Supporting Information

Anti-markovnikov radical hydroxychlorination of alkenes enabled by amine-promoted chlorine radical generation

Renhua Su[a], Duoduo Xiao[a,*], Yanfu Jiang[a], Xian Jiang, Jiantao Zhang[a,*], Yaju Chen[a], and Weibing Liu[a,*]

[a] College of Chemistry, Guangdong University of Petrochemical Technology, Kechuang Road, Maoming, 525024, China;

*Emails: dd.xiao@gdupt.edu.cn, zhangjt@gdupt.edu.cn, lwb409@gdupt.edu.cn.

Table of contents

General Information.....2

General Procedures for Products **4**.....2

References.....5

Radical inhibition and trapping experiments 6

Possible Mechanism for the Synthesis of **4**.....8

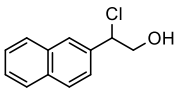
Copies of ^{1}H, ^{13}C NMR spectra 9

General Information.

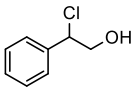
Unless otherwise stated, all reagents were used as received from commercial sources and used without purification. All reactions (for the synthesis of **4**) were carried out at 60 ℃ (oil bath) in a round-bottom flask equipped with a magnetic stir bar. ^{1}H, ^{13}C NMR spectra were recorded on a Bruker AVANCE (400 MHz for ^{1}H; 101 MHz for ^{13}C) in $CDCl_3$ with tetramethylsilane as the internal standard. Chemical shifts (δ) are reported in ppm, and coupling constants (J) are in Hertz (Hz). Mass spectra were obtained from high resolution *ESI* mass spectrometer. The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. HR-MS were obtained on a quadrupole time-off light (Q-TOF) micro spectrometer.

General Procedures for Products 4

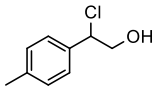
To a solution of **1** (0.5 mmol, 1.0 equiv.) in 1,1,2,2-tetrachloroethane (**2a**, 0.5 mL) was added TBHP (5.5 M in decane, 3.0 mmol, 6.0 equiv.), $HNEt_2$ (0.5 mmol, 1.0 equiv.), TMSCN (2.0 mmol, 4.0 equiv.) and CH_3CN at room temperature in a N_2 atmosphere. Then the solution mixture was stirred at 60 ℃ for 24 h, after completion of the reaction, the solvent was removed under reduced pressure and the crude product was subjected to silica gel column chromatography to afford **4**.



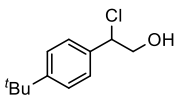
4a[1], yield (65%), yellow oil; R_f = 0.36 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.98 – 7.76 (m, 4H), 7.54 (dd, J = 6.3, 3.1 Hz, 3H), 5.27 – 5.12 (m, 1H), 4.16 – 3.98 (m, 2H), 2.15 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.1, 133.4, 133.0, 128.9, 128.1, 127.8, 127.0, 126.74, 126.66, 124.7, 67.8, 65.0. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_{12}H_{11}ClONa^+$ 229.0391; Found 229.0384.



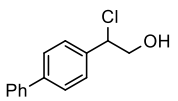
4b[1], yield (68%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 – 7.32 (m, 5H), 5.02 (dd, J = 7.4, 5.7 Hz, 1H), 4.03 – 3.87 (m, 2H), 2.23 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.8, 128.9, 128.8, 127.5, 67.9, 64.9.



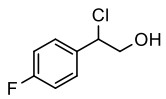
4c[1], yield (70%), yellow oil; R_f = 0.36 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 – 7.42 (m, 1H), 7.30 – 7.24 (m, 2H), 7.22 (dd, J = 9.9, 4.3 Hz, 1H), 5.31 (dd, J = 8.1, 5.0 Hz, 1H), 4.00 (qd, J = 12.1, 6.6 Hz, 2H), 2.44 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.9, 130.8, 128.7, 126.7, 67.0, 61.3, 19.2.



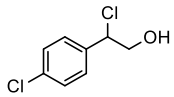
4d[1], yield (72%), yellow oil; R_f = 0.38 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 – 7.40 (m, 2H), 7.36 (d, J = 8.4 Hz, 2H), 5.01 (dd, J = 7.5, 5.6 Hz, 1H), 4.00 – 3.88 (m, 2H), 2.34 (s, 1H), 1.35 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 152.0, 134.8, 127.2, 125.8, 67.8, 64.8, 34.7, 31.3. HRMS (*ESI*) m/z: $[M+Na]^+$ Calcd for $C_{12}H_{17}ClONa^+$ 235.0860; Found 235.0857.



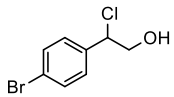
4e, yield (67%), yellow oil; R_f = 0.37 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 – 7.59 (m, 4H), 7.51 (dd, J = 8.5, 2.0 Hz, 2H), 7.49 – 7.44 (m, 2H), 7.40 (ddd, J = 7.4, 3.8, 1.2 Hz, 1H), 5.08 (dd, J = 7.3, 5.7 Hz, 1H), 4.12 – 3.92 (m, 2H), 2.20 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.9, 140.4, 136.8, 128.9, 127.9, 127.7, 127.6, 127.1, 67.9, 64.7. HRMS (*ESI*) m/z: $[M+Na]^+$ Calcd for $C_{14}H_{13}ClNaO^+$ 255.0547; Found 255.0552.



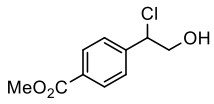
4f, yield (62%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 – 7.36 (m, 2H), 7.16 – 7.00 (m, 2H), 5.00 (dd, J = 7.3, 5.6 Hz, 1H), 4.00 – 3.83 (m, 2H), 2.08 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.8 (d, J = 248.2 Hz), 133.8 (d, J = 3.4 Hz), 129.3 (d, J = 8.4 Hz), 115.8 (d, J = 21.7 Hz), 67.8, 64.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ -112.56. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9ClFO^+$ 175.0320; Found 175.0316.



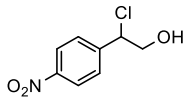
4g[1], yield (64%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 – 7.27 (m, 4H), 5.07 – 4.83 (m, 1H), 3.93 (dd, J = 5.4, 1.8 Hz, 2H), 2.23 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.4, 134.8, 129.0, 128.9, 67.7, 63.9. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9Cl_2O^+$ 191.0025; Found 191.0016.



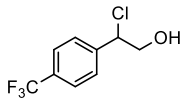
4h[1], yield (60%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 – 7.46 (m, 2H), 7.33 – 7.19 (m, 2H), 5.03 – 4.87 (m, 1H), 4.01 – 3.82 (m, 2H), 2.18 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.9, 132.0, 129.2, 122.9, 67.7, 63.9. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9ClBrO^+$ 234.9520; Found 234.9515.



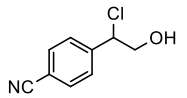
4i, yield (53%), yellow oil; R_f = 0.32 (EtOAc/cyclohexane = 1/8). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 – 8.02 (m, 2H), 7.59 – 7.43 (m, 2H), 5.09 – 4.97 (m, 1H), 4.00 – 3.95 (m, 2H), 3.95 (s, 3H), 2.23 (t, J = 6.8 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.5, 142.7, 130.6, 130.0, 127.6, 126.1, 67.7, 63.9, 52.3. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_{10}H_{12}ClO_3^+$ 215.0469; Found 215.0459.



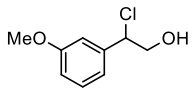
4j, yield (39%), yellow oil; R_f = 0.37 (EtOAc/cyclohexane = 1/5). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (d, J = 8.7 Hz, 2H), 7.64 (d, J = 8.7 Hz, 2H), 5.08 (t, J = 6.2 Hz, 1H), 4.00 (d, J = 6.2 Hz, 2H), 2.30 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.0, 131.3, 128.6, 124.0, 67.5, 62.8. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9ClNO_3^+$ 202.0265; Found 202.0261.



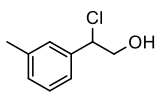
4k[1], yield (42%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, J = 8.3 Hz, 2H), 7.57 (d, J = 8.1 Hz, 2H), 5.05 (t, J = 6.3 Hz, 1H), 3.97 (t, J = 6.2 Hz, 2H), 2.22 (t, J = 6.6 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.9 – 141.7 (m),131.2, 130.9, 127.9, 126.0 – 125.6 (m), 125.2, 122.5, 67.7, 63.6. ^{19}F NMR (376 MHz, $CDCl_3$) δ -62.77. HRMS (*ESI*) m/z: $[M+K]^+$ Calcd for $C_9H_8ClF_3OK^+$ 262.9853; Found 262.9856.



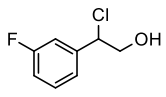
4l[1], yield (40%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/5). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, J = 8.4 Hz, 2H), 7.57 (d, J = 8.3 Hz, 2H), 5.03 (t, J = 6.2 Hz, 1H), 4.07 – 3.88 (m, 2H), 2.20 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.1, 132.6, 128.4, 118.3, 112.7, 67.5, 63.3.



4m, yield (67%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/8). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 (dd, J = 14.2, 6.3 Hz, 1H), 7.02 – 6.96 (m, 2H), 6.91 (ddd, J = 8.3, 2.6, 0.9 Hz, 1H), 4.98 (dd, J = 7.1, 6.0 Hz, 1H), 3.98 – 3.92 (m, 2H), 3.84 (s, 3H), 2.20 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.8, 139.3, 129.9, 119.7, 114.3, 113.2, 67.9, 64.7, 55.3. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_9H_{12}ClO_2^+$ 187.0520; Found 187.0526.

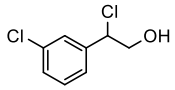


4n, yield (65%), yellow oil; R_f = 0.36 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (dd, J = 9.6, 5.3 Hz, 1H), 7.23 (d, J = 9.8 Hz, 2H), 7.18 (d, J = 7.5 Hz, 1H), 4.98 (dd, J = 7.5, 5.7 Hz, 1H), 4.04 – 3.85 (m, 2H), 2.40 (s, 3H), 2.29 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.6, 137.8, 129.7, 128.7, 128.1, 124.5, 67.9, 64.9, 21.4. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_9H_{12}ClO^+$ 171.0571; Found 171.0570.

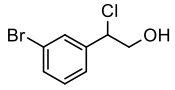


4o, yield (56%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (td, J = 8.0, 5.9 Hz, 1H), 7.18 (ddd, J = 9.7, 6.4, 4.8 Hz, 2H), 7.12 –

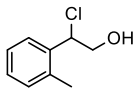
7.00 (m, 1H), 4.99 (t, J = 6.4 Hz, 1H), 3.95 (d, J = 6.5 Hz, 2H), 2.20 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.8 (d, J = 247.1 Hz), 140.3 (d, J = 7.3 Hz), 130.4 (d, J = 8.2 Hz), 123.2 (d, J = 3.0 Hz), 115.9 (d, J = 21.1 Hz), 114.6 (d, J = 22.7 Hz), 67.8, 63.8. ^{19}F NMR (376 MHz, $CDCl_3$) δ -111.96. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9ClFO^+$ 175.0320; Found 175.0319.



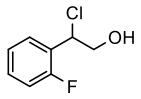
4p, yield (60%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 – 7.40 (m, 1H), 7.37 – 7.28 (m, 3H), 5.06 – 4.90 (m, 1H), 3.94 (d, J = 6.5 Hz, 2H), 2.22 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.9, 134.7, 130.1, 129.0, 127.7, 125.7, 67.7, 63.7. HRMS (*ESI*) m/z: $[M+Na]^+$ Calcd for $C_8H_8Cl_2O^+$ 212.9844; Found 212.9851.



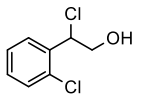
4q, yield (59%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (t, J = 1.8 Hz, 1H), 7.49 (m, 1H), 7.36 (dd, J = 6.6, 1.2 Hz, 1H), 7.28 (d, J = 7.8 Hz, 1H), 4.94 (t, J = 6.4 Hz, 1H), 4.04 – 3.85 (m, 2H), 2.41 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.1, 132.0, 130.6, 130.3, 126.2, 122.8, 67.7, 63.6. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_8H_9ClBrO^+$ 234.9520; Found 234.9514.



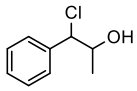
4r, yield (60%), yellow oil; R_f = 0.36 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (dd, J = 6.5, 2.6 Hz, 1H), 7.29 – 7.25 (m, 2H), 7.24 – 7.19 (m, 1H), 5.31 (dd, J = 8.1, 5.0 Hz, 1H), 4.10 – 3.85 (m, 2H), 2.44 (s, 3H), 2.35 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.9, 130.8, 128.7, 126.9, 126.7, 67.0, 61.3, 19.2. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_9H_{12}ClO^+$ 171.0571; Found 171.0565.



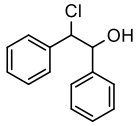
4s, yield (57%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (t, J = 7.4 Hz, 1H), 7.39 – 7.31 (m, 1H), 7.21 (t, J = 7.6 Hz, 1H), 7.15 – 7.02 (m, 1H), 5.38 (t, J = 6.3 Hz, 1H), 4.00 (d, J = 6.3 Hz, 2H), 2.27 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.8 (d, J = 248.3 Hz), 130.5 (d, J = 8.4 Hz), 129.1 (d, J = 3.1 Hz), 125.1 (d, J = 12.8 Hz), 124.6 (d, J = 3.6 Hz), 115.7 (d, J = 21.8 Hz), 66.9, 57.7, 26.3. ^{19}F NMR (376 MHz, $CDCl_3$) δ -117.50. HRMS (*ESI*) m/z: $[M+K]^+$ Calcd for $C_8H_8ClFOK^+$ 212.9885; Found 212.9879.



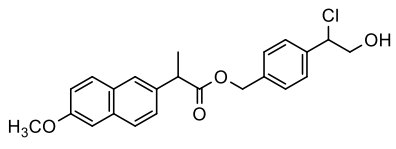
4t[1], yield (54%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (dd, J = 7.6, 1.8 Hz, 1H), 7.41 (dd, J = 7.7, 1.5 Hz, 1H), 7.35 (td, J = 7.5, 1.5 Hz, 1H), 7.32 – 7.27 (m, 1H), 5.59 (dd, J = 7.7, 4.4 Hz, 1H), 4.01 (d, J = 11.8 Hz, 1H), 3.91 (d, J = 11.9 Hz, 1H), 2.28 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.3, 133.0, 129.8, 129.7, 129.1, 127.4, 66.8, 61.0.



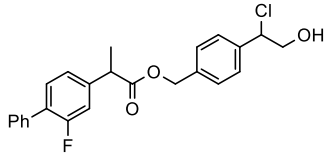
4u[1], yield (60%, dr > 20:1), yellow oil; R_f = 0.36 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, J = 7.5 Hz, 2H), 7.38 (dt, J = 16.6, 6.9 Hz, 3H), 4.83 (d, J = 5.9 Hz, 1H), 4.18 (dq, J = 11.4, 5.7 Hz, 1H), 1.99 (d, J = 4.7 Hz, 1H), 1.31 (d, J = 6.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.8, 128.7, 128.6, 128.1, 71.8, 68.2, 19.0.



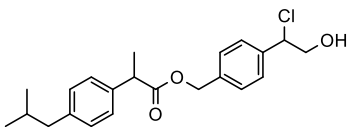
4v (1.2:1), yield (47%), yellow oil; R_f = 0.38 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.32 (m, 8H), 7.30 (dd, J = 4.6, 3.1 Hz, 2H), 7.27 – 7.17 (m, 6H), 7.13 (dd, J = 6.8, 2.8 Hz, 2H), 5.11 (d, J = 6.5 Hz, 1H), 5.04 (d, J = 6.5 Hz, 1H), 5.03 (d, J = 3.1 Hz, 1H), 4.98 (d, J = 8.3 Hz, 1H), 3.09 (s, 1H), 2.40 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.5, 138.7, 137.7, 137.2, 128.7, 128.6, 128.5, 128.39, 128.35, 128.3, 128.21, 128.19, 128.15, 128.0, 127.1, 127.0, 78.8, 78.2, 70.7, 66.9. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_{14}H_{14}ClO^+$ 233.0728; Found 233.0721.



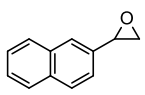
4y (>20:1), yield (53%), yellow oil; R_f = 0.38 (EtOAc/cyclohexane = 1/5). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (t, J = 8.3 Hz, 2H), 7.66 (s, 1H), 7.41 (dd, J = 8.5, 1.4 Hz, 1H), 7.34 (d, J = 8.1 Hz, 2H), 7.25 (d, J = 8.2 Hz, 2H), 7.19 – 7.12 (m, 2H), 5.20 – 5.07 (m, 2H), 5.02 – 4.90 (m, 1H), 3.94 (s, 3H), 3.92 (dd, J = 7.1, 3.7 Hz, 2H), 2.10 (s, 1H), 1.62 (d, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.4, 157.7, 137.6, 136.8, 135.4, 133.7, 129.3, 128.9, 128.2, 127.6, 127.2, 126.2, 126.0, 119.0, 105.6, 67.8, 65.9, 64.4, 55.3, 45.5, 18.5. HRMS (*ESI*) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{23}ClNaO_4^+$ 421.1177; Found 421.1184.



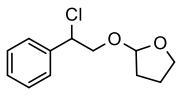
4z (>20:1), yield (64%), yellow oil; R_f = 0.35 (EtOAc/cyclohexane = 1/8). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 – 7.54 (m, 2H), 7.48 (dd, J = 10.3, 4.7 Hz, 2H), 7.44 – 7.37 (m, 4H), 7.31 (d, J = 8.2 Hz, 2H), 7.20 – 7.10 (m, 2H), 5.25 – 5.10 (m, 2H), 5.00 (dd, J = 7.2, 5.8 Hz, 1H), 3.94 (d, J = 5.0 Hz, 2H), 3.84 (q, J = 7.1 Hz, 1H), 2.21 (s, 1H), 1.59 (d, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.7, 159.7 (d, J = 248.5 Hz), 141.5 (d, J = 7.6 Hz), 137.9, 136.6, 135.4 (d, J = 1.1 Hz), 130.8 (d, J = 3.9 Hz), 129.0, 128.9, 128.5, 128.3, 127.73, 127.70, 123.6 (d, J = 3.2 Hz), 115.3 (d, J = 23.7 Hz), 67.8, 66.1, 64.4, 45.0, 18.3. ^{19}F NMR (376 MHz, $CDCl_3$) δ -117.56. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_{24}H_{23}ClFNaO_3^+$ 413.1314; Found 413.1311.



4aa (>20:1), yield (61%), yellow oil; R_f = 0.38 (EtOAc/cyclohexane = 1/8). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (dd, J = 8.6, 2.1 Hz, 2H), 7.24 (dd, J = 14.0, 5.6 Hz, 4H), 7.12 (d, J = 8.1 Hz, 2H), 5.12 (s, 2H), 4.99 (dd, J = 7.4, 5.6 Hz, 1H), 3.93 (d, J = 5.6 Hz, 2H), 3.77 (q, J = 7.2 Hz, 1H), 2.48 (d, J = 7.2 Hz, 2H), 2.15 (t, J = 6.3 Hz, 1H), 1.95 – 1.81 (m, 1H), 1.53 (d, J = 7.2 Hz, 3H), 0.93 (d, J = 6.6 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.5, 140.7, 137.6, 137.5, 136.9, 129.4, 128.0, 127.6, 127.2, 67.8, 65.7, 64.5, 45.1, 45.0, 30.2, 26.7, 22.4, 18.4. HRMS (*ESI*) m/z: $[M+H]^+$ Calcd for $C_{22}H_{28}ClO_3^+$ 375.1721; Found 375.1717.



5[2], yield (87%), yellow oil; R_f = 0.34 (EtOAc/cyclohexane = 1/10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 – 7.77 (m, 4H), 7.59 – 7.45 (m, 2H), 7.36 (dd, J = 8.5, 1.7 Hz, 1H), 4.06 (dd, J = 4.0, 2.6 Hz, 1H), 3.25 (dd, J = 5.4, 4.1 Hz, 1H), 2.94 (dd, J = 5.4, 2.6 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.1, 133.3, 133.2, 128.4, 127.8, 126.4, 126.1, 125.2, 122.7, 52.6, 51.3.



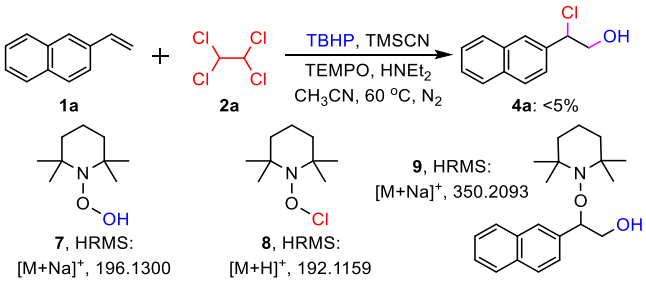
6, yield (72%, d.r. = 1:1), yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.41 (m, 2H), 7.40 – 7.32 (m, 3H), 5.23 (d, J = 4.2 Hz, 0.5H), 5.14 – 5.09 (m, 0.5H), 5.04 (dd, J = 7.9, 5.6 Hz, 1H), 4.07 (dd, J = 11.1, 7.1 Hz, 0.5H), 4.03 (dd, J = 11.1, 5.5 Hz, 0.5H), 3.89 (d, J = 6.6 Hz, 1H), 3.87 – 3.81 (m, 1.5H), 3.80 – 3.74 (m, 0.5H), 2.01 – 1.92 (m, 2H), 1.92 – 1.79 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.0, 138.8, 128.60, 128.55, 128.54, 128.50, 127.6, 127.5, 104.4, 103.9, 71.9, 71.5, 67.2, 67.1, 61.8, 61.0, 32.4, 32.3, 23.28, 23.27.

References

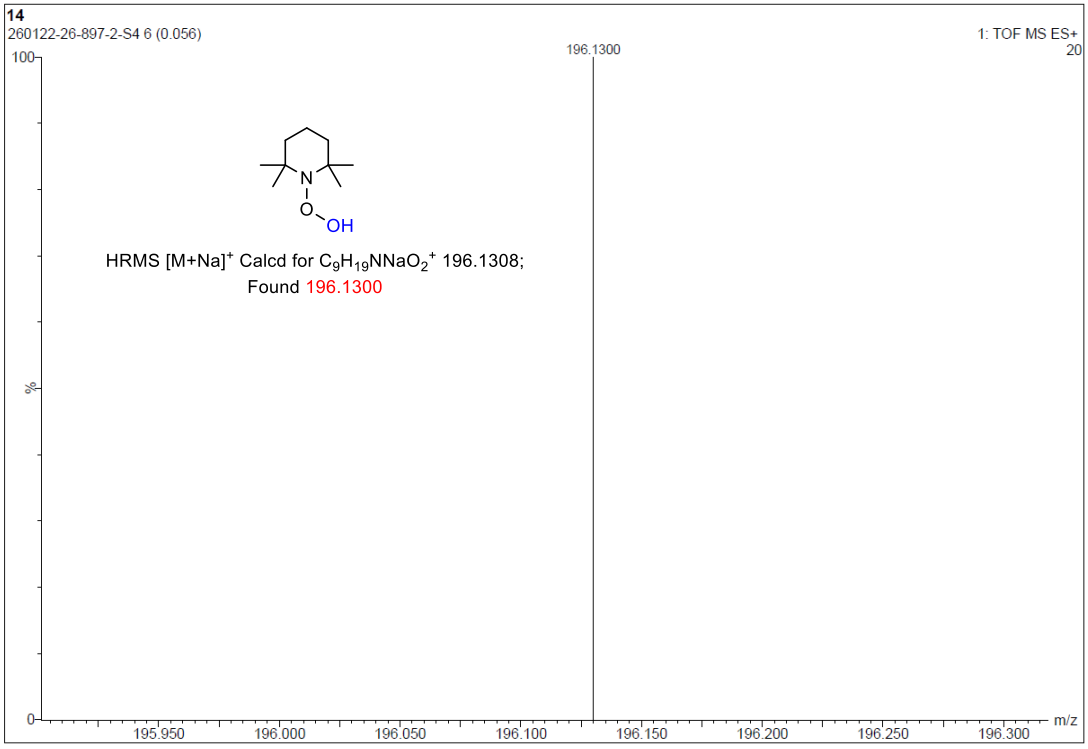
1. L. Yang, X. Li, Y. Wang, C. Li, X. Wu, Z. Zhang, X. Xie, *Tetrahedron* 2020, **76**, 131114.

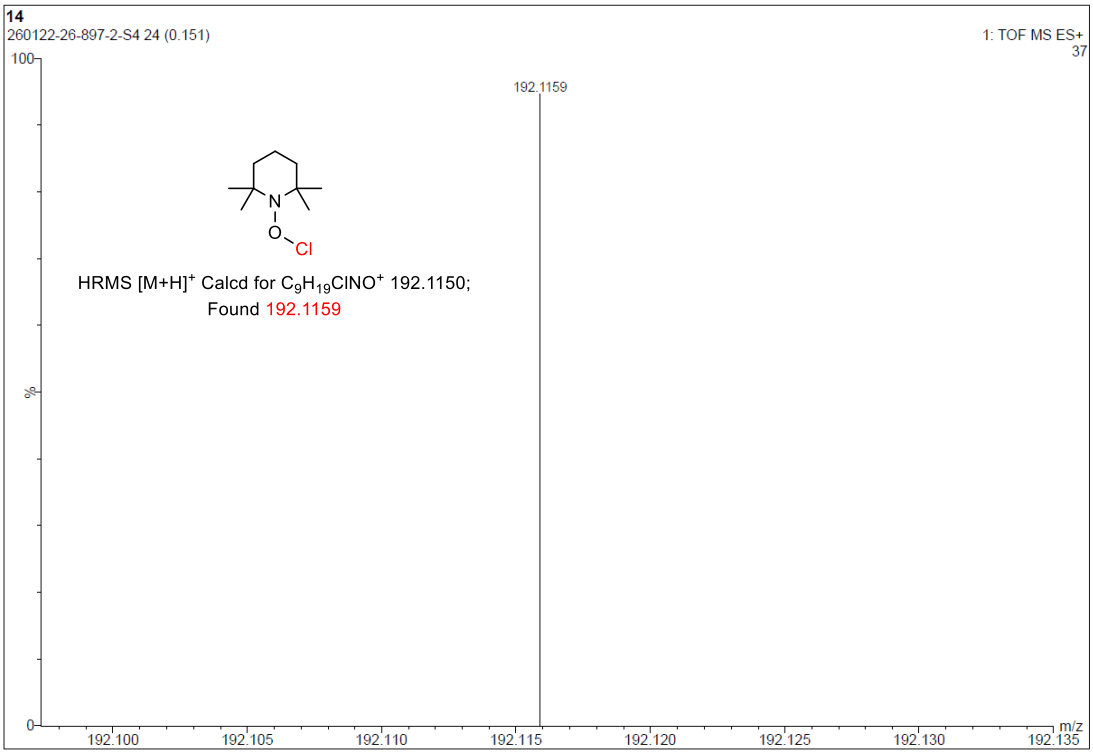
2. C. Yang, Z. Chen, Z. Wu, Q. Zheng, Y. Xue, X. Zeng, W. M. W. W. Kandegama, G. Zhang, R. Guo, *Green Chem.,* 2025, **27**, 13651–13657.

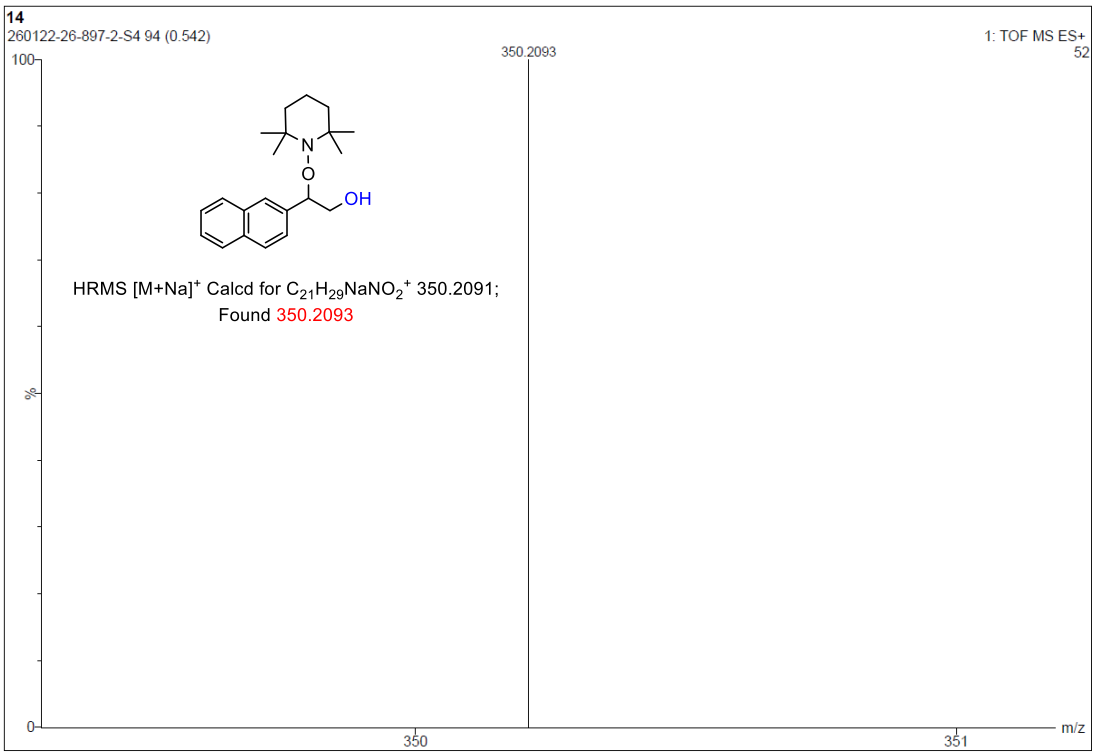
Radical inhibition and trapping experiments



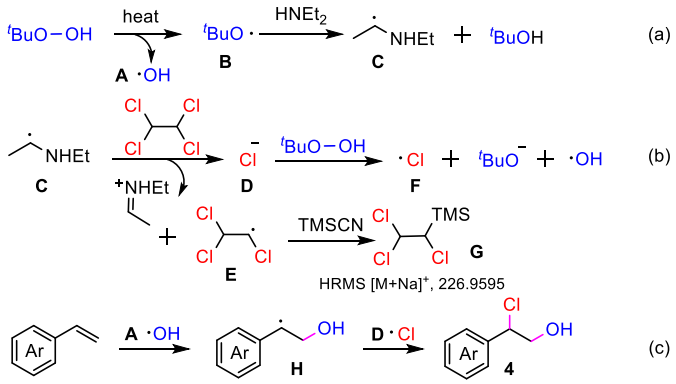
To a solution of **1a** (0.5 mmol, 1.0 equiv.) in 1,1,2,2-tetrachloroethane (**2a**, 0.5 mL) was added **3a** (3.0 mmol, 6.0 equiv.), $HNEt_2$ (0.5 mmol, 1.0 equiv.), TMSCN (2.0 mmol, 4.0 equiv.), TEMPO (1.0 mmol, 2.0 equiv.) and CH_3CN at room temperature. Then the solution mixture was stirred at 60 ℃ for 24 h.

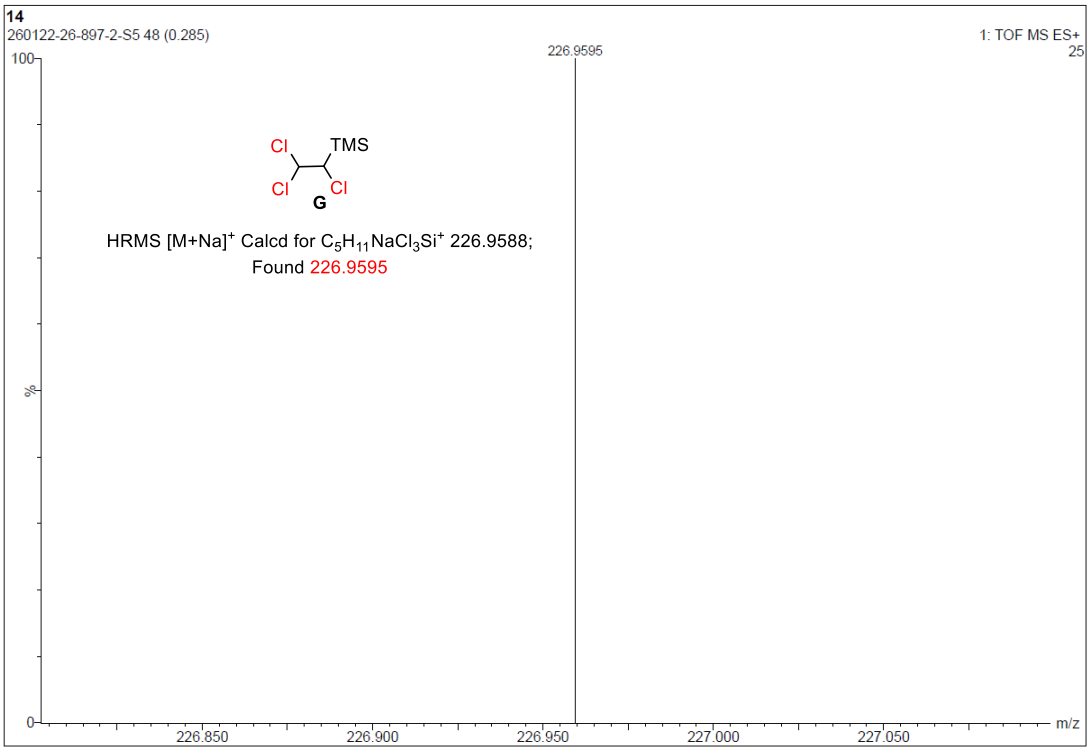



14
260122-26-897-2-S4 24 (0.151)
1: TOF MS ES+
37
100
%
0
192.1159
Cl
HRMS [M+H]+ Calcd for C9H19ClNO+ 192.1150;
Found 192.1159
192.100
192.105
192.110
192.115
192.120
192.125
192.130
192.135
m/z


14
260122-26-897-2-S4 94 (0.542)
1: TOF MS ES+
52
100
%
0
350.2093
OH
HRMS [M+Na]+ Calcd for C21H29NaNO2+ 350.2091;
Found 350.2093
350
351
m/z

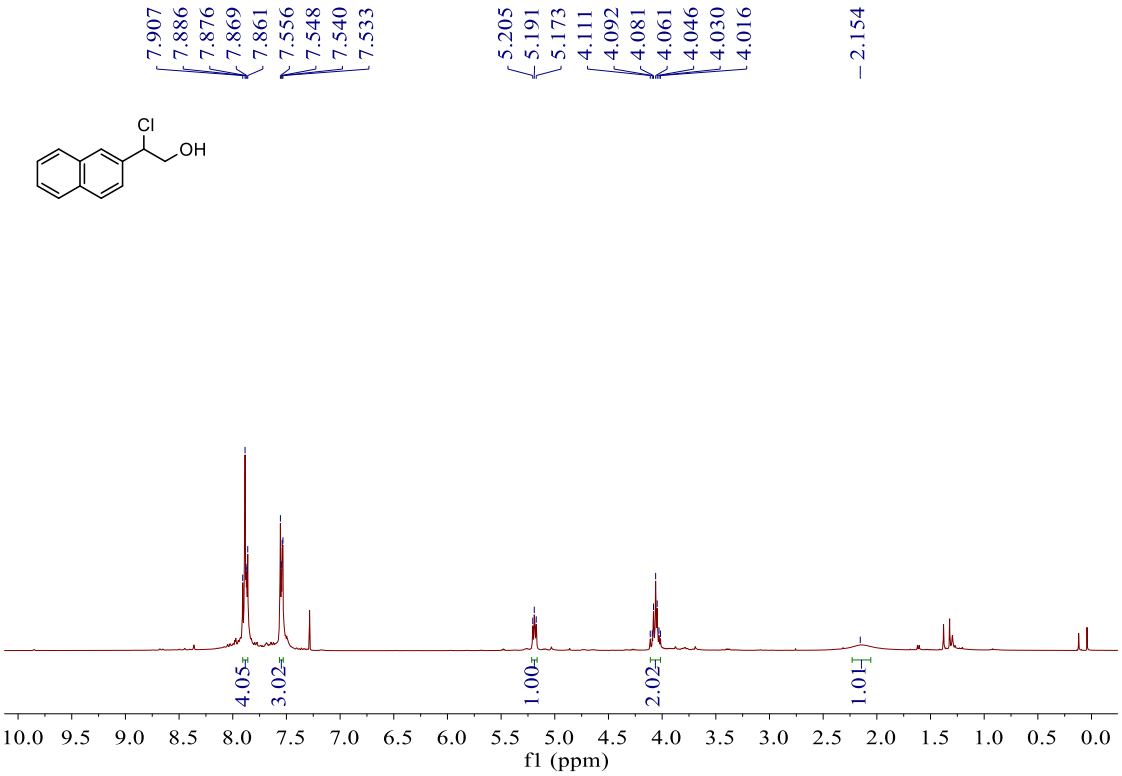
Possible Mechanism for the Synthesis of 4

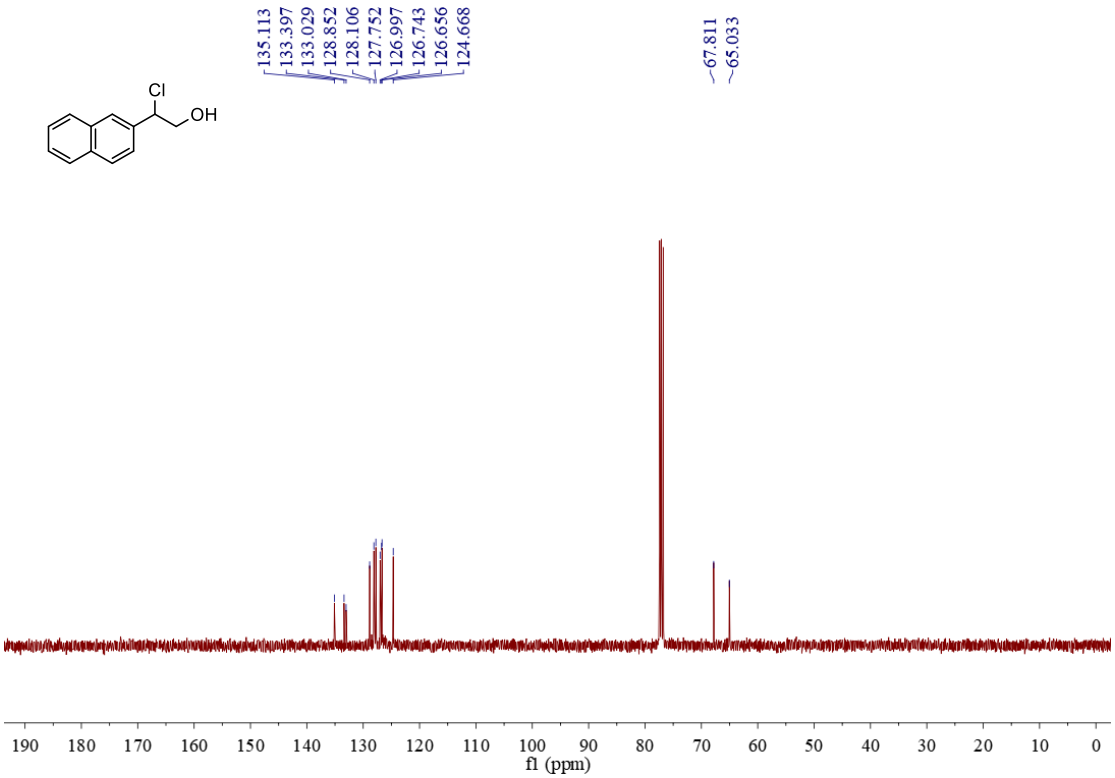




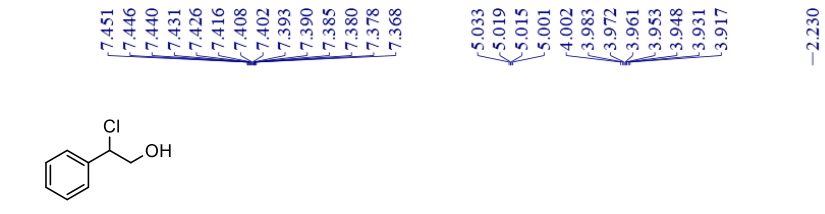
Copies of ^{1}H, ^{13}C NMR spectra

4a

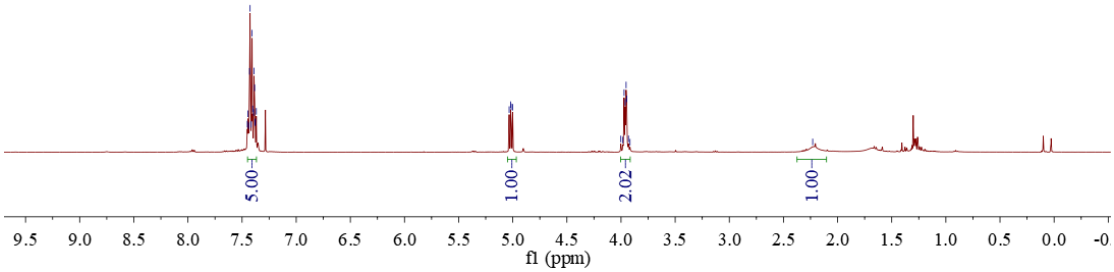




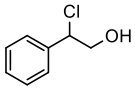
4b

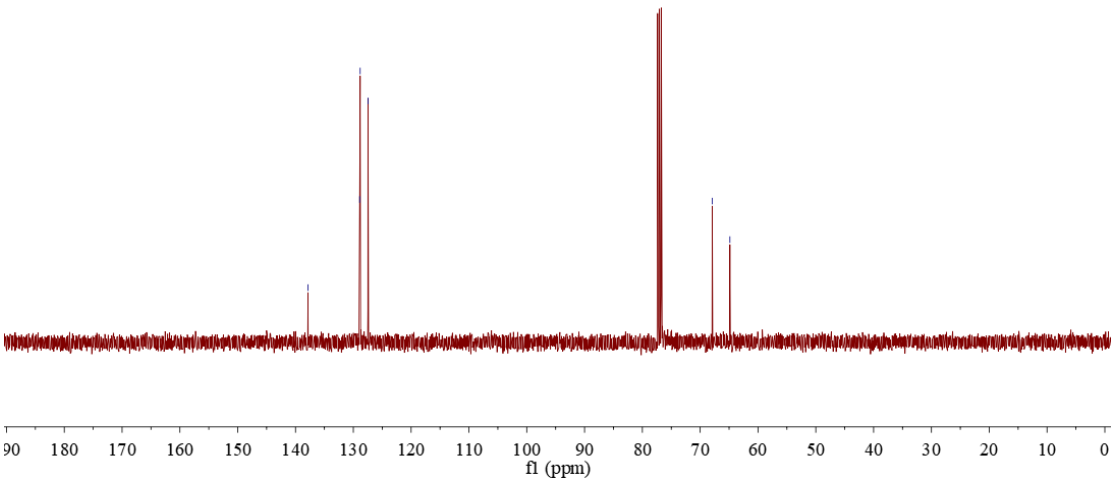

7.451
7.446
7.440
7.431
7.426
7.416
7.408
7.402
7.393
7.390
7.385
7.380
7.378
7.368
5.033
5.019
5.015
5.001
4.002
3.983
3.972
3.961
3.953
3.948
3.931
3.917
2.230

Cl
OH

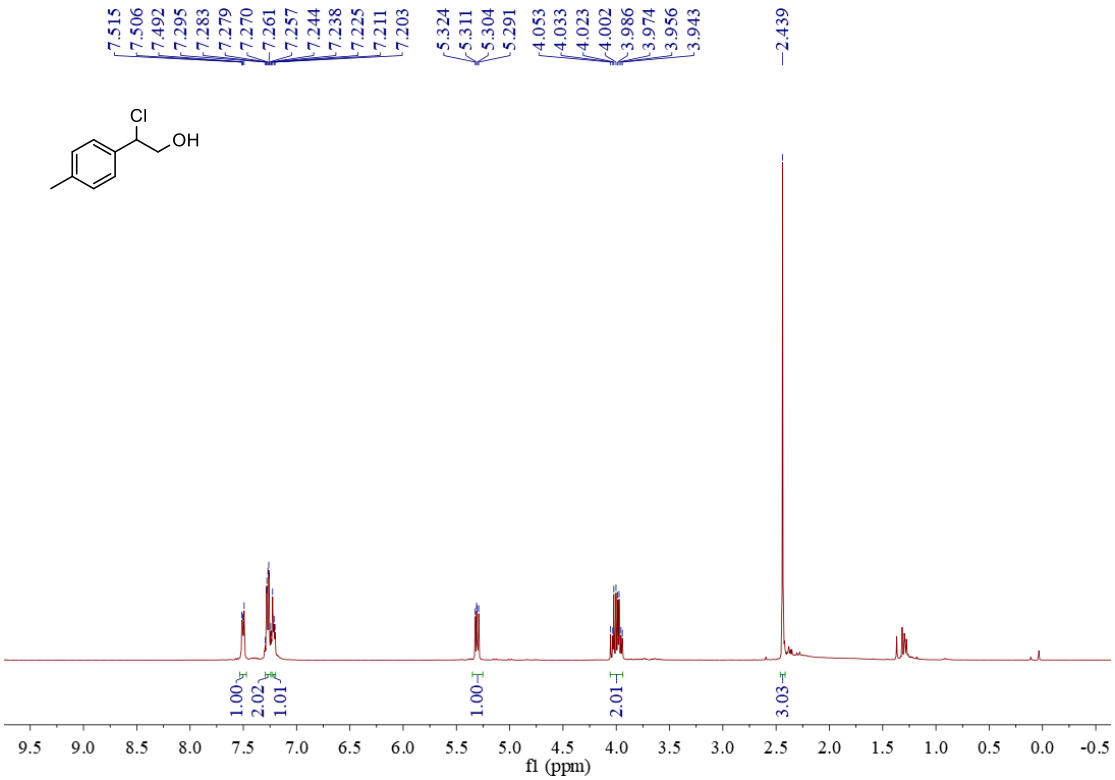

5.00
1.00
2.02
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

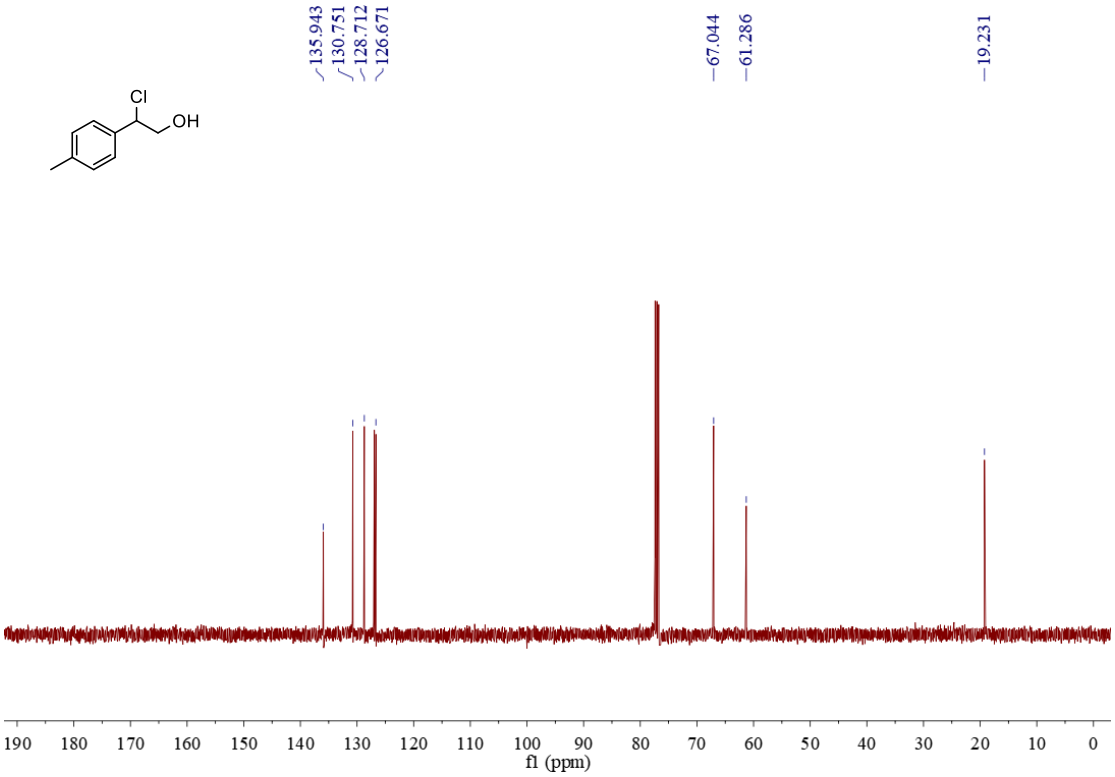

137.843
128.905
128.817
127.466
67.909
64.860


Cl
OH

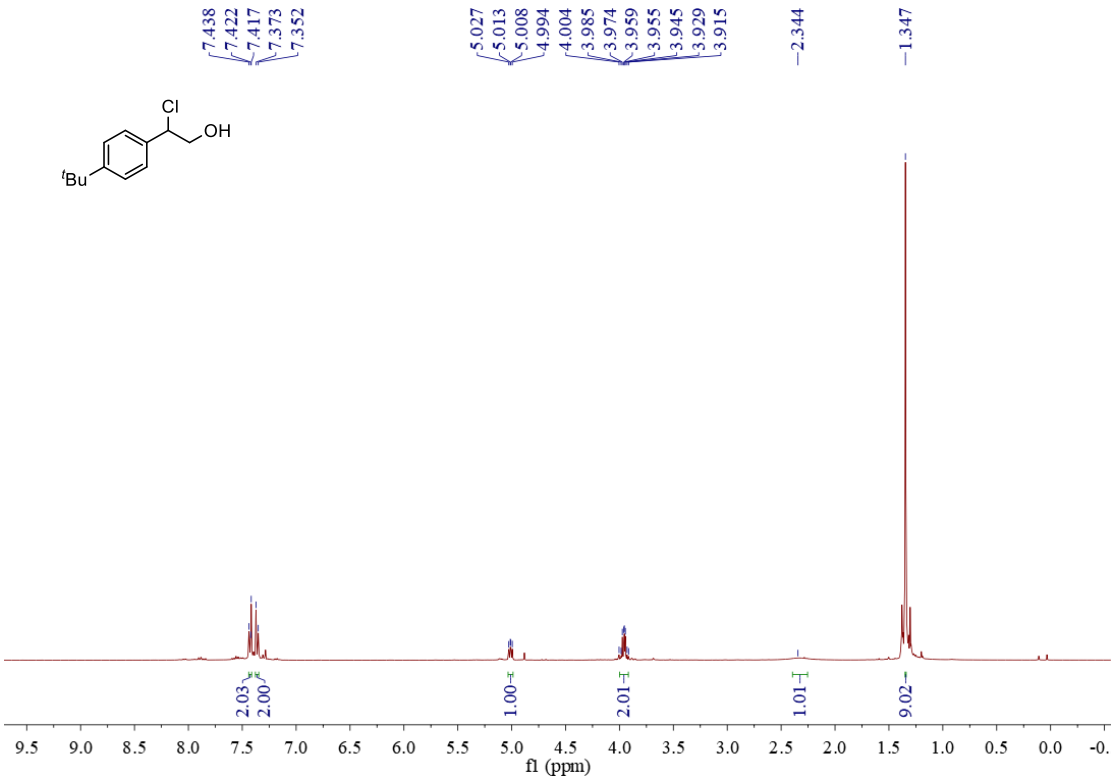

190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

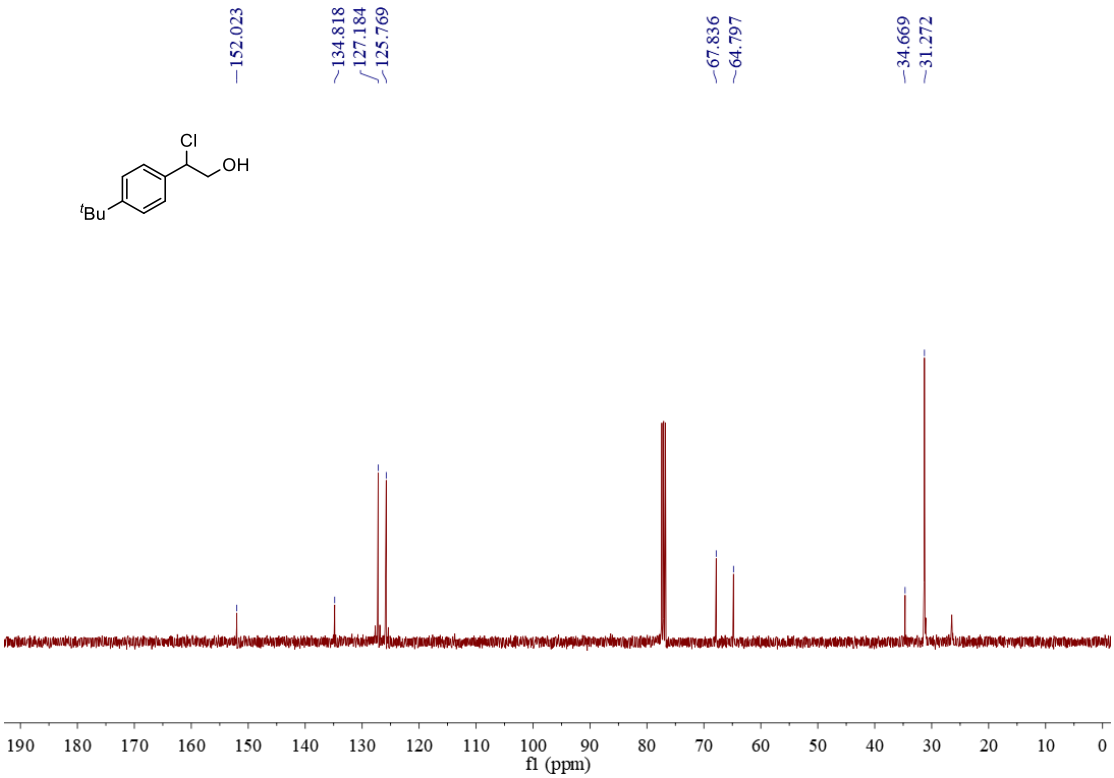
4c


7.515
7.506
7.492
7.295
7.283
7.279
7.270
7.261
7.257
7.244
7.238
7.225
7.211
7.203
5.324
5.311
5.304
5.291
4.053
4.033
4.023
4.002
3.986
3.974
3.956
3.943
2.439
Cl
OH
1.00
2.02
1.01
1.00
2.01
3.03
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

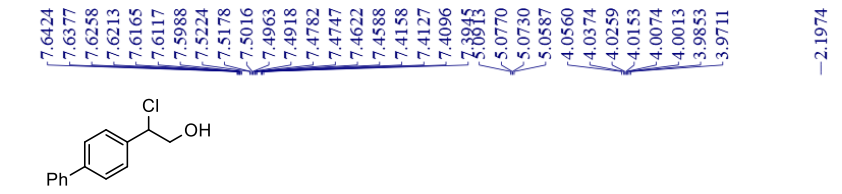

135.943
130.751
128.712
126.671
67.044
61.286
19.231
Cl
OH
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

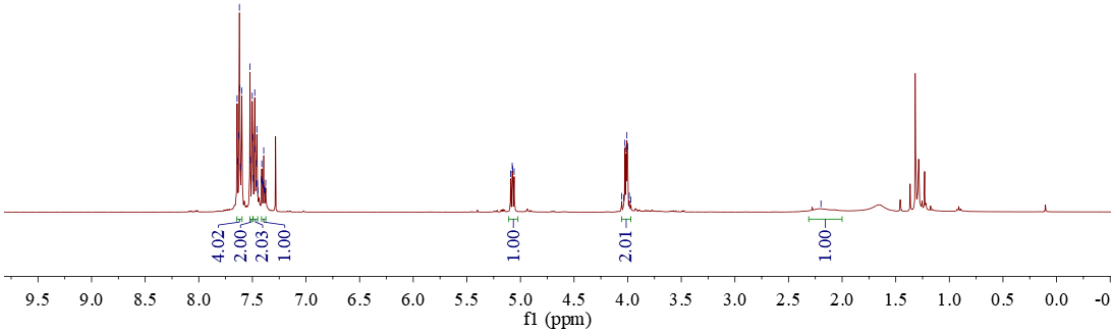
4d

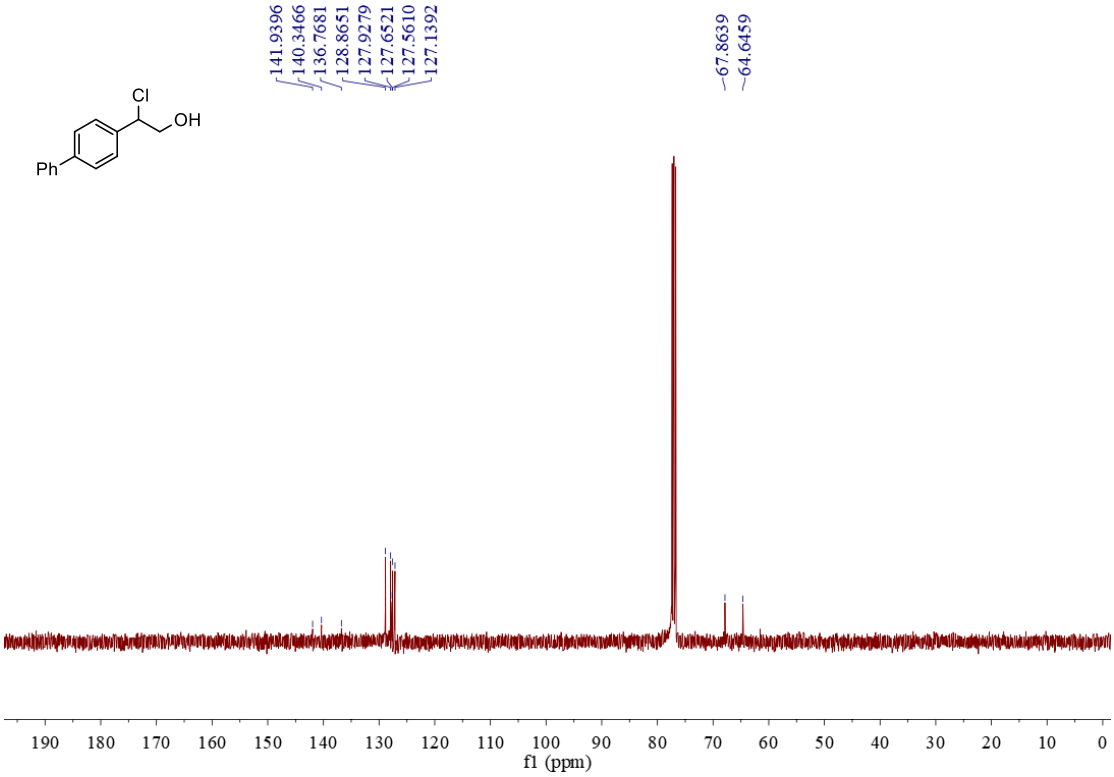

7.438
7.422
7.417
7.373
7.352
5.027
5.013
5.008
4.994
4.004
3.985
3.974
3.959
3.955
3.945
3.929
3.915
2.344
1.347
Cl
OH
tBu
2.03
2.00
1.00
2.01
1.01
9.02
f1 (ppm)


152.023
134.818
127.184
125.769
67.836
64.797
34.669
31.272
Cl
OH
tBu
f1 (ppm)

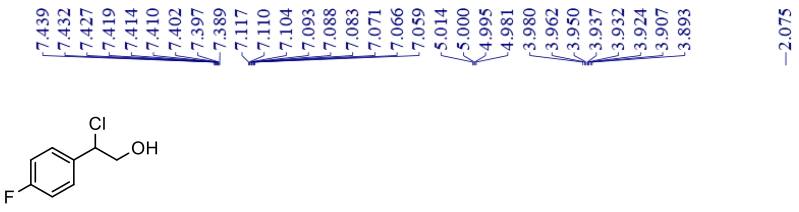
4e


7.6424
7.6377
7.6258
7.6213
7.6165
7.6117
7.5988
7.5224
7.5178
7.5016
7.4963
7.4918
7.4782
7.4747
7.4622
7.4588
7.4158
7.4127
7.4096
5.0913
5.0770
5.0730
5.0587
4.0560
4.0374
4.0259
4.0153
4.0074
4.0013
3.9853
3.9711
2.1974
Cl
OH
Ph

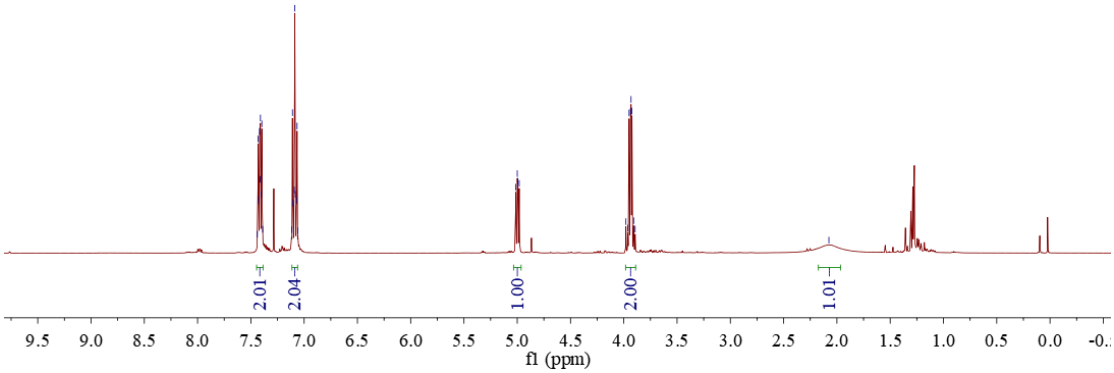

4.02
2.00
2.03
1.00
1.00
2.01
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0
f1 (ppm)


141.9396
140.3466
136.7681
128.8651
127.9279
127.6521
127.5610
127.1392
67.8639
64.6459
Cl
OH
Ph
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

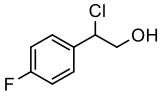
4f

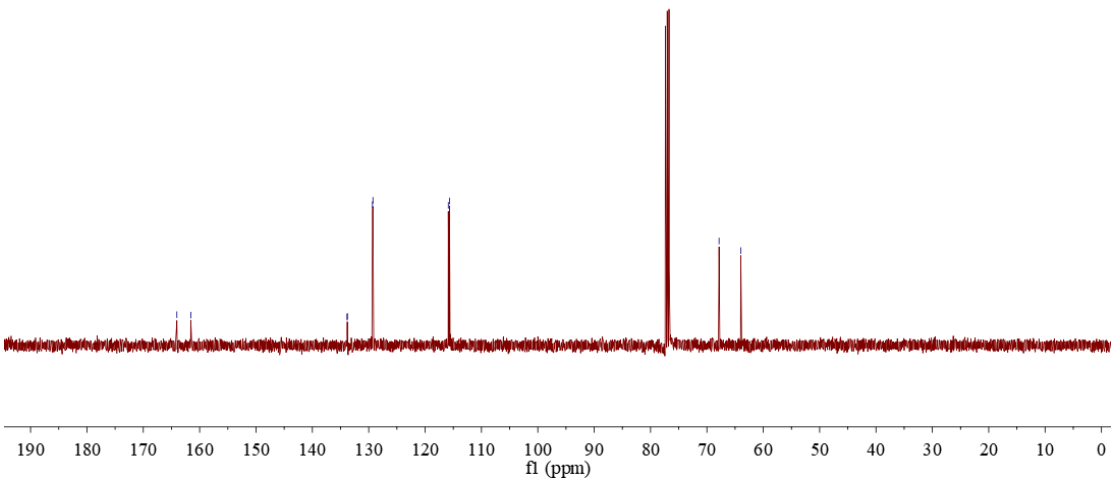

7.439
7.432
7.427
7.419
7.414
7.410
7.402
7.397
7.389
7.117
7.110
7.104
7.093
7.088
7.083
7.071
7.066
7.059
5.014
5.000
4.995
4.981
3.980
3.962
3.950
3.937
3.932
3.924
3.907
3.893
2.075

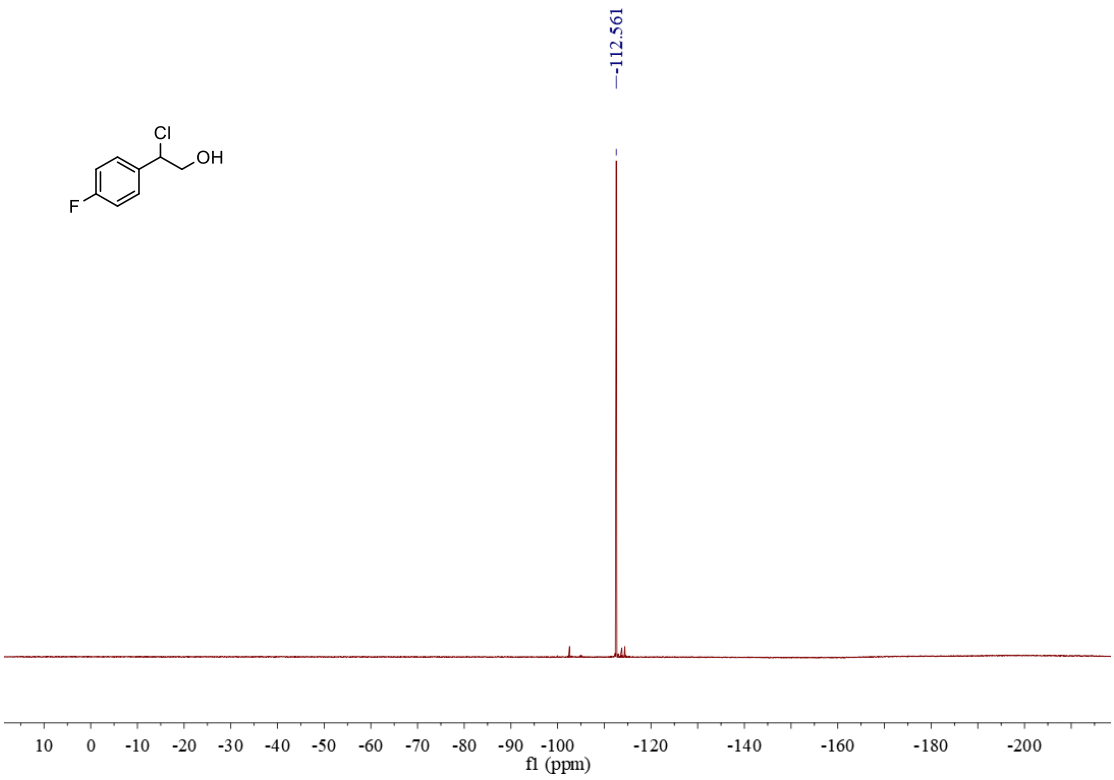
Cl
OH
F


2.01
2.04
1.00
2.00
1.01
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

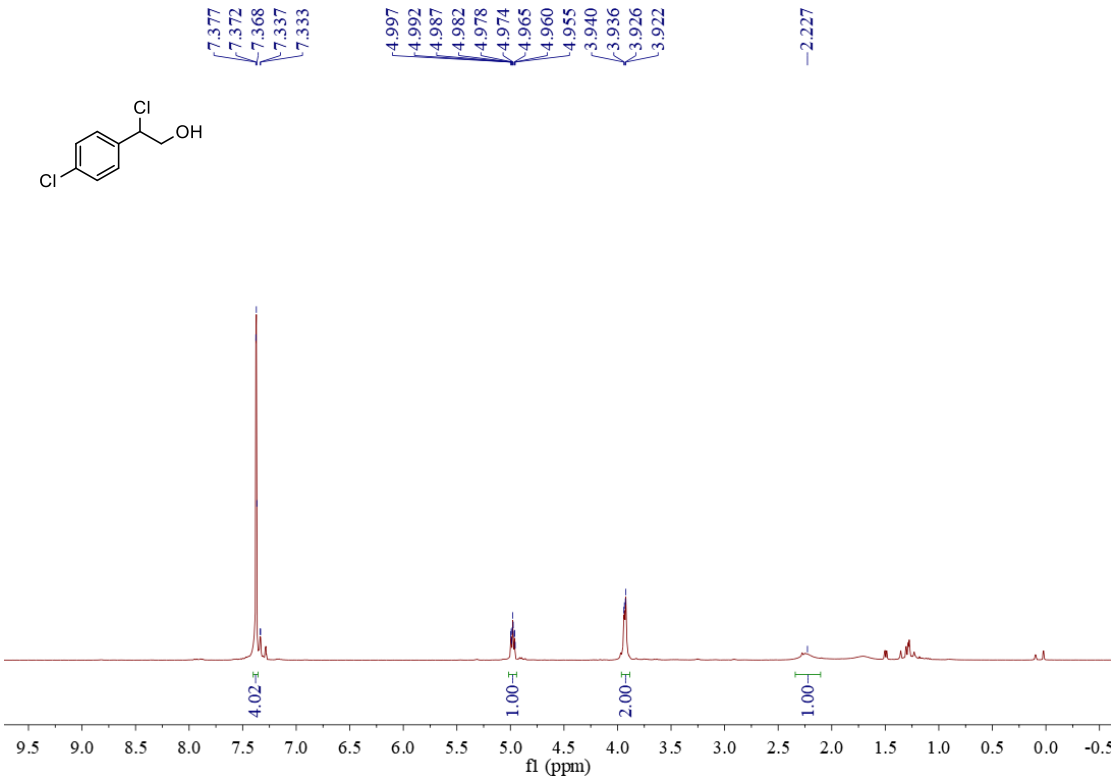

164.040
161.573
133.832
133.799
129.338
129.255
115.884
115.668
67.843
63.989

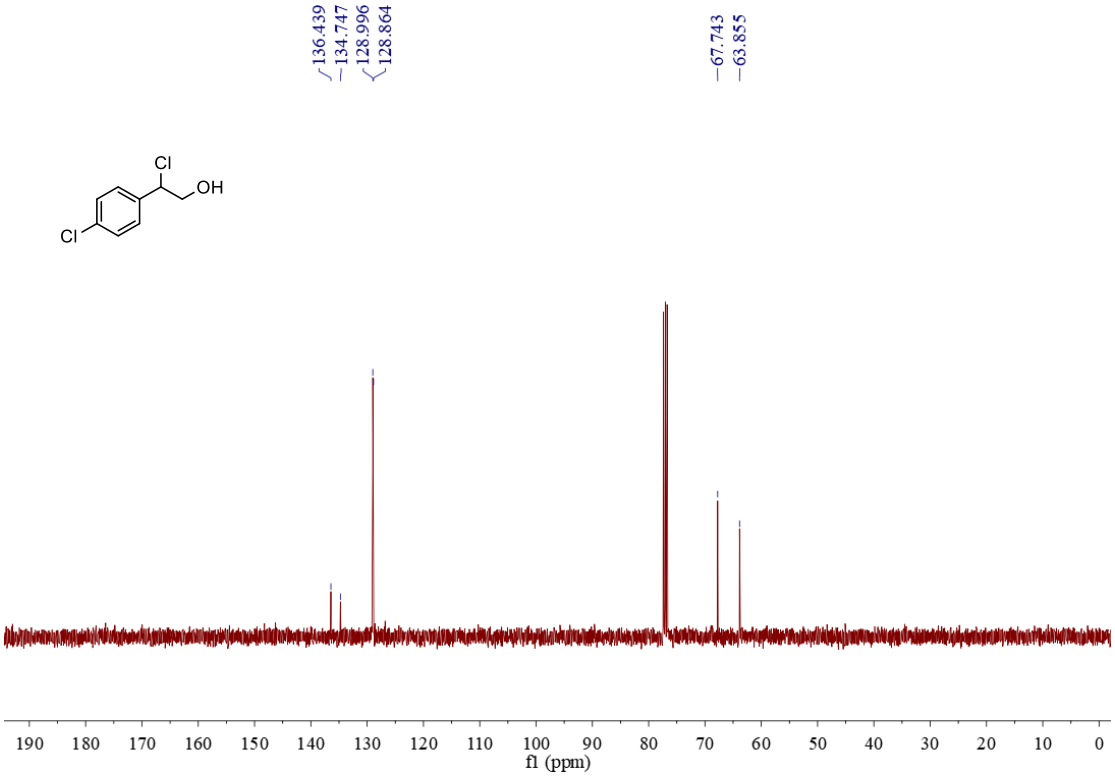

Cl
OH
F


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


-112.561
Cl
OH
F
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

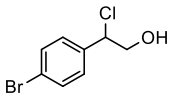
4g

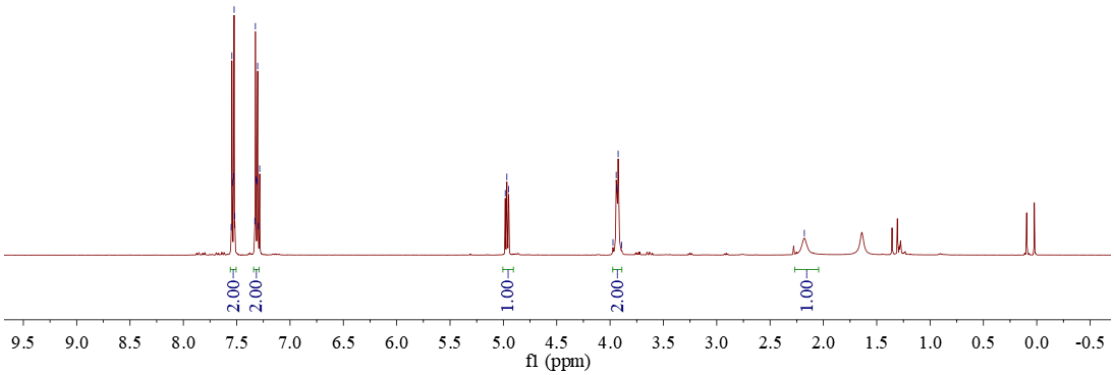

7.377
7.372
7.368
7.337
7.333
4.997
4.992
4.987
4.982
4.978
4.974
4.965
4.960
4.955
3.940
3.936
3.926
3.922
2.227
Cl
OH
Cl
4.02
1.00
2.00
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


136.439
134.747
128.996
128.864
67.743
63.855
Cl
OH
Cl
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

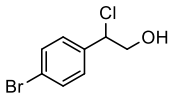
4h

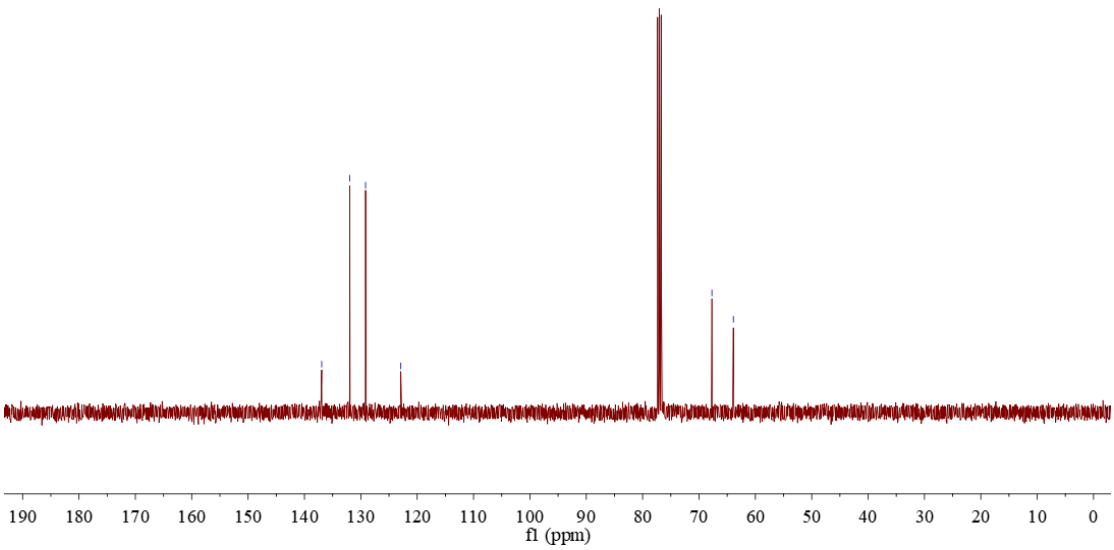

7.551
7.545
7.540
7.529
7.524
7.518
7.331
7.325
7.320
7.308
7.303
7.297
7.285
4.982
4.967
4.950
3.973
3.942
3.935
3.924
3.891
2.179


Cl
OH
Br

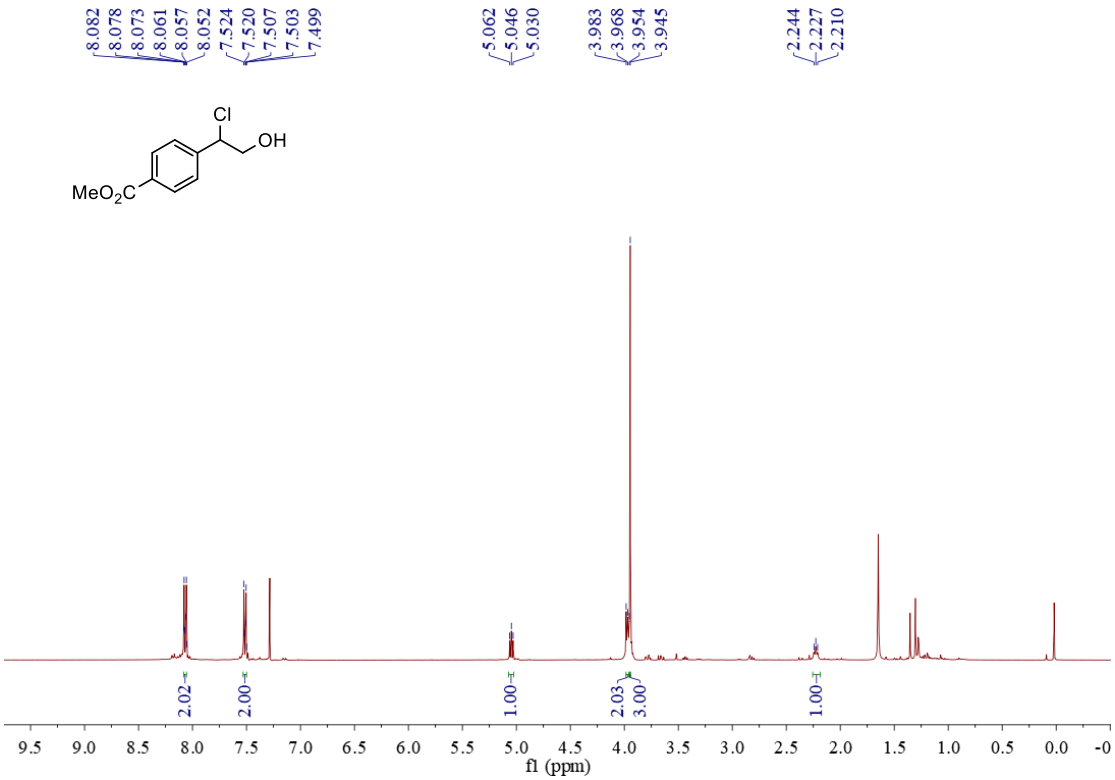

2.00
2.00
1.00
2.00
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

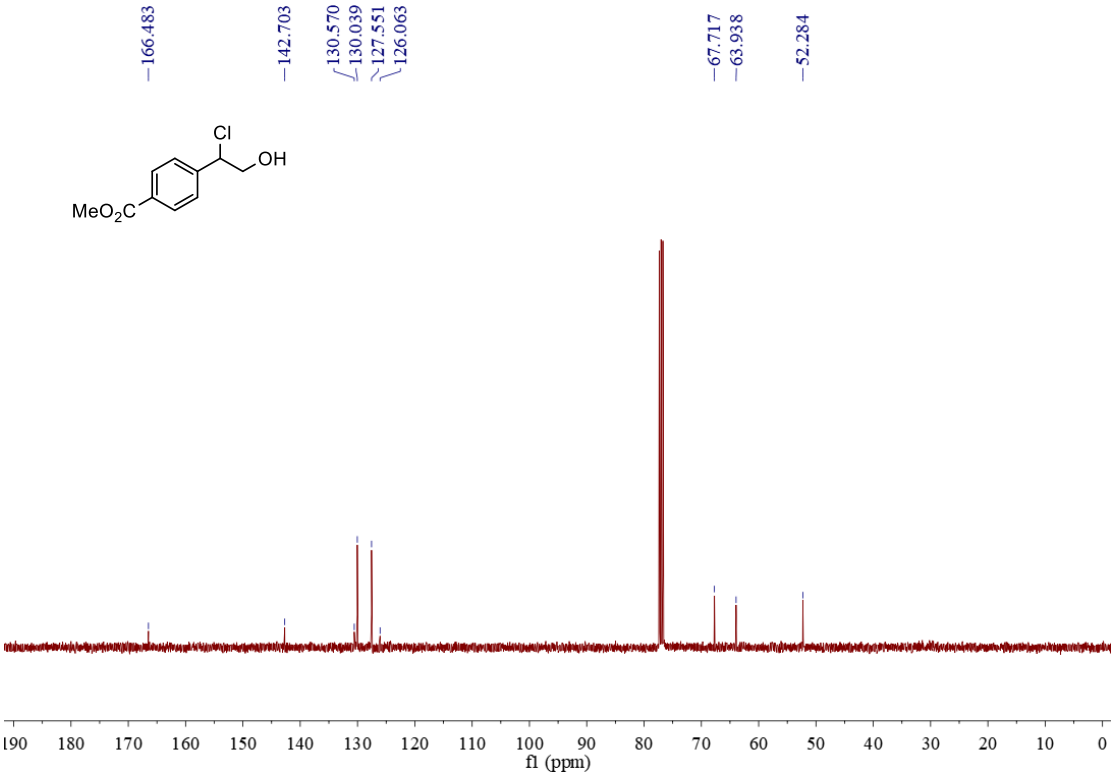

136.938
131.963
129.156
122.907
67.707
63.896


Cl
OH
Br

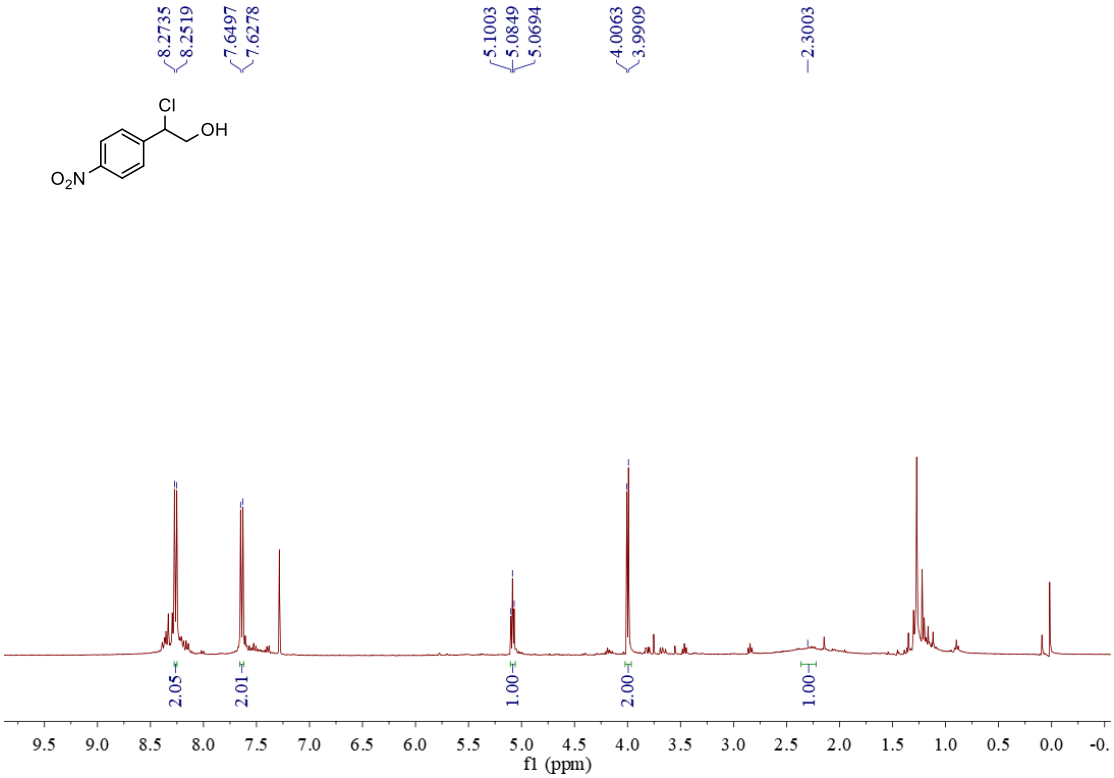

190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

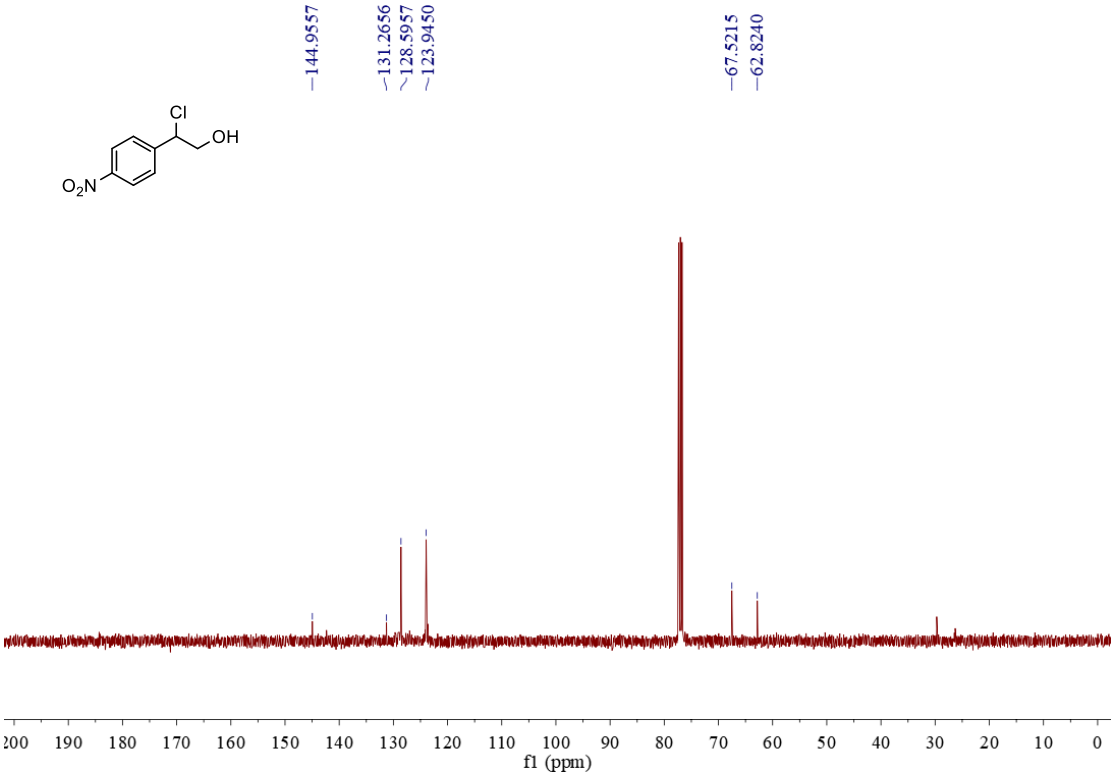
4i


8.082
8.078
8.073
8.061
8.057
8.052
7.524
7.520
7.507
7.503
7.499
5.062
5.046
5.030
3.983
3.968
3.954
3.945
2.244
2.227
2.210
Cl
OH
MeO2C
2.02
2.00
1.00
2.03
3.00
1.00
fl (ppm)

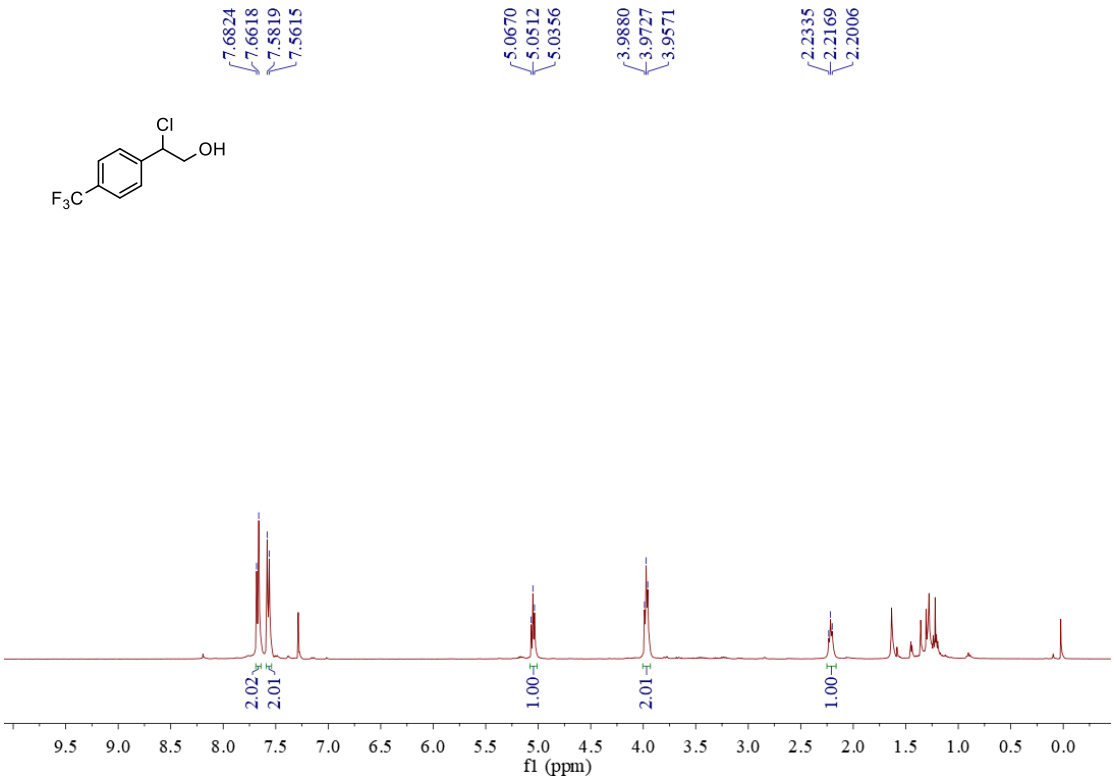

166.483
142.703
130.570
130.039
127.551
126.063
67.717
63.938
52.284
Cl
OH
MeO2C
fl (ppm)

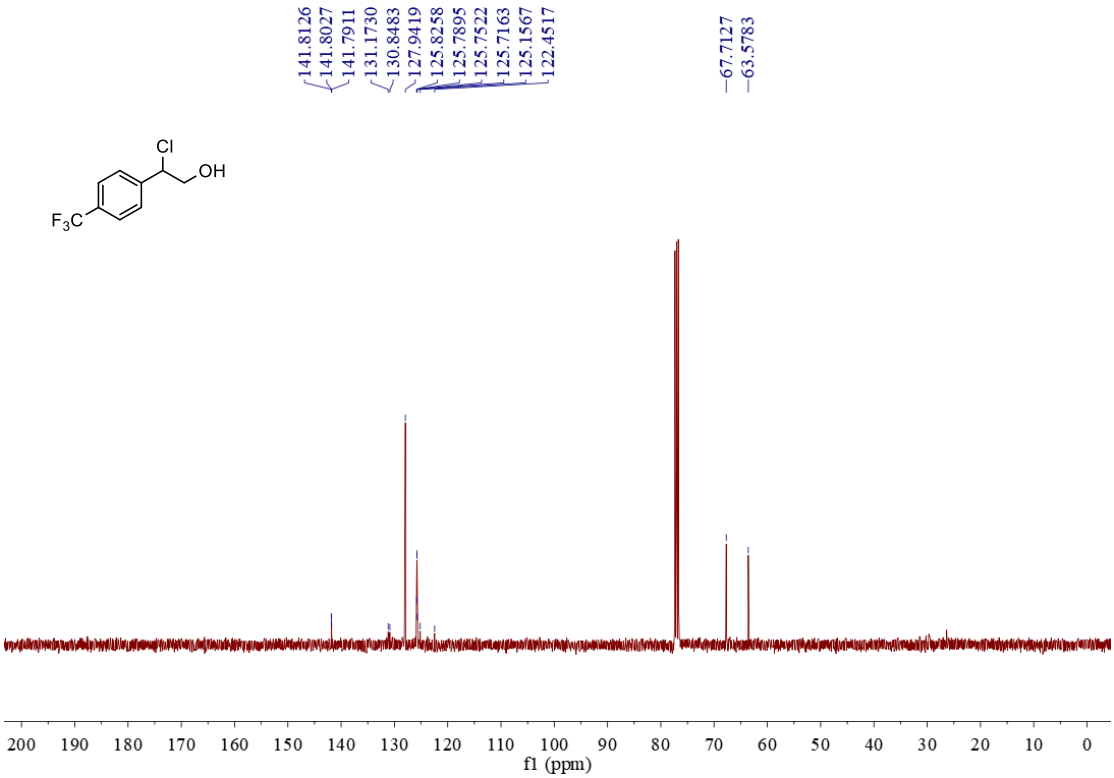
4j

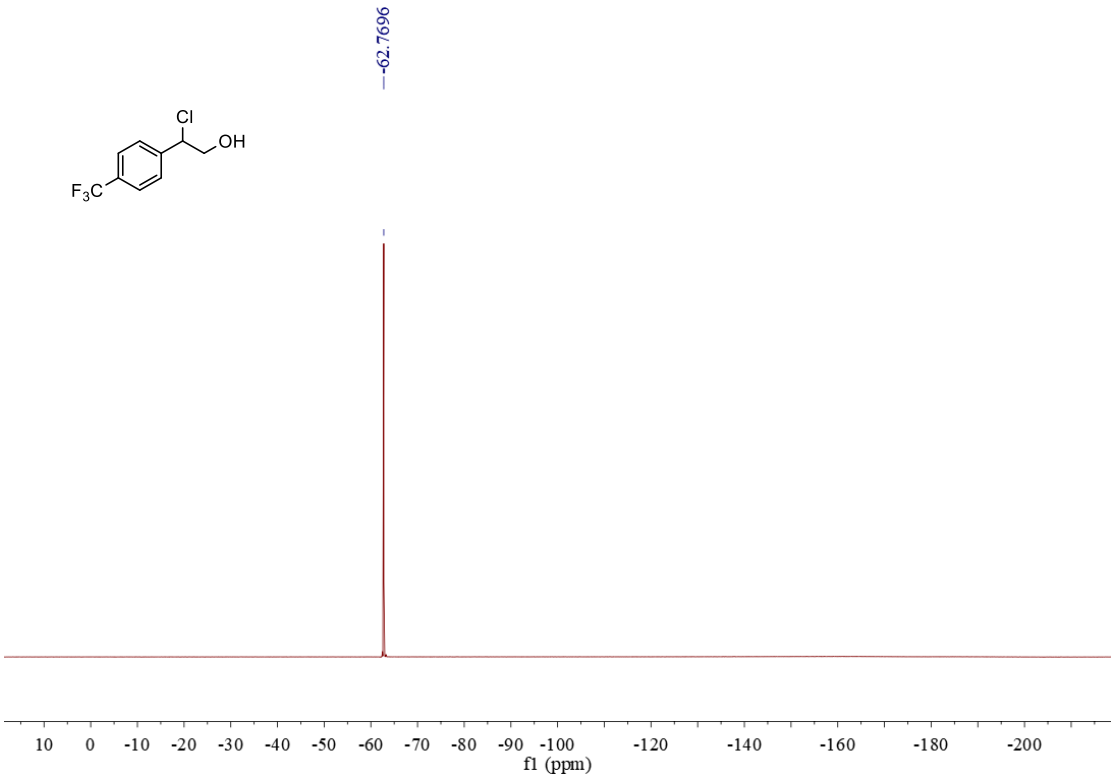

8.2735
8.2519
7.6497
7.6278
5.1003
5.0849
5.0694
4.0063
3.9909
2.3003
Cl
OH
O2N
2.05
2.01
1.00
2.00
1.00
f1 (ppm)


144.9557
131.2656
128.5957
123.9450
67.5215
62.8240
Cl
OH
O2N
f1 (ppm)

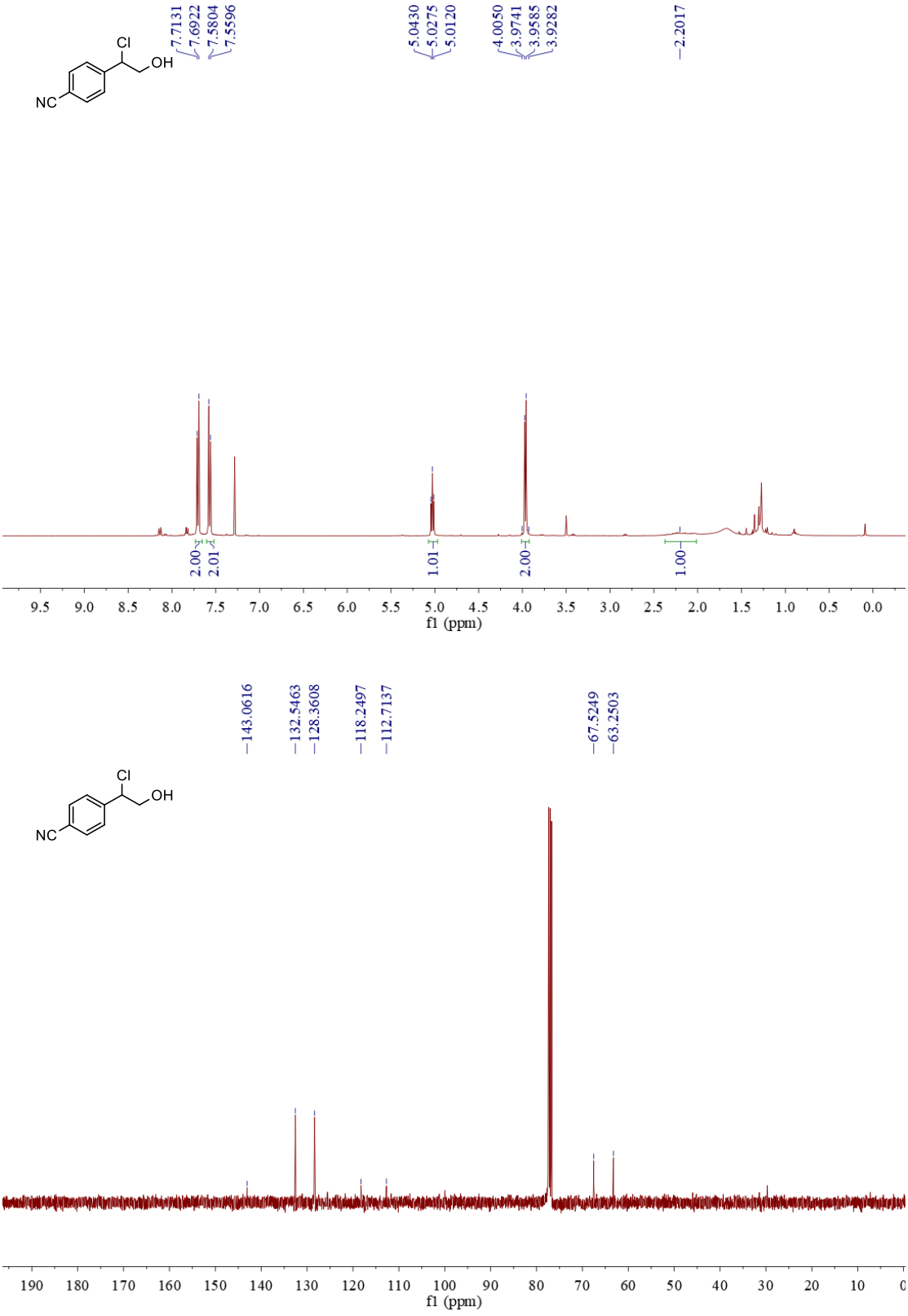
4k


7.6824
7.6618
7.5819
7.5615
5.0670
5.0512
5.0356
3.9880
3.9727
3.9571
2.2335
2.2169
2.2006
Cl
OH
F3C
2.02
2.01
1.00
2.01
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

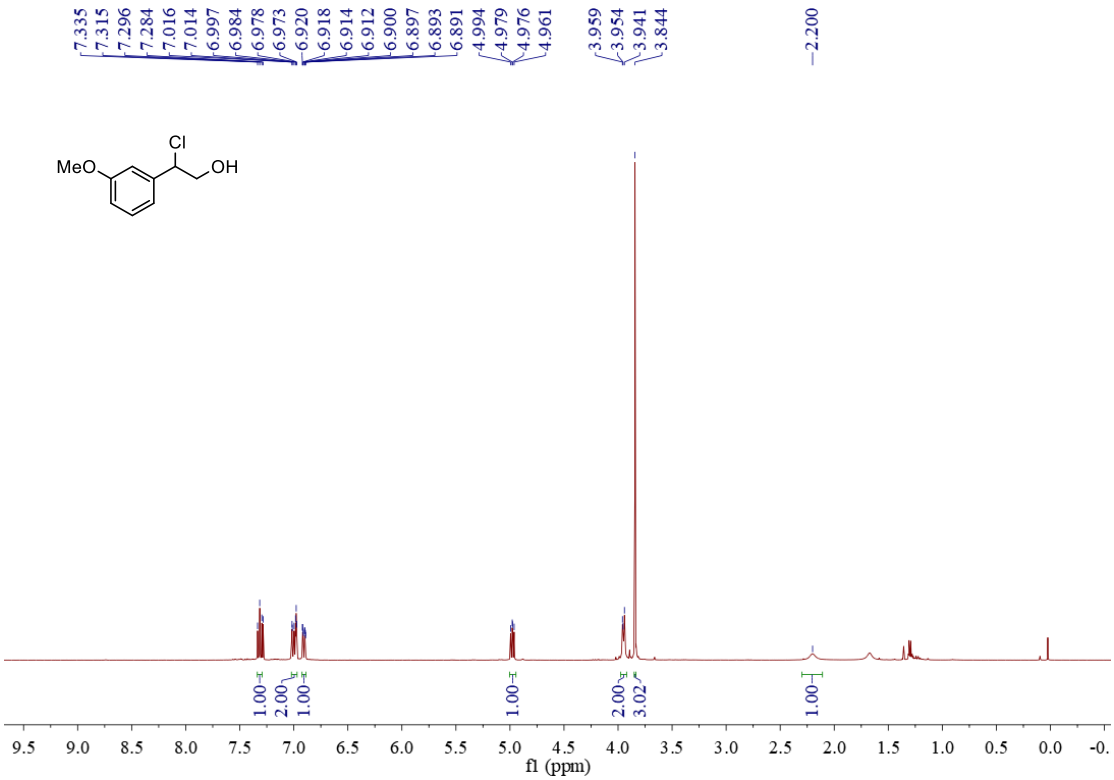

141.8126
141.8027
141.7911
131.1730
130.8483
127.9419
125.8258
125.7895
125.7522
125.7163
125.1567
122.4517
67.7127
63.5783
Cl
OH
F3C
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

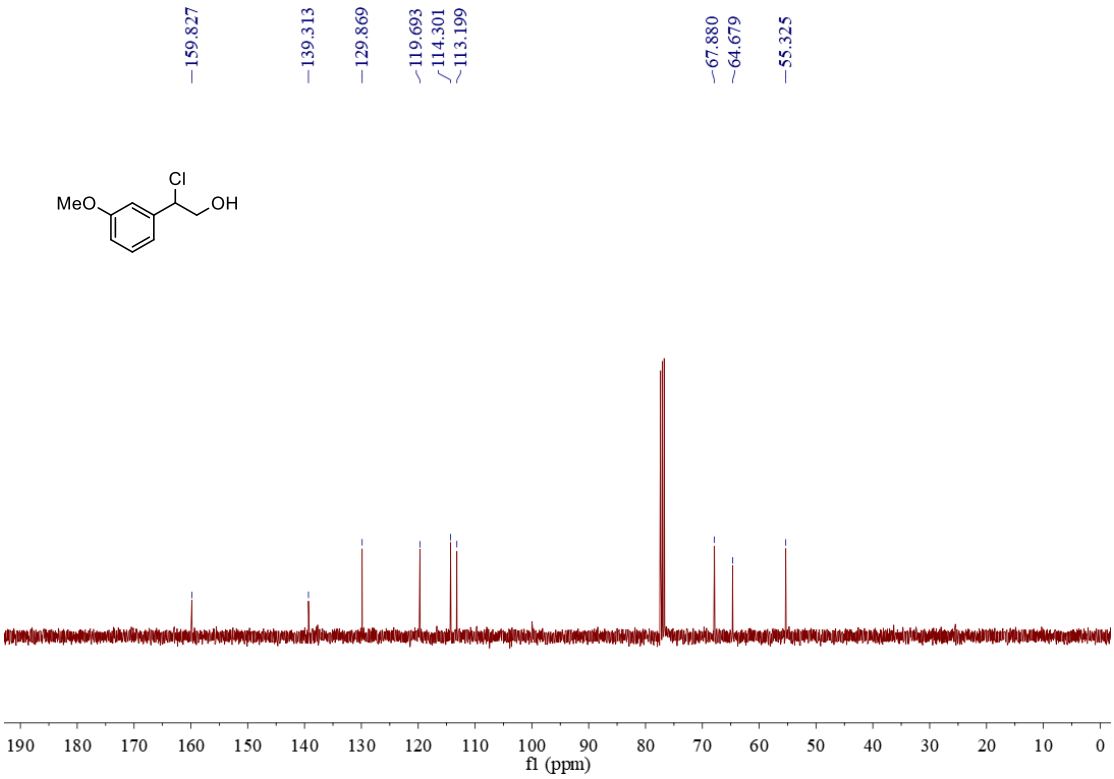

-62.7696
Cl
OH
F3C
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

4l

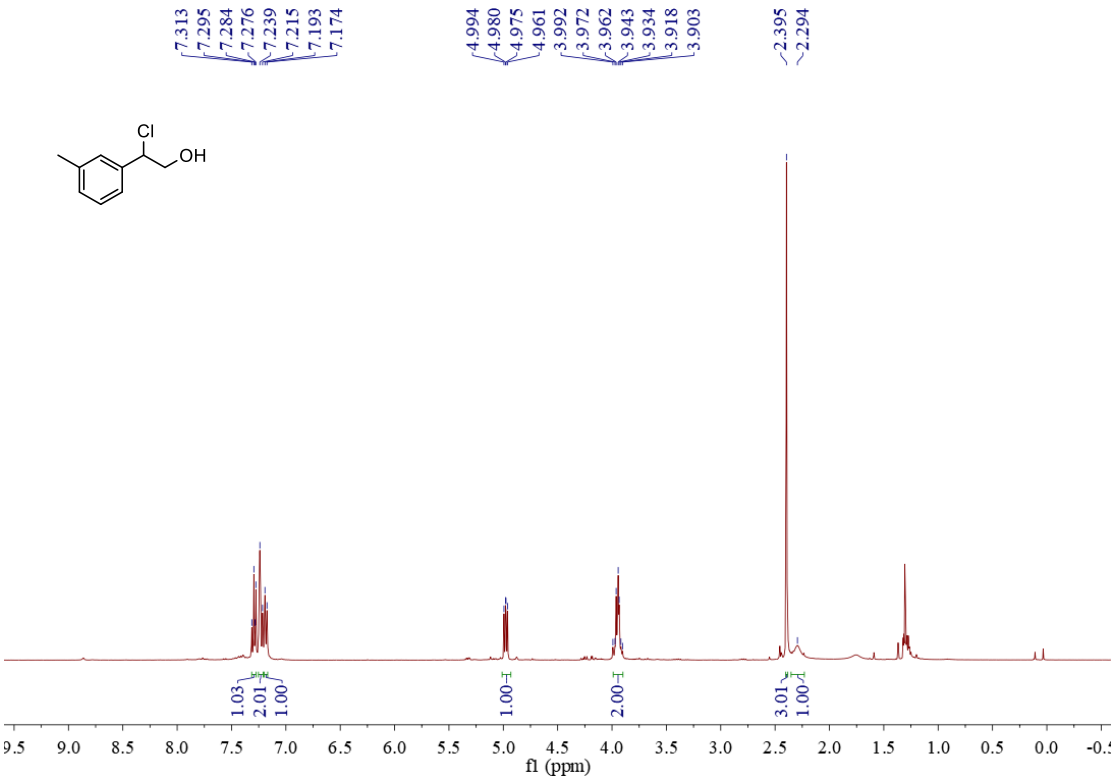

Cl
OH
NC
7.7131
7.6922
7.5804
7.5596
5.0430
5.0275
5.0120
4.0050
3.9741
3.9585
3.9282
2.2017
2.00
2.01
1.01
2.00
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)
143.0616
132.5463
128.3608
118.2497
112.7137
67.5249
63.2503
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

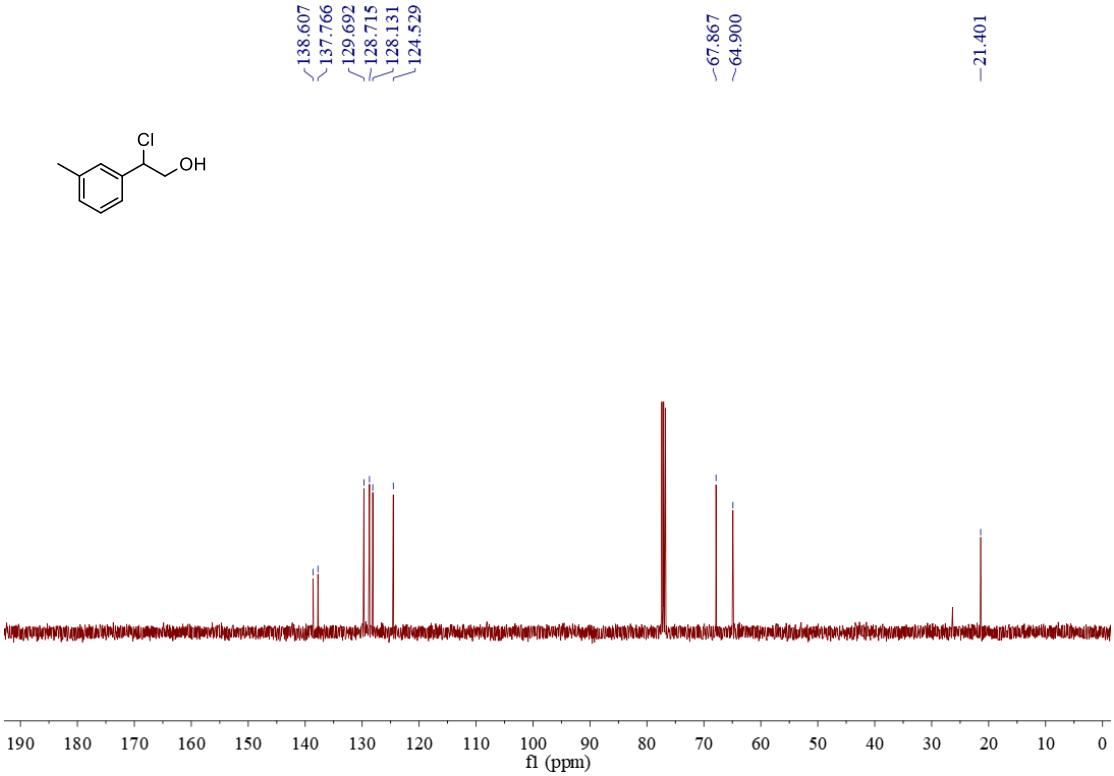
4m


7.335
7.315
7.296
7.284
7.016
7.014
6.997
6.984
6.978
6.973
6.920
6.918
6.914
6.912
6.900
6.897
6.893
6.891
4.994
4.979
4.976
4.961
3.959
3.954
3.941
3.844
2.200
Cl
MeO
OH
1.00
2.00
1.00
1.00
2.00
3.02
1.00
f1 (ppm)

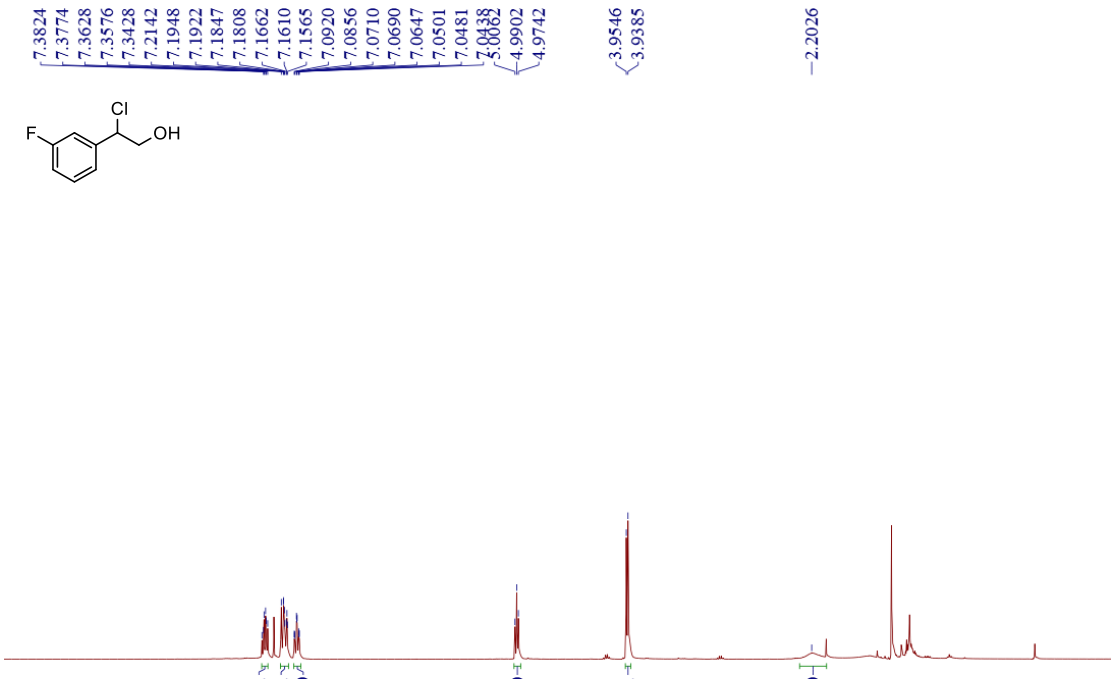

159.827
139.313
129.869
119.693
114.301
113.199
67.880
64.679
55.325
Cl
MeO
OH
f1 (ppm)

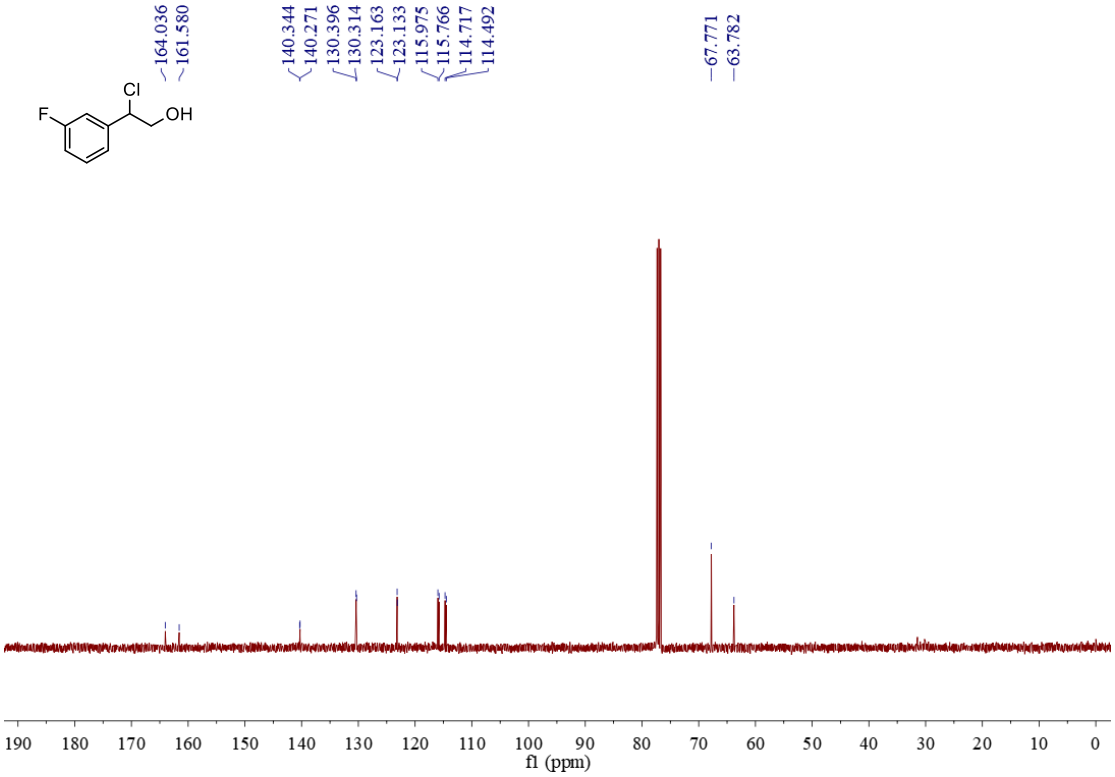
4n

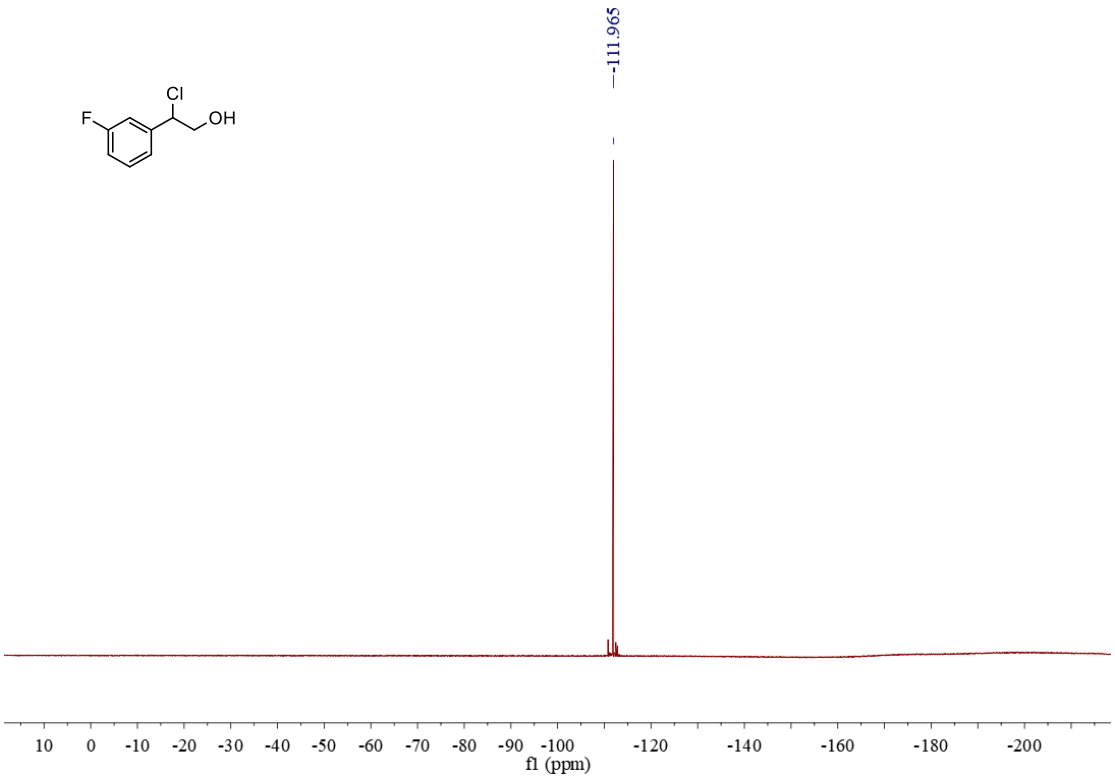

7.313
7.295
7.284
7.276
7.239
7.215
7.193
7.174
4.994
4.980
4.975
4.961
3.992
3.972
3.962
3.943
3.934
3.918
3.903
2.395
2.294
Cl
OH
1.03
2.01
1.00
1.00
2.00
3.01
1.00
f1 (ppm)


138.607
137.766
129.692
128.715
128.131
124.529
67.867
64.900
21.401
Cl
OH
f1 (ppm)

4o

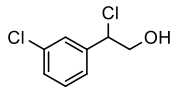

7.3824
7.3774
7.3628
7.3576
7.3428
7.2142
7.1948
7.1922
7.1847
7.1808
7.1662
7.1610
7.1565
7.0920
7.0856
7.0710
7.0690
7.0647
7.0501
7.0481
7.0438
5.0062
4.9902
4.9742
3.9546
3.9385
2.2026
Cl
F
OH
1.01
2.01
1.00
1.00
2.01
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

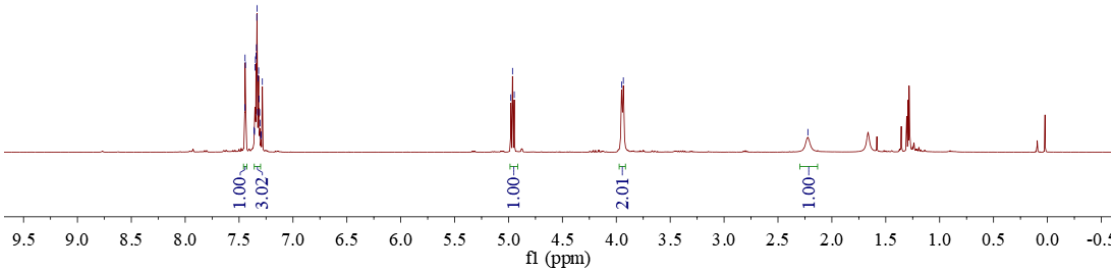

164.036
161.580
140.344
140.271
130.396
130.314
123.163
123.133
115.975
115.766
114.717
114.492
67.771
63.782
Cl
F
OH
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Cl
F
OH
-111.965
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

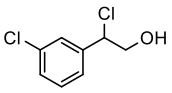
4p

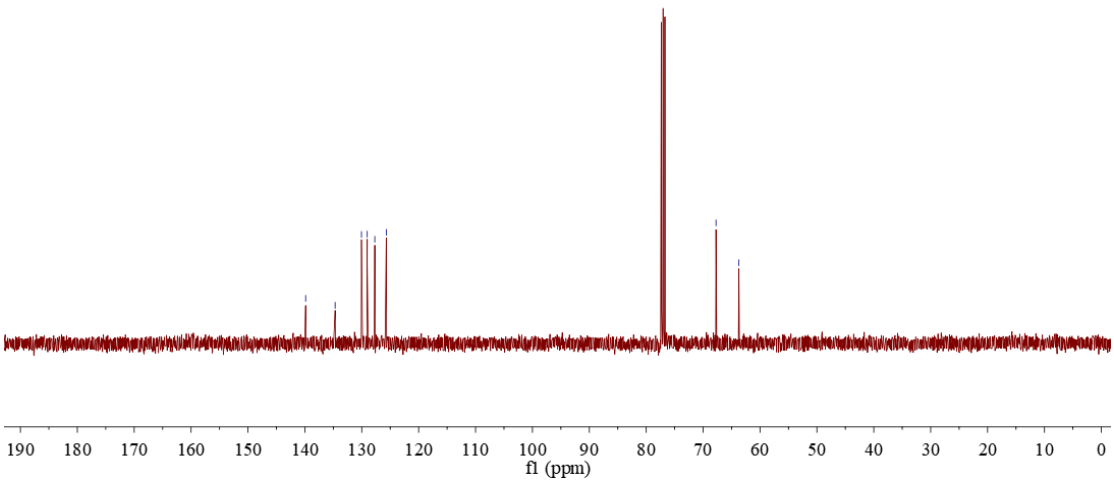

7.448
7.445
7.441
7.361
7.357
7.352
7.348
7.343
7.339
7.336
7.334
7.329
7.324
7.319
7.315
7.309
7.306
7.299
7.296
7.284
4.979
4.963
4.947
3.951
3.935
2.223


Cl
Cl
OH


1.00
3.02
1.00
2.01
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

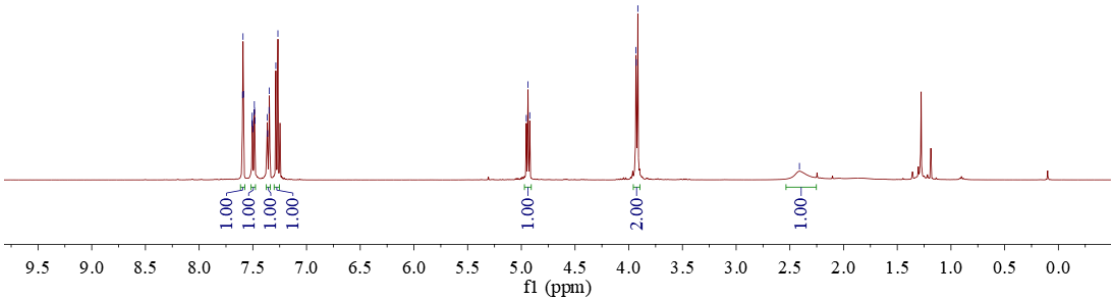

139.864
134.679
130.052
129.043
127.708
125.686
67.732
63.708

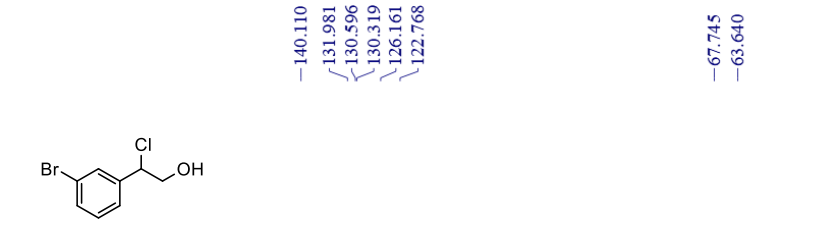

Cl
Cl
OH

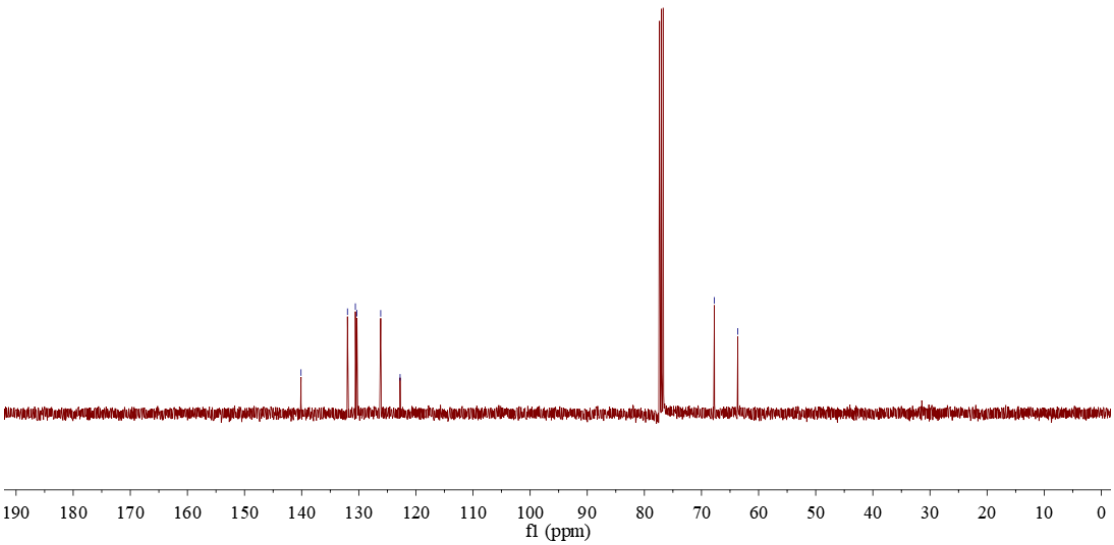

190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

4q

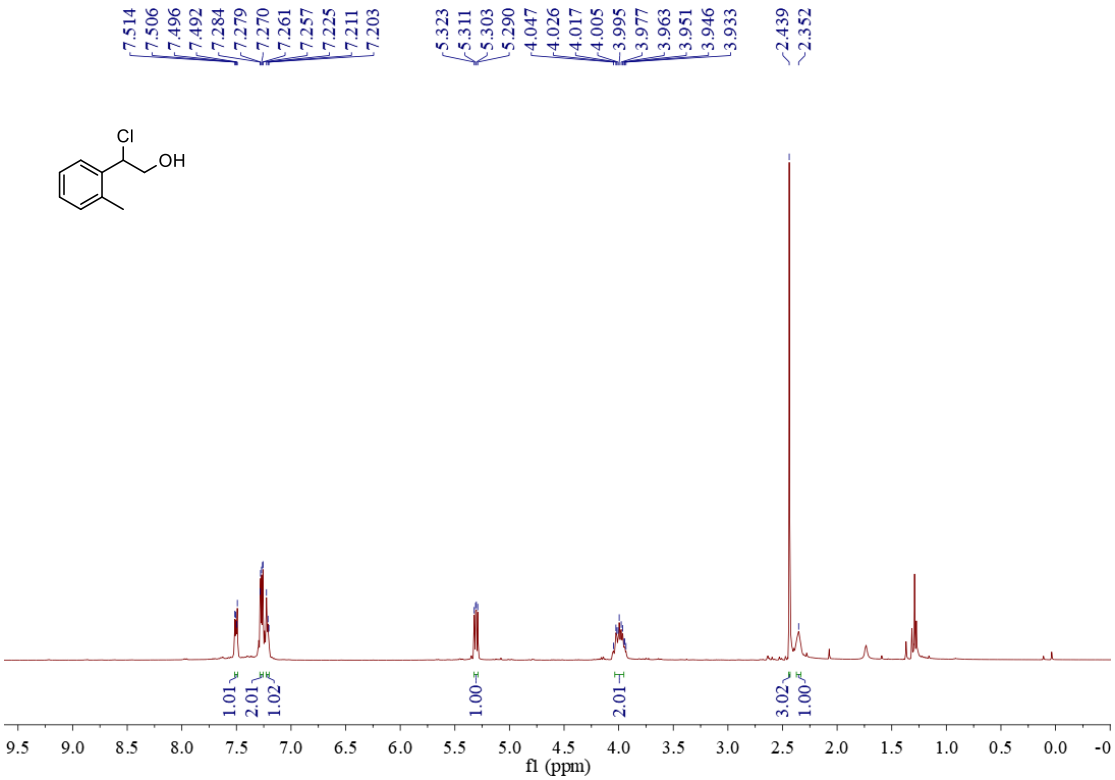

7.5957
7.5912
7.5867
7.5083
7.5055
7.5037
7.5008
7.4885
7.4857
7.4839
7.4810
7.3656
7.3625
7.3491
7.3461
7.2857
7.2663
4.9537
4.9379
4.9217
3.9333
3.9301
3.9157
2.4109
Cl
Br
OH

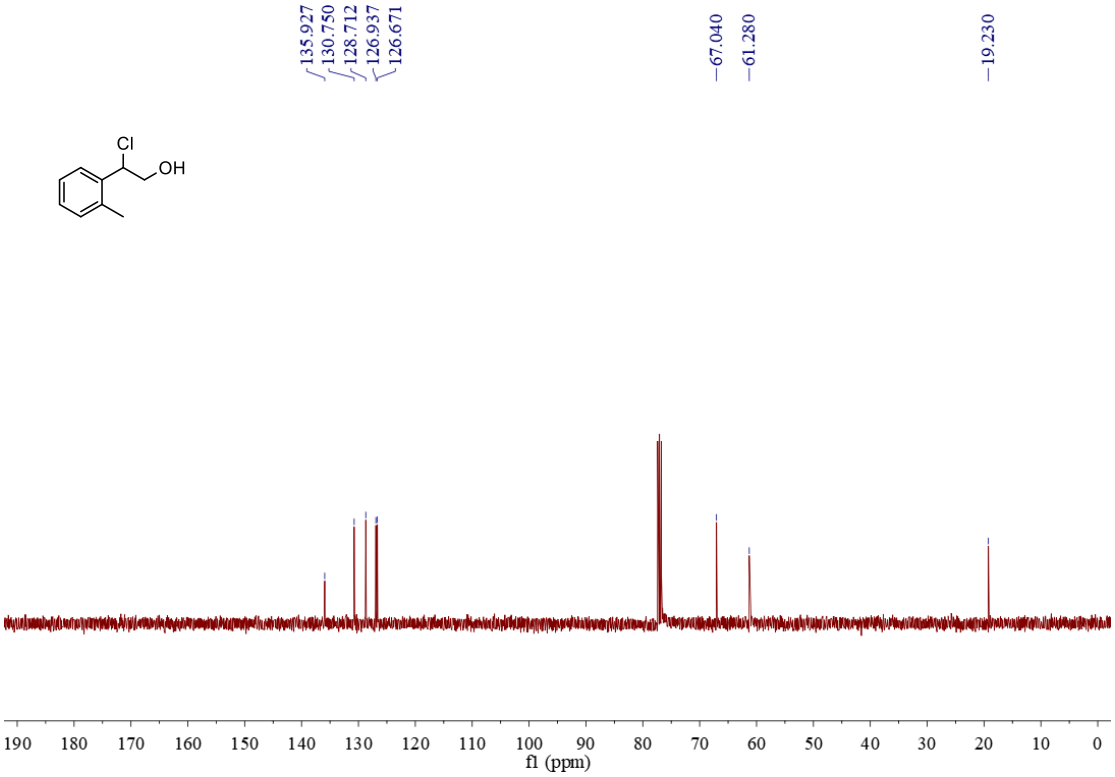

1.00
1.00
1.00
1.00
1.00
2.00
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


140.110
131.981
130.596
130.319
126.161
122.768
67.745
63.640
Cl
Br
OH

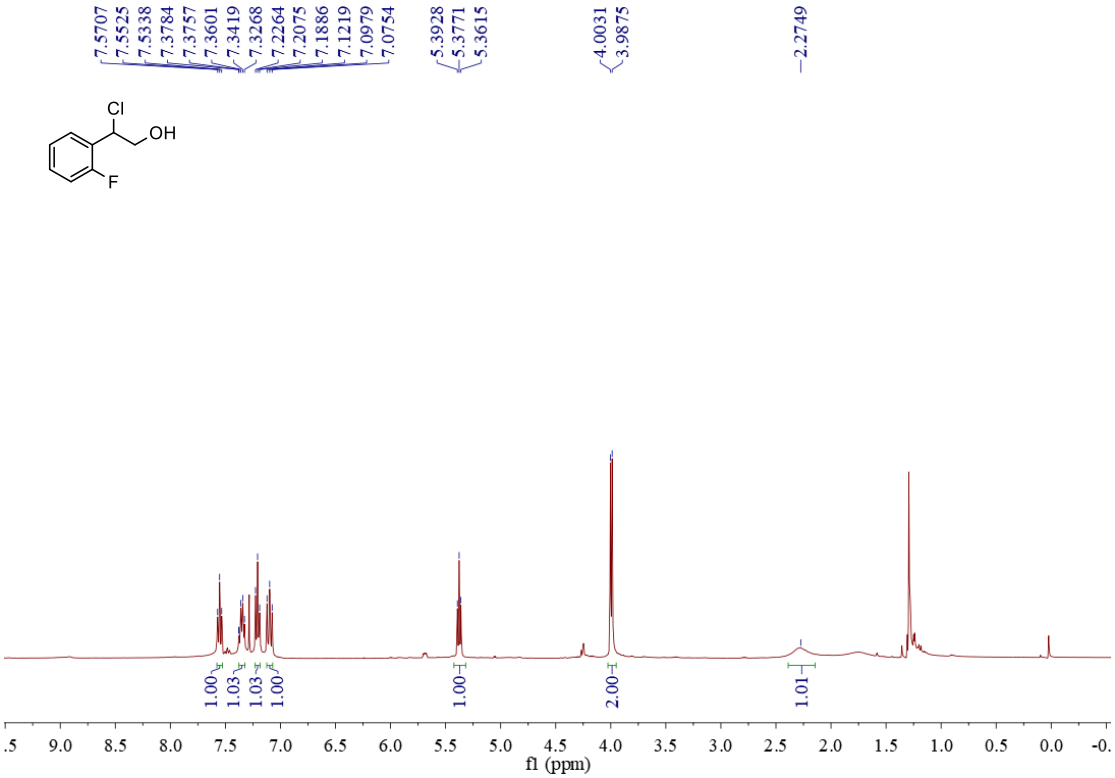

190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

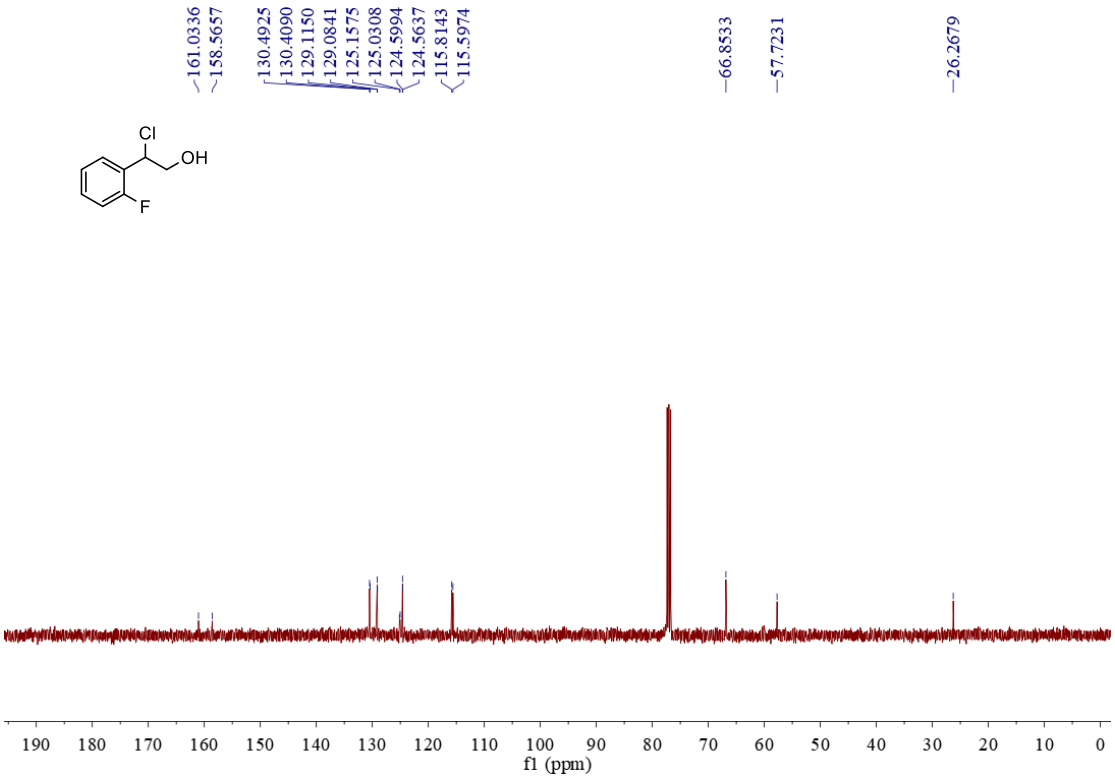
4r

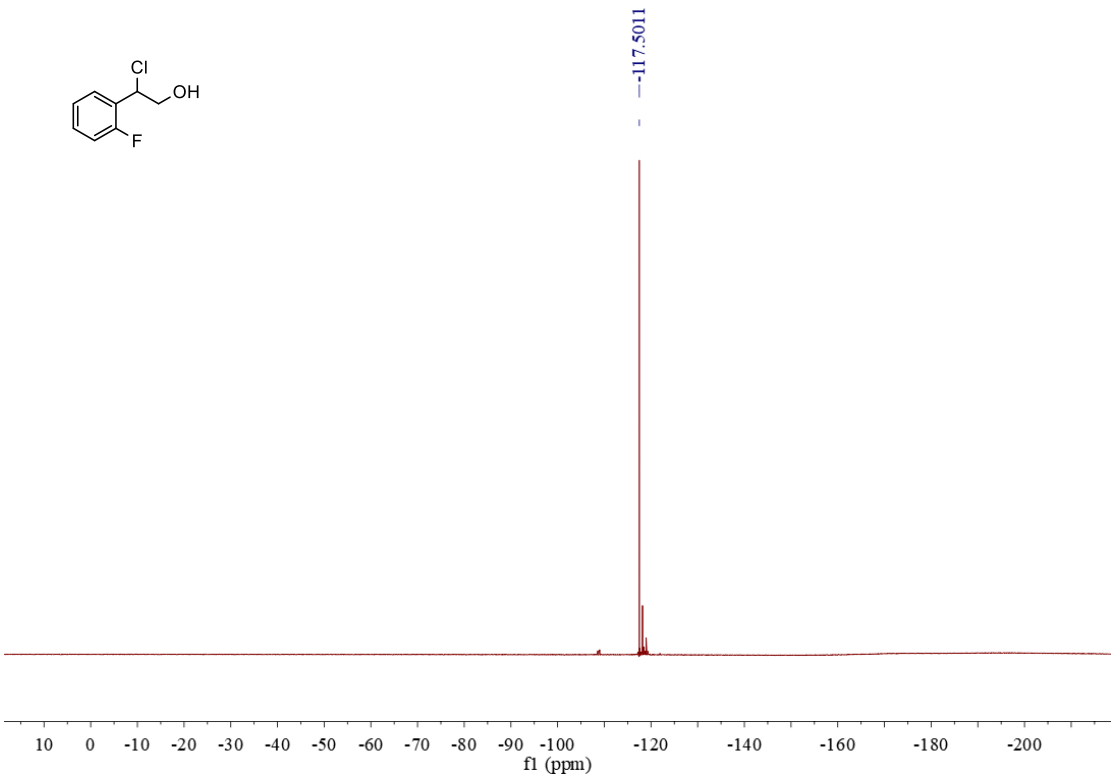

7.514
7.506
7.496
7.492
7.284
7.279
7.270
7.261
7.257
7.225
7.211
7.203
5.323
5.311
5.303
5.290
4.047
4.026
4.017
4.005
3.995
3.977
3.963
3.951
3.946
3.933
2.439
2.352
Cl
OH
1.01
2.01
1.02
1.00
2.01
3.02
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0
f1 (ppm)


135.927
130.750
128.712
126.937
126.671
67.040
61.280
19.230
Cl
OH
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

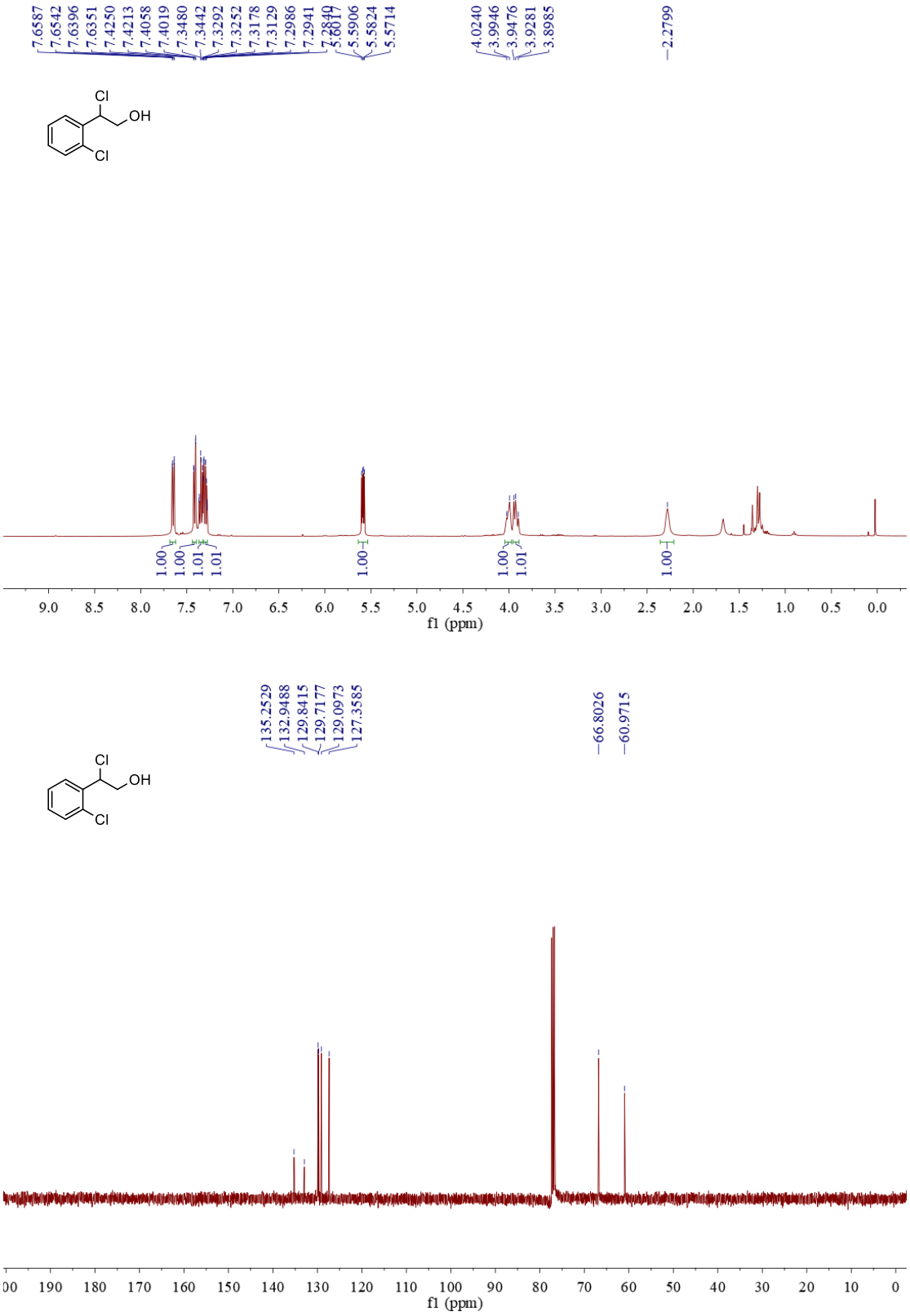
4s


7.5707
7.5525
7.5338
7.3784
7.3757
7.3601
7.3419
7.3268
7.2264
7.2075
7.1886
7.1219
7.0979
7.0754
5.3928
5.3771
5.3615
4.0031
3.9875
2.2749
Cl
OH
F
1.00
1.03
1.03
1.00
1.00
2.00
1.01
f1 (ppm)

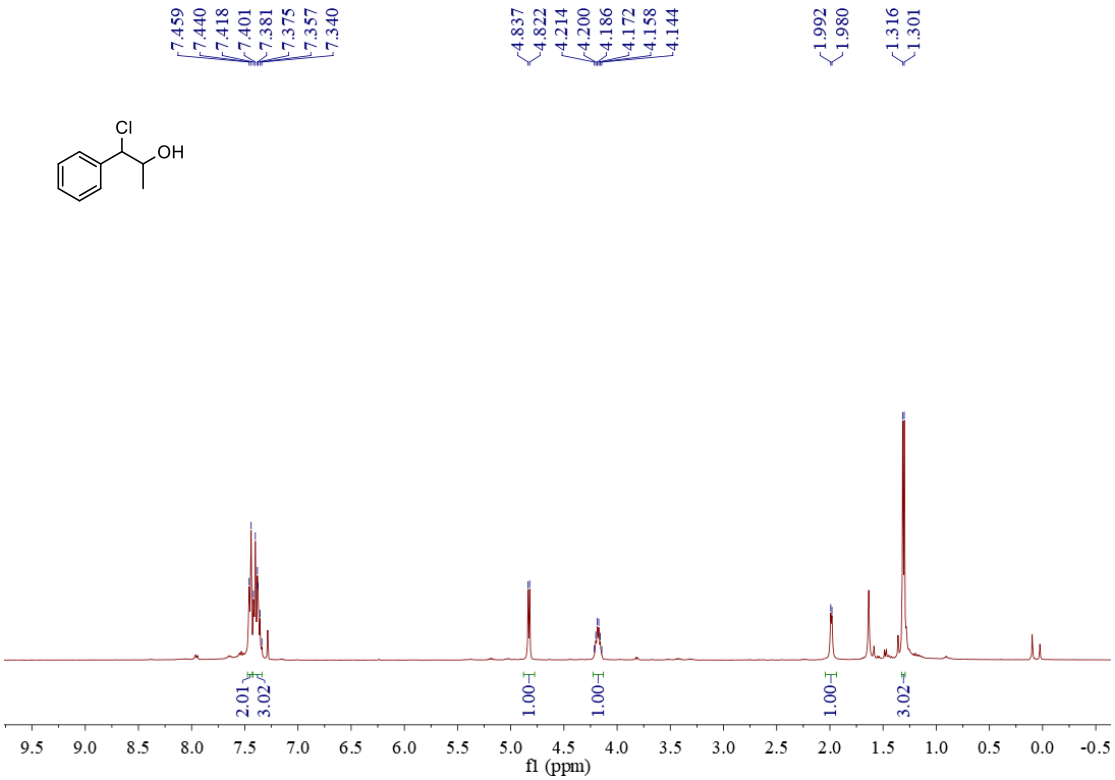

161.0336
158.5657
130.4925
130.4090
129.1150
129.0841
125.1575
125.0308
124.5994
124.5637
115.8143
115.5974
66.8533
57.7231
26.2679
Cl
OH
F
f1 (ppm)

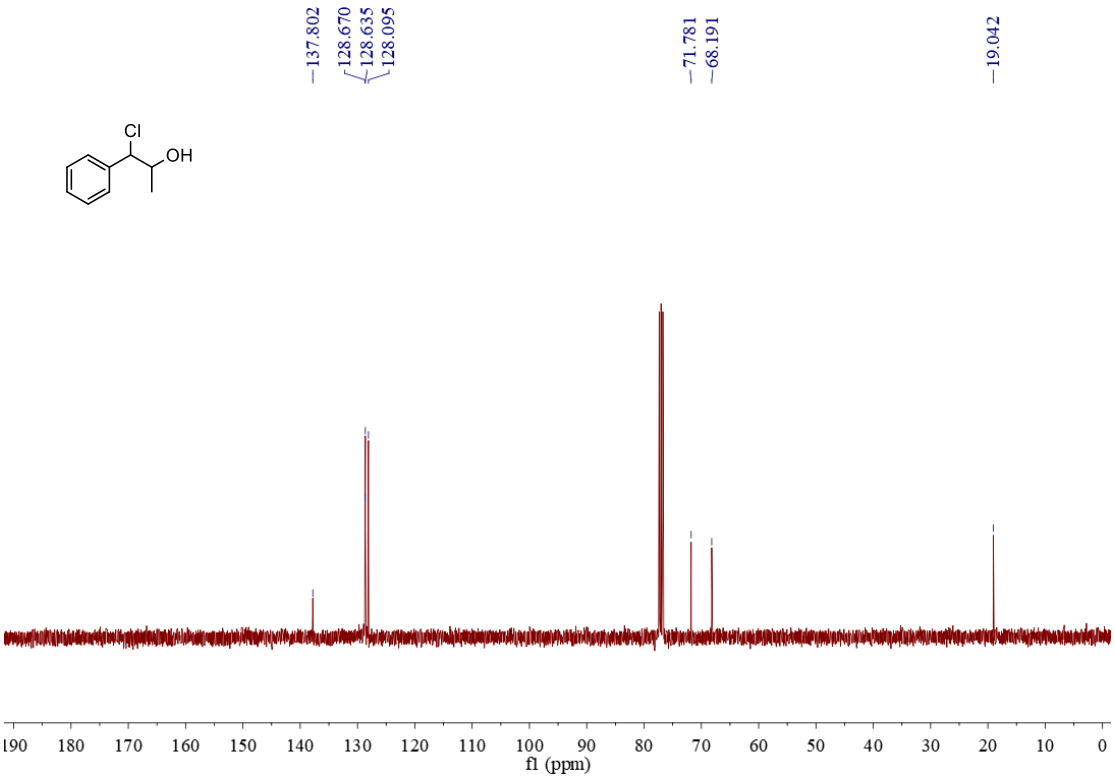

Cl
OH
F
-117.5011
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

4t

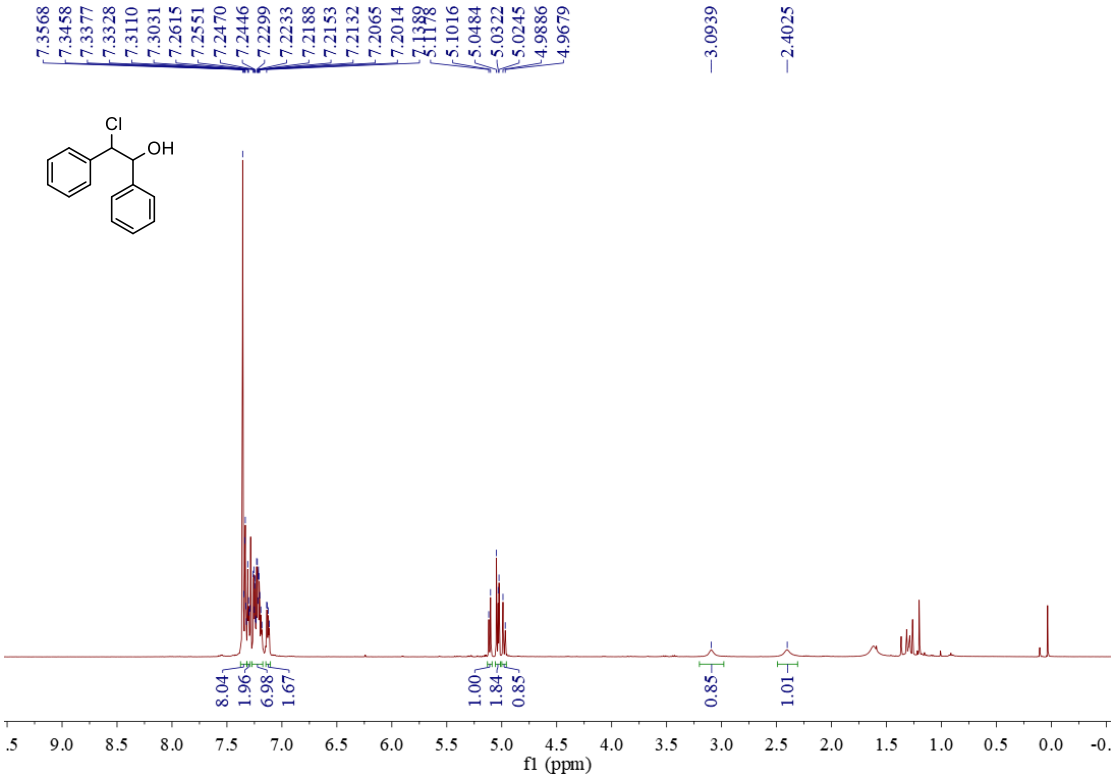

7.6587
7.6542
7.6396
7.6351
7.4250
7.4213
7.4058
7.4019
7.3480
7.3442
7.3292
7.3252
7.3178
7.3129
7.2986
7.2941
5.5906
5.5824
5.5714
4.0240
3.9946
3.9476
3.9281
3.8985
2.2799
Cl
OH
Cl
1.00
1.00
1.01
1.01
1.00
1.00
1.01
1.00
f1 (ppm)
135.2529
132.9488
129.8415
129.7177
129.0973
127.3585
66.8026
60.9715
Cl
OH
Cl
f1 (ppm)

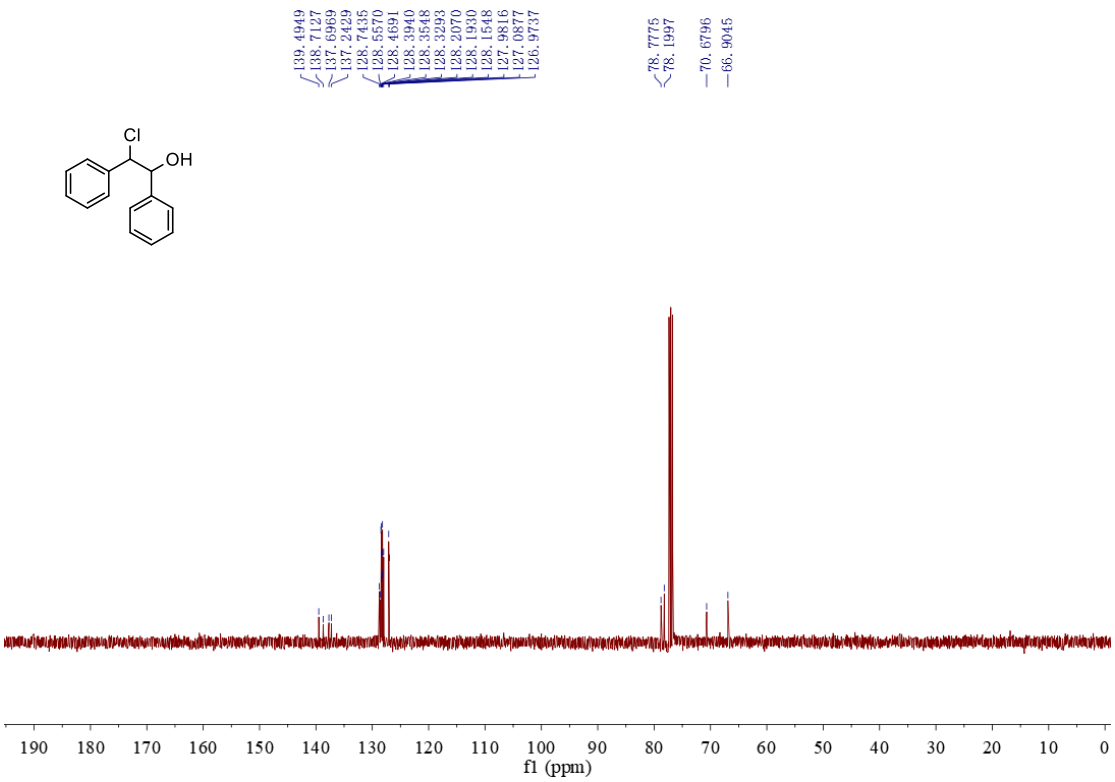
4u


7.459
7.440
7.418
7.401
7.381
7.375
7.357
7.340
4.837
4.822
4.214
4.200
4.186
4.172
4.158
4.144
1.992
1.980
1.316
1.301
Cl
OH
2.01
3.02
1.00
1.00
1.00
3.02
f1 (ppm)

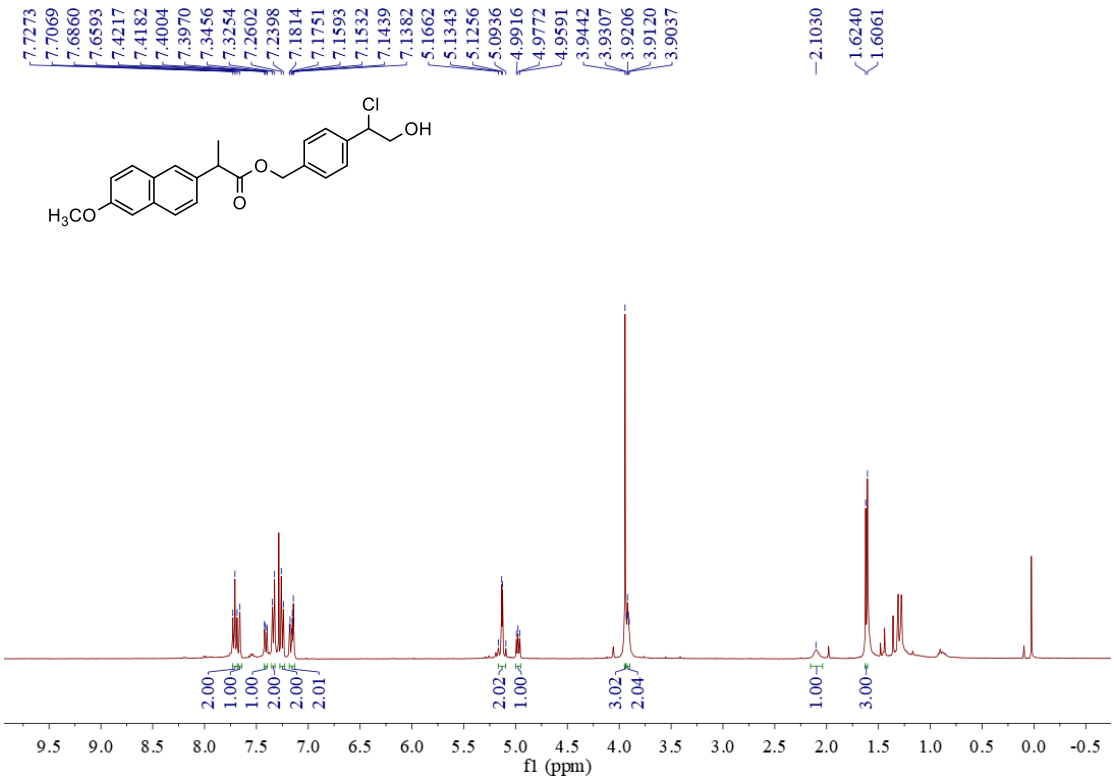

137.802
128.670
128.635
128.095
71.781
68.191
19.042
Cl
OH
f1 (ppm)

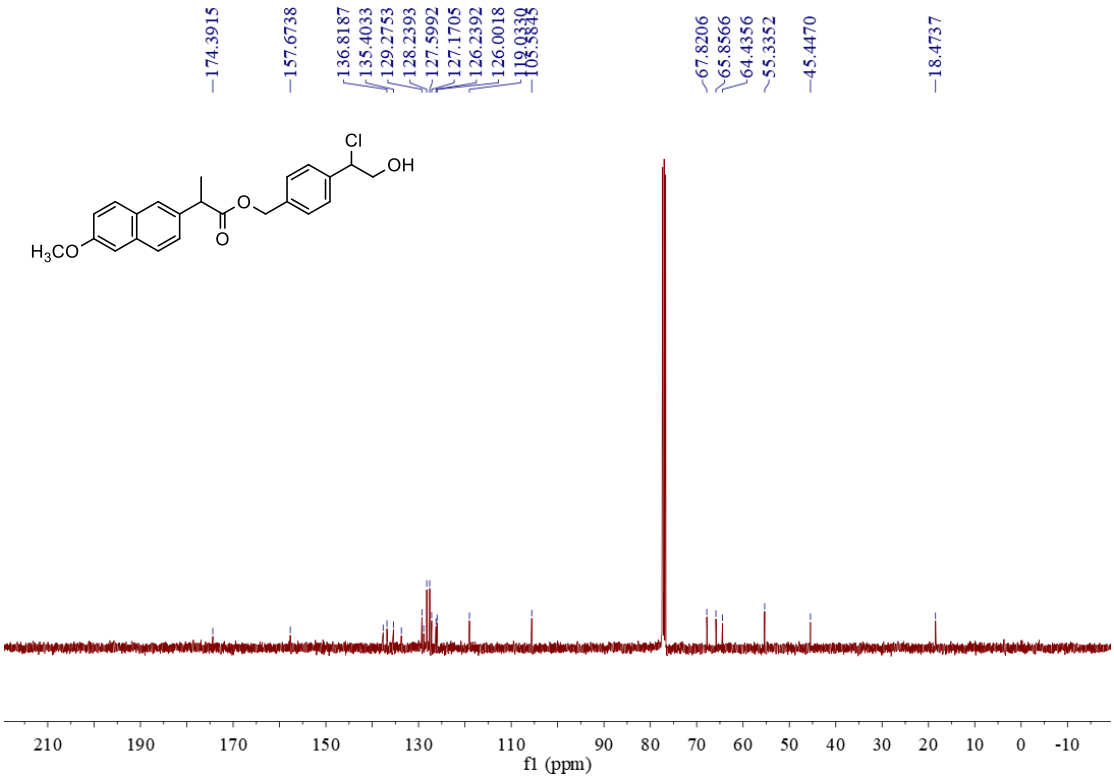
4v


7.3568
7.3458
7.3377
7.3328
7.3110
7.3031
7.2615
7.2551
7.2470
7.2446
7.2299
7.2233
7.2188
7.2153
7.2132
7.2065
7.2014
7.1389
5.1178
5.1016
5.0484
5.0322
5.0245
4.9886
4.9679
3.0939
2.4025
Cl
OH
8.04
1.96
6.98
1.67
1.00
1.84
0.85
0.85
1.01
f1 (ppm)

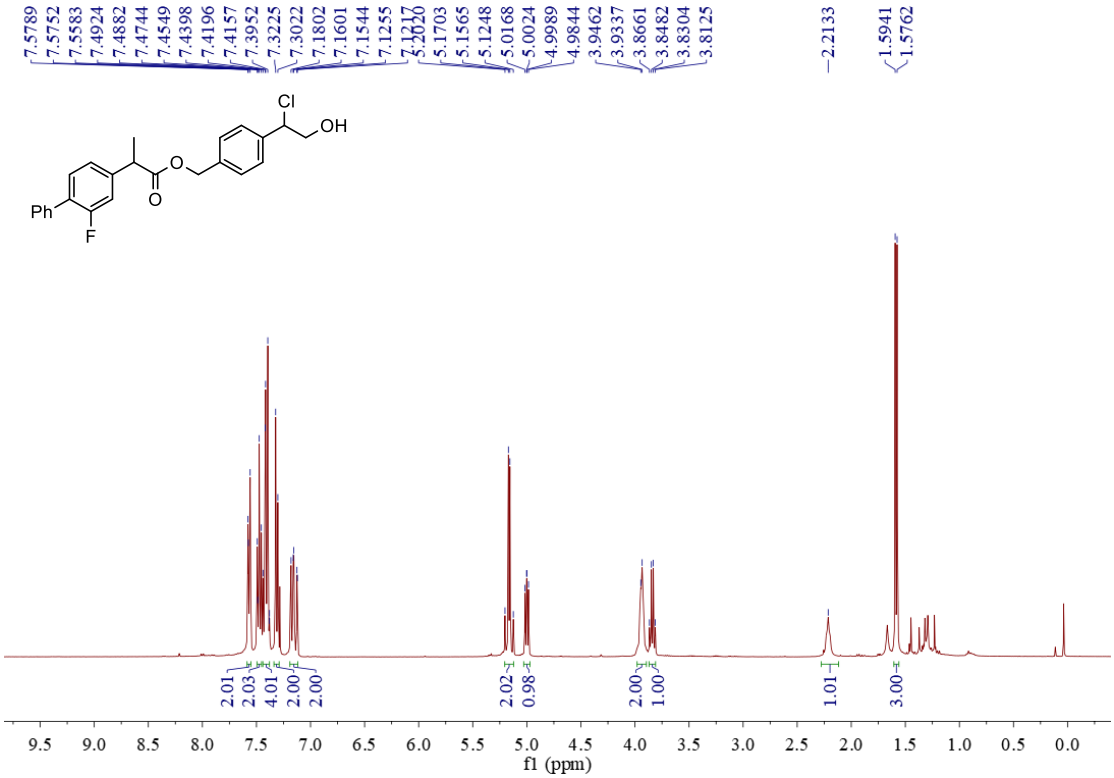

139.4949
138.7127
137.6969
137.2429
128.7435
128.5570
128.4691
128.3940
128.3548
128.3293
128.2070
128.1930
128.1548
127.9816
127.0877
126.9737
78.7775
78.1997
70.6796
66.9045
Cl
OH
f1 (ppm)

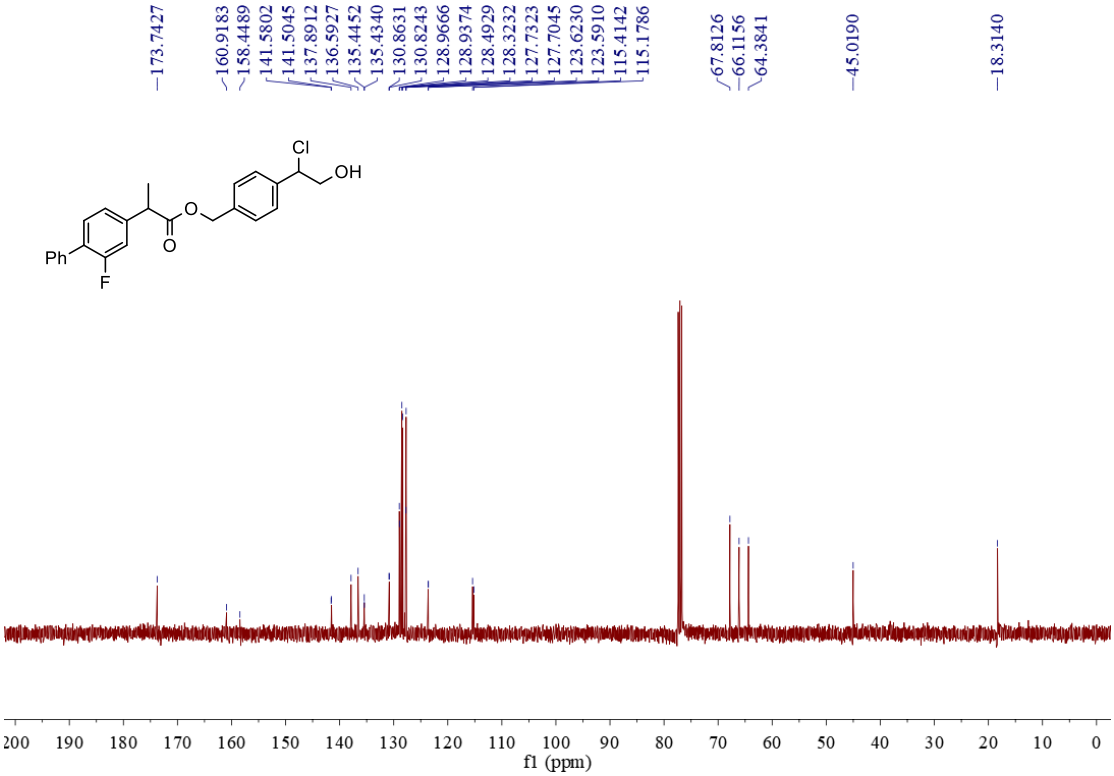
4y

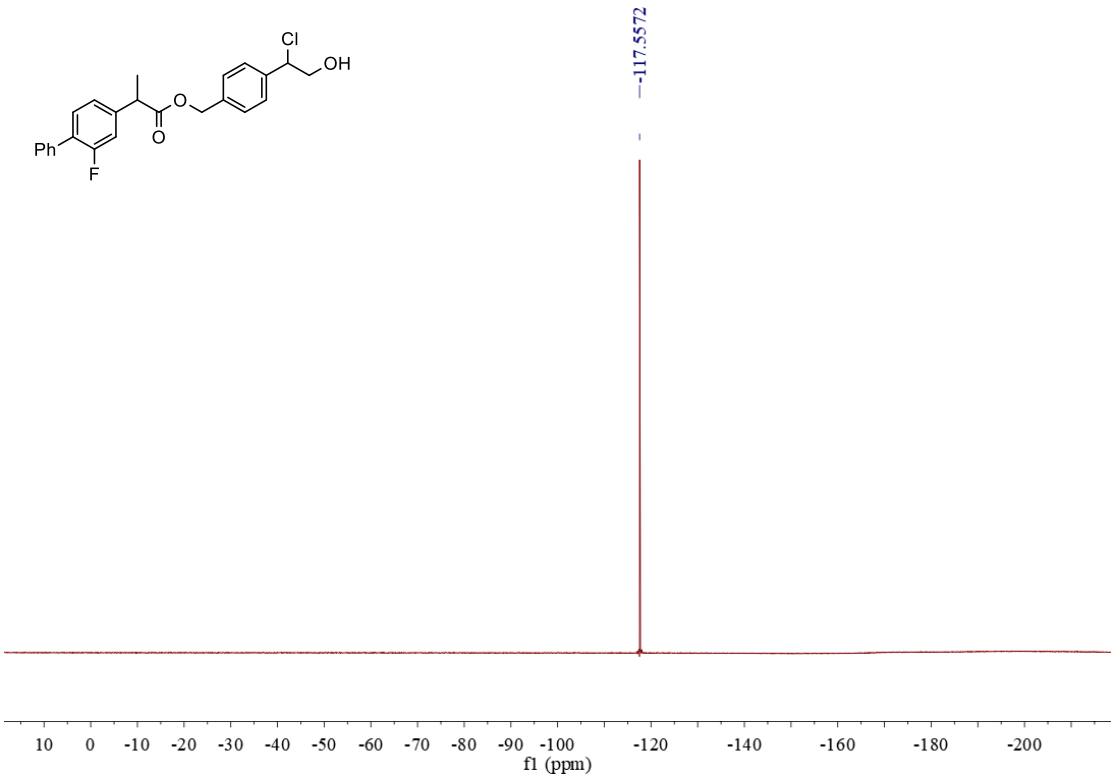

7.7273
7.7069
7.6860
7.6593
7.4217
7.4182
7.4004
7.3970
7.3456
7.3254
7.2602
7.2398
7.1814
7.1751
7.1593
7.1532
7.1439
7.1382
5.1662
5.1343
5.1256
5.0936
4.9916
4.9772
4.9591
3.9442
3.9307
3.9206
3.9120
3.9037
2.1030
1.6240
1.6061
Cl
OH
O
O
H3CO
2.00
1.00
1.00
2.00
2.00
2.01
2.02
1.00
3.02
2.04
1.00
3.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


174.3915
157.6738
136.8187
135.4033
129.2753
128.2393
127.5992
127.1705
126.2392
126.0018
67.8206
65.8566
64.4356
55.3352
45.4470
18.4737
Cl
OH
O
O
H3CO
210 190 170 150 130 110 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

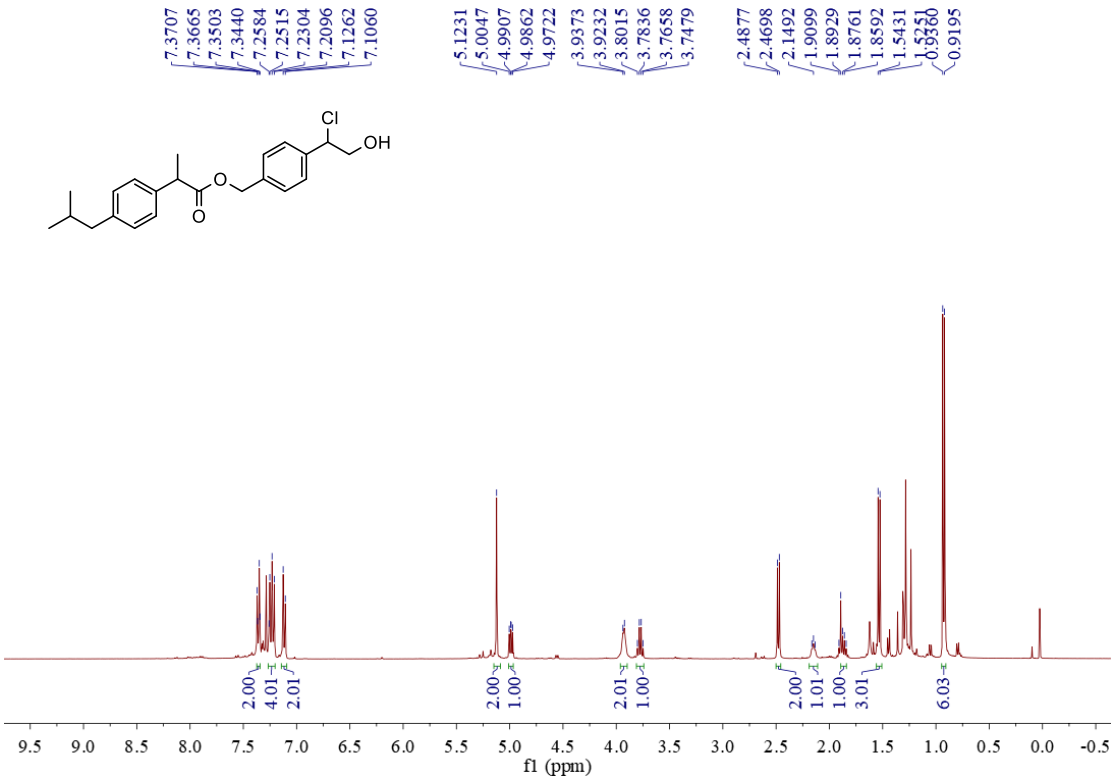
4z

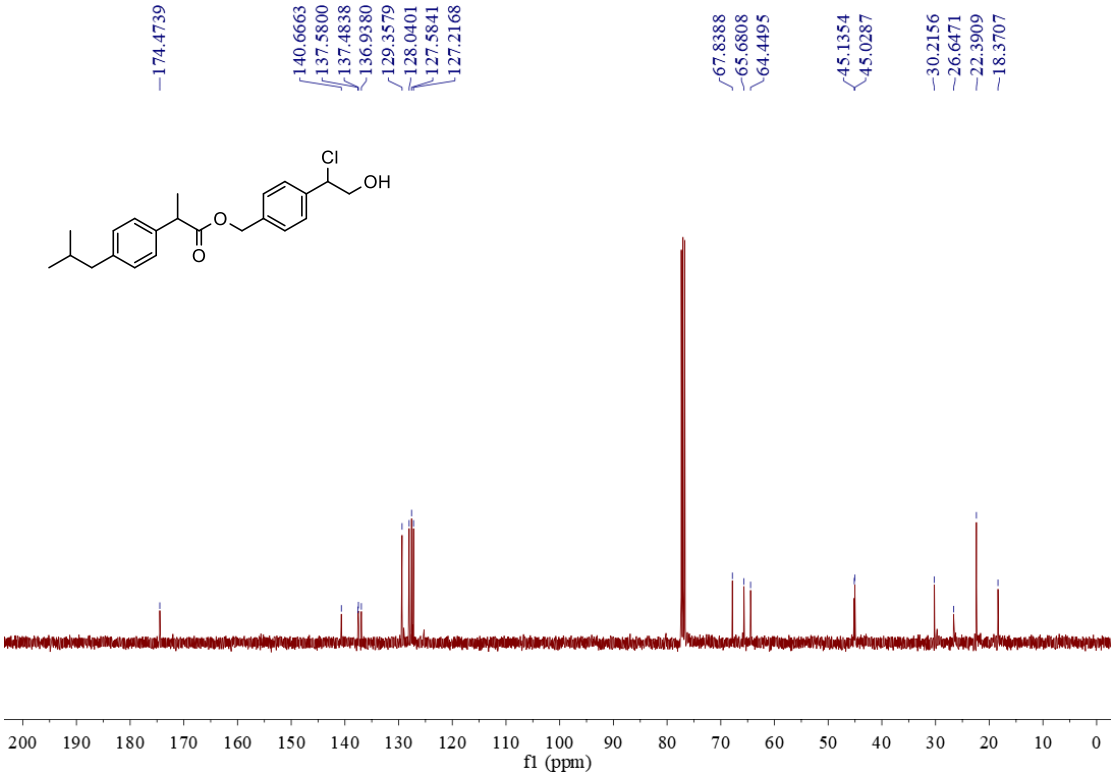

7.5789
7.5752
7.5583
7.4924
7.4882
7.4744
7.4549
7.4398
7.4196
7.4157
7.3952
7.3225
7.3022
7.1802
7.1601
7.1544
7.1255
5.1703
5.1565
5.1248
5.0168
5.0024
4.9989
4.9844
3.9462
3.9337
3.8661
3.8482
3.8304
3.8125
2.2133
1.5941
1.5762
Cl
OH
O
O
Ph
F
2.01
2.03
4.01
2.00
2.00
2.02
0.98
2.00
1.00
1.01
3.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


173.7427
160.9183
158.4489
141.5802
141.5045
137.8912
136.5927
135.4452
135.4340
130.8631
130.8243
128.9666
128.9374
128.4929
128.3232
127.7323
127.7045
123.6230
123.5910
115.4142
115.1786
67.8126
66.1156
64.3841
45.0190
18.3140
Cl
OH
O
O
Ph
F
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

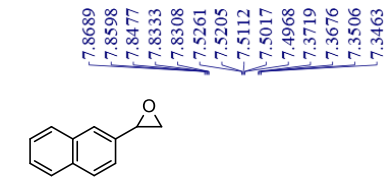

Cl
OH
O
O
Ph
F
-117.5572
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

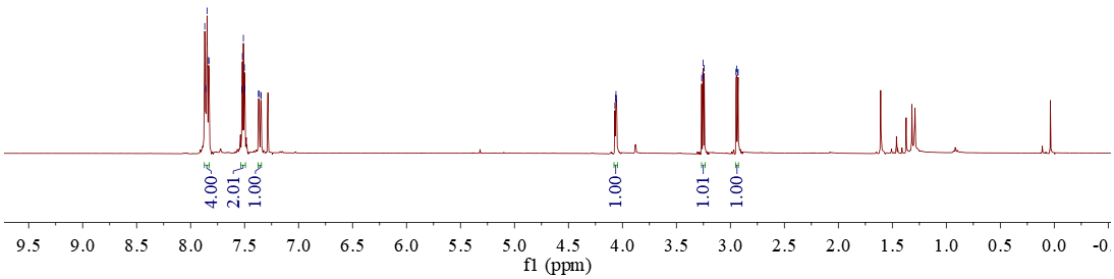
4aa

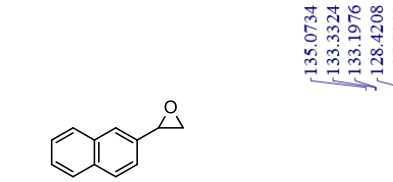

7.3707
7.3665
7.3503
7.3440
7.2584
7.2515
7.2304
7.2096
7.1262
7.1060
5.1231
5.0047
4.9907
4.9862
4.9722
3.9373
3.9232
3.8015
3.7836
3.7658
3.7479
2.4877
2.4698
2.1492
1.9099
1.8929
1.8761
1.8592
1.5431
1.5251
0.9360
0.9195
Cl
OH
O
O
2.00
4.01
2.01
2.00
1.00
2.01
1.00
2.00
1.01
1.00
3.01
6.03
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

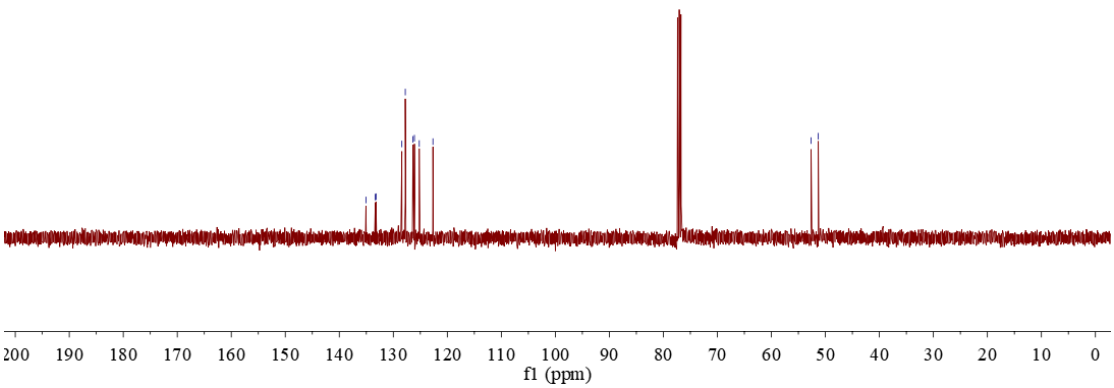

174.4739
140.6663
137.5800
137.4838
136.9380
129.3579
128.0401
127.5841
127.2168
67.8388
65.6808
64.4495
45.1354
45.0287
30.2156
26.6471
22.3909
18.3707
Cl
OH
O
O
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

5

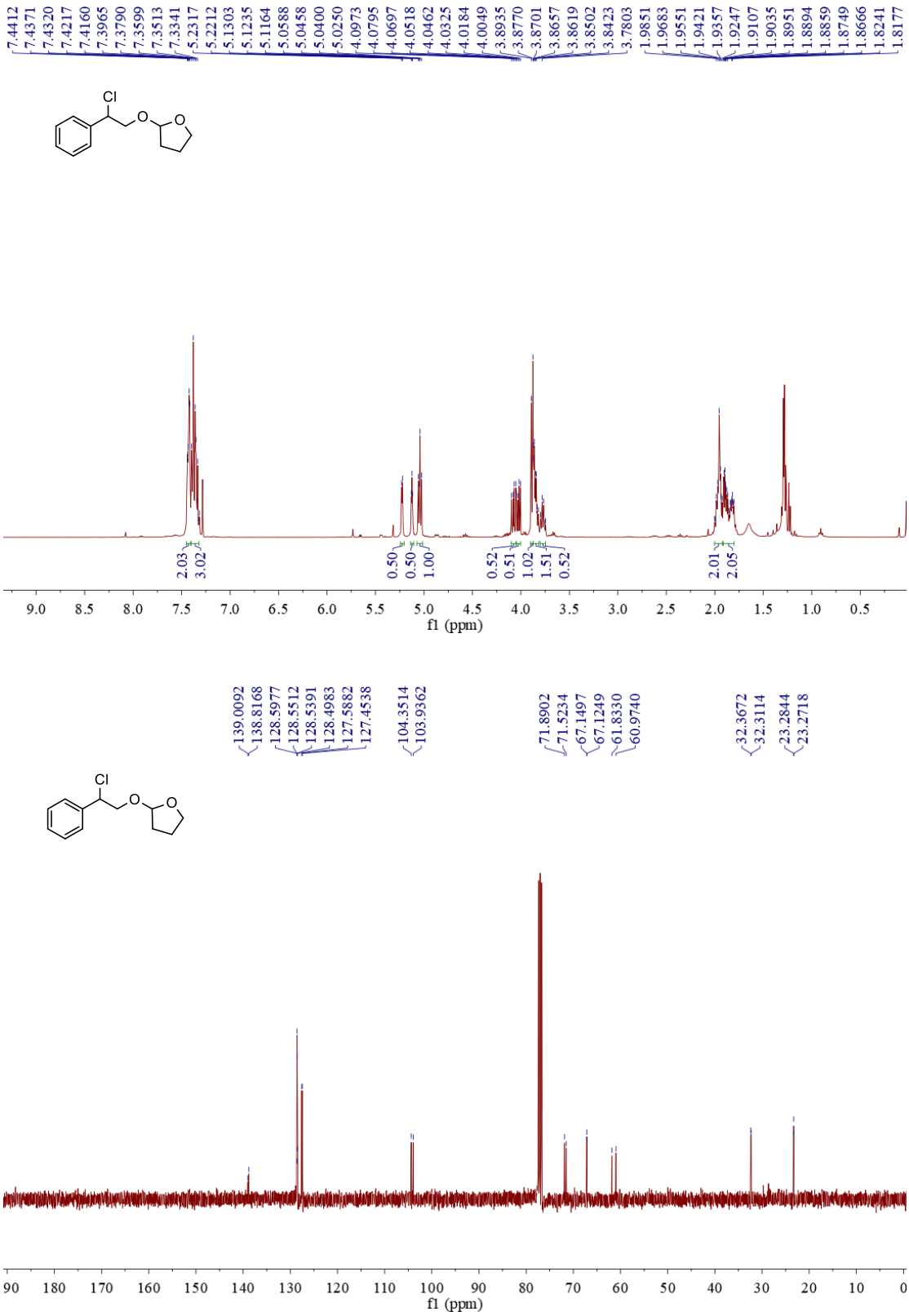

7.8689
7.8598
7.8477
7.8333
7.8308
7.5261
7.5205
7.5112
7.5017
7.4968
7.3719
7.3676
7.3506
7.3463
4.0700
4.0634
4.0600
4.0535
3.2662
3.2559
3.2526
3.2424
2.9484
2.9420
2.9348
2.9284


4.00
2.01
1.00
1.00
1.01
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


135.0734
133.3324
133.1976
128.4208
127.7839
126.3715
126.0931
125.1937
122.6640
52.6400
51.3075


200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

6


7.4412
7.4371
7.4320
7.4217
7.4160
7.3965
7.3790
7.3599
7.3513
7.3341
5.2317
5.2212
5.1303
5.1235
5.1164
5.0588
5.0458
5.0400
5.0250
4.0973
4.0795
4.0697
4.0518
4.0462
4.0325
4.0184
4.0049
3.8935
3.8770
3.8701
3.8657
3.8619
3.8502
3.8423
3.7803
1.9851
1.9683
1.9551
1.9421
1.9357
1.9247
1.9107
1.9035
1.8951
1.8894
1.8859
1.8749
1.8666
1.8241
1.8177
Cl
O
O
2.03
3.02
0.50
0.50
1.00
0.52
0.51
1.02
1.51
0.52
2.01
2.05
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)
139.0092
138.8168
128.5977
128.5512
128.5391
128.4983
127.5882
127.4538
104.3514
103.9362
71.8902
71.5234
67.1497
67.1249
61.8330
60.9740
32.3672
32.3114
23.2844
23.2718
Cl
O
O
90
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)