Synthesis of cyclic sulfides and allylic sulfides by phenylsulfanyl (PhS-) migration of β-hydroxy sulfides

Jason Eames *[ab] **and Stuart Warren** *[a]

[a] *University Chemical Laboratory, Lensfield Road, Cambridge, UK CB2 1EW*
[b] *Department of Chemistry, Queen Mary and Westfield College, Mile End Road, London, UK E1 4NS*

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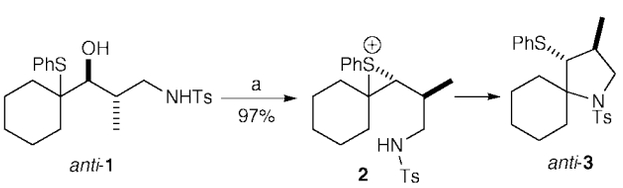
New routes to cyclic and spirocyclic sulfides involve aldol reactions of dithioesters or chemoselective Mitsunobu reactions of 1,*n*-diols to give 2-hydroxyalkyl sulfides with a terminal SH group. Treatment with acid gives unrearranged cyclic sulfides, or by rearrangement with PhS-migration, spirocyclic thiolanes and allylic sulfides in almost quantitative yield. We comment on the effect of the chain length on the mode of cyclisation and on the surprising differences between an OH group and an SH group as nucleophile towards an episulfonium ion.

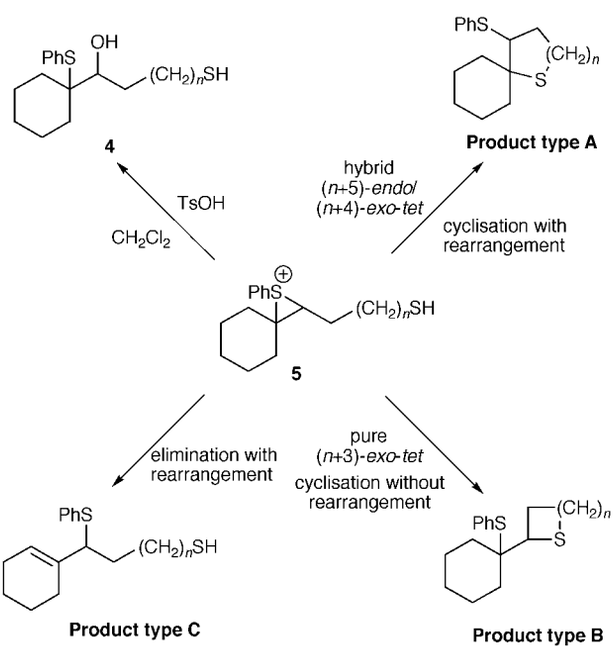
In the preceding paper,[1] we have reported the type of cyclisation observed in the acid-catalysed rearrangement of a series of 1,*n*-diols ($n = 2$ to 12) with an PhS group adjacent to one alcohol to give single compounds (either rearranged cyclic ethers, unrearranged cyclic ethers or allylic sulfides) in quantitative yield. Intramolecular capture of episulfonium ions with oxygen[2] nucleophiles such as alcohols[3] and esters,[4] to give stereospecifically spirocyclic ethers and lactones is well documented. Slightly less is known about the use of the more basic nitrogen[5] nucleophiles such as amines and sulfonamides to give spirocyclic amines.[6] For example, treatment of the β-hydroxy sulfide *anti*-**1** with TMSOTf in CH_2Cl_2 gives the episulfonium ion **2** which is captured intramolecularly at the most substituted end to give the spirocyclic amine *anti*-**3** in essentially quantitative yield (Scheme 1). This type of 1,2-PhS migration occurs stereospecifically with inversion of configuration at the migratory terminus.[7]



Scheme 1 *Reagents and conditions*: a, TMSOTf, CH_2Cl_2, −78 °C.

We were interested in extending this cyclisation procedure to the synthesis of cyclic sulfides and now report the successful use of a sulfanyl (SH) group as an intramolecular nucleophile[8] for the capture of an episulfonium ion such as **5**. The three distinct products from the rearrangement of the thiol **4** are the spirocyclic sulfide type **A** (formed with PhS migration by the hybrid (*n* + 5)-*endo*–(*n* + 4)-*exo-tet* cyclisation) disfavoured by Baldwin's rule,[9] the unrearranged cyclic sulfide of type **B** from the pure (*n* + 3)-*tet* cyclisation (where the position of the PhS group remains unchanged) and the allylic sulfide type **C**, formed by a [1,2]-PhS shift without cyclisation (Scheme 2).

Initial attempts to form the thiol **4**, $n = 1$ by conversion of the a primary OH group to an SH group by activation and displacement proved fruitless; in some cases chemoselective activation of the primary OH group promoted [1,4]-PhS migration and the formation of allylic sulfides[1,10,11] (by treatment with TsCl in pyridine) and in others oxetanes[12] (under Ziram® mediated Mitsunobu reaction conditions).[13] However, this



Scheme 2

problem was overcome using a masked sulfanyl equivalent (dithioester) as we supposed that reduction of such dithioesters as **8** would give the required thiol **4**, $n = 1$. These thiols were eventually synthesised by an aldol reaction with dithioester enolates.[14] Formation of the colourless lithium enolate of the yellow ethyl dithioester **6** (Fluka 43795) by treatment with n-BuLi at −78 °C and reaction with the aldehydes **7a–c** gave the corresponding yellow dithioesters **8a–c** in good yield as shown in Table 1. For successful reduction of **8a–c**, slow reverse addition of the dithioesters **8a–c** to a solution of $LiAlH_4$ in ether was required to prevent a reverse aldol reaction. The thiol **4**, $n = 1$, and the related thiols **9** and **10** were prepared in a reasonable chemical yield (Scheme 3).

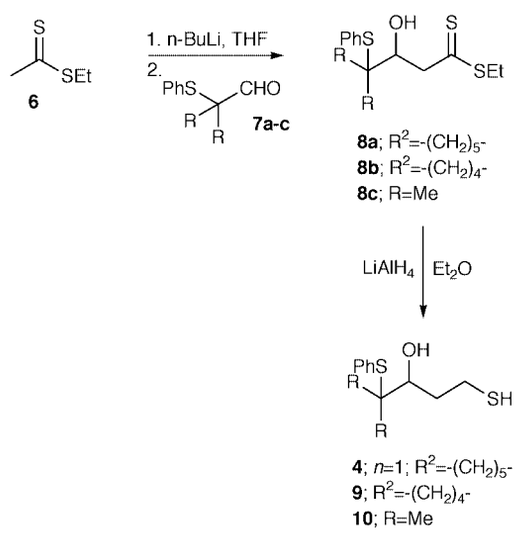
Rearrangement of these thiols **4**, $n = 1$, **9** and **10** with either TsOH or with TMSOTf in CH_2Cl_2 gave the type **A** rearranged spirocyclic sulfides **11**, **12** and **13** in near quantitative yield (Table 1) *via* the disfavoured hybrid 6-*endo*–5-*exo-tet* cyclisation (Scheme 4). This mode of cyclisation to form other spirocyclic heterocycles such as ethers and amines by similar methods is

Table 1 Yields in the synthesis and rearrangement of the thiols **4**, $n = 1$, **9** and **10**

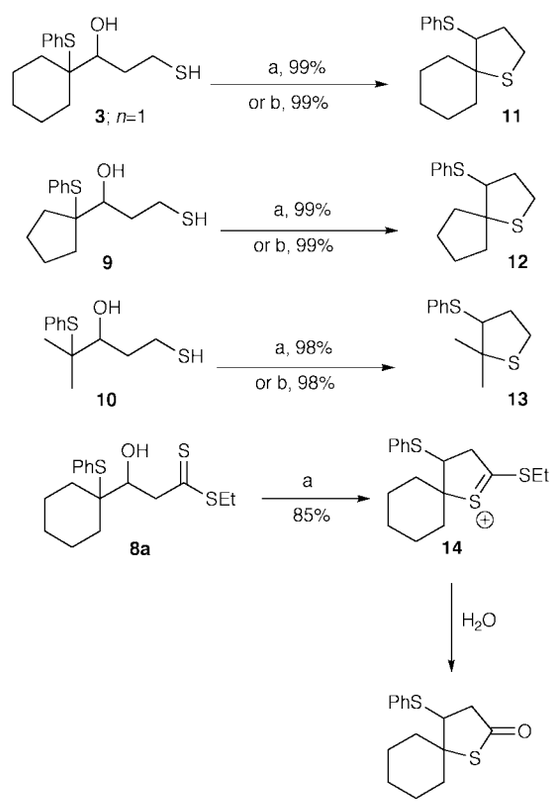
Reaction ⟶ aldol									
Aldehyde					$LiAlH_4$		TsOH	TMSOTf	
7	R	R	Dithioesters		Thiols		Spirocyclic sulfides		
7a	$-(CH_2)_5-$		**8a**	93%	**4**, $n = 1$	99%	**11**	99%	99%
7b	$-(CH_2)_4-$		**8b**	82%	**9**	83%	**12**	99%	99%
7c	Me	Me	**8c**	78%	**10**	79%	**13**	98%	98%

Table 2 Indentification of thiolanes and thiane by ^1H NMR and mass spectra

δ/ppm or J/Hz or mass spectrum (abundance)	Thiolanes				Thiane
	11	**12**	**13**	**18**	**19**
δ H^a	3.33 (dd)	3.64 (dd)	3.40 (dd)	3.60 (t)	2.59 (dd)
J_{syn} H^a	5.4	5.2	5.7	6.9	2.7
J_{anti} H^a	10.8	8.3	11.6	6.9	12.0
191.1 ($PhSC_6H_{10}$)	0%	—	—	90%	100%
M − 191.5	0%	—	—	80%	60%
M − SPh	100%	100%	100%	100%	100%



Scheme 3

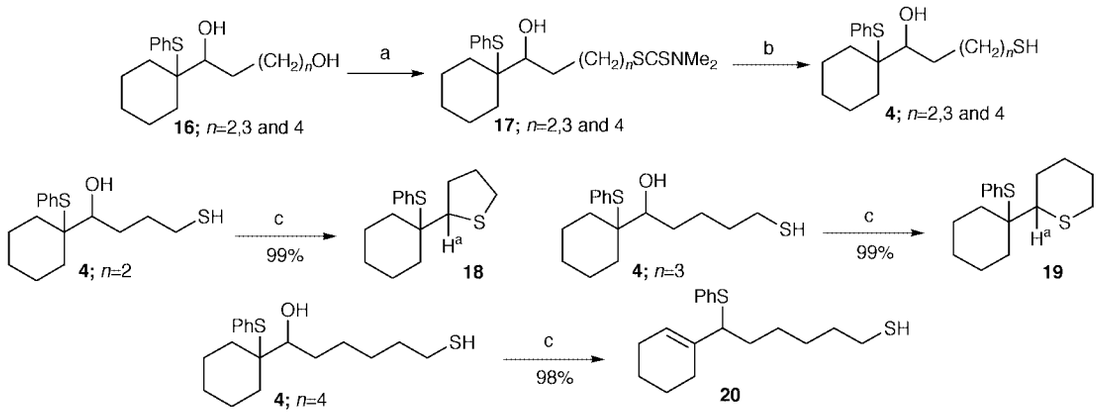


Scheme 4 *Reagents and conditions*: a, TsOH, CH_2Cl_2, reflux; b, TMSOTf, CH_2Cl_2, −78 °C.

common.[4,6] The ^1H NMR spectra of these compounds includes a double doublet for $\mathbf{H^a}$ with surprisingly dissimilar coupling constants (see Table 2). A more reliable method for determining which product type was formed was observed from the mass spectra; the $PhSC_2H_3$ group is the base peak, which is characteristic for rearranged heterocycles of product type **A**.[1]

Acid-catalysed rearrangement of the intermediate dithioester **8a** gave the spirocyclic thiolactone **15** in 85% yield by simple hydrolysis of the thionium ion **14**. In the ^{13}C NMR spectrum the C=O group appears at δ_C 205 ppm, which is characteristic of these thiolactones. Conversely, for dithiocarboxylic esters (such as ethyl dithioacetate **6**) the C=S group surprisingly appears at a much lower field (δ_C 250 ppm). Spirocyclic sulfides of this type are not well known, and some have been synthesised by an alkyl migration in a pinacol rearrangement[15] to give 1-thiaspiro[4.4]-nonanes (*e.g.* **12**), but the same route to the 1-thiaspiro[4.5]-decane (*e.g.* **11**) is very low yielding. Alternatively, we have synthesised this type of sulfide using [1,4]-SBn participation and debenzylation.[16]

The longer chain thiols **4**, $n = 2$, 3 and 4 were synthesised from the corresponding diols **16**, $n = 3$, 4 and 5 using a chemoselective Mitsunobu displacement of the primary alcohol involving Ziram® (zinc dimethyldithiocarbamate, Fluka 96480)[13] to give the dithiocarbamates **17**, $n = 2$, 3 and 4 in excellent yield (Table 3). Subsequent reduction ($LiAlH_4$) gave the longer chain length thiols **4**, $n = 2$, 3 and 4. These thiols **4**, $n = 2$, 3 and 4 were subjected to our standard TsOH rearrangement conditions[4] and these results are presented in Scheme 5. The thiol **4**, $n = 2$ rearranged exclusively to the thiolane **18** (type **B**) in 99% yield, *via* a pure 5-*exo-tet* cyclisation (favoured by Baldwin's rules).[9] The ^1H NMR spectrum of **18** included a triplet ($J = 6.9$ Hz) for $\mathbf{H^a}$ which is typical for a five-membered ring,[4] as $J_{gem} = J_{syn} = J_{anti}$ (Table 2). The coupling constants in the spirocyclic thiolanes **11** (type **A**) are not like this. In the mass spectrum, fragmentation between the thiolane and the



Scheme 5 *Reagents and conditions*: a, Ziram, DEAD, PPh_3, toluene; b, $LiAlH_4$, Et_2O; c, TsOH, CH_2Cl_2, reflux.

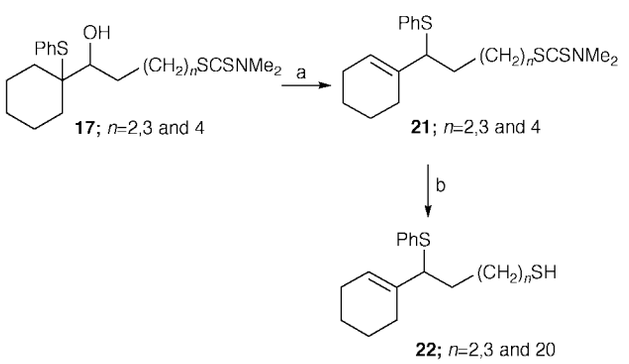
Table 3 Yields in the synthesis and rearrangement of the thiols **4**, $n = 2$, 3 and 4

Reaction ⟶ Mitsunobu		$LiAlH_4$		TsOH		
Diols	Dithiocarbamate	Thiols		Sulfides		
16; $n = 2$	**17**; $n = 2$	85%	**4**; $n = 2$	76%	**18**	99%
16; $n = 3$	**17**; $n = 3$	83%	**4**; $n = 3$	75%	**19**	99%
16; $n = 3$	**17**; $n = 3$	90%	**4**; $n = 3$	69%	**20**	98%

$C_6H_{10}SPh$ group is observed; which is characteristic of this product type (Table 2).[1]

With longer chain length thiol **4**, $n = 3$, acid-catalysed rearrangement gave the thiane **19**, of product type **B** in near quantitative yield, *via* a pure 6-*exo*-*tet* cyclisation.[1,2] In contrast to **11** and **18**, the thiane **19** has a double doublet for $\mathbf{H^a}$ with typical six-membered ring axial–axial (12 Hz) and axial–equatorial (2.7 Hz) couplings. In the mass spectrum, fragmentation between the thiane and the $C_6H_{10}SPh$ group is again observed (Table 2). However, in contrast, when the chain length was even longer **4**, $n = 4$, rearrangement gave the allylic sulfide **20** (of product type **C**) in near quantitative yield. The chain length now appears to be too long for efficient cyclisation, and elimination is now preferred, as the alternative would have been the unfavourable thiepine.

However, the alternative product allylic sulfide **20** and **22**, $n = 2$ and 3 (type **C**) from the rearrangement of thiols **8** was be obtained from the same starting materials **17**, simply by reversing the order of the reduction and the rearrangement as shown in Scheme 6. Acid-catalysed rearrangement of these dithiocarbamates **17**, $n = 2$, 3 and 4 gives the allylic dithiocarbamates **21**, $n = 2$, 3 and 4 by a simple [1,2]-SPh shift without cyclisation. Participation by the C=S group would require the formation of a medium ring heterocyclic intermediate and so it is less efficient than that of a dithioester in **8a**. Consequently, the dithiocarbamate functionality serves as a protection against this type of acid-catalysed cyclisation. Reduction of these allylic dithiocarbamates **21**, $n = 2$, 3 and 4 gave the allylic sulfides **20** and **22**, $n = 2$ and 3 of product type **C** in good yield (Table 4). Allylic sulfides of this type have potential in [2,3]-sigmatropic rearrangements of the corresponding sulfoxides and sulfonium salts.[17]



Scheme 6 *Reagents and conditions*: a, TsOH, CH_2Cl_2, reflux; b, $LiAlH_4$, Et_2O.

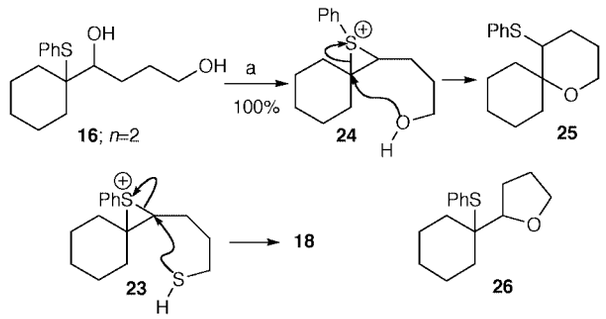
Table 4 Yields in the synthesis of allylic sulfide **20** and **22**, $n = 2$ and 3

Reaction ⟶ TsOH			$LiAlH_4$	
Dithiocarbamate	Allylic sulfides/ Dithiocarbamate		Allylic sulfides/ thiols **22**	
17; $n = 2$	**21**; $n = 2$	95%	**22**; $n = 2$	82%
17; $n = 3$	**21**; $n = 3$	97%	**22**; $n = 3$	76%
17; $n = 3$	**21**; $n = 3$	96%	**20**	69%

Conclusion

The acid-catalysed rearrangement of thiols **4**, $n = 1$, 2, 3 and 4 and the corresponding diols **16**,[1] are broadly rather similar. However, one example is quite different: rearrangement of thiol **4**, $n = 2$ gave the thiolane **18** of type **B**, whereas the diol **16**, $n = 2$ gave the tetrahydropyran **25** of type **A** by attack at the more substituted end of the episulfonium ion **24** *via* a hybrid 6-*endo*–5-*exo*-*tet* cyclisation;[1,2] both reactions occur in quantitative yield. The alternative type **B** tetrahydrofuran **26** can be prepared by simple ether formation (TsCl–pyridine) from the original diol (Scheme 7).[1,2] However, this tetrahydrofuran **26** does rearrange under the acid-catalysed reaction conditions (TsOH in CH_2Cl_2) to give the type **A** THP **25** in quantitative yield. Clearly, the THP **25** is the thermodynamic product of the cyclisation of diol **16**, $n = 2$, whereas the THF **26** has been shown to be the kinetic product—albeit in a 67 : 33 ratio **26** : **25** (determined from the decomposition of a cyclic sulfite).[18] Interestingly, the much less basic thiolane **18** does not rearrange to the thermodynamically preferred thiane (type **A**) in acid and must be the kinetic product.

In the kinetically controlled cyclisations with SH as a nucleophile, it appears that Baldwin's rules[9] are more important and the 5-*exo*-*tet* is more efficient, than when OH is the nucleophile,



Scheme 7 *Reagents and conditions*: a, TsOH, CH_2Cl_2, reflux.

perhaps because the greater nucleophilicity of the SH group demands a tighter transition state. Additionally, rearrangement of diol **16**, $n = 3$ gave a mixture of unrearranged THP (type **B**) in 59% and the allylic sulfide (type **C**) in 13% yield,[1,10] while the thiol **4**, $n = 3$ exclusively gave the type **B** thiane **19** in near quantitative yield.

In conclusion, we have shown that the shortest chain thiols **4**, $n = 1$ cyclise to form spirocyclic sulfides **11** of type **A**, and the intermediate chain length $n = 2$ gives the unrearranged type **B** cyclic sulfides **18**. Clearly five-membered ring formation in both cases is favoured over other ring sizes (four and six). However, six-membered ring formation becomes favoured (to give unrearranged thiane **19** of type **B**) over the alternative more strained seven-membered thiepines of type **A**. However, allylic sulfides **20** of type **C** are formed when the chain length *n* is too long for efficient cyclisation. The dithiocarbamates **17**, $n = 2$,3 and 4 also gave the allylic sulfide **21**, $n = 2$, 3 and 4 without cyclisation as the dithiocarbamate functionality serves as a protection against cyclisation.

Experimental

All solvents were distilled before use. Tetrahydrofuran (THF) and ether were freshly distilled from $LiAlH_4$, whilst dichloromethane (CH_2Cl_2) and toluene were freshly distilled from CaH_2. Triphenylmethane was used as the indicator for THF. n-BuLi was titrated against diphenylacetic acid before use. All reactions were carried out under nitrogen using oven-dried glassware. Flash column chromatography was carried out using Merck Kieselgel 60 (230–400 mesh). Thin layer chromatography (TLC) was carried out on commercially available pre-coated plates (Merck Kieselgel $60F_{254}$ silica). Proton and carbon NMR spectra were recorded on a Bruker WM 200, WM 250 or WM400. Fourier transform spectrometers were used with an internal deuterium lock. Chemical shifts are quoted in parts per milllion downfield from tetramethylsilane. Carbon NMR spectra were recorded with broad proton decoupling and Attached Proton Test (ATP). The symbol * after the carbon shift indicates an even number of attached protons; *i.e.*, CH_2 or quaternary carbons. The symbols *i*-, *o*-, *m*- and *p*- denote the *ipso-, ortho-*, *meta*- and *para*- positions respectively for the phenyl ring (PhS group). Mass spectra were recorded on a AEI Kratos MS30 or MS890 machine using a DS503 data system for high resolution analysis. All compounds were isolated using flash column chromatography and were assumed to have a purity of greater than 98% (determined by NMR).

3-Hydroxy-3-[1′-(phenylsulfanyl)cyclohexyl]-1-sulfanylpropane 4, *n* = 1

A solution of dithioester dithioacetate **8a** (0.1 g, 0.293 mmol) in ether (5 ml) was slowly added to a stirred solution of $LiAlH_4$ (34 mg, 0.91 mmol) in ether (3 ml) at 0 °C. The solution was stirred for 1 hour and poured onto ice–brine. NaOH (1 ml, 10%) was added and the solution was extracted with ether (3 × 40 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1) to give the *thiol* **4**, $n = 1$ (80 mg, 99%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.55; ν_{max} (film, $CDCl_3$)/cm^{-1} 1580 (SPh); δ_H(400 MHz, $CDCl_3$) 7.67–7.30 (5 H, m, SPh), 3.42 (1 H, dd, *J* 9.2 and 2.9, C*H*OH), 3.04 (1 H, s, OH), 2.84–2.75 (1 H, m, CH_AH_BSH), 2.59–2.54 (1 H, m, CH_AH_BSH), 2.03–1.15 (12 H, m, 6 × CH_2) and 1.34 (1 H, t, *J* 4.2, SH); δ_C(100 MHz, $CDCl_3$) 137.3 (*m*-SPh), 130.1* (*i*-SPh), 129.1 (*p*-SPh), 128.9 (*o*-SPh), 73.3 (CHOH), 61.3* (*C*SPh), 35.1* (CH_2-SH), 30.8*, 30.0*, 26.2*, 22.5*, 21.9* and 21.8* (6 × CH_2) (Found M$^+$, 282.1099. $C_{15}H_{22}OS_2$ requires 282.1112); *m*/*z* 282.1 (65%, M), 191.1 (95, $C_6H_{11}SPh$), 173.1 (20, M − SPh), 155.1 (42, M − SPh − H_2O), 110.0 (100, PhS + H) and 81.1 (80, C_6H_{11} − H).

4-Hydroxy-4-[1′-(phenylsulfanyl)cyclohexyl]-1-sulfanylbutane 44, *n* = 2

$LiAlH_4$ (74 mg, 1.98 mmol) was added to a stirred solution of the dithiocarbamate **17**, $n = 2$ (0.25 mg, 0.66 mmol) in ether (5 ml) at 0 °C. The solution was stirred for 12 hours and poured onto ice–brine. NaOH (2 ml, 10%) was added and the solution was extracted with ether (3 × 50 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1) to give the *thiol* **4**, $n = 2$ (0.19 g, 76%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.8; ν_{max} (film, $CDCl_3$)/cm^{-1} 3200 (OH); δ_H(400 MHz, $CDCl_3$) 7.55–7.25 (5 H, m, SPh), 3.23 (1 H, dd, *J* 10.0 and 2.2, C*H*OH), 3.08 (1 H, d, *J* 2.2, OH), 2.51 (1 H, q, *J* 7.2, CH_AH_BS), 2.50 (1 H, q, *J* 7.2, CH_AH_BS), 2.04–1.16 (14 H, m, 7 × CH_2) and 1.30 (1 H, t, *J* 7.61); δ_C(100 MHz, $CDCl_3$) 137.2 (*m*-SPh), 130.1* (*i*-SPh), 129.0 (*o*-SPh), 128.8 (*p*-SPh), 74.3 (CHO), 61.8* (*C*SPh), 31.7* (CH_2S), 30.6*, 29.6*, 29.2*, 26.2*, 24.7*, 21.8* and 21.8* (7 × CH_2) (Found M$^+$, 296.1265. $C_{16}H_{24}OS_2$ requires M, 296.1268); *m*/*z* 296.1 (95%, M), 191.1 (100, $C_6H_{10}SPh$), 110.0 (70, PhSH) and 81.1 (55, C_6H_9).

5-Hydroxy-5-[1′-(phenylsulfanyl)cyclohexyl]-1-sulfanylpentane 4, *n* = 3

In the same way as **4**, $n = 2$, the dithiocarbamate **17**, $n = 3$ (50 mg, 0.12 mmol) and $LiAlH_4$ (14 mg, 0.37 mmol) in ether (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *thiol* **4**, $n = 3$ (29.2 mg, 75%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.65; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH); δ_H(400 MHz, $CDCl_3$) 7.51–7.30 (5 H, m, SPh), 3.23 (1 H, d, *J* 9.4, C*H*OH), 3.06 (1 H, s, OH), 2.49 (1 H, q, *J* 7.5, CH_AH_BS), 2.48 (1 H, q, *J* 7.5, CH_AH_BS), 1.99–1.30 (16 H, m, 8 × CH_2) and 1.31 (1 H, t, *J* 7.7, SH); δ_C(100 MHz, $CDCl_3$) 137.2 (*m*-SPh), 130.1* (*i*-SPh), 129.0 (*p*-SPh), 128.8 (*o*-SPh), 74.5 (CHOH), 61.9* (*C*SPh), 34.1* (CH_2S), 30.6*, 30.0*, 29.6*, 26.2*, 24.5*, 21.9* and 21.8* (8 × CH_2) (Found M$^+$, 310.1428. $C_{17}H_{26}OS_2$ requires M, 310.1424); *m*/*z* 310.1 (100%, M), 201.1 (20, M − SPh), 191.1 (100, $C_6H_{10}SPh$), 109.0 (20, PhSH) and 81.0 (50, C_6H_9).

6-Hydroxy-6-[1′-(phenylsulfanyl)cyclohexyl]-1-sulfanylhexane 4, *n* = 4

In the same way as **4**, $n = 2$, the dithiocarbamate **17**, $n = 4$ (0.35 g, 0.85 mmol) and $LiAlH_4$ (93 mg, 2.54 mmol) in ether (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *thiol* **4**, $n = 4$ (0.19 g, 69%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.7; ν_{max} (film, $CDCl_3$)/cm^{-1} 3200 (OH); δ_H(250 MHz, $CDCl_3$) 7.51–7.27 (5 H, m, SPh), 3.23 (1 H, dd, *J* 9.3 and 2.3, C*H*OH), 2.50 (2 H, q, *J* 7.0, CH_2S), 2.09–1.08 (20 H, m, 10 × CH_2) and 1.31 (1 H, t, *J* 10.6, SH); δ_C(100 MHz, $CDCl_3$) 137.2 (*m*-SPh), 130.2

(*i*-SPh), 129.0 (*p*-SPh), 128.8 (*o*-SPh), 74.6 (CHOH), 61.9* (*C*SPh), 33.9* (CH_2S), 30.6*, 30.45, 29.6*, 28.4*, 26.8*, 26.3*, 24.5*, 21.9* and 21.8* ($10 \times CH_2$) (Found M^+, 324.1594. $C_{18}H_{28}OS_2$ requires M, 324.1581); *m*/*z* 324.2 (60%, M), 215.1 (30, M − SPh), 191.1 (100, $C_6H_{10}SPh$), 110.0 (90, PhSH) and 81.1 (80, C_6H_9).

Ethyl 3-hydroxy-3-[1′-(phenylsulfanyl)cyclohexyl]propanedithioate 8a

n-BuLi (1.77 ml, 1.3 M in hexanes, 2.31 mmol) was added slowly to a stirred solution of ethyl dithioacetate **6** (0.25 g, 0.26 ml, 2.1 mmol) in THF (10 ml) at −78 °C. The solution was stirred for 20 min. Aldehyde **7a** (0.43 g, 1.95 mmol) in THF (5 ml) was slowly added. The solution was stirred for 30 min. Saturated NH_4Cl (5 ml) was added and the solution was allowed to warm to room temperature and then extracted with ether (3×50 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1) to give the *dithioester* **8a** (0.35 g, 93%) as a yellow oil; R_f [light petroleum (40–60 °C)] 0.27; ν_{max} (film, $CDCl_3$)/cm^{-1} 3400–3100 (OH) and 1100 (CS_2Et); δ_H(400 MHz, $CDCl_3$) 7.58–7.27 (5 H, m, SPh), 4.03–3.98 (1 H, ddd, *J* 9.7, 1.5 and 3.4, C*H*OH), 3.66–3.62 (1 H, dd, *J* 14.3 and 1.4, CH_AH_BS), 3.29–3.24 (2 H, dq, *J* 12.3 and 7.5, CH_2S), 3.21–3.26 (1 H, dd, *J* 14.4 and 9.7, CH_AH_BS), 3.10–3.08 (1 H, d, *J* 7.5, OH), 1.91–1.19 (10 H, m, $5 \times CH_2$) and 1.36–1.32 (3 H, t, *J* 7.5, CH_3); δ_C(100 MHz, $CDCl_3$) 238.0* (C=S), 137.4 (*m*-SPh), 130.5* (*i*-SPh), 129.0 (*p*-SPh), 128.8 (*o*-SPh), 76.0 (CHOH), 59.1* (*C*SPh), 53.4* (CH_2C=S), 30.9*, 30.7*, 30.3*, 30.3* and 21.8* ($5 \times CH_2$), 26.0* (CH_2S) and 12.1 (CH_3) (Found M^+, 340.0982. $C_{17}H_{24}OS_3$ requires M, 340.0989); *m*/*z* 340.1 (45%, M), 231.1 (75, M − SPh), 213.1 (50, M − SPh − H_2O), 191.1 (90, $C_6H_{11}SPh$), 83.1 (100, C_6H_{12}) and 81.1 (80, C_6H_{10}).

Ethyl 3-hydroxy-3-[1′-(phenylsulfanyl)cyclopentyl]propanedithioate 8b

In the same way as **8a**, n-BuLi (2.01 ml, 1.3 M in hexanes, 2.62 mmol), ethyl dithioacetate **6** (0.28 g, 2.4 mmol) and aldehyde **7b** (0.45 g, 2.18 mmol) in THF (50 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *dithioester* **8b** (0.58 g, 82%) as a yellow oil; R_f [light petroleum (40–60 °C)] 0.30; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH) and 1120 (CS_2Et); δ_H(400 MHz, $CDCl_3$) 7.60–7.25 (5 H, m, SPh), 4.03–3.98 (1 H, dd, *J* 9.7 and 1.9, C*H*OH), 3.66–3.62 (1 H, dd, *J* 14.2 and 1.7, CH_AH_BCS), 3.30–3.22 (2 H, m, CH_2S), 3.21–3.26 (1 H, dd, *J* 14.4 and 9.8, CH_AH_BS), 3.15 (1 H, s, OH), 1.91–1.40 (8 H, m, $5 \times CH_2$) and 1.36–1.32 (3 H, t, *J* 7.5, CH_3); δ_C(100 MHz, $CDCl_3$) 238.1* (C=S), 137.4 (*m*-SPh), 130.4* (*i*-SPh), 129.2 (*p*-SPh), 128.7 (*o*-SPh), 76.0 (CHOH), 59.1* (*C*SPh), 53.3* (CH_2C=S), 30.9*, 30.7*, 21.8* and 21.8* ($4 \times CH_2$), 26.1* (CH_2S) and 12.1 (CH_3); *m*/*z* 326.1 (50%, M), 217.1 (100, M − SPh), 177.1 (80, C_5H_8SPh).

Ethyl-3-hydroxy-4-methyl-4-phenylsulfanylpentanedithioate 8c

In the same way as **8a**, n-BuLi (1.7 ml, 1.3 M in hexane, 2.21 mmol), ethyl dithioacetate **6** (0.26 g, 0.27 ml, 2.22 mmol) and aldehyde **7c** (0.4 g, 2.22 mmol) in THF (30 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–CH_2Cl_2 (1 : 1), the *dithioester* **8c** (0.51 g, 78%) as an oil; R_f [light petroleum (40–60 °C)–CH_2Cl_2 (1 : 1)] 0.4; ν_{max} (film, $CDCl_3$)/cm^{-1} 1050 (CS_2); δ_H(400 MHz, $CDCl_3$) 7.56–7.30 (5 H, m, SPh), 4.01 (1 H, dt, 9.8 and 1.9, C*H*OH), 3.48 (1 H, dd, *J* 14.2 and 1.6, CH_AH_BCS), 3.27 (2 H, m, CH_2S), 3.15 (1 H, d, *J* 2.7, OH), 3.11 (1 H, dd, *J* 14.2 and 9.7, CH_AH_BCS), 1.31 (3 H, t, *J* 7.4, CH_3CH_2), 1.30 (3 H, s, CH_3) and 1.26 (3 H, s, CH_3); δ_C(100 MHz, $CDCl_3$) 236.0* (C=S), 137.6* (*m*-SPh), 130.5* (*i*-SPh), 129.1 (*p*-SPh), 128.7 (*o*-SPh), 75.1 (CHOH), 55.8* (*C*SPh), 53.4* (CH_2C=S), 30.9* (CH_2S), 24.6 (CH_3), 24.42 (CH_3) and 12.0 (CH_3CH_2) (Found M^+, 300.0678. $C_{14}H_{20}OS_3$ requires M, 300.0676); *m*/*z* 300.1 (75%, M), 238.0 (50, M − CH_3-CH_2SH), 191.1 (30, M − SPh), 151.1 (100, C_3H_6SPh) and 110.0 (30, PhSH).

3-Hydroxy-3-[1′-(phenylsulfanyl)cyclopentyl]-1-sulfanylpropane 9

In the same way as **4**, $n = 1$, the dithioester **8b** (0.11 g, 0.35 mmol) and $LiAlH_4$ (40 mg, 1.05 mmol) in ether (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *thiol* **9** (85 mg, 83%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.75; ν_{max} (film, $CDCl_3$)/cm^{-1} 3200 (OH) and 1550 (SPh); δ_H(200 MHz, $CDCl_3$) 7.59–7.28 (5 H, m, SPh), 3.62 (1 H, dt, *J* 8.4 and 5.9, C*H*OH), 2.86 (1 H, d, *J* 6.0, OH), 2.71–2.51 (2 H, m, CH_2S), 1.95–1.51 (10 H, m, $5 \times CH_2$) and 1.38 (1 H, t, *J* 8.0, SH); δ_C(50 MHz, $CDCl_3$) 136.8 (*m*-SPh), 131.7 (*i*-SPh), 129.0 (*p*-SPh), 128.8 (*o*-SPh), 73.4 (CHOH), 67.3 (*C*SPh), 36.1 (CH_2), 34.8, 33.7, 24.8, 22.6 and 22.2 ($5 \times CH_2$) (Found M^+, 268.0953. $C_{14}H_{20}OS_2$ requires M, 268.0958); *m*/*z* 268.1 (5%, M), 177.1 (50, C_5H_8SPh), 159.1 (10, M − SPh), 110.0 (100, PhSH) and 67.1 (95, C_5H_7).

3-Hydroxy-4-methyl-4-phenylsulfanyl-1-sulfanylpentane 10

In the same way as **4**, $n = 1$, the dithioester **8c** (0.5 g, 1.66 mmol) and $LiAlH_4$ (0.12 g, 3.33 mmol) in ether (20 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *thiol* **10** (0.31 g, 79%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.16; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH); δ_H(400 MHz, $CDCl_3$) 7.52–7.31 (5 H, m, SPh), 3.44 (1 H, dt, *J* 9.8 and 2.5, C*H*OH), 2.95 (1 H, d, *J* 2.5, OH), 279 (1 H, m, CH_AH_BS), 2.58 (1 H, m, CH_AH_BS), 1.70 (2 H, m, CH_2), 1.37 (1 H, t, *J* 8.0, SH), 1.24 (3 H, s, CH_3) and 1.18 (3 H, s, CH_3); δ_C(100 MHz, $CDCl_3$) 137.4 (*m*-SPh), 130.2* (*i*-SPh), 129.2 (*p*-SPh), 128.8 (*o*-SPh), 73.5 (CHOH), 55.2* (*C*SPh), 35.0* (CH_2S), 25.8 (CH_3), 23.3* (CH_2) and 22.1 (CH_3) (Found M^+, 242.0803. $C_{12}H_{18}OS_2$ requires M, 242.0799); *m*/*z* 242.1 (32%, M), 151.1 (100, C_3H_6SPh) and 109.0 (30, PhS).

4-(Phenylsulfanyl)-1-thiaspiro[4.5]decane 11

Toluene-*p*-sulfonic acid (6 mg, 30 μmol) was added to a stirred solution of thiol **4**; $n = 1$ (50 mg, 0.18 mmol) in CH_2Cl_2 (2 ml). The solution was refluxed for 5 min. The solution was allowed to cool to room temperature and filtered through a silica plug. The solvent was removed under reduced pressure. The residue was purified by flash column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1) to give the *thiolane* **11** (47 mg, 99%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.34; ν_{max} (film, $CDCl_3$)/cm^{-1} 1600 (SPh); δ_H(400 MHz, $CDCl_3$) 7.47–7.20 (5 H, m, SPh), 3.35–3.29 (1 H, dd, *J* 10.8 and 5.4, CHSPh), 2.92–2.84 (1 H, m, CH_AH_BS), 2.80–2.73 (1 H, m, CH_AH_BS), 2.52–2.44 (1 H, m, CH_AH_B-CH_2S), 2.25–2.14 (1 H, m, $CH_AH_BCH_2S$), 2.01–1.92 (1H, dt, *J* 12.7 and 3.65, CH_AH_BC) and 1.72–1.20 (9 H, m, CH_AH_BC and $4 \times CH_2$); δ_C(100 MHz, $CDCl_3$) 131.9 (*m*-SPh), 129.0 (*p*-SPh), 126.9 (*o*-SPh), 76.5* ($CSCH_2$), 62.4 (CSPh), 39.2* (SCH_2), 35.4*, 35.0*, 30.9*, 27.4*, 25.7* and 25.6* ($6 \times CH_2$) (Found M^+, 264.1004. $C_{15}H_{20}S_2$ requires *M*, 264.1006); *m*/*z* 264.1 (35%, M), 155.1 (100, M − SPh) and 109 (15, SPh).

TMSOTf mediated rearrangement of the thiol 4, $n = 1$ to give thiolane 11

TMSOTf (43 mg, 37 μl, 0.18 mmol) was added to a stirred solution of thiol **4**, $n = 1$ (50 mg, 0.18 mmol) in CH_2Cl_2 (5 ml) at −78 °C. The solution was then allowed to warm to room temperature. Saturated NH_4Cl (1 ml) was added and the solution

was extracted with ether (3 × 10 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated under reduced pressure. The residue was purified by flash column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1) to give the *thiolane* **11** (47 mg, 99%) as an oil; identical spectroscopically to that obtained previously.

4-(Phenylsulfanyl)-1-thiaspiro[4.4]nonane 12

In the same way as **11**, the thiol **9** (20 mg, 74.6 μmol) and toluene-*p*-sulfonic acid (2.6 mg, 1.5 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *spirocyclic sulfide* **12** (18.2 mg, 99%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.5; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH); δ_H(200 MHz, $CDCl_3$) 7.47–7.23 (5 H, m, SPh), 3.64 (1 H, dd, *J* 8.3 and 5.1, C*H*SPh), 3.13–3.34 (2 H, m, CH_2S), 2.54–2.37 (1 H, m, CH_AH_B) and 2.26–1.64 (11 H, 10 × CH_2 and CH_AH_B); δ_C(100 MHz, $CDCl_3$) 135.9* (*i*-SPh), 131.6 (*m*-SPh), 129.0 (*o*-SPh), 126.9 (*p*-SPh), 66.0* (CS), 60.4 (C*H*SPh), 40.4* (CH_2S), 37.2*, 36.4*, 28.1*, 24.5* and 24.4* (5 × CH_2) (Found M$^+$, 250.0832. $C_{14}H_{18}S_2$ requires M, 250.0849); *m*/*z* 250.1 (70%, M), 141.1 (100, M − SPh), 109.1 (80, PhS) and 67.1 (55, C_5H_7).

TMSOTf mediated rearrangement of the thiol 9 to give thiolane 12

In the same way as **11**, the thiol **9** (20 mg, 74.6 μmol) and TMSOTf (16.4 mg, 14 μl, 74.6 μmol) in CH_2Cl_2 (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *spirocyclic sulfide* **12** (19 mg, 99%) as an oil; identical spectroscopically to that obtained previously.

2,2-Dimethyl-3-(phenylsulfanyl)thiolane 13

In the same way as **11**, the thiol **10** (50 mg, 0.20 mmol) and toluene-*p*-sulfonic acid (3.8 mg, 20 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *spirocyclic sulfide* **13** (49 mg, 98%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} broad 1580 (SPh); δ_H(400 MHz, $CDCl_3$) 7.55–7.20 (5 H, m, SPh), 3.39 (1 H, dd, *J* 11.6 and 5.7, C*H*SPh), 2.94–2.81 (2 H, m, CH_2S), 2.57–2.49 (1 H, m, CH_AH_B), 2.26–2.15 (1 H, m, CH_AH_B), 1.48 (3 H, s, CH_3) and 1.42 (1 H, m, CH_3); δ_C(100 MHz, $CDCl_3$) 131.9 (*m*-SPh), 129.0 (*o*-SPh), 127.0 (*p*-SPh), 62.2 (*C*HSPh), 54.0* (*C*SCH_2), 36.1* (CH_2S), 29.3 (CH_3), 27.6* (CH_2) and 27.4 (CH_3) (Found M$^+$, 224.0696. $C_{12}H_{16}S_2$ requires M, 224.0693); *m*/*z* 224.1 (60%, M), 135.0 (10, C_2H_2SPh) and 115.1 (100, M − SPh).

TMSOTf mediated rearrangement of the thiol 10 to give thiolane 13

In the same way as **11**, the thiol **10** (0.2 g, 0.83 mmol) and TMSOTf (0.18 mg, 0.16 ml, 0.83 mmol) in CH_2Cl_2 (2 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *thiolane* **13** (0.18 g, 98%) as an oil; identical spectroscopically to that obtained previously.

4-(Phenylsulfanyl)-1-thiaspiro[4.5]decan-2-one 15

In the same way as **11**, the dithioacetate **8a** (0.15 g, 0.44 mmol) and toluene-*p*-sulfonic acid (17 mg, 88 μmol) in CH_2Cl_2 (2 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *spirocyclic sulfide* **15** (0.12 g, 85%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.2; ν_{max} (film, $CDCl_3$)/cm^{-1} 1150 (CS_2); δ_H(400 MHz, $CDCl_3$) 7.46–7.25 (5 H, m, SPh), 3.72 (1 H, t, *J* 8.9, CHSPh), 2.94 (2 H, double AB quartet, *J* 9.0, CH_2CS) and 2.19–1.20 (10 H, m, 5 × CH_2); δ_C(100 MHz, $CDCl_3$) 20.8* (C=S), 134.3* (*i*-SPh), 132.7 (*m*-SPh), 129.3 (*p*-SPh), 127.9 (*o*-SPh), 65.6* (*C*SCH_2), 57.6 (*C*HSPh), 47.9* (CH_2C=S), 38.0*, 33.8*, 25.4*, 25.1* and 23.4* (5 × CH_2); *m*/*z* 218 (4%, M − CS_2), 136.0 (70, C_2H_3SPh), 109.1 (100, PhS) and 88.0 (30, CH_2(C=S)S).

1-(*N*,*N*-Dimethyldithiocarbamoyl)-4-hydroxy-4-[1′-(phenylsulfanyl)cyclohexyl]butane 17, *n* = 2

DEAD (0.12 g, 0.12 ml, 0.71 mmol) was added to a stirred solution of diol **16**, *n* = 2 (0.1 g, 0.36 mmol), Ziram® (0.22 g, 0.714 mmol) and PPh_3 (0.18 g, 0.71 mmol in toluene (2 ml)). The solution was stirred for 12 hours. The solution was filtered through a silica plug and the solvent was removed under reduced pressure. The residue was purified by flash column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1) to give the *dithiocarbamate* **17**, *n* = 2 (0.11 g, 85%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.55; ν_{max} (film, $CDCl_3$)/cm^{-1} 1254 (C=S); δ_H(400 MHz, $CDCl_3$) 7.54–7.23 (5 H, m, SPh), 3.50 (3 H, s, NCH_3), 3.30 (3 H, s, NCH_3), 3.28 (3 H, m, CH_2S and CHO), 3.05 (1 H, d, *J* 2.8, OH) and 2.05–1.11 (14 H, m, 7 × CH_2); δ_C(100 MHz, $CDCl_3$) 197.4* (C=S), 137.5 (*m*-SPh), 130.1* (*i*-SPh), 129.0 (*p*-SPh), 128.5 (*o*-SPh), 74.4 (CHOH), 61.6* (*C*SPh), 45.2 (NCH_3), 41.4 (NCH_3), 37.6* (CH_2S), 30.5*, 29.8*, 29.7*, 26.6*, 26.2*, 21.8* and 21.6* (7 × CH_2) (Found (M − SPh)$^+$, 274.1297. $C_{13}H_{24}OS_2N$ requires M − SPh, 274.1299); *m*/*z* 274.1 (35%, M − SPh), 191.1 (20, $C_6H_{10}SPh$), 110.0 (10, PhSH), 88.0 (100, C_3H_5SN) and 81.1 (20, C_6H_9).

1-(*N*,*N*-Dimethyldithiocarbamoyl)-5-hydroxy-5-[1′-(phenylsulfanyl)cyclohexyl]pentane 17, *n* = 3

In the same way as **17**, *n* = 2, the diol **16**, *n* = 3 (0.21 g, 0.71 mmol), Ziram® (0.33 g, 1.07 mmol), PPh_3 (0.37 g, 1.42 mmol) and DEAD (0.25 g, 0.23 ml, 1.42 mmol) in toluene (3 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *dithiocarbamate* **17**, *n* = 3 (0.23 g, 83%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.4; ν_{max} (film, $CDCl_3$)/cm^{-1} 1275 (C=S); δ_H(400 MHz, $CDCl_3$) 7.52–7.25 (5 H, m, SPh), 3.54 (3 H, s, NCH_3), 3.32 (3 H, s, NCH_3), 3.29–3.19 (3 H, m, CH_2S and C*H*OH), 3.04 (1 H, br s, OH) and 2.02–1.19 (16 H, m, 8 × CH_2); δ_C(100 MHz, $CDCl_3$) 197.6* (C=S), 137.2 (*m*-SPh), 130.2* (*i*-SPh), 129.0 (*p*-SPh), 128.8 (*o*-SPh), 74.6 (CHOH), 61.9* (*C*SPh), 45.2 and 41.4 (2 × NCH_3), 37.5* (CH_2S), 30.6*, 30.1*, 29.6*, 28.8*, 26.7*, 26.2*, 21.9* and 21.8* (8 × CH_2) (Found M$^+$, 397.1549. $C_{20}H_{31}OS_3N$ requires M, 397.1567); *m*/*z* 397.2 (10%, M), 288.1 (80, M − SPh), 277.2 (10, M − $S_2CN(CH_3)_2$ + H), 206 (60, M − $C_6H_{10}SPh$), 191.1 (100, $C_6H_{10}SPh$), 121.0 (75, $S_2CN(CH_3)_2$), 109 (25, PhSH) and 81.0 (20, C_6H_9).

1-(*N*,*N*-Dimethyldithiocarbamoyl)-6-hydroxy-6-[1′-(phenylsulfanyl)cyclohexyl]hexane 17, *n* = 4

In the same way as **17**, *n* = 2, the diol **16**, *n* = 4 (1.3 g, 4.2 mmol), Ziram® (1.92 g, 3 mmol), PPh_3 (2.21 g, 8.44 mmol) and DEAD (1.42 g, 1.32 ml, 8.44 mmol) in toluene (15 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *dithiocarbamate* **17**, *n* = 4 (1.56 g, 90%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.4; ν_{max} (film, $CDCl_3$)/cm^{-1} 1270 (C=S); δ_H(250 MHz, $CDCl_3$) 7.56–7.28 (5 H, m, SPh), 3.53 and 3.34 (6 H, s, 2 × NCH_3), 3.25 (2 H, t, *J* 7.3, CH_2S), 3.22 (1 H, m, C*H*OH), 3.07 (1 H, d, *J* 1.9, OH) and 2.05–1.13 (18 H, m, 10 × CH_2); δ_C(62.5 MHz, $CDCl_3$) 197.6* (C=S), 137.2 (*m*-SPh), 130.1* (*i*-SPh), 128.9 (*p*-SPh), 128.8 (*o*-SPh), 74.6 (CHOH), 61.9* (*C*SPh), 45.1 and 41.40 (2 × NCH_3), 37.6* (CH_2S), 30.6*, 30.4*, 29.6*, 29.1*, 28.5*, 27.0*, 26.2*, 21.8* and 21.8* (9 × CH_2) (Found M$^+$, 411.1690. $C_{21}H_{33}OS_3N$ requires M, 411.1724); *m*/*z* 411.1 (50%, M), 302.2 (30, M − SPh), 220.1 (45, M − $C_6H_{10}SPh$), 191.1 (50, $C_6H_{10}SPh$) and 88.0 (100, C_3H_5NS).

2-[1′-(Phenylsulfanyl)cyclohexyl]thiolane 18

In the same way as **11**, the thiol **4**, $n = 2$ (10 mg, 33.7 μmol) and toluene-*p*-sulfonic acid (1.1 mg, 6.7 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *thiolane* **18** (9.3 mg, 99%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.6; ν_{max} (film, $CDCl_3$)/cm^{-1} 1550 (SPh); δ_H(400 MHz, $CDCl_3$) 7.53–7.27 (5 H, m, SPh), 3.56 (1 H, t, *J* 6.9, CHS), 2.78 (2 H, dd, *J* 7.7 and 4.8, CH_2S) and 2.18–1.20 (14 H, m, 7 × CH_2); δ_C(100 MHz, $CDCl_3$) 137.5 (*m*-SPh), 131.6* (*i*-SPh), 128.9 (*p*-SPh), 128.7 (*o*-SPh), 58.9 (CHS), 57.7* (CS), 33.2* (CH_2S), 32.5*, 31.7*, 31.2*, 31.1*, 26.1*, 21.9* and 21.9* (7 × CH_2) (Found M$^+$, 278.1158. $C_{16}H_{22}S_2$ requires M, 278.1162); *m*/*z* 278.1 (70%, M), 191.1 (95, $C_6H_{10}SPh$), 169.1 (100, M − SPh), 87.0 (70, M − $C_6H_{10}SPh$) and 81.1 (30, C_6H_9).

2-[1′-(Phenylsulfanyl)cyclohexyl]thiane 19

In the same way as **11**, the thiol **4**, $n = 3$ (25 mg, 80.6 μmol) and toluene-*p*-sulfonic acid (3 mg, 16.1 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *thiane* **19** (23.3 mg, 99%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.75; ν_{max} (film, $CDCl_3$)/cm^{-1} 1580 (SPh); δ_H(400 MHz, $CDCl_3$) 7.51–7.22 (5 H, m, SPh), 2.72–2.60 (2 H, m, CH_2S), 2.59 (1 H, dd, *J* 12.0 and 2.7, CHS) and 2.00–1.23 (16 H, m, 8 × CH_2); δ_C(100 MHz, $CDCl_3$) 137.7 (*m*-SPh), 131.5* (*i*-SPh), 128.7 (*p*-SPh), 128.5 (*o*-SPh), 58.3* (*C*SPh), 51.5 (CHS), 32.9* (CH_2S), 31.8*, 30.2*, 29.2*, 27.6*, 27.4*, 25.8* and 22.0* (8 × CH_2) (Found M$^+$, 292.1318. $C_{17}H_{25}S_2$ requires M, 292.1319); *m*/*z* 292.1 (15%, M), 191.1 (100, $C_6H_{10}SPh$), 183.1 (70, M − SPh), 109.0 (10, PhSH), 109.0 (20, PhSH), 101.0 (60, M − $C_6H_{10}SPh$) and 81.1 (40, C_6H_9).

6-Cyclohexenyl-6-(phenylsulfanyl)-1-sulfanylhexane 20

In the same way as **11**, the thiol **4**, $n = 4$ (30 mg, 92.6 μmol) and toluene-*p*-sulfonic acid (3.2 mg, 18.5 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *allylic sulfide* **20** (27 mg, 98%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.9; ν_{max} (film, $CDCl_3$)/cm^{-1} 1600 (SPh); δ_H(250 MHz, $CDCl_3$) 7.34–7.14 (5 H, m, SPh), 5.24 (1 H, br s, CH=C), 3.49 (1 H, t, *J* 7.6, C*H*SPh), 2.57 (2 H, t, *J* 7.2, CH_2S), 2.21–1.23 (16 H, m, 8 × CH_2) and 1.55 (1 H, s, SH); δ_C(62.5 MHz, $CDCl_3$) 135.7* (*C*=CH), 135.6* (*i*-SPh), 133.1 (*m*-SPh), 128.3 (*o*-SPh), 126.8 (*p*-SPh), 125.4 (*C*H=C), 57.2 (*C*HSPh), 35.6* (CH_2S), 32.3*, 31.0*, 30.0*, 29.7*, 29.1*, 23.8*, 22.7* and 22.5* (8 × CH_2) (Found M$^+$, 306.1478. $C_{18}H_{26}S_2$ requires M, 306.1475); *m*/*z* 306.1 (95%, M), 197.1 (70, M − SPh), 115.1 (20, M − C_6H_{10}-SPh), 109.0 (20, PhS) and 81.1 (55, C_6H_9).

4-Cyclohexenyl-4-(phenylsulfanyl)butyl *N*,*N*-dimethyldithiocarbamate 21, $n = 2$

In the same way as **11**, the dithiocarbamate **17**, $n = 2$ (64 mg, 0.16 mmol) and toluene-*p*-sulfonic acid (5.73 mg, 33.3 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *allylic dithiocarbamate* **21**, $n = 2$ (57.9 mg, 95%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.82; ν_{max} (film, $CDCl_3$)/cm^{-1} 1570 (SPh) and 1270 (C=S); δ_H(250 MHz, $CDCl_3$) 7.40–7.16 (5 H, m, SPh), 5.26 (1 H, br s, CH=C), 3.53 (4 H, m, NCH_3 and C*H*SPh), 3.29 (3 H, s, NCH_3), 3.26 (2 H, t, *J* 6.7, CH_2S) and 2.20–1.41 (12 H, m, 6 × CH_2); δ_C(100 MHz, $CDCl_3$) 197.3* (C=S), 135.3* (*C*=CH), 133.3 (*m*-SPh), 129.1* (*i*-SPh), 128.4 (*o*-SPh), 127.0 (*p*-SPh), 125.8 (*C*H=C), 56.8 (C*H*SPh), 45.2 and 41.4 (2 × CH_3), 37.2* (CH_2S), 31.6*, 26.8*, 25.2*, 23.8*, 22.7* and 22.5* (6 × CH_2) (Found M$^+$, 365.1299. $C_{19}H_{27}S_3N$ requires M, 365.1305); *m*/*z* 365.1 (5%, M), 277.1 (10, M − C_3H_5NS), 256.1 (80, M − SPh) and 88.0 (100, C_3H_5NS).

5-Cyclohexenyl-5-(phenylsulfanyl)pentyl *N*,*N*-dimethyldithiocarbamate 21, $n = 3$

In the same way as **11**, the dithiocarbamate **17**, $n = 3$ (40 mg, 0.1 mmol) and toluene-*p*-sulfonic acid (3.4 mg, 20 μmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *allylic dithiocarbamate* **21**, $n = 3$ (37 mg, 97%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.8; ν_{max} (film, $CDCl_3$)/cm^{-1} 1280 (C=S); δ_H(250 MHz, $CDCl_3$) 7.48–7.16 (5 H, m, SPh), 5.25 (1 H, s, CH=C), 3.62–3.50 (4 H, m, NCH_3 and C*H*SPh), 3.35 (3 H, s, NCH_3), 3.24 (2 H, t, *J* 7.1, CH_2S) and 1.94–1.10 (14 H, m, 7 × CH_2); δ_C(62.5 MHz, $CDCl_3$) 210.0* (C=S), 137.0* (*C*=CH), 135.5* (*i*-SPh), 133.2 (*m*-SPh), 128.6 (*o*-SPh), 126.9 (*p*-SPh), 125.9 (*C*H=C), 57.1 (*C*SPh), 45.2 and 41.3 (2 × NCH_3), 37.4* (CH_2S), 32.0*, 28.3*, 27.0*, 25.2*, 23.8*, 22.7* and 22.6* (7 × CH_2) (Found M$^+$, 379.1441. $C_{20}H_{29}S_3N$ requires M, 379.1462); *m*/*z* 379.1 (30%, M), 270.1 (70, M − SPh), 110.0 (40, PhSH) and 88.0 (100, C_3H_5SN).

6-Cyclohexenyl-6-(phenylsulfanyl)hexyl *N*,*N*-dimethyldithiocarbamate 21, $n = 4$

In the same way as **11**, the dithiocarbamate **17**, $n = 4$ (50 mg, 0.12 mmol) and toluene-*p*-sulfonic acid (23 mg, 0.12 mmol) in CH_2Cl_2 (1 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *allylic dithiocarbamate* **21**, $n = 4$ (45 mg, 96%) as an oil; R_f [light petroleum (40–60 °C)–ether (1 : 1)] 0.8; ν_{max} (film, $CDCl_3$)/cm^{-1} 3350 (OH) and 1275 (C=S); δ_H(250 MHz, $CDCl_3$) 7.45–7.18 (5 H, m, SPh), 5.36 (1 H, br s, CH=C), 3.53 (3 H, s, NCH_3), 3.50 (1 H, t, *J* 7.6, C*H*SPh), 3.35 (3 H, s, NCH_3), 3.26 (2 H, t, *J* 7.2, CH_2S) and 2.28–1.26 (16 H, m, 8 × CH_2); δ_C(62.5 MHz, $CDCl_3$) 197.5* (C=S), 135.6* (*C*=CH), 131.14* (*i*-SPh), 133.0 (*m*-SPh), 128.7 (*o*-SPh), 126.8 (*p*-SPh), 125.4 (*C*H=C), 57.2 (*C*HSPh), 45.2 and 41.4 (2 × CH_3N), 37.5* (CH_2S), 32.3*, 28.6*, 28.5*, 27.2*, 25.2*, 23.7*, 22.5* and 19.6* (8 × CH_2) (Found M$^+$, 393.1614. $C_{21}H_{31}S_3N$ requires M, 393.1618); *m*/*z* 393.2 (20%, M), 284.1 (40, M − PhS), 109.0 (40, PhS) and 88.0 (100, C_3H_5NS).

4-Cyclohexenyl-4-(phenylsulfanyl)-1-sulfanylbutane 22, $n = 2$

In the same way as **4**, $n = 2$, the allylic dithiocarbamate **21**, $n = 2$ (0.13 g, 0.38 mmol) and $LiAlH_4$ (28 mg, 0.38 mmol) in ether (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), the *allylic sulfide* **22**, $n = 2$ (85 mg, 82%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.8; ν_{max} (film, $CDCl_3$)/cm^{-1} 1550 (SPh); δ_H(250 MHz, $CDCl_3$) 7.46–7.25 (5 H, m, SPh), 5.25 (1 H, br s, CH=C), 3.48 (1 H, t, *J* 7.2, C*H*SPh), 2.52 (2 H, q, *J* 7.7, CH_2S), 2.19–1.24 (10 H, m, 5 × CH_2) and 1.34 (1 H, t, *J* 7.8, SH); δ_C(62.5 MHz, $CDCl_3$) 133.2* (*i*-SPh), 133.1* (*m*-SPh), 128.4 (*o*-SPh), 127.0 (*p*-SPh), 125.0 (*C*H=C), 56.8 (*C*HSPh), 32.5* (CH_2S), 31.2*, 30.9*, 25.5*, 25.2*, 23.8* and 22.6* (6 × CH_2) (Found M$^+$, 278.1145. $C_{16}H_{22}S_2$ requires M, 278.1162); *m*/*z* 278.1 (10%, M), 244.1 (65, M − H_2S), 169.0 (50, M − SPh), 110.0 (50, PhSH) and 87.0 (100, C_4H_7S).

5-Cyclohexenyl-5-(phenylsulfanyl)-1-sulfanylpentane 22, $n = 3$

In the same way as **4**, $n = 2$, the allylic dithiocarbamate **21**, $n = 3$ (50 mg, 0.13 mmol) and $LiAlH_4$ (10 mg, 0.26 mmol) in ether (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (9 : 1), the *allylic sulfide* **22**, $n = 3$ (29.2 mg, 76%) as an oil; R_f [light petroleum (40–60 °C)–ether (9 : 1)] 0.78; ν_{max} (film, $CDCl_3$)/cm^{-1} 1600 (SPh); δ_H(250 MHz, $CDCl_3$) 7.35–7.17 (5 H, m, SPh), 5.25 (1 H, br s, CH=C), 3.49 (1 H, t, *J* 7.5, C*H*SPh), 2.51 (2 H, q, *J* 7.2, CH_2S) and 2.16–1.20 (14 H, m, 7 × CH_2); δ_C(62.5 MHz, $CDCl_3$) 135.6* (*i*-SPh), 133.2 (*m*-SPh), 128.4 (*o*-SPh), 126.9 (*p*-SPh), 125.6 (*C*H=C), 57.1 (*C*HSPh), 33.7* (CH_2S), 31.9*, 26.3*, 25.2*,

24.4*, 23.8*, 22.7* and 22.5* (7 × CH_2) (Found M^+, 292.1319. $C_{17}H_{24}S_2$ requires M, 292.1319); *m/z* 292.1 (70%, M), 191.1 (45, $C_6H_{10}SPh$), 183.1 (M − SPh), 109.0 (20, PhS) and 87.0 (100, C_4H_7S).

6-Cyclohexenyl-6-(phenylsulfanyl)-1-sulfanylhexane 20

In the same way as **4**, $n = 2$, the dithiocarbamate **21**, $n = 4$ (20 mg, 50 μmol) and $LiAlH_4$ (5.6 mg, 0.15 mmol) in ether (5 ml) gave, after column chromatography on silica gel eluting with light petroleum (40–60 °C)–ether (1 : 1), gave the *allylic sulfide* **20** (10.7 mg, 69%) as an oil; identical spectroscopically to that obtained previously.

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References

1 L. Djakovitch, J. Eames, D. J. Fox, F. H. Sansbury and S. Warren, *J. Chem. Soc.*, *Perkin Trans. 1*, 1999, 2771.
2 F. H. Sansbury and S. Warren, *Tetrahedron Lett.*, 1991, **28**, 3425.
3 V. K. Aggarwal and S. Warren, *Tetrahedron Lett.*, 1986, **27**, 101.
4 V. K. Aggarwal, I. Coldham, S. McIntyre and S. Warren, *J. Chem. Soc.*, *Perkin Trans. 1*, 1991, 451.
5 I. Coldham and S. Warren, *Tetrahedron Lett.*, 1989, **30**, 5937.
6 I. Coldham and S. Warren, *J. Chem. Soc.*, *Perkin Trans. 1*, 1993, 1637.
7 Inversion also occurs at the migratory origin, see V. K. Aggarwal, I. Coldham, S. McIntye, F. H. Sansbury, M.-J. Villa and S. Warren, *Tetrahedron Lett.*, 1988, **29**, 4885.
8 Preliminary communication: J. Eames, R. V. H. Jones and S. Warren, *Tetrahedron Lett.*, 1996, **37**, 707.
9 J. E. Baldwin, *J. Chem. Soc.*, *Chem. Commun.*, 1976, 734.
10 L. Djakovitch, J. Eames, R. V. H. Jones, S. McIntyre and S. Warren, *Tetrahedron Lett.*, 1995, **36**, 1723.
11 J. Eames, M. A. de las Heras, R. V. H. Jones and S. Warren, *Tetrahedron Lett.*, 1996, **37**, 1117.
12 J. Eames and S. Warren, *Tetrahedron Lett.*, 1996, **36**, 3525.
13 P. Rollin, *Tetrahedron Lett.*, 1986, **27**, 4169; *Synth. Commun.*, 1986, **16**, 611.
14 A. I. Meyers and R. D. Walkup, *Tetrahedron*, 1985, **41**, 5089.
15 L. A. Paquette, U. Dullweber and B. M. Branan, *Heterocycles*, 1994, **37**, 189.
16 J. Eames, N. Kuhnert, R. V. H. Jones and S. Warren, *Tetrahedron Lett.*, 1998, **39**, 1247.
17 R. C. Hartley, S. Warren and I. C. Richards, *Tetrahedron Lett.*, 1992, **33**, 8155.
18 J. Eames, N. Kuhnert, F. H. Sansbury and S. Warren, *Synlett*, 1999, 1211.

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