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Enantioselective synthesis of (+)-5,6-*exo*-(isopropylidendioxy)-2-phenylsulfonyl-7-oxabicyclo[2.2.1]hept-2-ene

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Abstract

The title compound (+)-**1** has been synthesized in four steps from furan and dienophile (+)-**3** via an asymmetric Diels–Alder reaction.

1. Introduction

In several previous reports, we have described the use of 7-oxanorbornenic sulfone **1** as a starting material for the synthesis of several interesting compounds such as the aminocyclitol fragment of the antitumoral alkaloid pancratistatin,[1] the antibiotic rancynamycin III,[2] the naturally occurring inositol derivative (+)-pinitol[3] and a modified A ring of vitamin D_3.[4] Synthesis of enantiomerically pure **1** has been achieved by resolution of its alcohol precursor camphanoyl ester derivative **2** (Fig. 1). The absolute configuration of compound **1** has been established by chemical correlation[3] and X-ray analysis of the camphanoyl derivative **2b**.[4] Nevertheless, tedious separations of diastereomeric mixtures are necessary in both cases.

Thus, we envisaged the use of a dienophilic sulfone attached to a chiral auxiliary in order to achieve an enantioselective Diels–Alder reaction using furan as the 4π component.[5] It should be pointed out that

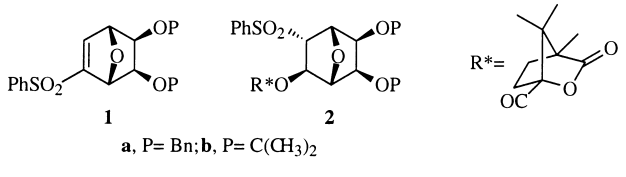

Figure 1.

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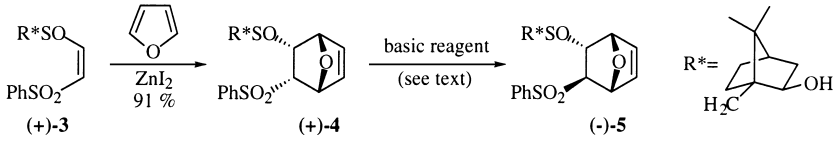
enantioselective Diels–Alder reactions of furan and chiral dienophilic sulfones have not been, to the best of our knowledge, previously described.

For this purpose, we selected the sulfinyl-activated sulfone **3**,[6] previously described as a diastereomeric mixture by De Lucchi et al.[7] Chromatographic (SiO_2, Hex:AcOEt 50:1) separation of the diastereomeric mixture of **3** gave pure (+)-**3**.[8]

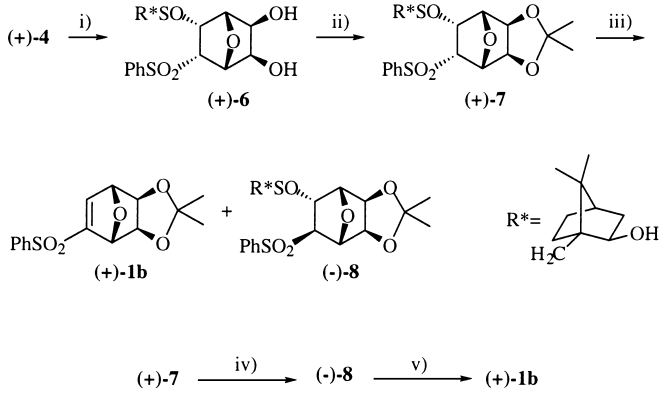
2. Results and discussion

Reaction of (+)-**3** with furan as solvent in the presence of ZnI_2 as catalyst afforded adduct (+)-**4** (d.e.=99%) in 91% isolated yield (Scheme 1). All attempts to eliminate the chiral auxiliary using the conditions described by De Lucchi et al.[7] in the case of the related cyclopentadiene adduct were unsuccesful. For instance, using DBU in CH_2Cl_2, variable amounts (37–50%) of epimeric *trans*-sulfone (−)-**5** were obtained. The same compound (−)-**5** was obtained with *t*-BuOK/THF (60%). Finally, pyrolytic elimination (toluene, reflux) performed on (−)-**5** afforded an unidentified aromatic compound in 73% isolated yield.



Scheme 1.

Due to the difficulty in removing the chiral auxiliary at this stage, we decided to transform (+)-**4** into protected *exo*-diol (+)-**7** using standard conditions (Scheme 2).[9] Reaction of (+)-**7** with KOH in CH_3CN gave sulfone (+)-**1b**[10] in 63% isolated yield together with 33% of epimeric sulfoxide (−)-**8**. Compound (−)-**8** can also be obtained from (+)-**7** by reaction with DBU in CH_2Cl_2 in 90% isolated yield. Pyrolytic elimination (xylene, reflux) performed on (−)-**8** also gave (+)-**1b** in 40% isolated yield.



Scheme 2. Reagents and conditions: (i) OsO_4, 4-methylmorpholine *N*-oxide, $NaHCO_3$, 90%; (ii) 2,2-dimethoxypropane, *p*-TsOH, 100%; (iii) KOH, CH_3CN, 63%; (iv) DBU, CH_2Cl_2, 90%; (v) xylene, reflux, 40%; 46% of compound (−)-**8** was recovered

In summary, an efficient method for the synthesis of sulfone (+)-**1b**, a useful chiral building block for the synthesis of a variety of natural products, has been described using as the key step the enantioselective Diels–Alder reaction of dienophile (+)-**3** and furan.

3. Experimental

3.1. General methods

All air-sensitive reactions were carried out under a positive pressure of dry argon using freshly distilled solvents under anhydrous conditions. Reagents and solvents were handled by using standard syringe techniques. Tetrahydrofuran (THF) was distilled from sodium and benzophenone; dichloromethane, acetonitrile and xylene from CaH_2. Flash chromatography was performed using Merck 230–400 mesh silica gel. Analytical TLC was carried out on 0.20 mm Merck precoated silica gel plates (60F-254). Melting points were determined on a Büchi 512 apparatus and are uncorrected. Infrared spectra were recorded on a Perkin–Elmer 781 spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker AM-300 or Varian VXR-300S instruments using $CDCl_3$ as solvent. The following abbreviations are used to describe peak patterns when appropriate: br, broad; s, singlet; d, doublet; t, triplet; m, multiplet. Optical rotations were measured on a Perkin–Elmer 241 polarimeter. Elemental analyses were performed at the Universidad Complutense de Madrid.

3.2. *(+)-(1*R,*4*S,*5*S,*6*R*)-6*-endo-*[1-(*S*)-Isobornyl-10-sulfinyl]-5*-endo-*phenylsulfonyl-7-oxabicyclo-[2.2.1]hept-2-ene, (+)-**4***

To a solution of (+)-**3** (244 mg, 0.67 mmol) in furan (13.4 ml), ZnI_2 (85 mg, 0.27 mmol) was added. The mixture was stirred protected from light for 7 days. Solvent was removed in vacuo and the crude product was purified by column chromatography (CH_2Cl_2:AcOEt, 10:1) to afford adduct (+)-**4** (291 mg, 91%) as a colorless oil. $[\alpha]_D$ +22.2 (*c* 0.01, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.90 (s, 3H, Me), 1.15 (s, 3H, Me), 1.24–1.28 (m, 1H, CH), 1.42–1.49 (m, 1H, CH_2), 1.72–1.89 (m, 5H, CH_2), 3.30 (d, 1H, *J*=12.7 Hz, CH_2SO), 3.67 (d, 1H, *J*=12.7 Hz, CH_2SO), 3.91 (d, 1H, *J*=2.9 Hz, C*H*OH), 3.99 (br s, 1H, OH), 4.03 (dd, 1H, *J*=3.4, 8.8 Hz, H-6), 4.19 (dd, 1H, *J*=4.4, 8.8 Hz, H-5), 4.64 (dd, 1H, *J*=1.0, 3.4 Hz, H-1), 5.40 (dd, 1H, *J*=1.0, 3.4 Hz, H-4), 6.75 (dd, 1H, *J*=1.5, 5.9 Hz, H-2), 6.99 (dd, 1H, *J*=1.5, 5.9 Hz, H-3), 7.66 (t, 2H, *J*=6.8 Hz, SO_2Ph), 7.76 (t, 1H, *J*=7.3 Hz, SO_2Ph), 7.92 (d, 2H, *J*=7.3 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 20.0, 20.5, 27.1, 30.3, 38.5, 45.1, 48.2, 51.6, 55.5, 66.5, 67.0, 79.9, 82.5, 97.3, 127.8, 129.9, 134.6, 134.9, 136.7, 140.7. IR ($CHCl_3$): ν 3676, 3018, 1425, 1163 cm^{-1}. Anal. calcd for $C_{22}H_{28}O_5S_2$: C, 60.55; H, 6.42. Found: C, 60.49; H, 6.38.

3.3. *(−)-(1*R,*4*S,*5*R,*6*R*)-6*-endo-*[1-(*S*)-Isobornyl-10-sulfinyl]-5*-exo-*phenylsulfonyl-7-oxabicyclo-[2.2.1]hept-2-ene, (−)-**5***

To a solution of (+)-**4** (30 mg, 0.07 mmol) in THF (0.7 ml) cooled to −78°C, *t*-BuOK (18 mg, 0.14 mmol) was added. The mixture was stirred for 30 min. The reaction was quenched with distilled water and extracted with AcOEt. Organic layers were dried over $MgSO_4$ and solvent was evaporated under reduced pressure. After purification by column chromatography (hexane:AcOEt, 5:1), (−)-**5** was obtained as a colorless oil (18 mg, 60%). $[\alpha]_D$ −69.3 (*c* 0.01, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.90 (s, 3H, Me), 1.17 (s, 3H, Me), 1.26 (s, 1H, CH), 1.41–1.54 (m, 2H, CH_2), 1.70–1.83 (m, 4H, CH_2), 2.97 (d, 1H, *J*=4.1 Hz, H-5), 3.13 (d, 1H, *J*=13.4 Hz, CH_2SO), 3.41 (d, 1H, *J*=13.4 Hz, CH_2SO), 3.72 (d, 1H, *J*=3.2 Hz, OH), 3.84 (t, 1H, *J*=4.1 Hz, H-6), 3.96 (ddd, 1H, *J*=3.4, 4.4, 7.8 Hz, C*H*OH), 5.28 (dd, 1H, *J*=1.2, 4.4 Hz, H-1), 5.31 (dd, 1H, *J*=1.0, 1.9 Hz, H-4), 6.52 (dd, 1H, *J*=1.7, 5.9 Hz, H-2), 6.77 (dd, 1H, *J*=1.7, 5.9 Hz, H-3), 7.65 (t, 2H, *J*=7.6 Hz, SO_2Ph), 7.73 (t, 1H, *J*=7.1 Hz, SO_2Ph), 7.95 (d, 2H, *J*=6.8 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 19.9, 20.4, 27.1, 30.9, 38.6, 44.9, 48.3, 51.4, 53.5, 62.4, 65.5,

76.9, 80.2, 81.3, 129.2, 129.6, 134.7, 135.5, 136.7, 137.1. IR ($CHCl_3$): ν 3394, 2926, 1308, 1134 cm^{-1}. Anal. calcd for $C_{22}H_{28}O_5S_2$: C, 60.55; H, 6.42. Found: C, 60.61; H, 6.50.

*3.4. (+)-(1*R,*2*S,*3*R,*4*S,*5*S,*6*R)*-6*-endo-*[1-(*S)*-Isobornyl-10-sulfinyl]-5*-endo-*phenylsulfonyl-7-oxabicyclo[2.2.1]heptane-2,3-diol, (+)-**6***

A solution of (+)-**4** (282 mg, 0.65 mmol), 4-methylmorpholine *N*-oxide (114 mg, 0.95 mmol) and OsO_4 (2.5% *t*-BuOH) (0.06 ml, 4.4×10^{-3} mmol) in THF (1 ml) was added dropwise to a solution of $NaHCO_3$ (55 mg, 0.65 mmol) in *t*-BuOH:H_2O 4:1 (5.2 ml of *t*-BuOH, 1.3 ml of H_2O). The reaction mixture was stirred at room temperature for 16 h and then excess 40% aqueous $NaHSO_3$ solution was added. Stirring was continued for 30–45 min, the reaction mixture was diluted with a large volume of AcOEt and extracted. The organic layer was dried over $MgSO_4$, evaporated in vacuo and purified by column chromatography (hexane:AcOEt, 1:2) to afford (+)-**6** (274 mg, 90%) as a colorless oil. $[\alpha]_D$ +30.0 (*c* 2.6, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.91 (s, 3H, Me), 1.13 (s, 3H, Me), 1.49–1.55 (m, 1H, CH), 1.74–1.88 (m, 5H, CH_2), 2.12 (br s, 1H, OH), 3.33 (d, 1H, *J*=12.7 Hz, CH_2SO), 3.76 (d, 2H, *J*=12.7 Hz, CH_2SO, OH), 3.87 (dd, 2H, *J*=4.9, 10.7 Hz, H-6, C*H*OH), 3.92 (d, 1H, *J*=4.9 Hz, H-1), 3.97 (dd, 1H, *J*=5.4, 10.7 Hz, H-5), 4.03 (br s, 1H, OH), 4.73 (br s, 1H, OH), 4.76 (d, 1H, *J*=4.9 Hz, H-4), 4.83 (d, 1H, *J*=5.6 Hz, H-2), 5.01 (t, 1H, *J*=5.6 Hz, H-3), 7.66 (t, 2H, *J*=7.8 Hz, SO_2Ph), 7.76 (t, 1H, *J*=7.3 Hz, SO_2Ph), 7.93 (d, 2H, *J*=7.6 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 14.1, 19.9, 20.4, 27.0, 30.3, 38.6, 45.0, 48.3, 51.6, 55.9, 61.2, 64.9, 69.6, 70.5, 84.1, 86.0, 127.7, 130.0, 134.8, 138.5. IR ($CHCl_3$): ν 3676, 3404, 1364, 1151 cm^{-1}. Anal. calcd for $C_{22}H_{30}O_7S_2$: C, 56.17; H, 6.38. Found: C, 56.22; H, 6.27.

*3.5. (+)-(1*R,*2*S,*3*R,*4*S,*5*S,*6*R)*-6*-endo-*[1-(*S)*-Isobornyl-10-sulfinyl]-2,3*-exo-*(isopropylidendioxy)-5*-endo-*phenylsulfonyl-7-oxabicyclo[2.2.1]heptane, (+)-**7***

To a solution of diol (+)-**6** (213 mg, 0.45 mmol) in acetone (4.5 ml), *p*-TsOH (catalytic amounts) and 2,2-dimethoxypropane (0.22 ml, 1.81 mmol) were added. After 1 h of stirring, a saturated aqueous solution of $NaHCO_3$ was added. The mixture was extracted with AcOEt, the organic layer was dried over $MgSO_4$, filtered and solvent was eliminated in vacuo. The crude product was purified by column chromatography on silica gel (hexane:AcOEt, 1:1) to produce (+)-**7** (229 mg, 100%) as a colorless oil. $[\alpha]_D$ +20.3 (*c* 0.01, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.90 (s, 3H, Me), 1.15 (s, 3H, Me), 1.25 (s, 1H, CH), 1.35 (s, 3H, Me), 1.42 (s, 3H, Me), 1.74–1.84 (m, 6H, CH_2), 3.31 (d, 1H, *J*=12.7 Hz, CH_2SO), 3.79 (d, 1H, *J*=12.7 Hz, CH_2SO), 3.84 (br s, 1H, C*H*OH), 3.88 (dd, 1H, *J*=4.6, 10.7 Hz, H-6), 3.94 (d, 1H, *J*=5.1 Hz, H-1), 3.98 (d, 1H, *J*=3.9 Hz, OH), 4.02–4.06 (m, 1H, H-5), 4.82 (d, 1H, *J*=5.1 Hz, H-4), 5.20 (d, 1H, *J*=5.6 Hz, H-2 or H-3), 5.35 (d, 1H, *J*=5.4 Hz, H-2 or H-3), 7.67 (t, 2H, *J*=7.1 Hz, SO_2Ph), 7.76 (t, 1H, *J*=7.3 Hz, SO_2Ph), 7.93 (d, 2H, *J*=7.1 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 8.5, 19.9, 20.0, 20.5, 25.0, 25.5, 27.1, 30.4, 38.6, 45.1, 48.3, 51.7, 56.7, 60.8, 64.8, 77.1, 79.1, 81.1, 83.4, 111.5, 127.7, 130.1, 135.0, 138.7. IR ($CHCl_3$): ν 3350, 1425, 1024 cm^{-1}. Anal. calcd for $C_{25}H_{34}O_7S_2$: C, 58.82; H, 6.67. Found: C, 58.75; H, 6.72.

*3.6. (−)-(1*R,*2*S,*3*R,*4*S,*5*R,*6*R)*-6*-endo-*[1-(*S)*-Isobornyl-10-sulfinyl]-2,3*-exo-*(isopropylidendioxy)-5*-exo-*phenylsulfonyl-7-oxabicyclo[2.2.1]heptane, (−)-**8***

To a solution of (+)-**7** (17 mg, 0.03 mmol) in CH_2Cl_2 (0.33 ml), DBU (0.01 ml, 0.07 mmol) was added. The reaction mixture was stirred at room temperature for 30 min, then quenched with 0.5N aqueous HCl solution and extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$ and solvent was evaporated

under reduced pressure to afford (−)-**8** (15 mg, 90%) as a colorless oil. $[\alpha]_D$ −78.2 (*c* 0.03, $CHCl_3$). ^1H NMR ($CDCl_3$, 300 MHz): δ 0.89 (s, 3H, Me), 0.97 (s, 1H, CH), 1.15 (s, 3H, Me), 1.26 (s, 3H, Me), 1.43 (s, 3H, Me), 1.60 (s, 1H, CH_2), 1.74–1.86 (m, 5H, CH_2), 2.90 (d, 1H, *J*=13.2 Hz, CH_2SO), 3.26 (d, 1H, *J*=6.1 Hz, H-6), 3.46 (d, 1H, *J*=12.9 Hz, CH_2SO), 3.52 (d, 1H, *J*=6.1 Hz, H-5), 3.56 (d, 1H, *J*=3.9 Hz, OH), 3.97–4.09 (m, 1H, C*H*OH), 4.23 (d, 1H, *J*=5.6 Hz, H-2 or H-3), 4.73 (s, 1H, H-4), 4.85 (d, 1H, *J*=4.9 Hz, H-1), 5.12 (d, 1H, *J*=5.6 Hz, H-2 or H-3), 7.64 (t, 2H, *J*=7.3 Hz, SO_2Ph), 7.76 (t, 1H, *J*=7.6 Hz, SO_2Ph), 7.94 (d, 2H, *J*=7.3 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 19.9, 20.4, 25.2, 25.6, 27.1, 30.9, 38.6, 44.9, 48.4, 51.5, 58.6, 63.2, 63.7, 76.9, 78.9, 81.0, 81.1, 81.5, 112.6, 129.0, 129.8, 134.8, 136.7. IR ($CHCl_3$): ν 3352, 1425, 1022 cm^{-1}. Anal. calcd for $C_{25}H_{34}O_7S_2$: C, 58.82; H, 6.67. Found: C, 58.90; H, 6.61.

*3.7. (+)-(1*S*,4*S*,5*S*,6*R*)-5,6-*exo*-(Isopropylidendioxy)-2-phenylsulfonyl-7-oxabicyclo[2.2.1]hept-2-ene, (+)-**1b***

3.7.1. Procedure A

To a solution of (+)-**7** (50 mg, 0.1 mmol) in CH_3CN (1 ml), KOH (37 mg, 0.6 mmol) was added. The mixture was stirred at 40°C for 7 h. The reaction was quenched with distilled water and extracted with AcOEt. The organic layer was dried over $MgSO_4$ and solvent was evaporated in vacuo. The crude product was purified by column chromatography (hexane:AcOEt, 5:1) to afford (+)-**1b** (19 mg, 63%) as a white solid and (−)-**8** (16 mg, 33%) as a colorless oil.

3.7.2. Procedure B

A solution of (−)-**8** (41 mg, 0.08 mmol) in xylene (0.16 ml) was heated at reflux for 3 h to afford, after purification by column chromatography (hexane:AcOEt, 5:1), (+)-**1b** (10 mg, 40%) as a white solid. 46% (19 mg) of (−)-**8** was recovered. $[\alpha]_D$ +32.0 (*c* 0.01, $CHCl_3$). Mp: 112–114°C. ^1H NMR ($CDCl_3$, 300 MHz): δ 1.30 (s, 3H, Me), 1.45 (s, 3H, Me), 4.44 (d, 1H, *J*=5.1 Hz, H-5), 4.55 (d, 1H, *J*=5.1 Hz, H-6), 4.77 (d, 1H, *J*=0.6 Hz, H-1), 4.94 (dd, 1H, *J*=0.6, 2.0 Hz, H-4), 7.05 (d, 1H, *J*=2.0 Hz, H-3), 7.58 (t, 2H, *J*=7.0 Hz, SO_2Ph), 7.66 (t, 1H, *J*=7.5 Hz, SO_2Ph), 7.90 (d, 2H, *J*=7.5 Hz, SO_2Ph). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 25.6, 31.5, 79.2, 79.5, 81.2, 83.1, 116.5, 127.9, 129.6, 134.3, 138.4, 143.3, 150.4. IR (KBr): ν 3050, 1520, 1420 cm^{-1}. Anal. calcd for $C_{15}H_{16}O_5S$: C, 58.44; H, 5.20. Found: C, 58.40; H, 5.13.

Acknowledgements

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References

1. Aceña, J. L.; Arjona, O.; Iradier, F.; Plumet, J. *Tetrahedron Lett*. **1996**, *37*, 105–106.
2. Arjona, O.; Borrallo, C.; Iradier, F.; Medel, R.; Plumet, J. *Tetrahedron Lett*. **1998**, *39*, 1977–1980.
3. Aceña, J. L.; Arjona, O.; Plumet, J. *Tetrahedron: Asymmetry* **1996**, *7*, 3535–3544.
4. Arjona, O.; Iradier, F.; Martínez-Alcázar, M. P.; Cano, F. H.; Fonseca, I.; Plumet, J. *Tetrahedron Lett*. **1998**, *39*, 6741–6744.
5. For a general review on recent findings of cycloadditions in synthesis, see: (a) Dell, C. P. *J. Chem. Soc., Perkin Trans. 1* **1998**, 3873–3905. (See pages 3884–3885 concerning the asymmetric Diels–Alder reactions.) For a review on synthetic applications of furan Diels–Alder chemistry, see: (b) Kappe, C. O.; Murphree, S. S.; Padwa, A. *Tetrahedron* **1997**, *53*,

14179–14233. For reviews on the use of 7-oxanorbonenes in organic synthesis, see: (c) Viera, E.; Vogel, P. *Helv. Chim. Acta* **1983**, *66*, 1865–1871. (d) Reymond, J. L.; Vogel, P. *Tetrahedron: Asymmetry* **1990**, *1*, 729–736. (e) Vogel, P.; Fattori, D.; Gasparini, F.; Le Drian, C. *Synlett* **1990**, 173–185. (f) Corey, E. J.; Loh, J. L. *Tetrahedron Lett*. **1993**, *34*, 3979–3982. (g) Sevin, F.; Vogel, P. *J. Org. Chem*. **1994**, *59*, 5920–5926. (h) Woo, S.; Keay, B. A. *Synthesis* **1996**, 669–686. (i) Liu, P.; Lautens, M. *Topics in Current Chemistry* **1997**, *190*, 1–84.

6. For the use of optically pure ethylenic sulphoxides as 2π partners in furan Diels–Alder reactions, see, for instance: (a) Takayama, H.; Iyobe, A.; Koizumi, T. *J. Chem. Soc., Chem. Commun*. **1986**, 771–772. (b) Takayama, H.; Hayashi, K.; Takeuchi, Y.; Koizumi, T. *Heterocycles* **1986**, *24*, 2137–2140. (c) Takahashi, T.; Kotsubo, H.; Iyobe, A.; Namiki, T.; Koizumi, T. *J. Chem. Soc., Perkin Trans. 1* **1990**, 3065–3072. (d) Ronan, B.; Kagan, H. B. *Tetrahedron: Asymmetry* **1991**, *2*, 75–90. (e) Aggarwal, V. K.; Drabowicz, J.; Grainger, R. S.; Gültekin, Z.; Lightowler, M.; Spargo, P. L. *J. Org. Chem*. **1995**, *60*, 4962–4963. (f) Yamakoshi, Y. N.; Ge, W. Y.; Sugita, J.; Okayama, K. *Heterocycles* **1996**, *42*, 129–133. For other asymmetric Diels–Alder reactions using furan as the 4π component, see: (g) Fraile, J. M.; García, J. I.; Gracia, D.; Mayoral, J. A.; Pires, E. *J. Org. Chem*. **1996**, *61*, 9479–9482. (h) Trost, B. M.; Hachiya, I. *J. Am. Chem. Soc*. **1998**, *120*, 1104–1105.
7. De Lucchi, O.; Marchiero, C.; Valle, G.; Modena, G. *J. Chem. Soc., Chem. Commun*. **1985**, 878–880. In this paper, the authors describe the reaction between a diastereomeric mixture of **3** and cyclopentadiene.
8. The two epimeric sulphoxides were obtained in a 90:10 mixture in 95% yield. (+)-**3** ($[\alpha]_D$ +211.1, *c* 0.4, $CHCl_3$) was isolated from the mixture in 75% yield as previously described. The absolute configuration of (+)-**3** remains unknown.
9. Wagner, J.; Viera, E.; Vogel, P. *Helv. Chim. Acta* **1988**, *71*, 624–630.
10. Enantiomeric sulfone (−)-**1b** shows $[\alpha]_D$ −39.1 (*c* 0.8, $CHCl_3$). See Ref. 4.