	92/8	90
5	**1ae**	Me	allyl	**2ae**	93/7	87
6	**1af**	Me	CH_2Ph	**2af**	94/6	86
7	**1cb**	Ph	Et	**2cb**	>99/1	88
8	**1gb**	4-MeOPh	Et	**2gb**	94/6	88
9	**1hb**	4-NO_2Ph	Et	**2hb**	93/7	83
10	**1cb**	Ph	Et	**2cb**	50/50[d]	76
11	**1cb**	Ph	Et	**2cb**	70/30[e]	54

[a] By adding the BH_3/py complex to the solution of the CH_2Cl_2 solution of **1**/$TiCl_4$ complex at −78 °C. [b]Determined by ^1H and ^{13}C NMR spectroscopy. [c]Calculated on the mixture of diastereomers isolated by column chromatography. [d]The reaction was carried out in THF. [e]Temperature was held at −50 °C for 15 min.

boranes are among the strongest nonionic hydride donors, which are valuable reducing agents because of their solubility in many organic solvents. In reactions with positively charged electrophiles, they are more reactive hydride donors than trialkylsilanes and comparable with $NaBH_3CN$. As a consequence, amine boranes may replace this expensive and toxic reagent in many applications. We found that the reduction of **1** in dichloromethane at low temperature (−78 °C) with BH_3·py (1.5 equiv) in the presence of $TiCl_4$ (1.5 equiv) led to the prevalent formation of *erythro*-*β*-hydroxy sulfones (*erythro*-**2**) (Table 1). This result can be rationalized if the formation of a chelate between the oxygen atoms to the carbonyl function and to the sulfonyl group with metal atom is assumed. The resulting six-membered cyclic intermediate is then attacked by the incoming hydride, preferentially from the less hindered opposite axial side of the most populated conformation **A** (Scheme 2). We also found interesting solvent effects. While the reactions were successfully carried out in CH_2Cl_2, which ensured good yields and high diastereoselectivity, on the contrary, the reactions carried out in a coordinating solvent, such as THF, led to the complete loss of diastereoselectivity (Table 1, entry 10). Temperature is also an important factor in these reductions: values higher than −78 °C considerably lower both selectivity and yields (Table 1, entry 11).

The most relevant finding from data reported in Table 1 is that this reductive system always ensure a high stereoselectivity level, independent of the size of the R^1 and R^2 substituents. In accordance with a chelation-controlled mechanism, the minimum level of stereoselectivity should be observed when R^1 and R^2 are the small methyl group; in fact, an *erythro*/*threo* ratio of 87/13 is obtained in this unfavorable case under our experimental conditions. It is obvious that every increase in bulkiness of both R^1 and R^2, shifting the conformational equilibrium toward the more stable **A** conformation, increases the *erythro*/*threo* ratio (Table 1, entries 2−9).

Scheme 2

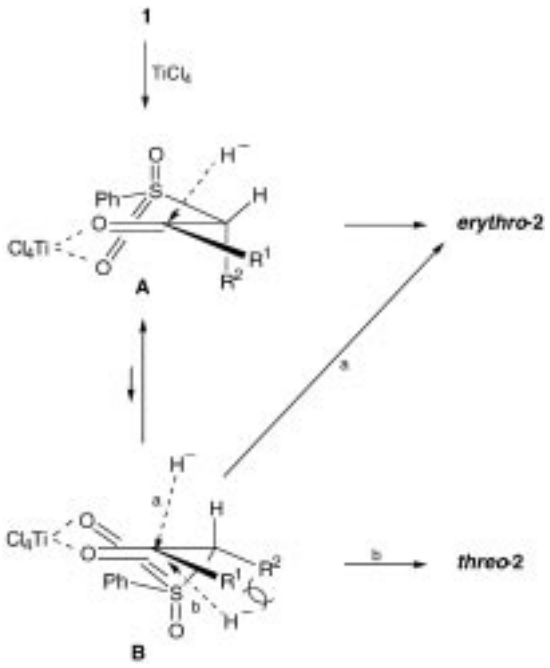


Table 2. Stereoselective Reduction of *β*-Keto Sulfones (1) to *β*-Hydroxy Sulfones with $LiBEt_3H$ in the Presence of $CeCl_3$ Dry in THF at −78 °C

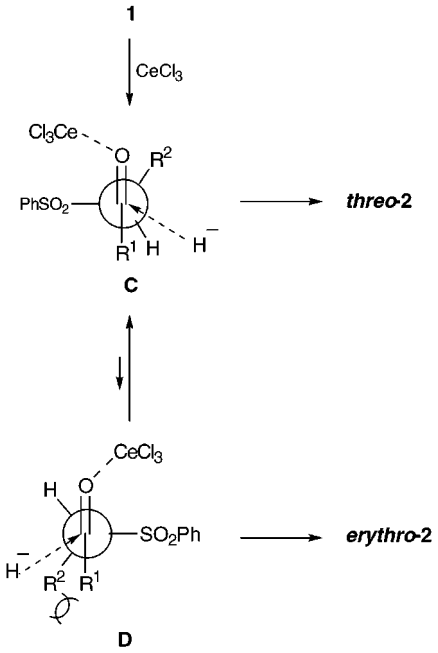
entry	starting material	R^1	R^2	product[a]	time (h)	threo/erythro[b]	yield[c] (%)
1	**1aa**	Me	Me	**2aa**	3.0 h	>99/1	85
2	**1aa**	Me	Me	**2aa**	3.0 h	54/46[d]	89
3	**1ab**	Me	Et	**2ab**	3.0 h	97/3	88
4	**1ac**	Me	Ph	**2ac**	3.5 h	96/4	90
5	**1ad**	Me	c−C_6H_{11}	**2ad**	3.0 h	81/19	79
6	**1ae**	Me	allyl	**2ae**	3.5 h	98/2	88
7	**1af**	Me	CH_2Ph	**2af**	2.5 h	95/5	89
8	**1cb**	Ph	Et	**2cb**	4.0 h	>99/1	83
9	**1gb**	4-MeOPh	Et	**2gb**	4.0 h	>99/1	81
10	**1hb**	4-NO_{2Ph}	Et	**2hb**	6.0 h	>99/1	82

[a] By adding a 1 M solution of $LiBEt_3H$ in THF to the THF solution of **1**−$CeCl_3$ complex at −78 °C. [b]Determined by ^1H and ^{13}C NMR spectroscopy. [c]Calculated on the mixture of diastereomers isolated by column chromatography. [d]The reaction was carried out in CH_2Cl_2.

Reduction in the Presence of Dry Cerium Trichloride. The reduction of *β*-keto sulfones with a THF solution of $LiEt_3BH$ in the presence of dry $CeCl_3$ proceeds smoothly at low temperature (−78 °C), giving the expected *β*-hydroxy sulfones in good yields, but with reversed stereoselectivity with respect to the $TiCl_4/BH_3$· py system (Table 2). These findings strongly support an open-chain mechanism, and the *threo* selectivity may explained by Felkin−Anh's model[19] controlled reaction. In fact, the sterically demanding alkyl chains favor the **C** over the **D** conformation, and the hydride anion attacks the *β*-carbonyl group from the side opposite to the bulky sulfonyl group leading to the *threo* isomer (Scheme 3). The fact that *β*-keto sulfones give essentially the *threo*-*β*-hydroxy sulfones indicates that the *β*-chelate pathway,

(18) Sarko, C. R.; Collibee, S. E.; Knorr, A. L.; DiMare, M. *J. Org. Chem.* **1996**, *61*, 868.

Scheme 3



even if feasible, does not participate in these cases to a noticeable extent. To explain this, we have proposed that the system $LiEt_3BH/CeCl_3$ reacts mainly under nonchelation control because of the weak donor ability of the sulfonyl group.[20] Then, we believe that the *β*-keto sulfones would complex with $TiCl_4$, but it is likely that they will not complex with $CeCl_3$, even though this is apparently a good Lewis acid and its anhydrous form is highly hydroscopic.[21]

The reduction of α-alkyl-*β*-keto sulfone **1aa** was studied in different solvents such as dichloromethane and THF. This latter solvent turned out to be a suitable solvent for the reaction, since the use of coordinating solvents ensures good yields and high diastereoselectivity. On the other hand, an appreciable diastereoselectivity lowering was observed when substrate **1aa** was dissolved in CH_2Cl_2 (Table 2, entry 2). It may be expected that the use of noncoordinating solvents favors chelation phenomena, but the poor chelating ability of Ce(III) on these *β*-keto sulfones causes only a decrease in diastereoselectivity and not a complete inversion to *erythro* products, as the powerful chelating $TiCl_4$.

As previously outlined, the **1**−$CeCl_3$ complex can be represented by an equilibrium between **C** and **D** conformations (Scheme 3) and is completely shifted to the top, if the steric demand of R^2 is smaller than the sulfonyl group. Obviously, bulky R^1 moieties have the same positive effect on the conformational equilibrium. However, in the present case, this effect is not evident, since a high diastereoselectivity is even observed when both R^1 and R^2 are the small methyl groups (Table 2, entry 1). Invoking the Bürgi−Dunitz trajectory,[22,23] that is, approach at an angle of about 109° with respect to the plane of the carbonyl group, the attack to the **C** conformation should be preferred by steric effects. This means that it is no longer necessary to make the somewhat dubious assumption that the R^2 group should be gauche to the oxygen atom of the carbonyl group in the preferred transition sate. Alternatively, it may be assumed that the two conformations **C** and **D** are energetically similar and that differentiation arises out of nonbonded interactions between the incoming nucleophile with an R^2 group and between the two substituents R^1 and R^2, in the **D** conformation (Scheme 3). When R^2 is an α-branched alkyl group such as a cyclohexyl framework, a low *threo*/*erythro* ratio is observed, demonstrating that the steric demand of this group is higher than that of the linear alkyl chain on interaction with oxygen atom of the carbonyl group.

The presence of $CeCl_3$ is essential for the reaction, and at −78 °C, the reduction with $LiEt_3BH$ alone is extremely slow and the yields are low (30%) too. Reduction can be carried out over a short time interval at 0 °C, but a detriment of diastereoselectivity and of yields was observed. When the reaction is carried out at 0 °C in the presence of $CeCl_3$, the same low yields and low diastereoselectivity are observed.

Further, the parent compound of $LiEt_3BH$, lithium borohydride,[24] does not work at −78 °C with or without $CeCl_3$. To eliminate complexity due to the disproportion of the reducing species, those having complex hydride anions of a less dissociative nature should have been the choice. After examination of various types of metal hydride complex, $LiEt_3BH$ was among the best. The data clearly reveal that lithium triethylborohydride is an exceptionally powerful hydride reducing agent,[25] far more powerful than lithium borohydride. Then the $LiEt_3BH$ exhibits a remarkable selectivity, a property normally considered to be characteristic of relatively mild reducing agent, such as lithium borohydride.

Finally, since both $LiEt_3BH$ and $CeCl_3$ are required for efficient and selective reduction at −78 °C, the existence of reducing species requiring examination: THF is a polar solvent system, and the cerium hydride species (CeH_nCl_{3-n}) may be one possibility for the reaction. However, Fukazawa *et al.*[26] have suggested that such hydride species are unlikely to be the reducing agent in the reduction reactions with $LiAlH_4$ in the presence of $CeCl_3$; therefore, from our results, a similar behavior seems to be plausible.

Stereoselective Reduction of α-Chloro-*β*-keto Sulfones. On extending our procedure to obtain both *erythro*- and *threo*-α-alkyl-*β*-hydroxy sulfones by reduction of the corresponding *β*-keto sulfones, the stereoselectivity of the reduction on *β*-keto sulfones without α-hydrogens was examined (Scheme 4). The preferential choice of α-chloro-*β*-keto sulfone **4** as a model substrate was made because the *erythro*- and *threo*-*β*-hydroxysul-

(19) (a) Chérest, M.; Felkin, H.; Prudent, N. *Tetrhedron Lett.* **1968**, 2199. (b) Anh, N. T.; Einsenstein, O. *Nouv. J. Chim.* **1977**, *1*, 61.

(20) Bordwell, F. G.; Van Der Puy, M.; Vanier, N. R. *J. Org. Chem.* **1976**, *41*, 1883.

(21) It has been recently reported (Evans, W. J.; Feldman, J. D.; Ziller, J. W. *J. Am. Chem. Soc.* **1996**, *118*, 4581) that the material obtained after drying of $CeCl_3 \cdot 7H_2O$ (at 150 °C and 0.03 Torr for 12 h) was $[CeCl_3 \cdot (H_2O)]_n$. We have not analyzed the $CeCl_3$ prepared by the present procedure; however, the material was highly efficient without a large excess of reducing agent.

(22) (a) Bürgi, H. B.; Dunitz, J. D.; Shefter, E. J. *J. Am. Chem. Soc.* **1973,** *95*, 5065. (b) Bürgi, H. B.; Dunitz, J. D.; Lehn, J. M.; Wipff, G. *Tetrahedron* **1974**, *30*, 1563.

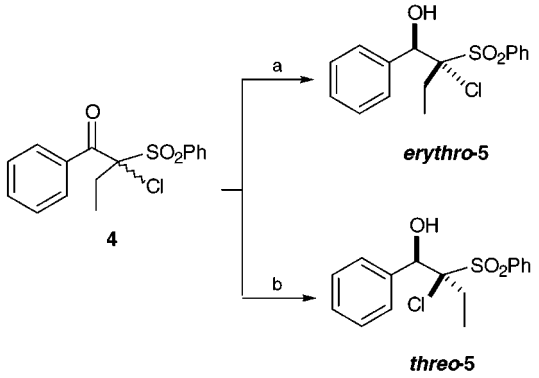
(23) Bürgi, H. B.; Lehn, J. M.; Wipff, G. *J. Am. Chem. Soc.* **1974**, *96*, 1956.

(24) Bartoli, G.; Bosco, M.; Marcantoni, E.; Sambri, L. *Tetrahedron Lett.* **1996**, *37*, 7421.

(25) Brown, H. C.; Kim, S. C.; Krishnamurthy, S. *J. Org. Chem.* **1980**, *45*, 1.

(26) Fukuzawa, S.; Fujinami, T.; Yamanchi, S.; Sakai, S. *J. Chem. Soc., Perkin Trans. 1* **1986**, 1929.

Scheme 4[a]

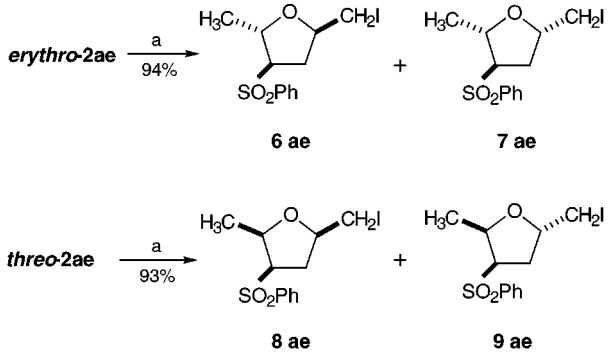


[a] Key: (a) $TiCl_4$ in CH_2Cl_2 at −78 °C, then BH_3/py, 87/13 *erythro*/*threo* isomers; (b) $CeCl_3$ in THF at −78 °C, then $LiBEt_3H$, 4/96 *erythro*/*threo* isomers.

fones **5**,[27] which are obtained by reduction, may be converted upon treatment with base into *cis*- and *trans*-epoxides.[28,29] These compounds are known to be labile compounds that are easily rearranged to α-substituted aldehydes and ketones.[30] Very interestingly, once more, the reduction with BH_3·py in the presence of strong chelating $TiCl_4$ gave *erythro*-**5** isomer as a major product, and the reduction with $LiBEt_3H$ in the presence of $CeCl_3$ afforded *threo*-**5** predominantly. This last excellent *threo* selectivity may again be explained by Felkin−Ahn's model, in which the hydride anion attacks the *β*-carbonyl group at the opposite side of the bulky sulfonyl group (Scheme 3). In addition, the reduction of ketone **4** shows that the method does not involve the base-catalyzed cleavage of α-chloro-*β*-keto sulfones;[31,32] in fact, the hydroxy sulfones **5** were found not to be contaminated with benzyl alcohol, from which purification is difficult.

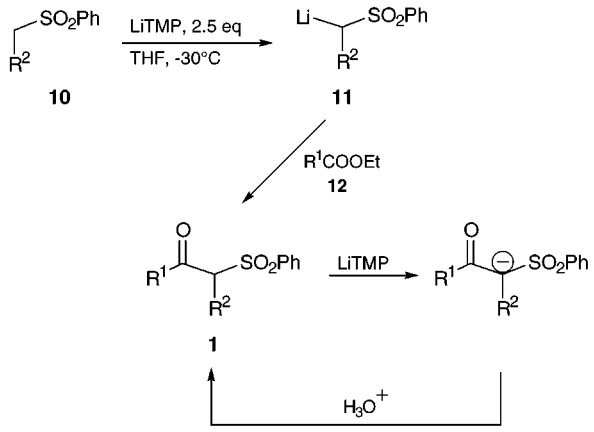
Synthesis of 2,5-Disubstituted Tetrahydrofuran Units. α-Allyl-*β*-hydroxy sulfones are key intermediates in the synthesis of 2,5-disubstituted tetrahydrofurans with high regioselectivity, since they can undergo easy electrophilic cyclization.[33] For this purpose, the reaction mixtures obtained from reduction of **1ae** with $TiCl_4$/BH_3·py (Table 1, entry 5) and $CeCl_3$/$LiEt_3BH$ (Table 2, entry 6), respectively, were separated. These compounds, submitted to iodocyclization,[34] gave the 2,5-disubstituted tetrahydrofurans in high yields, and any formation of six-membered cyclic product was not observed (Scheme 5). To elucidate the stereochemical problem of these two reactions, the four possible isomeric products generated [**6ae** to **9ae**] were isolated and characterized by ^1H and ^{13}C NMR. In the products (**8ae** and **9ae**), the methyl group must be *cis* to the sulfonyl group because its proton signal appeared at lower field (1.53 and 1.61 ppm). Moreover, in the *trans* 2,5-disubstituted tetrahydrofurans (**6ae** and **9ae**), one of the proton signals of the methylene

Scheme 5[a]



[a] Key: (A) I_2, NA_2CO_3, CH_3CN, RT, 2.5 H.

Scheme 6



group in the ring appeared at lower field owing to the deshield effects of both sulfonyl and iodomethyl groups *cis* to that proton.[35] These findings suggest that the introduction of a sulfonyl group facilitates the separation and the identification of the products. Since a sulfonyl group and iodine would be converted into other functional groups, the present strategy may be widely applicable to organic synthesis, and we are currently expanding the synthetic utility of this methodology.

Synthesis of α-Alkyl-*β*-keto Sulfones. There are various methods to prepare α-alkyl-*β*-keto sulfones. The alkylation reaction of unsubstituted *β*-keto sulfones[36] was found to be somewhat sluggish, and the reaction proceeds smoothly with short alkyl chains (R^2 = Me, Et) or with highly reactive derivatives, such as benzyl bromide, under phase-transfer conditions, especially using an ultrasonic bath to assist with the stirring.[37] Therefore, it is more convenient to prepare these compounds from the reaction of α-sulfonyl anions **11** followed by quenching of the reaction mixture with the appropriate ester **12** (Scheme 6). However, this procedure,[38] used on the metalation of **10** with a slight excess of LDA (1.2 equiv), needed a stoichiometric ratio of 2.2:1 between **10** and the ester because 1 equiv of **10** was engaged in the irreversible abstraction of the very acidic proton of the α-alkyl-*β*-keto sulfone **1**. Certainly, this fast enolization process

(27) To avoid ambiguity when indicating the hydroxy sulfones **5** we will follow the relative position of hydroxy group and α-ethyl group.

(28) Bohlmann, F.; Haffer, G. *Chem. Ber.* **1969**, *102*, 4017.
(29) Grossert, J. S.; Dharmaratne, H. R. W.; Cameron, T. S.; Vincent, B. R. *Can. J. Chem.* **1988**, *66*, 2860.
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Table 3. Synthesis of β-Keto Sulfones (1) from Reaction of Alkyl Sulfones (10), Anions, and Esters (12) in THF at −78 °C

entry	alkyl sulfone	R^2	ester	R^1	product	yield[a] (%)
1	**1aa**	Me	**12a**	Me	**1aa**	88
2	**1ab**	Et	**12a**	Me	**1ab**	87
3	**1ac**	Ph	**12a**	Me	**1ac**	88
4	**1ad**	c−C_6H_{11}	**12a**	Me	**1ad**	77[b]
5	**1ae**	allyl	**12a**	Me	**1ae**	79
6	**1af**	CH_2Ph	**12a**	Me	**1af**	90
7	**1cb**	Et	**12c**	Ph	**1cb**	90
8	**1gb**	Et	**12g**	4-MeOPh	**1gb**	85
9	**1hb**	Et	**12h**	4-NO_{2Ph}	**1hb**	89

[a] Calculated on the product purified by column chromatography. [b]By adding dried cerium trichloride.

prevents ketone **1** from undergoing a further nucleophilic addition of **11**, but serious difficulties arise in the separation of **1** and **10**. We modified this methodology by simply metalating **10** with 2.5 equiv of a strong nonnucleophilic base, such as lithium tetramethylpiperidide (LiTMP). Its presence does not interfere with ester and **10** can be remetalated by the excess of LiTMP, so that α-alkyl-β-keto sulfones **1** are obtained in high yields on the basis of **10**. This procedure has been proven to be very efficient in preparing a large variety of α-alkyl-β-keto sulfones (Table 3), demonstrating once more the potential of our synthesis of easily enolizable compounds.[24] It completely fails when R^2 is a branched alkyl substituent, where the enolization of the ester **12** becomes an important side reaction, and this drawback can be efficiently avoided by adding dry cerium trichloride[39−41] to the α-sulfonyl anion (Table 3, entry 4).

Conclusion

In conclusion, we have shown that a general highly efficient multistep methodology can be set up to obtain both *erythro*- and *threo*-β-hydroxy sulfones, key intermediates for the synthesis of 2,5-disubstituted tetrahydrofurans. The success of this methodology has been the correct choice of chelating or nonchelating metallic complexes. In the former case ($TiCl_4/BH_3$·py), the *erythro* isomer largely prevails, while in the latter one ($CeCl_3$/$LiEt_3BH$) the *threo* isomer is obtained. Hence, it has been clearly demonstrated that cerium trichloride cannot give chelation when a six-membered transition state is involved. To summarize, we have developed a new and convenient methodology that reaches the goal of a high-yield and high-purity synthesis of α-alkyl-β-hydroxy sulfones from easily available and cheap starting materials. Finally, we are currently expanding the synthetic utility of this reducing methodology, and our efforts will be reported in the future.

Experimental Section

General Comments. ^1H and ^{13}C NMR data were collected on a 200 MHz NMR spectrometer with TMS as internal reference in $CDCl_3$. All mass spectra were determined on a HP5890 Series II capillary GC operating in split mode with helium carrier gas and fitted with a mass selective detector (MSD). The column used was a HP5 capillary column 30 m × 0.25 mm, with 0.25 μm film thickness of 5% phenylmethylsilicone gum. The temperature program used the initial temperature of 65 °C for 3 min and then ramped at 15 °C min^{-1} to 280 °C. Column chromatography was carried out using 230−400 mesh silica. Diastereomeric purity was determined by NMR analysis. In all compounds listed in Tables 1 and 2, we have noted an upfield shift of the carbinol carbons in the erythro isomer compared with those in the threo isomer. Alkyl sulfones **10**[42] and 1-phenyl-2-chloro-2-(phenylsulfonyl)butan-1-one (**4**)[29] were prepared according to the published procedures.

General Procedure for Preparing α-Alkyl-β-keto Sulfones (1). A solution of lithium 2,2,6,6-tetramethylpiperidide (2.3 equiv) was prepared in THF (35 mL) from 2,2,6,6-tetramethylpiperidine (2.28 mL) and a 1.6 M solution (8.32 mL) of *n*-butyllithium in hexane under nitrogen at −30 °C. After 30 min, to this reagent solution was added with stirring, under nitrogen at −30 °C, a solution of the alkyl sulfone **10** (5.89 mmol) in THF (2.5 mL). Stirring was continued for 1 h, and then the mixture was cooled to −78 °C and a solution of the ester **12** (14.7 mmol) in THF (2.5 mL) was added. Two hours later, the reaction was allowed to reach room temperature and then quenched with diluted HCl (10%) and extracted with diethyl ether. The combined organic extracts were washed with saturated aqueous NaCl, dried, and evaporated to give the crude product, which was purified by flash column chromatography on silica gel to afford the pure product.

Spectra and analytical data of new α-alkyl-β-keto sulfones prepared are as follows.

3-(Phenylsulfonyl)pentan-2-one (1ab): IR (neat) 1712, 1320, 1118 cm^{-1}; ^1H NMR δ 0.84 (t, 3H, J = 7.33 Hz), 1.85−1.92 (m, 2H), 2.37 (s, 3H), 3.97 (dd, 1H, J = 4.9, 7.6 Hz), 7.49−7.68 (m, 3H), 7.70−7.78 (m, 2H); EI-MS m/z 226 (M^+), 184, 169 (100), 141, 77, 51, 43. Anal. Calcd for $C_{11}H_{14}O_3S$: C, 58.38; H,6.23; S, 14.17. Found: C, 58.39; H, 6.20; S, 14.12.

1-(4-Methoxyphenyl)-2-(phenylsulfonyl)butan-1-one (1gb): mp 104−105 °C; IR (Nujol) 1678, 1339, 1017 cm^{-1}; ^1H NMR δ 0.89 (t, 3H, J = 7.32 Hz), 2.05−2.20 (m, 2H), 3.73 (s, 3H), 4.89 (dd, 1H, J = 4.20, 10.44 Hz), 6.83−6.92 (m, 2H), 7.18−7.23 (d, 2H, J = 8.71 Hz), 7.51−7.67 (m, 3H), 7.86−7.95 (m, 2H); EI-MS m/z 318 (M^+), 176, 163, 141, 135 (100), 109, 77, 51. Anal. Calcd for $C_{17}H_{18}O_4S$: C, 64.13; H, 5.70; S, 10.07. Found: C, 64.11; H, 5.62; S, 10.06.

1-(4-Nitrophenyl)-2-(phenylsulfonyl)butan-1-one (1hb): mp 112−115 °C; IR (Nujol) 1680, 1550, 1332, 1086 cm^{-1}; ^1H NMR δ 0.89 (t, 3H, J = 7.40 Hz), 2.03−2.17 (m, 2H), 4.99 (dd, 1H, J = 4.07, 10.50 Hz), 7.51−7.66 (m, 2H), 7.70−7.78 (m, 3H), 8.14−8.19 (m, 2H), 8.31−8.37 (m, 2H); EI-MS m/z 333 (M^+), 305, 269, 150 (100), 141, 104, 77, 51. Anal. Calcd for $C_{16}H_{15}NO_3S$: C, 57.65; H,5.01; S, 10.64. Found: C, 57.62; H, 4.96; S, 10.63.

Preparation of 1-Cyclohexyl-1-(phenylsulfonyl)propan-2-one (1ad). The alkyl sulfone **10d** (1 mmol) was dissolved in Et_2O at room temperature and cooled to −78 °C. To the cooled solution was added *n*-BuLi (1.2 mmol) to give a bright yellow solution. The anion was stirred at the same temperature for 0.5 h before cannulation to cerium(III) chloride dried according to Imamoto's procedure.[39] The suspension was stirred for 0.5 h, and the reaction was quenched with ester **12a** (2 mmol). The reaction mixture was slowly warmed to room temperature to ensure complete reaction as assayed by TLC. The reaction was then quenched with diluted HCl (10%). The organic layer was separated, and the aqueous layer was extracted with ether. The combined organic layers were washed with aqueous saturated sodium bicarbonate solution and saturated brine solution and dried over anhydrous sodium sulfate. The extracts were then concentrated under reduced pressure, and the residue was chromatographed on silica gel column (eluent: hexane−ethyl acetate 9:1) to give the corresponding α-alkyl-β-keto sulfone (yield 77%) as an oil: IR (neat) 1710, 1330, 1075 cm^{-1}; ^1H NMR δ 1.15−1.25 (m, 4H), 1.61−1.72 (m, 6H), 2.20 (s, 3H), 3.98 (d, 1H, J = 6.91 Hz), 7.52−7.67 (m, 3H), 7.82−7.86 (m, 2H); EI-MS m/z 280 (M^+), 238, 199 (100), 141, 79, 51, 43. Anal. Calcd for $C_{15}H_{20}O_3S$: C, 64.25; H, 7.19; S, 11.43. Found: C, 64.24; H, 7.12; S, 11.40.

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(41) Imamoto, T. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: Oxford, 1991; Vol. 1, pp 231−250.

General $TiCl_4$-BH_3.py Reduction Procedure. To a cold (−78 °C) solution of keto sulfone **1** (1.0 mmol) in 10 mL of dry CH_2Cl_2 was added $TiCl_4$ (1.3 mmol, solution 1 M in CH_2Cl_2) to give immediately a bright yellow solution, which was stirred for 10 min at this temperature. The complex BH_3·py (1.3 mmol) in 5 mL of CH_2Cl_2 was then added. After 15 min, 25 mL of 1 N HCl was added, and the reaction was warmed to room temperature. The organic layer was separated, the aqueous layer was washed with CH_2Cl_2, and the combined organics were concentrated in vacuo. The resulting residue was partitioned between Et_2O and H_2O. The etheral layer was washed with water and brine, dried over anhydrous Na_2SO_4, and concentrated in vacuo. Flash column chromatography gave *erythro*-α-alkyl-*β*-hydroxy sulfones **2**[43] contaminated only by a minor amount of the *threo*-diastereoisomer. Diastereomeric purity, determined by NMR analysis, and yields are reported in Table 1. Elemental analyses of products were performed on diastereomeric mixtures.

(*R*,S)-3-(Phenylsulfonyl)butan-2-ol (*erythro*-2aa):** IR (neat) 3480, 1305, 1148 cm^{-1}; ^1H NMR δ 1.19 (d, 3H, J = 6.55 Hz), 1.32 (d, 3H, J = 7.17 Hz), 2.94−3.13 (m, 2H), 4.39−4.47 (m, 1H), 7.54−7.69 (m, 3H), 7.87−7.94 (m, 2H); EI-MS *m/z* 170, 141, 105, 77, 73 (100), 55, 44. Anal. Calcd for $C_{10}H_{14}O_3S$: C, 56.05; H, 6.58; S, 14.96. Found: C, 56.01; H, 6.50; S, 14.95.

(*R*,S)-3-(Phenylsulfonyl)pentan-2-ol (*erythro*-2ab):** IR (neat) 3496, 1300, 1100 cm^{-1}; ^1H NMR δ 0.95 (t, 3H, J = 7.63 Hz), 1.25 (d, 3H, J = 6.10 Hz), 1.86−1.91 (m, 2H), 2.80−2.84 (m, 1H), 3.21 (bs, 1H, OH), 4.31−4.38 (m, 1H), 7.54−7.66 (m, 3H), 7.86−7.90 (m, 2H); EI-MS *m/z* 213, 184, 169, 143, 141, 87, 77, 51, 45 (100). Anal. Calcd for $C_{11}H_{16}O_3S$: C, 57.87; H, 7.06; S, 14.04. Found: C, 57.85; H, 7.01; S, 14.02.

(*R*,S)-1-Phenyl-1-(phenylsulfonyl)propan-2-ol (*erythro*-2ac):** IR (neat) 3499, 1300, 1105 cm^{-1}; ^1H NMR δ 1.77 (d, 3H, J = 6.10 Hz), 3.12 (bs, 1H, OH), 3.95 (d, 1H, J = 4.74 Hz), 4.96−4.99 (m, 1H), 7.21−7.50 (m, 7H), 7.53−7.61 (m, 3H); EI-MS *m/z* 232, 141, 135 (100), 91, 77, 55, 43. Anal. Calcd for $C_{15}H_{16}O_3S$: C, 65.19; H, 5.83; S, 11.60. Found: C, 65.18; H, 5.79; S, 11.57.

(*R*,S)-1-Cyclohexyl-1-(phenylsulfonyl)propan-2-ol (*erythro*-2ad):** IR (neat) 3487, 1325, 1109 cm^{-1}; ^1H NMR δ 1.16−1.34 (m, 4H), 1.37 (d, 3H, J = 6.64 Hz), 1.43−1.87 (m, 8H), 2.95 (t, 1H, J = 4.15 Hz), 4.19−4.23 (m, 1H), 7.59−7.67 (m, 3H), 7.88−7.93 (m, 2H); ^{13}C NMR δ 20.75, 25.83, 26.92, 27.03, 31.68, 36.52, 65.97, 128.05, 129.00, 129.26, 133.67, 139.85; EI-MS *m/z* 238, 141, 123, 81 (100), 77, 65, 51, 44. Anal. Calcd for $C_{15}H_{22}O_3S$: C, 63.79; H, 7.85; S, 11.35. Found: C, 63.77; H, 7.79; S, 11.33.

(*R*,S)-3-(Phenylsulfonyl)hex-6-en-2-ol (*erythro*-2ae):** IR (neat) 3490, 1640, 1309, 1117 cm^{-1}; ^1H NMR δ 1.28 (d, 3H, J = 6.63 Hz), 2.18 (bs, 1H, OH), 2.60−2.64 (m, 2H), 3.00−3.07 (m, 1H), 4.39 (dq, 1H, J = 1.60, 6.65 Hz), 4.92−5.05 (m, 2H), 5.54−5.74 (m, 1H), 7.27−7.78 (m, 3H), 7.87−7.92 (m, 2H); ^{13}C NMR δ 20.76, 27.76, 65.49, 69.42, 125.81, 129.11, 129.86, 135.27, 139.53, 148.02; EI-MS *m/z* 239, 143, 141, 97, 83, 77, 51, 43 (100), 41. Anal. Calcd for $C_{12}H_{16}O_3S$: C, 59.97; H, 6.71; S, 13.34. Found: C, 59.95, H, 6.68; S, 13.30.

(*R*,S)-4-Phenyl-3-(phenylsulfonyl)butan-2-ol (*erythro*-2af):** IR (neat) 3500, 1315, 1103 cm^{-1}; ^1H NMR δ 1.24 (d, 3H, J = 6.68 Hz), 3.15 (d, 2H, J = 5.92 Hz), 3.30 (bs, 1H, OH), 3.34−3.41 (m, 1H), 4.31−4.36 (m, 1H), 7.00−7.05 (m, 2H), 7.14−7.20 (m, 3H), 7.48−7.64 (m, 3H), 7.83−7.88 (m, 2H); EI-MS *m/z* 199, 168, 148, 141, 131, 105, 91 (100), 77, 51, 43. Anal. Calcd for $C_{16}H_{18}O_3S$: C, 66.18; H, 6.24; S, 11.04. Found: C, 66.16; H, 6.17; S, 11.02.

(*R*,S)-1-Phenyl-2-(phenylsulfonyl)butan-1-ol (*erythro*-2cb):** IR (neat) 3469, 1307, 1109 cm^{-1}; ^1H NMR δ 0.63 (t, 3H, J = 7.60 Hz), 1.86−1.95 (m, 2H), 3.05−3.10 (m, 1H), 3.45 (bs, 1H, OH), 5.39 (d, 1H, J = 5.07 Hz), 7.21−7.33 (m, 5H), 7.59−7.73 (m, 3H), 7.97−8.01 (m, 2H); EI-MS *m/z* 290 (M^+), 184, 169 (100), 148, 141, 91, 77, 51. Anal. Calcd for $C_{16}H_{18}O_3S$: C, 66.18; H, 6.24; S, 11.64. Found: C, 66.14; H, 6.17; S, 11.01.

(*R*,S)-1-(4-Methoxyphenyl)-2-(phenylsulfonyl)butan-1-ol (*erythro*-2gb):** IR (neat) 3490, 1318, 1100 cm^{-1}; ^1H NMR δ 0.66 (t, 3H, J = 7.57 Hz), 1.86−1.94 (m, 2H), 3.04 (t, 1H, J = 3.58 Hz), 3.42 (bs, 1H, OH), 3.78 (s, 3H), 5.35 (d, 1H, J = 5.90 Hz), 6.81−6.86 (m, 2H), 7.14−7.27 (m, 2H), 7.57−7.71 (m, 3H), 7.92−8.00 (m, 2H); EI-MS *m/z* 320 (M^+), 302, 178, 163, 141, 137 (100), 109, 77, 51. Anal. Calcd for $C_{17}H_{20}O_4S$: C, 63.72; H, 6.29; S, 10.00. Found: C, 63.70; H, 6.21; S, 9.98.

(*R*,S)-1-(4-Nitrophenyl)-2-(phenylsulfonyl)butan-1-ol (*erythro*-2hb):** IR (neat) 3495, 1545, 1302, 1107 cm^{-1}; ^1H NMR δ 0.68 (t, 3H, J = 7.50 Hz), 1.79−1.93 (m, 2H), 3.06−3.12 (m, 1H), 3.40 (bs, 1H, OH), 5.54 (d, 1H, J = 5.85 Hz), 7.43−7.49 (m, 2H), 7.55−7.75 (m, 3H), 7.97−8.02 (m, 2H), 8.15−8.20 (m, 2H); EI-MS *m/z* 335 (M^+), 317, 193, 178, 152 (100), 141, 77, 51. Anal. Calcd for $C_{16}H_{17}NO_5S$: C, 57.30; H, 5.11; N, 4.17; S, 9.56. Found: C, 57.29; H, 5.07; N, 4.12; S, 9.54.

(*R*,R)-1-Phenyl-2-chloro-2-(phenylsulfonyl)butan-1-ol (*erythro*-5):** IR (neat) 3495, 1303, 1148, 731 cm^{-1}; ^1H NMR δ 1.09 (t, 3H, J = 7.37 Hz), 2.26−2.30 (m, 1H), 2.60−2.68 (m, 1H), 4.21 (bs, 1H, OH), 5.11 (s, 1H), 7.31−7.38 (m, 3H), 7.46−7.72 (m, 5H), 7.94−8.06 (m, 2H); ^{13}C NMR δ 8.77, 26.20, 73.52, 91.93, 128.15, 128.50, 129.11, 129.40, 133.96, 134.10, 138.96, 139.75; EI-MS *m/z* 326 (M^+ + 2), 324 (M^+), 220, 218, 203, 147, 141, 107 (100), 105, 91, 77, 51. Anal. Calcd for $C_{16}H_{17}ClO_3S$: C, 59.16; H, 5.27; S, 9.87. Found: C, 59.14; H, 5.22; S, 9.84.

General $CeCl_3$−$LiEt_3BH$ Reduction Procedure. Finely ground $CeCl_3$·$7H_2O$ (3.2 mmol) was dried by heating at 140 °C/01 Torr for 2 h. Dry THF (10 mL) was then added at 0 °C, and the milky suspension was stirred overnight under nitrogen at room temperature. At this temperature, a solution of **1** (1 mmol) in 5 mL of THF was added and left to stir for 1 h. Then it was cooled to −78 °C, and $LiEt_3BH$ (2 mmol, solution 1 M in THF) was added by syringe. The reaction mixture was then left to stir until TLC indicated that no starting material remained (Table 2). The reaction was quenched with 0.5 N HCl and extracted with Et_2O. The ethereal extracts were combined and washed with water and brine, dried over anhydrous Na_2SO_4, and concentrated in vacuo. Flash column chromatography gave *threo*-α-alkyl-*β*-hydroxy sulfones **2** contaminated only by a minor amount of the *erythro*-diastereomer. Diastereomeric purity, determined by NMR analysis, and yields are reported in Table 2. Elemental analyses of products were performed on diastereomeric mixtures.

(*R*,R)-3-(Phenylsulfonyl)butan-2-ol (*threo*-2aa):** IR (neat) 3492, 1307, 1130 cm^{-1}; ^1H NMR δ 1.13 (d, 3H, J = 7.17 Hz), 1.23 (d, 3H, J = 6.37 Hz), 3.10−3.18 (m, 1H), 4.16−4.20 (m, 1H), 5.45 (bs, 1H, OH), 7.52−7.67 (m, 3H), 7.84−7.90 (m, 2H); EI-MS *m/z* 170, 141, 105, 77, 73 (100), 55, 43. Anal. Calcd for $C_{10}H_{14}O_3S$: C, 56.05; H, 6.58; S, 14.96. Found: C, 56.01; H, 6.56; S, 14.93.

(*R*,R)-3-(Phenylsulfonyl)pentan-2-ol (*threo*-2ab):** IR (neat) 3496, 1300, 1100 cm^{-1}; ^1H NMR δ 0.95 (t, 3H, J = 7.03 Hz), 1.33 (d, 3H, J = 6.40 Hz), 1.60−1.76 (m, 2H), 2.96−3.02 (m, 1H), 3.52 (bs, 1H, OH), 4.29−4.35 (m, 1H), 7.54−7.67 (m, 3H), 7.88−7.92 (m, 2H); EI-MS *m/z* 228 (M^+), 213, 184, 169, 141, 87, 77, 51, 45 (100). Anal. Calcd for $C_{11}H_{16}O_3S$: C, 57.87; H, 7.06; S, 14.04. Found: C, 57.84; H, 7.00; S, 14.00.

(*R*,R)-1-Phenyl-1-(phenylsulfonyl)propan-2-ol (*threo*-2ac):** IR (neat) 3500, 1580, 1320, 1109 cm^{-1}; ^1H NMR δ 1.05 (d, 3H, J = 6.10 Hz), 3.26 (bs, 1H, OH), 4.95−5.02 (m, 1H), 7.19−7.27 (m, 4H), 7.34−7.39 (m, 3H), 7.45−7.55 (m, 3H); EI-MS *m/z* 276 (M^+), 232, 141, 135 (100), 91, 77, 43. Anal. Calcd for $C_{15}H_{16}O_3S$: C, 65.19, H, 5.83; S, 11.60. Found: C, 65.18; H, 5.82; S, 11.52.

(*R*,R)-1-Cyclohexyl-1-(phenylsulfonyl)propan-2-ol (*threo*-2ad):** IR (neat) 3490, 1321, 1115 cm^{-1}; ^1H NMR δ 1.13−1.28 (m, 4H), 1.36 (d, 3H, J = 6.47 Hz), 1.40−1.76 (m, 8H), 2.99 (dd, 1H, J = 2.16, 6.65 Hz), 4.31−4.34 (m, 1H), 7.54−7.66 (m, 3H), 7.90−7.95 (m, 2H); ^{13}C NMR δ 23.00, 25.93, 26.74, 27.06, 28.86, 31.66, 38.05, 65.46, 75.46, 128.23, 129.14, 133.60, 140.63; EI-MS *m/z* 282 (M^+), 238, 141, 123, 81 (100),

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(43) Descriptors *R*,S** indicate that diastereomeric compounds are obtained as racemates. We prefer this terminology to avoid the ambiguities that could arise from the use of *erythro,threo*.

77, 55, 51, 44. Anal. Calcd for $C_{15}H_{22}O_3S$: C, 63.79; H, 7.85; S, 11.35. Found: C, 63.77; H, 7.88; S, 11.29.

(*R*,R)-3-(Phenylsulfonyl)hex-6-en-2-ol (*threo*-2ae):** IR (neat) 3501, 1638, 1315, 1109 cm^{-1}; ^1H NMR δ 1.33 (d, 3H, J = 6.54 Hz), 2.41−2.49 (m, 2H), 3.15−3.37 (m, 1H), 3.40 (bs, 1H, OH), 4.24−4.34 (m, 1H), 4.97−5.05 (m, 2H), 5.58−5.75 (m, 1H), 7.54−7.70 (m, 3H), 7.88−7.91 (m, 2H); ^{13}C NMR δ 21.09, 30.79, 66.62, 70.31, 118.65, 129.18, 129.77, 134.19, 134.48, 138.89; EI-MS m/z 240 (M^+), 143, 141, 97, 83, 77, 51, 43 (100). Anal. Calcd for $C_{12}H_{16}O_3S$: C, 59.97; H, 6.71; S, 13.34. Found: C, 59.93; H, 6.68; S, 13.30.

(*R*,R)-4-Phenyl-3-(phenylsulfonyl)butan-2-ol (*threo*-2af):** IR (neat) 3498, 1313, 1108 cm^{-1}; ^1H NMR δ 1.34 (d, 3H, J = 6.40 Hz), 2.90−2.98 (m, 1H), 3.06−3.13 (m, 1H), 3.47−3.51 (m, 1H), 4.25−4.30 (m, 2H), 7.01−7.04 (m, 2H), 7.14−7.17 (m, 3H), 7.48−7.61 (m, 3H), 7.81−7.84 (m, 2H); EI-MS m/z 290 (M^+), 199, 168, 148, 141, 131, 105, 91 (100), 77, 51, 43. Anal. Calcd for $C_{16}H_{18}O_3S$: C, 66.18, H, 6.24; S, 11.04. Found: C, 66.17; H, 6.18; S, 10.99.

(*R*,R)-1-Phenyl-2-(phenylsulfonyl)butan-1-ol (*threo*-2cb):** IR (neat) 3489, 1307, 1118 cm^{-1}; ^1H NMR δ 0.52 (t, 3H, J = 8.00 Hz), 1.29−1.38 (m, 1H), 1.57−1.67 (m, 1H), 3.24−3.30 (m, 1H), 4.37 (bs, 1H, OH), 5.03 (d, 1H, J = 5.80 Hz), 7.32−7.35 (m, 5H), 7.55−7.71 (m, 3H), 7.91−7.95 (m, 2H); EI-MS m/z 290 (M^+), 184, 169 (100), 148, 141, 91, 77, 51. Anal. Calcd for $C_{16}H_{18}O_3S$: C, 66.18; H, 6.24; S, 11.04. Found: C, 66.15; H, 6.17; S, 11.01.

(*R*,R)-1-(4-Methoxyphenyl)-2-(phenylsulfonyl)butan-1-ol (*threo*-2gb):** IR (neat) 3500, 1309, 1107 cm^{-1}; ^1H NMR δ 0.53 (t, 3H, J = 7.40 Hz), 1.81−1.87 (m, 2H), 3.21−3.26 (m, 2H), 3.73 (s, 3H), 4.98 (d, 1H, J = 5.85 Hz), 6.81−6.85 (m, 2H), 7.19−7.27 (m, 2H), 7.51−7.67 (m, 3H), 7.86−7.95 (m, 2H); EI-MS m/z 320 (M^+), 302, 178, 163, 141, 137 (100), 109, 77, 51. Anal. Calcd for $C_{17}H_{20}O_4S$: C, 63.72; H, 6.29; S, 10.00. Found: C, 63.09; H, 6.27; S, 9.97.

(*R*,R)-1-(4-Nitrophenyl)-2-(phenylsulfonyl)butan-1-ol (*threo*-2hb):** IR (neat) 3494, 1502, 1309, 1105 cm^{-1}; ^1H NMR δ 0.58 (t, 3H, J = 7.43 Hz), 1.74−1.78 (m, 2H), 3.13−3.20 (m, 2H), 5.17 (d, 1H, J = 5.96 Hz), 7.02−7.08 (m, 2H), 7.44−7.50 (m, 2H), 7.56−7.78 (m, 3H), 7.98−8.04 (m, 2H); EI-MS m/z 335 (M^+), 317, 193, 178, 152 (100), 141, 77, 51. Anal. Calcd for $C_{16}H_{17}NO_5S$: C, 57.30; H, 5.11; N, 4.17; S, 9.56. Found: C, 57.30; H, 5.07; N, 4.10; S, 9.52.

(*R*,S)-1-Phenyl-2-chloro-2-(phenylsulfonyl)butan-1-ol (*threo*-5):** IR (neat) 3495, 1305, 1140, 736 cm^{-1}; ^1H NMR δ 0.72 (t, 3H, J = 7.37 Hz), 1.88−2.06 (m, 2H), 4.26 (bs, 1H, OH), 5.54 (s, 1H), 7.26−7.34 (m, 3H), 7.39−7.44 (m, 2H), 7.58−7.76 (m, 3H), 8.02−8.07 (m, 2H); ^{13}C NMR δ 9.10, 29.23, 74.65, 92.82, 128.09, 128.45, 129.45, 129.72, 133.89, 134.01, 138.43, 139.60; EI-MS m/z 326 ($M^+ + 2$), 324 (M^+), 220, 218, 203, 147, 143, 141, 107 (100), 105, 91, 79, 77. Anal. Calcd for $C_{16}H_{17}ClO_3S$: C, 59.16; H, 5.27; S, 9.87. Found: C, 59.14; H, 5.20; S, 9.84.

Preparation of 1-Methyl-2-(phenylsulfonyl)-5-(iodomethyl)tetrahydrofurans (6ae and 7ae). To a stirred solution of *erythro*-**2ae** (1 mmol) in 11 mL of dry acetonitrile were added anhydrous sodium carbonate (10 mmol) and iodine (5.02 mmol). The mixture was stirred in the dark for 2 h at room temperature, diluted with 35 mL of ether, and then treated with 17 mL of 10% aqueous Na_2SO_3. The organic layer was separated, washed with 20 mL of saturated aqueous NaCl, dried (Na_2SO_4), and evaporated to give a mixture (yield 94%) of two diastereomers **6ae** and **7ae** (5.5:4.5 ratio by NMR), which were separated by column chromatography.

(R*, S*, S*)-6ae: IR (neat) 1310, 1140 cm^{-1}; ^1H NMR δ 1.23 (d, 3H, J = 6.10 Hz), 2.19−2.23 (m, 1H), 2.30−2.41 (m, 1H), 3.25 (d, 2H, J = 5.10 Hz), 3.39−3.42 (m, 1H), 4.39−4.45 (m, 2H), 7.56−7.70 (m, 3H), 7.85−7.92 (m, 2H); ^{13}C NMR δ 7.65, 17.90; 34.85, 65.78, 76.30, 77.90, 128.15, 129.43, 133.97, 139.76; EI-MS m/z 354 (M^+), 239, 224, 143, 125, 97 (100%), 83, 79, 77. Anal. Calcd for $C_{11}H_{15}IO_3S$: C, 37.29; H, 4.26; S, 9.05. Found: C, 37.26; H, 4.20; S, 9.05.

(R*, S*, R*)-7ae: IR (neat) 1310, 1140 cm^{-1}; ^1H NMR δ 1.22 (d, 3H, J = 6.18 Hz), 1.89−2.01 (m, 1H), 2.52−2.62 (m, 1H), 3.22 (d, 2H, J = 5.09 Hz), 3.32−3.36 (m, 1H), 4.39−4.45 (m, 2H), 7.55−7.73 (m, 3H), 7.88−7.93 (m, 2H); ^{13}C NMR δ 9.87, 16.95, 33.65, 65.44, 76.20, 76.95, 128.10, 129.43, 133.76, 138.30; EI-MS m/z 354 (M^+), 239, 224, 143, 125, 97 (100%), 83, 79, 77. Anal. Calcd for C11$H_{15}IO_3S$: C,37.29; H,4.26; S,9.05. Found: C, 37.26; H, 4.20; S, 9.05.

Similar treatment of *threo*-(**2ae**) with iodine and sodium carbonate in acetonitrile gave a mixture (yield 93%) of two tetrahydrofurans **8ae** and **9ae** (8.3:1.7 ratio by NMR) which were separated by column chromatography.

(*R*,R*,R)-8ae**: IR (neat) 1308, 1109 cm^{-1}; ^1H NMR δ 1.53 (d, 3H, J = 6.68 Hz), 1.91−2.08 (m, 2H), 3.15−3.21 (m, 2H), 3.72−3.82 (m, 1H), 3.95−4.00 (m, 1H), 4.48−4.58 (m, 1H), 7.52−7.76 (m, 3H), 7.86−7.90 (m, 2H); ^{13}C NMR δ 10.69, 16.99, 33.74, 65.67, 75.72, 76.40, 128.05, 129.43, 133.95, 138.45; EI-MS m/z 354 (M^+), 239, 224, 143, 125, 97 (100), 79, 77. Anal. Calcd for $C_{11}H_{15}IO_3S$: C, 37.29; H, 4.26; S, 9.05. Found: C, 37.26; H, 4.01; S, 8.99.

(*R*,R*,S)-9ae:** IR (neat) 1308, 1109 cm^{-1}; ^1H NMR δ 1.61 (d, 3H, J = 6.63 Hz), 2.17−2.27 (m, 2H), 3.19−3.35 (m, 2H), 3.72−3.84 (m, 1H), 3.95−4.00 (m, 1H), 4.39−4.45 (m, 1H), 7.52−7.76 (m, 3H), 7.86−7.90 (m, 2H); ^{13}C NMR δ 7.12, 17.85, 34.89, 65.79, 76.62, 77.87, 128.14, 129.43, 133.90, 139.78; EI-MS m/z 354 (M^+), 239, 224, 143, 141, 125, 97 (100), 79, 77. Anal. Calcd for $C_{11}H_{15}IO_3S$: C, 37.29; H, 4.26; S, 9.05. Found: C, 37.26; H, 4.01; S, 8.99.

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