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Stereocontrolled Synthesis of Novel Enantiomerically Pure Sulfides and Selenides from (+)-Camphor and (+)-Camphor-10-sulfonyl chloride.

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Abstract: Synthetic approaches to novel enantiomerically pure sulfides and selenides derived from (+)-camphor and (+)-camphor-10-sulfonate esters are described. Lewis acid mediated hemiacetal formation between a camphor-derived ketone and a thiol or selenol, and subsequent *in situ* reduction using triethylsilane selectively gives the *exo*-sulfide or -selenide in moderate overall yields. The initial sulfonate ester products can be converted into the corresponding sulfones by subsequent treatment with Grignard or organolithium reagents.

Organosulfur and organoselenium compounds are used extensively in organic synthesis.[1] More recently, there has been an increasing number of reports of their use in asymmetric synthesis, for example, organosulfur compounds have been used in the preparation of chiral epoxides,[2] aziridines,[3] as catalysts for addition of organozinc reagents to aldehydes,[4] other organometallic mediated processes,[5] and for the synthesis of other chiral sulfides, including some of our own work on asymmetric sulfenylation.[6] Organoselenium derivatives have been used for the preparation of enantiomerically enriched allylic alcohols *via* 2,3-sigmatropic rearrangements of allylic selenoxides,[7] or allenes and alkenes by elimination of selenenic acid,[8] *via* enantiomerically enriched selenoxides produced either by asymmetric oxidation or chirality transfer. Chiral diselenides have also recently been reported as enantioselective selenylating agents[9] and selenides have been shown to act as catalysts for the asymmetric addition of organozinc reagents to aldehydes.[10] Our interest in the chemistry of selenoxides[11] led us to develop improved routes to

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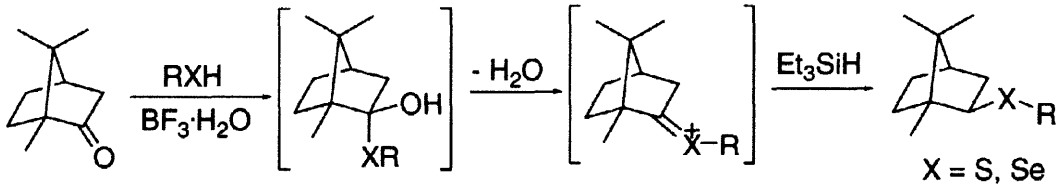
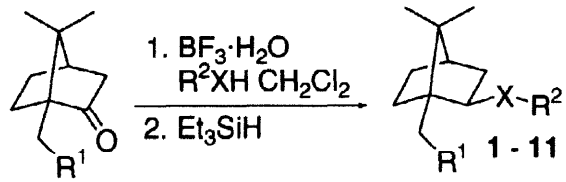
new homochiral selenides and sulfides which may be of use in developing our own asymmetric reactions, and in other areas of sulfur and selenium mediated asymmetric synthesis.

We decided to investigate a reaction originally reported by Olah[12] which utilises the Lewis acid catalysed hemithioacetal formation of simple ketones and a thiol, and *in situ* reduction of the derived thionium ion with triethylsilane. Although this reaction had only been reported for simple sulfide formation, we believed it also had potential for selenide synthesis. Adaptation of this reaction for the synthesis of enantiomerically pure sulfides and selenides looked particularly promising as it had been shown to work well with sterically hindered systems, and had significant potential for diastereocontrol (*vide infra*). Using camphor as our original chiral ketone, we investigated sulfide and selenide formation with various thiols and selenols. We reasoned that *in situ* reduction of the thionium or selonium ion formed from camphor derivatives should occur from the less hindered face to give selectively *exo*-sulfide and selenide products (Scheme 1).



Scheme 1

After considerable experimentation, we were able to achieve acceptable yields (*ca.* 50%) of the desired sulfides and selenides derived from camphor (Table 1, entries 1-5). As predicted, the products were obtained as single diastereoisomers (*vide infra*). The stereochemistry of the newly introduced heteroalkyl group was confirmed to be *exo* by ^{1}H nOe experiments (Fig. 1). Importantly, no enhancement of the proton at C-2 was observed when the bridgehead methyl groups were irradiated. The main byproduct of the reaction (up to 30%) was campheol formed by direct acid catalysed reduction of the carbonyl group.



Entry	X	R^1	R^2	Yield (%)[a]	product
1	S	H	Ph	40	**1**
2	S	H	CH_2Ph	57	**2**
3	S	H	^nBu	47	**3**
4	Se	H	Ph	60	**4**
5	Se	H	CH_2Ph	47	**5**
6	S	SO_2Ph	Ph	0[b]	**6**
7	S	SO_2OPh	Ph	27	**7**
8	Se	SO_2OPh	Ph	45	**8**
9	Se	SO_2OPh	CH_2Ph	20	**9**
10	Se	SO_2OPr^i	Ph	30	**10**
11	Se	SO_2OPr^i	CH_2Ph	30	**11**

[a] Isolated yield of single diastereoisomers
[b] Expected product **6** can be prepared by an alternative route (Scheme 3)

Table 1

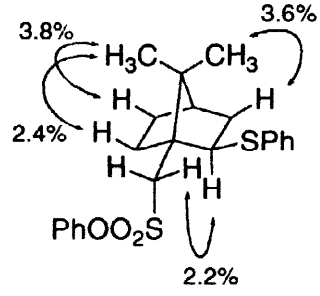
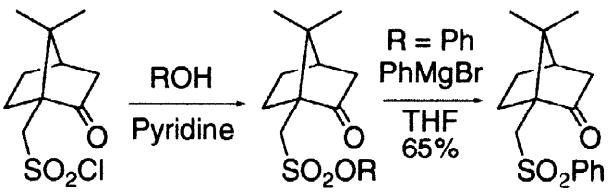


Figure 1. nOes for **7**

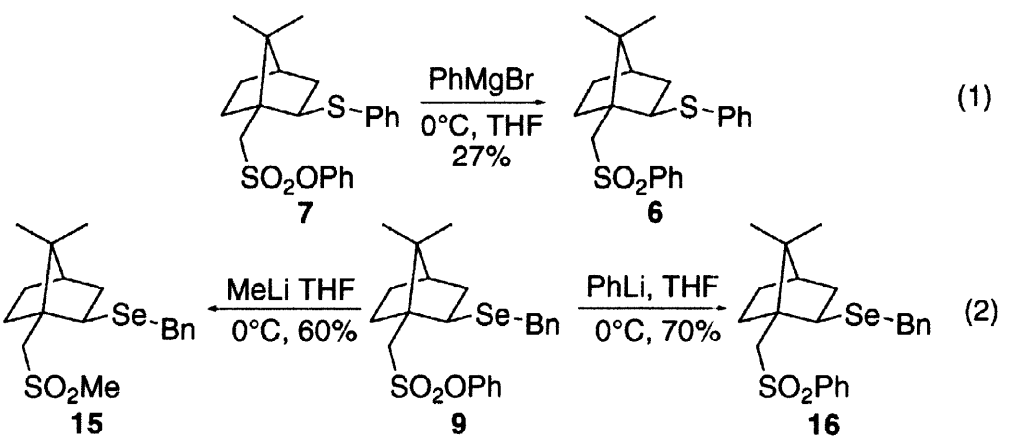
We next turned our attention to camphor-10-sulfonic acid derivatives, the substrates being prepared by reaction of phenol (to give **12**) or 2-propanol (to give **13**) with commercially available (+)-camphor-10-sulfonyl chloride (Scheme 2). Substrates **12** and **13** turned out to be considerably less reactive in the thiol and selenol addition reactions, with only modest yields of the desired sulfides and selenides being isolated. However, the addition was again found to occur with complete diastereocontrol, the *exo*-isomer being the only product (Table 1, entries 6-11). Although the yields of sulfide and selenide were relatively low, the starting materials were readily available in large quantities, and isolation of the products was simple.



12 R = Ph, 76%
13 R = Pr^{i}, 75%

Scheme 2

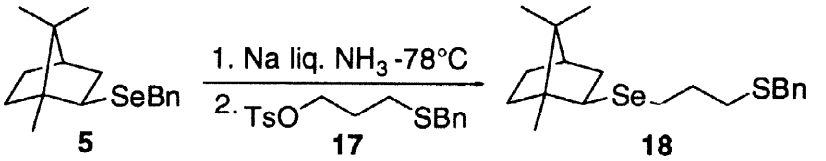
The phenyl sulfone **14** was conveniently prepared from sulfonate **12** by treatment with phenyl magnesium bromide (Scheme 2) . However, the attempted addition of thiophenol to phenyl sulfone **14** gave none of the desired product (Table 1, entry 6). This was not a serious problem as the desired product **6** was later prepared by an alternative route (scheme 3, equation 1)



Scheme 3

Products derived from thiol and selenol addition to sulfonate **12** could be further transformed into sulfones by addition of Grignard or organolithium reagents. Phenyl sulfonate **7** could be converted into sulfone **6** by treatment with phenyl magnesium bromide. Interestingly, phenyl sulfonate **9** remained unchanged upon treatment with Grignard reagents, however, the use of methyl- or phenyl-lithium gave the corresponding phenyl and methyl sulfones in good yield (Scheme 3, equation 2).

The enantiomerically pure sulfides and selenides resulting from this study are potentially useful sources for related optically active sulfur and selenium containing compounds. For example, benzyl selenide derivative **5** is readily converted to the sodium selenolate by reductive cleavage, and can be trapped with electrophiles such as tosylate **17** to give the interesting mixed thioselenide **18** (Scheme 4).



5 17 18

THF, 0°C, 53%

Scheme 4

In conclusion, we have described the preparation of a variety of novel homochiral sulfides and selenides from (+)-camphor and (+)-camphor-10-sulfonyl chloride. Applications of these new enantiomerically pure sulfur and selenium derivatives in asymmetric synthesis are currently under development in our group, and will be reported in due course.

Experimental Section.

General Procedures and Instrumentation.

Melting points were determined on a Reichert hot stage apparatus and are uncorrected. Nuclear magnetic resonance spectra were recorded on a General Electric QE 300 spectrometer or a Bruker AM400 spectrometer. Chemical shifts are expressed in parts per million (ppm) downfield of tetramethylsilane for ^{1}H resonances, and referenced to the central peak of the deuterated chloroform triplet for ^{13}C resonances. Infrared spectra were recorded on a Philips PU 8706 infrared spectrophotometer and signals were referenced to the polystyrene 1601 cm^{-1} absorbtion. Mass spectra were recorded on a VG Autospec mass spectrometer. Optical rotations were measured on an Optical Activity AA-1000 polarimeter and calibrated using a solution of camphor in ethanol of known rotation, $[\alpha]_D^{20}$ +44.1 (*c* 10, ethanol). Microanalyses were carried out at the University of Leeds Microanalytical Laboratory. All C, H, N, and S analytical figures are percentage values. Flash chromatography signifies column chromatography on Merck silica gel (230-400) or equivalent according to the method of Still.[13] Thin layer chromatography was carried out using precoated aluminium (or plastic) backed silica plates which were visualised using either ultraviolet light, permanganate or anisaldehyde stain. All glassware was washed with acetone, oven dried overnight at 125°C and allowed to cool under a stream of dry nitrogen prior to use. Reactions were carried out under a positive pressure of dry oxygen-free nitrogen. Solvents were removed under reduced pressure using a Büchi rotary evaporator at water aspirator pressure, followed by drying under high vacuum at 0.5 mm Hg. Solvents were purified prior to use by established procedures[14] and other reagents used as received. Petroleum ether refers to petroleum ether (b.p. 40-60°C) unless otherwise stated.

Experimental details.

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-phenylsulfanylbicyclo[2.2.1]heptane (1, Table 1, entry 1)

To a solution of (1*R*)-(+)-camphor (413 mg, 2.71 mmol) in dry CH_2Cl_2 (5 ml) under nitrogen was added thiophenol (320 mg, 2.90 mmol). The mixture was cooled to 0 °C before $BF_3.H_2O$ (249 mg, 0.166 ml, 2.90 mmol) was added dropwise. The reaction was then left to stir at room temperature for 1h before triethylsilane (460 mg, 0.59 ml, 3.95 mmol) was added after which it was left stirring for 3 days. The mixture was then poured onto ice-water (5 ml) and extracted with CH_2Cl_2 (3 x 10 ml), the organic layer was washed with water (2 x 7 ml), $NaHCO_3$ (10% aqueous solution, 3 x 5 ml), water (2 x 7 ml), dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Chromatography on silica gel with petroleum ether-ethyl acetate (99:1) as the eluant yielded **1** (266 mg, 1.08 mmol, 40%) as a colourless oil: δ_H(300 MHz; $CDCl_3$)

0.85 (3H, s, MeC-1), 1.01 (3H, s, $(Me)_2$C-7), 1.04 (3H, s, $(Me)_2$C-7), 1.16-1.25 (2H, m, CH_2-5 or CH_2-6), 1.66-1.75 (3H, m, CH-4 and CH_2-5 or CH_2-6), 1.99 (2H, d, J 7.2, CH_2-3), 3.22 (1H, dd, J 9.6, 6.0, CH-2), 7.12 (1H, t, J 6.5, ArH *para*), 7.23 (2H, t, J 7.9, ArH *meta*), 7.34 (2H, d, J 7.3, ArH *ortho*); δ_C(75 MHz; $CDCl_3$) 13.9 (1, *Me*C-1), 20.14 (1, $(Me)_2$C-7), 20.45 (1, $(Me)_2$C-7), 27.30 (1, CH_2-5 or CH_2-6), 38.39 (1, CH_2-5 or CH_2-6), 40.87 (1, CH_2-3), 45.73 (1, CH-4), 47.39 (1, C-7), 49.66 (1, C-1), 55.93 (1, CH-2), 125.27 (1, ArC- *para*), 128.52 (2, ArC- *meta*), 129.01 (2, ArC- *ortho*), 139.16 (1, ArC- *ipso*); ν_{max}(neat)/cm^{-1} 3100 (m, C-H), 2980 (s, C-H), 2900 (s), 1580 (s, C=C), 1475 (s), 1390 (s), 1270 (m), 1090 (s), 1020 (s), 790 (w), 730 (s), 690 (s); *m/z* (EI) 246 (M^+, %), 186, 137, 121, 109, 95, 81; $[\alpha]_D^{20}$ -9.3 (*c* 2.1 in $CHCl_3$); (Found: C, 77.75; H, 9.05; S, 12.85. Calc. for $C_{16}H_{22}S$: C, 77.99; H, 9.00; S, 13.01%)

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-benzylsulfanylbicyclo[2.2.1]heptane (2, Table 1, entry 2)

A similar procedure to **1** using (1*R*)-(+)-camphor (2.82 g, 18.5 mmol), benzylthiol (2.53 g, 20.4 mmol), $BF_3.H_2O$ (1.74 g, 1.16 ml, 20.4 mmol), and triethylsilane (3.26 g, 4.18 ml, 28.0 mmol) gave **2** (2.73 g, 10.5 mmol, 57%) as a colourless oil: δ_H(300 MHz; $CDCl_3$) 0.80 (3H, s, CMe-1), 0.96 (3H, s, $(Me)_2$C-7), 0.97 (3H, s, $(Me)_2$C-7), 1.01-1.06 (2H, m, CH_2-5 or CH_2-6), 1.62-1.67 (3H, m, CH-4 and CH_2-5 or CH_2-6), 1.77-1.80 (2H, m, CH_2-3), 2.60 (1H, dd, J 8.2, 6.1, CH-2), 3.71 (2H, s, CH_2Ph), 7.21-7.23 (1H, m, ArH *para*), 7.26-7.32 (4H, m, ArH); δ_C(75 MHz; $CDCl_3$) 13.76 (1, *Me*C-1), 20.13 (1, $(Me)_2$C-7), 20.38 (1, $(Me)_2$C-7), 27.21 (1, CH_2-5 or CH_2-6), 38.26 (1, CH_2-5 or CH_2-6), 38.62 (1, CH_2Ph), 40.41 (1, CH_2-3), 45.67 (1, CH-4), 47.15 (1, C-7), 49.22 (1, C-1), 53.14 (1, CH-2), 126.56 (1, ArC- *para*), 128.14 (2, ArC- *meta*), 128.75 (2, ArC- *ortho*), 138.63 (1, ArC- *ipso*); ν_{max}(neat)/cm^{-1} 3060 (s, C-H), 2980 (s, CH), 2900 (s), 1601 (m, C=C), 1490 (m), 1450 (s), 1380 (m), 1230 (w), 1065 (m), 1020 (m), 760 (m), 690 (s); *m/z* (EI) 260 (M^+, 22%), 170 (12), 169 (93), 150 (20), 137 (27), 135 (24), 109 (21), 107 (11), 95 (27), 93 (24), 92 (13), 91 (100), 81 (41), 79 (13), 67 (17), 65 (13), 55 (10), 41 (21); $[\alpha]_D^{20}$ -21.1 (*c* 1.8 in $CHCl_3$); (Found: C, 77.85; H, 9.45; S, 12.05. Calc. for $C_{17}H_{24}S$: C, 78.40; H, 9.29; S, 12.31%)

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-*n*-butylsulfanylbicyclo[2.2.1]heptane (3, Table 1, entry 3)

A similar procedure to **1** using (1*R*)-(+)-camphor (1.85 g, 12.2 mmol), 1-butanethiol (1.21 g, 13.4 mmol), $BF_3.H_2O$ (1.14 g, 0.76 ml, 13.4 mmol), and triethylsilane (2.02 g, 2.59 ml 17.4 mmol) gave **3** (1.30 g, 5.71 mmol, 47%) as a colourless oil: δ_H(300 MHz; $CDCl_3$) 0.82 (3H, s, MeC-1), 0.91 (3H, s, $(Me)_2$C-7), 0.97 (3H, s, $(Me)_2$C-7), 0.99 (3H, t, J 7.4, CH_2CH_3), 1.03-1.16 (2H, m, CH_2-5 or CH_2-6), 1.37-1.42 (2H, m, CH_2CH_3), 1.53-1.57 (2H, m, CH_2-5 or CH_2-6), 1.67-1.70 (3H, m, CH-4 and CH_2-5 or CH_2-6), 1.84-1.89 (2H, m, $CH_2CH_2CH_3$), 2.51 (2H, td, J 7.2, 4.2, CH_2S), 2.62 (1H, dd, J 9.3, 6.1, CH-2); δ_C(75 MHz; $CDCl_3$) 13.60 (1, CH_2CH_3), 13.76 (1, *Me*C-1), 20.11 (1, $(Me)_2$C-7), 20.28 (1, $(Me)_2$C-7), 21.95 (1, CH_2CH_3), 27.26 (1, CH_2-5 or CH_2-6), 31.89 (1, $CH_2CH_2CH_3$), 34.42 (1, CH_2S), 38.41 (1, CH_2-5 or CH_2-6), 40.87 (1, CH_2-3), 45.71 (1, CH-4), 47.04 (1, C-7), 49.11 (1, C-1), 54.49 (1, CH-2); ν_{max}(neat)/cm^{-1} 2985 (s, C-H), 2953 (s, C-H), 2874 (s), 1455 (s), 1389 (m), 1372 (m), 1311 (m), 1273 (w), 1254 (w), 1222 (m), 1080 (w), 930 (m), 801 (s); *m/z* 226 (M^+, 88%), 211 (10), 170 (33), 169 (100), 137 (70), 136 (60), 135 (17), 121 (74), 117 (13), 116 (75), 109 (21), 108 (34), 107 (21), 101 (41), 95 (76), 93 (59), 81 (87), 67 (43), 60 (48), 41 (66), 39 (18); $[\alpha]_D^{20}$ -39.4 (*c* 3.6 in $CHCl_3$); (Found: C, 74.4; H, 11.6; S, 14.2. Calc. for $C_{14}H_{26}S$: C, 74.27; H, 11.57; S, 14.16%)

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-phenylselenylbicyclo[2.2.1]heptane (4, Table 1, entry 4)

A similar procedure to **1** using (1*R*)-(+)-camphor (2.44 g, 16.0 mmol), phenyl selenol (2.55 g, 16.0 mmol), $BF_3.OEt_2.H_2O$ (2.10 ml, 32.0 mmol) and triethylsilane (3.85 ml, 24.0 mmol) gave **4** (2.80 g, 9.60 mmol, 60%) as a colourless oil; δ_H (400 MHz; $CDCl_3$) 0.86 (3H, s, MeC-1), 1.01 (3H, s, $(Me)_2$C-7), 1.05 (3H, s, $(Me)_2$C-7), 1.14-1.19 (1H, m, CH-4), 1.22-1.33 (2H, m, CH_2-5 or CH_2-6), 1.72-1.76 (2H, m, CH_2-5

or CH_2-6), 1.99-2.06 (1H, m, CH_2-3-*axial*), 2.15-2.20 (1H, m, CH_2-3-equat), 3.30 (1H, dd, J 9.2, 5.8 Hz, CH-2), 7.21-7.27 (3H, m, ArH) and 7.51-7.54 (2H, m, ArH); δ_C (100 MHz; $CDCl_3$) 15.64 (*Me*C-1), 20.05 ((*Me*)$_2$C-7), 20.49 ((*Me*)$_2$C-7), 27.41 (CH_2-5 or CH_2-6), 38.41 (CH_2-5 or CH_2-6), 41.48 (CH_2-3), 46.33 (CH-4), 47.48 (C-1 or C-7), 49.60 (C-1 or C-7), 54.13 (CH-2), 126.48 (ArCH-*para*), 128.87 (ArCH-*meta*), 132.73 (ArCH-*ortho*) and 133.63 (ArC-*ipso*); ν_{max} (neat)/cm^{-1} 2940-2860s (C-H), 1600w (C=C), 1450s, 1400m, 1360m, 1220w, 1170m, 1060w and 1010m; MS (EI) (Found: M$^+$, 294.089. Calc. for $C_{16}H_{22}Se^{80}$: M, 294.089) *m/z* 294 (M$^+$, 5%), 157(11), 155(6), 138(12), 137(87), 95(36), 93(12), 91(11), 82(9), 81(100), 78(13), 77(20), 69(27), 67(30) and 43(18); $[\alpha]_D^{20}$ -12.0 (*c* 2.1, $CHCl_3$).

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-benzylselenylbicyclo[2.2.1]heptane (5, Table 1, entry 5)

A similar procedure to **1** using (1*R*)-(+)-camphor (500 mg, 3.28 mmol), benzyl selenol (0.57 ml, 3.65 mmol), $BF_3.OEt_2.H_2O$ (0.48 ml, 7.30 mmol) and triethyl silane (0.88 ml, 5.48 mmol) gave selenide **5** (473 mg, 1.54 mmol, 47%) as a colourless oil; δ_H (400 MHz; $CDCl_3$) 0.81 (3H, s, MeC-1), 0.94 (6H, s, (Me)$_2$C-7), 1.12 (2H, br.d, J 10.0 Hz, CH_2-5 or CH_2-6), 1.67-1.72 (3H, m, CH_2-5 or CH_2-6 and CH-4), 1.84 (1H, dd, J 13.3, 9.3 Hz, CH_2-3-*ax*), 1.93-1.99 (1H, m, CH_2-3-*eq*), 2.85 (1H, dd, J 9.24, 5.9 Hz, CH-2), 3.80 (2H, s, $PhCH_2$), 7.17-7.23 (1H, m, ArH-*para*), and 7.26-7.31 (4H, m, ArH); δ_C (100 MHz; $CDCl_3$) 15.31 (*Me*C-1), 20.08 ((*Me*)$_2$C-7), 20.46 ((*Me*)$_2$C-7), 27.37 (CH_2-5 or CH_2-6), 29.90 (CH_2-5 or CH_2-6), 38.33 (Ar*CH*$_2$), 41.03 (CH_2-3), 46.23 (CH-4), 47.32 (C-7), 49.09 (C-1), 49.22 (CH-2). 126.44 (ArCH-*para*), 128.34 (ArCH-*meta*), 128.84 (ArCH-*ortho*) and 139.81 (ArC-*ipso*); ν_{max} (neat)/cm^{-1} 2940-2860s (C-H), 1600w (C=C), 1450s, 1400m, 1360m, 1220w, 1170m, 1060w and 1010m; MS (EI) (Found: M$^+$, 308.104. Calc. for $C_{17}H_{24}{}^{80}Se$: M, 308.104) *m/z* 308 (M$^+$, 7%), 137(97), 91(54), 81(100), 67(21), 55(9) and 41(19); $[\alpha]_D^{20}$ -3.9 (*c* 0.8, $CHCl_3$).

(1*S*)-(7,7-Dimethyl-2-oxobicyclo[2.2.1]hept-1-yl)methane sulfonic acid phenyl ester (**12**)[15]

To a solution of phenol (1.88 g, 0.02mol, 1.0eq) in pyridine (50 ml) at -5°C was added (1*S*)-(+)-camphor-10-sulfonyl chloride (5.00 g, 0.02mol, 1.0eq). After maintaining the reaction at 0°C for a further 2 h, H_2O (50 ml) was added gradually and the aqueous layer then extracted with CH_2Cl_2 (3x10 ml). The combined organic extracts were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [silica gel, 10% ethyl acetate / 90% petroleum ether (bp 40-60°C) eluant] gave **12** as a colourless, crystalline solid (4.68 g, 0.02mol, 76%); δ_H (300 MHz; $CDCl_3$) 0.91 (3H, s, (Me)$_2$C-7), 1.16 (3H, s, (Me)$_2$C-7), 1.45-1.58 (1H, m, CH_2-5 or CH_2-6), 1.72-1.77 (1H, m, CH_2-5 or CH_2-6), 2.01-2.17 (3H, m, CH-4 and CH_2-5 or CH_2-6), 2.39-2.57 (2H, CH_2-6), 3.20 (1H, d, J 15.0 Hz, CH_2-10), 3.81 (1H, d, J 15.0 Hz, CH_2-10) and 7.26-7.45 (5H, m, ArH); δ_C (100 MHz; $CDCl_3$) 19.41 ((*Me*)$_2$C-7), 19.65 ((*Me*)$_2$C-7), 24.88 (CH_2-5 or CH_2-6), 26.58 (CH_2-5 or CH_2-6), 42.17 (CH_2-3), 42.53 (CH-4), 47.26 (CH_2-10), 47.68 (C-7), 57.83 (C-1), 121.77 (ArC-*para*), 126.91 (ArC-*meta*), 129.67 (ArC-*ortho*), 148.99 (ArC-*ipso*) and 213.66 (C-2); ν_{max} (neat)/cm^{-1} 2940m (C-H), 1730s (C=O), 1570m (C=C), 1470m (C=C), 1440w, 1350s (SO_2-O), 1270w, 1180m (SO_2-O), 1155m, 1130s, 1040w, 1010w, 900w and 850s; MS (EI) *m/z* 308 (M$^+$, 0.3%), 215(100), 151(72), 133(16), 109(97), 107(44), 95(32), 94(43), 93(41), 81(90), 79(36), 67(25), 65(57), 55(42), 41(38) and 39(55); $[\alpha]_D^{20}$ +38.2 (*c* 2.0, $CHCl_3$), lit. [15] +40.6 (*c* 2.5, $CHCl_3$); (Found: C, 62.35; H, 6.5; S, 10.25. $C_{16}H_{20}O_4S$ requires C, 62.32; H, 6.54; S, 10.40%).

(1*S*, 2*R*)-(7,7-Dimethyl-2-*exo*-phenylsulfanylbicyclo[2.2.1]hept-1-yl) methane sulfonic acid phenyl ester (7, Table 1, entry 7)

A similar procedure to **1** using **12** (515 mg, 1.67 mmol) in CH_2Cl_2 (5 ml), thiophenol (368 mg, 3.34 mmol), $BF_3.H_2O$ (314 mg, 0.21 ml, 3.34 mmol) and triethylsilane (427 mg, 0.55 ml, 3.67 mmol) gave **7** (180 mg, 0.45 mmol, 27%) as a colourless oil: δ_H(300 MHz; $CDCl_3$) 0.92 (3H, s, (Me)$_2$C-7), 1.08 (3H, s,

$(Me)_2C$-7), 1.22-1.30 (2H, m, CH_2-5 or CH_2-6), 1.70-1.85 (3H, m, CH-4 and CH_2-5 or 6-CH_2-6), 2.10-2.30 (2H, m, CH_2-3), 3.32 (1H, d, J 15.1, CH_2-10), 3.48-3.55 (1H, m, CH-2), 4.20 (1H, d, J 15.1, CH_2-10), 7.18-7.41 (10H, m, ArH); ν_{max}(neat)/cm^{-1} 3040 (m), 2930 (s, C-H), 2860 (m), 1940 (w), 1570 (s, C=C), 1470 (s), 1430 (m), 1360 (s, SO_3), 1340 (s, SO_3), 1300 (w), 1270 (w), 1240 (w), 1180 (m), 1130 (s, SO_3), 1060 (m), 1015 (s), 900 (m), 850 (s), 780 (m), 680 (s); MS (EI) (Found: M$^+$, 402.131. Calc. for $C_{22}H_{26}O_3S_2$: M, 402.131; *m/z* 402 (M$^+$, 15%), 309 (6), 293 (10), 136 (12), 135 (100), 110 (7), 107 (18), 93 (29), 91 (10), 79 (18); $[\alpha]_D^{20}$ +1.9 (*c* 2.1 in $CHCl_3$).

(1*R*, 2*R*)-(7,7-Dimethyl-2-*exo*-phenylselenylbicyclo[2.2.1]hept-1-yl)methane sulfonic acid phenyl ester (8, Table 1, entry 8)

A similar procedure to **1** using **12** (250 mg, 0.81 mmol), phenyl selenol (0.10 ml, 0.90 mmol), $BF_3.OEt_2.H_2O$ (0.08 ml, 0.90 mmol) and triethylsilane (0.20 ml, 1.22 mmol) gave **8** (164 mg, 0.37 mmol, 45%) as a colourless oil; δ_H (300 MHz; $CDCl_3$) 0.94 (3H, s, $(Me)_2C$-7), 1.01 (3H, s, $(Me)_2C$-7), 1.22-1.30 (2H, m, CH_2-5 or CH_2-6), 1.75-2.10 (3H, m, CH-4 and CH_2-5 or CH_2-6), 2.18-2.46 (2H, m, CH_2-3), 3.37 (1H, d, J 15.0 Hz, CH_2-10), 3.58 (1H, dd, J 12.0, 6.0 Hz, CH-2), 4.22 (1H, d, J 15.0 Hz, CH_2-10) and 7.18-7.54 (10H, m, ArH); ν_{max} (neat)/cm^{-1} 2940-2860s (C-H), 1570s (C=C), 1470s (C=C), 1440m, 1420m, 1360s (SO_2-O), 1340s, 1260w, 1170m, 1150s (SO_2-O), 1130s, 1050w, 1010m and 840s; MS (EI) (Found: M$^+$, 450.077. Calc. for $C_{22}H_{26}O_3S^{80}Se$: M, 450.076) *m/z* 450 (M$^+$, 4.3%), 293(18), 157(10), 135(100), 107(26), 93(42), 79(26), 65(13) and 55(9). Major by-product. **(1*S*, 2*R*)-(7,7-dimethyl-2-hydroxybicyclo[2.2.1]hept-1-yl)methane sulfonic acid phenyl ester** was obtained as a colourless oil (76.0 mg, 0.24 mmol, 30%); δ_H (400 MHz; $CDCl_3$) 0.86 (3H, s, $(Me)_2C$-7), 1.08 (3H, s, $(Me)_2C$-7), 1.13-1.21 (1H, m), 1.50-1.55 (1H, m), 1.76-1.85 (5H, m), 2.84 (1H, br.s, OH), 3.17 (1H, d, J 13.6 Hz, CH_2-10), 3.73 (1H, d, J 13.7 Hz, CH_2-10), 4.12 (1H, dd, J 8.0, 4.2 Hz, CH-2), 7.27-7.35 (3H, m, ArH) and 7.40-7.45 (2H, m, ArH); δ_C (100 MHz; $CDCl_3$) 19.86 ((*Me*)$_2$C-7), 20.55 ((*Me*)$_2$C-7), 27.30 (CH_2-5 or CH_2-6), 30.26 (CH_2-5 or CH_2-6), 39.30 (CH_2-3), 44.48 (CH-4), 48.98 (C-7), 50.02 (C-1), 50.03 (CH_2-10), 76.14 (CH-2), 121.99 (ArCH-*para*), 127.26 (ArCH-*meta*), 129.98 (ArCH-*ortho*) and 149.01 (ArC-*ipso*); ν_{max} (neat)/cm^{-1} 3440br.s (OH), 2940-2860m (C-H), 1580m (C=C), 1480s (C=C), 1350s, 1330s, 1180s, 1160s, 1130s, 1060m, 1010m and 860s; MS (EI) *m/z* 310 (M$^+$, 0.5%), 279(1), 251(2), 215(3), 153(4), 108(37), 94(100), 79(15), 65(16) and 41(23); (Found: C, 61.65; H, 7.00; S, 10.30. Calc. for $C_{16}H_{22}SO_4$: C, 61.91; H, 7.14; S, 10.33%).

(1*R*, 2*R*)-(7,7-Dimethyl-2-*exo*-benzylselenylbicyclo[2.2.1]hept-1-yl)methane sulfonic acid phenyl ester (9, Table 1, entry 9)

A similar procedure to **1** using **12** (250 mg, 0.81 mmol), benzyl selenol (139 mg, 0.90 mmol), $BF_3.OEt_2.H_2O$ (0.08 ml, 0.90 mmol) and triethylsilane (0.20 ml, 1.22 mmol) gave **9** (75.0 mg, 0.16 mmol, 20%) as a colourless oil; δ_H (300 MHz; $CDCl_3$) 0.85 (3H, s, $(Me)_2C$-7), 0.89 (3H, s, $(Me)_2C$-7), 1.23-1.27 (1H, m, CH-4), 1.69-1.91 (4H, m, CH_2-5 and CH_2-6), 1.99-2.10 (1H, m. CH_2-3-*eq*), 2.22-2.35 (1H, m, CH_2-3-*ax*), 3.22 (1H, dd, J 9.5, 5.6 Hz, CH-2), 3.32 (1H, d, J 14.1 Hz, CH_2-10), 3.83 (1H, d, J 11.1 Hz, ArCH_2), 3.89 (1H, d, J 11.4 Hz, ArCH_2), 4.41 (1H, d, J 14.1 Hz, CH_2-10) and 7.17-7.46 (10H, m, ArH); ν_{max} (neat)/cm^{-1} 2910-2820s (C-H), 1570m (C=C), 1470m (C=C), 1440m, 1350s, 1340m, 1170m, 1150m, 1130s, 1050w, 1010w, 890w and 840; MS (EI) (Found: M$^+$, 462.093. Calc. for $C_{23}H_{28}SO_3{}^{78}Se$: M, 462.093) *m/z* 464 (M$^+$, 26%), 293(22), 135(100), 107(24), 91(75), 77(12), 65(22) and 55(8).

(1*S*)-(7,7-Dimethyl-2-oxobicyclo[2.2.1]hept-1-yl)methane sulfonic acid *iso*-propyl ester (13)

To a solution of propan-2-ol (1.20 g, 0.02mol, 1.0 eq) in pyridine (50 ml) at -5 °C was added (1*S*-(+)-camphor-10-sulfonyl chloride (5.00 g, 0.02mol, 1.0 eq). After maintaining the reaction at 0 °C for a

further 2 h, H_2O (50 ml) was added gradually and the aqueous layer then extracted with CH_2Cl_2 (3x10 ml). The combined organic extracts were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [silica gel, 10% ethyl acetate / 90% petroleum ether (bp 40-60 °C) eluant] gave **13** (5.48 g, 0.020mol, 75%) as a colourless, crystalline solid, mp 45.0-46.0 °C; δ_H (300 MHz; $CDCl_3$) 0.89 (3H, s, $(Me)_2C$-7), 1.14 (3H, s, $(Me)_2C$-7), 1.42 (3h, d, J 6.3 Hz, $(Me)_2CH$), 1.43 (3H, d, 6.0 Hz, $(Me)_2CH$), 1.61-1.70 (2H, m, CH_2-5 or CH_2-6), 1.99-2.18 (3H, m, CH-4 and CH_2-5 or CH_2-6), 2.43 (1H, app.d, 15.0 Hz, CH_2-3-*ax*), 2.52 (1H, td, 14.7, 3.3 Hz, CH_2-3-*eq*), 2.99 (1H, d, J 15.0 Hz, CH_2-10), 3.60 (1H, d, J 15.0 Hz, CH_2-10) and 5.00 (1H, heptet, J 6.0 Hz, $(Me)_2CH$); δ_C (63 MHz; $CDCl_3$) 19.64 ($(Me)_2$C-7), 19.85 ($(Me)_2$C-7), 23.10 ($(Me)_2CH$), 23.16 ($(Me)_2CH$), 24.83 (CH_2-5 or CH_2-6), 26.80 (CH_2-5 or CH_2-6), 42.44 (CH_2-3), 42.70 (CH-4), 47.78 (C-7), 47.82 (CH_2-10), 57.97 (C-1), 76.87 ($(Me)_2CH$) and 214.33 (C-2); ν_{max} (CH_2Cl_2)/cm^{-1} 2980-2900s (C-H), 1750s (C=O), 1475m, 1560m, 1360s ($(Me)_2C$), 1290s, 1230m, 1210m, 1180s, 1100s, 1070w, 1050w, 910s, 890s and 810s; MS *m/z* 274 (M^+, 2%), 232 (8), 215(10), 168(13), 151(85), 133(14), 123(77), 109(100), 93(44), 81(78), 67(52), 55(36) and 43(80); (Found: C, 56.95; H, 8.20; S, 11.80. Calc. for $C_{13}H_{22}O_4S$: C, 56.91; H, 8.08; S, 11.69%).

(1*R*, 2*R*)-(7,7-Dimethyl-2-*exo*-phenylselenylbicyclo[2.2.1]hept-1-yl)methane sulfonic acid iso-propyl ester (10, Table 1, entry 10)

A similar procedure to **1** using **13** (222 mg, 0.81 mmol), phenyl selenol (0.10 ml, 0.90 mmol), $BF_3.OEt_2.H_2O$ (0.08 ml, 0.90 mmol) and triethylsilane (0.20 ml, 1.22 mmol) gave **10** (101 mg, 0.24 mmol, 30%) as a colourless oil, δ_H (300 MHz; $CDCl_3$) 0.93 (3H, s, $(Me)_2C$-7), 1.01 (3H, s, $(Me)_2C$-7), 1.20-1.32 (1H, m, CH_2-5 or CH_2-6), 1.34-1.38 (6H, m, $(Me)_2CH$), 1.63-1.82 (3H, m, CH_2-5 or CH_2-6 and CH-4), 2.13-2.30 (2H, m, CH_2-3-*ax*), 2.36-2.39 (1H, m, CH_2-3-*eq*), 3.14 (1H, d, J 14.1 Hz, CH_2-10), 3.62 (1H, dd, J 9.3 Hz, 5.2 Hz, 1H), 3.94 (1H, J 14.1 Hz, CH_2-10), 4.97 (1H, hept, J 6.6 Hz, $(Me)_2CH$), 7.22-7.28 (3H, m, ArH) and 7.62-7.65 (2H, m, ArH); ν_{max} (thin film)/cm^{-1} 2940-2860s (C-H), 1600w (C=C), 1570m, 1460m, 1380m ($(Me)_2CH$), 1350s ($(Me)_2CH$), 1170s, 1090m, 910s and 870s; MS (EI) (Found: M^+, 416.093. Calc. for $C_{19}H_{28}O_3S^{80}Se$: M, 416.092) *m/z* 416 (M^+, 4%), 217(78), 161(8), 135(74), 109(19), 93(39), 81(50) and 69(60); (Found: C, 54.85; H, 6.60; S, 7.85. $C_{19}H_{28}O_3SSe$ requires C, 54.93; H, 6.79; S, 7.73%).

(1*R*, 2*R*)-(7,7-Dimethyl-2-*exo*-benzylselenylbicyclo[2.2.1]hept-1-yl)methane sulfonic acid iso-propyl ester (11, Table 1, entry 11)

A similar procure to **1** using **13** (250 mg, 0.91 mmol), benzyl selenol (173 mg, 1.01 mmol), $BF_3.OEt_2.H_2O$ (0.08 ml, 0.91 mmol) and triethylsilane (0.20 ml, 1.22 mmol) gave **11** (117 mg, 0.27 mmol, 30%) as a colourless oil; δ_H (300 MHz; $CDCl_3$) 0.84 (3H, s, $(Me)_2C$-7), 0.87 (3H, s, $(Me)_2C$-7), 1.08-1.29 (2H, m, CH_2-5 or CH_2-6), 1.46 (3H, J 6.0 Hz, $(Me)_2CH$), 1.46 (3H, d, J 6.3 Hz, $(Me)_2CH$), 1.45-1.90 (3H, m, CH_2-5 or CH_2-6 and CH-4), 2.01-2.05 (1H, m, CH_2-3-*eq*), 2.09-2.20 (1H, m, CH_2-3-*ax*), 3.09 (1H, d, 14.1 Hz, CH_2-10), 3.25 (1H, dd, J 9.6, 5.1 Hz, CH-2), 4.00 (1H, d, J 11.4 Hz, CH_2-10), 4.06 (1H, d, J 14.1 Hz, $ArCH_2$), 4.13 (1H, d, J 14.1 Hz, $ArCH_2$), 5.05 (1H, heptet, J 6.6 Hz, $(Me)_2CH$) and 7.33-7.36 (5H, m, ArH); ν_{max} (neat)/cm^{-1} 3020-2940s (C-H), 1520s (C=C), 1480m, 1420m, 1380s ($(Me)_2CH$), 1370s ($(Me)_2CH$), 1200s, 1120m, 940s and 910s; MS (EI) (Found: M^+, 430.108. Calc. for $C_{20}H_{30}{}^{80}SeO_3S$: M, 430.108) *m/z* 430 (M^+, 11%), 217(61), 161(13), 135(100), 107(18), 91(87), 79(21), 65(13), 55(7) and 41(17).

(1*S*)-7,7-Dimethyl-1-(phenylsulfonylmethyl)bicyclo[2.2.1]heptan-2-one (14)

A solution of phenylmagnesium bromide (30.0 mmol) in THF (40 ml) was transferred by syringe into a solution of **12** (3.17 g, 10.3 mmol) in THF (30 ml) at 0 °C. The reaction mixture was left to reach

room temperature and then stirred for 2 h before being poured onto HCl (1M aq., 10 ml) at 0 °C. The mixture was then extracted with CH_2Cl_2 (3 x 15 ml), dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Chromatography on silica gel with petroleum ether-ethyl acetate (9:1) as the eluant yielded **14** (1.94 g, 6.63 mmol, 65%) as a colourless oil: δ_H(300 MHz; $CDCl_3$) 0.86 (3H, s, $(Me)_2$C-7), 1.17 (3H, s, $(Me)_2$C-7), 1.44-1.73 (2H, m, CH_2-5 or CH_2-6), 2.01-2.18 (3H, m, CH-4 and CH_2-5 or CH_2-6), 2.30-2.70 (2H, m, CH_2-3), 2.94 (1H, d, J 15.2, CH_2-10), 3.58 (1H, d, J 15.1, CH_2-10), 7.55-7.65 (3H, m, *meta* and *para* ArH), 7.97-8.00 (2H, m, *ortho* ArH); δ_C(75 MHz; $CDCl_3$) 19.39 (1, $(Me_3)_2$C-7), 19.63 (1, $(Me)_2$C-7), 24.32 (1, CH_2-5 or CH_2-6), 26.65 (1, CH_2-5 or CH_2-6), 42.07 (1, CH-4), 42.14 (1, CH_2-3), 47.71 (1, C-7), 52.64 (1, CH_2-10), 58.67 (1, C-1), 127.33 (1, ArC-*para*), 128.80 (2, ArC-*meta*), 133.20 (2, ArC-*ortho*), 140.93 (1, ArC-*ipso*), 213.93 (1, C-2); ν_{max}($CHCl_3$)/cm^{-1} 3420 (s), 2920 (s, C-H), 2400 (w), 1725 (s, CO), 1600 (m, C=C), 1430 (m), 1380 (m), 1305 (s, SO_2), 1270 (m), 1245 (m), 1215 (m), 1130 (s, SO_2), 1070 (m), 1040 (m), 1010 (w), 990 (w), 830 (w), 800 (m), 670 (m); *m/z* (EI) 292 (M^+, %), 215, 167, 151, 133, 123, 109; $[\alpha]_D^{20}$ +124 (*c* 1.8 in $CHCl_3$); (Found: C, 66.0; H, 7.15; S, 10.95. Calc. for $C_{16}H_{20}O_3S$: C, 65.73; H, 6.89; S, 10.96%).

(1*S*,2*R*)-7,7-Dimethyl-1-(phenylsulfonylmethyl)-2-*exo*-phenylsulfanylbicyclo[2.2.1]heptane (6, Scheme 3, equation 1)

A freshly prepared solution of phenylmagnesium bromide (3.1 mmol) in THF (15 ml) was added to a solution of **7** (1.03 g, 2.50 mmol) in THF (10 ml) at 0 °C. The reaction mixture was then left to reach room temperature and further stirred for 24 h before being poured onto water (30 ml), extracted with CH_2Cl_2 (3 x 15 ml), dried ($MgSO_4$), filtered, concentrated *in vacuo*. Chromatography on silica gel with petroleum ether-ethyl acetate (19:1) as the eluant gave **6** (262 mg, 0.68 mmol, 27%) as a colourless oil: δ_H(300 MHz; $CDCl_3$) 0.90 (3H, s, 7-$C(CH_3)_2$), 1.01 (3H, s, 7-$C(CH_3)_2$), 1.20-1.35 (2H, m, 5-CH_2 or 6-CH_2), 1.80-1.96 (3H, m, 4-CH and 5-CH_2 or 6-CH_2), 2.05- 2.38 (2H, m, 3-CH_2), 3.05 (1H, d, J 15.1, 10-CH_2), 3.69-3.74 (1H, m, 2-CH), 3.89 (1H, d, J 15.0, 10-CH_2), 7.20-7.62 (8H, m, H-Ar), 7.90-8.00 (2H, m, H-Ar); ν_{max}(neat)/cm^{-1}3040 (m, CH_{arm}), 2940 (s, CH), 2860 (s), 1570 (s, $C{=}C_{arm}$), 1470 (s), 1430 (s), 1380 (s, SO_2), 1360 (w), 1300 (s), 1240 (m), 1220 (w), 1130 (s, SO_2), 1070 (s), 1010 (m), 990 (w), 950 (w), 820 (m), 730 (s), 680 (s); MS (EI) (Found: M^+, 386.133. Calc. for $C_{22}H_{26}O_2S_2$: M, 386.14) *m/z* 386 (M^+, 31%), 277 (45), 245 (26), 143 (21), 136 (35), 135 (100), 123 (14), 109 (27), 107 (44), 95 (18), 93 (54), 79 (37), 77 (38), 41 (26); $[\alpha]_D^{20}$ +11.8 (*c* 3.4 in $CHCl_3$).

(1*R*,2*R*)-7,7-Dimethyl-1-(methylsulfonylmethyl)-2-*exo*-benzylselenylbicyclo[2.2.1]heptane (15, Scheme 3, equation 2)

To a solution of **9** (48.0 mg, 0.10 mmol) in THF (4 ml) at 0°C was added methyllithium (1.4 M in THF, 0.13 ml, 0.19 mmol) and the solution stirred for 2 h. H_2O (3 ml) was then added followed by aqueous saturated $NaHCO_3$ (2 ml) and the aqueous layer separated and extracted with CH_2Cl_2 (3 x 2 ml). The combined organic extracts were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [silica gel, 5% ethyl acetate / hexane] gave **15** (20.8 mg, 0.05 mmol, 60%) as a colourless oil; δ_H (250 MHz; $CDCl_3$) 0.87 (6H, s, $(Me)_2$C-7), 1.20-1.26 (1H, m, CH_2-5 or CH_2-6), 1.67-1.90 (4H, m, CH_2-5 or CH_2-6 and CH-4), 2.00-2.10 (1H, m, CH_2-3-*eq*), 2.12-2.20 (1H, m, CH_2-3-*ax*), 2.97 (3H, s, SO_2Me), 3.03 (1H, d, J 13.7 Hz, CH_2-10), 3.31 (1H, dd, J 9.4, 5.5 Hz, CH-2), 3.93-4.07 (3H, m, CH_2-10 and CH_2Se) and 7.18-7.35 (5H, m, ArH); δ_C (63 MHz; $CDCl_3$) 20.08 ($(Me)_2$C-7), 20.59 ($(Me)_2$C-7), 27.52 (CH_2-5 or CH_2-6), 31.55 (CH_2-5 or CH_2-6), 32.58 (CH_2Se), 42.64 (CH_2-3). 43.93 (SO_2Me), 45.47 (CH-4), 47.91 (CH-2), 49.65 (C-7 or C-1), 50.71 (C-7 or C-1), 56.82 (CH_2-10), 126.54 (ArCH), 128.39 (ArCH), 128.99 (ArCH) and 139.75 (ArC-*ipso*); ν_{max} (thin film)/cm^{-1} 2980-2910m (C-H), 1490m (C=C), 1440m,

1380m, 1300s (SO_2), 1130s (SO_2) and 1045m; MS (EI) (Found M^+, 386.082. Calc. for $C_{18}H_{26}SO_2Se$: M, 386.082) *m/z* 385 (M^+, 10%), 215(17), 135(100), 107(22), 91(72), 79(20), 65(12) and 55(7).

(1*R*,2*R*)-7,7-Dimethyl-1-(phenylsulfonylmethyl)-2-*exo*-benzylselenylbicyclo[2.2.1]heptane (16, Scheme 3, equation 2)

To a solution of **9** (48.0 mg, 0.10 mmol) in THF (4 ml) at 0 °C was added phenyllithium (1.8M in hexane, 0.12 ml, 0.21 mmol) and the solution stirred for 2h. H_2O (3 ml) was then added followed by aqueous saturated $NaHCO_3$ (2 ml) and the aqueous layer separated and extracted with CH_2Cl_2 (3 x 2 ml). The combined organic extracts were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [silica gel, 10% ethyl acetate / hexane] gave **16** (31.3 mg, 0.07 mmol, 70%) as a colourless crystalline solid, mp 99.3-101.7 °C; δ_H (250 MHz; $CDCl_3$) 0.79 (3H, s, $(Me)_2C$-7), 0.83 (3H, s, $(Me)_2C$-7), 1.24-1.28 (1H, m, CH_2-5 or CH_2-6), 1.59-1.93 (4H, m, CH_2-5 or CH_2-6 and CH-4), 2.04-2.08 (1H, m, CH_2-3-*equat*), 2.27 (td, J 9.1, 4.6 Hz, CH_2-3-*axial*), 3.04 (1H, d, J 13.6 Hz, CH_2-10), 3.44 (dd, J 9.4, 5.4 Hz, CH-2), 4.07 (1H, d, J 13.6 Hz, CH_2-10), 4.10 (1H, d, J 11.2 Hz, CH_2Se), 4.21 (1H, d, J 11.3 Hz, CH_2Se), 7.18-7.33 (3H, m, ArH), 7.40-7.43 (2H, m, ArH), 7.57-7.65 (3H, m, ArH) and 8.03 (2H, app. d, J 9.7 Hz, ArH); δ_C (63 MHz; $CDCl_3$) 20.06 ((*Me*)$_2$C-7), 20.54 ((*Me*)$_2$C-7), 27.63 (CH_2-5 or CH_2-6), 31.94 (CH_2-5 or CH_2-6), 32.67 (CH_2Se), 42.88 (CH_2-3), 45.45 (CH-4), 48.62 (CH-2), 49.74 (C-7 or C-1), 51.24 (C-7 or C-1), 58.30 (CH_2-10), 126.53 (ArCH), 127.56 (ArCH), 128.41 (ArCH), 129.10 (ArCH), 129.19 (ArCH), 133.32 (ArCH), 139.93 (ArC) and 142.02 (ArC); ν_{max} (thin film)/cm^{-1} 2980-2900s (C-H), 1500m (C=C), 1450m, 1390m, 1300s (SO_2), 1140s (SO_2), and 1070m; MS (EI) (Found M^+, 448.098. Calc. for $C_{23}H_{28}O_2S^{80}Se$: M, 448.098) *m/z* 447 (M^+, 6%), 277(16), 135(100), 107(23), 91(60), 79(17), 65(9) and 55(6).

1-(Benzylsulfanyl)-3-(*p*-toluenesulfonyloxy)propane (**17**)[16]

To a solution of 3-bromopropanol (0.59 ml, 6.56 mmol, 1 eq) in pyridine (10 ml) at 0 °C was added *p*-toluene sulfonyl chloride (1.50 g, 7.87 mmol, 1.2 eq) dropwise as a solution in pyridine (15 ml). The reaction mixture was then stirred at 0 °C for 24 h. H_2O (15 ml) and aqueous HCl (1 M, 10 ml) were then added and the aqueous layer separated and extracted with diethyl ether (3x15 ml). The combined organic layers were then washed with aqueous HCl (1M, 2 x 10 ml) and dried ($MgSO_4$) before concentration *in vacuo*. Purification by column chromatography [SiO_2, 10% ethyl acetate, hexane] gave 1-bromo-3-(*p*-toluenesulfonyloxy)propane[17] (1.57 g, 5.35 mmol, 82%) as a pale yellow oil; δ_H (400 MHz; $CDCl_3$) 2.16 (2H, quintet, J 6.1 Hz, CH_2), 2.44 (3H, s, ArMe), 3.40 (2H, J 6.3 Hz, CH_2Br), 4.16 (2H, t, J 5.8 Hz, CH_2O), 7.35 (2H, d, J 8.4 Hz, ArH) and 7.79 (2H, d, J 8.3 Hz, ArH); δ_c (100 MHz; $CDCl_3$) 21.61 (ArMe), 28.43 (CH_2), 31.69 (CH_2Br), 67.7 (CH_2O), 127.82 (ArCH), 129.86 (ArCH), 132.55 (ArC-Me) and 144.92 (ArC-SO_3); ν_{max} (neat)/cm^{-1} 3000-2880m (C-H), 1600m (C=C), 1500w, 1450m, 1370s, 1300m, 1170s, 1090m, 990m, 930m and 810s; MS (EI) *m/z* 294 (M^+, 9%), 213 (M-Br, 5), 172(100), 155(64), 107(10), 91(99), 65(31) and 41(28); (Found: Br, 27.45; C, 41.20; H, 4.65; S, 10.85. $BrC_{10}H_{13}O_3S$ requires Br, 27.25; C, 40.97; H, 4.47; S, 10.94%).

To a solution of benzylthiol (0.06 ml, 0.55 mmol, 0.8 eq) in DMF (5 ml) was added sodium (16.0 mg, 0.68 mmol, 1 eq) and the mixture stirred at room temperature for 25 min. The resulting solution was then added dropwise to a cooled solution of 1-bromo-3-(*p*-toluenesulfonyloxy)propane (200 mg, 0.68 mmol, 1 eq) in DMF (5 ml) at 0 °C. The reaction was then stirred at 0 °C for 1 h. H_2O (10 ml) was then added and the aqueous layer separated and extracted with diethyl ether (3 x 10 ml). The combined organic extracts were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [SiO_2, 4% ethyl acetate / hexane as eluant] gave **17**[16] (180 mg, 0.53 mmol, 78%) as a colourless oil; δ_H (400 MHz; $CDCl_3$) 1.86 (2H, m, CH_2), 2.42 (2H, t, J 7.1 Hz, 2H), 2.45 (3H, s, ArMe), 3.64 (2H, s,

CH_2Ar), 4.09 (2H, t, J 6.1 Hz, CH_2O), 7.22-7.35 (7H, m, ArH) and 7.77 (2H, dd, J 8.3, 1.7 Hz, ArH); δC (100 MHz; $CDCl_3$) 21.68 ($ArCH_3$), 27.04 (CH_2), 28.48 (CH_2S), 36.21 ($ArCH_2S$), 68.81 (CH_2O), 127.05 (ArCH), 127.86 (ArCH), 128.51 (ArCH), 128.74 (ArCH), 129.82 (ArCH), 132.90 (ArC), 137.98 (ArC) and 144.76 (ArC); ν_{max} (neat)/cm^{-1} 3010-2860m (C-H), 1590m (C=C), 1450m, 1350s, 1170s, 980s, 920s and 810m; MS (EI) *m/z* 336 (M^+, 16%), 181(9), 164(27), 155(6), 136(10), 122(16), 91(100), 65(18) and 45(10); (Found: C, 60.50; H, 5.80; S, 18.80. $C_{17}H_{20}O_3S_2$ requires C, 60.68; H, 5.99; S, 19.06%).

(1*R*, 2*R*)-1,7,7-Trimethyl-2-*exo*-(3'-(benzylsulfanyl)propylselenyl)bicyclo[2.2.1]heptane (18)

To a solution of **5** (136 mg, 0.44 mmol) in liquid ammonia (4 ml) at -40 °C was added sodium (12.2 mg, 0.53 mmol, 1 eq). The reaction was then allowed to warm to 0 °C and stirred for 10min before 1-(benzylsulfanyl)-3-(*p*-toluenesulfonyloxy)propane **17** (100 mg, 0.30 mmol, 0.7 eq) was added as a solution in THF (2 ml). The mixture was then stirred at 0 °C for 30 min and the ammonia then allowed to evaporate. Aqueous HCl (1 M, 5 ml) and H_2O (5 ml) were then added and the aqueous layer separated and extracted with diethyl ether (3 x 5 ml). The combined organic layers were then dried ($MgSO_4$) and concentrated *in vacuo*. Purification by column chromatography [SiO_2, hexane as eluant] gave **18** (60.0 mg, 0.22 mmol, 53%) as a pale yellow oil; δ_H (400 MHz; $CDCl_3$) 0.83 (3H, s, MeC-1), 0.94 (3H, s, $(Me)_2C$-7), 1.00 (3H, s, $(Me)_2C$-7), 1.14-1.18 (2H, m, CH_2-5 or CH_2-6), 1.170-1.77 (3H, m, CH_2-5 or CH_2-6 and CH-4), 1.86-1.96 (2H, m, -CH_2-2'), 1.97-2.05 (2H, m, CH_2-3), 2.51 (2H, t, J 7.2 Hz, SCH_2), 2.58-2.63 (2H, m, $SeCH_2$), 2.81 (1H, dd, J 9.1, 6.0 Hz, SeCH-2), 3.71 (2H, s, $PhCH_2$), 7.22-7.25 (1H, m, ArH-*para*) and 7.26-7.32 (4H, m, ArH); δ_C (100 MHz; $CDCl_3$) 15.56 (*Me*C-1), 20.10 ($(Me)_2$C-7), 20.45 ($(Me)_2$C-7), 25.52 ($SeCH_2$), 27.43 (CH_2-5 or CH_2-6), 30.20 (CH_2-5 or CH_2-6), 31.37 (SCH_2), 36.27 (CH_2-2'), 38.45 ($PhCH_2$), 41.51 (CH_2-3), 46.30 (CH-4), 47.32 (C-7), 49.06 (C-1), 50.05 (SeCH-2), 126.91 (ArCH), 128.45 (ArCH), 128.80 (ArH) and 138.40 (ArC-*ipso*); ν_{max} (neat)/cm^{-1} 2940-2860s (C-H), 1600m (C=C), 1500m, 1450s, 1410m, 1380m, 1360m, 1220m, 1070m and 1020m; MS (EI) *m/z* no M^+ detected, 291(5), 245(7), 165(16), 137(100), 91(94), 81(74), 67(18) and 41(20); $[\alpha]_D^{20}$ -24.0 (*c* 0.7, $CHCl_3$); (Found: C, 62.97; H, 7.93; S, 8.41. $C_{20}H_{30}SSe$ requires C, 63.05; H, 8.20; S, 8.3%).

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