

Studies on a catalytic version of the Matteson asymmetric homologation reaction

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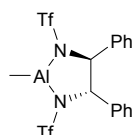
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Experimental section

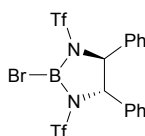
General chemicals, reagents and solvents were purchased from Aldrich Chemical Company. The solvents were purified using standard procedures.¹ The concentration of butyllithium was determined prior to use.² Reported procedures were used for the preparation of chiral ligands.^{3–10} NMR spectra were recorded in CDCl₃ on a Bruker AV500 spectrometer operating at 500 MHz (¹H), 125 MHz (¹³C) and 160 MHz (¹¹B) or on a Bruker AV400 spectrometer operating at 400 MHz (¹H) or 100 MHz (¹³C). The coupling constants (*J*; Hz) are rounded to the nearest integer. An Atago 5223 POLAX-2L semi-automatic polarimeter was used to measure optical purity. All reactions were conducted under a nitrogen atmosphere.

Synthesis of **6**^{3,4}



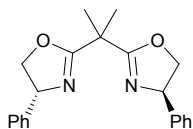
A solution in dry dichloromethane (DCM, 20 mL) of (1*S*,2*S*)-1,2-diphenyl-1,2-*bis*-(trifluoromethylsulfonylamino)ethane (**16**) (1.20 g, 2.5 mmol) was heated to 80 °C under nitrogen with stirring for 1 min to ensure complete solubility. When the mixture had cooled to 20 °C a solution of trimethylaluminium in toluene (2.0 M; 1.25 mL, 2.5 mmol) was added dropwise. When gas evolution stopped, the mixture was heated to 80 °C for 3 h, then cooled to 20 °C. The solvent was removed under reduced pressure and the resulting solid dissolved in dry DCM (10 mL) was used without further isolation.

Synthesis of **7**⁵

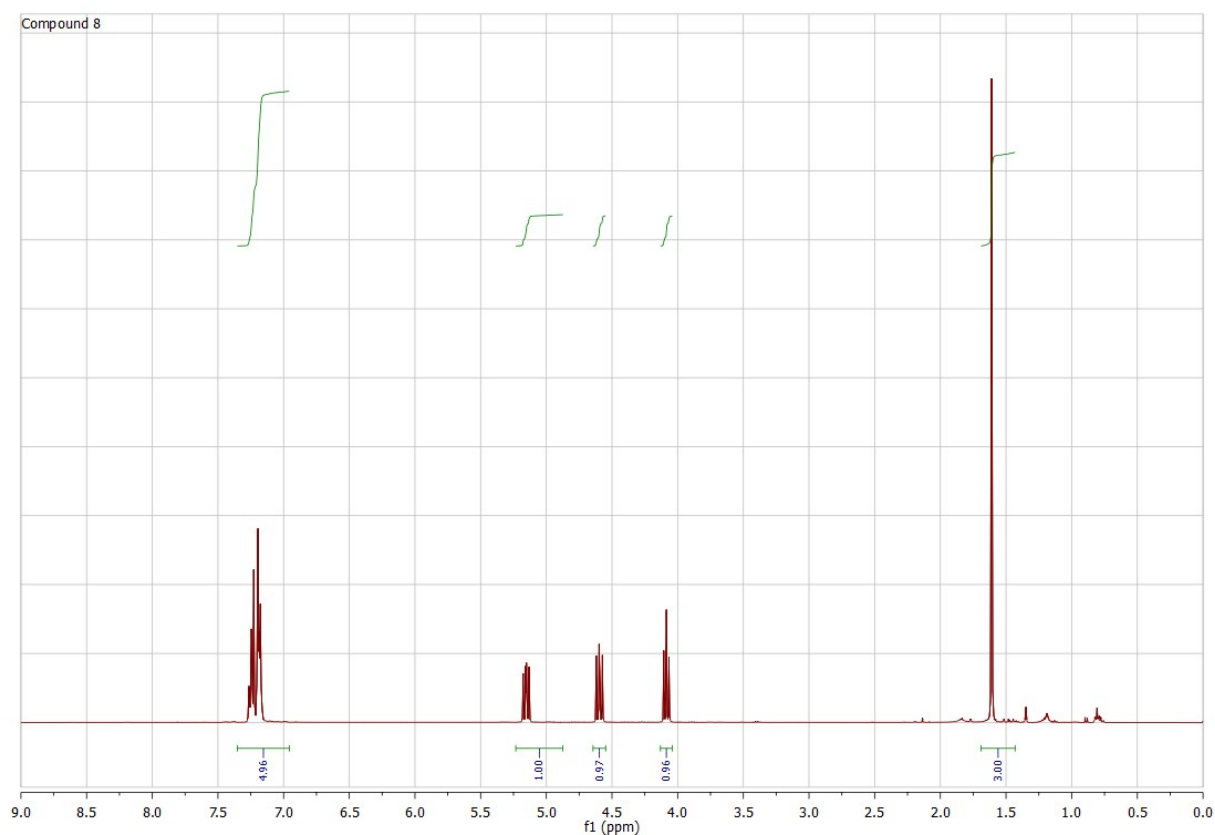


The procedure was identical with that used to produce **6** except that a solution of boron tribromide in DCM (1.0 M; 2.5 mL, 2.5 mmol) was used instead of trimethylaluminium.

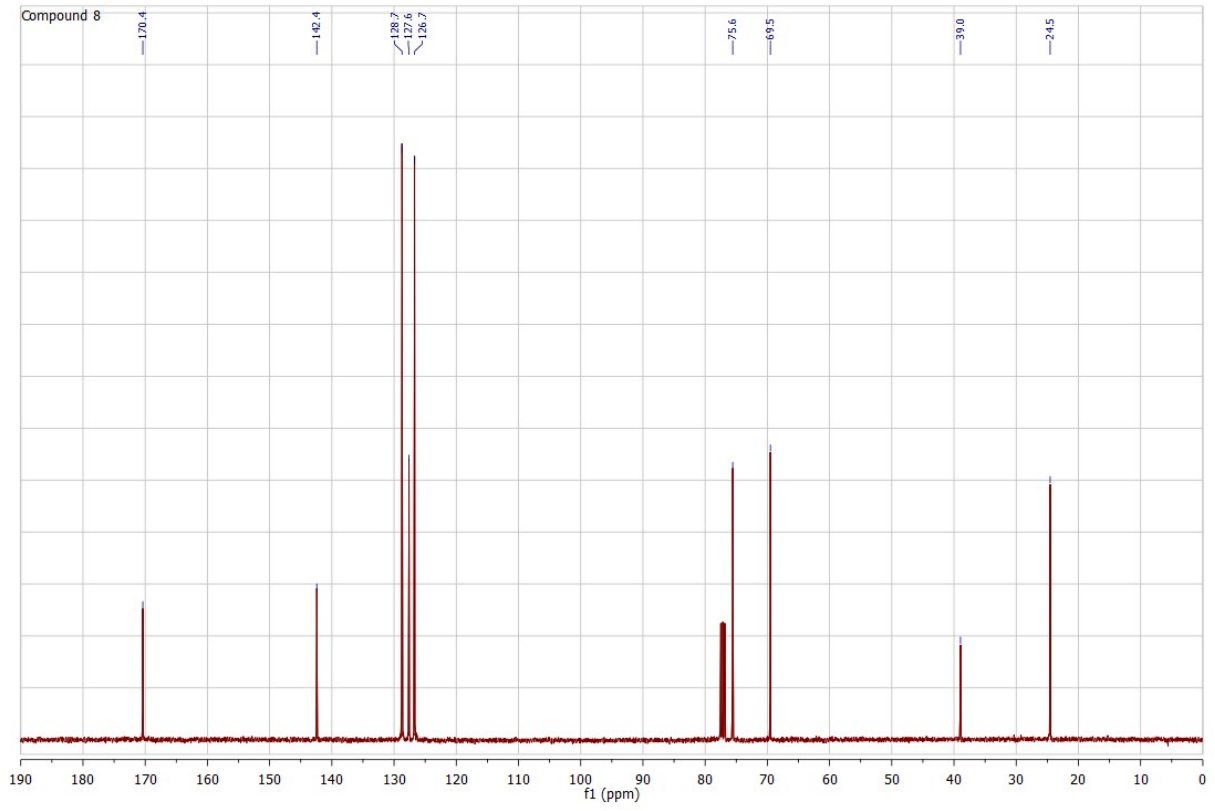
Synthesis of **8**⁶



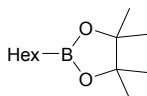
To a round-bottomed flask (100 mL) fitted with a Dean-Stark apparatus was added a solution of *N*¹,*N*³-bis((*R*)-2-hydroxy-1-phenylethyl)-2,2-dimethylmalonamide (0.74 g, 2.0 mmol) and ammonium molybdate (78 mg, 0.4 mmol) in toluene (40 mL). The mixture was heated under reflux for 3 h then cooled to 20 °C. The solvent was removed under reduced pressure and the crude product was subjected to flash column chromatography (silica gel; Et₂O/hexane 3/1 by volume) to give pure **8** (0.56 g, 83%) as a light-yellow oil. $[\alpha]_D^{20} = +169^\circ$, $c = 1$, EtOH (lit.¹¹ -171.3° , $c = 1$, EtOH, for *S* enantiomer). δ_H (400 MHz; CDCl₃) 7.35–6.96 (10 H, m), 5.15 (2 H, dd, J 10, 8 Hz), 4.60 (2 H, dd, J 10, 8 Hz), 4.09 (2 H, app. t, J 8 Hz), 1.61 (6 H, s); δ_C (100 MHz; CDCl₃) 170.4, 142.4, 128.7, 127.6, 126.7, 75.6, 69.5, 39.0, 24.5.



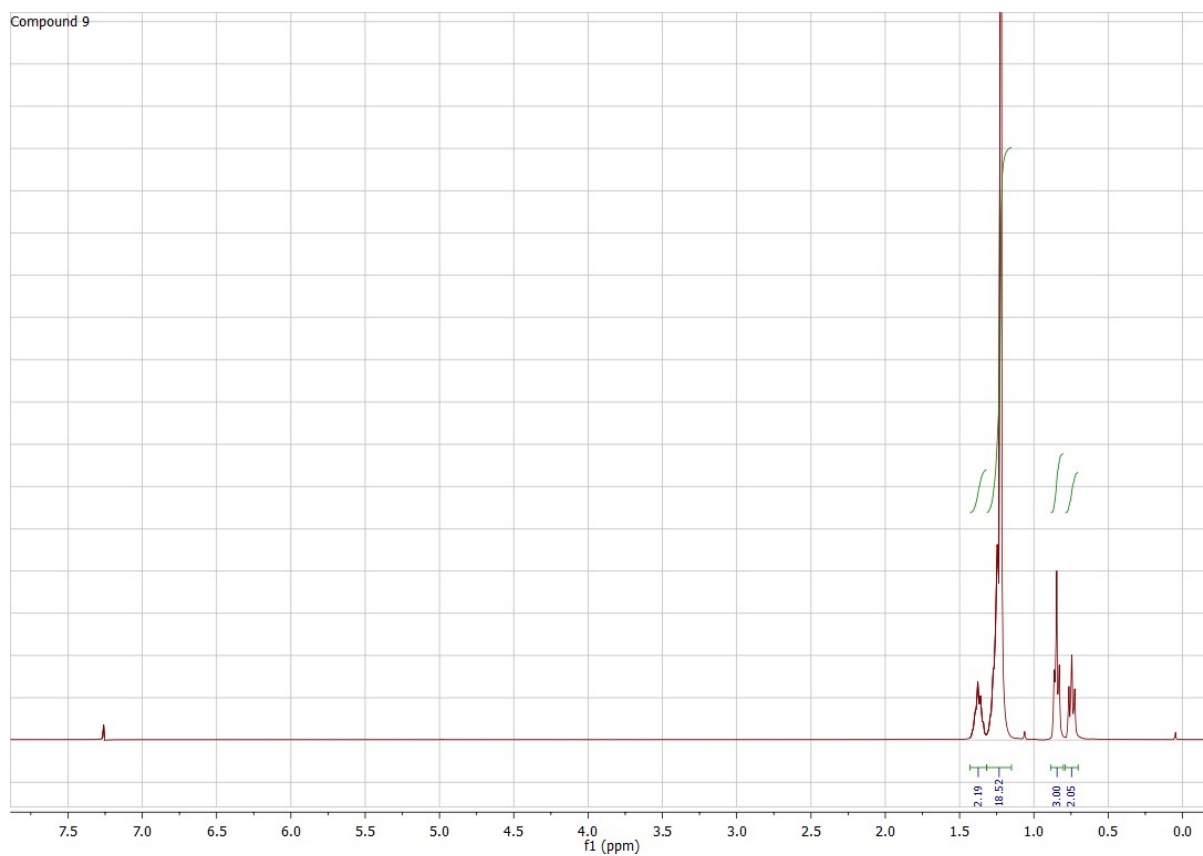
Compound 8



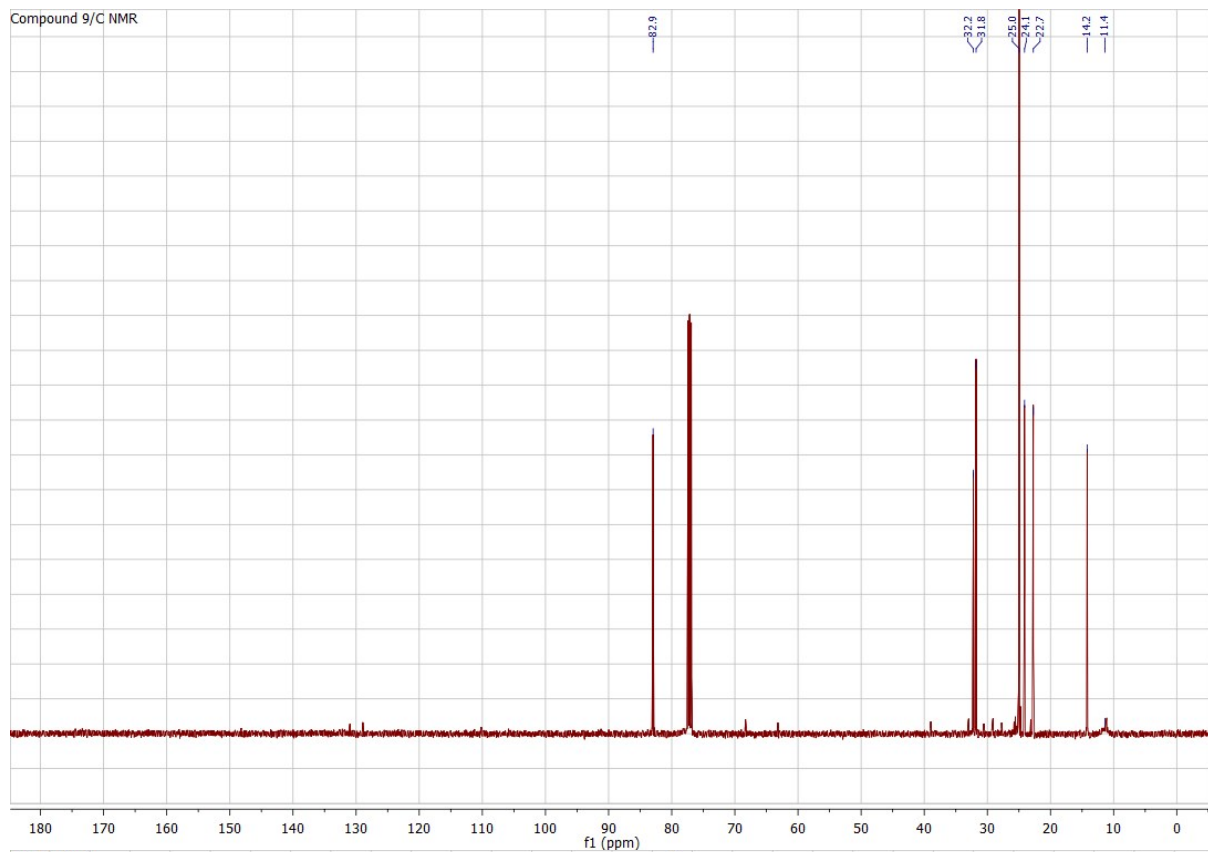
Synthesis of **9**¹²



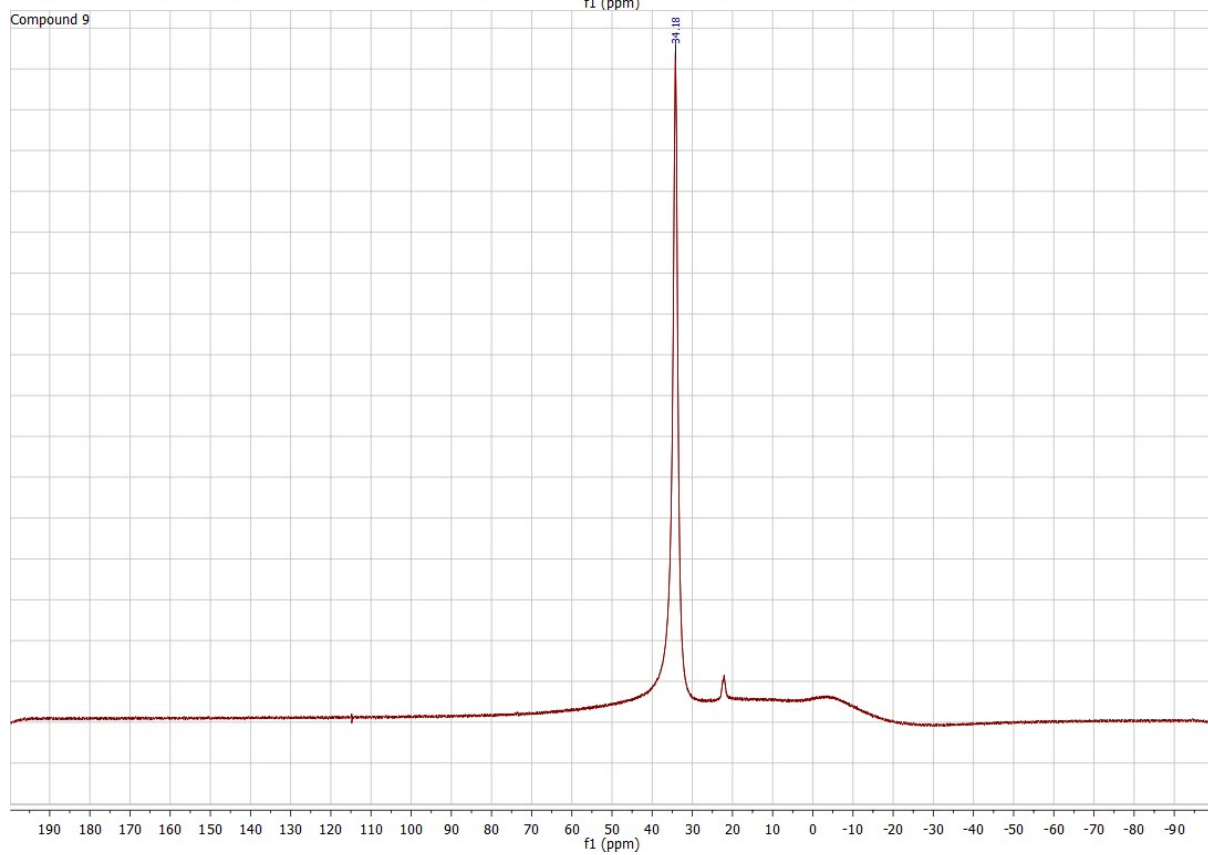
To a mixture of hexylboronic acid (2.7 g, 20.7 mmol) and MgSO_4 (5.0 g) in Et_2O (25 mL) was added pinacol (2.45 g, 20.7 mmol). The mixture was stirred for 1 h at 20 °C, filtered, and the filtrate was evaporated under reduced pressure to give **9** (4.2 g, 96%) as a colourless oil. IR (FT) ν_{max} 2996, 1319, 1113, 1227, 805, 734 cm^{-1} ; δ_{H} (400 MHz; CDCl_3) 1.42 – 1.32 (2 H, m), 1.32 – 1.16 (18 H, m), 0.85 (3 H, t, J 8 Hz), 0.75 (2 H, t, J 8 Hz); δ_{C} (125 MHz; CDCl_3) 82.9, 32.2, 31.8, 25.0, 24.1, 22.7, 14.2, 11.4 (br); δ_{B} (160 MHz; CDCl_3) 34.2; MS (EI) m/z (%) 212 ($[\text{M}]^+$, 2), 197 (100), 155 (50), 129 (99), 112 (95), 97 (51), 85(98); HRMS (EI) m/z calc. for $\text{C}_{12}\text{H}_{25}\text{BO}_2$ (M^+) 212.1901, found 212.1898.



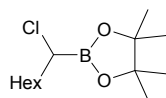
Compound 9/C NMR



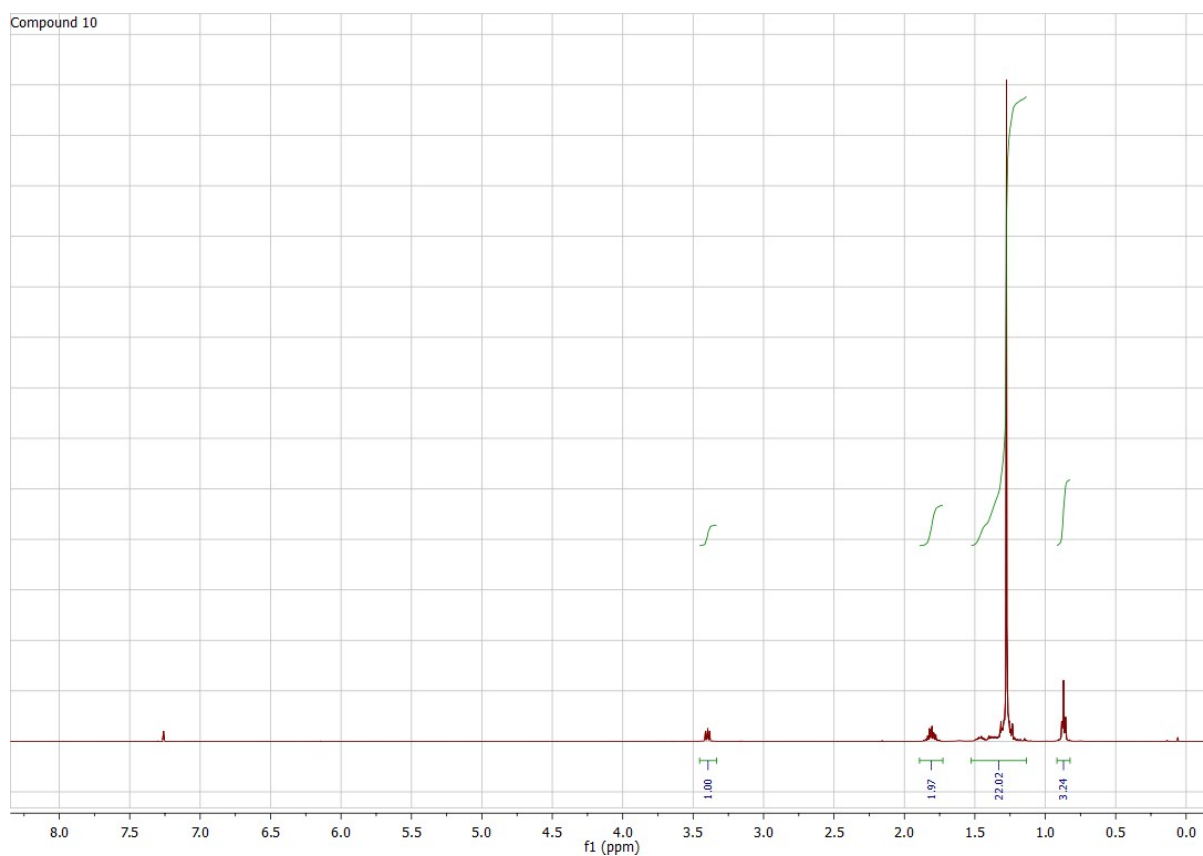
Compound 9



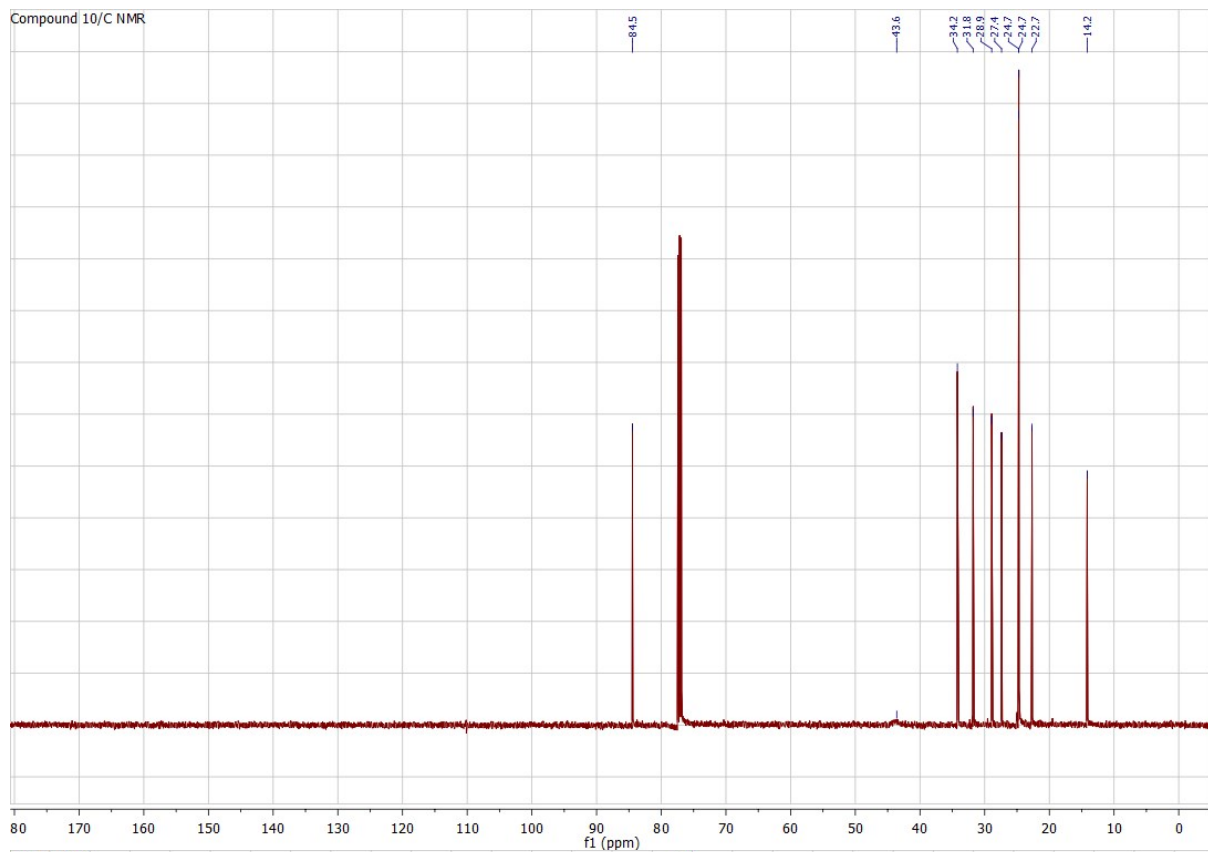
Synthesis of 10¹³



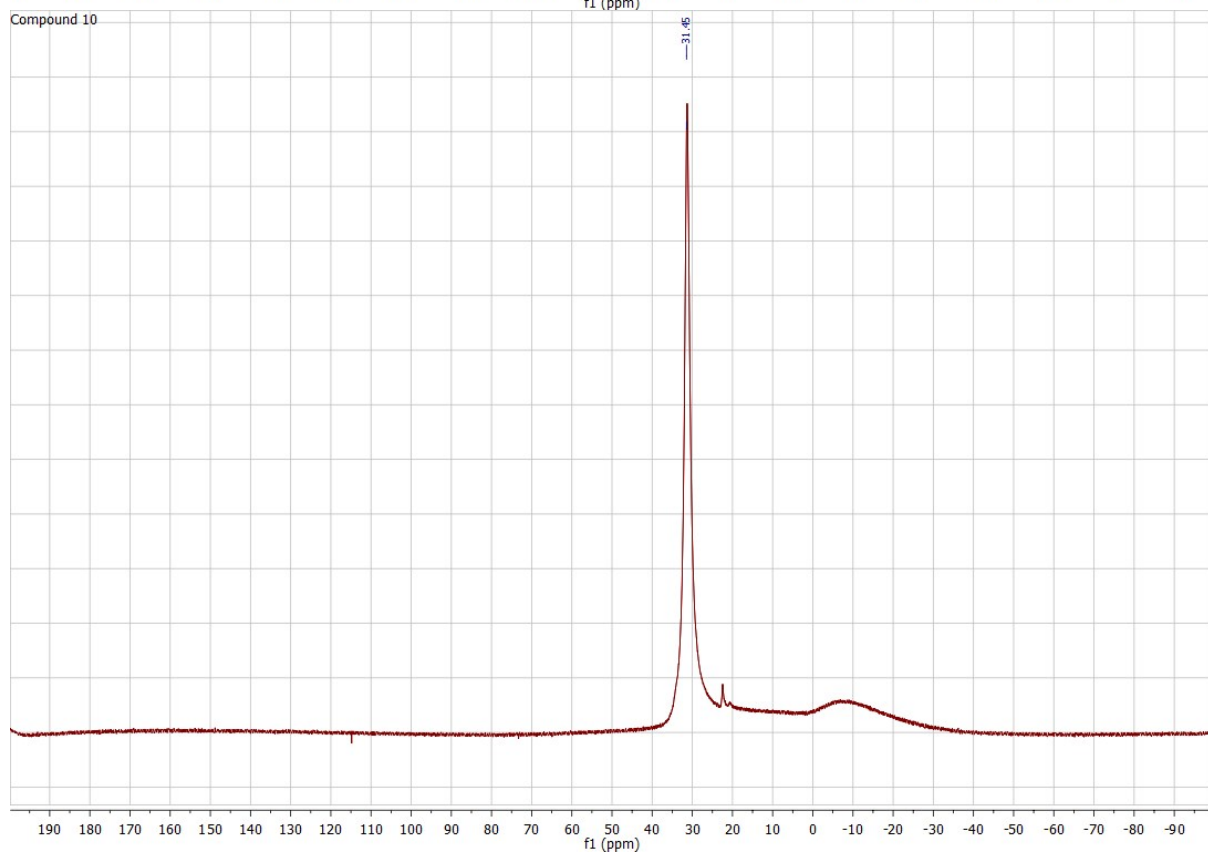
A cold ($-100\text{ }^{\circ}\text{C}$) solution of *n*-BuLi in hexane (1.6 M, 0.62 mL, 1.0 mmol) was added to a cold ($-100\text{ }^{\circ}\text{C}$) stirred mixture of THF (3 mL) and DCM (0.8 mL, 1.2 mmol). The mixture was stirred for 30 min followed by the addition of a solution of pinacol hexylboronate (**9**; 0.21 g, 1.0 mmol) in THF (1 mL). The mixture was warmed up to room temperature and stirred overnight. In the case of using a chiral Lewis acid, the catalyst was added at $-60\text{ }^{\circ}\text{C}$ to the mixture as a solution in an appropriate amount of DCM). The mixture was concentrated under reduced pressure and the residue was purified by column chromatography (silica gel; DCM) to give **10** in high yields (0.23–0.25 g, 88–98%) as a colourless oil. IR (FT) ν_{max} 2958, 1342, 1141, 1214, 1007, 808 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 3.34 (1 H, app. t, J 7 Hz), 1.78 – 1.72 (2 H, m), 1.28 – 1.17 (20 H, m), 0.81 (3 H, t, J 7 Hz); δ_{C} (125 MHz; CDCl_3) 84.5, 43.6 (br), 34.2, 31.8, 28.9, 27.4, 24.7, 24.7, 22.7, 14.2; δ_{B} (160 MHz; CDCl_3) 31.5. MS (EI) m/z (%) 262 ([M, ^{37}Cl]⁺, 2), 260 ([M, ^{35}Cl]⁺, 6), 225 (28), 198 (20), 159 (57), 161 (23), 147 (100), 149 (29), 131 (55), 112 (35), 101 (20), 83 (49), 69 (31); HRMS (EI) m/z calc. for $\text{C}_{13}\text{H}_{26}^{11}\text{BO}_2^{35}\text{Cl}$ [M]⁺ 260.1707, found 260.1705.



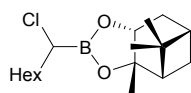
Compound 10/C NMR



Compound 10



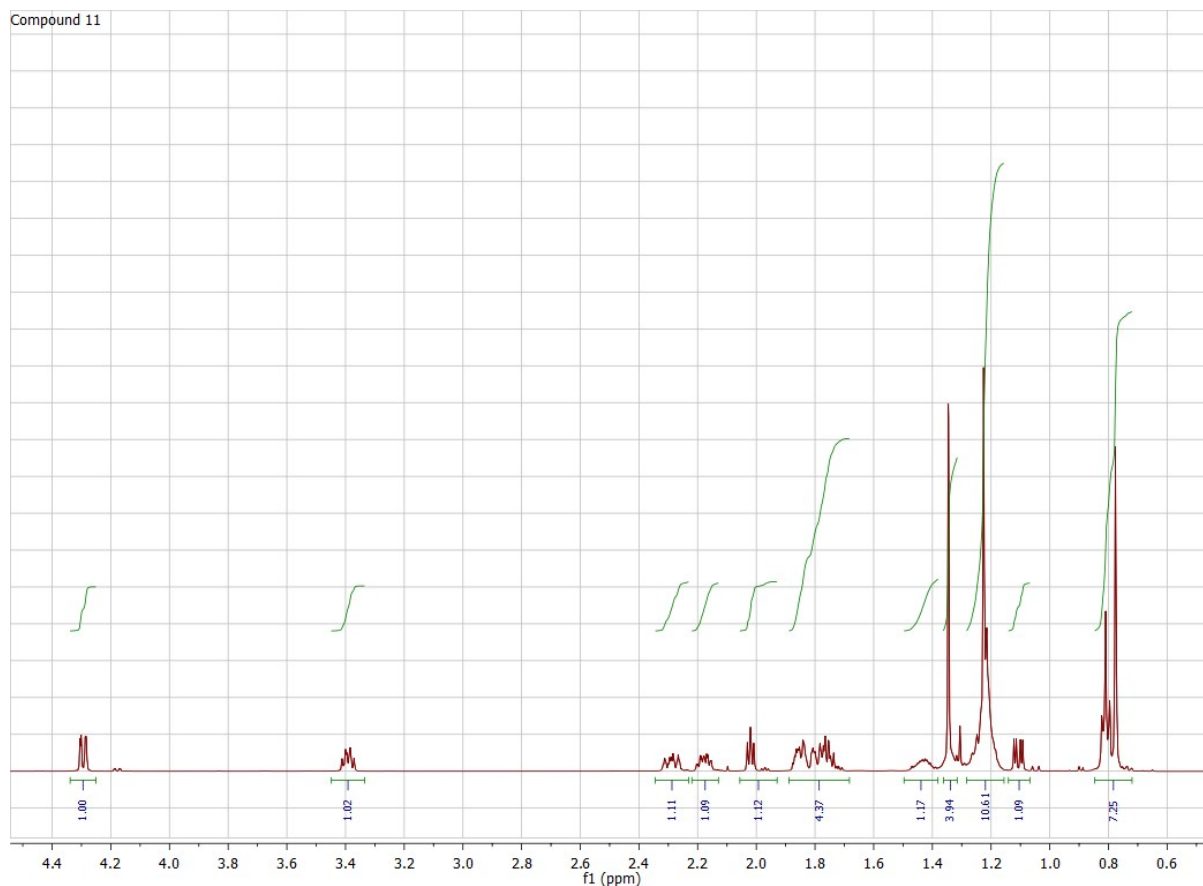
Synthesis of **11**¹⁴



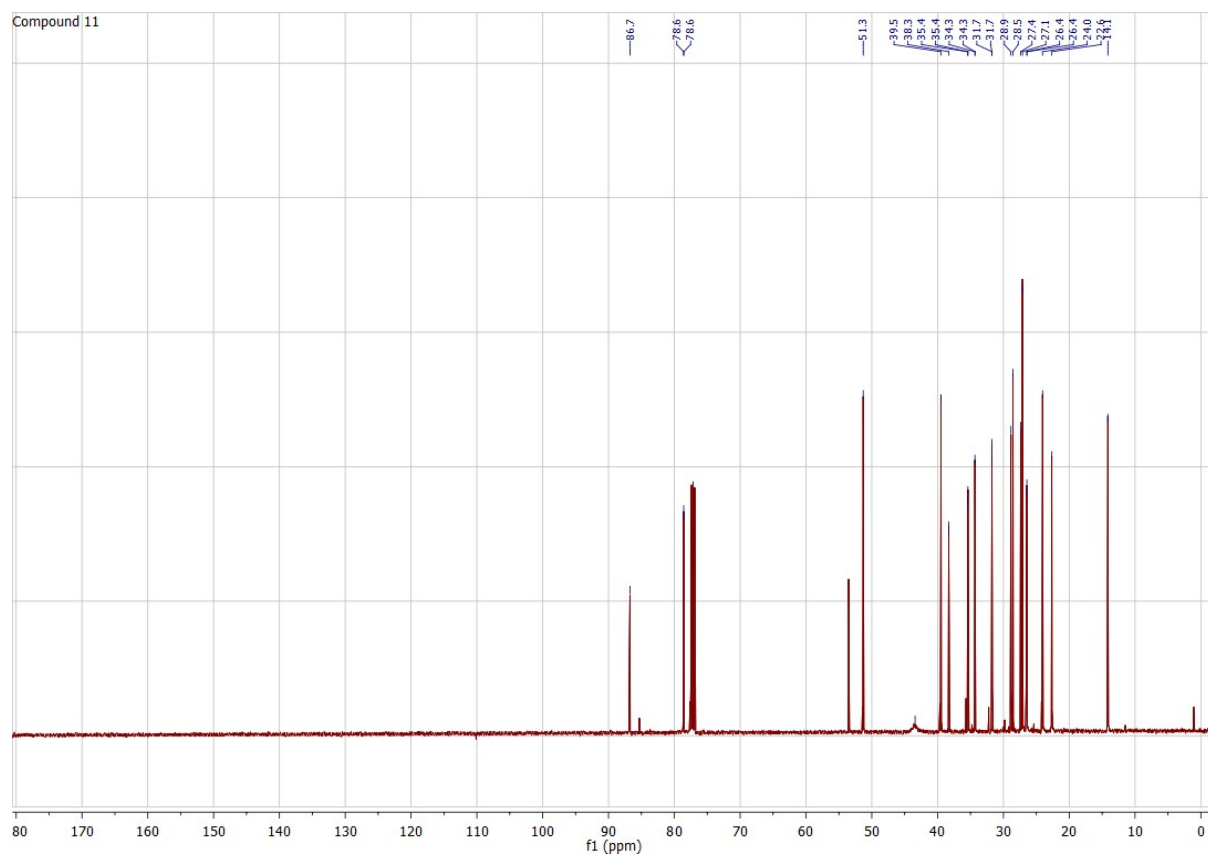
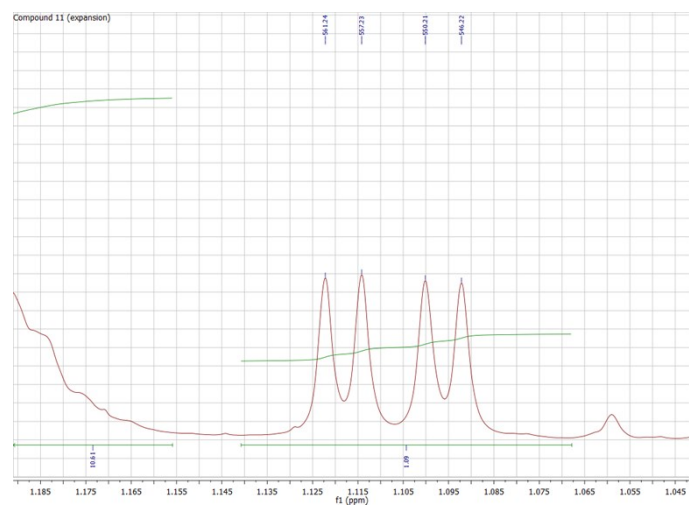
To a stirring mixture of pinacol (α -chloroheptyl)boronate (**10**) (0.23–0.25 g, 0.88–0.98 mmol), Et₂O (25 mL) and a saturated solution of NH₄Cl (20 mL), a solution of (*S*)-pinanediol (0.22–0.25 g, 1.3–1.5 mmol) in Et₂O (3 mL) was added. After 15 min the layers were separated and the organic layer was washed with H₂O (15 mL) and brine (10 mL), then dried (MgSO₄). The solvent was removed under reduced pressure and the crude product was subjected to column chromatography (silica gel; DCM) to give **11** (0.22–0.27 g, 81–90%) as a mixture of two diastereoisomers.

Data from a 1:1 Mixture of Diastereoisomers Derived from Racemic Boronic Ester **10**

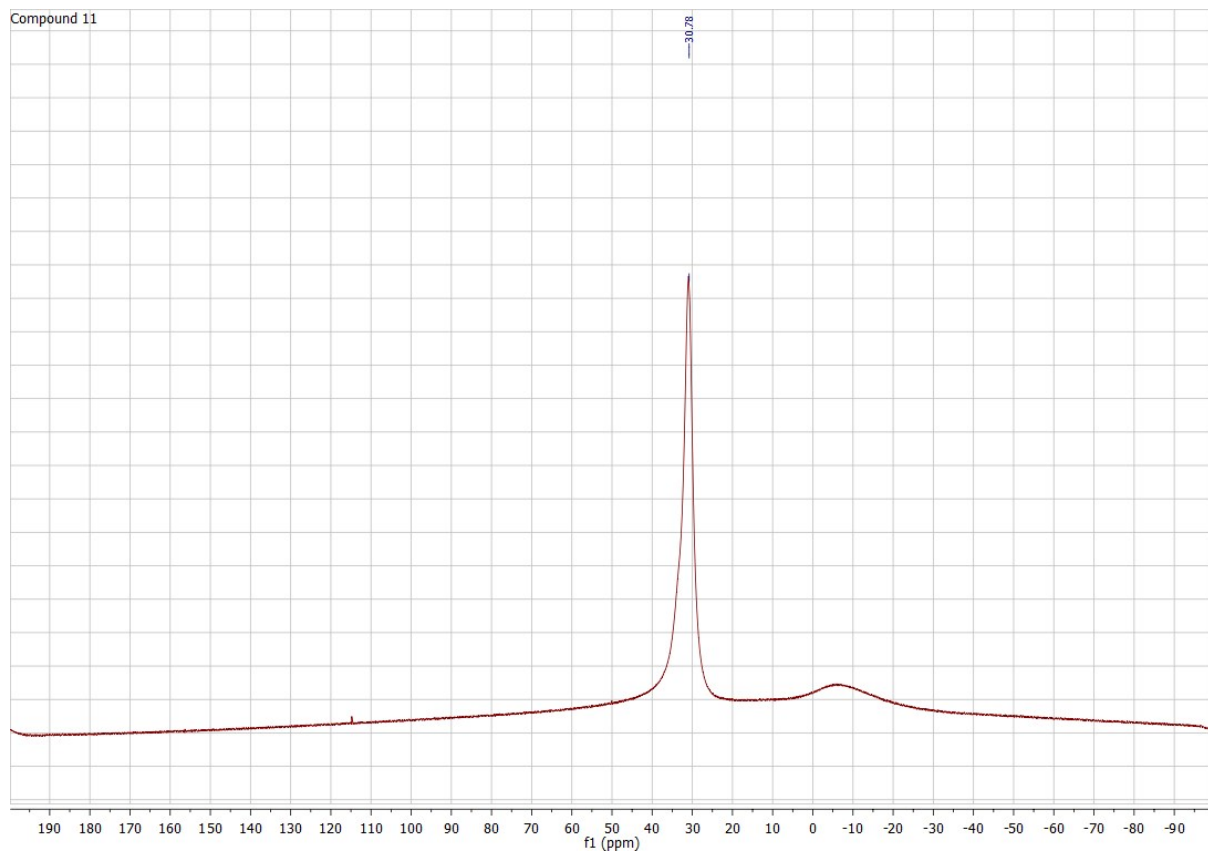
IR (FT) ν_{\max} 2958, 1319, 1114, 1228, 1004, 804, 721 cm⁻¹; δ_{H} (500 MHz; CDCl₃) 4.30 (1 H, dd, J 9, 2 Hz), 3.42 – 3.36 (1 H, m), 2.33 – 2.25 (1 H, m), 2.21 – 2.14 (1 H, m), 2.02 (1 H, app. t, J 6 Hz), 1.89–1.69 (4 H, m), 1.48 – 1.38 (1 H, m), 1.35 (3 H, s), 1.21 – 1.25 (10 H, m), 1.11 (1 H of one diastereoisomer, d, J 11 Hz), 1.10 (1 H of one diastereoisomer, d, J 11 Hz), 0.81 (3 H, t, J 7 Hz), 0.78 (3 H, s); δ_{C} (125 MHz; CDCl₃) 86.7, 78.6, 78.6, 51.3, 43.4 (br), 39.5, 38.3, 38.3, 35.4, 35.4, 34.3, 34.3, 31.7, 31.7, 28.9, 28.6, 27.4, 27.1, 26.5, 26.4, 24.1, 22.7, 14.1; δ_{B} (160 MHz; CDCl₃) 30.8. MS (EI) m/z (%) 354 ([M + MeCNH]⁺, 45), 313 ([MH]⁺, 33), 306 (25), 194 (100); HRMS (EI) m/z calc. for C₁₇H₃₁¹¹BO₂³⁵Cl (MH⁺) 313.2106, found 313.2101.



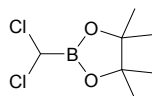
The two doublets appearing at 1.11 and 1.10 ppm (each $J = 11$ Hz and with a combined integration value of 1H) in the ^1H NMR spectrum of **11**, corresponding to the H_{axial} proton at the 7-position of the (*S*)-pinanediol moiety for the two diastereoisomers, were used to calculate the % de.



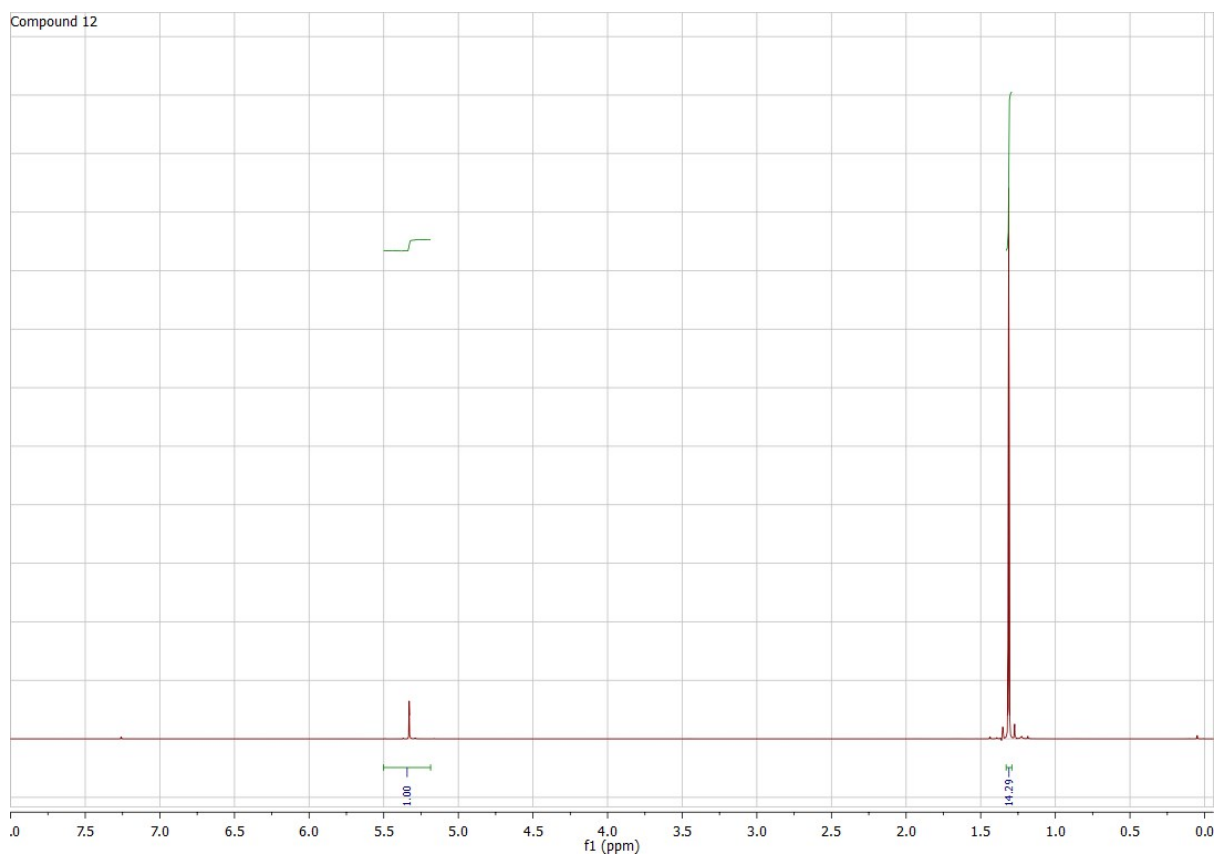
Compound 11



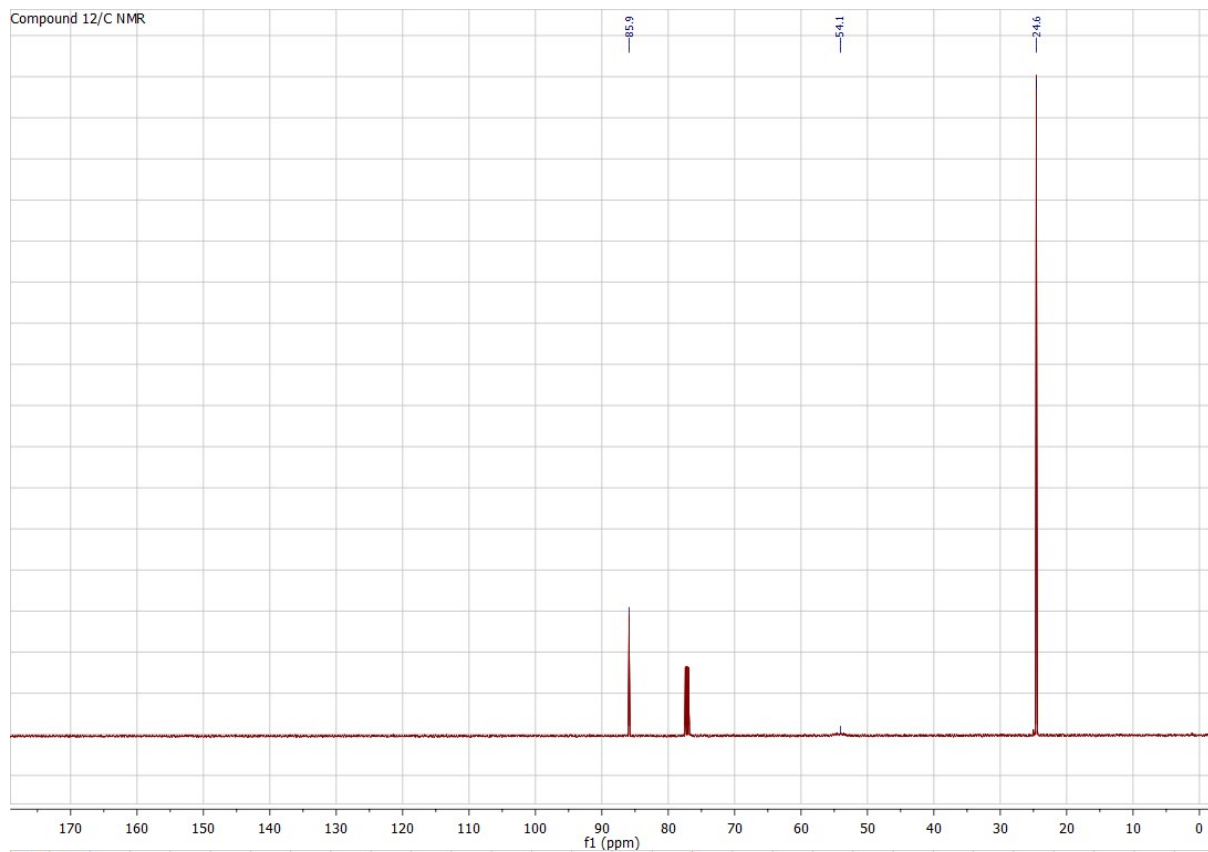
Synthesis of **12**¹⁵



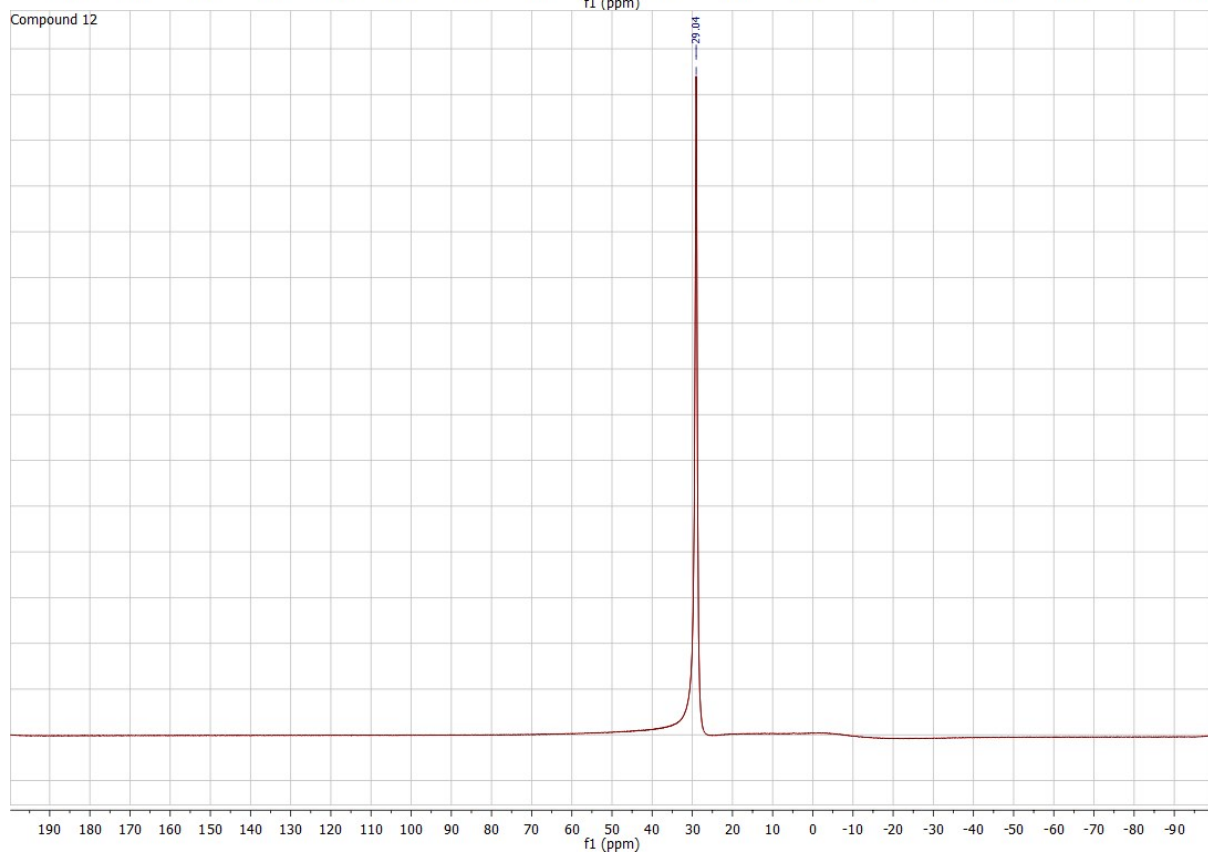
To a stirring solution of DCM (2.8 mL, 44.0 mmol) in THF (80 mL) at $-100\text{ }^{\circ}\text{C}$ was added dropwise a solution of *n*-BuLi in hexane (1.6 M; 27.5 mL, 44.0 mmol). After 30 min, trimethyl borate (5.0 mL, 44.0 mmol) was added and the mixture was stirred for 30 min. HCl (5 M; 9 mL) was added, the mixture was allowed to warm to $20\text{ }^{\circ}\text{C}$ and the layers were then separated. The aqueous layer was extracted with Et_2O ($3 \times 20\text{ mL}$), the extracts were dried (MgSO_4) and the solvent was removed under reduced pressure to give dichloromethylboronic acid. This was dissolved in Et_2O (80 mL) and anhydrous MgSO_4 (10 g) and a solution of pinacol (4.7 g, 40.0 mmol) in Et_2O (10 mL) were added. The mixture was refluxed for 5 h then allowed to cool to $20\text{ }^{\circ}\text{C}$. After filtration, the filtrate was concentrated under reduced pressure. The residue was distilled under low pressure to give **12** (6.1 g, 73%). bp $50\text{--}55\text{ }^{\circ}\text{C}$, 1 torr; (lit.¹⁵ bp $52\text{ }^{\circ}\text{C}$, 1 torr). IR (FT) ν_{max} 2954, 1361, 1114, 1213, 846, 738 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 5.27 (1 H, s), 1.26 (12 H, s); δ_{C} (125 MHz; CDCl_3) 85.9, 54.1, 24.6; δ_{B} (160 MHz; CDCl_3) 29.0; MS (EI) m/z (%) 210 ($[\text{M}]^+$, 25), 195 (59), 167 (23), 151 (90), 102 (89), 89 (100); HRMS (EI) m/z calc. for $\text{C}_7\text{H}_{13}^{11}\text{BO}_2^{35}\text{Cl}_2$ (M^+) 210.0386, found 210.0388.



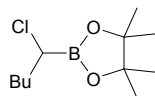
Compound 12/C NMR



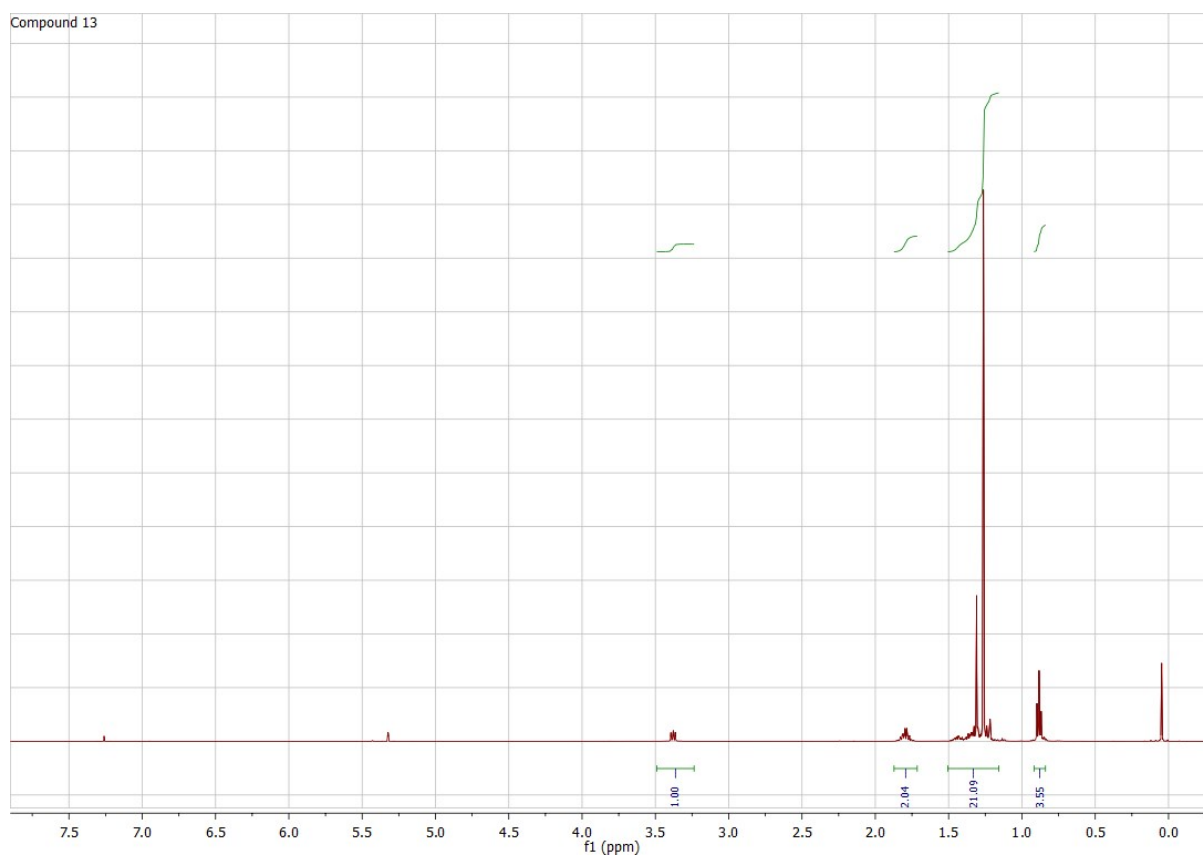
Compound 12



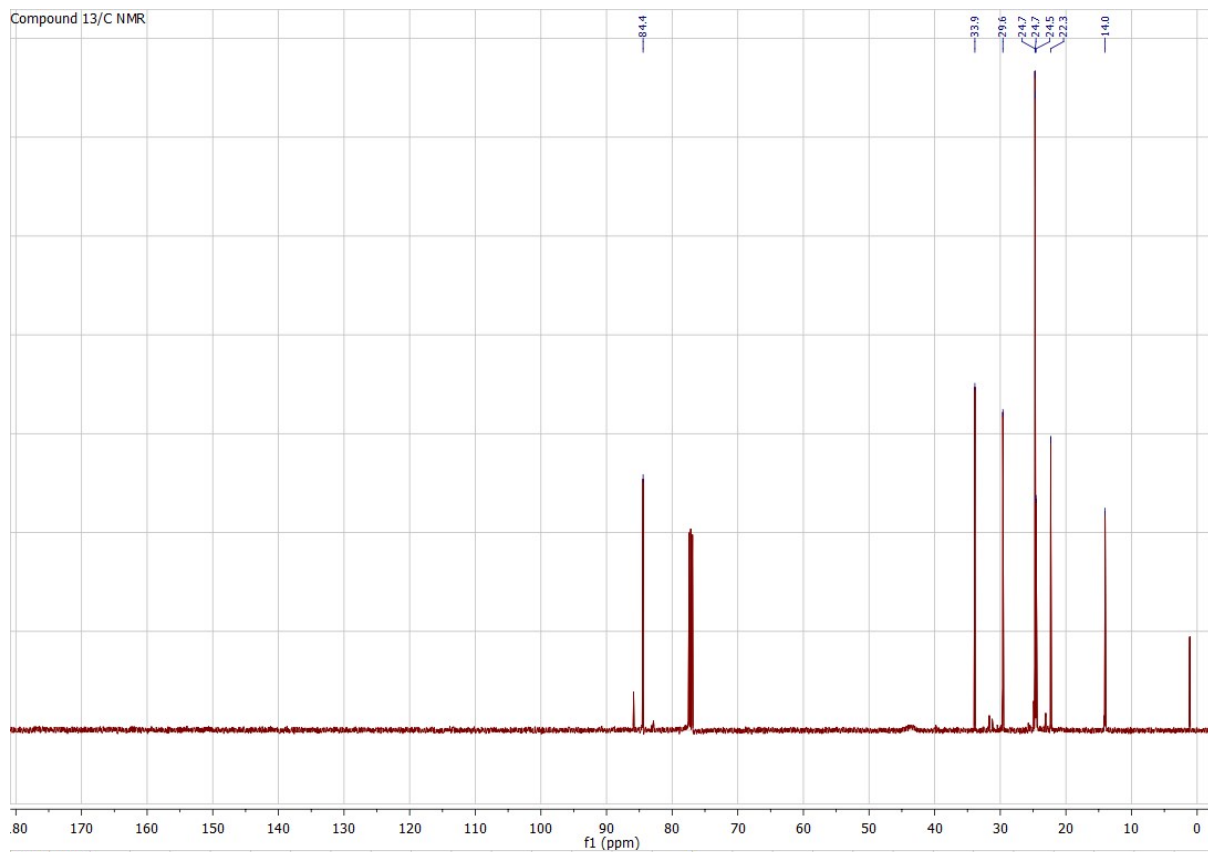
Synthesis of **13**¹⁶



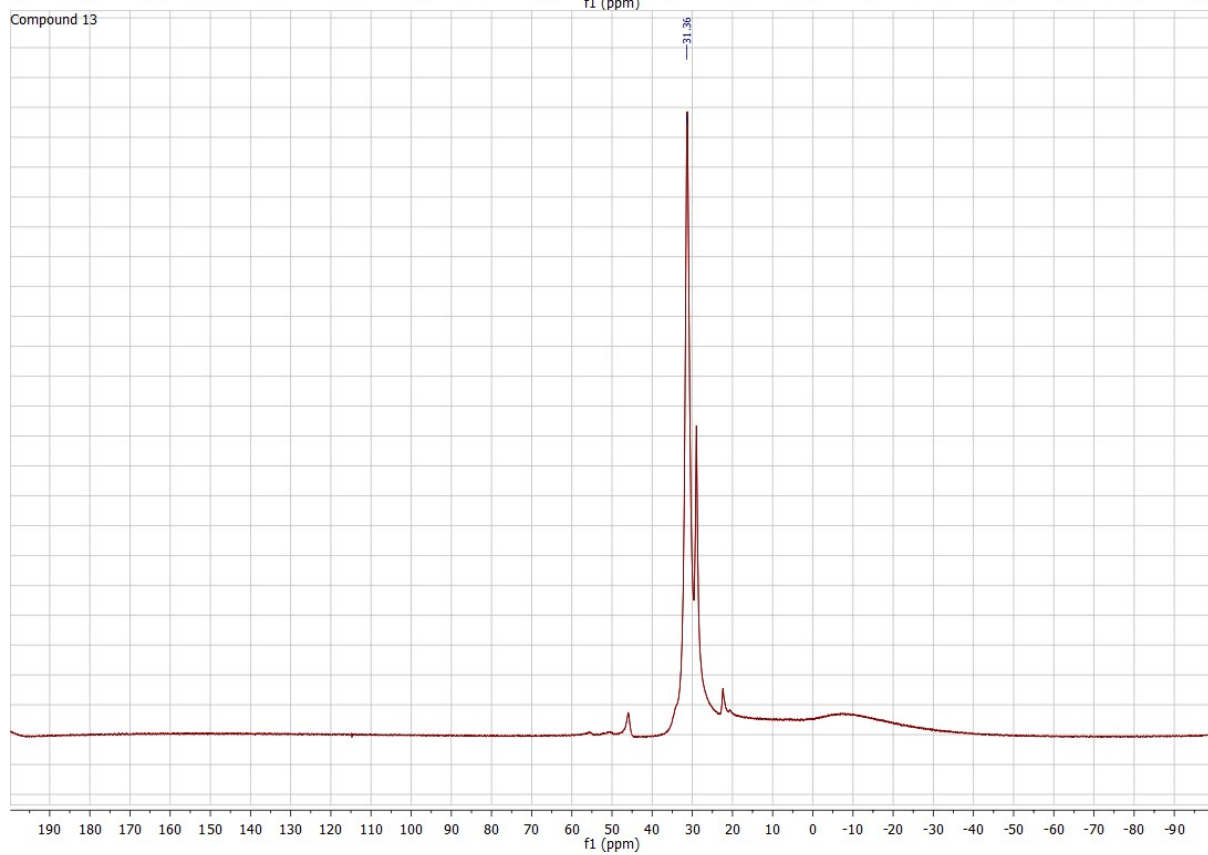
To a stirring solution of pinacol (α,α -dichloromethyl)boronate (**12**, 0.21 g, 1.0 mmol) in dry hexane (1.5 mL) at -40 °C, a solution of *n*-BuLi in hexane (1.6 M; 0.62 mL, 1.0 mmol) was added dropwise. The mixture was warmed up and stirred at 20 °C overnight. The mixture was concentrated under reduced pressure and the residue subjected to column chromatography (silica gel; DCM) to give **13** (0.20 g, 89%) as a colourless oil. IR (FT) ν_{max} 2955, 1339, 1142, 1214, 1005, 801 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 3.32 (1 H, dd, J 9, 7 Hz), 1.77 – 1.71 (2 H, m), 1.27 – 1.12 (16 H, m), 0.83 (3 H, t, J 7 Hz); δ_{C} (125 MHz; CDCl_3) 84.4, 43.7 (br), 33.9, 29.6, 24.7, 24.7, 24.5, 22.3, 14.0; δ_{B} (160 MHz; CDCl_3) 31.4; MS (EI) m/z (%) 234 ($[\text{M}^{37}\text{Cl}]^+$, 4), 232 ($[\text{M}^{35}\text{Cl}]^+$, 8), 217 (10), 197 (19), 170 (44), 163 (40), 147 (100), 131 (91), 118 (31), 83 (55); HRMS (EI) m/z calc. for $\text{C}_{11}\text{H}_{22}\text{BO}_2^{35}\text{Cl}$ (M^+) 232.1401, found 232.1406.



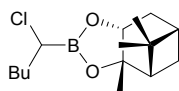
Compound 13/C NMR



Compound 13



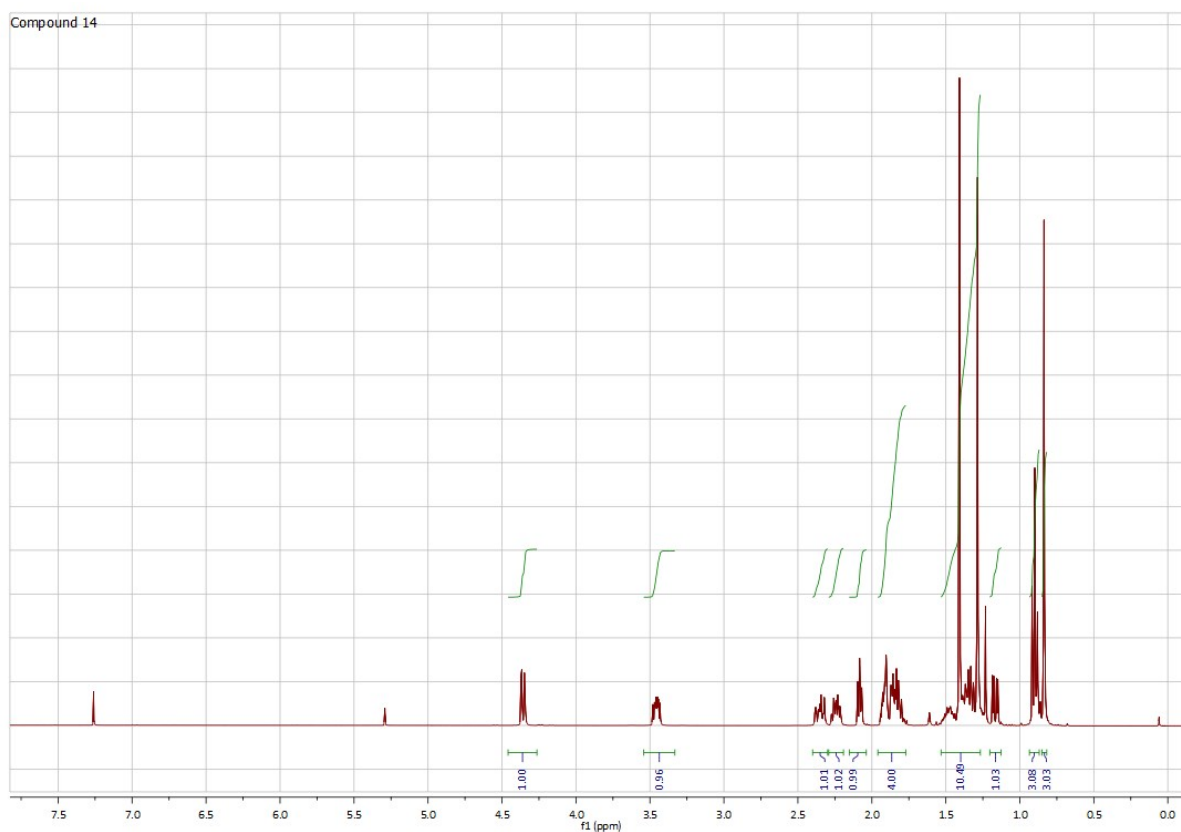
One-pot synthesis of **14**¹⁴

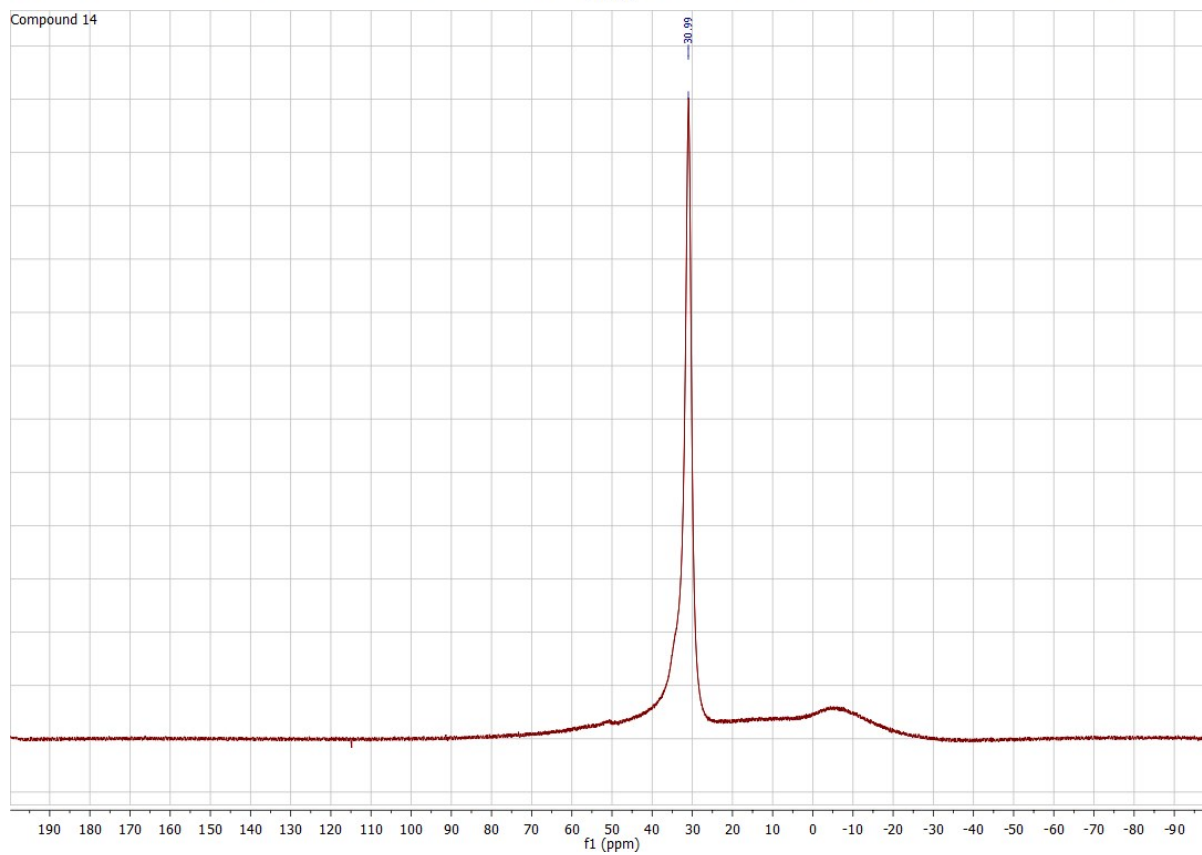
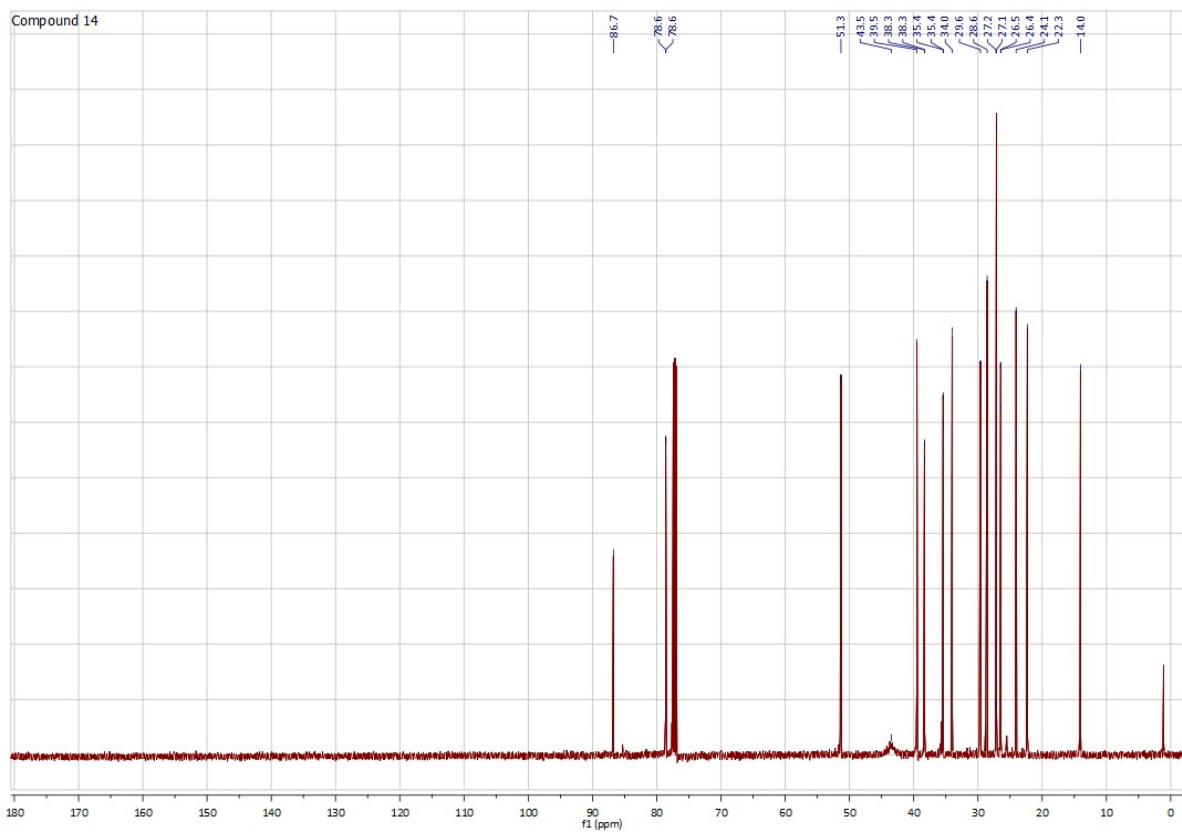


To a cold ($-40\text{ }^{\circ}\text{C}$) solution of **12** (0.21 g, 1.0 mmol) in anhydrous hexane (1.5 mL), *n*-BuLi (1.6 M; 0.62 mL, 1.0 mmol) in hexane was added dropwise. DCM (20 mL) was added to the mixture followed by chiral ligand or Lewis acid or mixture thereof (2.5–3.0 equivalents) as a solid using an addition tube. The mixture was left to warm to $20\text{ }^{\circ}\text{C}$ and then stirred overnight. It was poured onto a mixture of Et₂O (25 mL) and sat. NH₄Cl solution (20 mL), (*S*)-pinanediol (0.20 g, 1.2 mmol) in Et₂O (3 mL) was added and the mixture was stirred for 15 min. After separation, the organic phase was washed with H₂O (15 mL) and NaCl solution (10 mL), dried (MgSO₄), filtered, and evaporated under reduced pressure. The product was subjected to column chromatography (silica gel; DCM) to give pure **14** as a colourless oil (0.24–0.25 g, 84–89%).

Data from a 1:1 Mixture of Diastereoisomers of Compound **14**

IR (FT) ν_{max} 2955, 1314, 1122, 1209, 1029, 805, 733 cm^{-1} ; δ_{H} (400 MHz; CDCl₃) 4.36 (1 H, dd, J 9, 2 Hz), 3.49–3.32 (1 H, m), 2.39–2.32 (1 H, m), 2.27–2.21 (1H, m), 2.08 (1 H, app. t, J 7 Hz), 1.95–1.77 (4 H, m), 1.54–1.22 (4 H, m), 1.41 (3 H, s), 1.28 (3 H, s), 1.17 (1 H of one diastereoisomer, d J 11 Hz), 1.16 (1 H of one diastereoisomer, d, J 11 Hz), 0.90 (3 H, t, J 7 Hz), 0.84 (3 H, s); δ_{C} (125 MHz; CDCl₃) 86.6, 78.5, 51.2, 43.2, 39.4, 38.2, 35.3, 33.9, 29.5, 28.4, 27.0, 26.3, 23.9, 22.2, 13.9; δ_{B} (160 MHz; CDCl₃) 31.0; MS (EI) m/z (%) 286 ([M³⁷Cl]⁺, 2), 284 ([M³⁵Cl]⁺, 8), 214 (69), 199 (90), 145 (100); HRMS (EI) m/z calc. for C₁₅H₂₆¹¹B₂³⁵Cl (M⁺) 284.1714, found: 284.1717.



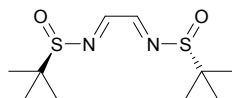


Synthesis of 14 using 12-crown-4

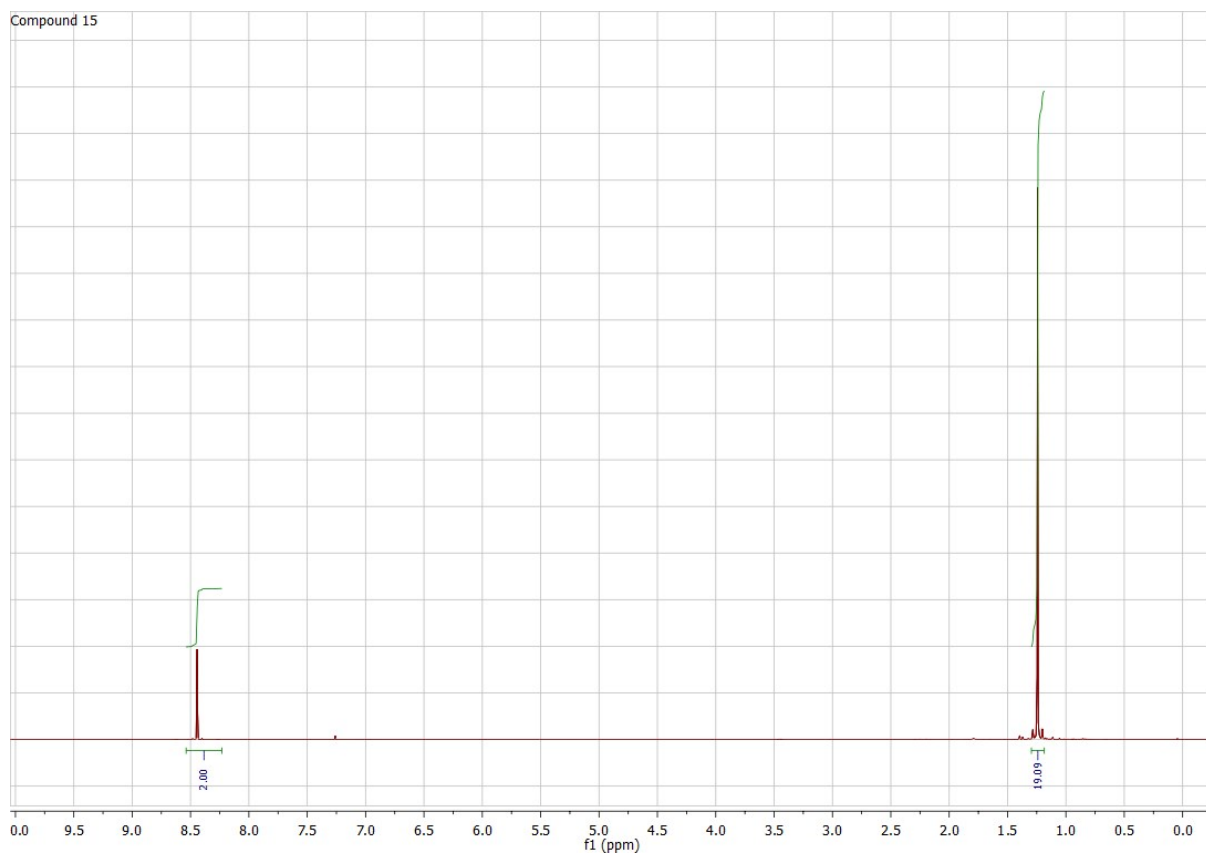
To a solution of **12** (0.21 g, 1.0 mmol) in hexane (1.5 mL) at $-78\text{ }^{\circ}\text{C}$, *n*-BuLi (1.6 M; 0.75 mL, 1.2 mmol) in hexane was added dropwise and the mixture was then stirred for 5 min. To the mixture, a cold solution of 12-crown-4

(0.18 g, 1.0 mmol) in DCM (1 mL) was added. The mixture was stirred for 5 min and cold ($-78\text{ }^{\circ}\text{C}$) DCM (20 mL) was then added. To the mixture, **8** (0.17 g, 0.5 mmol) and $\text{Yb}(\text{OTf})_3$ (0.13 g, 0.2 mmol) were added as solids using an addition tube. The mixture was warmed to $20\text{ }^{\circ}\text{C}$ and stirred for 1 h. Sat. NH_4Cl solution (20 mL) followed by Et_2O (25 mL) and (*S*)-pinanediol (0.17 g, 1.0 mmol) were added and the mixture was stirred for 15 min. The aqueous layer was saturated with NaCl and extracted with CHCl_3 ($3 \times 20\text{ mL}$). The extracts were dried (MgSO_4), filtered, and evaporated under vacuum to give **14** (0.23 g) in 81% yield.

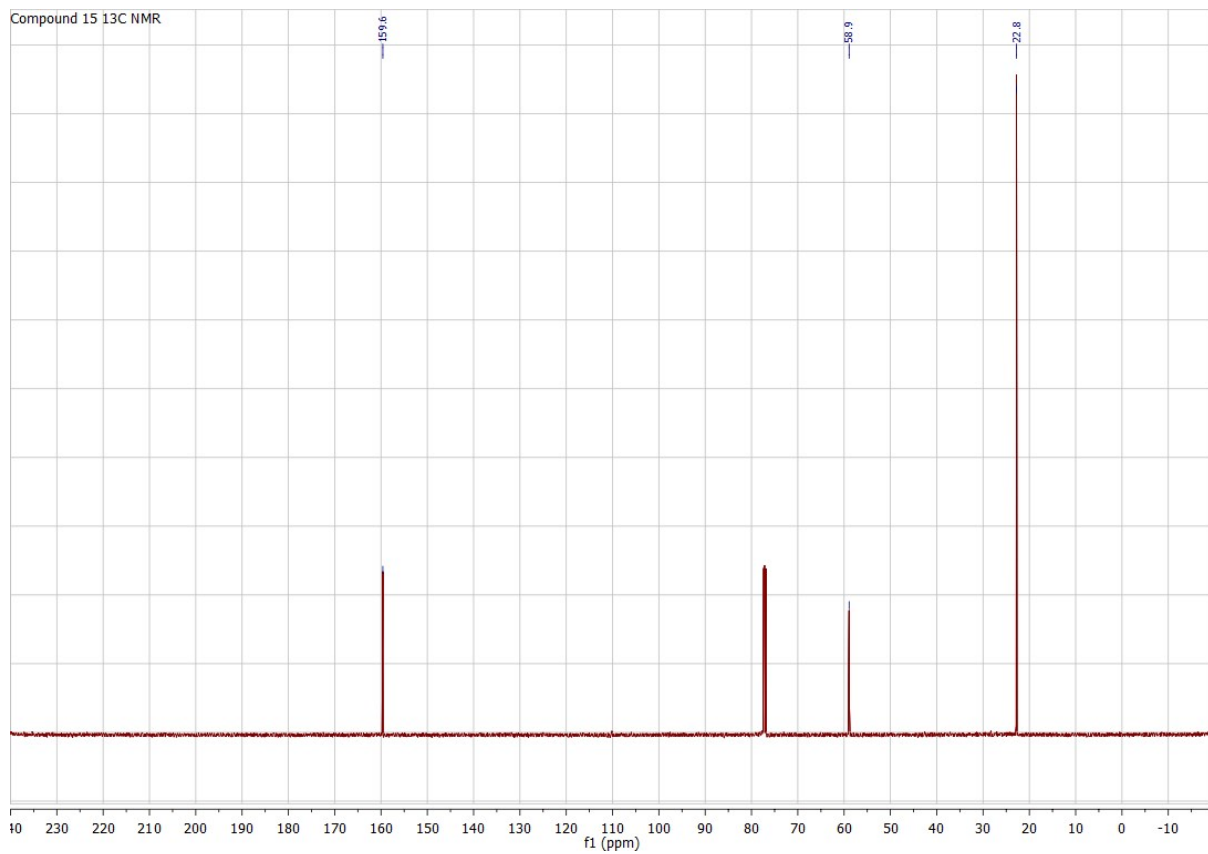
Synthesis of **15**⁷



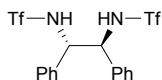
Anhydrous CuSO_4 (6.4 g, 40.0 mmol) followed by aqueous glyoxal (40% w/v; 0.72 mL, 5.0 mmol) were added to a solution of (*R*)-*tert*-butanesulfinamide (1.2 g, 10.0 mmol) in DCM (40 mL). The mixture was stirred at 20 °C for 48 h and then filtered through Celite. The Celite was washed with DCM (3 × 10 mL) and the solvent was removed from the combined filtrates under reduced pressure. The crude product was subjected to column chromatography (silica gel; Et_2O /hexane, 1/1 by volume) and recrystallized from hexane to give pure **15** (0.94 g, 68%) as a pale yellow crystalline solid, mp 117–221 °C. IR (FT) ν_{max} 2982, 1651, 1385, 1128, 1039, 1207 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 8.44 (2 H, s), 1.24 (18 H, s); δ_{C} (125 MHz; CDCl_3) 159.6, 58.9, 22.8; MS (APCI) m/z (%) 265 ($[\text{MH}]^+$, 100), 250 (48), 209 (30), 175 (17), 115 (12); HRMS (APCI) m/z calc. for $\text{C}_{10}\text{H}_{21}\text{N}_2\text{O}_2\text{S}_2$ (MH^+) 265.1044, found 265.1047.



Compound 15 ¹³C NMR

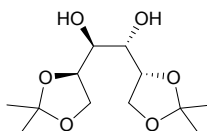


Synthesis of **16**³



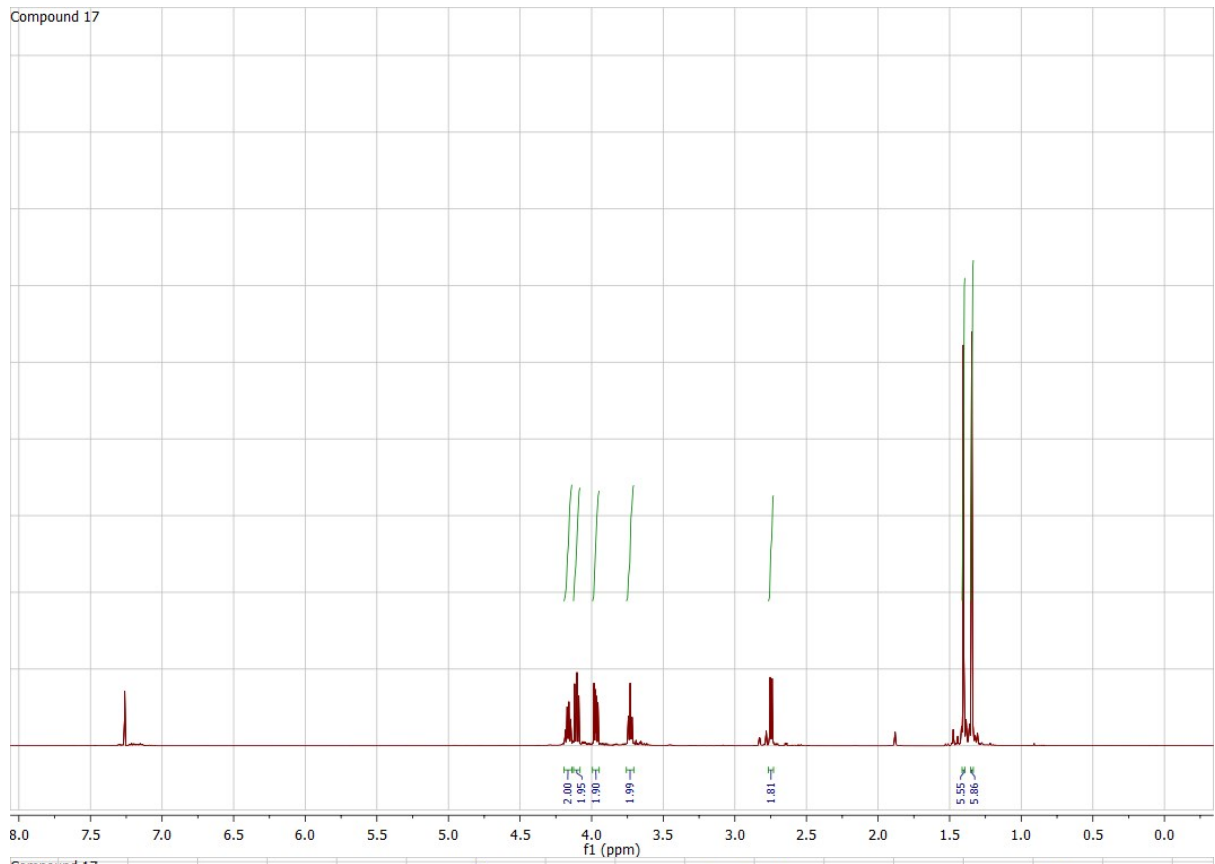
To a stirred solution of (1S,2S)-1,2-diphenylethylenediamine (2.0 g, 9.4 mmol), triethylamine (2.85 g, 28.2 mmol) and 4-dimethylaminopyridine (23 mg, 0.19 mmol) in DCM (15 mL) at $-78\text{ }^{\circ}\text{C}$ was added trifluoromethanesulfonic anhydride (6.37 g, 22.6 mmol) dropwise. The mixture was allowed to warm to $20\text{ }^{\circ}\text{C}$ over 30 min and then poured into aqueous Na_2CO_3 solution (4% w/v, 20 mL). The separated aqueous phase was extracted with DCM ($2 \times 20\text{ mL}$) and the combined organic extracts were washed with HCl (1 M, 20 mL), saturated NaCl solution (20 mL) and H_2O ($2 \times 20\text{ mL}$), then dried (MgSO_4), and evaporated under reduced pressure. The product was subjected to column chromatography (silica gel; Et_2O /hexane, 1/3 by volume) to give **16** (2.5 g, 57%) as colourless crystals, mp $213\text{--}217\text{ }^{\circ}\text{C}$ (lit.³ $213\text{--}214\text{ }^{\circ}\text{C}$); $[\alpha]_D^{20} = -6.7$, CHCl_3 , $c = 0.1$ (lit.⁴ $[\alpha]_D^{20} = -6.8$, CHCl_3 , $c = 0.0277$). IR (FT) ν_{max} 3327, 2916, 285, 1371, 1233, 1207, 1149 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 7.20 – 6.91 (10 H, m), 5.82 (2 H, br. s), 4.72 (2 H, s); δ_{C} (125 MHz; CDCl_3) 149.3, 135.5, 129.0, 128.9, 127.0, 63.7; MS (EI) m/z (%) 407 ($[\text{M} - \text{CF}_3]^+$, 57), 343 (8), 328 (14), 239 (100), 104 (98), 77 (99), 68 (78); HRMS (EI) m/z calc. for $\text{C}_{15}\text{H}_{14}\text{F}_3\text{N}_2\text{O}_4\text{S}_2$ ($[\text{M} - \text{CF}_3]^+$) 407.0303, found: 407.0308.

Synthesis of **17**⁸

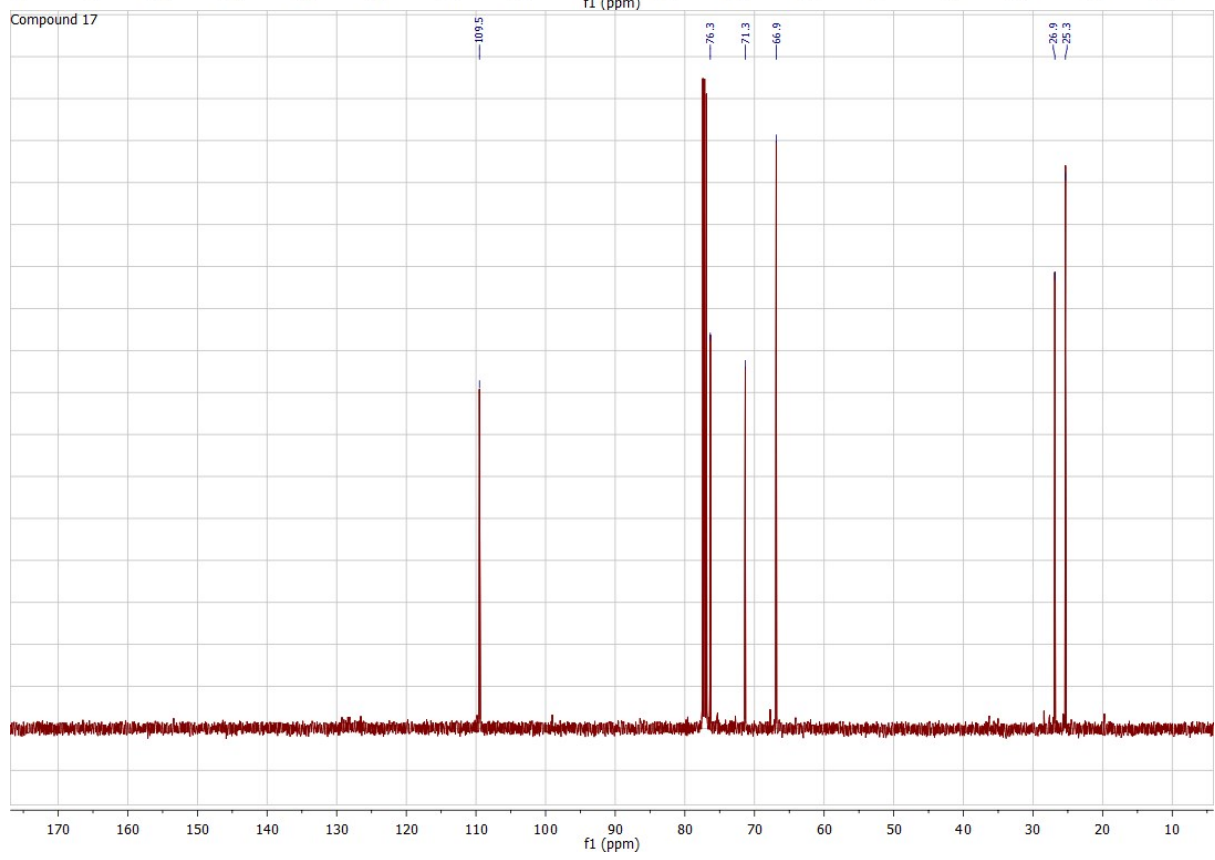


To a solution of anhydrous ZnCl_2 (20.0 g, 146.7 mmol) in dry acetone (200 mL) was added *D*-mannitol (10.0 g, 54.8 mmol) and the mixture was stirred at $20\text{ }^{\circ}\text{C}$ for 4 h, then poured onto a mixture of K_2CO_3 (25.0 g), H_2O (25 mL) and Et_2O (200 mL). The mixture was vigorously stirred for 1.5 h at $20\text{ }^{\circ}\text{C}$, filtered and concentrated under reduced pressure. The solid obtained was recrystallized from acetone to give **17** (11.5 g, 80%) as a colourless solid, mp $119\text{--}122\text{ }^{\circ}\text{C}$ (lit.⁸ $122\text{ }^{\circ}\text{C}$), $[\alpha]_D^{20} = +6.2$, CHCl_3 , $c = 0.5$ (lit.⁸ $[\alpha]_D^{20} = +6 \pm 1$, CHCl_3 , $c = 0.5$). IR (FT) ν_{max} 2992, 1406, 1242, 1066 cm^{-1} ; δ_{H} (500 MHz; CDCl_3) 4.19 (2 H, app. q, J 6 Hz), 4.10 (2 H, dd, J 8, 6 Hz), 3.97 (2 H, dd, J 8, 5 Hz), 3.73 (2 H, app. t, J 6 Hz), 2.75 (2 H, d, J 6 Hz, exch.), 1.40 (6 H, s), 1.35 (6 H, s); δ_{C} (125 MHz; CDCl_3) 109.5, 76.3, 71.3, 66.9, 26.9, 25.3; MS (APCI) m/z (%) 263 ($[\text{MH}]^+$, 65), 205 (53), 188 (100), 187 (27), 147 (87); HRMS (APCI) m/z calc. for $\text{C}_{12}\text{H}_{23}\text{O}_6$ (MH^+) 263.1495, found 263.1487.

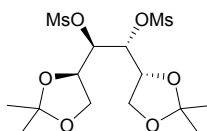
Compound 17



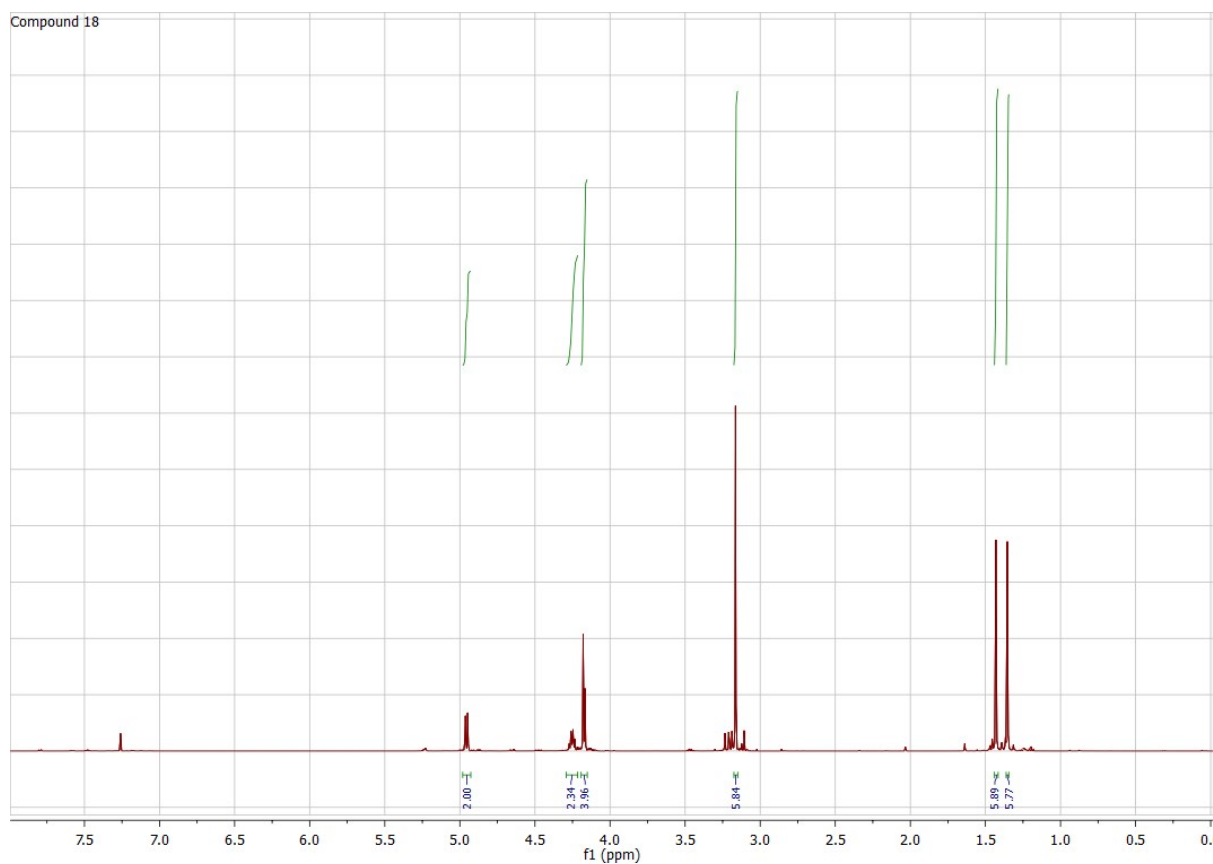
Compound 17



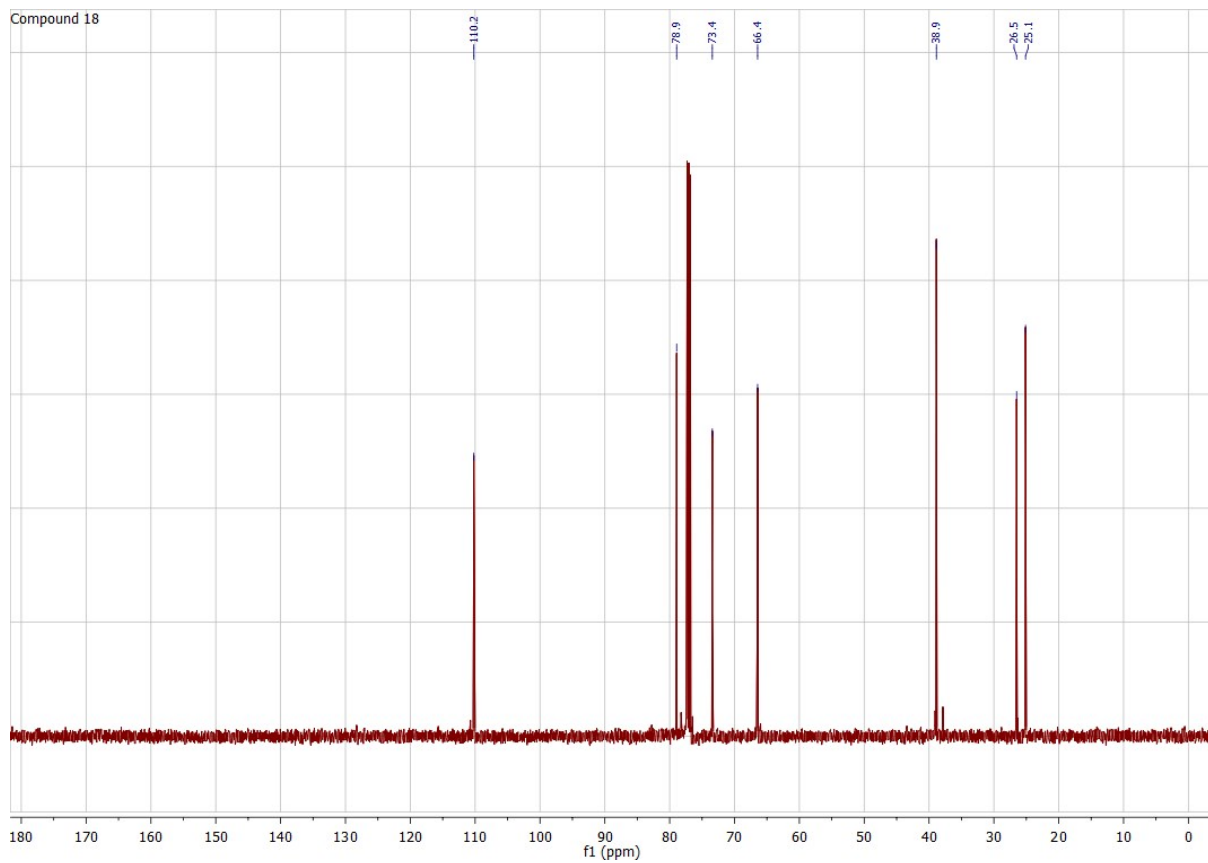
Synthesis of **18**⁹



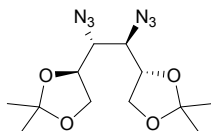
To a stirred solution of **17** (5.0 g, 19.1 mmol) in dry pyridine (25 mL) at 0 °C was added methanesulfonyl chloride (4.8 g, 42.2 mmol) over a period of 15 min. The mixture was stirred for 1.5 h, then stored in a refrigerator for 24 h. Water (2.5 mL) was added, and the mixture was stirred for 15 min. The mixture was poured into cold water (50 mL) and extracted with chloroform (3 × 25 mL). The combined CHCl₃ extracts were washed with HCl (10%, 2 × 20 mL) aqueous Na₂CO₃ (5%, 40 mL) and H₂O (20 mL), dried (MgSO₄), filtered and concentrated under reduced pressure. The product was recrystallized from Et₂O to give pure **18** (6.8 g, 85%) as colourless crystals, mp 137–141 °C (lit.⁹ 135 °C), [α]_D²⁰ = −5.5, CHCl₃, *c* = 0.5 (lit.⁹ [α]_D²⁰ = −5, CHCl₃, *c* = 1). IR (FT) ν_{max} 2953, 1455, 1374, 1219 cm⁻¹; δ_{H} (500 MHz; CDCl₃) 4.96 (2 H, broad d, *J* 7 Hz), 4.25 (2 H, app. q, *J* 6 Hz), 4.19 – 4.16 (4 H, m), 3.16 (6 H, s), 1.43 (6 H, s), 1.35 (6 H, s); δ_{C} (125 MHz; CDCl₃) 110.2, 78.9, 73.4, 66.4, 38.9, 26.5, 25.1; MS (APCI) *m/z* (%) 419 ([MH]⁺, 100), 361 (7), 181 (5), 154 (9); HRMS (APCI) *m/z* calc. for C₁₄H₂₇O₁₀S₂ (MH⁺) 419.1046, found: 419.1044.



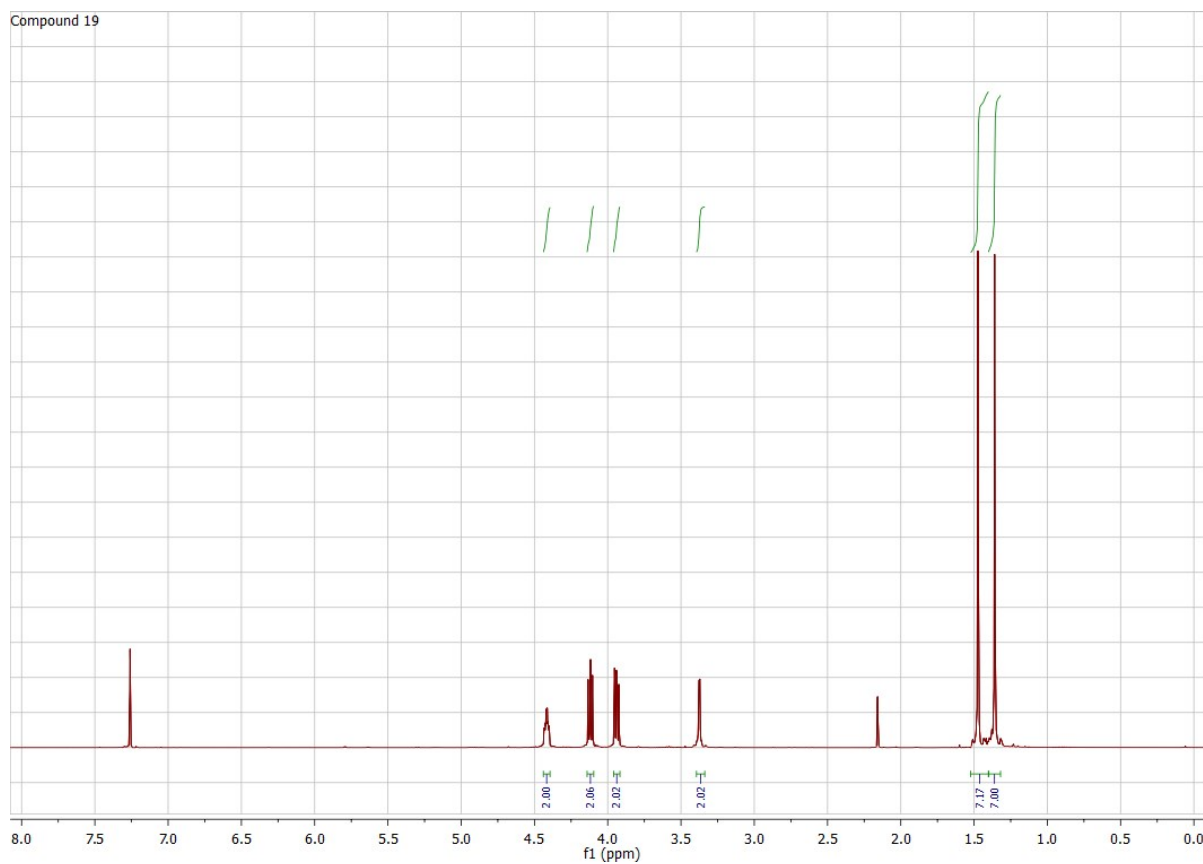
Compound 18



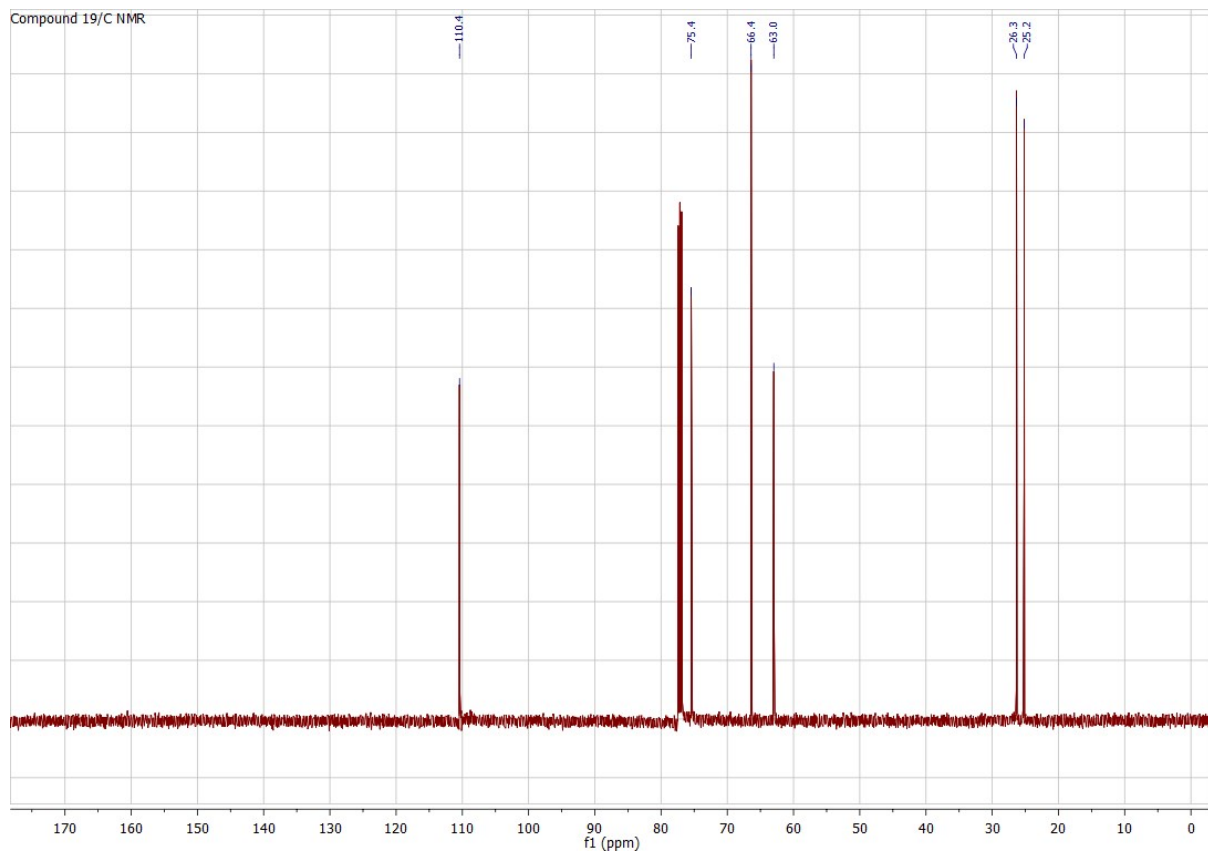
Synthesis of **19**¹⁰



To a stirred solution of **18** (5.0 g, 12.0 mmol) in dry DMF (25 ml) was added sodium azide (1.7 g, 26.4 mmol). The mixture was heated under nitrogen at 90 °C for 48 h, then cooled to 20 °C and concentrated under reduced pressure. The product was subjected to column chromatography (silica gel; Et₂O/hexane, 1/5 by volume) to give pure **19** (2.0 g, 54%) as a pale yellow oil. $[\alpha]^{20}_{\text{D}} = +127$, CHCl₃, $c = 0.5$ (lit.¹⁰ $[\alpha]^{20}_{\text{D}} = +130$, CHCl₃, $c = 1$). IR (FT) ν_{max} 2934, 2109, 1452, 1258 cm⁻¹; δ_{H} (500 MHz; CDCl₃) 4.44 – 4.39 (2 H, m), 4.12 (2 H, dd, J 8, 6 Hz), 3.94 (2 H, dd, J 8, 6 Hz), 3.38 (2 H, dd, J 3, 1 Hz), 1.47 (6 H, s), 1.36 (6 H, s); δ_{C} (125 MHz; CDCl₃) 110.4, 75.4, 66.4, 63.0, 26.3, 25.2; MS (EI) m/z (%) 297 ([M – Me]⁺, 5), 269 (7), 213 (12), 183 (49), 101 (53), 84 (100), 73 (44), 59 (36); HRMS (EI) m/z calc. for C₁₁H₁₇N₆O₄ ([M – Me]⁺) 297.1311, found 297.1313.



Compound 19/C NMR



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