Supporting Information

For

α- and α′-Lithiation–Electrophile Trapping of *N*-Thiopivaloyl and *N*-*t*-Butoxythiocarbonyl α-Substituted Azetidines: Rationalization of the Regiodivergence Using NMR and Computation

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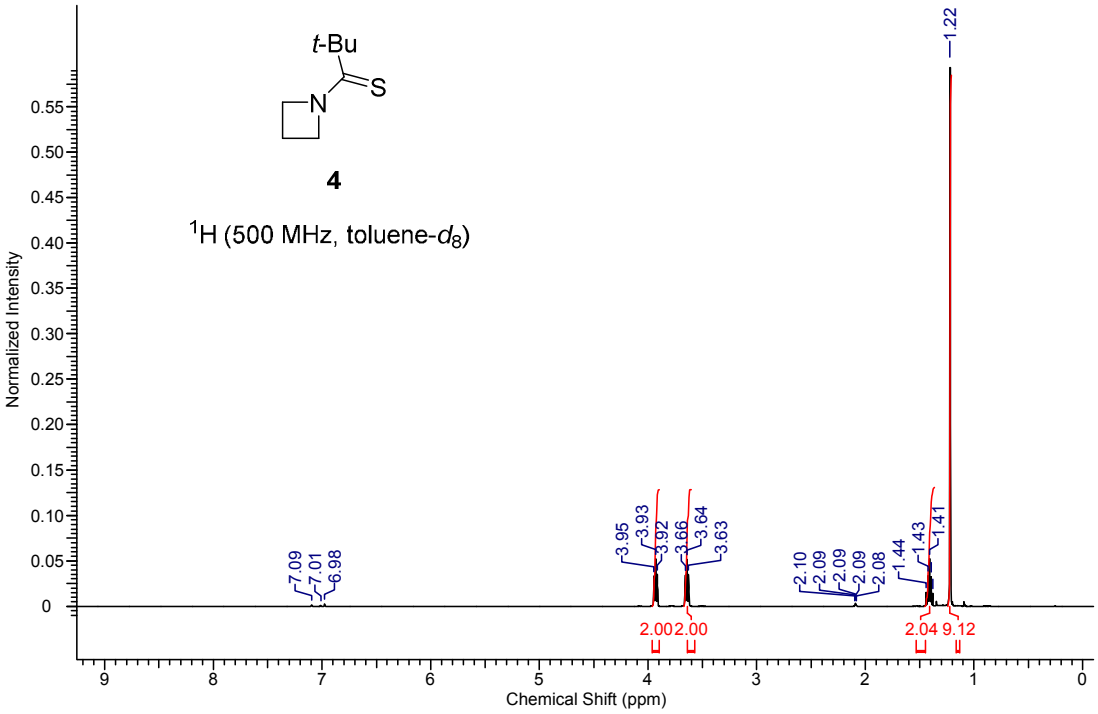
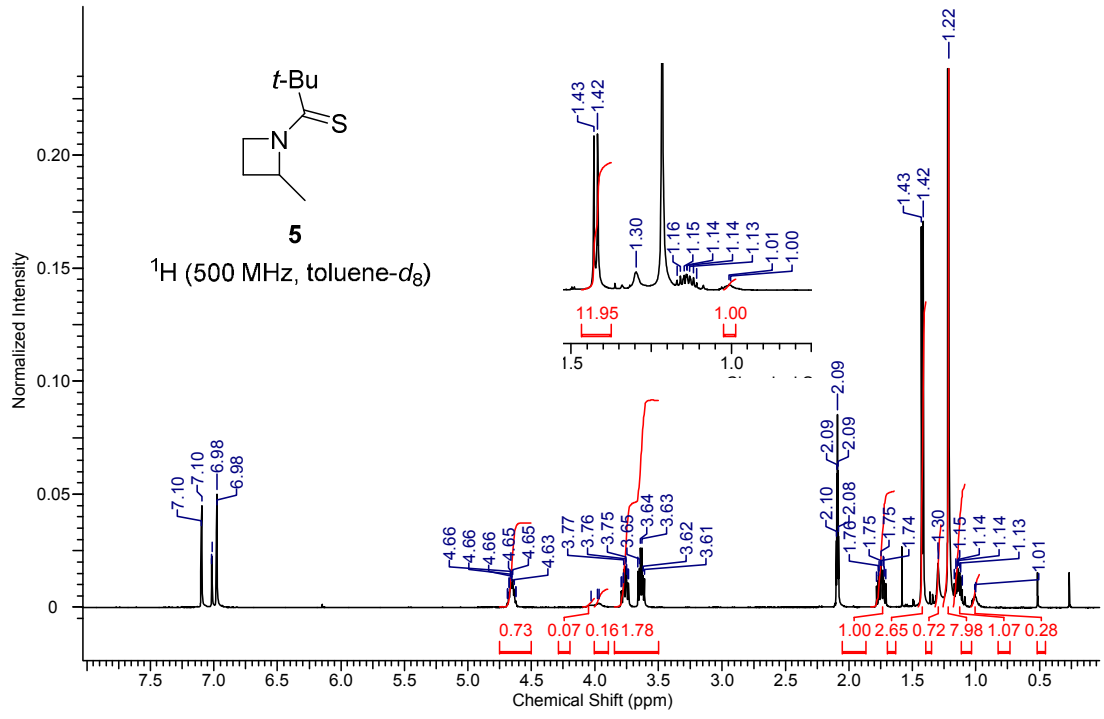
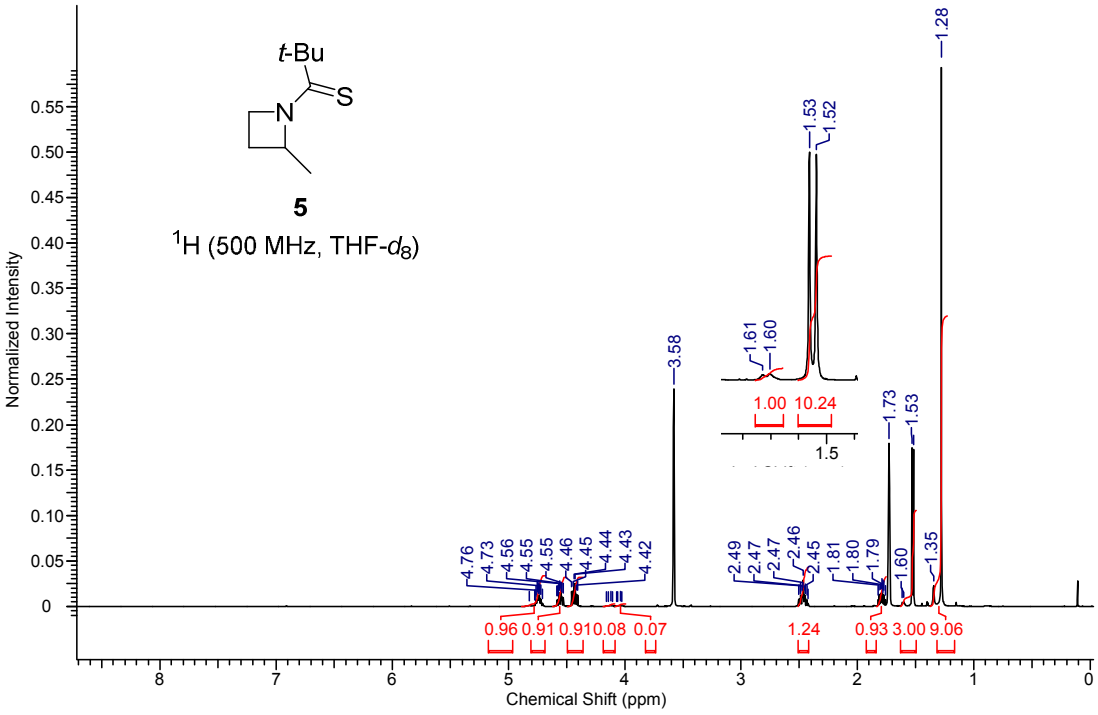
1. ^{1}H and ^{13}C NMR spectra






t-Bu
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S
5
1H (500 MHz, THF-d8)
Normalized Intensity
Chemical Shift (ppm)
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4.73
4.56
4.55
4.55
4.46
4.45
4.44
4.43
4.42
3.58
2.49
2.47
2.47
2.46
2.45
1.81
1.80
1.79
1.73
1.61
1.60
1.60
1.53
1.53
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1.28
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1.24
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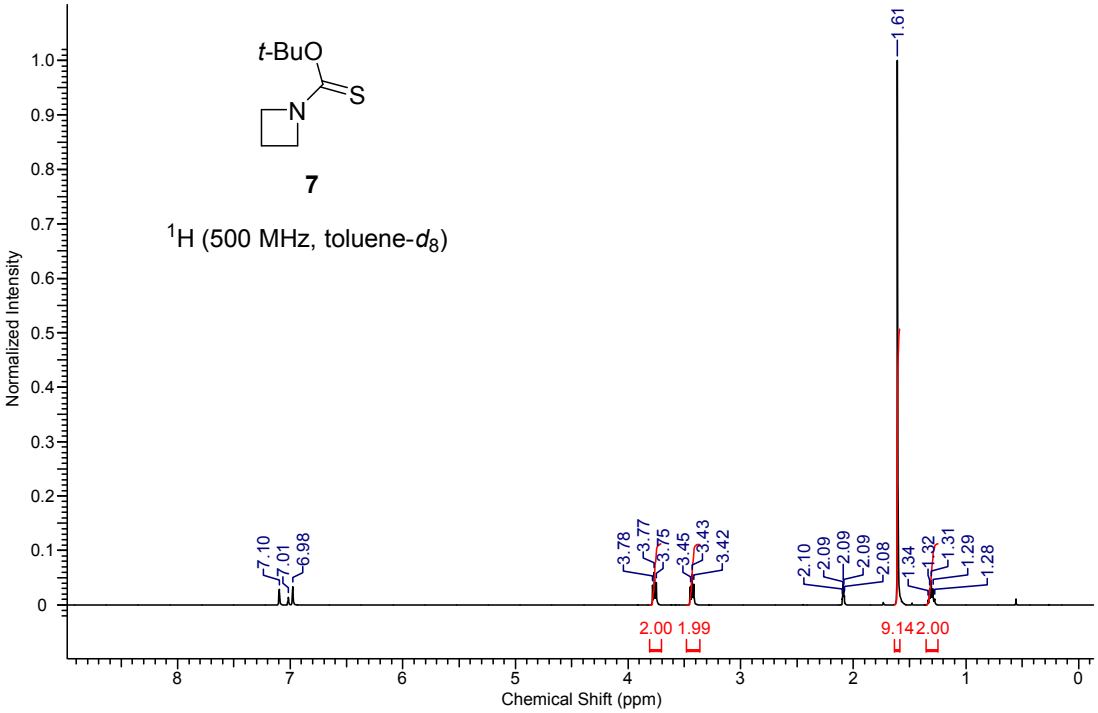
1.00 10.24


t-BuO
N
S
7
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Normalized Intensity
Chemical Shift (ppm)
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3.77
3.75
3.45
3.43
3.42
2.10
2.09
2.09
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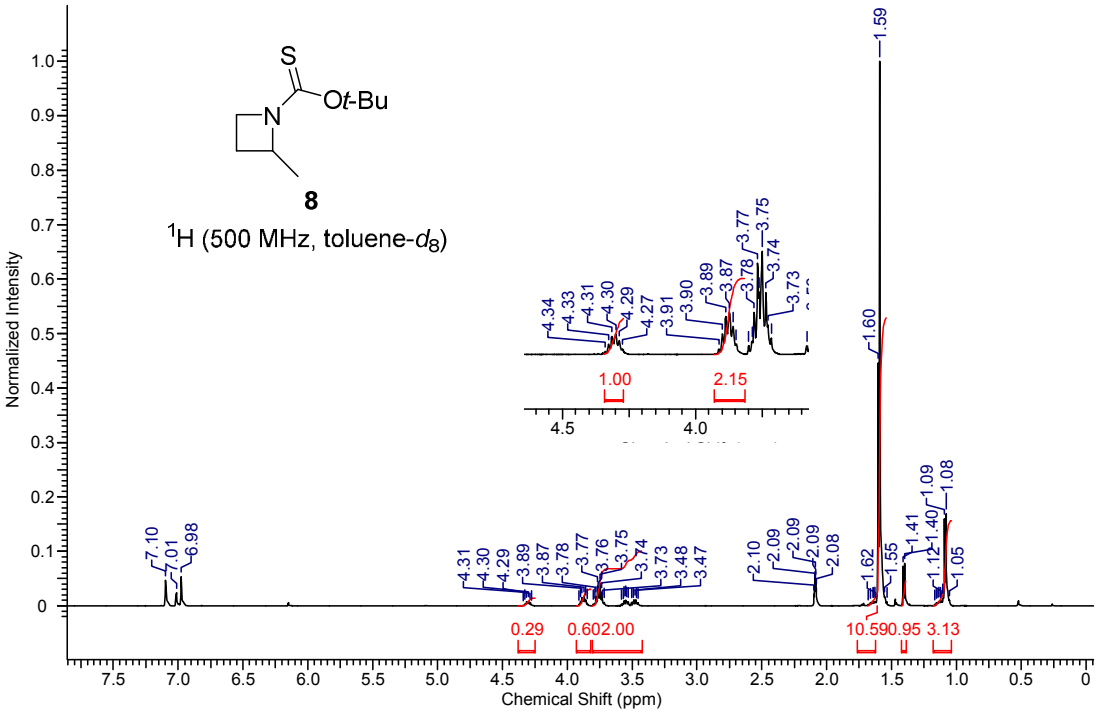
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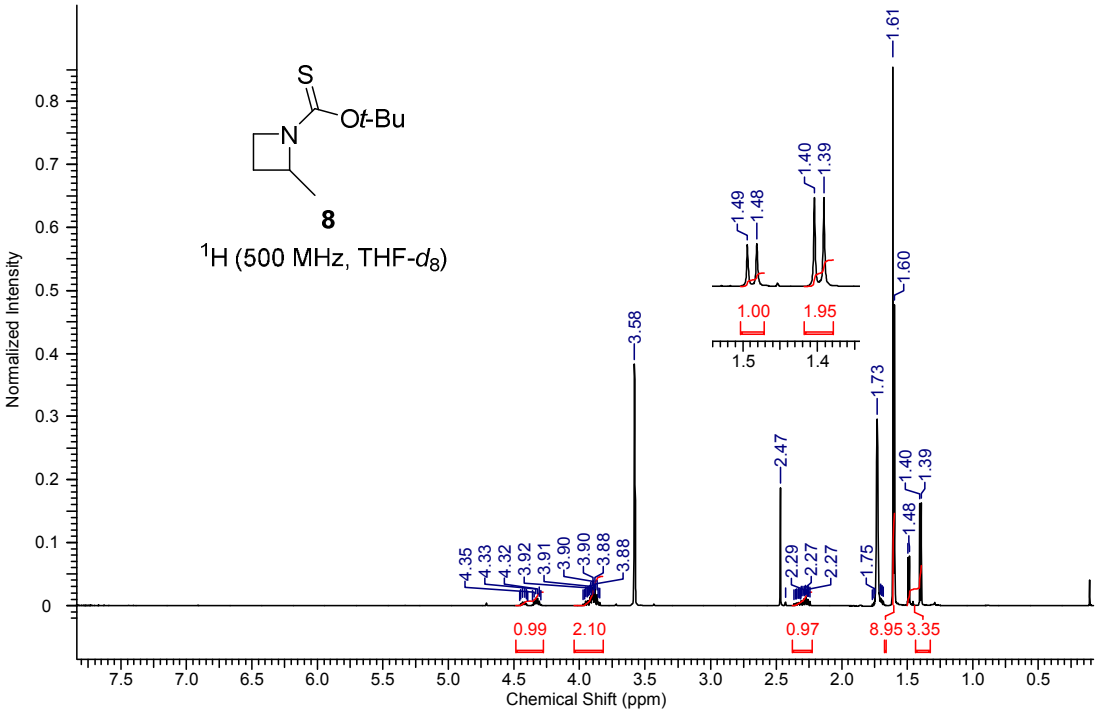
Normalized Intensity
Chemical Shift (ppm)


S
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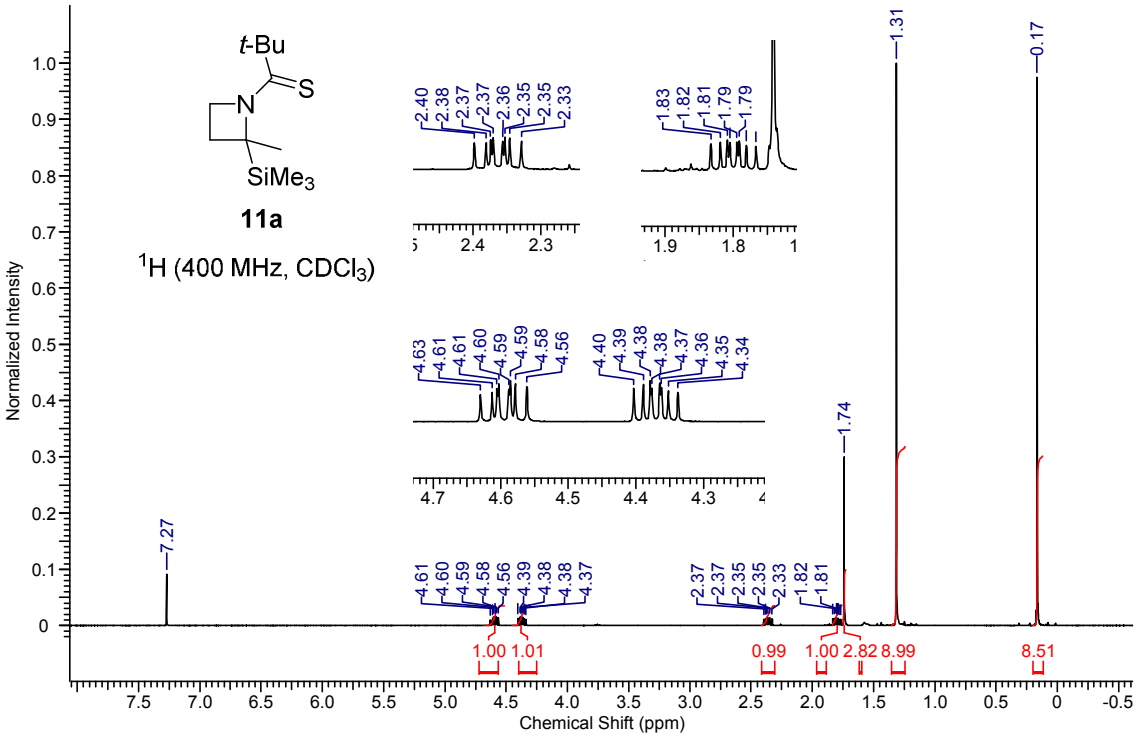
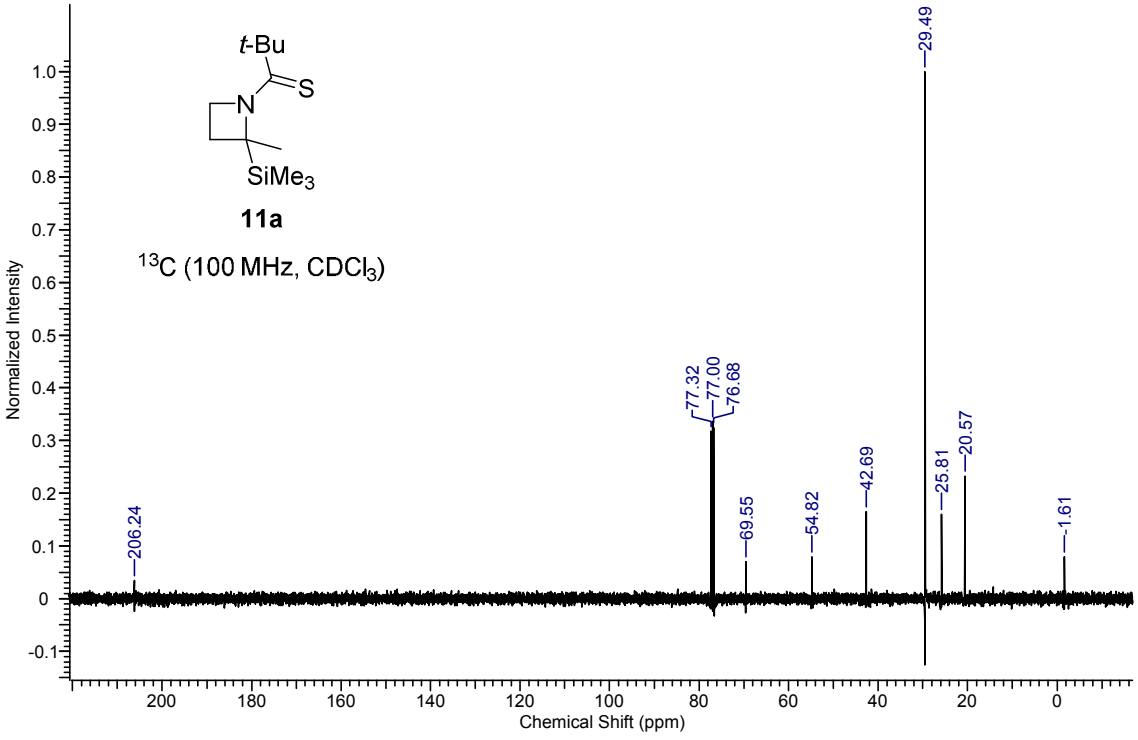
N
8
1H (500 MHz, THF-d8)
Normalized Intensity
Chemical Shift (ppm)


t-Bu
N
S
SiMe3
11a
1H (400 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.61
4.60
4.59
4.58
4.56
4.39
4.38
4.38
4.37
2.37
2.37
2.35
2.35
2.33
1.82
1.81
1.74
1.31
0.17
1.00 1.01 0.99 1.00 2.82 8.99 8.51


t-Bu
N
S
SiMe3
11a
13C (100 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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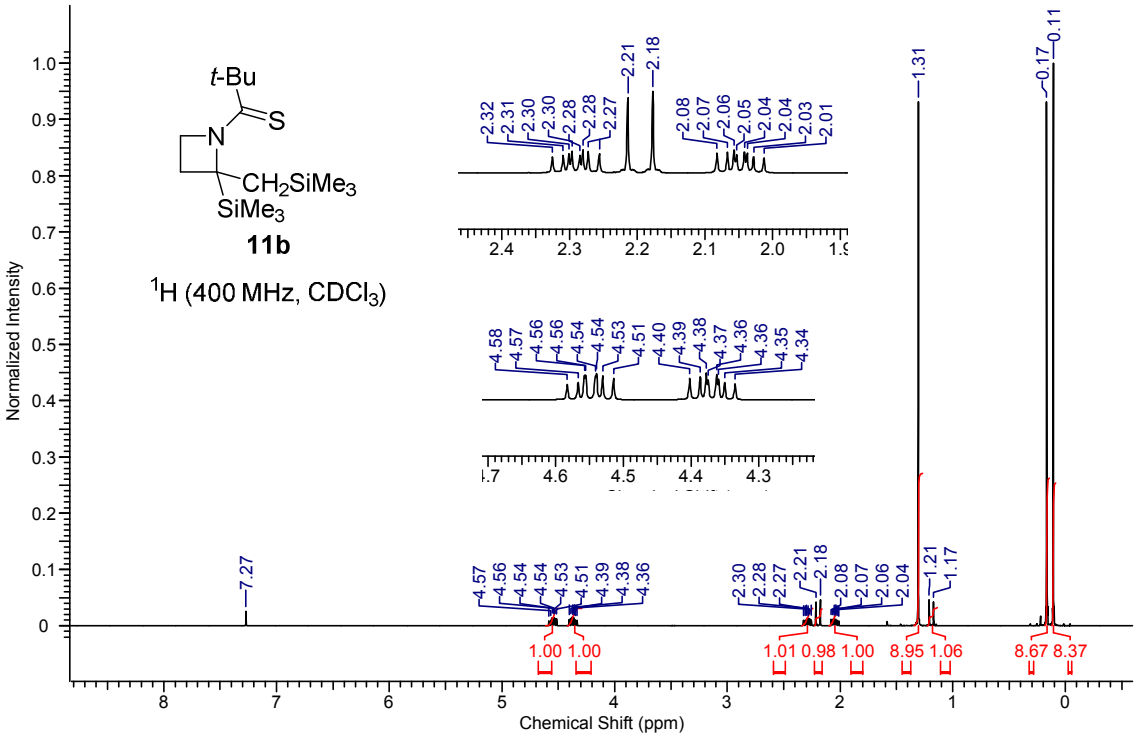
77.32
77.00
76.68
69.55
54.82
42.69
29.49
25.81
20.57
1.61


t-Bu
S
N
CH2SiMe3
SiMe3
11b
1H (400 MHz, CDCl3)
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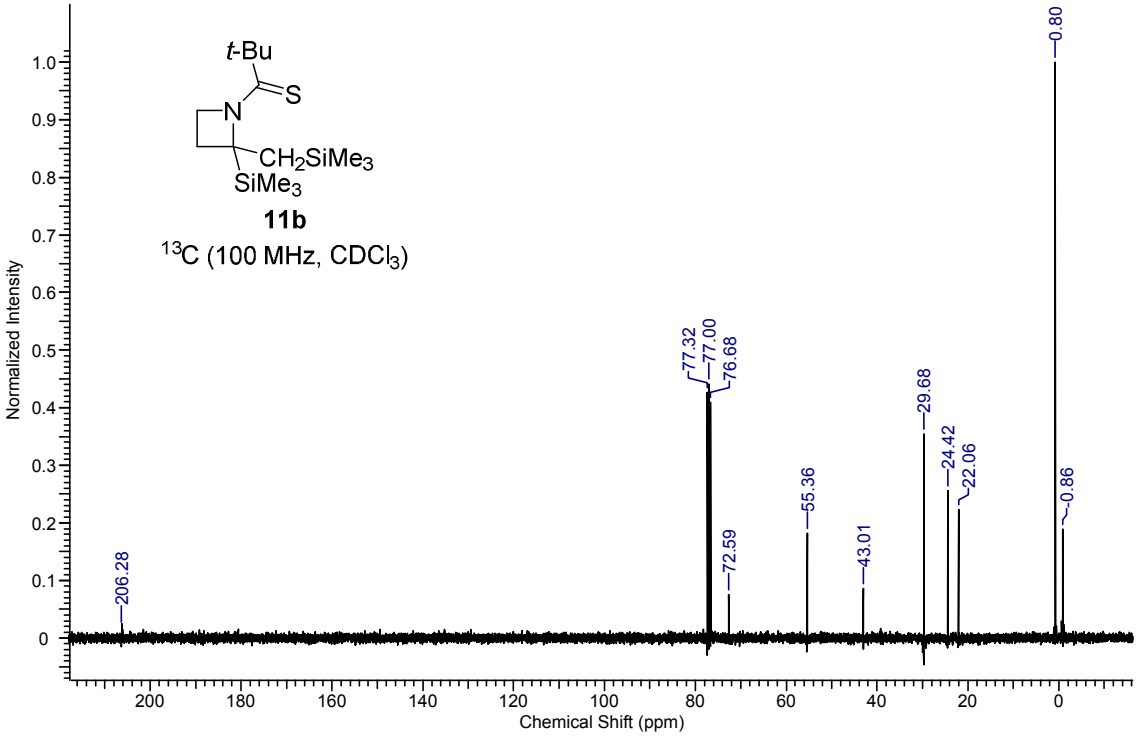
Chemical Shift (ppm)
7.27
1.00 1.00
1.01 0.98 1.00 8.95 1.06
8.67 8.37


t-Bu
S
N
CH2SiMe3
SiMe3
11b
13C (100 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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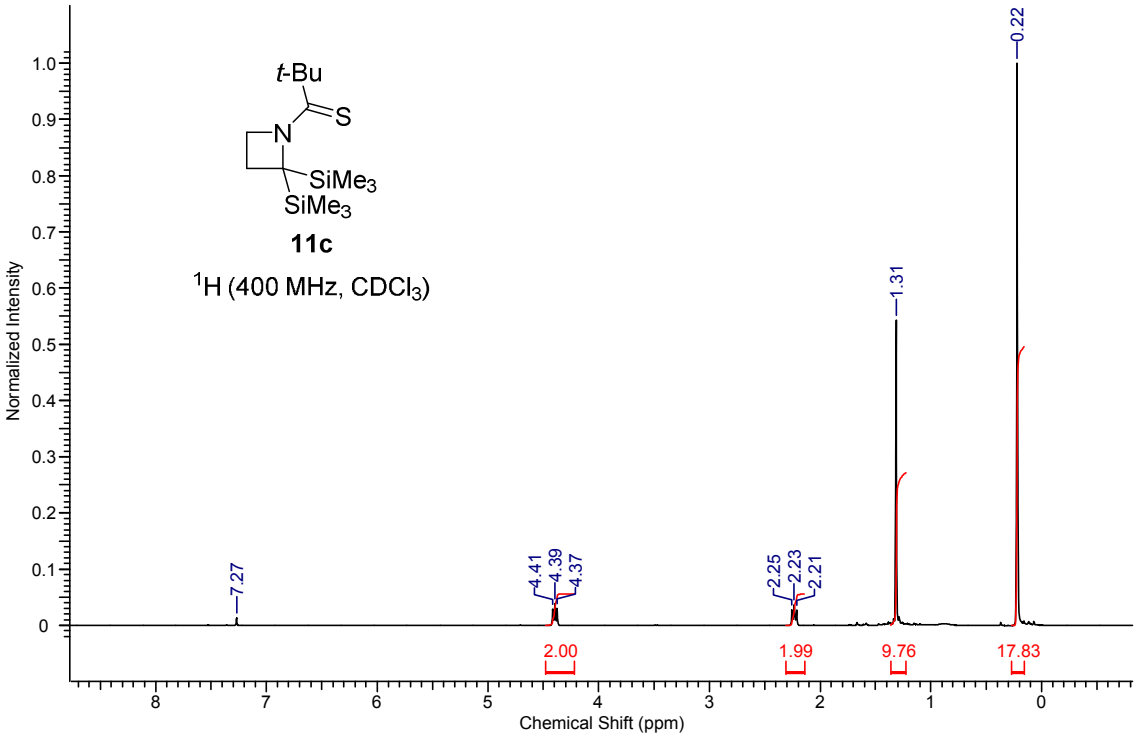
43.01
29.68
24.42
22.06
0.80
0.86


t-Bu
S
N
SiMe3
SiMe3
11c
1H (400 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.41
4.39
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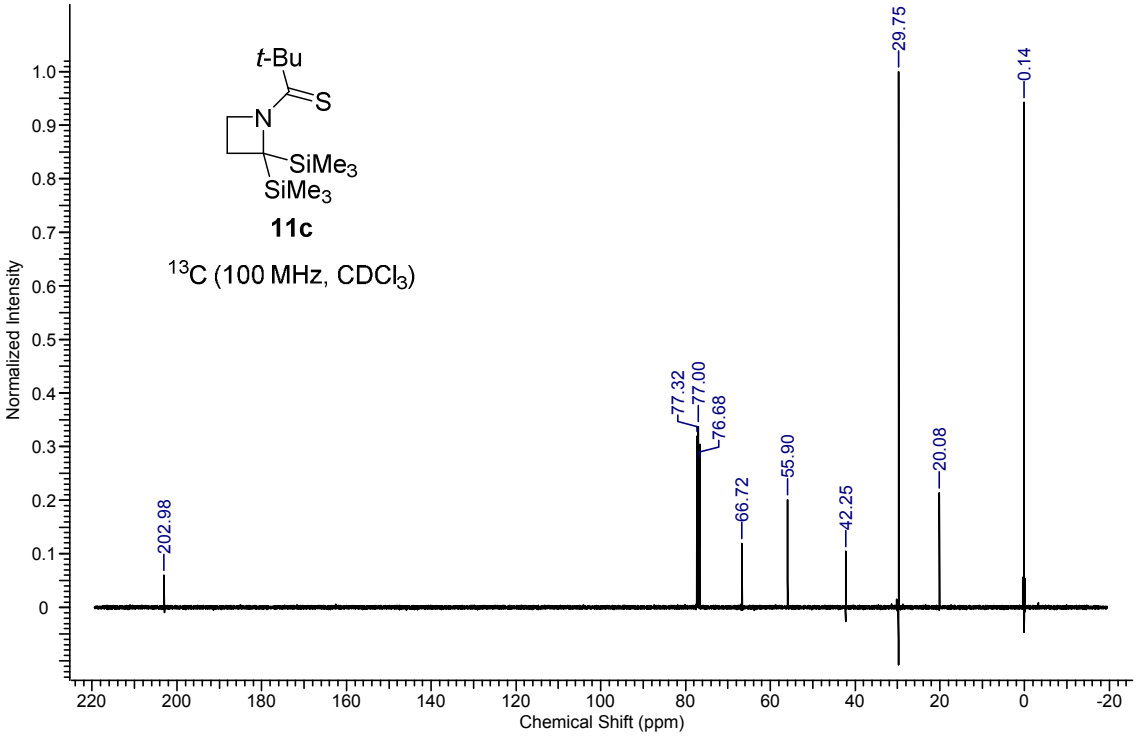
2.21
1.31
0.22
2.00
1.99
9.76
17.83


t-Bu
S
N
SiMe3
SiMe3
11c
13C (100 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
202.98
77.32
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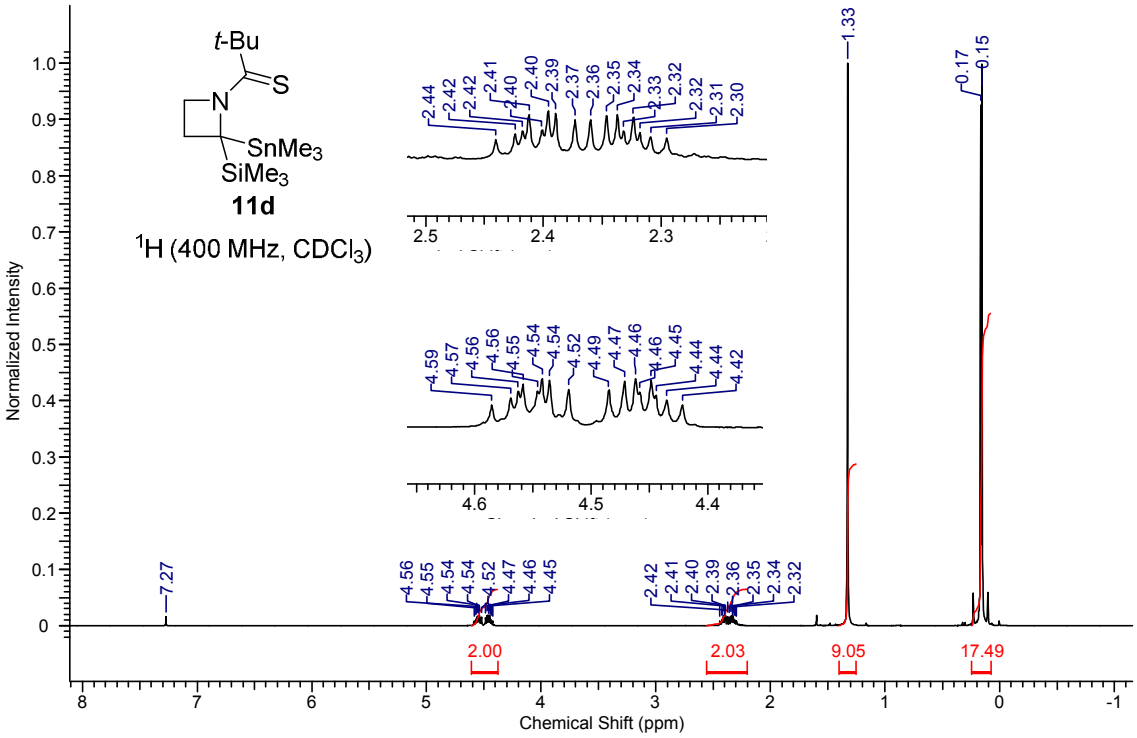
55.90
42.25
29.75
20.08
0.14


t-Bu
S
N
SnMe3
SiMe3
11d
1H (400 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.56
4.55
4.54
4.54
4.52
4.47
4.46
4.45
2.42
2.41
2.40
2.39
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2.35
2.34
2.32
1.33
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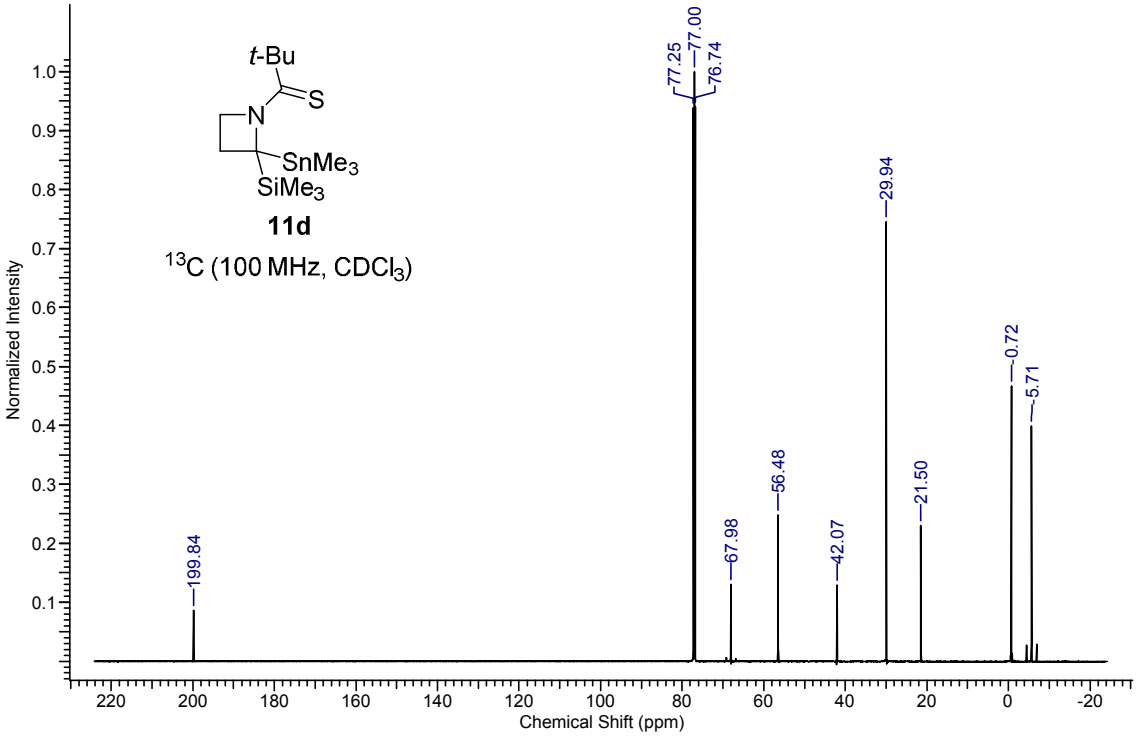
0.15
2.00
2.03
9.05
17.49


t-Bu
S
N
SnMe3
SiMe3
11d
13C (100 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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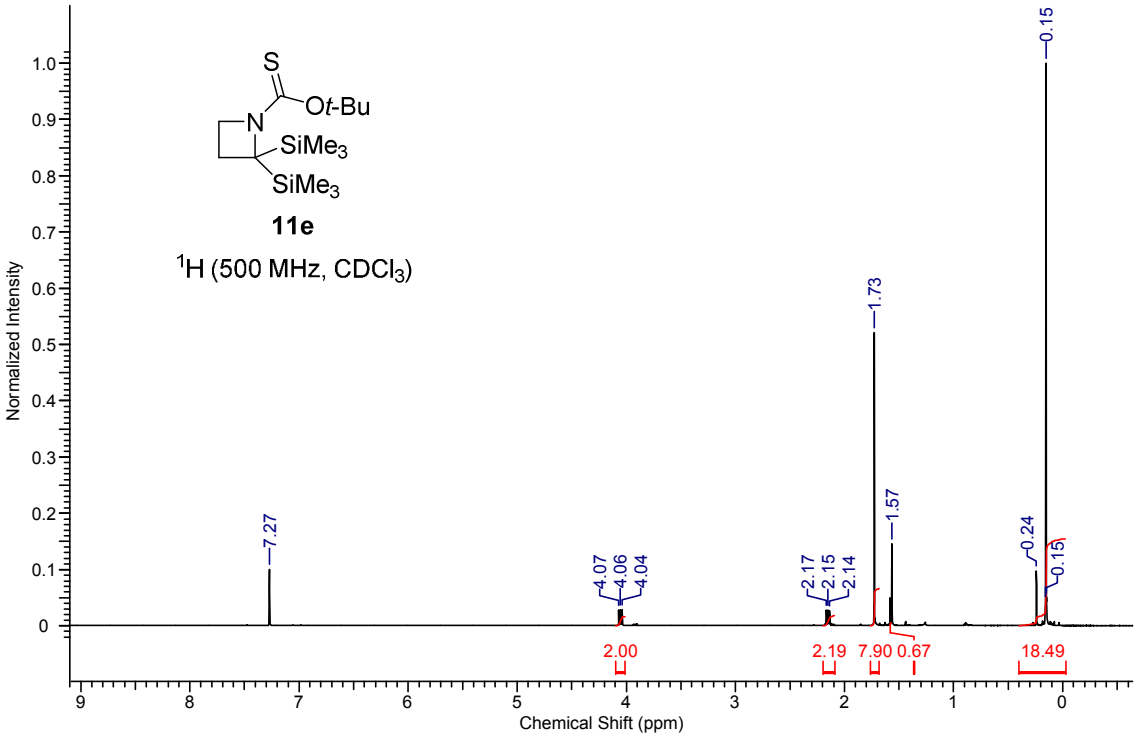
21.50
0.72
5.71


S
Ot-Bu
N
SiMe3
SiMe3
11e
1H (500 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.07
4.06
4.04
2.17
2.15
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0.15
0.15
2.00
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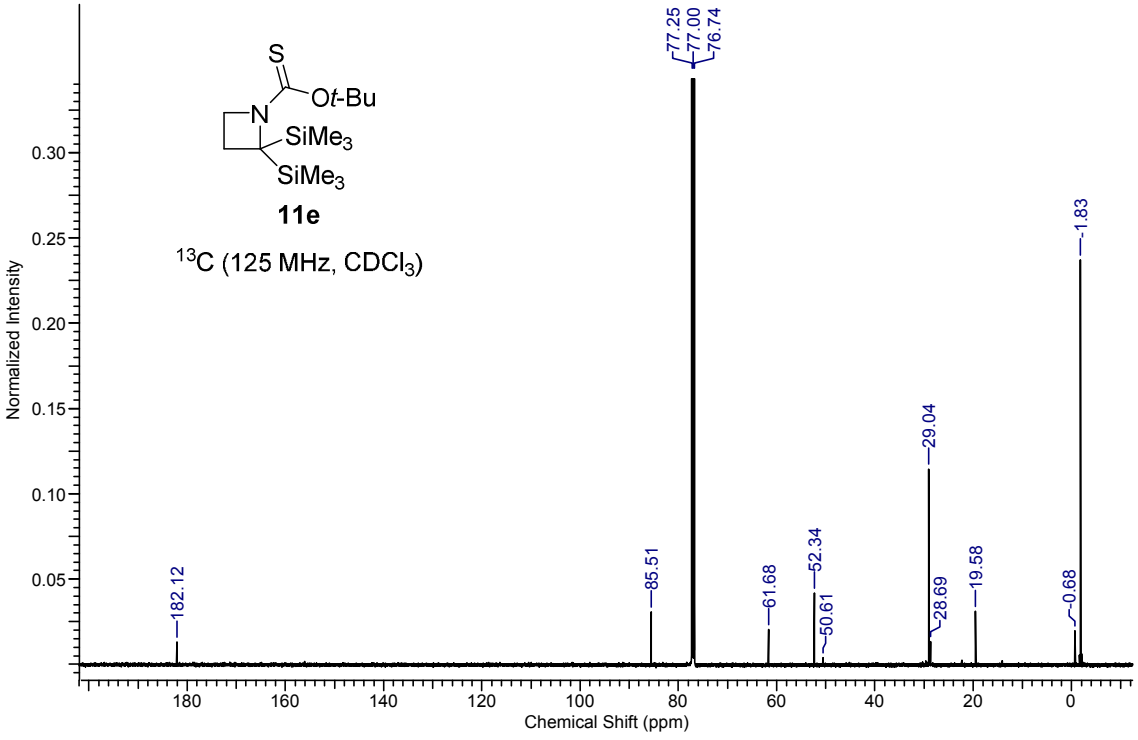
0.67
18.49


S
Ot-Bu
N
SiMe3
SiMe3
11e
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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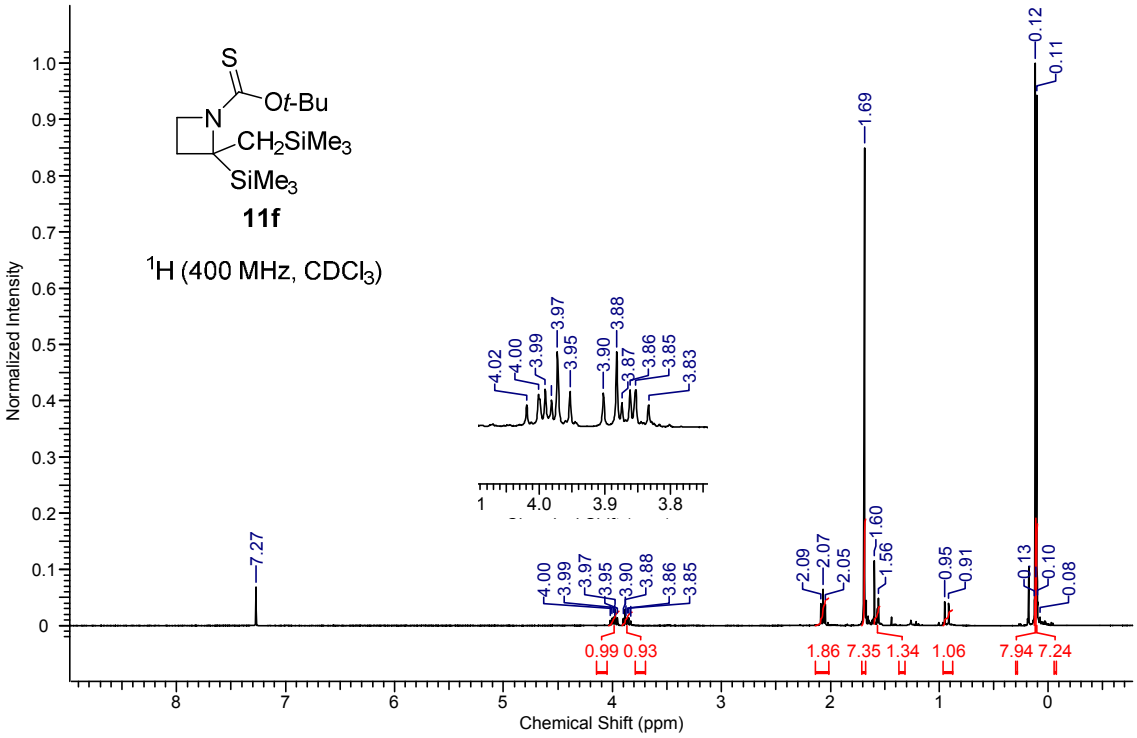
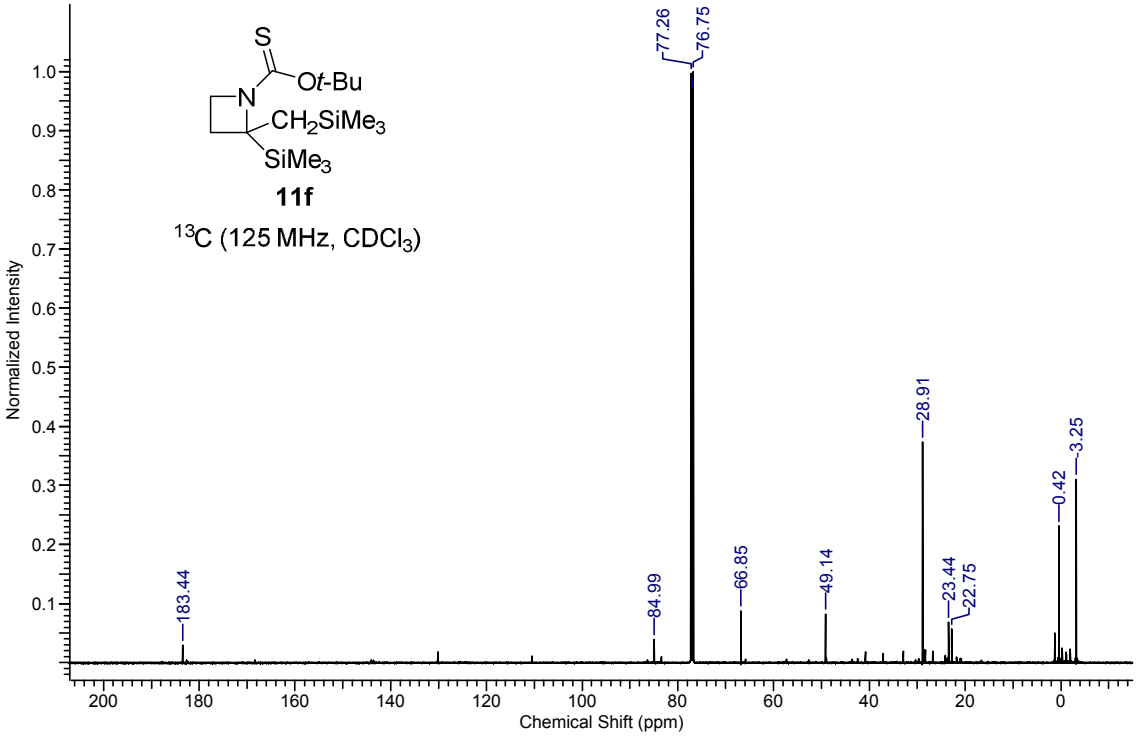
52.34
50.61
29.04
28.69
19.58
1.83
0.68


S
Ot-Bu
N
CH2SiMe3
SiMe3
11f
1H (400 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.02
4.00
3.99
3.97
3.95
3.90
3.88
3.87
3.86
3.85
3.83
2.09
2.07
2.05
1.69
1.60
1.56
0.95
0.91
0.13
0.12
0.11
0.10
0.08
0.99
0.93
1.86
7.35
1.34
1.06
7.94
7.24


S
Ot-Bu
N
CH2SiMe3
SiMe3
11f
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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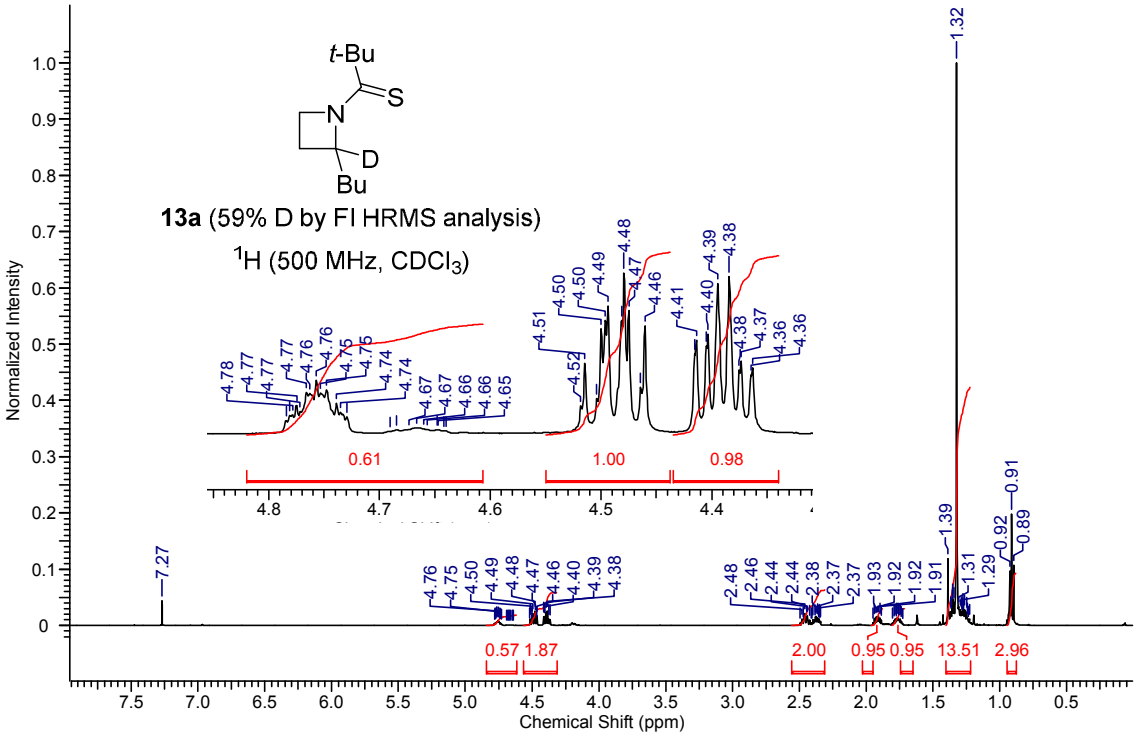
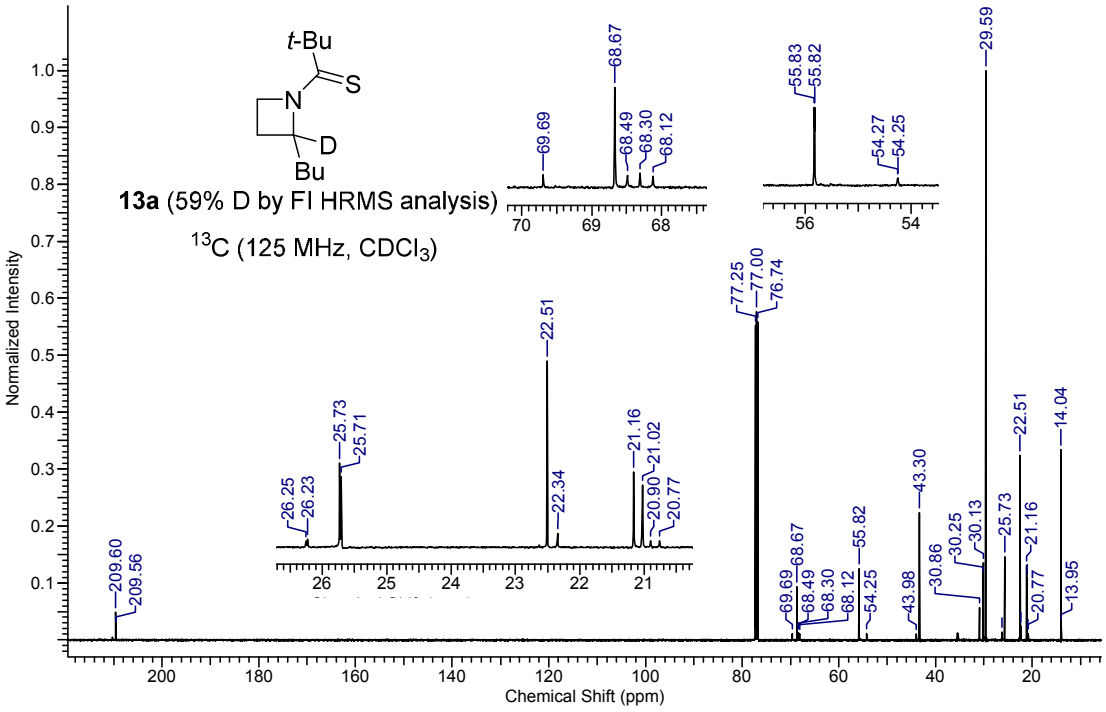
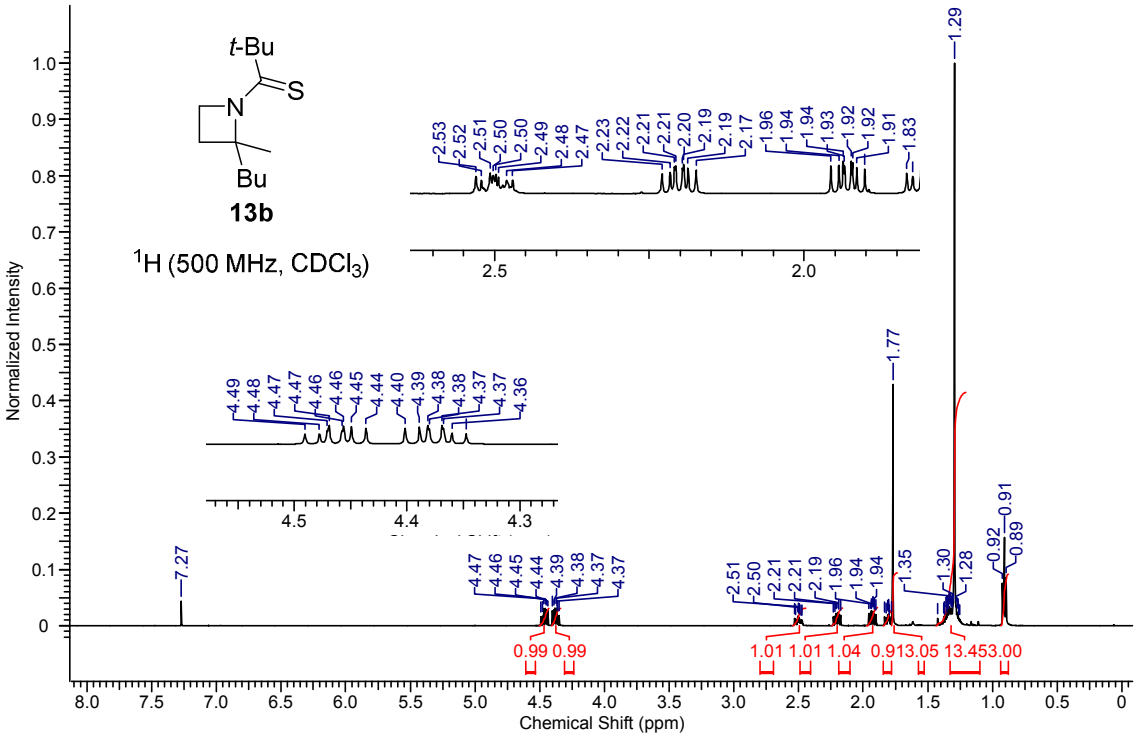
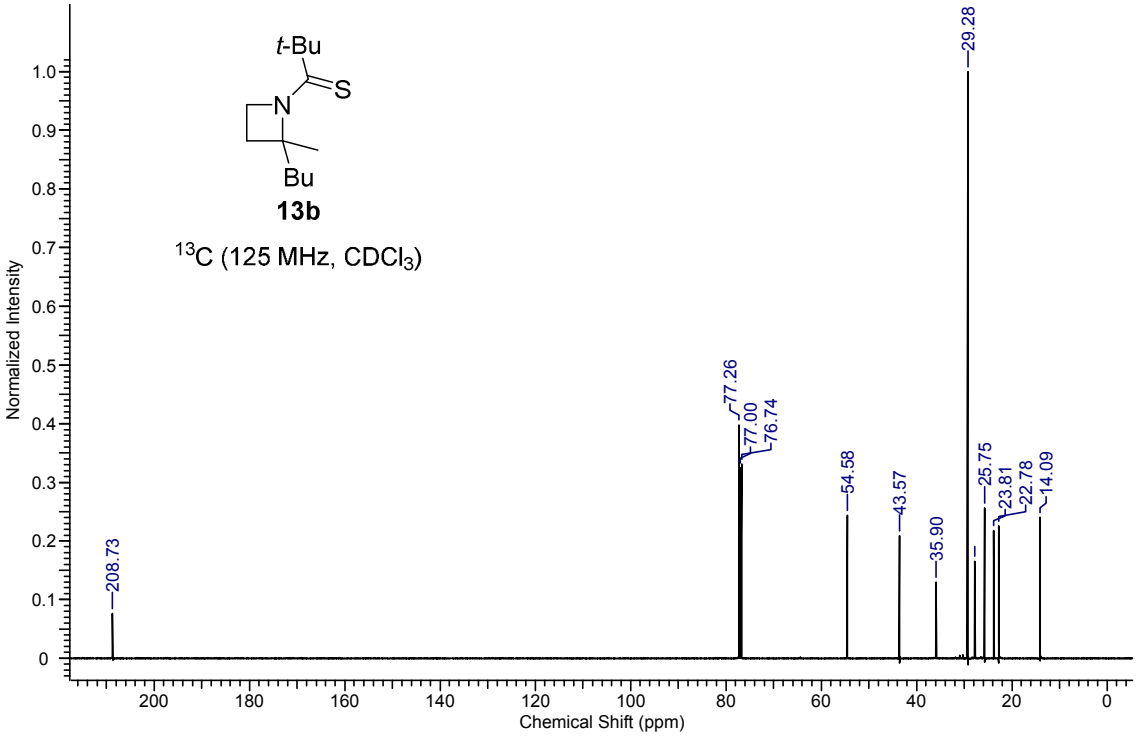
84.99
77.26
76.75
66.85
49.14
28.91
23.44
22.75
0.42
3.25


t-Bu
S
N
D
Bu
13a (59% D by FI HRMS analysis)
1H (500 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)


t-Bu
S
N
D
Bu
13a (59% D by FI HRMS analysis)
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)


t-Bu
N
S
Bu
13b
1H (500 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
1.29
1.77
0.99 0.99
1.01 1.01 1.04 0.91 3.05 13.45 3.00


t-Bu
N
S
Bu
13b
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
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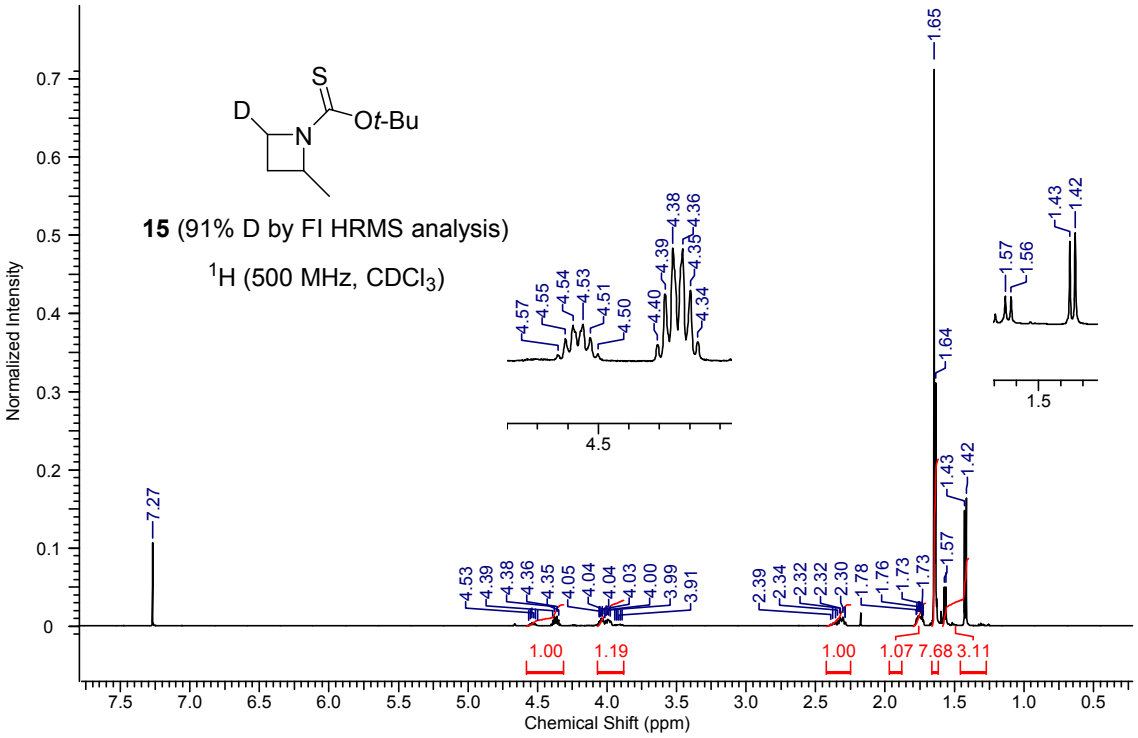
23.81
22.78
14.09


S
D
N
Ot-Bu
15 (91% D by FI HRMS analysis)
1H (500 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.53
4.39
4.38
4.36
4.35
4.05
4.04
4.04
4.03
4.00
3.99
3.91
2.39
2.34
2.32
2.32
2.30
1.78
1.76
1.73
1.73
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1.57
1.43
1.42
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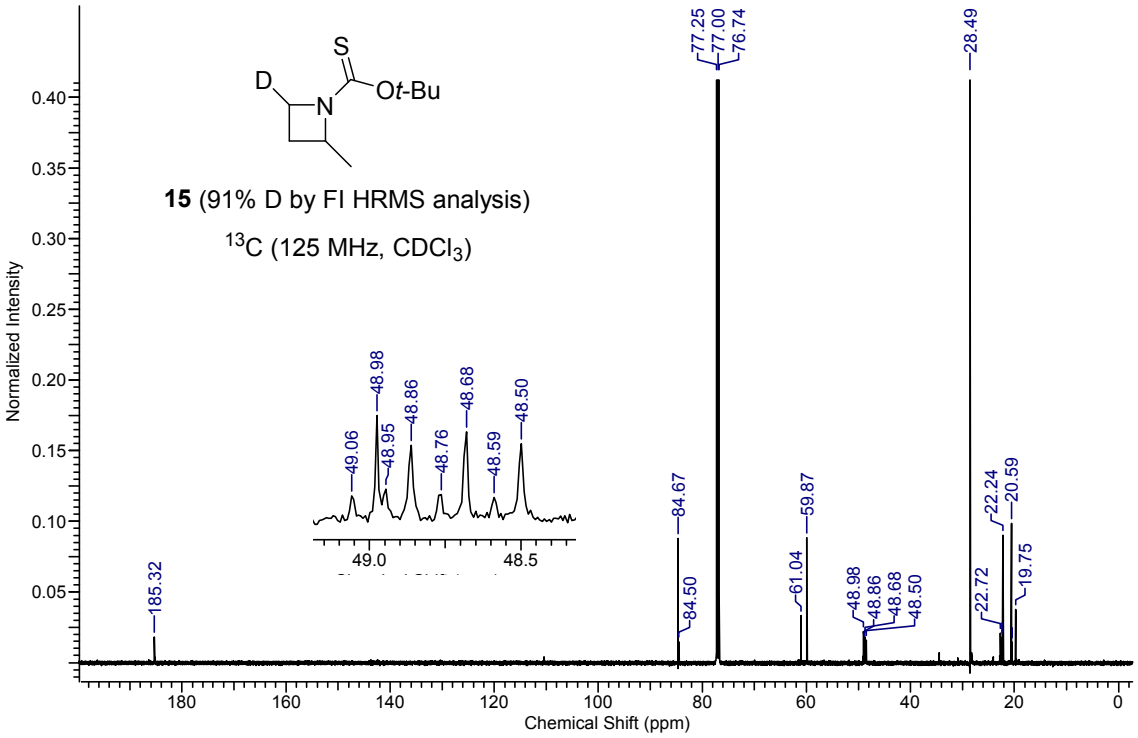
1.19
1.00
1.07
7.68
3.11


S
D
N
Ot-Bu
15 (91% D by FI HRMS analysis)
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
185.32
84.67
84.50
77.25
77.00
76.74
61.04
59.87
48.98
48.86
48.68
48.50
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28.49
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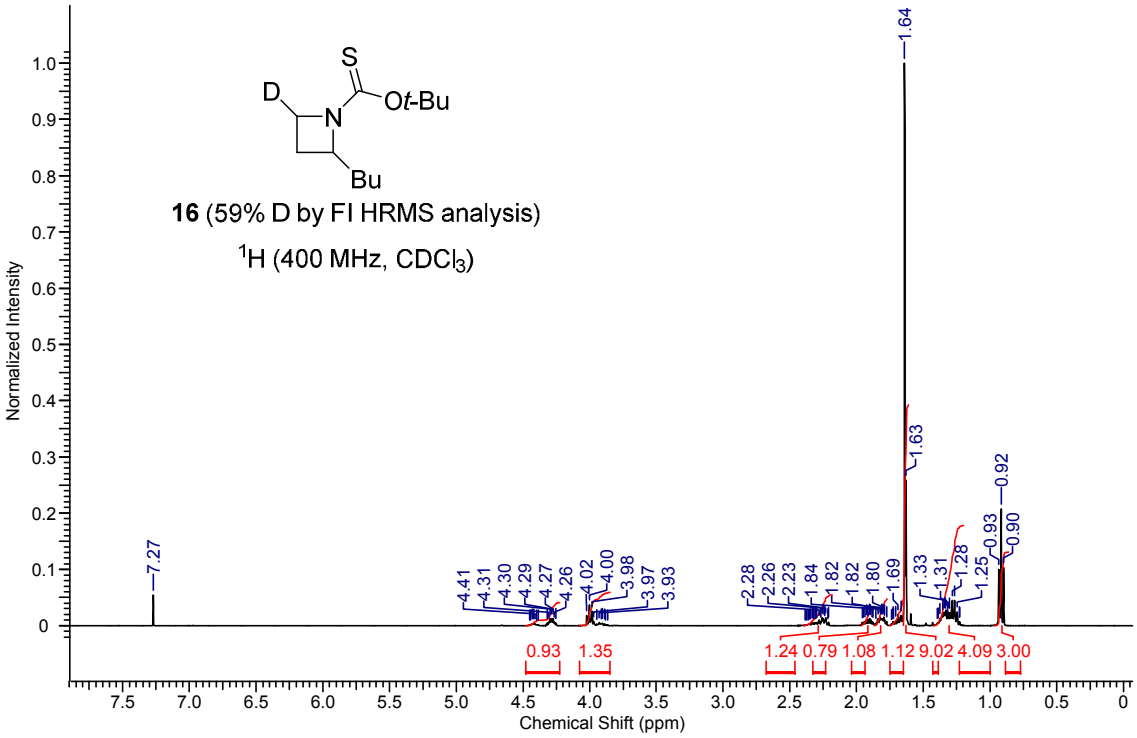
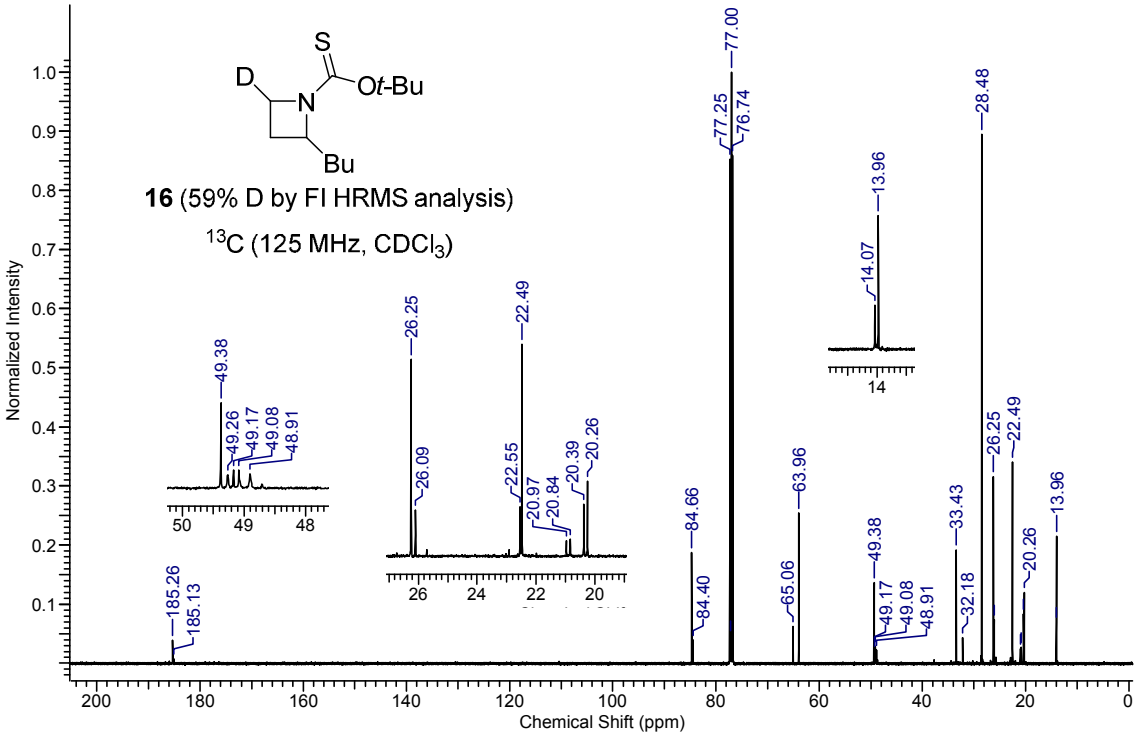
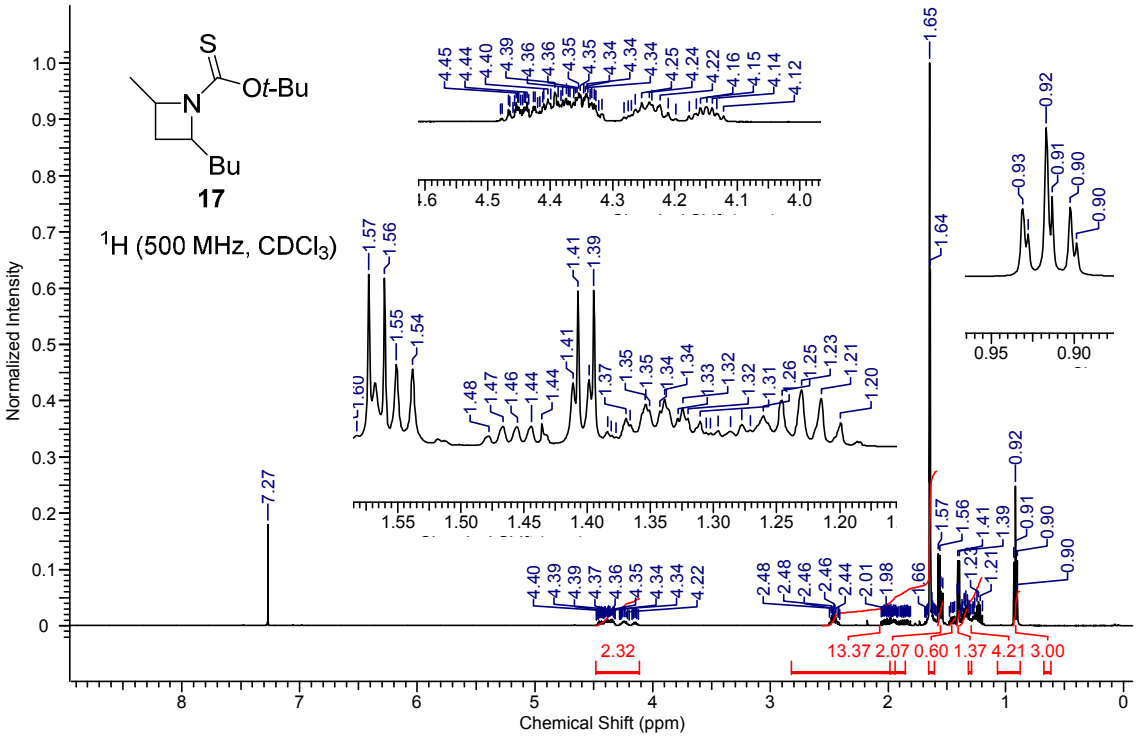
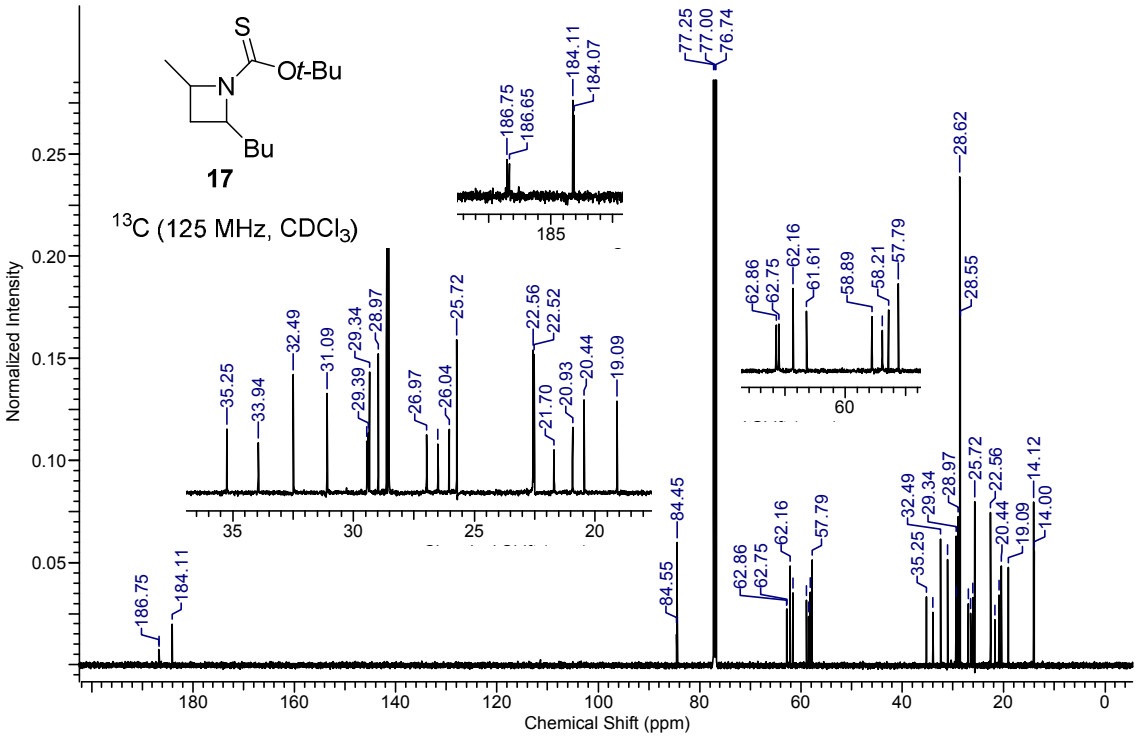
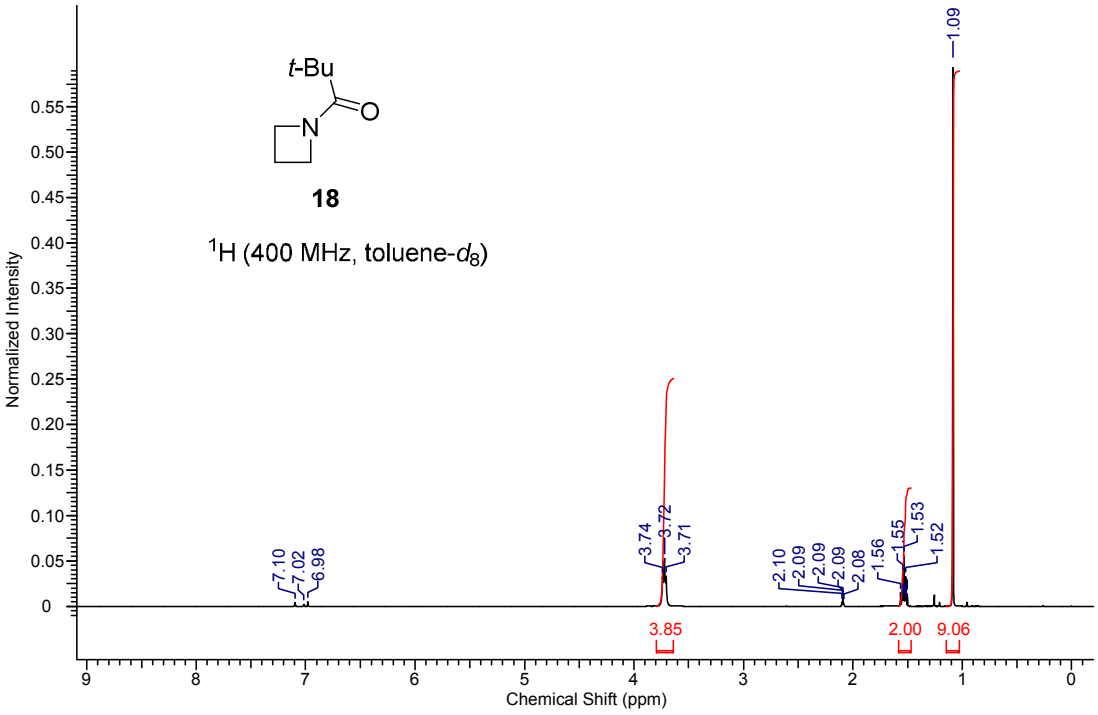
22.24
20.59
19.75


S
D
N
Ot-Bu
Bu
16 (59% D by FI HRMS analysis)
1H (400 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
4.41
4.31
4.30
4.29
4.27
4.26
4.02
4.00
3.98
3.97
3.93
2.28
2.26
2.23
1.84
1.82
1.82
1.80
1.69
1.64
1.63
1.33
1.31
1.28
1.25
0.93
0.92
0.90
0.93
1.35
1.24
0.79
1.08
1.12
9.02
4.09
3.00


S
D
N
Ot-Bu
Bu
16 (59% D by FI HRMS analysis)
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
185.26
185.13
84.66
84.40
77.25
77.00
76.74
65.06
63.96
49.38
49.17
49.08
48.91
33.43
32.18
28.48
26.25
26.09
22.49
22.55
20.97
20.84
20.39
20.26
14.07
13.96


S
Ot-Bu
N
Bu
17
1H (500 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)
7.27
2.32
13.37 2.07 0.60 1.37 4.21 3.00


S
Ot-Bu
N
Bu
17
13C (125 MHz, CDCl3)
Normalized Intensity
Chemical Shift (ppm)


t-Bu
N
O
18
1H (400 MHz, toluene-d8)
Normalized Intensity
Chemical Shift (ppm)
7.10
7.02
6.98
3.74
3.72
3.71
2.10
2.09
2.09
2.09
2.08
1.56
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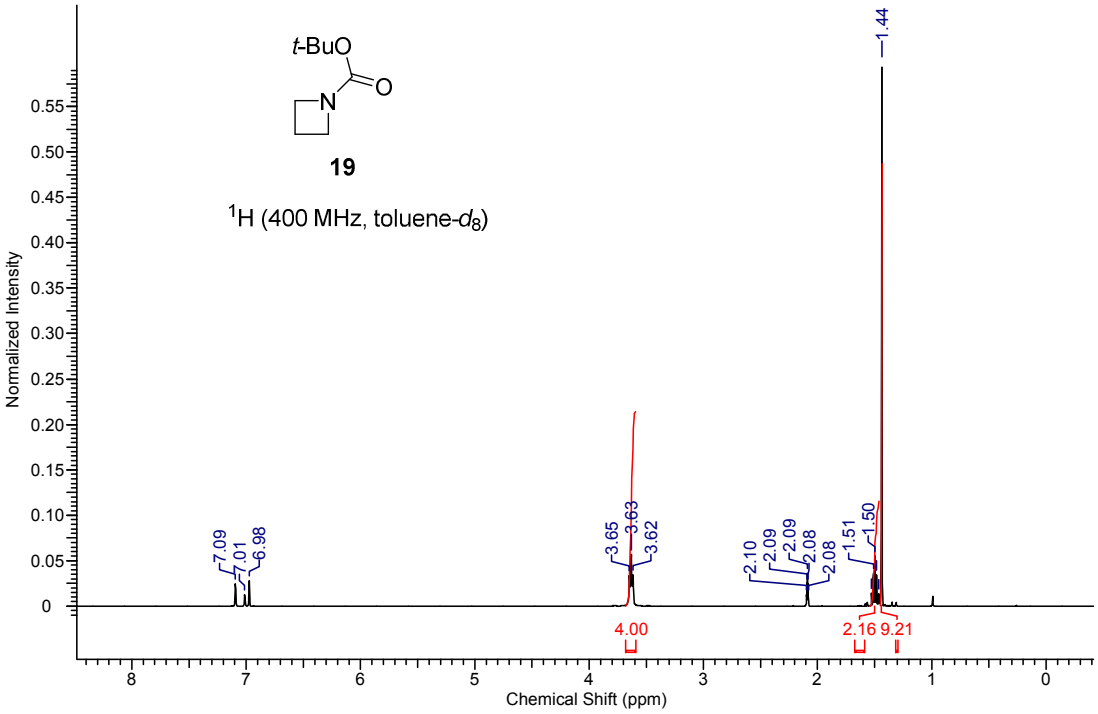
1.53
1.52
1.09
3.85
2.00
9.06


t-BuO
N
O
19
1H (400 MHz, toluene-d8)
Normalized Intensity
Chemical Shift (ppm)
7.09
7.01
6.98
3.65
3.63
3.62
2.10
2.09
2.09
2.08
1.51
1.50
1.44
4.00
2.16
9.21

2. NOESY and Variable Temperature NMR Data

2D NOESY spectra were acquired with mixing times of 800 ms to define the preferred conformations of the substituted azetidines. Data were recorded on Bruker AVII 500 spectrometers equipped with either a ^{13}C cryoprobe (25 °C) or a ^{1}H/^{13}C/^{19}F TXI room temperature probe (low temperature).

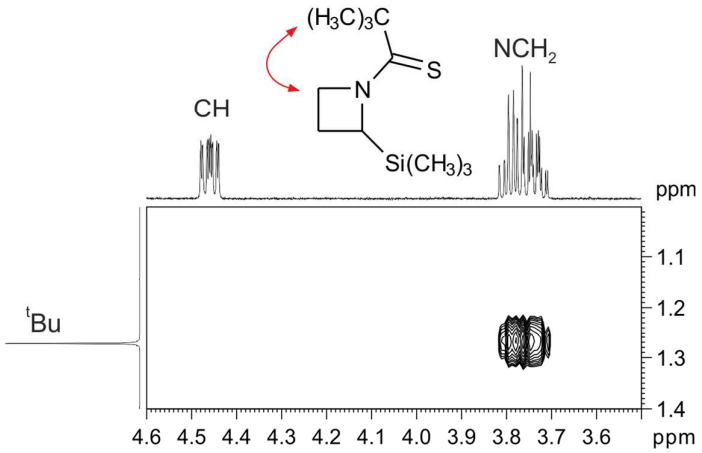


Figure S1. 2D NOESY spectrum (500 MHz, 25 °C, toluene-d_8) for *N*-thiopivaloyl-2-(trimethylsilyl)azetidine **10** showing NOEs from the *t*Bu group.

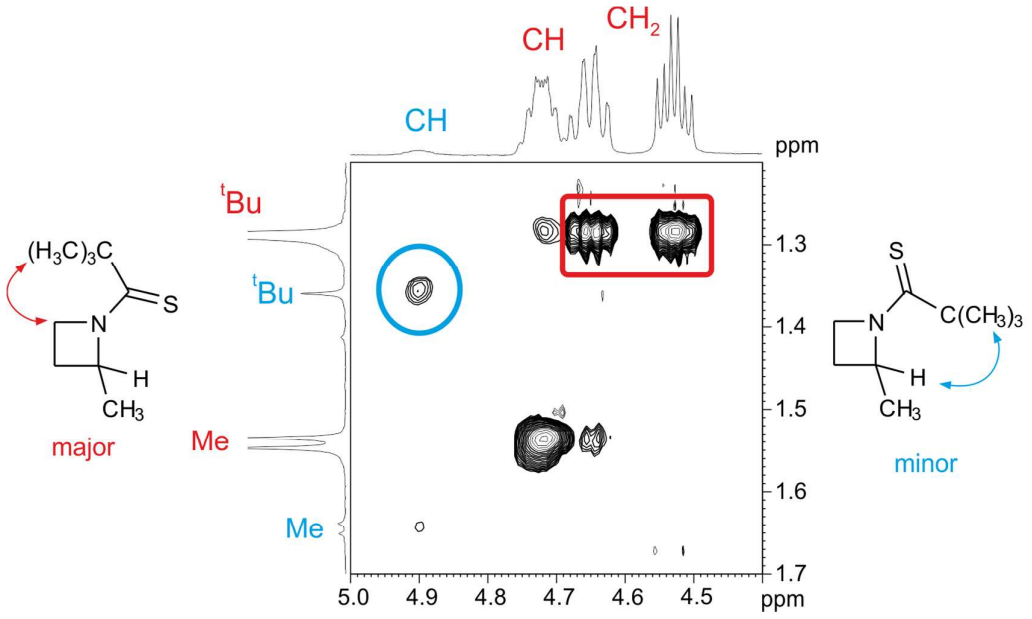


Figure S2. 2D NOESY spectrum (500 MHz, −78 °C, THF-d_8) for 2-methyl-*N*-thiopivaloyl-azetidine **5** highlighting NOEs from the *t*Bu groups.

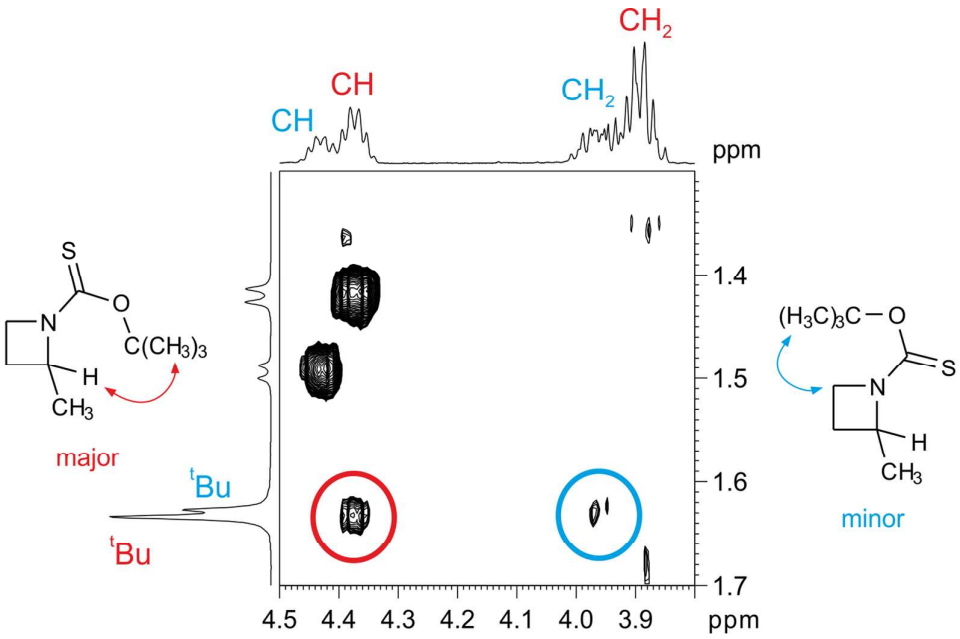


Figure S3. 2D NOESY spectrum (500 MHz, −78 °C, THF-d_8) for 2-methyl-*N*-Botc-azetidine **8** highlighting NOEs from the *t*Bu groups.

Variable temperature NMR studies were performed on samples in toluene-d_8 on a Bruker DRX500 spectrometer equipped with a BBO multinuclear probe. Probe temperature calibrations were performed using neat methanol samples containing a trace of HCl (below ambient) or with neat ethylene glycol (above ambient), and experiments performed with active correction of the sample temperature set-points. Spectra were referenced to residual toluene Me-D_2 at 2.09 ppm. ^{1}H NMR lineshape simulations were performed using the gNMR program (http://home.cc.umanitoba.ca/~budzelaa/gNMR/gNMR.html) running under Windows 7 (executed in WinXP compatibility mode) to yield exchange rate constants *k*, as shown with the variable temperature spectra below. In all cases, simulations of spectra at temperatures approaching coalescence made use of chemical shift values extrapolated from chemical shift temperature dependences observed under slow-intermediate exchange regimes (shown below). Thermodynamic parameters were estimated from the Eyring plot (ln(*k*/T) *vs* 1/T) for each compound (in some cases it was not possible to continue far beyond resonance coalescence due to solvent temperature limitations). Errors for $\Delta G^{\ddagger}$ values determined at 25 °C and listed in Table 1 of the main text were derived from estimates of reasonable upper and lower rate constants during fitting procedures, from which the thermodynamic parameters derived thereafter yielded bounds for $\Delta G^{\ddagger}$.

2.1. *N*-Pivaloyl-azetidine 18

A sample of *N*-pivaloyl-azetidine (**18**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from −73 °C to 27 °C, allowing coalescence of the NCH_2 signals (Figure S4).

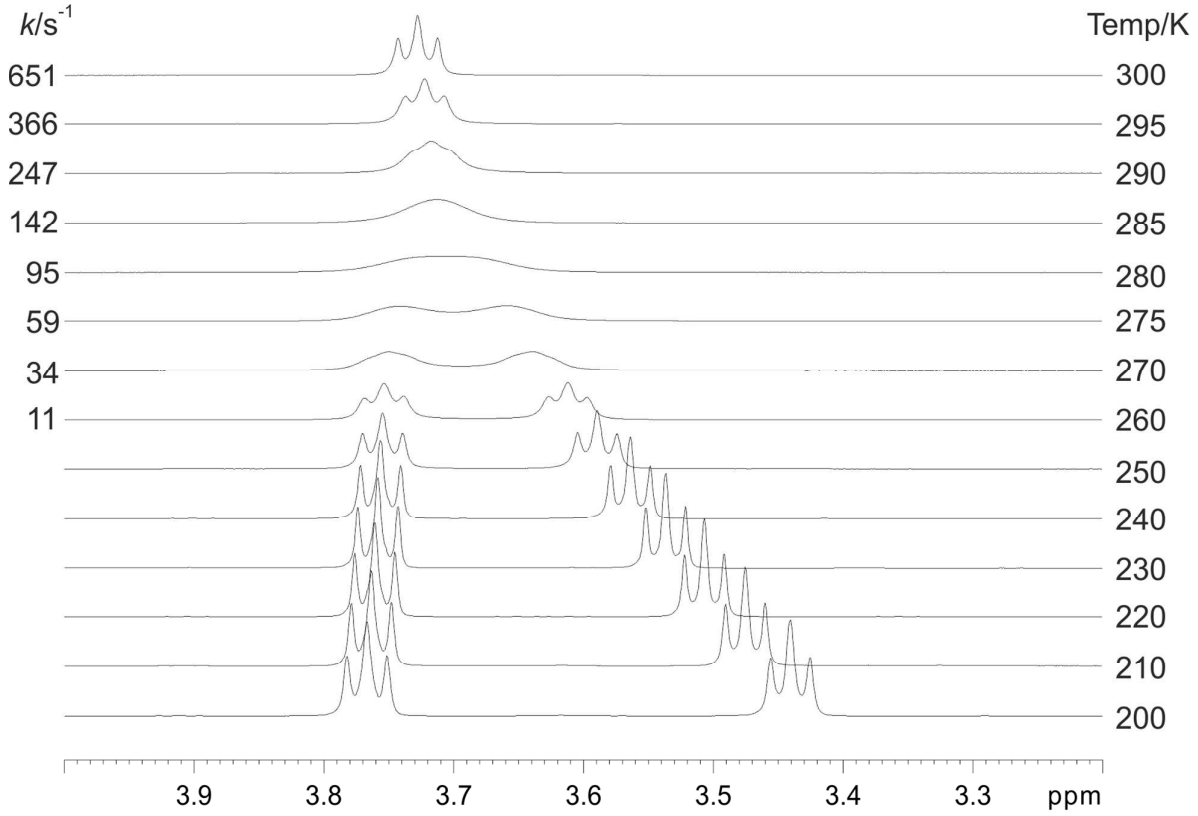


Figure S4. Variable temperature ^{1}H NMR for *N*-pivaloyl-azetidine (**18**) (CH_2NCH_2 region).

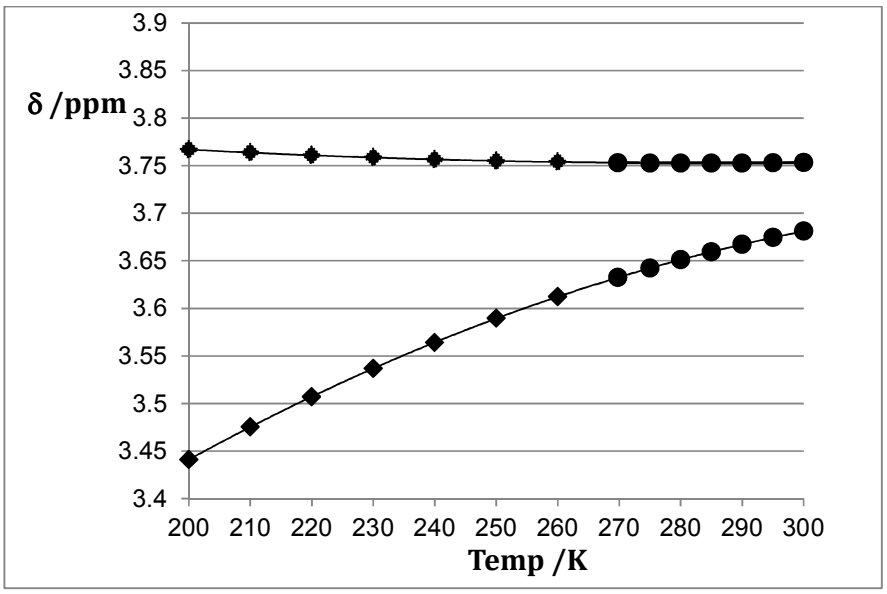


Figure S5. Temperature dependence of ^{1}H chemical shifts for *N*-pivaloyl-azetidine (**18**) (CH_2NCH_2 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

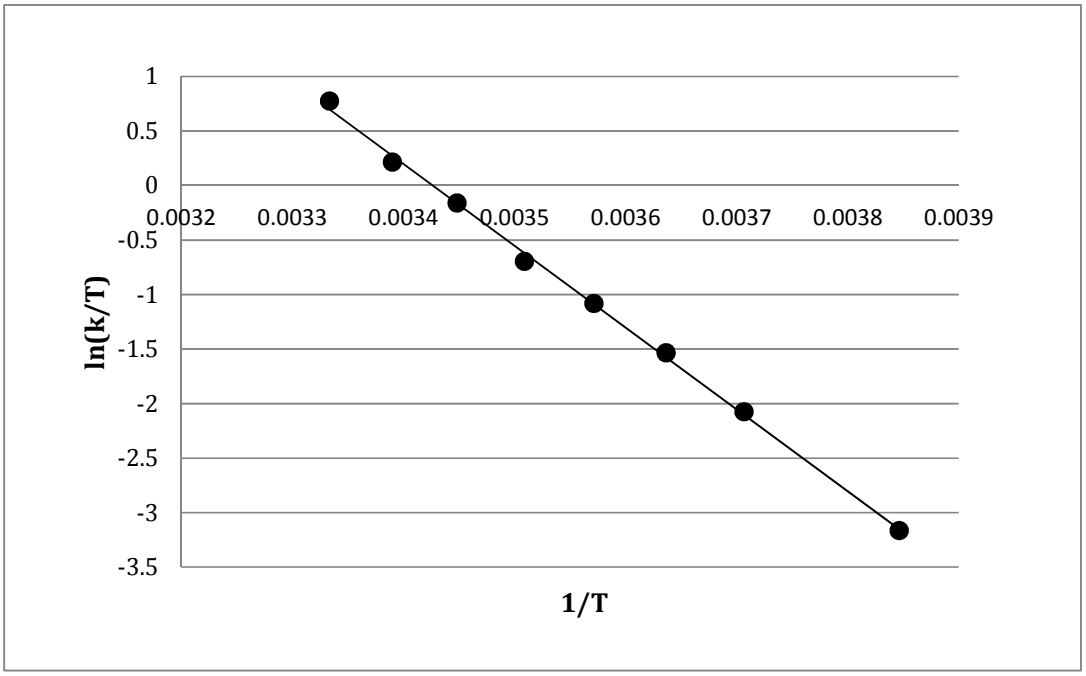


Figure S6. Eyring plot for *N*-pivaloyl-azetidine (**18**).

From the Eyring plot it was determined:

$\Delta H^{\ddagger} \approx 62.4$ kJmol^{-1}

$\Delta S^{\ddagger} \approx 16.3$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 57.6$ kJmol^{-1} at 25 °C, $k \approx 4.970 \times 10^{2}$ s^{-1}, $t_{1/2} \approx 0.001$ s.

$\Delta G^{\ddagger} \approx 59.2$ kJmol^{-1} at −78 °C, $k \approx 5.628 \times 10^{-4}$ s^{-1}, $t_{1/2} \approx 1231$ s.

2.2. *N*-Boc-azetidine 19

A sample of *N*-Boc-azetidine (**19**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from −60 °C to 25 °C, allowing coalescence of the NCH_2 signals (Figure S7).

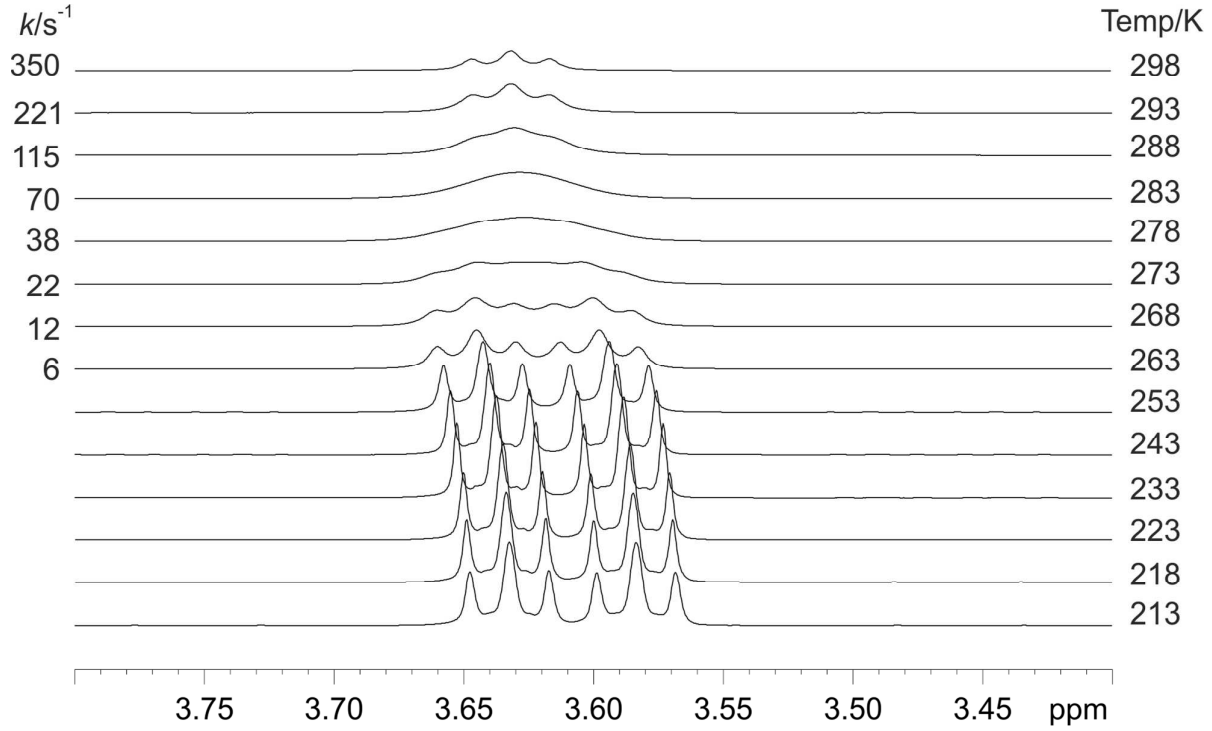


Figure S7. Variable temperature ^{1}H NMR for *N*-Boc-azetidine (**19**) (CH_2NCH_2 region).

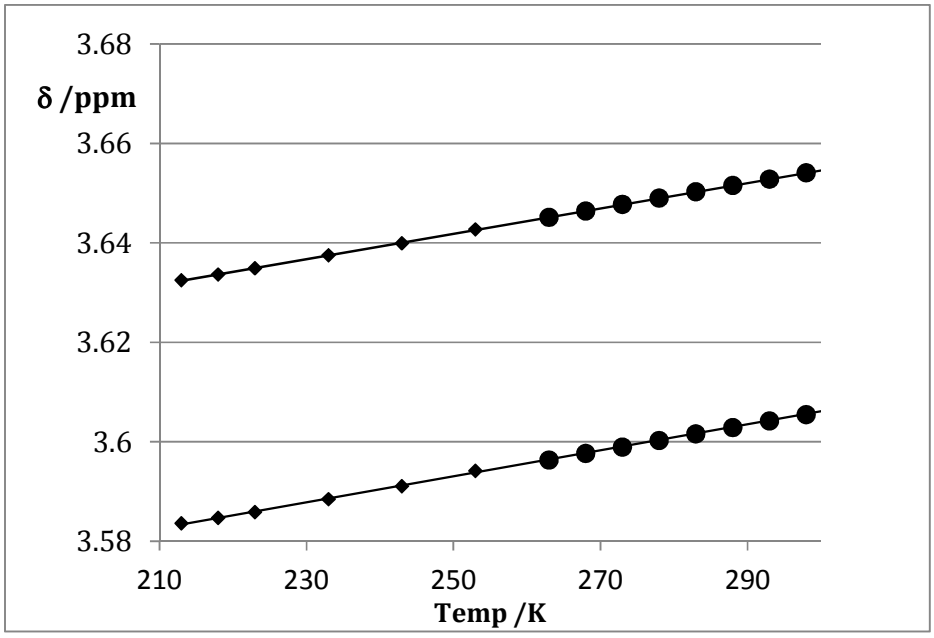


Figure S8. Temperature dependence of ^{1}H chemical shifts for *N*-Boc-azetidine (**19**) (CH_2NCH_2 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

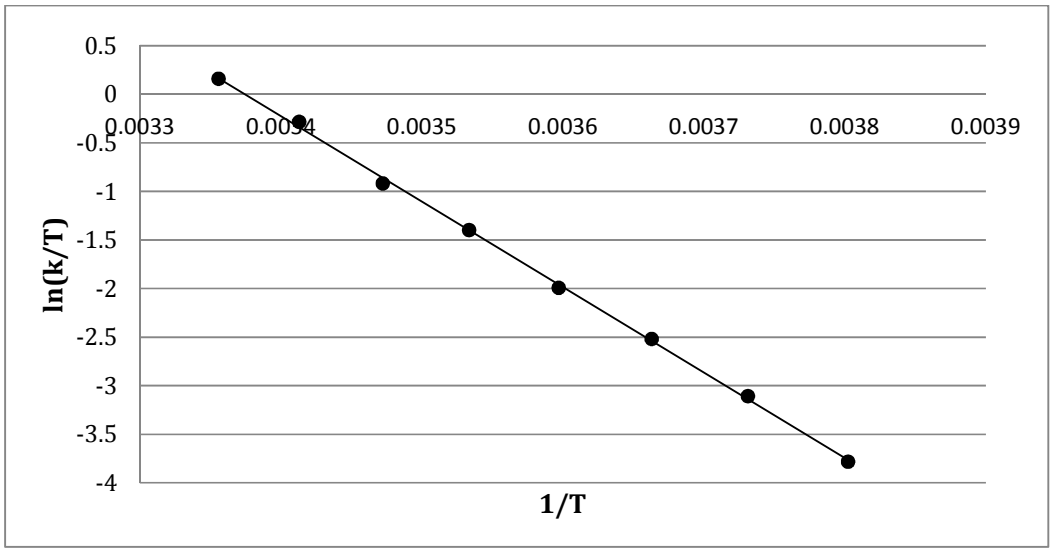


Figure S9. Eyring plot for *N*-Boc-azetidine (**19**).

From the Eyring plot it was determined:

$\Delta H^{\ddagger} \approx 73.1$ kJmol^{-1}

$\Delta S^{\ddagger} \approx 49.3$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 58.5$ kJmol^{-1} at 25 °C, $k \approx 3.454 \times 10^{2}$ s^{-1}, $t_{1/2} \approx 0.002$ s.

$\Delta G^{\ddagger} \approx 63.5$ kJmol^{-1} at −78 °C, $k \approx 3.966 \times 10^{-5}$ s^{-1}, $t_{1/2} \approx 4.9$ h.

2.3. *N*-Thiopivaloyl-azetidine 4

A sample of *N*-thiopivaloyl-azetidine (**4**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from 27 °C to 97 °C, allowing coalescence of the NCH_2 signals (Figure S9)

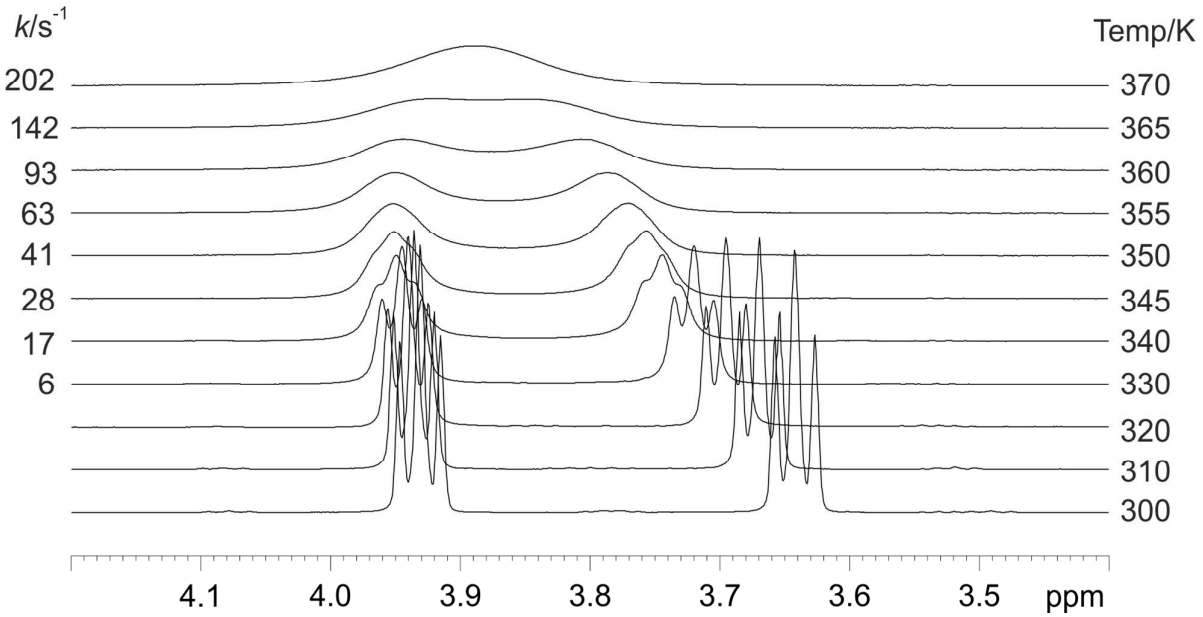


Figure S9. Variable temperature ^{1}H NMR for *N*-thiopivaloyl-azetidine (**4**) (CH_2NCH_2 region).

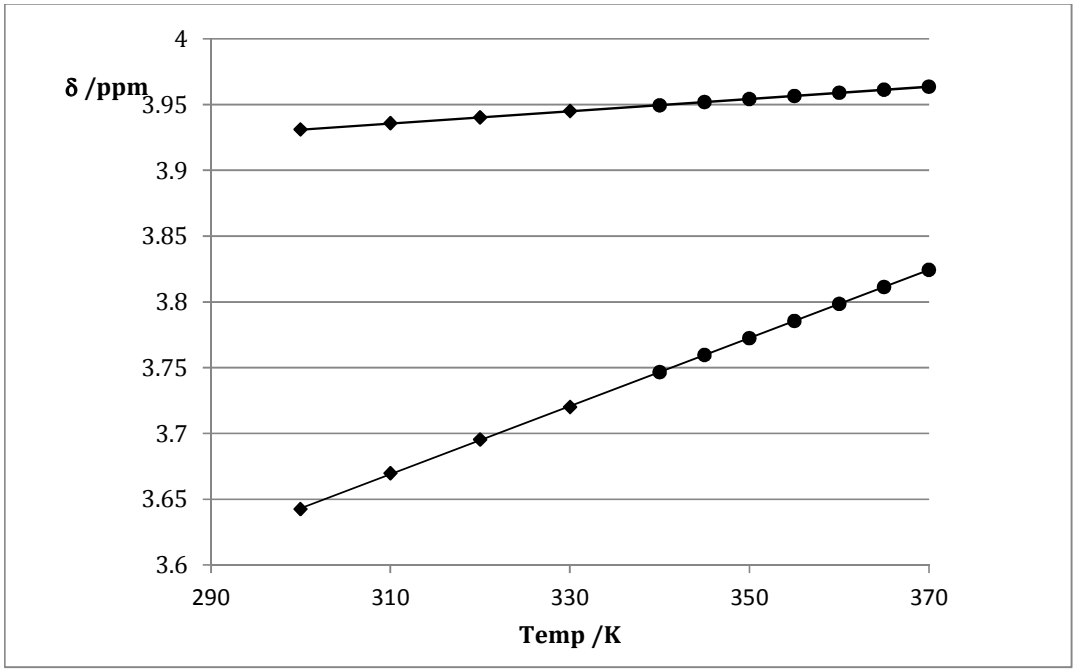


Figure S10. Temperature dependence of ^{1}H chemical shifts for *N*-thiopivaloyl-azetidine (**4**) (CH_2NCH_2 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

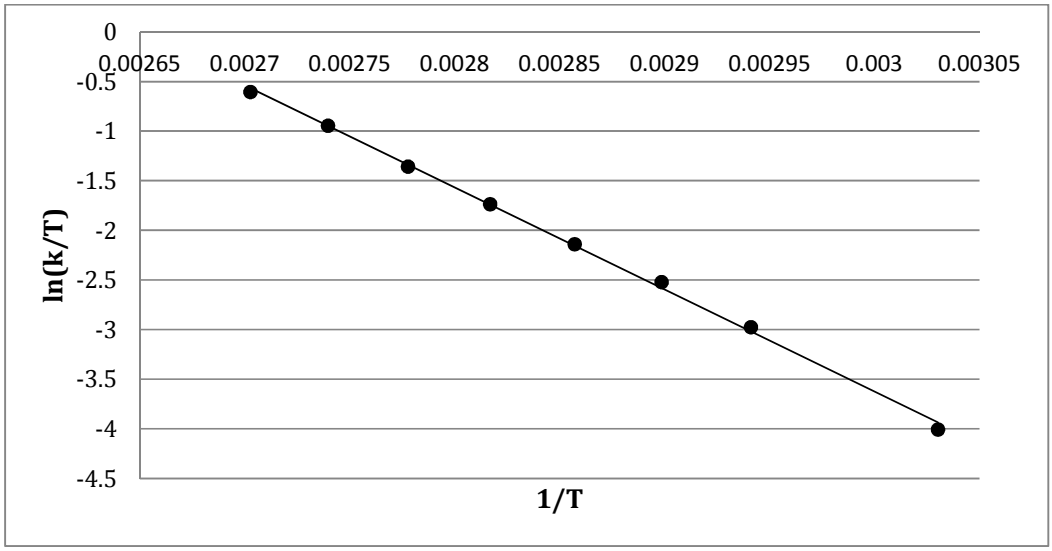


Figure S11. Eyring plot for *N*-thiopivaloyl-azetidine (**4**).

From the Eyring plot it was determined:

$\Delta H^{\ddagger} \approx 85.5$ kJmol^{-1}

$\Delta S^{\ddagger} \approx 28.7$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 76.9$ kJmol^{-1} at 25 °C, $k \approx 2.057 \times 10^{-1}$ s^{-1}, $t_{1/2} \approx 3.4$ s.

$\Delta G^{\ddagger} \approx 79.9$ kJmol^{-1} at −78 °C, $k \approx 1.604 \times 10^{-9}$ s^{-1}, $t_{1/2} \approx 13.7$ years.

2.4. *N*-Botc-azetidine 7

A sample of *N*-Botc-azetidine (**7**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from 25 °C to 100 °C, allowing coalescence of the NCH_2 signals (Figure S12).

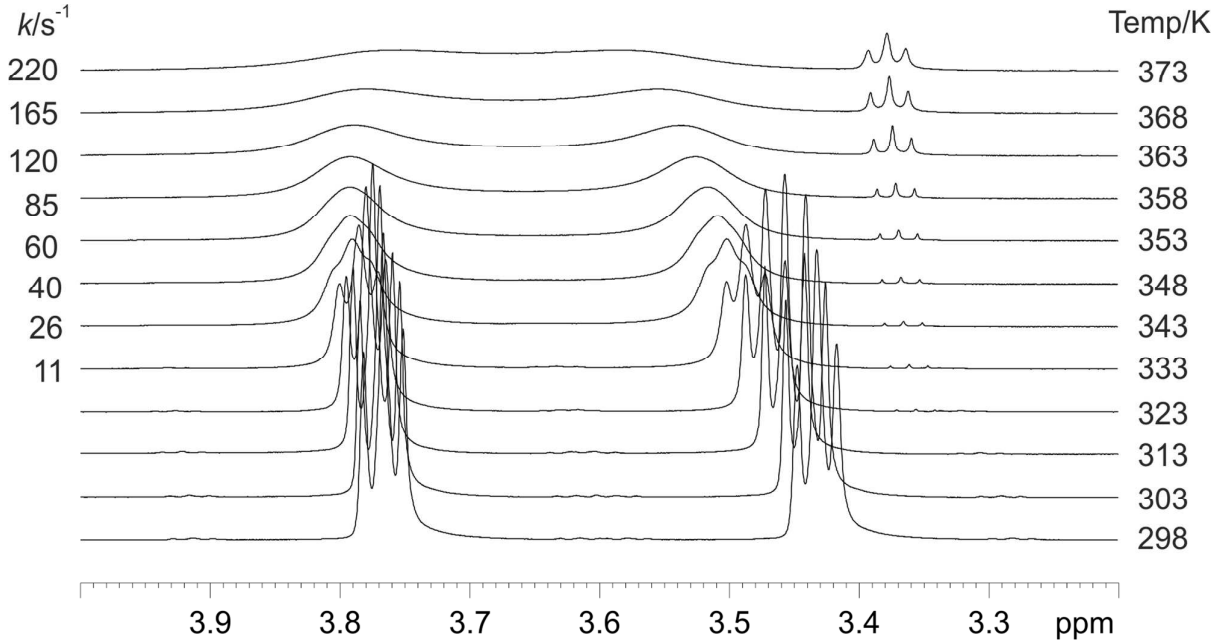


Figure S12. Variable temperature ^{1}H NMR for *N*-Botc-azetidine (**7**) (CH_2NCH_2 region).

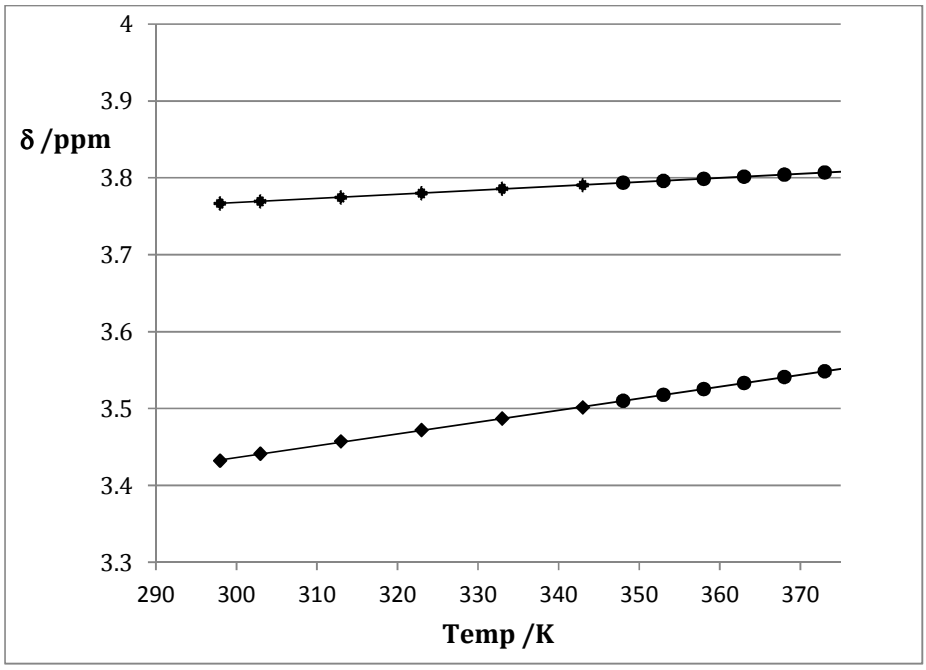


Figure S13. Temperature dependence of ^{1}H chemical shifts for *N*-Botc-azetidine (**7**) (CH_2NCH_2 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

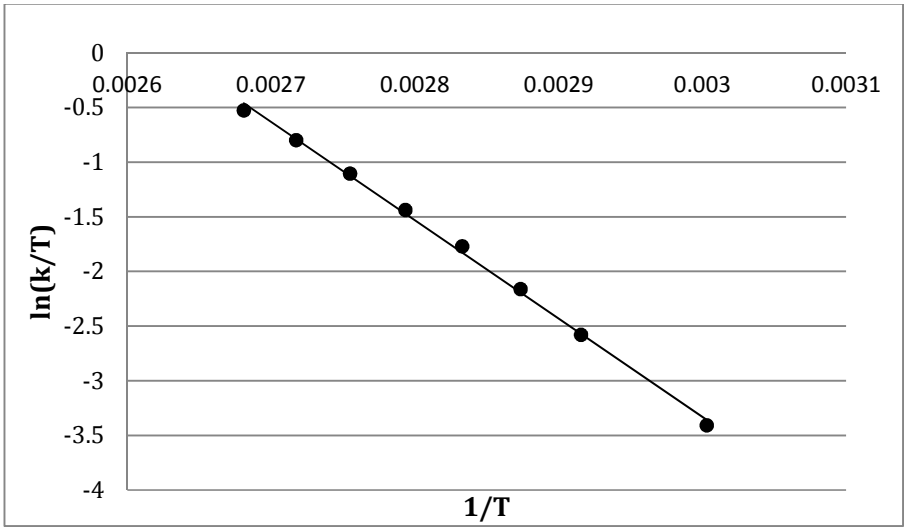


Figure S14. Eyring plot for *N*-Botc-azetidine **7**.

From the Eyring plot it was determined:

$\Delta H^{\ddagger} \approx$ 74.7 kJmol^{-1}

$\Delta S^{\ddagger} \approx$ −1.0 JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx$ 75.0 kJmol^{-1} at 25 °C, $k \approx 4.427 \times 10^{-1}$ s^{-1}, $t_{1/2} \approx$ 1.6 s.

$\Delta G^{\ddagger} \approx$ 74.9 kJmol^{-1} at −78 °C, $k \approx 3.505 \times 10^{-8}$ s^{-1}, $t_{1/2} \approx$ 228 days.

2.5. 2-Methyl-*N*-thiopivaloyl-azetidine 5

A sample of 2-methyl-*N*-thiopivaloyl-azetidine (**5**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from 25 °C to 100 °C, allowing coalescence of the NCHCH_3 and C$(CH_3)_3$ signals (Figure S15). At −20 °C the conformer ratio was 12.5:1 as measured by integration.

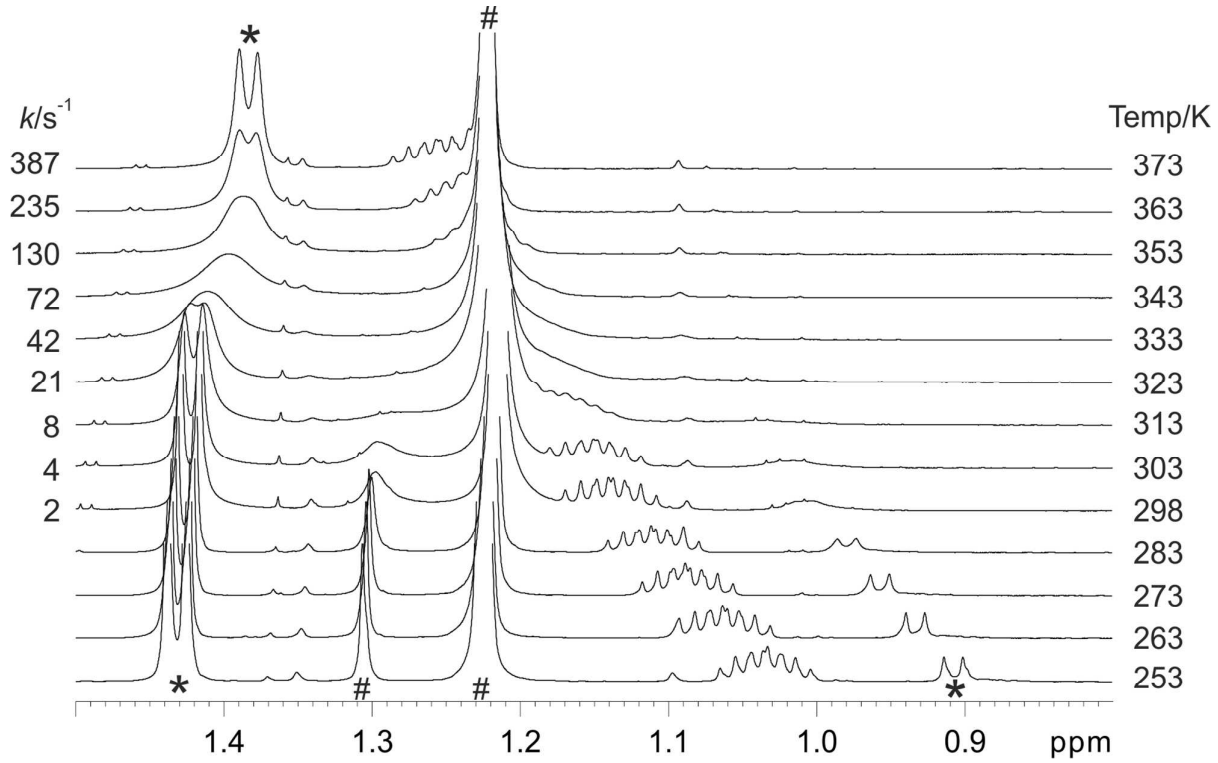


Figure S15. Variable temperature ^{1}H NMR for 2-methyl-*N*-thiopivaloyl-azetidine (**5**) (NCHCH_3 (*) and C$(CH_3)_3$ (#) region).

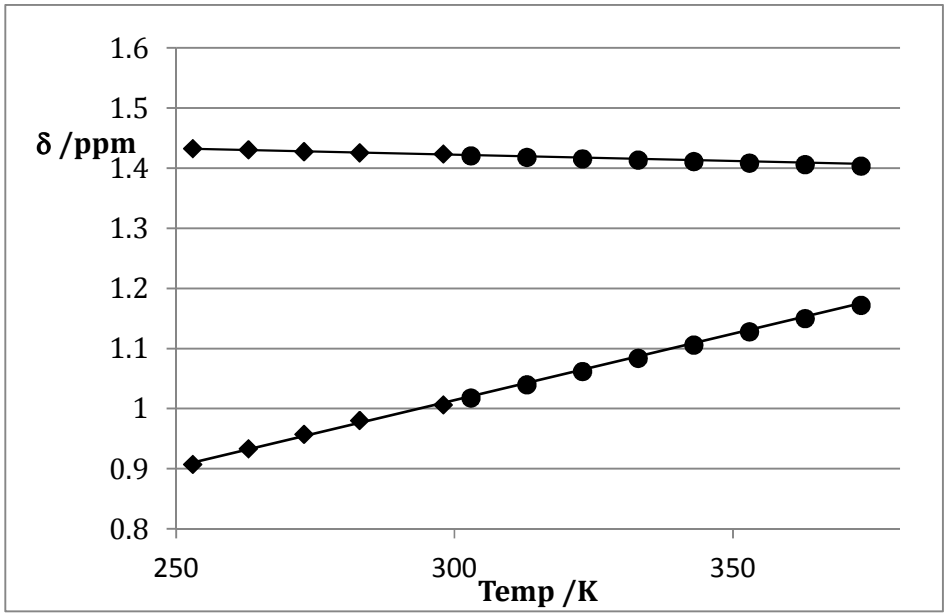


Figure S16. Temperature dependence of ^{1}H chemical shifts for 2-methyl-*N*-thiopivaloyl-azetidine (**5**) (NCHCH_3 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

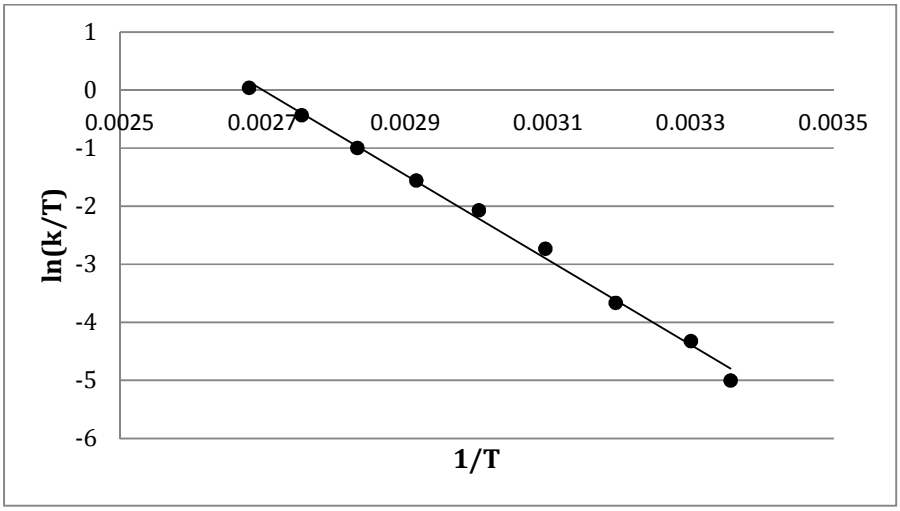


Figure S17. Eyring plot for major rotamer of 2-methyl-*N*-thiopivaloyl-azetidine (**5**).

From the Eyring plot for rotation of major rotamer it was determined:

$\Delta H^{\ddagger} \approx 60.9$ kJmol^{-1}

$\Delta S^{\ddagger} \approx -32.9$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 70.7$ kJmol^{-1} at 25 °C, $k \approx 2.511$ s^{-1}, $t_{1/2} \approx 0.3$ s.

$\Delta G^{\ddagger} \approx 67.3$ kJmol^{-1} at −78 °C, $k \approx 3.805 \times 10^{-6}$ s^{-1}, $t_{1/2} \approx 2.1$ d.

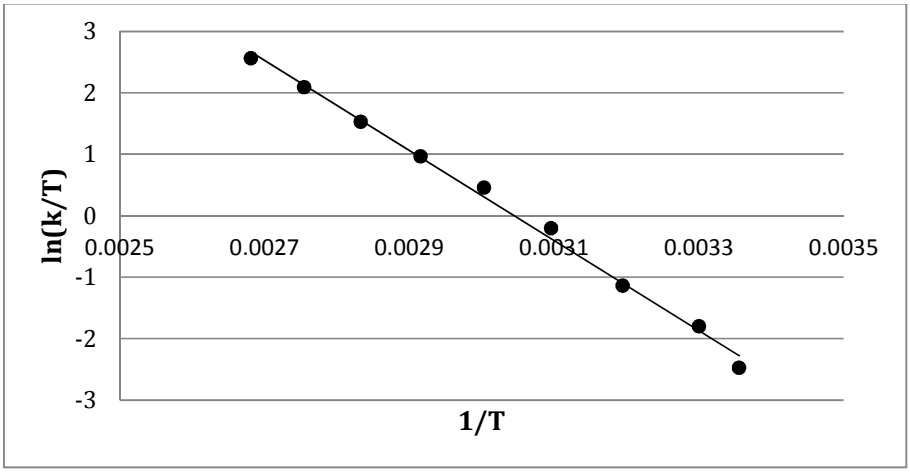


Figure S18. Eyring plot for minor rotamer of 2-methyl-*N*-thiopivaloyl-azetidine (**5**).

From the Eyring plot for rotation of the minor rotamer it was determined:

$\Delta H^{\ddagger} \approx 60.9$ kJmol^{-1}

$\Delta S^{\ddagger} \approx -12.2$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 64.5$ kJmol^{-1} at 25 °C, $k \approx 3.066 \times 10^{1}$ s^{-1}, $t_{1/2} \approx 0.02$ s.

$\Delta G^{\ddagger} \approx 63.2$ kJmol^{-1} at −78 °C, $k \approx 4.772 \times 10^{-5}$ s^{-1}, $t_{1/2} \approx 4.0$ h.

2.6. 2-Methyl-*N*-Botc-azetidine 8

A sample of 2-methyl-*N*-Botc-azetidine (**8**) was subjected to variable temperature ^{1}H NMR analysis (500 MHz, toluene-d_8), from 25 °C to 100 °C, allowing coalescence of the NCHCH_3 and C(CH_3)$_3$ signals (Figure S19). At −20 °C the conformer ratio was 2.2:1 as measured by integration.

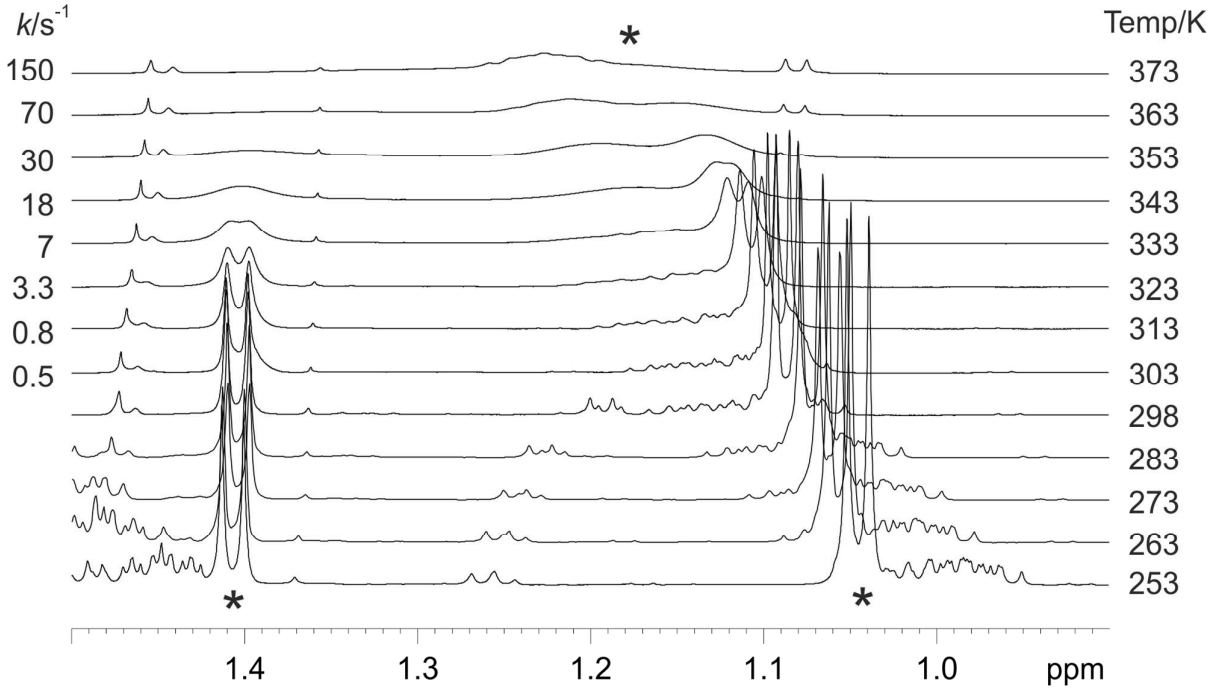


Figure S19. Variable temperature ^{1}H NMR for 2-methyl-*N*-Botc-azetidine (**8**) (NCHCH_3 region (*)).

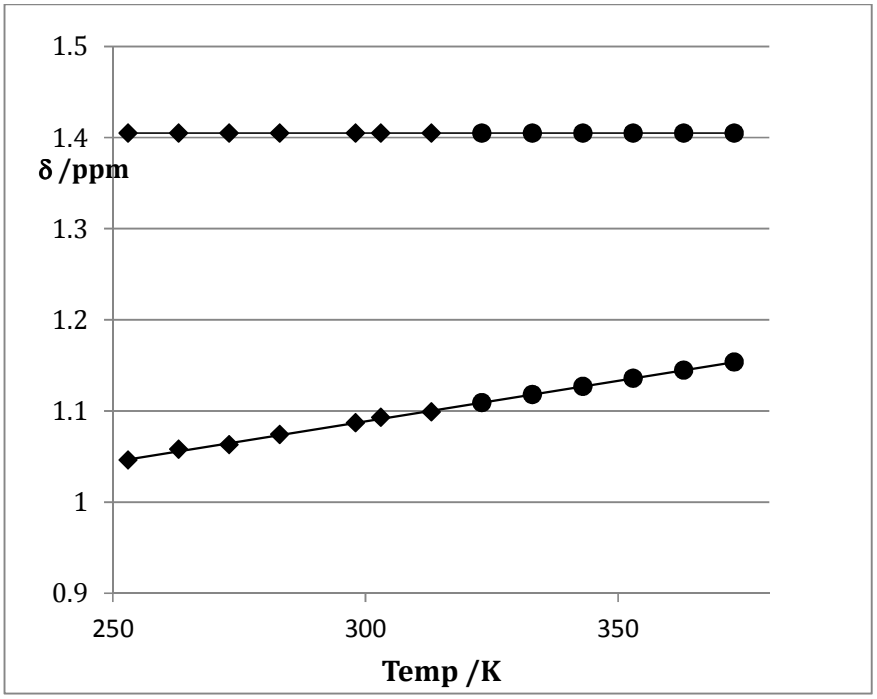


Figure S20. Temperature dependence of ^{1}H chemical shifts for 2-methyl-*N*-Botc-azetidine (**8**) (NCHCH_3 resonances). Diamonds represent experimentally measured chemical shifts under slow exchange conditions and circles are the predicted shifts employed in spectrum lineshape simulations.

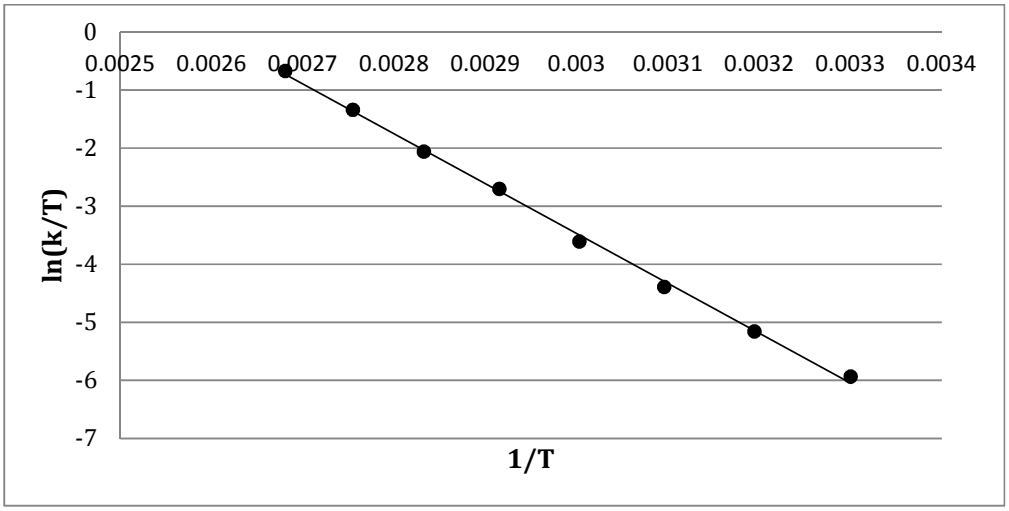


Figure S21. Eyring plot for major rotamer of 2-methyl-*N*-Botc-azetidine (**8**).

From the Eyring plot for rotation of the major rotamer it was determined:

$\Delta H^{\ddagger} \approx 71.5$ kJmol^{-1}

$\Delta S^{\ddagger} \approx -12.0$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 75.0$ kJmol^{-1} at 25 °C, $k \approx 4.429 \times 10^{-1}$ s^{-1}, $t_{1/2} \approx 1.6$ s.

$\Delta G^{\ddagger} \approx 73.8$ kJmol^{-1} at −78 °C, $k \approx 6.908 \times 10^{-8}$ s^{-1}, $t_{1/2} \approx 116$ days.

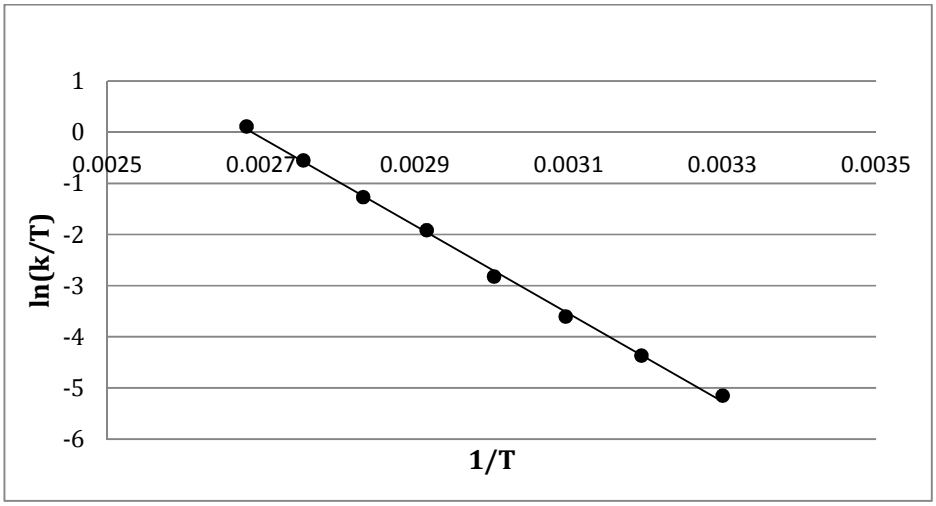


Figure S22. Eyring plot for minor rotamer of 2-methyl-*N*-Botc-azetidine (**8**).

From the Eyring plot for rotation of the minor rotamer it was calculated:

$\Delta H^{\ddagger} \approx 71.5$ kJmol^{-1}

$\Delta S^{\ddagger} \approx -5.5$ JK^{-1}mol^{-1}

From these values it was calculated:

$\Delta G^{\ddagger} \approx 73.1$ kJmol^{-1} at 25 °C, $k \approx 9.535 \times 10^{-1}$ s^{-1}, $t_{1/2} \approx 0.7$ s.

$\Delta G^{\ddagger} \approx 72.5$ kJmol^{-1} at −78 °C, $k \approx 1.540 \times 10^{-7}$ s^{-1}, $t_{1/2} \approx 52$ d.

3. Computational Methods

Calculations were performed using the Gaussian 09[1] program, primarily using the M06-2X functional,[2] a hybrid meta-generalized gradient approximation (GGA) density functional. Through the inclusion of a local spin kinetic energy density term in the exchange-correlation functional, this method has proved to be effective at modelling thermochemical and kinetic parameters of organic/organocatalytic transformations, particularly where non-local dispersion interactions play a role.[3] The other density functionals used for benchmarking were wB97XD[4] and B3LYP,[5] both of which gave similar results to M06-2X. We used a valence triple-ζ polarized 6-311++G(d,p) basis set[6] for all geometry optimizations. An implicit simulation of the reaction medium, toluene was used in all optimizations through the use of a conductor-like polarizable continuum solvation model (CPCM),[7] with the United Atom Topological Model (UAKS) which defines the solute cavity in terms of radii for functional groups;[8] while a UFF cavity definition (as is default in recent versions of the *Gaussian*) gave comparable results in most cases, it also showed pathalogical failures for structures with close nonbonded contacts between neighbouring groups. In addition to DFT methods, we also used the composite *ab initio* calculations CBS-QB3 for comparative purposes.[9] Gibbs free energies were evaluated at 25 °C with vibrational entropy contributions computed using a free-rotor approximation for low frequency modes.[10] A smooth damping function centred about a frequency of 100 cm^{-1} was used to switch between the harmonic approximation for vibrations above this value and the free-rotor approximation below.[11] All processes studied are unimolecular and therefore free energy changes are independent of the choice of standard state. Vibrational frequencies were computed for all stationary points to confirm them as either minima or transition structures (TSs), possessing zero or a single imaginary frequency, respectively. TSs were found using dihedral scans and were confirmed with the use of intrinsic reaction coordinate (IRC) calculations,[12] which connected each TS to the appropriate species on either side of the rotation barrier on the potential energy surface (PES). Molecular graphics have been produced with *Pymol*[13] and illustrations showing the planes and distances associated with pyramidalization were generated using our in-house Compiled Graphics Objects (CGO) generating software, written in OpenGL,[14] a graphics programming language. Analysis of non-covalent interactions was carried out using NCIPLOT[15], NBO[16] and AIMALL[17] software.

4. Computational Data

Level of theory	Solvent model	ΔE/kJ/mol	ΔG/kJ/mol
wB97XD	gas-phase	4.7	6.5
	CPCM(UFF)	3.7	5.0
	CPCM(UAKS)	4.0	5.2
	SMD	3.6	3.2
M062X	**CPCM(UFF)**	**4.7**	**6.2**
	CPCM(UAKS)	**5.0**	**6.3**
	SMD	**4.6**	**5.9**
B3LYP	CPCM(UFF)	5.8	8.7
	CPCM(UAKS)	6.0	8.2
	SMD	5.6	7.6
CBS-QB3	-	6.3	8.4
Experiment	-	-	**5.7**

Table S1. *N*-thiopivaloyl-2-methyl-azetidine (**5**) conformer ΔE and ΔG values between obtained at different levels of theory (with the 6-311++G(d,p) basis set) and solvent models. The *trans*-form is universally favoured.

Level of theory	Solvent model	ΔE/kJ/mol	ΔG/kJ/mol
wB97XD	gas-phase	4.7	1.9
	CPCM(UAKS)	4.0	4.1
	SMD	3.6	2.8
M06-2X	**CPCM(UAKS)**	**5.0**	**1.6**
	SMD	**4.6**	**1.3**
B3LYP	CPCM(UAKS)	6.0	1.5
	SMD	5.6	1.0
CBS-QB3	-	6.3	1.1
Experiment	-	-	**2.6**

Table S2. *N*-*tert*-butoxythiocarbonyl-2-methyl-azetidine (**8**) conformational ΔE and ΔG differences between obtained at different levels of theory (with the 6-311++G(d,p) basis set) and solvent models. The *cis*-form is universally favoured.

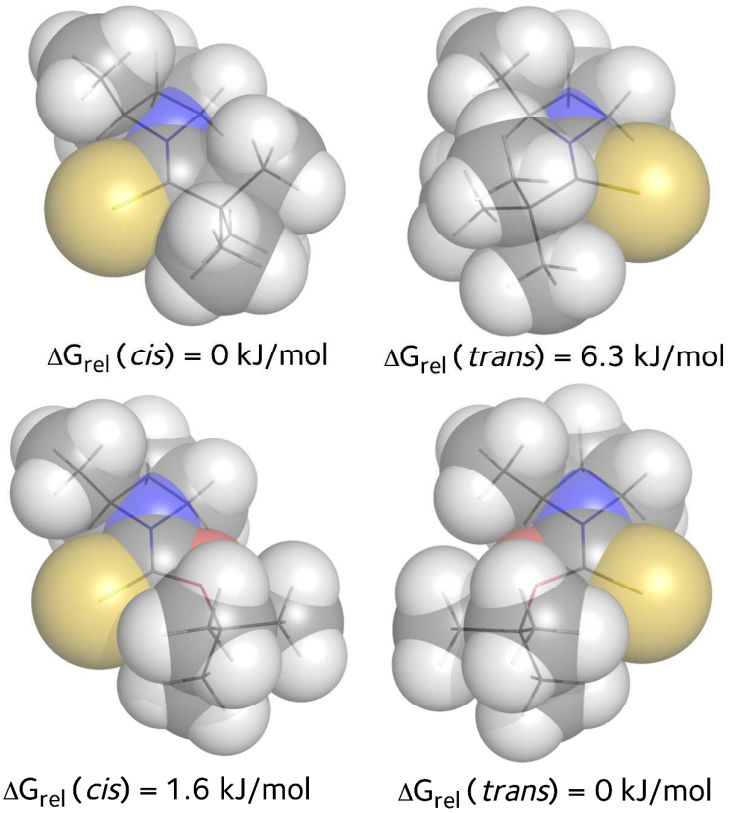


Figure S23. M06-2X/6-311++G(d,p) space filling models for *N*-thiopivaloyl-2-methyl-azetidine (**5**) and *N*-*tert*-butoxythiocarbonyl-2-methyl-azetidine (**8**) conformers.

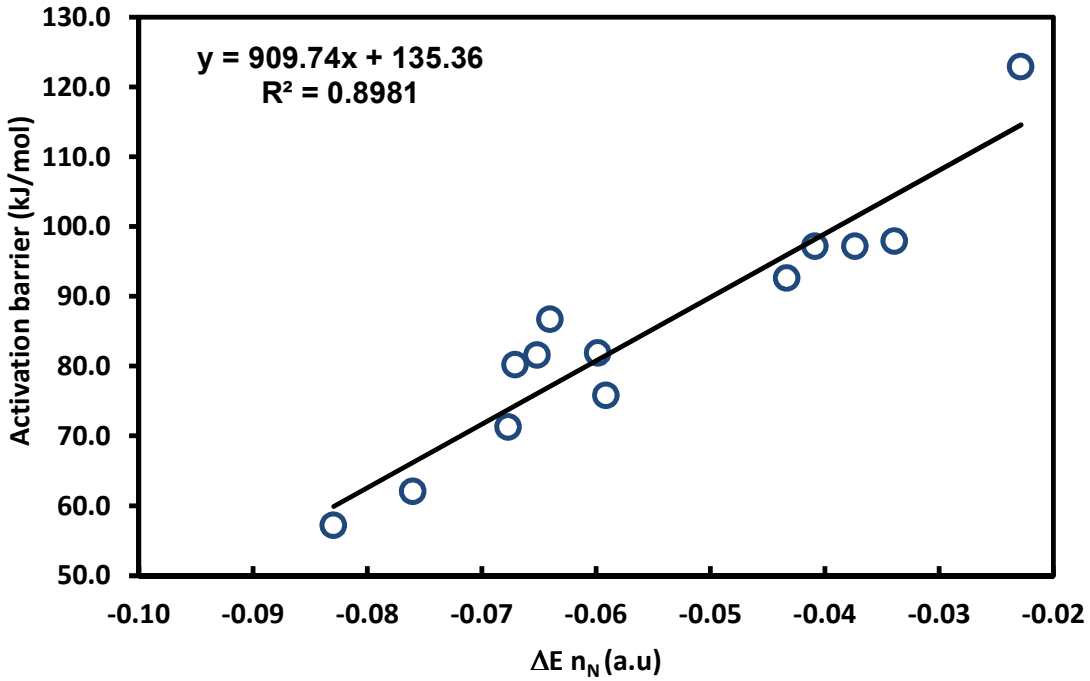


Figure S24. Linear correlation between M06-2X/6-311++G(d,p) activation barrier for rotation for all fourteen TSs and the change in NBO energy of the nitrogen lone pair.

The two expected TSs were found for the rotation of the azetidine ring in the amide **18** (Figure S25), the lowest of which had an activation barrier of 57.2 kJ/mol, in excellent agreement with experiment (Table 1, main paper). The less stable TS was significantly higher in energy with a relative free energy of 97.2 kJ/mol. The origin of the large free energy difference between the two TSs can be explained using a combination of steric and electronic effects. The C−O σ* is a better acceptor than the C−CMe_3 σ* and the NBO analysis of the TSs shows a greater stabilisation from hyperconjugation (by 6.3 kJ/mol) in the more stable TS, in which the N lone pair is able to donate into the σ* of the carbonyl. The lower degree of pyramidalization in the less stable TS might suggest a stronger contribution from hyperconjugation; however, this can be more rationally explained in terms of steric interactions between the axial C-H bonds of the azetidine ring and the *t*-Bu group forcing the ring away.

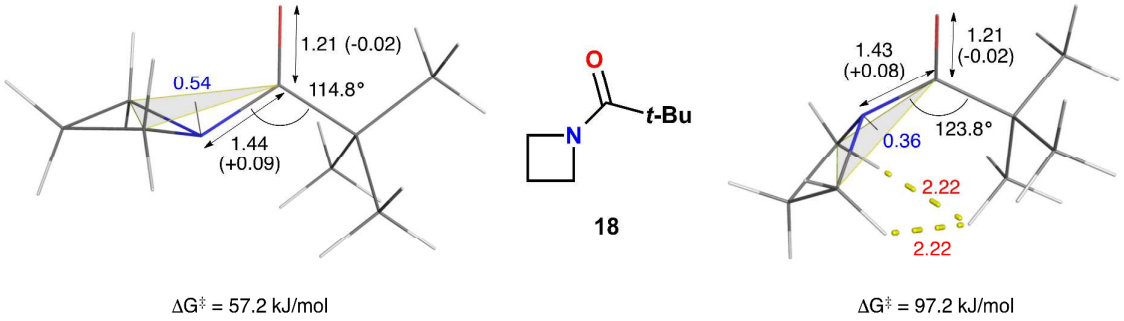


Figure S25. Rotation TS structures found for *N*-pivaloyl-azetidine (**18**) [CPCM-M06-2X/6-311++G(d,p) optimisations, with G computed at 25 °C]. Interatomic distances (black), pyramidalization (blue), and steric interactions (red), are all shown in Å. Parentheses indicate changes relative to the ground state.

A single TS conformer was found for the carbamate system **19** (Figure S26). In the methyl-substituted analogue of this system (2-Me on azetidine, **20**), all four TSs were found and the most stable two conformers for pyramidalization in each direction differed by 3.9 kJ/mol, with the most stable TS having the N lone pair *trans* to the C=O (N lone pair -> C-O σ* of the carbonyl). The energy difference between the two lowest energy conformers in the methylated system is small, but this still suggests that there is a missing lower energy conformer for the unmethylated system **19**.

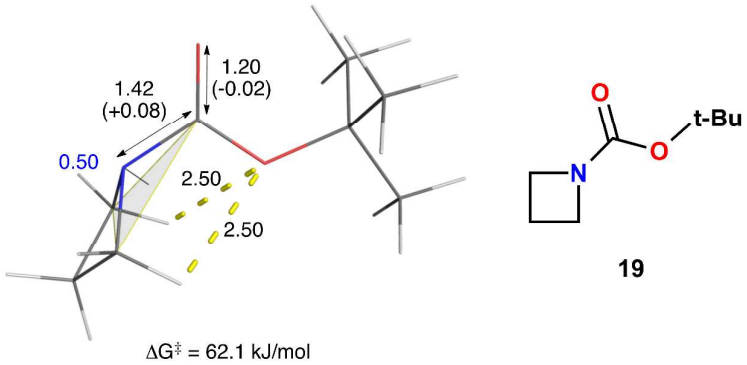


Figure S26. Rotation TS structure found for *N*-Boc-azetidine (**19**) [CPCM-M06-2X/6-311++G(d,p) optimizations, with G computed at 25 °C]. Interatomic distances (black), pyramidalization (blue), and steric interactions (red), are all shown in Å. Parentheses indicate changes relative to the ground state.

The free energy difference between the two TSs for N−CS rotation in *N*-thiopivaloyl-azetidine (**4**) can be explained as follows. In the higher energy TS, pyramidalization at N puts the lone pair *cis* to the thiocarbonyl results in greater steric clashing between C-H bonds on the azetidine and the *t*Bu group (Figure S27); the degree of pyramidalization is reduced in order to alleviate this repulsive steric interaction and this is evidenced in the N to plane distance, the C-N bond length and the increased N-C-C bond angle.

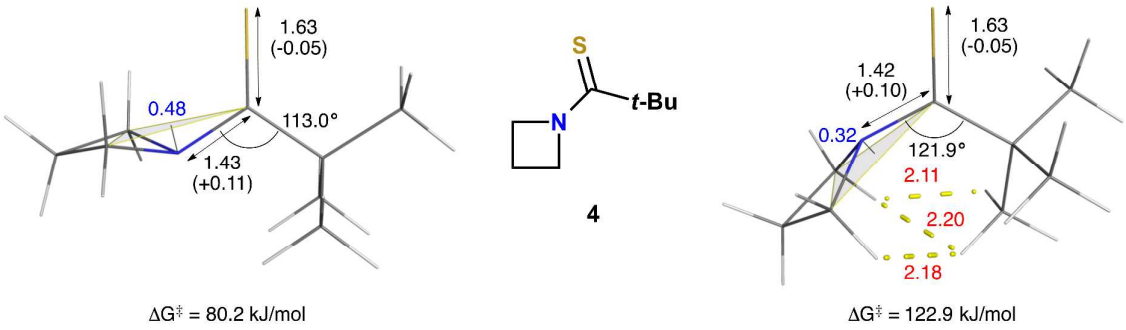


Figure S27. Rotation in *N*-thiopivaloylazetidine (**4**) [CPCM-M06-2X/6-311++G(d,p) optimizations, with G computed at 25 °C]. Interatomic distances (black), pyramidalization (blue), and steric interactions (red), are all shown in Å. Parentheses indicate changes relative to the ground state.

Similar arguments to those used in the carbamate system **19** can be used to explain the similarity in the TSs for *N*-Botc-azetidine (**7**) (Figure S28). There is no steric penalty to the N lone pair being *trans* to the thiocarbonyl and the lack of a methyl group on the azetidine removes issues of 1,3-diaxial clashing. The difference in energies is down to electronics, specifically the σ* acceptor abilities of the C-S or C-O bonds, with the thiocarbonyl being the stronger.

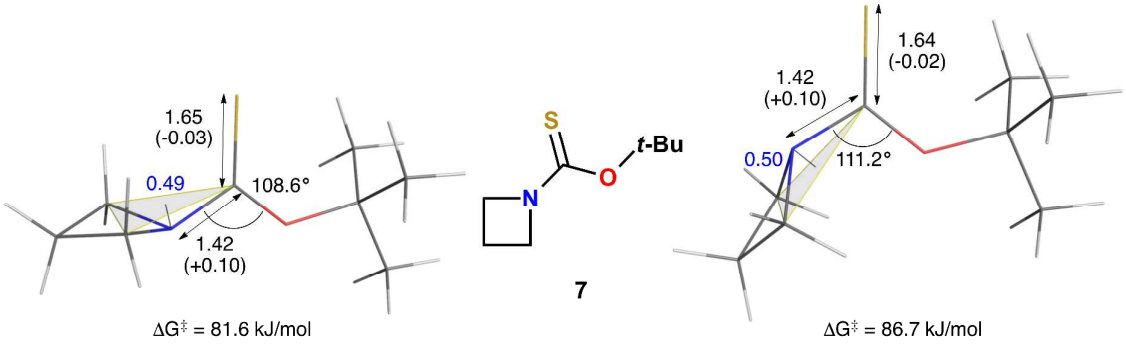


Figure S28. Rotation TS structure found for in *N*-Botc-azetidine (**7**) [CPCM-M06-2X/6-311++G(d,p) optimizations, with G computed at 25 °C]. Interatomic distances (black), pyramidalization (blue), and steric interactions (red), are all shown in Å. Parentheses indicate changes relative to the ground state.

5. Cartesian Coordinates

CPCM-M06-2X/6-311++G(d,p) optimized stationary points with United Atom Topological Model (UAKS) defining the solute cavity in terms of radii for functional groups with toluene as the implicit solvent unless specified otherwise; energy and G(298K) in Hartree; imaginary frequencies (where appropriate) in wavenumbers.

4:

E = -766.73231; G = -766.55058

C	-2.28595	0.76524	-0.01868
C	-3.06605	-0.56579	0.09533
C	-1.72612	-1.31035	-0.08610
C	0.20396	0.46878	-0.06484
N	-1.03489	0.00170	-0.08620
H	-2.31745	1.43228	0.85065
H	-3.52639	-0.72022	1.07888
H	-3.80206	-0.74510	-0.69708
H	-1.62402	-1.82971	-1.04462
H	-1.41790	-1.96966	0.73278
S	0.43431	2.13740	-0.03288
C	1.36230	-0.53915	0.00727
C	1.42625	-1.04270	1.46125
C	1.15390	-1.72282	-0.95557
C	2.70011	0.11957	-0.34335
H	1.62961	-0.21217	2.14304
H	0.49180	-1.52121	1.76613
H	2.23328	-1.77595	1.55592
H	0.85918	-1.37591	-1.95098
H	2.09883	-2.26422	-1.05344
H	0.41070	-2.43456	-0.59644
H	3.49112	-0.63032	-0.24935
H	2.69546	0.49600	-1.36974
H	2.92333	0.95317	0.32212
H	-2.46053	1.35066	-0.93022

4 TS1:

E = -766.70229; G = -766.51980

Imaginary freq. = -87.8 cm^{-1}

C	-2.00700	-0.23082	-1.04649
C	-3.08576	-0.56479	0.00003
C	-2.00699	-0.23079	1.04652
C	0.20230	0.37040	-0.00001
N	-0.96624	-0.45005	0.00001
H	-2.05105	0.82272	-1.35718
H	-3.98998	0.05470	0.00003
H	-3.34859	-1.63066	0.00005
H	-1.89377	-0.88539	1.91786
H	-2.05103	0.82276	1.35719
S	0.12759	2.00057	-0.00003
C	1.49149	-0.43420	-0.00001
C	2.74677	0.43402	-0.00003
C	1.48078	-1.32430	1.25857
C	1.48076	-1.32433	-1.25856
H	2.78600	1.07502	-0.88420
H	2.78601	1.07504	0.88413
H	3.62855	-0.21351	-0.00003
H	0.60591	-1.97701	1.26945
H	2.38228	-1.94432	1.26397
H	1.47975	-0.71124	2.16533
H	2.38226	-1.94436	-1.26396
H	0.60589	-1.97704	-1.26940
H	1.47972	-0.71130	-2.16533
H	-1.89380	-0.88545	-1.91781

4 TS2:

E = -766.68513; G = -766.50365

Imaginary freq. = -104.4 cm^{-1}

C	-2.02920	-0.18386	-1.07112
C	-3.07660	-0.25279	0.06466
C	-1.92399	0.05353	1.04622
C	0.29203	0.56037	-0.11399
N	-1.12176	0.49640	-0.11672
H	-2.27157	0.44196	-1.93751
H	-3.80666	0.56495	0.01059
H	-3.58808	-1.21322	0.19954
H	-1.53655	-0.85447	1.53231
H	-2.07780	0.83726	1.79744
S	0.97130	2.04699	-0.07393
C	1.16301	-0.70458	-0.00239
C	1.55251	-0.82412	1.49021
C	0.44265	-1.99293	-0.41890
C	2.44646	-0.58309	-0.83614
H	2.13089	0.04822	1.80258
H	0.67068	-0.90696	2.13158
H	2.16316	-1.72256	1.62601
H	0.22694	-2.00295	-1.49006
H	1.10289	-2.83877	-0.20616
H	-0.48756	-2.15090	0.13035
H	3.01903	-1.51126	-0.74546
H	2.20874	-0.42560	-1.89248
H	3.06746	0.24575	-0.49590
H	-1.71131	-1.17325	-1.41425

5 *trans*:

E = -806.04114; G = -805.83338

C	2.14137	0.23299	-0.30483

C	2.58548	-1.23209	-0.53457
C	1.19541	-1.68109	-0.04165
C	-0.36765	0.41486	-0.05616
N	0.77177	-0.26009	-0.04267
H	2.16129	0.88508	-1.19231
H	2.76716	-1.47205	-1.58990
H	3.43226	-1.56075	0.08221
H	1.19246	-2.10631	0.96838
H	0.61668	-2.31858	-0.71677
S	-0.33881	2.08028	-0.32359
C	2.77413	0.91385	0.89598
H	3.82652	1.12082	0.68078
H	2.26791	1.85354	1.12106
H	2.72276	0.26043	1.77294
C	-1.68107	-0.37108	0.10542
C	-2.01061	-0.99481	-1.26353
C	-1.56515	-1.46470	1.18325
C	-2.83758	0.55239	0.50664
H	-2.15415	-0.21064	-2.01202
H	-1.21973	-1.66425	-1.61094
H	-2.93683	-1.57253	-1.18364
H	-1.10661	-1.06934	2.09519
H	-2.56978	-1.81409	1.43603
H	-0.99631	-2.33335	0.85295
H	-3.74865	-0.04819	0.58606
H	-2.64619	1.02587	1.47340
H	-2.99630	1.33866	-0.23066

5 *cis*:

E = -806.03924; G = -805.83086

C	-1.84663	-0.75562	-0.33516
C	-2.94194	0.32408	-0.48718
C	-1.88230	1.38768	-0.13354
C	0.45830	0.53591	-0.02927
N	-0.84566	0.34942	-0.18119
H	-1.67310	-1.35989	-1.23552
H	-3.32799	0.41667	-1.51003
H	-3.77225	0.22891	0.22477
H	-1.96597	1.83289	0.86618
H	-1.70872	2.18356	-0.86631
S	1.00319	2.09801	0.31309
C	-2.01625	-1.61500	0.90624
H	-2.92554	-2.21353	0.79544
H	-1.17788	-2.29427	1.06900
H	-2.12747	-0.97918	1.79033
C	1.43584	-0.64813	-0.12028
C	1.67281	-1.15741	1.31354
C	0.92622	-1.79231	-1.01102
C	2.78081	-0.18716	-0.70310
H	2.12081	-0.36982	1.92450
H	0.74181	-1.47663	1.78909
H	2.35661	-2.01173	1.28457
H	0.60388	-1.41970	-1.98808
H	1.74788	-2.49485	-1.17437
H	0.11034	-2.35568	-0.56026
H	3.45221	-1.04950	-0.75052
H	2.65297	0.21136	-1.71369
H	3.23998	0.58492	-0.08761

5 TS1:

E = -806.01323; G = -805.80582

Imaginary freq. = -55.6 cm^{-1}

C	1.95821	0.23356	-0.51050
C	2.90287	-0.20580	0.62166
C	1.66337	-0.85868	1.25370
C	-0.43361	-0.44947	-0.07603
N	0.80268	0.04385	0.43595
H	1.91654	-0.54470	-1.29642
H	3.73887	-0.86216	0.35177
H	3.25950	0.65757	1.20293
H	1.49958	-0.74749	2.33121
H	1.55673	-1.90932	0.95274
S	-0.56170	-1.90235	-0.81313
C	2.11039	1.61230	-1.10899
H	3.06469	1.67272	-1.64211
H	1.30918	1.83163	-1.82004
H	2.10125	2.37235	-0.32254
C	-1.61019	0.48362	0.17371
C	-2.91620	-0.01380	-0.44088
C	-1.76919	0.58304	1.70512
C	-1.27977	1.87462	-0.39349
H	-2.82795	-0.12146	-1.52513
H	-3.20929	-0.98191	-0.02866
H	-3.70830	0.70997	-0.22684
H	-0.85791	0.96737	2.16771
H	-2.59486	1.26387	1.93343
H	-2.00109	-0.39683	2.13413
H	-2.10595	2.55445	-0.16485
H	-0.36537	2.27522	0.04626
H	-1.16254	1.83293	-1.48100

5 TS2:

E = -806.00594; G = -805.79769

Imaginary freq. = -77.5 cm^{-1}

C	-1.97652	-0.30713	0.76404
C	-2.69644	-1.19042	-0.28211
C	-1.47018	-0.97361	-1.18761
C	0.39173	0.32703	-0.12465
N	-0.70075	-0.56431	0.01296
H	-1.90250	-0.73745	1.77575
H	-2.80203	-2.23426	0.04125
H	-3.65512	-0.80501	-0.65388
H	-1.60465	-0.13343	-1.88683
H	-1.05061	-1.83858	-1.71470
S	0.23882	1.88963	-0.57960
C	-2.53739	1.10265	0.85487
H	-3.51553	1.03217	1.34344
H	-1.90375	1.76023	1.45363
H	-2.67022	1.55443	-0.13002
C	1.73266	-0.33872	0.16586
C	1.84521	-1.59767	-0.71457
C	2.93212	0.56846	-0.09637
C	1.71850	-0.75157	1.65090
H	1.03813	-2.30124	-0.50315
H	1.81655	-1.33163	-1.77633
H	2.80080	-2.09043	-0.51181
H	2.90130	1.46440	0.52774
H	3.85012	0.01822	0.13079
H	2.96751	0.88702	-1.14151
H	2.64776	-1.27981	1.88534
H	1.65235	0.12984	2.29644
H	0.87593	-1.41250	1.86467

7:

E = -841.96069; G = -841.77929

C	-2.90509	0.48791	0.00002
C	-3.51280	-0.94182	-0.00003
C	-2.06906	-1.50921	0.00000
C	-0.36514	0.39962	0.00004
C	2.00430	-0.40745	-0.00003
C	2.46539	0.29596	-1.27072
C	2.46542	0.29610	1.27057
C	2.48176	-1.85543	0.00004
N	-1.58046	-0.12559	0.00010
O	0.54639	-0.57386	0.00001
H	-3.09043	1.09244	0.89613
H	-4.09192	-1.18556	0.89850
H	-4.09189	-1.18553	-0.89859
H	-1.77028	-2.06453	-0.89678
H	-1.77035	-2.06465	0.89673
H	3.55507	0.22124	-1.33218
H	2.18309	1.34747	-1.27716
H	2.03643	-0.19696	-2.14782
H	3.55511	0.22142	1.33199
H	2.03651	-0.19673	2.14774
H	2.18311	1.34761	1.27690
H	3.57412	-1.88006	0.00003
H	2.11805	-2.37630	-0.88940
H	2.11807	-2.37620	0.88955
S	-0.13444	2.06749	0.00002
H	-3.09030	1.09243	-0.89613

7 TS1:

E = -841.92903; G = -841.74566

Imaginary freq. = -91.4 cm^{-1}

C	-2.31498	-0.44825	-1.05161
C	-3.29827	-0.99850	-0.00186
C	-2.30977	-0.46042	1.04928
C	-0.35847	0.69899	0.00069
C	1.78819	-0.60343	0.00013
C	2.40458	0.01107	-1.25056
C	2.37964	-0.05332	1.29104
C	1.91639	-2.12121	-0.03915
N	-1.75387	0.45128	0.00276
O	0.32590	-0.42838	-0.00237
H	-2.71423	0.09198	-1.91571
H	-4.24530	-0.44291	0.00363
H	-3.48491	-2.07860	-0.00753
H	-1.58395	-1.22582	1.35760
H	-2.70464	0.07004	1.92140
H	3.42855	-0.36152	-1.34440
H	2.43100	1.09832	-1.20530
H	1.84437	-0.29963	-2.13725
H	3.43390	-0.34130	1.33561
H	1.86764	-0.48694	2.15477
H	2.31338	1.03260	1.33901
H	2.97258	-2.40030	-0.01419
H	1.46959	-2.51760	-0.95477
H	1.41384	-2.56753	0.82277

S	0.22342	2.23485	0.00179
H	-1.59052	-1.20996	-1.37229

7 TS2:

E = -841.93157; G = -841.74762

Imaginary freq. = -81.2 cm^{-1}

C	-2.55972	-0.36237	1.04741
C	-3.65058	-0.64985	-0.00031
C	-2.55956	-0.36231	-1.04785
C	-0.33887	0.14280	-0.00003
C	2.11840	-0.31607	0.00016
C	2.48071	0.44028	-1.27193
C	2.48047	0.44043	1.27222
C	2.77683	-1.69083	0.00031
N	-1.53054	-0.62688	-0.00014
O	0.68858	-0.67498	0.00002
H	-2.47802	-1.02117	1.91767
H	-3.95763	-1.70407	-0.00036
H	-4.52778	0.00755	-0.00036
H	-2.55751	0.69255	-1.35638
H	-2.47772	-1.02107	-1.91813
H	3.57128	0.48292	-1.34312
H	2.09234	1.45704	-1.27297
H	2.10076	-0.09354	-2.14759
H	3.57103	0.48271	1.34383
H	2.10000	-0.09307	2.14785
H	2.09244	1.45732	1.27291
H	3.86312	-1.57429	0.00033
H	2.48178	-2.25411	-0.88852
H	2.48173	-2.25395	0.88922
S	-0.31744	1.79239	0.00004
H	-2.55772	0.69248	1.35600

8 *trans*:

E = -881.27021; G = -881.06193

C	-2.66278	-0.09845	-0.28375
C	-3.07186	1.39908	-0.36364
C	-1.59930	1.78006	-0.06867
C	-0.12407	-0.28898	-0.09559
C	2.30756	0.28679	0.09456
C	2.61334	-0.59594	1.29844
C	2.80329	-0.30671	-1.21874
C	2.90366	1.67542	0.29905
N	-1.28647	0.34641	-0.01309
O	0.87335	0.58835	0.02282
H	-2.71523	-0.64226	-1.24248
H	-3.43256	1.72218	-1.34765
H	-3.78285	1.70119	0.41728
H	-1.41545	2.29581	0.88077
H	-1.06608	2.29283	-0.87756
H	3.69807	-0.62920	1.43553
H	2.24480	-1.61114	1.16248
H	2.16625	-0.16808	2.20033
H	3.89689	-0.32405	-1.19855
H	2.48504	0.31944	-2.05713
H	2.43662	-1.32024	-1.36952
H	3.99167	1.60045	0.36736
H	2.52203	2.12007	1.22171
H	2.64707	2.32578	-0.54115
S	-0.03159	-1.95190	-0.34143
C	-3.29740	-0.90073	0.83552
H	-4.36009	-1.04603	0.61964
H	-2.82116	-1.87789	0.93347
H	-3.20568	-0.36335	1.78438

8 *cis*:

E = -881.27078; G = -881.06276

C	-2.07899	-1.02347	-0.36462
C	-3.42752	-0.25474	-0.39133
C	-2.64877	1.05056	-0.07929
C	-0.15132	0.62631	0.01469
C	2.09877	-0.46965	-0.08132
C	2.71695	0.33956	-1.21461
C	2.57511	-0.02556	1.29644
C	2.38438	-1.95447	-0.27863
N	-1.42415	0.25658	-0.02920
O	0.63470	-0.43622	-0.16372
H	-1.74631	-1.38638	-1.35198
H	-3.94302	-0.26013	-1.35914
H	-4.11649	-0.56619	0.40568
H	-2.87996	1.54306	0.87222
H	-2.62489	1.79740	-0.88245
H	3.79416	0.14970	-1.22962
H	2.54860	1.40760	-1.08685
H	2.29752	0.02064	-2.17312
H	3.63766	-0.26779	1.38961
H	2.02937	-0.56724	2.07459
H	2.44380	1.04451	1.44691
H	3.46308	-2.12659	-0.25326

H	1.99664	-2.29250	-1.24313
H	1.91558	-2.53991	0.51682
S	0.28650	2.23482	0.24949
C	-1.93414	-2.10401	0.68940
H	-2.57380	-2.95334	0.43150
H	-0.90068	-2.45160	0.75238
H	-2.24061	-1.72181	1.66762

8 TS1:

E = -881.23499; G = -881.02440

Imaginary freq. = -77.0 cm^{-1}

C	2.51453	-0.30222	-0.83570
C	3.28366	-1.20137	0.16176
C	2.04043	-1.12344	1.06769
C	0.10780	0.09896	0.06152
C	-2.36602	-0.25100	-0.14085
C	-2.74328	-0.00199	1.31426
C	-2.68457	0.92781	-1.05343
C	-3.05587	-1.51005	-0.65430
N	1.25728	-0.69460	-0.11608
O	-0.94757	-0.62978	-0.24966
H	2.48175	-0.66745	-1.87352
H	3.45682	-2.21375	-0.22601
H	4.21320	-0.77925	0.56595
H	2.11445	-0.32076	1.81753
H	1.67733	-2.04626	1.53254
H	-3.83295	0.07060	1.37638
H	-2.31162	0.91955	1.70096
H	-2.41996	-0.84249	1.93494
H	-3.77193	1.00309	-1.14555
H	-2.26747	0.75395	-2.04950
H	-2.30114	1.86840	-0.66271
H	-4.13938	-1.37479	-0.61794
H	-2.78557	-2.37010	-0.03668
H	-2.75960	-1.71041	-1.68709
S	0.10561	1.64950	0.62651
C	2.97275	1.14699	-0.81693
H	3.96370	1.18021	-1.28238
H	2.30482	1.79755	-1.38466
H	3.05082	1.53823	0.19940

8 TS2:

E = -881.23540; G = -881.02477

Imaginary freq. = -72.6 cm^{-1}

C	-2.33232	-0.38533	-0.72140
C	-3.30245	-0.36817	0.48289
C	-2.18562	0.34176	1.27165
C	-0.15134	0.82451	-0.08943
C	1.89927	-0.60271	0.15356
C	2.47066	-0.34544	-1.23512
C	2.61296	0.17646	1.25062
C	1.92037	-2.09521	0.46322
N	-1.55348	0.69827	-0.02667
O	0.45598	-0.31515	0.17874
H	-2.74110	-0.00575	-1.67013
H	-4.17122	0.28200	0.31584
H	-3.62250	-1.35051	0.85471
H	-1.57244	-0.35926	1.85673
H	-2.45252	1.21142	1.88077
H	3.46800	-0.79175	-1.28353
H	2.55308	0.71717	-1.45658
H	1.84318	-0.82440	-1.99264
H	3.63974	-0.19368	1.32221
H	2.11951	0.00879	2.21224
H	2.63993	1.24460	1.04087
H	2.95405	-2.44683	0.50533
H	1.38931	-2.65201	-0.31322
H	1.44313	-2.28897	1.42753
S	0.54590	2.27947	-0.41715
C	-1.67099	-1.73627	-0.94795
H	-2.42584	-2.41249	-1.36238
H	-0.84295	-1.67009	-1.65819
H	-1.29255	-2.16408	-0.01674

8 TS3:

E = -881.24264; G = -881.03295

Imaginary freq. = -56.9 cm^{-1}

C	-2.46604	0.39504	0.44119
C	-3.44405	-0.03988	-0.66644
C	-2.23142	-0.73287	-1.31227
C	-0.11045	-0.32998	-0.03295
C	2.29407	0.34199	-0.15016
C	2.55628	0.47667	1.34496
C	2.85016	-0.94714	-0.74331
C	2.85645	1.54779	-0.89382
N	-1.34346	0.16766	-0.52307
O	0.85350	0.46787	-0.43282
H	-2.43463	-0.36626	1.24274
H	-4.28907	-0.67309	-0.37125

H	-3.79034	0.82090	-1.25749
H	-2.08939	-0.64945	-2.39424
H	-2.13639	-1.77808	-0.98564
H	3.63262	0.60412	1.49206
H	2.23031	-0.40016	1.90189
H	2.04958	1.36351	1.73611
H	3.94184	-0.88093	-0.73590
H	2.52055	-1.05611	-1.78042
H	2.55090	-1.82675	-0.17620
H	3.94040	1.58453	-0.76186
H	2.42141	2.47139	-0.50399
H	2.63217	1.47457	-1.96091
S	0.02449	-1.69175	0.88989
C	-2.53061	1.79324	1.00897
H	-3.42389	1.90684	1.63102
H	-1.65324	1.99766	1.63127
H	-2.56483	2.52958	0.20169

8 TS4:

E = -881.24016; G = -881.03074

Imaginary freq. = -59.8 cm^{-1}

C	-1.88790	-0.54741	-1.53156
C	-2.99273	-1.10431	-0.61579
C	-2.16797	-0.53650	0.55526
C	-0.11839	0.66210	-0.24368
C	2.03221	-0.57504	0.14390
C	2.82144	-0.01666	-1.03320
C	2.40509	0.06606	1.47417
C	2.19588	-2.08813	0.22057
N	-1.49281	0.37575	-0.42553
O	0.58534	-0.44384	-0.09642
H	-2.17567	-0.02651	-2.44982
H	-3.94090	-0.56005	-0.73776
H	-3.16419	-2.18714	-0.63297
H	-1.45924	-1.29751	0.93038
H	3.86361	-0.33095	-0.92606
H	2.78655	1.07074	-1.07193
H	2.43493	-0.42403	-1.97187
H	3.43286	-0.21874	1.71700
H	1.74875	-0.30485	2.26671
H	2.34444	1.15252	1.43547
H	3.24420	-2.33371	0.40636
H	1.88635	-2.55231	-0.71949
H	1.58914	-2.49544	1.03347
S	0.42542	2.21312	-0.23162
H	-1.11154	-1.29732	-1.73811
C	-2.85833	0.17942	1.69265
H	-3.40722	-0.53557	2.31338
H	-2.12776	0.69303	2.32555
H	-3.55980	0.92118	1.30176

18:

E = -443.78028; G = -443.59714

C	-2.27512	0.91340	-0.04129
C	-3.01180	-0.44121	0.11315
C	-1.64440	-1.15062	-0.04395
C	0.21433	0.71886	-0.08190
N	-1.01622	0.17608	-0.18402
H	-2.28100	1.56454	0.84114
H	-3.48469	-0.58647	1.09194
H	-3.72967	-0.66443	-0.68524
H	-1.54782	-1.77146	-0.94122
H	-1.29983	-1.71226	0.83262
O	0.32877	1.94208	-0.02388
C	1.43558	-0.20661	0.00309
C	1.56166	-0.65369	1.46965
C	1.31726	-1.43115	-0.91495
C	2.67942	0.59517	-0.39053
H	1.68397	0.21255	2.12635
H	0.68228	-1.21597	1.79669
H	2.43926	-1.29856	1.58083
H	1.02712	-1.14073	-1.92954
H	2.29092	-1.92731	-0.97075
H	0.59981	-2.16436	-0.54393
H	3.56559	-0.03628	-0.27768
H	2.61806	0.92513	-1.43159
H	2.79106	1.47903	0.23886
H	-2.53324	1.50245	-0.92899

18 TS1:

E = -443.75950; G = -443.57483

Imaginary freq. = -86.6 cm^{-1}

C	-1.99755	-0.01930	-1.04509
C	-3.09301	-0.29518	0.00003
C	-1.99754	-0.01928	1.04512
N	-0.96680	-0.30640	0.00001
H	-1.98105	1.03768	-1.34707
H	-3.96867	0.36464	0.00002
H	-3.40427	-1.34843	0.00004

H	-1.92777	-0.67123	1.92237
H	-1.98103	1.03770	1.34708
C	1.52301	-0.16913	-0.00001
C	2.67047	0.83767	-0.00003
C	1.58376	-1.05232	1.25698
C	1.58374	-1.05235	-1.25698
H	2.63047	1.47909	-0.88422
H	2.63049	1.47912	0.88414
H	3.62520	0.30372	-0.00003
H	0.76297	-1.77280	1.26795
H	2.53088	-1.60016	1.26453
H	1.53444	-0.44451	2.16613
H	2.53086	-1.60019	-1.26453
H	0.76295	-1.77284	-1.26791
H	1.53440	-0.44457	-2.16614
H	-1.92780	-0.67127	-1.92233
C	0.18702	0.55516	-0.00001
O	0.08202	1.75715	-0.00002

18 TS2:

E = -443.74467; G = -443.55979

Imaginary freq. = -92.0 cm^{-1}

C	-1.90572	-0.35121	-1.02895
C	-2.94394	-0.38093	0.11525
C	-1.84853	0.23533	1.01089
N	-1.12040	0.61752	-0.22529
H	-2.23077	0.06032	-1.99047
H	-3.77400	0.31588	-0.05923
H	-3.32695	-1.36496	0.41100
H	-1.32494	-0.52573	1.60881
H	-2.11797	1.08489	1.64789
C	1.32307	-0.30593	0.02600
C	1.77736	-0.12446	1.49006
C	0.80892	-1.73464	-0.15898
C	2.52439	-0.07920	-0.90092
H	2.17763	0.87998	1.64589
H	0.95279	-0.28613	2.19082
H	2.56197	-0.85454	1.71216
H	0.57637	-1.94930	-1.20490
H	1.59830	-2.42621	0.15176
H	-0.07435	-1.94442	0.44907
H	3.28662	-0.83789	-0.69849
H	2.22852	-0.16276	-1.95121
H	2.95972	0.90859	-0.74205
H	-1.43462	-1.32503	-1.18968
C	0.29448	0.81990	-0.21803
O	0.70053	1.95393	-0.30203

19 TS1:

E = -518.99439; G = -518.80722

Imaginary freq. = -85.5 cm^{-1}

C	2.31086	0.24724	-1.04919
C	3.30834	0.77269	-0.00012
C	2.31076	0.24776	1.04914
C	-1.82816	0.30844	-0.00003
C	-2.35841	-0.35207	-1.26733
C	-2.35848	-0.35169	1.26741
C	-2.14177	1.79833	-0.00028
N	1.73056	-0.64364	0.00017
O	-0.36064	0.28637	0.00007
H	2.69951	-0.29418	-1.91718
H	4.24394	0.19798	0.00007
H	3.51755	1.84871	-0.00037
H	1.60282	1.02621	1.36594
H	2.69935	-0.29324	1.91742
H	-3.43887	-0.19199	-1.32131
H	-2.16229	-1.42405	-1.27311
H	-1.89955	0.10432	-2.14909
H	-3.43896	-0.19169	1.32126
H	-1.89974	0.10502	2.14906
H	-2.16227	-1.42366	1.27354
H	-3.22444	1.94598	-0.00039
H	-1.72188	2.27543	-0.88964
H	-1.72202	2.27572	0.88899
H	1.60293	1.02553	-1.36644
C	0.32634	-0.85871	0.00013
O	-0.16773	-1.95544	0.00014

19:

E = -519.01653; G = -518.83033

Imaginary freq. = -104.0 cm^{-1}

C	2.87160	0.78943	-0.00001
C	3.57250	-0.59808	0.00000
C	2.16725	-1.26080	0.00004
C	0.34173	0.56502	0.00013
C	-1.98496	-0.19193	0.00000
C	-2.39117	0.55378	1.26673
C	-2.39091	0.55476	-1.26623
C	-2.57753	-1.59582	-0.00059

N	1.59354	0.08435	-0.00007
O	-0.54740	-0.44840	0.00002
H	3.02916	1.40134	-0.89640
H	4.16706	-0.80359	-0.89815
H	4.16712	-0.80357	0.89811
H	1.91529	-1.84014	0.89612
H	1.91529	-1.84030	-0.89594
H	-3.48286	0.59337	1.32034
H	-2.00180	1.57126	1.27179
H	-2.02294	0.02215	2.14888
H	-3.48259	0.59447	-1.32000
H	-2.02255	0.02377	-2.14873
H	-2.00147	1.57221	-1.27045
H	-3.66866	-1.53377	-0.00067
H	-2.25676	-2.14534	0.88828
H	-2.25659	-2.14466	-0.88983
O	0.06833	1.75378	0.00003
H	3.02908	1.40130	0.89642

20 TS1:

E = -558.30194; G = -558.08684

Imaginary freq. = -63.9 cm^{-1}

C	2.49813	0.25620	-0.74393
C	3.37413	-0.86237	-0.13571
C	2.10916	-1.32827	0.60689
C	-2.31073	-0.04790	-0.09098
C	-2.57634	-0.37992	1.37360
C	-2.51419	1.43113	-0.39997
C	-3.18239	-0.90741	-0.99737
N	1.29053	-0.55948	-0.37216
O	-0.95463	-0.45964	-0.46670
H	2.56142	0.37129	-1.83642
H	3.71214	-1.59099	-0.88431
H	4.21713	-0.52915	0.48415
H	2.03957	-0.90675	1.62028
H	1.88387	-2.39926	0.62575
H	-3.63803	-0.22109	1.58223
H	-1.99090	0.24977	2.04297
H	-2.34246	-1.43066	1.56792
H	-3.56913	1.67897	-0.25230
H	-2.25642	1.63514	-1.44317
H	-1.91184	2.06432	0.25104
H	-4.23651	-0.68853	-0.80970
H	-3.00209	-1.96766	-0.80259
H	-2.95979	-0.69919	-2.04696
C	2.68493	1.60616	-0.06835
H	3.66311	1.99704	-0.36616
H	1.92019	2.32370	-0.37430
H	2.65760	1.52139	1.02030
C	0.11703	0.05689	0.13054
O	0.08215	0.90476	0.98897

20 TS2:

E = -558.30041; G = -558.08580

Imaginary freq. = -77.8 cm^{-1}

C	2.29388	0.45562	-0.65176
C	3.27320	0.10689	0.49361
C	2.16962	-0.81432	1.04686
C	-1.98390	0.23767	0.15706
C	-2.49218	0.26062	-1.28011
C	-2.59639	-0.89228	0.97609
C	-2.22804	1.58201	0.83056
N	1.52523	-0.78349	-0.29316
O	-0.52203	0.13565	0.16902
H	2.70298	0.36741	-1.66947
H	4.15039	-0.45488	0.14680
H	3.58177	0.94602	1.13115
H	1.55809	-0.32106	1.81639
H	2.45327	-1.81864	1.37697
H	-3.55878	0.50200	-1.27324
H	-2.35551	-0.70253	-1.77148
H	-1.96868	1.03463	-1.84927
H	-3.66909	-0.70831	1.08371
H	-2.15067	-0.91613	1.97474
H	-2.45238	-1.85928	0.49491
H	-3.30147	1.78095	0.87960
H	-1.74575	2.38333	0.26428
H	-1.82448	1.57648	1.84652
C	1.62588	1.81234	-0.48323
H	2.38009	2.58127	-0.67995
H	0.80121	1.95032	-1.18655
H	1.23975	1.95271	0.52890
C	0.11781	-0.90507	-0.36882
O	-0.42754	-1.86949	-0.84193

20 TS3:

E = -558.30690; G = -558.09334

Imaginary freq. = -61.8 cm^{-1}

C	-2.43802	0.46890	0.32042

C	-3.41579	-0.58480	-0.23143
C	-2.16770	-1.44244	-0.49791
C	2.28829	0.10627	-0.11717
C	2.45298	1.01698	1.09442
C	2.73953	-1.32328	0.16025
C	3.02815	0.67664	-1.31977
N	-1.33979	-0.19802	-0.45467
O	0.89202	0.11480	-0.56865
H	-2.28117	0.31505	1.40443
H	-4.16871	-0.98592	0.45754
H	-3.88685	-0.24287	-1.16503
H	-2.09408	-1.98585	-1.44463
H	-1.93973	-2.10530	0.34878
H	3.52022	1.13844	1.29962
H	1.97126	0.60163	1.97922
H	2.03034	2.00331	0.88194
H	3.81925	-1.32338	0.33304
H	2.53046	-1.95701	-0.70639
H	2.24545	-1.73860	1.03829
H	4.09930	0.71726	-1.10755
H	2.67309	1.68662	-1.53978
H	2.86566	0.04692	-2.19820
C	-2.64021	1.92984	-0.00825
H	-3.51461	2.31877	0.52265
H	-1.76827	2.51990	0.29121
H	-2.79373	2.05781	-1.08307
C	-0.09037	-0.30967	0.21624
O	0.04917	-0.72872	1.33990

20 TS4:

E = -558.30517; G = -558.09203

Imaginary freq. = -68.1 cm^{-1}

C	1.86080	-1.51109	0.50120
C	2.97699	-1.03456	-0.44512
C	2.14981	0.25610	-0.60039
C	-2.09098	-0.05365	-0.29524
C	-2.78692	-0.72493	0.88318
C	-2.40005	1.43619	-0.38515
C	-2.44927	-0.75404	-1.59893
N	1.45903	-0.08513	0.68502
O	-0.64136	-0.26057	-0.20626
H	2.14089	-2.01065	1.43350
H	3.91696	-0.84278	0.09329
H	3.16401	-1.62722	-1.34858
H	1.45050	0.16281	-1.45139
H	-3.86743	-0.69352	0.71772
H	-2.56228	-0.22124	1.82312
H	-2.48085	-1.77280	0.95217
H	-3.46127	1.56217	-0.61743
H	-1.81626	1.89241	-1.19000
H	-2.18388	1.94888	0.55172
H	-3.52541	-0.67892	-1.77349
H	-2.17395	-1.81089	-1.55107
H	-1.92444	-0.28920	-2.43768
H	1.09269	-2.09013	-0.02994
C	2.84211	1.59934	-0.60333
H	3.39781	1.73610	-1.53616
H	2.11300	2.41115	-0.51715
H	3.53765	1.66749	0.23717
C	0.07835	0.21927	0.81152
O	-0.37314	0.84263	1.73659

20 *cis*:

E = -558.32757; G = -558.11589

C	2.58928	-0.25573	0.35378
C	3.10110	1.20292	0.22619
C	1.65365	1.62805	-0.12233
C	-2.29356	0.06970	-0.03706
C	-2.61693	-1.04639	-1.02445
C	-2.58471	-0.32928	1.40583
C	-3.05491	1.33787	-0.40183
N	1.30379	0.20083	-0.20908
O	-0.89726	0.48095	-0.17589
H	2.45795	-0.57525	1.40330
H	3.52403	1.64528	1.13595
H	3.79967	1.32624	-0.61363
H	1.50930	2.17838	-1.05741
H	1.12393	2.13678	0.69280
H	-3.69596	-1.22432	-1.01645
H	-2.10636	-1.97226	-0.76177
H	-2.32527	-0.74837	-2.03559
H	-3.66083	-0.48828	1.51960
H	-2.28261	0.47379	2.08426
H	-2.06244	-1.24588	1.67842
H	-4.12992	1.15703	-0.32481
H	-2.82092	1.64005	-1.42593
H	-2.78559	2.15157	0.27651
C	3.29881	-1.32671	-0.44690
H	4.29183	-1.51079	-0.02549
H	2.73252	-2.26114	-0.42438

H	3.41282	-1.00801	-1.48705
C	0.10730	-0.38351	0.04533
O	-0.01634	-1.53871	0.40761

20 *trans*:

E = -558.32767; G = -558.11567

C	2.06432	0.76390	-0.36668
C	3.36606	-0.07645	-0.42263
C	2.53146	-1.30752	0.00835
C	-2.12962	0.20666	-0.07332
C	-2.55153	-0.66185	-1.25361
C	-2.66931	-0.31590	1.25375
C	-2.56581	1.65004	-0.29215
N	1.40554	-0.39958	0.26650
O	-0.67344	0.31719	-0.02097
H	1.63684	0.95466	-1.36683
H	3.85256	-0.14617	-1.40278
H	4.09402	0.23668	0.33943
H	2.87371	-1.85552	0.89185
H	2.31111	-2.01423	-0.80244
H	-3.63829	-0.60651	-1.36413
H	-2.26612	-1.70270	-1.10399
H	-2.09344	-0.29007	-2.17470
H	-3.75978	-0.23244	1.24941
H	-2.28171	0.28776	2.07946
H	-2.39722	-1.35884	1.41272
H	-3.65572	1.70092	-0.35494
H	-2.14175	2.03917	-1.22161
H	-2.23163	2.27746	0.53844
C	2.07740	2.02986	0.46280
H	2.70226	2.78645	-0.02162
H	1.06677	2.43158	0.57119
H	2.48380	1.82534	1.45753
C	0.10073	-0.76120	0.19089
O	-0.29362	-1.90490	0.31637

5 cis (in THF)

E = -806.05031; G = -805.84442

C	2.14538	0.24126	-0.30682
C	2.58258	-1.22244	-0.55297
C	1.20104	-1.67180	-0.03886
C	-0.36796	0.41434	-0.05748
N	0.77037	-0.24903	-0.05013
H	2.17164	0.90968	-1.18967
H	2.74072	-1.45480	-1.62025
H	3.44486	-1.55823	0.04942
H	1.21176	-2.07790	0.98205
H	0.61077	-2.31931	-0.69855
S	-0.35087	2.09209	-0.32197
C	2.77701	0.89518	0.90988
H	3.83245	1.09602	0.70113
H	2.28038	1.83621	1.15370
H	2.71736	0.22393	1.77345
C	-1.67837	-0.37683	0.10536
C	-1.99785	-1.01559	-1.25944
C	-1.55790	-1.45949	1.19410
C	-2.84513	0.53899	0.49476
H	-2.14532	-0.24000	-2.01735
H	-1.20046	-1.68387	-1.59521
H	-2.92147	-1.59795	-1.17519
H	-1.11163	-1.04990	2.10664
H	-2.56185	-1.81768	1.43994
H	-0.97489	-2.32347	0.87574
H	-3.74880	-0.07287	0.57812
H	-2.66270	1.02291	1.45888
H	-3.01431	1.31516	-0.25176

5 trans (in THF)

E = -806.04851; G = -805.84192

C	-1.84795	-0.75743	-0.33542
C	-2.94242	0.32122	-0.49383
C	-1.88784	1.38602	-0.13247
C	0.45438	0.53170	-0.03116
N	-0.84388	0.35073	-0.17669
H	-1.66666	-1.36642	-1.23846
H	-3.32122	0.41445	-1.52583
H	-3.78083	0.22433	0.21799
H	-1.97780	1.82549	0.87229
H	-1.71212	2.18470	-0.86571
S	1.00773	2.10376	0.31133
C	-2.01698	-1.60835	0.91127
H	-2.92337	-2.21181	0.79713
H	-1.17517	-2.28265	1.08228
H	-2.13865	-0.96675	1.79077
C	1.43488	-0.64986	-0.12012
C	1.68008	-1.15067	1.31567
C	0.92378	-1.80139	-1.00035
C	2.77629	-0.19181	-0.71414
H	2.13017	-0.36041	1.92294

H	0.75155	-1.47292	1.79527
H	2.36706	-2.00308	1.28450
H	0.59797	-1.43665	-1.97974
H	1.74768	-2.50348	-1.15810
H	0.10896	-2.36135	-0.54278
H	3.44364	-1.05755	-0.76548
H	2.64163	0.20413	-1.72566
H	3.24533	0.57816	-0.10261

8 cis (in THF)

E = -881.27843; G = -881.07225

C	-2.67261	-0.10404	-0.28462
C	-3.07820	1.39375	-0.36887
C	-1.60625	1.77408	-0.07123
C	-0.12677	-0.28993	-0.10898
C	2.30916	0.29138	0.09747
C	2.60743	-0.57846	1.31209
C	2.82113	-0.30863	-1.20615
C	2.89506	1.68501	0.29634
N	-1.28743	0.33845	-0.04178
O	0.87132	0.58499	0.00884
H	-2.74631	-0.66139	-1.24144
H	-3.43201	1.71354	-1.36326
H	-3.79656	1.70159	0.41180
H	-1.42238	2.26916	0.89260
H	-1.07279	2.30336	-0.87283
H	3.69142	-0.59870	1.46197
H	2.25239	-1.59941	1.18005
H	2.14502	-0.14705	2.20538
H	3.91521	-0.31596	-1.17409
H	2.50615	0.30872	-2.05314
H	2.46600	-1.32740	-1.35185
H	3.98343	1.61460	0.37374
H	2.50414	2.13417	1.21375
H	2.64211	2.32764	-0.55181
S	-0.02503	-1.96326	-0.34336
C	-3.28875	-0.88572	0.85978
H	-4.35791	-1.02038	0.66705
H	-2.82454	-1.86879	0.96338
H	-3.17258	-0.33522	1.79922

8 trans (in THF)

E = -881.27921; G = -881.07231

C	-2.07703	-1.03537	-0.37254
C	-3.43219	-0.27830	-0.38241
C	-2.66333	1.03360	-0.07391
C	-0.15726	0.62811	-0.02014
C	2.10091	-0.46625	-0.07837
C	2.78015	0.38606	-1.14266
C	2.50666	-0.08696	1.34023
C	2.38800	-1.94297	-0.32664
N	-1.42330	0.25818	-0.07631
O	0.63986	-0.41837	-0.23004
H	-1.75864	-1.42152	-1.36284
H	-3.95273	-0.28227	-1.35449
H	-4.11756	-0.60042	0.42194
H	-2.86997	1.50131	0.89910
H	-2.67757	1.79751	-0.86476
H	3.85475	0.17926	-1.11646
H	2.62147	1.44987	-0.97194
H	2.40184	0.11853	-2.13411
H	3.56323	-0.33783	1.47559
H	1.92010	-0.66249	2.06355
H	2.37165	0.97661	1.53228
H	3.46415	-2.12186	-0.25406
H	2.04884	-2.23471	-1.32469
H	1.87668	-2.56016	0.41778
S	0.27648	2.24107	0.25605
C	-1.90066	-2.08371	0.70953
H	-2.54166	-2.94292	0.48746
H	-0.86401	-2.42605	0.76163
H	-2.19142	-1.67551	1.68299

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