Synthesis and stereoselective addition reactions of 2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloalk-2-enones

Donald Craig,*[a] Neil J. Geach,[b] Fatema E. Sardharwala,[a] Andrew J. P. White,[a] and David J. Williams[a]

[a] *Department of Chemistry,Imperial College of Science, Technology and Medicine, London SW7 2AY, U.K*
[b] *Rhône–Poulenc Agriculture Ltd, Fyfield Road, Ongar, Essex CM5 0HW, U.K.*
E-mail: d.craig@ic.ac.uk

Dedicated with respect and affection to Professor Charles W. Rees FRS on the occasion of his seventy-fifth birthday

(received 06 Jun 02; accepted 02 Aug 02; published on the web 10 Aug 02)

Abstract

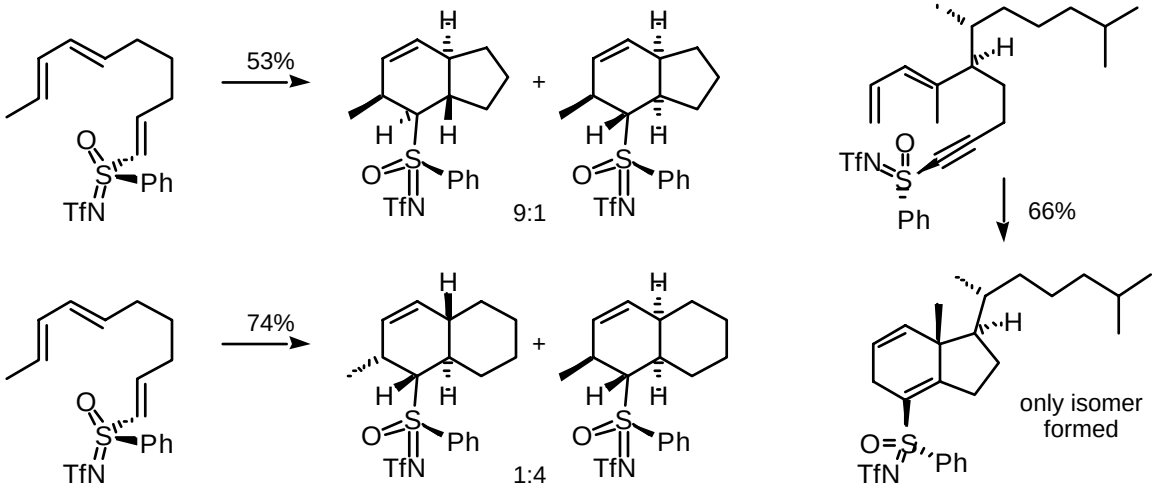
(±)-2-(*S*-Phenyl-*N*-tosylsulfoximinoyl)cyclohex-2-enone and the homologue 2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cyclohept-2-enone (as both the racemate and the R_S-isomer) have been synthesised in two steps from respectively racemic 2-(*S*-phenyl-*N*-tosylsulfoximinoyl)methane and δ-valerolactone, and 2-(*S*-phenyl-*N*-tosylsulfoximinoyl)methane (racemate and S_S-isomer) and ε-caprolactone. Highly stereoselective organocuprate addition, epoxidation and cyclopropanation reactions of these unsaturated ketones are described.

Keywords: Sulfoximine, stereoselective, conjugate addition, epoxyketone, cyclopropanation

Introduction

Asymmetric synthesis enabled by sulfoximines continues to attract substantial research effort.[1] Our own research in the area of sulfoximine chemistry was initiated over ten years ago when we began to investigate asymmetric intramolecular Diels–Alder (AIMDA) reactions of trienes and dienynes substituted on the dienophile with various sulfoximine residues. The reactivity of these systems could be fine-tuned by varying the sulfonyl residue on the sulfoximine nitrogen atom; the most reactive AIMDA substrates underwent cycloadditions which were more rapid than those of the analogues possessing arylsulfones as the dienophile-activating groups, and some of these transformations showed enhanced stereoselectivity.[2] Most recently we showed that highly substituted diastereomeric dienynes possessing alkynylsulfoximine dienophiles and containing an additional stereocentre in the chain linking diene and dienophile showed matched and

mismatched cycloaddition behaviour resulting from cooperative or competing directing effects of the sulfur and carbon stereocentres.[3] This chemistry was applied to the synthesis of the CD-ring fragment of vitamin D_3, and the sulfoximine-containing substrates showed improved cycloaddition selectivity in comparison with the reactions of a sulfone-containing analogue.[4] An overview of this synthetic methodology is provided in Scheme 1.



Scheme 1. AIMDA Reactions of Unsaturated Sulfoximines.

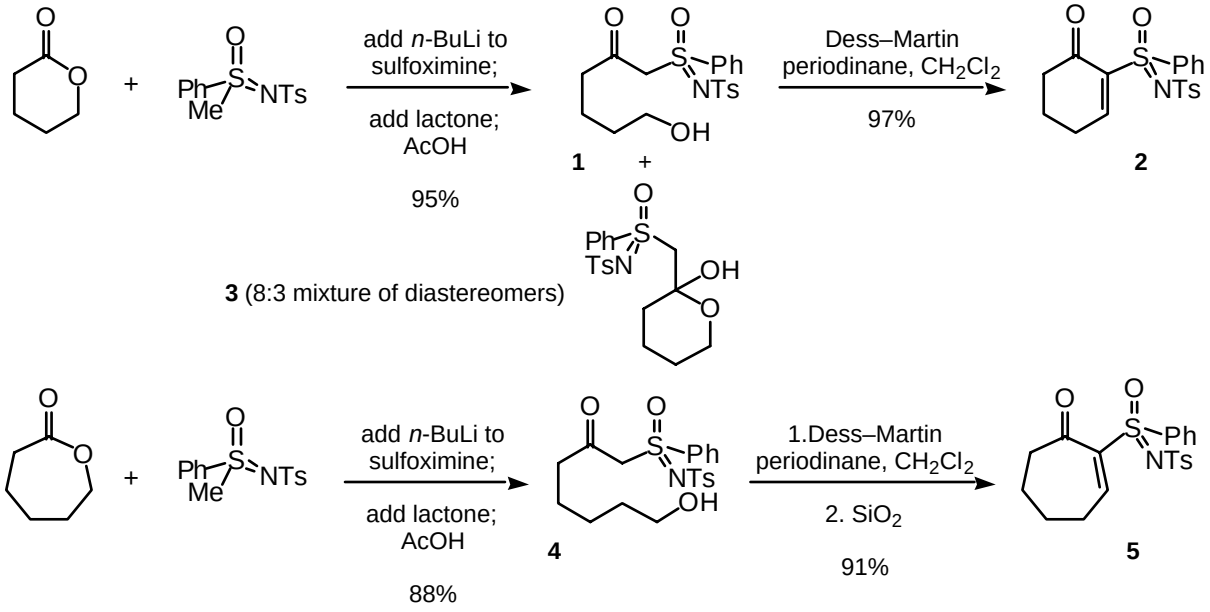
We became interested in exploring further the utility of the sulfoximine residue in addition reactions. It occurred to us that enhanced reactivity might be attainable by positioning an additional electron-withdrawing group such as a carbonyl function on the sulfoximine-bearing carbon atom. Given the substantial precedent in sulfoxide chemistry[5] we elected to look at addition reactions of 2-(*S*-aryl-*N*-arylsulfonylsulfoximinoyl)cycloalk-2-enones; this paper presents the results of this investigation.[6]

Results and Discussion

Synthesis of 2-(*S*-aryl-*N*-arylsulfonylsulfoximinoyl)cycloalk-2-enones

The 2-[*S*-aryl-*N*-(arylsulfonyl)sulfoximinoyl]cycloalk-2-enones required for this study were accessed straightforwardly *via* an intramolecular aldol condensation route. Thus, (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cyclohexenone **2** was made by first treating δ-valerolactone with the lithio-anion of (±)-(*S*-phenyl-*N*-tosylsulfoximinoyl)methane;[7] low-temperature proton quench provided the adduct as a 1:3:8 mixture of the acylic hydroxyketone **1** and two diastereomeric ketols **3** in excellent yield after chromatographic purification. Treatment of this mixture with Dess–Martin periodinane gave the desired enone **2** in virtually quantitative yield, without the need for chromatography. Compound **2** was found to undergo rapid decomposition in the

presence of silica gel, and slowly decomposed on standing at ambient temperature to give an unidentified mixture; it was stable over several months when stored under an inert atmosphere at -4°C. The higher homologue 2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cyclohept-2-enone **5** was similarly synthesised as the racemate and the R_S-enantiomer, starting from ε-caprolactone and respectively (±)-(*S*-phenyl-*N*-tosylsulfoximinoyl)methane and the optically pure S_S-sulfoximine. Key differences in the synthesis of the higher homologue were that (i) the initial lithiosulfoximine addition reaction gave as expected only the acyclic hydroxyketone **4**, and (ii) Dess–Martin periodinane-mediated oxidation of **4** gave the corresponding aldehyde as the crude product, from which enone **5** was formed during careful silica gel chromatography. Attempts to make the five-membered analogue of **2** and **5** met with failure. Although treatment of γ-butyrolactone with the lithio-anion of racemic (*S*-phenyl-*N*-tosylsulfoximinoyl)methane gave in moderate yield a mixture of the expected ketol lower homologue of **3** and the corresponding enol ether dehydration product, this mixture resisted all efforts to convert it into the cyclopentenone derivative. The syntheses of **2** and **5** are shown in Scheme 2.



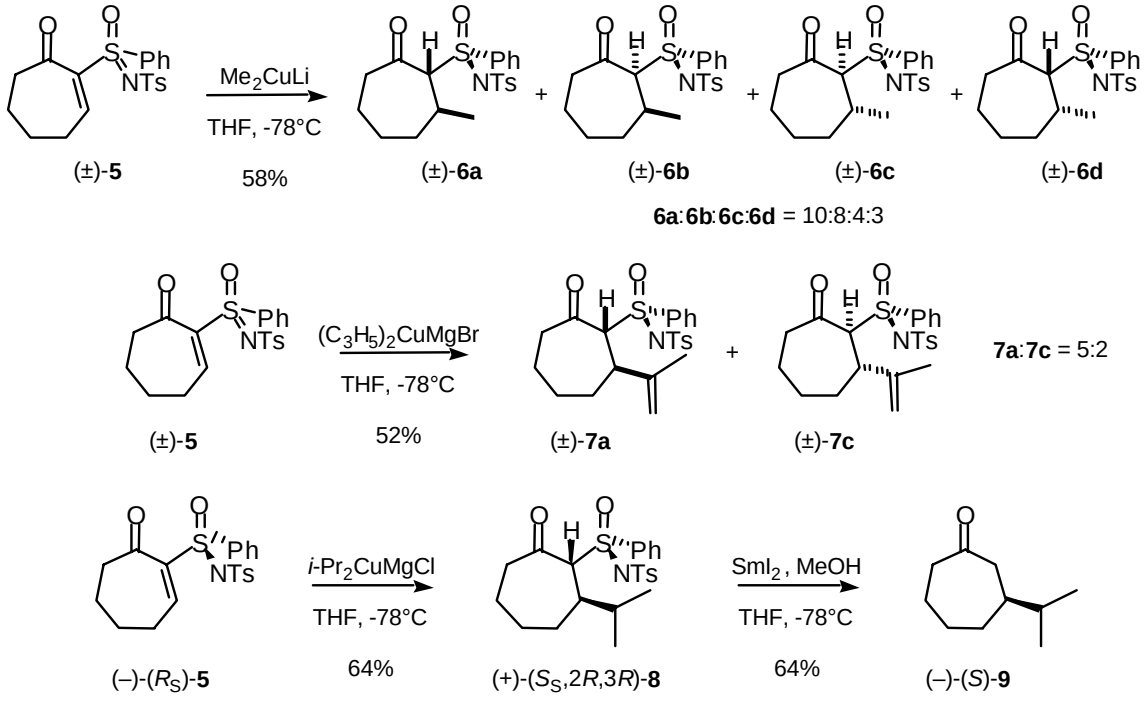
Scheme 2. Syntheses of **2** and **5**.

Cuprate addition reactions of 2-(*S*-aryl-*N*-arylsulfonylsulfoximinoyl)cycloalk-2-enones

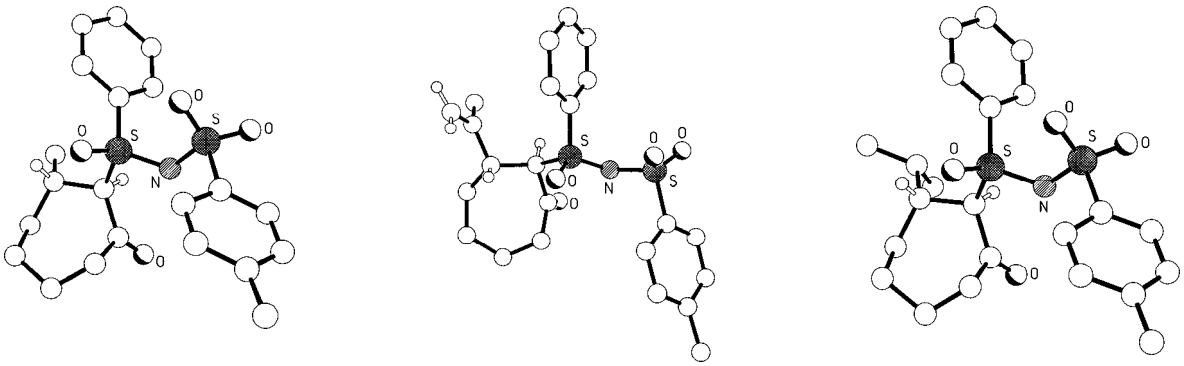
Initial studies focused on the addition of organocuprates to **2** and **5**. Exposure of the lower homologue **2** to lithium dimethylcuprate[8] gave in 71% isolated yield a 27:6:4:3 mixture of methyl addition products, the ratios being measured by ^{1}H nmr analysis of the crude mixture. Difficulties in separating this mixture precluded further study. A similar reaction carried out on the racemic cycloheptenone substrate **5** was likewise unselective, with four components **6a-d** being formed in a 10:8:4:3 ratio. The major component **6a** crystallised as a single enantiomer, and the structure was assigned by X-ray crystallographic analysis. ^{1}H Nmr spectroscopic analysis

of **6a** showed a H2–H3 coupling constant of 8 Hz consistent with the 2,3-*anti*-relationship, and the same H2–H3 coupling constant of 8 Hz allowed assignment of the other possible 2,3-*anti*-structure to **6c**. Later studies (see below) enabled the unequivocal structural assignment of the major 2,3-*syn* compound **6b**, and therefore that of the minor isomer **6d**, both of which showed 0 Hz H2–H3 coupling constants. Thus, Me_2CuLi treatment of **5** exhibited 72:28 facial selectivity for methyl addition to the enone C–C double bond; both pairs of products were formed as *ca*. 56:44 2,3-*anti*:2,3-*syn* mixtures.

Next, reactions of racemic cycloheptenone **5** with *n*-Bu_2CuLi were carried out, which gave similar product ratios. However, use of the sterically more demanding reagent bromomagnesium bis(isopropenyl)cuprate gave only two products, in a 5:2 ratio. Both of these were assigned 2,3-*anti*-stereochemistry on the basis of the H2–H3 nmr coupling constants, and the major compound was assigned structure **7a** following X-ray crystallographic analysis, implying that the minor product had structure **7b**; **7a** has the same C_β–S relative stereochemistry as the major product **6a** from the Me_2CuLi addition reaction of **5**. The exclusive formation of *anti*-2,3-disubstituted cycloheptanones **7a** and **7c** may be attributed to the greater steric bulk of the isopropenyl moiety, which destabilises the 2,3-*syn* isomer. Finally, treatment of (±)-**5** or (R_S)-**5** with chloromagnesium diisopropylcuprate gave a *single* product **8**, whose structure was again assigned by X-ray crystallography. This product was further elaborated by SmI_2-mediated[9] reductive desulfoximinoylation, which yielded (–)-(*S*)-3-isopropylcycloheptanone **9** in good yield. The cuprate addition reactions of **5** are summarised in Scheme 3. The X-ray structures of (±)-**6a**, (±)-**7a** and (+)-**8** are shown in Figure 1.



Scheme 3. Cuprate addition reactions of **5**.



(S_S,2*R*,3*S*)-**6a** (±)-**7a** (+)-(S_S,2*R*,3*R*)-**8**

Figure 1. X-ray structures of (S_S,2*R*,3*S*)-**6a**, (±)-**7a** and (+)-(S_S,2*R*,3*R*)-**8**.

Discussion of stereochemistry

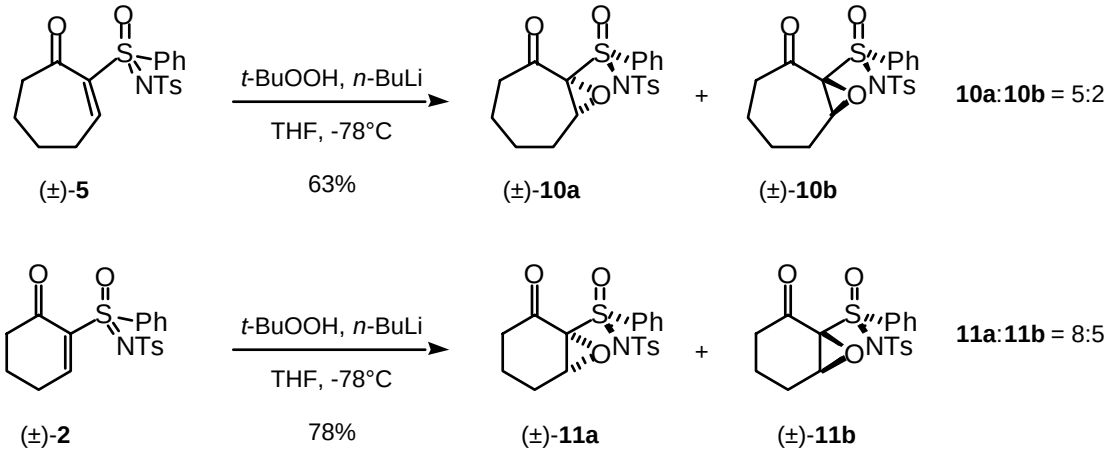
All of the cuprate addition reactions of the seven-membered substrate had shown the same sense of 1,3- asymmetric induction from sulfoximine sulfur to the β- carbon of the enone. Although the observed selectivities were modest for the addition of straight-chain alkyl groups and a branched alkenyl group, a more hindered reagent possessing a branched alkyl group had enabled the realisation of *complete* selectivity. We rationalise this tendency in terms of delivery of the carbon nucleophile to the enone having a preferred conformation in which the C=O and S=O bonds are oriented in a mutually *anti* sense so as to minimise dipole–dipole repulsion; addition takes place *syn* with respect to the sulfoximine phenyl group, *anti* with respect to the bulkier NTs group.

Nucleophilic epoxidation reactions of 2-**(*S*-aryl-*N*-arylsulfonylsulfoximinoyl)cycloalk-2-enones**

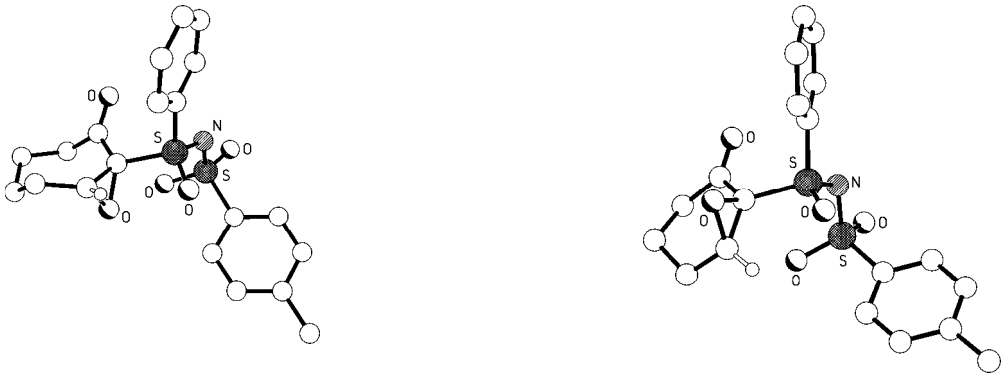
Our attention was turned next to nucleophilic epoxidation reactions of enones **2** and **5**. Following extensive literature precedent, mostly from the work of Jackson and co-workers,[10] we elected to use the *t*-BuOOLi reagent system. Treatment of **5** with *t*-BuOOLi generated from *n*-BuLi and *t*-BuOOH gave a 5:2 mixture of epoxyketone diastereomers. X-Ray crystallographic analysis of the major isomer allowed its assignment as **10a**, which indicated that initial, nucleophilic attack by *t*-$BuOO^-$ had taken place with the sense of asymmetric induction opposite to that found in the organocuprate additions. Interestingly, when the epoxidations were carried out in aqueous media ($NaOH–H_2O_2$), or under anhydrous conditions with potassium as the counter-cation the transformations were modestly selective in the opposite sense.

We explain this varying behaviour in terms of the involvement of a chelating or non-chelating enone substrate. In the reactions containing lithium the enone coordinates to the metal cation in a bidentate fashion such that the ketone C=O and sulfoximine S=O bonds are aligned; nucleophilic attack takes place *syn* to the sulfoximine phenyl moiety. In aqueous media, or in the presence of the weakly oxaphilic potassium counter-cation such chelation is no longer significant, and the dipole–dipole repulsion effect observed in the organocuprate reactions dominates. Reaction of the lower homologous enone **2** with *t*-BuOOLi gave a 8:5 mixture of

epoxides, with the same stereochemical preference observed in the cycloheptenone reaction with BuOOLi, as evidenced by X-ray analysis of the minor product **11b**. The epoxidation reactions of **2** and **5** are summarised in Scheme 4; the X-ray structures of **10a** and **11b** are depicted in Figure 2.



Scheme 4. Nucleophilic Epoxidation Reactions of **2** and **5**.



(±)-**10a** (±)-**11b**

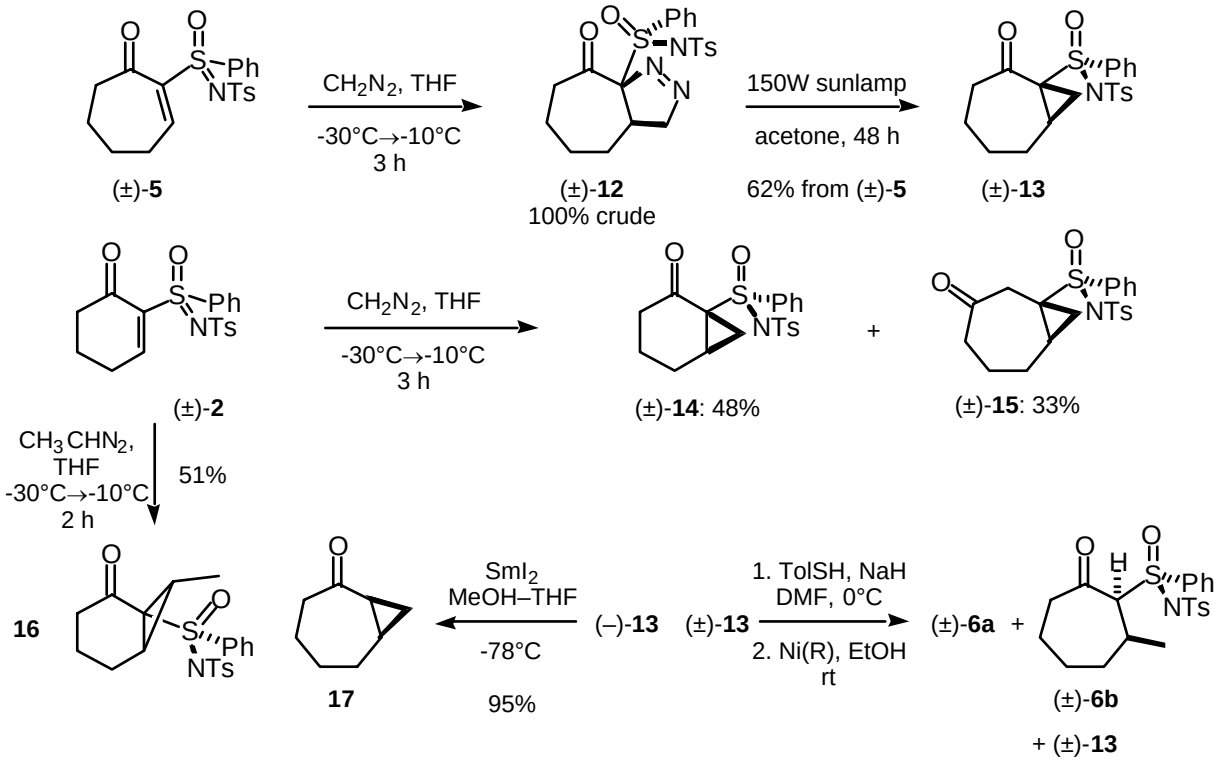
Figure 2. X-ray structures of (±)-**10a** and (±)-**11b**.

Cyclopropanation reactions of 2-(*S*-aryl-*N*-arylsulfonylsulfoximinoyl)cycloalk-2-enones

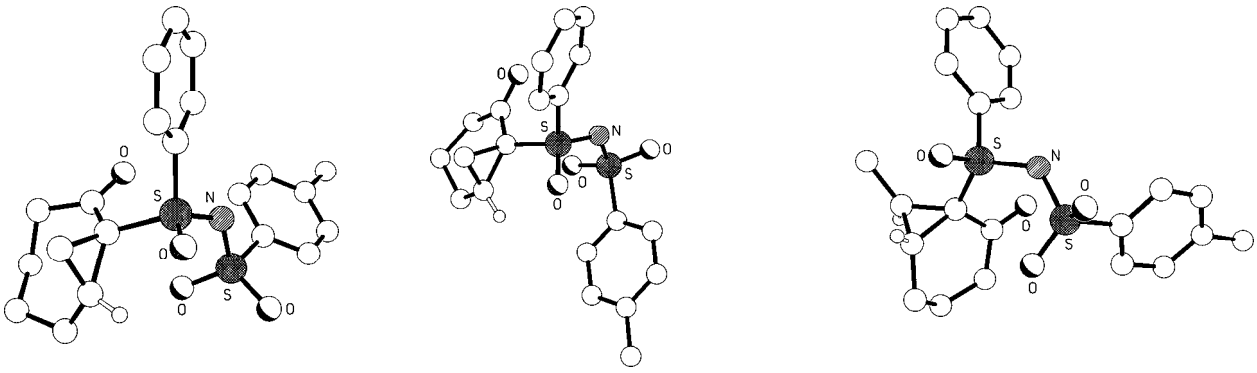
The final phase of our study sought to establish a protocol for the cyclopropanation of enones **2** and **5**. Reaction of the seven-membered analogue **5** with a large excess of diazomethane gave an unstable pyrazoline[11] as a *single* isomer, as evidenced by ^{1}H nmr analysis (500 MHz) of the crude product. The appearance in the spectrum of a pair of highly second-order double doublets assigned to the ex-CH_2N_2 methylene group strongly suggested that pyrazoline formation had occurred by C–C bond formation at the β- rather than at the α-position of the enone. Irradiation of crude, freshly prepared pyrazoline in dilute acetone solution during 48 h using a 150W lamp with external cooling gave a single bicyclic cyclopropane, shown by X-ray crystallographic analysis to have the structure **13**. The precursor pyrazoline was assigned structure **12** on the basis

of its ^{1}H nmr characteristics and the X-ray structure of **13**. The sense of asymmetric induction was in accord with that observed in the cuprate addition reactions and in the non-chelation-controlled nucleophilic epoxidation reactions. An enantiomerically pure sample of (–)-**13** was subjected to reductive desulfoximinoylation using SmI_2 in MeOH–THF, providing (–)-**17** in 95% yield. Alternatively, ring-opening of racemic **13** using the sodium salt of thiocresol gave a 4:1 mixture of two α-sulfoximine-substituted cycloheptanones, which were further desulfurised with retention of the sulfoximine moiety to give two of the four compounds formed in the lithium dimethylcuprate-mediated reaction of **5**, clearly establishing the identity of **6b** (Scheme 3).

Diazomethane treatment of the lower homologous enone **2** was strikingly different: no pyrazoline was isolated, with the cyclopropane being formed directly in 48% yield on exposure of **2** to diazomethane in THF at –20°C. The methylene insertion product **15** was isolated also, in 33% yield. X-Ray crystallographic analysis confirmed the now expected structure **14** for the simple cyclopropanation product. Finally, reaction of lower homologue **2** with diazoethane[12] gave directly a single product **16** in 51% yield; the *exo*-nature of the methyl substituent on the cyclopropane moiety was shown by X-ray crystallographic analysis. The cyclopropanation reactions of **2** and **5** are summarised in Scheme 5; the X-ray structures of **13**, **14** and **16** are depicted in Figure 3.[13]



Scheme 5. Cyclopropanation Reactions of **2** and **5**.



(±)-**13** (±)-**14** (±)-**16**

Figure 3. X-ray structures of (±)-**13**, (±)-**14** and (±)-**16**.

Experimental Section

General Procedures. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ on either Jeol GX-270Q, Bruker WM-250, Bruker AM-500, Bruker DRX-400, Bruker DRX-300 spectrometers, using residual isotopic solvent ($CHCl_3$, δ_H = 7.26 ppm or $CDCl_3$, δ_C = 77.0 ppm) as an internal reference. Multiplets in some ^{1}H NMR spectra were assigned with the aid of a recently published practical guide.[93] Infrared spectra were recorded as a thin film on either KBr or NaCl plates with Mattson 5000 FTIR or Perkin–Elmer 983G spectrophotometers. Mass spectra were recorded using VG Trio, VG Quattro, VG 707E or VG Autospec Q instruments. Accurate masses were determined using the VG Autospec Q instrument at Imperial College. Elemental combustion analyses were performed in the Imperial College microanalytical laboratory. Melting points were determined using a Mettler FP62 Automatic Melting Point machine, a Büchi Melting Point Unit B-545 or a Stewart Scientific SPM1 melting point apparatus. Optical rotations were measured using a Perkin–Elmer Polarimeter 241. Flash column chromatography refers to chromatography on BDH (230-400 mesh) silica gel or Merck Kieselgel 60 (230-400 mesh) under pressure using hand bellows. Filtration through a short pad of silica gel refers to filtration through BDH (230-400 mesh) silica gel under vacuum suction. HPLC separations were carried out on analytical and semi-preparative scales using Dynamax Macro Si columns. Analytical thin layer chromatography was performed using pre-coated glass-backed plates (Merck Kieselgel 60 F_{254}) and visualised with ultraviolet light and/or iodine, acidic ammonium molybdate (IV), 2,4-dinitrophenyhydrazine, *p*-anisaldehyde or potassium permanganate solutions as appropriate. Standard solvents were distilled under dried nitrogen: Et_2O and THF from sodium-benzophenone ketyl, CH_2Cl_2 from phosphorus pentoxide, MeCN from calcium hydride and toluene from sodium. Petrol refers to petroleum ether bp 40-60^{o} C which was distilled prior to use; EtOAc was also distilled before use. Freshly distilled refers to bulb-to-bulb distillation using a Kugelrohr apparatus or standard fractional distillation either under nitrogen or under vacuum as appropriate. Diazomethane was generated from Diazald® and distilled using a kit constructed

from glass tubing with flame-smoothed joints. Diazoethane was generated from 2-ethylamino-2-methyl-*N*-nitroso-4-pentanone and distilled using an Aldrich Mini Diazald® Apparatus. Other solvents and reagents were obtained from commercial sources and purified where necessary according to standard procedures.[14]

(±)-7-Hydroxy-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-heptanone (4). To a stirred solution of (±)-*S*-methyl-*S*-phenyl-*N*-tosylsulfoximine (5.00 g, 16.2 mmol, 1.0 equiv) in dry THF (162 ml) at -78 ˚C under nitrogen was added dropwise *n*-BuLi (6.8 ml of a 2.37 M solution in hexanes, 16.2 mmol, 1.0 equiv). The resulting pale yellow solution was stirred at this temperature for 10 min then freshly distilled ε-caprolactone (1.97 ml, 2.03 g, 17.8 mmol, 1.1 equiv) was added dropwise and the resulting mixture stirred at -78˚C for 5 min. Tlc examination indicated new material and some starting material remaining and after a further 15 min tlc indicated no change. The mixture was quenched by the dropwise addition of AcOH (16 ml of a 1.0 M solution in THF, 16 mmol, 1.0 equiv) and allowed to warm to rt. The mixture was diluted with saturated aqueous NH_4Cl (300 ml) and extracted with CH_2Cl_2 (3 x 170 ml). The combined organic extracts were washed with water (2 x 300 ml) then dried ($MgSO_4$) and the solvents removed by evaporation under reduced pressure to give a colourless semi-solid. Flash column chromatography (90 % EtOAc–petrol) gave *(±)-7-hydroxy-1-(S-phenyl*-N-*tosylsulfoximinoyl)-2-heptanone* **4** (6.06 g, 88%) as a colourless solid; R_f 0.55, EtOAc; mp 90˚C; υ_{max} (film) 3551, 3441, 3425, 2933, 2865, 1723, 1448, 1314, 1304, 1298, 1243, 1151, 1101, 1066, 1020, 1018, 742, 683, 668 cm^{-1}; δ_H (500 MHz) 7.95 (2H, d with extra fine structure, J 7.5 Hz, ortho on Ph), 7.86 (2H, d, J 8.5 Hz, ortho on Ts), 7.70 (1H, t with extra fine structure, J 7.5 Hz, para on Ph), 7.58 (2H, t with extra fine structure, J 8.0 Hz, meta on Ph), 7.27 (2H, d, J 8.0 Hz, meta on Ts), 4.83 (1H, d, J 14.0 Hz, H-1a), 4.57 (1H, d, J 14.0 Hz, H-1b), 3.62 (2H, t, J 6.5 Hz, H-7), 2.70 (2H, m, H-3), 2.40 (3H, s, PhCH_3), 1.63-1.57 (1H, br s, OH), 1.56-1.49 (4H, m, H-4 and H-6), 1.32 (2H, m, H-5); δ_C (125 MHz) 197.3 (C=O), [143.1, 140.3, 136.1, 134.7, 129.4, 129.3, 128.4 and 126.6 (Ar)], [66.4, 62.3 (C-1 and C-7)], [44.2, 32.1, 24.8, 22.6, 21.4 (C-3, C-4, C-5, C-6 and Ph*C*H_3)]; *m/z* (CI^+) 441 $[M+NH_4]^+$, 406 $[M+H-H_2O]^+$, 360, 344, 327, 310, 270, 189 $[TsNH_2+NH_4]^+$, 148, 132, 108 (Found: $[M+NH_4]^+$, 441.1558. $C_{20}H_{25}NO_5S_2$ requires $[M+NH_4]^+$, 441.1517) (Found: C, 56.24; H, 5.93; N, 3.27. $C_{20}H_{25}NO_5S_2$ requires C, 56.72; H, 5.95; N, 3.31%).

(+)-(S_S)-7-Hydroxy-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-heptanone (+)-(4). This was prepared in the same manner as (±)-**4** on a 16.2 mmol scale starting from (+)-(S_S)-*S*-methyl-*S*-phenyl-*N*-tosylsulfoximine to give, after chromatography (90% EtOAc–petrol), *(+)-(*S*S)-7-hydroxy-1-(*S*-phenyl*-N-*tosylsulfoximinoyl)-2-heptanone* (+)-**4** (6.1 g, 88%) as a colourless solid; mp 75.0-77.0˚C; $[\alpha]_D^{25}$ +38.0 (*c* 1.0, $CHCl_3$); the spectroscopic properties were identical to those of (±)-**4**.

(±)-2-(*S*-Phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone (5). To a stirred solution of Dess–Martin periodinane[15] (1.24 g, 2.83 mmol, 1.2 equiv) in dry CH_2Cl_2 (15 ml) under nitrogen at rt was added a solution of (±)-7-hydroxy-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-heptanone **4**

(1.00 g, 2.36 mmol, 1.0 equiv) in dry CH_2Cl_2 (5 ml). After 5 min at rt a thick white precipitate was observed and tlc examination indicated complete consumption of starting material. The mixture was diluted with EtOAc (100 ml) and poured into saturated aqueous $NaHCO_3$ (100 ml) containing $Na_2S_2O_3$ (4.9 g, 19.8 mmol, 8.4 equiv) and the resulting 2-phase mixture allowed to stir vigorously for *ca.* 5 min (until the white precipitate had been consumed). The layers were separated and the aqueous layer extracted with EtOAc (100 ml). The combined organic extracts were washed with saturated aqueous $NaHCO_3$ (100 ml), water (100 ml) then dried ($MgSO_4$) and the solvent removed under reduced pressure at 0-5˚C to give a colourless gum (1.02 g). Flash column chromatography (67% EtOAc–petrol) gave *(±)-2-(*S*-phenyl*-N*-tosylsulfoximinoyl)-2-cycloheptenone* **5** (893 mg, 94%) as a colourless foam; R_f 0.44, 67% EtOAc–petrol; υ_{max} (film) 3061, 2932, 2867, 1722, 1887, 1603, 1453, 1316, 1235, 1154, 1097, 1084, 1004, 908, 813, 737, 678 cm^{-1}; δ_H (500 MHz) 8.02-7.98 (3H, m, ortho on Ph and H-3), 7.83 (2H, d, J 8.5 Hz, ortho on Ts), 7.61 (1H, t with extra fine structure, J 7.5 Hz, para on Ph), 7.51 (2H, t with extra fine structure, J 8.0 Hz, meta on Ph), 7.25 (2H, d, J 7.5 Hz, meta on Ts), 2.92 (1H, ddd, J 14.5, 8.5, 6.0 Hz, H-7a), 2.73 (2H, m, H-4), 2.65 (1H, ddd, J 15.0, 7.5, 5.5 Hz, H-7b), 2.39 (3H, s, PhCH_3), 2.04-1.90 (2H, m, H-5a, H-6a), 1.86-1.80 (1H, m, H-6b), 1.74-1.68 (1H, m, H-5b); δ_C (75 MHz) 197.0 (C-1), 155.1 (C-3), [142.8, 142.6, 140.8, 138.5 (C-2, ipso Ph, ipso Ts, para Ts)], [133.9, 129.2, 129.0, 128.6, 126.6 (ortho Ph, ortho Ts, meta Ph, meta Ts, para Ph)], [43.9, 29.7 (C-4 and C-7)], [24.6, 21.5 (C-5 and C-6)], 21.5 (Ph*C*H3); *m/z* (CI^+) 421 $[M+NH_4]^+$, 404 $[M+H]^+$, 360, 327 $[M+H-Ph]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 297, 268, 231, 206, 189 $[TsNH_2+NH_4]^+$, 175, 159, 124, 107, 52 (Found: $[M+NH_4]^+$, 472.1978. $C_{20}H_{21}NO_4S_2$ requires $[M+NH_4]^+$, 472.1980).

(–)-(*S*S)-2-(*S*-Phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone (–)-(5). This was prepared in the same manner as (±)-**5** on a 14.0 mmol scale starting from (+)-(***S*S**)-7-hydroxy-1-(*S*-phenyl*N*-tosylsulfoximinoyl)-2-heptanone (+)-**4** to give, after chromatography (67% EtOAc–petrol), *(-)-(*S*S)-2-(*S*-phenyl*-N-*tosylsulfoximinoyl)-2-cycloheptenone* (–)-**5** (5.2 g, 91%) as a colourless foam; $[\alpha]_D^{25}$ -75.9 (*c* 1.0, $CHCl_3$); the spectroscopic properties were identical to those of (±)-**5**.

(±)-6-Hydroxy-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-hexanone (1) and (±)-2-hydroxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)methyltetrahydropyran (3). To a stirred solution of (±)-*S*-methyl-*S*-phenyl-*N*-tosylsulfoximine (500 mg, 1.6 mmol, 1.0 equiv) at -78˚C under nitrogen was added dropwise *n*-BuLi (1.3 ml of a 1.24 M solution in hexanes, 1.62 mmol, 1.0 equiv). The resulting pale yellow solution was stirred at this temperature for 15 min then freshly distilled δ-valerolactone (165 µl, 178 mg, 1.8 mmol, 1.1 equiv) was added dropwise and the resulting solution stirred at -78˚C for 5 min. Tlc examination indicated new material and some starting material remaining and after a further 15 min tlc indicated no change. The mixture was quenched by the dropwise addition of AcOH (1.6 ml of a 1.0 M solution in THF, 16 mmol, 1.0 equiv) and allowed to warm to rt. The mixture was diluted with saturated aqueous NH_4Cl (30 ml) and extracted with CH_2Cl_2 (3 x 50 ml). The combined organic extracts were washed with water (2 x 50 ml) then dried (($MgSO_4$) and the solvents removed by evaporation under reduced pressure to give a colourless oil (780 mg). Flash column chromatography (60% EtOAc–petrol) gave a 1:3:8 mixture of *(±)-6-hydroxy-1-(S-phenyl*-N-*tosylsulfoximinoyl)-2-hexanone* 1 and two

diastereomers of *(±)-2-hydroxy-2-(S-phenyl*-N-*tosylsulfoximinoyl)methyltetrahydropyran* 3 (628 mg, 95%) as a colourless gum; R_f 0.20, 67% EtOAc–petrol; υ_{max} (film) 3499, 3489, 2942, 2977, 1725, 1448, 1316, 1303, 1288, 1245, 1241, 1151, 1088, 1057, 1018, 1001, 684 cm^{-1}; δ_H (400 MHz) 8.04 (2H, m, ortho on Ph_{min}), 7.97-7.95 (2H, m, ortho on $Ph_{acyclic}$) overlapping with 7.96 (2H, d, J 8.0 Hz, ortho on Ph_{maj}), 7.87-7.81 (4H, m, ortho on $Ts_{min+acyclic}$) overlapping with 7.83 (2H, d, J 8.5 Hz, ortho on Ts_{maj}), 7.72-7.63 (3H, m, para on $Ph_{maj+min+acyclic}$), 7.60-7.52 (6H, m, meta on $Ph_{maj+min+acyclic}$), 7.28-7.24 (4H, m, meta on $Ts_{min+acyclic}$) overlapping with 7.25 (2H, d, J 8.5 Hz, meta on Ts_{maj}), 5.01 (1H, d, J 2.0 Hz, OH_{min}), 4.82 (1H, d, J 14.0 Hz, H-$1a_{acyclic}$), 4.75 (1H, d, J 2.5 Hz, OH_{maj}), 4.59 (1H, d, J 14.0 Hz, H-$1b_{acyclic}$), 4.27 (1H, d, J 14.5 Hz, H-$2'a_{maj}$), 3.91-3.77 (2H, m, H-$6a_{maj+min}$), 3.64 (1H, d, J 14.5 Hz, H-$2'a_{min}$) overlapping with 3.66-3.59 (2H, m, H-$3_{acyclic}$), 3.55 (1H, d, J 14.5 Hz, H-$2'b_{min}$) overlapping with 3.53 (1H, d, J 14.5 Hz, H-$2'b_{maj}$), 3.38 (1H, m, H-$6b_{min}$), 3.28 (1H, m, H-$6b_{maj}$), 2.75 (2H, m, H-$6_{acyclic}$), 2.39 (9H, s, PhC$H_{3maj+min+acyclic}$), 1.90-1.25 (16H, m, H-3, H-4, H-$5_{maj+min}$ and H-4, H-$5_{acyclic}$); *m/z* (CI^+) 464, 427 $[M+NH_4]^+$, 417, 410 $[M+H]^+$, 409, 400, 392 $[M+H-H_2O]^+$, 374, 327, 310, 294, 139, 118, 101 (Found: $[M+NH_4]^+$, 427.1365. $C_{19}H_{23}NO_5S_2$ requires $[M+NH_4]^+$, 427.1361).

(±)-2-(*S*-Phenyl-*N*-tosylsulfoximinoyl)-2-cyclohexenone (2). This was prepared in an analogous manner to (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** on a 1.20 mmol scale starting from a mixture of (±)-6-hydroxy-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-hexanone **1** and 2 diastereomers of (±)-2-hydroxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)methyltetrahydropyran **3** to give, *without* chromatography, *(±)-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)-2-cyclohexenone* **2** (453 mg, 97%) as a pale pink foam; R_f 0.61, 10% Et_2O–CH_2Cl_2; $_{max}$ (film) 3063, 2952, 2931, 2882, 1725, 1697, 1579, 1496, 1462, 1447, 1316, 1304, 1290, 1239, 1226, 1153, 1101, 1089, 1069, 1016, 997, 765, 752, 731 cm^{-1}; $_H$ (270 MHz) 8.27 (1H, t, J 4.0 Hz, H-3), 8.04 (2H, d with extra fine structure, J 7.0 Hz, ortho on Ph), 7.80 (2H, d with extra fine structure, J 8.5 Hz, ortho on Ts), 7.61-7.55 (1H, m, para on Ph), 7.48 (2H, t with extra fine structure, J 8.5 Hz, meta on Ph), 7.22 (2H, d with extra fine structure, J 8.5 Hz, meta on Ts), 2.72 -2.26 (2H, m, H-4), 2.52-2.32 (2H, m, H-6) overlapping with 2.36 (3H, s, PhCH_3), 2.06-1.75 (2H, m, H-5); *m/z* (FAB^+) 390 $[M+H]^+$, 236, 221, 165, 150, 135, 123, 109, 95, 81 (Found: $[M+H]^+$, 390.0874. $C_{19}H_{19}NO_4S_2$ requires $[M+H]^+$, 390.0834).

3-Methyl-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone (6). To a stirred mixture of freshly recrystallised CuBr:Me_2S complex[16] (66 mg, 0.32 mmol, 1.3 equiv), anhydrous Me_2S (460 µl) and dry Et_2O (460 µl) at rt under nitrogen was added dropwise MeLi (462 µl of a 1.34 M solution in Et_2O, 0.62 mmol, 2.5 equiv). The initially-formed bright yellow precipitate dissolved to give a pale yellow solution which was cooled to -78˚C and stirred for 10 min. A solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** (100 mg, 0.25 mmol, 1.0 equiv) in dry THF (990 µl) was then added under nitrogen. The mixture turned brown and after 10 min, tlc examination indicated complete consumption of starting material. The mixture was quenched by the addition of saturated aqueous NH_4Cl (3 ml) and allowed to warm to rt. The resulting blue mixture was diluted with further saturated aqueous NH_4Cl (10 ml) and enough water to dissolve the precipitate (*ca.* 2 ml) and extracted with EtOAc (3 x 15 ml). The combined

organic extracts were washed with saturated aqueous NH_4Cl (15 ml), water (15 ml) and brine (15 ml) then dried ($MgSO_4$) and the solvents removed under reduced pressure to give a colourless film (94 mg). Flash column chromatography (50% EtOAc–petrol) gave a 10:8:4:3 mixture of diastereomers of *3-methyl-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **6a-d** (61 mg, 58%) as a colourless solid; R_f 0.54, 67% EtOAc–petrol; υ_{max} (film) 3060, 2931, 1714, 1447, 1347, 1304, 1290, 1232, 1152, 1120, 1088, 1058, 1202, 998, 738, 686, 562, 537 cm^{-1}; *m/z* (CI^+) 437 $[M+NH_4]^+$, 420 $[M+H]^+$, 404 $[M-Me]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 296, 294, 278, 189 $[TsNH_2+NH_4]^+$, 155, 142, 125 [methylcyclohexanone]+, 108 (Found: $[M+H]^+$, 420.1312. $C_{21}H_{25}NO_4S_2$ requires $[M+H]^+$ 420.1303). A small quantity of the mixture was separated using analytical HPLC to give, in order of elution, *[*R**S,2*S**,3*R**]-3-methyl-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **6a** (as the main component of the first fraction) as a colourless solid; δ_H (500 MHz) 7.94 (2H, d, J 7.5 Hz, ortho on Ph), 7.78 (2H, d, J 8.0 Hz, ortho on Ts), 7.70 (1H, t, J 7.5 Hz, para on Ph), 7.59 (2H, t, J 7.5 Hz, meta on Ph), 7.23 (2H, d, J 8.0 Hz, meta on Ts), 3.84 (1H, d, J 8.0 Hz, H-2), 2.98 (1H, td, J 12.0, 3.5 Hz, H-7a), 2.40 (3H, s, PhCH_3) overlapping with [2.48-2.27, 1.96-1.76, 1.75-1.64, 1.54-1.16 (2H, 2H, 1H and 3H respectively, 4m, H-3, H-4, H-5, H-6, H-7b)], 0.90 (3H, d, J 7.0 Hz, Me); *[*R**S,2*R**,3*S**]-3-methyl-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **6c** and *[*R**S,2*S**,3*S**]-3-methyl-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **6d** (as the main components of the second fraction) as a colourless gum; δ_H (500 MHz) 8.17 (2H, d with extra fine structure, J 8.5 Hz, ortho on Ph), 7.95 (2H, d with extra fine structure, J 8.5 Hz, ortho on Ph), 7.86 (2H, d, J 8.5 Hz, ortho on Ts), 7.79 (2H, d, J 8.0 Hz, ortho on Ts), 7.69 (1H, t, J 7.5 Hz, para on Ph) overlapping with 7.67 (1H, t, J 7.5 Hz, para on Ph), 7.60-7.54 (4H, m, meta on Ph), 7.27-7.22 (4H, m, meta on Ts), 5.62 (1H, s, H-2), 4.24 (1H, d, J 8.0 Hz, H-2), 2.82 (1H, m, H-7), 2.74 (1H, dt, J 19.0, 3.5 Hz, H-7), 2.66 (1H, td, J 12.0, 4.0 Hz, H-7), 2.51 (1H, m, H-7), 2.39 (3H, s, PhCH_3), 2.38 (3H, s, PhCH_3), [2.35-2.28, 2.01-1.21, 0.98-0.81 (4H, 8H and 2H respectively, 3m, H-3, H-4, H-5, H-6)] overlapping with 0.88 (3H, d, J 8.0 Hz, Me), 0.47 (3H, d, J 7.5 Hz, Me); *[*R**S,2*R**,3*R**]-3-methyl-2-(*S-*phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **6c** (as the main component of the third fraction, contaminated with **6a**) as a colourless gum; δ_H (500 MHz) 8.11 (2H, dd, J 8.5, 1.0 Hz, ortho on Ph), 7.82 (2H, d with extra fine structure, J 8.5 Hz, ortho on Ts), 7.68-7.63 (1H, m, para on Ph), 7.57-7.53 (2H, m, meta on Ph), 7.25 (2H, m, meta on Ts), 5.26 (1H, s, H-2), 2.73-2.69 (1H, m, H-7a), (3H, s, PhCH_3) overlapping with 2.48-1.17 (8H, m, H-3, H-4, H-5, H-6 H-7b), 0.49 (3H, d, J 7.0 Hz, Me).

3-Isopropenyl-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone (7). To a stirred mixture of freshly recrystallised CuBr:Me_2S complex (33 mg, 0.16 mmol, 1.3 equiv), anhydrous Me_2S (229 µl) and dry Et_2O (229 µl) at -78˚C under nitrogen was added dropwise *i*-propenylMgBr (620 µl of a 0.5 M solution in Et_2O, 2.5 equiv) and the resulting orange-yellow mixture stirred at this temperature for 3 min. A solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** (50 mg, 0.12 mmol, 1.0 equiv) in dry THF was added under nitrogen. Tlc analysis of the resulting dark orange mixture indicated complete consumption of starting material and the mixture was quenched by the addition of saturated aqueous NH_4Cl (2 ml) and allowed to

warm to rt. The resulting blue mixture was diluted with further saturated aqueous NH_4Cl (10 ml) and extracted with EtOAc (3 x 10 ml). The combined organic extracts were washed with saturated aqueous NH_4Cl (10 ml), water (10 ml) and brine (10 ml) then dried ($MgSO_4$) and the solvents removed under reduced pressure to give a pale yellow solid (63 mg). Flash column chromatography (25% EtOAc–petrol) gave a 5:2 mixture of diastereomers of *3-isopropenyl-2-(*S*-phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* (**7**) (28 mg, 52%) as a colourless solid (the major diastereomer was the [R^*S,2S^*,3S^*] isomer **7a**); R_f 0.59, 50% EtOAc–petrol; υ_{max} (film) 3087, 3066, 2968, 2942, 2891, 2862, 1714, 1448, 1381, 1322, 1304, 1290, 1234, 1155, 1113, 1089, 1051, 1090, 1051, 1018, 997, 901, 816, 738, 710, 685, 661 cm^{-1}; δ_H (500 MHz) 7.94 (2H, d, J 8.5 Hz, ortho on Ph_{min}), 7.90 (2H, d with extra fine structure, J 8.0 Hz, ortho on Ph_{maj}), 7.79 (2H, d, J 8.0 Hz, ortho on Ts_{min}), 7.74 (2H, d, H 8.0 Hz, ortho on Ts_{maj}), 7.68-7.64 (2H, m, para on $Ph_{maj+min}$), 7.56-7.51 (2H, m, meta on Ph_{min}) overlapping with 7.52 (2H, t, J 7.5 Hz, meta on Ph_{maj}), 7.23-7.20 (4H, m, meta on $Ts_{maj+min}$), 4.68 (1H, s, H-3"a_{min}), 4.58 (1H, s, H-3"b_{min}), 4.44 (1H, s, H-3"a_{maj}), 4.41 (1H, d, J 1.0 Hz, H-3"b_{maj}), 4.38 (1H, d, J 9.5 Hz, H-2_{min}), 4.15 (1H, d, J 9.0 Hz, H-2_{maj}), 3.10 (1H, t, J 9.5 Hz, H-3_{min}), 3.00 (1H, d, J 10.5 Hz, H-3_{maj}), 2.95 (1H, dd, J 12.5, 3.0 Hz, H-7a_{maj}), 2.76 (1H, td, J 12.0, 3.5 Hz, H-7a_{min}), 2.47-2.43 (1H, m, H-7b_{maj}), 2.39 (6H, s, PhCH_3), 2.35-2.27 (1H, m, H-7b_{min}), 1.95-1.25 (6H, several m, H-4_{min}, H-5_{min}, H-6_{min}, overlapping with all remaining signals), 1.96-1.93 (1H, m, H-6a_{maj}), 1.89-1.81 (1H, m, H-5a_{maj}), 1.68 (1H, dd, J 15.0, 6.5 Hz, H-4a_{maj}), 1.59 (3H, s, propenyl Me_{min}) overlapping with 1.60-1.52 (1H, m, H-5b_{maj}), 1.48-1.43 (1H, m, H-6b_{maj}), 1.38 (3H, s, propenyl-Me_{maj}), 1.34-1.25 (1H, m, H-4b_{maj}); *m/z* (CI^+) 463 $[M+NH_4]^+$, 446 $[M+H]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 296, 290, 276, 235, 225, 214, 189 $[TsNH_2+NH_4]^+$, 168, 151 $[M-TsNS(O)Ph]^+$, 139, 125, 108, 93, 81, 55 (Found: $[M+H]^+$, 446.1459. $C_{23}H_{27}NO_4S_2$ requires $[M+H]^+$, 446.1460).

[R^*S,2S^*,3S^*]-3-Isopropyl-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone (±)-(8). To a stirred mixture of freshly recrystallised CuBr:Me_2S complex (328 mg, 1.61 mmol, 1.3 equiv), anhydrous Me_2S (2.3 ml) and dry Et_2O (2.3 ml) at -78˚C under nitrogen was added dropwise *i*-PrMgCl (1.6 ml of a 2.0 M solution in THF, 3.10 mmol, 2.5 equiv) and the resulting dark brown mixture stirred for 5 min at this temperature. A solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** (500 mg, 1.24 mmol, 1.0 equiv) in dry THF (5 ml) was added under nitrogen. The resulting dark brown mixture was stirred for 5 min then tlc examination indicated complete consumption of starting material. The reaction was quenched by the addition of saturated aqueous NH_4Cl (5 ml) and allowed to warm to rt. The resulting blue mixture was diluted with further saturated aqueous NH_4Cl (30 ml) and enough water to dissolve the precipitate (*ca.* 5 ml) then extracted with with EtOAc (3 x 30 ml). The combined organic extracts were washed with saturated aqueous NH_4Cl (30 ml), water (30 ml) and brine (30 ml) then dried ($MgSO_4$) and the solvents removed under reduced pressure to give a pale yellow semi-solid (505 mg). Flash column chromatography (40% EtOAc–petrol) gave *[*R**S,2*S**,3*S**]-3-isopropyl-2-(*S*-phenyl*-N-*tosylsulfoximinoyl)cycloheptanone* **8** (344 mg, 62%) as a colourless solid; R_f 0.69, 50% EtOAc–petrol; mp 172-174˚C; υ_{max} (film) 3095, 3066, 2961, 2933, 2933, 2866, 2866, 1714, 1463, 1449, 1322, 1301, 1288, 1233, 1183, 1128, 1045, 1019, 997, 815, 765,

732, 685 cm^{-1}; δ_H (400 MHz) 7.95 (2H, d, J 7.5 Hz, ortho on Ph), 7.77 (2H, d, J 8.0 Hz, ortho on Ts), 7.70 (1H, t, J 7.5 Hz, para on Ph), 7.59 (2H, t, J 8.0 Hz, meta on Ph), 7.23 (2H, d, J 8.5 Hz, meta on Ts), 3.94 (1H, d, J 7.5 Hz, H-2), 3.00 (1H, td, J 12.0, 4.0 Hz, H-7a), 2.40 (3H, s, PhCH_3), 2.40-2.34 (1H, m, H-7b), 2.24 (1H, m, H-3), 1.93-1.86 (2H, m, H-6a, H-5a), 1.81-1.76 (1H, m, H-5b), 1.48-1.40 (1H, m, H-6b), 1.38-1.30 (1H, m, H-3'), 0.92-0.81 (2H, m, H-4), 0.71 (3H, d, J 7.0 Hz, Me), 0.55 (3H, d, J 7.0 Hz, Me); δ_C (100 MHz) 201.6 (C=O), [142.8, 140.6, 137.9 (ipso Ph, ipso Ts, para Ts)], [134.7, 129.7, 129.2, 128.7, 126.5 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 82.0 (C-2), 42.1 (C-7), [41.1, 30.7 (C-3, C-3')], [28.3, 27.1, 26.1 (C-4, C-5, C-6)], [21.5, 20.4, 15.0 (Me, Me, Ph*C*H_3)]; *m/z* (CI^+) 465 $[M+NH_4]^+$, 448 $[M+H]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 296, 278, 235, 189 $[TsNH_2+NH_4]^+$, 155, 153, 139, 128, 125, 111, 108 (Found: $[M+H]^+$, 448.1624. $C_{23}H_{29}NO_4S_2$ requires $[M+H]^+$, 448.1616).

(+)-[*S*$_S$,2*R*,3*R*]-3-Isopropyl-2-(*S*-phenyl-*N*-tosylsulfoximinoyl cycloheptanone (+)-(8). This was prepared in the same manner as (±)-**8** on a 0.25 mmol scale starting from (–)-(*S*$_S$)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone (–)-**5** to give, after chromatography (40% EtOAc–petrol), *(+)-[*S*$_S$,2*R*,3*R*)-3-isopropyl-2-(*S*-phenyl-N-tosylsulfoximinoyl)cycloheptanone* (+)-**8** (72 mg, 64%) as a colourless solid; mp 161˚C; $[\alpha]_D^{25}$ +71.2 (*c* 1.0, $CHCl_3$); spectroscopic properties were identical to those of (±)-**8**.

(–)-[*S*]-3-Isopropylcycloheptanone (–)-(9). To a stirred solution of (+)-[*S*$_S$,2*R*,3*R*]-3-isopropyl-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone (+)-**8** (241 mg, 0.54 mmol, 1.0 eq) in dry THF (20 ml) and dry MeOH (10 ml) at -78˚C under nitrogen was added dropwise SmI_2 (48.6 ml of a 0.1 M solution in THF, 4.86 mmol, 9.0 equiv). The mixture initially turned pale yellow and when addition of SmI_2 was complete, a blue colour persisted. Tlc analysis indicated complete consumption of starting material and the mixture was quenched by the addition of saturated aqueous NH_4Cl (25 ml) and allowed to warm to rt. The mixture was diluted with saturated aqueous $Na_2S_2O_3$ (25 ml) and extracted with Et_2O (3 x 50 ml). The combined organic extracts were washed with saturated aqueous $Na_2S_2O_3$ (2 x 25 ml), water (2 x 25 ml) and brine (25 ml) then dried ($MgSO_4$) and the solvents removed by evaporation under reduced pressure to give, after chromatography of the residue (75% Et_2O–pentane), *(–)-[S]-3-isopropylcycloheptanone* (-)-**9** (53 mg, 64%) as a colourless film; R_f 0.83, 33% EtOAc–pet. ether; $[\alpha]_D^{25}$ -75.2 (*c* 0.2, $CHCl_3$); υ_{max} (film) 2960, 2929, 2871, 1703, 1464, 1444, 1387, 1369, 1169, 1159 cm^{-1}; δ_H (400 MHz) 2.48-2.49 (3H, m, H-2, H-7a), 2.35 (1H, ddd, J 14.0, 3.0, 2.0 Hz, H-7b), [1.99-1.83, 1.80-1.74, 1.67-1.49, 1.41-1.21 (2H, 1H, 2H, 3H respectively, 4m, H-3, H-3', H-4, H-5, H-6)], 0.86 (3H, d, J 7.0 Hz, Me) overlapping with 0.85 (3H, d, J 7.0 Hz, Me); *m/z* (CI^+) 172 $[M+NH_4]^+$, 155 $[M+H]^+$, 142, 124, 111 [M-*i*-Pr]$^+$, 96, 81 (Found: $[M+NH_4]^+$, 172.1703. $C_{10}H_{18}O$ requires $[M+NH_4]^+$, 172.1701); in agreement with previously reported data for the (+)-enantiomer.[17]

[*R**S,2*R**,3*S**]- and [*R**S,2*S**,3*R**]-2,3-Epoxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cyclo-heptanone (10). To a stirred solution of *t*-BuOOH (372 µl of a 5 M solution in decane, 1.86 mmol, 1.5 equiv) in dry THF (9 ml) at -78˚C under nitrogen was added dropwise *n*-BuLi (852 µl of a 1.60 M solution in hexanes, 1.36 mmol, 1.1 equiv). The mixture was stirred for

5 min. A solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** (500 mg, 1.24 mmol, 1.0 equiv) in dry THF (3 ml) was added at -78˚C. The resulting pale yellow mixture was stirred for 10 min at which point tlc analysis indicated complete consumption of starting material. The reaction was quenched by the addition of saturated aqueous NH_4Cl (30 ml) and the mixture allowed to warm to rt. The yellow mixture was further diluted with saturated aqueous NH_4Cl (30 ml) and extracted with CH_2Cl_2 (3 x 30 ml). The combined organic extracts were washed with saturated aqueous NH_4Cl (60 ml), water (60 ml) and brine (60 ml) and dried ($MgSO_4$), and the solvents removed under reduced pressure to give a pale yellow semi-solid (640 mg). Flash column chromatography (40% EtOAc–petrol) gave, in order of elution, *[*R**S,2*R**,3*S**]-2,3-epoxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone* **10b** (93 mg, 18%) as a colourless solid; R_f 0.57, 50% EtOAc–petrol; mp 85˚C (decomp); υ_{max} (film) 2962, 2940, 2863, 1716, 1448, 1321, 1299, 1281, 1242, 1154, 1121, 1088, 1062, 997, 751 cm^{-1}; δ_H (500 MHz) 7.99 (2H, d, J 7.5 Hz, ortho on Ph), 7.89 (2H, d, J 8.5 Hz, ortho on Ts), 7.68 (1H, t, J 7.5 Hz, para on Ph), 7.55 (2H, d, J 8.0 Hz, meta on Ph), 7.27 (2H, d, J 8.0 Hz, meta on Ts), 4.32 (1H, d, J 5.0 Hz, H-3), 2.49 (2H, t with extra fine structure, J 5.0 Hz, H-7) overlapping with 2.46-2.36 (1H, m, H-4a), 2.40 (3H, s, PhC*H*$_3$), 2.24 (1H, t with extra fine structure, J 13.5 Hz, H-4b), 1.82-1.73 (2H, m, H-6a and H-5a), 1.64-1.54 (1H, m, H-5b), 1.44-1.28 (1H, m, H-6b); δ_C (75 MHz) 200.0 (C=O), [143.0, 140.6, 133.9 (ipso Ph, ipso Ts, para Ts)], [134.9, 129.8, 129.3, 129.3, 126.6 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 77.4 (C-2), 61.0 (C-3), 42.0 (C-7), [26.6, 23.5, 22.1 (C-4, C-5, C-6)], 21.5 (Ph*C*H$_3$); *m/z* (CI^+) 453, 437 $[M+NH_4]^+$, 420 $[M+H]^+$, 419, 391, 361, 344, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 296, 282, 268, 189 $[TsNH_2+NH_4]^+$, 174, 160, 139, 108 (Found: $[M+NH_4]^+$, 437.1200. $C_{20}H_{21}NO_5S_2$ requires $[M+NH_4]^+$, 437.1205) (Found: C, 57.24; H, 5.13; N, 3.07. $C_{20}H_{21}NO_5S_2$ requires C, 57.26; H, 5.05; N, 3.34%) and *[*R**S,2*S**,3*R**]-2,3-epoxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone* **10a** (236 mg, 45%) as a colourless solid; R_f 0.46, 50% EtOAc–petrol; mp 105˚C (decomp); υ_{max} (film) 3064, 2937, 2867, 1715, 1596, 1448, 1317, 1244, 1156, 1088, 1058, 913, 814, 729, 822, 861 cm^{-1}; δ_H (500 MHz) 8.10 (2H, d with extra fine structure, J 8.0 Hz, ortho on Ph), 7.89 (2H, d, J 8.5 Hz, ortho on Ts), 7.70 (1H, t, J 7.5 Hz, para on Ph), 7.58 (2H, t, J 8.0 Hz, meta on Ph), 7.27 (2H, d, J 8.0 Hz, meta on Ts), 3.88 (1H, d, J 6.0 Hz, H-3), 2.97 (1H, td, J 12.0, 4.0 Hz, H-7a), 2.58 (1H, ddd, J 11.5, 6.0, 3.0 Hz, H-7b), 2.43-2.35 (2H, m, H-4), 2.40 (3H, s, PhC*H*$_3$), 1.89-1.85 (1H, m, H-6a), 1.76-1.73 (2H, m, H-5), 1.71-1.08 (1H, m, H-6b); δ_C (75 MHz) 201.5 (C=O), [143.3, 140.3, 135.9 (ipso Ph, ipso Ts, para Ts)], [134.9, 130.0, 129.3, 129.3, 126.8 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 65.9 (C-2), 60.1 (C-3), 41.3 (C-7), [26.7, 24.2, 22.2 (C-4, C-5, C-6)], 21.6 (Ph*C*H$_3$); *m/z* (CI^+) 455 $[M+2NH_4]^+$, 437 $[M+NH_4]^+$, 422 $[M+H_2+H]^+$, 420 $[M+H]^+$, 404, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 297, 296, 280, 278, 189 $[TsNH_2+NH_4]^+$, 172, 156 $[MePhSO_2+H]^+$, 144, 142, 127, 125, 108 (Found: $[M+NH_4]^+$, 437.1230. $C_{20}H_{21}NO_5S_4$ requires $[M+NH_4]^+$, 437.1205) (Found: C, 57.02; H, 4.77; N, 3.19. $C_{20}H_{21}NO_5S_2$ requires C, 57.26; H, 5.05; N, 3.34%).

[*RS,2*R**,3*S**]- and [*R**S,2*S**,3*R**]-2,3-Epoxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cyclohexanone (11).** This were prepared in an analogous manner to [*R**S,2*R**,3*S**]- and [*R**S,2*S**,3*R**]-

2,3-epoxy-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)cycloheptanone **10** on a 0.23 mmol scale starting from (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cyclohexenone **2** to give, after chromatography (40% EtOAc–petrol) in order of elution, *[*R**S,2*R**,3*S**]-2,3-epoxy-2-(*S*-phenyl-N-tosylsulfoximinoyl)-cyclohexanone* **11b** (30 mg, 29%) as a colourless solid; R_f 0.69, 67% EtOAc–petrol; mp 146.0-146.2˚C; υ_{max} (film) 3059, 2948, 2922, 2889, 1723, 1601, 1448, 1317, 1304, 1244, 1152, 1096, 1088, 1073, 1045, 986, 818, 761, 752, 721, 680, 666 cm^{-1}; δ_H (500 MHz) 8.15 (2H, dd, J 8.5, 1.0 Hz, ortho on Ph), 7.84 (2H, d, J 8.5 Hz, ortho on Ts), 7.70 (1H, t with extra fine structure, J 7.5 Hz, para on Ph), 7.57 (2H, t with extra fine structure, J 8.0 Hz, meta on Ph), 7.29 (2H, d, J 8.0 Hz, meta on Ts), 4.51 (1H, s, H-3), 2.56-2.48 (2H, m, H-6) overlapping with 2.49-2.30 (1H, m, H-4a) and with 2.41 (3H, s, PhC*H*$_3$), 2.36-2.30 (1H, m, H-4b), 1.83-1.77 (1H, m, H-5a), 1.75-1.65 (1H, m, H-5b); δ_C (75 MHz) 196.5 (C=O), [143.2, 140.1, 133.7 (ipso Ph, ipso Ts, para Ts)], [134.9, 130.5, 129.4, 128.9, 126.5 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 72.5 (C-2), 61.1 (C-3), 38.0 (C-6), [22.9, 15.7 (C-4, C-5)], 21.5 (Ph*C*H$_3$); *m/z* (CI^+) 423 $[M+NH_4]^+$, 406 $[M+H]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 297, 282, 268, 251, 234, 189 $[TsNH_2+NH_4]^+$, 175, 159, 139, 126, 108 (Found: $[M+NH_4]^+$, 423.1072. $C_{19}H_{19}NO_5S_2$ requires $[M+NH_4]^+$, 423.1048) (Found: C, 56.13; H, 4.46; N, 3.27. $C_{19}H_{19}NO_5S_2$ requires C, 56.28; H, 4.72; N, 3.45%) and *[*R***S*,2*S**,3*R**]-2,3-epoxy-2-(*S*-phenyl-N-tosylsulfoximinoyl)cyclohexanone* **11a** (49 mg, 47%) as an off-white gum; R_f 0.58, 67% EtOAc–petrol; υ_{max} (film) 3093, 3064, 3031, 2954, 2924, 2887, 2855, 1725, 1592, 1448, 1314, 1291, 1247, 1224, 1154, 1103, 1101, 1088, 1045, 994, 915, 815, 757, 684 cm^{-1}; δ_H (500 MHz) 8.06 (2H, d with extra fine structure, J 7.5 Hz, ortho on Ph), 7.78 (2H, d with extra fine structure, J 8.5 Hz, ortho on Ts), 7.68 (1H, td, J 7.5, 1.5 Hz, para on Ph), 7.56 (2H, t with extra fine structure, J 8.0 Hz, meta on Ph), 7.22 (2H, d, J 8.0 Hz, meta on Ts), 4.53 (1H, dd, J 2.5, 1.5 Hz, H-3), 2.51 (1H, dt, J 17.0, 4.5 Hz, H-6a), 2.40-2.35 (1H, m, H-4a) overlapping with 2.38 (3H, s, PhC*H*$_3$), 2.22 (1H, ddd, J 17.5, 9.5, 8.5 Hz, H-6b), 2.12 (1H, m, H-4b), 1.75-1.70 (2H, m, H-5); δ_C (100 MHz) 196.2 (C=O), [143.0, 140.5, 135.4 (ipso Ph, ipso Ts, para Ts)], [134.7, 129.8, 129.3, 129.0, 126.6 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 71.6 (C-2), 61.6 (C-3), 38.3 (C-6), [22.8, 16.2 (C-4, C-5)], 21.5 (Ph*C*H$_3$); *m/z* (CI^+) 828 $[2M+NH_4]^+$, 702, 687, 669, 608, 592, 576, 561, 543, 531, 515, 423 $[M+NH_4]^+$, 406 $[M+H]^+$, 329, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 297, 282, 268, 215, 189 $[TsNH_2+NH_4]^+$, 173, 159, 139, 126, 108 (Found: $[M+NH_4]^+$, 423.1066. $C_{19}H_{19}NO_5S_2$ requires $[M+NH_4]^+$, 423.1048).

[*RS,1*R**,7*R**]-1-(*S*-Phenyl-*N*-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone (13).** To a suspension of Diazald® (3.42 g, 16 mmol, 10 equiv) in Et_2O:EtOH (2:1) (10 ml) was added 60% aqueous KOH (2 ml). A stream of nitrogen was bubbled through the resulting yellow effervescent mixture and into another vessel containing a stirred solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone **5** (645 mg, 1.60 mmol, 1.0 equiv) in THF (10 ml), held between -10 and -30˚C during 3 h. The resulting bright yellow cooled THF solution was allowed to warm slowly to rt with a rapid stream of nitrogen passing through it until the solution became colourless. ^{1}H NMR analysis of an aliquot indicated complete consumption of starting material. (The original vessel containing excess base and Diazald® was quenched by the rapid addition of

25 % aqueous AcOH (50 ml).) The solvent was removed by evaporation under reduced pressure to give *[*R**S,1*R**,7*R**]-1-(*S*-phenyl-N-tosylsulfoximinoyl)-9,10-diazabicyclo[5.3.0]-9-octen-2-one* **12** (710 mg, 100%) as a colourless, air- and thermally-sensitive foam; υ_{max} (film) 3064, 2933, 1721, 1692, 1598, 1474, 1448, 1424, 1402, 1320, 1235, 1154, 1089, 1058, 1020, 998, 954, 816, 754, 700, 685, 664 cm^{-1}; δ_H (500 MHz) 7.84 (2H, dd, J 8.5, 1.0 Hz, ortho on Ph), 7.79 (2H, d, J 8.5 Hz, ortho on Ts), 7.70 (1H, t, J 7.5 Hz, para on Ph), 7.54 (2H, dd, J 8.5, 7.5 Hz, meta on Ph), 7.24 (2H, d, J 8.0 Hz, meta on Ts), 4.50 (1H, dd, J 19.0, 2.5 Hz, H-8a), 4.40 (1H, dd, J 19.0, 8.0 Hz, H-8b), 3.44 (1H, td, J 12.0, 4.0 Hz, H-3a), 2.98 (1H, ddt, J 11.0, 8.0, 3.0 Hz, H-7), 2.57 (1H, ddd, J 11.0, 8.0, 3.5 Hz, H-3b), 2.39 (3H, s, PhCH_3) overlapping with 2.38-2.36 (1H, m, H-5a), 1.96 (1H, m, H-4a), 1.89-1.77 (1H, m, H-6a), 1.68-1.63 (1H, m, H-5b), 1.44-1.38 (1H, m, H-4b), 0.95 (1H, dd with extra fine structure, J 26.5, 12.0 Hz, H-6b); *m/z* (CI^+) 543, 526, 490, 467, 450, 435, [**13**+NH_4]$^+$, 418 [**13**+H]$^+$, 313 [TsNS(O)(Ph)(H)+NH_4]$^+$, 297, 250, 233, 189 [$TsNH_2$+NH_4]$^+$, 155. A solution of freshly-prepared **12** (1.10 g, 2.48 mmol, 1.0 equiv) in acetone (124 ml) was placed in a vessel and thermally insulated using a surrounding cooling water jacket. The solution was irradiated using a 150 Watt sunlamp over a period of 48 h. The solvent was removed by evaporation under reduced pressure to give a pale yellow foam (1.10 g). Flash column chromatography (50% EtOAc–petrol) gave *[S*S,1R*,7R*]-1-(*S*-phenyl-N-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone* **13** (644 mg, 62%) as a colourless solid; R_f 0.43, 50 % EtOAc–petrol; mp 137-139˚C; υ_{max} (film) 3093, 3050, 2934, 2861, 1704, 1689, 1447, 1315, 1285, 1289, 1234, 1144, 1089, 1062, 1018, 998, 873, 815, 751, 685 cm^{-1}; δ_H (500 MHz) 7.80 (2H, d with extra fine structure, J 8.0 Hz, ortho on Ph), 7.74 (2H, d, J 8.0 Hz ortho on Ts), 7.62 (1H, t, 7.5 Hz, para on Ph), 7.50 (2H, t, J 7.4 Hz, meta on Ph), 7.20 (2H, d, J 8.0 Hz, meta on Ts), 3.28 (1H, ddd, J 13.5, 9.0, 4.0 Hz, H-3a), 2.46-2.37 (3H, m, H-3b, H-6a, H-7), 2.37 (3H, s, PhCH_3), 2.00 (1H, dtd, J 18.0, 9.0, 4.5 Hz, H-4a), 1.77-1.70 (1H, m, H-5a), 1.64-1.56 (1H, m, H-5b), 1.58 (1H, dd, J 9.0, 6.0 Hz, H-8a), 1.52-1.45 (1H, m, H-4b) 1.25 (1H, t, J 6.5 Hz, H-8b), 1.81 (1H, ddd, J 16.5, 5.5, 3.0 Hz, H-6b); δ_C (125 MHz) 200.4 (C=O), [142.6, 140.9, 137.8 (ipso-Ph, ipso-Ts and para-Ts)], [134.0, 129.1, 128.5, 126.5 (ortho-Ph, ortho-Ts, para-Ph, meta-Ph and meta-Ts)], 55.7 (C-1), 43.2 (C-3), [29.1, 24.5, 24.3 (C-4, C-5, C-6)], [23.9, 21.4 (C-7 and PhCH_3)], 19.6 (C-8); *m/z* (CI^+) 437 [M+2H+NH_4]$^+$, 435 [M+NH_4]$^+$, 419 [M+2H]$^+$, 313 [TsNS(O)(Ph)(H)+NH_4]$^+$, 294 [M-C_8H_{10}]$^+$, 264, 249 [M-Ph-$PhCH_3$]$^+$, 233, 191, 189 [$TsNH_2$+NH_4]$^+$, 159, 143, 142, 141, 125, 108 (Found: [M+NH_4]$^+$, 435.1400. $C_{21}H_{23}NO_4S_2$ requires [M+NH_4]$^+$, 435.1412) (Found: C, 60.67; H, 5.43; N, 3.32. $C_{21}H_{23}NO_4S_2$ requires C, 60.41; H, 5.55; N, 3.35%).

(–)-[*R*S,1*R*,7*R*]-1-(*S*-Phenyl-*N*-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone (–)-(13). This was prepared in the same manner as [*R**S,1*R**,7*R**]-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone **13** on a 2.4 mmol scale starting from (–)-(S_S)-2-[*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cycloheptenone (–)-**5** to give, after chromatography (50% EtOAc–petrol), *(–)-[*R*S,1*R*,7*R*]-1-(*S*-phenyl-N-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone* (–)-**13** (510 mg, 51%) as a colourless solid; mp 120-121˚C; $[\alpha]_D^{25}$ -43.8 (*c* 1.0, $CHCl_3$); the spectroscopic properties were identical to those of (±)-**13**.

(–)-[1*S*,7*R*]-Bicyclo[5.1.0]-2-octanone (–)-(17). To a stirred solution of (–)-[R_S,1*R*,7*R*]-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)bicyclo[5.1.0]-2-octanone (–)-**13** (440 mg, 1.1 mmol, 1.0 equiv) in dry THF (40 ml) and dry MeOH (20 ml) at -78˚C under nitrogen was added dropwise SmI_2 (44 ml of a 0.1 M solution in hexanes, 4.4 mmol, 4.0 eq). The mixture initially turned pale yellow and when addition of SmI_2 was complete, a blue colour persisted. Tlc examination indicated complete consumption of starting material and the mixture was quenched by the addition of saturated aqueous NH_4Cl (50 ml) and allowed to warm to rt. The mixture was diluted with saturated aqueous $Na_2S_2O_3$ (50 ml) and extracted with Et_2O (3 x 75 ml). The combined organic extracts were washed with saturated aqueous $Na_2S_2O_3$ (2 x 50 ml), water (2 x 50 ml) and brine (50 ml) then dried ($MgSO_4$) and the solvents removed by evaporationunder reduced pressure to give a pale yellow semi-solid (436 mg). Flash column chromatography (33% Et_2O–pentane) gave *(–)-[1*S*,7*R*]-bicyclo[5.1.0]-2-octanone* (–)-**17** (124 mg, 95%) as a colourless mobile oil; R_f 0.67, 33% EtOAc–pet. ether; $[\alpha]_D^{25}$ -36.0 (*c* 0.4, $CHCl_3$); υ_{max} (film) 2854, 2788, 1703, 1666, 1462, 1449, 1366, 1322, 1237, 1176, 1109, 1064 cm^{-1}; δ_H (500 MHz) 2.38-2.35 (2H, m, H-3), [1.98-1.88, 1.74-1.60, 1.51-1.42, 1.34-1.15 (2H, 2H, 2H, 2H, 3H respectively, 5m, H-4, H-5, H-6, H-7, H-8a)], 1.04 (1H, td, J 8.5, 5.5 Hz, H-8b); *m/z* (CI^+) 142 $[M+NH_4]^+$, 125 $[M+H]^+$, 80, 52 (Found: $[M+NH_4]^+$, 142.1229. $C_8H_{12}O$ requires $[M+NH_4]^+$, 142.1232); in agreement with previously reported data for the (+)-enantiomer.[18]

[*R$_S$,1*R**,6*R**]-1-(*S*-Phenyl-*N*-tosylsulfoximinoyl)bicyclo[4.1.0]-2-heptanone (14).** To a suspension of Diazald® (1.21 g, 5.7 mmol, 10.0 equiv) in Et_2O:EtOH (2:1) (10 ml) was added 60 % aqueous KOH (*ca.* 1.5 ml). A stream of nitrogen was bubbled through the resulting yellow effervescent mixture and into another vessel containing a stirred solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cyclohexenone **2** (220 mg, 0.57 mmol, 1.0 equiv) in THF (10 ml), held between -10 and -30˚C, over a period of *ca.* 4 h. The THF mixture turned from pink to orange to yellow. The resulting bright yellow cooled THF solution was slowly allowed to warm to rt with a rapid stream of nitrogen through it until the solution turned colourless. ^1H NMR examination of an aliquot indicated complete consumption of starting material. (The original vessel containing excess base and Diazald® was quenched by the rapid addition of 25% aqueous AcOH (50 ml).) The solvent was removed by evaporation under reduced pressure to give a pale yellow foam (249 mg). Flash column chromatography (50% EtOAc–petrol) gave, in order of elution, *[*R**S*,1*R**,6*R**]-1-(*S*-phenyl-N-tosylsulfoximinoyl)bicyclo[4.1.0]-2-heptanone* **14** (109 mg, 48%), as a colourless solid; R_f 0.57, 67% EtOAc–petrol; mp 148-152˚C; υ_{max} (film) 3094, 3064, 3026, 2950, 2925, 2890, 2864, 1703, 1593, 1476, 1449, 1316, 1301, 1234, 1215, 1152, 1106, 1087, 1068, 1050, 1015, 998, 919, 868, 759, 749, 722, 684 cm^{-1}; δ_H (500 MHz) 8.10 (2H, d with extra fine structure, J 7.5 Hz, ortho on Ph), 7.84 (2H, d with extra fine structure, J 7.5 Hz, ortho on Ts), 7.63 (1H, t, with extra fine structure, J 7.5 Hz, para on Ph), 7.53 (2H, t with extra fine structure, J 7.5 Hz, meta on Ph), 7.25 (2H, d, J 8.0 Hz, meta on Ts), 3.01-2.98 (1H, m, H-6), 2.53 (1H, ddd, 18.5, 13.0, 6.5 Hz, H-3a), 2.41-2.36 (1H, m, H-5a), 2.39 (3H, s, PhCH_3), 2.32 (1H, dt, J 18.0, 3.5 Hz, H-3b), 2.15-2.12 (1H, m, H-4a), 1.86-1.82 (1H, m, H-4b), 1.79 (1H, dd, J 9.5, 6.5 Hz, H-7a), 1.62 (1H, t, J 6.5 Hz, H-7b), 1.53-1.49 (1H, m, H-5b); δ_C (100 MHz) 199.0 (C=O), [142.8,

140.7, 137.7 (ipso Ph, ipso Ts, para Ts)], [134.0, 129.6, 129.2, 128.7, 126.5 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 50.9 (C-1), 37.9 (C-3), 25.6 (C-6), 21.5 (Ph*C*H_3), [20.6, 16.9, 16.7 (C-4, C-5, C-7)]; *m/z* (CI^+) 421 $[M+NH_4]^+$, 404 $[M+H]^+$, 297, 250, 235 $[M\text{-}Ph\text{-}PhCH_3]^+$, 206, 189 $[TsNH_2+NH_4]^+$, 160, 128, 111, 100 (Found: $[M+NH_4]^+$, 421.127572. $C_{20}H_{21}NO_4S_2$ requires $[M+NH_4]^+$, 421.125576) (Found: C, 59.60; H, 5.04; N, 3.33. $C_{20}H_{21}NO_4S_2$ requires C, 59.53; H, 5.25; N, 3.47%), and a by-product assigned as 1-(*S*-phenyl-*N*-tosylsulfoximinoyl)bicyclo[5.1.0]-3-octanone **15** (77 mg, 33%) as a colourless film; R_f 0.39, 67% EtOAc–petrol; υ_{max} (film) 2955, 2925, 2853, 1724, 1694, 1447, 1316, 1302, 1287, 1230, 1152, 1089, 1041 cm^{-1}; δ_H (270 MHz) 8.09 (2H, d with extra fine structure, J 7.5 Hz, ortho on Ph), 7.81 (2H, d with extra fine structure, J 8.0 Hz, ortho on Ts), 7.62-7.51 (1H, m, para on Ph), 7.51-7.47 (2H, m, meta on Ph), 7.22 (2H, d with extra fine structure, J 8.5 Hz, meta on Ts), 2.65 (1H, d, J 7.0 Hz, H-2a), 2.55 (1H, d, J 7.0 Hz, H-2b) overlapping with 2.58-2.50 (1H, m, H-4a), 2.39 (3H, s, PhCH_3), 2.29-0.93 (8H, several m, H-4b, H-5, H-6, H-7, H-8); *m/z* (CI^+) 435 $[M+NH_4]^+$, 418 $[M+H]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 297, 206, 189 $[TsNH_2+NH_4]^+$, 142, 125, 108.

[*RS,1*R**,6*R**,7*R**]-7-Methyl-1-(*S*-phenyl-*N*-tosylsulfoximinoyl)bicyclo[4.1.0]-2-heptanone (16).** To a stirred mixture of benzyl alcohol (996 µl, 1.04 g, 9.7 mmol, 37.5 equiv) and freshly cut Na (32 mg, 1.3 mmol, 5.2 equiv) at rt under nitrogen was added dry Et_2O (4.8 ml) and the resulting effervescent mixture allowed to stir until complete consumption of Na was observed (*ca.* 15 min). A solution of 2-ethylamino-2-methyl-*N*-nitroso-4-pentanone[12] (868 µl, 885 mg, 5.1 mmol, 20 equiv) in dry Et_2O (9.3 ml) was added dropwise and the resulting dark brown mixture was heated slowly to 55˚C. The resulting yellow distillate was collected under nitrogen into a receiver flask containing a stirred solution of (±)-2-(*S*-phenyl-*N*-tosylsulfoximinoyl)-2-cyclohexenone **2** (100 mg, 0.26 mmol, 1.0 equiv) in dry THF (15 ml), kept between -10 and -30 ˚C. After *ca.* 15 min the distillate turned colourless and heating was stopped. The resulting yellow-brown solution in the receiver flask was allowed to stir for a further 2 h, then slowly allowed to warm to rt with a rapid stream of nitrogen passing through it until the solution turned colourless. ^1H NMR examination of an aliquot indicated complete consumption of starting material. (The vessel containing excess base and *N*-nitroso compound was quenched by the rapid addition of 25% aqueous AcOH (50 ml).) The solvent was removed by evaporation under reduced pressure to give a pale yellow foam (111 mg). Flash column chromatography (40→50% EtOAc–petrol) gave *[*R**S*,1*R**,6*R**,7*R**]-7-methyl-1-(*S-*phenyl-N-*tosylsulfoximinoyl)-bicyclo[4.1.0]-2-heptanone* **16** (55 mg, 51%) as a colourless solid; R_f 0.44, 50% EtOAc–petrol; mp 150-154˚C (decomp); υ_{max} (film) 3097, 3064, 2937, 2887, 1699, 1446, 1317, 1304, 1288, 1234, 1153, 1117, 1088, 1070, 1018, 999, 816, 742, 684, 661 cm^{-1}; δ_H (400 MHz) 8.18 (2H, d with extra fine structure, J 8.0 Hz, ortho on Ph), 7.80 (2H, d, J 8.5 Hz, ortho on Ts), 7.61 (1H, t with extra fine structure, J 7.5 Hz, para on Ph), 7.50 (2H, t with extra fine stucture, J 8.0 Hz, meta on Ph), 7.23 (2H, d, J 8.0 Hz, meta on Ts), 2.83 (1H, m, H-6), 2.61 (1H, ddd, J 19.0, 12.5, 6.3 Hz, H-3a), 2.47-2.32 (2H, m, H-3b, H-4a) overlapping with 2.38 (3H, s, PhCH_3) 2.08 (1H, m, H-4b), 1.91-1.82 (2H, m, H-5a), 1.62-1.46 (1H, m, H-5b), 1.31 (3H, d, J 6.5 Hz, Me); δ_C (100 MHz) 199.3 (C=O), [142.7, 140.9, 138.6 (ipso Ph, ipso Ts, para Ts)], [133.8, 129.4, 129.2,

128.6, 126.5 (ortho Ph, ortho Ts, para Ph, meta Ph, meta Ts)], 55.6 (C-1), 38.2 (C-3), [30.6, 25.8 (C-6, C-7)], [21.5, 11.8 (Ph*C*H_3, Me)], [20.3, 17.8 (C-4, C-5)]; *m/z* (CI^+) 435 $[M+NH_4]^+$, 418 $[M+H]^+$, 313 $[TsNS(O)(Ph)(H)+NH_4]^+$, 296, 249, 206, 189 $[TsNH_2+NH_4]^+$, 142, 125 $[M-TsNS(O)(Ph)+2H]^+$, 108 (Found: $[M+H]^+$, 418.1159. $C_{21}H_{23}NO_4S_2$ requires $[M+H]^+$, 418.1147).

Acknowledgments

We thank Rhône–Poulenc Agriculture Ltd (Studentship to F. E. S.) for financial support of this research.

References

1. For a recent review of the application of sulfoximines in synthesis, including pericyclic reactions, see: Reggelin, M.; Zur, C. *Synthesis* **2000**, 1.
2. Craig, D.; Geach, N. J.; Pearson, C. J.; Slawin, A. M. Z.; White, A. J. P.; Williams, D. J. *Tetrahedron* **1995**, *21*, 6071.
3. Craig, D.; Guerrero de la Rosa, V. *Synlett* **2001**, 761.
4. Clasby, M. C.; Craig, D.; Jaxa-Chamiec, A. A.; Lai, J. Y. Q.; Marsh, A; Slawin, A. M. Z.; White, A. J. P.; Williams, D. J. *Tetrahedron* **1996**, *52*, 4769.
5. Posner, G. H. *Acc. Chem. Res.* **1987**, *20*, 72.
6. For an account of the use of sulfoximines in stereoselective synthesis, see: Pyne, S G. *Sulfur Reports* **1999**, *21*, 281.
7. (a) Johnson, C. R.; Reischer, R. J.; Kirchoff, R. A.; Katekar, G. F. *J. Am. Chem. Soc*. **1973**, *95*, 4287. (b) Johnson, C. R.; Schroeck, C. W. *J. Am. Chem. Soc*. **1973**, *95*, 7418.
8. House, H. O.; Chu, C.-Y.; Wilkins, J. M.; Umen, M. J. *J. Org. Chem.* **1975**, *40*, 1460.
9. Molander, G. A.; Hahn, G. *J. Org. Chem.* **1986**, *51*, 1135.
10. Bailey, P. L.; Clegg, W.; Jackson, R. F. W.; Meth-Cohn, O. *J. Chem. Soc., Perkin Trans. 1* **1990**, 200; **1993**, 343.
11. (a) Helquist, P. In *Comprehensive Organic Synthesis*, Trost, B. M., Ed.; Pergamon: Oxford, 1991; Vol. 4, p 951. (b) Engel, P. S. *Chem. Rev*. **1980**, *80*, 99.
12. Adamson, D. W.; Kenner, J. *J. Chem. Soc.* **1937**, 1551.
13. Crystallographic data (excluding structure factors) for all structures determined in this work have been deposited with the Cambridge Crystallographic Data Centre as the following supplementary data numbers: **6a**: CCDC 187077; (±)-**7a**: CCDC 187078; (+)-**8**: CCDC 187079; (±)-**10a**: CCDC 187080; (±)-**11b**: CCDC 187081; (±)-**13**: CCDC 187082; (±)-**14**: CCDC 187083; (±)-**16**: CCDC 187084. Copies of the data may be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, U.K. [fax: +44(0)-1223-336033 or e-mail: deposit@ccdc.cam.ac.uk].

14. Perrin, D. D.; Armarego, W. L. F. *Purification of Laboratory Chemicals*, 3rd Edn; Pergamon: Oxford, 1988.
15. Dess, D. B.; Martin, J. C. *J. Am. Chem. Soc.* **1991**, *113*, 7277.
16. Parikh, J. R.; Doering, W. von E. *J. Am. Chem. Soc.* **1967**, *89*, 5505.
17. Zhou, Q.-L.; Pfaltz, A. *Tetrahedron* **1994**, *50*, 4467.
18. Mash, E. A.; Nelson, K. A. *J. Am. Chem. Soc.* **1985**, *107*, 8256.