# Synthesis and oxidation of chiral 2-thiazolines (4,5-dihydro-1,3-thiazoles)

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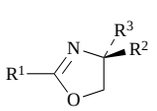
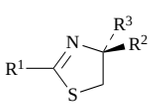
**Eight new chiral 2-thiazolines (4,5-dihydro-1,3-thiazoles) 2 have been prepared by treatment of the 2-methyloxazolines 1, the benzoylamino alcohols 4 or the trimethylacetylamino alcohols 5 with $P_2S_5$. With a 2-methyl substituent, reaction with Oxone® results in ring-opening to give the acetylamino disulfides 9 and with MCPBA there is also ring-opening with incorporation of a *m*-chlorobenzoyl group to give 12. Treatment of the 2-phenyl compounds with a variety of oxidants gives the benzoylamino sulfonic acids 10 and the disulfides 9 together with the thiazoles 11 in varying proportions. The sulfonic acids and thiazoles are obtained in pure form by reaction with 3 equiv. of peracetic acid and with sulfur, respectively. Although reaction of 2d–f with $KMnO_4$ under phase-transfer conditions gives the thiazoles 11, addition of 1 equiv. of benzoic acid results in a complete change in selectivity to afford the thiazoline 1,1-dioxides 3d–f in excellent yield. These compounds prove to be exceptionally moisture-sensitive and readily hydrolyse to give the benzoylamino sulfinic acids 8 whose further oxidation and disproportionation probably explains the formation of the sulfonic acids and disulfides with the other oxidants. The high reactivity of the sulfones 3 towards nucleophilic ring-opening precludes their deprotonation and alkylation. Upon flash vacuum pyrolysis at 600 °C, they fragment to give $SO_2$, benzonitrile and the alkenes 16 in high yield. Fully assigned $^{13}C$ NMR spectra are presented for the 18 heterocyclic compounds prepared and for 17 acyclic derivatives.**

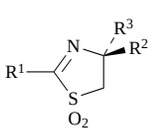
The chiral 2-oxazolines (4,5-dihydro-1,3-oxazoles) **1**, readily



**1**



**2**



**3**

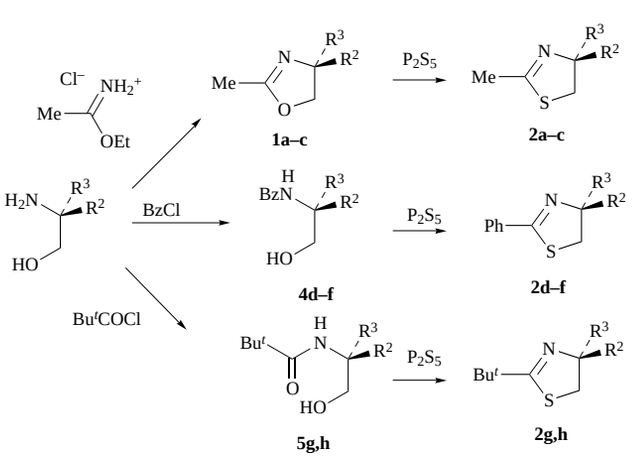
prepared from amino acid-derived amino alcohols, have been widely used as chiral auxiliary groups for asymmetric synthesis.[1] In contrast, there has been much less work on the corresponding 2-thiazolines (4,5-dihydro-1,3-thiazoles) **2**, although achiral examples ($R^2 = R^3 = H$) have been used for the synthesis of substituted aldehydes,[2] and some $C_2$-symmetric chiral 2,2′-bithiazolines have proved to be effective catalysts for asymmetric hydrosilylation of acetophenone.[3] We were interested to examine the synthetic applications of the 2-thiazoline 1,1-dioxides **3** and, in particular, to attempt deprotonation and diastereoselective alkylation at the 5-position. The success of this strategy would provide a new stereoselective synthesis of alkenes by subsequent thermal extrusion of $SO_2$ and $R^1CN$, with the unusual feature that the *E*/*Z* geometry of the alkene is controlled by the diastereoselectivity of the alkylation. As described in a recent review,[4] the oxidation of 2-thiazolines has been little investigated and we are only aware of two previous reports of 2-thiazoline, 1,1-dioxides, one formed from the corresponding thiazoline using MCPBA[5] and the other using $KMnO_4$[6] and both involving rather hindered compounds. There has been more work on the alternative oxidative process of dehydrogenation to give thiazoles and this has been of particular recent interest in connection with the synthesis of various marine natural products.[7] Here we describe the synthesis of eight new chiral 2-thiazolines and their behaviour towards a variety of common oxidants.

## Results and discussion

The 2-thiazolines **2** were prepared by two different methods depending on the nature of the 2-substituent $R^1$ (Scheme 1). For the 2-methyl substituted compounds **2a–c**, the 2-oxazolines **1** were first prepared by reaction of the appropriate amino alcohols with ethyl acetimidate hydrochloride following the method of Meyers *et al.*[8] These were then converted into the

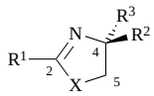
**Table 1** Preparation of the chiral 2-thiazolines **2**

| | | | | Products (%) | | |
|---|---|---|---|---|---|---|
| | $R^1$ | $R^2$ | $R^3$ | **1** | **4** or **5** | **2** |
| **2a** | Me | Pr$^i$ | H | 65 | — | 41 |
| **2b** | Me | Bn | H | 70 | — | 49 |
| **2c** | Me | H | Et | 52 | — | 32 |
| **2d** | Ph | Pr$^i$ | H | — | 48 | 85 |
| **2e** | Ph | Bn | H | — | 83 | 86 |
| **2f** | Ph | H | Et | — | 90 | 96 |
| **2g** | Bu$^t$ | Pr$^i$ | H | — | 25 | 60 |
| **2h** | Bu$^t$ | Bn | H | — | 49 | 59 |



**Scheme 1**

**Table 2** $^{13}$C NMR Spectra of heterocycles **1**, **2**, **3**, **6** and **11**

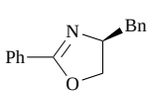


| | | | | | $\delta_C$(ppm)[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $R^1$ | $R^2$ | $R^3$ | X | C-2 | C-4 | C-5 | $R^1$ | $R^2/R^3$ |
| **1a** | Me | Pr$^i$ | H | O | 164.3 | 70.2 | 72.5 | 13.8 | 32.8, 18.8, 18.3 |
| **1b** | Me | Bn | H | O | 164.9 | 67.4 | 71.8 | 13.8 | 41.8, 138.1 (4ry), 192.2 (2 C), 128.5 (2 C), 126.4 |
| **1c** | Me | H | Et | O | 164.4 | 67.9 | 72.2 | 13.8 | 28.8, 10.1 |
| **6** | Ph | Bn | H | O | 163.8 | 67.9 | 71.8 | 131.2 (4ry), 128.3 (4 C), 127.9 | 41.8, 138.0 (4ry), 129.3 (2 C), 128.5 (2 C), 126.5 |
| **2a** | Me | Pr$^i$ | H | S | 164.9 | 83.9 | 36.4 | 20.3 | 33.0, 19.6, 18.8 |
| **2b** | Me | Bn | H | S | 165.8 | 78.4 | 38.5 | 20.4 | 40.5, 138.5 (4ry), 129.2 (2 C), 128.5 (2 C), 126.4 |
| **2c** | Me | H | Et | S | 165.1 | 79.0 | 38.8 | 20.3 | 28.1, 11.0 |
| **2d** | Ph | Pr$^i$ | H | S | 165.9 | 84.2 | 35.5 | 133.8 (4ry), 130.8, 128.3 (4 C) | 33.4, 19.8, 19.1 |
| **2e** | Ph | Bn | H | S | 167.0 | 78.4 | 37.1 | 133.2 (4ry), 131.0, 128.3 (4 C) | 40.3, 138.4 (4ry), 129.2 (2 C), 128.3 (2 C), 126.3 |
| **2f** | Ph | H | Et | S | 166.6 | 79.7 | 36.1 | 133.9 (4ry), 131.5 (2 C), 130.3 (2 C), 126.9 | 28.6, 11.5 |
| **2g** | Bu$^t$ | Pr$^i$ | H | S | 177.4 | 83.8 | 34.8 | 37.9 (4ry), 29.3 (3 C) | 33.0, 19.3, 18.6 |
| **2h** | Bu$^t$ | Bn | H | S | 178.5 | 77.9 | 36.8 | 37.7 (4ry), 29.2 (3 C) | 40.1, 138.5 (4ry), 129.3 (2 C), 128.2 (2 C), 126.2 |
| **3d** | Ph | Pr$^i$ | H | $SO_2$ | 161.3 | 66.8 | 48.8 | 132.5, 128.8 (2 C), 128.0 (2 C), 126.2 (4ry) | 33.1, 18.4, 18.0 |
| **3e** | Ph | Bn | H | $SO_2$ | 162.2 | 62.7 | 50.6 | 132.8, 129.1 (2 C), 128.2 (2 C), 126.3 (4ry) | 41.7, 136.2 (4ry), 129.3 (2 C), 128.8 (2 C), 127.2 |
| **3f** | Ph | H | Et | $SO_2$ | 161.5 | 62.8 | 50.9 | 132.7, 129.1 (2 C), 128.2 (2 C), 126.3 (4ry) | 29.1, 10.0 |
| **11d** | Ph | Pr$^i$ | | S | 167.3 | 164.8 | 110.9 | 134,0 (4ry), 129.7, 128.8 (2 C), 126.5 (2 C) | 31.1, 22.4 (2 C) |
| **11e** | Ph | Bn | | S | 167.5 | 157.5 | 114.3 | 133.9 (4ry), 129.8, 128.8 (2 C), 126.5 (2 C) | 38.0, 139.0 (4ry), 129.1 (2 C), 128.5 (2 C), 126.4 |
| **11f** | Ph | Et | | S | 167.5 | 160.1 | 112.1 | 133.9 (4ry), 129.7, 128.8 (2 C), 126.4 (2 C) | 25.0, 13.4 |

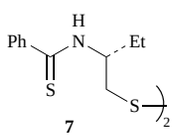
[a] 4ry = quaternary.

thiazolines in moderate yield by direct reaction with $P_2S_5$ in boiling $CH_2Cl_2$ (Table 1). Comparison of the $^{13}$C NMR data for **1** and **2** (Table 2) shows the expected large shift to lower frequency of the C-5 signals, from $\delta_C$ ~72 for the oxazolines **1** to $\delta_C$ ~38 for the thiazolines **2**. While the position of the C-2 signals is almost unchanged between the two series, the signals due to C-4 and the 2-Me are moved to higher frequency by 10–14 and 6.5 ppm, respectively, on going from **1** to **2**.

For preparation of the 2-phenyl- and 2-*tert*-butyl-substituted examples **2d**–**h**, the amino alcohols were first acylated using benzoyl or trimethylacetyl chloride to give **4** and **5**. For **4e**, ring closure to give the oxazoline **6** was accomplished using $P_2O_5$ but



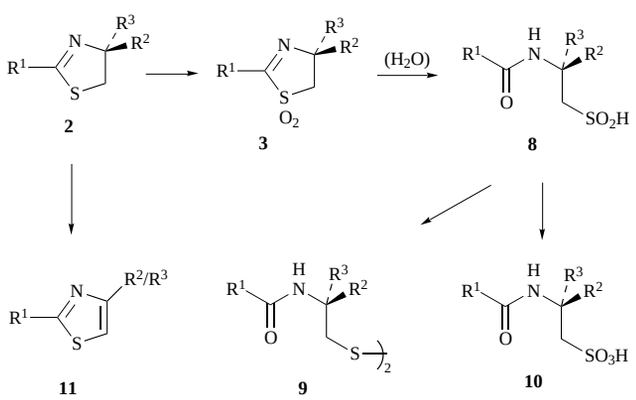
**6**



**7**

the yield was low and although this could be transformed into the thiazoline **2e** with $P_2S_5$, the alternative of reacting **4** or **5** directly with $P_2S_5$ was found to be preferable. The conversion of **4d**–**f**, **5g** and **h** into the 2-thiazolines **2d**–**h** was achieved in good to excellent yield by prolonged reaction with $P_2S_5$ in boiling $CH_2Cl_2$ (Table 1). The conditions for this reaction were found to be important and an attempt to reduce the reaction time in the case of **4f**, by using the higher boiling 1,2-dichloroethane as the solvent, led to isolation of the acyclic thiobenzoyl disulfide **7** as the main product. Although this was not obtained in pure form, its identity was indicated by a substantial shift of the thiocarbonyl signal to higher frequency as compared to the carbonyl analogue **9f** ($\delta_C$ 185.0 *vs.* 166.1). The $^{13}$C NMR data for **2d**–**h** (Table 2) were in good agreement with the trends already established for **2a**–**c**. Although no direct measurement of the enantiomeric purity of the heterocycles was made, there seems to be little opportunity for racemisation in their synthesis and they are assumed to be essentially enantiomerically pure.

The behaviour of the thiazolines **2** towards oxidation was now examined and, as shown in Scheme 2, a rather complex



**Scheme 2**

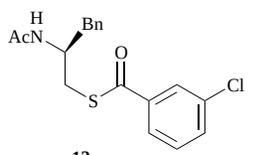
pattern emerged. The yields of oxidation products obtained using different conditions are summarised in Table 3.

Reaction of **2a** and **2b** with the potassium peroxymonosulfate complex Oxone® in aqueous THF gave the corresponding ring-opened disulfides **9** in low yield and **9b** was fully characterised. Treatment of **2b** with MCPBA in diethyl ether also gave a ring-opened product for which the spectroscopic data clearly showed incorporation of an *m*-chlorobenzoyl group. The mechanism of formation of this compound, assigned the structure **12**, is unclear. As a result of the apparent lability of the 2-methylthiazolines towards ring-opening, attention was turned to the 2-phenyl and 2-*tert*-butyl examples where this was expected to be less of a problem.

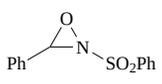
**Table 3** Oxidation of the chiral 2-thiazolines **2**

| Thiazoline | $R^1$ | $R^2$ | $R^3$ | Reagent | Product (%)[a] **3** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|
| **2a** | Me | $Pr^i$ | H | Oxone® | — | (20) | — | — |
| **2b** | Me | Bn | H | Oxone® | — | 24 | — | — |
| **2b** | Me | Bn | H | MCPBA | | *b* | | |
| **2d** | Ph | $Pr^i$ | H | $AcO_2H$ (1 equiv.) | (10) | — | (10) | — |
| **2d** | Ph | $Pr^i$ | H | oxaziridine **13** | (23) | — | (23) | — |
| **2d** | Ph | $Pr^i$ | H | $AcO_2H$ (3 equiv.) | — | — | 28 | — |
| **2d** | Ph | $Pr^i$ | H | sulfur | — | — | — | 54 |
| **2d** | Ph | $Pr^i$ | H | $KMnO_4$, $PhCO_2H$, PTC | 85 | — | — | — |
| **2e** | Ph | Bn | H | $AcO_2H$ (1 equiv.) | (48) | — | (48) | — |
| **2e** | Ph | Bn | H | $AcO_2H$ (3 equiv.) | — | — | 37 | — |
| **2e** | Ph | Bn | H | MCPBA | — | — | 53 | — |
| **2e** | Ph | Bn | H | $Bu^tOOH$ | — | — | 40 (72) | (27) |
| **2e** | Ph | Bn | H | $KMnO_4$, PTC | — | — | — | (51) |
| **2e** | Ph | Bn | H | sulfur | — | — | — | 53 |
| **2e** | Ph | Bn | H | $KMnO_4$, $PhCO_2H$, PTC | 93 | — | — | — |
| **2f** | Ph | H | Et | $AcO_2H$ (1 equiv.) | (8) | — | — | — |
| **2f** | Ph | H | Et | $AcO_2H$ (3 equiv.) | — | — | 15 | — |
| **2f** | Ph | H | Et | $Bu^tOOH$ | — | 3 | (13) | 30 |
| **2f** | Ph | H | Et | $H_2O_2$, acetone | — | (5) | (19) | (19) |
| **2f** | Ph | H | Et | $Bu_4N^+IO_4^-$ | — | — | (39) | (39) |
| **2f** | Ph | H | Et | $H_2O_2$, MeCN | — | (12) | (30) | (30) |
| **2f** | Ph | H | Et | $HCO_3H$ | — | (7) | — | (3) |
| **2f** | Ph | H | Et | $KMnO_4$, PTC | — | — | — | (34) |
| **2f** | Ph | H | Et | sulfur | — | — | — | 81 |
| **2f** | Ph | H | Et | $KMnO_4$, $PhCO_2H$, PTC | 90 | — | — | — |
| **2g** | $Bu^t$ | $Pr^i$ | H | $AcO_2H$ (3 equiv.) | — | — | 96 | — |
| **2h** | $Bu^t$ | Bn | H | $AcO_2H$ (3 equiv.) | — | — | 48 | — |

[a] Yields in parentheses have been estimated by $^1$H NMR while those without refer to isolated products. [b] Compound **12** formed (25%).



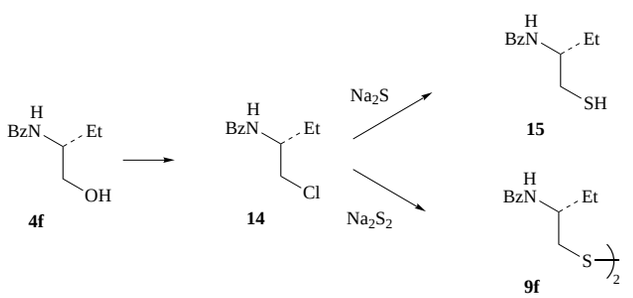

**12**




**13**

Treatment of the thiazoline **2d** with either 1 equiv. of peracetic acid or the oxaziridine **13**[9] in $CH_2Cl_2$ gave, in low yield, a 1 : 1 mixture of the desired thiazoline 1,1-dioxide **3d** and the ring-opened benzoylamino sulfonic acid **10d**. By using 3 equiv. of peracetic acid, the latter was obtained in low yield and fully characterised. The formation of this product is consistent with an early report where **2** ($R^1$ = Ph, $R^2 = R^3$ = H) was converted into the corresponding sulfonic acid **10** upon treatment with bromine water.[10] All attempts to separate the more interesting sulfone **3d** in pure form from the mixtures were unsuccessful. For reference, the thiazole **11d** was prepared by heating **2d** with sulfur,[11] but it was found not to be present in any of the other oxidations. A similar pattern was observed for the 4-benzylthiazoline **2e**, with 1 equiv. of peracetic acid giving a 1 : 1 mixture of **3e** and **10e** and 3 equiv. of either peracetic acid or MCPBA giving the latter as the sole product. With *tert*-butyl hydroperoxide, **2e** also gave mainly the sulfonic acid **10e**, but this was now accompanied by the thiazole **11e**, identical to an authentic sample prepared from **2e** and sulfur. The 4-ethylthiazoline **2f** was also found to give the sulfonic acid **10f** and the thiazole **11f** using a variety of oxidants (Table 3) and these were both fully characterised. In some cases the benzoylamino disulfide **9f** was also formed and this could be isolated in low yield from the reaction with *tert*-butyl hydroperoxide. The identity of this compound was confirmed by an authentic synthesis from **4f**, as shown in Scheme 3, which gave a product identical to that from the oxidation. Treatment of the 2-*tert*-butylthiazolines **2g** and **h** with 3 equiv. of peracetic acid similarly gave the corresponding sulfonic acids **10**, although **10h** could not be obtained in pure form.

As shown in Table 3, oxidation of **2e** and **2f** with potassium

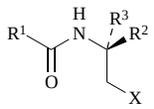



**Scheme 3**

permanganate under phase-transfer conditions (PTC) led to the corresponding thiazoles **11** in moderate yield. However it was serendipitously observed that, on one occasion, oxidation of an impure sample of **2e** afforded the desired sulfone **3e** as the main product. This remarkable change in selectivity for oxidation was traced to the presence of a small quantity of benzoic acid carried through from the preparation of **4e**. By using 1 equiv. of benzoic acid, 1.5 equiv. of $KMnO_4$ and catalytic benzyltriethylammonium chloride in $CH_2Cl_2$–water, an efficient and convenient procedure was developed which allowed the conversion of **2d–f** into the corresponding 1,1-dioxides **3d–f** in excellent yield.

Once the thiazoline dioxides **3** were obtained, the reason for the earlier difficulties became clear: these compounds proved to be extraordinarily moisture-sensitive, undergoing complete hydrolysis in a normal laboratory atmosphere in a few hours to give the acylamino sulfinic acids **8**. This prevented fully satisfactory analytical data being obtained and indeed recrystallisation produced the sulfinic acids **8** in good yield which were characterised spectroscopically (Table 4) and **8e** was isolated in analytically pure form. It therefore seems likely that compounds **3** may well have been generated with many of the oxidising systems used, but underwent *in situ* hydrolysis to the sulfinic acids **8** which then disproportionated to give **9** and **10** or underwent further oxidation to give **10** as the isolated products.

**Table 4** $^{13}$C NMR spectra of acyclic compounds **4**, **5**, **8**, **9**, **10**, **12**, **14** and **15**



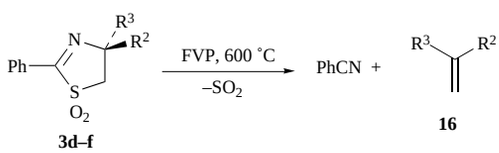
| | | | | | $\delta_C$(ppm)[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $R^1$ | $R^2$ | $R^3$ | X | CO | *C*HN | $CH_2X$ | $R^1$ signals | $R^2$/$R^3$ signals |
| **4d** | Ph | Pr$^i$ | H | OH | 166.4 | 62.7 | 57.3 | 134.5 (4ry), 131.3, 128.4 (2 C), 127.0 (2 C) | 29.0, 19.5, 19.2 |
| **4e**[b] | Ph | Bn | H | OH | 166.0 | 62.7 | 53.0 | 134.6 (4ry), 130.6, 128.8 (2 C), 126.9 (2 C) | 36.3, 139.1 (4ry), 127.8 (4 C), 125.6 |
| **4f** | Ph | H | Et | OH | 166.4 | 64.3 | 53.5 | 134.4 (4ry), 131.4, 128.4 (2 C), 127.0 (2 C) | 24.2, 10.6 |
| **5g** | Bu$^t$ | Pr$^i$ | H | OH | 179.1 | 62.8 | 56.4 | 38.8 (4ry), 27.6 (3 C) | 28.8, 19.6, 18.9 |
| **5h** | Bu$^t$ | Bn | H | OH | 179.2 | 63.7 | 52.5 | 38.7 (4ry), 27.4 (3 C) | 36.7, 137.9 (4ry), 129.3 (2 C), 128.5 (2 C), 126.5 |
| **9b**[b] | Me | Bn | H | $-S-)_2$ | 168.9 | 49.7 | 42.9 | 22.6 | 38.9, 138.4 (4ry), 129.1 (2 C), 128.1 (2 C), 126.1 |
| **12** | Me | Bn | H | SCOAr | 169.9 | 52.2 | 32.3 | 30.5[c] | 40.2, 136.9 (4ry), 129.3 (2 C), 128.6 (2 C), 127.4 |
| **10d**[b] | Ph | Pr$^i$ | H | $SO_3H$ | 166.3 | 51.8 | 39.2 | 135.4 (4ry), 131.1, 128.4 (2 C), 127.4 (2 C) | 31.3, 18.9, 18.5 |
| **10e**[b] | Ph | Bn | H | $SO_3H$ | 165.8 | 53.7 | 48.7 | 134.9 (4ry), 131.1, 128.3 (2 C), 127.2 (2 C) | 39.4, 138.9 (4ry), 129.4 (2 C), 128.3 (2 C), 126.1 |
| **10f**[b] | Ph | H | Et | $SO_3H$ | 165.8 | 63.1 | 46.2 | 135.1 (4ry), 128.4 (2 C), 127.1 (2 C), 126.9 | 27.3, 10.2 |
| **10g**[b] | Bu$^t$ | Pr$^i$ | H | $SO_3H$ | 176.8 | 51.8 | 50.9 | 37.5 (4ry), 27.6 (3 C) | 30.9, 19.1, 18.5 |
| **9f**[b] | Ph | H | Et | $-S-)_2$ | 166.1 | 50.3 | 43.2 | 134.7 (4ry), 130.9, 128.0 (2 C), 127.1 (2 C) | 26.4, 10.3 |
| **14** | Ph | H | Et | Cl | 167.2 | 51.3 | 47.8 | 134.4 (4ry), 131.6, 128.6 (2 C), 127.0 (2 C) | 25.0, 10.4 |
| **15** | Ph | H | Et | SH | 168.3 | 65.1 | 53.7 | 134.5 (4ry), 131.6, 128.6 (2 C), 127.0 (2 C) | 24.4, 10.7 |
| **8d**[b] | Ph | Pr$^i$ | H | $SO_2H$ | 166.6 | 54.2 | 63.0 | 134.7 (4ry), 131.0, 128.1 (2 C), 127.2 (2 C) | 32.5, 18.4, 17.8 |
| **8e**[b] | Ph | Bn | H | $SO_2H$ | 165.7 | 46.0 | 62.4 | 134.3 (4ry), 131.1, 128.2 (2 C), 127.1 (2 C) | 40.0, 137.9 (4ry), 129.2 (2 C), 128.2 (2 C), 126.2 |
| **8f**[b] | Ph | H | Et | $SO_2H$ | 165.8 | 48.3 | 54.4 | 135.2 (4ry), 131.1, 128.3 (2 C), 127.2 (2 C) | 26.6, 10.3 |

[a] 4ry = quaternary. [b] In $CD_3SOCD_3$. [c] Additional signals for $COC_6H_4Cl$ at 165.8 (CO), 134.6 (4ry), 131.4 (4ry), 133.6, 130.2, 129.7 and 128.2 (all CH).

The identity of the thiazoline dioxides **3d–f** is clear from their $^{13}$C NMR data (Table 2) which show the expected shift of the C-5 signals to higher frequency by 13–15 ppm as compared to the starting thiazolines **2**, but also the rather unexpected shift of both the C-2 and C-4 signals to lower frequency by ~5 and ~17 ppm, respectively. Further evidence for the sulfone structure was provided by the IR absorptions for all three compounds at 1300–1315 and 1130–1140 cm$^{-1}$, and the relatively sharp $^{33}$S NMR signal at $\delta_S$ 36.6 ($w_{1/2}$ 200 Hz) for **3f**. Although this is the first heterocyclic sulfone to be examined by this technique, the chemical shift falls in the expected range (*cf.* $\delta_S$ 35–40 for tetrahydrothiophene dioxide and 39 for 2,3-dihydrothiophene dioxide[12]) and, more significantly, the relatively sharp line rules out less symmetrical alternative structures such as the sulfoxide (tetrahydrothiophene oxide $w_{1/2}$ 3000 Hz[12]) or cyclic sulfinate which would give a signal too broad to be observed.[13]

The high susceptibility of these compounds to hydrolysis is not surprising in view of Schank's finding[14] that acyclic α-oxosulfones are also subject to very ready hydrolysis to give a mixture of carboxylic and sulfinic acids. The compounds **3** are effectively α-imino sulfones and the hydrolysis is further favoured by ring-opening. Unfortunately this property made all attempts at deprotonation and alkylation in the 5-position futile. Using a wide variety of bases and electrophiles under anhydrous conditions gave only complex mixtures of acyclic products resulting from nucleophilic ring-opening and decomposition.

Despite this, it was of interest to confirm whether the thiazoline dioxides **3** would undergo thermal fragmentation in the desired sense. Although thermal extrustion of $SO_2$ from a wide range of heterocyclic systems has been examined and forms the basis of several useful synthetic methods,[15] no example of this ring-system had previously been examined. Upon flash vacuum pyrolysis (FVP) at 600 °C and 10$^{-3}$ Torr, the sulfones **3d–f** underwent essentially quantitative loss of $SO_2$ to afford benzonitrile and the alkenes **16** (Scheme 4).




**3d–f** **16**

**Scheme 4**

The remarkable effect of added benzoic acid upon the oxidation of **2d–f** with $KMnO_4$ under phase-transfer conditions merits some further comment. The use of $KMnO_4$ under phase-transfer conditions for the oxidation of sulfides is well established,[16] although the mechanism involved is still the subject of some controversy.[17] Gokel *et al.*[18] previously reported the use of this method for the oxidation of hydrolytically sensitive cyclic sulfides, and noted that 1 equiv. of acetic acid could be successfully substituted for the phase-transfer catalyst. In the case of **2e**, oxidation using 1 equiv. of acetic acid in place of benzoic acid gave **3e** in comparable yield. At first sight it might appear that the acid in these systems acts simply in the role of a buffer to prevent the medium becoming basic as the oxidation progresses and thus to prevent loss of the product by hydrolysis. This is similar to the role played by magnesium sulfate in the permanganate oxidation of stabilised phosphorus ylides.[19] However, the complete change in selectivity from formation of the thiazoles **11** to the thiazoline dioxides **3** observed upon adding benzoic acid in the cases of **2e**,**f** suggests that a different oxidising species may actually be involved, perhaps a benzoic permanganic anhydride. The more obvious explanation that perbenzoic acid is being formed *in situ* was discounted by reaction of **2e** with perbenzoic acid in chloroform, which gave a mixture of **9**, **10** and **11** with no trace of **3**. Whatever the species involved, we have found this method to be ideal for oxidation of a range of thiazolidine-2-thiones to the corresponding thiazolidin-2-one 1,1-dioxides,[20] as well as a variety of other organosulfur compounds, and the results will be reported shortly.

## Experimental

Melting points were determined on a Reichert hot-stage microscope and are uncorrected. Infrared spectra were recorded for solids as Nujol mulls and for liquids as thin films on a Perkin-Elmer 1420 spectrophometer. NMR Spectra were recorded for $^{1}$H at 80 MHz on a Bruker WP80 instrument or at 300 MHz on a Bruker AM300 instrument, for $^{13}$C at 20 MHz on a Varian CFT 20 or at 75 MHz on a Bruker AM300 instrument, and for $^{33}$S at 38 MHz on a Bruker MSL500 spectrometer. Spectra were obtained for solutions in $CDCl_3$ unless otherwise indicated with $SiMe_4$ as internal reference for $^{1}$H and $^{13}$C and aqueous $Na_2SO_4$ as external reference for $^{33}$S. Chemical shifts ($\delta$) are reported in ppm to high frequency of the reference and coupling constants ($J$) are given in Hz. Mass spectra were obtained on a A.E.I. MS902 instrument using electron impact at 70 eV unless otherwise stated. Chemical ionisation mass spectra were obtained on a VG Autospec instrument using isobutane as the ionising ags. GC–MS Analysis was performed with a Hewlett Packard 5890A chromatograph coupled to a Finnigan Incos 50 mass spectrometer. Optical rotations were measured on an Optical Activity AA1000 polarimeter and are given in units of $10^{-1}$ deg cm$^2$ g$^{-1}$. Light petroleum refers to the fraction of bp 40–60 °C.

### Preparation of 2-methyl-4,5-dihydro-1,3-oxazoles 1a–c

Following the general method of Meyers *et al.*,[8] a solution of the appropriate amino alcohol (167 mmol) in $CH_2Cl_2$ (150 cm$^3$) was added dropwise to a stirred solution of ethyl iminoacetate hydrochloride[21] (29.4 g, 235 mmol) in $CH_2Cl_2$ (400 cm$^3$) at 0 °C. After the addition the mixture was stirred at room temperature for 72 h and then washed with water (2 × 150 cm$^3$), dried and the solvent was evaporated. Kugelrohr distillation of the residue afforded the product.

**(4*S*)-4-Isopropyl-2-methyl-4,5-dihydro-1,3-oxazole 1a.** From (2*S*)-2-amino-3-methylbutan-1-ol (valinol) (65%) as a colourless liquid, bp 62–63 °C (oven temp.) at 3 Torr (Found: C, 65.9; H, 10.45; N, 11.0. $C_7H_{13}NO$ requires C, 66.1; H, 10.3; N, 11.0%); $[\alpha]_D^{25}$ −94.2 (*c* 1.0 in $CHCl_3$); $\nu_{max}$/cm$^{-1}$ 1720, 1520, 1490, 1430, 1390, 1340, 1320, 1280, 1030, 950, 850 and 720; $\delta_H$ 4.4–3.9 (3 H, m), 2.00 (3 H, d, *J* 2), 1.75 (1 H, septet of d, *J* 8 and 2), 1.00 (d, H, d, *J* 8) and 0.98 (3 H, d, *J* 8); $\delta_C$ see Table 2; *m*/*z* 127 (M$^+$, 21%), 112 (4), 97 (6), 85 (60), 84 (100), 83 (90), 82 (75), 70 (12) and 56 (95).

**(4*S*)-4-Benzyl-2-methyl-4,5-dihydro-1,3-oxazole 1b.** From (2*S*)-2-amino-3-phenylpropan-1-ol (phenylalaninol) (70%) as a colourless liquid, bp 96 °C (oven temp.) at 0.02 Torr (HRMS: found M$^+$, 175.0999. $C_{11}H_{13}NO$ requires *M*, 175.0997); $[\alpha]_D^{25}$ −48.9 (*c* 2.95 in $CHCl_3$) [lit.,[22] −50.7 (*c* 2.83 in $CHCl_3$)]; $\nu_{max}$/cm$^{-1}$ 1670, 1450, 1390, 1230, 980 and 700; $\delta_H$ 7.3–7.5 (5 H, m), 4.6–4.2 (1 H, m), 4.20 and 4.00 (2 H, AB pattern of d, *J* 8 and 8), 3.10 (1 H, half AB pattern of d, *J* 14 and 6), 2.70 (1 H, half AB pattern of d, *J* 14 and 8) and 1.95 (3 H, d, *J* 1); $\delta_C$ see Table 2; *m*/*z* 175 (M$^+$, 31%), 172 (11), 152 (9), 145 (26), 130 (19), 117 (33), 103 (39) and 91 (100).

**(4*R*)-4-Ethyl-2-methyl-4,5-dihydro-1,3-oxazole 1c.** From (2*R*)-2-aminobutan-1-ol (52%) as a colourless liquid, bp 70 °C (oven temp.) at 14 Torr (HRMS: found M$^+$, 113.0834. $C_6H_{11}NO$ requires *M*, 113.0841); $[\alpha]_D^{20}$ +25.5 (*c* 7.7 in $CH_2Cl_2$); $\nu_{max}$/cm$^{-1}$ 2980, 1740, 1675, 1390, 1270, 1230, 985 and 900; $\delta_H$ 4.28 (1 H, half AB pattern of d, *J* 8 and 9), 3.95 (1 H, m), 3.82 (1 H, half AB pattern of d, *J* 8 and 8), 1.94 (3 H, d, *J* 1), 1.66–1.44 (2 H, m) and 0.95 (3 H, t, *J* 7); $\delta_C$ see Table 2; *m*/*z* 113 (M$^+$, 55%), 84 (100), 68 (75), 56 (80) and 43 (80).

**CAUTION**: Compound **1c** was unexpectedly found to be highly toxic, exposure to the vapour causing severe headaches and vertigo.

### Preparation of 2-methyl-4,5-dihydro-1,3-thiazoles 2a–c

A mixture of the appropriate oxazoline **1** (110 mmol) and phosphorus pentasulfide (40 g, 180 mmol) in $CH_2Cl_2$ (400 cm$^3$) was heated under reflux with vigorous stirring for 140 h. The resulting suspension was filtered and the filtrate washed with 2 M sodium hydroxide (3 × 100 cm$^3$) and then water (2 × 100 cm$^3$), dried and the solvent was evaporated. Kugelrohr distillation of the residue gave the product.

**(4*S*)-4-Isopropyl-2-methyl-4,5-dihydro-1,3-thiazole 2a.** From **1a** (41%) as a colourless liquid, bp 95 °C (oven temp,) at 7 Torr (lit.,[23] 74–75 °C at 20 Torr for racemic material) (HRMS: found M$^+$, 143.0759. $C_7H_{13}NS$ requires *M*, 143.0769); $[\alpha]_D^{25}$ −72.1 (*c* 1.2 in $CH_2Cl_2$); $\nu_{max}$/cm$^{-1}$ 1650, 1470, 1440, 1380, 1160 and 960; $\delta_H$ 4.4–4.0 (1 H, m), 3.25 (1 H, half AB pattern of d, *J* 11 and 8), 3.05 (1 H, half AB pattern of d, *J* 11 and 9), 2.20 (3 H, d, *J* 2), 2.00 (1 H, m), 1.05 (3 H, d, *J* 8) and 0.95 (3 H, d, *J* 8); $\delta_C$ see Table 2; *m*/*z* 143 (M$^+$, 44%), 100 (100), 87 (27), 82 (22), 69 (37) and 59 (45).

**(4*S*)-4-Benzyl-2-methyl-4,5-dihydro-1,3-thiazole 2b.** From **1b** (49%) as a colourless liquid, bp 233 °C (oven temp.) at 2 Torr (HRMS: found M$^+$, 191.0777. $C_{11}H_{13}NS$ requires *M*, 191.0769); $[\alpha]_D^{25}$ −95.4 (*c* 1.15 in $CH_2Cl_2$); $\nu_{max}$/cm$^{-1}$ 1630, 1490, 1450, 1435, 1370, 1160, 745 and 700; $\delta_H$ 7.40 (5 H, s), 5.0–4.5 (1 H, m), 3.30 and 3.10 (2 H, AB pattern of d, *J* 12 and 8), 3.20 (1 H, half AB pattern of d, *J* 14 and 6), 2.70 (1 H, half AB pattern of d, *J* 14 and 9) and 2.20 (3 H, d, *J* 2); $\delta_C$ see Table 2; *m*/*z* 191 (M$^+$, 9%), 144 (2), 117 (19), 115 (7), 104 (8), 102 (8), 100 (100) and 92 (19).

**(4*R*)-4-Ethyl-2-methyl-4,5-dihydro-1,3-thiazole 2c.** From **1c** (32%) as a yellow liquid, bp 85 °C (oven temp.) at 14 Torr (lit.,[23] 67 °C at 20 Torr for racemic material) (HRMS: found M$^+$, 129.0619. $C_6H_{11}NS$ requires *M*, 129.0612); $[\alpha]_D^{20}$ +99.9 (*c* 1.3 in $CH_2Cl_2$); $\nu_{max}$/cm$^{-1}$ 2980, 2920, 2860, 1635, 1460, 1435, 1370 and 1155; $\delta_H$ 4.34 (1 H, m), 3.38 (1 H, half AB pattern of d, *J* 11 and 8.5), 2.98 (1 H, half AB pattern of d, *J* 11 and 8), 2.20 (3 H, d, *J* 2), 1.81 (1 H, m), 1.64 (1 H, m) and 1.02 (3 H, t, *J* 7); $\delta_C$ see Table 2; *m*/*z* 129 (M$^+$, 70%), 100 (50), 88 (80), 68 (50), 60 (60) and 55 (100).

### Preparation of benzoyl- and trimethylacetyl-amino alcohols 4 and 5

A solution of the appropriate amino alcohol (338 mmol) and triethylamine (34.1 g, 338 mmol) in $CH_2Cl_2$ (150 cm$^3$) was stirred at room temperature while a solution of benzoyl chloride or trimethylacetyl chloride (338 mmol) in $CH_2Cl_2$ (150 cm$^3$) was added dropwise. After 20 h, the mixture was washed with water (2 × 100 cm$^3$), 2 M hydrochloric acid (100 cm$^3$) and water (100 cm$^3$), dried and the solvent was evaporated. The residue was recrystallised from hexane–ethyl acetate (3:1) to afford the product.

**(2*S*)-2-Benzoylamino-3-methylbutan-1-ol 4d.** From (2*S*)-2-amino-3-methylbutan-1-ol (valinol) (48%) as colourless crystals, mp 107–108 °C (Found: C, 69.6; H, 8.5; N, 6.7. $C_{12}H_{17}NO_2$ requires C, 69.5; H, 8.3; N, 6.8%); $[\alpha]_D^{25}$ −29.8 (*c* 2.5 in MeOH); $\nu_{max}$/cm$^{-1}$ 3700–3100 (br, OH), 3400 (NH), 1640 (CO), 1600, 1520, 1480, 1220, 1070 and 700; $\delta_H$ 7.8 (2 H, m), 7.5 (3 H, m), 6.6–6.2 (1 H, br s), 4.1–3.9 (1 H, m), 3.8 (2 H, m), 2.8–2.6 (1 H, br s), 2.00 (1 H, octet, *J* 8), 1.05 (3 H, d, *J* 8) and 1.00 (3 H, d, *J* 8); $\delta_C$ see Table 4; *m*/*z* 207 (M$^+$, 1%), 176 (34), 164 (1), 122 (9), 105 (100) and 77 (48).

**(2*S*)-2-Benzoylamino-3-phenylpropan-1-ol 4e.** From (2*S*)-2-amino-3-phenylpropan-1-ol (phenylalaninol) (83%) as colourless crystals, mp 174–175 °C (Found: C, 75.3; H, 6.7; N, 5.5. $C_{16}H_{17}NO_2$ requires C, 75.3; H, 6.7; N, 5.5%); $[\alpha]_D^{25}$ −85.1 (*c* 2.2 in MeOH); $\nu_{max}$/cm$^{-1}$ 3700–2300 (br, OH), 3300 (NH), 1630 (CO), 1540, 1460, 1330, 1080, 1050, 1030 and 700; $\delta_H$($CD_3SOCD_3$) 8.15 (1 H, d, *J* 8), 7.9–7.7 (2 H, m), 7.5–7.4 (3 H, m), 7.25 (5 H, s), 6.85 (1 H, t, *J* 6), 4.4–4.0 (1 H, m), 3.50 (2 H, t, *J* 6), 3.00 (1 H, half pattern AB of d, *J* 14 and 6) and 2.85 (1 H, half AB pattern of d, *J* 14 and 8); $\delta_C$ see Table 4; *m*/*z* 255 (M$^+$, 12%), 224 (31), 164 (100), 144 (51), 134 (26) and 122 (42).

**(2*R*)-2-Benzoylaminobutan-1-ol 4f.** From (2*R*)-2-aminobutan-1-ol (90%) as colourless crystals, mp 93–94 °C (Found:

C, 68.6; H, 8.05; N, 7.25. $C_{11}H_{15}NO_2$ requires C, 68.4; H, 7.8; N, 7.2%); $[\alpha]_D^{25}$ +26.3 (*c* 1.8 in MeOH); $\nu_{max}(CHCl_3)/cm^{-1}$ 3700–3100 (br, OH), 3440 (NH), 1640 (CO), 1520, 1480, 1290, 1220, 1080, 1040 and 700; $\delta_H$ 7.7 (2 H, m), 7.4 (3 H, m), 6.9–6.5 (1 H, br d), 4.2–3.8 (1 H, m), 3.70 (2 H, d, *J* 6), 3.5 (1 H, br s), 1.9–1.4 (2 H, m) and 0.90 (3 H, t, *J* 6); $\delta_C$ see Table 4; *m*/*z* 193 ($M^+$, 1%), 162 (35), 122 (11), 105 (100), 77 (57) and 51 (18).

**(2*S*)-2-Trimethylacetylamino-3-methylbutan-1-ol 5g.** From (2*S*)-2-amino-3-methylbutan-1-ol (valinol) (25%) as colourless prisms, mp 65–66 °C (Found: C, 64.3; H, 11.5; N, 7.5. $C_{10}H_{21}NO_2$ requires C, 64.3; H, 11.5; N, 7.5%), $[\alpha]_D^{25}$ −33.6 (*c* 1.8 in MeOH); $\nu_{max}(CHCl_3)/cm^{-1}$ 3700–3100 (br, OH), 3400 (NH), 1640 (CO), 1580, 1520, 1480, 1220, 1070 and 700; $\delta_H$ 6.2 (1 H, br d, *J* 6), 4.3 (1 H, br s), 3.7–3.5 (3 H, m), 1.95 (1 H, octet, *J* 8), 1.20 (9 H, s), 1.00 (3 H, d, *J* 8) and 0.90 (3 H, d, *J* 8); $\delta_C$ see Table 4; *m*/*z* 187 ($M^+$, 4%), 169 (2), 156 (57), 144 (15), 102 (19), 85 (29), 72 (25) and 57 (100).

**(2*S*)-2-Trimethylacetylamino-3-phenylpropan-1-ol 5h.** From (2*S*)-2-amino-3-phenylpropan-1-ol (phenylalaninol) (49%) as colourless prisms, mp 75–76 °C (Found: C, 71.3; H, 9.2; N, 5.9. $C_{14}H_{21}NO_2$ requires C, 71.5; H, 9.0; N, 6.0%); $[\alpha]_D^{25}$ −16.4 (*c* 1.8 in MeOH); $\nu_{max}(CHCl_3)/cm^{-1}$ 3700–3100 (br, OH), 3460 (NH), 1640 (CO), 1510, 1370, 1200, 1090, 1040, 730 and 670; $\delta_H$ 7.25 (4 H, s), 6.1–5.9 (1 H, br d, *J* 7), 4.4–4.0 (1 H, m), 3.8 (1 H, br s), 3.60 (2 H, d, *J* 5), 2.95 (1 H, half AB pattern of d, *J* 14 and 7), 2.80 (1 H, half AB pattern of d, *J* 14 and 8) and 1.10 (9 H, s); $\delta_C$ see Table 4; *m*/*z* 235 ($M^+$, 4%), 204 (6), 144 (32), 120 (12), 102 (16), 91 (26), 85 (28), 60 (18) and 57 (100).

### Preparation of (4*S*)-4-benzyl-2-phenyl-4,5-dihydro-1,3-oxazole 6

A mixture of (2*S*)-2-benzoylamino-3-phenylpropan-1-ol **4e** (2.0 g, 13.2 mmol) and phosphorus pentoxide (3.5 g, 24.6 mmol) in toluene (70 $cm^3$) was heated under reflux for 18 h. The toluene was decanted off from the solid mass which was cautiously dissolved with shaking in $CH_2Cl_2$ (50 $cm^3$) and saturated aqueous sodium carbonate (50 $cm^3$). The organic layer was separated, dried and the solvent was evaporated to give an oil which was Kugelrohr distilled to afford the *title product* (32%) as a colourless liquid, bp 221 °C (oven temp.) at 0.3 Torr (Found: C, 81.6; H, 6.15; N, 6.55. $C_{16}H_{15}NO$ requires C, 81.0; H, 6.4; N, 5.9%) (HRMS: found $M^+$, 237.1174. $C_{16}H_{15}NO$ requires *M*, 237.1154); $[\alpha]_D^{25}$ −12.2 (*c* 1.53 in $CHCl_3$); $\nu_{max}/cm^{-1}$ 1640, 1600, 1580, 1490, 1450, 1360, 1280, 1080, 1060, 1020, 960, 780 and 690; $\delta_H$ 8.0–7.9 (2 H, m), 7.5–7.4 (3 H, m), 7.0 (5 H, m), 4.75–4.45 (1 H, qd, *J* 8 and 6), 4.35 and 4.10 (2 H, AB pattern of d, *J* 8 and 8), 3.25 (1 H, half AB pattern of d, *J* 14 and 6) and 2.70 (1 H, half AB pattern of d, *J* 14 and 8); $\delta_C$ see Table 2; *m*/*z* 237 ($M^+$, 21%), 209 (17), 202 (16), 201 (18), 196 (9), 195 (8), 160 (15), 146 (10), 142 (40), 128 (32) and 121 (70).

### Preparation of the 2-phenyl- and 2-*tert*-butyl-4,5-dihydro-1,3-thiazoles 2d–h

A mixture of the appropriate benzoyl- or trimethylacetyl-amino alcohol **4** or **5** (48 mmol) and phosphorus pentasulfide (17.8 g, 80 mmol) in $CH_2Cl_2$ (250 $cm^3$) was heated under reflux with vigorous stirring for 40 h. The resulting suspension was filtered and the filtrate was washed with 2 M sodium hydroxide (3 × 100 $cm^3$) and water (2 × 100 $cm^3$), dried and the solvent was evaporated. Kughelrohr distillation of the residue gave the product.

**(4*S*)-4-Isopropyl-2-phenyl-4,5-dihydro-1,3-thiazole 2d.** From **4d** (85%) as a colourless liquid, bp 176 °C (oven temp.) at 1.3 Torr (HRMS: found $M^+$, 205.0942. $C_{12}H_{15}NS$ requires *M*, 205.0925); $[\alpha]_D^{25}$ −62.2 (*c* 1.16 in $CHCl_3$); $\nu_{max}/cm^{-1}$ 1600, 1575, 1470, 1450, 1250, 1020, 940, 770 and 650; $\delta_H$ 7.8 (2 H, m), 7.4 (3 H, m), 4.45 (1 H, td, *J* 8 and 6), 3.40 and 3.15 (2 H, AB pattern of d, *J* 10 and 8), 2.10 (1 H, octet, *J* 6), 1.10 (3 H, d, *J* 8) and 1.00 (3 H, d, *J* 8); $\delta_C$ see Table 2; *m*/*z* 205 ($M^+$, 21%), 162 (100), 144 (26), 121 (14) and 104 (40).

**(4*S*)-4-Benzyl-2-phenyl-4,5-dihydro-1,3-thiazole 2e.** From **4e** (86%) as a colourless liquid, bp 220 °C (oven temp.) at 0.1 Torr (HRMS: found $M^+$, 253.0957. $C_{16}H_{15}NS$ requires *M*, 253.0925); $[\alpha]_D^{25}$ −52.5 (*c* 1.12 in $CH_2Cl_2$); $\nu_{max}/cm^{-1}$ 1600, 1570, 1490, 1450, 1310, 1250, 1030, 940, 770, 750 and 700; $\delta_H$ 7.9–7.8 (2 H, m), 7.4–7.3 (3 H, m), 7.15 (5 H, s), 5.1–4.7 (1 H, m), 3.30 and 3.15 (2 H, AB pattern of d, *J* 10 and 8), 3.30 (1 H, half AB pattern of d, *J* 12 and 5) and 2.85 (1 H, half AB pattern of d, *J* 12 and 9); $\delta_C$ see Table 2; *m*/*z* 253 ($M^+$, 4%), 206 (6), 162 (100), 121 (20), 117 (50), 115 (30) and 104 (47).

**(4*R*)-4-Ethyl-2-phenyl-4,5-dihydro-1,3-thiazole 2f.** From **4f** (96%) as a colourless liquid, bp 92–93 °C (oven temp.) at 0.4 Torr (Found: C, 69.2; H, 6.8; N, 7.1. $C_{11}H_{13}NS$ requires C, 69.1; H, 6.8; N, 7.3%); $[\alpha]_D^{25}$ +55.9 (*c* 0.8 in $CHCl_3$); $\nu_{max}/cm^{-1}$ 1600, 1490, 1450, 1320, 1250, 990, 960, 940, 720 and 640; $\delta_H$ 7.8 (2 H, m), 7.4 (3 H, m), 4.60 (1 H, m), 3.50 and 3.10 (2 H, AB pattern of d, *J* 10 and 8), 1.90 (1 H, m), 1.75 (1 H, m) and 1.10 (3 H, t, *J* 8); $\delta_C$ see Table 2; *m*/*z* 191 ($M^+$, 42%), 162 (100), 145 (10), 130 (31), 122 (12) and 104 (60).

Reaction of **4f** with $P_2S_5$ as above but using 1,2-dichloroethane as the solvent gave colourless needles (33%) which consisted mainly of *bis*[(2R)-2-*thiobenzoylaminobutyl*] *disulfide* **7**, mp 109–111 °C (Found: C, 57.85; H, 6.2; N, 6.1. $C_{22}H_{28}N_2S_4$ requires C, 58.9; H, 6.3; N, 6.2%); $[\alpha]_D^{25}$ +41.0 (*c* 2.1 in MeOH); $\nu_{max}/cm^{-1}$ 3400 (NH), 1600, 1400, 1380, 1300, 1260, 1220, 960, 920, 880, 780 and 700; $\delta_H$ 13.0–12.9 (approx. 1 H, br s), 8.5–8.3 (4 H, m), 7.8–7.5 (6 H, m), 5.2–4.8 (2 H, m), 3.90 (2 H, half AB pattern of d, *J* 12 and 9), 3.45 (2 H, half AB pattern of d, *J* 12 and 7), 2.5–1.8 (4 H, m) and 1.10 (6 H, t, *J* 7); $\delta_C$ 185.0 (C=S), 136.6 (C quaternary), 130.8 (2 C), 129.7 (2 C), 125.4, 69.6 (CH), 34.9 ($SCH_2$), 26.1 ($CH_2$) and 9.5 ($CH_3$).

**(4*S*)-2-*tert*-Butyl-4-isopropyl-4,5-dihydro-1,3-thiazole 2g.** From **5g** (60%) in slightly impure form as a colourless liquid, bp 164 °C (oven temp.) at 1.4 Torr (Found: C, 62.45; H, 10.2; N, 8.65. $C_{10}H_{19}NS$ requires C, 64.8; H, 10.3; N, 7.6%); $\nu_{max}/cm^{-1}$ 1620, 1460, 1360, 1250, 1030 and 970; $\delta_H$ 4.30 (1 H, td, *J* 9 and 6), 3.20 and 3.00 (2 H, AB pattern of d, *J* 11 and 9), 2.00 (1 H, octet, *J* 6), 1.25 (9 H, s), 1.00 (3 H, d, *J* 6) and 0.90 (3 H, d, *J* 6); $\delta_C$ see Table 2; *m*/*z* 185 ($M^+$, 85%), 170 (5), 142 (100), 124 (20), 102 (15), 96 (15) and 87 (70).

**(4*S*)-4-Benzyl-2-*tert*-butyl-4,5-dihydro-1,3-thiazole 2h.** From **5h** (59%) as a colourless liquid, bp 172 °C (oven temp.) at 1.0 Torr (Found: C, 71.35; H, 8.25; N, 6.7. $C_{14}H_{19}NS$ requires C, 72.1; H, 8.2; N, 6.0%) (HRMS: found $M^+$, 233.1212. $C_{14}H_{19}NS$ requires *M*, 233.1238); $[\alpha]_D^{25}$ −59.7 (*c* 2.0 in $CHCl_3$); $\nu_{max}/cm^{-1}$ 1620, 1450, 1360, 1040, 990, 740 and 650; $\delta_H$ 7.25 (5 H, s), 4.9–4.6 (1 H, m), 3.10 (1 H, half AB pattern of d, *J* 14 and 5), 2.75 (1 H, half AB pattern of d, *J* 14 and 6), 3.10 and 2.95 (2 H, AB pattern of d, *J* 10 and 5) and 1.25 (9 H, s); $\delta_C$ see Table 2; *m*/*z* 233 ($M^+$, 20%), 218 (20), 142 (100), 126 (60) and 117 (80).

### Oxidation of 2a and 2b using Oxone®

A solution of the 4,5-dihydrothiazole **2a** (1.1 g, 7.7 mmol) in THF (100 $cm^3$) was stirred at 0 °C while a solution of Oxone® (5.1 g, 8.3 mmol) in water (200 $cm^3$) was added dropwise. After the addition the mixture was stirred for 48 h at room temperature and then extracted with diethyl ether (100 $cm^3$) and ethyl acetate (2 × 100 $cm^3$). The combined extracts were dried and the solvent was evaporated to give yellow crystals (0.3 g, 20%) which consisted mainly of *bis*[(2S)-2-*acetylamino*-3-*methylbutyl*] *disulfide* **9a**; $\delta_H(CD_3SOCD_3)$ 6.2–5.9 (2 H, br s, NH), 4.1–4.0 (2 H, m), 2.90 (4 H, d, *J* 6), 2.1–1.8 (2 H, m), 2.00 (6 H, s), 0.90 (6 H, d, *J* 9) and 0.85 (6 H, d, *J* 9); *m*/*z* 320 ($M^+$, 25%), 305 (21), 160 ($M^+/2$, 16), 144 (24), 128 (32) and 43 (100).

The above procedure using the 4,5-dihydrothiazole **2b** (5.0 g, 26 mmol) and Oxone® (23.9 g, 39 mmol) followed by recrystallisation of the product from hexane–ethyl acetate (1:2) gave *bis*[(2S)-2-*acetylamino*-3-*phenylpropyl*] *disulfide* **9b** as colourless needles, mp 160–162 °C (Found: C, 63.0; H, 6.85; N, 6.6. $C_{22}H_{28}N_2O_2S_2$ requires C, 63.4; H, 6.8; N, 6.7%); $[\alpha]_D^{25}$ −45.3 (*c* 0.8 in MeOH); $\nu_{max}/cm^{-1}$ 3300 (NH), 1710, 1630, 1520, 740 and 700; $\delta_H(CD_3SOCD_3)$ 7.80 (2 H, d, *J* 6, NH), 7.20 (10 H, s), 4.3–

3.9 (2 H, m), 2.9–2.7 (8 H, m) and 1.75 (6 H, s); $\delta_C$ see Table 4; *m*/*z* 325 ($M^+ - CH_2Ph$, 2%), 210 (2), 208 ($M^+/2$, 2), 191 (3), 176 (5), 162 (4), 150 (10), 120 (20), 117 (25) and 100 (100).

**Oxidation of 2b using MCPBA**

A solution of the 4,5-dihydrothiazole **2b** (1.6 g, 8.4 mmol) in diethyl ether (350 $cm^3$) was stirred at −78 °C while solid *m*-chloroperoxybenzoic acid (3.5 g, 20.3 mmol) was added. After the addition the solution was stirred at −78 °C for 2 h and then at room temperature for 40 h. It was then washed with saturated aqueous sodium carbonate (6 × 50 $cm^3$) and dried, and the solvent was evaporated. Chromatography of the residue ($SiO_2$, diethyl ether–light petroleum, 1:1) gave, at $R_f$ 0.2, colourless crystals (0.73 g, 25%) which consisted mainly of *S*-[(2S)-2-*acetylamino*-3-*phenylpropyl*] m-*chlorothiobenzoate* **12**; $\nu_{max}$/$cm^{-1}$ 3320 (NH), 1690, 1640, 1530, 1130, 960, 760 and 600; $\delta_H$ 7.75–7.30 (4 H, m), 7.30 (5 H, s), 6.6–6.4 (1 H, br d, *J* 6), 4.7–4.2 (1 H, m), 3.10 (1 H, half AB pattern of d, *J* 12 and 6), 3.05 (2 H, d, *J* 6), 2.90 (1 H, half AB pattern of d, *J* 12 and 8) and 2.30 (3 H, s); $\delta_C$ see Table 4; *m*/*z* 258 [$M^+(^{37}Cl) - CH_2Ph$, 35%], 256 [$M^+(^{35}Cl) - CH_2Ph$, 100], 216 (12), 214 (35), 208 (25), 158 (15) and 156 (45).

**Standard procedures for oxidation of 2d–h**

**Peracetic acid.** A solution of the 4,5-dihydrothiazole **2** (5 mmol) in $CH_2Cl_2$ (25 $cm^3$) was stirred vigorously at room temperature in the presence of anhydrous sodium carbonate (2.0 g, 22 mmol) while a 30% solution of peracetic acid in acetic acid (5 mmol or 15 mmol) was added dropwise. After the addition the mixture was stirred for 20 h and then filtered and the filtrate evaporated to give the product.

**2-Phenylsulfonyl-3-phenyloxaziridine.** A solution of the oxaziridine **13**[9] (0.70 g, 2.7 mmol) in $CH_2Cl_2$ (20 $cm^3$) was added slowly to a solution of the 4,5-dihydrothiazole **2** (2.5 mmol) in $CH_2Cl_2$ (20 $cm^3$) at room temperature. After stirring for 65 h, the solution was evaporated and the residue extracted with diethyl ether (10 $cm^3$) to leave the insoluble product.

***m*-Chloroperoxybenzoic acid.** A solution of the 4,5-dihydrothiazole **2** (5 mmol) in $CH_2Cl_2$ (100 $cm^3$) was stirred at room temperature while MCPBA (15 mmol) was added. After stirring for 40 h, the resulting precipitate was filtered off and recrystallised from diethyl ether–acetonitrile (1:1).

***tert*-Butyl hydroperoxide.** A solution of the 4,5-dihydrothiazole **2** (1.5 mmol) in $CH_2Cl_2$ (40 $cm^3$) was stirred at room temperature while a 3 M solution of *tert*-butyl hydroperoxide in $CH_2Cl_2$ (1.0 $cm^3$, 3 mmol) was added. After stirring for 35 h, the solution was evaporated to afford the products.

**Potassium permanganate under phase-transfer conditions.** A solution of the 4,5-dihydrothiazole **2** (2 mmol) and benzyltriethylammonium chloride (0.05 g, 0.2 mmol) in $CH_2Cl_2$ (25 $cm^3$) was stirred vigorously with a solution of potassium permanganate (0.63 g, 4 mmol) in water (50 $cm^3$) for 12 h. The mixture was filtered to remove $MnO_2$ and the organic layer was separated, washed with 1 M aqueous hydrazine dihydrochloride, dried and evaporated to give the products.

**Hydrogen peroxide in acetone.** A solution of the 4,5-dihydrothiazole **2** (3 mmol) in acetone (25 $cm^3$) was stirred at room temperature while 30% hydrogen peroxide (0.73 $cm^3$, 6.5 mmol) was added. After stirring for 20 h, the solution was evaporated to give the product.

**Tetrabutylammonium periodate.** A solution of the 4,5-dihydrothiazole **2** (1.5 mmol) and tetrabutylammonium periodate (1.3 g, 3 mmol) in 1,2-dichloroethane (40 $cm^3$) was heated under reflux for 90 h and then evaporated to dryness. Extraction of the residue with diethyl ether followed by evaporation gave the products.

**Hydrogen peroxide in acetonitrile (peracetimidic acid).** A mixture of 30% hydrogen peroxide (0.33 $cm^3$, 3 mmol) and acetonitrile (20 $cm^3$) was stirred for 20 min and then a solution of the 4,5-dihydrothiazole **2** (1.5 mmol) in acetonitrile (15 $cm^3$) was added and the mixture stirred for a further 40 h. The solvent was evaporated to give the product.

**Performic acid.** A solution of the 4,5-dihydrothiazole **2** (10 mmol) in formic acid (10 $cm^3$) was added to a mixture of 30% hydrogen peroxide (2.3 $cm^3$, 20 mmol) and formic acid (10 $cm^3$) and the mixture stirred at room temperature for 40 h. The solvent was evaporated and the residue purified by column chromatography on silica.

The yields of products obtained using these conditions are listed in Table 3 and the characterisation of the isolated samples is given below.

**(2*S*)-2-Benzoylamino-3-methylbutane-1-sulfonic acid 10d.** Colourless prisms, mp 178–180 °C (Found: C, 53.2; H, 6.3; N, 5.1. $C_{12}H_{17}NO_4S$ requires C, 53.1; H, 6.3; N, 5.2%); $[\alpha]_D^{25}$ +26.6 (*c* 0.84 in MeOH); $\nu_{max}$/$cm^{-1}$ 3700–2100 (br, OH), 3340 (NH), 1650, 1540, 1250, 1100, 1030, 990, 880, 780, 720 and 690; $\delta_H$ 8.45 (1 H, br d, *J* 8, NH), 8.3 (1 H, br s, OH), 8.2–8.0 (2 H, m), 7.6–7.4 (3 H, m), 4.30 (1 H, q, *J* 6), 3.30 and 3.00 (2 H, AB pattern of d, *J* 14, 6), 2.10 (1 H, octet, *J* 6), 1.10 (3 H, d, *J* 6) and 1.00 (3 H, d, *J* 6); $\delta_C$ see Table 4; *m*/*z* (CI) 271 ($M^+$, 1%), 270 (20), 256 (15), 238 (17), 224 (67), 208 (70), 190 (100), 176 (10), 139 (78), 122 (56) and 104 (24).

**(2*S*)-2-Benzoylamino-3-phenylpropane-1-sulfonic acid 10e.** Colourless prisms, mp 211–212 °C (HRMS: found $M^+$, 320.0975. $C_{16}H_{17}NO_4S$ requires *M*, 320.0956); $[\alpha]_D^{25}$ −40.0 (*c* 0.37 in MeOH); $\nu_{max}$/$cm^{-1}$ 3600–2400 (br, OH), 3300 (NH), 1710, 1650, 1250, 1100, 1010 and 710; $\delta_H(CD_3SOCD_3)$ 8.55 (1 H, br d, *J* 8, NH), 8.3 (1 H, br s, OH), 7.9–7.7 (2 H, m), 7.6–7.4 (3 H, m), 7.30 (5 H, s), 4.6–4.3 (1 H, m), 3.20, 3.00, 2.90 and 2.80 (4 H, two AB patterns of d, *J* 14, 6); $\delta_C$ see Table 4; *m*/*z* (CI) 320 ($M + H^+$, 5%), 302 (12), 272 (52), 254 (46), 238 (100), 180 (6), 122 (44) and 105 (27).

**(2*R*)-2-Benzoylaminobutane-1-sulfonic acid 10f.** Colourless needles, mp 160–162 °C (Found: C, 51.1; H, 5.95; N, 5.45. $C_{11}H_{15}NO_4S$ requires C, 51.3; H, 5.9; N, 5.4%); $[\alpha]_D^{25}$ +31.2 (*c* 0.9 in MeOH); $\nu_{max}$/$cm^{-1}$ 3300 (NH), 1630, 1520, 1300, 1180, 1060, 870, 840, 730 and 700; $\delta_H(CD_3SOCD_3)$, 8.40 (1 H, br d, *J* 7), 7.9–7.7 (2 H, m), 7.6–7.4 (3 H, m), 6.0–5.7 (1 H, br s, OH), 4.4–4.0 (1 H, m), 3.00 (1 H, half AB pattern of d, *J* 12, 9), 2.70 (1 H, half AB pattern of d, *J* 12.5), 1.8–1.4 (2 H, m) and 0.85 (3 H, t, *J* 6); $\delta_C$ see Table 4; *m*/*z* 257 ($M^+$, 17%), 228 (11), 176 (51), 162 (62), 146 (100) and 130 (81).

**(2*S*)-3-Methyl-2-trimethylacetylaminobutane-1-sulfonic acid 10g.** Colourless prisms, mp 150–152 °C (Found: C, 46.9; H, 8.1; N, 5.4. $C_{10}H_{21}NO_4S$ requires C, 47.8; H, 8.4; N, 5.6%) (HRMS: found $M + H^+$, 252.1289. $C_{10}H_{21}NO_4S$ requires $M + H^+$, 252.1270); $[\alpha]_D^{25}$ +18.7 (*c* 0.5 in MeOH); $\nu_{max}$/$cm^{-1}$ 3700–2100 (br, OH), 3340 (NH), 1620, 1540, 1230, 1100, 1040, 810 and 800; $\delta_H$ 8.4 (1 H, br d, *J* 8), 8.3 (1 H, br s, OH), 4.05 (1 H, q, *J* 7), 3.15 and 2.80 (2 H, AB pattern of d, *J* 14, 7), 2.00 (1 H, octet, *J* 7), 1.40 (9 H, s), 1.00 (3 H, t, *J* 7) and 0.95 (3 H, t, *J* 7); $\delta_C$ see Table 4; *m*/*z* 252 ($M + H^+$, 100%), 251 ($M^+$, 6), 234 (8), 208 (10), 170 (28), 128 (26) and 85 (44).

**(2*S*)-3-Phenyl-2-trimethylacetylaminopropane-1-sulfonic acid 10h.** Colourless crystals (impure); $\nu_{max}$/$cm^{-1}$ 3700–2100 (br, OH), 3440 (NH), 1650, 1510, 1370, 1320, 1220, 1120, 1030, 920 and 800; $\delta_H$ 8.3 (1 H, br d, *J* 8), 8.2 (1 H, br s, OH), 7.25 (5 H, s), 4.6–4.4 (1 H, m), 3.20 (1 H, half AB pattern of d, *J* 14, 6), 3.00 (1 H, half AB pattern of d, *J* 12, 7), 2.80 (1 H, half AB pattern of d, *J* 14, 10), 2.75 (1 H, half AB pattern of d, *J* 12, 9) and 1.40 (9 H, s); *m*/*z* 299 ($M^+$, 21%), 284 (32), 266 (35), 250 (71), 218 (82), 208 (65), 204 (51), 160 (100) and 142 (79).

**Bis[(2*R*)-2-benzoylaminobutyl] disulfide 9f.** Colourless needles, mp 145–147 °C (Found: C, 62.0; H, 6.6; N, 6.6. $C_{22}H_{28}N_2O_2S_2$ requires C, 63.4; H, 6.8; N, 6.7%); $[\alpha]_D^{25}$ −37.1 (*c* 1.0 in MeOH); $\nu_{max}$/$cm^{-1}$ 3300 (NH), 1640, 1530, 1370, 1310, 1250, 1180, 1150, 1120, 1080, 1030 and 700; $\delta_H(CD_3SOCD_3)$ 8.35 (2 H, d, *J* 8, NH), 8.0–7.8 (4 H, m), 7.6–7.4 (6 H, m), 4.10 (2 H, quintet, *J* 7), 3.40 (2 H, half AB pattern of d, *J* 14, 6), 3.15 (2 H, half AB pattern of d, *J* 14, 8), 1.8–1.4 (4 H, m) and (6 H, t,

*J* 7); $\delta_C$ see Table 4; *m*/*z* 416 ($M^+$, 5%), 387 (9), 370 (12), 295 (29), 241 (15), 208 (52), 189 (81), 176 (40) and 162 (100).

**Preparation of the thiazoles 11**

Following the method of Asinger *et al.*,[11] a mixture of the appropriate 4,5-dihydrothiazole **2** (10.5 mmol) and sulfur (0.67 g, 21 mmol) was heated at 200–210 °C for 30 min. The mixture was placed under vacuum (20 Torr) and heated at 200 °C for a further 2 h. The resulting mixture was cooled and extracted with diethyl ether (20 $cm^3$). The extract was filtered, the solvent was evaporated and the residue again taken up in diethyl ether (20 $cm^3$). This extract was filtered, the solvent was evaporated and the residue Kugelrohr distilled to give the product.

**4-Isopropyl-2-phenylthiazole 11d.** From **2d** (54%) as a yellow oil, bp 125 °C (oven temp.) at 0.1 Torr (HRMS: found $M^+$, 203.0763. $C_{12}H_{13}NS$ requires *M*, 203.0769); $\nu_{max}/cm^{-1}$ 1513, 1499, 1458, 1002, 764 and 689; $\delta_H$ 8.1–7.9 (2 H, m), 7.5–7.3 (3 H, m), 6.85 (1 H, s), 3.15 (1 H, m) and 1.40 (6 H, d, *J* 8); $\delta_C$ see Table 2; *m*/*z* 203 ($M^+$, 80%), 188 (80), 104 (80), 85 (80), 77 (90) and 45 (100).

**4-Benzyl-2-phenylthiazole 11e.** From **2e** (53%) as a yellow oil, bp 250 °C (oven temp.) at 4 Torr (HRMS: found $M^+$, 251.0778. $C_{16}H_{13}NS$ requires *M*, 251.0769); $\nu_{max}/cm^{-1}$ 1520, 1500, 1460, 1440, 775, 730 and 705; $\delta_H$ 8.0–7.8 (2 H, m), 7.4–7.3 (8 H, m), 6.70 (1 H, t, *J* 1) and 4.20 (2 H, d, *J* 1); $\delta_C$ see Table 2; *m*/*z* 251 ($M^+$, 60%), 147 (45), 122 (35), 115 (45), 104 (15) and 77 (15).

**4-Ethyl-2-phenylthiazole 11f.** From **2f** (81%) as a red oil, bp 165 °C (oven temp.) at 1 Torr (Found: C, 69.7; H, 5.8; N, 7.6. $C_{11}H_{11}NS$ requires C, 69.8; H, 5.9;N, 7.4%) (HRMS: found $M^+$, 189.0620. $C_{11}H_{11}NS$ requires *M*, 189.0612); $\nu_{max}/cm^{-1}$ 1520, 1500, 1460, 1440, 770 and 700; $\delta_H$ 8.0–7.8 (2 H, m), 7.5–7.3 (3 H, m), 6.90 (1 H, t, *J* 1), 2.85 (2 H, qd, *J* 8 and 1) and 1.35 (3 H, t, *J* 8); $\delta_C$ see Table 2; *m*/*z* 189 ($M^+$, 90%), 188 (100), 174 (50), 161 (25), 121 (35), 104 (60), 85 (8), 77 (70) and 71 (90).

**Preparation of the 4,5-dihydro-1λ⁶,3-thiazole 1,1-dioxides 3**

A solution of the appropriate 4,5-dihydrothiazole **2** (5.24 mmol), benzoic acid (0.64 g, 5.24 mmol) and benzyltriethylammonium chloride (0.20 g, 0.88 mmol) in $CH_2Cl_2$ (50 $cm^3$) was stirred vigorously for 15 h at room temp. with a solution of potassium permanganate (1.66 g, 10.48 mmol) in water (100 $cm^3$). Sodium metabisulfite was then added until the colour of the mixture changed from dark brown to beige. The mixture was filtered through Celite, the organic layer separated and the aqueous layer extracted with $CH_2Cl_2$. The combined organic extracts were washed with aqueous hydrazine dihydrochloride (1 M), saturated aqueous sodium carbonate and brine, dried, and the solvent was evaporated to afford the product.

**(4*S*)-4-Isopropyl-2-phenyl-4,5-dihydro-1λ⁶,3-thiazole 1,1-dioxide 3d.** From **2d** (85%) as colourless crystals, mp 78–80 °C (HRMS: found $M^+$, 237.0827. $C_{12}H_{15}NO_2S$ requires *M*, 237.0823); $[\alpha]_D^{20}$ +10.4 (*c* 1.02 in $CH_2Cl_2$); $\nu_{max}/cm^{-1}$ (melt) 3000–2900, 1620, 1460, 1310 and 1130 ($SO_2$), 770 and 690; $\delta_H$ 8.1 (2 H, m), 7.5 (3 H, m), 4.25 (1 H, m), 3.34 (1 H, half AB pattern of d, *J* 13 and 7), 2.96 (1 H, half AB pattern of d, *J* 13 and 6), 2.1 (1 H, m), 1.08 (3 H, d, *J* 7) and 1.00 (3 H, d, *J* 7); $\delta_C$ see Table 2; *m*/*z* 237 ($M^+$, 5%), 172 (60), 157 (20), 145 (15), 129 (30), 116 (20) and 103 (100).

Attempted recrystallisation of **3d** afforded a mixture of 2-benzoylamino-3-methylbutane-1-sulfonic acid **10d** and 2-*benzoylamino*-3-*methylbutane*-1-*sulfinic acid* **8d**; $\delta_C$ see Table 4.

**(4*S*)-4-Benzyl-2-phenyl-4,5-dihydro-1λ⁶,3-thiazole 1,1-dioxide 3e.** From **2e** (93%) as a yellow oil (Found: C, 67.8; H, 5.2; N, 4.9. $C_{16}H_{15}NO_2S$ requires C, 67.3; H, 5.3; N, 4.9%); $[\alpha]_D^{20}$ −0.375 (*c* 1.6 in $CH_2Cl_2$); $\nu_{max}/cm^{-1}$ 3060, 3020, 1630, 1500, 1455, 1315 and 1140 ($SO_2$), 775, 750 and 700; $\delta_H$ 8.11 (2 H, m), 7.6–7.2 (8 H, m), 4.7 (1 H, m), 3.37 (1 H, half AB pattern of d, *J* 13.8 and 6), 3.23 (1 H, half AB pattern of d, *J* 13.6 and 7.1), 2.95 (1 H, half AB pattern of d, *J* 13.6 and 6), 2.90 (1 H, half AB pattern of d, *J* 13.8 and 9); $\delta_C$ see Table 2; *m*/*z* 145 ($M^+$ − 140, 5%), 128 (5), 117 (100), 103 (15), 91 (30) and 77 (10).

Attempted recrystallisation of **3e** produced 2-*benzoylamino*-3-*phenylpropane*-1-*sulfinic acid* **8e** (Found: C, 63.1; H, 5.6; N, 4.6. $C_{16}H_{17}NO_3S$ requires C, 63.3; H, 5.6; N, 4.6%); $\delta_H(CD_3SOCD_3)$ 8.6 (1 H, m), 7.75 (2 H, m), 7.5 (3 H, m), 7.35 (5 H, m), 5.5 (1 H, br s), 4.5 (1 H, m) and 3.15–2.75 (4 H, m); $\delta_C$ see Table 4.

**(4*R*)-4-Ethyl-2-phenyl-4,5-dihydro-1λ⁶,3-thiazole 1,1-dioxide 3f.** From **2f** (90%) as colourless crystals, mp 69–70 °C (Found: C, 58.5; H, 6.2; N, 6.2. $C_{11}H_{13}NO_2S$ requires C, 59.2; H, 5.9; N, 6.3%) (HRMS: found $M^+$, 223.0650. $C_{11}H_{13}NO_2S$ requires *M*, 223.0667); $[\alpha]_D^{20}$ +11.25 (*c* 1.04 in $CH_2Cl_2$); $\nu_{max}/cm^{-1}$ (melt) 3300, 1630, 1460, 1300 and 1140 ($SO_2$), 1000, 780 and 700; $\delta_H$ 8.1 (2 H, m), 7.5 (3 H, m), 4.37 (1 H, m), 3.41 (1 H, half AB pattern of d, *J* 13 and 7), 2.92 (1 H, half AB pattern of d, *J* 13 and 6), 1.97–1.75 (2 H, m) and 1.10 (3 H, t, *J* 8); $\delta_C$ see Table 2; $\delta_S$ 36.6 ($w_{1/2}$ 200 Hz); *m*/*z* 223 ($M^+$, 1%), 177 (5), 159 (65), 130 (13), 122 (5), 117 (5), 104 (100) and 77 (70).

Attempted recrystallisation of **3f** afforded a mixture of 2-benzoylaminobutane-1-sulfonic acid **10f** and 2-*benzoylamino*-*butane*-1-*sulfinic acid* **8f**; $\delta_H(CD_3SOCD_3)$ 11.1 (1 H, br s), 8.4 (1 H, br s), 7.95 (2 H, m), 7.55 (3 H, m), 4.4 (1 H, m), 3.15 (1 H, half AB pattern of d, *J* 16 and 8), 3.0 (1 H, half AB pattern of d, *J* 16 and 5), 1.95 (1 H, m), 1.75 (1 H, m) and 1.00 (3 H, t, *J* 9); $\delta_C$ see Table 4; *m*/*z* (GC–MS) 241 ($M^+$, 1%), 239 (20), 210 (20), 146 (50), 122 (55), 105 (100) and 77 (80).

**Preparation of bis[(2*R*)-2-benzoylaminobutyl] disulfide 9f**

**(2*R*)-2-Benzoylamino-1-chlorobutane 14.** This was prepared by stirring a solution of (2*R*)-2-benzoylaminobutanol **4f** (2.0 g, 10.4 mmol) and triethylamine (1.57 g, 15.5 mmol) in 1,2-dichloroethane (50 $cm^3$) at room temperature while a solution of methanesulfonyl chloride (1.77 g, 15.5 mmol) in 1,2-dichloroethane (50 $cm^3$) was added dropwise. After the addition the mixture was heated under reflux for 20 h and then cooled, washed with water (3 × 50 $cm^3$), dried and the solvent was evaporated. Recrystallisation of the residue from hexane–ethyl acetate (3:1) gave the *title chloride* **14** (0.90 g, 41%) as colourless needles, mp 96–99 °C (Found: C, 62.7; H, 6.6; N, 6.65. $C_{11}H_{14}ClNO$ requires C, 62.4; H, 6.7; N, 6.6%); $[\alpha]_D^{25}$ +44.4 (*c* 0.9 in $CHCl_3$); $\nu_{max}/cm^{-1}$ ($CH_2Cl_2$) 3440 (NH), 1660, 1510, 1490, 1460, 1440, 1350, 1290, 1150, 1070, 1030 and 800; $\delta_H$ 7.8–7.7 (2 H, m), 7.6–7.4 (3 H, m), 6.40 (1 H, br d, *J* 8), 4.4–4.3 (1 H, m), 3.80 (1 H, half AB pattern of d, *J* 8 and 4), 3.75 (1 H, half AB pattern of d, *J* 8 and 2), 1.80–1.65 (2 H, m) and 1.00 (3 H, t, *J* 6); $\delta_C$ see Table 4; *m*/*z* (CI) 214 [$M(^{37}Cl) + H^+$, 32%], 212 [$M(^{35}Cl) + H^+$, 100], 176 (32), 162 (5), 122 (3), 105 (25) and 94 (3).

In an alternative approach, reaction of (2*R*)-2-benzoylaminobutanol **4f** with triphenylphosphine in carbon tetrachloride gave the same product in 41% yield after chromatographic purification; spectroscopic data were identical to those reported above.

**(2*R*)-2-Benzoylaminobutanethiol 15.** A solution of chloride **14** (1.0 g, 4.7 mmol) and sodium sulfide nonahydrate (3.4 g, 14.2 mmol) in ethanol and water (1:1, 50 $cm^3$) was heated under reflux for 44 h. Evaporation of the ethanol and extraction of the aqueous residue with $CH_2Cl_2$ followed by drying and evaporation of the solvent gave the *title thiol* **15** (0.42 g, 43%) as colourless needles, mp 89–91 °C (HRMS: found $M^+$, 209.0893. $C_{11}H_{15}NOS$ requires *M*, 209.0874); $[\alpha]_D^{25}$ +41.1 (*c* 0.9 in $CHCl_3$); $\nu_{max}/cm^{-1}$ 3280 (NH), 1640, 1530, 1330, 1300, 1260, 1150, 1100, 1050, 800 and 700; $\delta_H$ 7.9–7.7 (2 H, m), 7.6–7.3 (3 H, m), 6.5–6.2 (1 H, br s, NH), 4.2–3.9 (1 H, m), 3.85 (1 H, half AB pattern of d, *J* 12, 4), 3.80 (1 H, half AB pattern of d, *J* 12, 5), 2.6–2.3 (1 H, br s, SH), 1.9–1.5 (2 H, m) and 1.00 (3 H, t, *J* 8); $\delta_C$ see Table 4; *m*/*z* 209 ($M^+$, 5%), 208 (26), 176 (28), 162 (18), 122 (10), 105 (100) and 77 (46).

**Bis[(2*R*)-2-benzoylaminobutyl] disulfide 9f.** Following the

method of Friedländer *et al.*,[24] sulfur (0.54 g, 2.1 mmol) was added to molten sodium sulfide nonahydrate (1.64 g, 6.84 mmol) to form $Na_2S_2$. To this was added a solution of the above chloride **14** (1.0 g, 4.73 mmol) in ethanol (50 $cm^3$) with stirring. After stirring at room temperature for 20 h, the ethanol was evaporated and the residue partitioned between water and $CH_2Cl_2$. Drying, evaporation of the organic layer and recrystallisation of the residue from ethyl acetate–propan-2-ol (2:1) gave the *title disulfide* **9f** (0.49 g, 50%) which had identical physical and spectroscopic properties to that obtained from the oxidation reactions.

**Flash vacuum pyrolysis of the thiazole 1,1-dioxides 3**

The apparatus used was similar to one which has been illustrated and described recently.[25] The sample was volatilised from a tube in a Büchi Kugelrohr oven through a 30 × 2.5 cm horizontal fused quartz tube. This was heated externally by a Carbolite Eurotherm tube furnace MTF-12/38A to temperatures in the range 250–1000 °C, the temperature being monitored by a Pt/Pt-13%Rh thermocouple situated at the centre of the furnace. The products were collected in a U-shaped trap cooled in liquid nitrogen. The whole system was maintained at a pressure of $10^{-3}$ mmHg by an Edwards Model E2M5 high capacity rotary oil pump, the pressure being measured by a Pirani gauge situated between the cold trap and the pump. Under these conditions the contact time in the hot zone was estimated to be *ca.* 10 ms.

After the material had all sublimed the products were recovered directly from the cold trap and analysed by $^1$H and $^{13}$C NMR. Yields were determined by calibration of the $^1$H NMR spectra by adding an accurately weighed quantity of a solvent such as $CH_2Cl_2$ and comparing integrals, a procedure estimated to be accurate to ±10%.

**(4*S*)-4-Isopropyl-2-phenyl-4,5-dihydro-1λ$^6$,3-thiazole 1,1-dioxide 3d.** The FVP of **3d** (212.9 mg, 600 °C, 1.0 × $10^{-3}$ Torr, 50–60 °C) gave a yellow oil which was analysed by $^{13}$C and $^1$H NMR specroscopy and GC–MS and shown to contain two compounds; 3-methylbut-1-ene **16d** (68%) and benzonitrile (83%).

**(4*S*)-4-Benzyl-2-phenyl-4,5-dihydro-1λ$^6$,3-thiazole 1,1-dioxide 3e.** The FVP of **3e** (236.6 mg, 600 °C, 4.0 × $10^{-3}$ Torr, 60–70 °C) gave a yellow oil which was analysed by $^{13}$C and $^1$H NMR spectroscopy and GC–MS and shown to contain three compounds; allyl benzene **16e** (>90%), benzonitrile (>90%) and the starting sulfone (4%).

**(4*R*)-4-Ethyl-2-phenyl-4,5-dihydro-1λ$^6$,3-thiazole 1,1-dioxide 3f.** The FVP of **3f** (213 mg, 600 °C, 1.0 × $10^{-3}$ Torr, 50–60 °C) gave a yellow oil in the cold trap and a white solid at the furnace exit. The $^{13}$C and $^1$H NMR spectra of the solid showed it to be the starting material (trace) and $^{13}$C and $^1$H NMR and GC–MS analysis of the oil showed two compounds; but-1-ene **16f** (78%) and benzonitrile (94%).

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