Palladium-Catalyzed γ-C(sp^3)–H Carbonylation of Aliphatic Amines: Direct approach to synthesis Pyrrolidones via Oxalyl Amide Assistance

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Supporting information

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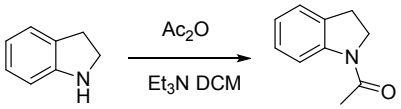
1. Reagents: Unless otherwise noted, all reagents were purchased from commercial suppliers and used without further purification. Column chromatography purifications were performed using 300–400 mesh silica gel.

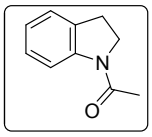
2. Instruments: NMR spectra were recorded on Varian Inova–400 MHz, Inova–300 MHz, Bruker DRX–400 or Bruker DRX–500 instruments and calibrated using residual solvent peaks as internal reference. Multiplicities are recorded as: s = singlet, d = doublet, t = triplet, dd = doublet of doublets, br = broad singlet, m = multiplet. HRMS analyses were carried out using a Bruker micrOTOF–Q instrument or a TOF–MS instrument.

3. Preparation of various directing groups protected substrates

3.1 Preparation of Ac amide

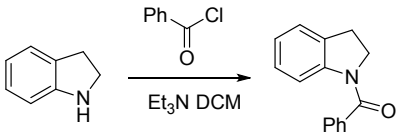


A solution of Indoline (20 mmol, 1.0 equiv) and triethylamine (2.92 ml, 21 mmol, 1.05 equiv) in CH_2Cl_2 (40 mL) was added dropwise to a solution of Acetic anhydride (25 mmol, 1.25 equiv) in CH_2Cl_2 (50 mL) at 0 °C, then the mixture was stirred for 6 hours at room temperature before quenched by water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 2). The combined organic phase was washed with brine (30 mL), and then dried over anhydrous Na_2SO_4. Evaporation and column chromatography on silica gelafforded corresponding amide substrates as white solid.

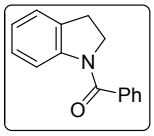


^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (d, *J* = 8.0 Hz, 1H), 7.18 – 7.13 (m, 2H), 6.98 (t, *J* = 7.4 Hz, 1H), 3.98 (t, *J* = 8.5 Hz, 2H), 3.14 (t, *J* = 8.5 Hz, 2H), 2.17 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.2, 142.4, 130.7, 127.0, 124.1, 123.1, 116.4, 48.2, 27.5, 23.7; HRMS Calcd for $C_{10}H_{12}NO$ [M+H$^+$]:162.0919; Found: 162.0931.

3.2 Preparation of N-benzoyl amide.

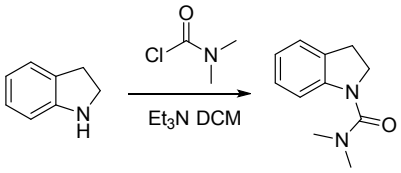


A solution of Indoline (20 mmol, 1.0 equiv) and triethylamine (2.92 ml, 21 mmol, 1.05 equiv) in CH_2Cl_2 (40 mL) was added dropwise to a solution of Benzoyl Chloride (25 mmol, 1.25 equiv) in CH_2Cl_2 (50 mL) at 0 °C, then the mixture was stirred for 6 hours at room temperature before quenched by water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 2). The combined organic phase was washed with brine (30 mL), and then dried over anhydrous Na_2SO_4. Evaporation and column chromatography on silica gelafforded corresponding amide substrates as white solid.

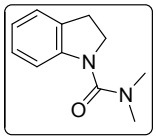


^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (s, 1H), 7.56 – 7.54 m(dd, *J* = 7.7, 1.5 Hz, 2H), 7.49 – 7.43 (m, 3H), 7.21 (d, *J* = 7.6 Hz, 1H), 7.13 (s, 1H), 7.02 (s, 1H), 4.07 (s, 2H), 3.11 (t, *J* = 8.3 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.1, 142.7, 141.1, 137.1, 132.5, 130.4, 128.7, 127.3, 127.2, 125.0, 124.0, 119.5, 117.2, 50.8, 28.2; HRMS Calcd for $C_{15}H_{14}NO$ [M+H$^+$]:224.1075; Found: 224.1082.

3.3 Preparation of N- Dimethylcarbamyl amide.

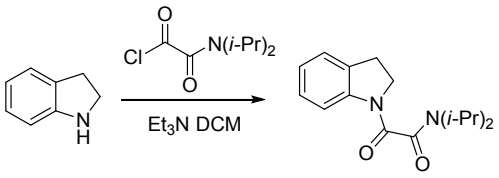


A solution of Indoline (20 mmol, 1.0 equiv) and triethylamine (2.92 ml, 21 mmol, 1.05 equiv) in CH_2Cl_2 (40 mL) was added dropwise to a solution of Dimethylcarbamyl Chloride (25 mmol, 1.25 equiv) in CH_2Cl_2 (50 mL) at 0 °C, then the mixture was stirred for 6 hours at room temperature before quenched by water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 2). The combined organic phase was washed with brine (30 mL), and then dried over anhydrous Na_2SO_4. Evaporation and column chromatography on silica gelafforded corresponding amide substrates as white solid.

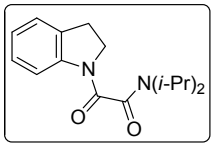


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.14 – 7.06 (m, 2H), 6.94 – 6.88 (m, 1H), 6.86 – 6.803 (m, 1H), 3.91 – 3.81 (m, 2H), 2.99 (t, *J* = 8.4 Hz, 2H), 2.90 (d, *J* = 1.2 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.8, 143.8, 130.9, 126.5, 124.3, 120.9, 112.9, 49.9, 37.7, 27.6; HRMS Calcd for $C_{11}H_{15}N_2O$[M+H$^+$]:191.1184; Found: 191.1189.

3.4 Preparation of oxalyl amide

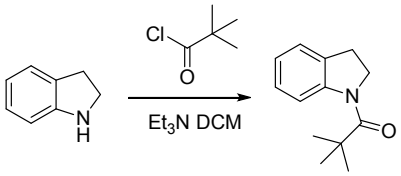


A solution of Indoline (20 mmol, 1.0 equiv) and triethylamine (2.92 ml, 21 mmol, 1.05 equiv) in CH_2Cl_2 (40 mL) was added dropwise to a solution of oxalyl Chloride (25 mmol, 1.25 equiv) in CH_2Cl_2 (50 mL) at 0 °C, then the mixture was stirred for 6 hours at room temperature before quenched by water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 2). The combined organic phase was washed with brine (30 mL), and then dried over anhydrous Na_2SO_4. Evaporation and column chromatography on silica gelafforded corresponding amide substrates as white solid.



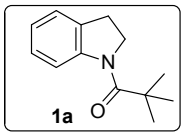
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.18 (d, *J* = 8.8 Hz, 0.60H), 7.26 – 6.96 (m, 3.30H), 4.17 (s, 0.56H), 4.09 (t, *J* = 8.4 Hz, 1.48H), 3.99 -3.92 (m, 0.72H), 3.79 – 3.68 (m, 1H), 3.56 – 3.49 (m, 1H), 3.20 (t, *J* = 8.4 Hz, 1.45H), 3.14 (t, *J* = 8.4 Hz, 0.52H), 1.57 (d, *J* = 6.8 Hz, 1.54H), 1.51 (d, *J* = 6.8 Hz, 4.46H), 1.25 (d, *J* = 6.6 Hz, 4.51H), 1.14 (s, 1.49H); ^{13}C NMR (151 MHz, cdcl$_3$) δ 164.5, 164.1, 162.6, 162.5, 141.9, 139.9, 133.0, 131.9, 127.8, 127.5, 125.8, 124.9, 124.8, 124.4, 117.4, 113.4, 51.1, 50.7, 48.1, 46.8, 46.1, 46.0, 28.3, 26.9, 21.0, 20.7, 20.3, 20.1; HRMS Calcd for $C_{16}H_{23}N_2O_2$[M+H$^+$]:275.1760; Found: 275.1797.

3.5 Preparation of N-heteroarenes substrates.

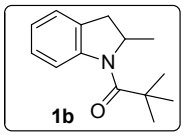


General procedures for the preparation of oxalyl amide substrates 1a–1r

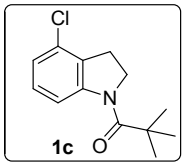
A solution of N-heteroarenes (20 mmol, 1.0 equiv) and triethylamine (2.92 ml, 21 mmol, 1.05 equiv) in CH_2Cl_2 (40 mL) was added dropwise to a solution of Pivaloyl Chloride (25 mmol, 1.25 equiv) in CH_2Cl_2 (50 mL) at 0 °C, then the mixture was stirred for 6 hours at room temperature before quenched by water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 2). The combined organic phase was washed with brine (30 mL), and then dried over anhydrous Na_2SO_4. Evaporation and column chromatography on silica gelafforded corresponding amide substrates as white solid or colour liquid.



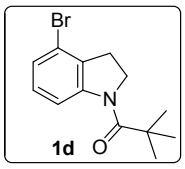
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 – 8.21 (m, 1H), 7.18 (t, *J* = 6.9 Hz, 2H), 7.01 (t, *J* = 7.4 Hz, 1H), 4.24 – 4.19 (m, 2H), 3.12 (t, *J* = 8.1 Hz, 2H), 1.37 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.5, 144.8, 130.82, 127.3, 124.3, 123.6, 118.4, 49.5, 40.2, 29.3, 27.8;. HRMS Calcd for $C_{13}H_{18}NO$ [M+H$^+$]:204.1388; Found: 204.1399.



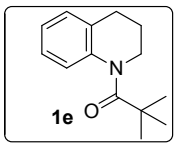
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 7.2 Hz, 1H), 6.94 (s, 2H), 6.77 (d, *J* = 6.1 Hz, 1H), 4.53 (d, *J* = 5.3 Hz, 1H), 3.09 – 2.88 (m, 1H), 2.28 (d, *J* = 14.9 Hz, 1H), 1.13 (s, 9H), 0.95 (d, *J* = 4.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.9, 142.5, 129.9, 126.1, 124.0, 122.9, 118.6 55.1, 39.6, 36.0, 27.6, 20.9; HRMS Calcd for $C_{14}H_{20}NO$ [M+H$^+$]:218.1545; Found: 218.1558.



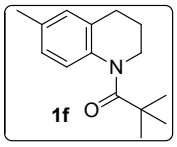
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.1 Hz, 1H), 7.13 (t, *J* = 8.1 Hz, 1H), 6.99 (d, *J* = 8.0 Hz, 1H), 4.26 (t, *J* = 8.3 Hz, 2H), 3.16 (t, *J* = 8.2 Hz, 2H), 1.36 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.8, 146.1, 130.1, 129.2, 128.9, 123.5, 116.6, 49.2, 40.3, 28.7, 27.7; HRMS Calcd for $C_{13}H_{17}ClNO$ [M+H$^+$]:238.0999; Found: 238.1009.



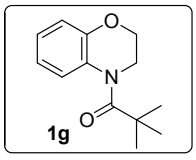
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (d, *J* = 8.1 Hz, 1H), 7.15 (d, *J* = 7.9 Hz, 1H), 7.06 (t, *J* = 8.1 Hz, 1H), 4.25 (t, *J* = 8.3 Hz, 2H), 3.13 (t, *J* = 8.2 Hz, 2H), 1.36 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.9, 145.8, 131.4, 129.1, 126.4, 119.0, 117.1, 48.9, 40.3, 30.8, 27.7;. HRMS Calcd for $C_{13}H_{17}BrNO$ [M+H$^+$]:282.0494; Found: 282.0503.



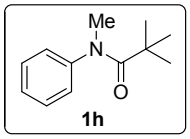
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (t, *J* = 4.7 Hz, 1H), 7.13 (d, *J* = 7.3 Hz, 2H), 7.10 – 7.04 (m, 1H), 3.81 – 3.76 (m, 2H), 2.76 (t, *J* = 7.1 Hz, 2H), 2.03 – 1.95 (m, 2H), 1.29 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.8, 141.3, 132.4, 128.9, 126.2, 126.0, 125.5, 45.6, 40.8, 29.4, 26.5, 24.6; HRMS Calcd for $C_{14}H_{20}NO$ [M+H$^+$]:218.1545; Found: 218.1555.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (d, *J* = 8.8 Hz, 1H), 6.98 (d, *J* = 7.1 Hz, 2H), 3.79 (t, *J* = 6.2 Hz, 2H), 2.74 (t, *J* = 7.0 Hz, 2H), 2.33 (s, 3H), 2.03 – 1.96 (m, 2H), 1.32 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.6, 137.9, 134.1, 131.4, 128.5, 125.8, 125.1, 44.7, 39.9, 28.5, 25.6, 23.7, 20.5;.HRMS Calcd for $C_{15}H_{22}NO$ [M+H$^+$]:232.1701; Found: 232.1719..

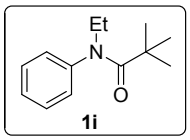


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 – 7.58 (m, 1H), 7.01 – 6.97 (m, 1H), 6.87 – 6.81 (m, 2H), 4.31 – 4.26 (m, 2H), 3.97 – 3.92 (m, 2H), 1.35 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.4, 146.8, 126.8, 125.6, 125.6, 119.8, 117.0, 66.4, 44.2, 39.8, 28.5; HRMS Calcd for $C_{13}H_{18}NO_2$ [M+H$^+$]:220.1338; Found: 220.1346.



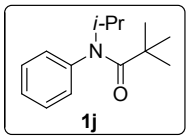
1h

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.35 (m, 2H), 7.33 – 7.27 (m, 1H), 7.23 – 7.17 (m, 2H), 3.19 (s, 3H), 1.02 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.2, 145.4, 129.3, 128.9, 127.9, 41.5, 40.9, 29.6.; HRMS Calcd for $C_{12}H_{18}NO$ [M+H$^+$]:192.1388; Found: 192.1392.



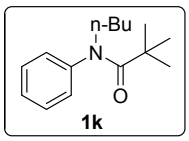
1i

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.26 (m, 3H), 7.17 – 7.11 (m, 2H), 3.64 – 3.59 (m, 2H), 1.06 (t, *J* = 9.3 Hz, 3H), 0.97 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.2, 143.4, 129.9, 129.0, 127.8, 47.8, 40.9, 29.6, 27.2, 12.7; HRMS Calcd for $C_{13}H_{20}NO$ [M+H$^+$]:206.1545; Found: 206.1558.



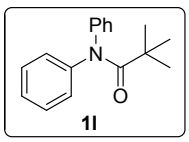
1j

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.34 (m, 3H), 7.14 – 7.12 (m, 2H), 5.01 – 4.91 (m, 1H), 1.00 (s, 3H), 0.98 (s, 3H), 0.98 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.3, 139.0, 132.2, 128.3, 128.2, 48.09, 41.5, 29.8, 20.9; HRMS Calcd for $C_{14}H_{22}NO$ [M+H$^+$]:220.1701; Found: 220.1710.



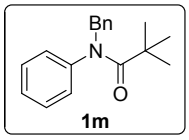
1k

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 – 7.14 (m, 2H), 7.12 (d, *J* = 7.2 Hz, 1H), 7.02 – 6.96 (m, 2H), 3.44 – 3.37 (m, 2H), 1.36 – 1.29 (m, 2H), 1.12 – 1.03 (m, 2H), 0.81 (s, 9H), 0.67 (t, *J* = 7.4 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.6, 143.3, 129.3, 128.5, 127.3, 52.4, 40.5, 29.1, 29.0, 19.6, 13.4; HRMS Calcd for $C_{15}H_{24}NO$ [M+H$^+$]:234.1858; Found: 134.1861.



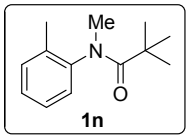
1l

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.32 (m, 4H), 7.24 (d, *J* = 1.8 Hz, 3H), 7.23 – 7.21 (m, 3H), 1.15 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.6, 144.5, 129.3, 129.1, 128.4, 126.9, 117.8, 41.7, 29.7; HRMS Calcd for $C_{17}H_{20}NO$ [M+H$^+$]:254.1545; Found: 254.1557.



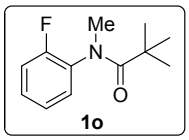
1m

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 – 7.27 (m, 3H), 7.25 (t, *J* = 6.7 Hz, 3H), 7.21 – 7.16 (m, 2H), 7.04 – 6.98 (m, 2H), 4.85 (s, 2H), 1.07 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.6, 143.3, 137.9, 129.9, 128.9, 128.8, 128.3, 127.9, 127.2, 56.4, 41.1, 29.6; HRMS Calcd for $C_{18}H_{22}NO$ [M+H$^+$]:268.1701; Found: 268.1709.



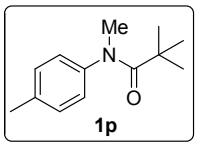
1n

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.02 – 6.93 (m, 2H), 6.93 – 6.88 (m, 1H), 6.88 – 6.82 (m, 1H), 2.83 (s, 3H), 1.98 (s, 3H), 0.75 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.2, 143.3, 135.2, 130.7, 128.4, 127.6, 126.07, 40.1, 39.0, 28.4, 17.2; HRMS Calcd for $C_{13}H_{20}NO$ [M+H$^+$]:206.1545; Found: 206.1553.



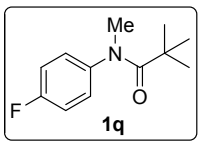
1o

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 – 7.20 (m, 2H), 7.09 (d, J = 1.5 Hz, 2H), 3.14 (s, 3H), 1.01 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.7, 158.0 ($J_{C\text{-}F}$ =248), 132.3($J_{C\text{-}F}$ =12), 130.4, 129.3 ($J_{C\text{-}F}$ =8), 124.0($J_{C\text{-}F}$ = 4), 116.1 ($J_{C\text{-}F}$ =20), 40.1, 39.5, 28.3; HRMS Calcd for $C_{12}H_{17}FNO$ [M+H$^+$]:210.1294; Found: 210.1299.



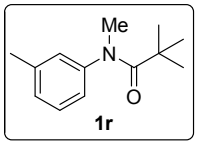
1p

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 (d, J = 8.0 Hz, 2H), 7.08 (d, J = 8.1 Hz, 2H), 3.17 (s, 3H), 2.36 (s, 3H), 1.02 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.2, 142.7, 137.6, 129.8, 128.5, 41.4, 40.8, 29.5, 21.1; HRMS Calcd for $C_{13}H_{20}NO$ [M+H$^+$]:206.1545; Found: 206.1557.



1q

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 – 7.10 (m, 2H), 7.03 (t, J = 8.6 Hz, 2H), 3.15 (s, 3H), 1.00 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.9, 161.6 ($J_{C\text{-}F}$ = 246), 141.2 ($J_{C\text{-}F}$ = 4), 130.1($J_{C\text{-}F}$ = 18), 116.0($J_{C\text{-}F}$ = 12), 41.3, 40.6, 29.4; HRMS Calcd for $C_{12}H_{17}FNO$ [M+H$^+$]:210.1294; Found: 210.1302.

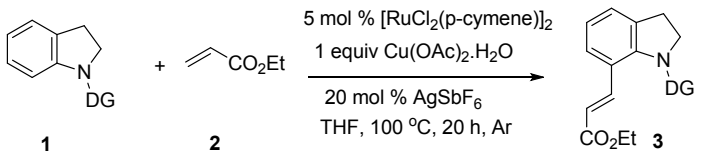


1r

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 (t, J = 7.7 Hz, 1H), 7.03 (d, J = 7.6 Hz, 1H), 6.96 – 6.86 (m, 2H), 3.09 (s, 3H), 2.26 (s, 3H), 0.94 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.0, 145.2, 139.2, 129.3, 129.0, 128.5, 125.7, 41.3, 40.8, 29.6, 21.3; HRMS Calcd for $C_{13}H_{20}NO$ [M+H$^+$]:206.1545; Found: 206.1552.

4. Alkenylation of pivaloyl amide Protected N-heteroarenes

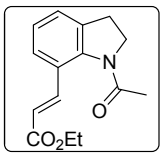
4.1 Substrates Scope of various directing groups protected amides



1 **2** **3**

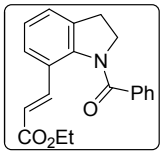
A mixture of amide (0.2 mmol, 1 equiv), olefin (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.4 mg, 0.05 equiv), $AgSbF_6$ (13.7 mg, 0.2 equiv), $Cu(OAc)_2 \cdot H_2O$ (40 mg, 1 equiv) and THF (1mL) in a 15 mL glass tube (sealed with PTFE cap) was heated at 100 °C for 20 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product.

4.11 DG= Ac



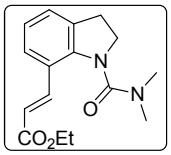
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 14.8 Hz, 1H), 7.42 (d, *J* = 7.8 Hz, 1H), 7.23 (d, *J* = 7.2 Hz, 1H), 7.11 (t, *J* = 7.6 Hz, 1H), 6.34 (d, *J* = 15.6 Hz, 1H), 4.27 – 4.22 (m, 2H), 4.17 (d, *J* = 4.8 Hz, 2H), 3.03 (t, *J* = 7.3 Hz, 2H), 2.23 (s, 3H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.0, 167.1, 143.0, 141.9, 138.8, 134.4, 125,9, 125.6, 125.4, 117.4, 60.5, 51.0, 29.7, 29.3, 14.3; HRMS Calcd for $C_{15}H_{18}NO_3$ [M+H$^+$]:260.1287; Found: 260.1298.

4.12 DG= benzoyl



^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 (d, *J* = 7.9 Hz, 0.56H), 7.77 (d, *J* = 15.9 Hz, 0.58H), 7.72 – 7.66 (m, 1H), 7.57 – 7.34 (m, 3H), 7.29 (d, *J* = 7.5 Hz, 0.56H), 7.20 (t, *J* = 8.8 Hz, 1H), 7.10 (t, *J* = 7.3 Hz, 0.62H), 6.88 (t, *J* = 7.2 Hz, 0.35H), 6.75 (t, *J* = 7.3 Hz, 0.35H), 6.47 (d, *J* = 15.9 Hz, 0.61H), 6.33 (d, *J* = 15.8 Hz, 0.33H), 5.60 (d, *J* = 8.0 Hz, 0.32H), 4.38 -4.32(m, 0.68H), 4.22 – 4.16 (m, 2H), 3.70 (t, *J* = 8.2 Hz, 1H), 3.13 (dt, *J* = 31.3, 8.1 Hz, 2H), 1.25 (t, *J* = 6.8 Hz, 4H).; ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.1, 166.5, 165.9, 165.8, 141.9 140.6, 140.3, 140.2, 137.6, 136.8, 133.0, 131.4, 130.6, 130.0, 129.8, 129.7, 129.2, 127.2, 127.0, 126.8 126.6, 126.5, 126.2, 125.1, 124.2, 124.1, 123.1 120.8 120.7, 117.2, 113.5, 76.9, 76.8, 76.6, 76.3, 60.2, 49.6, 47.8, 29.2, 27.7, 26.4, 13.7; HRMS Calcd for $C_{20}H_{21}NO_3$ [M+H$^+$]:322.1443; Found: 322.1452.

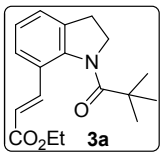
4.13, DG= Dimethylcarbamyl



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, *J* = 15.9 Hz, 1H), 7.35 (d, *J* = 7.8 Hz, 1H), 7.18 (dd, *J* = 7.3, 0.9 Hz, 1H), 6.98 (t, *J* = 7.6 Hz, 1H), 6.30 (d, *J* = 15.9 Hz, 1H), 4.23 – 4.18 (m, 2H), 3.93 (t, *J* = 8.1 Hz, 2H), 3.08 (t, *J* = 8.0 Hz, 2H), 2.99 (s, 6H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.7, 161.1, 144.3, 141.0, 133.7, 125.5, 125.1, 123.0, 123.0, 116.7, 59.8, 52.2, 37.1, 29.4, 29.2, 13.8.

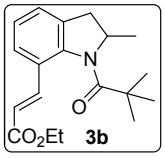
4.2 Substrates Scope of N-heteroarenes

A mixture of amide (0.2 mmol, 1 equiv), olefin (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.4 mg, 0.05 equiv), $AgSbF_6$ (13.7 mg, 0.2 equiv), $Cu(OAc)_2 \cdot H_2O$ (40 mg, 1 equiv) and THF (1mL) in a 15 mL glass tube (sealed with PTFE cap) was heated at 100 °C for 20 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product.



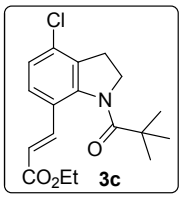
3a

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (t, *J* = 12.4 Hz, 2H), 7.23 – 7.21 (m, 1H), 7.08 (t, *J* = 7.6 Hz, 1H), 6.29 (d, *J* = 15.9 Hz, 1H), 4.24 – 4.19 (m, 2H), 4.16 (t, *J* = 7.5 Hz, 2H), 3.05 (t, *J* = 7.5 Hz, 2H), 1.41 (s, 9H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.3, 166.9, 143.5, 141.9, 134.5, 125.4, 125.3, 125.0, 124.8, 116.7, 60.0, 50.8, 40.0, 30.6, 28.3, 14.1; HRMS Calcd for $C_{18}H_{24}NO_3$ [M+H$^+$]:302.1756; Found: 302.1762.



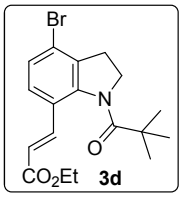
3b

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (t, *J* = 11.0 Hz, 2H), 7.24 (d, *J* = 7.3 Hz, 1H), 7.11 (t, *J* = 7.6 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 4.84 – 4.78 (m, 1H), 4.28 – 4.16 (m, 2H), 3.32 – 3.26 (m, 1H), 2.53 (d, *J* = 15.0 Hz, 1H), 1.41 (s, 9H), 1.31 (t, *J* = 7.1 Hz, 3H), 1.25 (d, *J* = 6.4 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.5, 167.7, 143.1, 142.5, 134.8, 127.7, 126.7, 125.8, 125.3, 117.3, 60.7, 57.9, 41.0, 38.4, 29.3, 21.1, 14.7; HRMS Calcd for $C_{19}H_{26}NO_3$ [M+H$^+$]:316.1913; Found: 316.1926.



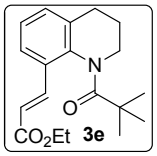
3c

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (d, *J* = 3.3 Hz, 1H), 7.33 (d, *J* = 11.0 Hz, 1H), 7.08 (d, *J* = 8.5 Hz, 1H), 6.27 (d, *J* = 16.0 Hz, 1H), 4.24 – 4.17(m, 4H), 3.10 (t, *J* = 7.6 Hz, 2H), 1.41 (s, 9H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.3, 166.5, 144.3, 140.6, 132.7, 131.0, 126.2, 124.6, 123.7, 116.8, 59.89, 50.2, 39.9, 29.8, 28.0, 13.8; HRMS Calcd for $C_{18}H_{23}ClNO_3$ [M+H$^+$]:336.1366 Found: 336.1372.

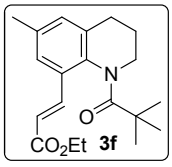


3d

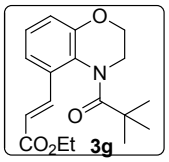
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (d, *J* = 16.0 Hz, 1H), 7.28 (d, *J* = 8.6 Hz, 1H), 7.22 (d, *J* = 8.4 Hz, 1H), 6.28 (d, *J* = 16.0 Hz, 1H), 4.24 – 4.16 (m, 4H), 3.07 (t, *J* = 7.6 Hz, 2H), 1.40 (s, 9H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.3, 166.5, 143.9, 140.7, 134.9, 127.5, 126.3, 124.2, 119.8, 116.9, 59.9, 49.8, 39.9, 31.8, 28.0, 13.8; HRMS Calcd for $C_{18}H_{23}ClNO_3$ [M+H$^+$]: 380.0861 Found: 380. 0881.



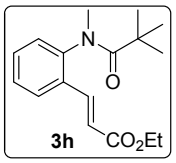
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (d, *J* = 15.7 Hz, 1H), 7.48 – 7.46 (m, 1H), 7.17 (t, *J* = 6.3 Hz, 2H), 6.38 (d, *J* = 16.0 Hz, 1H), 4.41 (s, 1H), 4.25 – 4.12 (m, 2H), 3.31 (s, 1H), 2.76 (s, 2H), 2.04 (s, 2H), 1.36 (d, *J* = 23.5 Hz, 9H), 1.30 (d, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.6, 167.5, 141.1, 130.9, 130.5, 126.3, 124.5, 118.8, 60.8, 45.8, 29.1, 26.1, 24.9, 14.8; HRMS Calcd for $C_{19}H_{26}NO_3$ [M+H$^+$]:316.1913; Found: 316.1916.



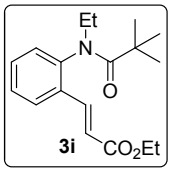
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, *J* = 14.8 Hz, 1H), 7.28 (s, 1H), 6.99 (s, 1H), 6.37 (d, *J* = 16.0 Hz, 1H), 4.43 (d, *J* = 2.4 Hz, 1H), 4.22 (q, *J* = 7.1 Hz, 2H), 3.28 (s, 1H), 2.72 (s, 2H), 2.32 (s, 3H), 2.00 (s, 2H), 1.39 – 1.29 (m, 12H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.1, 167.1, 140.7, 138.8, 135.4, 133.2, 130.8, 130.1, 124.6, 118.0, 60.3, 45.4, 28.7, 21.0, 14.4; HRMS Calcd for $C_{20}H_{28}NO_3$ [M+H$^+$]:330.2069; Found: 330.2071.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, *J* = 16.0 Hz, 1H), 7.19 – 7.16 (m, 1H), 7.09 (t, *J* = 7.9 Hz, 1H), 6.91 – 6.89 (m, 1H), 6.36 (d, *J* = 16.0 Hz, 1H), 4.45 (s, 2H), 4.24 – 4.19 (m, 3H), 3.66 (s, 1H), 1.40 (s, 9H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 167.1, 148.6, 140.6, 131.1, 126.8, 126.5, 118.7, 118.6, 118.4, 66.9, 60.5, 44.6, 40.3, 28.6, 14.5; HRMS Calcd for $C_{18}H_{24}NO_4$ [M+H$^+$]:318.1705; Found: 318.1720.

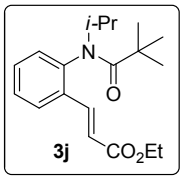


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 -7.68 (m, 2H), 7.43 – 7.34 (m, 2H), 7.23 – 7.17 (m, 1H), 6.46 (d, *J* = 16.1 Hz, 1H), 4.26 (q, *J* = 7.1 Hz, 2H), 3.16 (s, 3H), 1.33 (t, *J* = 7.1 Hz, 3H), 1.04 (s, 9H).; ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.6, 166.6, 144.7, 139.3, 132.6, 130.9,129.9, 128.7, 127.6, 121.1, 60.9, 40.9, 29.3, 14.4; HRMS Calcd for $C_{17}H_{24}NO_3$ [M+H$^+$]: 290.1756; Found: 290.1760.

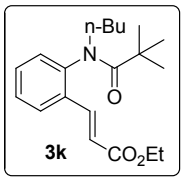


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 16.1 Hz, 1H), 7.72 – 7.68 (m, 1H), 7.39 (p, *J* = 7.7 Hz, 2H), 7.19 – 7.13 (m, 1H), 6.44 (d, *J* = 16.1 Hz, 1H), 4.26 (m, 2H), 4.20 – 4.12 (m, 1H), 3.01 (d, *J* = 5.4 Hz,

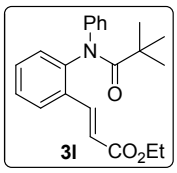
1H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.10 (t, *J* = 7.0 Hz, 3H), 1.01 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.8, 165.6, 141.8, 138.6, 132.0, 130.3, 129.4, 127.7, 126.67, 119.9, 59.9, 46.7, 40.2, 28.4, 13.5, 11.4; HRMS Calcd for $C_{18}H_{26}NO_3$ [M+H$^+$]:304.1913; Found: 304.1925.



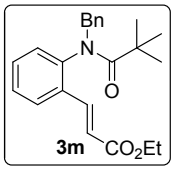
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (d, *J* = 16.2 Hz, 1H), 7.76 (dd, *J* = 6.2, 3.2 Hz, 1H), 7.47 – 7.38 (m, 2H), 7.17 (dd, *J* = 6.2, 3.0 Hz, 1H), 6.46 (d, *J* = 16.1 Hz, 1H), 4.66 (dt, *J* = 13.4, 6.7 Hz, 1H), 4.28 (q, *J* = 7.1 Hz, 2H), 1.35 (t, *J* = 7.1 Hz, 3H), 1.22 (d, *J* = 6.6 Hz, 3H), 1.02 (s, 9H), 0.96 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.8, 166.7, 140.7, 134.9, 132.1, 130.2, 128.7, 126.9, 120.0, 60.8, 51.4, 29.92, 29.9, 29.4, 27.4, 22.8, 19.7, 14.4; HRMS Calcd for $C_{19}H_{28}NO_3$ [M+H$^+$]:318.2069; Found: 318.2059.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.67 (m, 2H), 7.42 – 7.35 (m, 2H), 7.19 – 7.14 (m, 1H), 6.44 (d, *J* = 16.1 Hz, 1H), 4.29-4.23 (m, 2H), 4.15 – 4.07 (m, 1H), 2.86 (s, 1H), 1.65-1.57 (m, 1H), 1.47 – 1.39 (m, 1H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.28-1.22 (m, 2H), 1.00 (s, 9H), 0.87 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.2, 166.0, 142.4, 138.9, 132.3, 130.6, 129.8, 128.0, 127.0, 120.3, 60.2, 52.2, 40.5, 28.7, 28.6, 19.7, 13.8, 13.4; HRMS Calcd for $C_{20}H_{29}NO_3$ [M+H$^+$]:332.2226; Found: 332.2233.

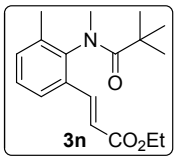


^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, *J* = 16.0 Hz, 1H), 7.67 – 7.64 (m, 1H), 7.39 – 7.31 (m, 3H), 7.30 (d, *J* = 7.5 Hz, 1H), 7.25 – 7,22 (m, 3H), 7.21 – 7.19 (m, 1H), 6.41 (d, *J* = 16.0 Hz, 1H), 4.29 – 4.23 (m, 2H), 1.33 (t, *J* = 7.1 Hz, 3H), 1.18 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 180.0, 166.7, 144.2, 143.9, 140.1, 132.2, 131.1, 129.64, 129.3, 128.5, 127.8, 127.3, 127.2, 120.4, 60.7, 42.0, 29.7, 14.5; HRMS Calcd for $C_{22}H_{26}NO_3$ [M+H$^+$]:352.1913; Found: 352.1926.

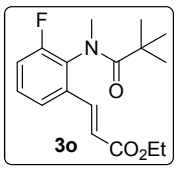


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (s, 1H), 7.64 (d, *J* = 7.4 Hz, 1H), 7.33 (t, *J* = 7.3 Hz, 1H), 7.24 – 7.22 (m, 1H), 7.21 – 7.20 (m, 3H), 7.14 – 7.10 (m, 2H), 6.79 – 6.76 (m, 1H), 6.39 (d, *J* = 16.1 Hz, 1H), 5.45 (d, *J* = 13.9 Hz, 1H), 4.29 – 4.23 (m, 2H), 4.06 (d, *J* = 13.9 Hz, 1H), 1.34 (t, *J* = 7.1 Hz, 3H), 1.01 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.7, 166.1, 141.9, 139.0, 136.7, 132.9, 131.5, 129.9, 129.4,

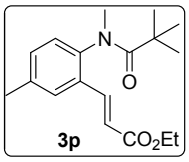
128.5, 128.0, 127.2, 127.1, 120.6, 60.5, 55.7, 41.0, 29.1, 14.1; HRMS Calcd for $C_{23}H_{28}NO_3$ [M+H$^+$]:366.2069; Found: 366.2074.



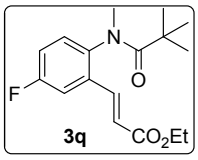
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 16.0 Hz, 1H), 7.49 (d, *J* = 6.9 Hz, 1H), 7.22 (t, *J* = 7.6 Hz, 1H), 7.02 (s, 1H), 6.36 (d, *J* = 16.0 Hz, 1H), 4.25 – 4.20 (m, 2H), 2.23 (s, 3H), 1.40 (s, 9H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.6, 166.3, 139.9, 135.9, 134.0, 131.8, 127.0, 124.0, 119.4, 60.0, 27.3, 17.7, 13.8; HRMS Calcd for $C_{18}H_{26}NO_3$ [M+H$^+$]:304.1913; Found: 304.1921.



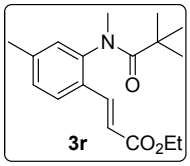
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, *J* = 16.1 Hz, 1H), 7.48 (d, *J* = 7.9 Hz, 1H), 7.38 – 7.32 (m, 1H), 7.16 (t, *J* = 8.5 Hz, 1H), 6.48 (d, *J* = 16.1 Hz, 1H), 4.28 – 4.23 (m, 2H), 3.40 (s, 1H), 3.12 (s, 3H), 1.31 (t, *J* = 7.1 Hz, 3H), 0.99 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 166.5, 158.9($J_{C\text{-}F}$ = 247), 138.4($J_{C\text{-}F}$ = 4), 135.5, 132.9($J_{C\text{-}F}$ = 14), 129.9 ($J_{C\text{-}F}$ = 8), 123.07 ($J_{C\text{-}F}$ = 3), 122.7, 118.1 ($J_{C\text{-}F}$ = 21), 61.3, 41.4, 40.1, 29.1, 14.7. HRMS Calcd for $C_{17}H_{23}NO_3F$ [M+H$^+$]:308.1662; Found: 308.1673.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (d, *J* = 16.1 Hz, 1H), 7.48 (s, 1H), 7.20 (d, *J* = 7.9 Hz, 1H), 7.07 (d, *J* = 8.0 Hz, 1H), 6.44 (d, *J* = 16.1 Hz, 1H), 4.28 – 4.23 (m, 2H), 3.13 (s, 3H), 2.39 (s, 3H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.02 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 166.9, 142.5, 139.7, 138.9, 132.5, 132.0, 130.0, 128.4, 121.1, 61.1, 41.3, 29.6, 21.6, 14.8; HRMS Calcd for $C_{18}H_{26}NO_3$ [M+H$^+$]:304.1913; Found: 304.1924.

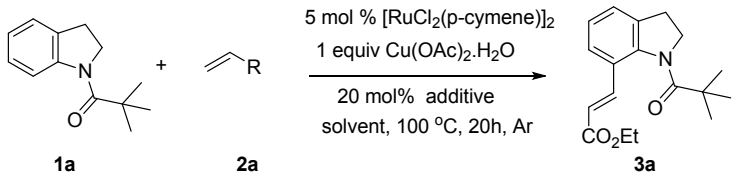


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 – 7.67 (m, 1H), 7.43 – 7.40 (m, 1H), 7.25 – 7.21 (m, 1H), 7.20 – 7.08 (m, 1H), 6.49 (d, *J* = 16.1 Hz, 1H), 4.35 – 4.29 (m, 2H), 3.21 (s, 3H), 1.38 (t, *J* = 7.1 Hz, 3H), 1.11 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.0 165.5, 161.4($J_{C\text{-}F}$ = 247), 140.2, 137.5 ($J_{C\text{-}F}$ = 2), 134.1($J_{C\text{-}F}$ = 9), 130.9($J_{C\text{-}F}$ = 8)), 121.69, 117.2($J_{C\text{-}F}$ = 23), 113.28($J_{C\text{-}F}$ = 23), 60.4, 40.4, 28.6, 13.8 HRMS Calcd for $C_{17}H_{23}NO_3F$ [M+H$^+$]:308.1662; Found: 308.1669.



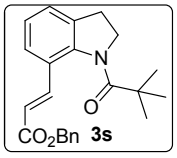
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (d, *J* = 16.1 Hz, 1H), 7.58 (d, *J* = 8.0 Hz, 1H), 7.18 (d, *J* = 8.0 Hz, 1H), 7.00 (s, 1H), 6.41 (d, *J* = 16.1 Hz, 1H), 4.28 – 4.23 (m, 2H), 3.15 (s, 3H), 2.38 (s, 3H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.04 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.0, 166.2, 144.0, 141.1, 138.7, 129.8, 128.9, 126.9, 119.4, 60.1, 40.3, 28.7, 20.7, 13.8; HRMS Calcd for $C_{18}H_{26}NO_3$ [M+H$^+$]:304.1913; Found: 304.1927.

4.2 Substrates Scope of Olefins



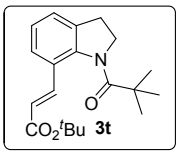
1a **2a** **3a**

A mixture of amide (0.2 mmol, 1 equiv), olefin (2 equiv), [$RuCl_2$(*p*-cymene)]$_2$ (6.4 mg, 0.05 equiv), $AgSbF_6$ (13.7 mg, 0.2 equiv), $Cu(OAc)_2 \cdot H_2O$ (40 mg, 1 equiv) and THF (1mL) in a 15 mL glass tube (sealed with PTFE cap) was heated at 100 °C for 20 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product



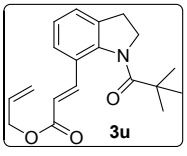
3s

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, *J* = 16.0 Hz, 1H), 7.43 – 7.30 (m, 6H), 7.23 (d, *J* = 7.3 Hz, 1H), 7.09 (t, *J* = 7.6 Hz, 1H), 6.36 (d, *J* = 16.0 Hz, 1H), 5.21 (s, 2H), 4.16 (t, *J* = 7.5 Hz, 2H), 3.05 (t, *J* = 7.5 Hz, 2H), 1.38 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.8, 167.3, 144.1, 143.2, 136.6, 135.1, 128.9, 128.7, 128.5, 126.1, 126.0, 125.6, 125.5, 116.9, 66.6, 51.5, 40.6, 31.2, 28.9; HRMS Calcd for $C_{23}H_{26}NO_3$ [M+H$^+$]:364.1913; Found: 364.1909.



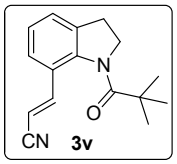
3t

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, *J* = 7.8 Hz, 1H), 7.33 (d, *J* = 16.0 Hz, 1H), 7.21 (d, *J* = 6.8 Hz, 1H), 7.07 (t, *J* = 7.6 Hz, 1H), 6.22 (d, *J* = 16.0 Hz, 1H), 4.15 (t, *J* = 7.5 Hz, 2H), 3.04 (t, *J* = 7.5 Hz, 2H), 1.50 (s, 9H), 1.41 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.7, 166.8, 144.0, 141.3, 135.1, 126.5, 125.75, 125.7, 125.4, 119.6, 80.5, 51.5, 40.6, 31.3, 29.0, 28.7; HRMS Calcd for $C_{20}H_{28}NO_3$ [M+H$^+$]:330.2069; Found: 330.2069.

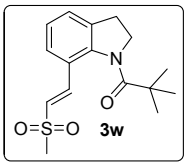


3u

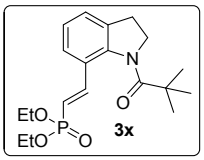
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (d, *J* = 16.0 Hz, 1H), 7.41 (d, *J* = 7.8 Hz, 1H), 7.23 (d, *J* = 0.9 Hz, 1H), 7.09 (t, *J* = 7.6 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.02 – 5.92 (m, 1H), 5.39 – 5.33 (m, 1H), 5.26 – 5.22 (m, 1H), 4.68 – 4.66 (m, 2H), 4.17 (t, *J* = 7.5 Hz, 2H), 3.06 (t, *J* = 7.5 Hz, 2H), 1.41 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.8, 166.9, 143.9, 142.8, 134.9, 132.6, 125.8, 125.8, 125.4, 125.2, 118.1, 116.6, 65.1, 51.2, 40.4, 30.9, 28.7; HRMS Calcd for $C_{19}H_{23}NO_3$ [M+H$^+$]:314.1756; Found: 314.1787.



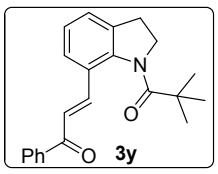
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 – 7.26 (m, 2H), 7.21 (d, *J* = 16.6 Hz, 1H), 7.11 (t, *J* = 7.6 Hz, 1H), 5.71 (d, *J* = 16.6 Hz, 1H), 4.19 (t, *J* = 7.5 Hz, 2H), 3.05 (t, *J* = 7.5 Hz, 2H), 1.40 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.4, 149.2, 143.5, 135.5, 126.9, 125.7, 125.5, 124.9, 119.1, 95.3, 5.5, 40.5, 31.0, 28.8; HRMS Calcd for $C_{16}H_{19}NO_2$ [M+H$^+$]:255.1497; Found: 255.1521.



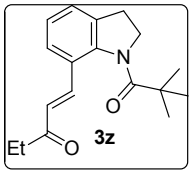
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 – 7.27 (m, 3H), 7.10 (t, *J* = 7.6 Hz, 1H), 6.71 (d, *J* = 15.5 Hz, 1H), 4.18 (t, *J* = 7.6 Hz, 2H), 3.07 (t, *J* = 7.7 Hz, 2H), 3.05 (s, 3H), 1.38 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.5, 143.8, 143.4, 134.7, 126.5, 125.6, 125.3, 124.7, 123.4, 51.1, 43.9, 40.2, 30.7, 28.4; HRMS Calcd for $C_{16}H_{22}NO_3S$ [M+H$^+$]:308.1320; Found: 308.1388.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, *J* = 7.8 Hz, 1H), 7.18 (d, *J* = 7.4 Hz, 1H), 7.17 – 7.08 (m, 1H), 7.05 (t, *J* = 7.5 Hz, 1H), 6.03 (t, *J* = 18.1 Hz, 1H), 4.17 – 4.07 (m, 6H), 3.00 (t, *J* = 7.4 Hz, 2H), 1.35 (s, 9H), 1.31 (t, *J* = 7.0 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 146.9, 146.8, 143.1, 134.5, 126.3, 126.1, 125.4, 125.0, 112.8, 110.9, 61.8, 61.8, 51.0, 40.0, 30.7, 28.3, 16.4, 16.3; HRMS Calcd for $C_{19}H_{29}NO_4P$ [M+H$^+$]:366.1834; Found: 366.1836.

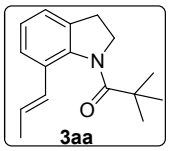


^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 – 7.96 (m, 2H), 7.56 – 7.53 (m, 2H), 7.50 (d, *J* = 11.0 Hz, 1H), 7.47 (t, *J* = 4.9 Hz, 2H), 7.29 (d, *J* = 15.8 Hz, 2H), 7.13 (t, *J* = 7.6 Hz, 1H), 4.18 (t, *J* = 7.5 Hz, 2H), 3.07 (t, *J* = 7.5 Hz, 2H), 1.38 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 192.1, 179.4, 144.3, 143.2, 138.6, 134.9, 132.4, 129.1, 128.8, 128.6, 128.3, 126.4, 126.0, 125.4, 125.2, 121.7, 51.2, 40.3, 30.9, 28.6, 28.4; HRMS Calcd for $C_{22}H_{23}NO_2$ [M+H$^+$]:334.1807; Found: 334.03.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, *J* = 7.8 Hz, 1H), 7.33 (d, *J* = 16.3 Hz, 1H), 7.24 – 7.19 (m, 1H), 7.08 (t, *J* = 7.6 Hz, 1H), 6.54 (d, *J* = 16.3 Hz, 1H), 4.16 (t, *J* = 7.5 Hz, 2H), 3.04 (t, *J* = 7.5 Hz, 2H), 2.69 – 2.64 (m, 2H), 1.40 (s, 9H), 1.13 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.8, 179.5,

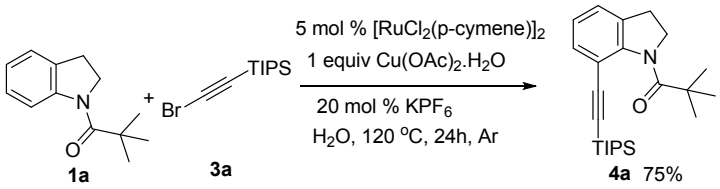
144.1, 140.8, 135.1, 126.2, 126.1, 125.5, 125.5, 51.5, 40.6, 33.2, 31.1, 28.9, 8.7; HRMS Calcd for $C_{18}H_{24}NO_3$ [M+H$^+$]:286.1807; Found: 286.1816.



3aa

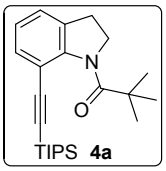
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (d, *J* = 7.5 Hz, 1H), 7.11 – 6.98 (m, 2H), 6.25 – 6.00 (m, 2H), 4.11 (t, *J* = 7.4 Hz, 2H), 3.00 (t, *J* = 7.4 Hz, 2H), 1.86 (d, *J* = 5.1 Hz, 3H), 1.40 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.8, 141.6, 134.5, 129.4, 128.8, 125.4, 125.1, 124.5, 122.6, 51.2, 40.2, 31.2, 28.7, 19.0; HRMS Calcd for $C_{16}H_{22}NO$ [M+H$^+$]:244.1701; Found: 244.1700.

5. Alkynylation of pivaloyl amide Protected N-heteroarenes



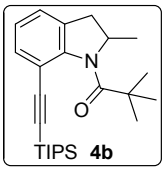
1a **3a** **4a** 75%

A mixture of amide (0.2 mmol, 1 equiv), alkyne; (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (3.2 mg, 0.05 equiv), KPF_6 (7.2 mg, 0.2 equiv), $Cu(OAc)_2 \cdot H_2O$ (12.6 mg, 1 equiv) and H_2O (0.5mL) in a 15 mL glass tube (sealed with PTFE cap) was heated at 120 °C for 24 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product.



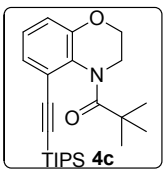
4a.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 7.6 Hz, 1H), 7.16 – 7.14 (m, 1H), 6.97 (t, *J* = 7.6 Hz, 1H), 4.14 (t, *J* = 7.6 Hz, 2H), 3.02 (t, *J* = 7.6 Hz, 2H), 1.37 (s, 9H), 1.13 (d, *J* = 2.3 Hz, 21H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.6, 145.3, 134.2, 132.8, 124.2, 123.8, 115.1, 104.5, 96.7, 50.8, 39.7, 30.7, 28.3, 18.8, 11.3; HRMS Calcd for $C_{24}H_{38}NOSi$ [M+H$^+$]:384.2723; Found: 384.2732.



4b

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 7.8 Hz, 1H), 7.18 (d, *J* = 7.4 Hz, 1H), 7.00 (t, *J* = 7.6 Hz, 1H), 4.78 – 4.72 (m, 1H), 3.31 – 3.25 (m, 1H), 2.48 (d, *J* = 14.9 Hz, 1H), 1.37 (s, 9H), 1.24 (d, *J* = 6.4 Hz, 3H), 1.18 – 1.05 (m, 21H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.8, 144.8, 134.0, 132.2, 125.0, 124.5, 117.4, 104.8, 95.6, 57.3, 40.2, 38.1, 28.9, 20.9, 18.9, 18.9, 11.5; HRMS Calcd for $C_{25}H_{40}NOSi$ [M+H$^+$]:398.2879; Found: 398.2885.

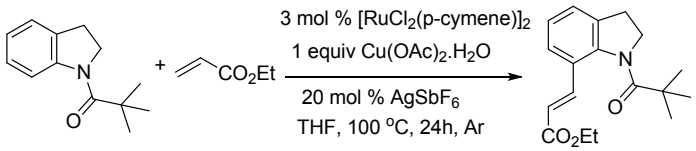


4c

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11 – 7.09 (m, 1H), 6.99 (t, *J* = 7.9 Hz, 1H), 6.85 – 6.83 (m, 1H), 4.38 (s, 1H), 4.22 (s, 2H), 3.76 (s, 1H), 1.36 (s, 9H), 1.12 (s, 21H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.9, 147.8, 128.2, 126.3, 125.4, 121.1, 116.9, 104.2, 95.2, 66.5, 43.9, 39.4, 28.0, 18.3, 10.9; HRMS Calcd for $C_{24}H_{38}NO_2Si$ [M+H$^+$]:400.2672; Found: 400.2667.

6. **Gram scale reaction and Indole derivatives**

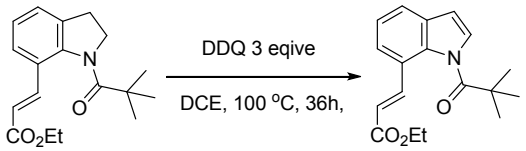
6.1 Gram scale reaction



1a 1.02g, 5 mmol **2a** **3a** 78%, 1.17 g

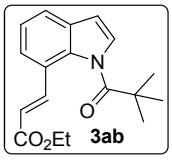
A mixture of amide (5 mmol, 1.02g), olefin (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (91.5 mg, 0.03 equiv), $AgSbF_6$ (342.5 mg, 0.2 equiv), $Cu(OAc)_2$ .H_2O (1g, 1 equiv) and THF (10mL) in a 50 mL glass tube (sealed with PTFE cap) was heated at 100 °C for 24 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product.

6.2 Indole derivatives



3a 78%, 1.17g **3ab** 97%

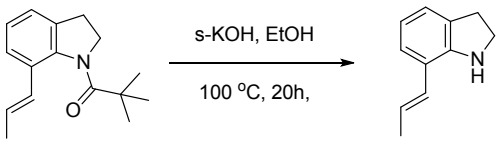
A mixture of **3a** (0.2 mmol, 1 equiv), DDQ (3 equiv) DCE (1mL) in a 15 mL glass tube (sealed with PTFE cap) was heated at 100 °C for 36 hours. The reaction mixture was cooled to room tempreture, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product3y.



3ab

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, *J* = 15.8 Hz, 1H), 7.61 – 7.58 (m, 2H), 7.47 (d, *J* = 7.5 Hz, 1H), 7.28 (d, *J* = 7.6 Hz, 1H), 6.63 (d, *J* = 3.7 Hz, 1H), 6.29 (d, *J* = 15.7 Hz, 1H), 4.2 9 – 4.24 (m, 2H), 1.56 (s, 9H), 1.34 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 166.5, 142.5, 134.4, 130.8, 126.0, 123.5, 123.1, 122.8, 121.9, 117.2, 107.0, 59.9, 41.6, 28.5, 13.8; HRMS Calcd for $C_{18}H_{22}NO_3$ [M+H$^+$]:300.1600; Found: 300.1610.

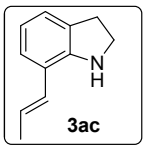
6.3 Removal of Directing Group



3aa **3ac**, 89%

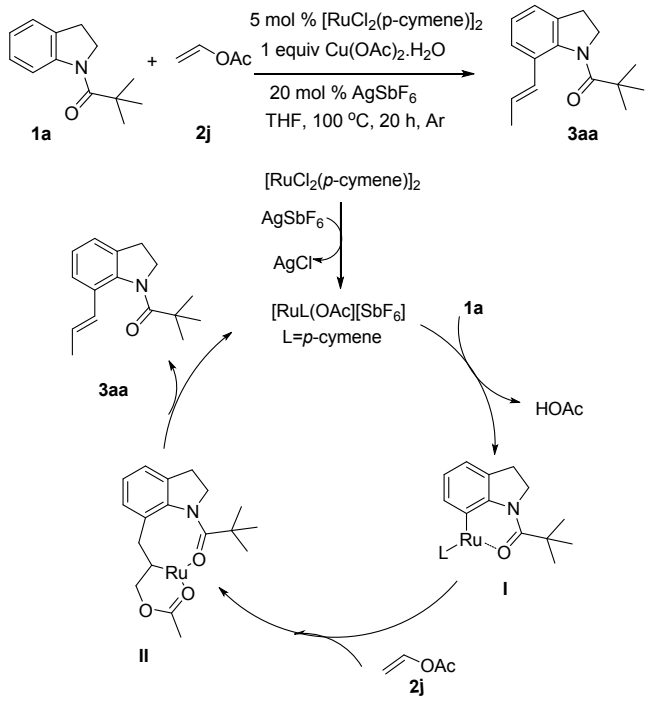
A mixture of **3aa** (48.6 mg, 0.2 mmol, 100 mol %) in EtOH (2 mL) was added aqueous s-KOH

solution (1 mL) at room temperature. The reaction mixture was stirred for 20 h at 100 °C and cooled to 0 °C. The reaction mixture was neutralized with aqueous s-NH_4Cl solution, and partitioned between DCM and H_2O. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the alkenylated product **3ac.**



^{1}H NMR (400 MHz, DMSO) δ 7.00 (d, *J* = 7.7 Hz, 1H), 6.88 (d, *J* = 7.0 Hz, 1H), 6.49 (t, *J* = 7.4 Hz, 1H), 6.40 – 6.36 (m, 1H), 6.10 – 6.01 (m, 1H), 5.50 (s, 1H), 3.43 – 3.36 (m, 2H), 2.89 (t, *J* = 8.6 Hz, 2H), 1.84 -1.82 (m, 3H); ^{13}C NMR (101 MHz, DMSO) δ 149.7, 129.8, 127.8, 124.0, 123.9, 123.0, 118.8, 117.7, 46.6, 29.5, 19.0; HRMS Calcd for $C_{11}H_{14}N$ [M+H$^+$]:160.1126; Found: 160.1138.

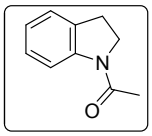
7. A plausible mechanism to explain 3aa

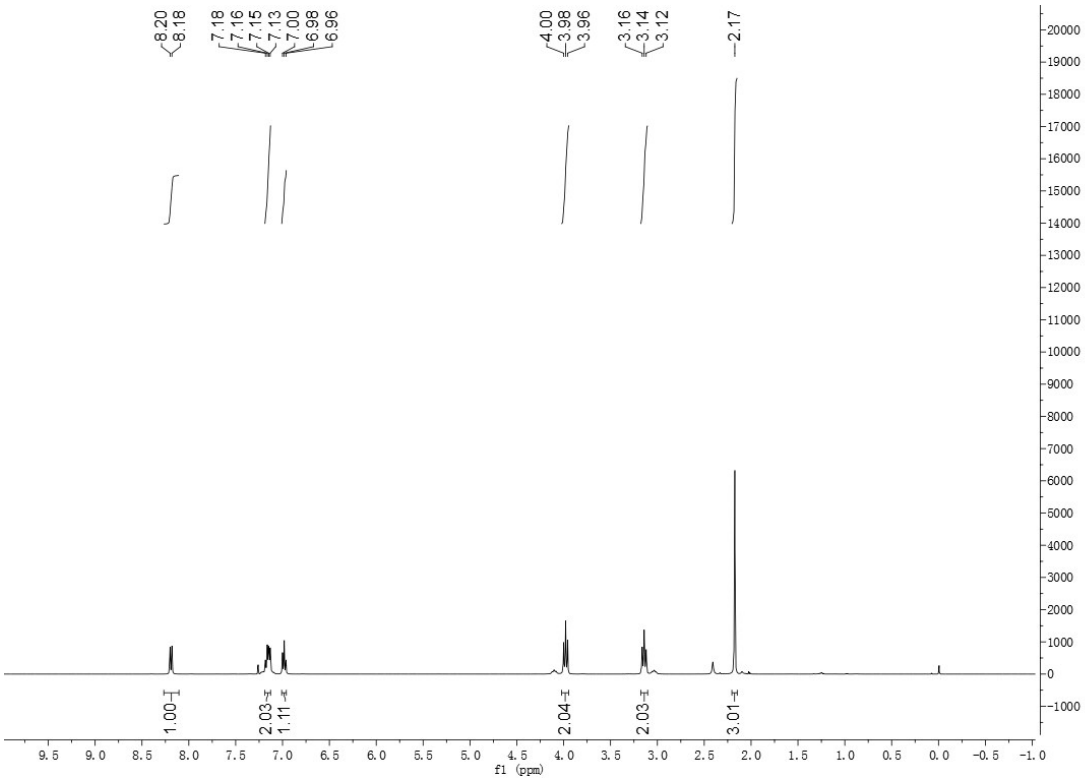


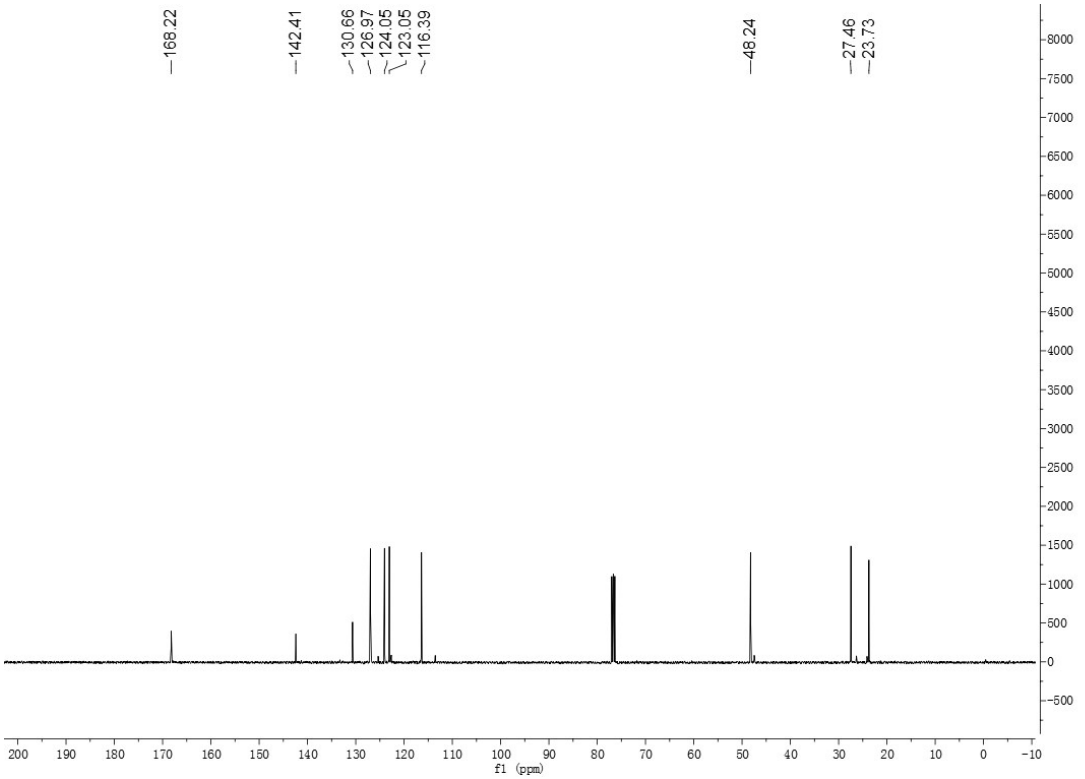
A proposed reaction mechanism of **3aa**(**3x** was coreected to **3aa**)was shown as above. Firstly, the $[RuCl_2(p\text{-cymene})]_2$ catalyst is activated by Ag^+ in the reaction. The ruthenium species coordinated with the directing group of pivaloyl, followed by ortho metalation, affording a six-membered metallacycle intermediate I, and then Regioselectiv coordinative insertion of olefin into the Ru-C bond provides an eight-membered ruthenium intermediate II. Futher, *β*-oxygen elimination affords the products **3aa.**[1]

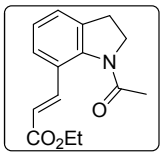
[1] J. Park, N. K. Mishra, Sharma, S. Han, Y. Shin, T. Jeong, J. S. Oh, J. H. Kwak, Y. H. Jung and I. S. Kim, J. Org. Chem. 2015, 80, 1818;

8. NMR Spectra





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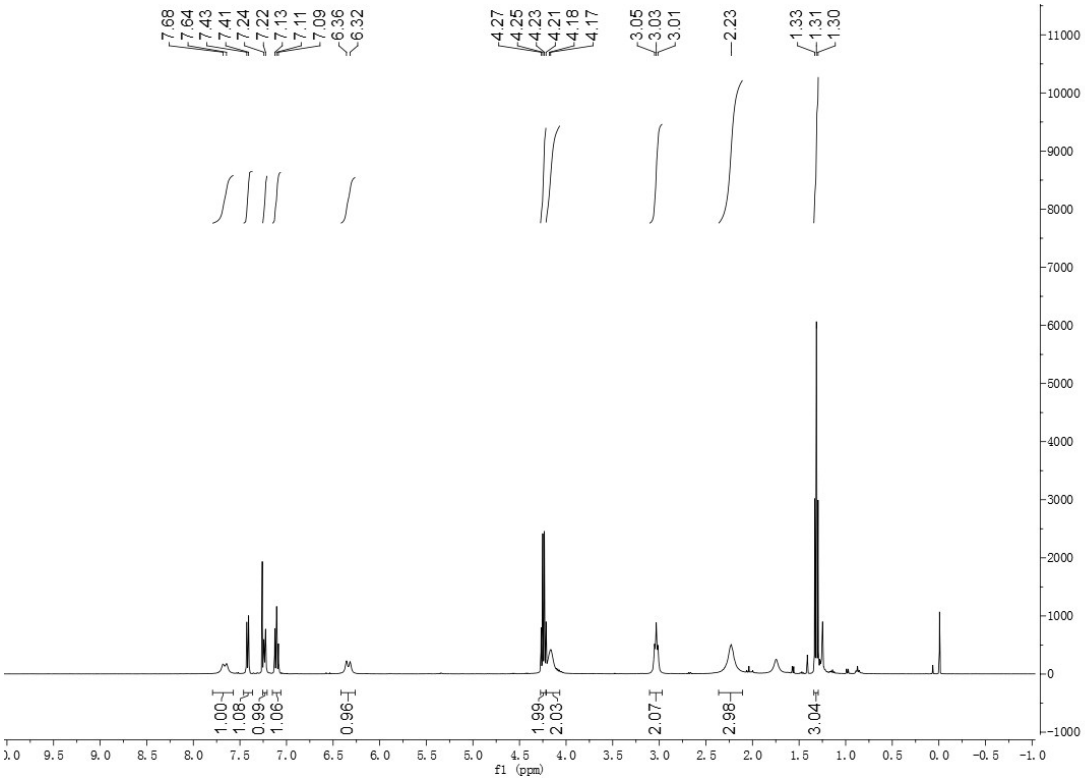
O
CO2Et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7.11
7.09
6.36
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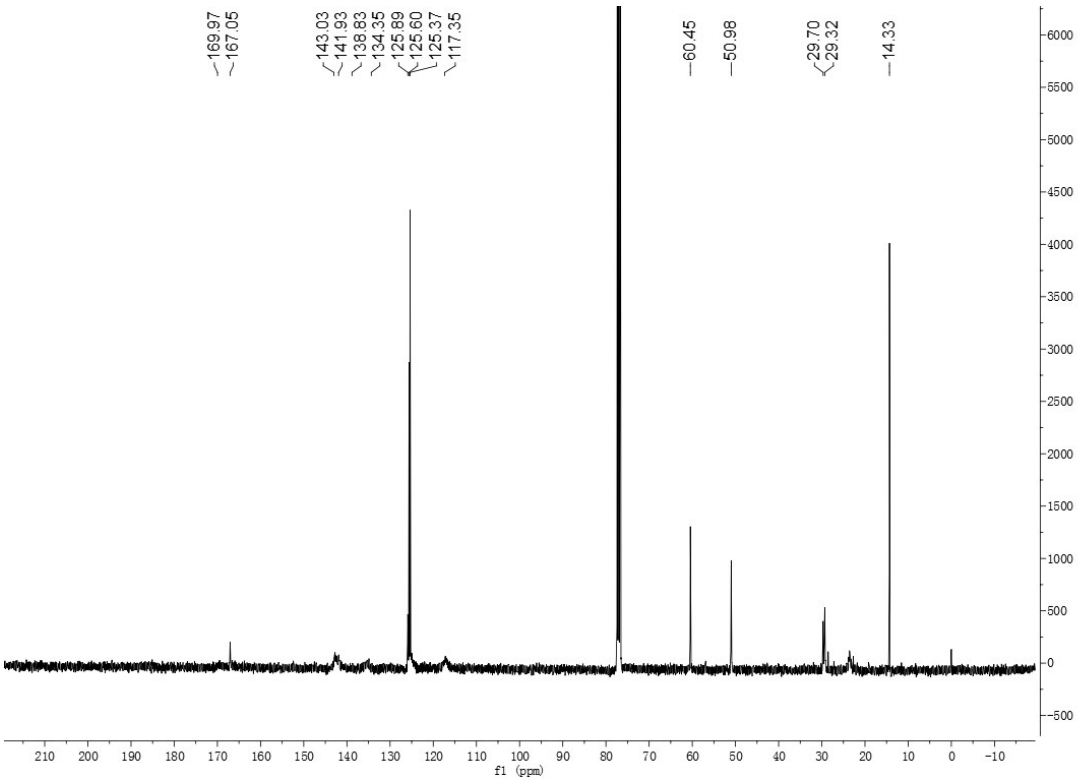
4.27
4.25
4.23
4.21
4.18
4.17
3.05
3.03
3.01
2.23
1.33
1.31
1.30
1.00
1.08
0.99
1.06
0.96
1.99
2.03
2.07
2.98
3.04
f1 (ppm)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167.05
143.03
141.93
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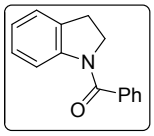
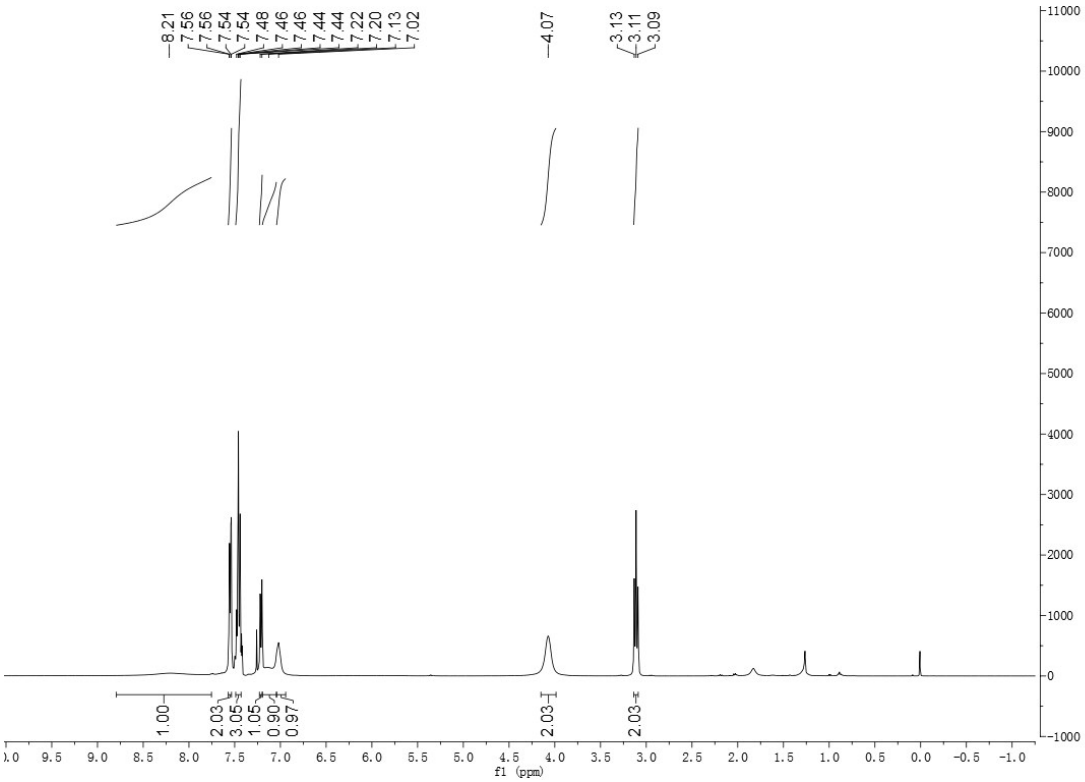
125.60
125.37
117.35
60.45
50.98
29.70
29.32
14.33
f1 (ppm)


N
O
Ph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7.46
7.46
7.44
7.44
7.22
7.20
7.13
7.02
4.07
3.13
3.11
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2.03
3.05
1.05
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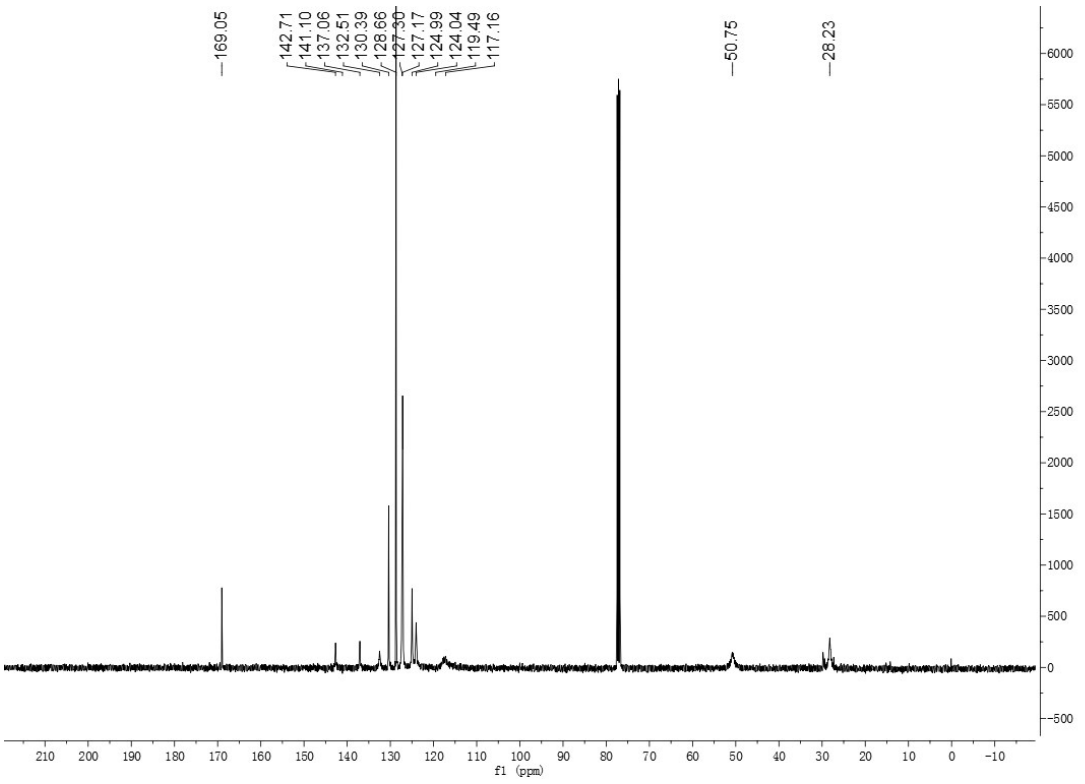
0.97
2.03
2.03
f1 (ppm)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124.04
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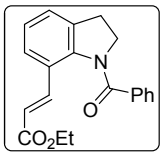
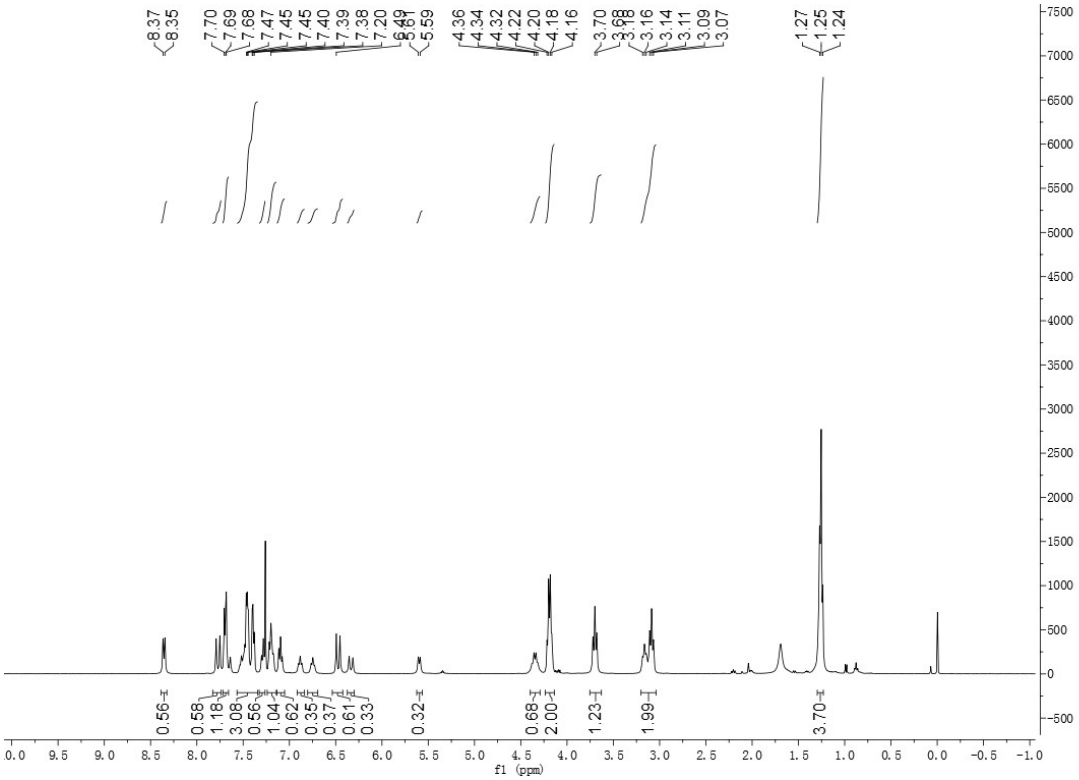
117.16
50.75
28.23
f1 (ppm)


N
O
Ph
CO2Et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6.49
5.81
5.59
4.36
4.34
4.32
4.22
4.20
4.18
4.16
3.70
3.68
3.16
3.14
3.11
3.09
3.07
1.27
1.25
1.24
0.56
0.58
1.18
3.08
0.56
1.04
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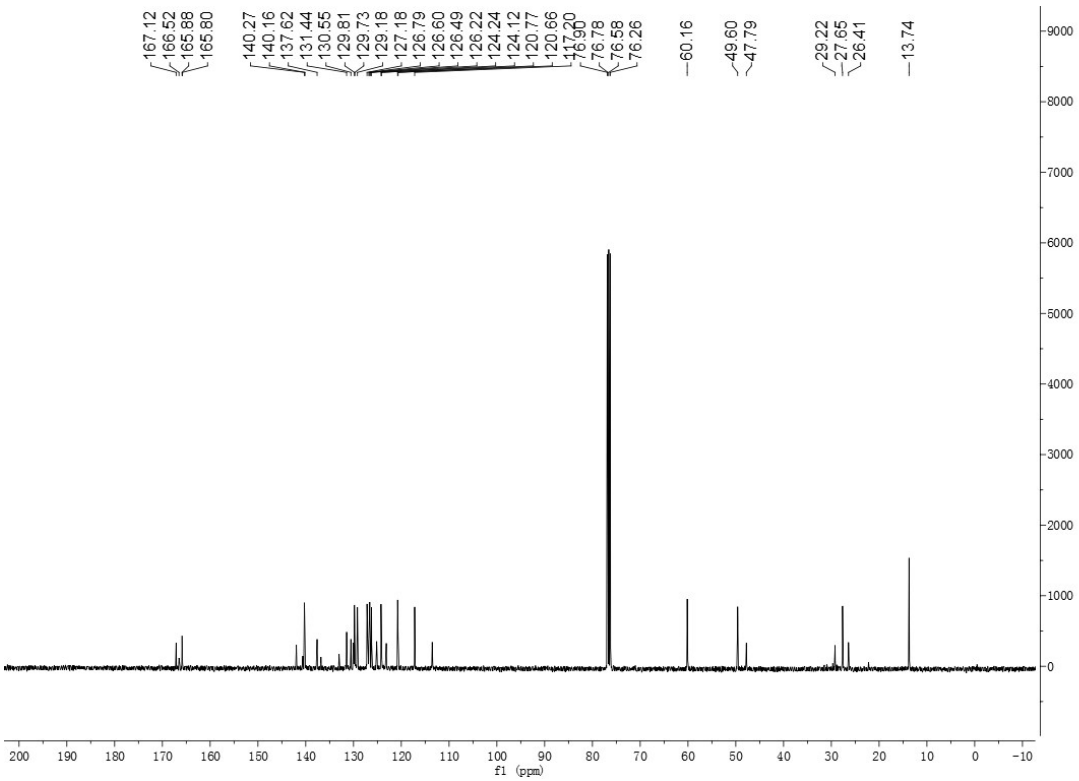
0.61
0.33
0.32
0.68
2.00
1.23
1.99
3.70
f1 (ppm)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127.18
126.79
126.60
126.49
126.22
124.24
124.12
120.77
120.66
117.20
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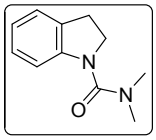
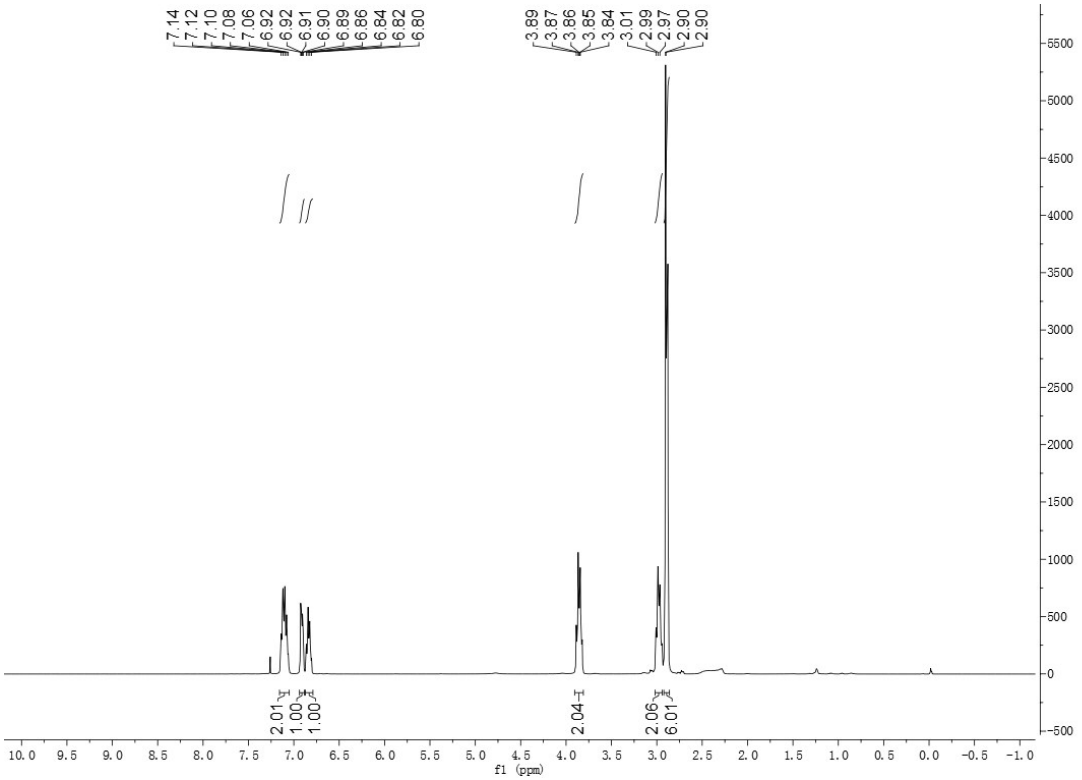
76.26
60.16
49.60
47.79
29.22
27.65
26.41
13.74
f1 (ppm)

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6.89
6.86
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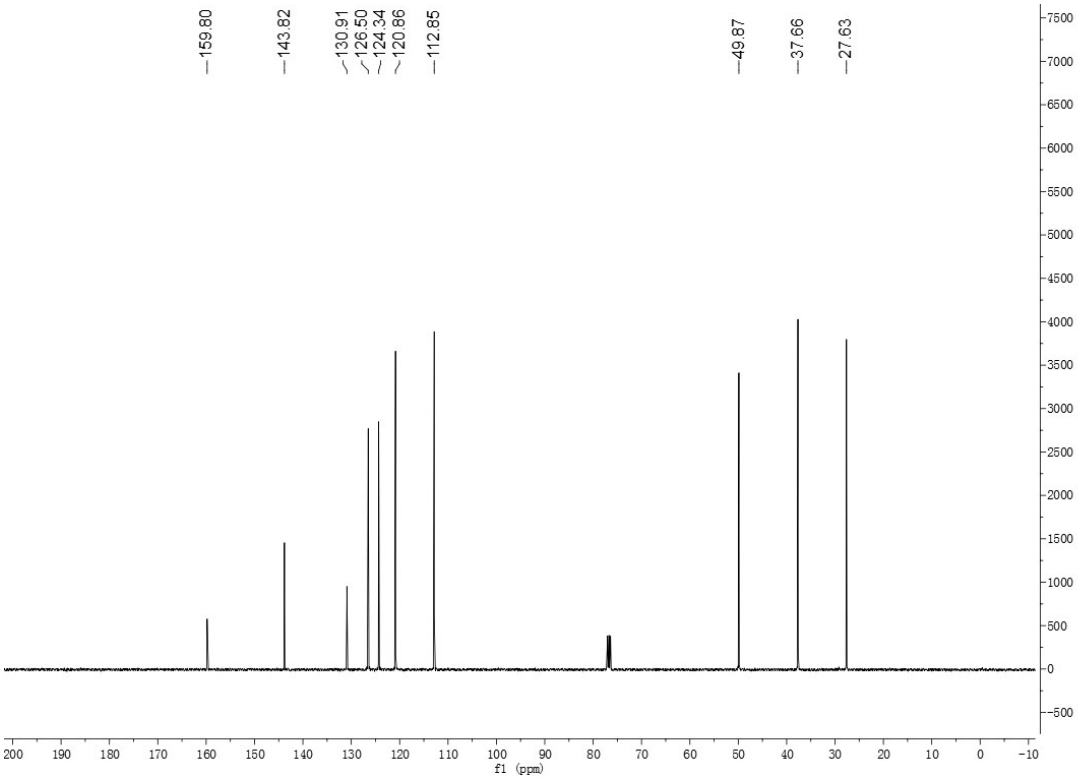
1.00
2.04
2.06
6.01
f1 (ppm)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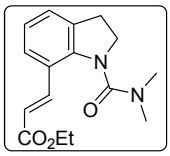
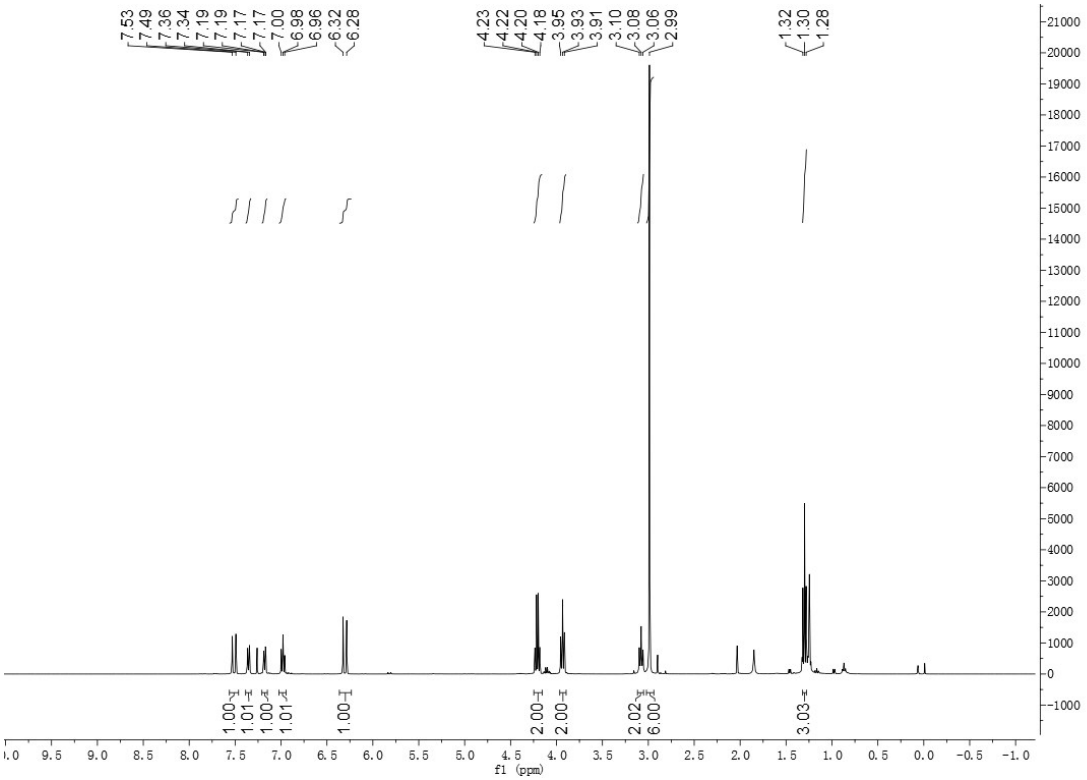
27.63
f1 (ppm)


N
O
N
CO2Et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4.22
4.20
4.18
3.95
3.93
3.91
3.10
3.08
3.06
2.99
1.32
1.30
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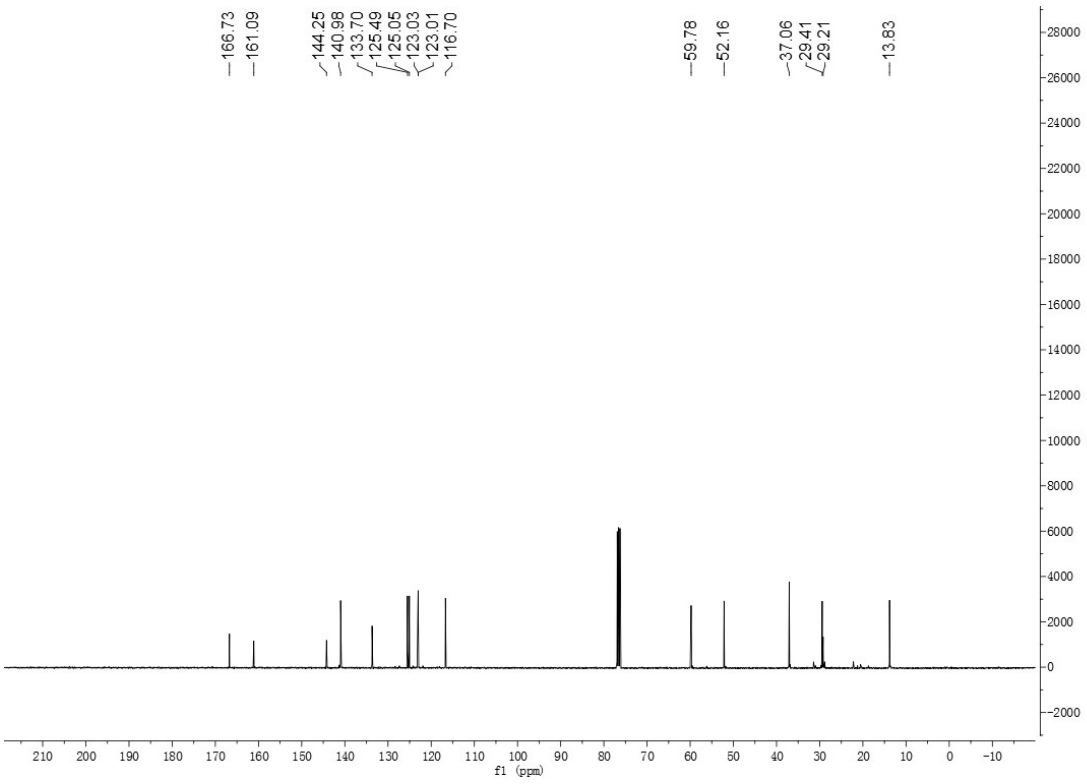
f1 (ppm)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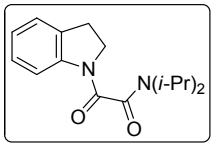
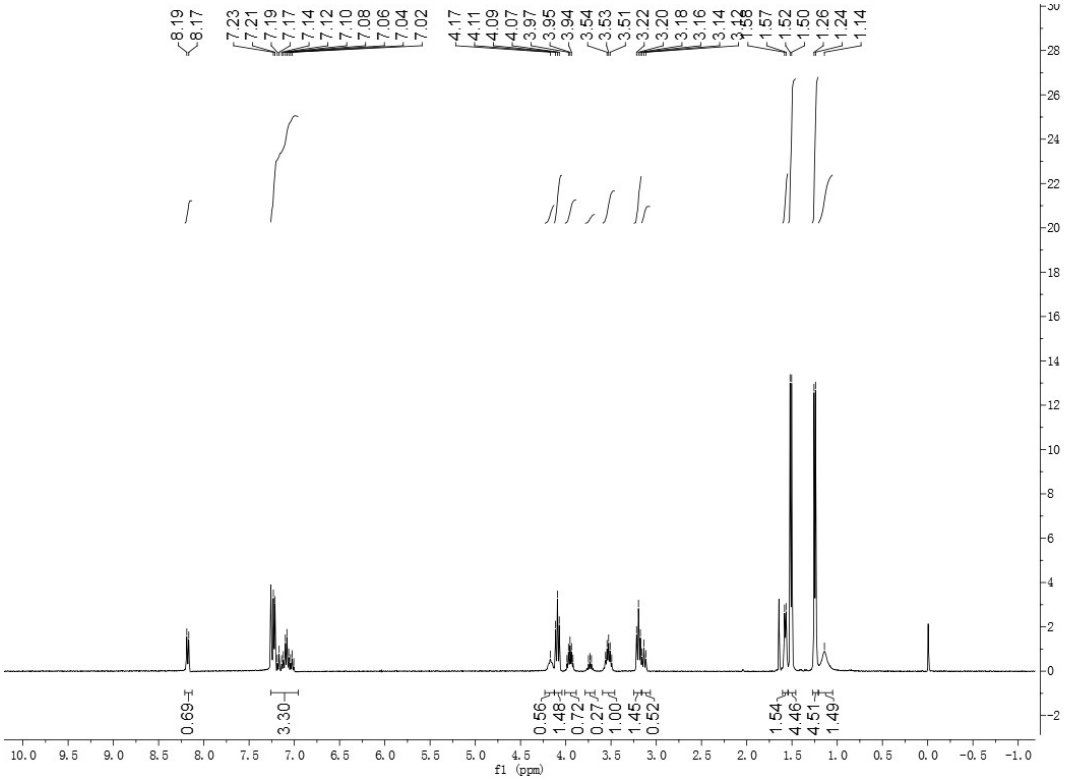
f1 (ppm)


N
N(i-Pr)2
O
O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7.02
4.17
4.11
4.09
4.07
3.97
3.95
3.94
3.54
3.53
3.51
3.22
3.20
3.18
3.16
3.14
1.57
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1.50
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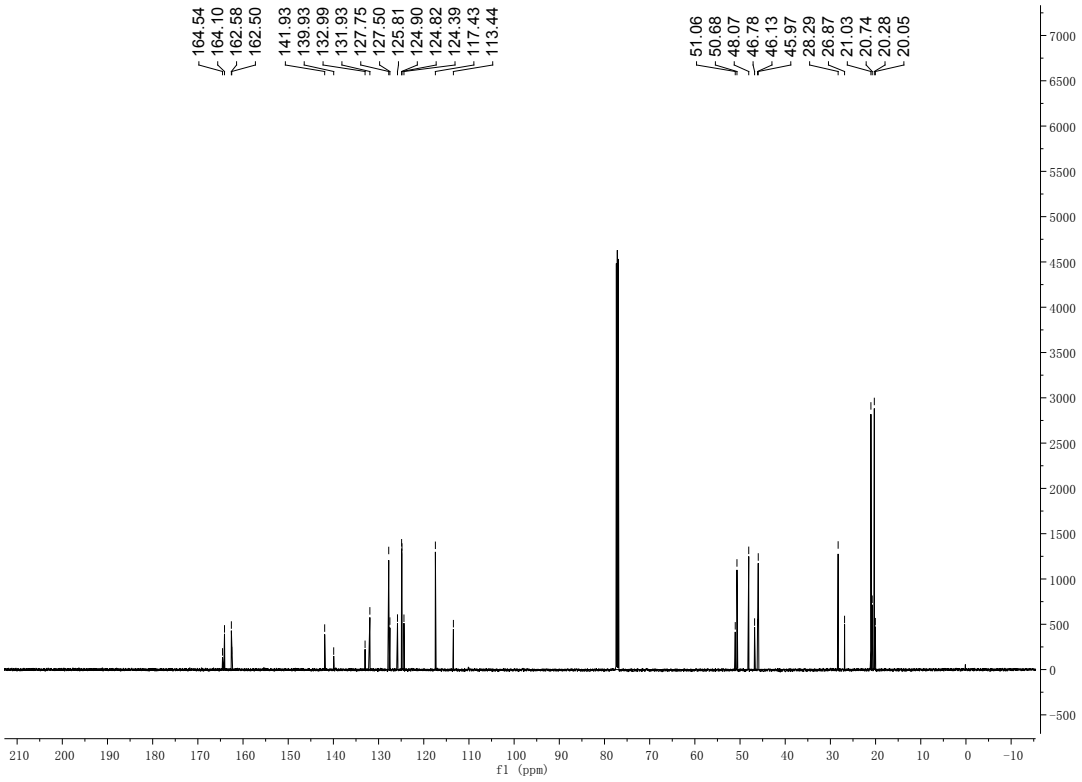
f1 (ppm)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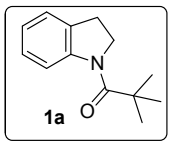
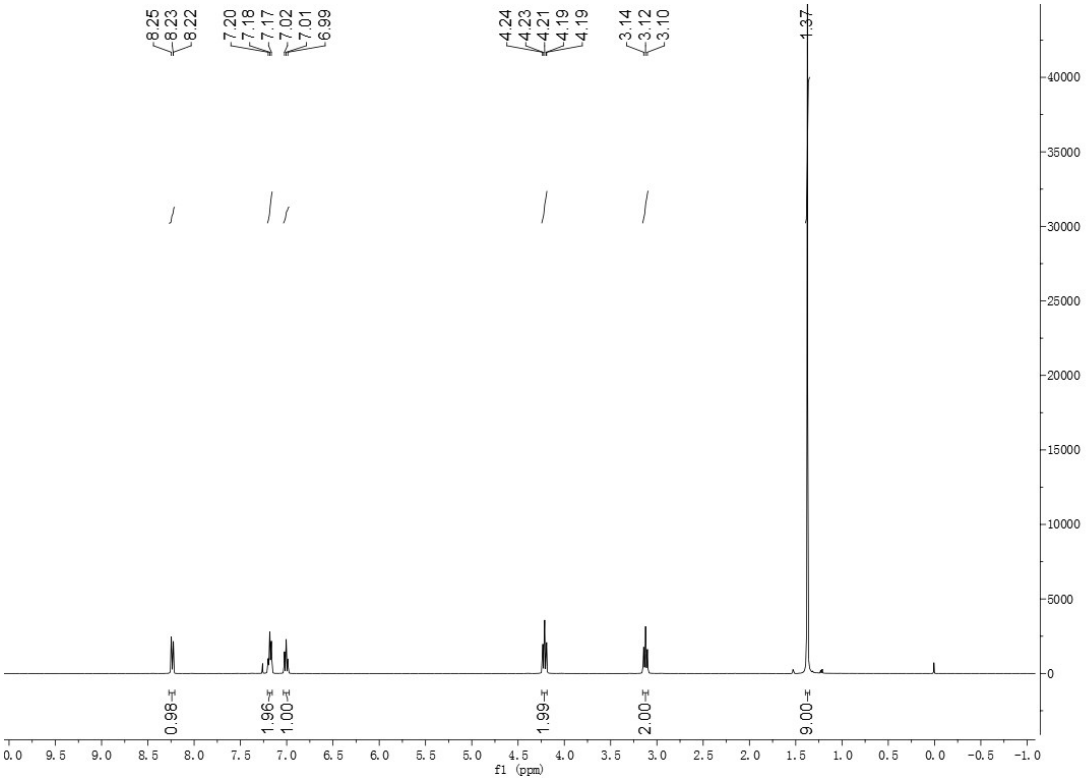
f1 (ppm)


N
O

1a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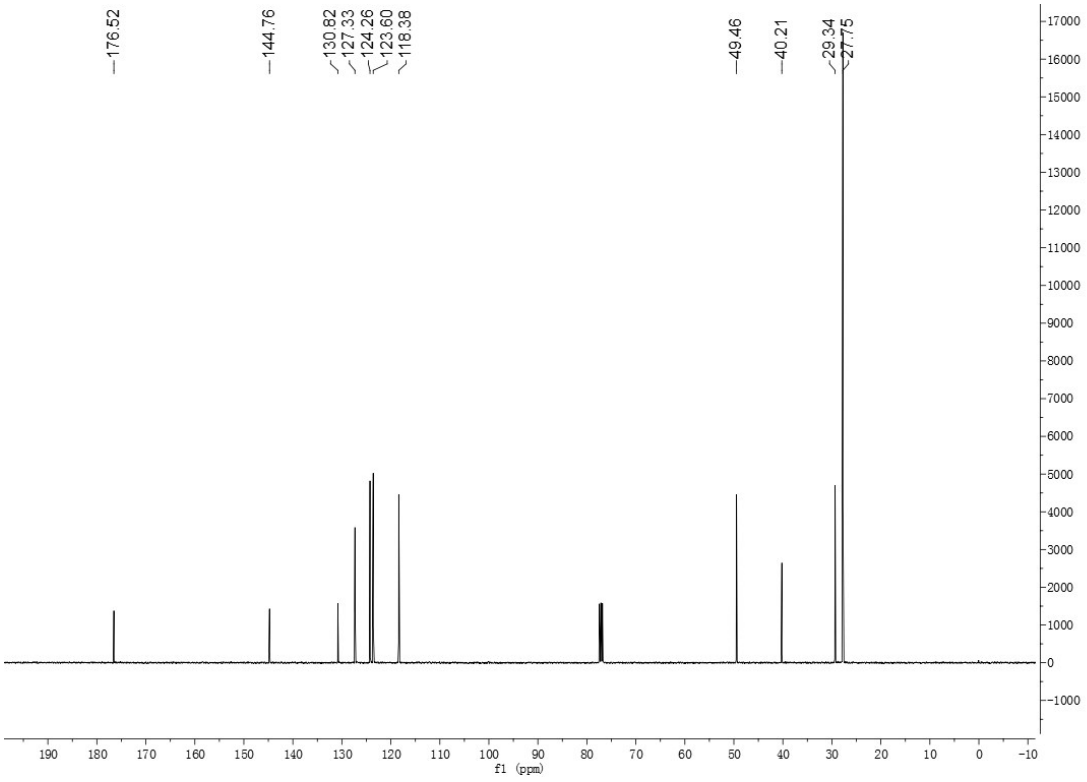
4.19
3.14
3.12
3.10
1.37
0.98
1.96
1.00
1.99
2.00
9.00
f1 (ppm)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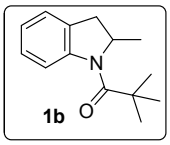
124.26
123.60
118.38
49.46
40.21
29.34
27.75
f1 (ppm)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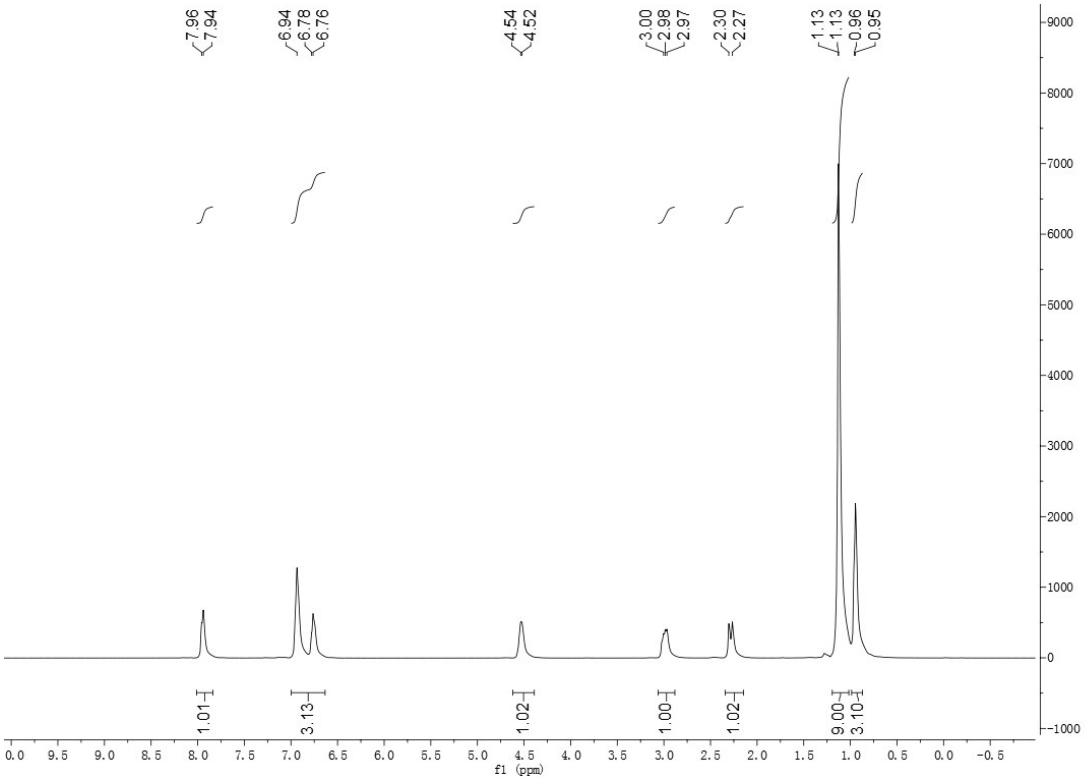
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7.94
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6.76
4.54
4.52
3.00
2.98
2.97
2.30
2.27
1.13
1.13
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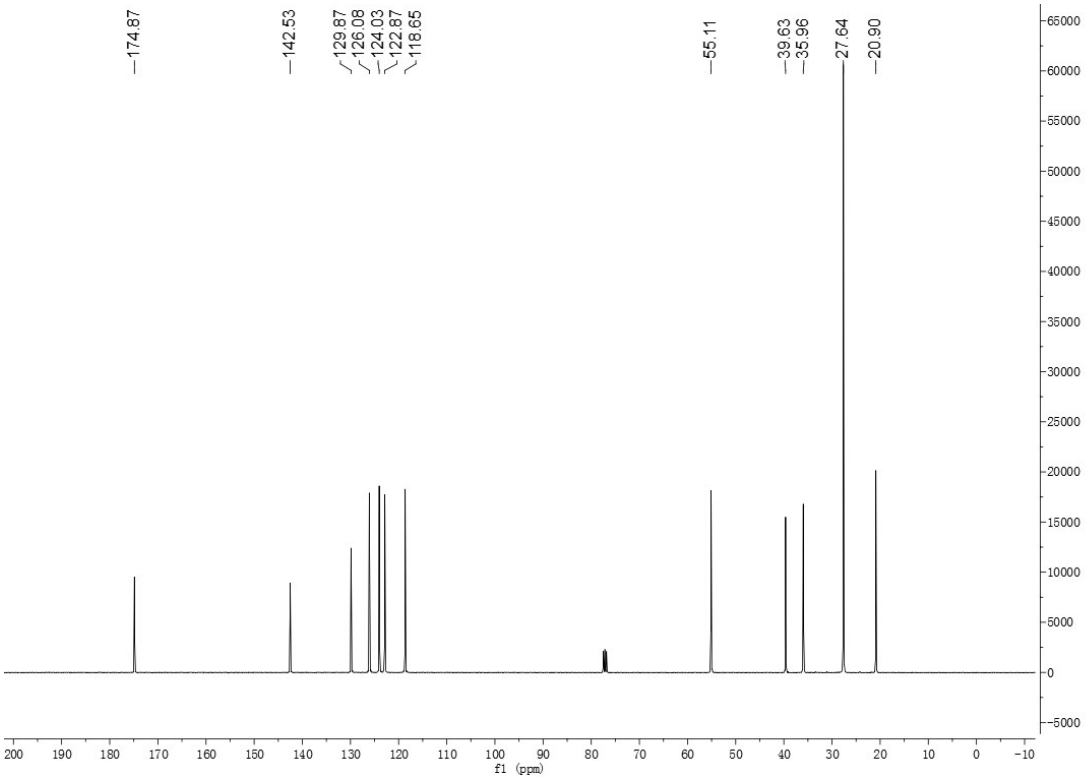
0.95
1.01
3.13
1.02
1.00
1.02
9.00
3.10
f1 (ppm)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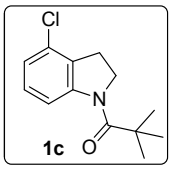
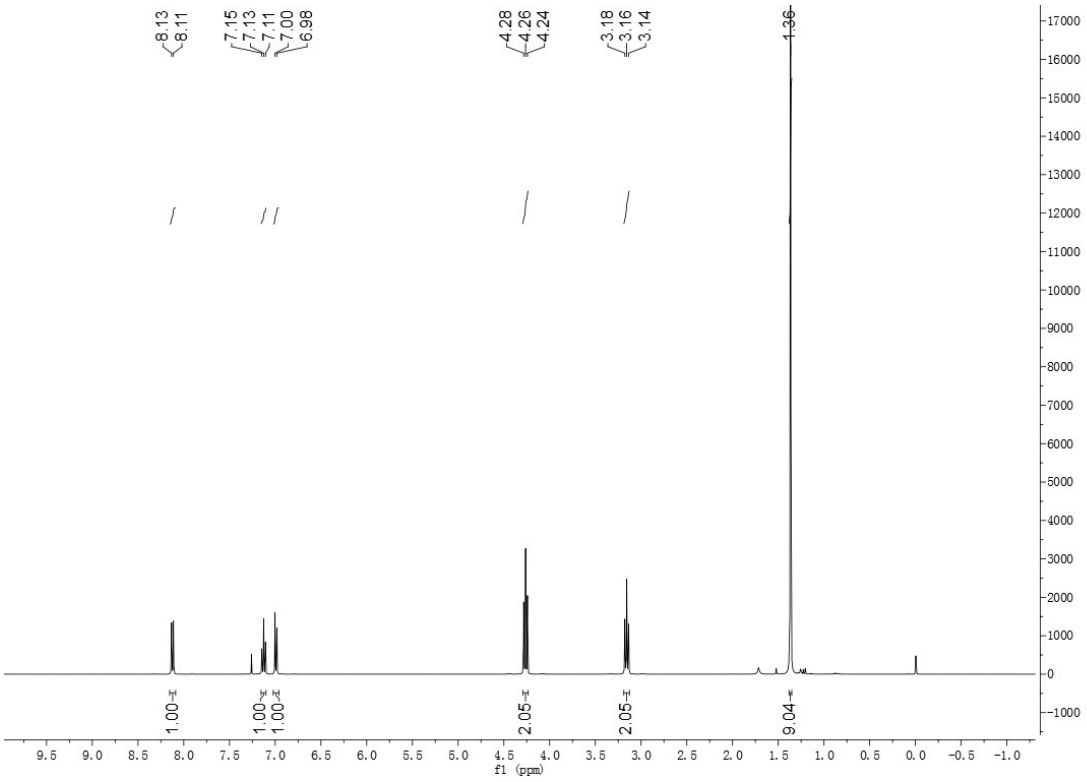
122.87
118.65
55.11
39.63
35.96
27.64
20.90
f1 (ppm)


Cl
N
O
1c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7.00
6.98
4.28
4.26
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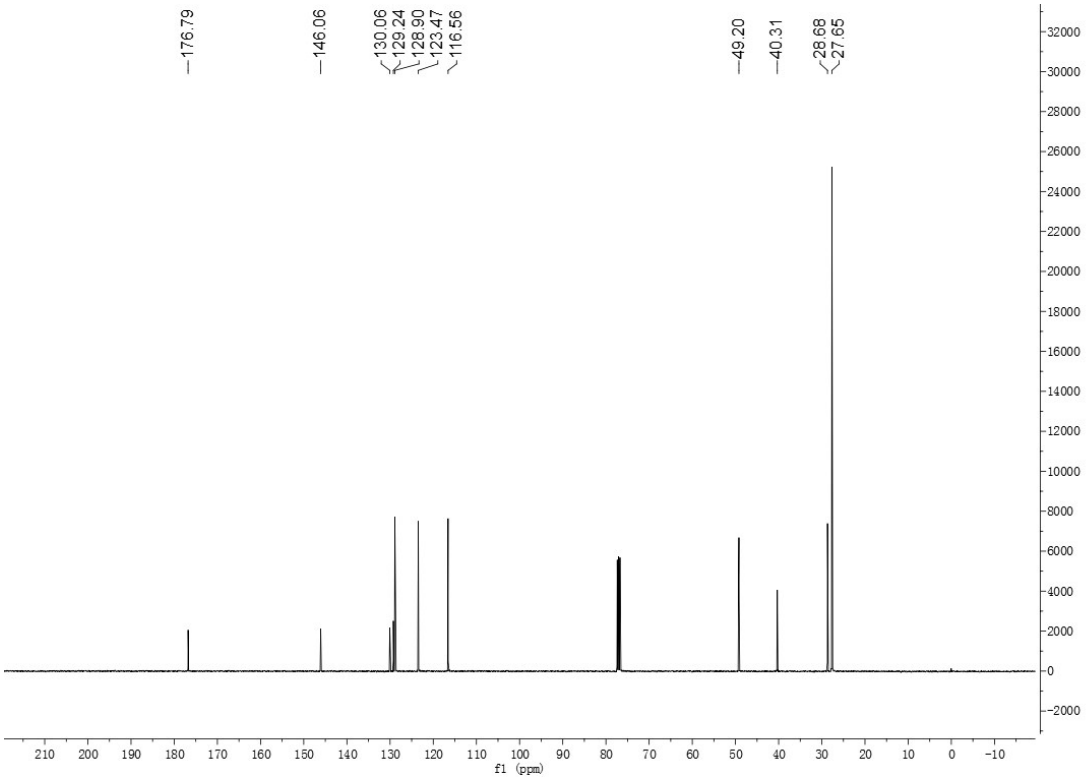
1.00
2.05
2.05
9.04
f1 (ppm)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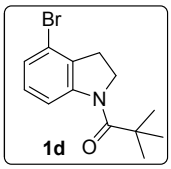
123.47
116.56
49.20
40.31
28.68
27.65
f1 (ppm)


Br
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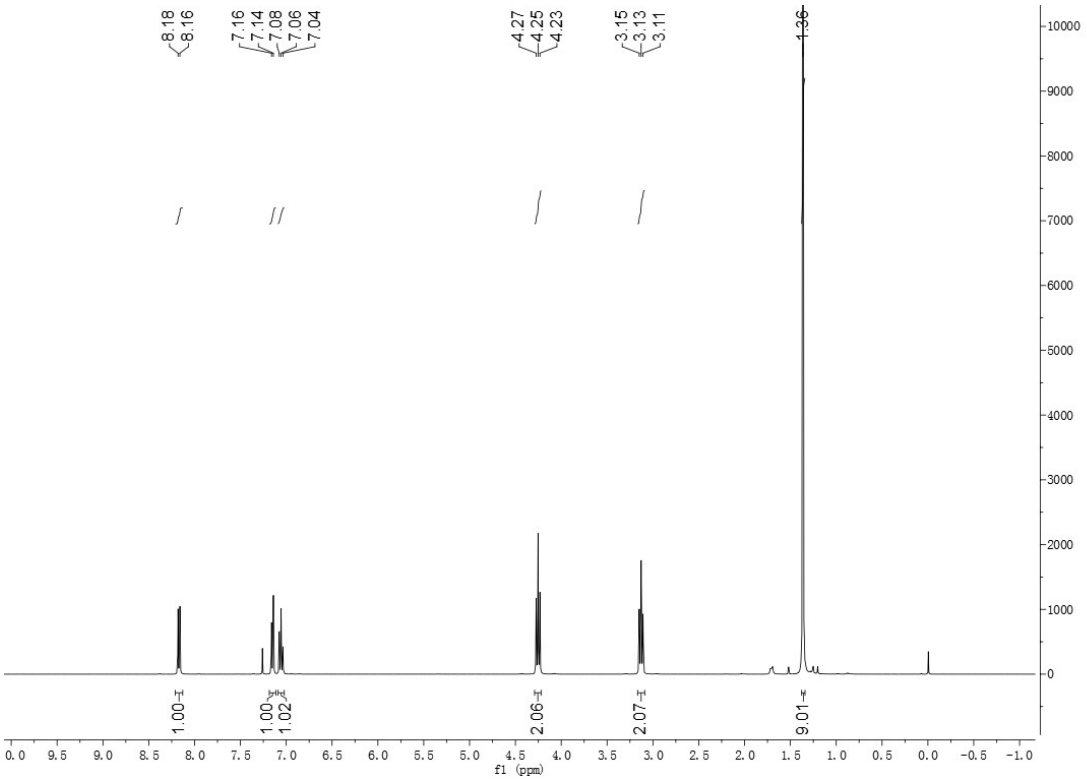
O
1d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7.08
7.06
7.04
4.27
4.25
4.23
3.15
3.13
3.11
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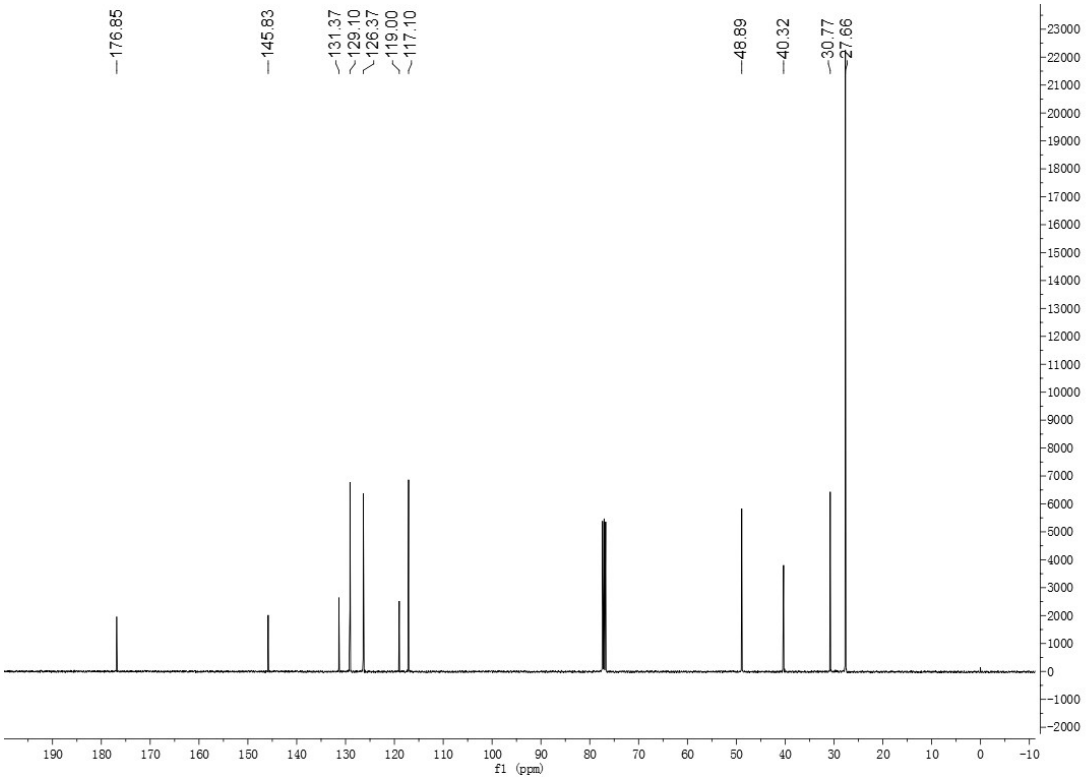
1.00
1.00
1.02
2.06
2.07
9.01
f1 (ppm)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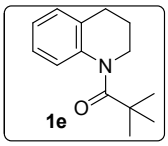
117.10
48.89
40.32
30.77
27.66
f1 (ppm)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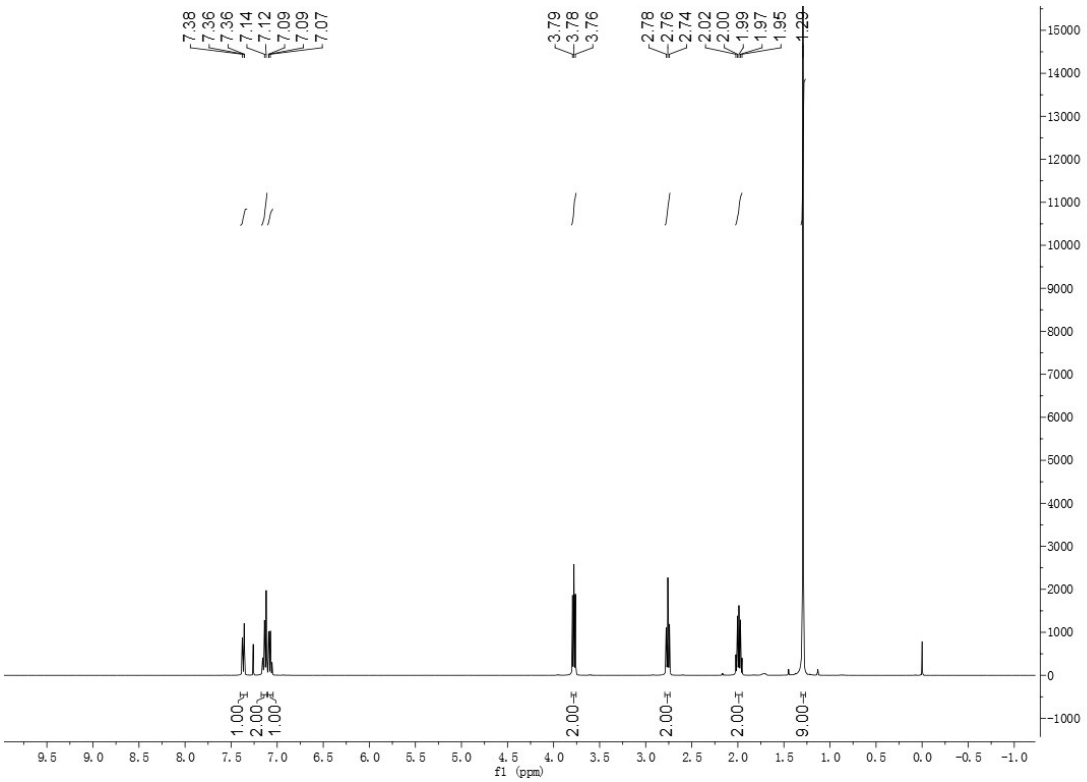
O
1e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7.36
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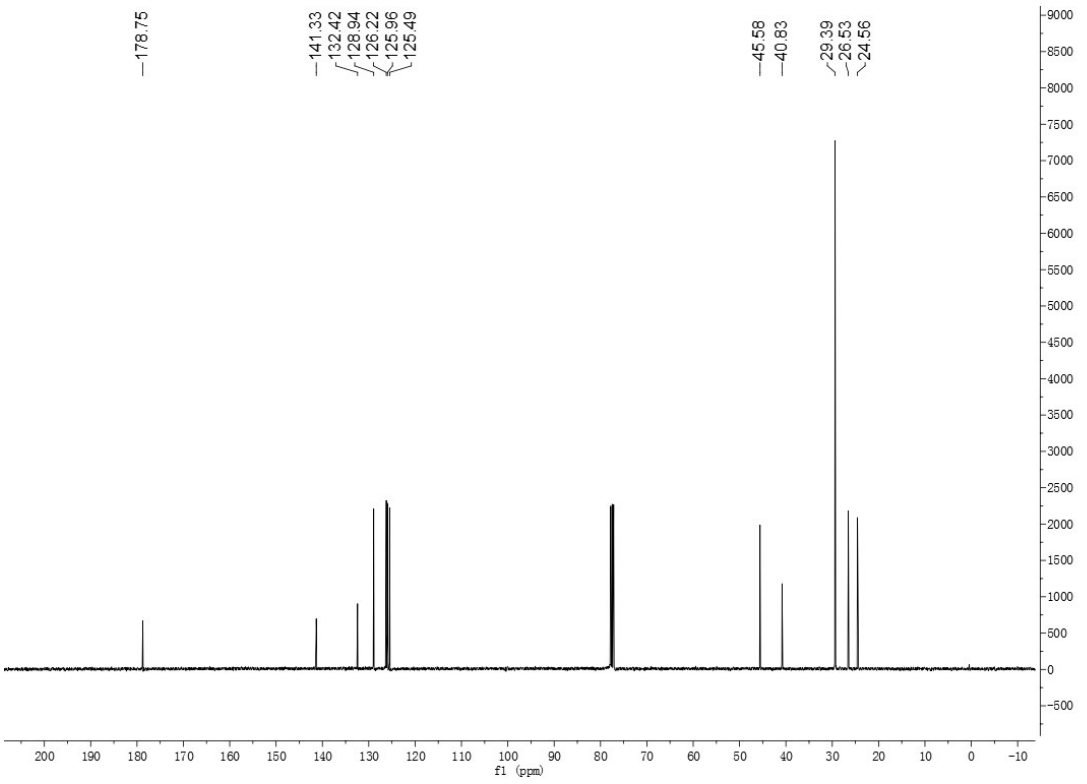
7.12
7.09
7.09
7.07
3.79
3.78
3.76
2.78
2.76
2.74
2.02
2.00
1.99
1.97
1.95
1.29
1.00
2.00
1.00
2.00
2.00
2.00
9.00
f1 (ppm)


178.75
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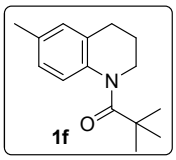
125.49
45.58
40.83
29.39
26.53
24.56
f1 (ppm)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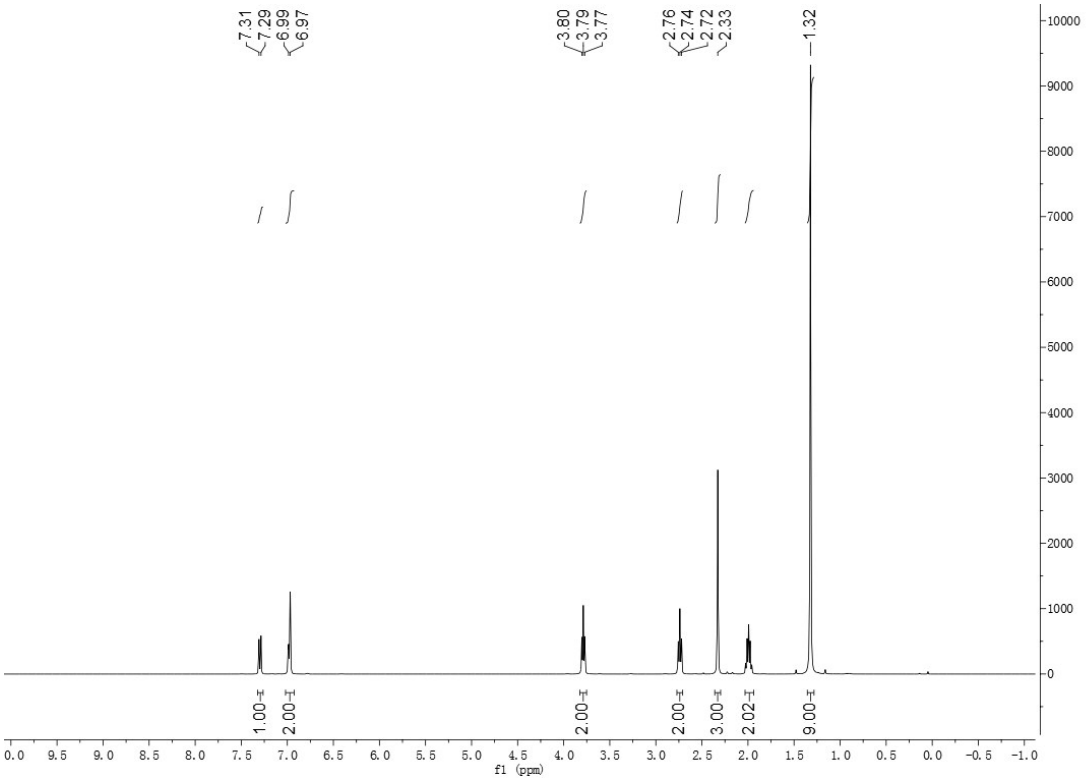
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2.76
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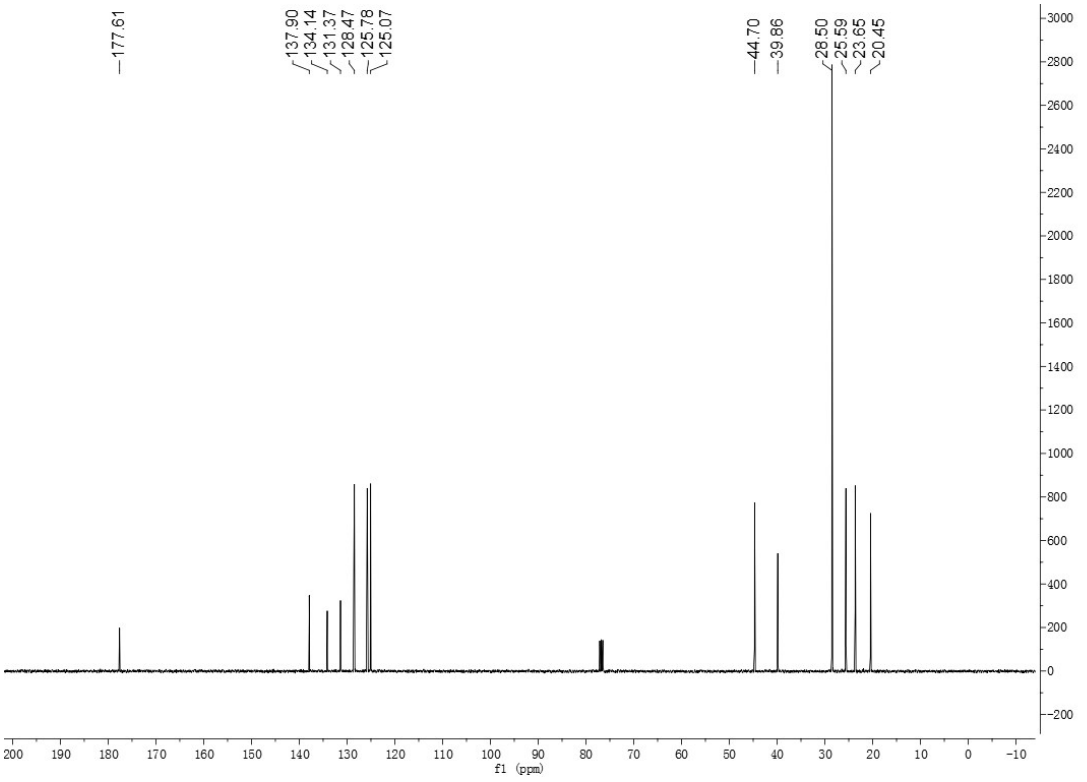
2.00
3.00
2.02
9.00
f1 (ppm)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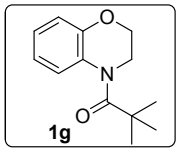
28.50
25.59
23.65
20.45
f1 (ppm)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O
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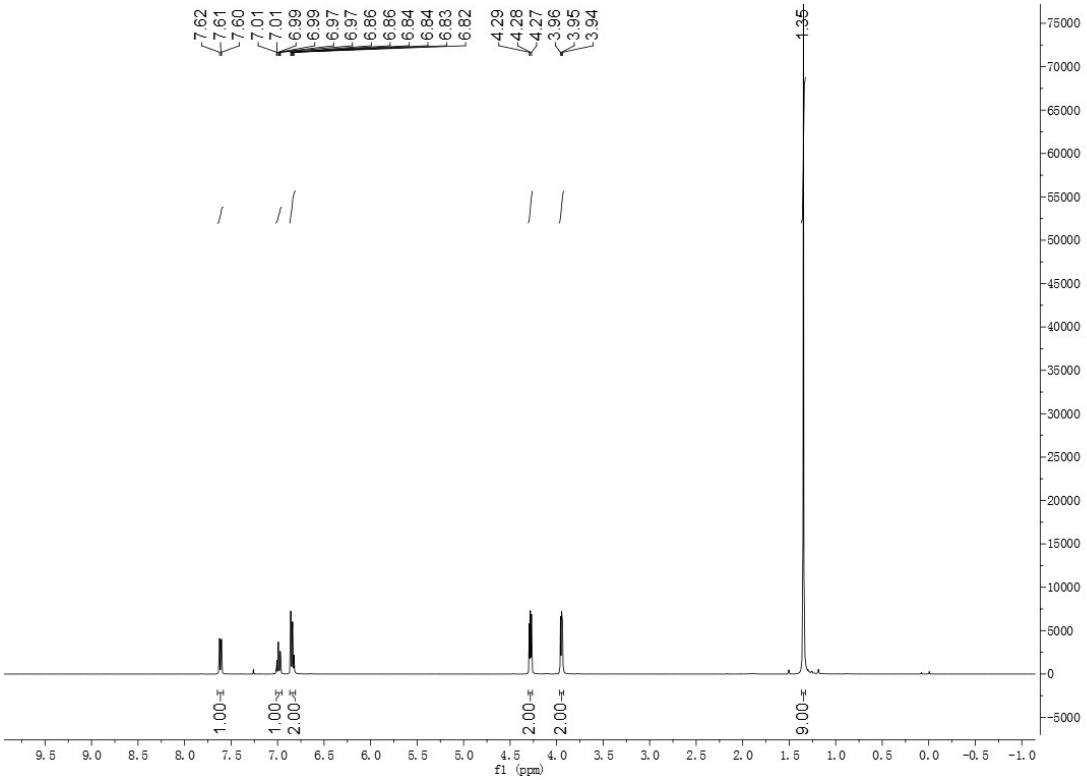
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6.86
6.84
6.84
6.83
6.82
4.29
4.28
4.27
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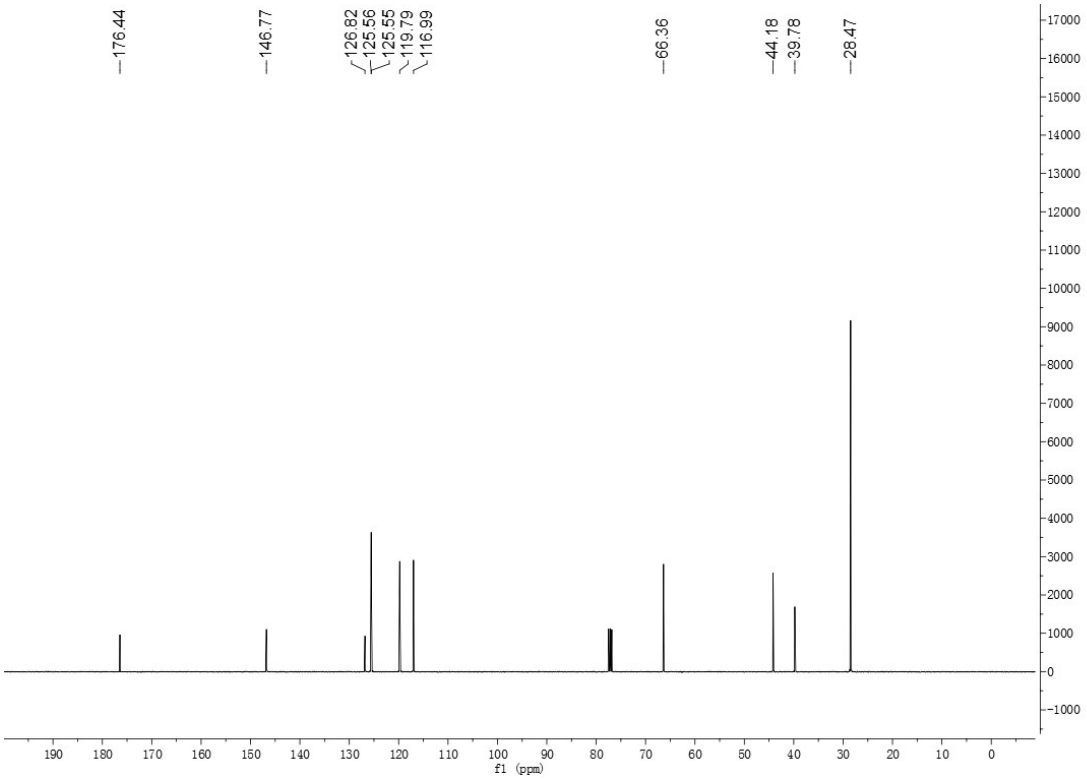
3.95
3.94
1.35
1.00
1.00
2.00
2.00
2.00
9.00
f1 (ppm)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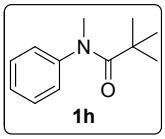
28.47
f1 (ppm)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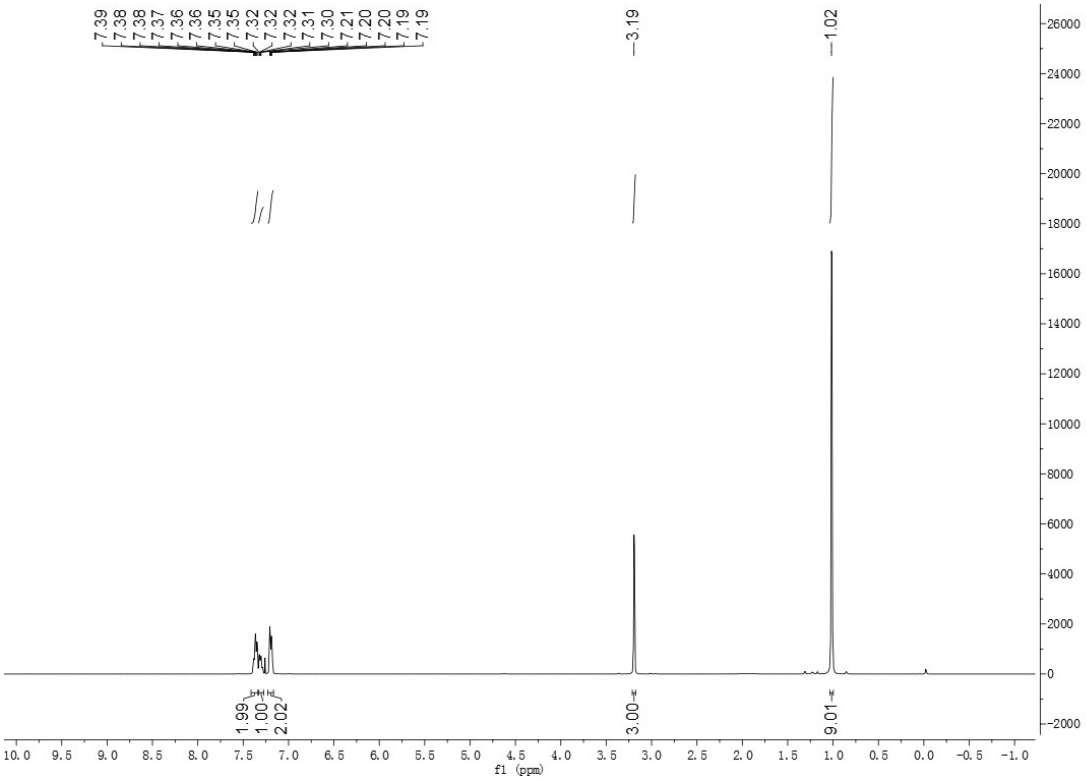
O

1h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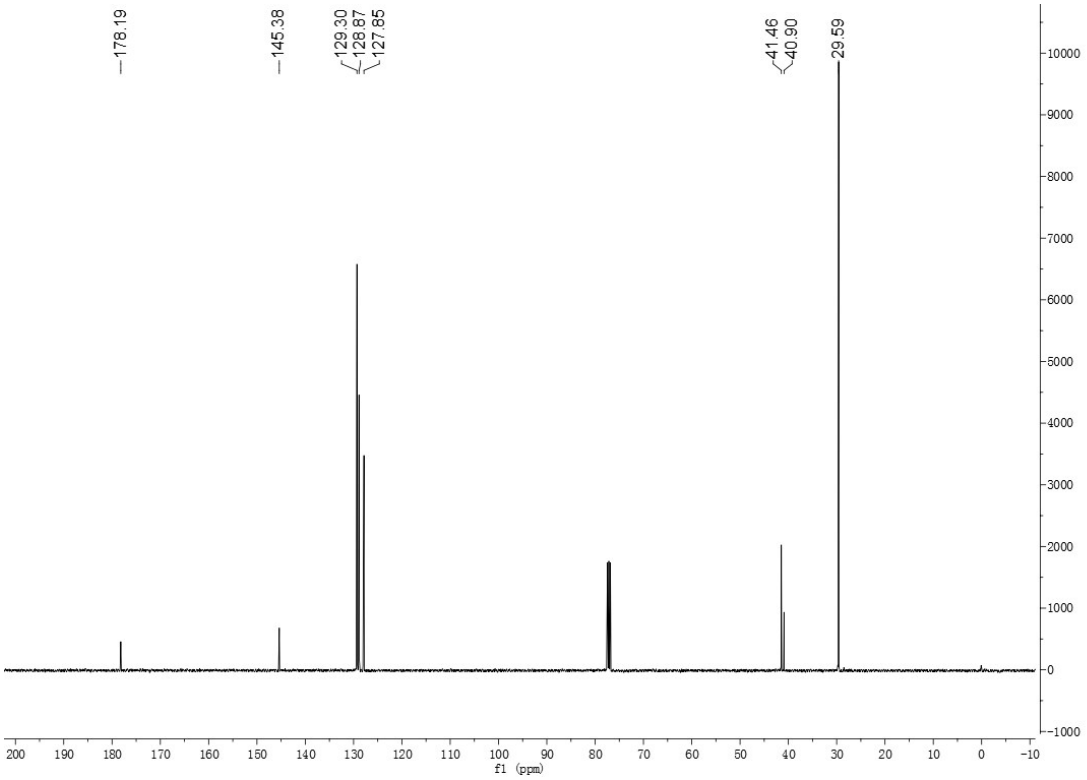
7.30
7.21
7.20
7.20
7.19
7.19
3.19
1.02
1.99
1.00
2.02
3.00
9.01
f1 (ppm)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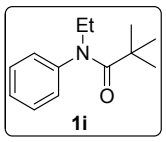
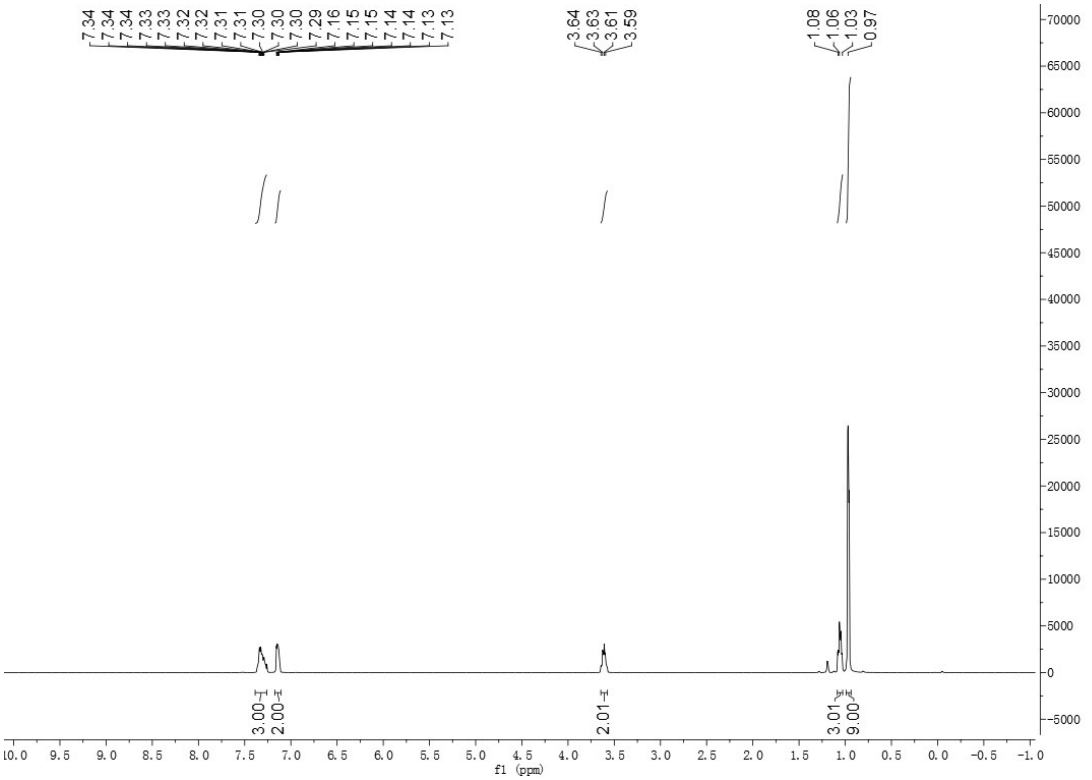
29.59
f1 (ppm)


Et
N
O

1i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7.32
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7.31
7.31
7.30
7.30
7.30
7.29
7.16
7.15
7.15
7.14
7.14
7.13
7.13
3.64
3.63
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3.59
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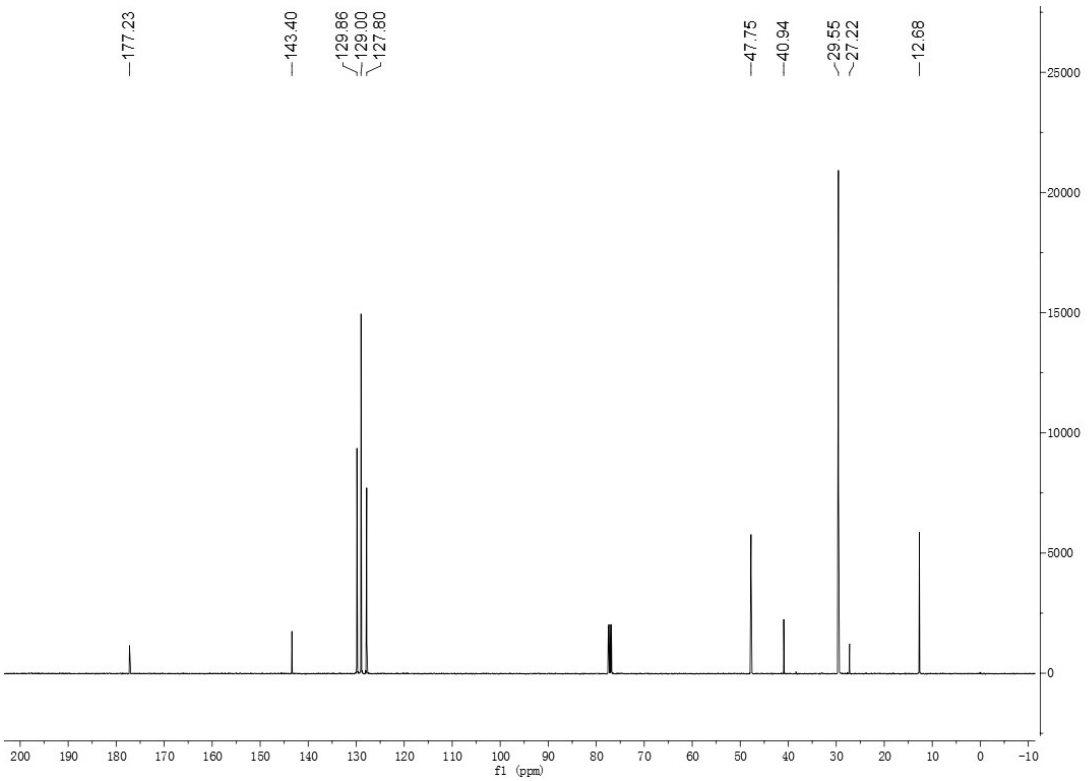
1.06
1.03
0.97
3.00
2.00
2.01
3.01
9.00
f1 (ppm)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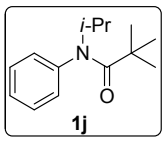
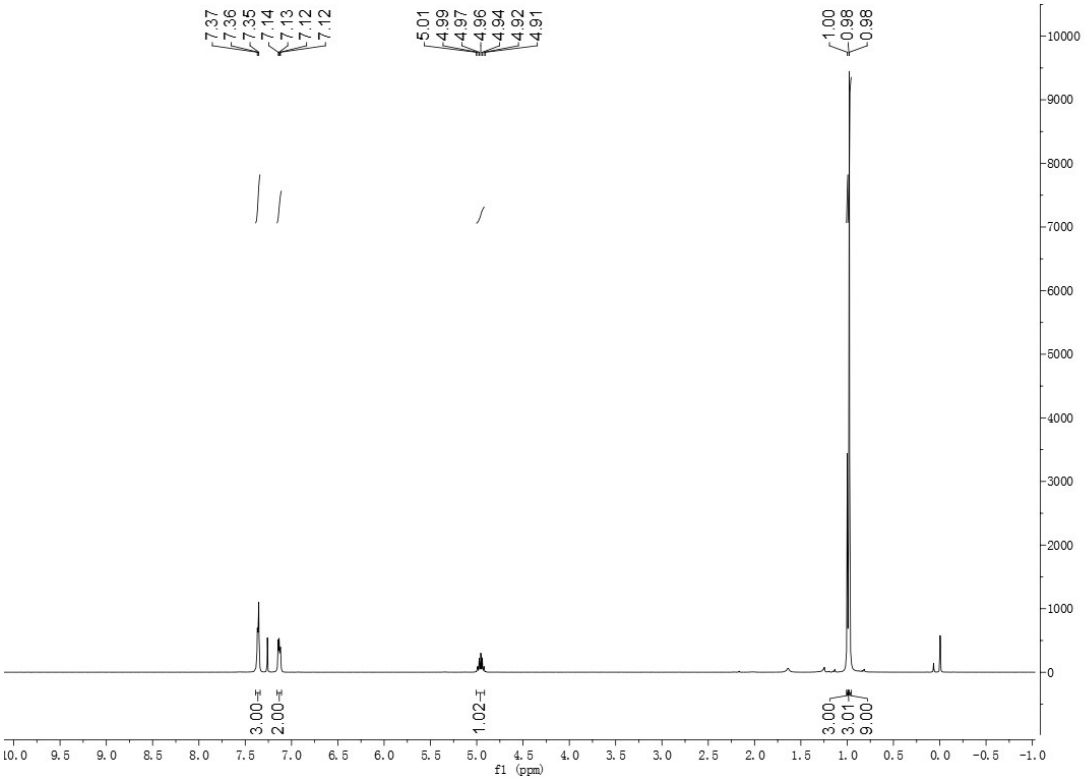
12.68
f1 (ppm)


i-Pr
N
O

1j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7.13
7.12
7.12
5.01
4.99
4.97
4.96
4.94
4.92
4.91
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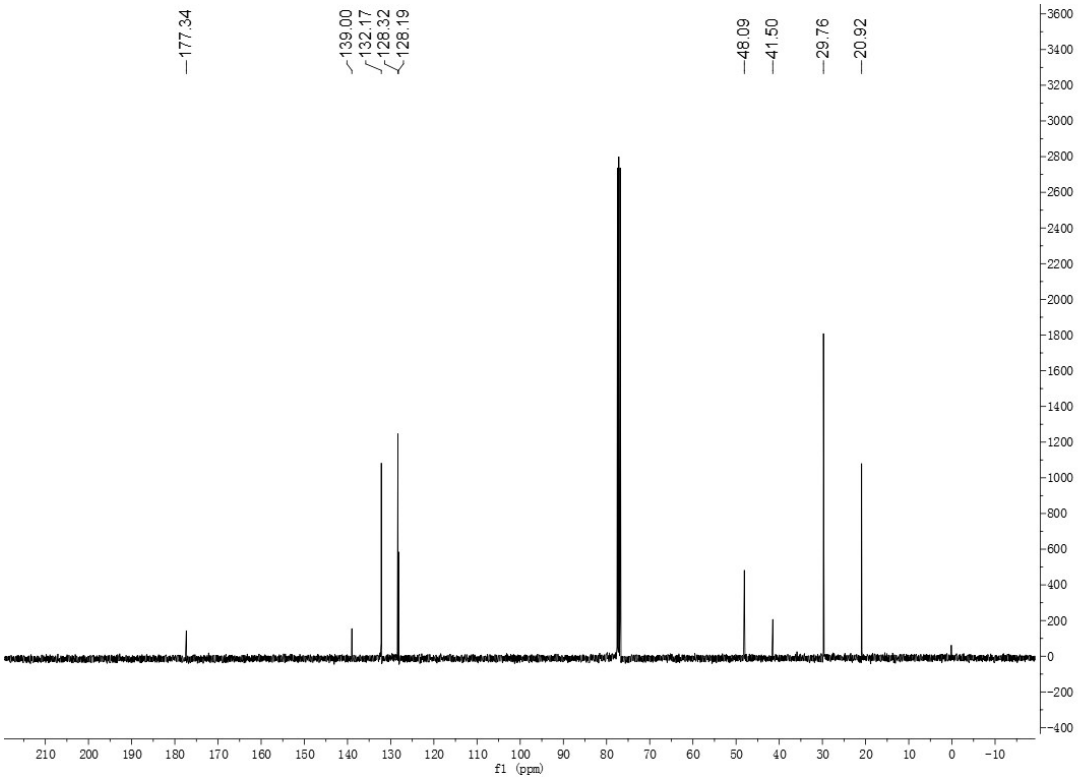
0.98
0.98
3.00
2.00
1.02
3.00
3.01
9.00
f1 (ppm)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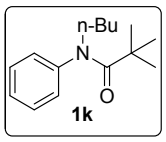
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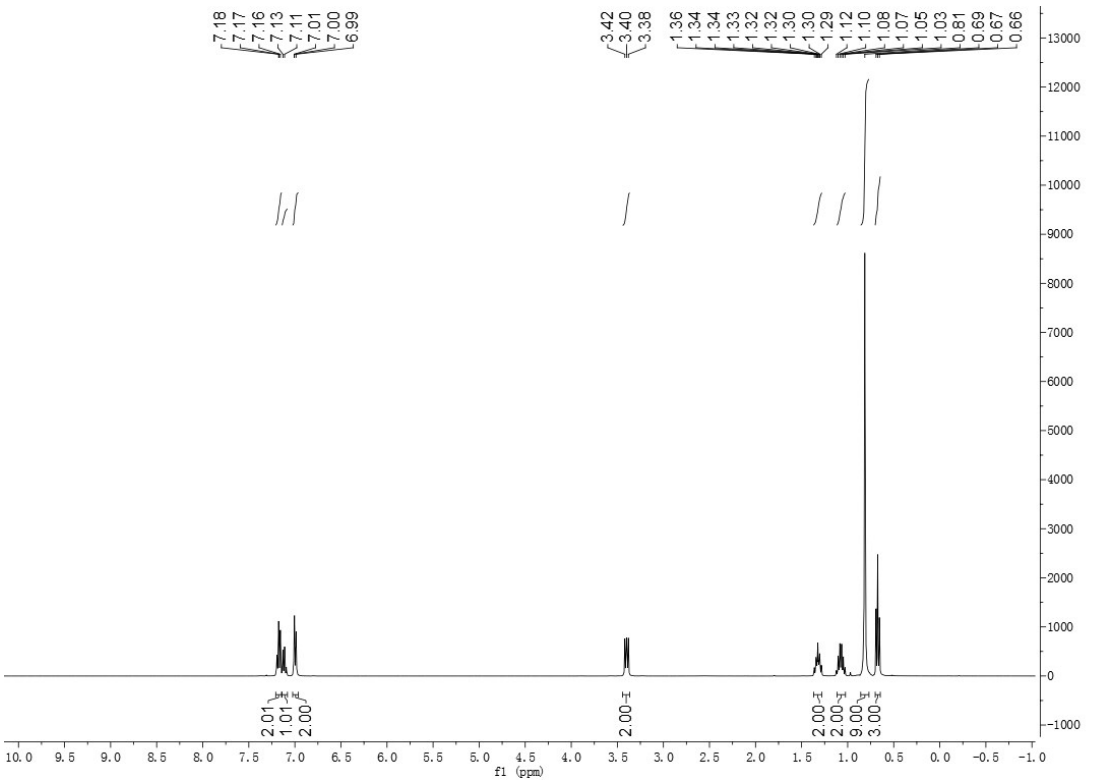
O
1k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1.34
1.33
1.32
1.32
1.30
1.30
1.29
1.12
1.10
1.08
1.07
1.05
1.03
0.81
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2.00
2.00
2.00
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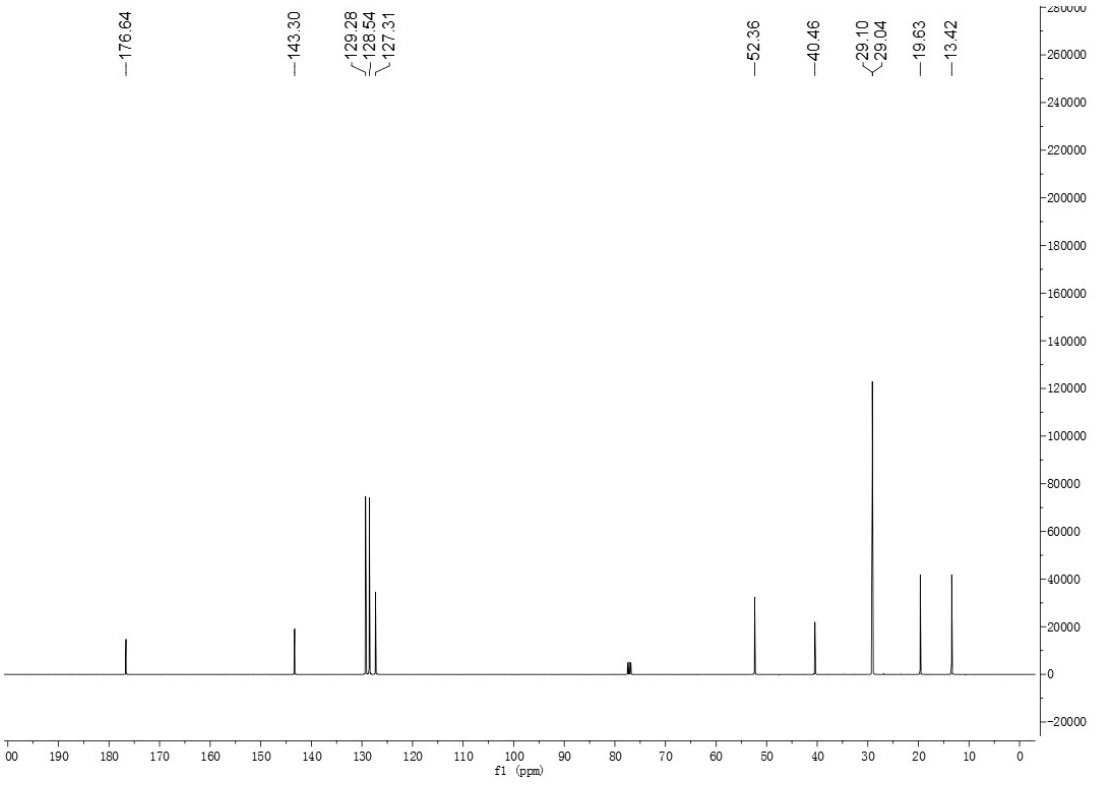
3.00
f1 (ppm)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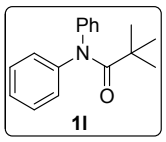
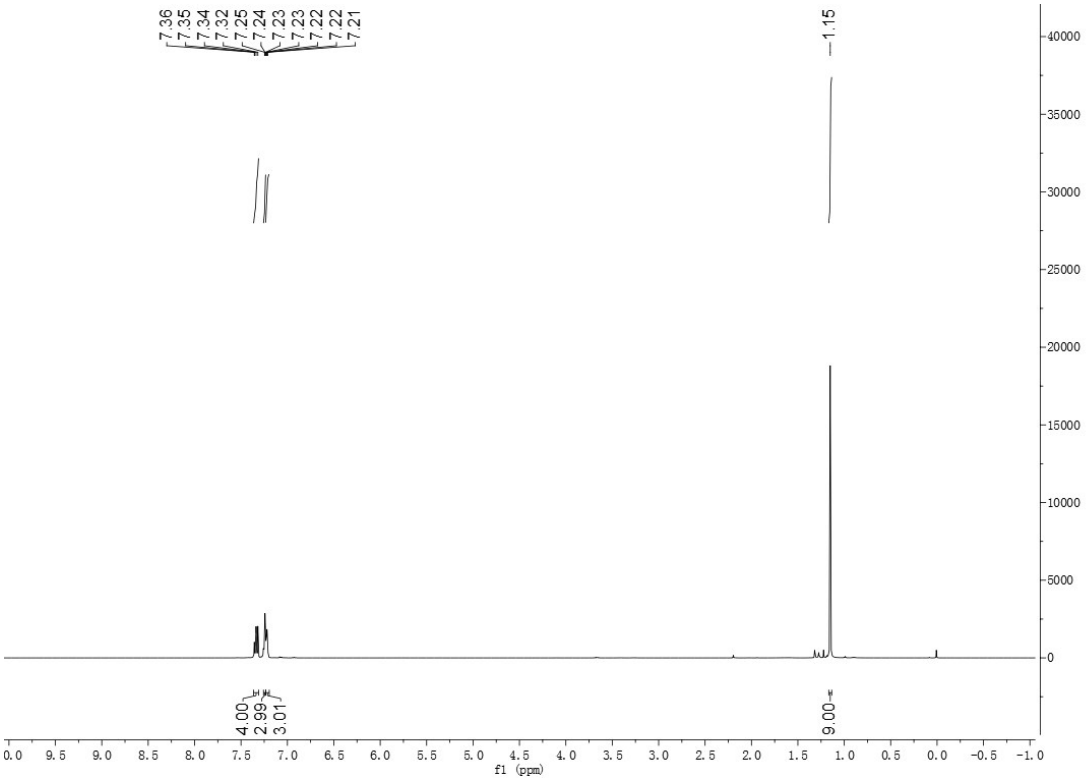
29.10
29.04
19.63
13.42
f1 (ppm)


Ph
N
O

1l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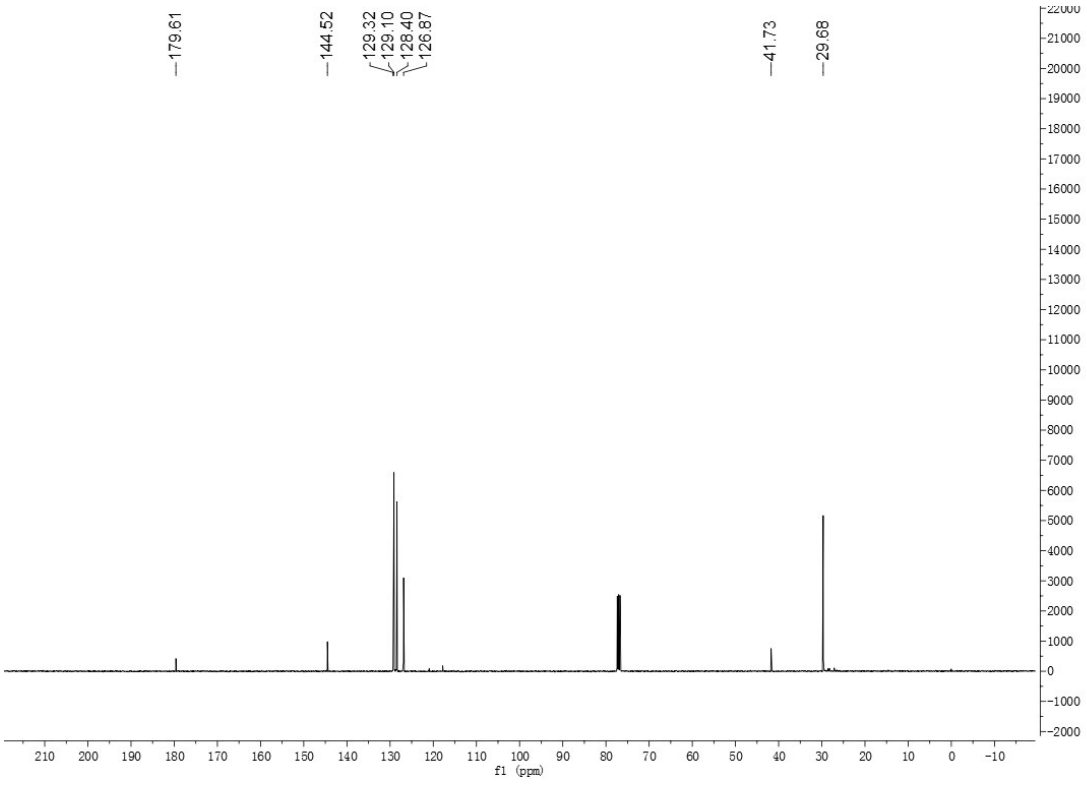
9.00
f1 (ppm)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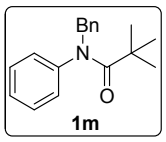
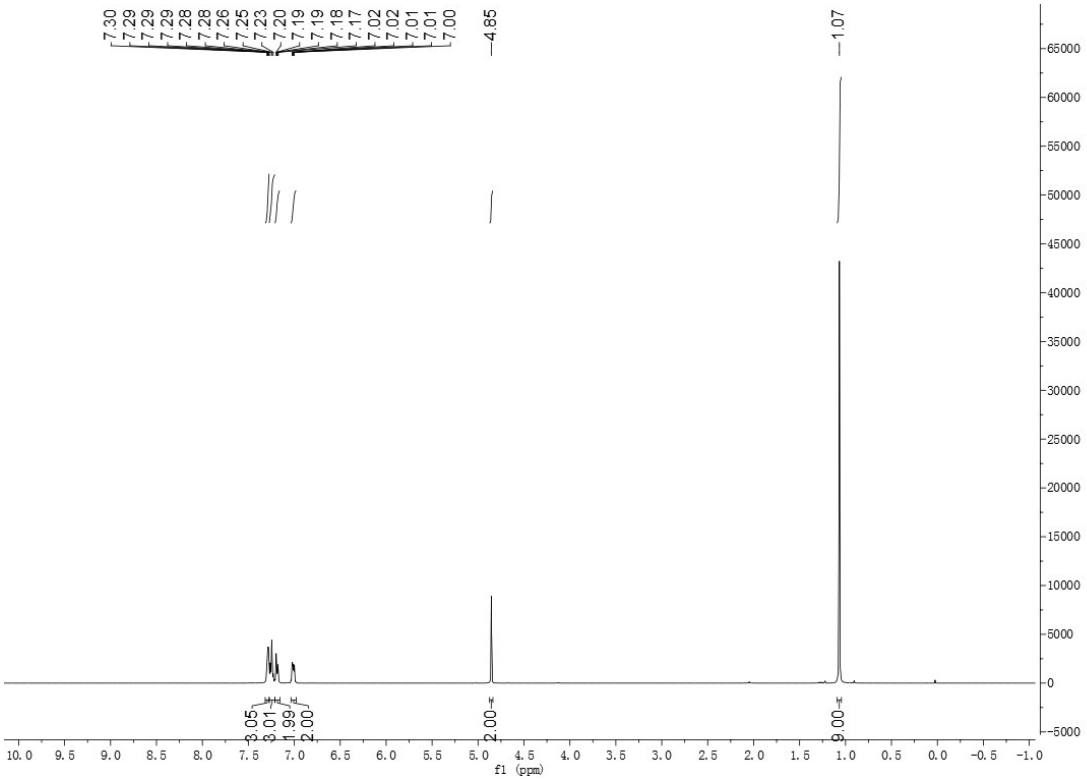
f1 (ppm)


Bn
N
O

1m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7.17
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2.00
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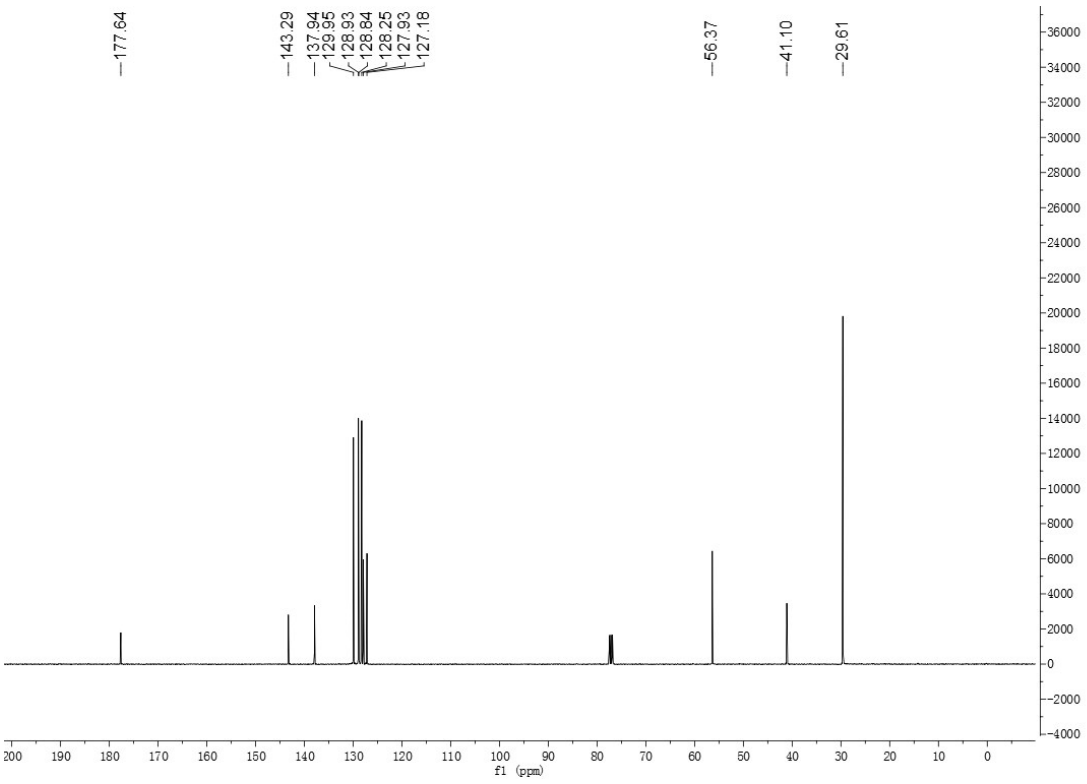
9.00
f1 (ppm)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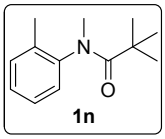
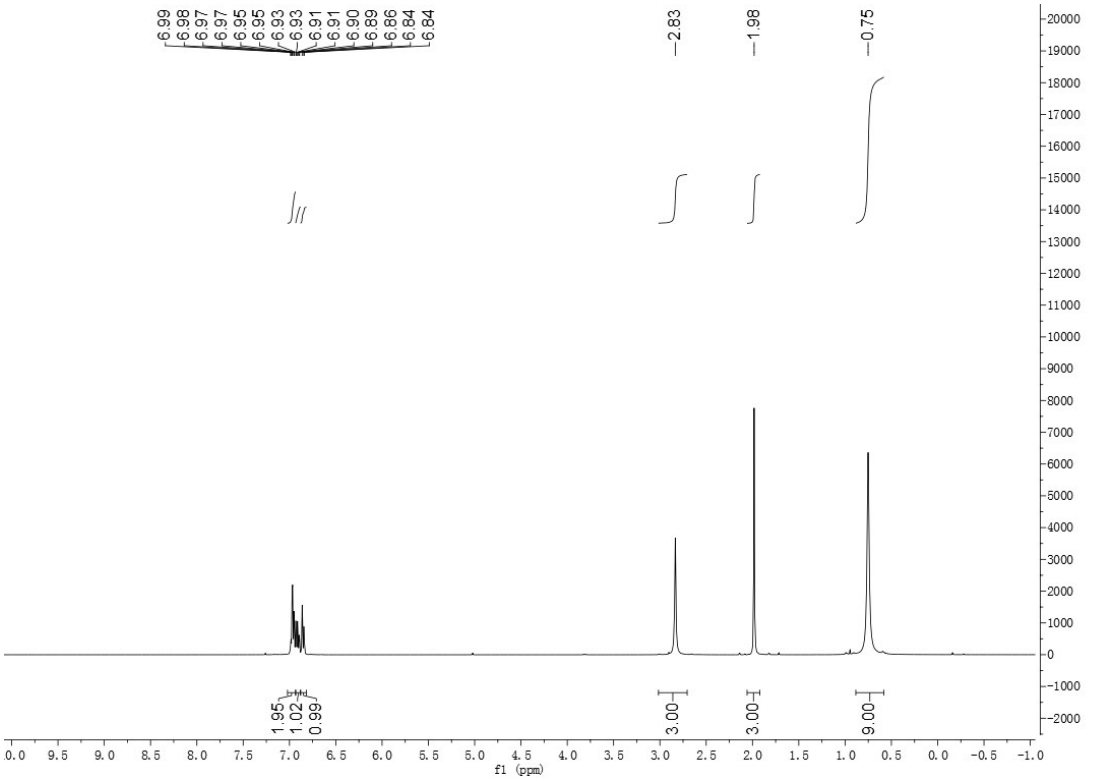
127.93
127.18
56.37
41.10
29.61
f1 (ppm)


N
O

1n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1.02
0.99
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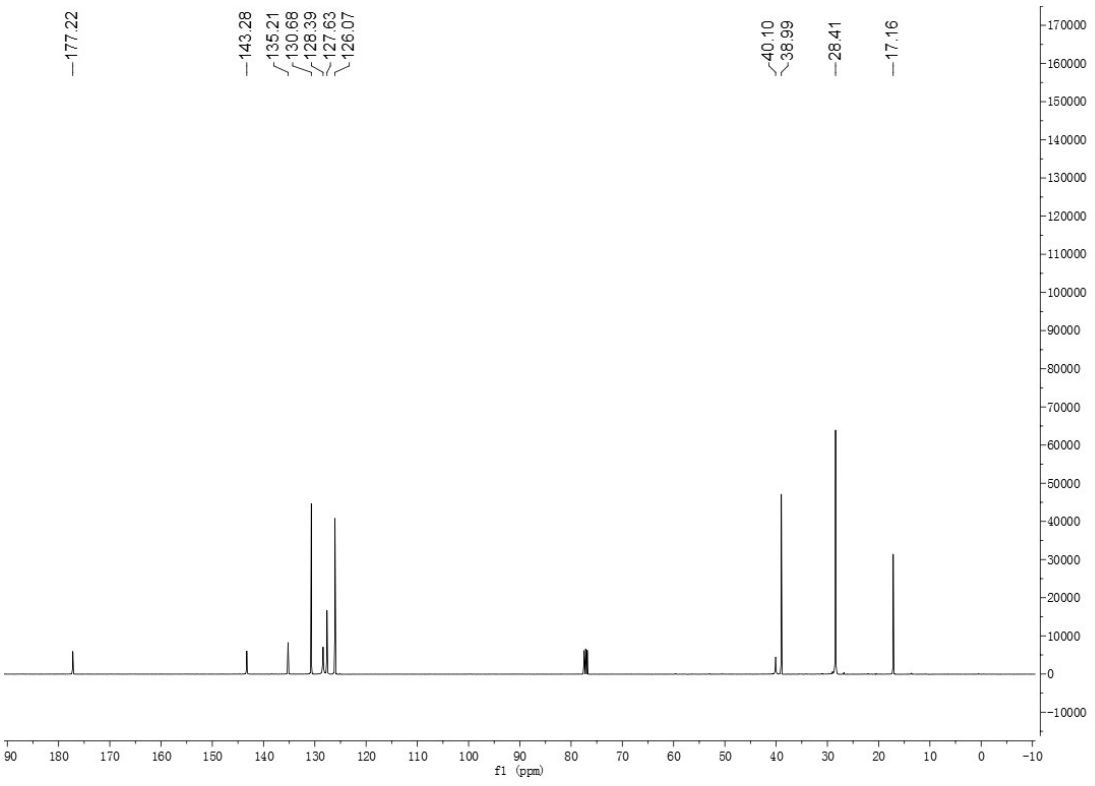
9.00
f1 (ppm)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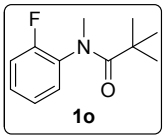
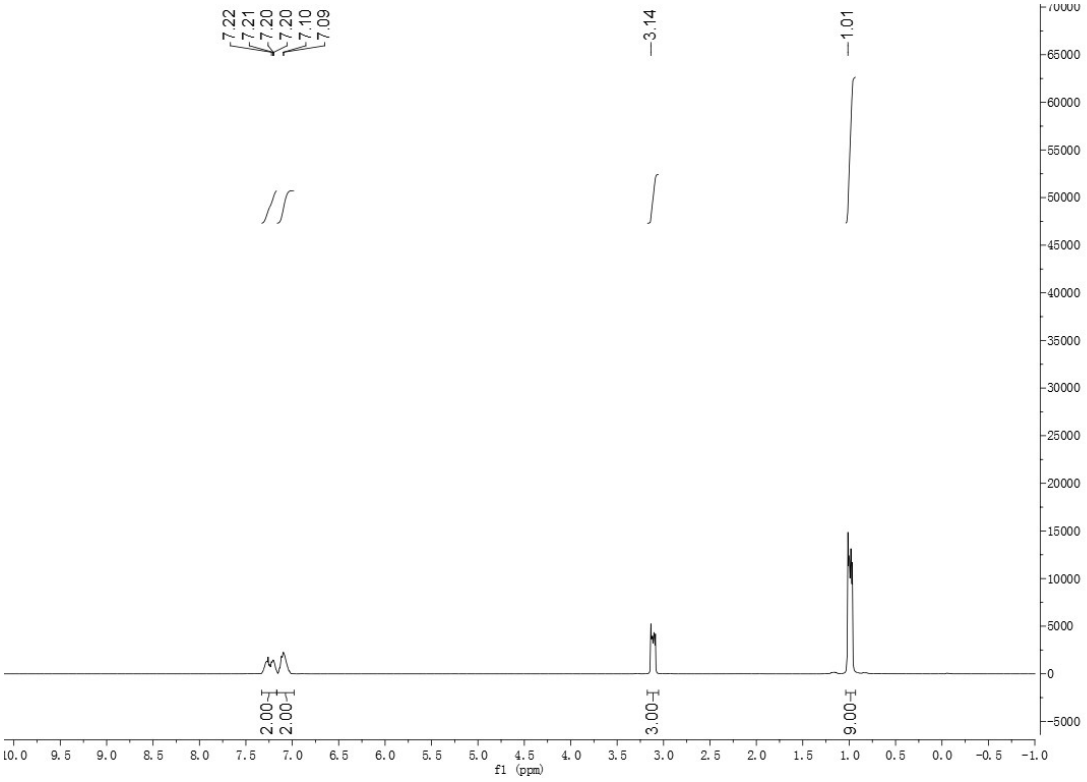
f1 (ppm)


F
N
O

1o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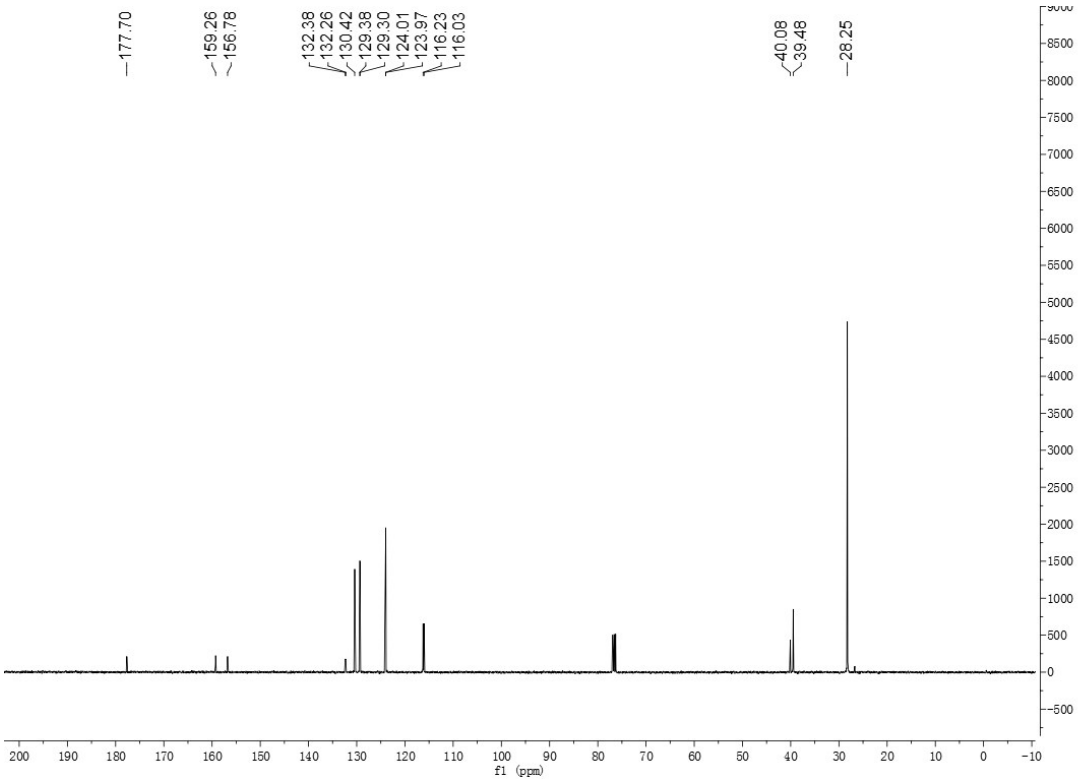
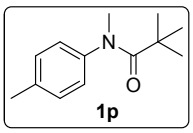
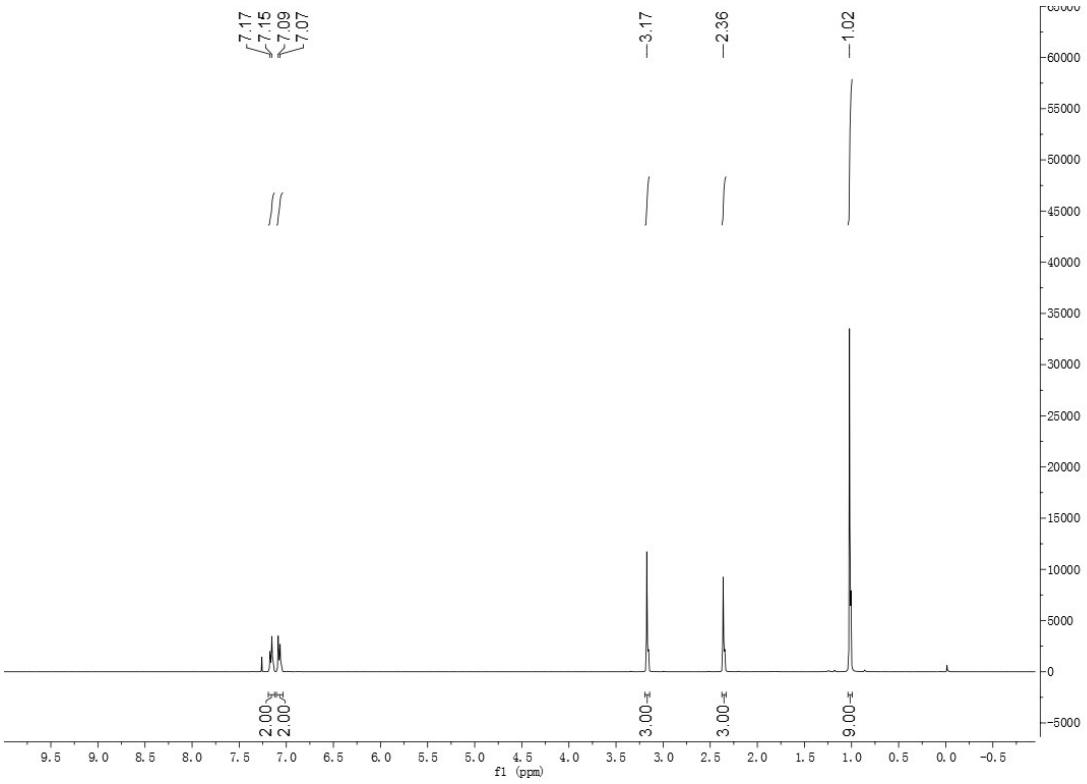
7.09
3.14
1.01
2.00
2.00
3.00
9.00
f1 (ppm)


177.70
159.26
156.78
132.38
132.26
130.42
129.38
129.30
124.01
123.97
116.23
116.03
40.08
39.48
28.25
f1 (ppm)


N
O

1p


7.17
7.15
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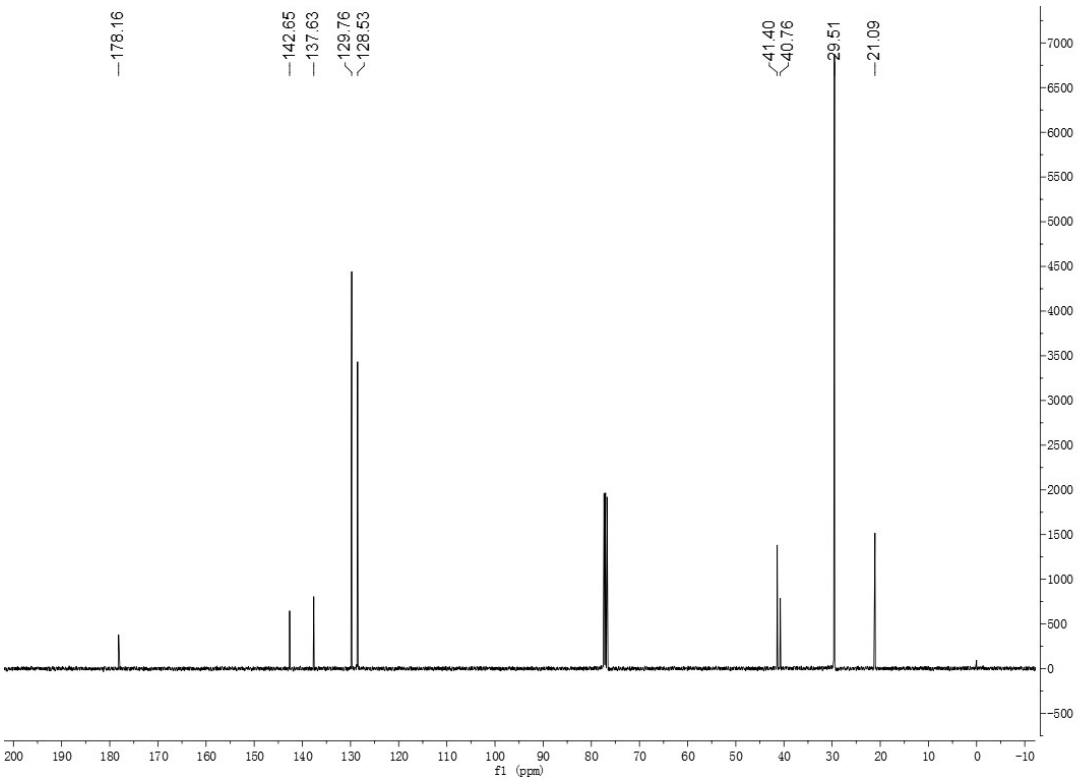
7.07
3.17
2.36
1.02
2.00
2.00
3.00
3.00
9.00
f1 (ppm)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142.65
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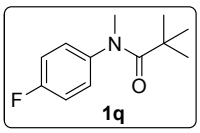
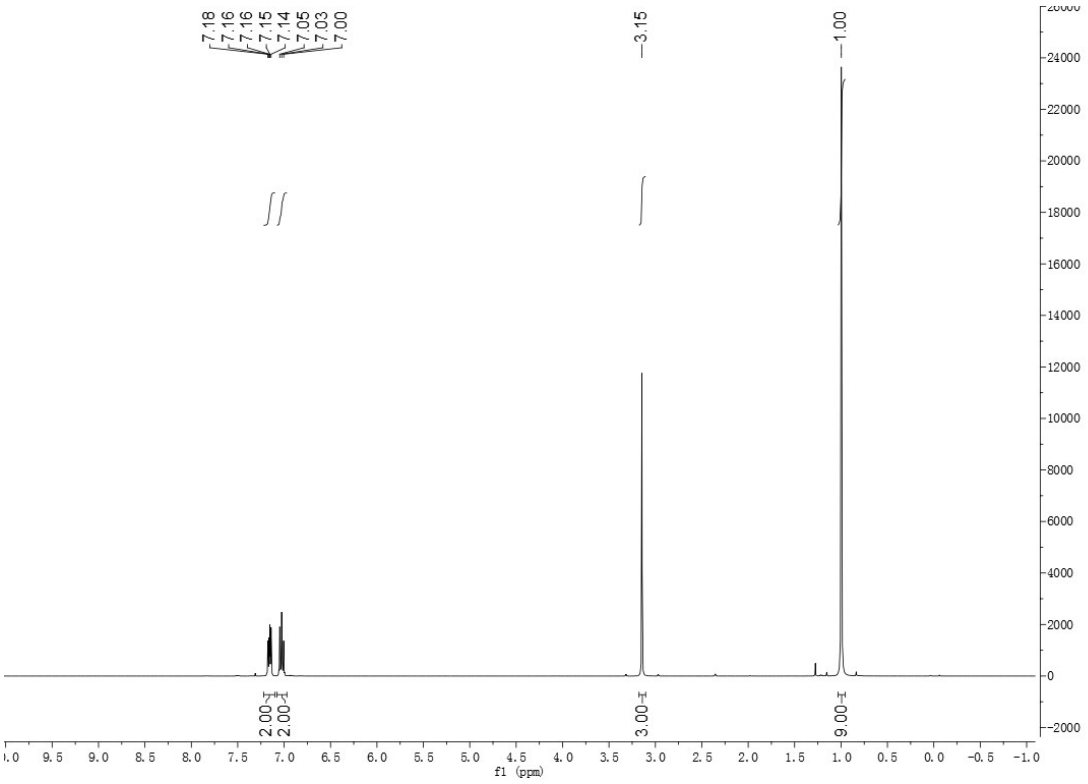
128.53
41.40
40.76
29.51
21.09
f1 (ppm)


N
O
F

1q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7.16
7.16
7.15
7.14
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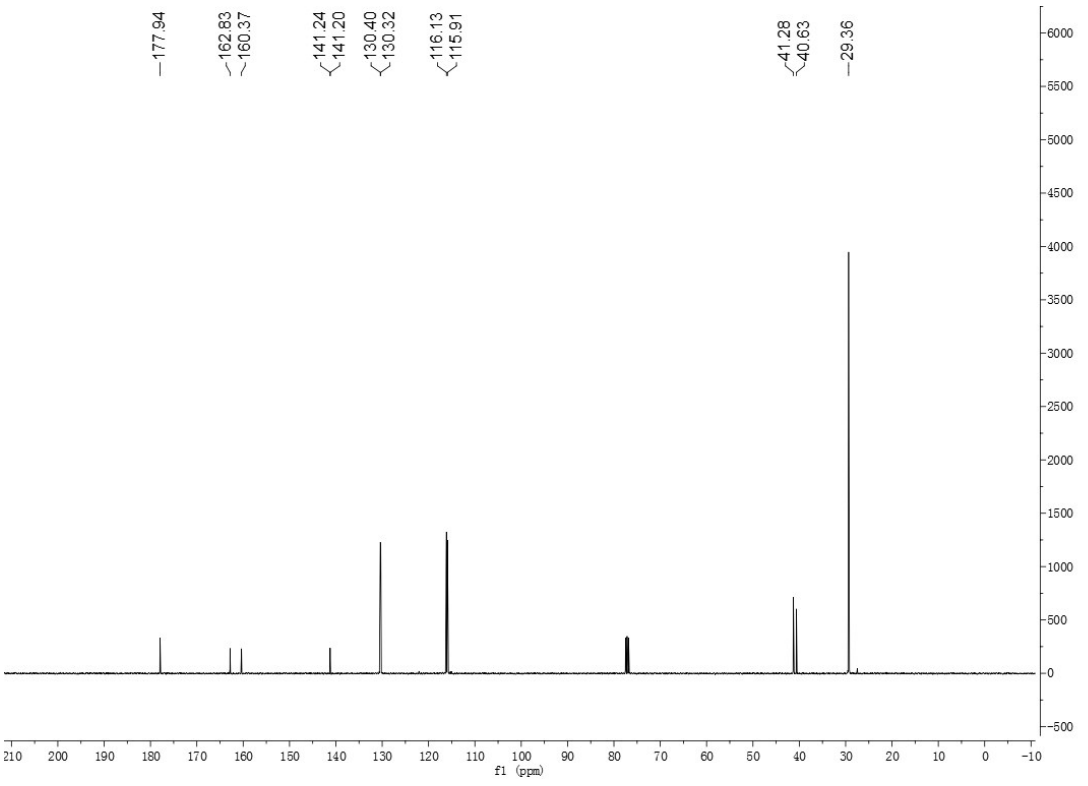
7.03
7.00
3.15
1.00
2.00
2.00
3.00
9.00
f1 (ppm)


177.94
162.83
160.37
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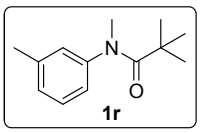
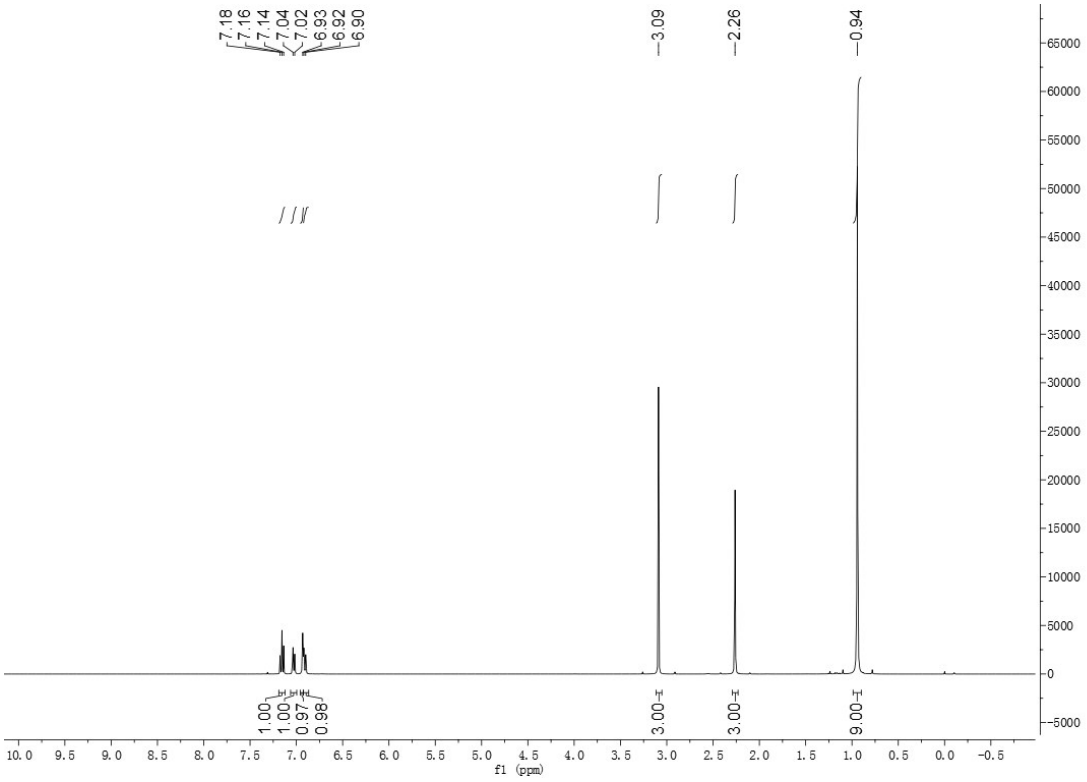
130.40
130.32
116.13
115.91
41.28
40.63
29.36
f1 (ppm)


N
O

1r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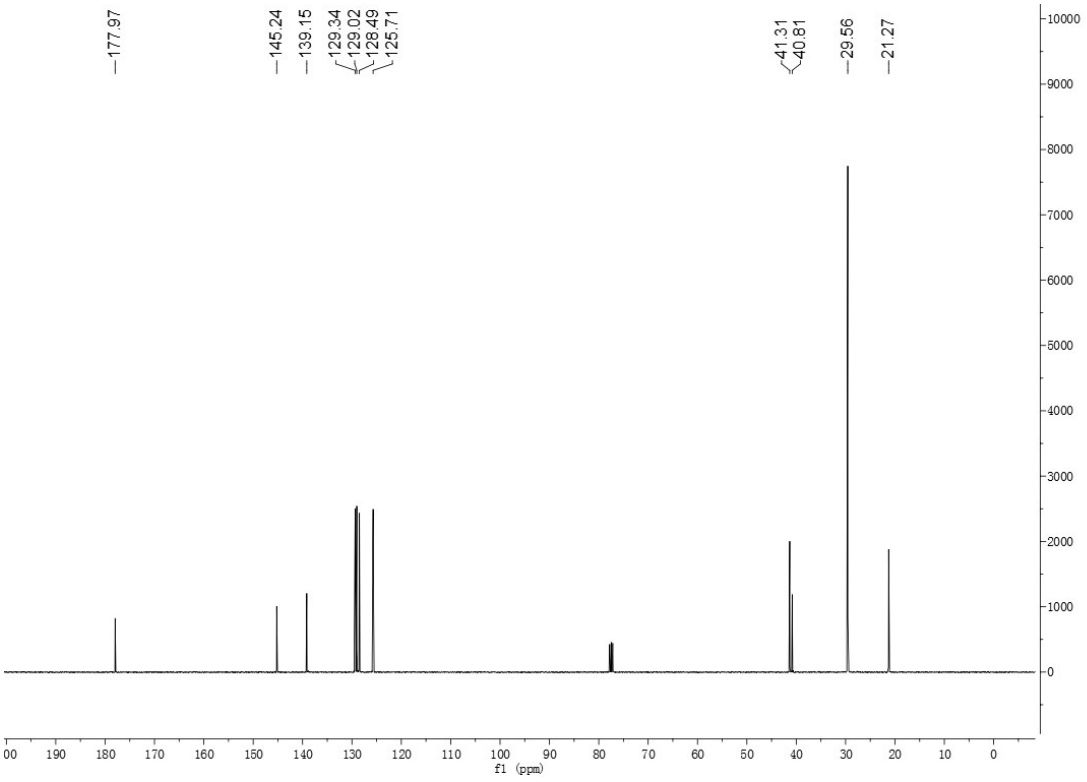
7.16
7.14
7.04
7.02
6.93
6.92
6.90
3.09
2.26
0.94
1.00
1.00
0.97
0.98
3.00
3.00
9.00
f1 (ppm)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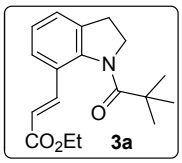
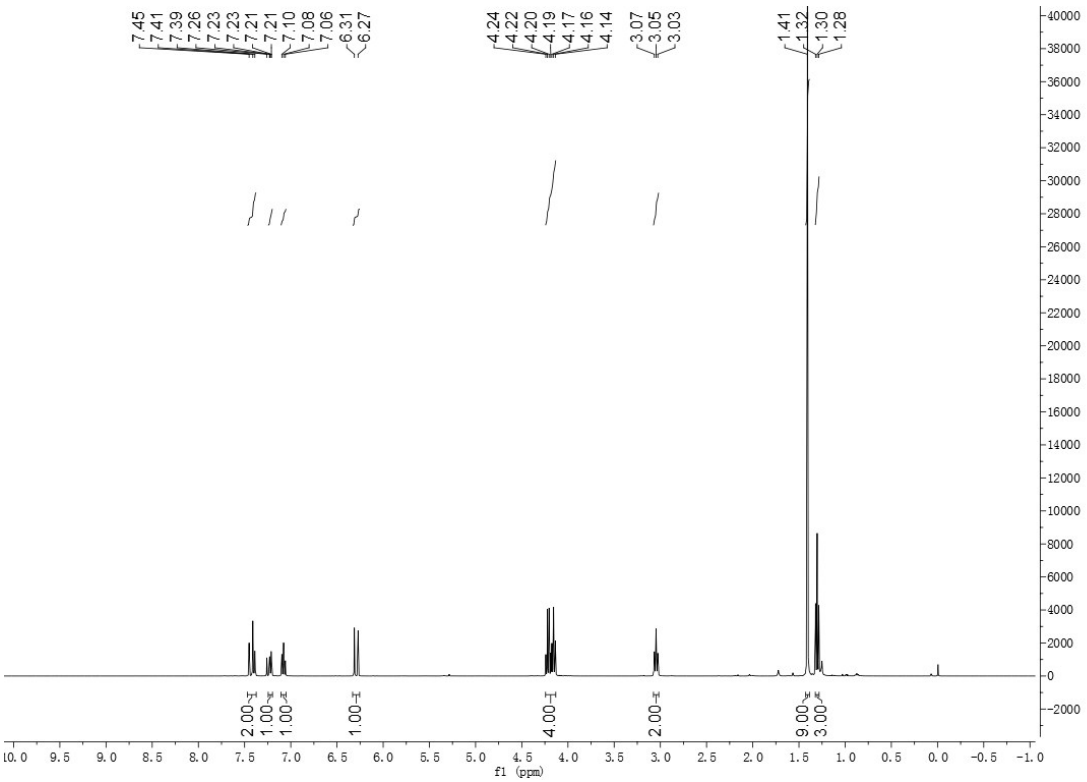
129.02
128.49
125.71
41.31
40.81
29.56
21.27
f1 (ppm)


N
O
CO2Et

3a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7.41
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7.26
7.23
7.23
7.21
7.21
7.10
7.08
7.06
6.31
6.27
4.24
4.22
4.20
4.19
4.17
4.16
4.14
3.07
3.05
3.03
1.41
1.32
1.30
1.28
2.00
1.00
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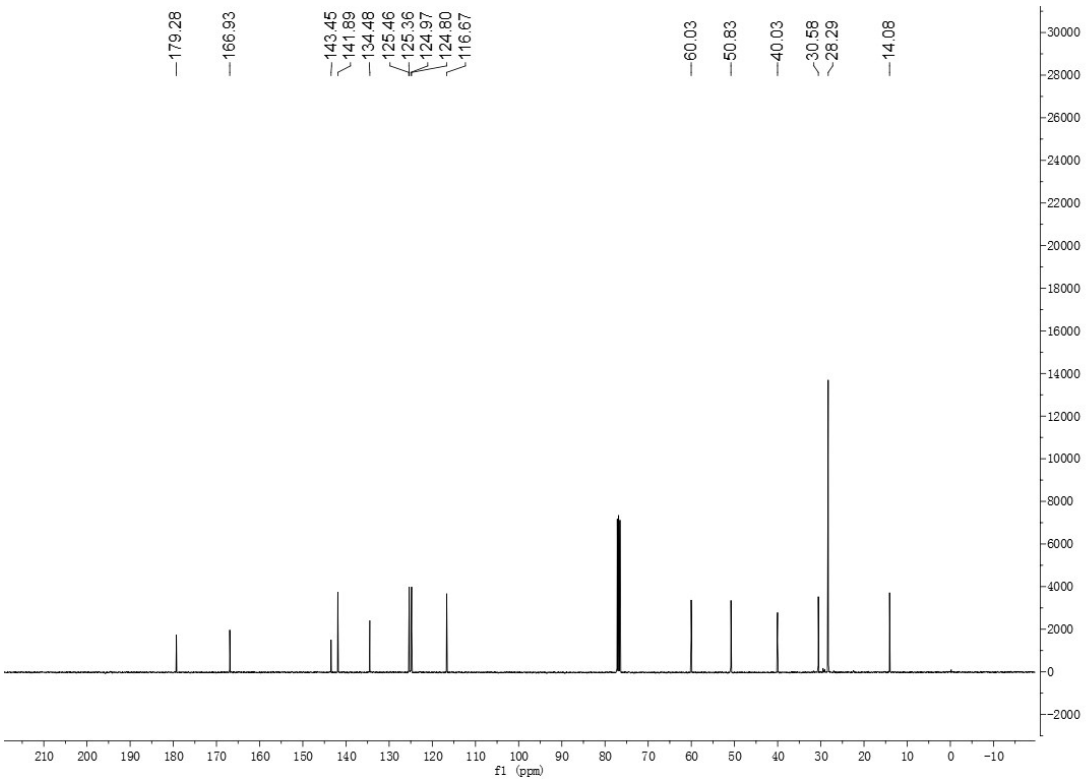
4.00
2.00
9.00
3.00
f1 (ppm)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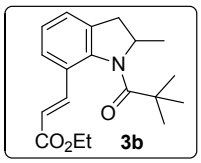
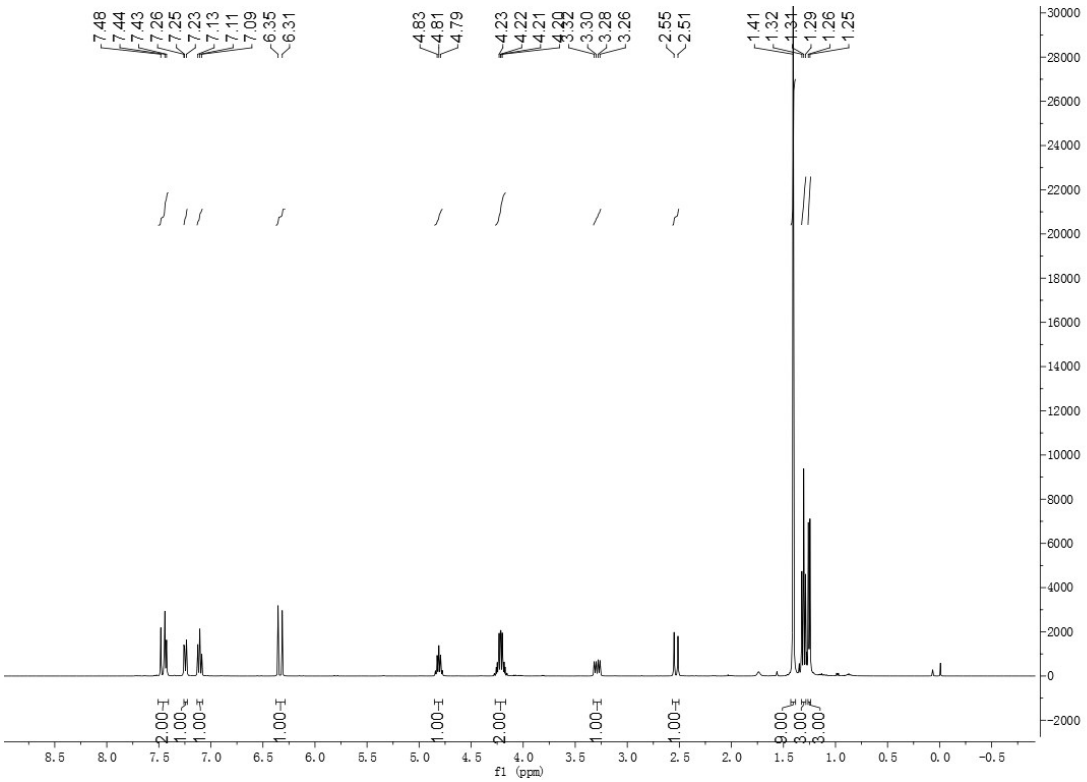
166.93
143.45
141.89
134.48
125.46
125.36
124.97
124.80
116.67
60.03
50.83
40.03
30.58
28.29
14.08
f1 (ppm)


N
O
CO2Et

3b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7.23
7.13
7.11
7.09
6.35
6.31
4.83
4.81
4.79
4.23
4.22
4.21
4.20
3.32
3.30
3.28
3.26
2.55
2.51
1.41
1.32
1.31
1.29
1.26
1.25
2.00
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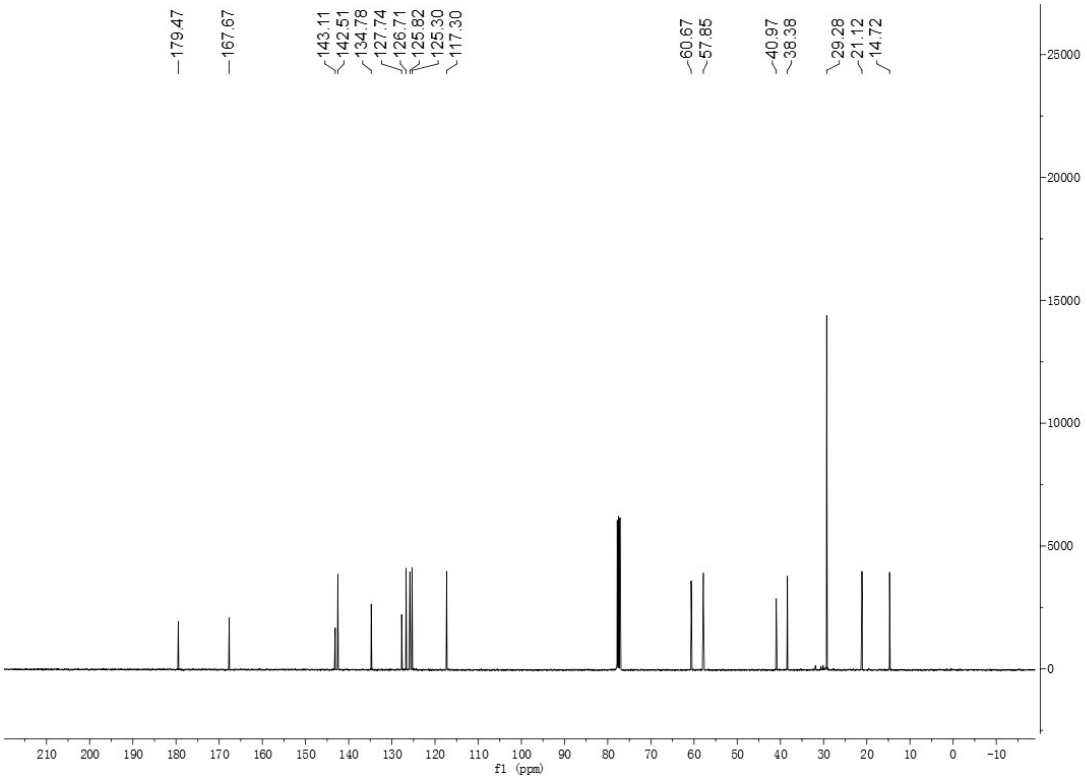
1.00
9.00
3.00
3.00
f1 (ppm)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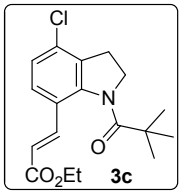
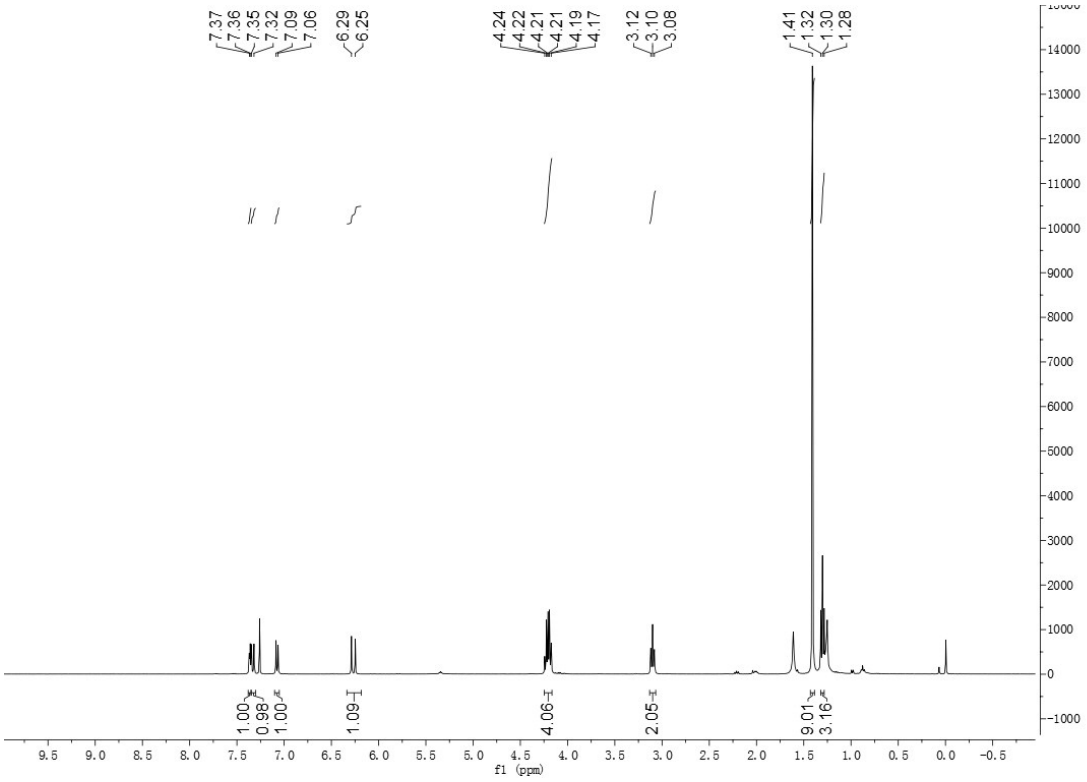
142.51
134.78
127.74
126.71
125.82
125.30
117.30
60.67
57.85
40.97
38.38
29.28
21.12
14.72
f1 (ppm)


Cl
N
O
CO2Et

3c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7.36
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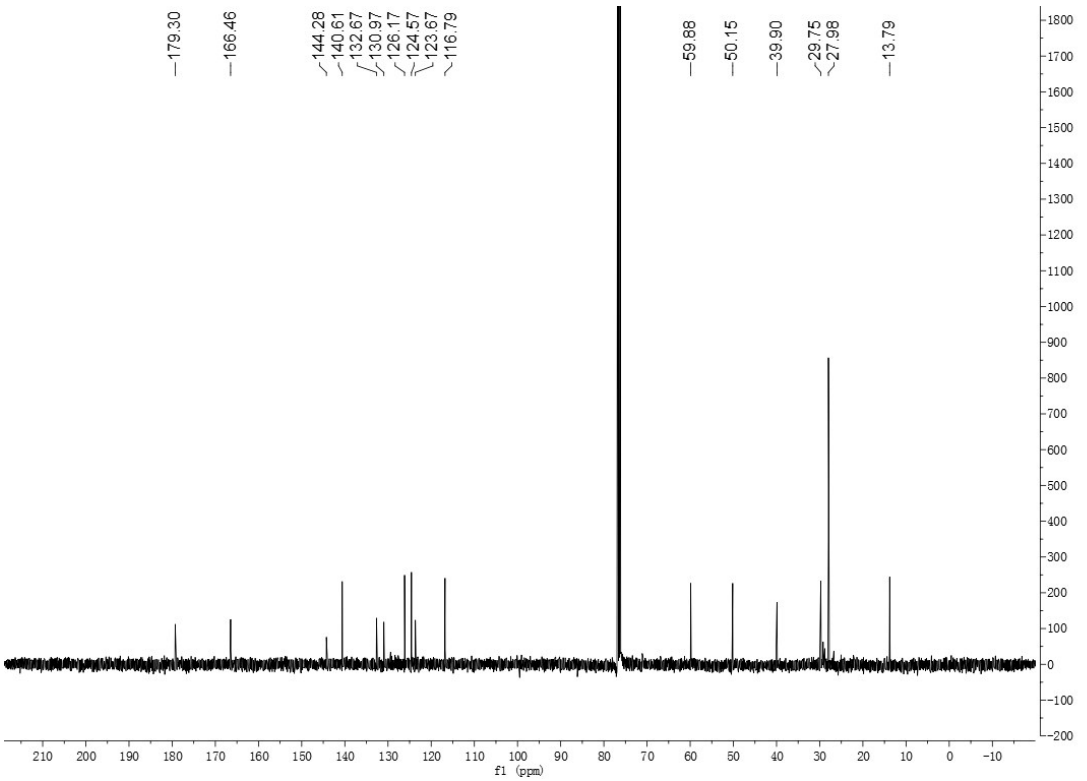
7.09
7.06
6.29
6.25
4.24
4.22
4.21
4.21
4.19
4.17
3.12
3.10
3.08
1.41
1.32
1.30
1.28
1.00
0.98
1.00
1.09
4.06
2.05
9.01
3.16
f1 (ppm)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144.28
140.61
132.67
130.97
126.17
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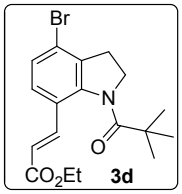
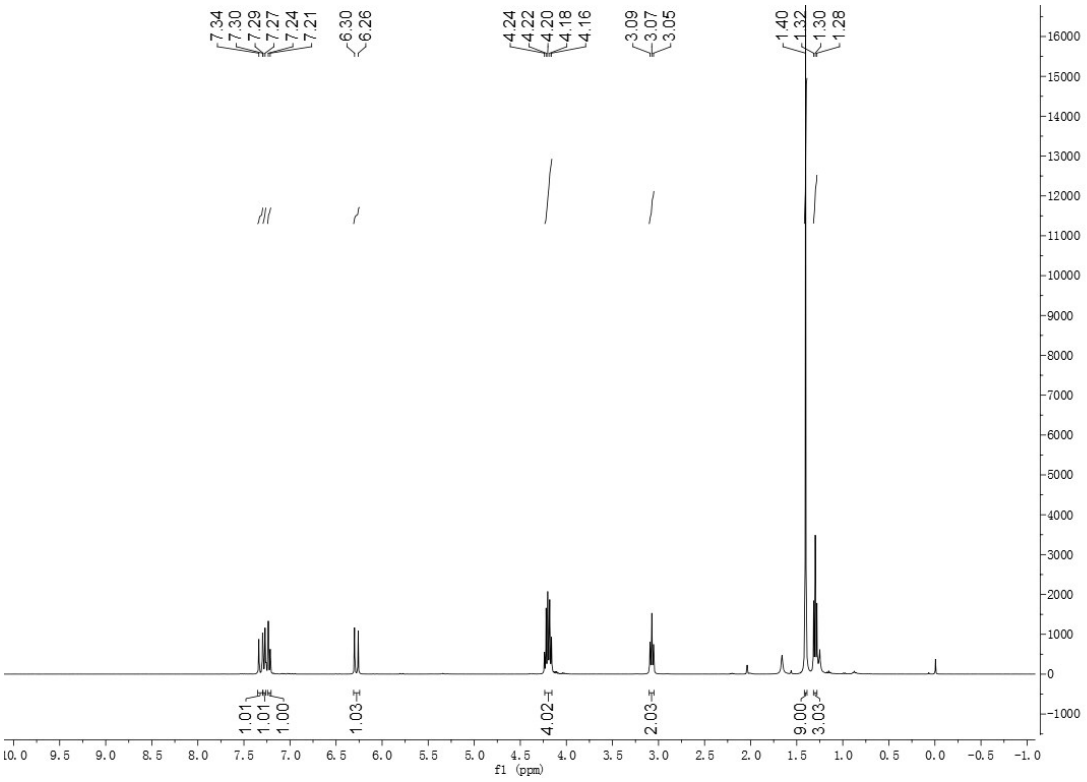
123.67
116.79
59.88
50.15
39.90
29.75
27.98
13.79
f1 (ppm)


Br
N
O
CO2Et

3d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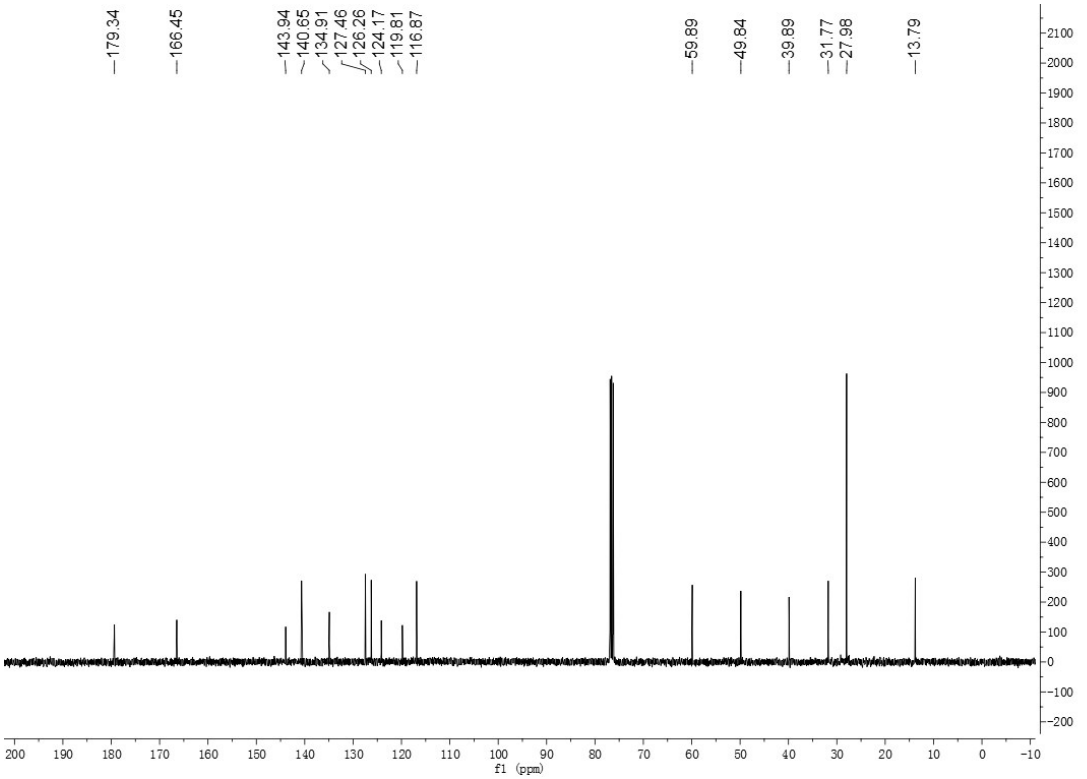
6.30
6.26
4.24
4.22
4.20
4.18
4.16
3.09
3.07
3.05
1.40
1.32
1.30
1.28
1.01
1.01
1.00
1.03
4.02
2.03
9.00
3.03
f1 (ppm)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140.65
134.91
127.46
126.26
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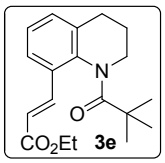
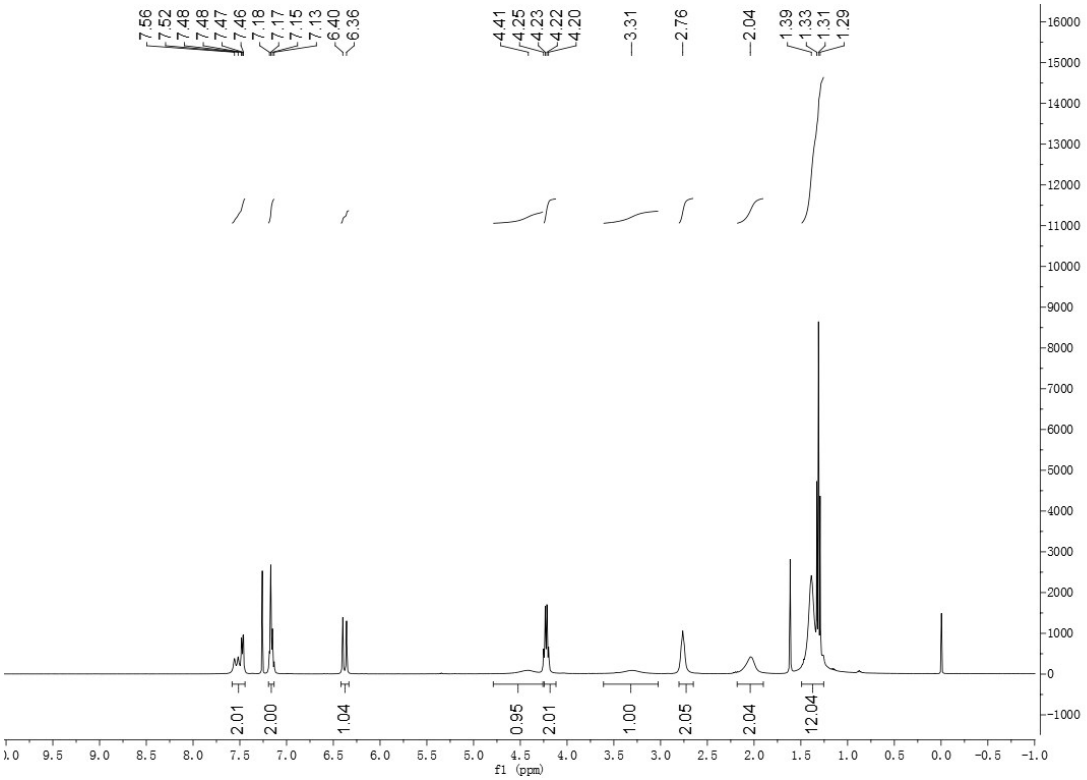
116.87
59.89
49.84
39.89
31.77
27.98
13.79
f1 (ppm)


N
O
CO2Et 3e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7.17
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7.13
6.40
6.36
4.41
4.25
4.23
4.22
4.20
3.31
2.76
2.04
1.39
1.33
1.31
1.29
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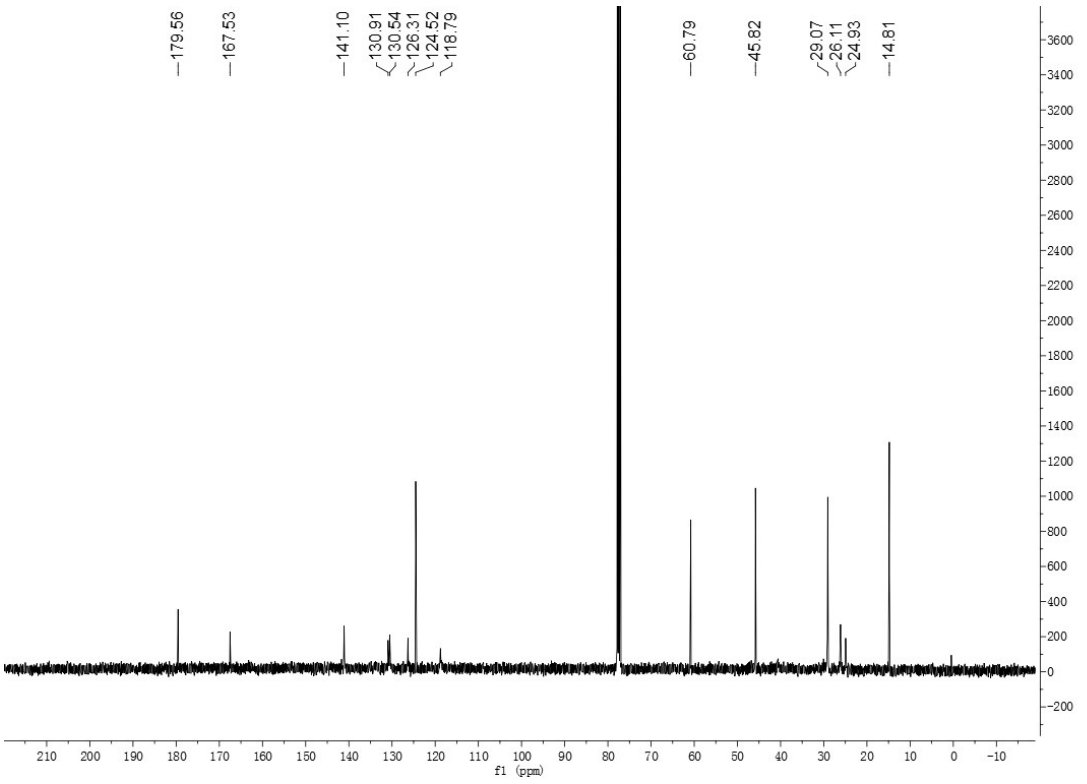
2.00
1.04
0.95
2.01
1.00
2.05
2.04
12.04
f1 (ppm)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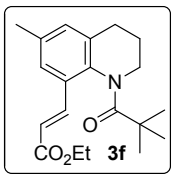
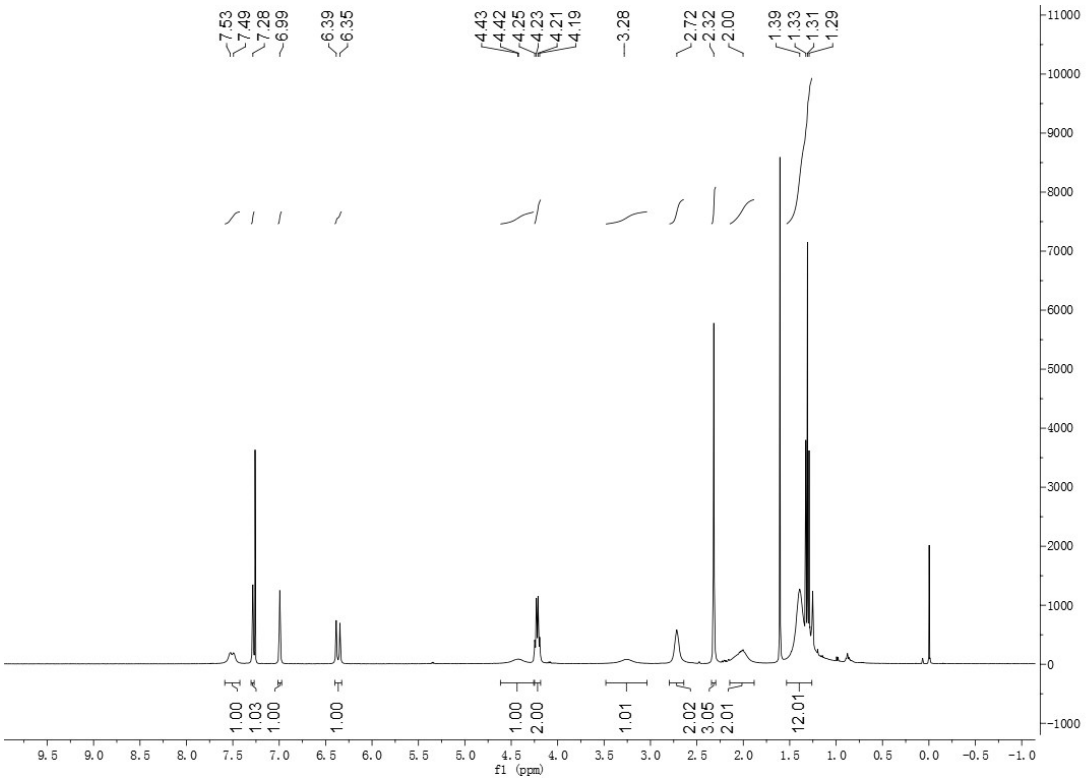
124.52
118.79
60.79
45.82
29.07
26.11
24.93
14.81
f1 (ppm)


N
O
CO2Et 3f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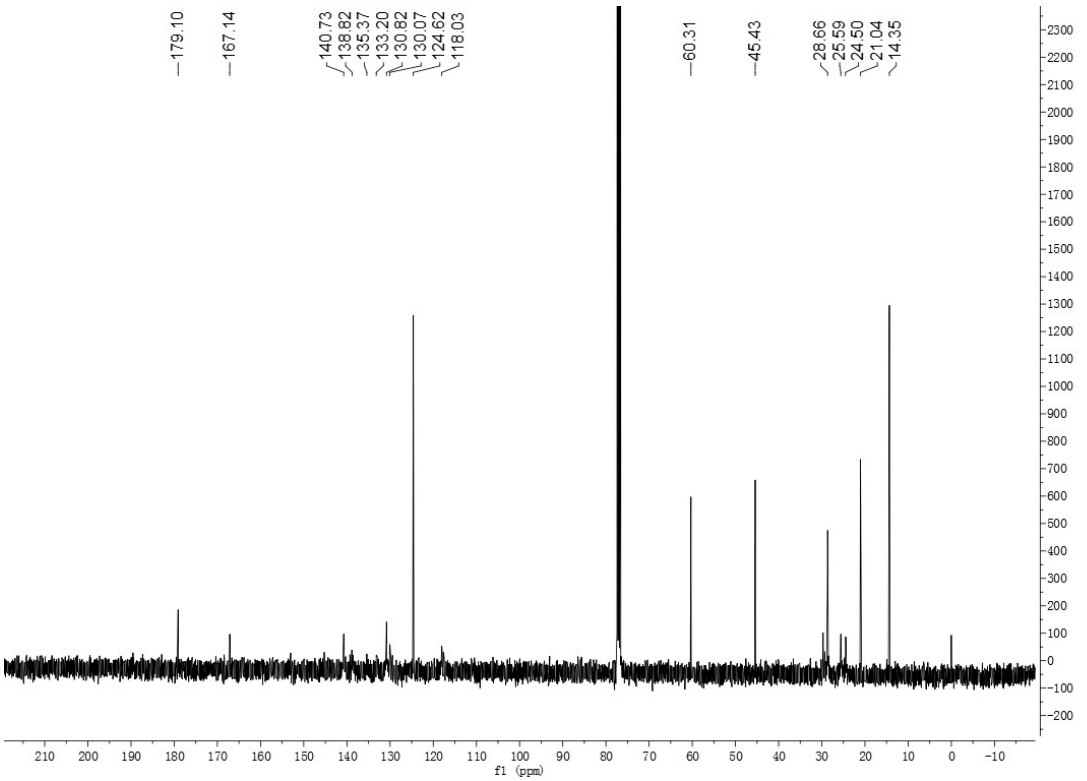
4.23
4.21
4.19
3.28
2.72
2.32
2.00
1.39
1.33
1.31
1.29
1.00
1.03
1.00
1.00
1.00
2.00
1.01
2.02
3.05
2.01
12.01
f1 (ppm)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138.82
135.37
133.20
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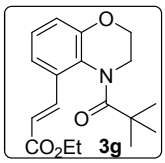
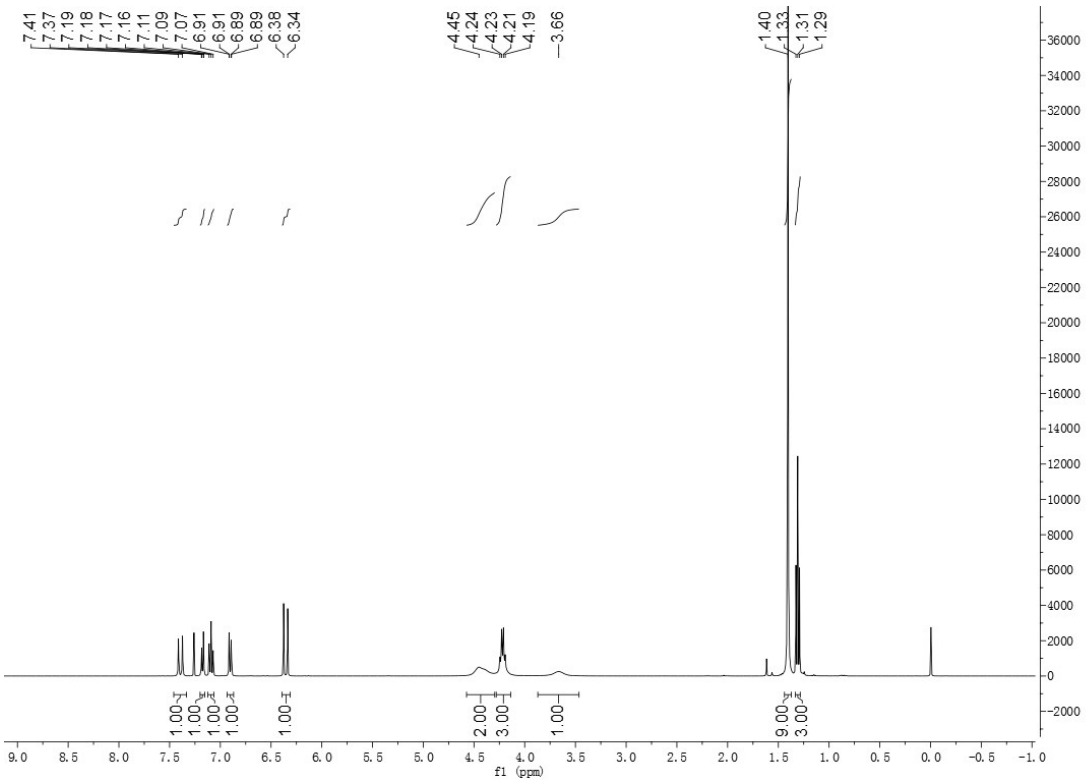
130.07
124.62
118.03
60.31
45.43
28.66
25.59
24.50
21.04
14.35
f1 (ppm)


O
N
O
CO2Et
3g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7.16
7.11
7.09
7.07
6.91
6.91
6.89
6.89
6.38
6.34
4.45
4.24
4.23
4.21
4.19
3.66
1.40
1.33
1.31
1.29
1.00
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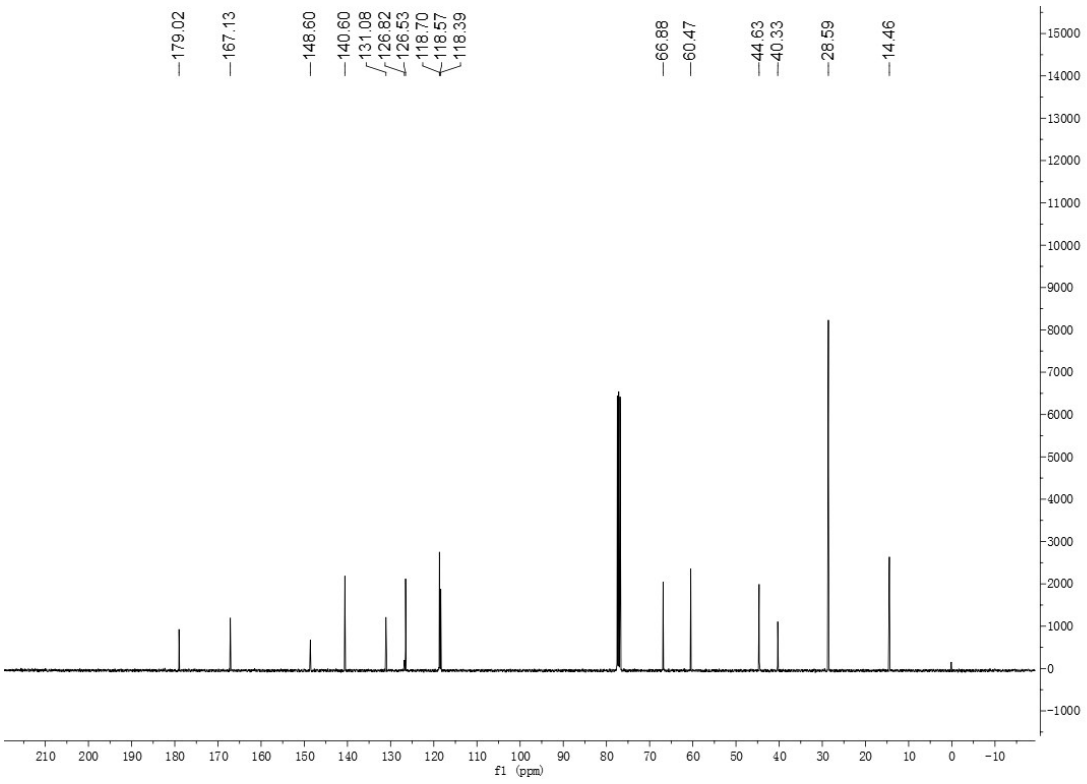
1.00
1.00
1.00
2.00
3.00
1.00
9.00
3.00
f1 (ppm)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140.60
131.08
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126.53
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118.57
118.39
66.88
60.47
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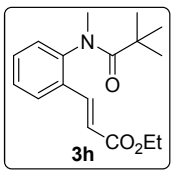
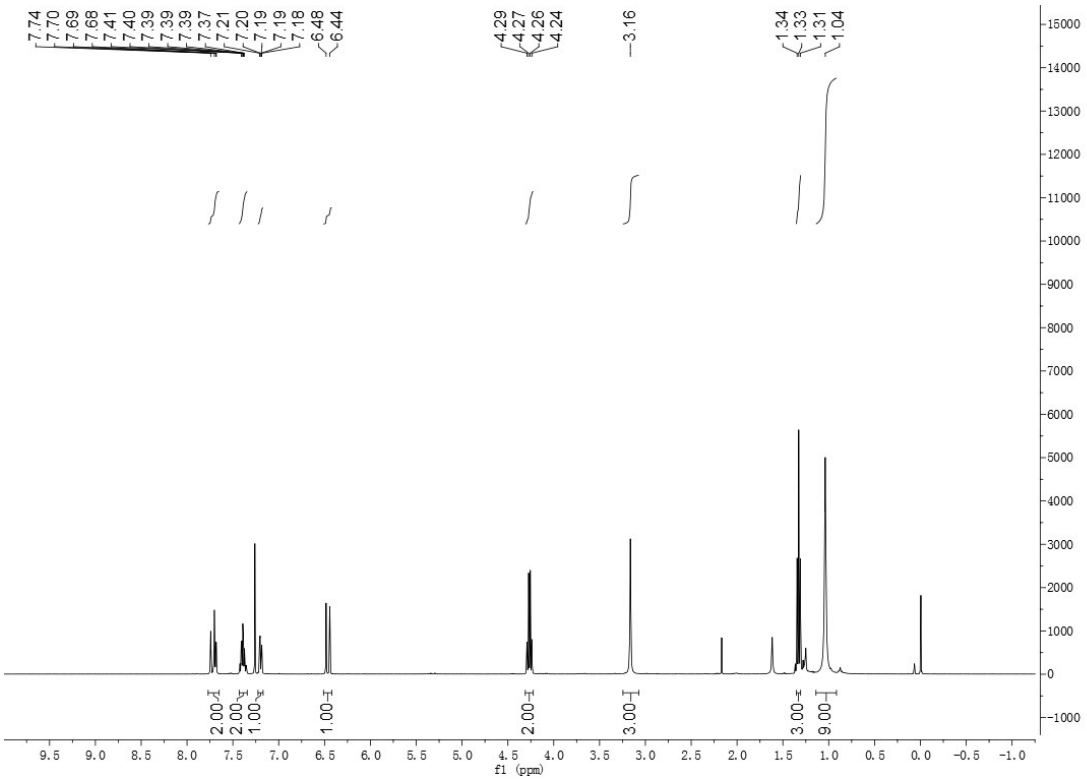
40.33
28.59
14.46
f1 (ppm)


N
O
CO2Et

3h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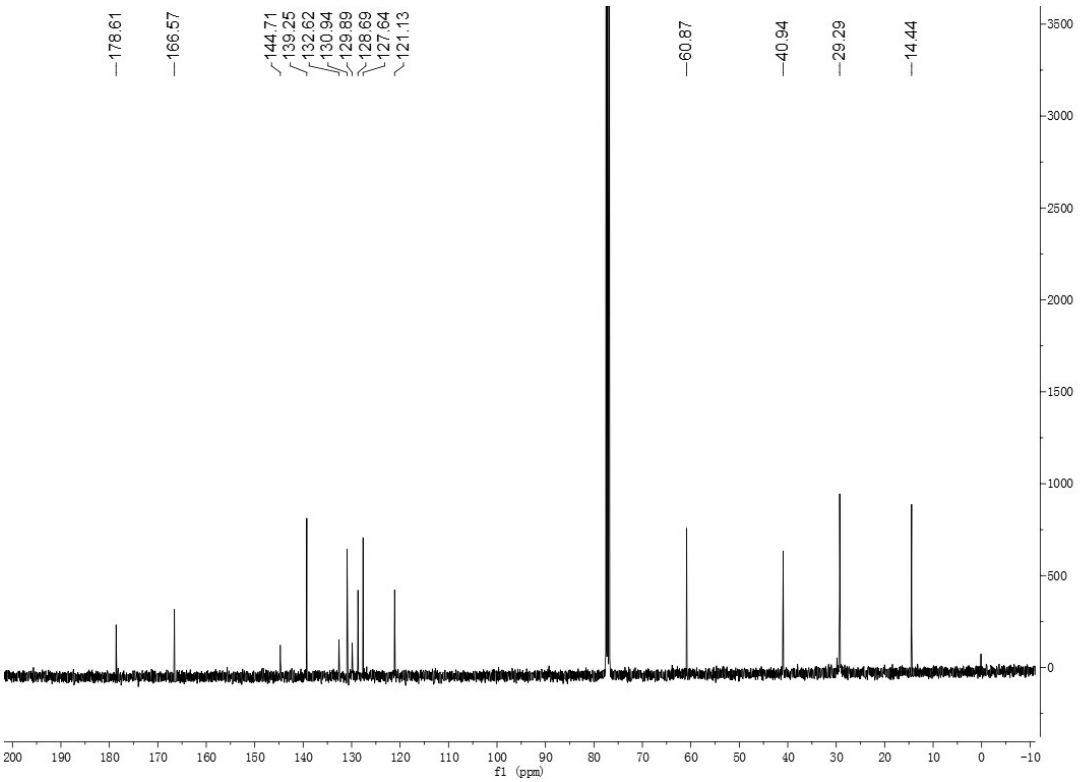
7.37
7.21
7.20
7.19
7.19
7.18
6.48
6.44
4.29
4.27
4.26
4.24
3.16
1.34
1.33
1.31
1.04
2.00
2.00
1.00
1.00
2.00
3.00
3.00
9.00
f1 (ppm)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132.62
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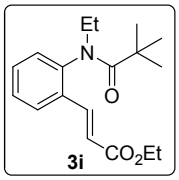
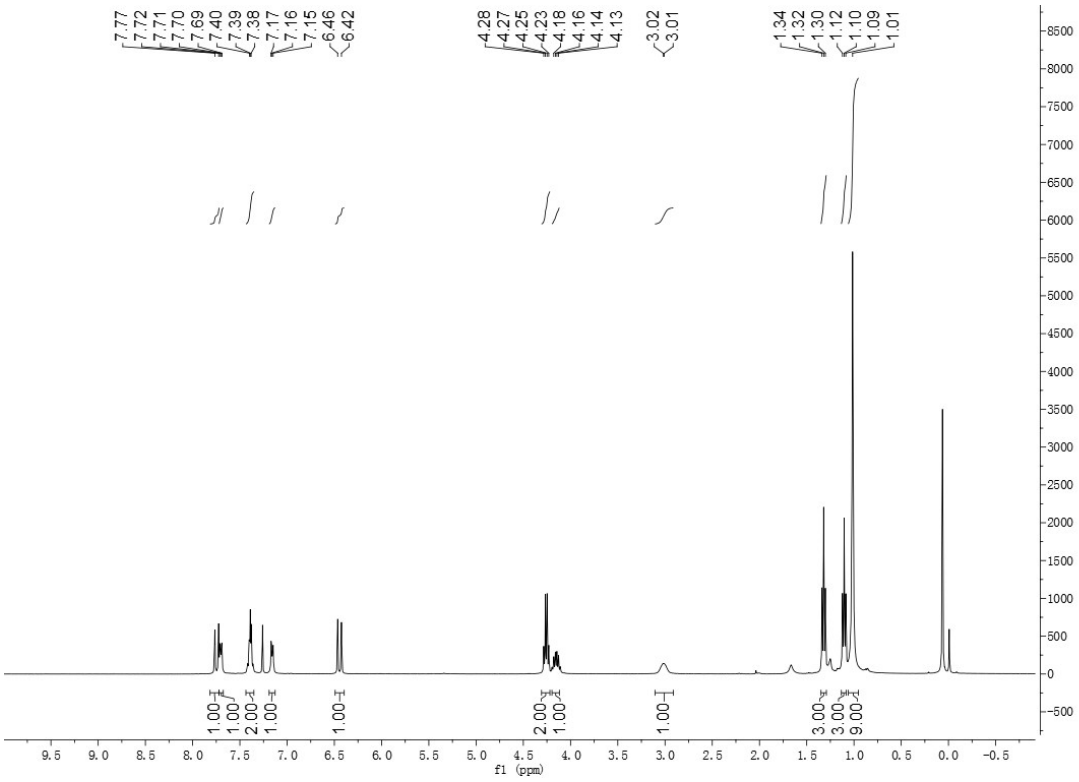
128.69
127.64
121.13
60.87
40.94
29.29
14.44
f1 (ppm)


Et
N
O
CO2Et

3i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7.38
7.17
7.16
7.15
6.46
6.42
4.28
4.27
4.25
4.23
4.18
4.16
4.14
4.13
3.02
3.01
1.34
1.32
1.30
1.12
1.10
1.09
1.01
1.00
1.00
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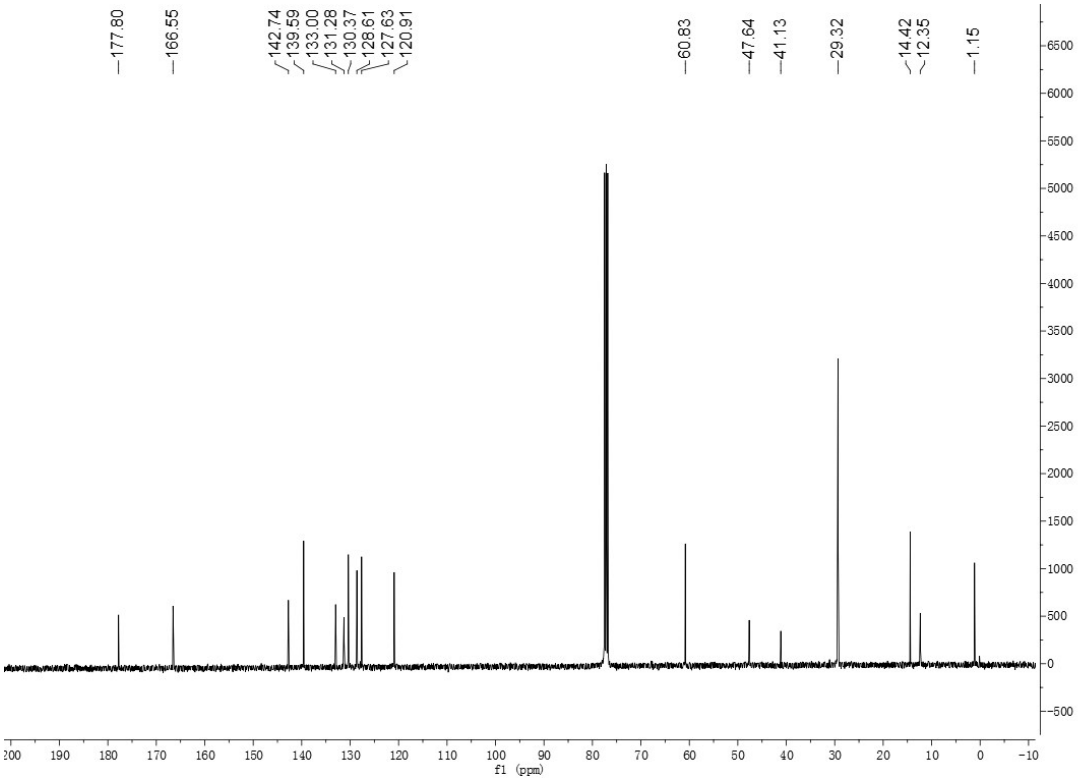
1.00
1.00
2.00
1.00
1.00
3.00
3.00
9.00
f1 (ppm)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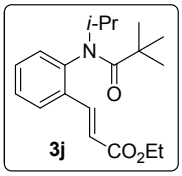
130.37
128.61
127.63
120.91
60.83
47.64
41.13
29.32
14.42
12.35
1.15
f1 (ppm)


i-Pr
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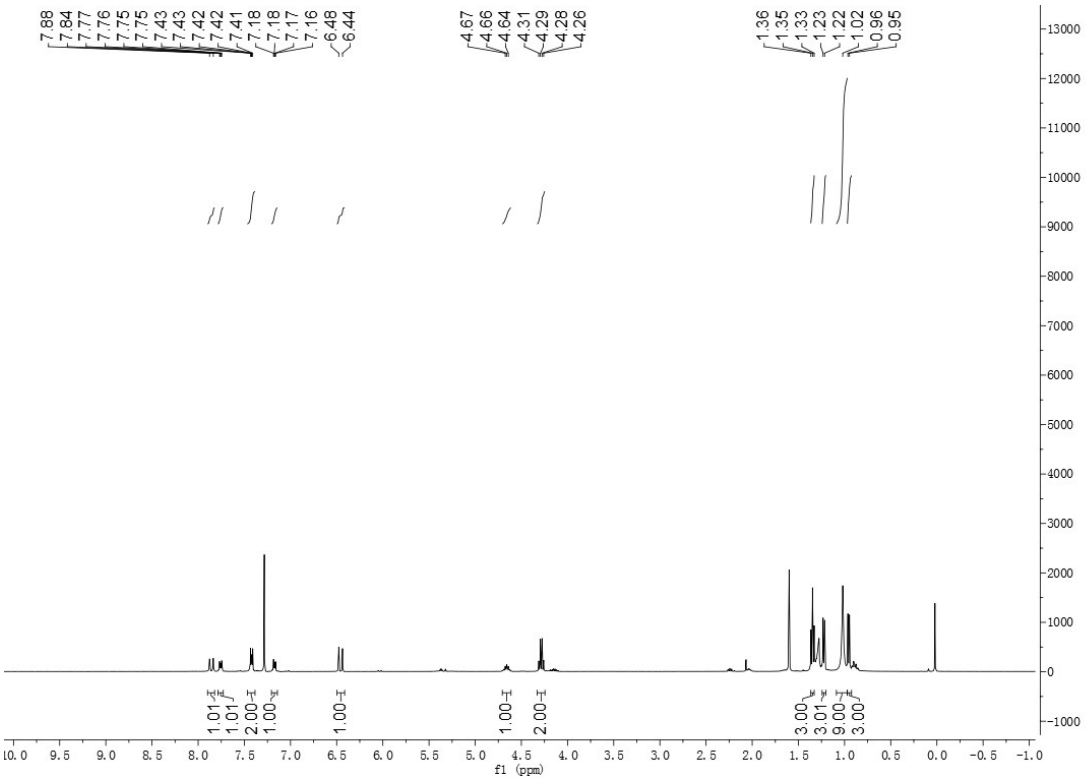
O
3j
CO2Et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4.66
4.64
4.31
4.29
4.28
4.26
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1.35
1.33
1.23
1.22
1.02
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0.95
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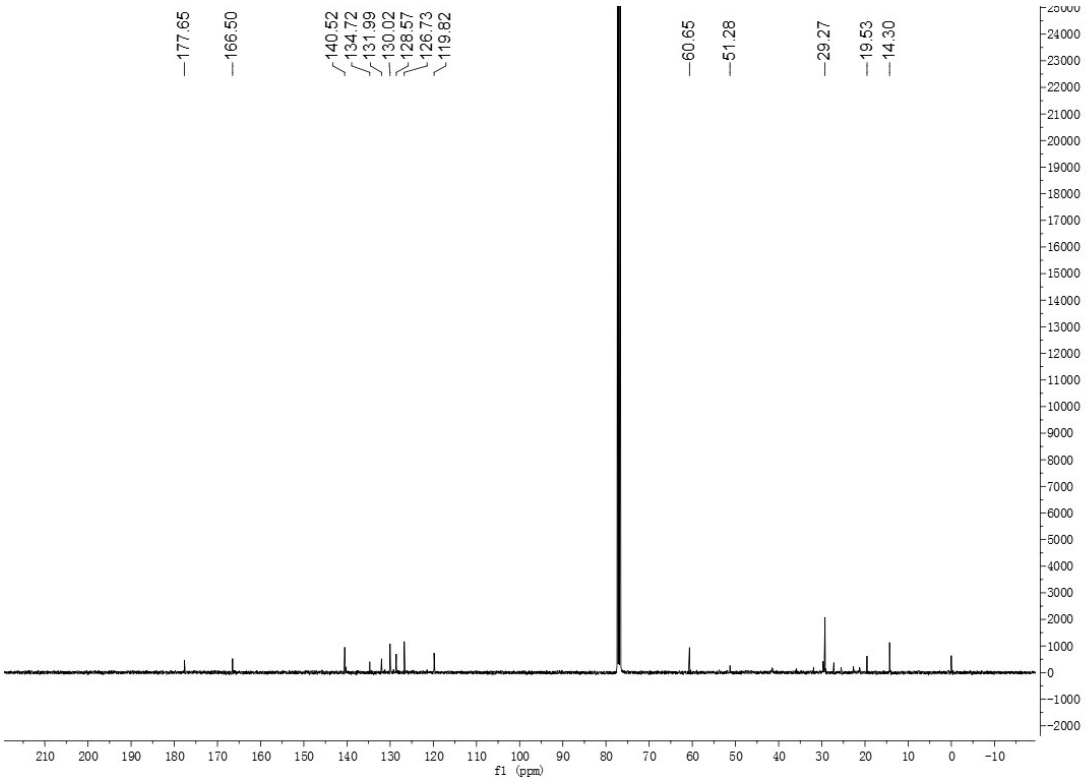
3.00
f1 (ppm)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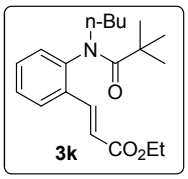
f1 (ppm)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CO2Et
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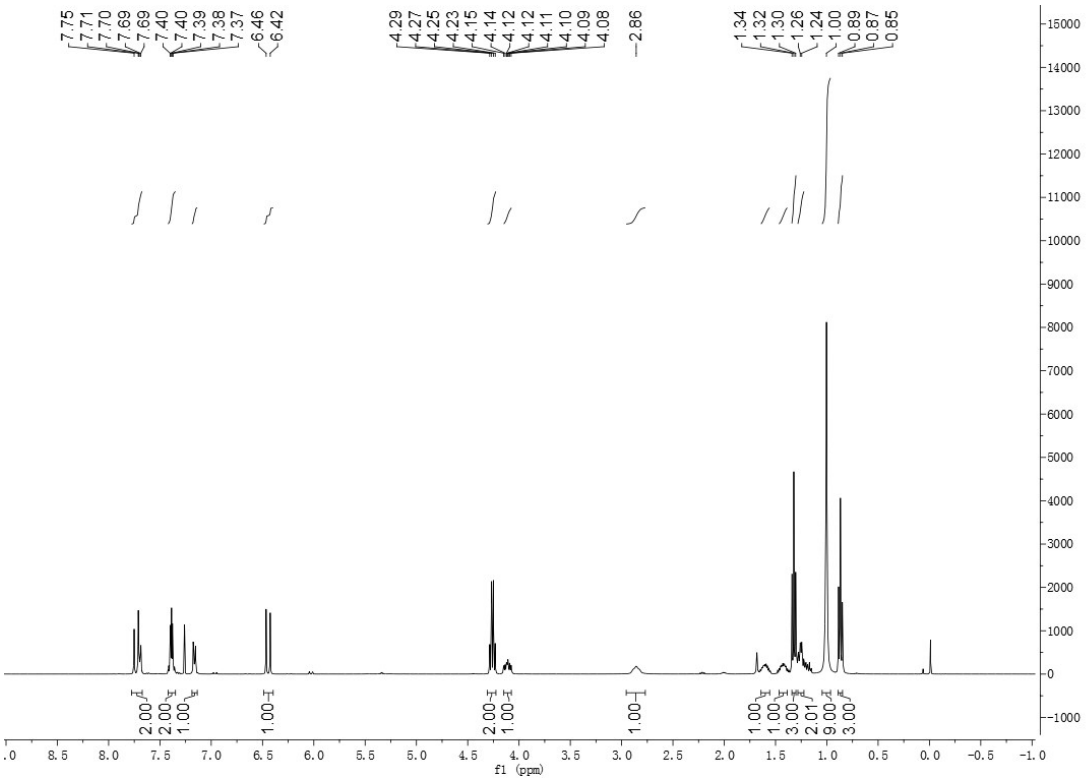
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4.09
4.08
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1.32
1.30
1.26
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0.87
0.85
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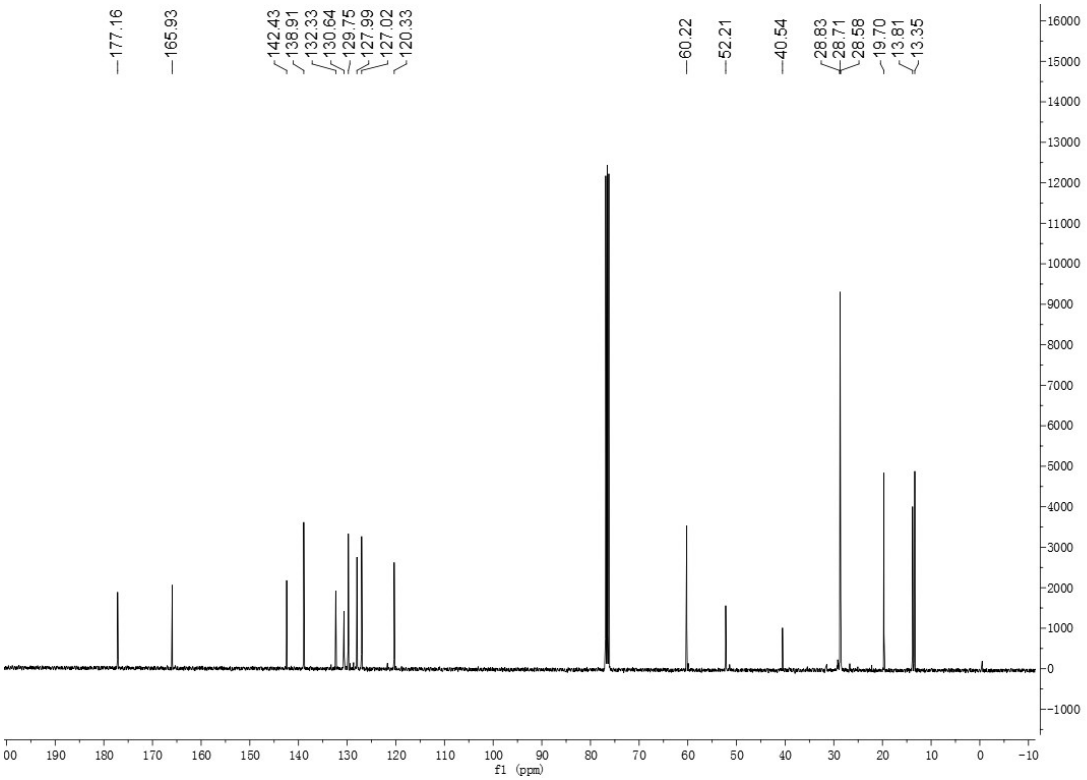
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13.35
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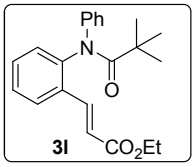
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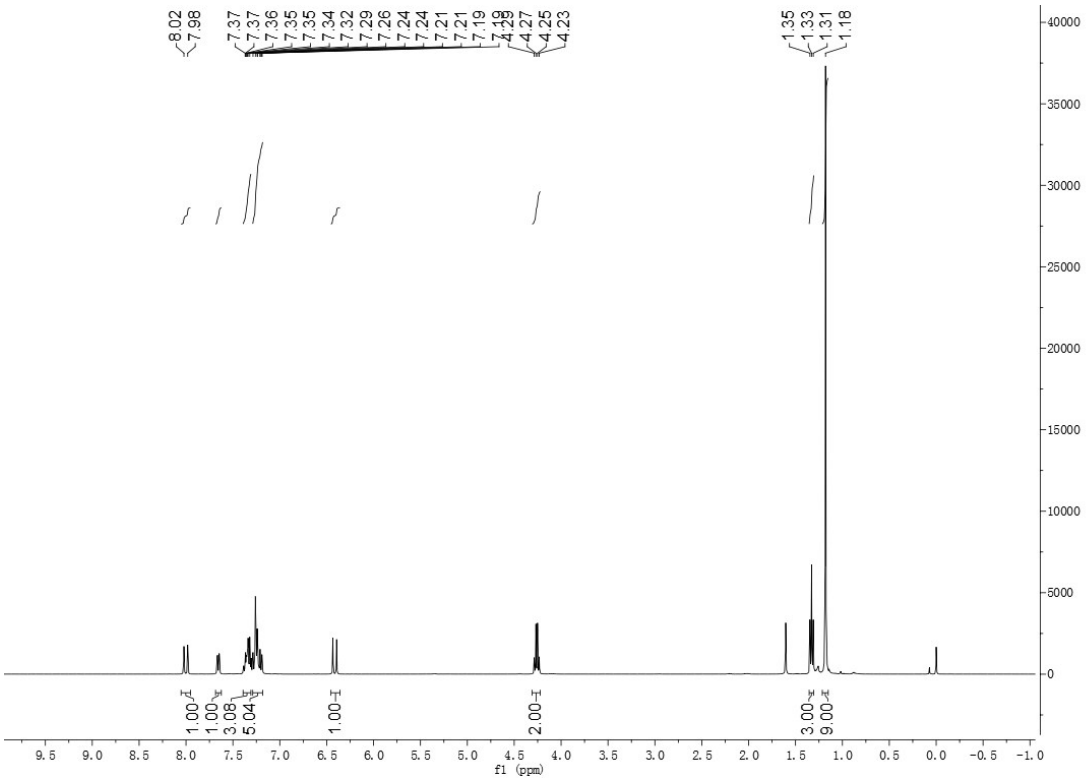
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4.23
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2.00
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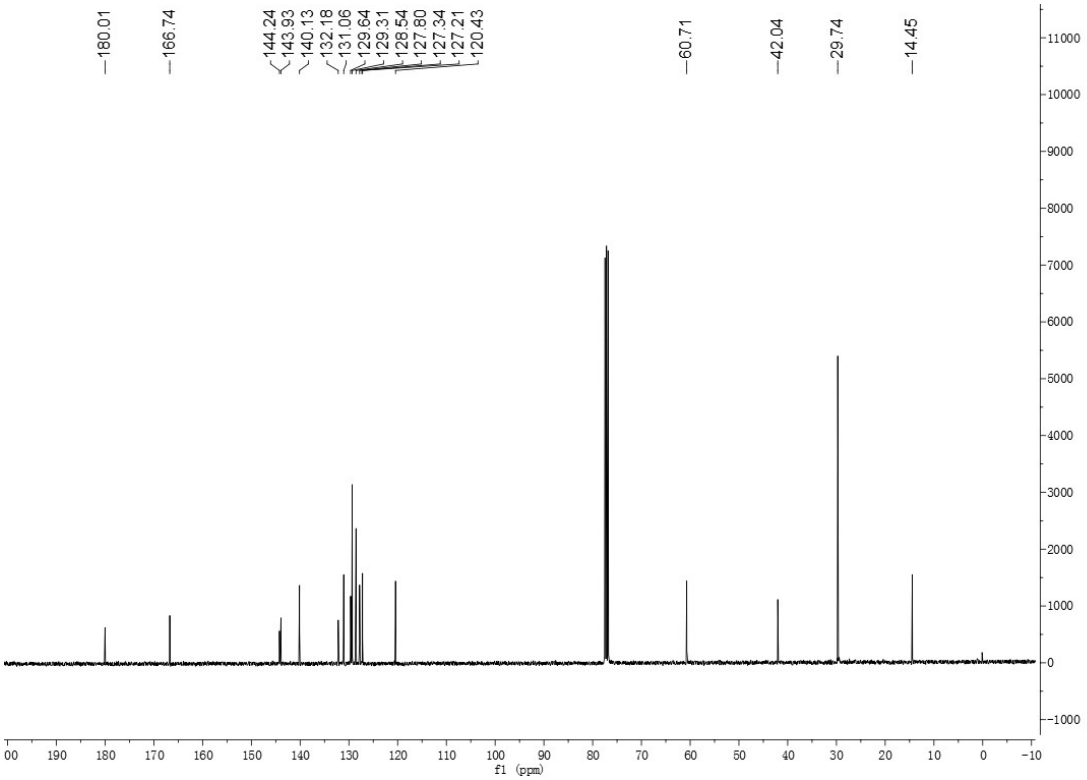
f1 (ppm)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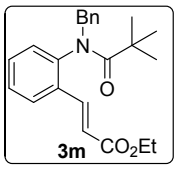
14.45
f1 (ppm)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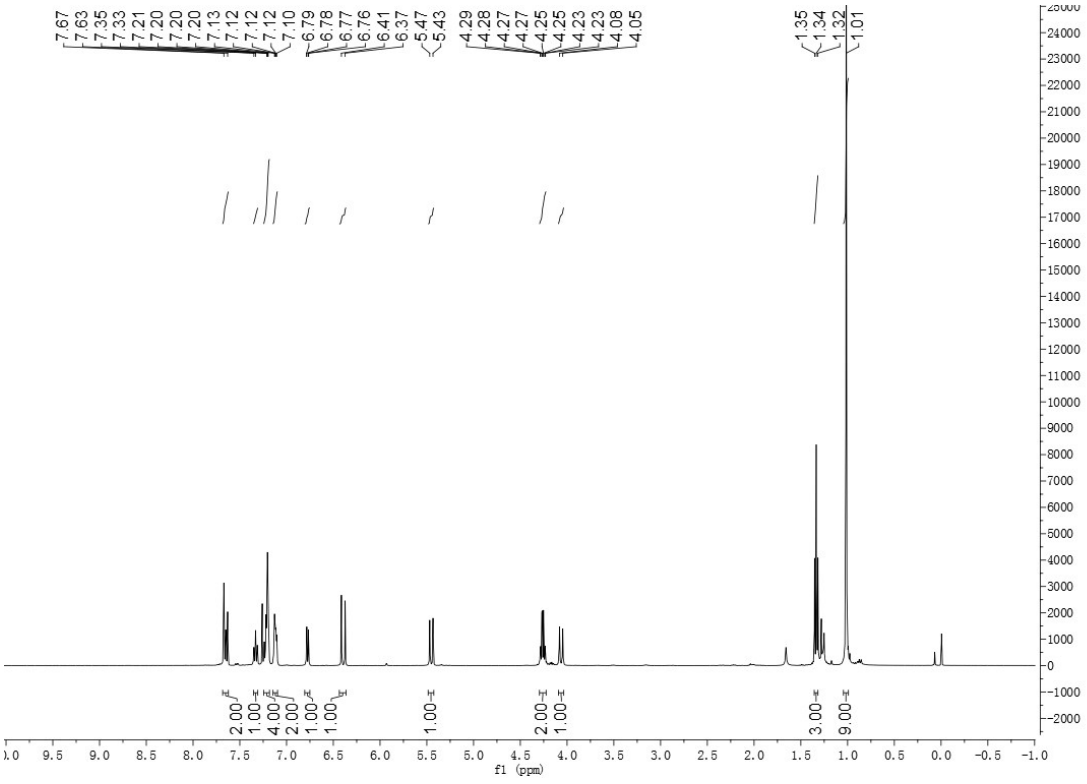
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5.47
5.43
4.29
4.28
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4.27
4.25
4.25
4.23
4.23
4.08
4.05
1.35
1.34
1.32
1.01
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1.00
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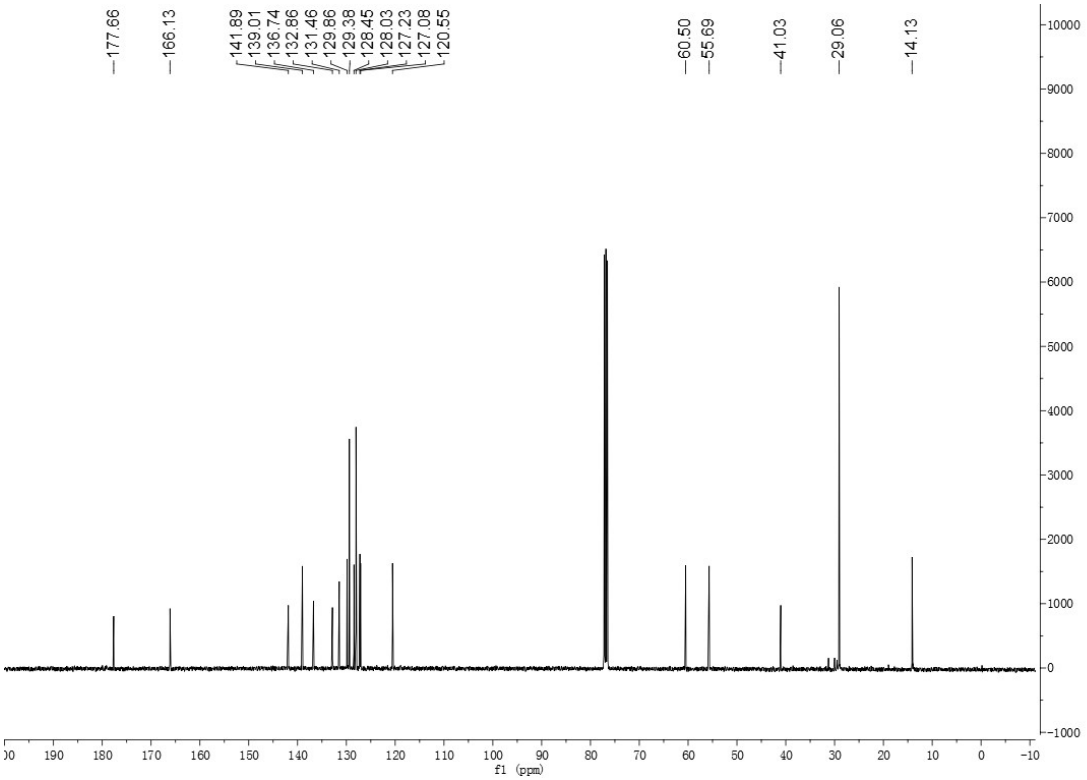
3.00
9.00
f1 (ppm)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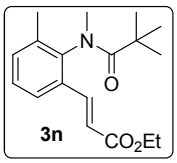
14.13
f1 (ppm)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CO2Et

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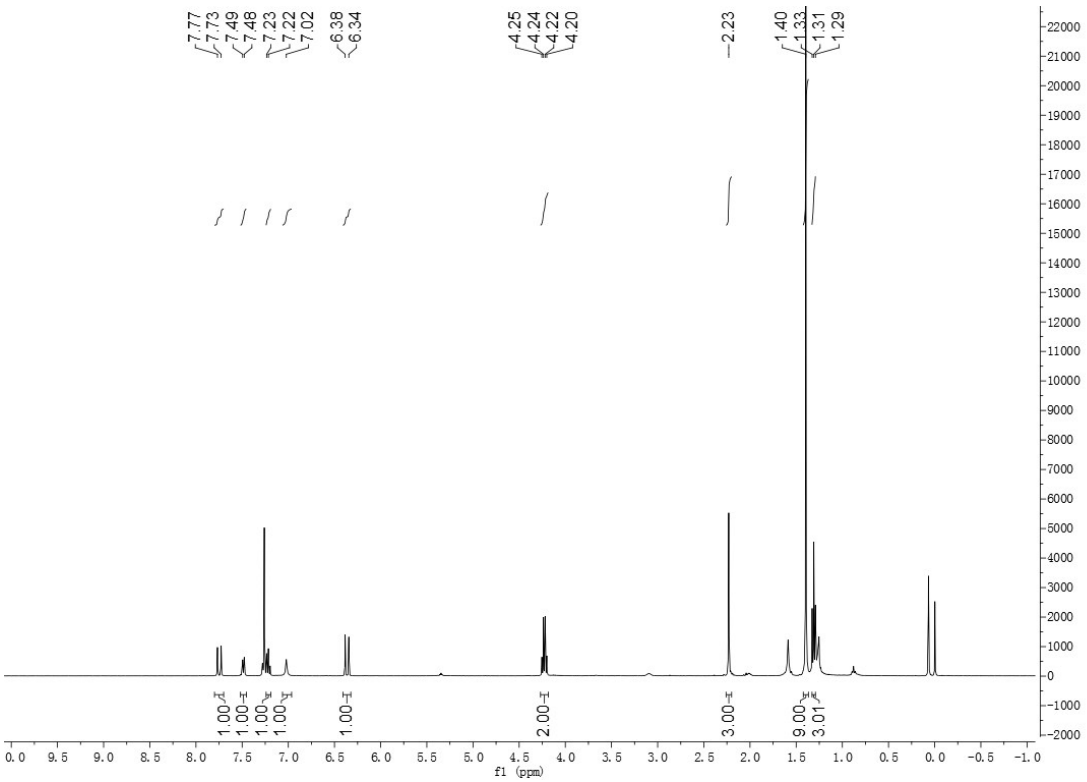
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1.33
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1.29
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1.00
1.00
2.00
3.00
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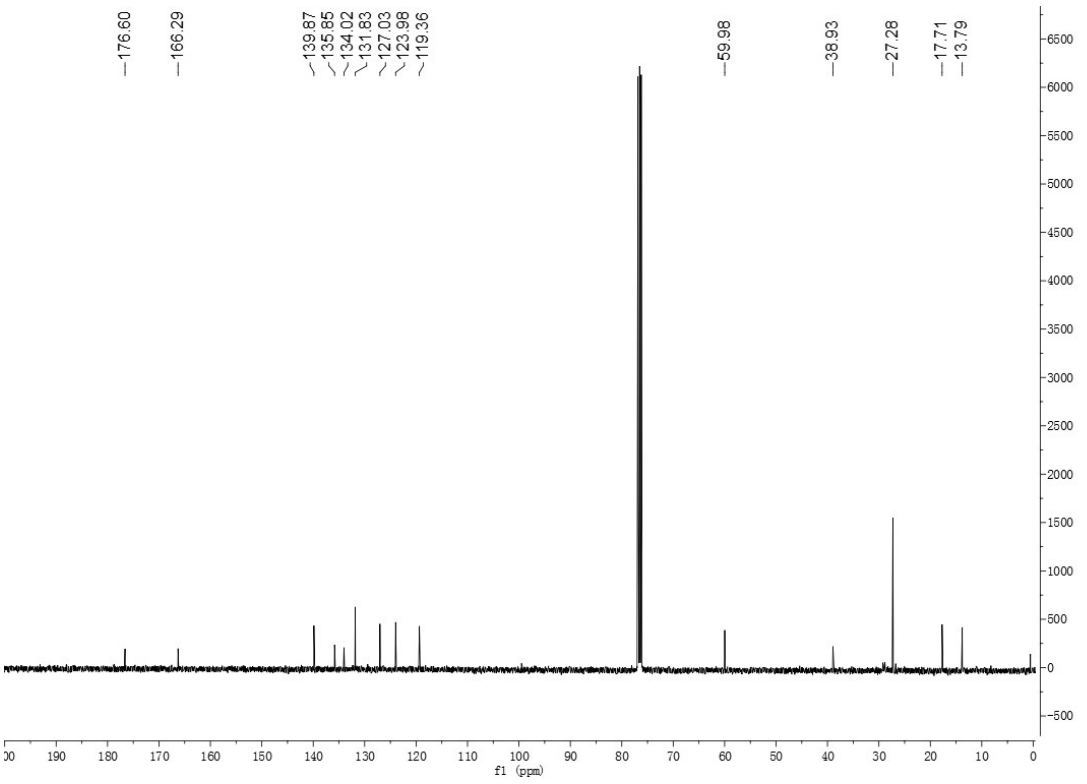
3.01
f1 (ppm)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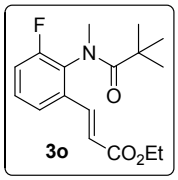
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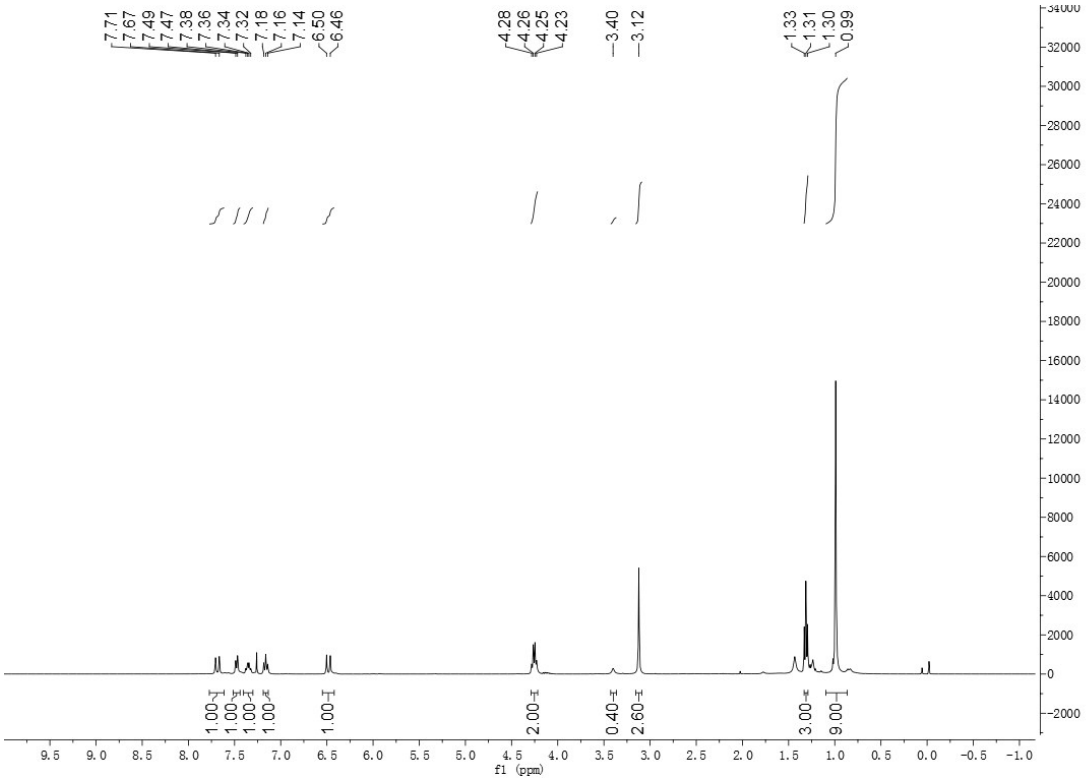
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4.25
4.23
3.40
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1.31
1.30
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1.00
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9.00
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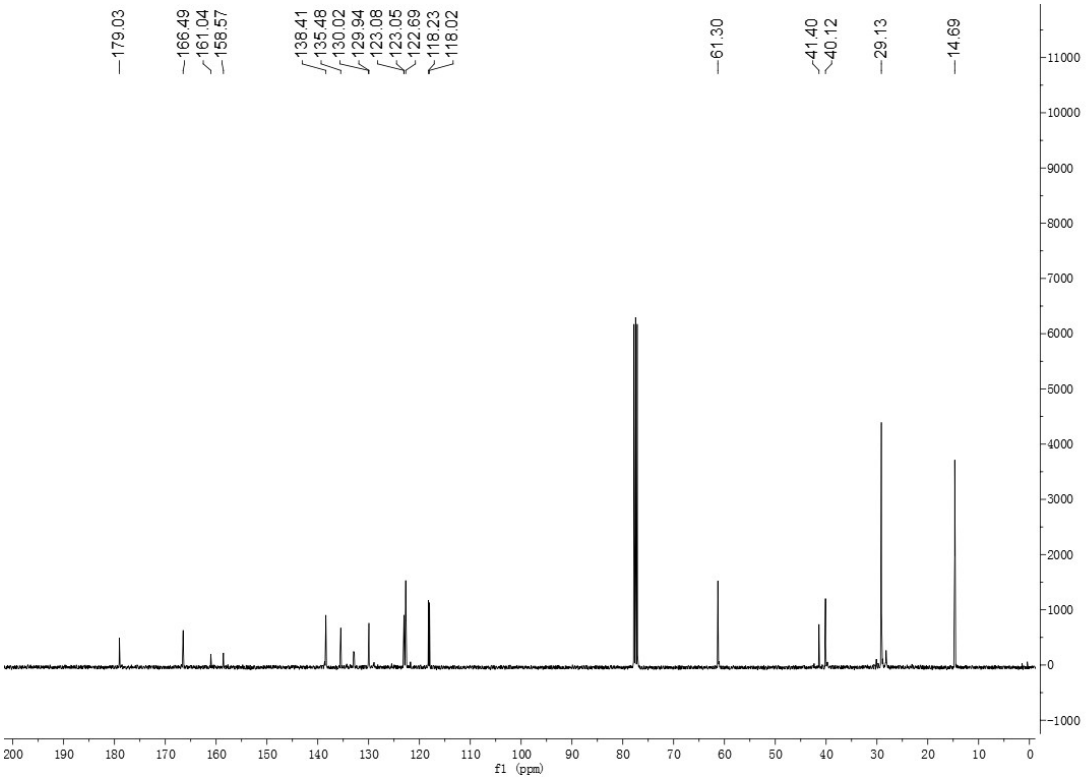
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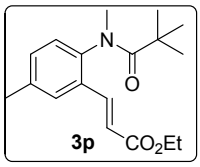
f1 (ppm)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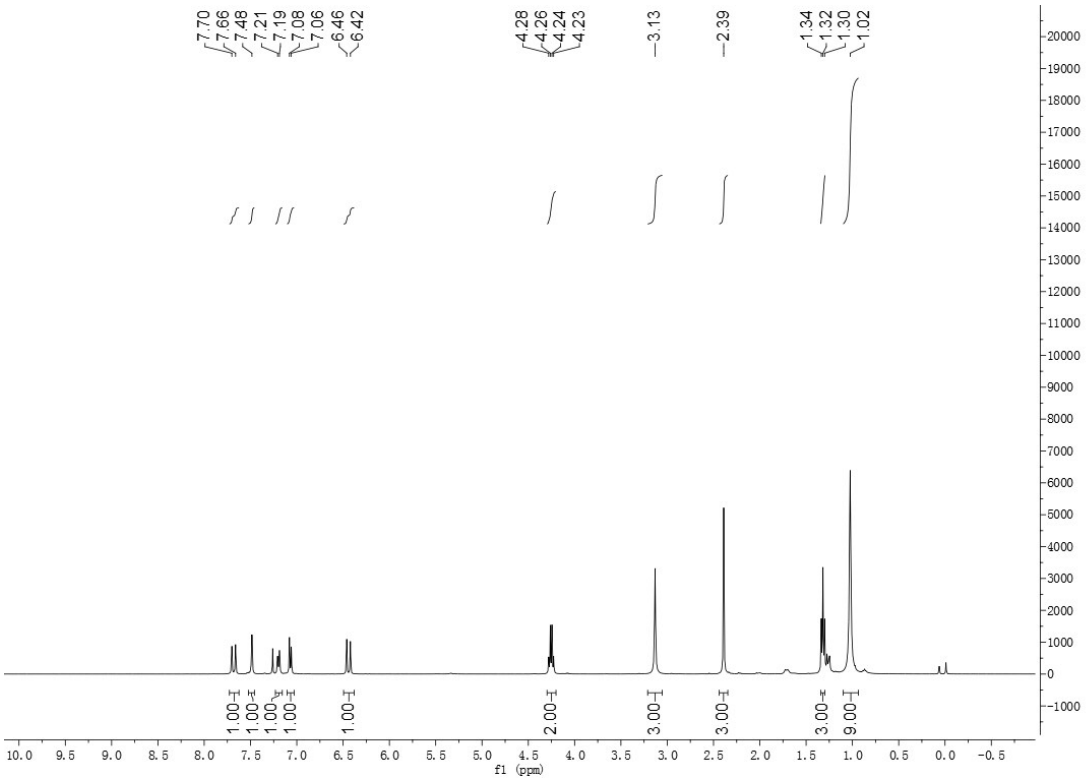
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4.24
4.23
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2.39
1.34
1.32
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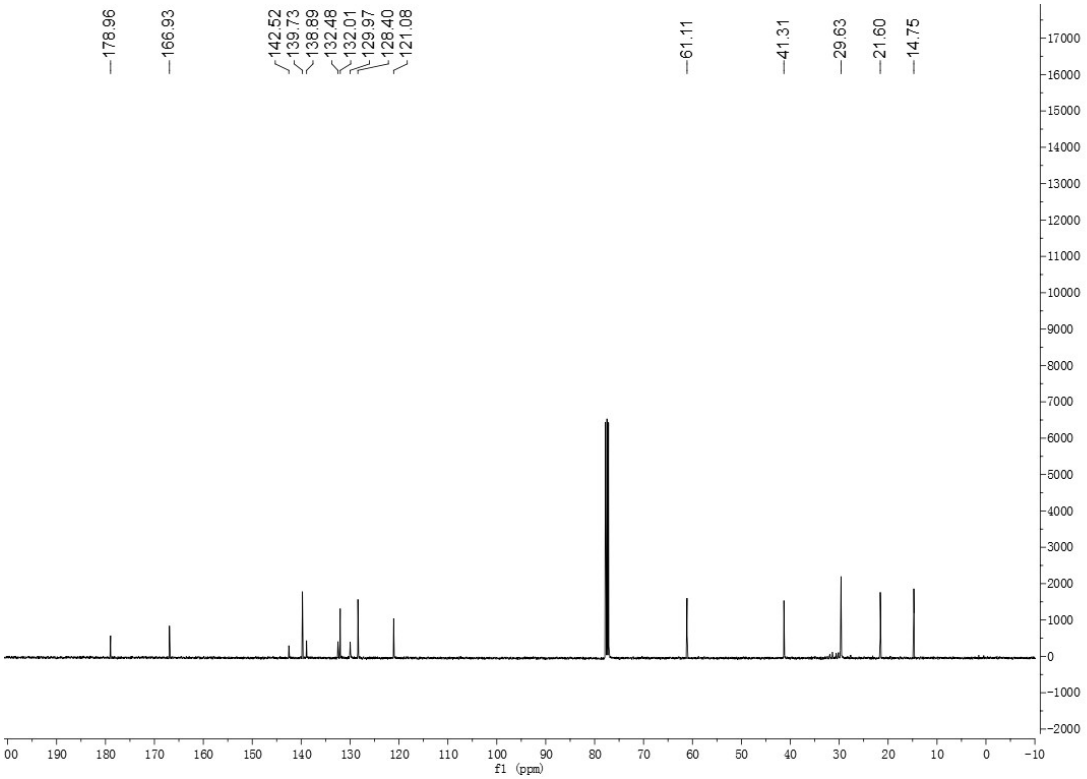
9.00
f1 (ppm)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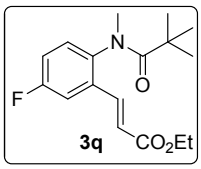
f1 (ppm)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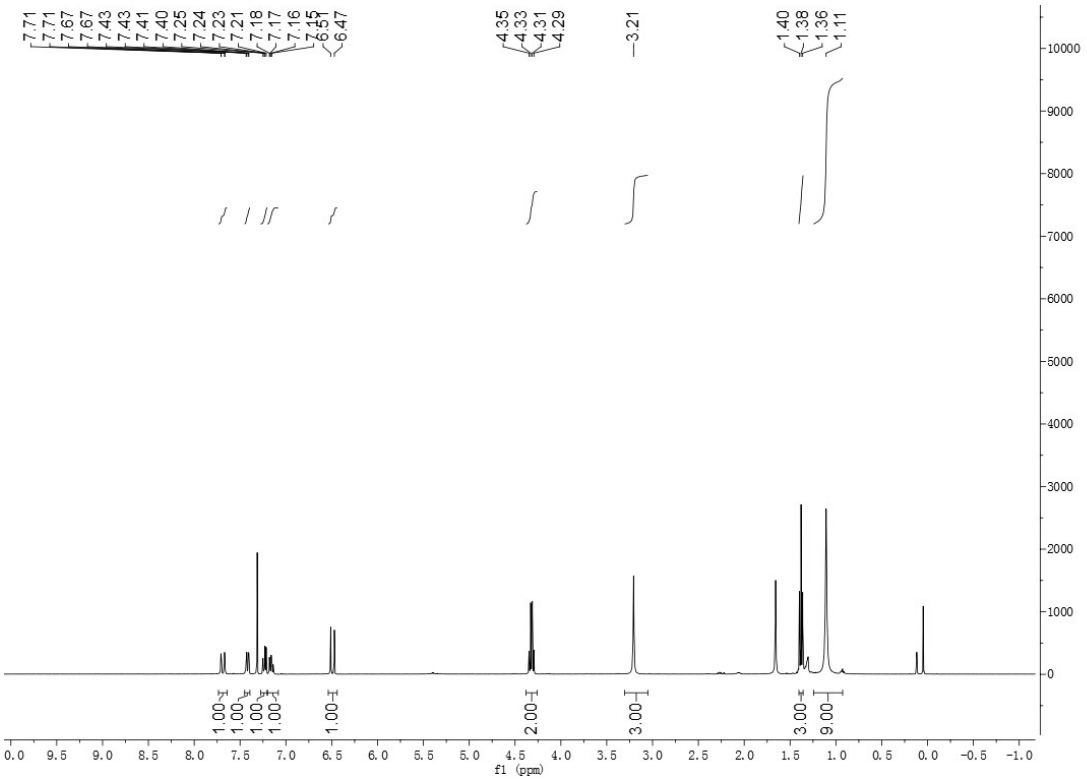
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4.29
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1.38
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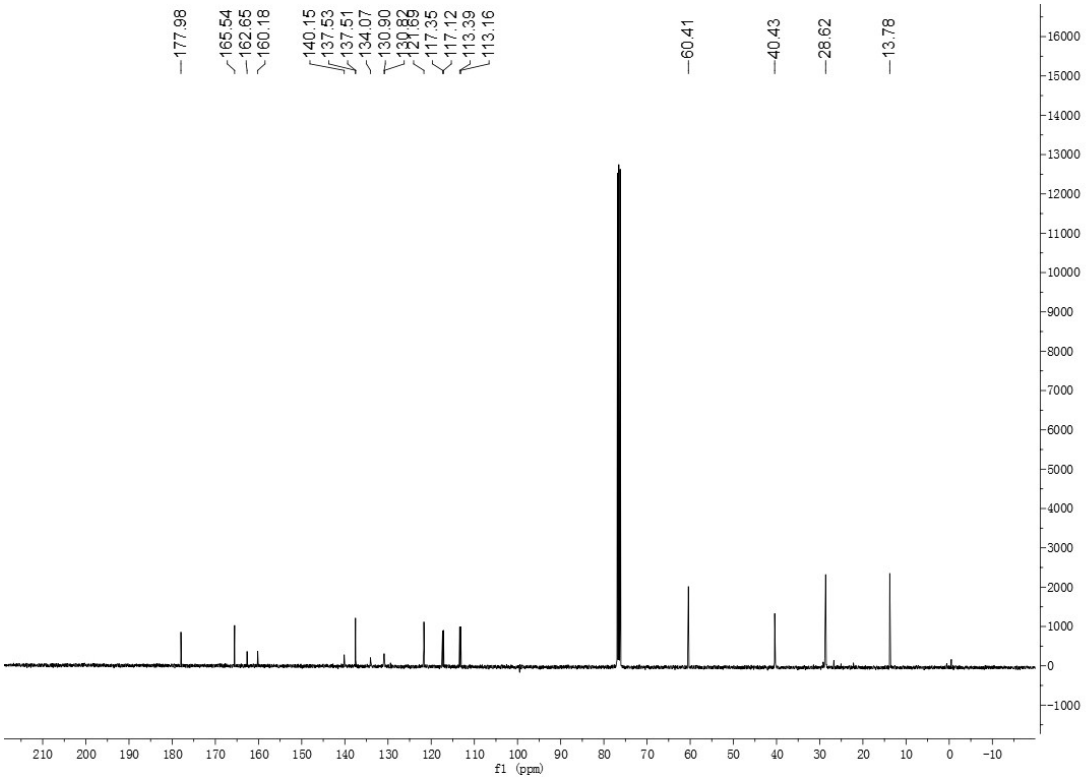
9.00
f1 (ppm)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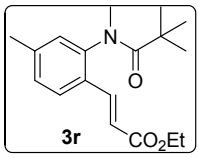
f1 (ppm)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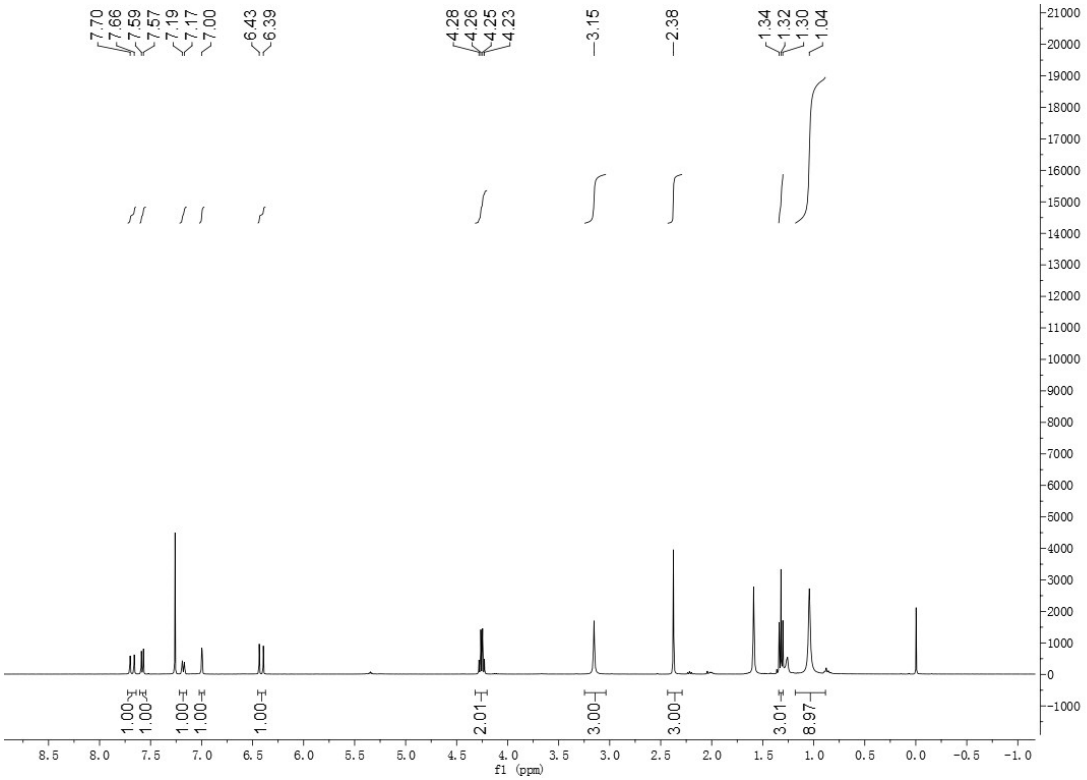
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1.34
1.32
1.30
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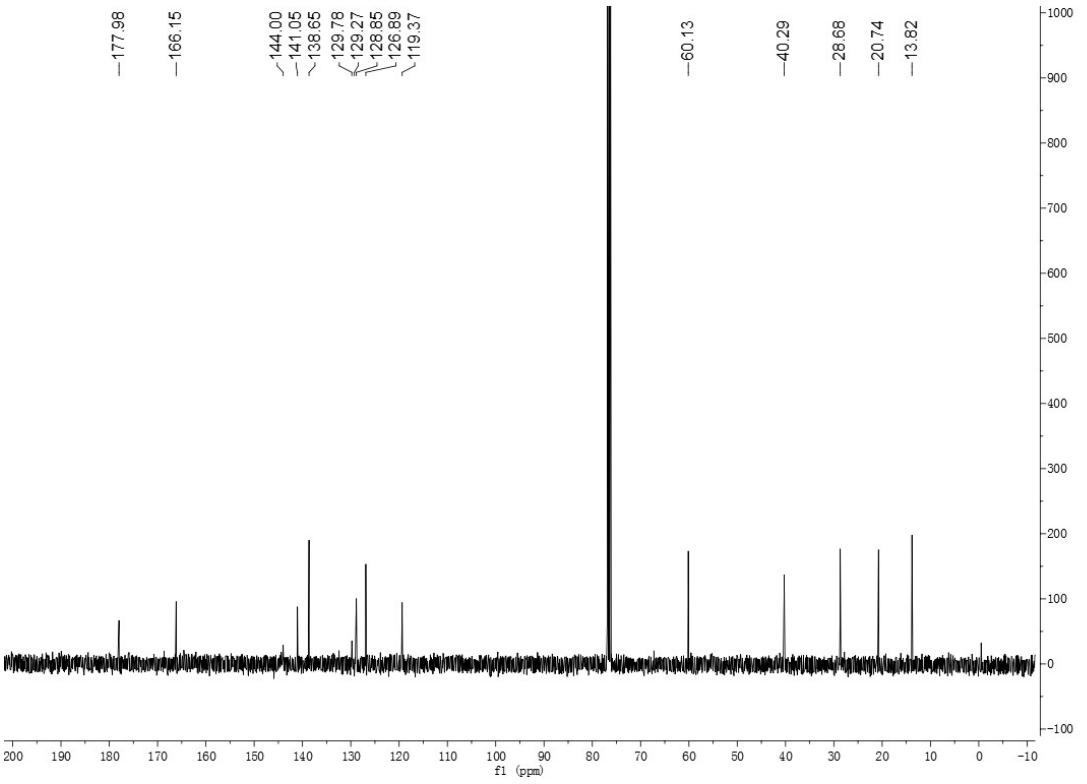
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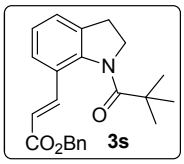
f1 (ppm)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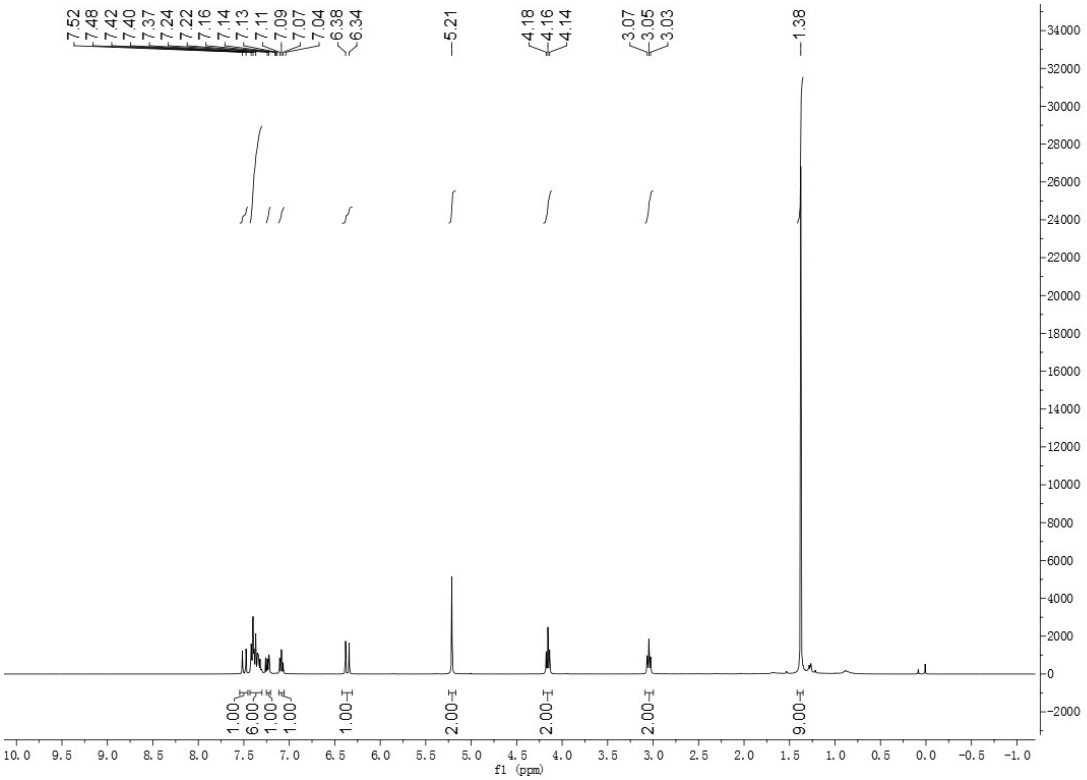
3s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5.21
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4.14
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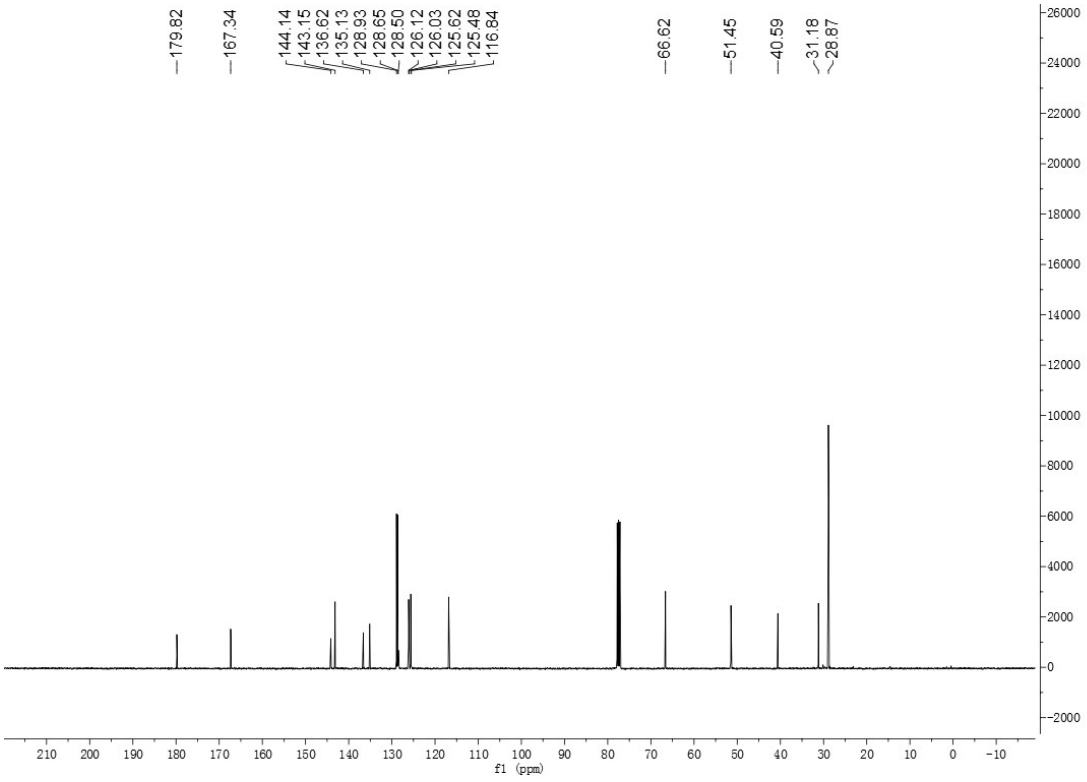
f1 (ppm)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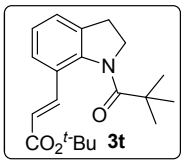
f1 (ppm)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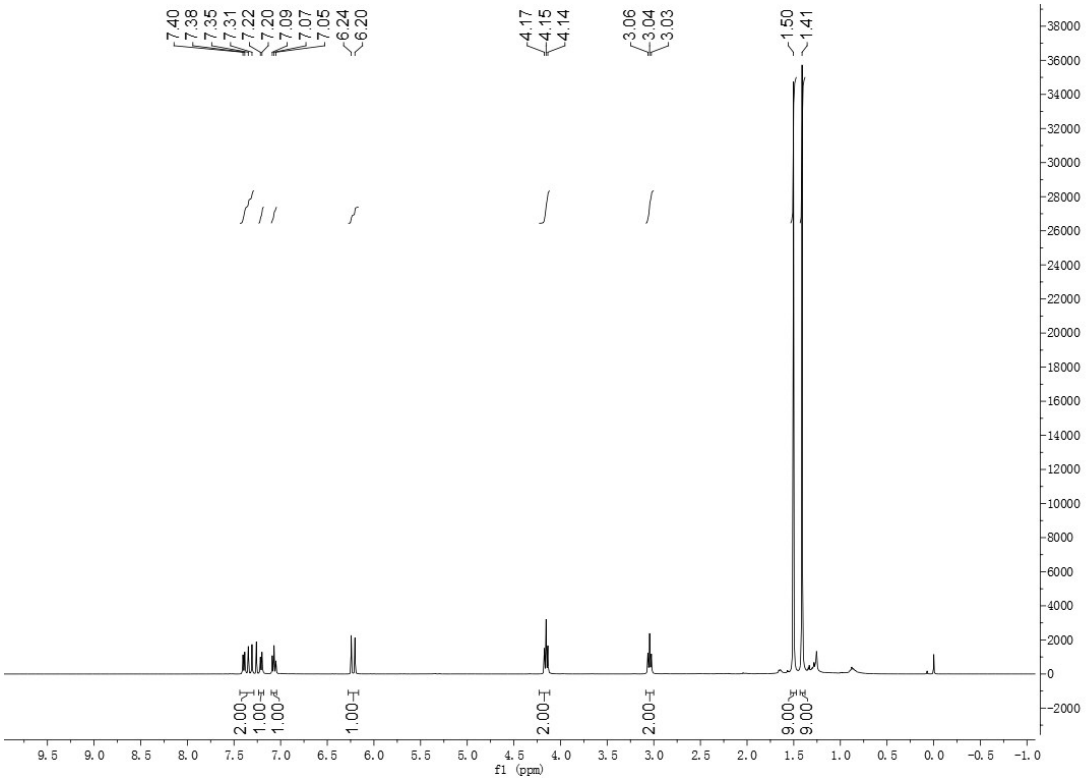
CO2t-Bu 3t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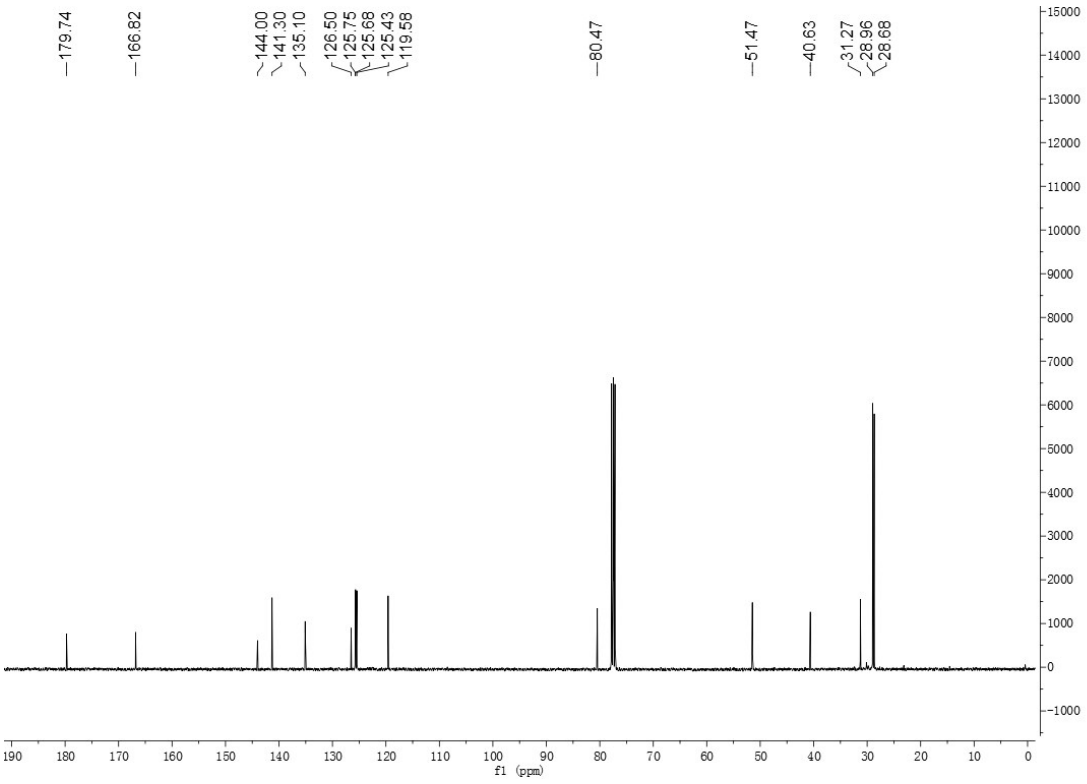
9.00
f1 (ppm)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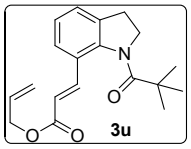
31.27
28.96
28.68
f1 (ppm)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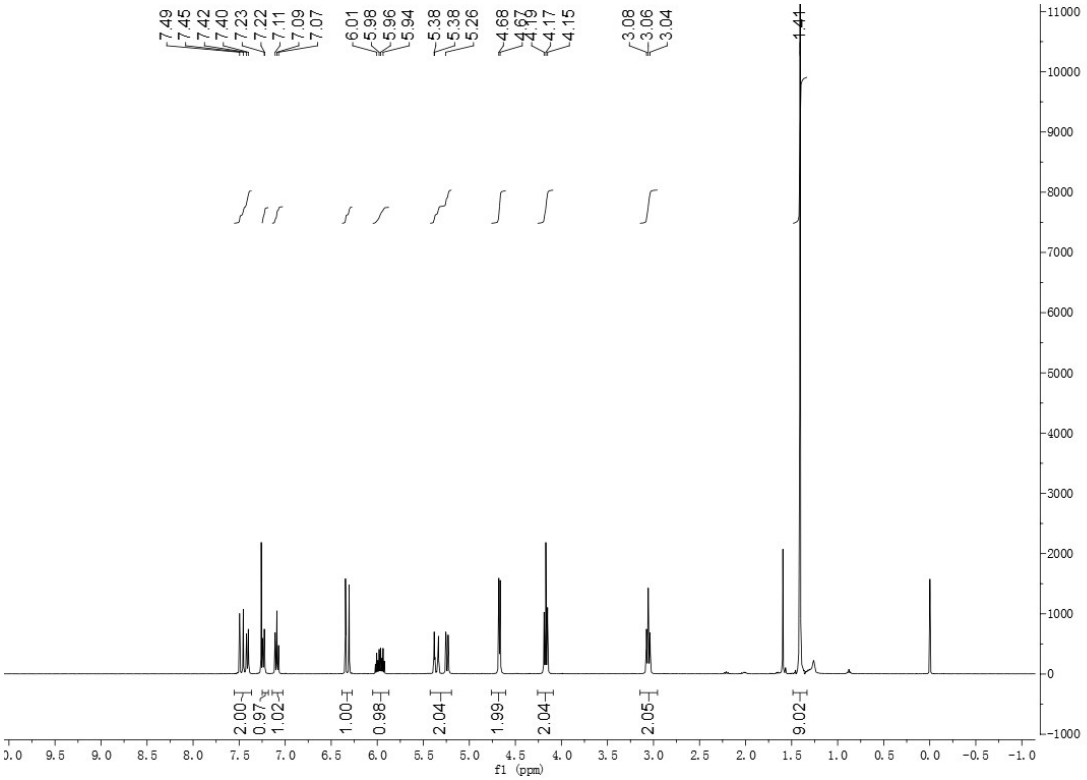
O
O
O
3u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4.67
4.19
4.17
4.15
3.08
3.06
3.04
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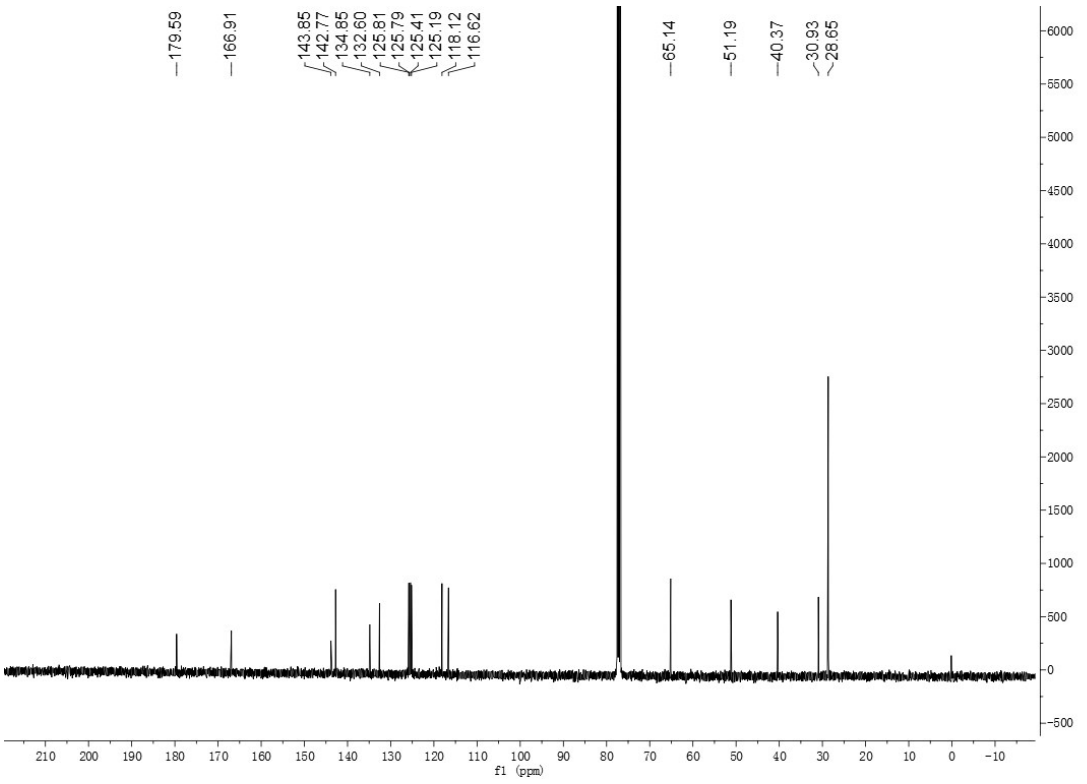
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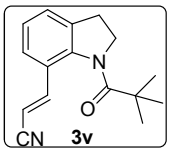
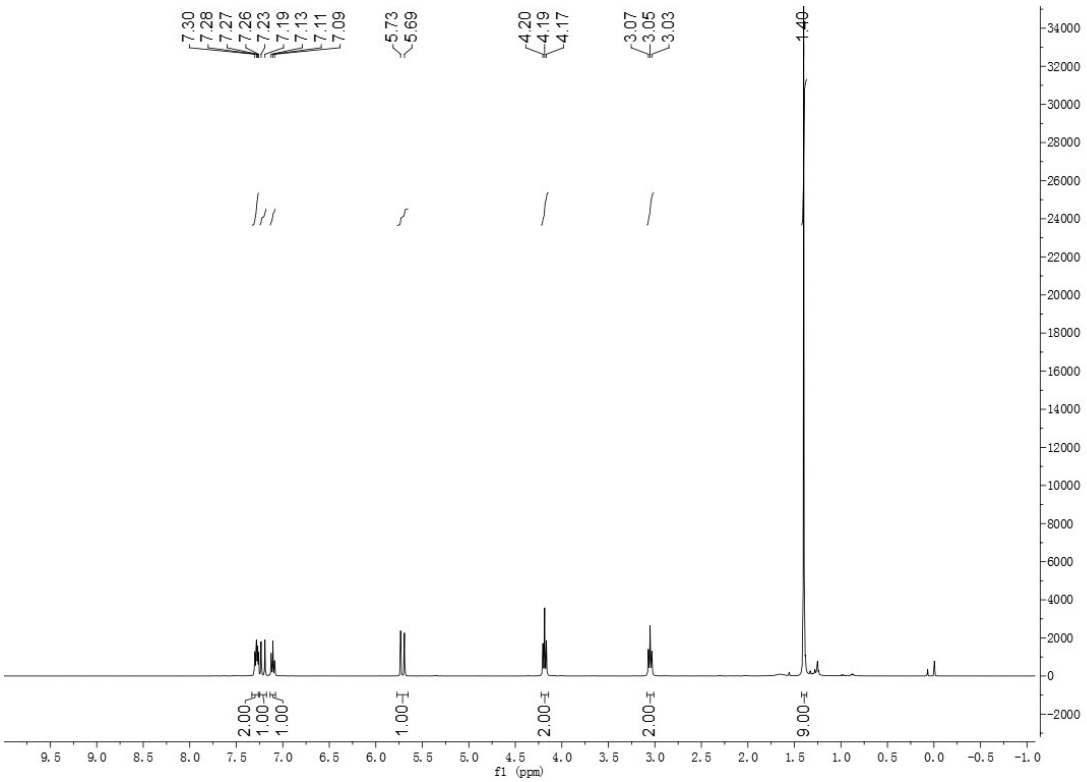
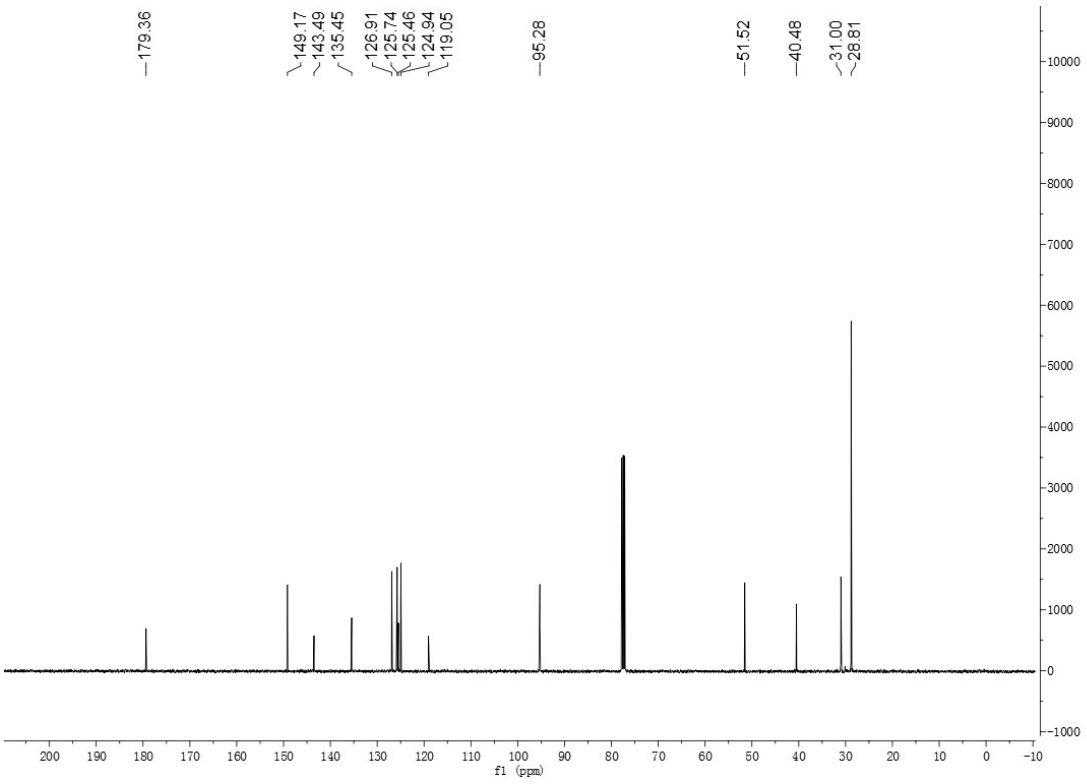
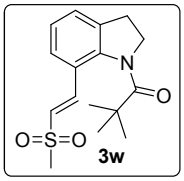
51.19
40.37
30.93
28.65
f1 (ppm)

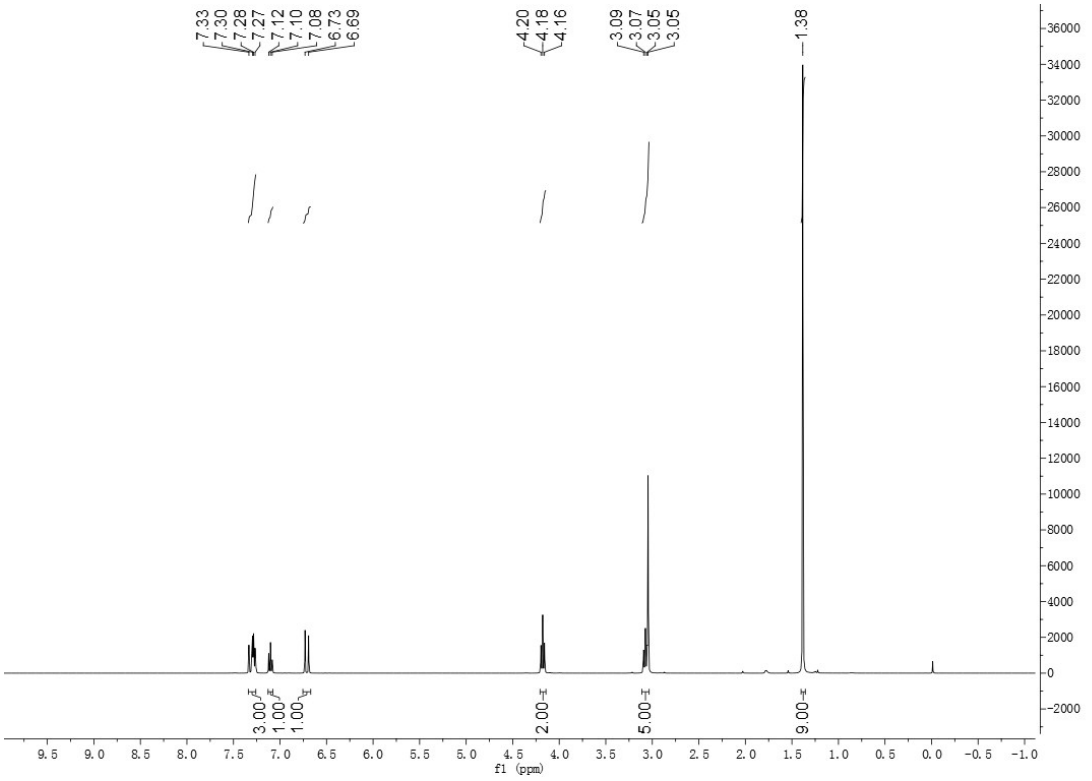

N
O
CN

3v


7.30
7.28
7.27
7.26
7.23
7.19
7.13
7.11
7.09
5.73
5.69
4.20
4.19
4.17
3.07
3.05
3.03
1.40
2.00
1.00
1.00
1.00
2.00
2.00
9.00
f1 (ppm)


179.36
149.17
143.49
135.45
126.91
125.74
125.46
124.94
119.05
95.28
51.52
40.48
31.00
28.81
f1 (ppm)


O=S=O
N
O
3w


7.33
7.30
7.28
7.27
7.12
7.10
7.08
6.73
6.69
4.20
4.18
4.16
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3.07
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3.05
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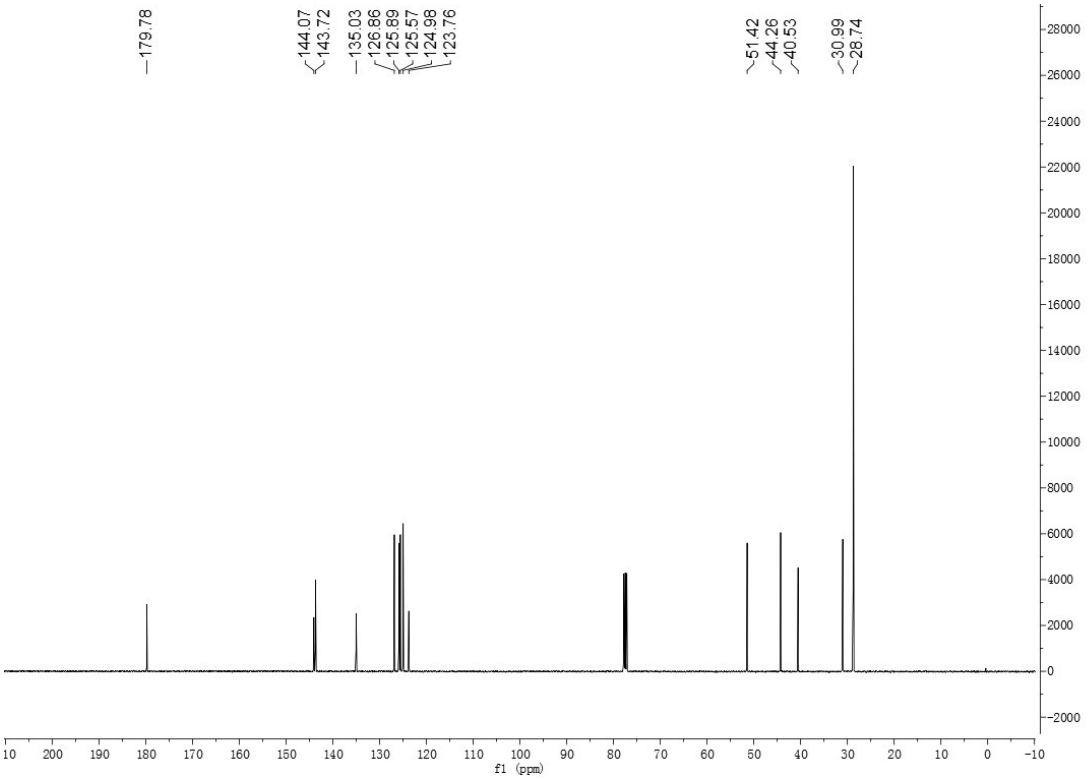
1.00
2.00
5.00
9.00
f1 (ppm)


179.78
144.07
143.72
135.03
126.86
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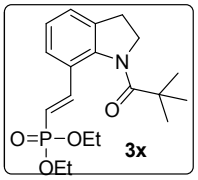
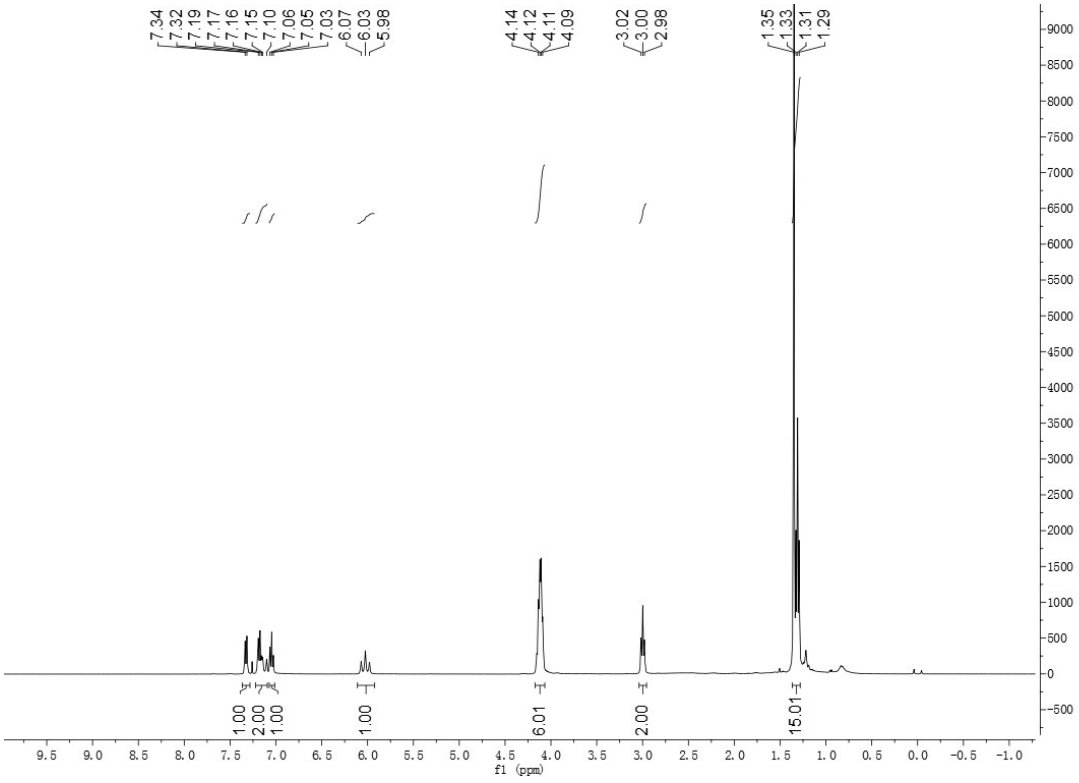
125.57
124.98
123.76
51.42
44.26
40.53
30.99
28.74
f1 (ppm)


O=P−OEt
OEt
3x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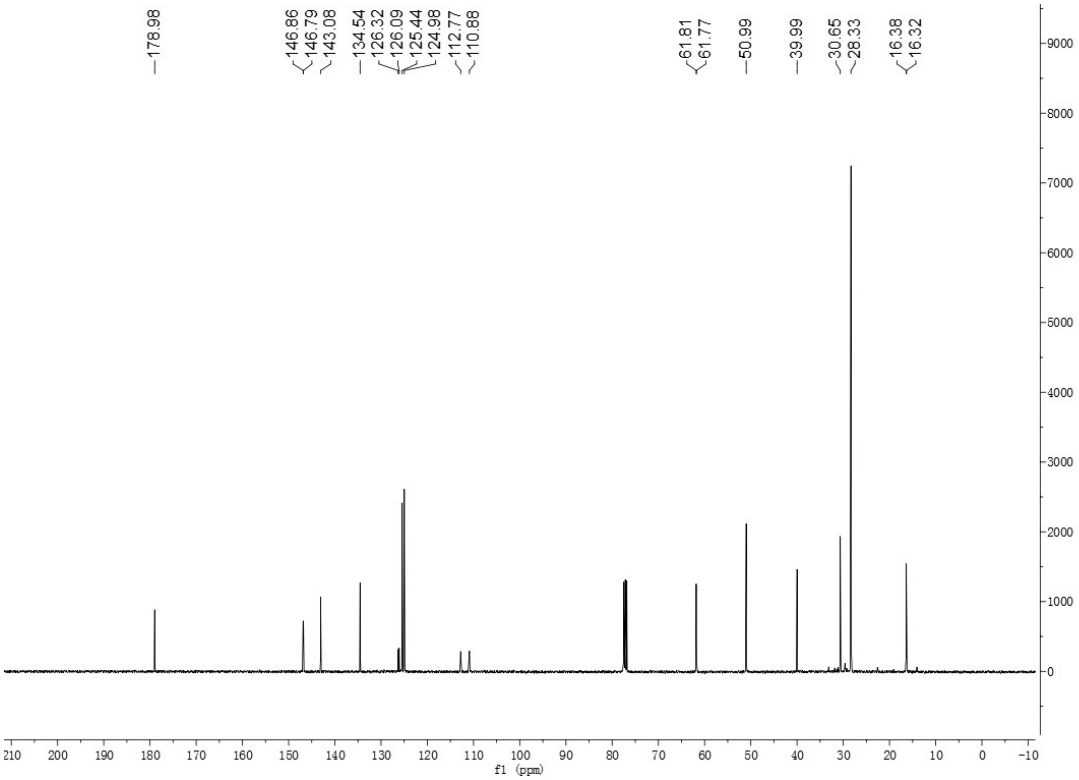
7.32
7.19
7.17
7.16
7.15
7.10
7.06
7.05
7.03
6.07
6.03
5.98
4.14
4.12
4.11
4.09
3.02
3.00
2.98
1.35
1.33
1.31
1.29
1.00
2.00
1.00
1.00
6.01
2.00
15.01
f1 (ppm)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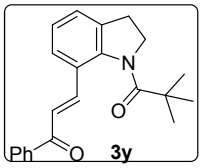
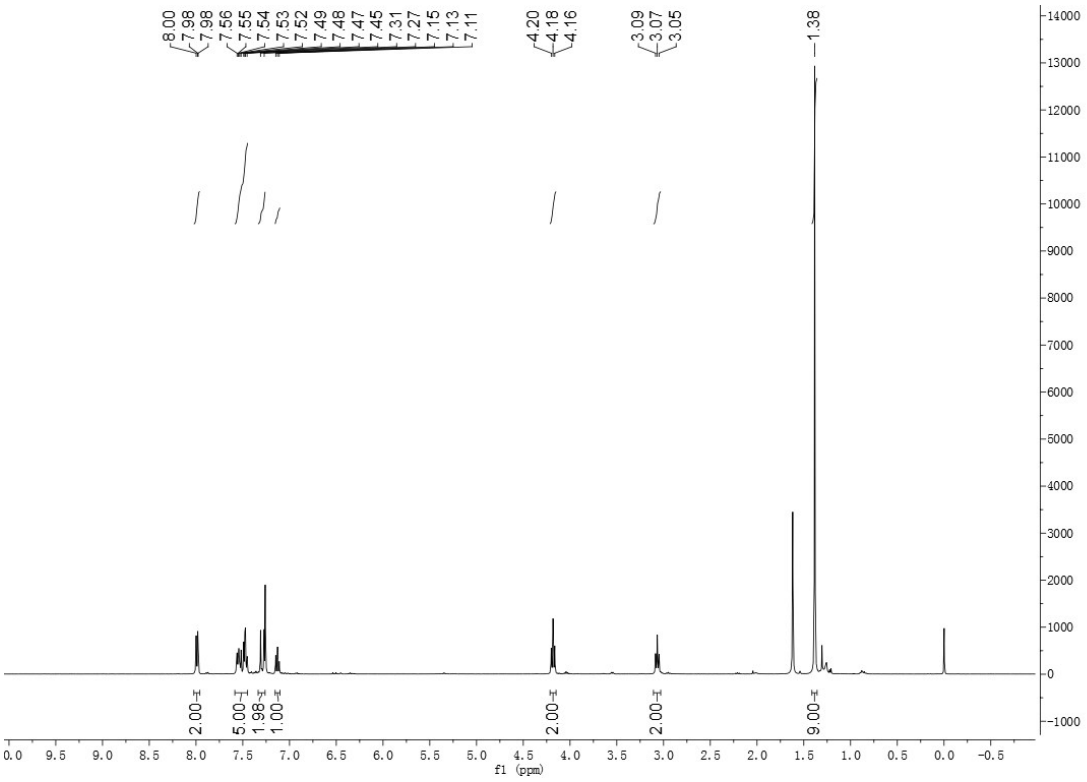
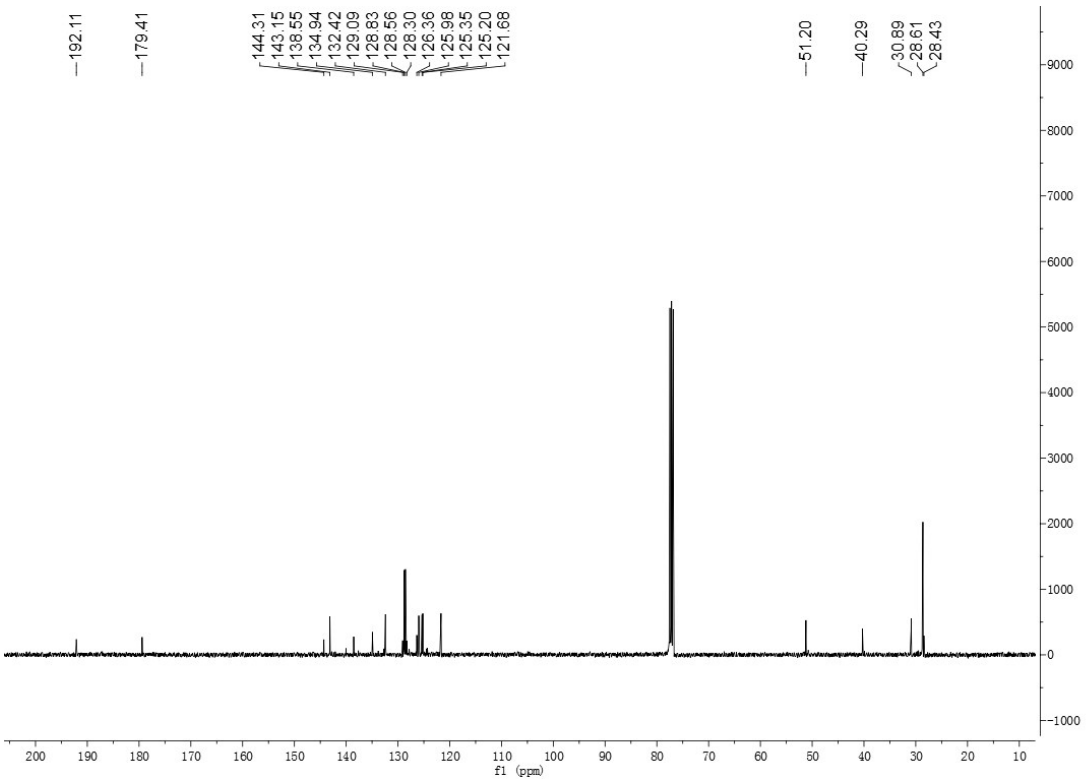
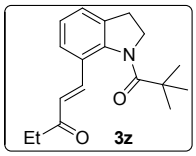
146.86
146.79
143.08
134.54
126.32
126.09
125.44
124.98
112.77
110.88
61.81
61.77
50.99
39.99
30.65
28.33
16.38
16.32
f1 (ppm)


N
O
Ph
O

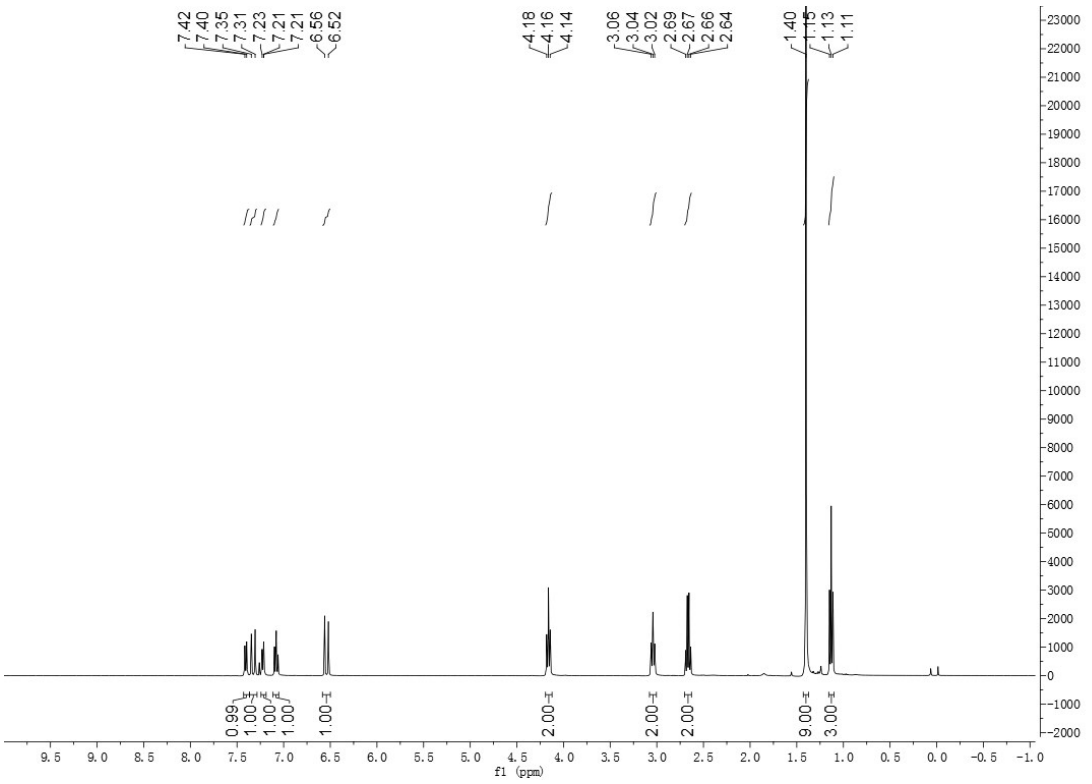
3y

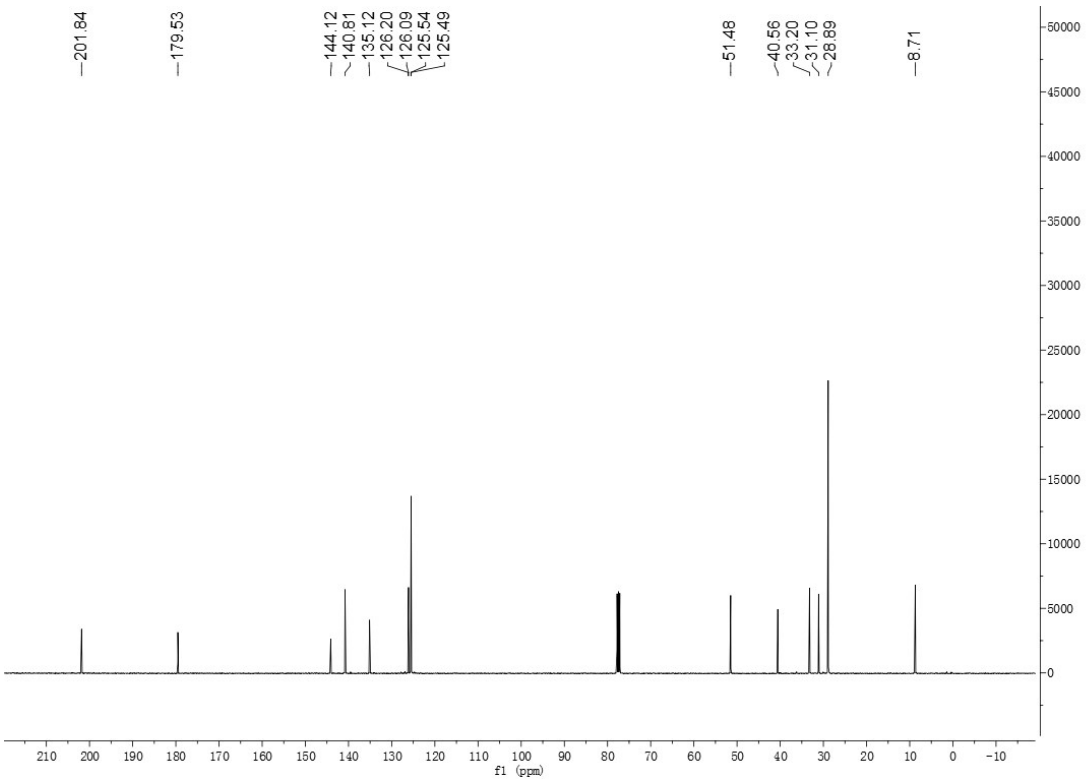

8.00
7.98
7.98
7.56
7.55
7.54
7.53
7.52
7.49
7.48
7.47
7.45
7.31
7.27
7.15
7.13
7.11
4.20
4.18
4.16
3.09
3.07
3.05
1.38
2.00
5.00
1.98
1.00
2.00
2.00
9.00
f1 (ppm)

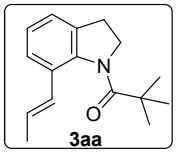

192.11
179.41
144.31
143.15
138.55
134.94
132.42
129.09
128.83
128.56
128.30
126.36
125.98
125.35
125.20
121.68
51.20
40.29
30.89
28.61
28.43
f1 (ppm)


Et
O
N
O

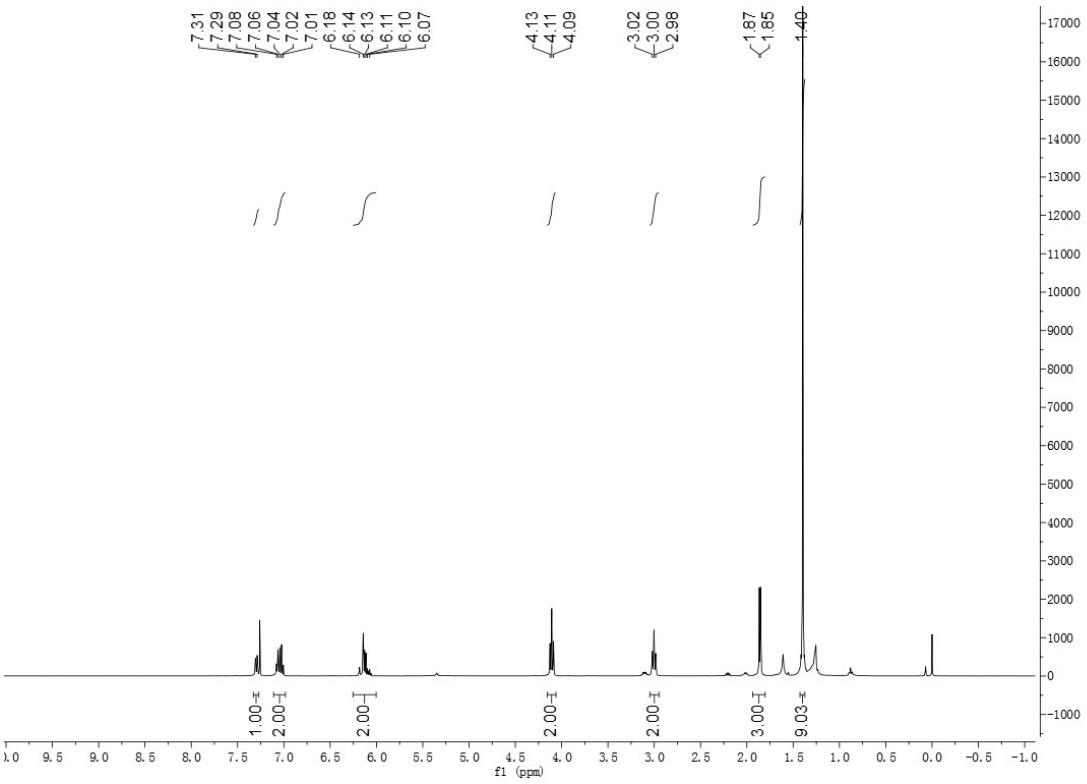
3z

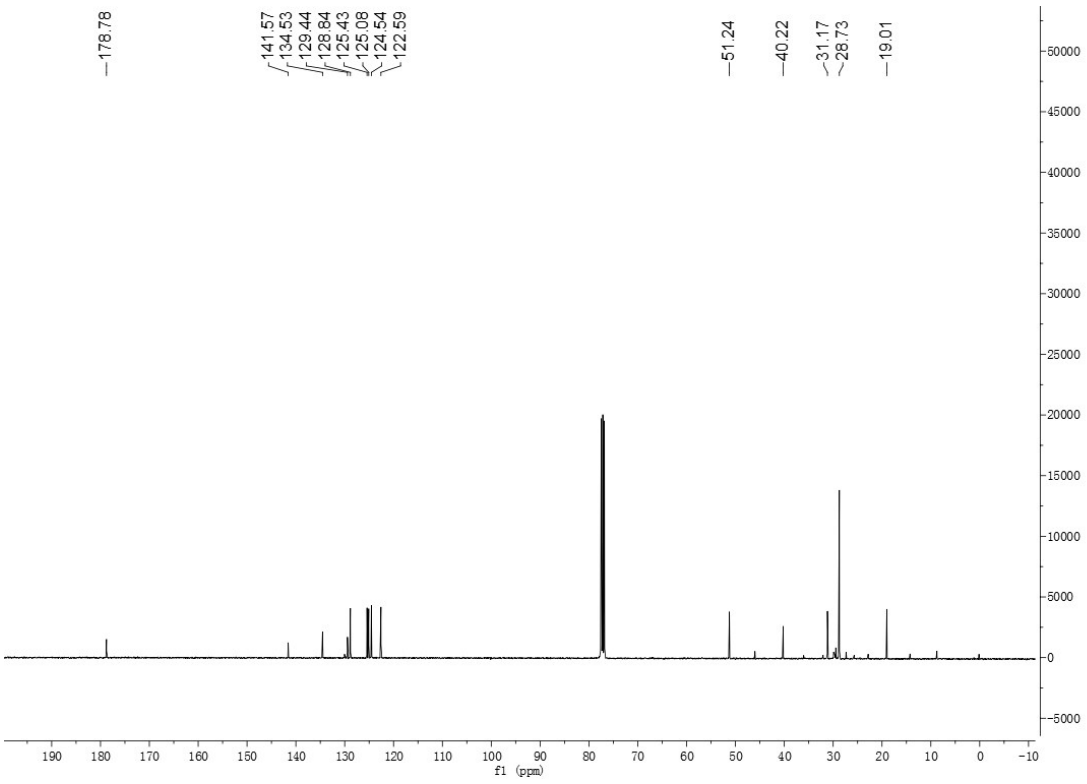

7.42
7.40
7.35
7.31
7.23
7.21
7.21
6.56
6.52
4.18
4.16
4.14
3.06
3.04
3.02
2.69
2.67
2.66
2.64
1.40
1.15
1.13
1.11
0.99
1.00
1.00
1.00
1.00
2.00
2.00
2.00
9.00
3.00
f1 (ppm)

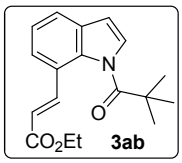

201.84
179.53
144.12
140.81
135.12
126.20
126.09
125.54
125.49
51.48
40.56
33.20
31.10
28.89
8.71
f1 (ppm)


N
O

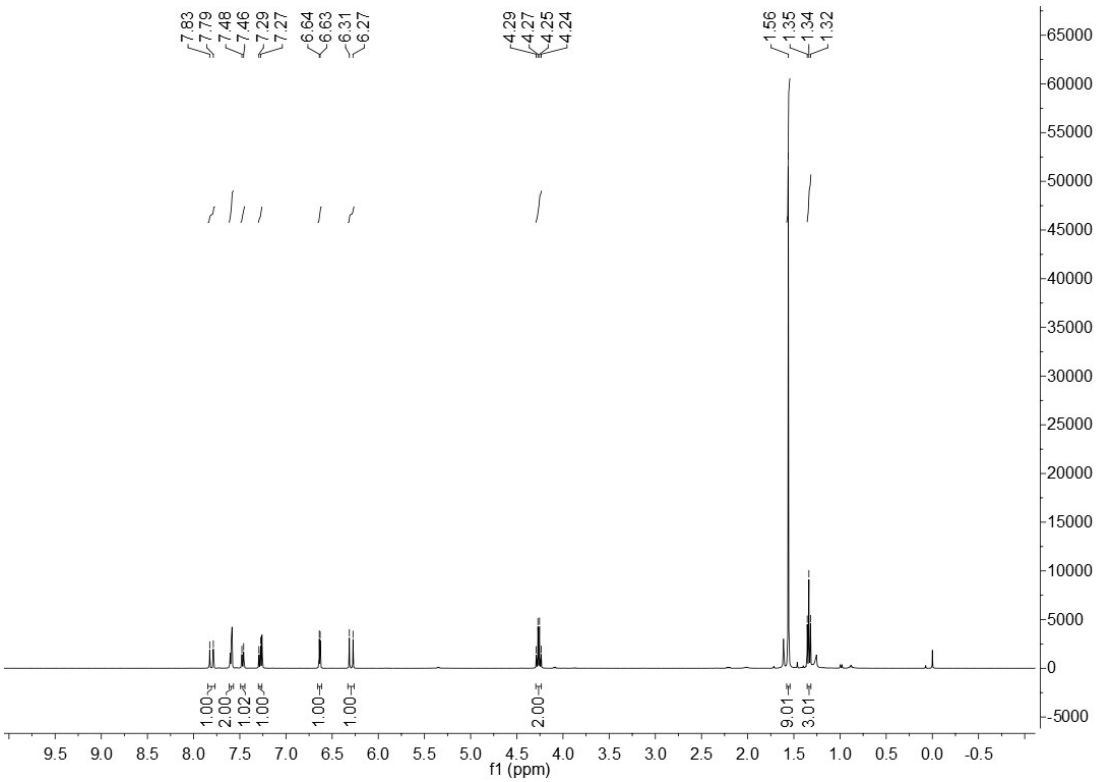
3aa

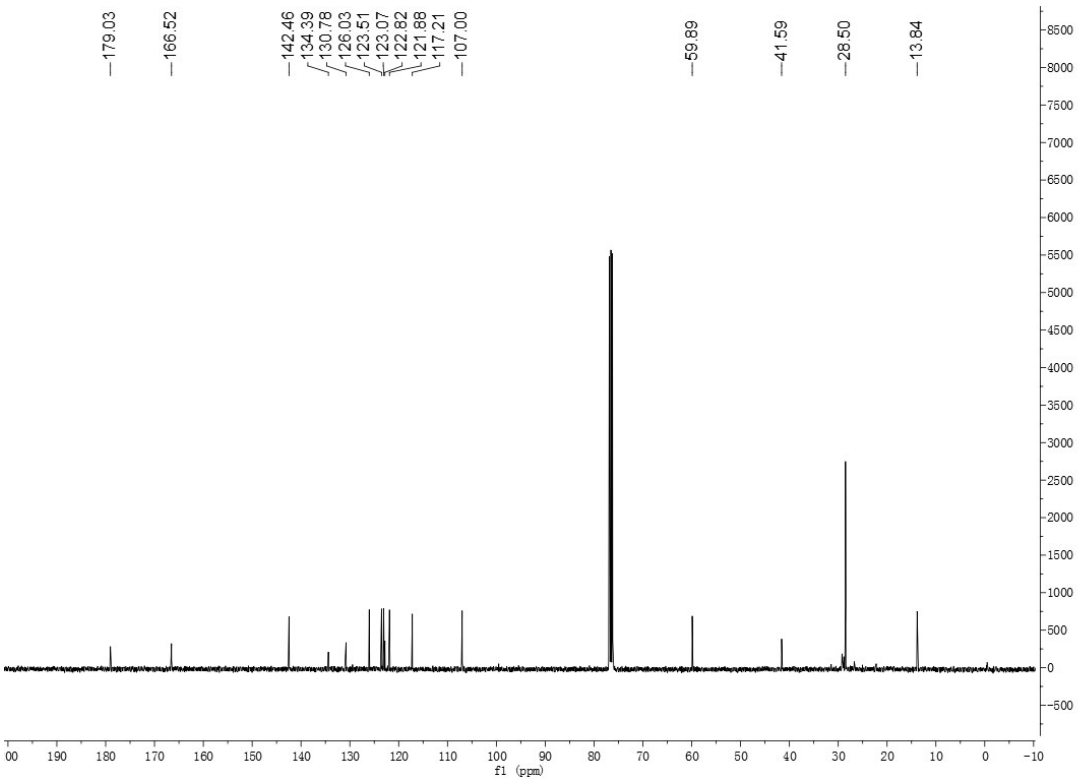

7.31
7.29
7.08
7.06
7.04
7.02
7.01
6.18
6.14
6.13
6.11
6.10
6.07
4.13
4.11
4.09
3.02
3.00
2.98
1.87
1.85
1.40
1.00
2.00
2.00
2.00
2.00
3.00
9.03
f1 (ppm)

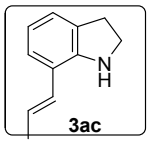

178.78
141.57
134.53
129.44
128.84
125.43
125.08
124.54
122.59
51.24
40.22
31.17
28.73
19.01
f1 (ppm)


N
O
CO2Et

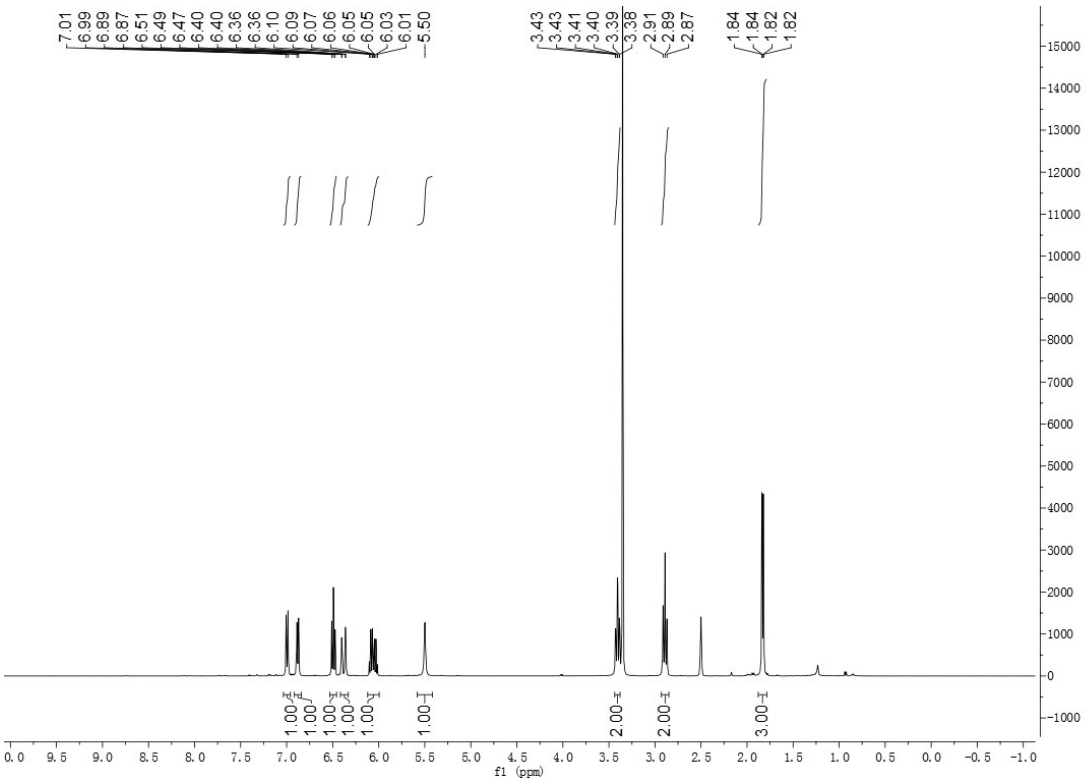
3ab


7.83
7.79
7.48
7.46
7.29
7.27
6.64
6.63
6.31
6.27
4.29
4.27
4.25
4.24
1.56
1.35
1.34
1.32
1.00
2.00
1.02
1.00
1.00
1.00
2.00
9.01
3.01
f1 (ppm)


179.03
166.52
142.46
134.39
130.78
126.03
123.51
123.07
122.82
121.88
117.21
107.00
59.89
41.59
28.50
13.84
f1 (ppm)


N
H

3ac


7.01
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6.87
6.51
6.49
6.47
6.40
6.40
6.36
6.36
6.10
6.09
6.07
6.06
6.05
6.05
6.03
6.01
5.50
3.43
3.43
3.41
3.40
3.39
3.38
2.91
2.89
2.87
1.84
1.84
1.82
1.82
1.00
1.00
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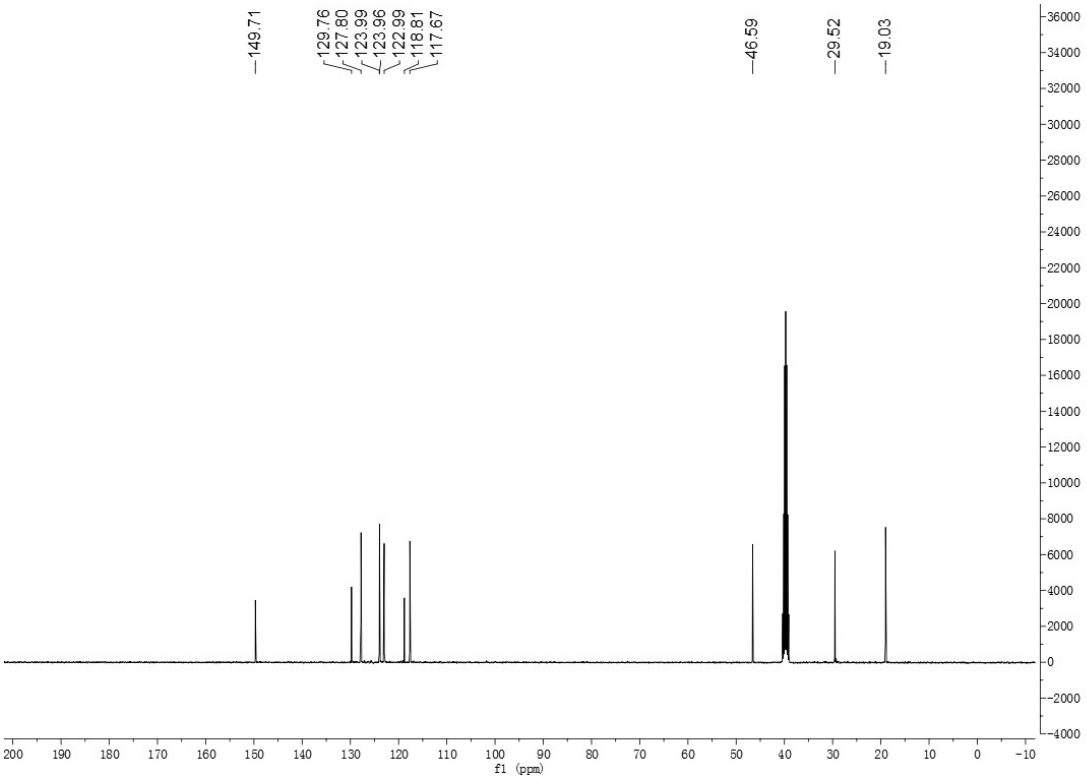
1.00
2.00
2.00
3.00
f1 (ppm)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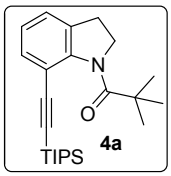
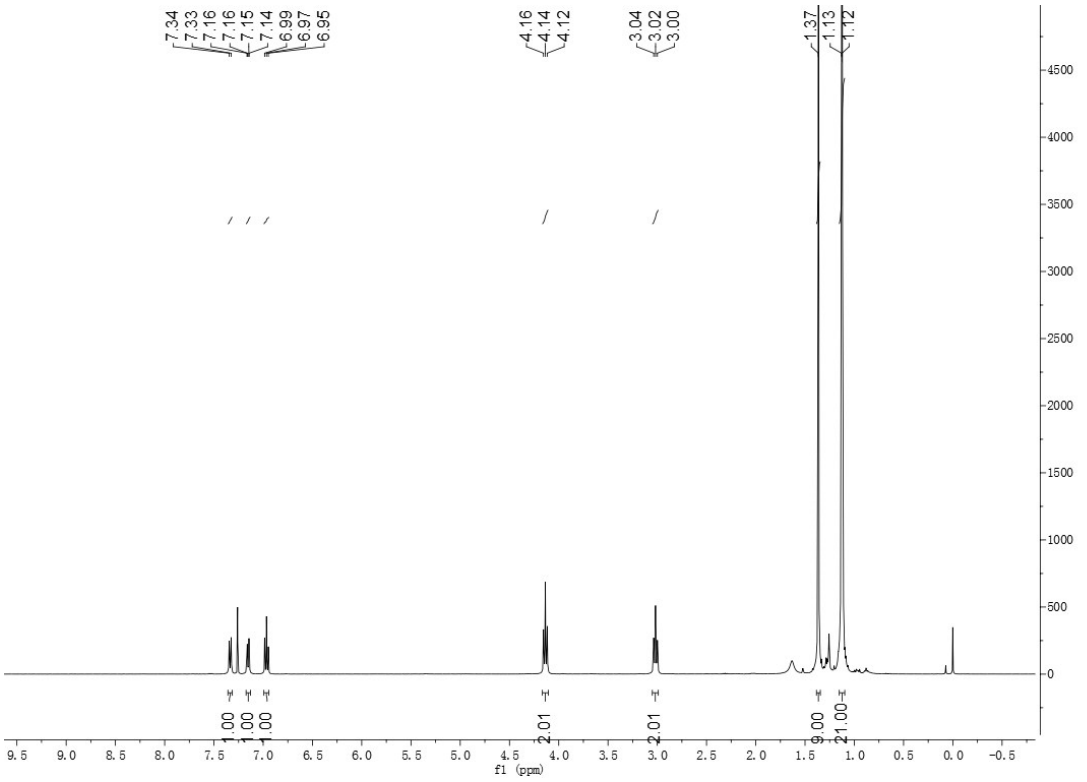
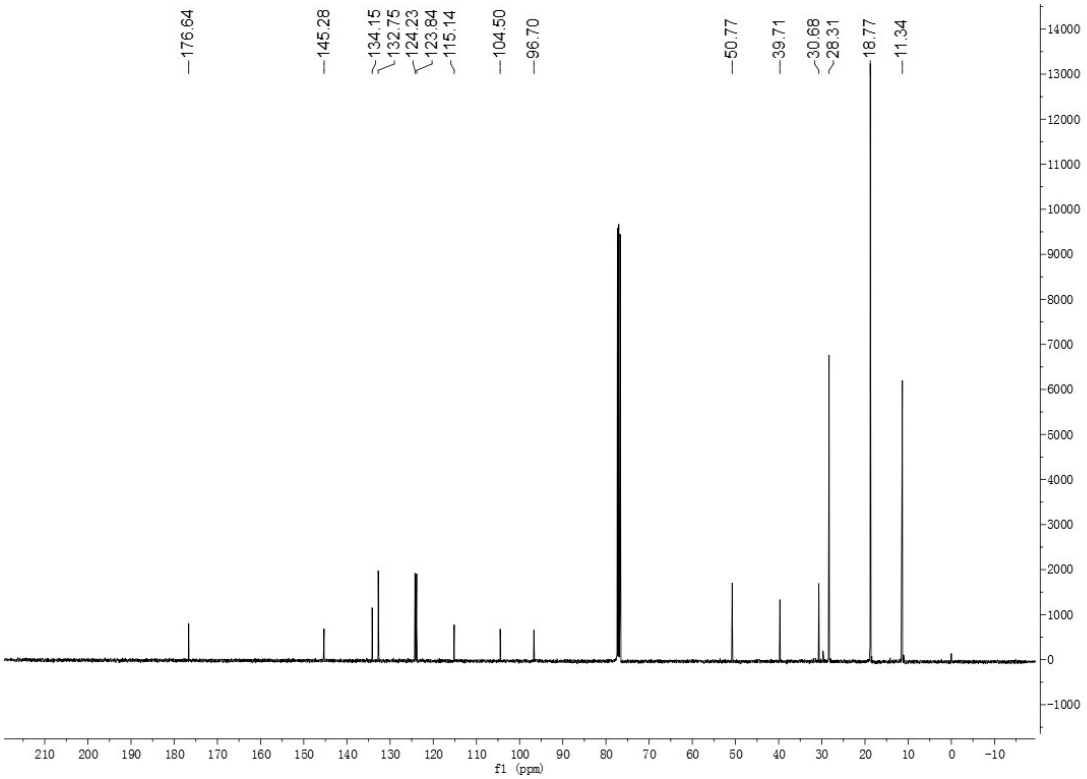
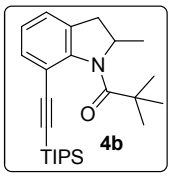
127.80
123.99
123.96
122.99
118.81
117.67
46.59
29.52
19.03
f1 (ppm)


N
O
TIPS

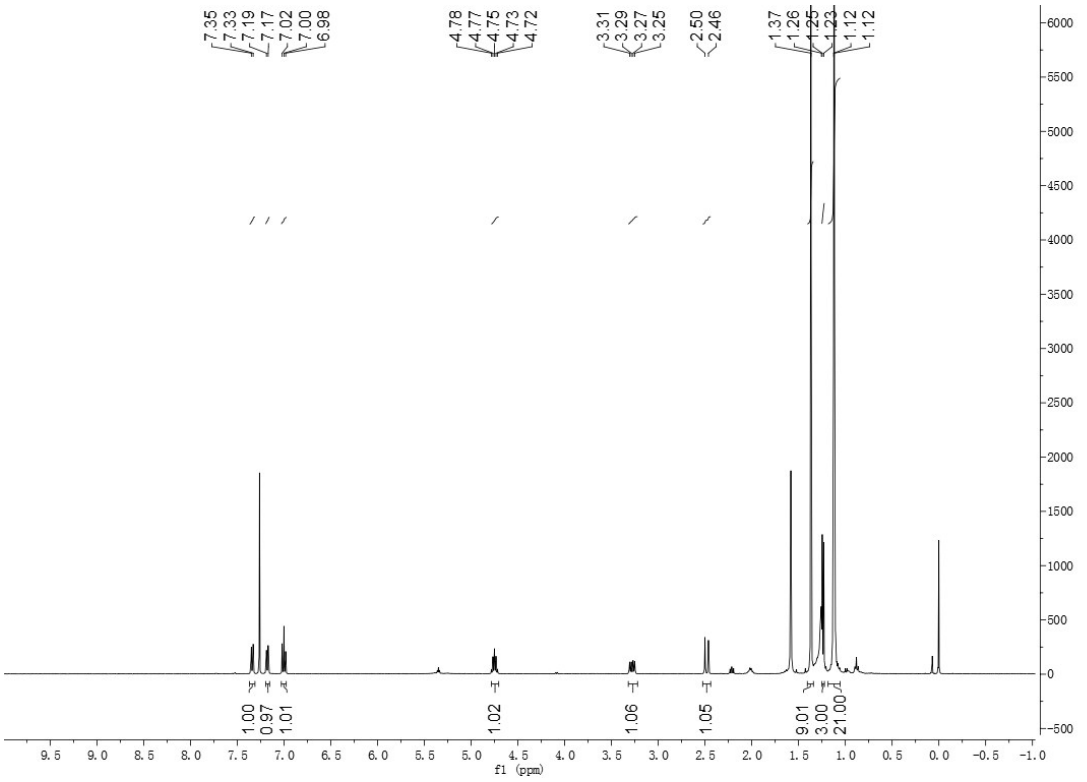
4a


7.34
7.33
7.16
7.16
7.15
7.14
6.99
6.97
6.95
4.16
4.14
4.12
3.04
3.02
3.00
1.37
1.13
1.12
1.00
1.00
1.00
2.01
2.01
9.00
21.00
f1 (ppm)


176.64
145.28
134.15
132.75
124.23
123.84
115.14
104.50
96.70
50.77
39.71
30.68
28.31
18.77
11.34
f1 (ppm)


N
O
TIPS

4b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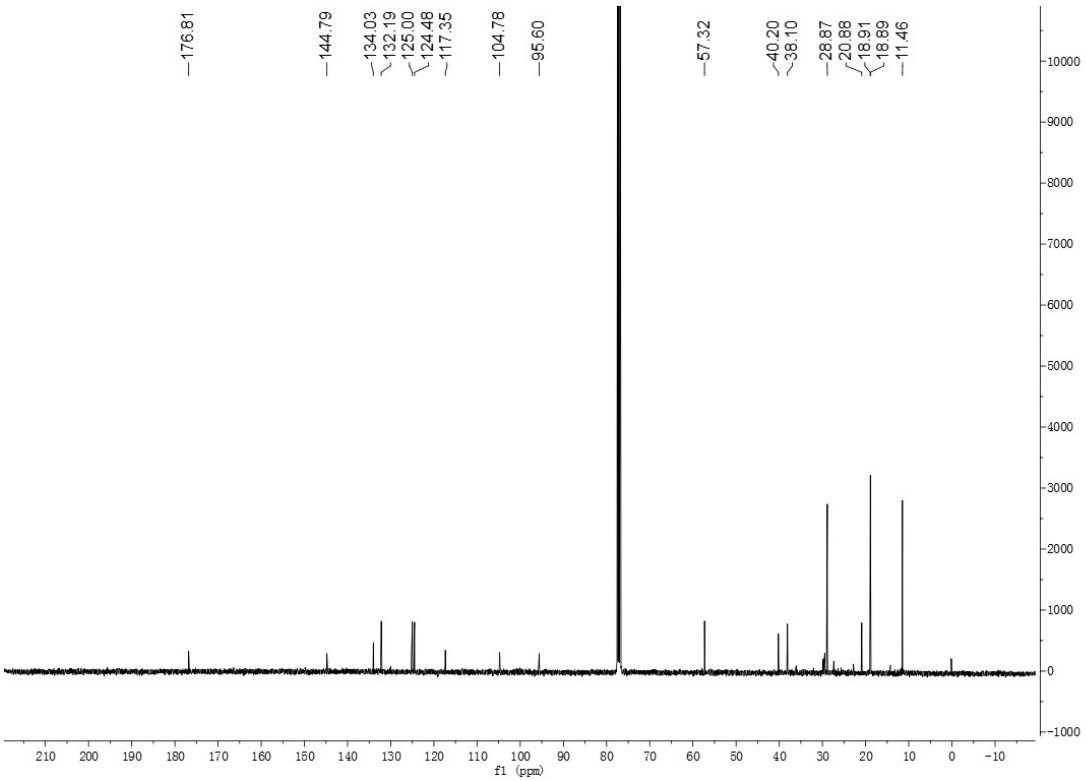
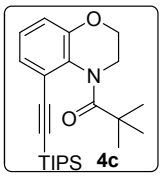
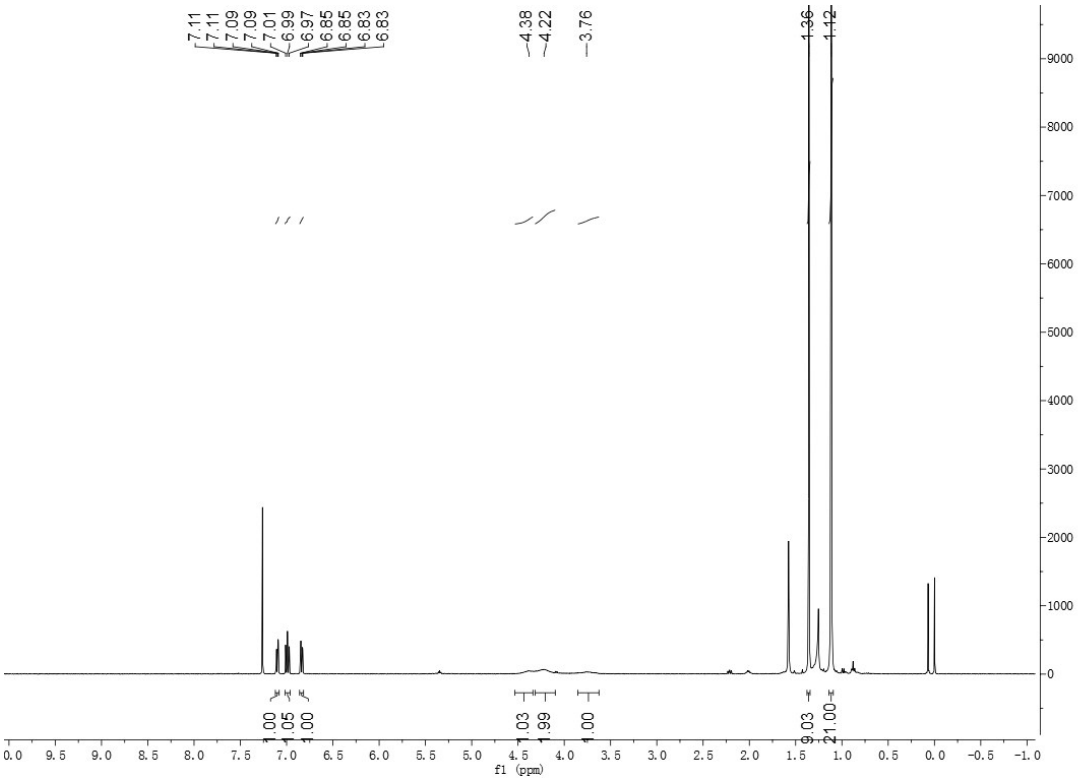
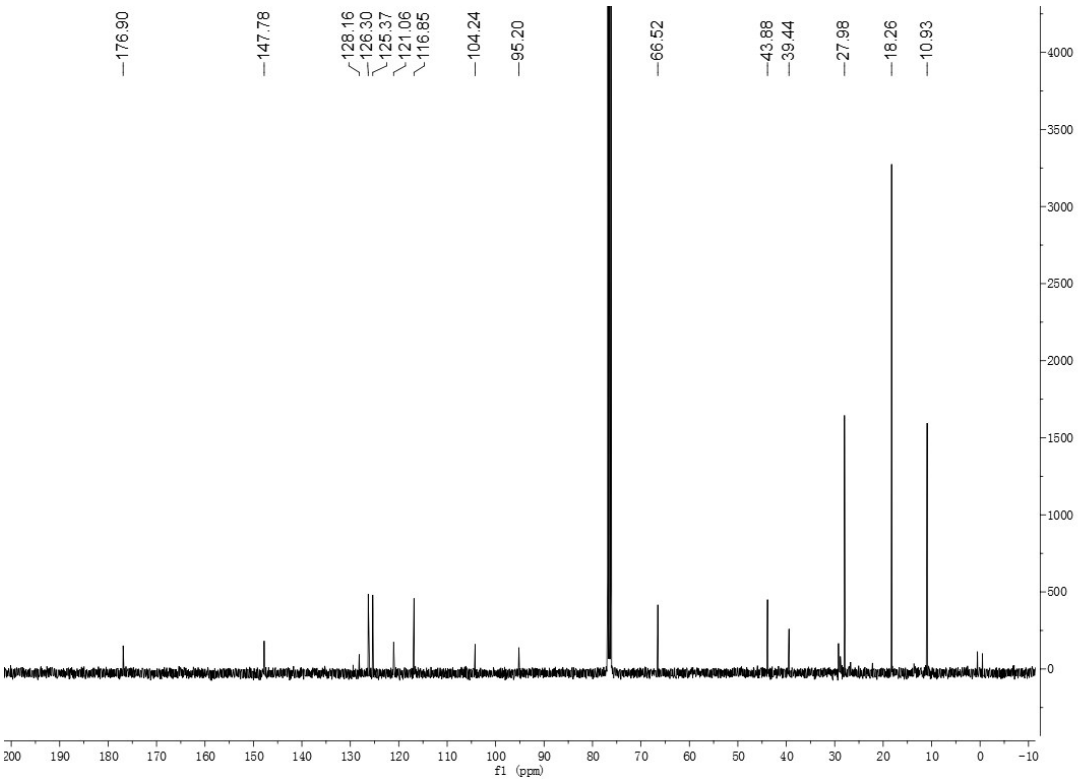
7.33
7.19
7.17
7.02
7.00
6.98
4.78
4.77
4.75
4.73
4.72
3.31
3.29
3.27
3.25
2.50
2.46
1.37
1.26
1.25
1.23
1.12
1.12
1.00
0.97
1.01
1.02
1.06
1.05
9.01
3.00
21.00
f1 (ppm)


176.81
144.79
134.03
132.19
125.00
124.48
117.35
104.78
95.60
57.32
40.20
38.10
28.87
20.88
18.91
18.89
11.46
f1 (ppm)


O
N
O
TIPS

4c


7.11
7.11
7.09
7.09
7.01
6.99
6.97
6.85
6.85
6.83
6.83
4.38
4.22
3.76
1.36
1.12
1.00
1.05
1.00
1.03
1.99
1.00
9.03
21.00
f1 (ppm)


176.90
147.78
128.16
126.30
125.37
121.06
116.85
104.24
95.20
66.52
43.88
39.44
27.98
18.26
10.93
f1 (ppm)