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Diastereoselective synthesis of aziridines from (1*R*)-10-(*N,N*-dialkylsulfamoyl)isobornyl 2*H*-azirine-3-carboxylates

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Reaction of the chiral azirine **1a** with nucleophiles and dienes is described. Thiols, heteroaromatic nitrogen compounds and phenylmagnesium bromide add to the azirine **1a** to give functionalised aziridines **2/3a**–**h**. X-Ray crystal structures for the products **3e** and **3g** have been obtained. Diastereodifferentiation of the two faces of the azirine **1a** is observed in most cases, but only thiophenol gives a single diastereomer (**2a**). Most mixtures of diastereomers were separated by dry flash chromatography. Benzylamine produced a dimer of the original azirine **1a**, compound **9**. Representative conjugated dienes (cyclopentadiene, furan and open chain dienes) were added to the chiral azirine **1a**. Only poor selectivities were observed. The selectivity was not significantly enhanced in the cycloaddition of cyclopentadiene to the more bulky azirine **1b**.

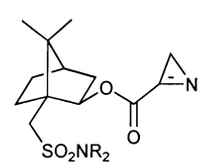
We have described reactions of 2*H*-azirine-3-carboxylic esters with nucleophiles. Sulfur nucleophiles,[1,2] oxygen nucleophiles[1] and aromatic nitrogen heterocycles[3] formed aziridines of type **2/3**. 2*H*-Azirine-3-carboxylates have also proved to be excellent aza dienophiles in Diels–Alder reactions; they add to nucleophilic dienes giving good yields of compounds having the aziridine fused to a six-membered ring.[4] These reactions offer a route to new aziridinecarboxylic acid derivatives, a group of compounds that are known to have biological activity.[5] The aziridinecarboxylic acids also have the potential to act as analogues of natural amino acids and to introduce rigidity into a peptide chain.[6] Recent work of F. A. Davis and co-workers[7] has shown the usefulness of phosphonate ester azirines, the 2*H*-3-phosphonates act as partners in Diels–Alder reactions to give bicyclic structures of the same type having a phosphonate ester group instead of a carboxylic ester group. These compounds also are expected to exhibit a range of biological activity.

We therefore set out to synthesise a chiral 2*H*-azirine that could be used to form chiral aziridines by diastereoselective nucleophilic addition and Diels–Alder cycloaddition. The chiral acrylate **4a** was first synthesised by Oppolzer *et al.*[8] and was successfully used in asymmetric Diels–Alder reactions, so this acrylate was chosen as a precursor to a chiral azirine **1a**. The azido ester **5a** was prepared from the acrylate **4a** *via* the dibromopropionate **6a**, following a general method, according to Scheme 1.[9] Finally the azirine **1a** was obtained by pyrolysis of the α-azidoacrylate **5a**. The azirine **1a** was characterized by NMR. The signal for the hydrogens attached to C-2 appear as a singlet at 1.93 ppm and that for C-3 at 157.4 ppm. Preliminary results with this azirine showed excellent selectivity for the addition of thiophenol but poor selectivity for Diels–Alder cycloaddition with cyclopentadiene.[2] In view of the high selectivity of the nucleophilic addition reaction a more extensive study of the addition of nucleophiles and dienes to this azirine has been carried out.

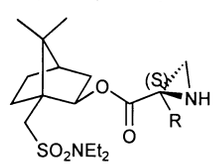
Results and discussion

Reaction with thiols

Freshly prepared azirine **1a** in toluene was used directly in reactions with thiols. The azirine solution was cooled in an ice–water bath and thiols were added with magnetic stirring.



1a; R = Et
1b; R = Cyclohexyl



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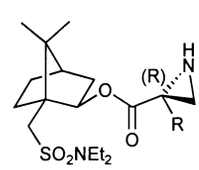

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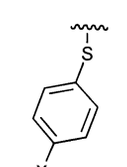
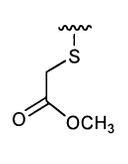
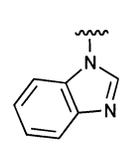


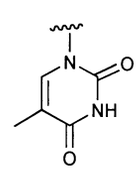
2a, X = H
2b/3b, X= Cl
2c/3c, X = NO_2



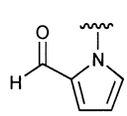
2d/3d



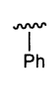
2e/3e



2f/3f



2g/3g



2h/3h

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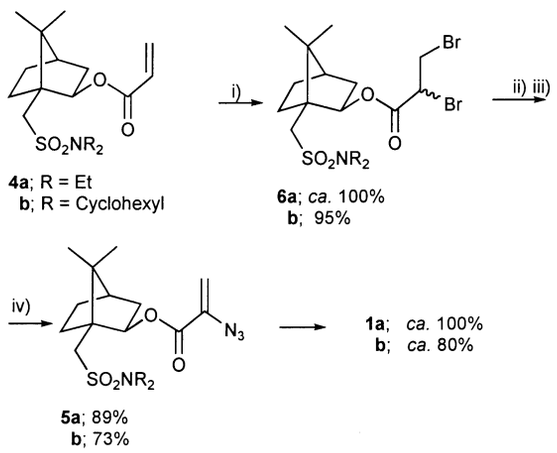
Table 1 Isolated yields (%) of compounds **2** and **3** after dry flash chromatography

Compound	Isomer **2**	Isomer **3**	Isomers **2** + **3**	Total yield
2/3a	58 (only)	—	—	58
2/3b	54	—	—	54
2/3c	18	—	54	72
2/3d	9	—	45	54
2/3e	[a]	21	16	37
2/3f	5	27	19	51
2/3g	26	34.5	—	60.5
2/3h	—	—	—	40

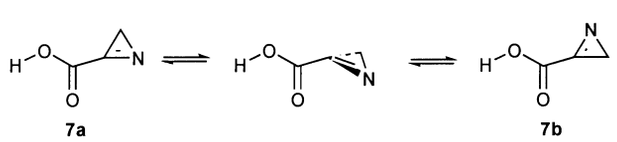
[a] The minor isomer fraction was contaminated with benzimidazole in the ratio 1 (minor isomer) : 5 (benzimidazole).



Scheme 1 *Reagents*: i, Br_2, DCM, 24 h; ii, NaN_3 (3 equiv.), DMF; iii, DBU; iv, toluene, 110 °C, 1.5 h.

The reaction mixture was then left to stir at room temperature for 2–19 hours. The reactions gave mixtures of diastereomers, generally a major and a minor isomer with the exception of thiophenol, which produced a single compound **2a** (Table 1). 4-Chlorothiophenol also showed good diastereoselectivity giving diastereomers **2b** : **3b** in an 8 : 1 ratio according to the ^{1}H NMR spectrum of the reaction mixture. The major adduct from 4-chlorothiophenol (**2b**) was obtained in a combined yield of 54% and the minor isomer could be detected by ^{1}H NMR but not isolated. 4-Nitrothiophenol did not react under neutral conditions after 2 days at room temperature but in the presence of sodium carbonate in acetonitrile a 4 : 1 mixture of isomers **2c** : **3c** was formed after 30 hours at room temperature in a combined yield of 72%. A sample of the major isomer was obtained almost pure by flash chromatography. Methyl thioglycolate gave a mixture of diastereomers **2d** : **3d** in an approximately 1 : 1 ratio either at room temperature or at 0 °C (as shown by ^{1}H NMR analysis).

Reaction of thiophenol with the azirine **1a** gave compound **2a** in an optically pure form (as evidenced by the NMR spectrum of the crude reaction mixture). After chromatography and crystallisation **2a** was obtained as a crystalline solid in 58% yield. X-Ray crystallography established that the newly formed stereogenic centre had the *S* configuration, as shown in structure **2**.[2] Molecular orbital calculations on the conformation of 2*H*-azirine-3-carboxylic acid indicate that the minimum energy conformers **7a** and **7b** have similar values and that the rotation barrier between them is only 8 kJ·mol^{-1} (Scheme 2).[2] The



Scheme 2

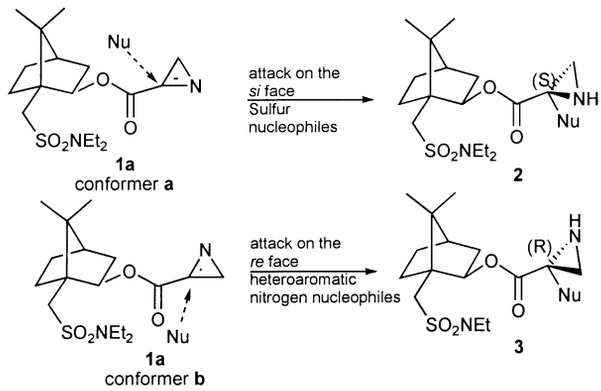
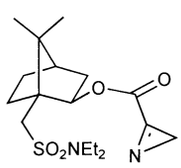


Fig. 1 Approach of nucleophiles to the less hindered face of two conformations of the azirine **1a**.

stereochemistry of **2a** would result from attack of thiophenol on the *Si* face of the azirine, probably as an approach at the rear face of conformer **a** (Fig. 1). Formation of the *S* aziridine after nucleophilic attack could be due to an unfavourable interaction with the ester carbonyl group or to steric hindrance by a methylene group of the norbornyl unit on the rear face (*Re*) of conformation **b**. Nucleophilic attack would also be possible through the less hindered face (*Si*) of the s-*cis* ester conformation **8**. A comparison of the NMR data for the thio aziridine derivatives **2** and **3** shows no clear pattern of difference between them. The *S* configuration was assigned to the major products **2** on the basis of an analogous mode of approach expected for the *p*-substituted thiophenols compared with thiophenol itself. Diastereoselectivity dropped to zero when methyl thioglycolate was used as the nucleophile. Possibly the higher reactivity of the alkyl thiol is a factor in the loss of selectivity.



8

Reactions with heteroaromatic nitrogen compounds

Reaction of the 2*H*-azirine **1a** with the heteroaromatic nitrogen compounds benzimidazole and thymine was carried out in the presence of sodium carbonate and in acetonitrile at room temperature for periods between 1 hour and 6 days. Compounds **2e/3e** and **2f/3f** were produced, in both cases as a mixture in a 2 : 1 ratio of diastereomers. The major isomers were separated by dry flash chromatography in both cases: **3e** in 21% and **3f** in 27% yield. Reaction of 2*H*-azirine **1a** with 2-formylpyrrole gave diastereomers **2g/3g** in a ratio of approximately 1 : 1. The two were completely separated (34.5% and 26%) and were fully characterized. X-Ray crystal structures of diastereomers **3e** and **3g** were obtained (Figs. 2 and 3) and in both cases the new stereogenic centre on the aziridine had the *R*-configuration. The major isomers **3e** and **3g** would form after attack of the nucleophile on the *Re* face of the azirine, probably as shown in conformer **b** (Fig. 1), but not on the less hindered (*Si*) face of the s-*cis* conformer **8**, where different stereochemistry would result. When the nucleophile is a heteroaromatic nitrogen anion the attack of the electron pair (which is coplanar with the aromatic ring) would be by approach to the azirine ring in an orthogonal plane, thus avoiding the interactions referred to above in the nucleophilic attack of thiols on the *Re* face of conformer **b**.

The first eluted products were separated from the other isomer by simple flash chromatography in each case; there was a considerable difference in polarity between each diastereomer

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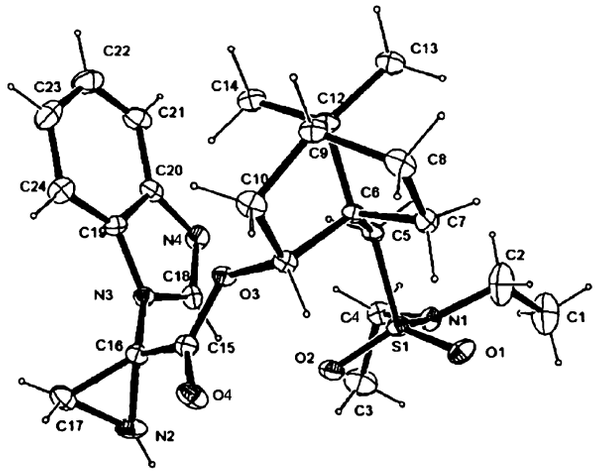


Fig. 2 ORTEP view of the molecular structure of the aziridine **3e**. The thermal ellipsoids are drawn at the 50% probability level.

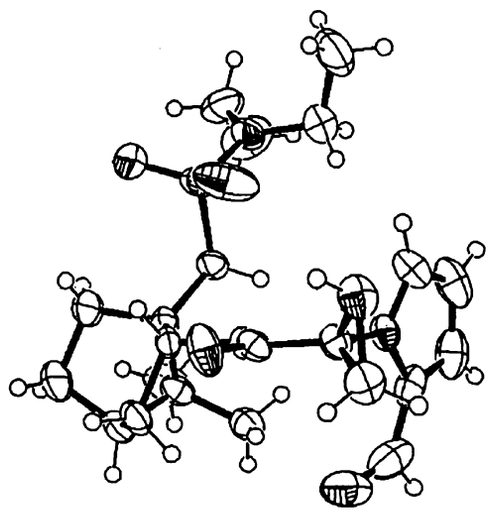
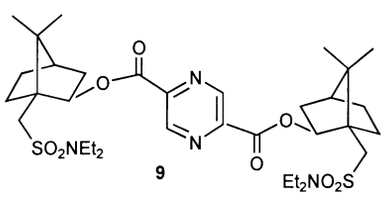


Fig. 3 ORTEP view of the molecular structure of the aziridine **3g**. The thermal ellipsoids are drawn at the 50% probability level.

in the pair. Based in this observation the first eluted isomer of reaction with thymine was assigned as the *R* isomer (**3f**). The minor isomer **2e** was contaminated with benzimidazole, and the major isomer **3f** with a small amount of the minor isomer. Electrophilic addition of the azirine to thymine was considered to occur at N-1 in accordance with the general reactivity of thymine. Moreover, an X-ray crystal structure of an adduct of thymine with a similar azirine showed it to follow the same rule.[10]



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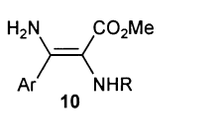

10

Ar = 2,6-dichlorophenyl
R = benzyl

When the reaction of the 2*H*-azirine **1a** and benzimidazole was carried out over 2 days at room temperature benzimidazole was recovered in almost quantitative yield and pyrazine **9** was isolated in 7% yield. The major characteristic feature of this compound was its high symmetry as shown by the ^{1}H and ^{13}C NMR spectra. The chemical shift of the hydrogens attached to the pyrazine ring (δ_H 9.31 ppm) is in accord with literature values for similar pyrazines.[11]

Reaction with phenylmagnesium bromide

Reaction of the azirine **1a** with 1 equivalent of phenylmagnesium bromide was carried out at −78 °C. The ester was partially cleaved giving back the alcohol, *N,N*-diethylsulfamoylisoborneol, which was isolated in 33.6% yield after flash chromatography. The product of addition of the phenylmagnesium bromide to the azirine was collected as a colourless oil in 40% yield. It was found to be a 1 : 1 mixture of two diastereomers **2h** : **3h** that could not be separated by dry flash chromatography.

Reaction with benzylamine

Several primary and secondary amines had previously been reacted with 2*H*-azirine-3-carboxylates giving open chain products of type **10**.[1] However **1a** and benzylamine gave the aromatised dimer **9** as the only characterizable product; this was isolated in 17% yield. A 1,2-dihydropyrazine dimer was previously obtained by passing a 2*H*-azirine-3-carboxylate through a column of silica gel.[4] The acidic properties of silica were assumed to promote dimerisation of the azirine. It now seems that an amine can also catalyse dimerisation. Traces of compound **9** were also detected in the reaction of the azirine with *p*-nitrothiophenol when performed in the presence of Na_2CO_3.

The aziridine ring was assigned on the basis of ^{1}H, ^{13}C NMR spectra and X-ray structures obtained for **2a**,[2] **3e** and **3g**. The major features of the ^{1}H NMR spectra of **2a**–**d** are the two broad signals for H-3 protons, one at *ca.* δ_H 2.0–2.5 ppm and the other at *ca.* δ_H 2.5–2.9 ppm (as broad singlets **2a**, **2b** and **2d**; as broad doublets **2c**), and the NH absorption appears at around δ_H 2.4 ppm as a very broad signal, with exception of **2c** where NH is a defined triplet (*J* 10.2) and **2d** where the NH signal is not visible. Addition of D_2O to the NMR sample tube causes the CH signals to sharpen and the NH signal to disappear. Minor isomers also show the aziridine CH as broad signals and the NH absorption is absent. Major isomers **3e** and **3f** and the first eluted isomer **3g** show a doublet for each of the CH protons and a triplet for the NH at around the same chemical shift as for the thiol adducts. There is a splitting of *ca.* 10.5 Hz that is due to the vicinal NH to CH coupling. After D_2O exchange the NH triplet disappears and the CH doublets collapse to singlets. The second isomer (**2g**) isolated by chromatography displays a similar pattern in the ^{1}H NMR spectra to the first eluted isomer (**3g**). The spectrum of compound **2e** showed a broad signal for NH and the aziridine CH appeared as broad singlets. These apparent differences in whether the NH signal is present or not are presumably due to traces of acid or moisture that cause the NH to exchange in some samples but not in others; for example two spectra were obtained for compound **2c**, one clearly showing the NH signal as a well defined triplet and the other not. Typically, no coupling is observed between the geminal hydrogens on the aziridine ring.

Reactions with dienes

Oppolzer and coworkers have studied the selectivity of Diels–Alder reactions in acrylates bearing the same type of chiral auxiliary with cyclopentadiene and found excellent diastereoselectivities.[8] The reason for this is that the acrylate function adopts a strict antiperiplanar disposition of the carbonyl and the carbon–carbon double bond and this causes a preferential attack on one face. Reactions of the azirine **1a** with four dienes, namely cyclopentadiene, 1-methoxybutadiene, (*E*, *E*)-1,4-diphenylbutadiene and furan, were investigated. The reactions with the first three of these dienes, which are *endo* additions,[4] showed poor diastereoselectivity and there was no diastereoselectivity at all in the addition to furan, a 1 : 1 mixture of two *exo* adducts being obtained (the *exo* mode of addition is characteristic of other azirine cycloadditions to furans[12]). Our results with the kinetically controlled *endo* cycloadditions probably reflect the easy interconversion of rotamers in the azirine (conformer **a** and conformer **b**) and the equivalent population of both in the reaction mixture. The 2 : 1 ratio of diastereomers

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observed with cyclopentadiene is probably due to a very small difference in the energy of the transition states. Two possible approaches of cyclopentadiene to the azirine are illustrated in Fig. 4. The interaction that would lead to the major diastereo-

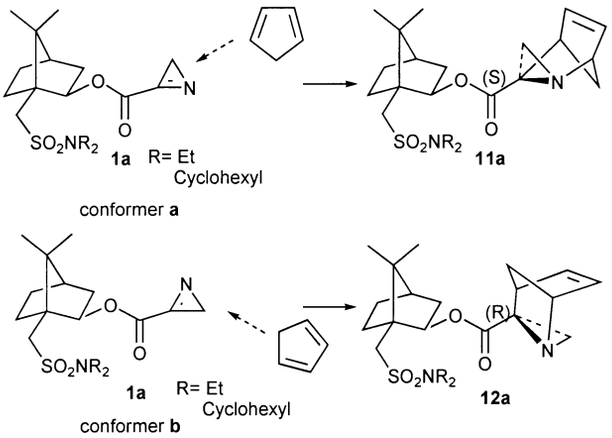
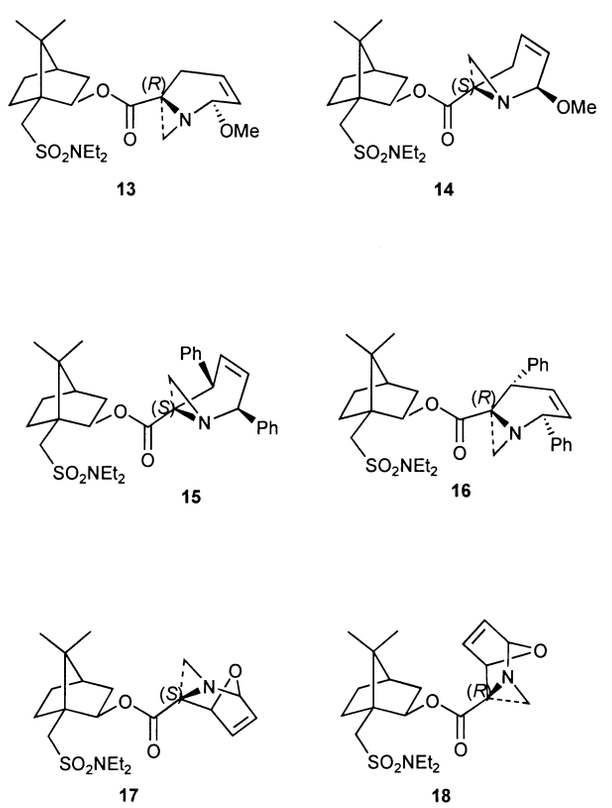


Fig. 4 Approach of cyclopentadiene to the less hindered face of two conformations of the azirine **1a**.

mer **12a** is indicated as the preferential direction of attack on the *Re* face of the azirine of conformer **b**. The minor isomer **11a** (the stereochemistry of the minor isomer has previously been determined by X-ray crystallography[2]) would result from an attack on the *Si* face of conformer **a**. The bulkier substituents in azirine **1b** scarcely improve the diastereodifferentiation of the two azirine faces: the diastereomeric ratio observed with azirine **1a** bearing the diethylsulfonamido group is 2 : 1 and with azirine **1b** bearing the dicyclohexylsulfonamido group it is 3 : 1. On the other hand, the thermodynamic control generally associated with the *exo* cycloadditions indicates similar energy states for both *exo* isomers. The reaction of the azirine **1a** with furan was performed either at 5 °C and at rt. The same diastereomeric mixture (**17** and **18**) in the same ratio (1 : 1) was obtained in the two experiments. Also, heating of the 1 : 1 mixture of isomers for 15 hours at 75 °C caused no observable change in the ratio.



A preliminary X-ray investigation of the major diastereomer **15** obtained from the reaction of the azirine **1a** with 1,4-diphenylbuta-1,3-diene showed that it has the *S*-configuration at the new asymmetric centre (Fig. 5). This result would be due

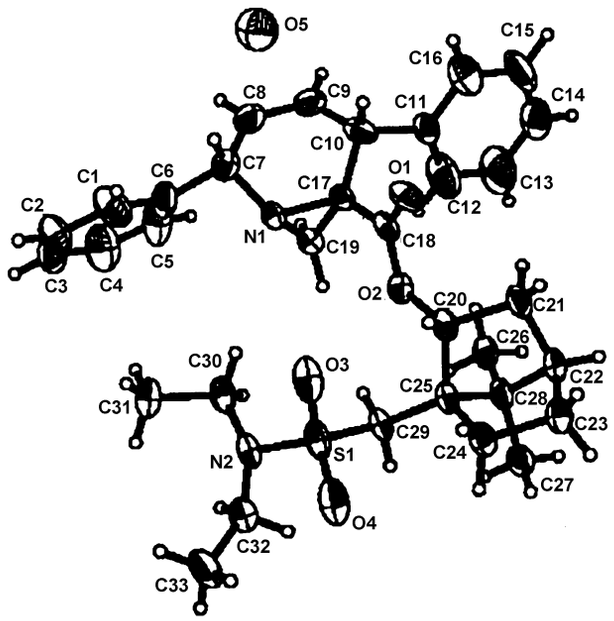


Fig. 5 ORTEP view of the molecular structure of the cycloadduct **15**. The thermal ellipsoids are at the 50% probability level.

to the stereoelectronic effect of the bulky Ph groups in the diene that cause severe interference with the isobornyl unit, especially when the attack occurs at the rear face of conformer **a**. The effect is minimized when the attack occurs at the rear face of conformer **b**. The presence of water of crystallisation was indicated from the crystal structure and also by elemental analysis.

Conclusions

Azirine **1a** reacted with thiols and nitrogen aromatic heterocycles to give addition products in which the three-membered ring is preserved. Of the reactions tested only 4-chlorothiophenol and thiophenol added to the chiral azirine **1a** with good to excellent diastereoselectivity. Major isomers (where formed) have the *S* configuration at the stereogenic centre of the aziridine. Heteroaromatic nitrogen compounds gave mixtures of both diastereomers with zero to modest diastereoselectivity. Major isomers (where formed) have the *R* configuration at the stereogenic centre of the aziridine. Phenylmagnesium bromide added with no selectivity. Cycloaddition reactions of the azirines **1** also showed low diastereoselectivity, whether they resulted from kinetic control (*endo* additions) or thermodynamic control (*exo* addition to furan). Nevertheless, in cases where the diastereomers can be separated by chromatography, these reactions represent a route to chiral aziridines of a novel type.

Experimental

General

^{1}H NMR spectra were recorded on a Varian Unity Plus 300 (300 MHz) spectrometer. Multiplicities are recorded as broad peaks (br), singlets (s), doublets (d), triplets (t), quartets (q) and multiplets (m). *J* values are in Hz. Infrared spectra were recorded on a Bomem MB 104 or on a Perkin–Elmer 1600 FT-IR spectrometer. Solid samples were run as Nujol mulls and liquids as thin films. Mass spectra were recorded on a VG Micromass 7070E machine as electron impact (EI) spectra

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(70 eV) or as chemical ionisation (CI) spectra. Microanalyses were performed in the University of Liverpool Department of Chemistry microanalytical laboratory using a Carlo Erba elemental analyzer or in the University of Minho using a LECO-CHNS-932 machine. Optical rotations were measured with an AA SERIES POLARIMETER (Optical Activity Ltd.) using a 0.25 dm cell and are given in units of 10^{-1} deg cm^2 g^{-1}.The X-ray data for compounds **3g** and **3e** were collected on a Stoe IPDS diffractometer at 213(2) K and X-ray data for compound **15** was collected on a Bruker SMART APEX CCD diffractometer at 150(2) K; all used Mo-Kα radiation at 0.71073 Å. Melting points (mp) were determined on a Gallenkamp block and are uncorrected. Dry column flash chromatography was carried out using Kieselgel 60 and a water pump vacuum. Thin layer chromatography (TLC) was carried out on 0.25 mm silica gel layers 60DC–Ferigplatter Durasil-25 UV_{254}. The azirine precursor azide **5a** was prepared as reported earlier.[2] The azirine **1a**, although prepared before, was isolated and characterized for the first time.

(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl 2-azidoacrylate 5a

(i) Addition of bromine to the ester **4a** gave the dibromopropionate ester **6a** (1.46 g, 100%) as a 1 : 1 mixture of isomers (Found: C, 40.8; H, 5.9; N, 2.7. $C_{17}H_{29}Br_2NO_4S$ requires C, 40.6; H, 5.8; N, 2.8); ν_{max} (Nujol)/cm^{-1} 1740; δ_H (300 MHz, $CDCl_3$) 0.91 (3 H, s[a]), 1.03 (3 H, s[a]), 1.20 (6 H, t,[a] *J* 7.2), 1.40–2.20 (7 H, m[a]), 2.72 (1 H, d,[a] *J* 13.5), 3.20–3.35 (5 H, m[a]), 3.65–3.73 (1 H, m[a]), 3.90 (0.5 H, t,[b] *J* 10.2), 3.97 (0.5 H, t,[b] *J* 10.2), 4.40 (0.5 H, dd,[b] *J* 4.8 and 2.1), 4.43 (0.5 H, dd,[b] *J* 4.8 and 2.1) and 5.06–5.12 (1 H, m,[a] C*H*OH). [[a]Signals due to both isomers. [b]Signals due to one isomer].

(ii) Addition of NaN_3 to the dibromopropionate ester **6a** (1.43 g, 2.84 mmol) in DMF followed by treatment with DBU gave *the azidoacrylate* **5a** as an oil (0.40 g, 89%) that slowly crystallised, mp 48.5–49.5 °C (Found: C, 53.0; H, 7.4; N, 14.3. $C_{17}H_{28}N_4O_4S$ requires C, 53.1; H, 7.3; N, 14.6%); ν_{max} (Nujol)/cm^{-1} 2111, 1726 and 1615; δ_H (300 MHz, $CDCl_3$) 0.91 (3 H, s), 1.04 (3 H, s), 1.19 (6 H, t, *J* 7.2), 1.60–1.90 (5 H, m), 1.90–2.10 (2 H, m), 2.73 (1 H, d, *J* 13.6), 3.20–3.30 (5 H, m), 5.12 (1 H, dd, *J* 7.7 and 2.6), 5.31 (1 H, d, *J* 1.4) and 5.75 (1 H, d, *J* 1.4); δ_C (75.5 MHz, $CDCl_3$) 14.4 (CH_3), 19.9 (CH_3), 20.3 (CH_3), 27.0 (CH_2), 30.0 (CH_2), 39.2 (CH_2), 41.5 (CH_2), 44.6 (CH), 49.3, 49.5, 49.7 (CH_2 + 2 C_q), 80.1 (CH), 109.9 (CH_2), 137.1 (C_q) and 160.6 (CO); *m*/*z* (CI) 402 $(M + NH_4)^+$.

[(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl]-2*H*-azirine 1a

The α-azido acrylate **5a** (0.67 g, 1.74 mmol) in dry toluene (30 ml) was heated under reflux and under N_2 for 90 min. The solution was cooled and the toluene was removed on a rotary evaporator to leave an oil (0.62 g, 1.74 mmol) which was identified as the *2H-azirine* **1a**; δ_H (300 MHz, $CDCl_3$) 0.93 (3 H, s), 1.05 (3 H, s), 1.17 (6 H, t, *J* 6.9), 1.60–2.20 (7 H, m), 1.93 (2 H, s), 2.66 (1 H, d, *J* 13.5), 3.23 (4 H, q, *J* 6.9), 3.27 (1 H, d, *J* 13.5) and 5.27–5.32 (1H, m); δ_C (75.5 MHz, $CDCl_3$) 14.5 (CH_3), 19.9 (CH_3), 20.3 (CH_3), 23.6 (CH_2), 26.9 CH_2), 30.0 (CH_2), 39.0 (CH_2), 41.6 (CH_2), 41.5 (CH_2), 44.4 (CH), 49.2 (CH_2), 49.3 (C_q), 49.5 (C_q), 80.1 (CH), 157.4 (C_q) and 165.0 (CO).

[(1*R*)-10-(*N,N*-Dicyclohexylsulfamoyl)isobornyl] acrylate 4b

The ester **4b** was prepared according to the method described by Oppolzer and co- workers.[8] Mp 197.1–199.5 °C (from ether–light petroleum) (Found: C 66.4; H, 9.1; N, 3.2. $C_{25}H_{41}NO_4S$ requires C, 66.5; H, 9.2; N, 3.1%); ν_{max} (Nujol)/cm^{-1} 1717; δ_H (300 MHz, $CDCl_3$) 0.90 (3 H, s), 1.02 (3 H, s), 1.00–1.35 (7 H, m), 1.55–1.85 (18 H, m), 1.90–2.10 (2 H, m), 2.69 (1 H, d, *J* 13.5), 3.27 (1 H, d, *J* 13.5), 3.15–3.30 (2 H, m), 5.05–5.15 (1 H, m), 5.81 (1 H, dd, *J* 10.4 and 3.0), 6.11 (1 H, dd, *J* 17.4 and 10.5) and 6.36 (1 H, dd, *J* 17.4 and 3.0); δ_C (75.5 MHz, $CDCl_3$) 20.0 (CH_3), 20.4 (CH_3), 25.1 (CH_2), 26.4 (CH_2), 27.0 (CH_2), 29.9 (CH_2), 32.7 (CH_2), 39.3 (CH_2), 44.5 (CH), 49.1 (C_q), 49.4 (C_q), 53.6 (CH_2), 57.3 (CH), 78.3 (CH), 129.1 (CH), 129.8 (CH_2) and 164.4 (CO).

[(1*R*)-10-(*N,N*-Dicyclohexylsulfamoyl)isobornyl] 2-azidoacrylate 5b

(i) A solution of the ester (0.8 g, 1.78 mmol) in freshly distilled CH_2Cl_2 (15 ml) was stirred in an ice–water bath. Bromine (0.28 g, 92 µl, 1.78 mmol) was added in one portion. The mixture was stirred at room temperature for 19 h. The solvent was removed on a rotary evaporator leaving a solid that was washed with ether. The product was identified as the dibromopropionate ester **6b** (1.03 g, 95%) as a 1 : 1 mixture of isomers [Found: M^+ (EI) 609.1127. $C_{25}H_{41}Br_2NO_4S$ requires M, 609.1123]; ν_{max} (Nujol)/cm^{-1} 1738; δ_H (300 MHz, $CDCl_3$) 0.90 (3 H, s[a]), 1.03 (3 H, s [a]), 1.10–1.40 (7 H, m[a]), 1.40–1.90 (18 H, m[a]), 1.90–2.10 (2 H, m[a]), 2.67 (1 H, d, *J* 13.3[a]), 3.22 (1 H, d,[a] *J* 13.3), 3.14–3.40 (2 H, m[a]), 3.62–3.78 (1 H, m[a]), 3.93 (0.5 H, t,[b] *J* 9.6), 4.00 (0.5 H, t,[b] *J* 9.6), 4.38–4.44 (1 H, m[a]) and 5.00–5.10 (1 H, m[a]). [[a]Signals due to both isomers. [b]Signals due to one isomer].

(ii) The dibromo ester (1.03 g, 1.68 mmol) was dissolved in DMF (15 ml) and NaN_3 (0.33 g, 5.04 mmol) was added in one portion. The suspension was stirred for 2.5 days at room temperature then diluted in CH_2Cl_2 (100 ml) and washed with water (8 × 50 ml). The organic phase was then dried over $MgSO_4$ and DBU (0.26 g, 250 µl, 1.68 mmol) was added. The solution was stirred for 20 min and then washed with 10% aq. citric acid (2 × 50 ml) and water (1 × 50 ml). The organic layer was dried over $MgSO_4$ and the solvent removed to give a thick transparent oil identified as *[(1R)-10-(N,N-cyclohexylsulfamoyl)isobornyl] 2-azidoacrylate* **5b** (0.62 g, 73%) (Found: C, 60.9; H, 8.2; N, 11.3. $C_{25}H_{40}N_4O_4S$ requires C, 61.0; H, 8.2; N, 11.4 %); ν_{max} (Nujol)/cm^{-1} 2110, 1727 and 1615; δ_H (300 MHz, $CDCl_3$) 0.91 (3 H, s), 1.03 (3 H, s), 1.10–1.40 (7 H, m), 1.50–1.90 (18 H, m), 1.95–2.10 (2 H, m), 2.68 (1 H, d, *J* 13.3), 3.25 (1 H, d, *J* 13.3), 3.10–3.25 (2 H, m), 5.16–5.19 (1 H, m), 5.30 (1 H, d, *J* 1.1) and 5.73 (1 H, d, *J* 1.1); δ_C (75.5 MHz, $CDCl_3$) 20.0 (CH_3), 20.4 (CH_3), 25.2 (CH_2), 26.5 (CH_2), 27.0 (CH_2), 30.1 (CH_2), 32.7 (CH_2), 33.0 (CH_2), 39.2 (CH_2), 44.5 (CH), 49.2 (C_q), 49.8 (C_q), 53.7 (CH_2), 57.6 (CH), 80.1 (CH), 109.7 (CH_2), 137.1 (C_q) and 160.6 (CO).

(1*R*)-10-[(*N,N*-Dicyclohexylsulfamoyl)isobornyl]-2*H*-azirine 1b

A solution of the 2-azidoacrylate **5b** (0.04 g, 0.08 mmol) in dry toluene (10 ml) was heated under reflux and under N_2 for 90 min. The solvent removed to leave a pale yellow oil that contained *ca.* 20% of the 2-*azidoacrylate* according to the NMR spectrum; the major component was identified as the azirine **1b**; ν_{max} (Nujol)/cm^{-1} 1721; δ_H (300 MHz, $CDCl_3$) 0.91 (3 H, s), 1.05 (3 H, s), 1.05–1.40 (7 H, m), 1.90 (2 H, s), 1.40–2.10 (20 H, m), 2.68 (1 H, d, *J* 13.3), 3.10–3.31 (2 H, m), 3.31 (1 H, d, *J* 13.3) and 5.25–5.35 (1 H, m); δ_C (75.5 MHz, $CDCl_3$) 19.9 (CH_3), 20.2 (CH_3), 23.4 (CH_2), 25.1 (CH_2), 26.2 (CH_2), 26.3 (CH_2), 26.9 (CH_2), 30.2 (CH_2), 32.7 (CH_2), 32.8 (CH_2), 39.0 (CH_2), 44.5 (CH), 49.1 (C_q), 49.8 (C_q), 53.4 (CH_2), 57.5 (CH), 81.2 (CH), 157.3 (C_q) and 164.8 (CO).

[(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl] 2-(phenylthio)-aziridine-2-carboxylate 2a

A solution of the azide **5a** (1.0 g, 2.6 mmol) in dry toluene (40 ml) was heated under reflux for 1.5 h. The solution was cooled in an ice–water bath and thiophenol (0.29 g, 2.6 mmol) was added. After 19 h the solvent was removed and the residue was subjected to dry flash chromatography (hexane–ether). This gave the ester **2a** (0.71 g, 58%), mp 89–89.5 °C (from ether–hexane) (Found: C, 59.3; H, 7.4; N, 6.0. $C_{23}H_{34}N_2O_4S_2$ requires C, 59.2; H, 7.3; N, 6.0%); $[\alpha]_D^{25}$ −48.7 (CH_2Cl_2, 1.6 g/100 ml);

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ν_{max} (Nujol)/cm^{-1} 3274 and 1719; δ_H (300 MHz, $CDCl_3$) 0.65 (3 H, s), 0.81 (3 H, s), 1.24 (6 H, t, *J* 7.2), 1.40–1.90 (7 H, m), 2.02 (1 H, br s), 2.40 (1 H br s), 2.45 (1 H, br s), 2.66 (1 H, d, *J* 13.5), 3.28 (4 H, q, *J* 7.2), 3.37 (1 H, d, *J* 13.5), 4.98–5.00 (1 H, m) and 7.14–7.35 (5 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 19.4 (CH_3), 20.2 (CH_3), 26.9 (CH_2), 30.0 (CH_2), 34.2 (CH_2), 38.6 (CH_2), 41.7 (CH_2), 43.4 (C_q), 44.5 (CH), 49.0 (CH_2), 49.1 (C_q), 49.3 (C_q), 81.0 (CH), 126.4 (CH), 128.2 (CH), 128.9 (CH), 134.5 (C_q) and 170.4 (CO); *m*/*z* (EI) 466 (M^+).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(4-chlorophenylthio)aziridine-2-carboxylates 2b and 3b

A solution of the azide **5a** (0.30 g, 0.78 mmol) in toluene (20 ml) was heated under reflux for 1.5 h, then cooled in an ice–water bath and 4-chlorothiophenol (0.11 g, 0.78 mmol) was added. After 2 h TLC showed that none of the azirine **1a** remained. Toluene was removed and ether was added giving the *ester* **2b** as a solid (0.17 g). The remaining oil was subjected to dry flash chromatography which gave (with hexane–ether 3 : 1) another fraction of the same solid (0.038 g); total yield 0.21 g, (54%), mp 128–130 °C (from CH_2Cl_2–hexane) (Found: C, 55.2; H, 6.6; N, 5.6. $C_{23}H_{33}ClN_2O_4S_2$ requires C, 55.1; H, 6.6; N, 5.6%); $[\alpha]_D^{23}$ −44.6 (CH_2Cl_2, 3 g/100 ml), ν_{max} (Nujol)/cm^{-1} 3276 and 1722; δ_H (300 MHz, $CDCl_3$) 0.69 (3 H, s) 0.83 (3 H, s), 1.24 (6 H, t, *J* 7.2), 1.40–2.00 (7 H, m), 2.11 (1 H, br s), 2.40 (1 H, br s), 2.50 (1 H, br s), 2.66 (1 H, d, *J* 13.5), 3.20–3.40 (5 H, m), 5.00 (1 H, dd, *J* 7.8 and 3.3) and 7.20–7.35 (4 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 19.5 (CH_3), 20.2 (CH_3), 26.9 (CH_2), 30.0 (CH_2), 34.3 (CH_2), 38.6 (CH_2), 41.7 (CH_2), 43.4 (C_q), 44.4 (CH), 49.1 (C_q), 49.2 (C_q), 49.4 (CH_2), 81.1 (CH), 129.0 (CH), 129.3 (CH), 132.4 (C_q), 132.9 (C_q) and 169.9 (CO).

Analysis of the product by ^{1}H NMR before chromatographic purification showed the presence of two diastereomers in a ratio of 8 : 1. Signals assigned to the minor isomer could be identified at δ_H 0.82 (3 H, s), 0.89 (3H, s), 2.64 (1 H, d, *J* 13.2) and 5.07 (1 H, dd, *J* 7.8 and 3.0).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(4-nitrophenylthio)aziridine-2-carboxylates 2c and 3c

A solution of the azide **5a** (0.28 g, 0.8 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. The reaction mixture was cooled in an ice–water bath and 4-nitrothiophenol (0.12 g, 0.8 mmol) was added. After 2 d there was no sign of reaction by TLC. Two parts (in three) of the toluene were removed and dry acetonitrile was added to make up the original volume of solvent. Sodium carbonate (0.67 g, 4. 8 mmol) was added. After 30 h the solvents were removed and the remaining oil was subjected to dry flash chromatography (hexane–ether) giving the *aziridine* as a mixture of a major and a minor isomer, 4 : 1 ratio (0.09 g, 28%). One of the fractions was almost pure (0.07 g, 0.14 mmol, 18%) by ^{1}H NMR.

In a separate experiment a solution of the azide **5a** (0.3 g, 0.78 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. The reaction mixture was cooled in an ice–water bath and two thirds of the toluene were removed and dry acetonitrile was added to make up the original volume of solvent. 4-Nitrothiophenol (0.12 g, 0.78 mmol) and sodium carbonate (0.5 g, 4.8 mmol) were added. The suspension was stirred for 24 h. The solids were then filtered off and washed with acetonitrile. The solvent was evaporated giving an oil that was chromatographed (dry flash, light petroleum–ether) giving a mixture of the two diastereomers in a 4 : 1 ratio, total yield (0.29 g, 72%). A small fraction of the major isomer was obtained (0.07 g, 0.14 mmol, 18%) as an almost pure sample according to ^{1}H NMR [Found: M^+ (EI) 511.181. $C_{23}H_{33}N_3O_6S_2$ requires M, 511.181]; ν_{max} (Nujol)/cm^{-1} 3272 and 1719; δ_H (300 MHz, $CDCl_3$) 0.56 (3 H, s), 0.81 (3 H, s), 1.25 (6 H, t, *J* 6.9), 1.50–2.00 (7 H, m), 2.20 (1 H, d, *J* 10.2), 2.52 (1H, t, *J* 10.2), 2.63 (1 H, d, *J* 8.4), 2.67 (1 H, d, *J* 13.2), 3.27–3.35 (5 H, m), 5.03 (1 H, dd, *J* 7.8 and 3.3), 7.43 (2 H, d, *J* 9.0) and 8.14 (2 H, d, *J* 9.0); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 19.2 (CH_3), 20.1 (CH_3), 26.8 (CH_2), 30.1 (CH_2), 34.8 (CH_2), 38.6 (CH_2), 41.7 (CH_2), 44.3 (CH), 49.1 (C_q), 49.4 (C_q), 49.6 (CH_2), 81.3 (CH), 124.1 (CH), 126.3 (CH), 145.1 (C_q), 145.7 (C_q) and 169.9 (CO).

^{1}H NMR data of the minor isomer was taken from a spectrum where both isomers were present; signals due to the minor isomer were detected at δ_H (300 MHz, $CDCl_3$) 0.70 (3 H, br s), 0.83 (3H, s), 1.19 (6 H, t, *J* 6.9), 2.18 (1 H, br s), 2.90 (1 H, br s), 5.05–5.15 (1 H, m), 7.63 (2 H, d, *J* 9.3) and 8.20 (2H, d, *J* 9.3).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(methoxycarbonylmethylthio)aziridine-2-carboxylates 2d and 3d

A solution of the azide **5a** (0.27 g, 0.76 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. The reaction solution was cooled in an ice–water bath, and stirred under nitrogen. Methyl thioglycolate (0.08 g, 0.77 mmol) was then added. After 18 h the toluene was removed and the remaining oil was shown to be a mixture (1 : 1 ratio) of the two isomers. The oil was chromatographed (dry flash, hexane–ether 3 : 1) giving a small fraction of the first eluting isomer as a transparent oil (31 mg, 9%) [Found: M^+ (EI) 462.185. $C_{20}H_{34}N_2O_6S_2$ requires M, 462.186); ν_{max} (Nujol)/cm^{-1} 3280 and 1737; δ_H (300 MHz, $CDCl_3$), 0.91 (3 H, s), 1.08 (3 H, s), 1.21 (6 H, t, *J* 7.2), 1.50–2.05 (7 H, m), 2.07 (1 H, br s), 2.47 (1 H, br s), 2.68 (1 H, d, *J* 13.2), 3.20–3.57 (7 H, m), 3.70 (3 H, s) and 5.01 (1 H, dd, *J* 7.5 and 3.6); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 19.9 (CH_3), 20.3 (CH_3), 27.0 (CH_2), 29.7 (CH_2), 30.1 (CH_2), 38.8 (CH_2), 41.5 (CH_2), 41.7 (CH_2), 44.5 (CH), 49.2 (2 × C_q), 49.4 (CH_2), 52.4 (CH_3), 80.9 (CH), 168.0 (CO) and 169.6 (CO).

Another portion of a colourless oil, a mixture of isomers (0.16 g, 45%), was obtained. ^{1}H NMR data for the second isomer was obtained from a spectrum of the isomer mixture, with additional signals at δ_H (300 MHz, $CDCl_3$) 1.05 (3 H, s), 0.91 (3H, s), 2.12 (1 H, s), 2.50 (1 H, br s), 2.70 (1 H, d, *J* 13.5) and 3.72 (3 H, s).

[(1*R*)-[10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(benzimidazol-1-yl)aziridine-2-carboxylates 2e and 3e

A solution of the azide **5a** (0.30 g, 0.80 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. Two thirds of the toluene were removed and dry acetonitrile was added to make up the original volume of solvent. Benzimidazole (0.94 g, 0.80 mmol) was added and then sodium carbonate (0.66 g, 4.68 mol). The mixture was stirred for 30 min at 0 °C and then for 30 min at room temperature. It was filtered and the filtrate was evaporated to leave an oil which ^{1}H NMR showed to be a mixture (2 : 1) of diastereomers. The mixture was subjected to dry flash chromatography giving the major isomer **3e** as a white solid (0.08 g, 21%) mp 154–158 °C, $[\alpha]_D^{23}$ −89.7 (CH_2Cl_2, 1.17 g/100 ml) (Found: C, 60.4; H, 7.2; N, 11.6. $C_{24}H_{34}N_4SO_4$ requires C, 60.7; H, 7.2; N, 11.8%); ν_{max} (Nujol)/cm^{-1} 3288 and 1743; δ_H (300 MHz, $CDCl_3$) 0.06 (3 H, s), 0.62 (3 H, s), 1.17 (6 H, t, *J* 7.2), 1.50–1.70 (6 H, m), 1.90 (1 H, dd, *J* 13.5 and 7.8), 2.29–2.35 (1 H, br, collapses to 2.31 s after D_2O exchange), 2.35 (1 H, d, *J* 13.8), 2.39 (1 H, t, *J* 10.2) (signal removed by D_2O exchange), 2.52 (H, d, *J* 13.8), 2.93 (1H, br d, *J* 10.2, collapses to s after D_2O exchange), 3.16 (4 H, q, *J* 7.2), 5.08 (1 H, dd, *J* 7.1 and 3.0), 7.22–7.34 (2 H, m), 7.40–7.48 (1 H, m), 7.74–7.82 (1 H, m) and 8.15 (1 H, s); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 18.6 (CH_3), 19.9 (CH_3), 26.7 (CH_2), 29.6 (CH_2), 30.2 (CH_3), 30.7 (CH_2), 34.1 (CH_2), 38.9 (CH_2), 41.6 (CH_2), 44.2 (CH), 48.4 (C_q), 48.9 (C_q), 49.2 (C_q), 49.5 (CH_2), 80.3 (CH), 110.1 (CH), 120.4 (CH), 122.6 (CH), 123.4 (CH), 134.0 (C_q), 143.0 (CH), 143.4 (C_q) and 168.2 (CO).

Further elution gave a mixture of the two isomers (0.06 g, 16%) then a mixture (0.09 g) of the minor isomer **2e** and benzimidazole. Data for the minor isomer were obtained from

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this sample after subtracting the peaks due to benzimidazole [Found: $(M + H)^+$ (FAB) 475.237. $C_{24}H_{35}N_4O_4S$ (M + H) requires 475.238]; δ_H (300 MHz, $CDCl_3$) −0.89 (3 H, s), 0.63 (3 H, s), 1.24 (6 H, t, *J* 7.2), 1.40–1.70 (6 H, m), 1.86 (1 H, dd, *J* 13.8 and 8.1), 2.40 (1H, br s), 2.49 (1 H, d, *J* 13.8), 2.53 (1 H, br s), 2.76 (1 H, d, *J* 13.8), 2.88 (1 H, br s), 3.22–3.30 (4 H, m), 5.03 (1 H, dd, *J* 7.8 and 3.0), 7.25–7.32 (2 H, m), 7.52–7.57 (1 H, m), 7.75–7.80 (1 H, m) and 8.02 (1 H, s); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 18.1 (CH_3), 19.8 (CH_3), 26.7 (CH_2), 29.6 (CH_2), 30.3 (CH_3), 30.6 (CH_2), 33.5 (CH_2), 38.9 (CH_2), 41.6 (CH_2), 44.1 (CH), 48.8 (C_q), 48.9 (C_q), 49.3 (C_q), 50.2 (CH_2), 80.6 (CH), 110.4 (CH), 120.3 (CH), 122.9 (CH), 123.8 (CH), 134.2 (C_q), 137.7 (C_q), 142.7 (CH) and 168.2 (CO).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(5-methyl-2,4-dioxo-1,2,3,4-tetrahydropyrimidin-1-yl)aziridine-2-carboxylates 2f and 3f

A solution of the azide **5a** (0.3 g, 0.78 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. Two thirds of the toluene were removed and dry acetonitrile was added to make up the original volume of solvent. Thymine (0.10 g, 0.78 mmol) and sodium carbonate (0.5 g, 4.68 mmol) were then added. After 6 days the reaction mixture was filtered and the filtrate was evaporated to leave an oil showing two diastereomers (2 : 1 ratio). Dry flash chromatography (hexane–ether) gave two diastereomers in a total yield of 51%. The major isomer **3f** was isolated as a solid (0.10 g, 27%), slightly contaminated with the minor isomer; ν_{max} (Nujol)/cm^{-1} 3284, 1719 and 1692; δ_H (300 MHz, $CDCl_3$) 0.84 (3 H, s), 0.90 (3 H, s), 1.22 (6H, t, *J* 7.2), 1.6–1.94 (7 H, m), 1.94 (3 H, d, *J* 1.5), 2.09 (1 H, t, *J* 10.5), 2.21 (1 H, d, *J* 10.5), 2.69 (1 H, d, *J* 13.8), 2.94 (1 H, d, *J* 10.5), 2.97 (1 H, d, *J* 13.8), 3.12–3.31 (4 H, m), 5.10–5.14 (1 H, m), 7.38 (2 H, br d, *J* 1.5) and 8.05 (1 H, br s); δ_C (75.5 MHz, $CDCl_3$) 12.3 (CH_3), 14.5 (CH_3), 19.3 (CH_3), 20.0 (CH_3), 26.9 (CH_2), 30.0 (CH_2), 30.7 (CH_2), 36.0 (CH_2), 38.7 (CH_2), 41.4 (CH_2), 44.3 (CH), 49.3 (C_q), 49.5 (C_q), 50.5 (CH_2), 51.4 (C_q), 80.1 (CH), 109.9 (C_q), 139.2 (CH), 150.4 (C_q), 163.7 (CO) and 167.6 (CO).

Further elution gave the minor isomer **2f** contaminated with the major isomer (0.07 g, 19%) and a small fraction of the pure minor isomer (0.02 g, 5%). ^{1}H NMR data of the minor isomer: δ_H (300 MHz, $CDCl_3$) 0.86 (3 H, s), 0.88 (3 H, s), 1.23 (6 H, t, *J* 7.2), 1.60–1.94 (7 H, m), 1.91 (3 H, d, *J* 1.2), 2.28 (1 H, d, *J* 11), 2.40 (1 H, t, *J* 10.8), 2.63 (1 H, d, *J* 13.2), 2.76 (1 H, d, *J* 11), 3.18–3.38 (5 H, m), 5.10–5.15 (1 H, m), 7.18 (1 H, br d, *J* 1.2) and 8.12 (1H, s); δ_C (75.5 MHz, $CDCl_3$) 12.3 (CH_3), 14.7 (CH_3), 19.6 (CH_3), 20.1 (CH_3), 26.9 (CH_2), 29.7 (CH_2), 30.3 (CH_3), 36.0 (CH_2), 30.4 (CH_2), 34.9 (CH_2), 39.0 (CH_2), 41.8 (CH_2), 44.3 (CH), 49.4 (C_q), 49.7 (C_q), 49.8 (CH_2), 51.8 (C_q), 80.6 (CH), 110.8 (C_q), 138.8 (CH), 150.4 (CO), 163.6 (CO) and 167.0 (CO).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-(2-formylpyrrol-1-yl)aziridine-2-carboxylates 2g and 3g

A solution of the azide **5a** (0.34 g, 0.88 mmol) in toluene (20 ml) was heated under reflux for 1.5 h. Two thirds of the toluene were removed and dry acetonitrile was added to make up the original volume of solvent. 2-Formylpyrrole (0.83 g, 0.88 mmol) and sodium carbonate (0.56 g, 5.28 mmol) were then added. The reaction flask was kept under nitrogen with stirring for 2 h, then filtered, and the solvent was removed from the filtrate to leave an oil that showed the two diastereomers in a 1 : 1 ratio. Dry flash chromatography (hexane–ether) gave the two diastereomers completely separated in a total yield of 60.5%. One isomer was isolated as white crystalline solid (0.13 g, 34.5%), mp 160–162 °C (from hexane–ether) (Found: C, 58.7; H, 7.25; N 9.1. $C_{22}H_{33}N_3O_5S$ requires C, 58.5; H, 7.3; N, 9.3%), $[\alpha]_D^{23}$ −62.3 (CH_2Cl_2, 2.4 g/100 ml); ν_{max} (Nujol)/cm^{-1} 3289, 1723 and 1665; δ_H (300 MHz, $CDCl_3$) 0.65 (3 H, s), 0.77 (3 H, s), 1.21 (6 H, t, *J* 7.2), 1.55–1.96 (7 H, m), 2.15 (1 H, br d, *J* 11.4), 2.22 (1H, t, *J* 10.5), 2.48 (1 H, d, *J* 13.8), 2.70 (1 H, d, *J* 13.8), 2.93 (1 H, d, *J* 11.4), 3.23 (4 H, q, *J* 7.2), 4.90–5.02 (1 H, m), 6.24 (1 H, dd, *J* 3.9 and 2.7) 6.95 (1 H, dd, *J* 3.9 and 1.8), 7.31 (1 H, br s) and 9.25 (1 H, d, *J* 1.2); δ_C (75.5 MHz, $CDCl_3$) 14.6 (CH_3), 19.6 (CH_3), 20.1 (CH_3), 26.9 (CH_2), 30.5 (CH_2), 36.0 (CH_2), 38.7 (CH_2), 41.5 (CH_2), 44.3 (CH), 49.1 (C_q), 49.2 (C_q), 49.5 (CH_2), 52.0 (C_q), 80.1 (CH), 109.5 (CH), 124.4 (CH), 130.1 (CH), 133.0 (C_q), 169.0 (CO) and 179.0 (CO); *m*/*z* (EI) 451.

The second isomer was a white crystalline solid (0.1 g, 26%), mp 124.9–129.1 °C [Found: $(M + H)^+$ (FAB) 452.221. $C_{22}H_{34}N_3O_5S$ (M + H) requires 452.222]; $[\alpha]_D^{23}$ −85.6 (CH_2Cl_2, 1.35 g/100 ml); ν_{max} (Nujol)/cm^{-1} 3298, 1736 and 1665; δ_H (300 MHz, $CDCl_3$) 0.60 (3 H, s), 0.78 (3 H, s), 1.23 (6 H, t, *J* 6.9), 1.60–2.00 (7 H, m), 2.35 (1 H, br s), 2.54 (1 H, d, *J* 13.8), 2.76 (1 H, d, *J* 9.6), 2.82 (1H, br d, *J* 13.8), 3.18–3.33 (4 H, m), 4.91–4.94 (1 H, m), 6.22 (1 H, dd, *J* 3.9 and 2.4), 6.93 (1 H, dd, *J* 3.9 and 1.8), 7.05 (1 H, br s) and 9.56 (1 H, d, *J* 0.9); δ_C (75.5 MHz, $CDCl_3$) 14.5 (CH_3), 19.3 (CH_3), 20.1 (CH_3), 26.9 (CH_2), 30.4 (CH_2), 35.1 (CH_2), 38.7 (CH_2), 41.5 (CH_2), 44.3 (CH), 49.1 (C_q), 49.2 (C_q), 49.8 (CH_2), 52.3 (C_q), 80.4 (CH), 109.6 (CH), 124.3 (CH), 129.7 (CH), 133.1 (C_q), 168.1 (CO) and 178.9 (CO).

[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] 2-phenylaziridine-2-carboxylates 2h and 3h

A solution of the azide **5a** (0.28 g, 0.72 mmol) in toluene (15 ml) was heated under reflux for 1.5 h. Phenylmagnesium bromide (3M solution in ether; 1.06 ml, 0.57 mmol) was added to the solution with stirring under nitrogen at −78 °C. The reaction mixture was allowed to reach room temperature. The toluene was then distilled off leaving a solid that was dissolved in ether, washed with 10% aq. citric acid (2 × 50 ml) and dried. The solution was concentrated on a rotary evaporator giving an oil that was subjected to dry flash chromatography in hexane–ether. The title compound was isolated as a mixture of two diastereomers in a 1 : 1 ratio (0.10 g, 40%); δ_H (300 MHz, $CDCl_3$) 0.39 (3 H, s), 0.79 (3 H, s), 0.84 (3 H, s), 1.06 (3 H, s), 1.10 (6 H, t, *J* 7.2) 1.23 (6 H, t, *J* 6.9), 1.50–1.97 (15 H, m), 2.05 (1 H, br s), 2.39 (1 H, d, *J* 13.2), 2.48 (1 H, br s), 2.53 (1 H, br s), 2.54 (1 H, d, *J* 13.2), 2.64 (1 H, d, *J* 13.5), 2.80–3.00 (5 H, m), 3.28 (4 H, q, *J* 7.2), 4.95–5.00 (2 H, m), 7.20–7.30 (6 H, m), 7.35–7.42 (2H, m) and 7.45–7.50 (2 H, m).

Bis[(1*R*)-10-(*N*,*N*-Diethylsulfamoyl)isobornyl] pyrazine-2,5-dicarboxylate 9

A solution of the azide **5a** (0.26 g, 0.72 mmol) in toluene (15 ml) was heated under reflux for 1.5 h. The solution was cooled in an ice–water bath and benzylamine (0.08 g, 0.72 mmol) was added under nitrogen. The reaction mixture was stirred at room temperature for 19 h, the solvents were evaporated, and the residual oil subjected to dry flash chromatography (hexane–ether) to give the *pyrazine* **9** (90 mg, 17%), mp 238.6–241 °C (from hexane–ether) (Found: C, 57.4; H, 7.7; N, 7.8. $C_{34}H_{54}N_4O_8S_2$ requires C, 57.4; H, 7.7; N, 7.9%); ν_{max} (Nujol)/cm^{-1} 1746 and 1718; δ_H (300 MHz, $CDCl_3$) 0.95 (6 H, s), 1.09 (12 H, t, *J* 7.2), 1.12 (6 H, s), 1.20–1.35 (2 H, m), 1.60–2.06 (10 H, m), 2.14 (2 H, dd, *J* 13.8 and 8.1), 2.75 (2 H, d, *J* 13.5), 3.10–3.30 (8 H, m), 3.51 (2 H, d, *J* 13.5), 5.31 (2 H, dd, *J* 8.1 and 3.6) and 9.31 (2 H, s); δ_C (75.5 MHz, $CDCl_3$) 14.4 (CH_3), 20.0 (CH_3), 20.3 (CH_3), 27.0 (CH_2), 30.1 (CH_2), 39.2 (CH_2), 41.4 (CH_2), 44.6 (CH), 49.4 (C_q), 49.5 (CH_2), 49.6 (C_q), 80.3 (CH), 145.2 (CH), 145.8 (C_q) and 162.2 (CO).

Further elution of the column gave (*R*)-10-(*N*,*N*-diethylsulfamoyl)isoborneol (0.07 g, 33.6%) identified by comparison of the ^{1}H NMR with an authentic sample.

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(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl (4*S*)-2-azatricyclo-[3.2.1.0^{2,4}]oct-6-ene-4-carboxylate 11a and (1*R*)-10-(*N,N*-diethylsulfamoyl)isobornyl (4*R*)-2-azatricyclo-[3.2.1.0^{2,4}]oct-6-ene-4-carboxylate 12a

A solution of the azide **5a** (0.51 g, 1.33 mmol) in dry toluene (30 ml) was heated under reflux for 1.5 h. The solution was cooled to room temperature and cyclopentadiene (0.90 g, 13.3 mmol) was added. After 19 h the solvent was removed and the residue subjected to dry flash chromatography (hexane–ether) giving the ester **11a** (0.08 g) as the first fraction, then a mixture of esters **11a** and **12a** (0.20 g, **12a** : **11a** = 72 : 28), and a third fraction containing the ester **12a** (0.13 g); total yield from azide 0.41 g (73%).

The ester **11a** had mp 152–155 °C (from ether–hexane) (Found: C, 62.2; H, 8.2; N 6.8. $C_{22}H_{34}N_2O_4S$ requires C, 62.6; H, 8.1; N, 6.6%); $[\alpha]_D^{23}$ +19.8 (CH_2Cl_2, 0.8 g/100 ml); ν_{max} (Nujol)/cm^{-1} 1726; δ_H (300 MHz, $CDCl_3$) 0.89 (3 H, br s), 0.98 (3 H, s), 1.24 (6 H, t, *J* 7.2), 1.50–1.80 (7 H, m), 1.90–2.00 (2 H, m), 2.15 (1 H, br d, *J* 7.8), 2.35 (1 H, d, *J* 2.4), 2.63 (1 H, *J* 13.2), 3.20–3.51 (5 H, m), 3.51 (1 H, s), 3.98 (1 H, s), 5.06–5.10 (1 H, m), 5.61–5.64 (1 H, m) and 6.12–6.15 (1 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.7 (CH_3), 20.0 (CH_3), 20.4 (CH_3), 27.0 (CH_2), 29.9 (CH_2), 39.3 (CH_2), 41.7 (CH_2), 42.9 (CH_2), 43.5 (C_q), 44.3 (CH), 44.6 (CH), 49.1 (2 C_q), 49.3 (CH_2), 60.5 (CH_2), 66.3 (CH), 78.5 (CH), 127.8 (CH), 133.1 (CH) and 171.5 (CO); *m*/*z* (EI) 422 (M^+).

The ester **12a** had mp 133–135 °C (from ether–hexane) (Found: C, 62.6; H, 8.1; N, 6.7. $C_{22}H_{34}N_2O_4S$ requires C, 62.6; H, 8.1; N, 6.6%); $[\alpha]_D^{23}$ −150.3 (CH_2Cl_2, 1.55 g/100 ml); ν_{max} (Nujol)/cm^{-1} 1711; δ_H (300 MHz, $CDCl_3$) 0.89 (3 H, s), 1.04 (3 H, s), 1.18 (6 H, t, *J* 7.2), 1.20–1.30 (1 H, m), 1.61 (2 H, br s), 1.60–1.80 (4 H, m), 1.93–2.02 (2 H, m), 2.20 (1 H, d, *J* 7.5), 2.37 (1 H, d, *J* 2.7), 2.70 (1 H, d, *J* 13.5), 3.05–3.15 (5 H, m), 3.46 (1 H, br s), 4.09 (1 H, br s), 5.02 (1 H, dd, *J* 8.1 and 3.0), 5.61–5.65 (1 H, m) and 6.12–6.17 (1 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.5 (CH_3), 20.1 (CH_3), 20.4 (CH_3), 27.1 (CH_2), 30.1 (CH_2), 39.5 (CH_2), 41.4 (CH_2), 42.3 (CH_2), 43.2 (C_q), 44.5 (CH), 44.8 (CH), 49.2 (C_q), 49.3 (C_q), 49.8 (CH_2), 60.7 (CH_2), 66.4 (CH), 80.0 (CH), 128.0 (CH), 133.2 (CH) and 171.5 (CO); *m*/*z* (EI) 422 (M^+).

(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl 2-methoxy-1-azabicyclo[4.1.0]hept-3-ene-6-carboxylates 13 and 14

The azide **5a** (0.40 g, 1.04 mmol) in toluene (20 ml) was heated for 1.5 h. The solution was cooled to rt and 1-methoxybuta-1,3-diene (0.9 ml, 10.4 mmol) added. The solution was stirred at rt for 5 days. The solvent was removed on a rotary evaporator to leave an oil which ^{1}H NMR showed a to be a mixture of diastereomers in a 2 : 1 ratio. The crude material was subjected to dry flash chromatography (light petroleum–ether) to give several fractions with different ratios of isomers (0.17 g in total, 36%). The major isomer was an oil slightly contaminated with the minor isomer (Found: C, 60.1; H, 8.2; N, 6.3. $C_{22}H_{36}N_2O_5S$ requires C, 60.0; H, 8.2; N, 6.4%); ν_{max} (Nujol)/cm^{-1} 1718; $[\alpha]_D^{23}$ −88.5 (CH_2Cl_2, 2.00 g/100 ml); δ_H (300 MHz, $CDCl_3$) 0.90 (3 H, s), 1.04 (3 H, s), 1.20 (6 H, t, *J* 6.9), 1.60–2.00 (7 H, m), 2.03 (2 H, s), 2.60–2.80 (2 H, m), 3.20–3.30 (6 H, m), 3.60 (3 H, s), 4.73 (1 H, br s), 4.96 (1 H, dd, *J* 8.1 and 3.0), 5.40–5.47 (1 H, d, *J* 10.2, showing further coupling) and 5.70–5.80 (1 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.5 (CH_3), 19.7 (CH_3), 20.4 (CH_3), 22.0 (CH_2), 27.0 (CH_2), 27.8 (CH_2), 29.9 (CH_2), 37.8 (C_q), 39.4 (CH_2), 41.4 (CH_2), 44.4 (CH), 49.2 (C_q), 49.3 (C_q), 49.8 (CH_2), 56.2 (CH_3), 78.7 (CH), 85.7 (CH), 123.7 (CH), 124.0 (CH) and 170.5 (CO).

The minor isomer showed additional peaks at δ_H (300 MHz; $CDCl_3$) 0.90 (3 H, s), 1.02 (3 H, s), 3.62 (3 H, s) and 4.90–5.06 (1 H, dd, *J* 8.1 and 3.3); δ_C (75.5 MHz, $CDCl_3$) 14.7 (CH_3), 20.0 (CH_3), 20.4 (CH_3), 22.1 (CH_2), 27.0 (CH_2), 28.8 (CH_2), 29.7 (CH_2), 38.0 (C_q), 39.3 (CH_2), 41.6 (CH_2), 78.5 (CH), 85.6 (CH), 123.6 (CH) and 123.8 (CH).

(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl 8-oxa-2-azatricyclo-[3.2.1.0^{2,4}]oct-6-ene-4-carboxylates 17 and 18

A solution of the azide **5a** (0.10 g, 0.26 mmol) in toluene (25 ml) was heated for 1.5 h. The solution was cooled to rt and freshly distilled furan (20 ml) was added. The solution was stirred for 3 days and the solvent removed to leave an oil that proved to be a 1 : 1 mixture of compounds assigned as the *exo* diastereomers **17** and **18** by ^{1}H NMR spectroscopy; δ_H (300 MHz, $CDCl_3$) 0.88 (1.5 H, s), 0.90 (1.5 H, s), 0.98 (1.5 H, s), 0.99 (1.5 H, s), 1.21 (3 H, t, *J* 6.9), 1.22 (3 H, t, *J* 6.9), 1.54–2.02 (7 H, m), 2.41 (1 H, s), 2.64 (0.5 H, d, *J* 13.5), 2.71 (0.5 H, d, *J* 13.2), 2.82 (0.5 H, s), 2.83 (0.5 H, s), 3.14–3.36 (5 H, m), 4.98 (0.5 H, dd, *J* 8.0 and 3.3), 5.03 (0.5 H, dd, *J* 8.0 and 3.3), 5.09 (0.5 H, d, *J* 1.5), 5.12 (0.5 H, d, *J* 1.5), 5.31 (0.5 H, d, *J* 1.5), 5.34 (0.5 H, d, *J* 1.5), 6.55 (0.5 H, dd, *J* 5.7 and 1.5), 6.58 (0.5 H, dd, *J* 5.4 and 1.5), 6.75 (0.5 H, dd, *J* 5.7 and 1.5) and 6.80 (0.5 H, dd, *J* 5.4 and 1.5). The mixture was not characterized further.

(1*R*)-10-(*N,N*-Diethylsulfamoyl)isobornyl (6*S*)-2,5-diphenyl-1-azabicyclo[4.1.0]hept-3-ene-6-carboxylate 15 and (1*R*)-10-(*N,N*-diethylsulfamoyl)isobornyl (6*R*)-2,5-diphenyl-1-azabicyclo[4.1.0]hept-3-ene-6-carboxylate 16

A solution of the azide **5a** (0.30 g, 0.80 mmol) in dry toluene (20 ml) was heated under reflux for 1.5 h. The solution was cooled to rt. 1,4-Diphenylbuta-1,3-diene (0.16 g, 0.80 mmol) was added to the reaction solution and the mixture was kept stirring at rt for 2 days. As TLC showed no product the reaction mixture was heated under reflux for 7 h. The solvent was removed on a rotary evaporator to give an oil that was subjected to dry flash chromatography (light petroleum ether–ether) to give a 2 : 1 mixture of two isomers (0.10 g, 0.18 mmol, 23%). By crystallization it was possible to enrich the product in the major isomer **15** to 9 : 1. The solid had mp 125–130 °C (Found: C, 69.5; H, 7.7; N, 4.8. $C_{33}H_{42}N_2O_4S{\cdot}0.5H_2O$ requires C, 69.4; H, 7.6; N, 4.9%); ν_{max} (Nujol)/cm^{-1} 1722; δ_H (300 MHz, $CDCl_3$) 0.76 (3 H, s), 0.82 (3 H, s), 1.00 (6 H, t, *J* 7.2), 1.06–1.28 (1 H, m), 1.34–1.44 (1 H, m), 1.48–1.76 (3 H, m), 1.81–2.04 (2 H, m), 2.06 (1 H, s), 2.27 (1 H, s), 2.55 (1 H, d, *J* 13.5), 3.02–3.16 (2 H, m), 3.16–3.30 (3 H, m), 4.40–4.44 (1 H, m), 4.82–4.86 (1 H, m), 4.99 (1 H, dd, *J* 8.1 and 3.3), 5.78 (1 H, ddd, *J* 10.5, 3.3 and 1.8), 5.91 (1 H, br d, *J* 10.5) and 7.30–7.40 (10 H, m); δ_C (75.5 MHz, $CDCl_3$) 14.4 (CH_3), 19.8 (CH_3), 20.4 (CH_3), 26.9 (CH_2), 27.5 (CH_2), 29.4 (CH_2), 37.4 (CH), 39.3 (CH_2), 41.3 (CH_2), 44.3 (CH), 45.3 (C_q), 48.7 (CH_2), 49.0 (C_q), 49.1 (C_q), 57.8 (CH), 57.3 (CH), 78.4 (CH), 124.8 (CH), 126.9 (CH), 127.4 (CH), 127.8 (CH), 128.4 (CH), 128.5 (CH), 128.6 (CH), 128.9 (CH), 141.7 (C_q), 142.3 (C_q) and 170.0 (CO).

Some signals due to the minor isomer **16** could be detected in the spectra of the major isomer at δ_H 0.85 (3 H, s), 0.96 (3 H, t, *J* 7.2), 2.62 (1 H, d, *J* 13.8), 4.42–4.48 (1 H, m), 4.94–4.89 (1 H, m), 5.70–5.84 (1 H, m) and 6.60–6.99 (1H, m).

(1*R*)-10-(*N,N*-Dicyclohexylsulfamoyl)isobornyl 2-azatricyclo-[3.2.1.0^{2,4}]oct-6-ene-4-carboxylates 11b and 12b

A solution of the azide **5b** (0.59 g, 1.2 mmol) in toluene (50 ml) was heated under reflux for 1.5 h and then cooled. Cyclopentadiene (0.85 g, 12.9 mmol) was added. The solution was stirred for 3 days at rt. Removal of the toluene gave an oil that crystallised as a white solid after addition of ether. The solid (0.10 g) was filtered and the remaining oil was subjected to dry flash chromatography (hexane–ether) to give another crop (0.21 g) of the same compound; (total yield 49%). ^{1}H NMR of the solid showed it to consist of a 1 : 3 mixture of diastereomers of *(1R)-10-(N,N-dicyclohexylsulfamoyl)isobornyl 2-azatricyclo-[3.2.1.0^{2,4}]oct-6-ene-4-carboxylates*. The major isomer showed

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δ_H (300 MHz, $CDCl_3$) 0.88 (3H, s), 1.02 (3H, s), 1.00–2.10 (32 H, m), 2.24 (1 H, dt, *J* 7.8 and 0.9), 2.41 (1 H, d, *J* 3.0), 2.65 (1 H, d, *J* 13.2), 3.15 (1 H, d, *J* 13.2), 3.10–3.40 (4 H, m), 3.48–3.52 (1 H, m), 4.10 (1 H, br s), 5.05–5.10 (1 H, dd, *J* 7.2 and 2.7), 5.65–5.70 (1 H, m) and 6.10–6.18 (1 H, m).

Some of the signals due to the minor isomer were detected at δ_H (300 MHz, $CDCl_3$) 0.90 (3 H, s), 1.01 (3 H, s), 2.18 (1 H, dt, *J* 7.8 and 0.9), 2.46 (1 H, d, *J* 3.0), 2.67 (1 H, d, *J* 13.2) and 3.45 (1 H, br s).

Crystal structure determination for 3e †

Crystal data: $C_{24}H_{34}N_4O_4S$, M = 474.61, orthorhombic, a = 10.1128(13) Å, b = 8.372(4) Å, c = 18.399(2) Å, α = 90°, β = 90°, γ = 90°, U = 2418.6(5) Å^3, T = 213(2) K, space group $P2_12_12_1$, Z = 4, μ(Mo-Kα) = 0.172 mm^{-1}, 15465 reflections collected, 3836 unique (R_{int} = 0.0770), which were used in all calculations. The final $wR(F^2)$ was 0.0949 (all data). Flack parameter [13] −0.10(11).

Crystal structure determination for 3g †

Crystal data: $C_{22}H_{33}N_3O_5S$, M = 451.57, monoclinic, a = 10.0165(15) Å, b = 12.3521(15) Å, c = 10.5145(16) Å, α = 90°, β = 115.807(16)°, γ = 90°, U = 1171.2(3) Å^3, T = 213(2) K, space group $P2_1$, Z = 2, μ(Mo-Kα) = 0.175 mm^{-1}, 7463 reflections collected, 3673 unique (R_{int} = 0.0603), which were used in all calculations. The final $wR(F^2)$ was 0.0871 (all data). Flack parameter [13] 0.03(8).

Crystal structure determination for 15 †

Crystal data: $C_{33}H_{44}N_2O_5S$, M = 580.76, monoclinic, a = 11.5114(9) Å, b = 10.7109(9) Å, c = 12.4297(10) Å, α = 90°, β = 100.9090(10)°, γ = 90°, U = 1504.9(2) Å^3, T = 213(2) K, space group $P2_1$, Z = 2 μ(Mo-Kα) = 0.151 mm^{-1}, 9431 reflections collected, 4817 unique (R_{int} = 0.0142), which were used in all calculations. The final $wR(F^2)$ was 0.2177 (all data). Flack parameter [13] 0.18(14).

† CCDC 184635–184637. See http://www.rsc.org/suppdata/p1/b2/b202321k/ for crystallographic data in .cif or other electronic format.

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References

1 M. J. Alves, T. L. Gilchrist and J. H. Sousa, *J. Chem. Soc., Perkin Trans 1*, 1999, 1305.
2 M. J. Alves, J. F. Bickley and T. L. Gilchrist, *J. Chem. Soc., Perkin Trans 1*, 1999, 1399.
3 M. J. Alves, P. M. T. Ferreira, H. L. S. Maia, L. S. Monteiro and T. L. Gilchrist, *Tetrahedron Lett.*, 2000, **41**, 4991.
4 M. J. Alves and T. L. Gilchrist, *J. Chem. Soc., Perkin Trans. 1*, 1998, 299.
5 D. Tanner, *Angew. Chem., Int. Ed. Engl.*, 1994, **33**, 599; H. M. I. Osborn and J. Sweeney, *Tetrahedron: Asymmetry*, 1997, **8**, 1693.
6 C. Toniolo, G. Bonora, A. Bavoso, E. Benedetti, B. di Blasio, V. Pavone and C. Pedrone, *Biopolymers*, 1983, **22**, 205.
7 F. A. Davis, Y. Wu, H. Yan, K. R. Prasad and W. McCoull, *Org. Lett.*, 2002, **4**, 655.
8 W. Oppolzer, C. Chapuis and G. Bernadinelli, *Tetrahedron Lett.*, 1984, **25**, 5885.
9 M. Kakimoto, M. Kai and K. Kondo, *Chem. Lett.*, 1982, 525.
10 T. L. Gilchrist and R. Mendonça, *Synlett*, 2000, 1843.
11 A. E. A. Porter, in *Comprenhensive Heterocyclic Chemistry*, Vol. 3, ed. A. J. Boulton and A. McKillop, Pergamon Press, Oxford, 1984, p. 159.
12 M. J. Alves, N. G. Azoia, J. F. Bickley, A. G. Fortes, T. L. Gilchrist and R. Mendonça, *J. Chem. Soc., Perkin Trans. 1*, 2001, 2969.
13 H. D. Flack, *Acta Crystallogr., Sect. A*, 1983, **39**, 876.

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