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Kinetic and thermodynamic stereocontrol in the atroposelective formation of sulfoxides by oxidation of 2-sulfanyl-1-naphthamides

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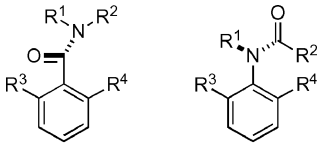
Atropisomeric aromatic amides bearing 2-sulfanyl groups are oxidised by *m*-CPBA to the corresponding sulfoxides apparently with very high diastereoselectivity. NMR studies and oxidations of chiral benzamides however indicate that the kinetic selectivity of the oxidation is in fact relatively poor, and that the final diastereoisomeric ratio (typically >99:1) is under thermodynamic control, with relatively unhindered Ar–CO rotation readily converting the less stable to the more stable product diastereoisomer. Molecular mechanics indicates that the thermodynamic diastereoselectivity results principally from electrostatic repulsion between the C=O and S–O dipoles.

Introduction

Amide groups bonded to aromatic rings have the potential to display atropisomerism,[1] both when the amide is attached to the ring *via* the carbonyl group (*e.g.* **1**)[2–4] and by the nitrogen atom (*e.g.* **2**). We (for the former, benzamide class of amide)[5] and others (mainly for the latter, anilide or maleimide, class)[6] have demonstrated that these atropisomeric amides, with their perpendicular arrangement of the planar amide group and ring, undergo stereoselective reactions in which the amide is able to exert kinetic control over the formation of new stereogenic centres. We have reported in full our observations of the way in which an amide group may control addition of an ortholithiated amide to an aldehyde,[3] addition of a nucleophile to formyl and acyl groups in the 2- or 8-positions of a naphthamide,[7] and addition of electrophiles to a laterally lithiated amide.[8] In this publication, we continue this series of publications with a report in full[9] of the results of an investigation of the role of an adjacent conformationally constrained amide group in the stereoselectivity of oxidation of some sulfides to sulfoxides. We show that very high stereoselectivity may be a feature of this reaction, but only when the reaction is under thermodynamic control. The kinetically controlled sulfoxidation is by contrast relatively unselective.

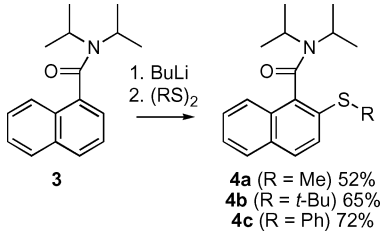


1 **2**

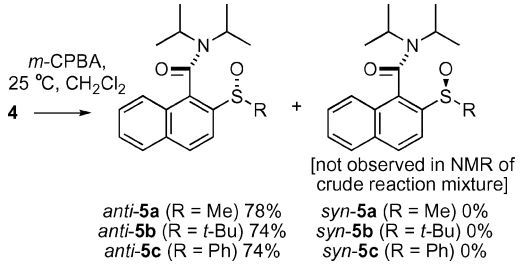
Results and discussion

Three sulfides were prepared by ortholithiation of *N*,*N*-diisopropyl-1-naphthamide **3**, treating with *s*-BuLi in THF (the addition of TMEDA is unnecessary with diisopropylnaphthamides)[10] and quenching the yellow organolithium with diphenyl, di-*tert*-butyl or dimethyl disulfide (Scheme 1).

The three sulfides were treated with *m*-CPBA at −15 °C in CH_2Cl_2 (Scheme 2) and the product mixtures were analysed by NMR spectroscopy both before and after purification. In principle, two diastereoisomers, *anti*- and *syn*-**5**, could be formed from each sulfide, but in the event >98% of a single diastereoisomer was observed by NMR in each case (for a more accurate quantification for **5a** and **5b** see below). In the case of the phenylsulfinyl-substituted amide **5c** the product



Scheme 1 Synthesis of 2-sulfanylnaphthamides.



Scheme 2 Oxidation of 2-sulfanylnaphthamides.

was crystalline and an X-ray crystal structure† (Fig. 1) proved the *anti* relative stereochemistry; we assume the other isolated sulfoxides **5b** and **5c** are also the *anti* diastereoisomer.

This seemed to us a remarkable result, and in order to obtain and characterise the *syn* diastereoisomer we took the three sulfoxides *anti*-**5a–c** and heated them in toluene at 80 °C for 3 h. For *anti*-**5b** some decomposition was observed during this time, but no new peaks suggestive of another diastereoisomer appeared in any of the three samples.

This meant that, unless the *syn* and *anti* diastereoisomers in all three cases had identical NMR spectra, which we ruled out as unlikely, either 80 °C was an insufficiently high temperature to overcome the kinetic barrier to epimerisation of the sulfoxides, or the sulfoxide atropisomers were already at thermodynamic equilibrium and that one (the *anti*) diastereoisomer was much more stable than the other. Given that the second row elements

† Crystal data $C_{23}H_{25}NO_2S$; $M = 379.50$; orthorhombic $P2_12_12_1$; $a = 10.712$ Å; $b = 13.782$ Å; $c = 14.260$ Å; $V = 2105.2$ Å^3; $T = 293(2)$ K; $Z = 4$; $\mu = 0.170$ mm^{-1}; 4202 reflections; $R_{int} = 0.042$; $R_1 = 0.0314$ and $wR_2 = 0.0877$ [$I > 2\sigma(I)$]. This data was reported in reference 9. CCDC reference number 187714. See http://dx.doi.org/10.1039/b511452g for crystallographic data in CIF or other electronic format.

DOI: 10.1039/b511452g

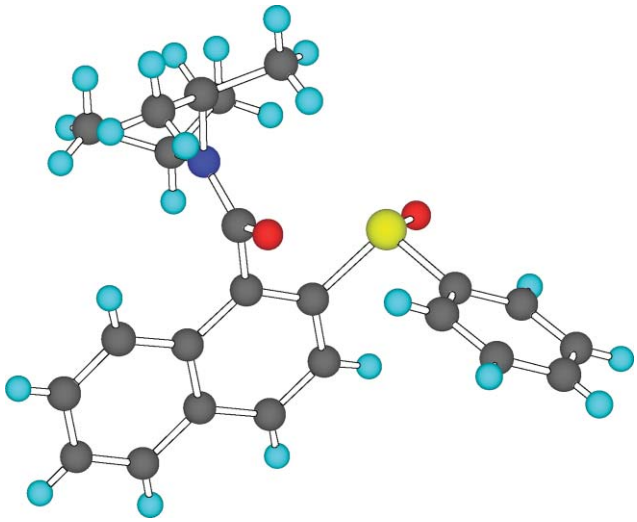


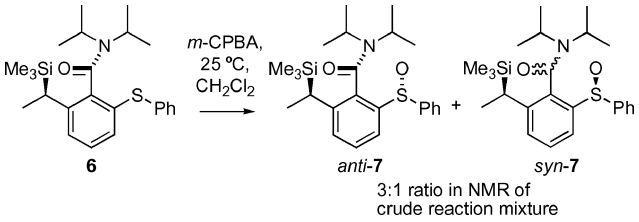
Fig. 1 X-Ray crystal structure of *anti*-**5c**.

P, Si and S typically present poor barriers to bond rotation in related amides,[4,11] probably due to the length of their bonds to C, we judged the latter, though remarkable, to be the more likely explanation for the high selectivity.

If the diastereoisomeric sulfoxides were indeed already in thermodynamic equilibrium then again there are two possible ways in which this ratio might have arisen: either the kinetic stereoselectivity of the sulfide oxidation happens to coincide with the thermodynamic stability of the products, or the initial kinetically controlled ratio of sulfoxides is, even at room temperature, rapidly overturned by easy equilibration to a thermodynamically controlled preponderance of the *anti* diastereoisomer.

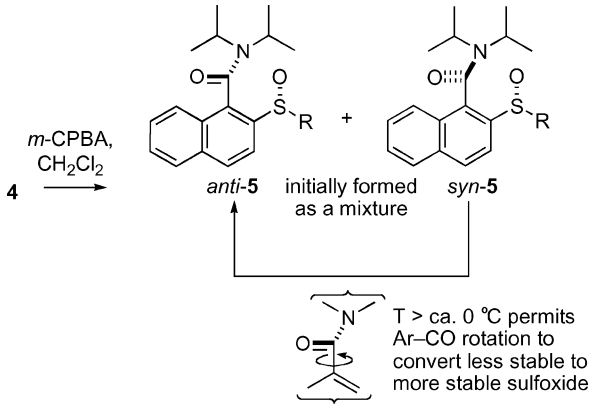
To distinguish between these two possibilities we oxidised a sulfoxide already containing a chiral centre as well as the potentially atropisomeric amide axis. Sulfide **6** was available from previous work on the synthesis of potential atropisomeric chiral ligands.[11] If the kinetic selectivity of the amide-directed oxidation of **4** is high, then it is reasonable to expect the oxidation of **6** also to provide a sulfoxide with a high degree of stereoselectivity. However, the alternative mechanism, by which the oxidation of **4** gives a single diastereoisomer of **5** by virtue of epimerisation about the Ar–CO axis after oxidation, is not possible for **6** since, although Ar–CO epimerisation may still take place, there is no available mechanism for inversion of the relative stereochemistry between the sulfoxide and silicon-bearing stereogenic centres.

Oxidation of **6** with *m*-CPBA gave two separable diastereoisomers of the sulfoxide **7** (Scheme 3) in a 3:1 ratio. Both aspects of the relative stereochemistry of *anti*-**7** are assigned on the basis of the discussion presented below; in *syn*-**7** the axial stereochemistry is unknown.



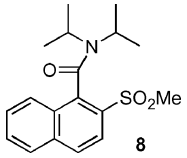
Scheme 3 Oxidation of a chiral sulfide.

From the poor selectivity in this reaction we concluded that the selective formation of *anti*-**5** was not due to a simple stereoselective oxidation of **4** under kinetic control. A more reasonable explanation of the selective formation of *anti*-**5** consists of a kinetically controlled oxidation of **4**, of unknown selectivity, to yield a mixture of *syn*- and *anti*-**5**, followed by rapid (at room temperature at least) equilibration about the Ar–CO bond which converts *syn*-**5** to the thermodynamically more stable *anti*-**5** (Scheme 4).



Scheme 4 Thermodynamic control over stereoselectivity.

In order to discover more about both the kinetic stereoselectivity of the oxidation and the rate of equilibration of the diastereoisomers we followed oxidation of **5a** by NMR at temperatures below room temperature. We carried out three such experiments. In the first, 25 mg of sulfide **4a** in $CDCl_3$ was treated, at −70 °C, with a slight excess of *m*-CPBA and the resulting mixture lowered into the NMR probe at 0 °C. Spectra were acquired every 2.7 min for 89 min, and the evolution of the spectrum during this time is shown in Fig. 2. The second experiment was identical except the temperature of the probe was −15 °C; spectra were acquired every 2.7 min for 84 min, and the evolution of the spectrum during this time is shown in Fig. 3. In the third experiment, a deficit (*ca.* 0.9 equiv.) of *m*-CPBA was added to 25 mg of sulfide **4a** in $CDCl_3$ at −70 °C and the mixture was lowered into the probe at −55 °C. Spectra were acquired every 2.7 min for 73 min, and the evolution of the spectrum during this time is shown in Fig. 4.



A total of four separate methyl singlets were discernible during these experiments: that of the starting sulfide **4a** (at $\delta = 2.60$), that of an over-oxidation product, the sulfone **8** (at $\delta = 3.25$), that of the *anti*-sulfoxide *anti*-**5a** at $\delta = 2.92$ and finally a further peak which we assume, for reasons given below, is the *syn*-sulfoxide *syn*-**5a** at $\delta = 2.98$.

At 0 °C, oxidation of the sulfide is complete even before the first spectrum is acquired, and a mixture of sulfoxides and sulfone is immediately evident (Fig. 2). The ratio of *anti* to *syn* sulfoxides in the first spectrum is 92:8; after 10 spectra have been acquired (27 min) it is 97:3, and by the end of the experiment (89 min) it is a more or less constant 99:1. The proportion of sulfone does appear slowly to increase during the experiment, but assuming that any differential rate of oxidation of the two sulfoxides to the sulfone is negligible, the change in ratio confirms our rationalisation of the source of stereoselectivity. The conversion of *syn*- to *anti*-**5a** follows a first order rate law with k_1 (the rate constant for Ar–CO rotation) = 0.0005 s^{-1} at 0 °C, or a half-life of 20 min.

At −15 °C, oxidation of the sulfide is incomplete in the first few spectra (Fig. 3), but an initial ratio of 75:25 *anti*:*syn*-**5a** is evident, which slowly decreases to 91:9 during the course of the reaction, as the amount of sulfone **8** also increases to about 15% of the total. However, we were able to establish that the change in the *anti*:*syn* ratio is not due to selective oxidation of the minor

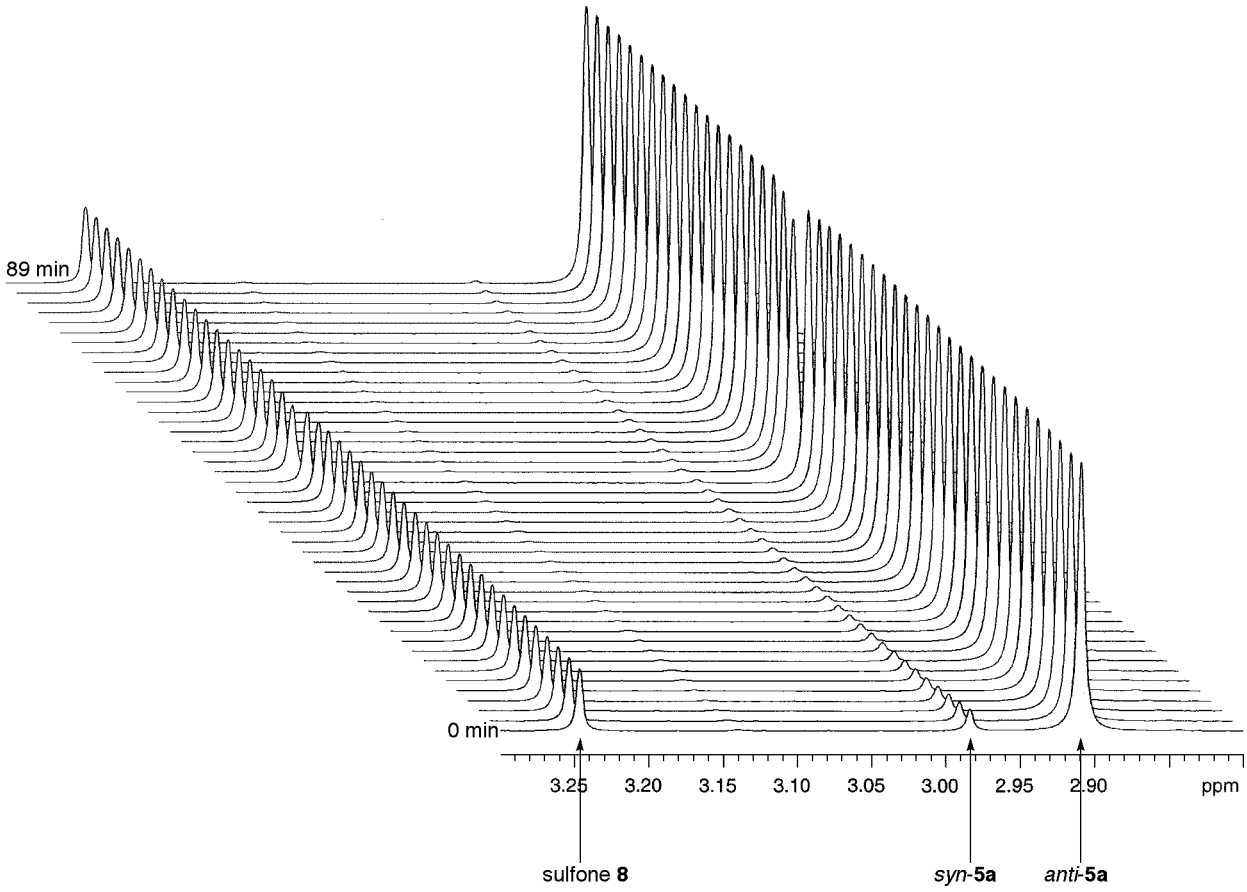


Fig. 2 Oxidation of **4a** at 0 °C.

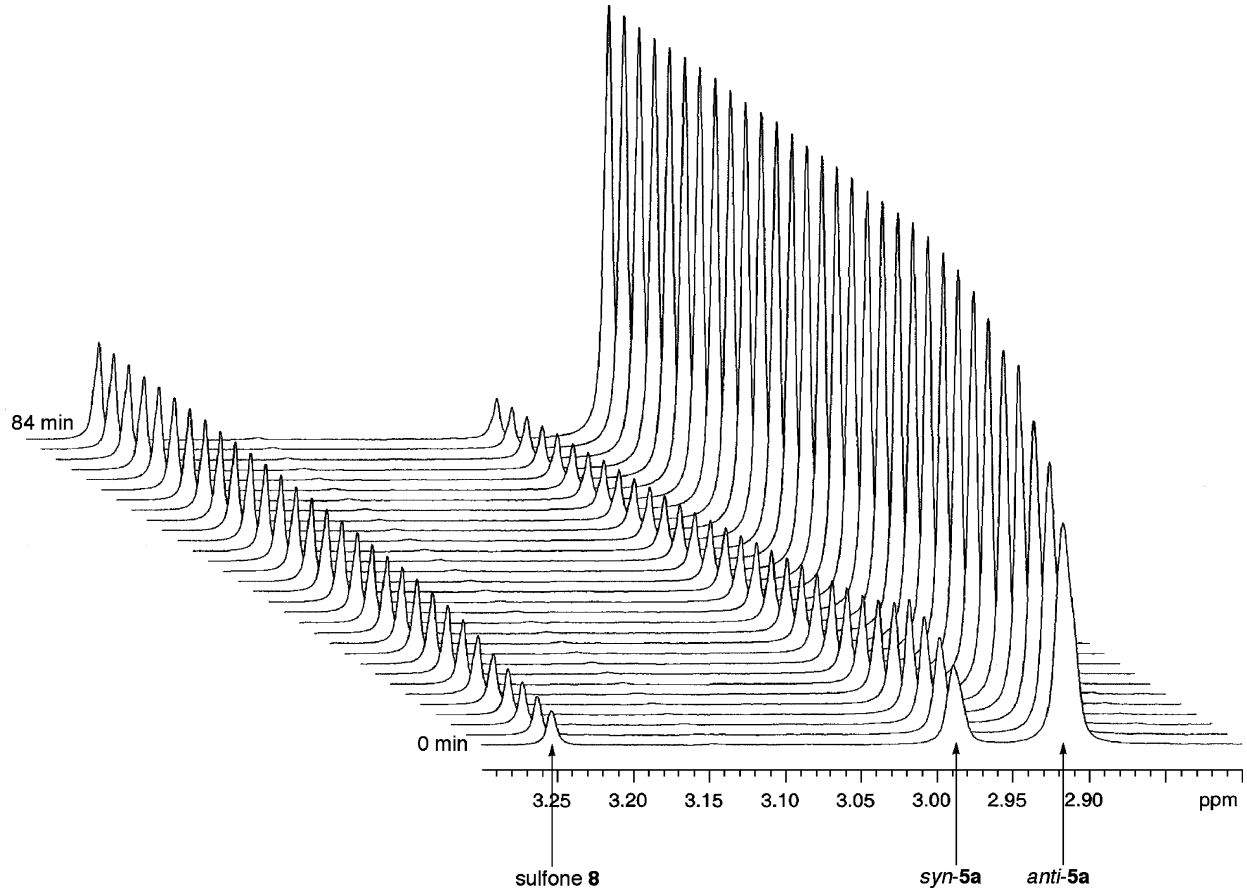


Fig. 3 Oxidation of **4a** at −15 °C.

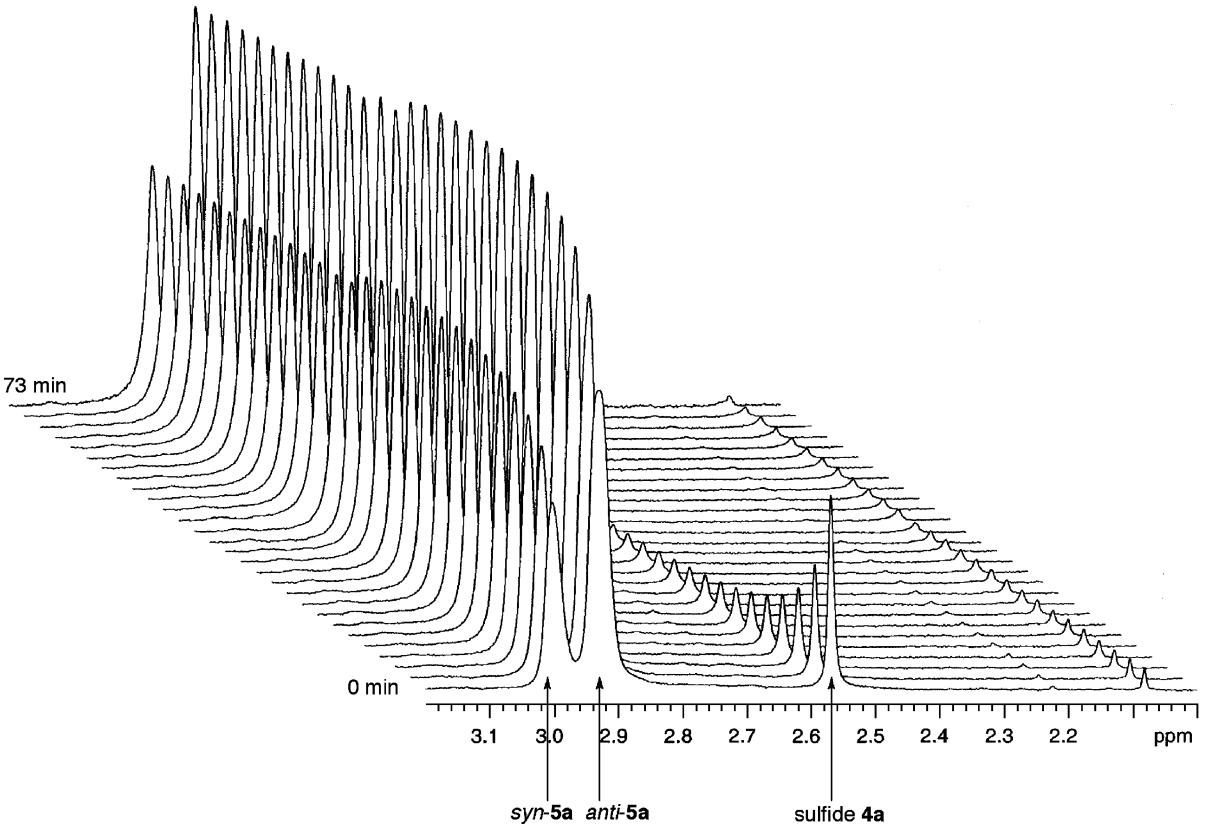


Fig. 4 Oxidation of **4a** at −55 °C.

isomer to the sulfone by warming this sample to 0 °C. After 3.5 h, the ratio of *anti*:*syn* was 99:1, with no further increase in the proportion of sulfone. The conversion of *syn*- to *anti*-**5a** follows a first order rate law with $k_1 = 0.0002\ s^{-1}$ at −15 °C, or a half-life of 50 min.

At −55 °C, with a deficit of *m*-CPBA, sulfide is never fully consumed, and no sulfone is formed. The ratio of *anti*:*syn*-**5a** remains more or less constant between 65:35 and 67:33 (Fig. 4) This ratio presumably represents the true kinetic selectivity of the oxidation at −55 °C, and probably represents a good estimate of the kinetic selectivity at higher temperatures too.

The rate of equilibration of the diastereoisomers of **5a** at 0 and at −15 °C extrapolates (assuming $\Delta S^{\ddagger} = 0$) to a half-life at 20 °C of less than 1 min, meaning that isolation of the unstable *syn* diastereoisomer of *syn*-**5a**, and presumably of sulfoxides *syn*-**5** in general, is impossible. 2-Substituted naphthamides are typically atropisomeric[12] at room temperature,[4] but comparably short half-lives for isomerisation about this bond are shown for example by 2-trialkylsilylnaphthamides;[4,13] presumably, like the C–Si bond, the C–S bond is relatively long and flexible.

Identifying the *syn* diastereoisomer in the ^{1}H NMR spectrum of **5a** also allows us to quantify accurately the ratio of sulfoxides returned by work up of the oxidation at room temperature (Scheme 2). The *syn*-sulfoxide's methyl singlet at $\delta = 2.98$ has a peak height less than that of the ^{13}C satellites of the *anti*-sulfoxide's methyl singlet (Fig. 5a) at $\delta = 2.92$, and we therefore have confidence in quantifying the ratio as >99.5:0.5. Given the fact that the rate of interconversion of the diastereoisomers at this temperature is fast, we also ran the NMR spectrum in CD_3OD to investigate whether the ratio of diastereoisomers was solvent-dependent The ratio of peak heights changed from 99.5:0.5 in $CDCl_3$ to 94:6 in CD_3OD (Fig. 5b). For the *tert*-butyl sulfoxide **5b** a similar change in peak ratio was seen from >98:2 to 97:3, although in this case we cannot be certain that the minor peak is indeed the *syn*-sulfoxide.

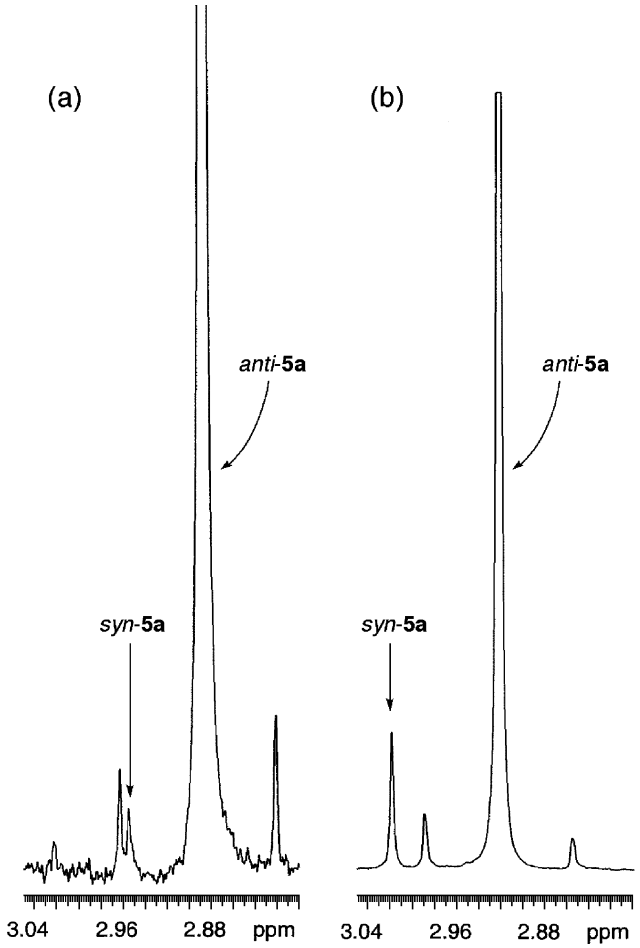
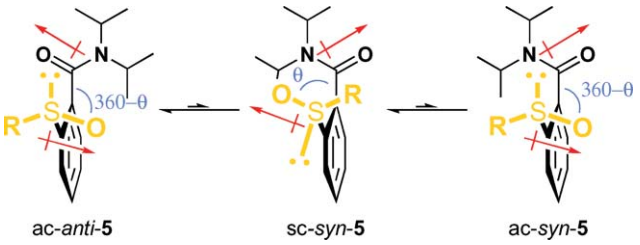


Fig. 5 (a) Portion of the ^{1}H spectrum of **5a** in $CDCl_3$. (b) Portion of the ^{1}H NMR spectrum of **5a** in CD_3OD.

Taken together these results point to a general mechanism for the oxidation of 2-sulfanyl-1-naphthamides to 2-sulfinyl-1-naphthamides in which an initial rather unselective (65:35 at −55 °C, presumably even less selective at 20 °C) kinetically controlled oxidation is followed by equilibration of the mixture to a product ratio which is entirely under thermodynamic control because of the rapid interconversion of the sulfoxides by rotation about the Ar–CO bond, as shown in Scheme 4. A few other examples of the diastereoselective synthesis of atropisomers under thermodynamic control have been reported by ourselves[14,15] and by others.[16–18]

The origin of the very strong thermodynamic preference for *anti*-**5** over *syn*-**5** was investigated by a molecular mechanics study. Two Monte Carlo conformational searches on **5a** (5000 steps for each search) were carried out using Macromodel,[19] one starting from a structure resembling *anti*-**5a**, with an Ar–CO dihedral angle of +90°, the other starting from a structure resembling *syn*-**5a**, with an Ar–CO dihedral angle of −90°. Energy minimisations were performed using MM2*, and in both searches the Ar–CO dihedral angle was constrained to within ±90° of its starting value, ensuring that only one of the two diastereoisomeric conformers about Ar–CO was minimised in each case.

The global minimum found from the first search was the conformer shown as ac-*anti*-**5**, with the sulfur lone pair occupying the most hindered *inside* position, and the C=O and S–O dipoles aligned almost exactly antiparallel, giving an anticlinal (ac) relationship between Ar–CO and S–Me or S–O bonds. The second search found two minima, each shown in Scheme 5. The more stable conformer is shown as sc-*syn*-**5**, in which the C=O and S–O dipoles are opposed but which also suffers a synclinal interaction between the O and Me substituents and the amide Ar–CO bond. The less stable conformer ac-*syn*-**5** avoids this synclinal interaction by placing the S lone pair *inside* but pays the price by aligning the C=O and S–O dipoles more parallel. The individual energy terms bear out this interpretation: ac-*syn*-**5** has an electrostatic potential some 15–20 kJ mol^{-1} higher than either of the other conformers, but is of comparable stability to ac-*anti*-**5** in its steric (Stretch + Bend + Torsion + van der Waals) terms (Table 1). The synclinal conformer sc-*syn*-**5a** on the other hand has the lowest electrostatic potential, but incurs bending and torsional steric penalties. Only in *anti*-**5a** can both steric and electrostatic potential be minimised. The difference in energy between the lowest energy conformer of *anti*-**5a** and the lowest energy conformer of *syn*-**5a** is



Scheme 5 Conformational preference in sulfoxides **5**.

Table 1 Molecular mechanics with **5a** (*i.e.* R = Me)

Energy term (kJ mol^{-1})	ac-*anti*-**5a**	sc-*syn*-**5a**	ac-*syn*-**5a**
Total energy[a]	**−18.4**	**−8.0**	**−4.66**
Stretch	5.4	6.2	5.6
Bend	14.0	22.7	13.1
Torsion	49.5	54.1	50.6
van der Waals	37.0	38.0	35.5
Electrostatic	−125.1	−129.9	−110.4

[a] Figures do not sum exactly because near-negligible improper torsion and cross terms have been omitted.

10.4 kJ mol^{-1}, which generates, by Boltzmann distribution, a 98.5:1.5 ratio at 298 K, a figure within an order of magnitude of that observed spectroscopically. The slightly lowered conformational selectivity in the more polar solvent CD_3OD furthermore argues in favour of an electronic, rather than a purely steric, explanation for the selectivity.

A pair of dihedral drive studies (Fig. 6) allowed us to locate the three significant conformers shown in Scheme 5 on the potential energy curve created by rotating (a) the *anti* and (b) the *syn* diastereoisomer of **5a** about their ArC–S bond. Starting from the minimised conformation of each diastereoisomer the dihedral angle θ (Scheme 5) in *anti*-**5a** (solid circles) and *syn*-**5a** (open circles) was varied from 0 to 360° in 3° steps and the total energy was minimised at each step. For *anti*-**5a** by far the most stable conformer is ac-*anti*-**5a** ($\theta = 240°$), with a very shallow and inconsequential local minimum as the lone pair passes through the plane of the ring ($\theta = 60°$). For *syn*-**5a**, sc-*syn*-**5a** is a broad global minimum ($\theta = 60 \pm 30°$), with another significant minimum resembling ac-*anti*-**5a** ($\theta = 230°$) and a shallow higher energy local minimum as the S–O bond passes through the plane of the ring ($\theta = 180°$). Whereas *anti*-**5a** lies happily in a low energy conformational well, *syn*-**5a** just can't get comfortable, in vain exchanging steric for dipole repulsions as the ArC–S bond rotates.

We are currently exploiting the fact that sulfoxides may be formed in enantiomerically pure form as a means of controlling the absolute orientation of functional groups, enabling the asymmetric synthesis of certain classes of atropisomers.

Experimental

General descriptions of spectrometers *etc*. have been provided before.[15] Amides **3**[3] and **6**[11] were prepared as previously described. The X-ray crystal structure of *anti*-**5c** has been deposited with the Cambridge Crystallographic Database (187714).†

2-Methylthio-*N*,*N*-diisopropyl-1-naphthamide 4a

sec-Butyllithium (1.3 mol dm^{-3} solution in hexane; 3.0 cm^3, 4.0 mmol) was added dropwise to a stirred solution of *N*,*N*-diisopropyl-1-naphthamide **3** (1.003 g, 3.9 mmol) in THF (18 cm^3) at −70 °C under nitrogen. After 35 minutes, dimethyl disulfide (0.5 cm^3, 5 mmol) was added dropwise to the yellow solution, which was warmed to room temperature. The mixture was treated with water (50 cm^3) and extracted with CH_2Cl_2 (3 × 10 cm^3). The combined extracts were washed with water (2 × 10 cm^3), dried ($MgSO_4$) and evaporated to give a crude product (1.076 g, 91%) which was recrystallised twice from petroleum ether to yield the *sulfide* **4a** (0.615 g, 52%). R_f(petroleum ether–EtOAc, 4:1) 0.47; ν_{max} (film)/cm^{-1} 1620 (C=O); δ_H (300 MHz; $CDCl_3$) 8.0–7.3 (6 H, m, ArH), 3.65 (1 H, septet, *J* 7 Hz, NCH), 3.55 (1 H, septet, *J* 7 Hz, NCH), 2.60 (3 H, s, SCH_3), 1.80 (3 H, d, *J* 7 Hz), 1.75 (3 H, d, *J* 7 Hz), 1.25 (3 H, d, *J* 7 Hz) and 1.05 (3 H, d, *J* 7 Hz) (CH_3 × 4); δ_C (75 MHz; $CDCl_3$) 167.9 (C=O), 136.0, 131.7, 130.9, 129.9, 128.3, 127.9, 127.0, 125.9, 125.8, 124.5 (Ar), 51.3, 46.1 (NCH × 2), 21.2, 20.8, 20.7, 20.3 (CH_3 × 4), 17.2 (SCH_3); *m*/*z* (CI) 302 (100%, M + H), *m*/*z* (EI) 201 (100%, M − N{CH[CH_3]$_2$}$_2$) (Found: M$^+$, 301.1505. $C_{18}H_{23}NOS$ requires *M*, 301.15003).

2-(*tert*-Butylthio)-*N*,*N*-diisopropyl-1-naphthamide 4b

In a similar way, *sec*-butyllithium (1.1 mol dm^{-3} solution in hexane; 3.7 cm^3, 4.1 mmol), *N*,*N*-diisopropyl-1-naphthamide **3** (1.004 g, 3.9 mmol), and di-*tert*-butyl disulfide (1.0 cm^3, 5 mmol) in THF (18 cm^3) gave a crude product (1.299 g, 96%) which was purified by flash chromatography (eluting with petroleum ether–EtOAc, 14:1) to yield the *sulfide* **4b** (0.870 g, 65%) as a solid. R_f(petroleum ether–EtOAc, 4:1) 0.80; ν_{max} (film)/cm^{-1} 1632 (C=O); δ_H (300 MHz; $CDCl_3$) 7.9–7.4 (6 H, m, ArH), 3.63 (1 H, septet, *J* 7 Hz, NCH), 3.43 (1 H, septet, *J* 7 Hz, NCH), 1.79 (3 H, d, *J* 7 Hz), 1.74 (3 H, d, *J* 7 Hz) (CH[CH_3]$_2$), 1.43

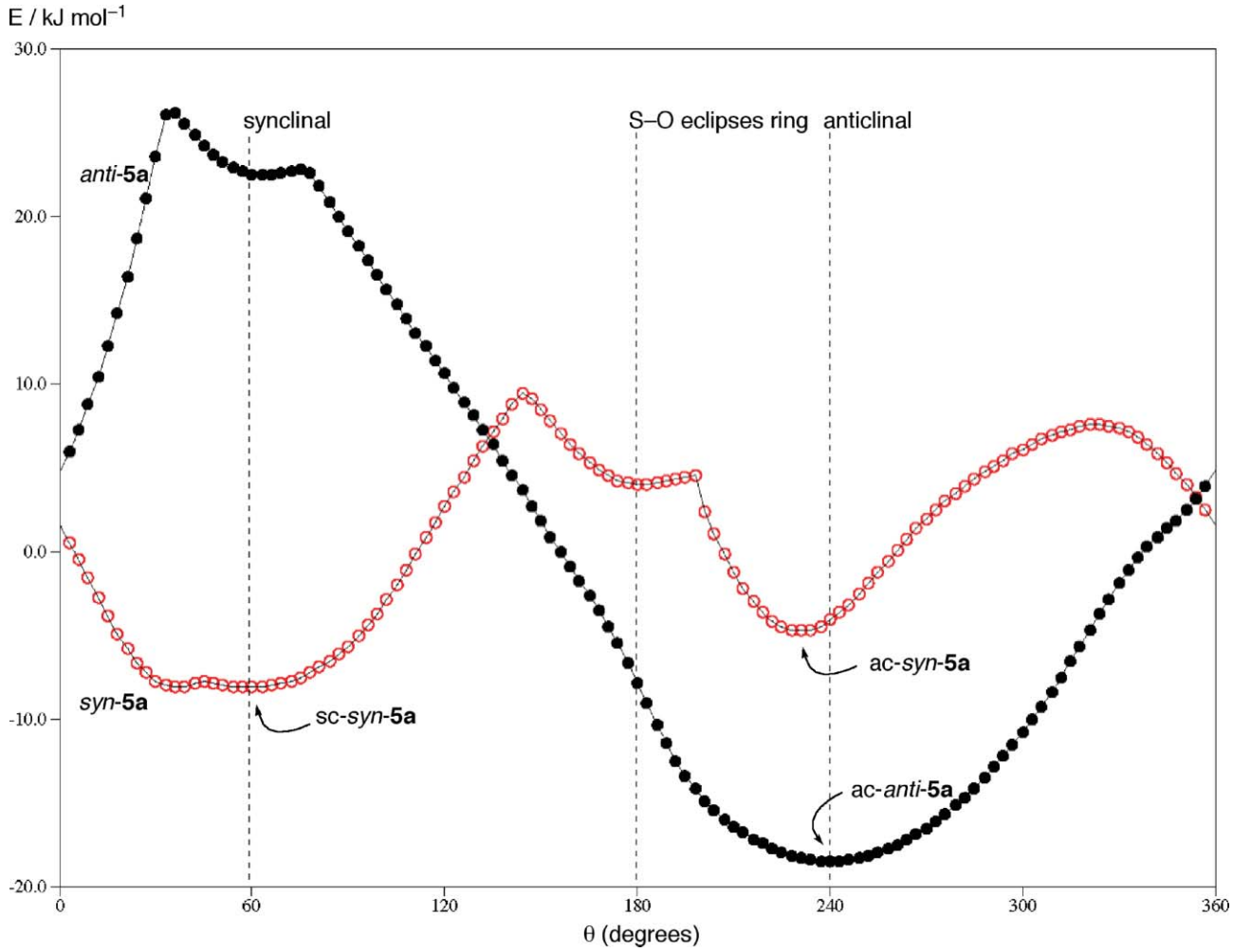


Fig. 6 Energy profile for rotation about Ar–S in (a) *anti*-**5a** (solid circles) and (b) *syn*-**5a** (open circles).

(9 H, s, SC[CH_3]$_3$), 1.22 (3 H, d, *J* 7 Hz) and 0.96 (3 H, d, *J* 7 Hz) (CH[CH_3]$_2$); δ_C (75 MHz; $CDCl_3$) 167.9 (C=O), 142.5, 134.1, 133.1, 130.2, 127.8, 127.2, 126.78, 126.76, 126.6, 125.6 (Ar), 51.0 (NCH), 48.0 (*C*[CH_3]$_3$), 46.0 (NCH), 31.8 (C[*C*H_3]$_3$), 21.3, 20.7, 20.5, 20.0 (CH_3 × 4); *m*/*z* (CI) 344 (100%, M + H) (Found: M^+, 343.1972. $C_{21}H_{29}NOS$ requires *M*, 343.19697).

2-Phenylthio-*N*,*N*-diisopropyl-1-naphthamide 4c

In a similar way, *sec*-butyllithium (1.1 mol dm^{-3} solution in hexane; 3.6 cm^3, 4 mmol), *N*,*N*-diisopropyl-1-naphthamide **3** (1.004 g, 3.9 mmol) and diphenyl disulfide (1.099 g, 5 mmol) gave a crude product (1.429 g, 99%) which was recrystallised with petroleum ether and ethyl acetate to yield the *sulfide* **4c** (1.022 g, 72%) as a solid. R_f(petroleum ether–EtOAc, 4:1) 0.58; ν_{max} (film)/cm^{-1} 1630 (C=O); δ_H (300 MHz; $CDCl_3$) 7.9–7.2 (11 H, m, ArH), 3.66 (2 H, m, NCH × 2), 1.81 (3 H, d, *J* 7 Hz), 1.74 (3 H, d, *J* 7 Hz), 1.23 (3 H, d, *J* 7 Hz) and 1.07 (3 H, d, *J* 7 Hz) (CH_3 × 4); δ_C (75 MHz; $CDCl_3$) 167.7 (C=O), 137.5, 135.5, 132.2, 131.2, 130.0, 129.1, 128.8, 128.4, 128.0, 127.4, 127.12, 127.06, 126.4, 124.9 (Ar), 51.3, 46.3 (NCH × 2), 21.2, 20.9, 20.7, 20.3 (CH_3 × 4); *m*/*z* (CI) 364 (100%, M + H), *m*/*z* (EI) 363 (50%, M), 263 (100%, M − N{CH[CH_3]$_2$}$_2$) (Found: M^+, 363.1666. $C_{23}H_{25}NOS$ requires *M*, 363.16568).

(*P**,*R**)-2-Methanesulfinyl-*N*,*N*-diisopropyl-1-naphthamide *anti*-5a

m-CPBA (70%, 0.415 g, 1.7 mmol) was added to a stirred solution of the sulfide **4a** (0.543 g, 1.8 mmol) in CH_2Cl_2 (9 cm^3) at −15 °C. The mixture was stirred for 2 h 45 min. and poured into water. The CH_2Cl_2 layer was separated and washed with aqueous $NaHSO_3$, aqueous $NaHCO_3$ and water. The CH_2Cl_2 layer was dried ($MgSO_4$) and concentrated to give a solid which was purified by flash chromatography (eluting with EtOAc–petroleum ether 2.5:1) to yield the *sulfoxide* **5a** (0.497 g, 78%) as a solid. Mp 157–157.5 °C; R_f(petroleum ether–EtOAc, 1:2) 0.13; ν_{max} (film)/cm^{-1} 1625 (C=O), 1059 (S=O); δ_H (300 MHz; $CDCl_3$) 8.2–7.5 (6 H, m, ArH), 3.69 (1 H, septet, *J* 7 Hz, NCH), 3.58 (1 H, septet, *J* 7 Hz, NCH), 2.89 (3 H, s, SO[CH_3]), 1.76 (3 H, d, *J* 7 Hz), 1.70 (3 H, d, *J* 7 Hz), 1.21 (3 H, d, *J* 7 Hz) and 1.08 (3 H, d, *J* 7 Hz) (CH_3 × 4); δ_C (75 MHz; $CDCl_3$) 166.1 (C=O), 138.7, 134.6, 133.8, 130.0, 128.6, 128.0, 127.83, 127.82, 125.0, 118.5 (Ar), 51.6, 46.5 (NCH × 2), 43.4 (SCH_3), 21.0, 20.7, 20.5 and 20.2 (CH_3 × 4); *m*/*z* (CI) 318 (80%, M + H), 217 (100%, M − N{CH[CH_3]$_2$}$_2$), *m*/*z* (EI) 217 (100%, M − N{CH[CH_3]$_2$}$_2$) (Found: M^+, 317.1452. $C_{18}H_{23}NO_2S$ requires *M*, 317.14494).

(*P**,*R**)-2-(*tert*-Butanesulfinyl)-*N*,*N*-diisopropyl-1-naphthamide *anti*-5b

In a similar way, *m*-CPBA (0.577 g, 2.3 mmol) and sulfide **4b** (0.846 g, 2.46 mmol) in CH_2Cl_2 (14 cm^3) gave a crude product which was purified by flash chromatography (eluting with petroleum ether–EtOAc, 1:1) to yield the *sulfoxide* **5b** (0.657 g, 74%) as a solid. Mp 132.5–133.5 °C; R_f (petroleum ether–EtOAc, 4:1) 0.09; ν_{max} (film)/cm^{-1} 1632 (C=O), 1043 (S=O); δ_H (300 MHz; $CDCl_3$) 8.1–7.5 (6 H, m, ArH), 3.67 (1 H, septet, *J* 7 Hz, NCH), 3.47 (1 H, septet, *J* 7 Hz, NCH), 1.78 (3 H, d, *J* 7 Hz), 1.70 (3 H, d, *J* 7 Hz) (CH[CH_3]$_2$), 1.34 (9 H, s, SC[CH_3]$_3$), 1.28 (3 H, d, *J* 7 Hz) and 0.97 (3 H, d, *J* 7 Hz) (CH[CH_3]$_2$); δ_C (75 MHz; $CDCl_3$) 166.3 (C=O), 137.5,

134.5, 134.0, 129.0, 128.5, 128.3, 128.2, 127.6, 125.7, 121.5 (Ar), 58.0 ($C[CH_3]_3$), 51.3, 46.4 (NCH × 2), 23.7 ($C[CH_3]_3$) 21.1, 20.6, 20.4 and 19.9 (CH_3 × 4); *m/z* (CI) 360 (80%, M + H), 259 (70%, M − N{CH[CH_3]$_2$}$_2$) (Found: M + H, 360.1996. $C_{21}H_{29}NO_2S$ requires *M* + *H*, 360.1997).

(*P**,*R**)-2-Benzenesulfinyl-*N*,*N*-diisopropyl-1-naphthamide *anti*-5c

In a similar way, *m*-CPBA (0.666 g, 2.7 mmol) and sulfide **4c** (1.017 g, 2.8 mmol) in CH_2Cl_2 (15 cm^3) gave a crude product which was purified by flash chromatography (eluting with petroleum ether–EtOAc, 5:1) to yield the *sulfoxide* **5c** (0.758 g, 74%) as a solid. Mp 202–203 °C; R_f (petroleum ether–EtOAc, 4:1) 0.16; ν_{max} (film)/cm^{-1} 1627 (C=O), 1046 (S=O); δ_H (300 MHz; $CDCl_3$) 8.0–7.2 (11 H, m, ArH), 3.75 (2 H, m, NCH × 2), 1.83 (3 H, d, *J* 7 Hz), 1.78 (3 H, d, *J* 7 Hz), 1.36 (3 H, d, *J* 7 Hz) and 1.12 (3 H, d, *J* 7 Hz) (CH_3 × 4); δ_C (75 MHz; $CDCl_3$) 166.3 (C=O), 144.7, 139.0, 136.0, 134.5, 130.3, 130.2, 129.0, 128.6, 128.5, 128.4, 127.8, 125.5, 124.3, 120.4 (Ar), 51.8, 46.6 (NCH × 2), 21.1, 20.9, 20.6 and 20.2 (CH_3 × 4); *m/z* (CI) 380 (100%, M + H), *m/z* (EI) 379 (20%, M) 279 (60%, M − N{CH[CH_3]$_2$}$_2$) (Found: M^+, 379.1604. $C_{23}H_{25}NO_2S$ requires *M*, 379.16059).

2-Benzenesulfinyl-*N*,*N*-diisopropyl-6-[(1-trimethylsilyl)ethyl]benzamide 7a and 7b

In a similar way, *m*-CPBA (70%, 0.025 g, 0.10 mmol) and amide **6** (0.047 g, 0.11 mmol) in CH_2Cl_2 (1 cm^3) gave a crude product which was purified by flash chromatography (eluting with petroleum ether–EtOAc, 6:1) to yield **7a** (0.012 g) and **7b** (0.006 g). **7a**: ν_{max} (film)/cm^{-1} 1627 (C=O), 1046 (S=O); δ_H (300 MHz; $CDCl_3$) 8.0–7.1 (8 H, m, ArH), 3.79 (1 H, septet, *J* 7 Hz, NCH), 3.66 (1 H, septet, *J* 7 Hz, NCH), 2.27 (1 H, q, *J* 7 Hz, C*H*CH_3Si), 1.68 (3 H, d, *J* 7 Hz, CHC*H*$_3$), 1.64 (3 H, d, *J* 7 Hz, CHC*H*$_3$), 1.43 (3 H, d, *J* 7 Hz, SiCHC*H*$_3$), 1.32 (3 H, d, *J* 7 Hz, CHC*H*$_3$), 1.23 (3 H, d, *J* 7 Hz, CHC*H*$_3$) and 0.2–0.0 (9 H, m, Si[CH_3]$_3$); *m/z* (CI) 430 (100%, M + H) (Found: M + H, 430.2246. $C_{23}H_{25}NO_2S$ requires *M* + *H*, 430.2236).

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