# The Preparation of Optically Active β-Keto Sulfoxides by Means of an Enantiomer-differentiating Reaction of α-Lithio Aryl Methyl Sulfoxides with Chiral Carboxylates[1)]

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(Received June 26, 1980)

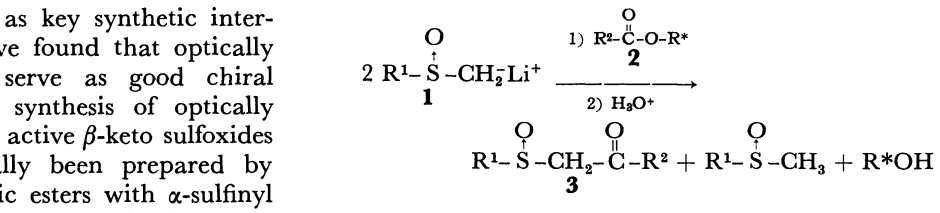
The reaction of α-lithio aryl methyl sulfoxides with a limited amount of chiral carboxylates ($R^2$–CO–O–R*) was found to be an enantiomer-differentiating reaction, affording the corresponding optically active β-keto sulfoxides (**3**), together with optically active aryl methyl sulfoxides which have the opposite configuration. The optical purity and the predominant configuration of **3** obtained were assigned by means of a combination of polarimetric analysis and NMR. The degree of enantioselectivity of this reaction was affected by the nature of the ester moiety $R^2$, indicating an increase in optical yields, from 1.3%, where $R^2$ was ethyl (**3b**), to 70.3%, where $R^2$ was *t*-butyl (**3f**). The stereochemical course of the reaction has been discussed by considering a six-membered cyclic transition state. Furthermore, the repeated recrystallizations of several β-keto sulfoxides thus obtained, such as (−)-**3e**, (−)-**3f**, (−)-**3g**, and (−)-**3p**, were found to give the corresponding highly optically pure β-keto sulfoxides.

β-Keto sulfoxides are useful as key synthetic intermediates.[2)] Previously, we have found that optically active β-keto sulfoxides can serve as good chiral precursors in the asymmetric synthesis of optically active alcohols.[3c)] The optically active β-keto sulfoxides hitherto reported have generally been prepared by either the reaction of carboxylic esters with α-sulfinyl carbanions, which are derived from optically active sulfoxides,[1,3c)] or by the oxidation of optically active β-hydroxy sulfoxides, which are prepared from optically active sulfoxides and aldehydes,[3e,4b)] exclusive of microbiological methods.[4)] However, these procedures involve the rather hard task of synthesizing optically active sulfoxides as the starting materials.[5)]

During the course of our research concerned with the asymmetric induction by the chiral sulfinyl group,[3)] we recently reported that 2 equivalents of a racemic α-sulfinyl carbanion reacted with a (−)-menthyl (*S*)-arenesulfinate to yield a diastereomeric mixture of (*R*,*S*)- and (*R*,*R*)-β-disulfoxides in a ratio of about 6 : 4.[3b)] In view of this finding, we considered that the reaction of a racemic α-sulfinyl carbanion with a limited amount of a chiral carboxylate might provide a kinetic resolution of the α-sulfinyl carbanion, together with the production of optically active β-keto sulfoxide. As expected, we have now found that the reaction of 2 equivalents of racemic α-lithio aryl methyl sulfoxides (**1**)[8)] with chiral carboxylates(**2**) affords the corresponding optically active β-keto sulfoxides(**3**), together with the optically active aryl methyl sulfoxides (Scheme 1). We wish herein to report on the application of this method to the synthesis of some optically active β-keto sulfoxides and the determination of their optical purities and absolute configurations.

## Results and Discussion

To cite a typical reaction, (*R*)-(−)-menthyl benzoate (**2h**), $[\alpha]_D^{20}$ −90.5°($C_2H_5OH$), was treated with 2 equivalents of α-lithiomethyl *p*-tolyl sulfoxide(**1a**), derived from racemic methyl *p*-tolyl sulfoxide and lithium diethylamide($Et_2NLi$), in tetrahydrofuran (THF) at −78 °C in an atmosphere of nitrogen. After 2 h reaction, the work-up, followed by a preparative



**1a**: $R^1$ = *p*-$CH_3C_6H_4$
**b**: $R^1$ = $C_6H_5$

**2a**: $R^2$ = $CH_3$, R* = (−)-Menthyl
**b**: $R^2$ = $C_2H_5$, R* = (−)-Menthyl
**c**: $R^2$ = *n*-$C_3H_7$, R* = (−)-Menthyl
**d**: $R^2$ = *n*-$C_9H_{19}$, R* = (−)-Menthyl
**e**: $R^2$ = *i*-$C_3H_7$, R* = (−)-Menthyl
**f**: $R^2$ = *t*-$C_4H_9$, R* = (−)-Menthyl
**g**: $R^2$ = $C_6H_{11}$, R* = (−)-Menthyl
**h**: $R^2$ = $C_6H_5$, R* = (−)-Menthyl
**i**: $R^2$ = *p*-$CH_3C_6H_4$, R* = (−)-Menthyl
**j**: $R^2$ = *o*-$CH_3C_6H_4$, R* = (−)-Menthyl
**k**: $R^2$ = 3,5-(*t*-$C_4H_9$)$_2C_6H_3$, R* = (−)-Menthyl
**l**: $R^2$ = α-$C_{10}H_7$, R* = (−)-Menthyl
**m**: $R^2$ = 2,4,6-$(CH_3)_3C_6H_2$, R* = (−)-Menthyl
**n**: $R^2$ = *t*-$C_4H_9$, R* = (−)-Bornyl
**o**: $R^2$ = $C_6H_5$, R* = (−)-Bornyl
**p**: $R^2$ = *t*-$C_4H_9$, R* = (+)-1-Methylheptyl
**q**: $R^2$ = $C_6H_5$, R* = (+)-1-Methylheptyl
**r**: $R^2$ = $C_6H_5$, R* = (−)-1-Methylheptyl

**3a**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = $CH_3$
**b**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = $C_2H_5$
**c**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *n*-$C_3H_7$
**d**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *n*-$C_9H_{19}$
**e**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *i*-$C_3H_7$
**f**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *t*-$C_4H_9$
**g**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = $C_6H_{11}$
**h**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = $C_6H_5$
**i**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *p*-$CH_3C_6H_4$
**j**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = *o*-$CH_3C_6H_4$
**k**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = 3,5-(*t*-$C_4H_9$)$_2C_6H_3$
**l**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = α-$C_{10}H_7$
**m**: $R^1$ = *p*-$CH_3C_6H_4$, $R^2$ = 2,4,6-$(CH_3)_3C_6H_2$
**n**: $R^1$ = $C_6H_5$, $R^2$ = $CH_3$
**o**: $R^1$ = $C_6H_5$, $R^2$ = *i*-$C_3H_7$
**p**: $R^1$ = $C_6H_5$, $R^2$ = *t*-$C_4H_9$
**q**: $R^1$ = $C_6H_5$, $R^2$ = $C_6H_5$

Scheme 1.

TABLE 1. REACTIONS OF α-LITHIO SOLFOXIDES (**1**) WITH CHIRAL CARBOXYLATES (**2**)[a]

| Chiral carboxylates | α-Lithio sulfoxides | Base | Reaction time/h | β-Keto sulfoxides | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Yield/%[c] | $[\alpha]_D$[d] | Config. | %o.p.[e] |
| (*R*)-(−)-**2a** | **1a** | $Et_2NLi$ | 3 | **3a** | 89 | +25.0°[f] | *R* | 12.7[g] (12.0)[h] |
| (*R*)-(−)-**2b** | **1a** | $Et_2NLi$ | 2 | **3b** | 93 | +3.5° | *R* | 1.3 |
| (*R*)-(−)-**2c** | **1a** | $Et_2NLi$ | 2 | **3c** | 90 | −13.5° | *S* | 5.3 |
| (*R*)-(−)-**2d** | **1a** | $Et_2NLi$ | 2 | **3d** | 92 | −13.2° | *S* | 7.1 |
| (*R*)-(−)-**2e** | **1a** | $Et_2NLi$ | 3 | **3e** | 90 | −19.0° | *S* | 7.4 |
| (*R*)-(−)-**2f** | **1a** | $Et_2NLi$ | 5 | **3f** | 85 | −185° | *S* | 70.3 (67.5)[h] |
| (*R*)-(−)-**2f** | **1a** | b) | 5 | **3f** | 76 | −174° | *S* | 66.2 |
| (*R*)-(−)-**2g** | **1a** | $Et_2NLi$ | 2.5 | **3g** | 96 | −52.0° | *S* | 21.7 |
| (*R*)-(−)-**2h** | **1a** | $Et_2NLi$ | 2 | **3h** | 94 | +35.5° | *R* | 13.4 |
| (*R*)-(−)-**2h** | **1a** | b) | 2 | **3h** | 90 | +32.0° | *R* | 12.1 |
| (*R*)-(−)-**2i** | **1a** | $Et_2NLi$ | 2 | **3i** | 94 | +43.8° | *R* | 16.9 |
| (*R*)-(−)-**2j** | **1a** | $Et_2NLi$ | 3 | **3j** | 70 | +20.3° | *R* | 7.6 |
| (*R*)-(−)-**2k** | **1a** | $Et_2NLi$ | 3 | **3k** | 80 | +45.1° | *R* | 26.5 |
| (*R*)-(−)-**2l** | **1a** | $Et_2NLi$ | 3 | **3l** | 82 | +36.0° | *R* | 15.2 |
| (*R*)-(−)-**2m** | **1a** | $Et_2NLi$ | 1 | **3m** | 60 | +12.0° | *R* | 3.8 |
| (*R*)-(−)-**2a** | **1b** | $Et_2NLi$ | 2 | **3n** | 80 | +22.7° | *R* | 14.6[j] (13.0)[h] |
| (*R*)-(−)-**2e** | **1b** | $Et_2NLi$ | 3 | **3o** | 83 | −12.0° | (*S*)[k] | |
| (*R*)-(−)-**2f** | **1b** | $Et_2NLi$ | 5 | **3p** | 83 | −152° | (*S*)[k] | (50.0)[h] |
| (*R*)-(−)-**2h** | **1b** | $Et_2NLi$ | 2 | **3q** | 92 | +50.2° | (*R*)[k] | |
| (*R*)-(−)-**2n** | **1a** | $Et_2NLi$ | 3.5 | **3f** | 81 | −69.0° | *S* | 26.2 (27.0)[h] |
| (*R*)-(−)-**2o** | **1a** | $Et_2NLi$ | 3 | **3h** | 93 | −68.5° | *S* | 25.8 |
| (*S*)-(+)-**2p** | **1a** | $Et_2NLi$ | 2.5 | **3f** | 72 | +50.4° | *R* | 19.2 |
| (*S*)-(+)-**2q** | **1a** | $Et_2NLi$ | 2.5 | **3h** | 90 | +22.0° | *R* | 8.3 |
| (*R*)-(−)-**2r** | **1a** | $Et_2NLi$ | 2.5 | **3h** | 90 | −21.8° | *S* | 8.2 |

a) In THF at −78 °C. b) $(i\text{-}C_3H_7)_2NLi$. c) Yields are based on the starting carboxylic esters (**2**). d) Average values of 2—7 experiments (in acetone, at 18—30 °C). e) Calculated on the basis of the specific rotations for the corresponding authentic β-keto sulfoxides (see Table 2). f) Determined in methanol. g) This value was calculated using the reported specific rotation of (*R*)-(+)-α-(*p*-tolylsulfinyl)acetate, $[\alpha]_D^{20}$ +197° ($CH_3OH$) (Ref. 4b). h) Evaluated by NMR using $Eu(TFC)_3$. i) Overnight at room temperature. j) Calculated using the reported specific rotation of (*R*)-(+)-α-(phenylsulfinyl)acetate, $[\alpha]_D$ +156° (Ref. 4a). k) Assigned on the basis of the absolute configuration of methyl phenyl sulfoxide which was produced concomitantly by the reaction.

TLC(diethyl ether), afforded dextrorotatory α-(*p*-tolylsulfinyl)acetophenone (**3h**) (93% yield, $[\alpha]_D^{20}$ +35.0° (*c* 0.622, acetone), 13.2% optical purity, (*R*)-rich) and (*S*)-(−)-methyl *p*-tolyl sulfoxide (92% yield, $[\alpha]_D^{20}$ −19.5° (*c* 0.995, acetone), 13.4% optical purity). By a similar procedure, a series of reactions were conducted using thirteen (*R*)-(−)-menthyl carboxylates (**2a**—**m**), two (*R*)-(−)-bornyl carboxylates (**2n**—**o**), and three (*R*)-(−)- and (*S*)-(+)-1-methylheptyl carboxylates (**2p**—**r**). The results are summarized in Table 1. The resultant β-keto sulfoxides (**3a**—**q**), which possess a variety of $R^2$ groups, were characterized by means of NMR, IR, mass-spectrum, and elemental analyses.

In order to get a clue as to the optical purity as well as the absolute configuration of the β-keto sulfoxides obtained, we synthesized, as authentic samples, twelve dextrorotatory alkyl and aryl α-(*p*-tolylsulfinyl)methyl ketones (**3b**—**m**) by the reactions of α-lithiomethyl *p*-tolyl sulfoxide, which has been derived from optically pure (*R*)-(+)-methyl *p*-tolyl sulfoxide, with the corresponding ethyl carboxylates. The specific rotations of the authentic β-keto sulfoxides are compiled in Table 2. Since the formation of carbanions from optically active aryl methyl sulfoxides has been known to take place without any loss of stereochemical integrity,[3b,10,13] and since the reaction of the carbanions with carboxylates is sure to proceed through the complete retention of the configuration at sulfur, the dextrorotatory, β-keto sulfoxides synthesized by the above method should be in an optically pure form with a (*R*)-configuration. This assignment may also be confirmed by the following reaction. That is, the treatment of (*R*)-(+)-α-(*p*-

TABLE 2. SPECIFIC ROTATIONS OF THE AUTHENTIC β-KETO SULFOXIDES ($p\text{-}CH_3C_6H_4\text{–}SO\text{–}CH_2\text{–}CO\text{–}R^2$)

| β-Keto sulfoxides ($R^2$) | Specific rotations in acetone (*c*) |
|---|---|
| (*R*)-(+)-**3b** ($C_2H_5$) | $[\alpha]_D^{23}$ +265° (0.194) |
| (*R*)-(+)-**3c** ($n\text{-}C_3H_7$) | $[\alpha]_D^{22}$ +256° (0.266) |
| (*R*)-(+)-**3d** ($n\text{-}C_9H_{19}$) | $[\alpha]_D^{15}$ +186.5° (0.222) |
| (*R*)-(+)-**3e** ($i\text{-}C_3H_7$) | $[\alpha]_D^{22}$ +258° (0.196) |
| (*R*)-(+)-**3f** ($t\text{-}C_4H_9$) | $[\alpha]_D^{25}$ +263° (0.275) |
| (*S*)-(−)-**3f** ($t\text{-}C_4H_9$) | $[\alpha]_D^{25}$ −263° (0.300) |
| (*R*)-(+)-**3g** ($C_6H_{11}$) | $[\alpha]_D^{14}$ +240° (0.224) |
| (*R*)-(+)-**3h** ($C_6H_5$) | $[\alpha]_D^{25}$ +265.5° (0.264) |
| (*S*)-(−)-**3h** ($C_6H_5$) | $[\alpha]_D^{25}$ −265° (0.500) |
| (*R*)-(+)-**3i** ($p\text{-}CH_3C_6H_4$) | $[\alpha]_D^{25}$ +258.5° (0.280) |
| (*R*)-(+)-**3j** ($o\text{-}CH_3C_6H_4$) | $[\alpha]_D^{20}$ +268° (0.320) |
| (*R*)-(+)-**3k** ($3,5\text{-}(t\text{-}C_4H_9)_2C_6H_3$) | $[\alpha]_D^{15}$ +170° (0.446) |
| (*R*)-(+)-**3l** ($\alpha\text{-}C_{10}H_7$) | $[\alpha]_D^{15}$ +237° (0.366) |
| (*R*)-(+)-**3m** ($2,4,6\text{-}(CH_3)_3C_6H_2$) | $[\alpha]_D^{15}$ +319° (0.263) |

Table 3. Effects of temperature on the reactions of **1a** with (−)-menthyl carboxylates (**2f** and **2h**) in THF

| (−)-Menthyl carboxylates | Temp °C | β-Keto sulfoxides | $[\alpha]_D$[a] | %o.p.[b] | $\Delta\Delta G^*$ kJ mol$^{-1}$ | $-\Delta\Delta H^*$ kJ mol$^{-1}$ | $\Delta\Delta S^*$ J K$^{-1}$ mol$^{-1}$ |
|---|---|---|---|---|---|---|---|
| **2f** | −78 | **3f** | −185°±7°(3) | 70.3 | 2.84 | 3.51 | −3.4 |
| | −35 | | −157°±6°(2) | 59.7 | 2.73 | | |
| | 0 | | −134°±6°(3) | 51.0 | 2.56 | | |
| **2h** | −78 | **3h** | +35.5°±2.3°(7) | 13.4 | 0.44 | 0.58 | −0.75 |
| | −35 | | +26.4°±1.2°(2) | 9.9 | 0.39 | | |
| | 0 | | +21.6°±1.0°(3) | 8.1 | 0.37 | | |
| | 25 | | +19.5°±0.8°(2) | 7.3 | 0.36 | | |

a) Average values of 2—7 experiments. The number of experiments is shown in parentheses. b) o.p.=Optical purities which were determined by comparison with the specific rotations for the authentic β-keto sulfoxides listed in Table 2.

tolylsulfinyl)acetophenone (**3h**), $[\alpha]_D^{25}$ +265.5° (acetone), with methylmagnesium iodide in THF yielded (*S*)-(−)-methyl *p*-tolyl sulfoxide, $[\alpha]_D^{25}$ −145°(acetone) (99.3% optical purity) *via* a normal $S_N2$-type process, with a complete inversion of the configuration at sulfur.[14] In addition, the optical purities, in the cases of the authentic **3b**, **3e**, and **3f**, were confirmed with the aid of NMR using the chiral-shift reagent tris[3-(trifluoromethylhydroxymethylene)-*d*-camphorato]europium(III) [Eu(TFC)$_3$] (see Experimental). By a similar procedure, optically pure (*S*)-(−)-**3f** and (*S*)-(−)-**3h** were also prepared using α-lithiomethyl *p*-tolyl sulfoxide derived from optically pure (*S*)-(−)-methyl *p*-tolyl sulfoxide.

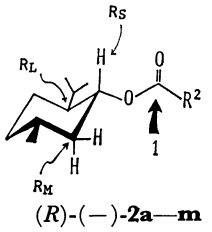
Accordingly, the optical purities and the predominant configurations of the β-keto sulfoxides listed in Table 1 were assigned mainly by comparison with the specific rotations for the corresponding authentic substances. In the cases of **3a**, **3f**, **3n**, and **3p**, their optical purities were further confirmed by NMR using Eu(TFC)$_3$.

The degree of enantioselectivity of the reaction was dependent on the reaction temperature (see Table 3). In the reactions of **1a** with **2f** and **2h**, the decrease in temperature favored the formation of the predominant enantiomers, (*S*)-(−)-**3f** and (*R*)-(+)-**3h** respectively, and the plot of $1/T$ *vs.* $\ln(R)/(S)$ (for **3h**) or $\ln(S)/(R)$ (for **3f**) gave a linear relationship with a positive slope. For both the reactions either the $\Delta\Delta H^*$ value or the $\Delta\Delta S^*$ value exhibited a negative sign.

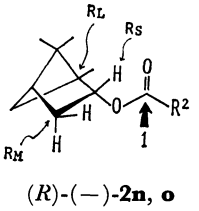
Table 1 reveals that the degree of enantioselectivity varies drastically from 1.3% to 70.3% depending on the nature of the ester moiety, $R^2$. Generally, the extent of the enantioselectivity is higher when the inducing chiral moiety is menthyl rather than bornyl and 1-methylheptyl, and the chiral carboxylates which have a bulky $R^2$ group ($R^2$=phenyl, naphthyl, 3,5-di-*t*-butylphenyl, cyclohexyl, or *t*-butyl) give a relatively high degree of enantioselectivity. The best result has been obtained from the reaction of (*R*)-(−)-menthyl pivalate (**2f**) with **1a**, affording (*S*)-(−)-**3f** of a 70.3% optical purity.

The reactions of two kinds of (*R*)-(−)-bornyl carboxylates, **2n** ($R^2$=*t*-butyl) and **2o** ($R^2$=phenyl), with **1a** both gave (*S*)-rich β-keto sulfoxides, (−)-**3f** and (−)-**3h**. From the reactions of both (*S*)-(+)-1-methylheptyl pivalate(**2p**) and (*S*)-(+)-1-methylheptyl benzoate (**2q**) with **1a**, the (*R*)-rich β-keto sulfoxides, (+)-**3f** and (+)-**3h**, were produced preferentially. However, a reversal in the configuration with the variation in the ester moiety, $R^2$, is observed in the series of reactions of (*R*)-(−)-menthyl carboxylates with **1a**. That is, the carboxylates (−)-**2a**($R^2$=methyl), (−)-**2b**($R^2$=ethyl), and (−)-**2h—m** ($R^2$=aryl) preferentially react with (*R*)-**1a** to yield an excess of (*R*)-β-keto sulfoxides, while the carboxylates (−)-**2c** ($R^2$=propyl), (−)-**2d** ($R^2$=nonyl), (−)-**2e** ($R^2$=isopropyl), (−)-**2f** ($R^2$=*t*-butyl), and (−)-**2g**($R^2$=cyclohexyl) preferentially react with (*S*)-**1a** to afford the (*S*)-β-keto sulfoxides in excess.

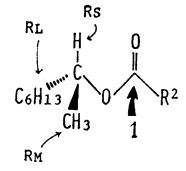
The oxygen atom of sulfoxides is known to have a donor ability towards electron acceptors.[15] Furthermore, in connection with the stereochemistry of the electrophilic substitution reactions of α-lithiosulfoxides, Marquet *et al.*[16] and Biellmann *et al.*[17] have proposed that an electrophilic assistance (a chelation) by the lithium cation on the α-lithiosulfoxides towards the electrophiles plays an important role. By considering this evidence together with a $B_{AC}$ 2-type of mechanism for the reactions of carbanions with carboxylic esters,[18] it appears that the stereochemical course of this reaction can be explained by a six-membered cyclic transition state, as in the case of the reaction of (*R*)-(+)-α-(*p*-tolylsulfinyl)acetophenone with alkyl Grignard reagents reported previously.[19] Therefore, the stereochemical feature of the reaction can be illustrated in terms of the



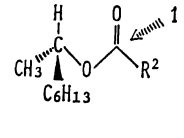

(*R*)-(−)-**2a—m**




(*R*)-(−)-**2n, o**



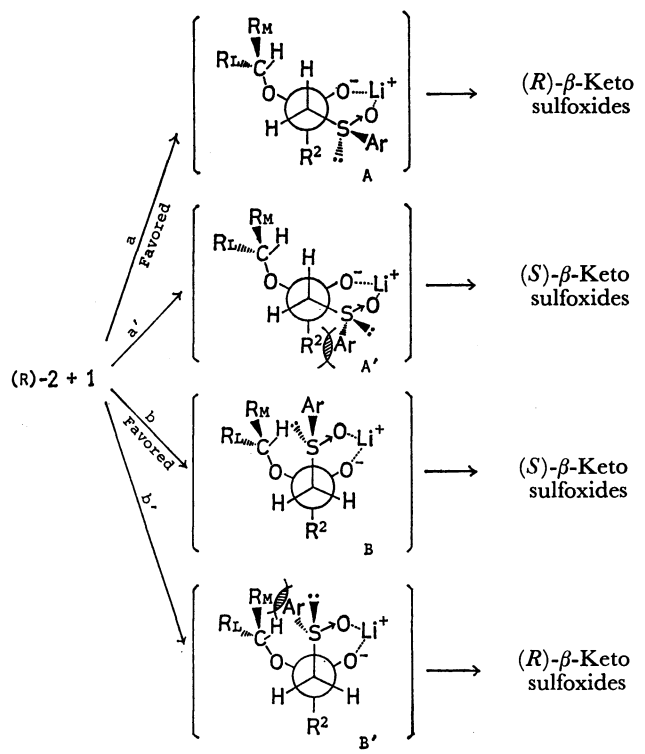

(*R*)-(−)-**2r**




(*S*)-(+)-**2p, q**

(The symbols $R_S$, $R_M$, and $R_L$ indicate small, medium, and large groups respectively.)

Scheme 2.




Scheme 3.

following schemes (Schemes 2 and 3). At first, by analogy with the empirical model predictions derived from Prelog's rule[20] and Cram's rule,[21] it can be recognized that the preferential attack of the α-lithiosulfoxides (**1**) towards the carbonyl carbon takes place from the less hindered diastereotopic face of the chiral carboxylates(**2**),[22] as indicated by the arrows (see Scheme 2). Next, the following four reaction paths, (a), (a'), (b), and (b'), involving the respective six-membered cyclic transitions, A, A', B, and B', are conceivable for the substitution reaction of (*R*)-**2** and **1** (see Scheme 3). However, the steric requirements in the transition states seem to indicate that Path (a) or (b) is the most likely possibility, while Paths (a') and (b') are unfavorable, since the significantly greater interactions of the arenesulfinyl group *vs.* the $R^2$ group or the substituents of the chiral alcohol moiety should contribute to the crowding of the transition states A' and B'. The (*R*)-β-keto sulfoxides will then be produced *via* the transition state A (Path a), while the reactions which proceed *via* the transition state B (Path b) will give the (*S*)-β-keto sulfoxides, and the direction and the degree of enantioselectivities of the reactions should depend upon the magnitudes of the mutual interactions among the arenesulfinyl group, the $R^2$ group, and the substituents of the chiral alcohol moiety (especially, the $R_M$ group acts as an effective bulk to influence the steric course of the reaction) in the A and B transition states. In the cases of the reactions of **1** with (*R*)(−)-bornyl carboxylates (**2n** and **2o**) and (*R*)-(−)-1-methylheptyl benzoate (**2r**), Path b will predominate, since the sterical interaction between the arenesulfinyl group and the $R_M$ group is considered to be smaller than that between the arenesulfinyl group and the bulky $R^2$ group. The reactions of the (*R*)-(−)-menthyl carboxylates, **2e**, **2f**, and **2g**, which have rather bulkier $R^2$ groups, will preferentially take place *via* the transition state B to yield the (*S*)-rich β-keto sulfoxides as well. On the other hand, in the cases of the reactions of the (*R*)-(−)-menthyl carboxylates, **2a** and **2b**, which have smaller $R^2$ groups, Path a will predominate, since the interaction between the arenesulfinyl group and the $R_M$ group should be larger than that between the arenesulfinyl group and the $R^2$ group in this case. Actually, most of the experimental results in Table 1 agree fairly well with these predictions. The reversal in configuration from (*R*) to (*S*) in going from **3b** to **3c** may be attributed to the fact that the differences in magnitudes of the interactions of the arenesulfinyl group *vs.* the $R^2$ group and of the arenesulfinyl group *vs.* the $R_M$ group are reversed with the change in the $R^2$ group from ethyl to propyl. On the other hand, contrary to our expections, the experimental results from the reactions of (*R*)-(−)-menthyl carboxylates (**2h**—**m**), which have aryl groups, indicate that the reactions proceed *via* the A transition state rather than B. We have now considered that, compared with the aryl groups, the $R_M$ moiety of the menthyl group involving a C-2 equatorial hydrogen and a C-1 methyl group would act more effectively as a steric bulk towards the arenesulfinyl group in this case.

Further investigations, including kinetic experiments, are now under way in an effort to obtain detailed knowledge of the stereochemistry of the reaction.

Finally, we have now found that some of the β-keto sulfoxides thus obtained, **3e**, **3f**, **3g**, **3h**, **3n**, and **3p**, increase their optical purities upon repeated recrystallizations. As is shown in Table 4, especially, the repeated recrystallizations of the partially optically pure **3e**, **3f**, **3g**, and **3p** from a mixture of diethyl ether and hexane

Table 4. Results of the repeated recrystallizations of some β-keto sulfoxides obtained[a]

| β-Keto sulfoxides | Specific rotation in acetone at 25 °C | |
|---|---|---|
| | Starting (%o.p.)[b] | After recrystallization(%o.p.)[b] |
| (−)-**3e** | −12.8° (*c* 0.530) (5.0) | −256° (*c* 0.190) (99.2) |
| (−)-**3f** | −180° (*c* 0.500) (68.4) | −262° (*c* 0.200) (99.6) |
| (−)-**3g** | −51.0° (*c* 0.680) (21.3) | −240° (*c* 0.331) (100) |
| (+)-**3h** | +32.3° (*c* 0.690)(12.2) | +55.0° (*c* 0.218) (20.7) |
| (−)-**3p** | −163°(*c* 0.460) | −266° (*c* 0.294)[c] |

a) The recrystallization was repeated three times by the use of a mixture of diethyl ether and hexane. b) o.p.=Optical purities which were determined by comparison with the specific rotations for the authentic β-keto sulfoxides listed in Table 2. c) A single enantiomer was detected by NMR using $Eu(TFC)_3$.

supplied the corresponding β-keto sulfoxides with optical purities higher than 99%. While, the β-keto sulfoxides, **3a**, **3b**, **3c**, and **3j**, decreased in their optical purities to nearly zero upon repeated recrystallizations from diethyl ether or a mixture of diethyl ether and hexane. In these cases, the crystals obtained from the mother liquid exhibited a larger specific rotation than that of the starting β-keto sulfoxides.

In summary, we suppose at present that the present reaction, in combination with the recrystallization procedure, should be satisfactorily applicable to the synthesis of optically active β-keto sulfoxides, provided that the appropriate chiral carboxylates are used.

## Experimental

*General.* The optical rotations were measured with a JASCO DIP-4 type polarimeter. The IR spectra were obtained with a JASCO IR-G type spectrometer. All the melting points are uncorrected. The NMR spectra were determined with a Hitachi-Perkin-Elmer R-20 or JEOL PS-100 spectrometer; the chemical shifts are reported in δ units, using tetramethylsilane as the internal reference. The CD spectra were determined for ethanol and cyclohexane solutions with a JASCO ORD/CD-5 spectrophotometer. The mass spectra were taken on a JEOL JMS 06 spectrometer.

*Starting Materials.* *(R)-(+)-Methyl* p-*Tolyl Sulfoxide* was prepared from (−)-menthyl (*S*)-(−)-*p*-toluenesulfinate, mp 107—107.5 °C, $[\alpha]_D^{25}$ −200°(*c* 0.520, acetone), and methylmagnesium iodide according to the method developed by Andersen;[6a] mp 74.5 °C, $[\alpha]_D^{20}$ +146°(*c* 0.460, acetone) [lit,[6b] mp 73—74.5 °C, $[\alpha]_D$ +145.5°(acetone)]. *(S)-(−)-Methyl* p-*Tolyl Sulfoxide* was prepared by the hydrolysis of the ethoxysulfonium salt of (*R*)-(+)-methyl *p*-tolyl sulfoxide according to the method of Johnson and McCants;[26] mp 74.5 °C, $[\alpha]_D^{20}$ −146° (*c* 0.325, acetone). *Racemic Methyl* p-*Tolyl Sulfoxide* and *Methyl Phenyl Sulfoxide* were prepared by the periodate oxidation of the corresponding sulfides.[27] $C_6H_5$–SO–$CH_3$; bp 98—99 °C/1 Torr (1 Torr=133.322 Pa)(lit,[28] bp 84 °C/0.25 Torr). *p*-$CH_3C_6H_4$–SO–$CH_3$; mp 43 °C (lit,[29] 42—43 °C). (−)-*Menthol* (Hoei Chemicals, $[\alpha]_D^{20}$ −50° ($C_2H_5OH$)) and (−)-*Borneol* (Aldrich, $[\alpha]_D^{20}$ −35.3° ($C_2H_5OH$)) used here are of a commercial grade. *(R)-(−)-* and *(S)-(+)-1-Methylhepty Alcohol* were prepared by the resolution of racemic 2-octyl alcohol.[30] (*R*)-(−)-1-Methylheptyl alcohol; $[\alpha]_D^{20}$ −10.1° (*c* 2.00, $C_2H_5OH$)(lit,[30] $[\alpha]_D^{17}$ −9.9° (neat)). (*S*)-(+)-*1*-Methylheptyl alcohol; $[\alpha]_D^{20}$ +10.0° (*c* 2.00, $C_2H_5OH$)(lit,[30] $[\alpha]_D^{17}$ +9.9° (neat)). *Optically Active Carboxylates* were prepared by treating optically active alcohols with the corresponding carboxylic acid chlorides in diethyl ether in the presence of pyridine. *(R)-(−)-Menthyl Corboxylates*: (−)-$C_{10}H_{19}$–O–CO–$R^2$; [$R^2$, mp or bp, Specific rotation (*c*, solvent)], $CH_3$(**2a**); 108.5—109.5 °C/15 Torr (lit, [31] 117.5—118 °C/25 Torr), $[\alpha]_D^{19}$ −85.0° (1.32, $C_2H_5OH$) (lit,[34] $[\alpha]_D$ −85.23° ($C_2H_5OH$)), $C_2H_5$ (**2b**); 136 °C/29 Torr (lit,[32] 118 °C/15 Torr), $[\alpha]_D^{20}$ −81.0° (1.45, $C_2H_5OH$)(lit,[32] $[\alpha]_D$ −76.66° ($C_2H_5OH$)), *n*-$C_3H_7$ (**2c**); 152 °C/30 Torr (lit,[33] 126 °C/12.5 Torr), $[\alpha]_D^{20}$ −76.0° (1.56, $C_2H_5OH$)(lit,[32] $[\alpha]_D$ −72.91° ($C_2H_5OH$)), $[\alpha]_D^{20}$ −72.4° (1.00, benzene) (lit,[33] $[\alpha]_D^{20}$ −70.56° (benzene)), $C_9H_{19}$ (**2d**); 145 °C/2 Torr, $[\alpha]_D^{22}$ −55.8° (2.00, $C_2H_5OH$), *i*-$C_3H_7$ (**2e**); 121 °C/13 Torr (lit,[33] 116—117 °C /12 Torr), $[\alpha]_D^{20}$ −76.8° (1.20, $C_2H_5OH$), $[\alpha]_D^{22}$ −72.0° (1.00, benzene) (lit,[33] $[\alpha]_D^{20}$ −72.05 °(benzene)), *t*-$C_4H_9$ (**2f**); 124.5 °C/13.5 Torr, $[\alpha]_D^{20}$ −76.4° (1.85, $C_2H_5OH$), $C_6H_{11}$ (**2g**); 48.3 °C (lit,[32] 48 °C), $[\alpha]_D^{17}$ −65.5° (0.531, $C_2H_5OH$) (lit,[32] $[\alpha]_D$ −59.11° ($C_2H_5OH$)), $C_6H_5$ (**2h**); 54.5 °C (lit,[32] 55 °C), $[\alpha]_D^{20}$ −90.5°(1.53, $C_2H_5OH$) (lit,[32] $[\alpha]_D^{20}$ −83.53° ($C_2H_5OH$)), *p*-$CH_3C_6H_4$ (**2i**); 140—141 °C/2 Torr (lit,[35] 196—198 °C/11 Torr), $[\alpha]_D^{22}$ −85.3° (1.26, $C_2H_5OH$) (lit,[35] $[\alpha]_D^{20}$ −89.9° (neat)), *o*-$CH_3C_6H_4$ (**2j**); 145 °C/3 Torr (lit,[35] 213—215 °C/25 Torr), $[\alpha]_D^{20}$ −81.0° (1.54, $C_2H_5OH$) (lit,[35] $[\alpha]_D^{20}$ −84.35° (neat)), 3,5-($t$-$C_4H_9$)$_2C_6H_3$ (**2k**); 167—169 °C/2 Torr, $[\alpha]_D^{20}$ −67.5° (0.550, $C_2H_5OH$), α-$C_{10}H_7$ (**2l**); 185 °C/2 Torr (lit,[32] 231—232 °C/11 Torr), $[\alpha]_D^{20}$ −84.5° (1.59, $C_2H_5OH$) (lit,[32] $[\alpha]_D$ −79.08° ($C_2H_5OH$)), Mesityl (**2m**); 156—157 °C/2 Torr, $[\alpha]_D^{20}$ −65.0° (0.735, $C_2H_5OH$). *(R)-(−)-Bornyl Carboxylates*: (−)-$C_{10}H_{17}$–O–CO–$R^2$; [$R^2$, bp, Specific rotation], *t*-$C_4H_9$(**2n**); 74.0 °C/1 Torr, $[\alpha]_D^{15}$ −39.5° (1.68, $C_2H_5OH$), $C_6H_5$ (**2o**); 129—130 °C/1 Torr, $[\alpha]_D^{15}$ −42.7° (1.69, $C_2H_5OH$). *(S)-(+)-1-Methylheptyl Carboxylates*: (+)-$C_8H_{17}$–O–CO–$R^2$; [$R^2$, bp, Specific rotation (*c*, solvent)]; *t*-$C_4H_9$(**2p**); 61.0 °C /1 Torr, $[\alpha]_D^{20}$ +11.3° (2.00, $C_2H_5OH$), $C_6H_5$(**2q**); 109 °C/1 Torr (lit,[36] 171 °C/20 Torr), $[\alpha]_D^{20}$ +40.0° (3.04, $C_2H_5OH$) (lit,[36] $[\alpha]_D^{20}$ +33.27° (neat)). *(R)-(−)-1-Methylheptyl Benzoate*; 109 °C/1 Torr, $[\alpha]_D^{20}$ −40.1° (*c* 2.18, $C_2H_5OH$).

*Reaction of α-Lithiosulfoxides (1) with Optically Active Carboxylates (2).* A typical procedure is as follows. A 50-ml, two-necked, round-bottomed flask containing a magnetic stirring bar was equipped with a rubber septum and a nitrogen-inlet tube. After flusing with dry nitrogen, 15 cm³ of tetrahydrofuran (THF) (freshly distilled over $LiAlH_4$), 3.2 cm³ of a 100 mg/cm³ solution of butyllithium in hexane, and 370 mg of diethylamine were successively injected into the flask through the septum *via* a syringe at 0 °C. The flask was then cooled to −78 °C with a dry ice–acetone bath, a solution of 5 mmol of an aryl methyl sulfoxide in 2.5 cm³ of dry THF was added, and the solution was stirred vigorously for 30 min. A solution of an optically active carboxylate (**2**) (2.5 mmol) in 2.5 cm³ of dry THF was injected *via* a syringe, drop by drop, into the solution. After being stirred for an adequate time at −78 °C (the progress of the reaction was checked from time to time by TLC), water (10 cm³) was added; the mixture was then acidified (*ca.* pH 3) with 10% hydrochloric acid and extracted with chloroform(3×30 cm³). The combined extracts were then washed with brine, dried ($Na_2SO_4$), and evaporated under a vacuum. The residue was chromatographed on silica gel using a preparative thin-layer chromatoplate. Elution with diethyl ether yielded optically active aryl methyl sulfoxide and the corresponding β-keto sulfoxide(**3**). These products, which exhibited satisfactory NMR and IR spectra, were subjected to optical rotation measurements. The optical purities and the predominant configurations of the β-keto sulfoxides listed in Table 1 were assigned mainly by direct comparison with the specific rotations for the corresponding authentic β-keto sulfoxides.

The NMR spectral non-equivalence was observed for the enantiomers of several β-keto sulfoxides in the presence of

Table 5. Chemical-shift differences induced by $Eu(TFC)_3$ for some alkyl-substituted β-keto sulfoxides

| β-Keto sulfoxides | Alkyl groups | $\Delta\Delta\delta$/Hz[a] |
|---|---|---|
| **3a** | $C\underline{H}_3$ | 3.5 |
| **3b** | $CH_2C\underline{H}_3$ | 3.8 |
| **3e** | $CH(C\underline{H}_3)_2$ | 2.7 |
| **3f** | $C(C\underline{H}_3)_3$ | 1.8(5.0)[b] |
| **3n** | $C\underline{H}_3$ | 4.0 |
| **3p** | $C(C\underline{H}_3)_3$ | (3.0)[b] |

a) $\Delta\Delta\delta=|\Delta\delta_R-\Delta\delta_S|$Hz. β-Keto sulfoxides =0.1mol/dm³ solution in $CCl_4$, $Eu(TFC)_3$=0.7 equiv. b) $Eu(TFC)_3$=1.0 equiv.

$Eu(TFC)_3$.[37] The chemical-shift differences for the resonances of alkyl substituents of β-keto sulfoxides are summarized in Table 5. The optical purities for **3a**, **3f**, **3n**, and **3p** were also evaluated from the NMR spectra by the integration of the respective signals (see Table 1).

By careful, repeated recrystallizations of the resulting **3e**, **3f**, **3g**, and **3p**, the corresponding highly optically pure β-keto sulfoxides were obtained. That is, when a 440 mg of (−)-**3f** ($[\alpha]_D^{25}$ −180° (*c* 0.500, acetone)) was recrystallized three times from a mixture of diethyl ether and hexane (1 : 3 volume ratio), highly optically pure (−)-**3f** (230 mg, $[\alpha]_D^{25}$ −262° (*c* 0.200, acetone), 99.6% optical purity) was obtained. Its physical properties were found to be identical with those of the authentic (*S*)-(−)-**3f**. Three recrystallizations of (−)-**3e** (1.06 g, $[\alpha]_D^{25}$ −12.8° (*c* 0.530, acetone)) and (−)-**3g** (800 mg, $[\alpha]_D^{25}$ −51.0° (*c* 0.680, acetone)) from a mixture of diethyl ether and hexane afforded (−)-**3e** (36 mg, $[\alpha]_D^{25}$ −256° (*c* 0.170, acetone), 99.2% optical purity) and optically pure (−)-**3g** (110 mg, $[\alpha]_D^{25}$ −240° (*c* 0.311, acetone)) respectively. Similarly, from the partially optically pure (−)-**3p** (380 mg, $[\alpha]^{25}$ −163° (*c* 0.460, acetone)), (−)-**3p** (146 mg, $[\alpha]_D^{25}$ −266° (*c* 0.294, acetone)) was obtained. Although the specific rotation for the optically pure (−)-**3p** has never been determined, one enantiomer of **3p** is detected by NMR using $Eu(TFC)_3$. The β-keto sulfoxide **3h** also increased its optical purity upon repeated recrystallizations from a mixture of diethyl ether and hexane. Three recrystallizations of (+)-**3h** (900 mg, $[\alpha]_D^{25}$ +32.3° (*c* 0.690, acetone)), which has been prepared by the reaction of **1a** with (−)-**2h**, afforded a 20.7% optically pure (+)-**3h** (320 mg, $[\alpha]_D^{25}$ +55.0° (*c* 0.218, acetone)). However, in the case of **3h**, we have not found a solvent for recrystallization effective enough to give a highly optically pure **3h**.

*Preparation of Authentic Optically Active β-Keto Sulfoxides* ($p$-$CH_3C_6H_4$–SO–$CH_2$–CO–$R^2$). The same experimental setup as has been described above was used. (*R*)-(+)-Methyl *p*-tolyl sulfoxide (1.54 g, 10 mmol) was treated with a solution of $Et_2NLi$ (prepared from 6.4 $cm^3$ of a 100 mg/$cm^3$ solution of butyllithium in hexane and 740 mg of diethylamine) in 20 $cm^3$ of dry THF at 0 °C under nitrogen. After 30 min, a solution of an ethyl carboxylate (5 mmol) in 2.5 $cm^3$ of dry THF was added, and the mixture was stirred for 1—5 h. To the solution was then added water (10 $cm^3$); the mixture was acidified (*ca.* pH 3) with 10% hydrochloric acid and extracted with chloroform (3×30 $cm^3$). The combined extracts were washed with brine, dried ($Na_2SO_4$), and evaporated under a vacuum. The residue was chromatographed using a preparative thin-layer chromatoplate on silica gel; subsequent elution with diethyl ether gave the corresponding dextrorotatory β-keto sulfoxide. The recrystallization of the product from diethyl ether or ethyl acetate afforded the analytically pure β-keto sulfoxide. The β-keto sulfoxides obtained by the above procedure exhibited the following preperties.

(*R*)-(+)-**3b**; mp 68—68.5 °C. $[\alpha]_D^{23}$ +265° (*c* 0.194, acetone). NMR ($CDCl_3$): δ 1.01 (t, 3H, *J*=7 Hz, $-CH_2C\underline{H}_3$) 2.41 (s, 3H, $-CH_3$), 2.50 (q, *J*=7 Hz, 2H, $-C\underline{H}_2CH_3$), 3.76, 3.82 (dd, 2H, *J*=14 Hz, $-CH_2-$), 7.36, 7.53 (dd, 4H, aromatic). IR (KBr): 2900, 1704, 1365, 1270, 1105, 1090, 1053, 1029, 1017, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 220 nm (log ε 3.97), 245 nm (log ε 3.72). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 220 nm (−10.8), 249 nm (+7.55), in cyclohexane 223 nm (−11.2), 260 nm (+5.78). MS: 210 ($M^+$).

Found: C, 62.65; H, 6.74%. Calcd for $C_{11}H_{14}SO_2$: C, 62.83; H, 6.71%.

(*R*)-(+)-**3c**; mp 60 °C. $[\alpha]_D^{22}$ +256° (*c* 0.266, acetone). NMR ($CDCl_3$): δ 0.87 (t, *J*=7 Hz, 3H, $-CH_2CH_2C\underline{H}_3$), 1.56 (six, *J*=7 Hz, 2H, $-CH_2C\underline{H}_2CH_3$), 2.43 (s, 3H, $-CH_3$), 2.48 (t, *J*=7 Hz, 2H, $-C\underline{H}_2CH_2CH_3$), 3.82, 3.86 (dd, *J*=14 Hz, 2H, $-CH_2-$), 7.43, 7.62 (dd, 4H, aromatic). IR (KBr): 2900, 1700, 1088, 1033, 1026, 1013, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 218 nm (log ε 4.00), 243.5 nm (log ε 3.83). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 220 nm (−9.98), 248 nm (+7.18), in cyclohexane 223 nm (−12.16), 260 nm (+6.45). MS: 224 ($M^+$).

Found: C, 64.46; H, 7.24%. Calcd for $C_{12}H_{16}SO_2$: C, 64.25; H, 7.19%.

(*R*)-(+)-**3d**; mp 75 °C. $[\alpha]_D^{15}$ +186.5° (*c* 0.222, acetone). NMR ($CDCl_3$): δ 0.60—1.70 (b, 17H, $-CH_2(C\underline{H}_2)_7C\underline{H}_3$), 2.44 (s, 3H, $-CH_3$), 2.46 (t, *J*=7 Hz, 2H, $-C\underline{H}_2(CH_2)_7CH_3$), 3.80, 3.86 (dd, *J*=14 Hz, 2H, $-CH_2-$), 7.39, 7.61 (dd, 4H, aromatic). IR (KBr): 2880, 1700, 1470, 1090, 1045, 1025, 1010, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 217.5 nm (log ε 4.04), 242.5 nm (log ε 3.73). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 220 nm (−11.34), 250 nm (+7.85), in cyclohexane 223 nm (−15.12), 258 nm (+8.33). MS: 308 ($M^+$).

Found: C, 69.89; H, 9.15%. Calcd for $C_{18}H_{28}SO_2$: C, 70.09; H, 9.15%.

(*R*)-(+)-**3e**; mp 68 °C. $[\alpha]_D^{22}$ +258° (*c* 0.196, acetone). NMR ($CDCl_3$): δ 1.01 (d, *J*=7 Hz, 3H, $-CH\langle^{C\underline{H}_3}_{CH_3}$), 1.09 (d, *J*=7 Hz, 3H, $-CH\langle^{CH_3}_{C\underline{H}_3}$), 2.43 (s, 3H, $-CH_3$), 2.60 (septet, 1H, $-C\underline{H}(CH_3)_2$), 3.85, 3.97 (dd, *J*=14 Hz, $-CH_2-$), 7.36, 7.58 (dd, 4H, aromatic). IR (KBr): 2900, 1696, 1380, 1088, 1055, 1035, 800 $cm^{-1}$. UV ($C_2H_5OH$) max: 220 nm (log ε 3.94), 245 nm (log ε 3.71). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 222 nm (−9.88), 249 nm (+6.87), in cyclohexane 224 nm (−12.15), 260 nm (+6.54). MS: 224 ($M^+$).

Found: C, 64.53; H, 7.33%. Calcd for $C_{12}H_{16}SO_2$: C, 64.25; H, 7.19%.

(*R*)-(+)-**3f**; mp 112.5—113 °C. $[\alpha]_D^{25}$ +263° (*c* 0.275, acetone). NMR ($CDCl_3$): δ 1.07 (s, 9H, $-C(CH_3)_3$), 2.40 (s, 3H, $-CH_3$), 3.83, 4.15 (dd, *J*=15 Hz, 2H, $-CH_2-$), 7.34, 7.59 (dd, 4H, aromatic). IR (KBr): 2900, 1697, 1360, 1041, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 217 nm (log ε 3.99), 244 nm (log ε 3.73). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 220 nm (−12.16), 247.5 nm (+8.31), in cyclohexane 223 nm (−14.22), 261 nm (+7.34). MS: 238 ($M^+$).

Found: C, 65.26; H, 7.63%. Calcd for $C_{13}H_{18}SO_2$: C, 65.51; H, 7.61%.

(*R*)-(+)-**3g**; mp 113 °C. $[\alpha]_D^{14}$ +240° (*c* 0.224, acetone). NMR ($CDCl_3$): δ 1.0—2.3 (b, 11H, cyclohexyl), 2.44 (s, 3H, $-CH_3$), 3.85, 4.00 (dd, *J*=14 Hz, 2H, $-CH_2-$), 7.42, 7.63 (dd, 4H, aromatic). IR (KBr): 2900, 1697, 1450, 1370, 1087, 1043, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 220 nm (log ε 3.90), 245 nm (log ε 3.68). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 221 nm (−10.85), 250 nm (+7.72), in cyclohexane 223 nm (−12.83), 262 nm (+6.60). MS: 264 ($M^+$).

Found: C, 68.30; H, 7.70%. Calcd for $C_{15}H_{20}SO_2$: C, 68.15; H, 7.63%.

(*R*)-(+)-**3h**; mp 89 °C. $[\alpha]_D^{25}$ +265.5° (*c* 0.264, acetone). NMR ($CDCl_3$): δ 2.40 (s, 3H, $-CH_3$), 4.26, 4.51 (dd, *J*=14 Hz, 2H, $-CH_2-$), 7.18—7.96 (m, 9H, aromatic). IR (KBr): 2950, 1676, 1593, 1447, 1257, 1085, 1062, 1041, 820, 725 $cm^{-1}$. UV ($C_2H_5OH$) max: 248.5 nm (log ε 4.08). CD ($[\theta]\times10^{-4}$): in $C_2H_5OH$ 217 nm (−9.35), 248 nm (+6.01). MS: 258 ($M^+$).

Found: C, 69.47; H, 5.33%. Calcd for $C_{15}H_{14}SO_2$: C, 69.74; H, 5.46%.

(*R*)-(+)-**3i**; mp 122—122.5 °C. $[\alpha]_D^{25}$ +258.5° (*c* 0.280, acetone). NMR ($CDCl_3$): δ 2.39 (s, 6H, 2×$-CH_3$), 4.27, 4.53 (dd, *J*=14 Hz, 2H, $-CH_2-$), 7.17—7.90 (m, 8H, aromatic). IR (KBr): 2920, 1674, 1606, 1300, 1190, 1041, 810 $cm^{-1}$.

Found: C, 70.21; H, 5.82%. Calcd for $C_{16}H_{16}SO_2$: C, 70.56; H, 5.90%.

(*R*)-(+)-**3j**; mp 77—77.5 °C. $[\alpha]_D^{20}$ +268°(*c* 0.320, acetone). NMR ($CDCl_3$): δ 2.38 (s, 3H, *o*-$CH_3$), 2.45 (s, 3H, *p*-$CH_3$), 4.29, 4.50 (dd, *J*=14 Hz, 2H, -$CH_2$-), 7.13—7.78 (m, 8H, aromatic). IR (KBr): 2950, 1666, 1300, 1253, 1033, 750 $cm^{-1}$.

Found: C, 70.38; H, 5.83%. Calcd for $C_{16}H_{16}SO_2$: C, 70.56; H, 5.90%.

(*R*)-(+)-**3k**; mp 100.5—101 °C. $[\alpha]_D^{15}$ +170°(*c* 0.446, acetone). NMR ($CDCl_3$): δ 1.32 (s, 18H, 2×-$C(CH_3)_3$), 2.35 (s, 3H, -$CH_3$), 4.36, 4.56 (dd, *J*=14 Hz, 2H, -$CH_2$-), 7.17—7.65 (m, 7H, aromatic). IR (KBr): 2950, 1676, 1058, 1045, 810 $cm^{-1}$. UV ($C_2H_5OH$) max: 260 nm (log ε 4.17).

Found: C, 74.59; H, 8.27%. Calcd for $C_{23}H_{30}SO_2$: C, 74.55; H, 8.16%.

(*R*)-(+)-**3l**; mp 110—110.5 °C. $[\alpha]_D^{15}$ +237°(*c* 0.366, acetone). NMR ($CDCl_3$): δ 2.32 (s, 3H, -$CH_3$), 4.34, 4.58 (dd, *J*=14 Hz, 2H, -$CH_2$-), 7.08—8.72 (m, 11H, aromatic). IR (KBr): 2900, 1672, 1290, 1080, 1040, 940, 815, 800 $cm^{-1}$. UV ($C_2H_5OH$) max: 242 nm (log ε 4.30), 320 nm (log ε 3.88).

Found: C, 73.77; H, 5.35%. Calcd for $C_{19}H_{16}SO_2$: C, 74.00; H, 5.23%.

(*R*)-(+)-**3m**; mp 89.5 °C. $[\alpha]_D^{15}$ +319° (*c* 0.263, acetone). NMR ($CDCl_3$): δ 2.14 (s, 6H, 2×*o*-$CH_3$), 2.23 (s, 3H, mesityl *p*-$CH_3$), 2.38 (s, 3H, *p*-$CH_3$), 3.98, 4.22 (dd, *J*=15 Hz, 2H, -$CH_2$-), 6.77 (s, 2H, aromatic), 7.29, 7.55 (dd, *J*=8 Hz, 4H, aromatic). IR (KBr): 2900, 1700, 1608, 1087, 1041, 985, 797 $cm^{-1}$. UV ($C_2H_5OH$) max: 252 nm (log ε 3.92).

Found: C, 71.97; H, 6.75%. Calcd for $C_{18}H_{20}SO_2$: C, 71.97; H, 6.71%.

*Preparation of (S)-(−)-α-(p-Tolylsulfinyl)acetophenone (**3h**).* Using a procedure similar to that described for (*R*)-(+)-**3h**, the treatment of α-lithiomethyl *p*-tolyl sulfoxide derived from (*S*)-(−)-methyl *p*-tolyl sulfoxide (771 mg, 5 mmol) and LDA (5 mmol)) with 375 mg (2.5 mmol) of ethyl benzoate in 20 $cm^3$ of dry THF at 0 °C afforded levorotatory α-(*p*-tolylsulfinyl)acetophenone (**3h**) (565 mg, 87.5% yield) after the usual work-up and chromatography on silica gel, with elution with diethyl ether. Subsequent recrystallization from diethyl ether gave analytically pure (S)-(−)-**3h**; mp 89 °C. $[\alpha]_D^{20}$ −265° (c 0.500, acetone). NMR ($CDCl_3$): δ 2.40 (s, 3H, -$CH_3$), 4.26, 4.51 (dd, *J*=14 Hz, 2H, -$CH_2$-), 7.18—7.95 (m, 9H, aromatic).

*Reaction of (R)-(+)-**3h** with Methylmagnesium Iodide.* An ethereal solution of methylmagnesium iodide (7 mmol; 1 mmol/$cm^3$ solution) was added, drop by drop, to a solution of 517 mg (2 mmol) of (*R*)-(+)-**3h**, $[\alpha]_D^{25}$ +265.5° (*c* 0.264, acetone), in 50 $cm^3$ of dry THF; the mixture was then stirred for 3 h at −5—0 °C under nitrogen, followed by the careful addition of 10 $cm^3$ of a saturated solution of ammonium chloride. After the separation of the ethereal layer, the aqueous layer was extracted with chloroform (3×30 $cm^3$). The combined organic layers were dried($Na_2SO_4$) and evaporated under a vacuum. The subsequent preparative TLC of the residue on silica gel, eluting with diethyl ether, afforded (*S*)-(−)-methyl *p*-tolyl sulfoxide (62 mg, 20% yield, $[\alpha]_D^{25}$ −145° (*c* 0.300, acetone), together with the recovery of 370 mg of (*R*)-(+)-**3h**.

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