Supporting information

Regiodivergent Electroreductive Defluorinative Carboxylation of *gem*-Difluorocyclopropanes

Bin Zhao, Zichen Pan, Jiayu Pan, Hongping Deng, Xiaoli Bu, Mengtao Ma, Fei Xue

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1. General Information

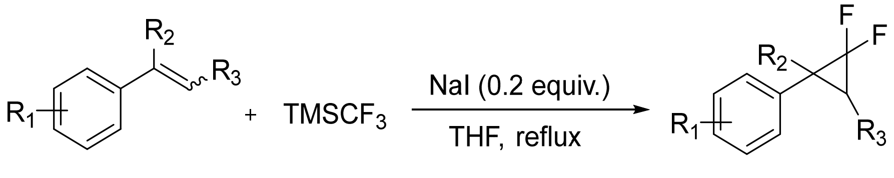
All anaerobic and moisture-sensitive manipulations were carried out with standard Schlenk techniques under nitrogen gas. Analytical thin-layer chromatography (TLC) was performed on silica gel, irradiation with UV light. For column chromatography, 200-300 mesh silica gel was used. NMR spectra were recorded on a BRUKER 600 MHz (or 400 Hz) spectrometer and ^{13}C NMR spectra were recorded in $CDCl_3$ or D_2O at 600 MHz (or 400 Hz). ^{1}H and ^{13}C NMR were referenced to $CDCl_3$ at δ 7.26 and 77.00 respectively. The following abbreviations were used to explain the multiplicities; s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (doublet of doublets), dq (doublet of quartets), dt (double of triplets), td (triple of double); coupling constants (J) are in Hertz (Hz). HRMS spectra were recorded on a Xevo G2-XS QTof (Waters Corporation) using electrospray ionization. DC power supply MT-152D was used for all experiments.

Pictures of the reaction setups

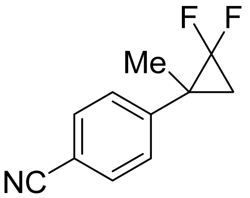
2. Preparation of the substrates

2.1 General procedure A:

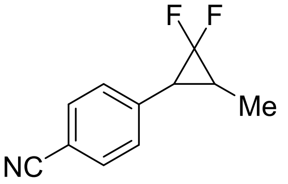
Synthesis of *gem*-difluorinated cyclopropanes



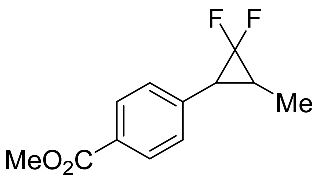
The *gem*-difluorocyclopropanes were prepared according to the known procedure.[1-6] To a 250 mL pressure tube charged with a tefloncoated stir bar was added anhydrous NaI (0.3 g, 2.0 mmol, 0.2 equiv), 50.0 mL of freshly distilled THF as solvent, and the corresponding alkene (10.0 mmol, 1.0 equiv) in that order under argon atmosphere. To this mixture was added $TMSCF_3$ (3.6 g, 25.0 mmol, 2.5 equiv). The reaction vessel was sealed and reflux in an oil bath for a period of 4 h. The reaction mixture was evaporated to dryness under reduced pressure to remove THF. The crude was extracted with ether (30.0 mL) and washed with water (20.0 mL), saturated Na_2SO_3 solution (20.0 mL), saturated $NaHCO_3$ solution (20.0 mL), and water (20.0 mL), in that order. The ether layer was then collected and dried over anhydrous Na_2SO_4. The ether layer was evaporated under reduced pressure to obtain the crude products. The crude products were purified by flash chromatography on silica gel (PE/EA) to afford the desired products. The gem-difluorinated cyclopropanes. Characterization of new *gem*-difluorocyclopropanes **1d, 1e, 1m-1r, 1t, 1v, 1w** are listed below.



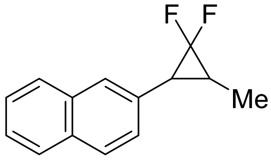
4-(2,2-difluoro-1-methylcyclopropyl)benzonitrile (1m). $R_f = 0.5$ (PE: EA = 40:1). The reaction was conducted with General Procedure A. Isolated yield: 1.25 g, 65%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.63-7.62 (m, 2H), 7.42 (d, J = 8.3 Hz, 2H), 1.72-1.67 (m, 1H), 1.52-1.51 (m, 1H), 1.50-1.47 (m, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 144.4, 132.4, 129.3 (d, $J_{C-F} = 1.5$ Hz), 118.6, 113.7 (dd, $J_{C-F} = 290.8, 286.6$ Hz), 111.2, 31.0 (t, $J_{C-F} = 10.7$ Hz), 22.7 (t, $J_{C-F} = 10.0$ Hz), 20.8 (d, J = 4.9 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -132.3 (dd, J = 151.9, 13.3 Hz, 1F), -137.3(dd, J = 151.8, 11.9 Hz, 1F)**. HRMS (ESI):** calculated for $C_{11}H_{10}F_2N$ $[M+H]^+$: 194.0776; Found: 194.0778.



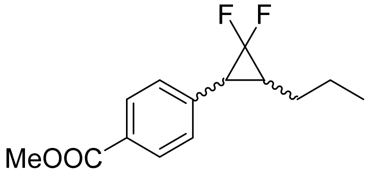
4-(2,2-difluoro-3-methylcyclopropyl)benzonitrile (1n). $R_f= 0.5$ (PE: EA = 40:1). The reaction was conducted with General Procedure A. **1n** was prepared from (E)-4-(prop-1-en-1-yl)benzonitrile. Isolated yield: 1.25g, 65%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.58 (d, J = 8.3 Hz, 2H), 7.28 (d, J = 8.3 Hz, 2H), 2.31 (dd, J = 13.3, 7.6 Hz, 1H), 1.92-1.86 (m, 1H), 1.36 (dd, J = 6.36, 1.6 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 140.0, 132.2, 128.5, 118.7, 114.1 (dd, J_{C-F} = 292.0, 289.3 Hz), 110.7, 34.1 (t, $J_{C-F} = 11.2$ Hz), 25.4 (t, $J_{C-F} = 9.9$ Hz), 11.3 (d, J = 5.2 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -137.0 ~ -136.7 (m, 1F), -138.0 ~ -137.7(m, 1F)**. HRMS (ESI):** calculated for $C_{11}H_{10}F_2N$ $[M+H]^+$: 194.0776; Found: 194.0780.



Methyl 4-(2,2-difluoro-3-methylcyclopropyl)benzoate (1o). R_f = 0.5 (PE: EA = 40:1). The reaction was conducted with General Procedure A. Isolated yield: 1.81 g, 80%. R_f = 0.5 (PE: EA = 40:1). The reaction was conducted with General Procedure. **1o** was prepared from a mixture of cis and trans methyl 4-(prop-1-en-1-yl)benzoate. Isolated yield: 1.25g, 65 %. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.98 (d, J = 8.4 Hz, 2H), 7.25 (d, J = 8.3 Hz, 2H), 3.91 (s, 3H), 2.31 (dd, J = 13. 7, 7.6 Hz, 1H), 1.93-1.86 (m, 1H), 1.36 (dd, J = 6.36, 1.56 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 166.8, 139.7, 129.7, 128.7, 127.7, 114.4 (dd, J_{C-F} = 291.7, 289.7 Hz), 52.1, 34.1 (t, J_{C-F} = 11.1 Hz), 25.0 (t, J_{C-F} = 10.4 Hz), 11.4 (d, J = 4.9 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -136.8 ~ -137.1 (m, 1F), -137.9 ~ -138.2 (m, 1F). **HRMS (ESI):** calculated for $C_{12}H_{13}F_2O_2$ $[M+H]^+$: 227.0878, Found: 227.0876.



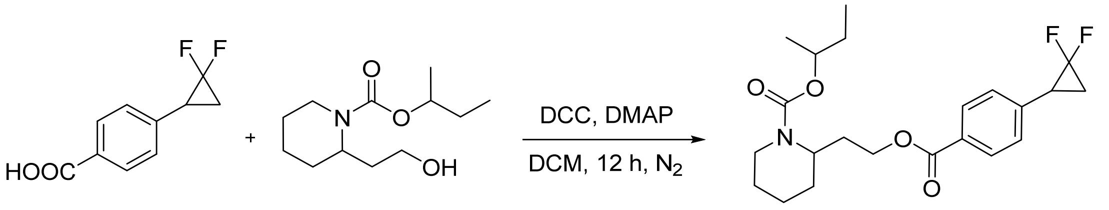
2-(2,2-difluoro-3-methylcyclopropyl)naphthalene (1p). R_f = 0.5 (PE: EA = 40:1). The reaction was conducted with General Procedure A. **1p** is prepared from a mixture of cis and trans 2-(prop-1-en-1-yl)naphthalene. Isolated yield: 1.66 g, 76%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.83-7.79 (m, 3H), 7.67 (s, 1H), 7.50-7.45 (m, 2H), 7.33-7.32 (m, 1H), 2.46 (dd, J = 13.6, 7.6 Hz, 1H), 2.01-1.94 (m, 1H), 1.42-1.40 (m, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 133.3, 132.4, 131.7, 128.1, 127.65, 127.60, 126.5, 126.3, 126.1, 125.8, 114.8 (dd, J_{C-F} = 290.0, 289.1 Hz) 34.2 (t, J_{C-F} = 10.8 Hz), 24.4 (dd, J_{C-F} = 19.9 Hz), 11.5 (d, J = 5.3 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -137.0 ~ -137.3 (m, 1F), -137.7 ~ -138.0 (m, 1F). **HRMS (ESI):** calculated for $C_{14}H_{13}F_2$ $[M+H]^+$: 219.0980; Found: 219.0982.



Methyl 4-(2,2-difluoro-3-propylcyclopropyl)benzoate (1q). R_f = 0.5 (PE: EA = 40:1). The reaction was conducted with General Procedure A. The mixture of cis and trans **1q** were prepared from a mixture of cis and trans methyl 4-(pent-1-en-1-yl)benzoate Isolated yield: 1.60g, 63 %. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.83-7.79 (d, J = 2.0 Hz, 2H), 7.99 (d, J = 2.0 Hz, 2H), 7.37 (d, J = 8.2 Hz, 2H), 7.28 (d, J = 8.4 Hz, 2H), 3.92 (s, 3H), 3.92 (s, 3H), 2.84-2.80 (m, 1H), 2.39-2.36 (m, 1H), 1.95-1.83 (m, 2H), 1.74-1.61 (m, 2H), 1.59-1.51 (m, 2H), 1.41-1.36 (m, 2H), 1.37-1.31 (m, 1H), 1.18-1.10 (m, 1H), 0.99 (t, J = 7.3 Hz, 3H), 0.87 (t, J = 7.2 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 166.9, 166.8, 139.8, 137.7, 129.9, 129.8, 129.7, 129.5, 128.8, 128.7, 128.2, 127.8, 114.6 (dd, J_{C-F} = 289.3,287.4 Hz), 114.4 (dd, J_{C-F} = 291.5, 290.0 Hz), 52.1, 33.3 (t, J_{C-F} = 11.1 Hz), 30.4 (dd, JC-F = 10.6, 8.9 Hz), 28.9 (dd, J_{C-F} = 12.9, 9.6 Hz), 28.71, 28.69, 27.9 (t, J_{C-F} = 10.0 Hz), 24.3 (d, J_{C-F} = 2.9 Hz), 21.9, 21.8, 13.53, 13.52. **HRMS (ESI):** calculated for $C_{14}H_{17}F_2O_2$ $[M+H]^+$: 255.1191; Found: 255.1190.

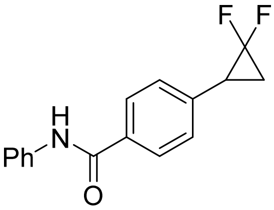
2.2 Procedure B

One typical example for the preparation of complex compounds and drug derivatives

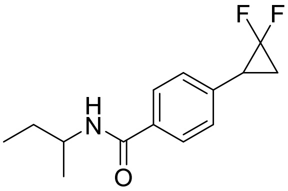


4-(2,2-difluorocyclopropyl)benzoic acid (0.99 g, 5 mmol) was dissolved in dry CH_2Cl_2 (25 mL) under

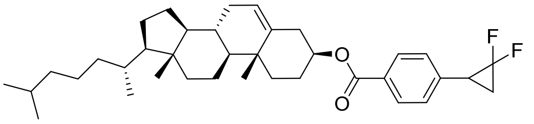
N_2 atmosphere and sec-butyl 2-(2-hydroxyethyl)piperidine-1-carboxylate (1.14 g, 5 mmol), DCC (1.03 g, 5mmol), DMAP (0.61 g, 5 mmol) was slowly added and stirred for 12 h at rt. The organic layer was washed with water and brine, dried over $MgSO_4$, removed by filtration. The crude products were purified by flash chromatography on silica gel (PE/EA) to afford the desired products (1.76 g, 86%).



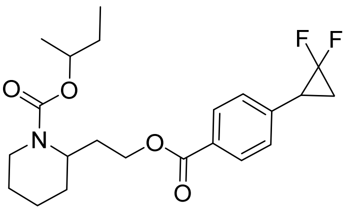
4-(2,2-difluorocyclopropyl)-N-phenylbenzamide (1d). R_f = 0.5 (PE: EA = 5:1). The reaction was conducted with Procedure B. Isolated yield: 1.10 g, 81%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.88 (s, 1H), 7.82 (d, J = 7.6 Hz, 2H), 7.63 (d, J = 7.4 Hz, 2H), 7.36 (t, J = 7.3 Hz, 2H), 7.31 (d, J = 7.5 Hz, 2H), 7.15 (t, J = 7.0 Hz, 2H), 2.82-2.77 (m, 1H), 1.91-1.87 (m, 1H), 1.69-1.67 (m, 1H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 137.9, 133.8, 130.2, 129.1, 128.4, 127.5, 127.2, 124.6, 120.2, 112.3 (dd, J_{C-F} = 1.5 Hz), 118.6, 113.7 (dd, J_{C-F} = 287.8 282.8 Hz), 27.1 (t, J_{C-F} = 11.5 Hz), 17.4 (t, J_{C-F} = 10.5 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -125.6 (dt, J = 153.5, 11.8 Hz, 1F), -142.1 (ddd, J = 153.5, 13.6, 3.5 Hz, 1F)**. HRMS (ESI):** calculated for $C_{16}H_{14}F_2NO$ $[M+H]^+$: 274.1038; Found: 274.1038.



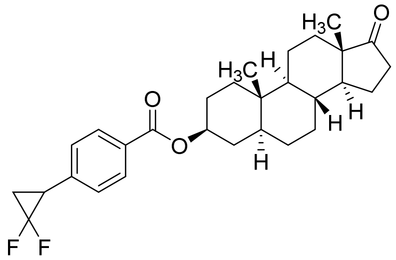
N-(sec-butyl)-4-(2,2-difluorocyclopropyl)benzamide (1e). R_f = 0.5 (PE: EA = 5:1). The reaction was conducted with Procedure B. Isolated yield: 1.05 g, 83%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.71 (d, J = 8.3 Hz, 2H), 7.25 (d, J = 7.9 Hz, 2H), 5.96 (d, J = 7.2 Hz, 1H), 4.13-4.08 (m, 1H), 2.79-2.74 (m, 1H), 1.89-1.83 (m, 1H), 1.67-1.62 (m, 1H), 1.59-1.54 (m, 2H), 1.21 (d, J = 6.6 Hz, 3H), 0.95 (t, J = 7.5 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 166.5, 137.1, 133.9, 128.1, 127.0, 112.3 (dd, J_{C-F} = 287.3, 283.9 Hz), 47.1, 29.8, 27.1 (t, J_{C-F} = 23.2 Hz), 20.5, 17.3 (t, J_{C-F} = 10.5 Hz), 10.4. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -125.6 ~ -125.9 (m, 1F), -142.1 ~ -142.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{14}H_{18}F_2NO$ $[M+H]^+$: 254.1351; Found: 254.1355.



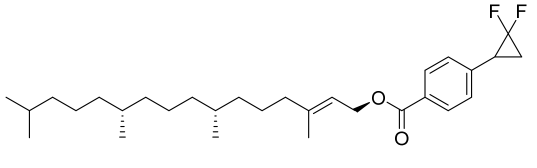
(3S,8S,9S,10R,13R,14S,17R)-10,13-dimethyl-17-((R)-6-methylheptan-2-yl)-2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl-4-(2,2-difluorocyclopropyl)benzoate (1r). R_f = 0.5 (PE: EA = 8:1). The reaction was conducted with Procedure B. Isolated yield: 2.35 g, 83%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.00 (d, J = 8.2 Hz, 2H), 7.28 (d, J = 8.2 Hz, 2H), 5.42 (d, J = 4.0 Hz, 1H), 4.88-4.83 (m, 1H), 2.81-2.76 (m, 1H), 2.46 (d, J = 7.7 Hz, 2H), 2.04-1.10 (m, 25H), 1.07 (s, 3H), 1.04-0.97 (m, 3H), 0.93 (d, J = 6.5 Hz, 3H), 0.87 (dd, J = 6.6, 2.6 Hz, 6H), 0.69 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ165.6, 139.6, 138.7, 129.7, 127.9, 122.8, 112.3 (dd, J_{C-F} = 287.0, 284.7 Hz), 74.6, 56.7, 56.2, 50.1, 42.3, 39.8, 39.5, 38.2, 37.0, 36.7, 36.2, 35.8, 32.0, 31.9, 28.3, 28.0, 27.9, 27.3 (t, J_{C-F} = 11.6 Hz), 24.3, 23.9, 22.8, 22.6, 21.1, 19.4, 18.7, 17.5 (t, J_{C-F} = 10.5 Hz), 11.9. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -125.4 ~ -125.7 (m, 1F), -142.0 ~ -142.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{37}H_{53}F_2O_2$ $[M+H]^+$: 567.4008; Found: 567.4002.



Sec-butyl 2-(2-((4-(2,2-difluorocyclopropyl)benzoyl)oxy)ethyl) piperidine-1-carboxylate (1t) R$_f$ = 0.5 (PE: EA = 10:1). The reaction was conducted with Procedure B. Isolated yield: 1.76 g, 86%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ. 7.99 (d, J = 8.2, 2H), 7.27 (d, J = 8.1 Hz, 2H),4.74-4.70 (m, 1H), 4.51 (s, 1H), 4.32-4.30 (m, 2H), 4.11-4.08 (m, 1H), 2.85 (t, J = 13.0 Hz, 1H), 2.80-2.74 (m, 1H), 2.22-2.17 (m, 1H), 1.90-1.84 (m, 2H), 1.69-1.41 (m, 9H), 1.15 (d, J = 6.3 Hz, 3H), 0.85 (t, J = 7.4 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 166.2, 155.5 (d, $J_{C\text{-}F}$ = 4.6 Hz), 138.9, 129.7, 129.2, 127.9, 112.2 (dd, $J_{C\text{-}F}$ = 287.8, 283.9 Hz), 72.99, 72.96, 62.69, 62.66, 48.0, 39.0, 29.1, 28.9, 28.6, 27.3 (t, $J_{C\text{-}F}$ = 11.6 Hz), 25.5, 19.7, 19.1, 17.5 (t, $J_{C\text{-}F}$ = 10.5 Hz), 9.71, 9.68. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -125.4 ~ -125.7 (m, 1F), -142.1 ~ -142.3 (m, 1F). **HRMS (ESI):** calculated for C$_{22}$H$_{30}$F$_2$NO$_4$ [M+H]$^+$: 410.2137; Found: 410.2137.

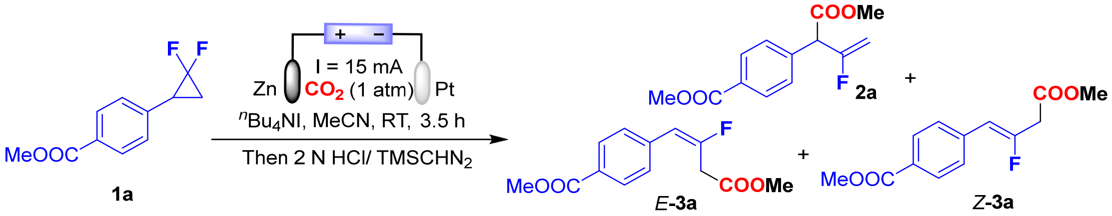


(3S, 5S, 8R, 9S, 10S, 13S, 14S)-10, 13-dimethyl-17-oxohexadecahydro-1H-cyclopenta[a]phenanthren-3-yl 4-(2, 2-difluorocyclopropyl)benzoate (1v). R$_f$ = 0.5 (PE: EA = 5:1). The reaction was conducted with Procedure B. Isolated yield: 1.81 g, 77%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 7.97 (d, J = 8.3, 2H), 7.26 (d, J = 8.2 Hz, 2H), 4.95-4.89 (m, 1H), 2.80-2.74 (m, 1H), 2.42 (dd, J = 19.3, 8.7 Hz, 1H), 2.09-2.02 (m, 1H), 1.94-1.45 (m, 13H), 1.37-1.21 (m, 6 H), 1.12-1.07 (m, 1H), 1.03-0.96 (m, 1H), 0.89 (s, 3H), 0.85 (s, 3H), 0.76-0.72 (m, 1H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ165.7, 138.8, 129.7, 127.8, 112.3 (dd, $J_{C\text{-}F}$ = 287.7, 283.9 Hz), 74.16, 54.3, 51.4, 47.8, 44.7, 36.7, 35.8, 25.7, 35.0, 34.0, 31.5,30.8, 28.3, 27.5, 27.2 (t, $J_{C\text{-}F}$ = 11.6 Hz), 21.8, 20.5, 17.4 (t, $J_{C\text{-}F}$ = 10.6 Hz), 13.8, 12.3. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -125.4 ~ -125.7 (m, 1F), -142.2 (dd, J = 153.9, 12.9, 1F). **HRMS (ESI):** calculated for C$_{29}$H$_{37}$F$_2$O$_3$ [M+H]$^+$: 471.2705; Found: 471.2701

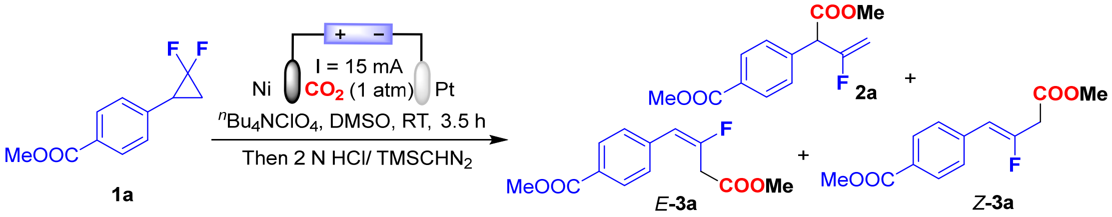


(7R, 11R, E)-3, 7, 11, 15-tetramethylhexadec -2-en-1-yl 4-(2, 2-difluorocyclopropyl)benzoate (1w). R$_f$ = 0.5 (PE: EA = 10:1). The reaction was conducted with Procedure B. Isolated yield: 1.93 g, 81%. **^{1}H NMR (600 MHz, CDCl$_3$)**: δ. 8.01 (d, J = 8.3, 2H), 7.27 (d, J = 8.2 Hz, 2H), 5.47-5.45 (m, 1H), 4.84 (d, J = 7.1 Hz, 2H), 2.81-2.75 (m, 1H), 2.06-2.01 (m, 2H), 1.91-1.84 (m, 1H), 1.76 (s, 3 H), 1.70-1.65 (m, 1H), 1.55- 1.50 (m, 1H), 1.47-1.04 (m, 18H), 0.88-0.84 (m, 12H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$)**: δ166.3, 142.9, 138.8, 129.8, 129.5, 127.9, 118.1, 112.2 (dd, $J_{C\text{-}F}$ = 287.2, 284.5 Hz), 61.9, 39.9, 39.4, 37.43, 37.37, 37.3, 36.6, 32.8, 32.7, 29.7, 28.0, 27.3 (t, $J_{C\text{-}F}$ = 11.6 Hz), 25.0, 24.8, 24.5, 22.7, 22.6, 19.7 (d, J = 4.4 Hz), 17.5 (t, $J_{C\text{-}F}$ = 10.5 Hz), 16.5. **^{19}F NMR (565 MHz, CDCl3):** δ -125.4 ~ -125.7 (m, 1F), -142.0 ~ -142.3 (m, 1F). **HRMS (ESI):** calculated for C$_{30}$H$_{47}$F$_2$O$_2$ [M+H]$^+$: 477.3539; Found: 477.3541.

3. General procedure for the synthesis of compounds 2 and 3

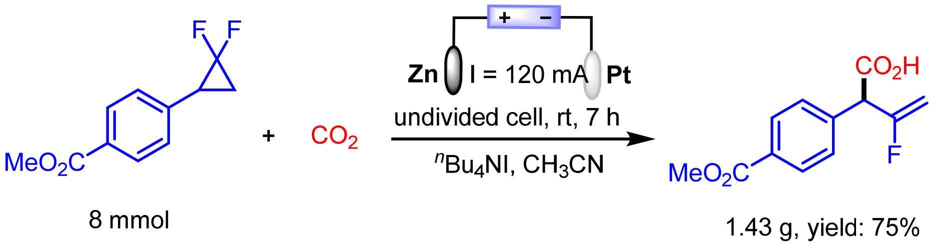


To a 10 mL hydrogenation tube containing a stir bar were added ${}^{n}Bu_4NI$ (74.0 mg, 0.2 mmol, 0.025 M), MeCN (8.0 mL), followed by the addition of **1a** (42.4 mg, 0.2 mmol). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 3.5 h. After that, the reaction mixture was transferred to a 50 mL Erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The crude residue was dissolved in Et_2O (2.0 mL) and MeOH (0.5 mL) and cooled to 0 °C. The hexane solution of $TMSCHN_2$ (0.2 mL, 2.0 mol/L, 0.4 mmol, 2.0 equiv) was added at 0 °C. The mixture was stirred at 0 °C for further 50 min. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using PE/EtOAc (10:1, v/v) as the eluent to afford the desired product **2**.



To a 10 mL hydrogenation tube containing a stir bar were added ${}^{n}Bu_4NClO_4$ (68.2 mg, 0.2 mmol, 0.025 M), DMSO (8.0 mL), followed by the addition of **1a** (42.4 mg, 0.2 mmol). Then the tube was installed with Ni-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 6 h. After that, the reaction mixture was transferred to a 50 mL Erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The crude residue was dissolved in Et_2O (2.0 mL) and MeOH (0.5 mL) and cooled to 0 °C. The hexane solution of $TMSCHN_2$ (0.2 mL, 2.0 mol/L, 0.4 mmol, 2.0 equiv) was added at 0 °C. The mixture was stirred at 0 °C for 50 min. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using PE/EtOAc (10:1, v/v) as the eluent to afford the desired product **3**.

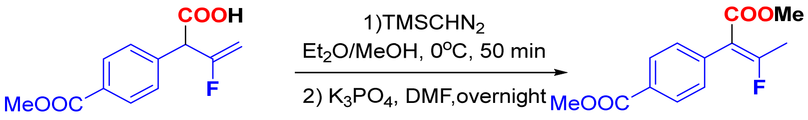
4. Gram-Scale Reaction



To a 100 mL hydrogenation tube containing a stir bar were added ${}^nBu_4NI$ (2.96 g, 8 mmol, 0.1 M), MeCN (80.0 mL), followed by the addition of **1a** (1.70 g, 8 mmol). Then the tube was installed with Zn-plate (30 mm x 30 mm x 0.2 mm) as anode and Pt-plate (30 mm x 30 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 6 h. After that, the reaction mixture was transferred to a 250 mL erlenmeyer flask and acidized with HCl (2 N, 100 mL). The aqueous layer extracted with EtOAc (2 x 50 mL) and the combined organics were washed with H_2O (80 mL), brine (80 mL) and dried over Na_2SO_4. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using PE/EtOAc (3:1, v/v) as the eluent to afford the desired product **2a-H**.

5. Procedure for the product derivatization

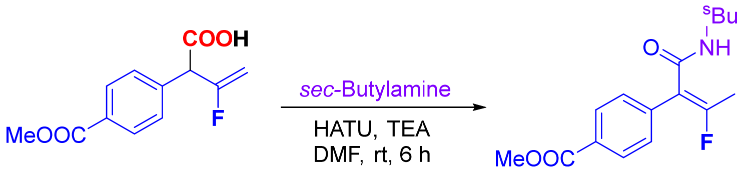
Procedure for the synthesis of 4



4, 78%

To a 10 mL flask were added **2a-H** (0.2 mmol, 47.6 mg), Et_2O (2.0 mL) and MeOH (0.5 mL), and the hexane solution of $TMSCHN_2$ (0.2 mL, 2 mol/L, 0.4 mmol) was added at 0 °C. The mixture was stirred at that temperature for another 50 min. Then the solvent was removed under reduced pressure, and the crude residue was dissolved in DMF (1 mL), followed by the addition of K_3PO_4 (0.2 mmol, 42 mg). The resulting mixture was slowly warmed to room temperature and stirred overnight. After monitored by TLC till full conversion to the product, the reaction was quenched by saturated aqueous solution of NaCl (5 mL) and extracted with Et_2O (5 mL x 3). The combined organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography using PE/EtOAc (10:1, v/v) as eluent to afford **4** in 39.3 mg with 78% yield. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.4 Hz, 2H), 7.30 (d, J = 8.2 Hz, 2H), 3.90(s, 3H), 3.71 (s, 3H), 2.48 (d, J = 19.7 Hz, 3H) . **$^{13}C\{^1H\}$ NMR (151 MHz, $CDCl_3$):** δ 168.6 (d, J_{C-F} = 271.8 Hz), 167.1, 167.0, 166.8, 137.4, 129.9 (d, J_{C-F} = 2.0 Hz), 129.3, 114.8 (d, J_{C-F} = 20.5 Hz), 52.2 (d, J_{C-F} = 4.9 Hz), 17.9, 17.7. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -68.3 (q, J = 19.7 Hz, 1F). HRMS (ESI): calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0875.

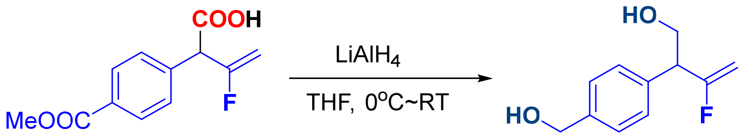
Procedure for the synthesis of 5



5, 85%

The carboxylic acid **2a-H** (0.2 mmol, 47.6 mg) was dissolved in DMF (2 mL), then sec-butylamine (21.9 mg, 0.3 mmol), *o*-(7-Azabenzotriazol-1-yl)-N,N,N',N'-tramethyluronium hexafluorophosphate (HATU, 152.0 mg, 0.4 mmol) and Et_3N (60.7 mg, 0.6 mmol) were added. The resulting mixture was stirred for 6 h at room temperature till full conversion of **2a-H**. Then the reaction was quenched with H_2O and extracted with EtOAc (3 x 10 mL). The combined organic layer was dried over Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography using PE/EtOAc (3:1, v/v) as eluent to afford **5** (85%, 49.8 mg). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.05 (d, J = 8.4 Hz, 2H), 7.40 (d, J = 8.2 Hz, 2H), 3.97-3.93 (m, 1H), 3.92 (s, 3H), 2.41 (d, J = 19.5 Hz, 3H), 1.44-1.33 (m, 2H), 1.06 (d, J = 6.6 Hz, 3H), 0.84 (t, J = 7.5 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 166.6, 165.8 (d, $J_{C\text{-}F}$ = 14.1 Hz), 163.7 (d, $J_{C\text{-}F}$ = 267.9 Hz), 137.7, 129.9, 129.6, 129.5 (d, $J_{C\text{-}F}$ = 3.2 Hz), 116.8 (d, $J_{C\text{-}F}$ = 14.9 Hz), 52.2, 47.1, 29.4, 20.2, 17.3 (d, $J_{C\text{-}F}$ = 26.8), 10.3. ^{19}F NMR (565 MHz, $CDCl_3$): δ -79.3 (q, J = 19.3 Hz, 1F). HRMS (ESI): calculated for $C_{16}H_{21}FNO_3$ $[M+H]^+$: 294.1500; Found: 294.1505.

Procedure for the synthesis of 6

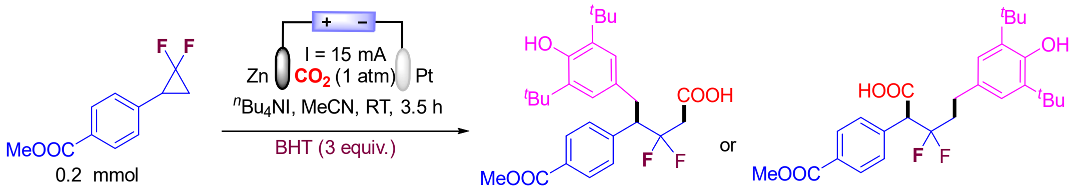


6, 50%

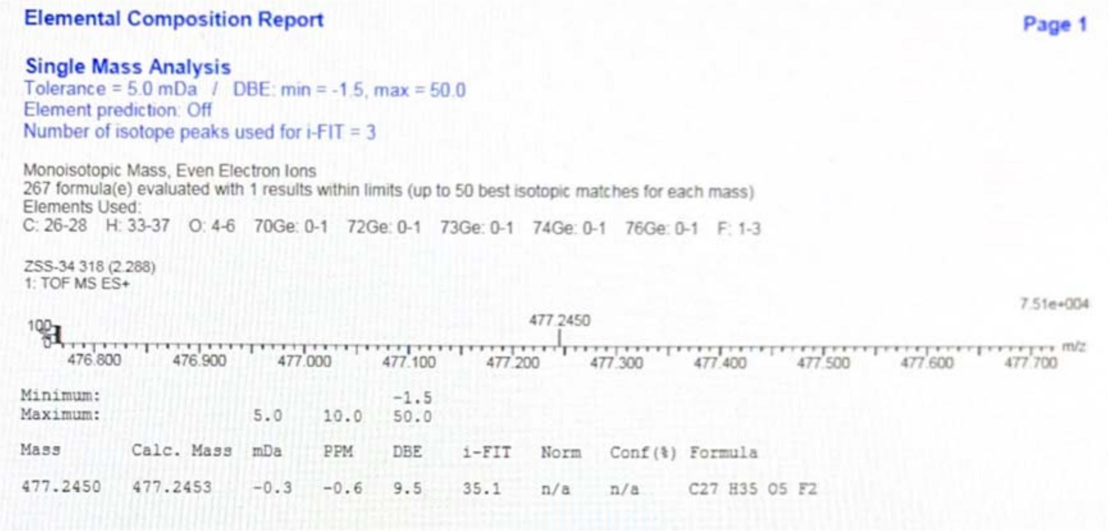
The carboxylic acid **2a-H** (0.2 mmol, 47.6 mg) was dissolved in anhydrous THF (1 mL) and cooled to 0 °C under an N_2 atmosphere. A solution of $LiAlH_4$ (1M in THF) 0.4 ml was added dropwise at 0 °C before the reaction was warmed to rt, and stirred then for 3 h. The reaction was cooled to 0°C before being carefully quenched with water. The solution was extracted with EtOAc (10 mL) and the combined organics dried over $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by silica-gel column chromatography to give the product **6** (50%, 19.6 mg). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.36 (d, J = 8.1 Hz, 2H), 7.31 (d, J = 8.0 Hz, 2H), 4.76 (dd, J = 18.0, 3.1 Hz, 1H), 4.68 (s, 2H), 4.45 (dd, J = 50.4, 3.1 Hz, 1H), 4.02 (dd, J = 11.0, 7.4 Hz, 1H), 3.88 (dd, J = 11.0, 6.7 Hz, 1H), 3.77-3.68 (m, 1H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ165.1 (d, $J_{C\text{-}F}$ = 259.9 Hz), 140.3, 136.8, 128.4, 127.5, 92.3 (d, $J_{C\text{-}F}$ = 19.5 Hz), 64.9, 63.6 (d, $J_{C\text{-}F}$ = 4.2 Hz), 51.1 (d, $J_{C\text{-}F}$ = 25.1 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -98.9 ~ -99.1. **HRMS (ESI):** calculated for $C_{11}H_{14}FO_2$ $[M+H]^+$: 197.0972; Found: 197.0973.

6. Control experiments

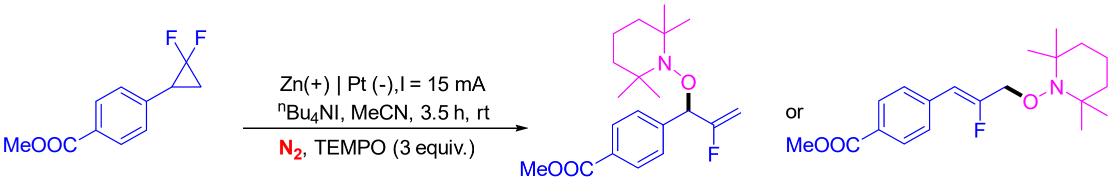
6.1 Radical trapping experiment



To a 10 mL hydrogenation tube containing a stir bar were added ${}^{n}Bu_4NI$ (74.0 mg, 0.2 mmol, 0.025 M), MeCN (8.0 mL), followed by the addition of **1a** (42.4 mg, 0.2 mmol) and BHT (132.2 mg, 0.6 mmol). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 3.5 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. Then the BHT-adduct was detected by HRMS (ESI, m/z), calculated for $[C_{27}H_{34}F_2O_5+H]^+$: 477.2453; Found: 477.2450.



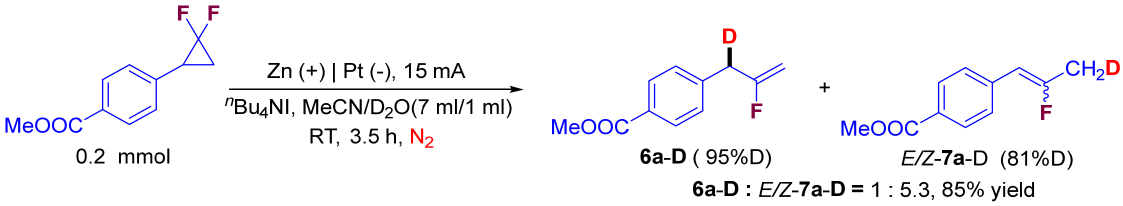
```
Elemental Composition Report                                          Page 1

Single Mass Analysis
Tolerance = 5.0 mDa  /  DBE: min = -1.5, max = 50.0
Element prediction: Off
Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions
267 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)
Elements Used:
C: 26-28   H: 33-37   O: 4-6   70Ge: 0-1   72Ge: 0-1   73Ge: 0-1   74Ge: 0-1   76Ge: 0-1   F: 1-3

ZSS-34 318 (2.288)
1: TOF MS ES+

Minimum:                                 -1.5
Maximum:                      5.0    10.0    50.0

Mass       Calc. Mass   mDa    PPM    DBE    i-FIT   Norm   Conf(%)  Formula

477.2450   477.2453     -0.3   -0.6   9.5    35.1    n/a    n/a      C27 H35 O5 F2
```



In an oven-dried undivided two-necked bottle (10 mL) equipped with a stir bar, *gem*-difluorocyclopropanes **1a** (0.2 mmol, 42.4 mg), ${}^{n}Bu_4NI$ (0.2 mmol, 74.0 mg) and TEMPO (93.7 mg, 0.6 mmol) were combined and added. The bottle was equipped with Zn-plate (10 mm × 10 mm × 0.2 mm) as the anode and Pt-plate (10 mm × 10 mm × 0.1 mm) as the cathode and was then charged with nitrogen. Under the protection of N_2, MeCN (8.0 mL) were injected respectively into the tubes via syringes. The reaction mixture was stirred and electrolyzed at a constant current of 15 mA at 25°C for 3.5 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. Then the TEMPO-adduct was detected by HRMS (ESI, m/z), calculated for $[C_{20}H_{28}FNO_3+H]^+$: 350.2126; Found: 350.2126.

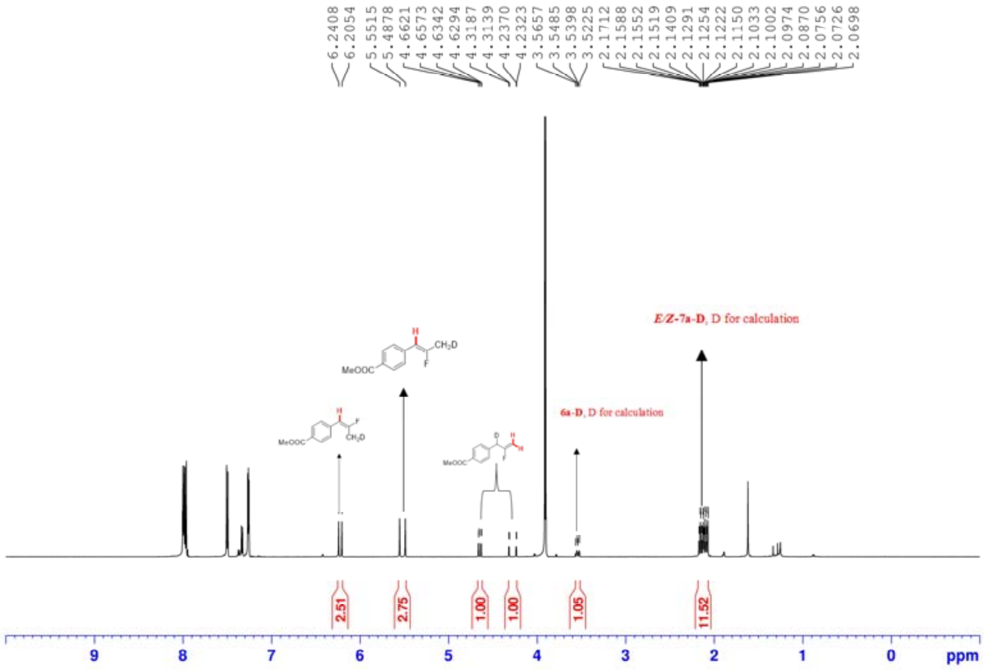
```
Elemental Composition Report                                              Page 1

Single Mass Analysis
Tolerance = 5.0 mDa  /  DBE: min = -1.5, max = 50.0
Element prediction: Off
Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions
4 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)
Elements Used:
C: 20-21    H: 27-32    N: 0-2    O: 3-4    F: 0-1

ZSS-470-9-1 289 (2.080)
1: TOF MS ES+

Minimum:                                  -1.5
Maximum:                   5.0     10.0    50.0

Mass       Calc. Mass    mDa     PPM     DBE     i-FIT    Norm    Conf(%)  Formula

350.2126   350.2131      -0.5    -1.4    6.5     26.2     n/a     n/a      C20 H29 N O3 F
```

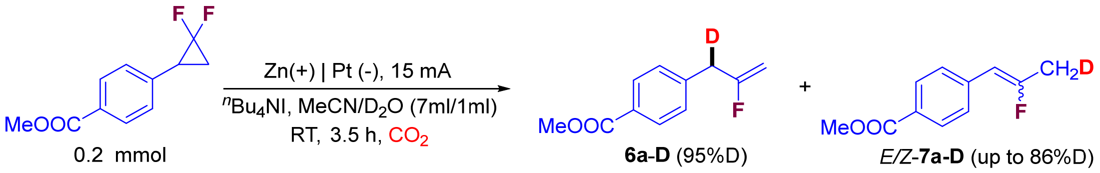
6.2 D-labeling experiments



In an oven-dried undivided two-necked bottle (10 mL) equipped with a stir bar, *gem*-difluorocyclopropanes **1a** (0.2 mmol, 42.4 mg), and $^{n}Bu_4NI$ (0.2 mmol, 74.0 mg) were combined and added. The bottle was equipped with Zn-plate (10 mm × 10 mm × 0.2 mm) as the anode and Pt-plate (10 mm × 10 mm × 0.1 mm) as the cathode and was then charged with nitrogen. Under the protection of N_2, D_2O (1.0 mL) and MeCN (8.0 mL) were injected respectively into the tubes via syringes. The reaction mixture was stirred and electrolyzed at a constant current of 15 mA at 25°C for 3.5 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using petroleum ether as the eluent to afford the desired product (total yield: 85%).

*The ^{1}H NMR spectrums were provided as below pictures. (Compounds **6a-D**, **E-7a-D** and **Z-7a-D** couldn't be separated by column chromatography, the mixture of them were provided as shown in below picture.*





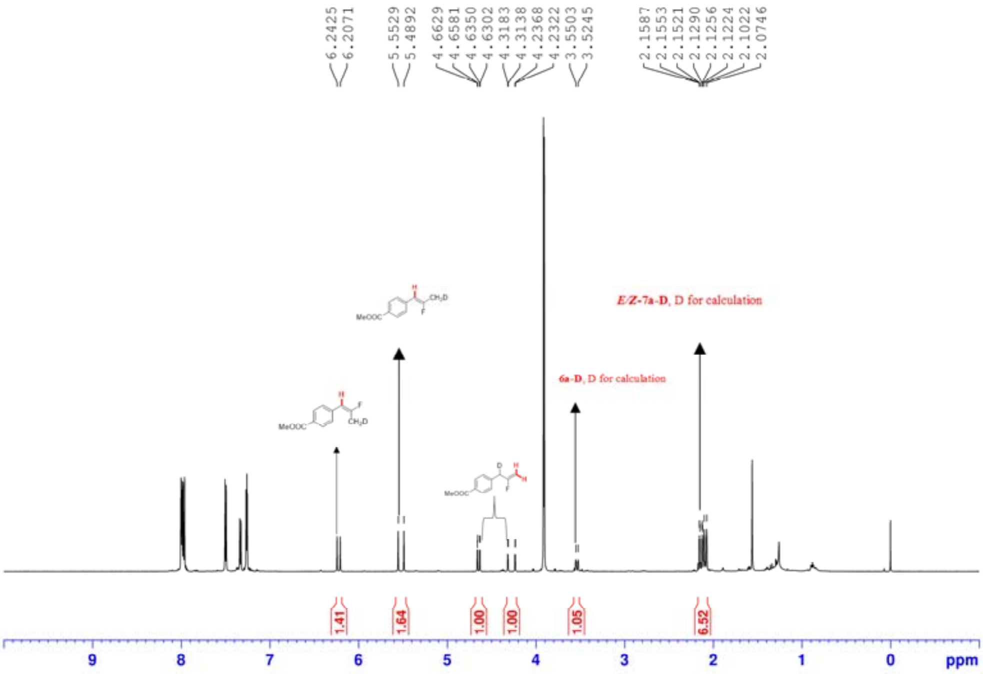
6a-D (95%D)

E/Z-**7a-D** (up to 86%D)

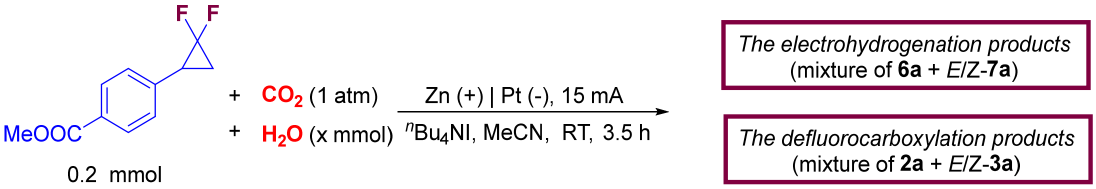
6a-D : *E/Z*-**7a**-D = 1.0 : 3.1, 43% yield

To a 10 mL hydrogenation tube containing a stir bar were added ${}^{n}Bu_4NI$ (74.0 mg, 0.2 mmol, 0.025 M), MeCN (7.0 mL), D_2O (1.0 mL) followed by the addition of **1a** (42.4 mg, 0.2 mmol). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 6 h. After that, the reaction mixture was transferred to a 50 mL Erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using petroleum ether as the eluent to afford the desired product (total yield: 43%).

*The ^1H NMR spectrums were provided as below pictures. (Compounds **6a-D**, **E-7a-D** and **Z-7a-D** couldn't be separated by column chromatography, the mixture of them were provided as shown in below picture.*



6.3 Competitive experiment between CO_2 and H_2O



To a 10 mL hydrogenation tube containing a stir bar were added ^{n}Bu$_4$NI (74.0 mg, 0.2 mmol, 0.025 M), MeCN (8.0 mL), followed by the addition of **1a** (42.4 mg, 0.2 mmol) and H_2O (36 µL, 2 mmol or 108µL, 6mmol). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. After bubbling of CO_2 gas into the electrolytes for 10 min, The reaction mixture was stirred and electrolyzed at a constant current of 15 mA at 25 °C for 3.5 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using PE: EtOAc (3:1, v/v) as the eluent to afford the defluorocarboxylation products (total yield: 52% and 62%).

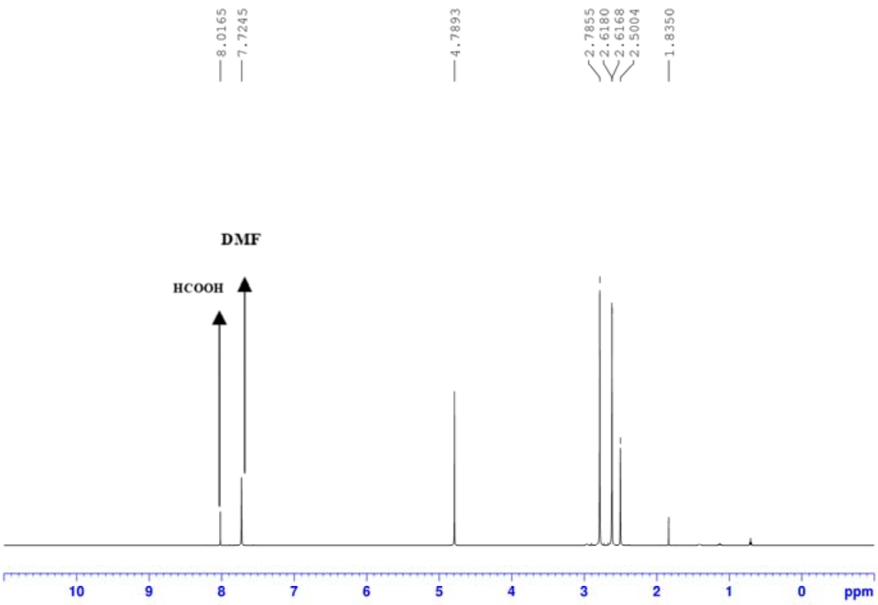
6.4 The investigation of CO_2 radical anion

$$CO_2\ (1\ \text{atm}) \xrightarrow[\text{3.5 h,}\ ^{n}\text{Bu}_4\text{NI, DMF, RT, 3.5 h}]{\text{Zn (+) | Pt (-), 15 mA}} \text{HCOOH}$$

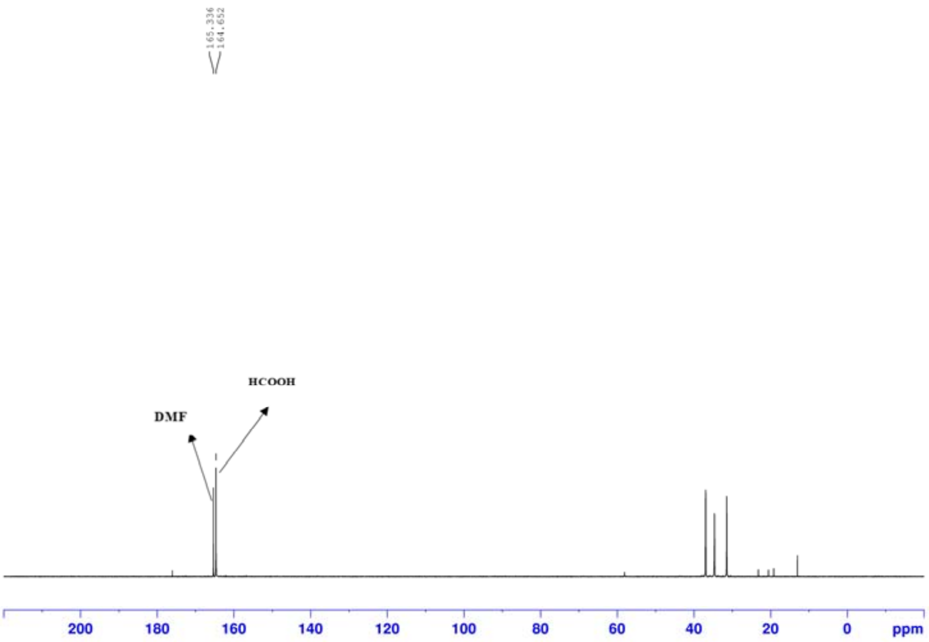
detected by NMR

To a 10 mL hydrogenation tube containing a stir bar were added ^{n}Bu$_4$NI (74.0 mg, 0.2 mmol, 0.025 M), DMF (8.0 mL). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. The resulting mixture was bubbled with CO_2 gas for 10 min. The reaction mixture was then stirred and electrolyzed at a constant current of 15 mA with a constant CO_2 flow for 6 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N). The aqueous layer was collected and concentrated in vacuo, and 2.0 mL D_2O was added. The aqueous phase was analyzed by crude ^{1}H NMR and ^{13}C NMR. The formic acid was detected. [8-9]

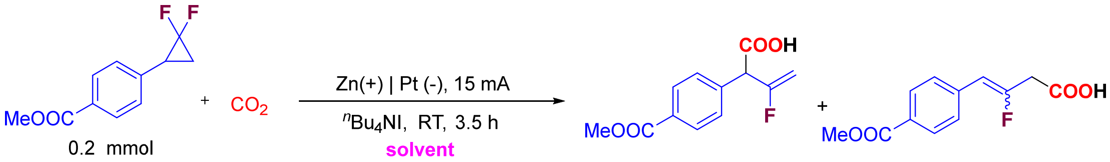
Crude ^{1}**H NMR** spectrum of the aqueous



Crude ^{13}**C NMR** spectrum of the aqueous



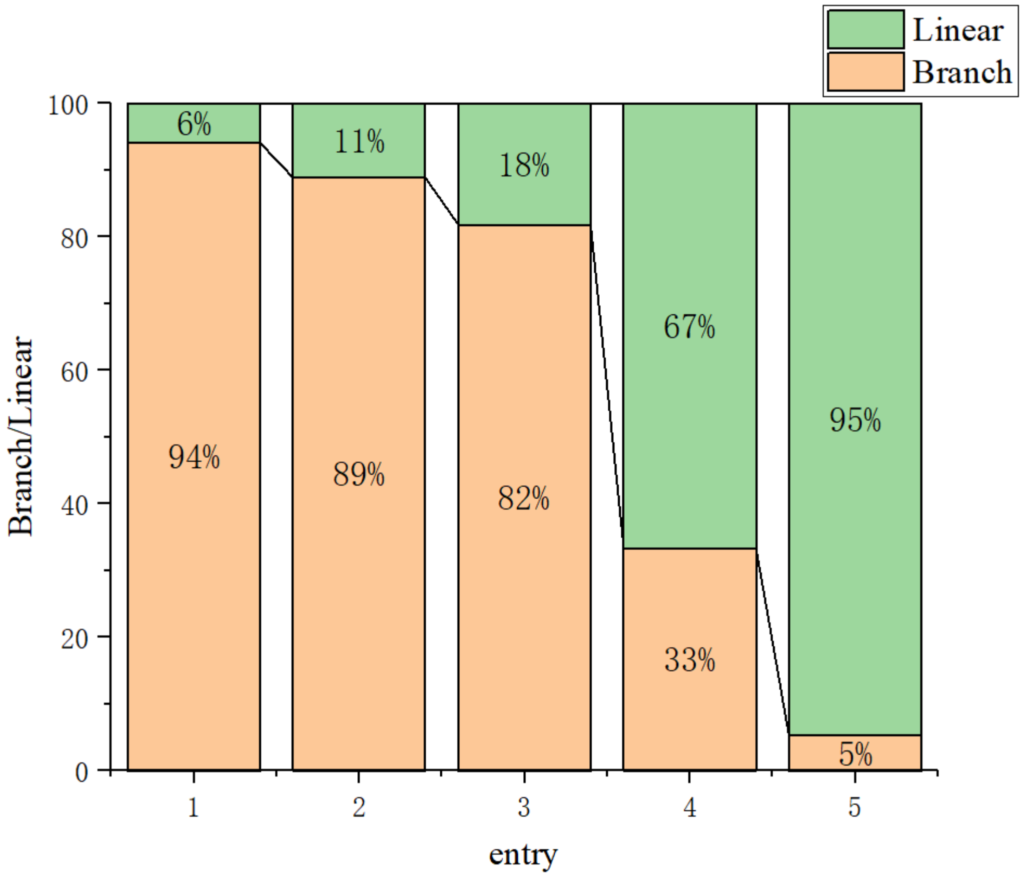
6.5 The effect of mixture solvent (Ch3CN/DMSO) on reaction



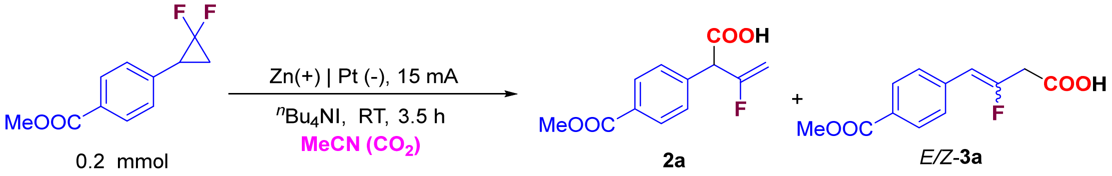
To a 10 mL hydrogenation tube containing a stir bar were added ^{n}Bu$_4$NI (74.0 mg, 0.2 mmol, 0.025 M), MeCN/DMSO (**x**/**y** mL), followed by the addition of **1a** (42.4 mg, 0.2 mmol). Then the tube was installed with Zn-plate (10 mm x 10 mm x 0.2 mm) as anode and Pt-plate (10 mm x 10 mm x 0.1 mm) as cathode. Firstly, Bubbling of CO_2 gas into the mixture solvent for 10 min, the reaction mixture was stirred and electrolyzed at a constant current of 15 mA at 25 ºC for 3.5 h. After that, the reaction mixture was transferred to a 50 mL Erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. Part of the organics was concentrated and applied to ^{1}H NMR analysis to determine the ratio of branched/linear product. See table 1.

Table S1. The ratio of branched/linear products

entry	solvent	Ratio of **2a/3a** (b/l)
1	MeCN (8 mL)	16/1
2	MeCN/DMSO (7 mL/1 mL)	8/1
3	MeCN/DMSO (6 mL/2 mL)	9/2
4	MeCN/DMSO (4 mL/4 mL)	1/2
5	DMSO (8 mL)	1/18



6.6 The effect of concentration of carbon dioxide in acetonitrile



In an oven-dried undivided two-necked bottle (10 mL) equipped with a stir bar, *gem*-difluorocyclopropanes **1a** (0.2 mmol, 42.4 mg), and ^{n}Bu$_4$NI (0.2 mmol, 74.0 mg) were combined and added. The bottle was equipped with Zn-plate (10 mm × 10 mm × 0.2 mm) as the anode and Pt-plate (10 mm × 10 mm × 0.1 mm) as the cathode and was then charged with nitrogen. Under the protection of N_2, CO_2-saturated-MeCN (bubbling of CO_2 gas into the MeCN (8.0 mL) for 30 min) were injected into the two-necked bottle via syringes. The reaction mixture was stirred and electrolyzed at a constant current of 15 mA at 25 °C for 3.5 h. After that, the reaction mixture was transferred to a 50 mL erlenmeyer flask and acidized with HCl (2 N, 10 mL). The aqueous layer extracted with EtOAc (3 x 10 mL) and the combined organics were washed with H_2O (10 mL), brine (10 mL) and dried over Na_2SO_4. The volatile was removed under reduced pressure and the crude residue was purified by column chromatography using petroleum ether as the eluent to afford the desired products.

Table S2. The ratio of branched/linear products

entry	Solvent	Ratio of **2a/3a** (b/l)
1	Saturated CO_2 in MeCN (8 mL)	4/1
2	Saturated CO_2 in MeCN (4 mL) + dry MeCN (4 mL)	3/1

7. Cyclic voltammetry

The cyclic voltammetry was carried out with a Wuhai Corrtest CS310H workstation. A glassy-carbon electrode (3mm-diameter) was used as the working electrode, a Pt wire (1mm-diameter) was used as the auxiliary electrode and an Ag/AgCl electrode was used as a reference electrode. The measurements of Methyl 4-(2,2-difluorocyclopropyl)benzoate **1a** (0.1 M) were carried out at a scan rate of 100 mV s^{-1} in MeCN/^{n}Bu$_4$NI (0.1 M) (Figure **S1a**) or DMSO/^{n}Bu$_4$NClO$_4$ (0.1 M) (Figure **S1b**); *gem*-difluorocyclopropane **1z** (0.1 M) was carried out at a scan rate of 100 mV s^{-1} in DMF/^{n}Bu$_4$NClO$_4$ (0.1 M) (Figure **S1c**).

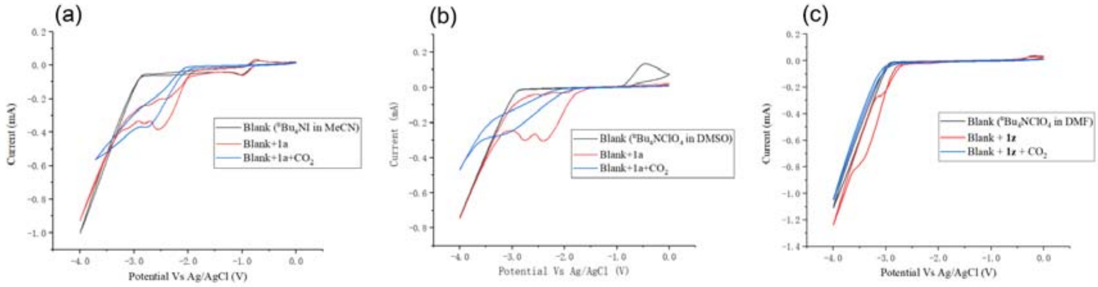
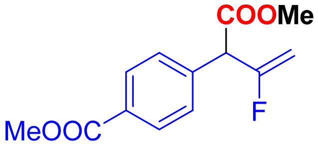
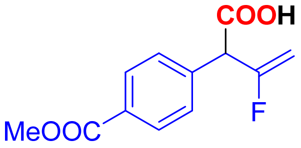


Figure S1. Cyclic voltammograms of *gem*-difluorocyclopropanes 1a and 1z.

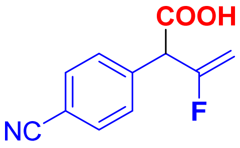
8. Characterization of products



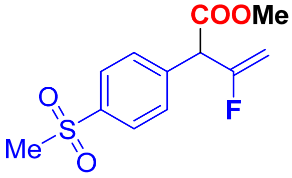
Methyl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2a). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 40.8 mg, 81%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.03 (d, J = 8.3 Hz, 2H), 7.45 (d, J = 8.3 Hz, 2H), 4.84 (dd, J = 17.1, 3.5 Hz, 1H), 4.56 (d, J = 12.2 Hz, 1H), 4.48 (dd, J = 48.7, 3.4 Hz, 1H), 3.91, 3.76. **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4, 166.6, 161.9 (d, $J_{C\text{-}F}$ = 259.8 Hz), 139.0 (d, $J_{C\text{-}F}$ = 3.1 Hz), 130.11, 130.07, 128.9, 94.3 (d, $J_{C\text{-}F}$ = 18.5 Hz), 54.3 (d, $J_{C\text{-}F}$ = 29.5 Hz), 52.9, 52.2. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.2 ~ -97.3 (m, 1F). **HRMS (ESI):** calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0871.



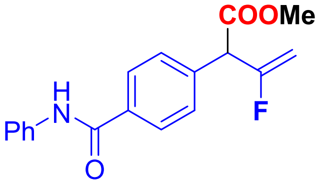
3-fluoro-2-(4-(methoxycarbonyl)phenyl)but-3-enoic acid (2a-H). R_f = 0.5 (PE: EA = 3:1). The reaction was conducted with **General Procedure**. Isolated yield: 38.6 mg, 81%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.04 (d, J = 8.2 Hz, 2H), 7.47 (d, J = 8.2 Hz, 2H), 4.87 (dd, J = 17.1, 3.5 Hz, 1H), 4.59 (d, J = 12.6 Hz, 1H), 4.48 (dd, J = 48.5, 3.4Hz, 1H), 3.92 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 174.4, 166.7, 161.3 (d, $J_{C\text{-}F}$ = 260.0 Hz), 138.4 (d, $J_{C\text{-}F}$ = 2.0 Hz),130.3 130.2, 129.0, 94.7 (d, $J_{C\text{-}F}$ = 18.4 Hz), 54.4 (d, $J_{C\text{-}F}$ = 29.5 Hz), 52.3 **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.4 ~ -97.5 (m, 1F). **HRMS (ESI):** calculated for $C_{12}H_{12}FO_4$ $[M+H]^+$: 239.0714; Found: 239.0717.



2-(4-cyanophenyl)-3-fluorobut-3-enoic acid (2b). R_f = 0.5 (PE: EA = 3:1). The reaction was conducted with **General Procedure**. Isolated yield: 29.5 mg, 72%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.68 (d, J = 8.0 Hz, 2H), 7.52 (d, J = 8.0 Hz, 1H), 4.90 (dd, J = 17.0, 3.5 Hz, 1H), 4.61 (d, J = 13.7 Hz, 1H), 4.53 (dd, J =48.4, 3.4 Hz, 1H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ173.9, 160.6 (d, $J_{C\text{-}F}$ = 260.1 Hz), 138.7, 132.6, 129.8, 118.2, 112.5, 95.1 (d, $J_{C\text{-}F}$ = 18.0 Hz), 54.4 (d, $J_{C\text{-}F}$ = 29.7 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -98.0 ~ -98.1 (m, 1F). **HRMS (ESI):** calculated for $C_{11}H_9FNO_2$ $[M+H]^+$: 206.0612; Found: 206.0616.

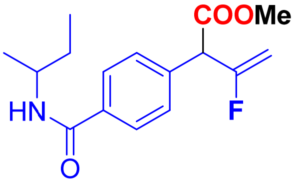


Methyl 3-fluoro-2-(4-(methylsulfonyl)phenyl)but-3-enoate (2c). R_f = 0.6 (PE: EA = 8:1). The reaction was conducted with **General Procedure**. Isolated yield: 30.5 mg, 56%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.95 (d, J = 8.2 Hz, 2H), 7.59 (d, J = 8.2 Hz, 2H), 4.87 (dd, J = 17.0, 3.6 Hz, 1H), 4.60 (d, J = 13.6 Hz, 1H), 4.51 (dd, J = 48.5, 3.5 Hz, 1H), 3.77 (s, 3H), 3.06 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ169.0, 161.2 (d, $J_{C\text{-}F}$ = 260.0 Hz), 140.4, 140.2, 129.9, 127.9, 94.6 (d, $J_{C\text{-}F}$ = 18.3 Hz), 54.3 (d, $J_{C\text{-}F}$ = 29.3 Hz), 53.1, 44.5. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.7 ~ -97.9 (m, 1F). **HRMS (ESI):** calculated for $C_{12}H_{14}FO_4S$ $[M+H]^+$: 273.0591; Found: 273.0591.

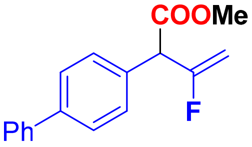


Methyl 3-fluoro-2-(4-(phenylcarbamoyl)phenyl)but-3-enoate (2d). R_f = 0.5 (PE: EA = 3:1). The reaction was conducted with **General Procedure**. Isolated yield: 33.2 mg, 53%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.86 (d, J = 8.3 Hz, 2H), 7.63 (d, J = 7.8 Hz, 2H), 7.49 (d, J = 8.2 Hz, 2H), 7.37 (t, J = 7.9 Hz, 2H), 7.16 (t, J = 7.4 Hz, 1H), 4.86 (dd, J = 17.1, 3.5 Hz, 1H), 4.57 (d, J = 12.4 Hz, 1H), 4.48 (dd, J = 48.7, 3.4 Hz, 1H), 3.77 (s, 3H). **^{13}C{^{1}H} NMR (151**

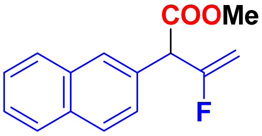
MHz, CDCl$_3$): δ169.5, 165.3, 161.8 (d, J_{C-F} = 259.8 Hz), 137.9 (d, J_{C-F} = 5.0 Hz), 135.0, 129.2, 129.1, 127.6, 124.7, 120.3, 94.3 (d, J_{C-F} = 18.2 Hz), 54.3 (d, J_{C-F} = 29.3 Hz), 52.9. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.3 ~ -97.4 (m, 1F)**. HRMS (ESI):** calculated for $C_{18}H_{17}FNO_3$ [M+H]$^+$: 314.1187; Found: 314.1188.



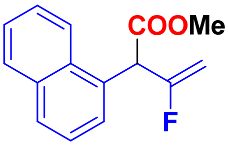
Methyl 2-(4-(sec-butylcarbamoyl)phenyl)-3-fluorobut-3-enoate (2e). R_f = 0.5 (PE: EA = 3:1). The reaction was conducted with **General Procedure**. Isolated yield: 31.1 mg, 53%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 7.75 (d, J = 8.3 Hz, 2H), 7.42 (d, J = 8.2 Hz, 2H), 5.90 (d, J = 5.7 Hz, 1H), 4.83 (dd, J = 17.2, 3.5 Hz, 1H), 4.54 (d, J = 11.9 Hz, 1H), 4.41 (dd, J = 48.7, 3.4 Hz, 1H), 4.13-4.10 (m, 1H), 3.75 (s, 3H), 1.59-1.54 (m, 2H), 1.22 (d, J = 6.6 Hz, 2H), 0.96 (t, J = 7.45 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 169.5, 166.4, 162.0 (d, J_{C-F} = 259.9 Hz), 137.3 (d, J_{C-F} = 2.9 Hz), 135.0, 129.0, 127.4, 94.2 (d, J_{C-F} = 18.5 Hz), 54.3 (d, J_{C-F} = 29.2 Hz), 52.8, 47.2, 29.8, 20.5, 10.4. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.2 ~ -97.4 (m, 1F)**. HRMS (ESI):** calculated for $C_{16}H_{21}FNO_3$ [M+H]$^+$: 294.1500; Found: 294.1497.



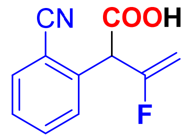
Methyl 2-([1,1'-biphenyl]-4-yl)-3-fluorobut-3-enoate (2f). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 30.2 mg, 56%, however, minor unidentified compounds mixed with the target compounds. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 7.61-7.58 (m, 4H), 7.46-7.43 (m, 4H), 7.37-7.35 (m, 1H), 4.85 (dd, J = 17.2, 3.3 Hz, 1H), 4.55 (d, J = 11.5 Hz, 1H), 4.47 (ddd, J = 48.7, 3.7, 0.6 Hz, 1H), 3.78 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ170.0, 162.6 (d, J_{C-F} = 259.2 Hz), 141.2, 140.5, 133.1 (d, J_{C-F} = 3.5 Hz), 129.2, 128.8, 127.6, 127.5, 127.1, 93.9 (d, J_{C-F} = 18.3 Hz), 54.7 (d, J_{C-F} = 29.7 Hz), 52.8. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.0 ~ -97.2 (m, 1F)**. HRMS (ESI):** calculated for $C_{17}H_{16}FO_2$ [M+H]$^+$: 271.1129; Found: 271.1133.



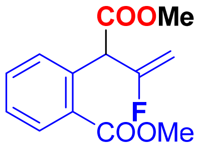
Methyl 3-fluoro-2-(naphthalen-2-yl)but-3-enoate (2g). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 25.9 mg, 53%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 7.87-7.83 (m, 4H), 7.52-7.49 (m, 3H), 4.86 (dd, J = 17.3, 3.4 Hz, 1H), 4.69 (d, J = 10.8 Hz, 1H), 4.45 (ddd, J_{C-F} = 48.7, 3.6, 0.5 Hz, 1H), 3.78 (s, 3H)**. ^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 170.0, 162.7 (d, J_{C-F} = 259.8 Hz), 133.3, 133.0, 131.5 (d, J_{C-F} = 4.1 Hz), 128.6, 128.04, 127.99, 127.7, 126.5, 126.3, 94.1 (d, J_{C-F} = 18.5 Hz), 54.7 (d, J_{C-F} = 29.0 Hz), 52.8 **^{19}F NMR (565 MHz, CDCl$_3$):** δ -96.7 ~ -96.8 (m, 1F)**. HRMS (ESI):** calculated for $C_{15}H_{14}FO_2$ [M+H]$^+$: 245.0972; Found: 245.0974.



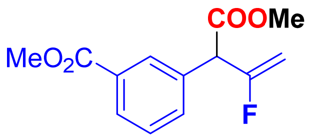
Methyl 3-fluoro-2-(naphthalen-1-yl)but-3-enoate (2h). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 20.0 mg, 41%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 7.99 (d, J = 8.5 Hz, 1H), 7.90 (d, J = 8.0 Hz, 1H),7.86 (d, J = 8.1 Hz, 1H), 7.58-7.47 (m, 4H), 5.30 (d, J = 10.3 Hz, 1H), 4.89-4.86 (m, 1H), 4.40-4.32 (m, 1H), 3.78 (s, 3H). **^{13}C NMR (151 MHz, CDCl$_3$):** δ 170.0, 162.2 (d, J_{C-F} = 259.8 Hz), 134.0, 131.4, 130.2 (d, J_{C-F} = 4.0 Hz), 129.1, 129.0, 126.8, 126.3, 126.0, 125.5, 122.7, 94.7 (d, J_{C-F} = 18.8 Hz), 52.8, 50.8 (d, J_{C-F} = 29.2 Hz). **^{19}F NMR (565 MHz, CDCl$_3$):** δ -95.3 ~ -95.4 (m, 1F)**. HRMS (ESI):** calculated for $C_{15}H_{14}FO_2$ [M+H]$^+$: 245.0972; Found: 245.0975.



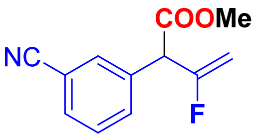
2-(2-cyanophenyl)-3-fluorobut-3-enoic acid (2i). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 28.7 mg, 70%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.71 (d, J = 7.7 Hz, 1H), 7.67-7.63 (m, 2H), 7.48-7.45 (m, 1H), 5.02 (d, J = 16.8 Hz, 1H), 4.91 (dd, J = 16.6, 3.7 Hz, 1H), 4.62 (dd, J = 47.9, 3.7 Hz, 1H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ173.1, 160.0 (d, J_{C-F} = 260.8 Hz), 137.3, 133.3, 133.2, 129.4, 128.8, 117.0, 113.3, 95.5 (d, J_{C-F} = 18.0 Hz), 52.4 (d, J_{C-F} = 28.8 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -99.1 ~ -99.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{11}H_9FNO_2$ $[M+H]^+$: 206.0612; Found: 206.0616.



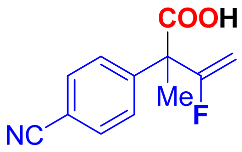
Methyl 2-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2j). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 35.3 mg, 70% (mixture with a small amount of ***E*-3j**). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.1 Hz, 1H), 7.57-7.53 (m, 2H), 7.42-7.39 (m, 1H), 5.74 (d, J = 16.7 Hz, 1H), 4.86 (dd, J = 16.9, 3.3 Hz, 1H), 4.45 (dd, J = 48.7, 3.3 Hz, 1H), 3.90 (s, 3H), 3.76 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 170.3, 167.4 162.3 (d, J_{C-F} = 260.7 Hz), 135.9, 132.6, 131.2, 129.7, 129.2, 128.0, 94.5 (d, J_{C-F} = 18.8 Hz), 52.7, 52.3, 51.2 (d, J_{C-F} = 28.5 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -96.1 ~ -96.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0871.



Methyl 3-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2k). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 23.2 mg, 46% (mixture with a small amount of ***E*-3k**). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.03-8.01 (m, 2H), 7.59 (d, J = 7.7 Hz, 1H), 7.46 (t, J = 7.7 Hz, 1H), 4.84 (dd, J = 17.2, 3.5 Hz, 1H), 4.56 (d, J = 12.3 Hz, 1H), 4.44 (dd, J = 48.7, 3.2 Hz, 1H), 3.92 (s, 3H), 3.76 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.6, 166.6 162.0 (d, J_{C-F} = 259.9 Hz), 134.6 (d, J_{C-F} = 3.1 Hz), 133.2, 130.8, 130.0, 129.5, 129.0, 94.2 (d, J_{C-F} = 18.6 Hz), 54.3 (d, J_{C-F} = 29.1 Hz), 52.8, 52.3. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.4 ~ -97.6 (m, 1F)**. HRMS (ESI):** calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0873.

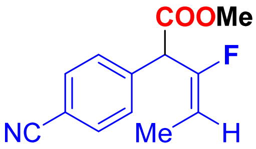


Methyl 2-(3-cyanophenyl)-3-fluorobut-3-enoate (2l). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 27.5 mg, 63%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.69 (s, 1H), 7.64-7.62 (m, 2H), 7.49 (t, J = 7.8 Hz, 1H), 4.87 (dd, J = 16.9, 3.5 Hz, 1H), 4.54-4.45 (m, 2H), 3.78 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ169.0, 161.2 (d, J_{C-F} = 260.1 Hz), 135.7, 133.3, 132.4, 131.9, 129.7, 118.3, 113.1, 94.5 (d, J_{C-F} = 18.4 Hz), 54.0 (d, J_{C-F} = 29.4 Hz), 53.1. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.9 ~ -98.0 (m, 1F)**. HRMS (ESI):** calculated for $C_{12}H_{11}FNO_2$ $[M+H]^+$: 220.0768; Found: 220.0766.

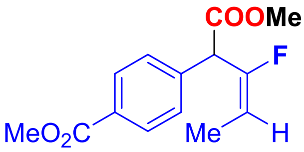


2-(4-cyanophenyl)-3-fluoro-2-methylbut-3-enoic acid (2m). R_f = 0.4 (PE: EA = 2:1). The reaction was conducted with **General Procedure**. Isolated yield: 32.9 mg, 75%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.67 (d, J = 8.5 Hz, 2H), 7.56 (d, J = 8.3 Hz, 2H), 4.93 (dd, J = 18.3, 3.8 Hz, 1H), 4.52 (dd, J = 49.1, 3.8 Hz, 1H), 1.84 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 176.7, 164.8 (d, J_{C-F} = 261.4 Hz), 143.8, 132.3, 128.2, 118.3, 112.0, 94.1 (d, J_{C-F} = 19.9 Hz), 55.3 (d, J_{C-F} = 25.8 Hz), 22.6 (d, J_{C-F} = 2.0 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -98.2 (dd, J = 49.1, 18.3 Hz, 1F)**. HRMS (ESI):** calculated for $C_{12}H_{11}FNO_2$

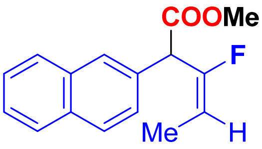
$[M+H]^+$: 220.0768; Found: 220.0772.



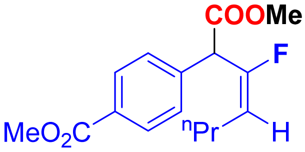
Methyl (E)-2-(4-cyanophenyl)-3-fluoropent-3-enoate (2n). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 30.3 mg, 65%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.65 (d, J = 8.2 Hz, 2H), 7.47 (d, J = 8.2 Hz, 1H), 4.77 (dq, J = 36.3, 6.9 Hz, 1H), 4.50 (d, J = 15.8 Hz, 1H), 3.76 (s, 3H), 1.63 (dd, J = 6.6, 1.74 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4, 154.8 (d, J_{C-F} = 255.5 Hz), 139.9, 132.5, 129.7, 118.5, 112.1, 105.0 (d, J_{C-F} = 14.5 Hz), 54.6 (d, J_{C-F} = 28.9 Hz), 52.9, 9.0 (d, J_{C-F} = 5.8 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -113.2 (dd, J = 35.8, 15.1 Hz, 1F)**. HRMS (ESI):** calculated for $C_{13}H_{13}FNO_2$ $[M+H]^+$: 234.0925; Found: 234.0927.



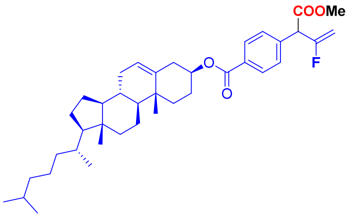
Methyl (E)-4-(3-fluoro-1-methoxy-1-oxopent-3-en-2-yl)benzoate (2o). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 36.2 mg, 68%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.3 Hz, 2H), 7.42 (d, J = 8.2 Hz, 1H), 4.70 (dq, J = 36.5, 6.9 Hz, 1H), 4.51 (d, J = 14.4 Hz, 1H), 3.91 (s, 3H), 3.74 (s, 3H), 1.62-1.61 (m, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.9, 166.7 155.5 (d, J_{C-F} = 255.3 Hz), 139.6, 130.0, 129.9, 128.9, 104.6 (d, J_{C-F} = 14.6 Hz), 54.6 (d, J_{C-F} = 29.4 Hz), 52.8, 52.2, 9.0 (d, J_{C-F} = 6.3 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -112.6 (dd, J = 36.5, 14.4 Hz, 1F)**. HRMS (ESI):** calculated for $C_{14}H_{16}FO_4$ $[M+H]^+$: 267.1027; Found: 267.1025.



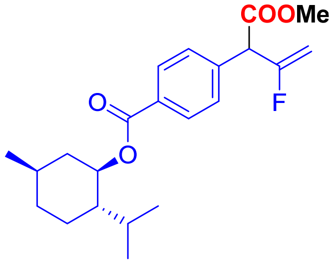
Methyl (E)-3-fluoro-2-(naphthalen-2-yl)pent-3-enoate (2p). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 21.7 mg, 42%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.85-7.82 (m, 3H), 7.80 (s, 1H), 7.50-7.46 (m, 3H), 4.71 (dq, J = 36.7, 6.9 Hz, 1H), 4.64 (d, J = 12.7 Hz, 1H), 3.76 (s, 3H), 1.63 (dd, J = 6.8, 1.0 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 170.6, 156.3 (d, J_{C-F} = 255.2 Hz), 133.3, 132.9, 132.0 (d, J_{C-F} = 3.4Hz), 128.5, 128.0, 127.9, 127.7, 126.4, 126.35, 126.33, 104.4 (d, J_{C-F} = 14.7 Hz), 54.8 (d, J_{C-F} = 29.2 Hz), 52.7, 9.0 (d, J_{C-F} = 6.6 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** δ -112.0 (dd, J = 36.7, 14.4 Hz, 1F)**. HRMS (ESI):** calculated for $C_{16}H_{16}FO_2$ $[M+H]^+$: 259.1129; Found: 259.1126.



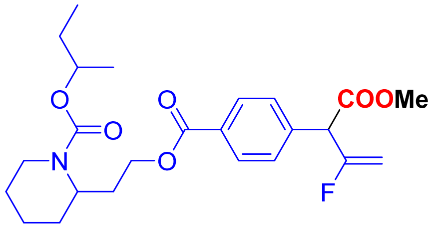
Methyl (E)-4-(3-fluoro-1-methoxy-1-oxohept-3-en-2-yl)benzoate (2q). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 41.1 mg, 70%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.3 Hz, 2H), 7.43 (d, J = 8.3 Hz, 2H), 4.67 (dt, J = 36.9, 7.6 Hz, 1H), 4.52 (d, J = 14.4 Hz, 1H), 3.91 (s, 3H), 3.75 (s, 3H), 2.08 (q, J = 7.2 Hz, 2H), 1.39-1.33 (m, 2H), 0.88 (t, J = 7.4 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 170.0, 166.7, 155.0 (d, J_{C-F} = 255.4 Hz), 139.7 (d, J_{C-F} = 2.5 Hz), 130.0, 129.9, 128.9, 109.9 (d, J_{C-F} = 14.6 Hz), 54.6 (d, J_{C-F} = 29.8 Hz), 52.7, 52.2, 25.6 (d, J_{C-F} = 4.2 Hz), 22.3, 13.6. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -111.9 (dd, J = 36.9, 14.5 Hz, 1F)**. HRMS (ESI):** calculated for $C_{16}H_{20}FO_4$ $[M+H]^+$: 295.1340; Found: 295.1345.



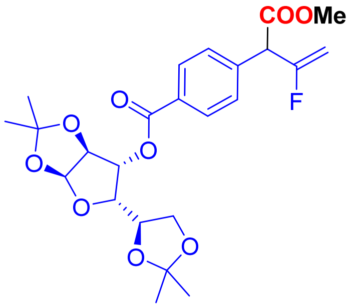
(3S,8S,9S,10R,13R,14S,17R)-10,13-dimethyl-17-((R)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2r). R$_f$ = 0.5 (PE: EA = 4:1). The reaction was conducted with **General Procedure**. Isolated yield: 36.4 mg, 30%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 8.04 (d, J = 8.3 Hz, 2H), 7.44 (d, J = 8.2 Hz, 2H), 5.42 (d, J = 4.1 Hz, 1H), 4.89-4.82 (m, 2H), 4.56 (d, J = 11.9 Hz, 1H), 4.42 (dd, J = 48.7, 3.3 Hz, 1H), 3.76 (s, 3H), 2.45 (d, J = 7.7 Hz, 2H), 2.04-1.69 (m, 6H), 1.61-1.08 (m, 18 H), 1.07 (s, 3H), 1.03-0.96 (m, 3H), 0.92 (d, J = 6.5 Hz, 2H), 0.87 (dd, J = 6.6, 2.6 Hz, 6H), 0.69 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 169.4, 165.5, 161.9 (d, J$_{C-F}$ = 259.8 Hz), 139.6, 138.8 (d, J$_{C-F}$ = 2.1 Hz), 130.8, 130.0, 128.8, 122.9, 94.2 (d, J$_{C-F}$ = 18.5 Hz), 74.8, 56.7, 56.1, 54.5 (d, J$_{C-F}$ = 29.2 Hz), 52.9, 50.1, 42.3, 39.7, 39.5, 38.2, 37.0, 36.7, 36.2, 35.8, 31.94, 31.89, 28.2, 28.0, 27.9, 24.3, 23.8, 22.8, 22.6, 21.1, 19.4, 18.7, 11.9. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.1~ -97.2 (m, 1F)**. HRMS (ESI):** calculated for C$_{39}$H$_{56}$FO$_4$ [M+H]$^+$: 607.4157; Found: 607.4153.



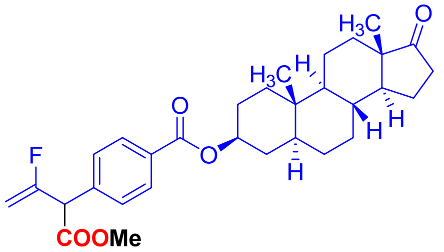
(1R,2S,5R)-2-isopropyl-5-methylcyclohexyl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2s). R$_f$ = 0.5 (PE: EA = 5:1). The reaction was conducted with **General Procedure**. Isolated yield: 45.1 mg, 60%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 8.04 (d, J = 8.2 Hz, 2H), 7.44 (d, J = 8.2 Hz, 2H),4.92 (td, J = 10.8, 4.3 Hz, 1H), 4.84 (ddd, J = 16.6, 3.9, 1.2 Hz, 1H), 4.56 (d, J = 12.0 Hz, 1H), 4.44 (ddd, J = 47.0, 7.7, 3.4 Hz. 1H), 3.75 (d, J = 2.1 Hz, 3H), 2.10 (d, J = 11.7 HZ, 1H), 1.95-1.93 (m, 1H), 1.73 (d, J = 11.4 Hz, 2H), 1.57-1.53 (m, 2H), 1.14-1.08 (m, 2H), 0,93-0.90 (m, 7H), 0.80-0.78 (m, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 169.4, 165.6, 161.9 (dd, J$_{C-F}$ = 259.9, 3.5 Hz), 138.8 (d, J$_{C-F}$ = 2.5 Hz), 130.8, 130.1, 128.8, 94.2 (d, J$_{C-F}$ = 19.3 Hz), 75.0, 54.5 (d, J$_{C-F}$ =29.6 Hz), 52.8, 47.3, 40.9, 34.3, 31.4, 26.5, 23.6, 22.0, 20.8, 16.5.**^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.1~ -97.3 (m, 1F)**. HRMS (ESI):** calculated for C$_{22}$H$_{30}$FO$_4$ [M+H]$^+$: 377.2123; Found: 377.2122.



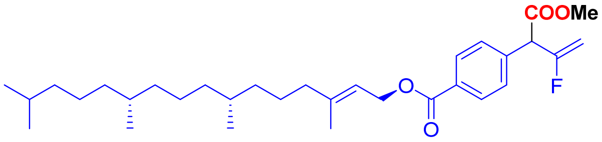
Sec-butyl 2-(2-((4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoyl)oxy)ethyl)piperidine-1-carboxylate(2t). R$_f$ = 0.5 (PE: EA = 4:1). The reaction was conducted with **General Procedure**. Isolated yield: 62.9 mg, 70%. **^{1}H NMR (600 MHz, CDCl$_3$):** δ 8.02 (d, J = 7.8 Hz, 2H), 7.43 (d, J = 7.8 Hz, 2H), 4.83 (dd, J = 17.1, 2.8 Hz, 1H), 4.72 (d, J = 5.7 Hz, 1H), 4.55 (d, J = 12.1 Hz, 1H), 4.41 (d, J = 48.7 Hz, 1H), 4.31 (d, J = 4.4 Hz, 1H), 4.08 (s, 1H), 3.75 (s, 3H), 2.85 (t, J = 12.0 Hz, 1H), 1.89-1.86 (m, 1H), 1.66-1.43 (m, 9H), 1.15 (d, J = 5.9 Hz, 3H), 0.85 (t, J = 7.0 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$):** δ 169.4, 166.0, 161.9 (d, J$_{C-F}$ = 259.9 Hz), 155.5 (d, J$_{C-F}$ = 4.9 Hz), 139.0, 130.1, 128.8, 128.1, 94.2 (d, J$_{C-F}$ = 18.3 Hz), 73.00, 72.97, 62.80, 62.76, 54.4 (d, J$_{C-F}$ = 29.6 Hz), 52.9, 48.0, 39.0, 29.1, 28.9, 28.6, 25.5, 19.8, 19.1, 9.71, 9.68. **^{19}F NMR (565 MHz, CDCl$_3$):** δ -97.2~ -97.3 (m, 1F)**. HRMS (ESI):** calculated for C$_{24}$H$_{33}$FNO$_6$ [M+H]$^+$: 450.2286; Found: 450.2284.



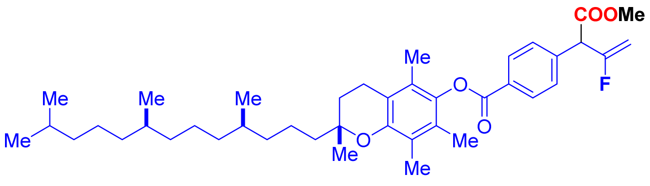
(3aS,5S,6R,6aS)-5-((R)-2,2-dimethyl-1,3-dioxolan-4-yl)-2,2-dimethyltetrahydrofuro[2,3-d][1,3]dioxol-6-yl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2u). R_f= 0.5 (PE: EA = 5:1). The reaction was conducted with **General Procedure**. Isolated yield: 38.4 mg, 40%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.1 Hz, 2H), 7.47 (d, J = 8.1 Hz, 2H), 5.93 (d, J = 3.3 Hz, 1H), 5.49 (d, J = 2.4 Hz, 1H), 4.85 (d, J = 17.0, 2.8 Hz, 1H), 4.61 (d, J = 3.5 Hz, 1H), 4.57 (d, J = 12.6 Hz, 1H), 4.45 (dt, J = 48.5, 3.8 Hz, 1H), 4.36-4.31 (m, 2H), 4.13-4.07 (m, 2H), 3.76 (d, J = 1.9 Hz, 3H), 1.55 (s, 3H), 1.41 (s, 3H), 1.32 (s, 3H), 1.27 (s, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.3, 164.7, 161.7 (d, $J_{C\text{-}F}$ = 261.8 Hz), 139.7, 130.2, 129.5, 129.1, 112.4, 109.4, 105.1, 94.3 (d, $J_{C\text{-}F}$ = 18.2 Hz), 83.4, 79.9, 72.6, 67.3, 54.3 (d, $J_{C\text{-}F}$ = 29.4 Hz), 52.9, 26.9, 26.7, 26.2, 25.2. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.3~ -97.5 (m, 1F)**. HRMS (ESI):** calculated for $C_{24}H_{30}FO_9$ [M+H]$^+$: 481.1868; Found: 481.1866.



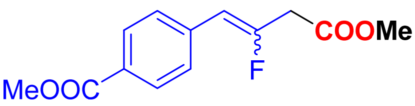
(3S,5S,8R,9S,10S,13S,14S)-10,13-dimethyl-17-oxohexadecahydro-1H-cyclopenta[a]phenanthren-3-yl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2v). R_f= 0.5 (PE: EA = 5:1). The reaction was conducted with **General Procedure**. Isolated yield: 42.9 mg, 42% (mixture with a small amount of ***E*-3v**). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.02 (d, J = 8.3 Hz, 2H), 7.43 (d, J = 8.2 Hz, 2H), 4.96-4.91 (m, 1H), 4.83 (dd, J = 17.1, 3.4 Hz, 1H), 4.55 (d, J = 12 Hz, 1H), 4.42 (dd, J = 48.7, 3.4 Hz, 1H), 3.75 (s, 3H), 2.43 (dd, J = 19.3, 8.7 Hz, 1H), 2.10-2.02 (m, 1H), 1.95-1.91 (m, 2H), 1.81-1.47 (m, 9H), 1.38-1.25 (m, 6H), 1.10 (td, J = 13.6, 3.7 Hz, 1H), 1.03-0.97 (m, 1H), 0.89 (s, 3H), 0.86 (s, 3H), 0.75 (td, J = 10.9, 3.8 Hz, 1H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4 (d, $J_{C\text{-}F}$ = 2.1 Hz), 165.6, 161.9 (d, $J_{C\text{-}F}$ = 259.8 Hz), 138.8 (d, $J_{C\text{-}F}$ = 3.0 Hz), 130.8, 130.0, 128.8, 94.2 (d, $J_{C\text{-}F}$ = 18.5 Hz), 74.3, 54.4 (d, $J_{C\text{-}F}$ = 31.7 Hz), 52.9, 51.4, 47.8, 44.7, 36.7, 35.8, 35.7, 35.1, 34.0, 31.5, 30.8, 28.3, 27.5, 21.8, 20.5, 13.8, 12.3. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.1~ -97.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{31}H_{40}FO_5$ [M+H]$^+$: 511.2854; Found: 511.2850.



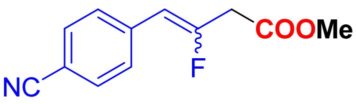
(7R,11R,E)-3,7,11,15-tetramethylhexadec-2-en-1-yl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2w). R_f= 0.5 (PE: EA = 5:1). The reaction was conducted with **General Procedure**. Isolated yield: 46.5 mg, 45% (mixture with a small amount of ***E*-3w**). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.04 (d, J = 8.3 Hz, 2H), 7.44 (d, J = 8.2 Hz, 2H), 5.45 (t, J = 5.9 Hz, 1H), 4.85-4.82 (m, 3H), 4.55 (d, J = 11.9 Hz, 1H), 4.42 (dd, J = 48.7, 3.4 Hz, 1H), 3.75 (s, 3H), 2.04-2.01(m, 2H), 1.75 (s, 3H), 1.54-1.50 (m, 1H), 1.47-1.04 (m, 18H), 0.87-0.83 (m, 12H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4 (d, $J_{C\text{-}F}$ = 2.0 Hz), 166.1, 161.9 (d, $J_{C\text{-}F}$ = 260.0 Hz), 143.1, 138.8 (d, $J_{C\text{-}F}$ = 3.0 Hz), 130.5, 130.1, 128.8, 118.0, 94.2 (d, $J_{C\text{-}F}$ = 18.1 Hz), 62.0, 54.5 (d, $J_{C\text{-}F}$ =29.7 Hz), 52.8, 39.9, 39.4, 37.42, 37.36, 37.3, 36.6, 32.8, 32.7, 28.0, 25.0, 24.8, 24.5, 22.7, 22.6, 19.8, 19.7, 16.5.**^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.1~ -97.2 (m, 1F). **HRMS (ESI):** calculated for $C_{32}H_{50}FO_4$ [M+H]$^+$: 517.3688; Found: 517.3687.



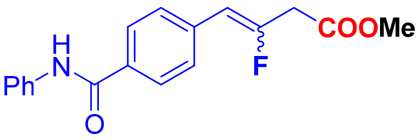
(R)-2,5,7,8-tetramethyl-2-((4R,8R)-4,8,12-trimethyltridecyl)chroman-6-yl 4-(3-fluoro-1-methoxy-1-oxobut-3-en-2-yl)benzoate (2x). R_f = 0.5 (PE: EA = 5:1). The reaction was conducted with **General Procedure**. Isolated yield: 57.2 mg, 44%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.26 (d, J = 8.2 Hz, 2H), 7.54 (d, J = 8.1 Hz, 2H), 4.88 (dd, J = 17.2, 3.5 Hz, 1H), 4.62 (d, J = 12.4 Hz, 1H), 4.51 (dd, J = 48.5, 3.3 Hz, 1H), 3.80 (s, 3H), 2.63 (t, J = 6.6 Hz, 2H), 2.13 (s, 3H), 2.06 (s, 3 H), 2.02 (s, 3H), 1.86-1.76 (m, 2H), 1.62-1.09 (m, 24 H), 0.88-0.86 (m, 12H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4 (d, J_{C-F} = 2.3 Hz), 164.7, 161.8 (d, J_{C-F} = 260.1 Hz),149.6, 140.6, 139.6, 130.7, 129.6, 129.1, 126.9, 125.1, 123.2, 117.5, 94.3 (d, J_{C-F} = 18.1 Hz), 75.1, 54.5 (d, J_{C-F} = 29.2 Hz), 52.9, 39.4, 37.6, 37.5, 37.4, 37.3, 32.8, 32.7, 28.0, 24.9, 24.8, 24.5, 22.8, 22.7, 21.1, 20.7, 19.8, 19.72, 19.70, 19.6, 13.1, 12.2, 11.9. **^{19}F NMR (565 MHz, $CDCl_3$):** δ -97.2~ -97.3 (m, 1F)**. HRMS (ESI):** calculated for $C_{41}H_{60}FO_5$ $[M+H]^+$: 651.4419; Found: 651.4415.



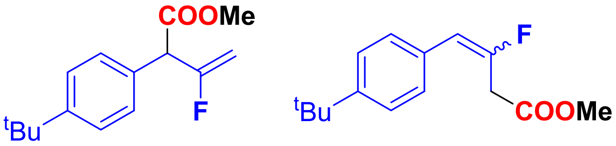
Methyl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate (3a). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 37.8 mg, 75%. **^{1}H NMR (600 MHz, $CDCl_3$): *E*-3a:** δ 8.01 (d, J = 8.3 Hz, 2H), 7.31 (d, J = 8.2 Hz, 2H), 6.46 (d, J = 19.8 Hz, 1H), 3.91 (s, 3H), 3.79 (s, 3H), 3.45 (d, J = 22.7 Hz, 2H); ***Z*-3a:** δ 7.99 (d, J = 8.4 Hz, 2H), 7.54 (d, J = 8.4 Hz, 2H), 5.72 (d, J = 37.4 Hz, 1H), 3.91 (s, 3H), 3.77 (s, 3H), 3.40 (d, J = 19.1 Hz, 2H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$): *E*-3a:** δ 168.7 (d, J_{C-F} = 3.5 Hz), 166.7, 155.8 (d, J_{C-F} = 255.2 Hz), 138.0 (d, J_{C-F} = 12 Hz), 129.9, 129.1, 128.4 (d, J_{C-F} = 2.6 Hz), 111.3 (d, J_{C-F} = 27.1 Hz), 52.6, 52.2, 35.7 (d, J = 29.3 Hz) ; **Z-3a:** δ 168.7, 166.8, 154.8 (d, J_{C-F} = 269.0 Hz), 130.2, 129.7, 128.5, 128.4, 109.3 (d, J_{C-F} = 7.3 Hz), 52.5, 52.1, 39.2 (d, J_{C-F} = 29.1 Hz). **^{19}F NMR (565 MHz, $CDCl_3$): *E*-3a:** δ -93.9 ~ -94.0 (m, 1F); ***Z*-3a:** δ -97.0 ~ -97.2 (m, 1F)**. HRMS (ESI): *E*-3a:** calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0867; ***Z*-3a:** calculated for $C_{13}H_{14}FO_4$ $[M+H]^+$: 253.0871; Found: 253.0875.



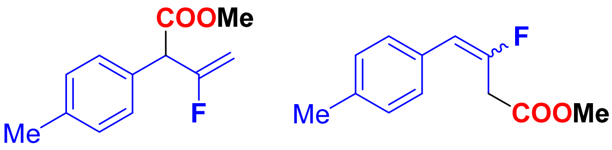
Methyl 4-(4-cyanophenyl)-3-fluorobut-3-enoate (3b). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 29.4 mg, 67%. **^{1}H NMR (600 MHz, $CDCl_3$): *E*-3b:** δ 7.64 (d, J = 8.3 Hz, 2H), 7.36 (d, J = 8.1 Hz, 2H), 6.45 (d, J = 19.4 Hz, 1H), 3.79 (s, 3H), 3.43 (d, J = 22.9 Hz, 2H); ***Z*-3b:** δ 7.60 (d, J = 8.5 Hz, 2H), 7.56 (d, J = 8.5 Hz, 2H), 5.71 (d, J = 36.8 Hz, 1H), 3.77 (s, 3H), 3.41 (d, J = 19.1 Hz, 2H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$): *E*-3b:** δ 168.4, 156.4 (d, J_{C-F} = 256.6 Hz), 138.1 (d, J_{C-F} = 13.4 Hz), 132.5, 129.0 (d, J_{C-F} = 2.2 Hz), 118.6, 111.2, 110.9 (d, J_{C-F} = 27.8 Hz), 52.8, 35.7 (d, J_{C-F} = 29.1 Hz); ***Z*-3b:** δ 168.4, 162.6, 155.8 (d, J_{C-F} = 271.1 Hz), 137.4, 132.2, 129.0 (d, J = 7.9 Hz), 108.7 (d, J_{C-F} = 6.8 Hz), 52.6, 39.1 (d, J_{C-F} = 28.8 Hz). **^{19}F NMR (565 MHz, $CDCl_3$): *E*-3b:** δ -91.8 ~ -92.0 (m, 1F); ***Z*-3b:** δ -95.3 ~ -95.5 (m, 1F)**. HRMS (ESI): *E*-3b:** calculated for $C_{12}H_{11}FO_4$ $[M+H]^+$: 220.0768; Found: 220.0772; ***Z*-3b:** calculated for $C_{12}H_{11}FNO_2$ $[M+H]^+$: 220.0768; Found: 220.0769.



Methyl 3-fluoro-4-(4-(phenylcarbamoyl)phenyl)but-3-enoate (3d). R_f = 0.6 (PE: EA = 10:1). The reaction was conducted with **General Procedure**. Isolated yield: 26.9 mg, 43%. ***Z*-3d** contain unidentified compounds. **^{1}H NMR (600 MHz, CDCl$_3$): *E*-3d:** δ 7.85 (d, J = 8.2 Hz, 2H), 7.64 (d, J = 7.9 Hz, 2H), 7.39-7.35 (m, 4H), 7.16 (t, J = 7.4 Hz), 6.48 (d, J = 19.7 Hz), 3.80 (s, 3H), 3.46 (d, J = 22.9 Hz, 2H); ***Z*-3d:** δ 7.83 (d, J = 8.4 Hz, 2H), 7.64 (d, J = 8.3 Hz, 2H), 7.58 (d, J = 8.3 Hz, 1H), 7.38-7.35 (m, 3H), 7.15 (t, J = 7.4 Hz, 1H), 5.73 (d, J = 37.4 Hz, 1H), 3.78 (s, 3H), 3.68 (d, J = 8.5 Hz, 2H), 3.41 (d, J = 19.1 Hz, 2H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$): *E*-3d:** δ 168.7, 165.1, 155.8 (d, J_{C-F} = 255.1 Hz), 137.8, 137.0 (d, J_{C-F} = 13.2 Hz), 133.8, 129.1, 128.8 (d, J_{C-F} = 2.3 Hz), 127.4, 124.7, 120.2, 111.2 (d, J_{C-F} = 27.3 Hz), 52.7, 35.7 (d, J_{C-F} = 29.8 Hz); ***Z*-3d:** δ 168.7, 165.2, 154.7 (d, J_{C-F} = 271.0 Hz), 137.9, 136.4, 133.5, 129.1, 128.9 (d, J_{C-F} = 7.6 Hz), 127.6, 124.7, 120.2, 109.1 (d, J_{C-F} = 7.5 Hz), 52.60, 39.2 (d, J_{C-F} = 29.0 Hz).**^{19}F NMR (565 MHz, CDCl$_3$): *E*-3d:** δ -94.1 (q, J = 21.7 Hz, 1F); **^{9}F NMR (376 MHz, CDCl$_3$): *Z*-3d:** -97.4 ~ - 97.6 (m, 1F)**. HRMS (ESI): *E*-3d:** calculated for $C_{18}H_{17}FNO_3$ [M+H]$^+$: 314.1187; Found: 314.1190; ***Z*-3d:** calculated for $C_{18}H_{17}FNO_3$ [M+H]$^+$: 314.1187; Found: 314.1191.

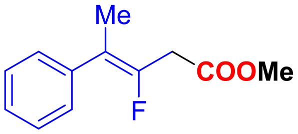


Methyl 2-(4-(tert-butyl)phenyl)-3-fluorobut-3-enoate compound with methyl 4-(4-(tert-butyl)phenyl)-3-fluorobut-3-enoate (3y/2y = 2/1). R$_f$ = 0.6 (PE: EA =20:1). The reaction was conducted with **General Procedure**. Isolated yield: 15.5 mg, 31%. **^{1}H NMR (600 MHz, CDCl$_3$): *E*-y/2y:** δ 7.38 (d, J = 6.6 Hz, 2H), 7.37 (d, J = 6.5 Hz, 2H), 7.29 (d, J = 8.3 Hz, 2H), 7.17 (d, J = 8.2 Hz, 2H), 6.42 (d, J = 20.3 Hz, 1H) **(*E*-3y),** 6.42 (d, J = 20.3 Hz, 1H), 4.80 (dd, J = 17.2, 3.2 Hz, 1H) **(2y)**, 4.48 (d, J = 11.5 Hz, 1H) **(2y)**, 4.41 (dd, J = 49.0, 3.2 Hz, 1H) **(2y)**,3.78 (s, 3H), 3.72 (s, 3H)**,** 3.48 (d, J = 22.7 Hz, 2H) **(*E*-3y)**, 1.32 (s, 18H); ***Z*-3y:** δ 7.43 (d, J = 8.4 Hz, 2H), 7.35 (d, J = 8.4 Hz, 2H), 5.63 (d, J = 38.6 Hz, 1H), 3.75 (s, 9H), 3.37 (d, J = 19.2 Hz, 2H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$): *E*-3y/2y:** δ 170.2, 169.2 (d, J_{C-F} = 3.3 Hz), 162.9 (d, J_{C-F} = 259.5 Hz), 154.4 (d, J_{C-F} = 250.9 Hz), 151.2, 150.4, 131.1 (d, J = 3.4 Hz), 130.3, 130.2,128.4, 128.1, 125.8, 125.6, 111.5 (d, J_{C-F} = 26.1 Hz), 93.7 (d, J_{C-F} = 18.5 Hz), 54.1 (d, J_{C-F} = 29.4 Hz), 52.6 (d, J_{C-F} = 21.8 Hz), 35.7, 35.5, 34.6, 31.29, 31.28; ***Z*-3y:** δ 169.1, 152.6 (d, J_{C-F} = 264.5 Hz), 150.5, 130.1, 128.3 (d, J_{C-F} = 7.4 Hz), 109.5 (d, J_{C-F} = 7.8 Hz), 52.4, 39.2 (d, J_{C-F} = 29.5 Hz), 34.6, 31.2. **^{19}F NMR (565 MHz, CDCl$_3$): *E*-3y/2y:** -98.1~ -98.3 (m, 1F), -97.0~ -97.2 (m, 1F); ***Z*-3y:** δ -101.9 ~ -102.0 (m, 1F). **HRMS (ESI): *E*-3y/2y:** calculated for $C_{15}H_{20}FO_2$ [M+H]$^+$: 251.1442; Found: 251.1440.

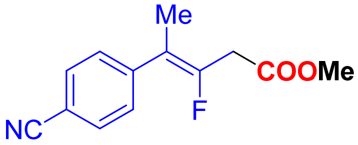


Methyl 3-fluoro-2-(p-tolyl)but-3-enoate compound with methyl 3-fluoro-4-(p-tolyl)but-3-enoate (3z/2z = 2/1). R$_f$ = 0.6 (PE: EA =20:1). The reaction was conducted with **General Procedure**. Isolated yield: 13.7 mg, 33%. **^{1}H NMR (600 MHz, CDCl$_3$): *E*-3z/2z:** δ 7.17 (d, J = 8.4 Hz, 2H), 7.10 (d, J = 7.9 Hz, 2H), 7.08 (d, J = 8.1 Hz, 2H), 7.05 (d, J = 8.0 Hz, 2H), 6.34 (d, J = 20.3 Hz, 1H) **(*E*-3z),** δ 4.72 (dd, J = 17.3, 3.2 Hz, 1H) **(2z)**, 4.39 (d, J = 11.0 Hz, 1H) **(2z)**, 4.32 (dd, J = 49.0, 3.0 Hz, 1H) **(2z)**, 3.70 (s, 3H), 3.67 (s, 3H), 3.38 (d, J = 22.6 Hz, 2H) **(*E*-3z),** 2.27 (s, 3H)**,** 2.27 (s, 3H); ***Z*-3z:** δ 7.38 (d, J = 8.0 Hz, 2H), 7.14 (d, J = 7.9 Hz, 2H), 5.62 (d, J = 38.2 Hz, 1H), 3.76 (s, 3H), 3.36 (d, J = 19.2 Hz, 2H), 2.34 (s, 3H). **^{13}C NMR (151 MHz, CDCl$_3$): *E*-3z/2z:** δ 170.2,169.2 (d, J_{C-F} = 3.4 Hz), 162.9 (d, J_{C-F} = 259.8 Hz), 154.3 (d, J_{C-F} = 250.7 Hz), 138.0, 137.2, 131.1 (d, J_{C-F} = 3.6 Hz), 130.3, 130.2, 129.5, 129.4, 128.6, 128.3 (d, J_{C-F} = 2.1 Hz), 111.7, 111.5, 93.7 (d, J_{C-F} = 18.5 Hz), 54.2 (d, J_{C-F} = 28.9 Hz), 52.6 (d, J_{C-F} = 23.2 Hz), 35.7, 35. 5, 21.2, 21.1. **^{13}C{^{1}H} NMR (101**

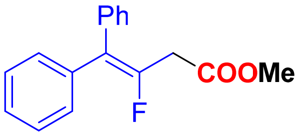
MHz, $CDCl_3$): *Z*-3z: δ 169.2, 152.5 (d, J_{C-F} = 264.7 Hz), 137.2, 130.0, 129.2, 128.5 (d, J_{C-F} = 7.3 Hz), 100.7 (d, J_{C-F} = 7.8 Hz), 52.4, 39.2 (d, J_{C-F} = 29.6 Hz), 21.2. **^{19}F NMR (565 MHz, $CDCl_3$): *E*-3z/2z:** -98.4 ~ -98.5 (m, 1F), -97.0~ -97.1 (m, 1F). **^{19}F NMR (376 MHz, $CDCl_3$): *Z*-3z:** -101.9 ~ -102.2 (m, 1F)**. HRMS (ESI): *E*-3z/2z:** calculated for $C_{12}H_{14}FO_2$ $[M+H]^+$: 209.0972; Found: 209.0975.



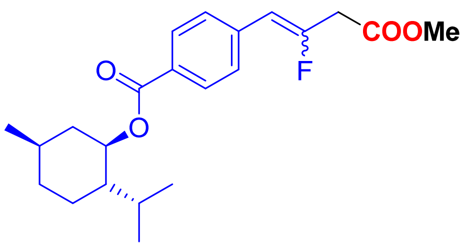
Methyl (Z)-3-fluoro-4-phenylpent-3-enoate (3aa). R_f = 0.6 (PE: EA = 20:1). The reaction was conducted with **General Procedure**. I Isolated yield: 13.3 mg, 32%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.39-7.33 (m, 4H), 7.26-7.24 (m, 1H), 3.76 (s, 3H), 2.46 (d, J = 22.1 Hz, 2H), 1.99 (d, J = 3.0 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.3 (d, J_{C-F} = 3.1 Hz), 148.3 (d, J_{C-F} = 249.9 Hz), 137.6, 128.1 (d, J_{C-F} = 4.2 Hz), 128.1, 127.1, 115.9 (d, J_{C-F} = 12.2 Hz), 52.4, 35.9 (d, J_{C-F} = 32.0 Hz), 17.5 (d, J_{C-F} = 3.5 Hz). **^{19}F NMR (565 MHz, $CDCl_3$):** -104.8 (t, J = 22.2 Hz, 1F). **HRMS (ESI):** calculated for $C_{12}H_{14}FO_2$ $[M+H]^+$: 209.0972; Found: 209.0972.



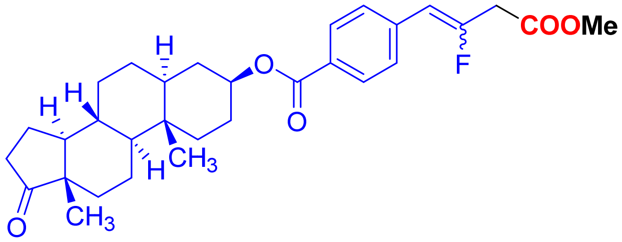
Methyl (Z)-4-(4-cyanophenyl)-3-fluoropent-3-enoate (3m). R_f= 0.6 (PE: EA =10:1). The reaction was conducted with **General Procedure**. Isolated yield: 19.1 mg, 41%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.63 (d, J = 8.3 Hz, 2H), 7.49 (d, J = 8.1 Hz, 2H), 3.77 (s, 3H), 3.47 (d, J = 22.2 Hz, 2H), 2.00 (d, J = 3.0 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 168.7 (d, J_{C-F} = 3.1 Hz), 150.1 (d, J_{C-F} = 254.5 Hz), 142.3, 131.9, 128.9 (d, J_{C-F} = 4.7 Hz), 118.9, 114.7 (d, J_{C-F} = 11.3 Hz), 110.7, 52.5, 35.9 (d, J_{C-F} = 31.4 Hz), 17.0 (d, J_{C-F} = 3.4 Hz). **^{19}F NMR (565 MHz, $CDCl_3$) :** -101.3 (t, J = 22.5 Hz, 1F). **HRMS (ESI):** calculated for $C_{13}H_{13}FNO_2$ $[M+H]^+$: 234.0925; Found: 234.0923.



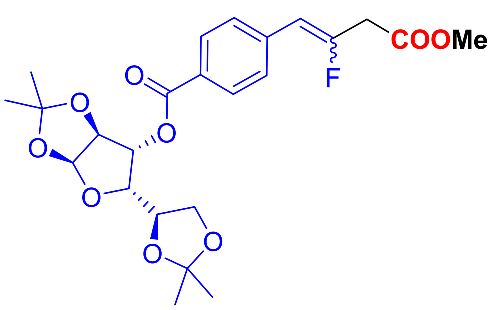
(1R,2R,5R)-2-isopropyl-5-methylcyclohexyl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate. (3ab). R_f = 0.5 (PE: EA = 20:1). The reaction was conducted with **General Procedure**. Isolated yield: 32.4 mg, 60%. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.37-7.23 (m, 10H), 3.75 (s, 3H), 1.92 (s, 3H), 3.38 (d, J = 22.2 Hz, 2H). **^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$):** δ 169.4, 150.7 (d, J_{C-F} = 259.2 Hz), 138.2 (d, J_{C-F} = 7.0 Hz), 136.7, 130.1 (d, J_{C-F} = 3.0 Hz), 129.6 (d, J_{C-F} = 5.3 Hz), 128.6, 128.0, 127.8, 127.4, 123.9 (d, J_{C-F} = 13.2 Hz), 52.4, 37.1 (d, J_{C-F} =25.4 Hz).**^{19}F NMR (565 MHz, $CDCl_3$):** δ -104.5 ~ -104.6 (m, 1F)**. HRMS (ESI):** calculated for $C_{17}H_{16}FO_2$ $[M+H]^+$: 271.1129; Found: 271.1130.



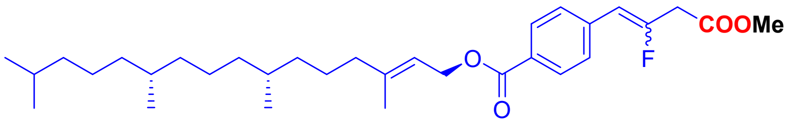
(1R,2R,5R)-2-isopropyl-5-methylcyclohexyl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate (3s). R_f = 0.5 (PE: EA = 8:1). The reaction was conducted with **General Procedure**. Isolated yield: 30.8 mg, 41%. **^{1}H NMR (600 MHz, $CDCl_3$): *E*-3s:** δ 8.01 (d, J = 8.2 Hz, 2H), 7.31 (d, J = 8.2 Hz, 2H), 6.47 (d, J = 19.8 Hz, 1H), 4.92 (td, J = 10.9, 4.4 Hz, 1H), 3.79 (s, 3H), 3.45 (d, J = 22.8 Hz, 2H), 2.12 (d, J = 11.8 Hz, 1H), 1.96-1.93 (m, 1H), 1.73 (d, J = 11.6 Hz, 2H), 1.58-1.52 (m, 2H), 1.16-1.06 (m, 2H), 0.92 (t, J = 6.7 Hz, 7H), 0.79 (d, J = 6.9 Hz, 3H); **Z-3s:** δ 7.99 (d, J = 8.3 Hz, 2H), 7.54 (d, J = 8.3 Hz, 2H), 5.72 (d, J = 37.4 Hz, 1H), 4.92 (td, J = 10.8, 4.4 Hz, 1H), 3.77 (s, 3H), 3.40 (d, J = 19.0 Hz, 2H), 2.12 (d, J = 12.0 Hz, 1H), 1.97-1.94 (m, 1H), 1.73 (d, J = 11.5 Hz, 2H), 1.59-1.53 (m, 2H), 1.14-1.07 (m, 2H), 0.92 (t, J = 8.1 Hz, 7H), 0.79 (d, J = 6.9 Hz, 3H). **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$): *E*-3s:** δ 168.7, 165.7, 155.7 (d, $J_{C\text{-}F}$ = 255.2 Hz), 137.8 (d, $J_{C\text{-}F}$ = 12.5 Hz), 129.9, 128.32, 128.30, 111.4 (d, $J_{C\text{-}F}$ = 27.1 Hz), 78.0, 52.6, 47.3, 41.0, 35.7 (d, $J_{C\text{-}F}$ =29.6 Hz), 34.3, 31.5, 26.5, 23.6, 22.0, 20.8, 16.5. ***Z*-3s:** δ 168.7, 165.8, 154.6 (d, $J_{C\text{-}F}$ = 269.4 Hz), 137.2, 129.7, 128.42, 128.37, 109.3 (d, $J_{C\text{-}F}$ = 7.0 Hz), 74.9, 52.5, 47.3, 41.0, 39.2 (d, $J_{C\text{-}F}$ = 29.0 Hz), 34.3, 31.5, 26.5, 23.7, 22.0, 20.8, 16.6. **^{19}F NMR (565 MHz, CDCl$_3$): *E*-3s:** δ -94.1 ~ -94.3 (m, 1F); ***Z*-3s:** δ -97.3 ~ -97.5 (m, 1F)**. HRMS (ESI): *E*-3s:** calculated for $C_{22}H_{30}FO_4$ [M+H]$^+$: 377.2123; Found: 377.2125; **Z-3s:** calculated for $C_{22}H_{30}FO_4$ [M+H]$^+$: 377.2123; Found: 377.2123.



(3S,5S,8R,9S,10S,13S,14S)-10,13-dimethyl-17-oxohexadecahydro-1H-cyclopenta[a]phenanthren-3-yl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate (3v). R$_f$ = 0.5 (PE: EA = 8:1). The reaction was conducted with **General Procedure**. Isolated yield: 44.9 mg, 44%. **^{1}H NMR (600 MHz, CDCl$_3$): *E*-3v:** δ 8.00 (d, J = 8.3 Hz, 2H), 7.29 (d, J = 8.2 Hz, 2H), 6.46 (d, J = 19.8 Hz, 1H), 4.96-4.91 (m, 1H), 3.78 (s, 3H), 3.45 (d, J = 22.8 Hz, 2H), 2.44 (dd, J = 19.4, 8.8 Hz, 1H), 2.09-2.03 (m, 1H), 1.96-1.91 (m, 2H), 1.82-1.1.47 (m, 9H), 1.37-1.25 (m, 6H), 1.11 (td, J = 13.6, 3.7 Hz, 1H), 1.06-0.98 (m, 1H), 0.90 (s, 3H), 0.87 (s, 3H), 0.75 (td, J = 10.8, 3.9 Hz, 1H); **Z-3v:** δ 7.97 (d, J = 8.4 Hz, 2H), 7.53 (d, J = 8.4 Hz, 1H), 5.71 (d, J = 37.4 Hz. 1H), 4.96-4.90 (m, 1H), 3.77 (s, 3H), 3.40 (d, J = 19.0 Hz, 2H), 2.43 (dd, J = 19.3, 8.52 Hz, 1H), 2.10-2.04 (m, 1H), 1.96-1.91 (m, 2H), 1.81-1.48 (m, 9H), 1.36-1.1.25 (m, 6H), 1.11 (td, J = 13.6, 3.6 Hz, 1H), 1.04-0.97 (m, 1H), 0.90 (s, 3H), 0.86 (s, 3H), 0.75 (td, J = 11.2, 3.8 Hz, 1H). **^{13}C{^{1}H} NMR (101 MHz, CDCl$_3$): *E*-3v:** δ 168.7, 165.7, 155.7 (d, $J_{C\text{-}F}$ = 255.1 Hz), 137.8 (d, $J_{C\text{-}F}$ = 12.9 Hz), 129.9, 129.8, 128.3 (d, $J_{C\text{-}F}$ = 2.6 Hz, 111.4 (d, $J_{C\text{-}F}$ = 26.9 Hz), 74.2, 54.3, 52.6, 51.4, 47.8, 44.7, 36.8, 35.8 (d, $J_{C\text{-}F}$ = 14.6 Hz), 35.1, 34.1, 31.5, 30.8, 28.3, 27.5, 21.8, 20.5, 13.8, 12.3. **^{13}C NMR (151 MHz, CDCl$_3$): *Z*-3v:** δ 168.7, 165.8, 154.6 (d, $J_{C\text{-}F}$ = 269.3 Hz), 137.2, 129.7, 128.4, 128.3, 109.3 (d, $J_{C\text{-}F}$ = 7.4 Hz), 74.1, 54.3, 52.5, 51.4, 47.8, 44.7, 39.2 (d, $J_{C\text{-}F}$ = 29.3 Hz), 36.8, 35.9, 35.7, 35.1, 34.1, 31.5, 30.8, 28.3, 27.5, 21.8, 20.5, 13.8, 12.3. **^{19}F NMR (565 Mz, CDCl$_3$): *E*-3t:** δ -94.1 ~ -94.2 (m, 1F); ***Z*-3v:** δ -97.2 ~ -97.4 (m, 1F). **HRMS (ESI): *E*-3v:** calculated for $C_{31}H_{40}FO_5$ [M+H]$^+$: 511.2854; Found: 511.2856; ***Z*-3v:** calculated for $C_{31}H_{40}FO_5$ [M+H]$^+$: 511.2854; Found: 511.2856.



(3aS,5S,6R,6aS)-5-((R)-2,2-dimethyl-1,3-dioxolan-4-yl)-2,2-dimethyltetrahydrofuro[2,3-d][1,3]dioxol-6-yl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate (3u). R$_f$ = 0.5 (PE: EA = 8:1). The reaction was conducted with **General Procedure**. Isolated yield: 20.2 mg, 21%. **^{1}H NMR (600 MHz, CDCl$_3$): *E*-3u:** δ 8.00 (d, J = 8.2 Hz, 2H), 7.33 (d, J = 8.2 Hz, 2H), 6.47 (d, J = 19.7 Hz, 1H), 5.94 (d, J = 3.6 Hz, 1H), 5.49 (d, J = 2.6 Hz, 1H), 4.62 (d, J = 3.6 Hz, 1H), 4.37-4.31 (m, 2H), 4.13-4.07 (m, 2H), 3.80 (s, 3H), 3.45 (d, J = 22.8 Hz, 2H), 1.56 (s, 3H), 1.41 (s, 3H), 1.32 (s, 3H), 1.27 (s, 3H); **Z-3u:** δ 7.97 (d, J = 8.4 Hz, 2H), 7.56 (d, J = 8.4 Hz, 2H), 5.95 (d, J = 3.6 Hz, 1H), 5.73 (d, J = 37.2 Hz, 1H), 5.49 (d, J = 2.8 Hz, 1H), 4.63 (d, J = 3.6 Hz, 1H), 4.37-4.31 (m, 2H), 4.13-4.07 (m, 2H), 3.77 (s, 3H), 3.41 (d, J = 19.0 Hz, 2H), 1.55 (s, 3H), 1.41 (s, 3H), 1.32 (s, 3H), 1.26 (s, 3H). **^{13}C NMR (151 MHz, CDCl$_3$): _E_-3u:** δ 168.6, 164.8, 156.0 (d, $J_{C\text{-}F}$ = 255.9 Hz), 138.7, 130.1, 128.5 (d, $J_{C\text{-}F}$ = 2.1 Hz), 112.4, 111.2 (d, $J_{C\text{-}F}$ = 26.9 Hz), 109.4, 105.1, 83.4, 79.9, 72.6, 67.3, 52.7, 38.7 (d, $J_{C\text{-}F}$ = 29.6 Hz), 26.9, 26.7, 26.2, 25.3; **^{13}C{^{1}H} NMR (101 MHz, CDCl$_3$): _Z_-3u:** δ 168.6, 164.9, 155.1 (d, $J_{C\text{-}F}$ = 269.5 Hz), 138.0 (d, $J_{C\text{-}F}$ = 3.1 Hz), 129.9, 128.6 (d, $J_{C\text{-}F}$ = 7.5 Hz), 112.4, 109.4, 109.1 (d, $J_{C\text{-}F}$ = 7.2 Hz), 105.2, 83.4, 80.0, 72.6, 67.3, 52.6, 39.2 (d, $J_{C\text{-}F}$ = 29.0 Hz), 26.8, 26.7, 26.2, 25.2. **^{19}F NMR (565 MHz, CDCl$_3$): _E_-3u:** δ -93.1 ~ -93.2 (m, 1F), **Z-3u:** δ -96.4 ~ -96.5 (m, 1F). **HRMS (ESI): _E_-3u:** calculated for $C_{24}H_{30}FO_9$ $[M+H]^+$: 481.1868; Found: 481.1865; **_Z_-3u:** calculated for $C_{24}H_{30}FO_9$ $[M+H]^+$: 481.1868; Found: 481.1869.



(7R,11R,E)-3,7,11,15-tetramethylhexadec-2-en-1-yl 4-(2-fluoro-4-methoxy-4-oxobut-1-en-1-yl)benzoate (3w). R_f = 0.5 (PE: EA = 8:1). The reaction was conducted with **General Procedure**. Isolated yield: 44.4 mg, 43%. **^{1}H NMR (600 MHz, CDCl$_3$): _E_-3w:** δ 8.02 (d, J = 8.2 Hz, 2H), 7.30 (d, J = 8.2 Hz, 2H), 6.46 (d, J = 19.8 Hz, 1H), 5.45 (t, J = 6.6 Hz, 1H), 4.83 (d, J = 7.1 Hz, 1H), 3.78 (s, 3H), 3.45 (d, J = 22.8 Hz, 2H), 2.03 (q, J = 6.6 Hz, 2H), 1.75 (s, 3H), 1.54-1.50 (m, 1H), 1.49-1.02 (m, 18H), 0.87-0.83 (m, 12H); **Z-3w:** δ 7.99 (d, J = 8.4 Hz, 2H), 7.53 (d, J = 8.3 Hz, 2H), 5.71 (d, J = 37.4 Hz, 1H), 5.46 (t, J = 6.9 Hz, 1H), 4.83 (d, J = 7.1 Hz, 2H), 3.77 (s, 3H), 3.40 (d, J = 19.0 Hz, 2H), 2.05-2.01 (m, 2H), 1.75 (s, 3H), 1.54-1.48 (m, 1H), 1.45-1.04 (m, 18H), 0.86-0.83 (m, 12H). **^{13}C NMR (101 MHz, CDCl$_3$): _E_-3w:** δ 168.7, 166.2, 155.7 (d, $J_{C\text{-}F}$ = 254.9 Hz), 143.0, 137.8 (d, $J_{C\text{-}F}$ = 12.7 Hz), 130.0, 128.3 (d, J = 2.6 Hz), 118.0, 111.4 (d, $J_{C\text{-}F}$ = 27.0 Hz), 62.0, 52.6, 37.43, 37.36, 37.3, 36.6, 35.7 (d, $J_{C\text{-}F}$ = 29.7 Hz), 32.8, 32.7, 29.7, 28.0, 25.1, 24.8, 24.5, 22.7, 22.6, 19.8, 19.7, 16.5. **^{13}C{^{1}H} NMR (151 MHz, CDCl$_3$): Z-3w:** δ 168.7, 166.4, 154.7 (d, $J_{C\text{-}F}$ = 269.0 Hz), 142.9, 137.3, 130.1, 129.8, 128.9, 128.4 (d, JC-F = 7.5 Hz), 118.1, 109.3 (d, J = 7.1Hz), 61.9, 52.5, 39.9, 39.4, 39.1, 37.42, 37.37, 37.3, 36.6, 32.8, 32.7, 28.0, 25.0, 24.8, 24.5, 22.7, 22.6, 19.8, 19.7, 16.5. **^{19}F NMR (565 MHz, CDCl$_3$): _E_-3w:** δ -94.0 ~ -94.2 (m, 1F); **_E_-3w:** δ -97.2 ~ -97.3 (m, 1F). **HRMS (ESI): _E_-3u:** calculated for $C_{32}H_{50}FO_4$ $[M+H]^+$: 517.3688; Found: 517.3689; **Z-3w:** calculated for $C_{32}H_{50}FO_4$ $[M+H]^+$: 517.3688; Found: 517.3688.

9. References

[1] Z. Fu, J. Zhu, S. Guo, A. Lin, *Chem. Commun.* **2021**, *57,* 1262–1265.

[2] J. Xu, E.-A. Ahmed, B. Xiao, Q.-Q. Lu, Y .-L. Wang, C.-G. Y u, Y . Fu, *Angew. Chem. Int. Ed.* **2015**, *54,* 8231–8235.

[3] Ni, J.; Nishonov, B.; Pardaev, A.; Zhang, A. J. Org. Chem. 2019, 84, 13646–13654.

[4] L. Lv, C.-J. Li, *Angew. Chem. Int. Ed.* **2021**, *60,* 13098–13104

[5] P. S. Nosik, S. V. Ryabukhin, O. O. Grygorenko, D. M. Volochnyuk, *Adv. Synth. Catal.* **2018**, *360,* 4104–4114.

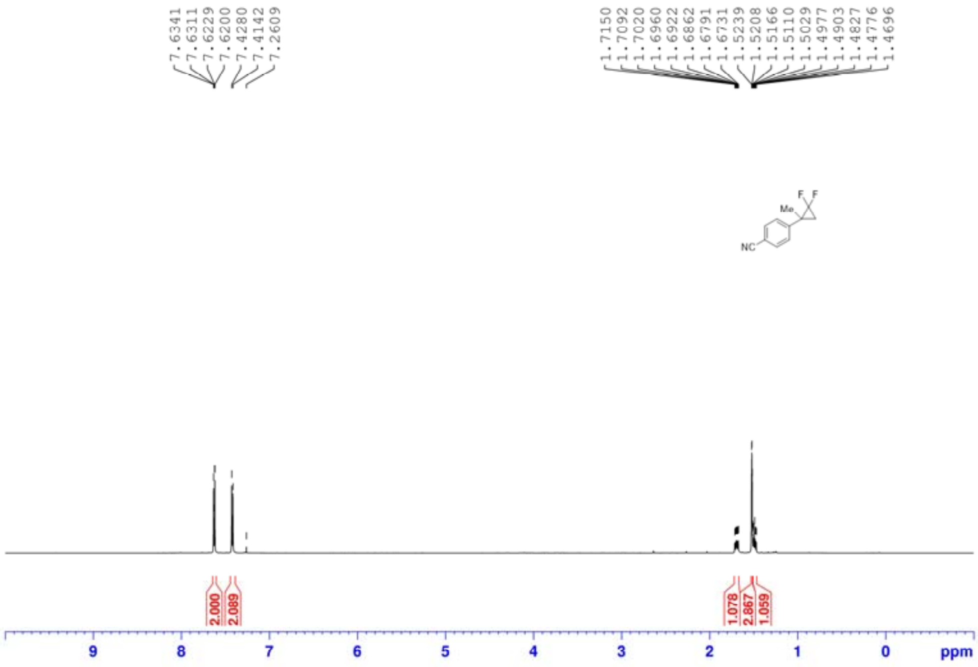
[6] B. Xiong, X. Chen, J. Liu, X. Zhang, Y. Xia, Z. Lian, *ACS Catal.* **2021**, *11,* 11960−11965.

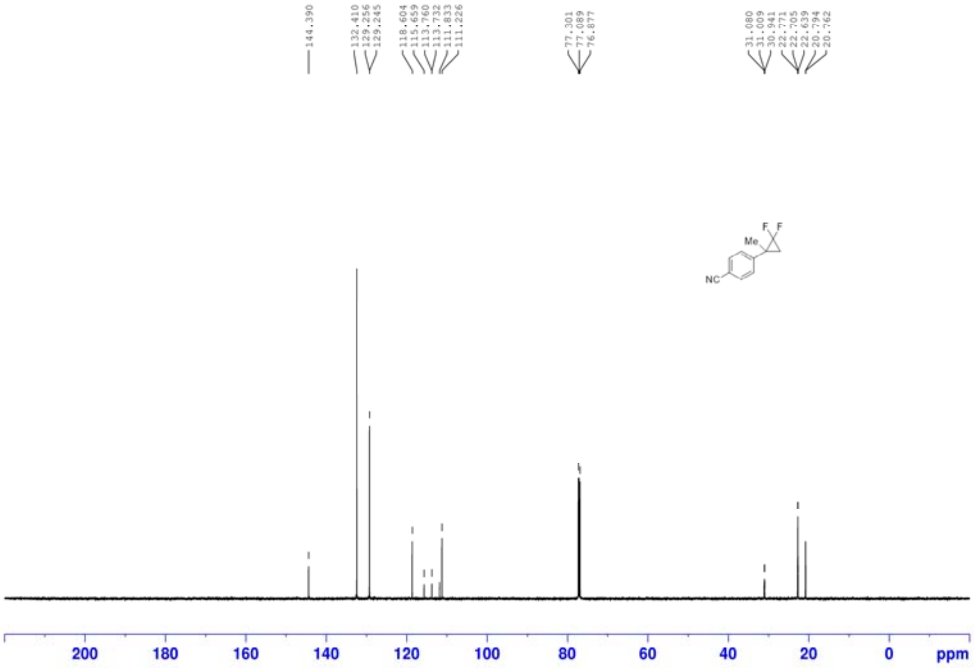
[7] C.-T. Li, X. Yan, Z.-Y. Tang, *Tetrahedron Lett.* **2016**, *57,* 5624–5627.

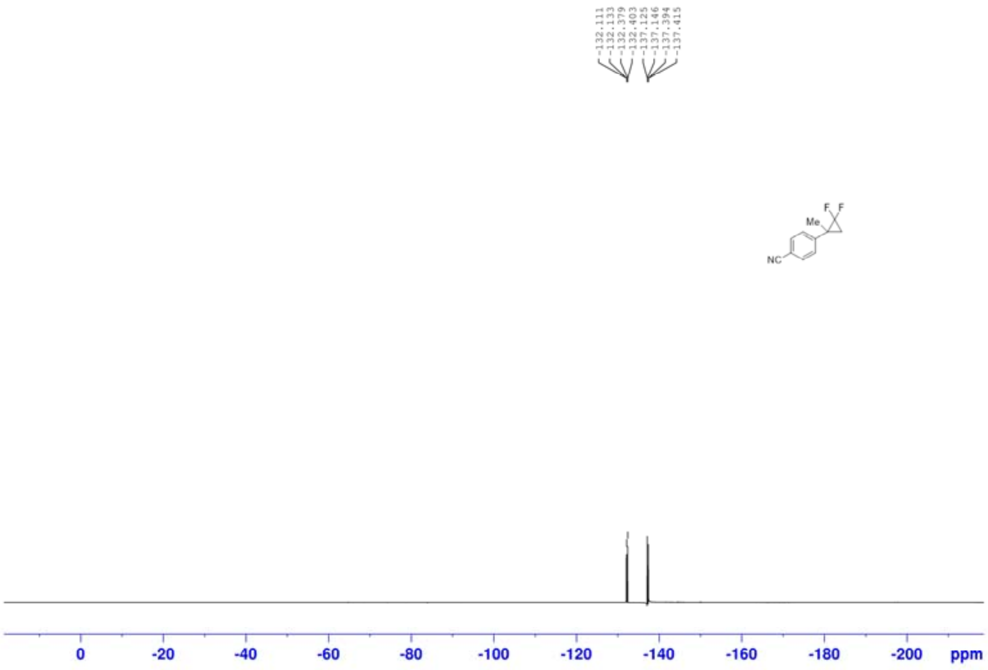
[8] L.-L. Liao, Z.-H. Wang, K.-G. Cao, G.-Q. Sun, W. Zhang, C.-K. Ran, Y. Li, L. Chen, G.-M. Cao, D.-G. Yu, *J. Am. Chem. Soc.* **2022**, *144,* 2062−2068.

[9] Y. Wang, S. Tang, G. Yang, S. Wang, D. Ma, Y. Qiu, *Angew. Chem. Int. Ed.* **2022**, doi: 10.1002/anie.202207746.

10. NMR Spectra



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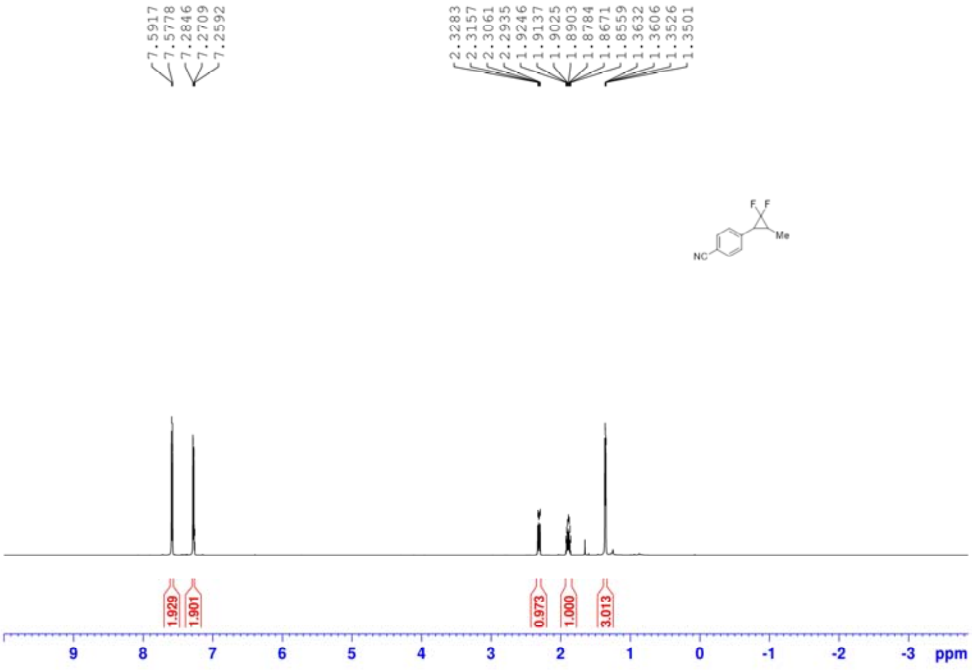
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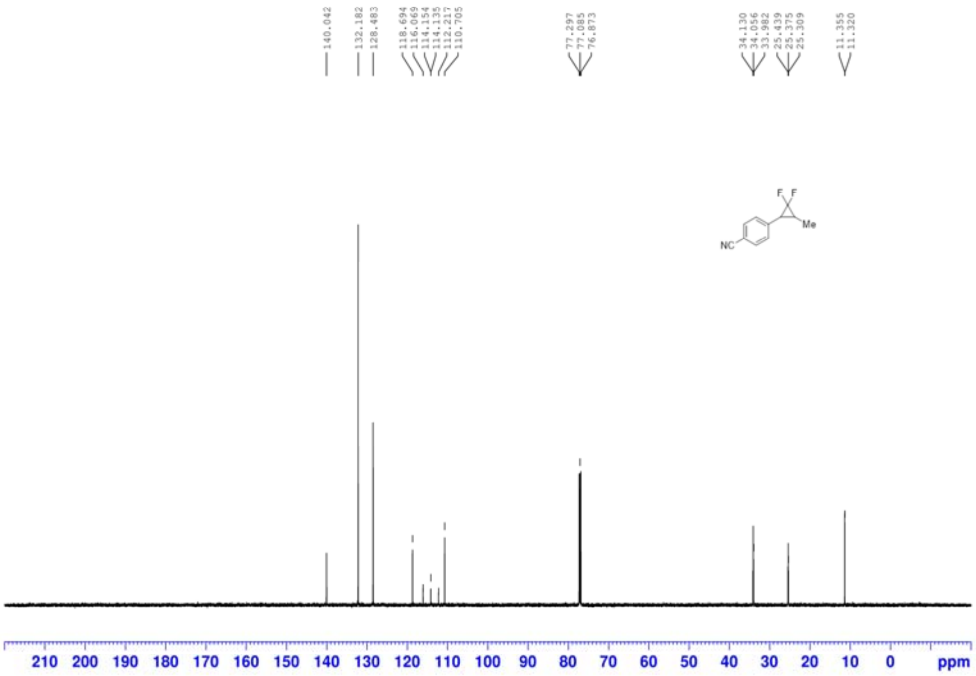
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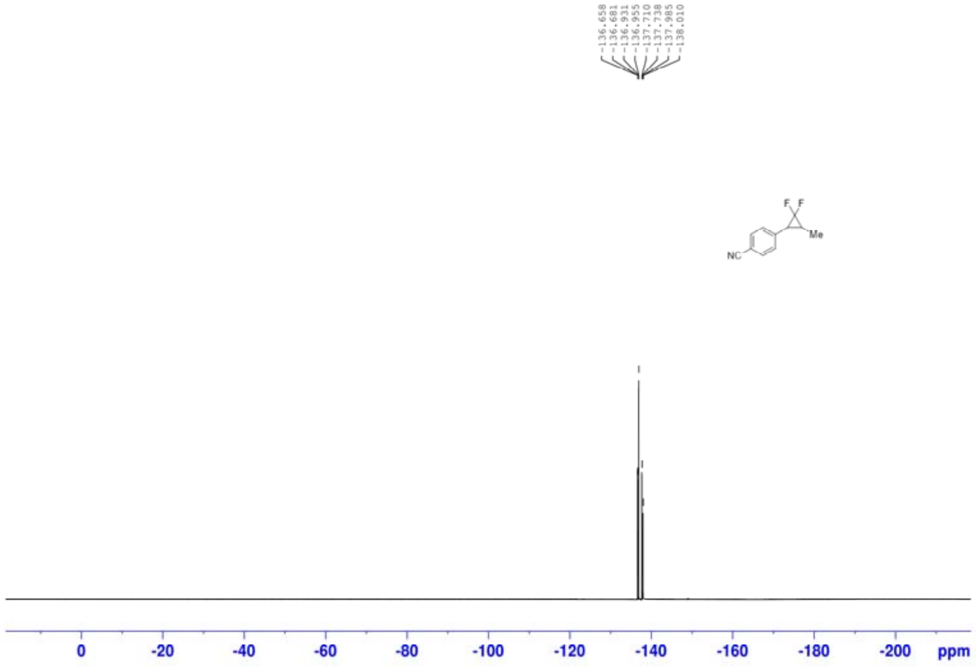
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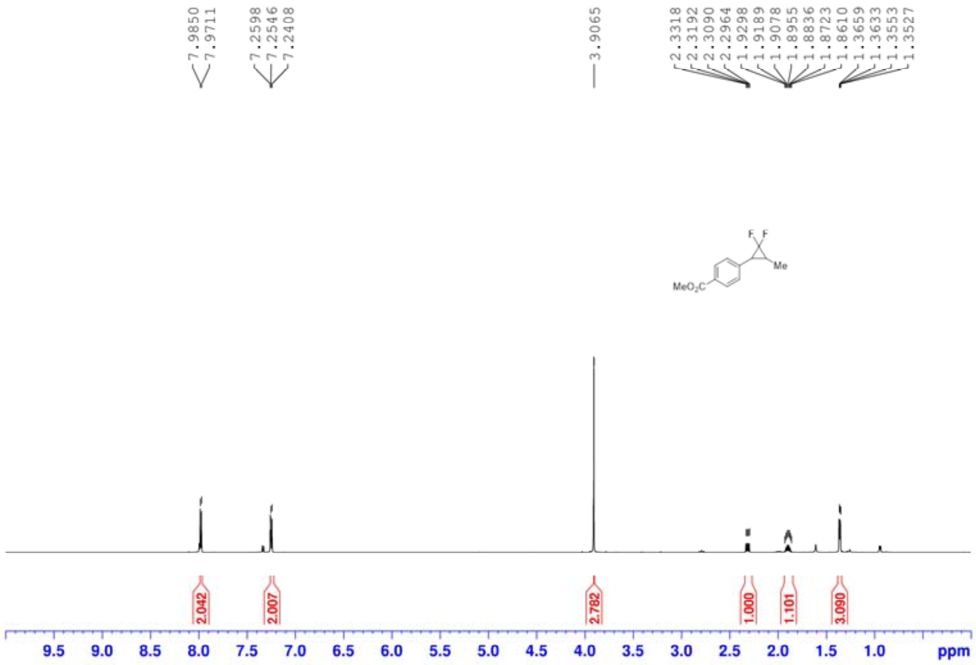
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MeO$_2$C
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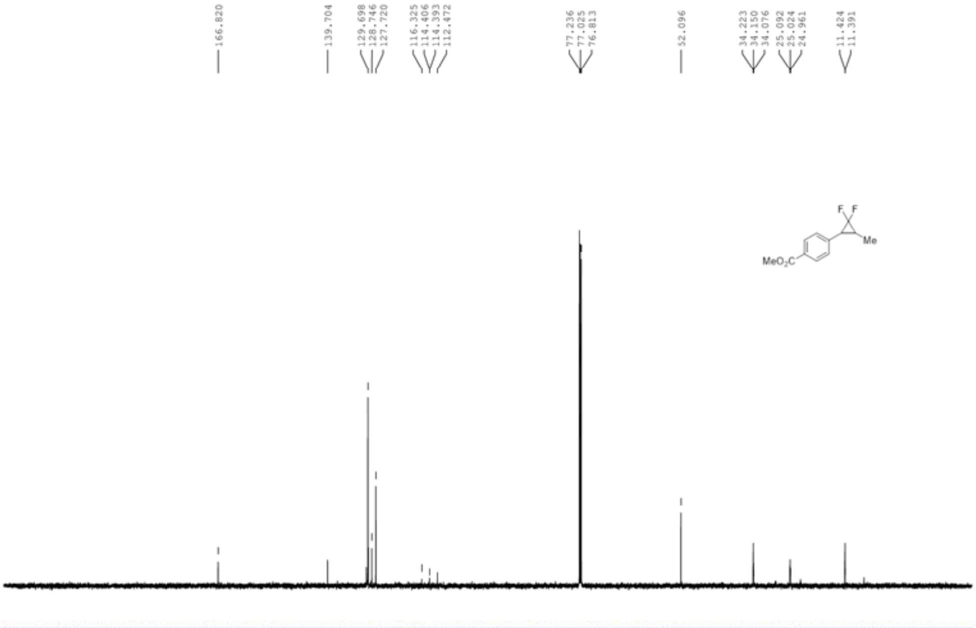
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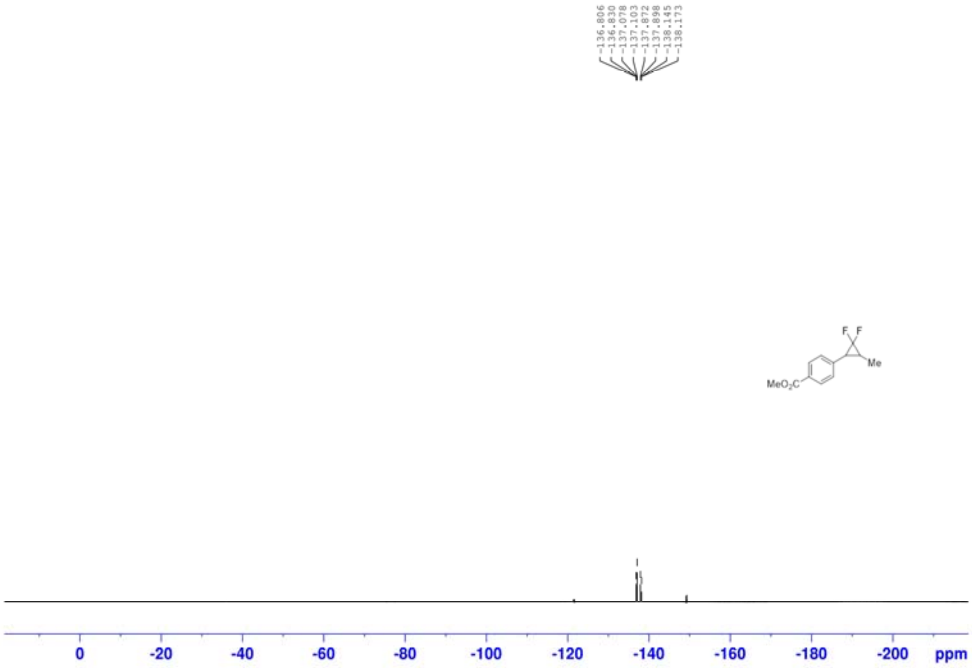
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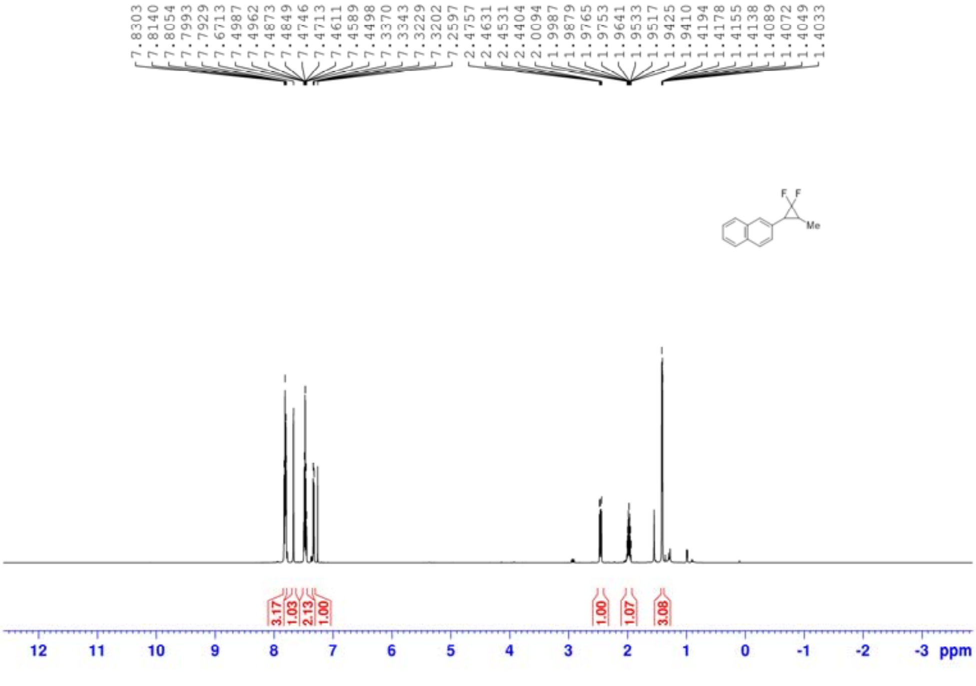
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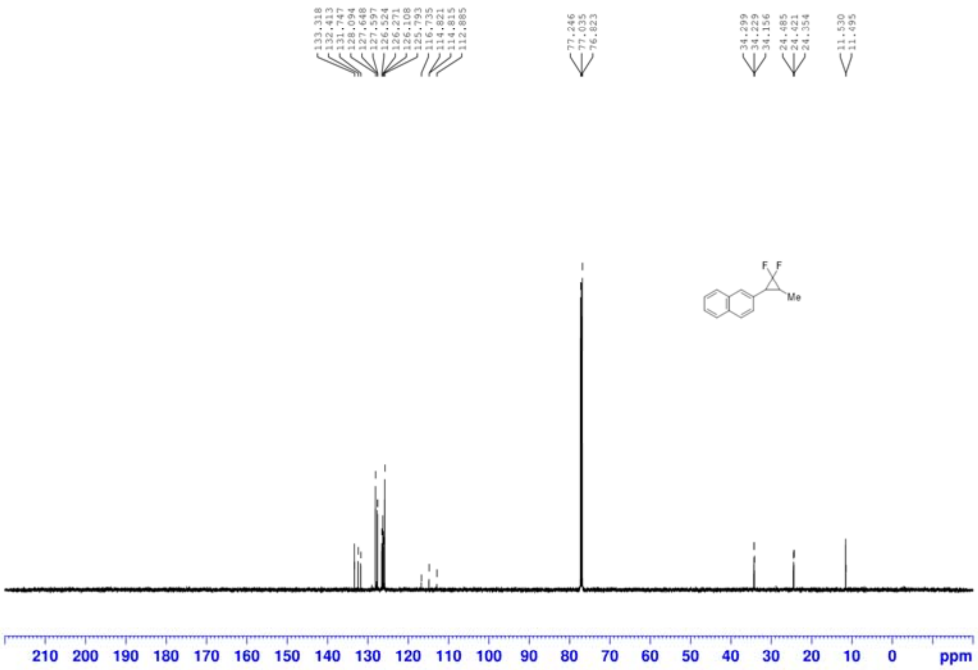
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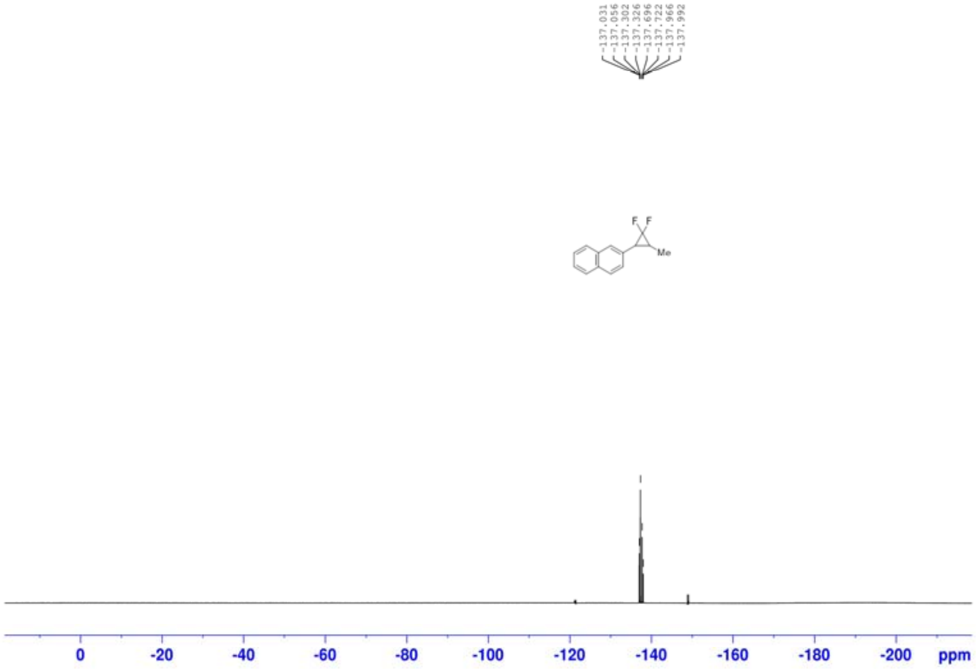
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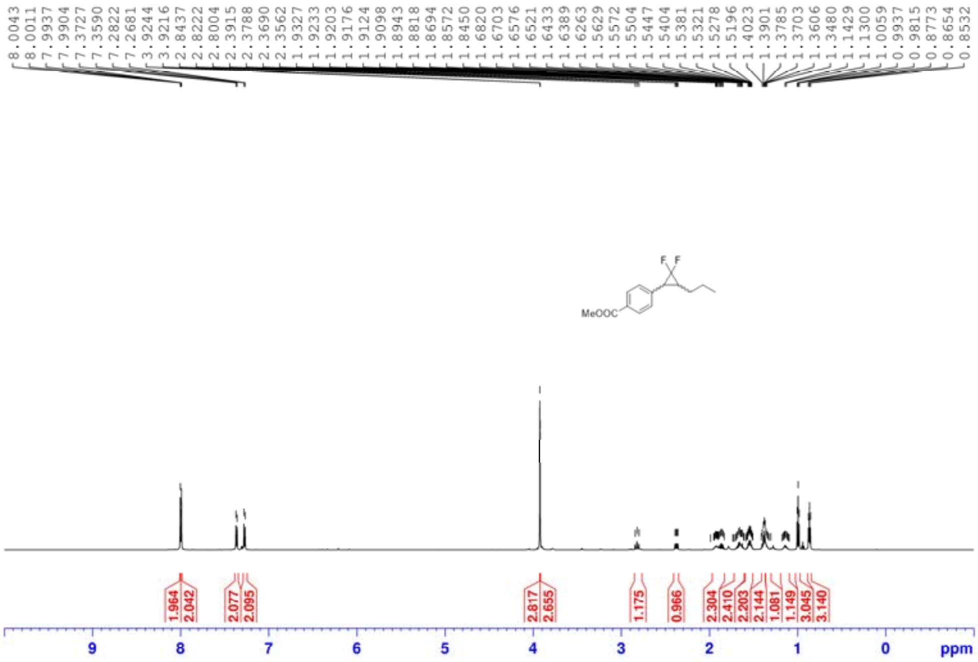
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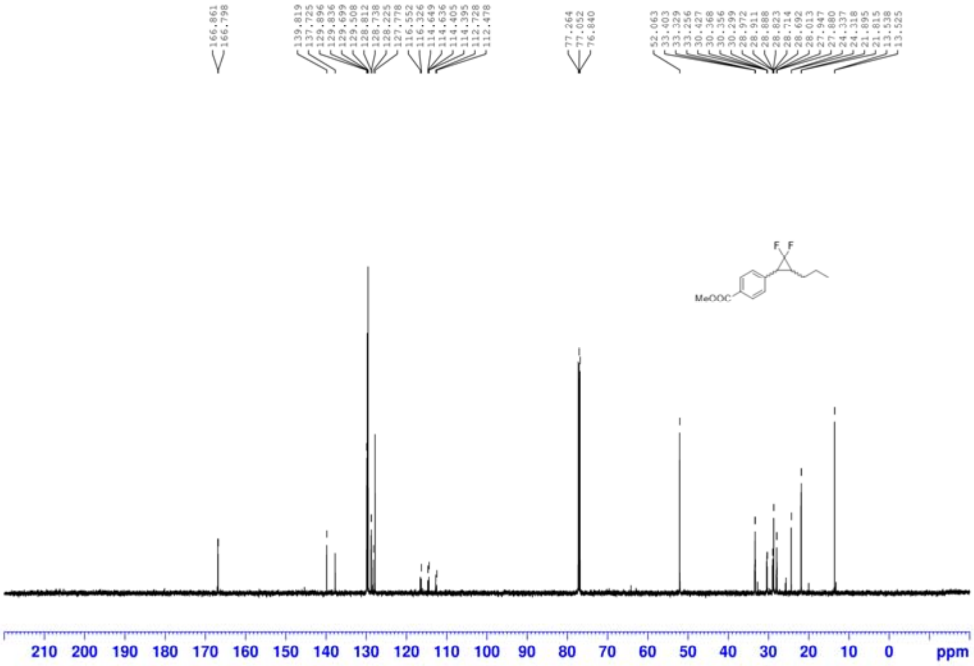
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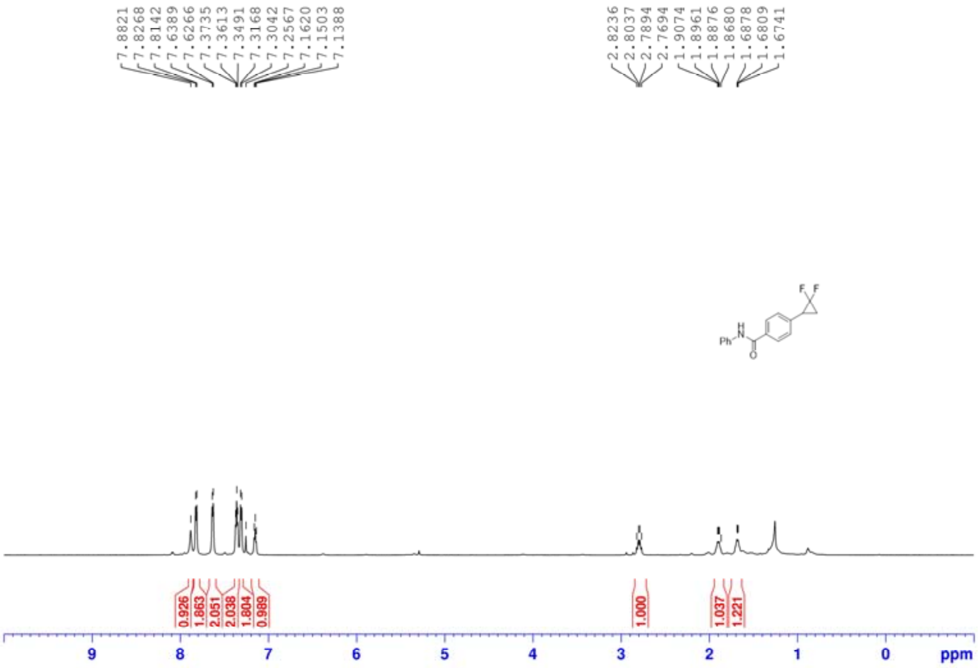
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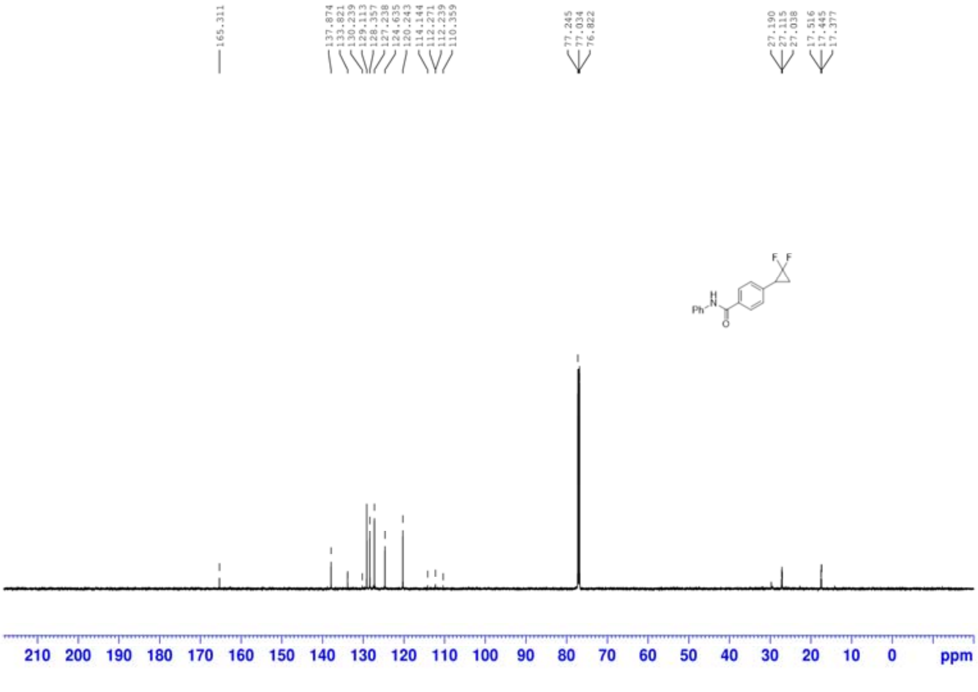
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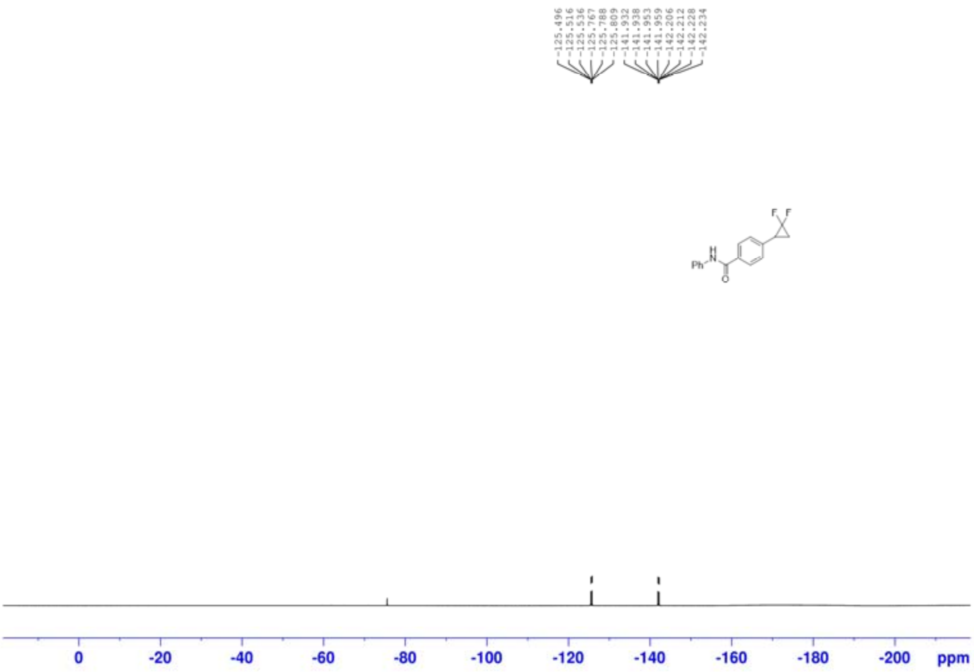
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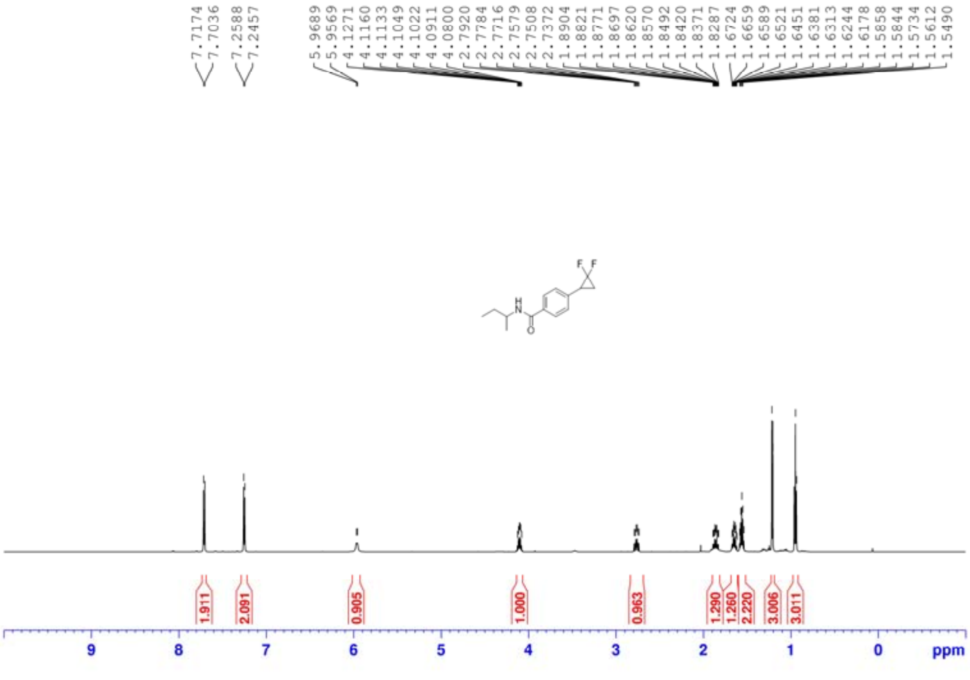
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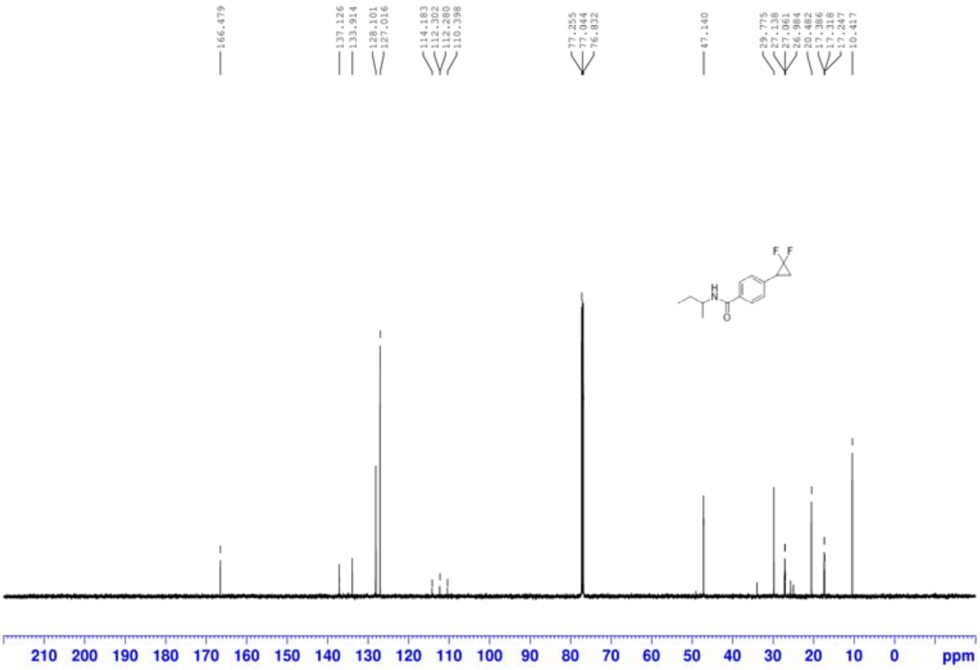
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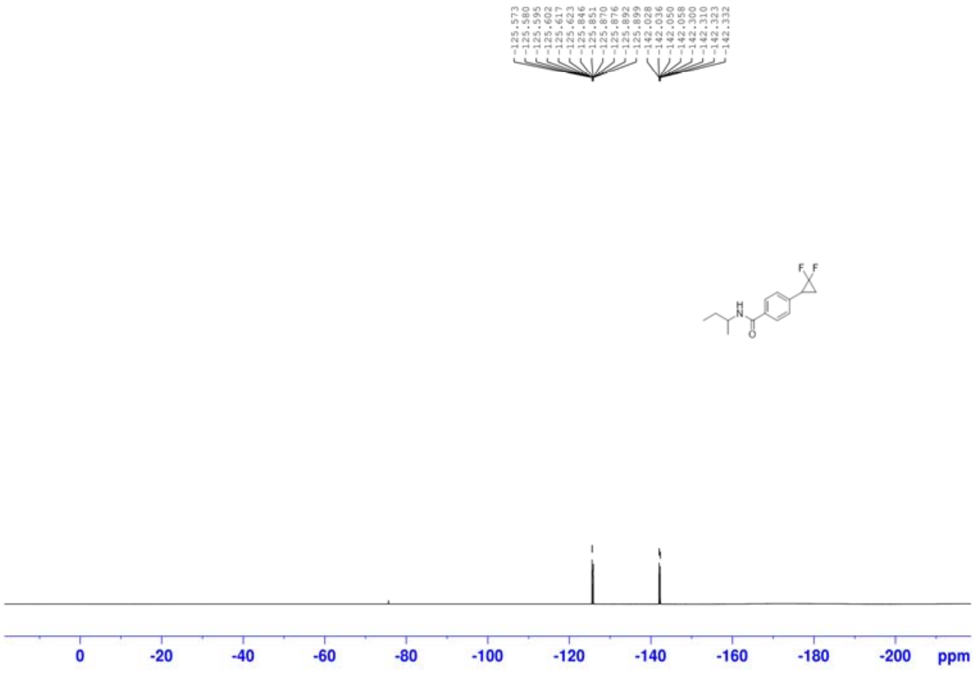
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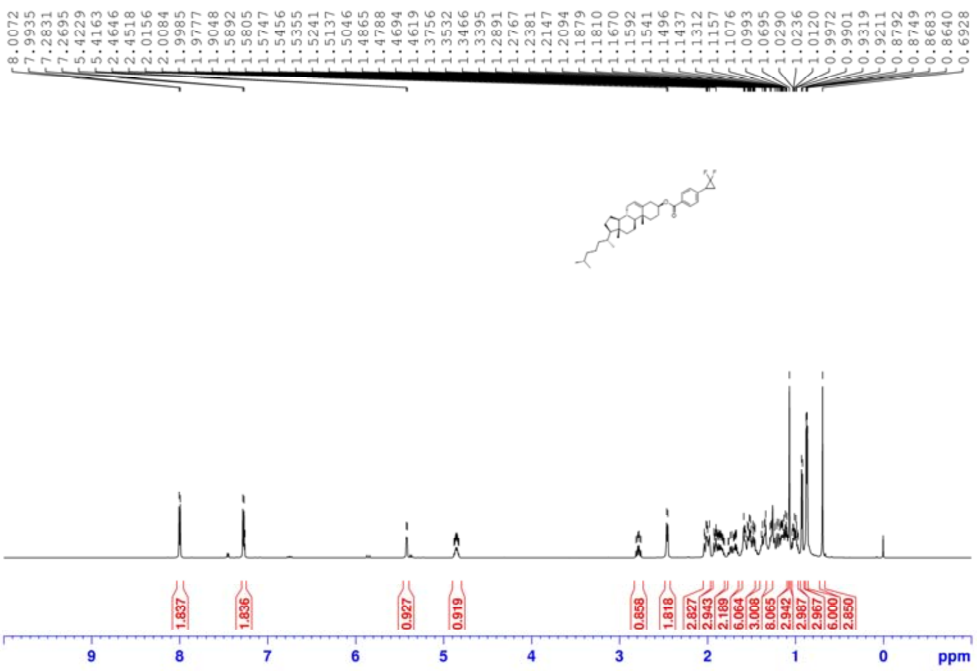
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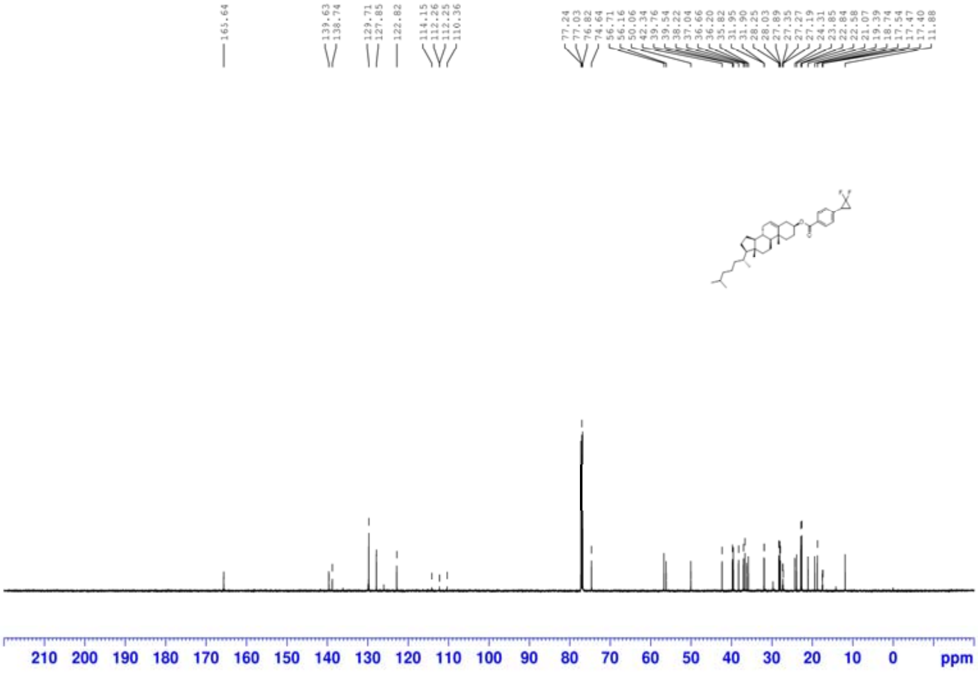
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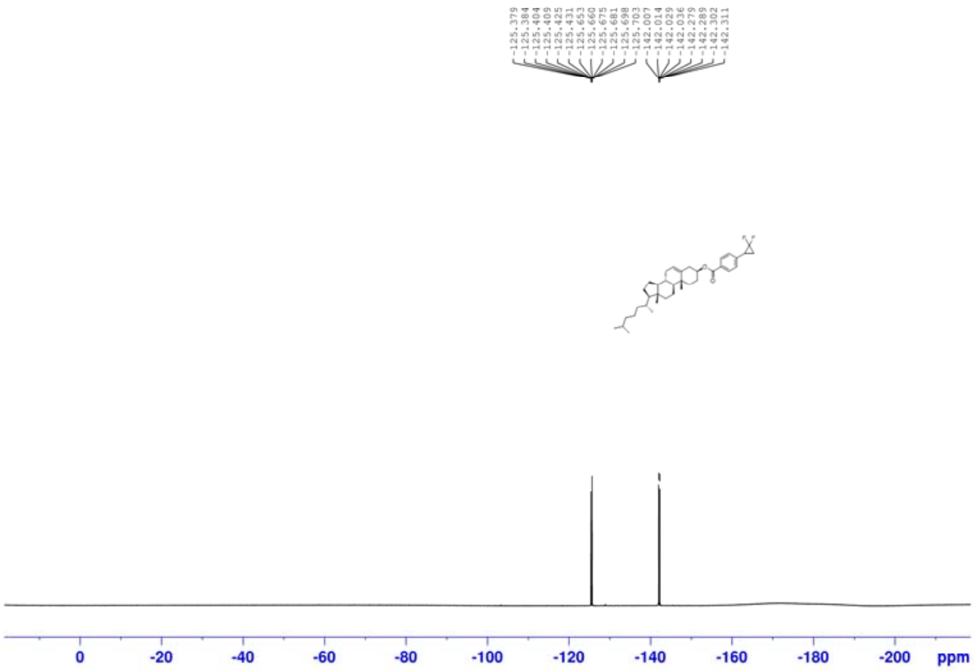
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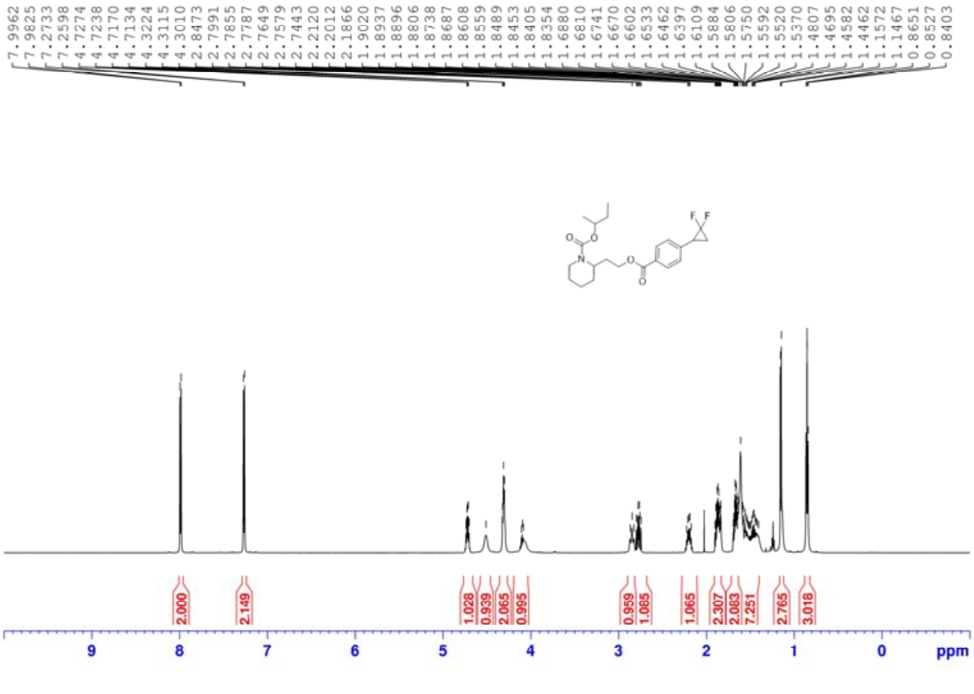
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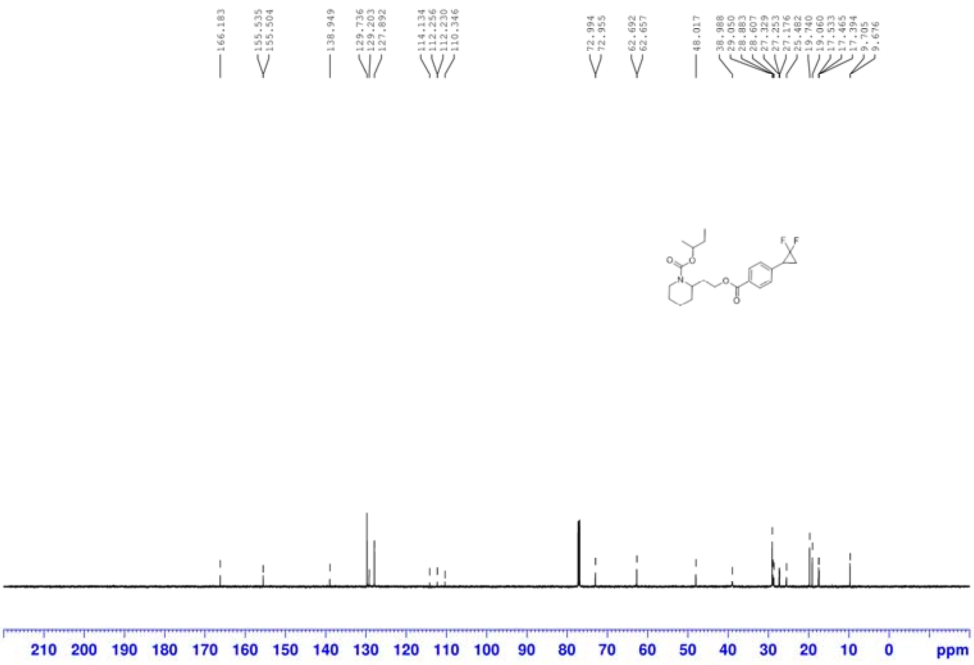
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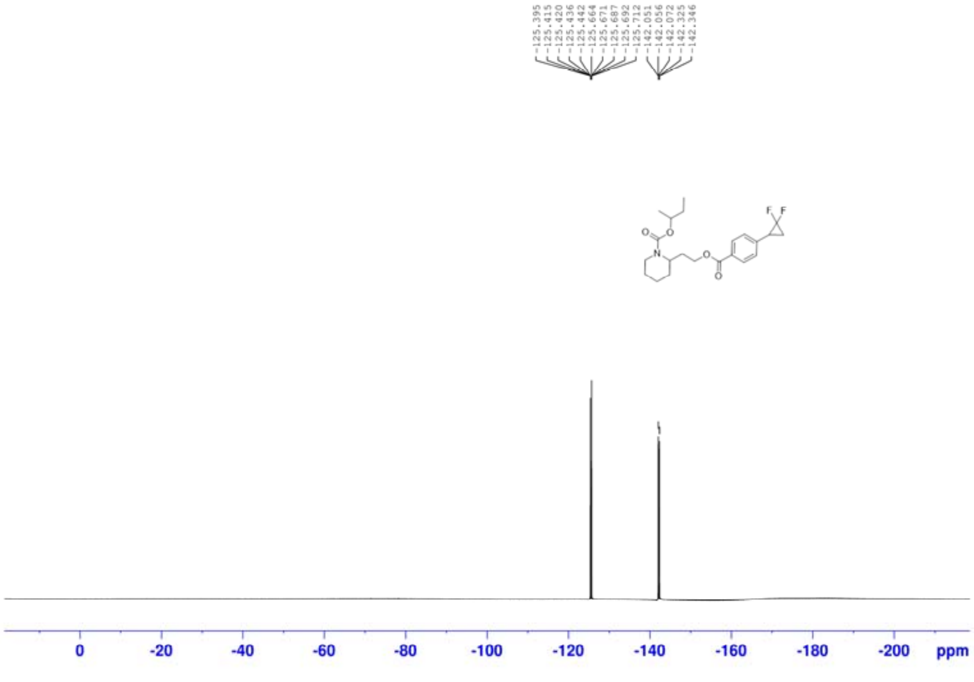
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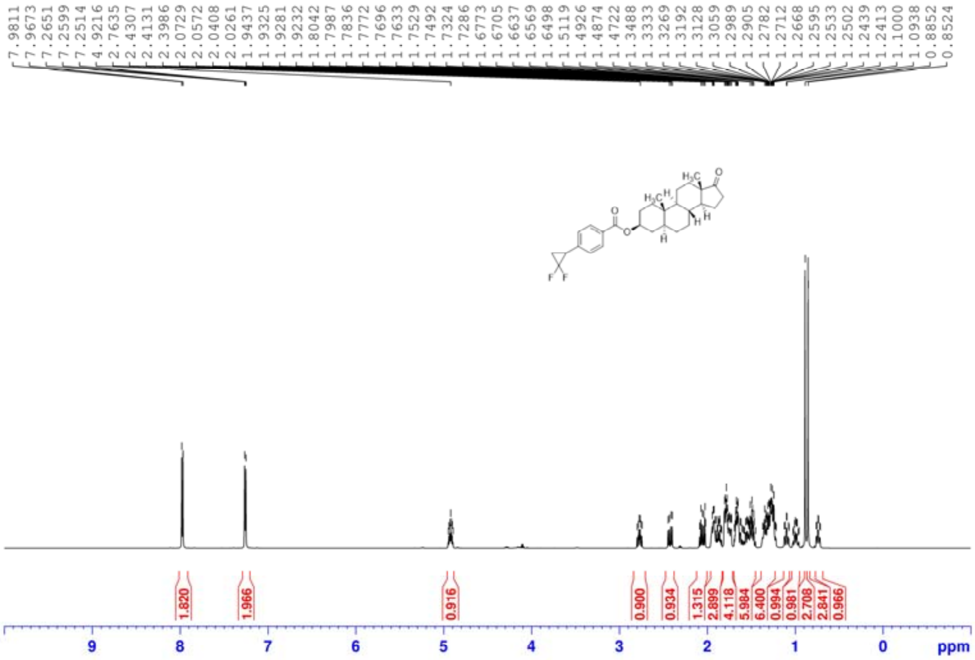
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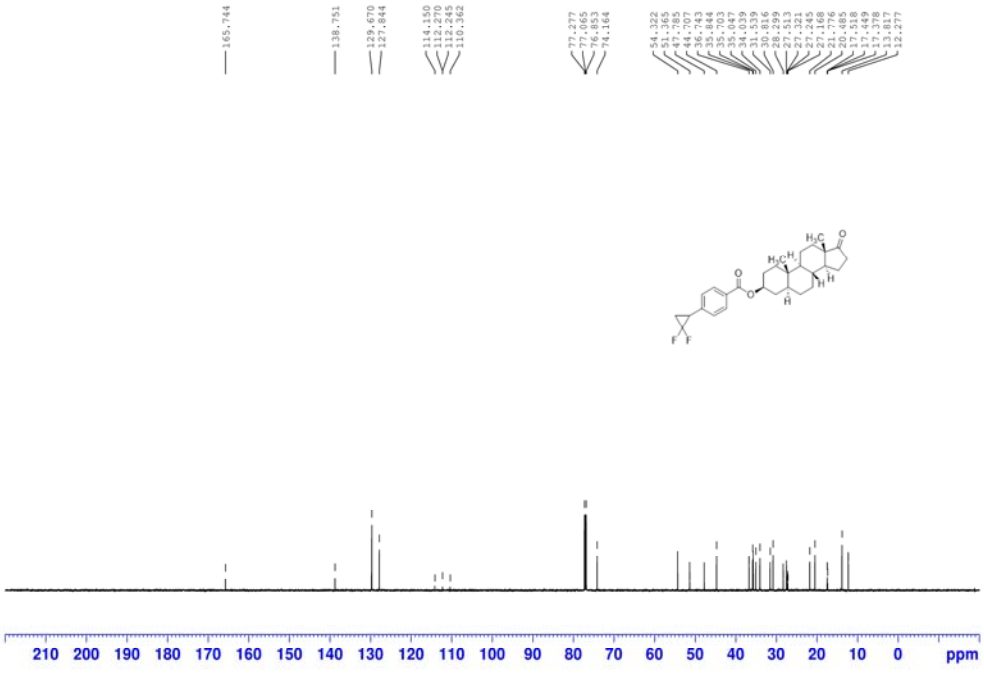
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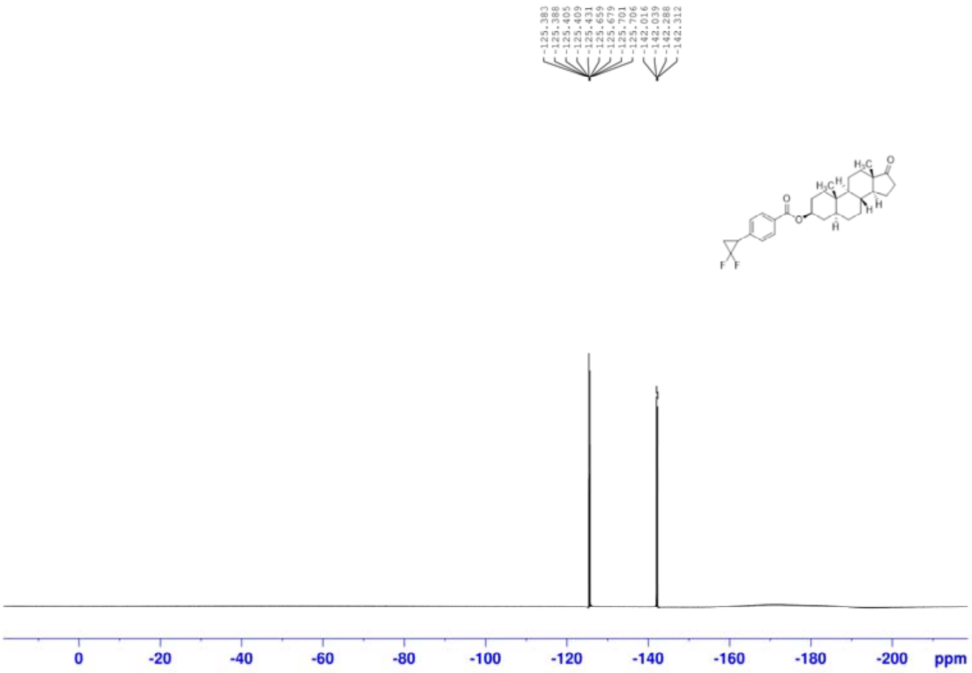
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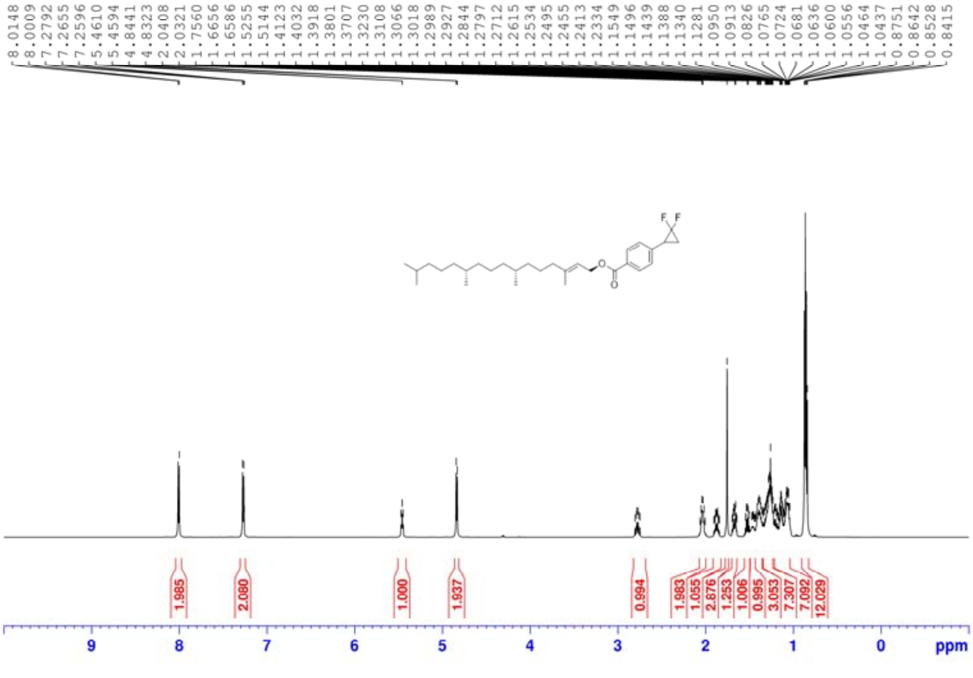
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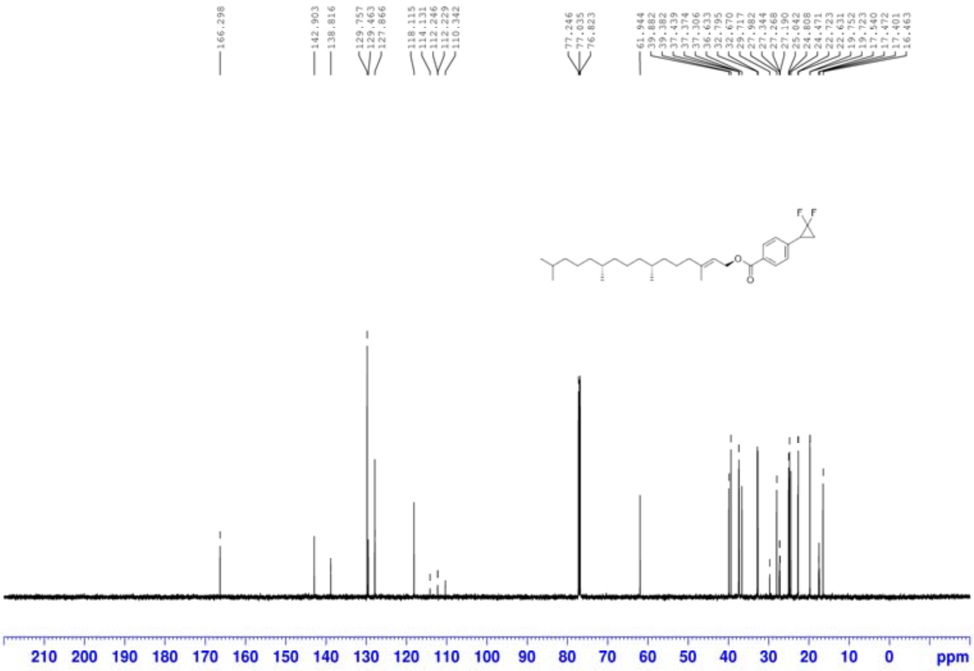
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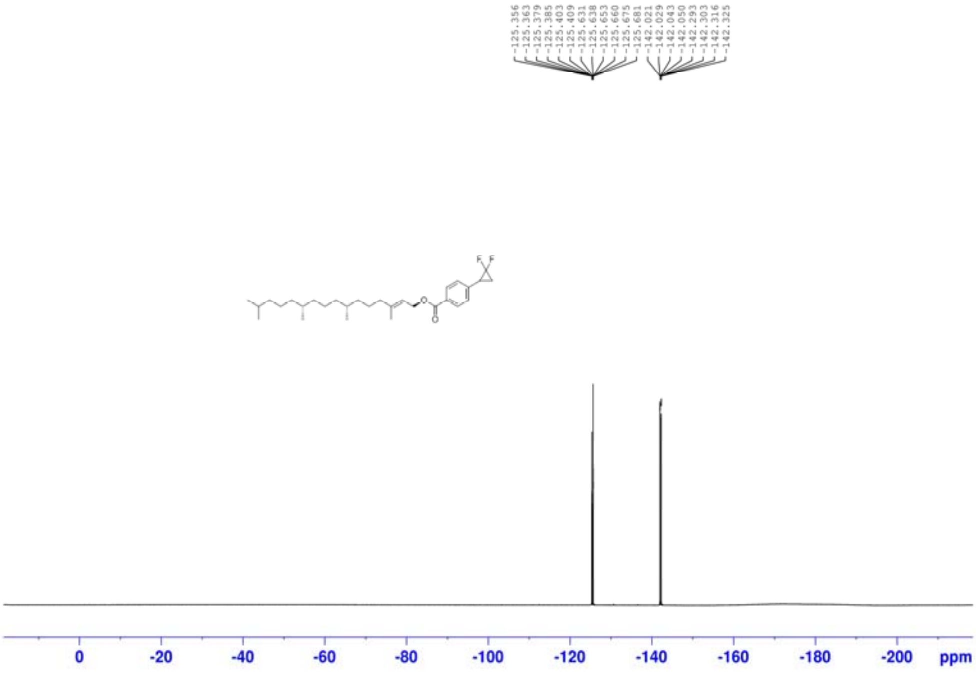
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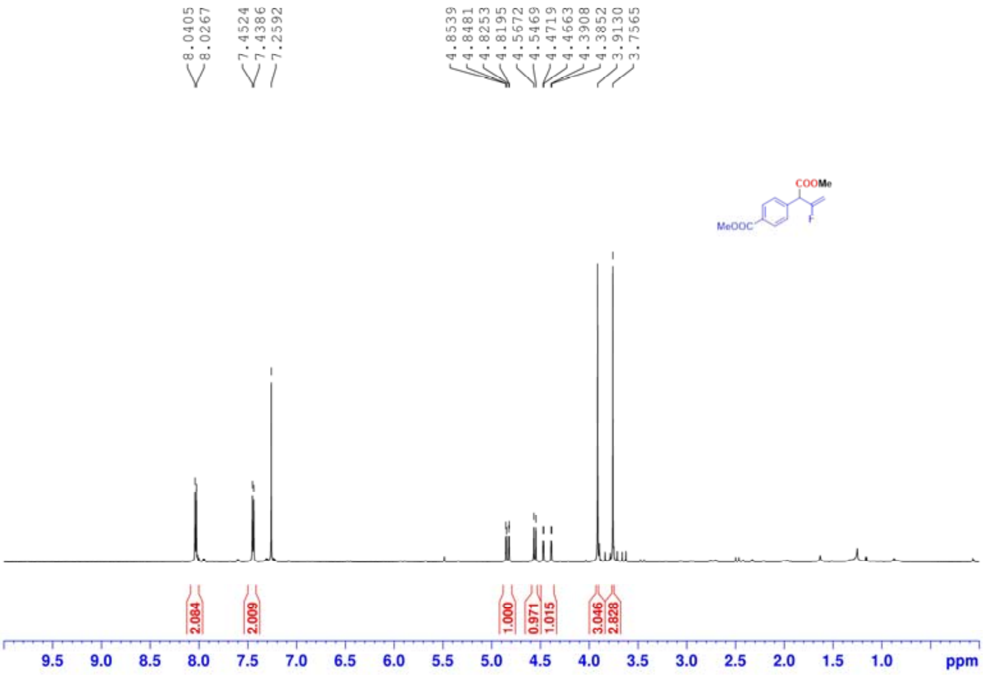
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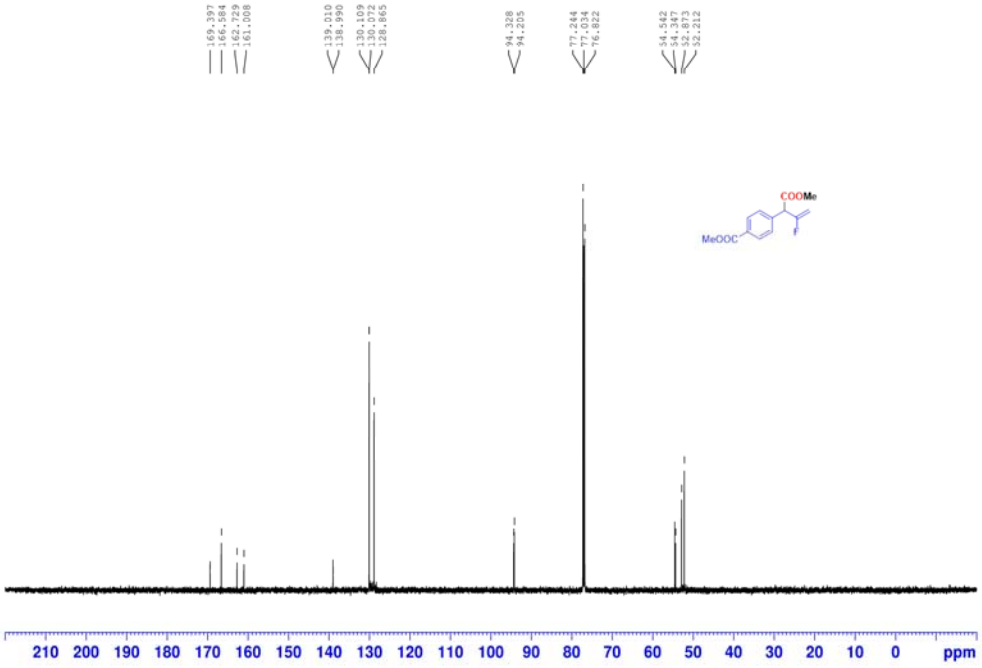
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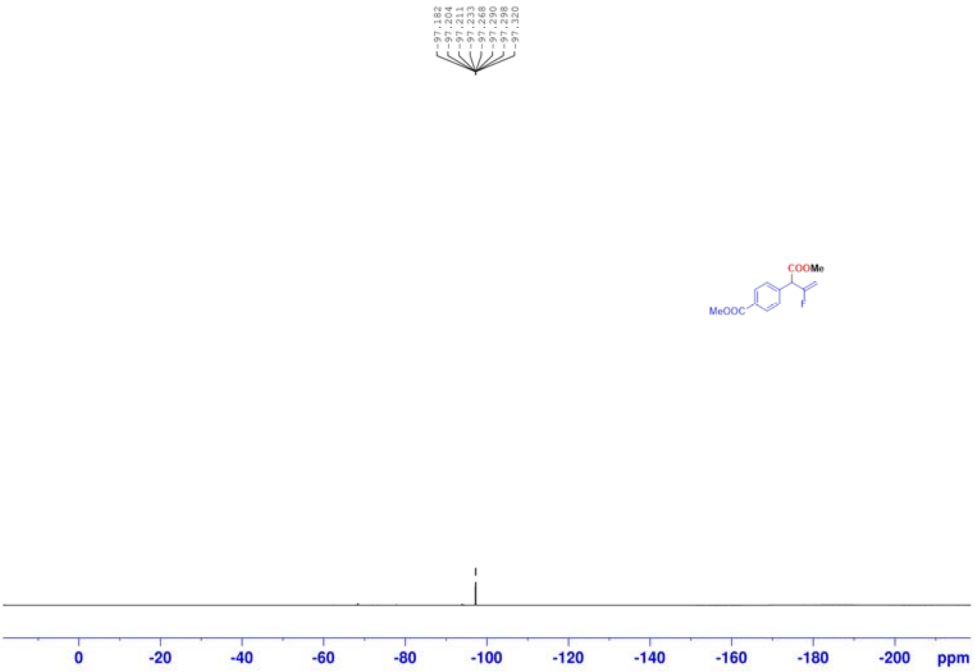
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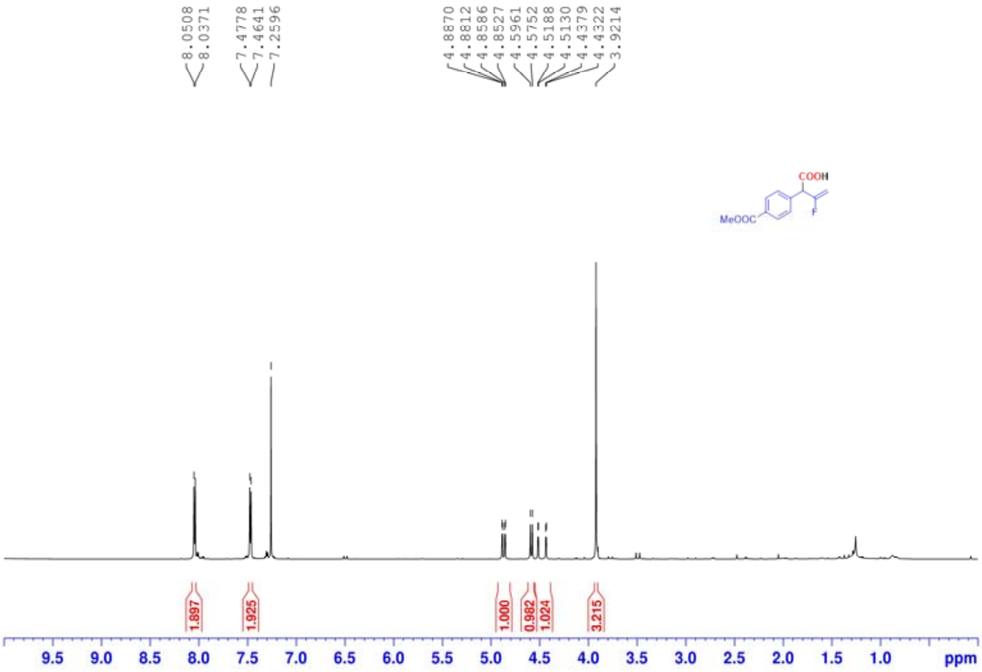
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2.0
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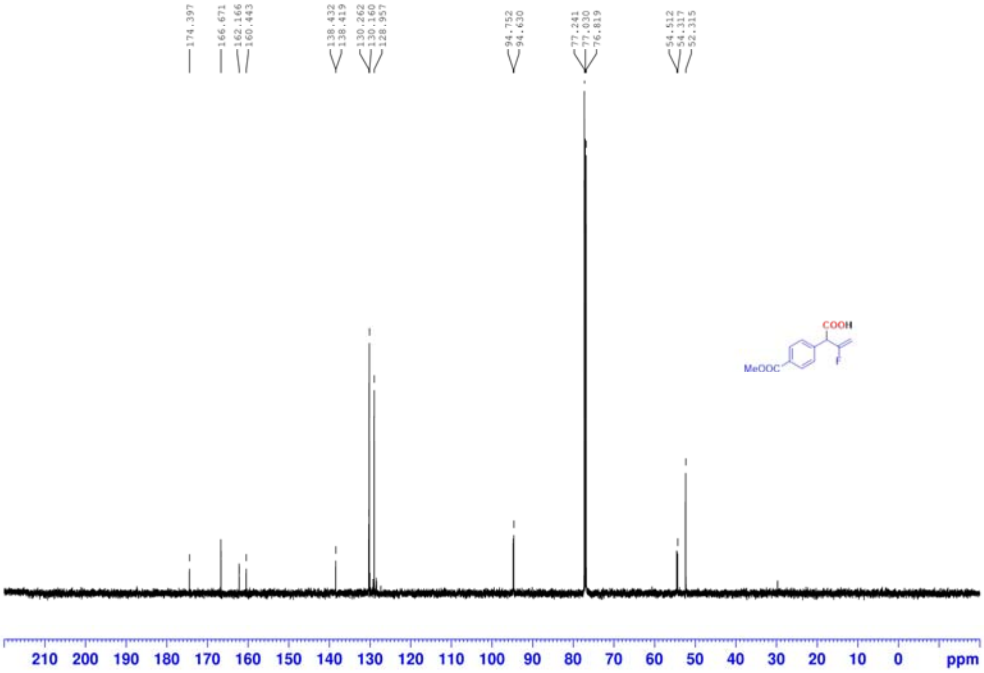
ppm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138.419
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130.160
128.957
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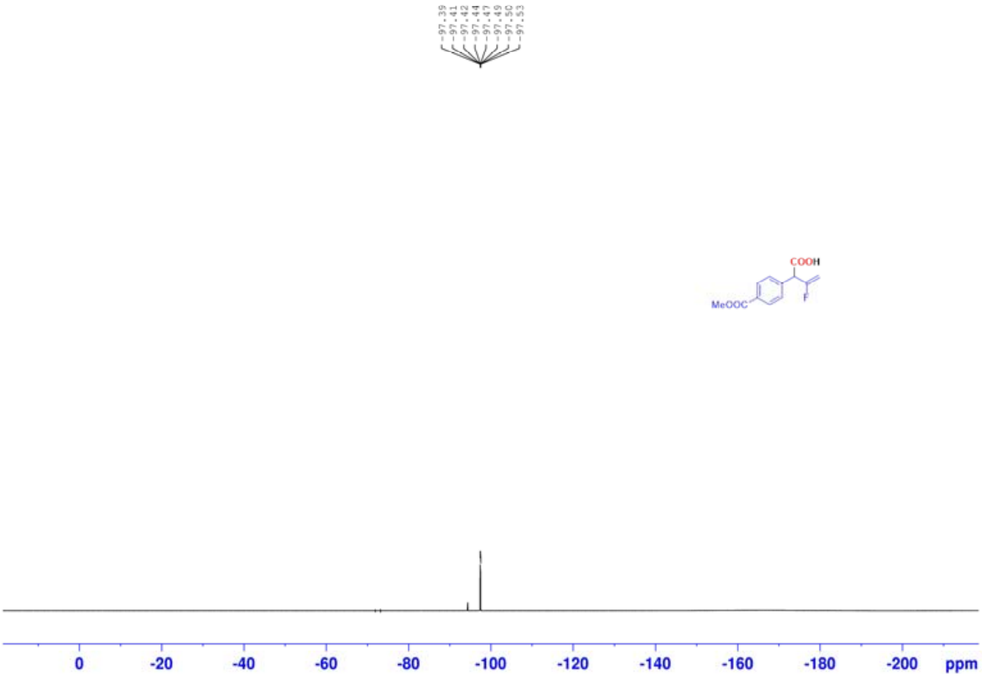
94.630
77.241
77.030
76.819
54.512
54.317
52.315
COOH
MeOOC
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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-97.42
-97.44
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-97.50
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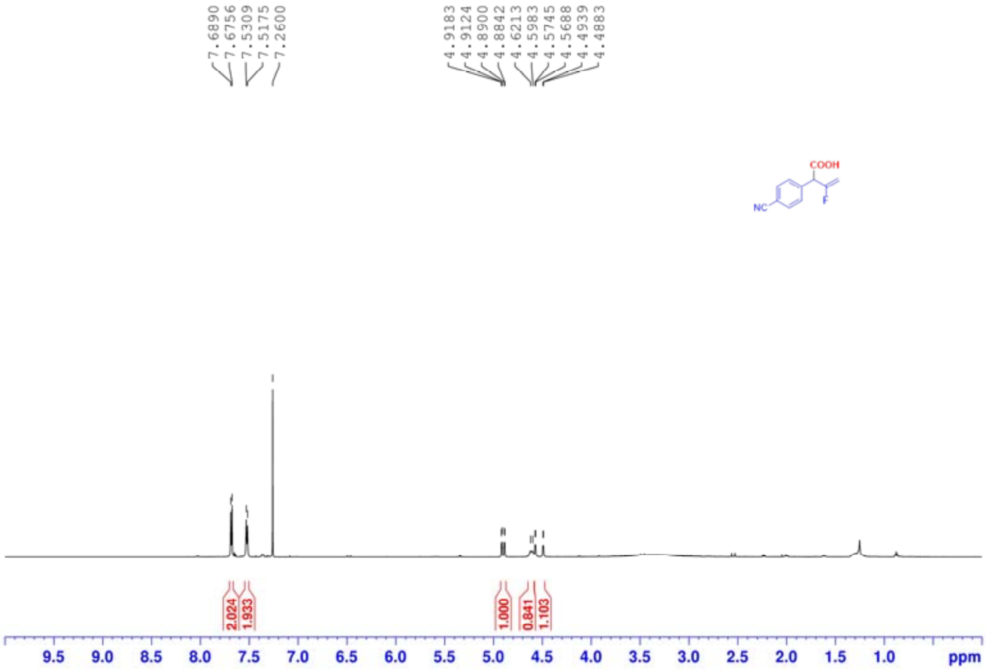
COOH
MeOOC
F
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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4.9124
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4.8842
4.6213
4.5983
4.5745
4.5688
4.4939
4.4883
COOH
NC
F
2.024
1.933
1.000
0.841
1.103
9.5
9.0
8.5
8.0
7.5
7.0
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5.0
4.5
4.0
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2.5
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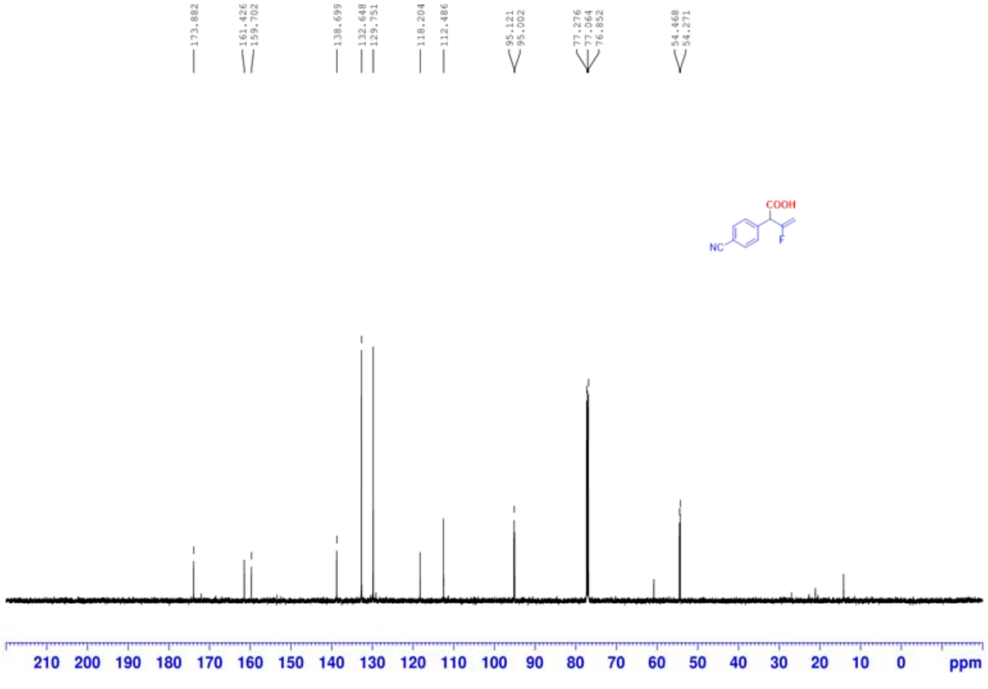
1.5
1.0
ppm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54.468
54.271
COOH
NC
F
210
200
190
180
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140
130
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10
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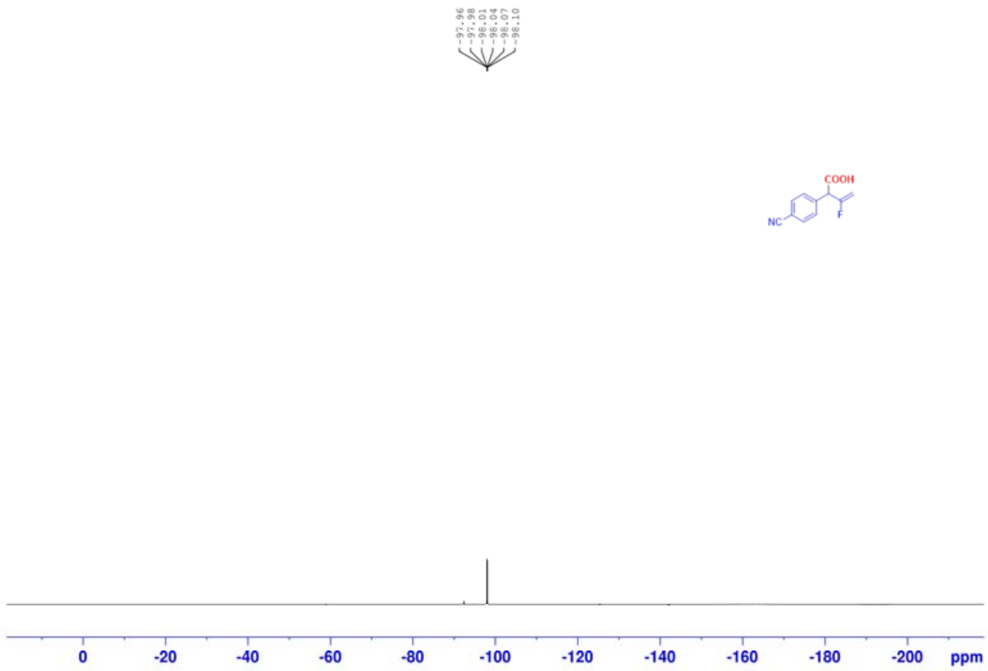
ppm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-98.07
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COOH
NC
F
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-80
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-120
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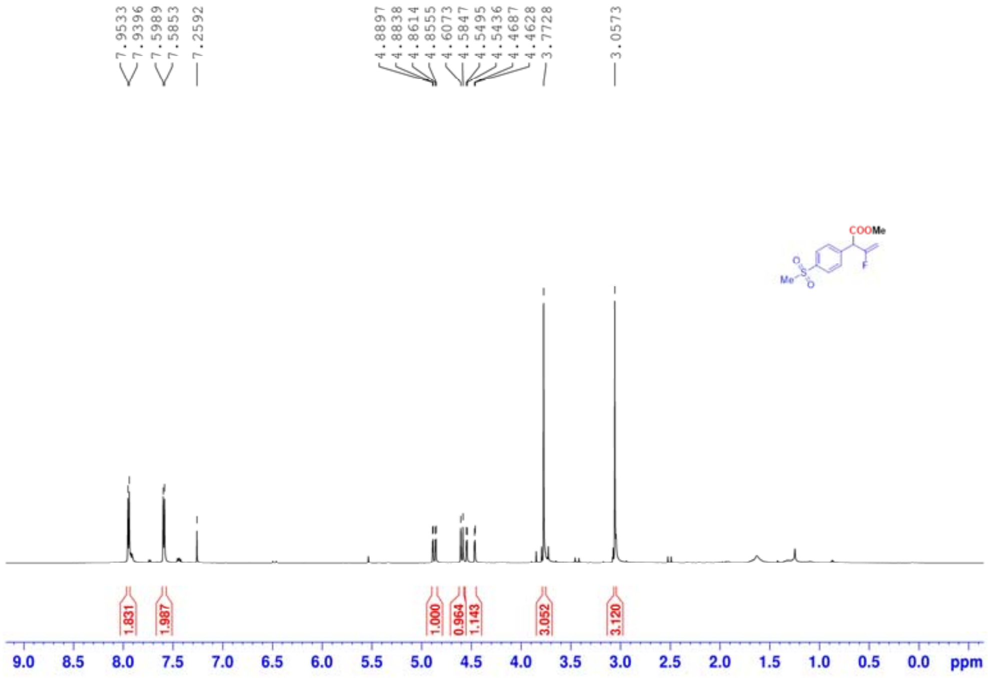
-160
-180
-200
ppm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4.8838
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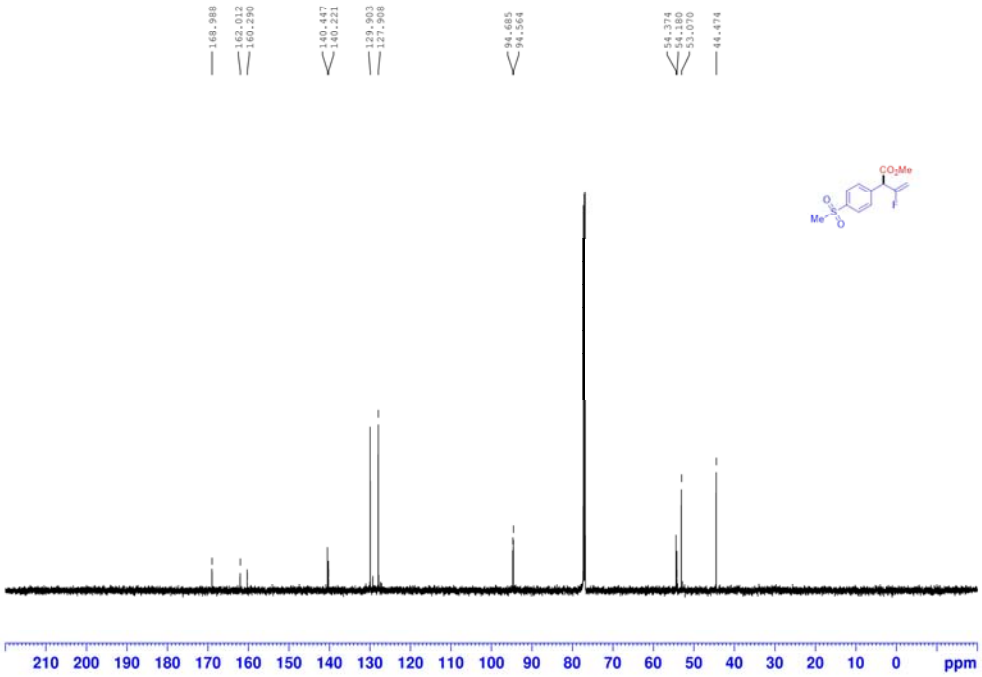
4.5847
4.5495
4.5436
4.4687
4.4628
3.7728
3.0573
COOMe
Me
S
O
O
F
1.831
1.987
1.000
0.964
1.143
3.052
3.120
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm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127.908
94.685
94.564
54.374
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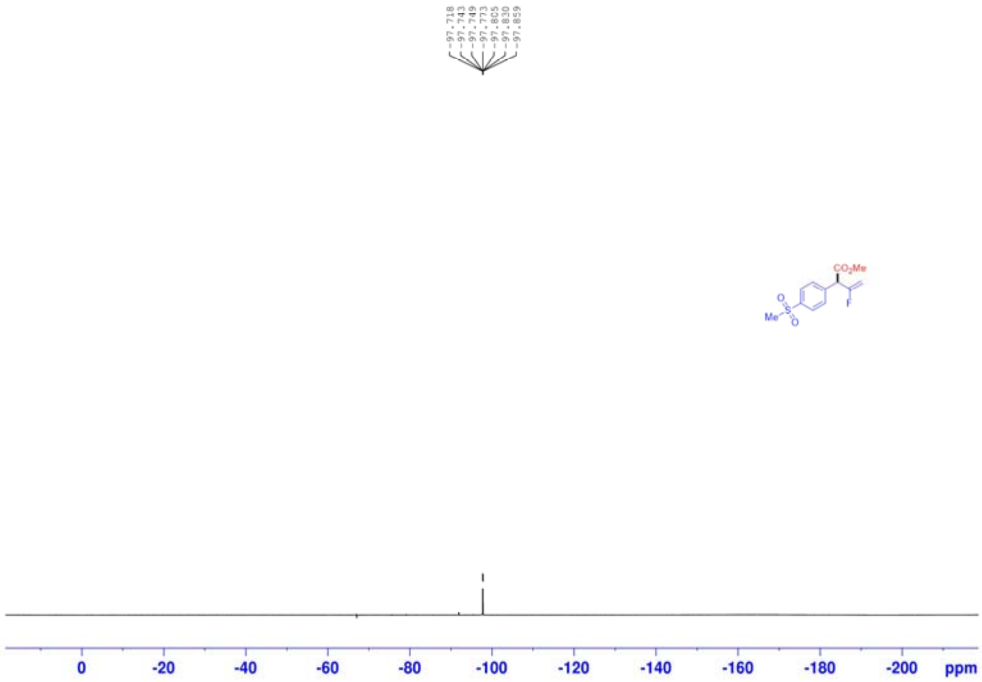
44.474
CO2Me
F
Me
S
O
O
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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-97.749
-97.773
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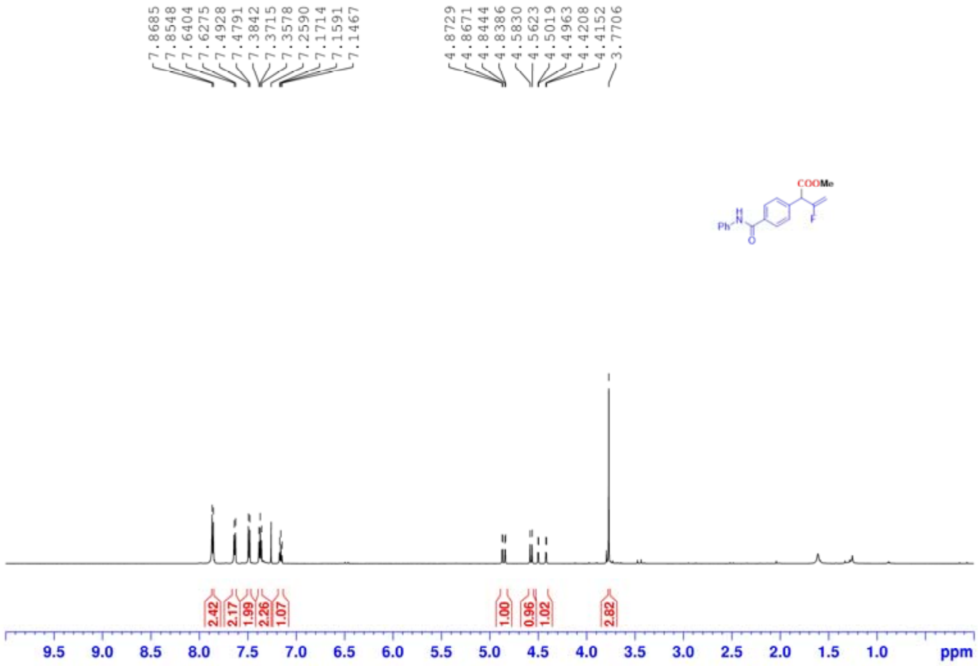
-97.859
CO2Me
F
Me
S
O
O
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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7.6404
7.6275
7.4928
7.4791
7.3842
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7.3578
7.2590
7.1714
7.1591
7.1467
4.8729
4.8671
4.8444
4.8386
4.5830
4.5623
4.5019
4.4963
4.4208
4.4152
3.7706
COOMe
Ph
N
H
O
F
2.42
2.17
1.99
2.26
1.07
1.00
0.96
1.02
2.82
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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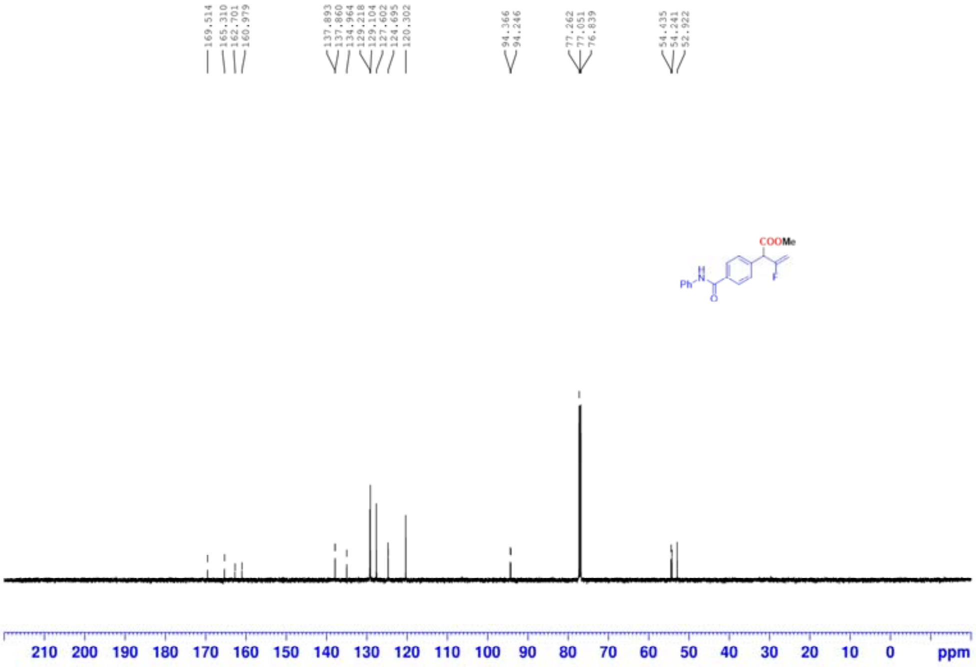
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165.310
162.701
160.979
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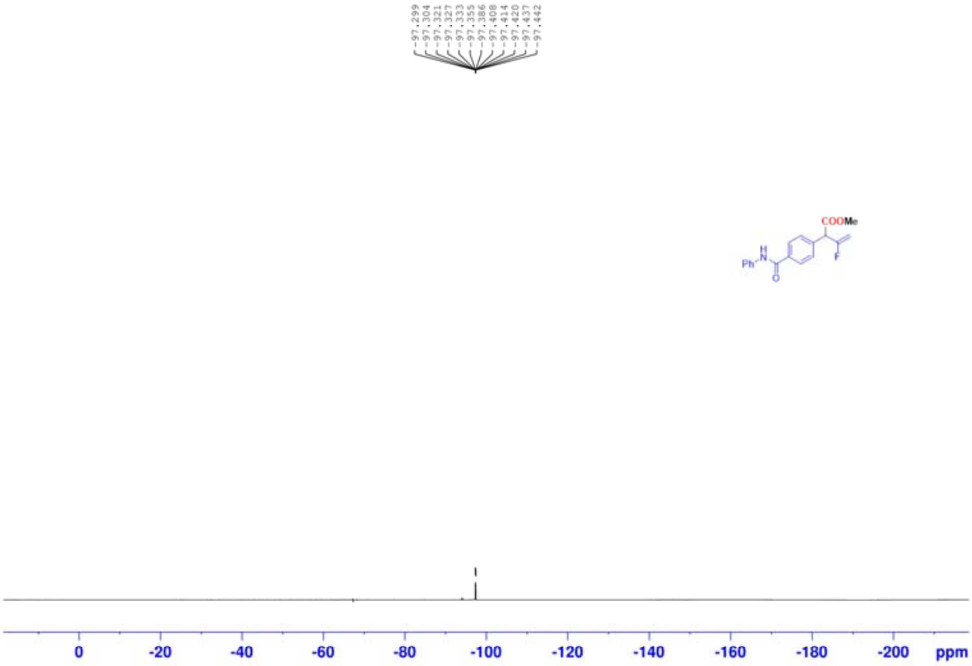
137.860
134.964
129.218
129.104
127.602
124.695
120.302
94.366
94.246
77.262
77.051
76.839
54.435
54.241
52.922
COOMe
Ph
N
H
O
F
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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-97.414
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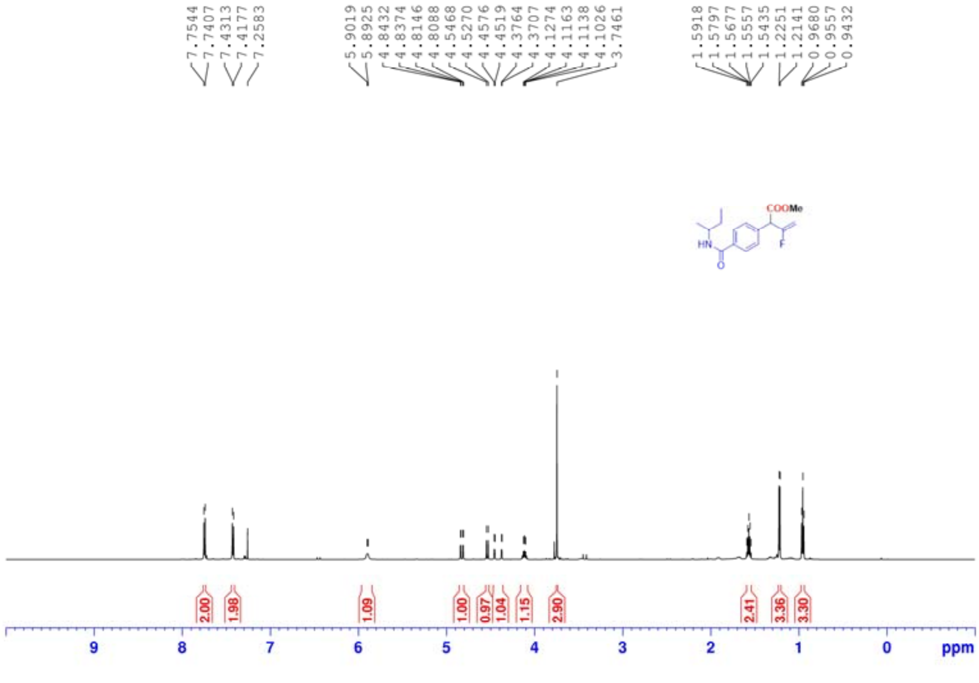
-97.437
-97.442
COOMe
Ph
N
H
O
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm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7.4313
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5.9019
5.8925
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4.8374
4.8146
4.8088
4.5468
4.5270
4.4576
4.4519
4.3764
4.3707
4.1274
4.1163
4.1138
4.1026
3.7461
1.5918
1.5797
1.5677
1.5557
1.5435
1.2251
1.2141
0.9680
0.9557
0.9432
COOMe
HN
O
F
2.00
1.98
1.09
1.00
0.97
1.04
1.15
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2.41
3.36
3.30
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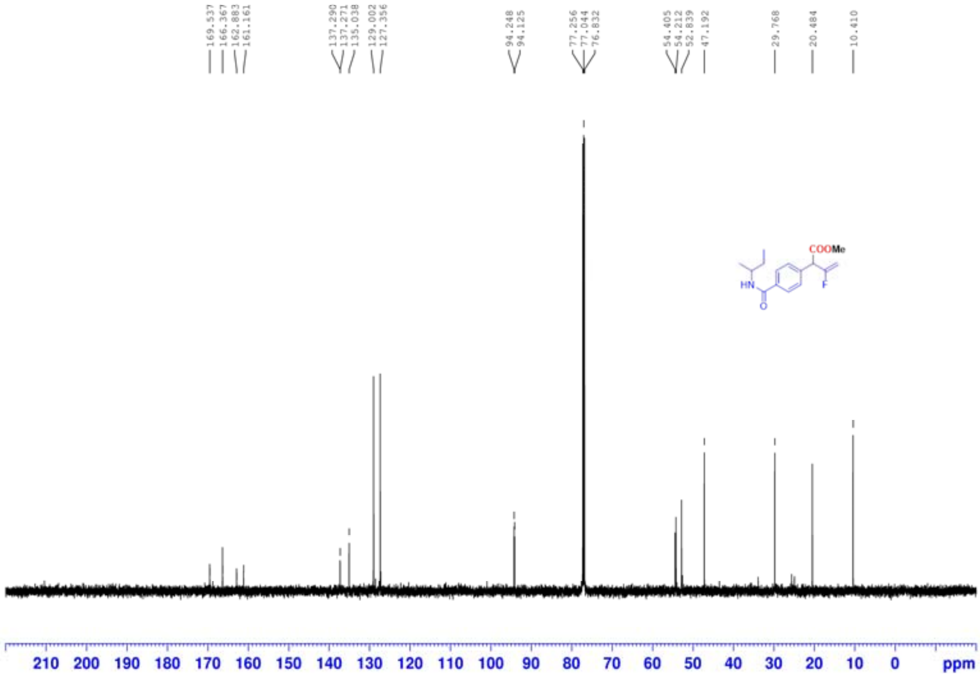
8
7
6
5
4
3
2
1
0
ppm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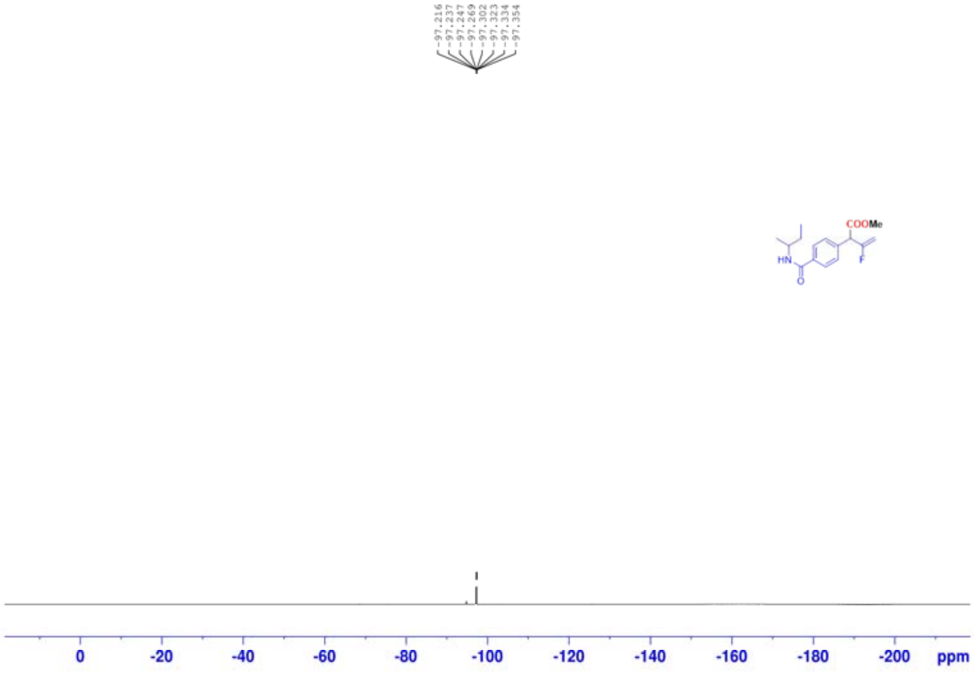
94.248
94.125
77.256
77.044
76.832
54.405
54.212
52.839
47.192
29.768
20.484
10.410
COOMe
HN
O
F
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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-97.334
-97.354
COOMe
HN
O
F
0
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-40
-60
-80
-100
-120
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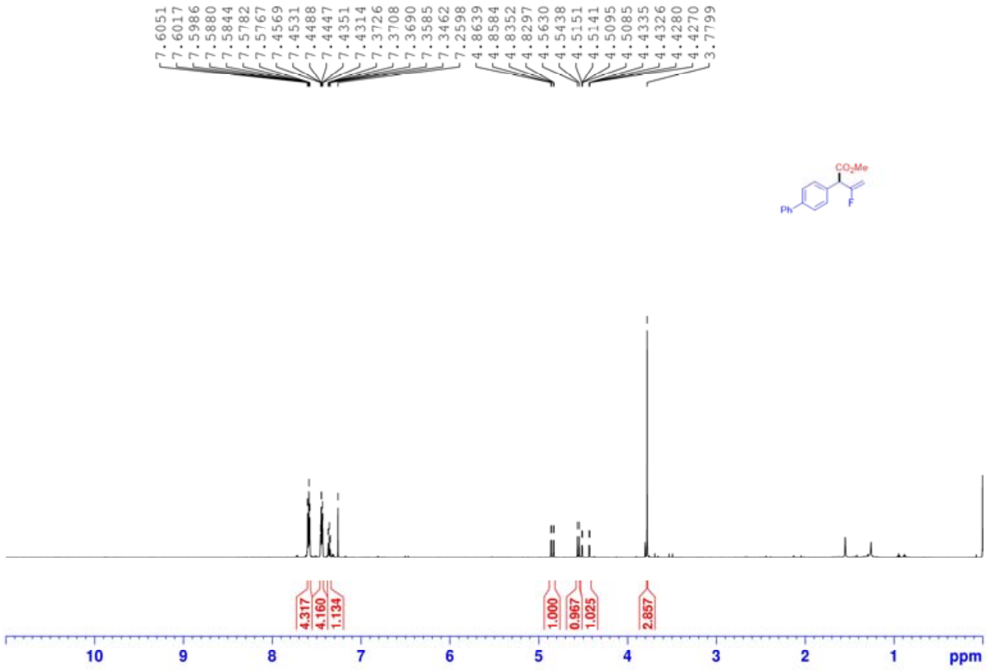
-160
-180
-200
ppm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7.5767
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7.4531
7.4488
7.4447
7.4351
7.4314
7.3726
7.3708
7.3690
7.3585
7.3462
7.2598
4.8639
4.8584
4.8352
4.8297
4.5630
4.5438
4.5151
4.5141
4.5095
4.5085
4.4335
4.4326
4.4280
4.4270
3.7799
CO2Me
Ph
F
4.317
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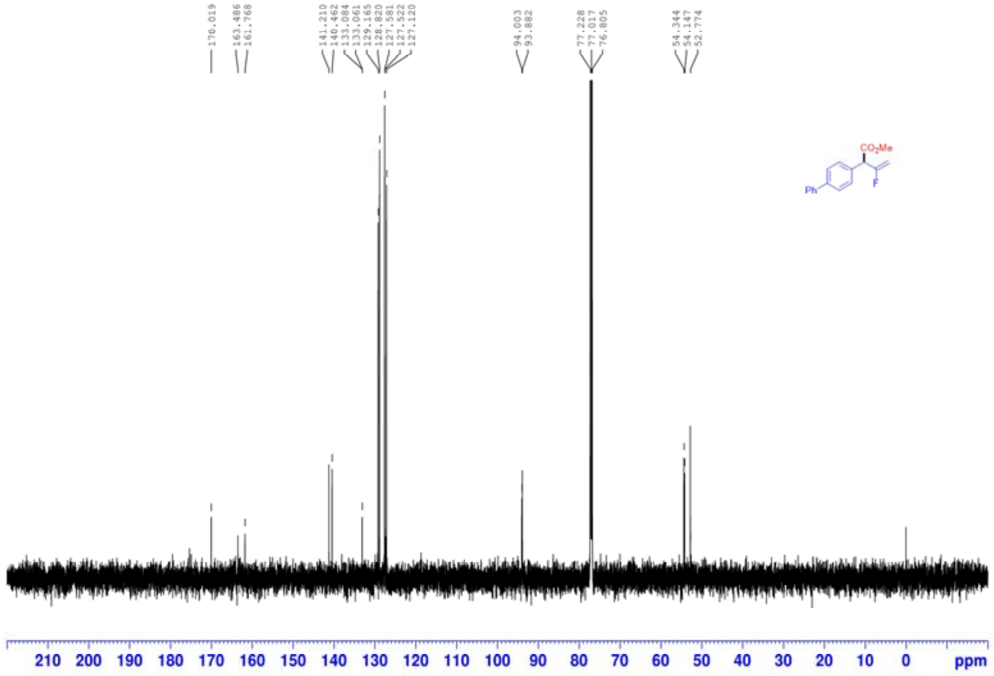
1.000
0.967
1.025
2.857
10
9
8
7
6
5
4
3
2
1
ppm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140.462
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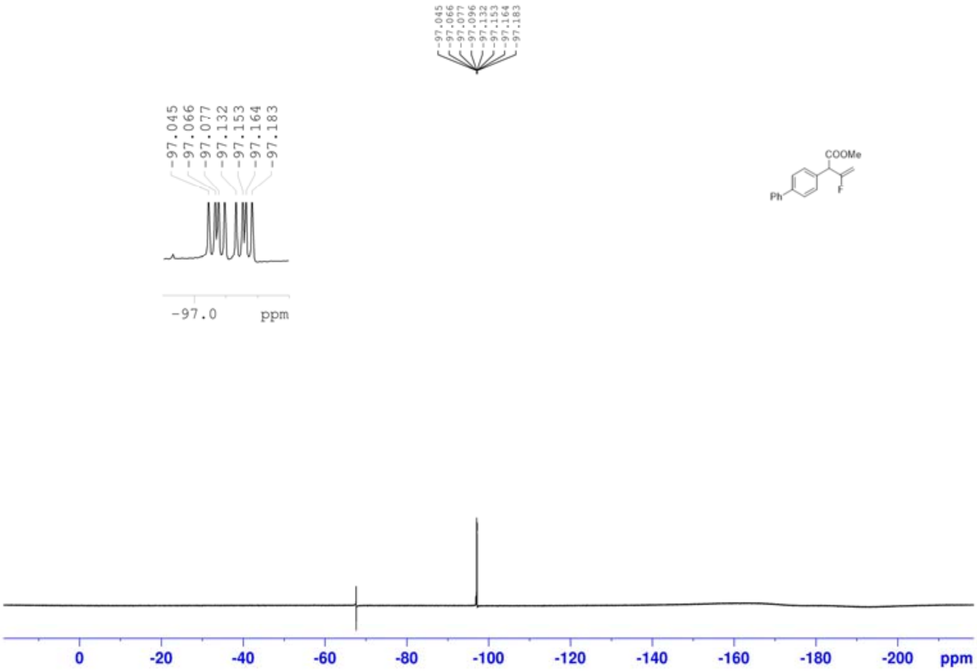
127.522
127.120
94.003
93.882
77.228
77.017
76.805
54.344
54.147
52.774
CO2Me
Ph
F
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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-97.066
-97.077
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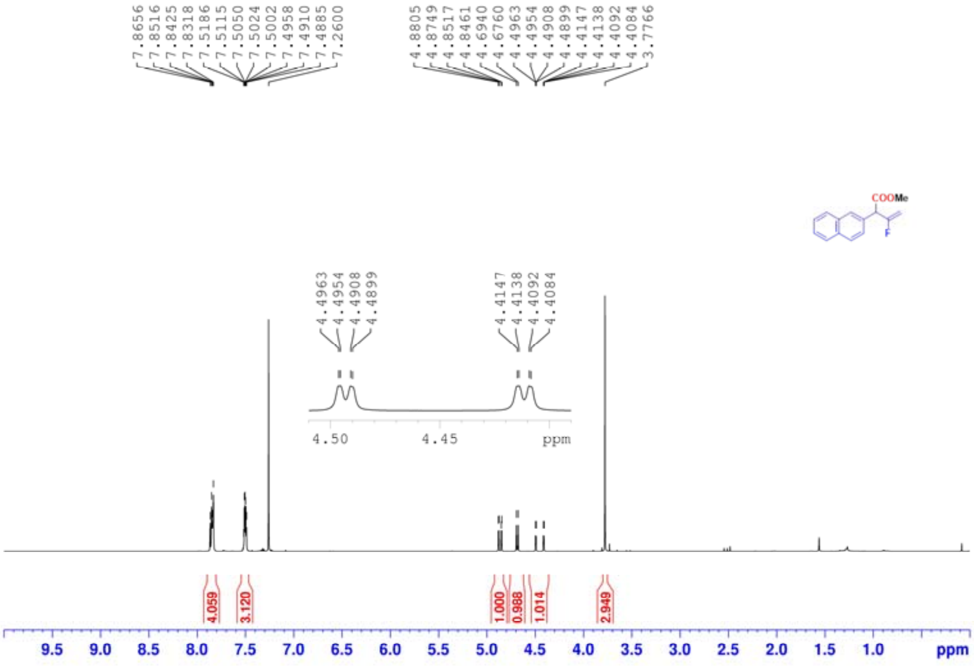
-97.164
-97.183
-97.045
-97.066
-97.077
-97.132
-97.153
-97.164
-97.183
-97.0
ppm
COOMe
Ph
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm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7.8425
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7.5002
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7.4910
7.4885
7.2600
4.8805
4.8749
4.8517
4.8461
4.6940
4.6760
4.4963
4.4954
4.4908
4.4899
4.4147
4.4138
4.4092
4.4084
3.7766
COOMe
F
4.4963
4.4954
4.4908
4.4899
4.4147
4.4138
4.4092
4.4084
4.50
4.45
ppm
4.059
3.120
1.000
0.988
1.014
2.949
9.5
9.0
8.5
8.0
7.5
7.0
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5.0
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1.5
1.0
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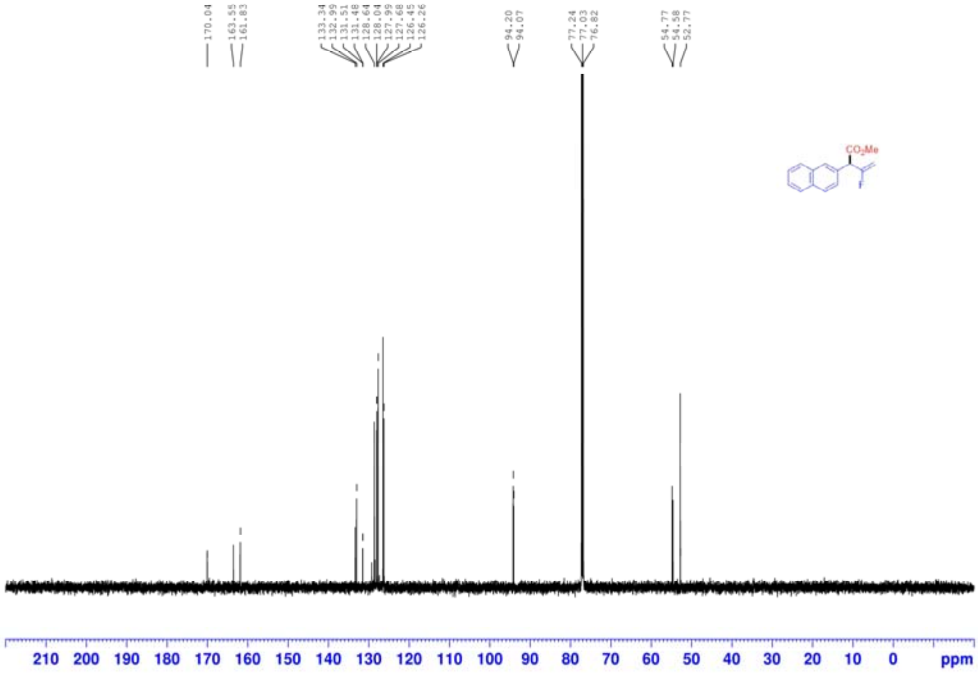
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127.99
127.68
126.45
126.26
94.20
94.07
77.24
77.03
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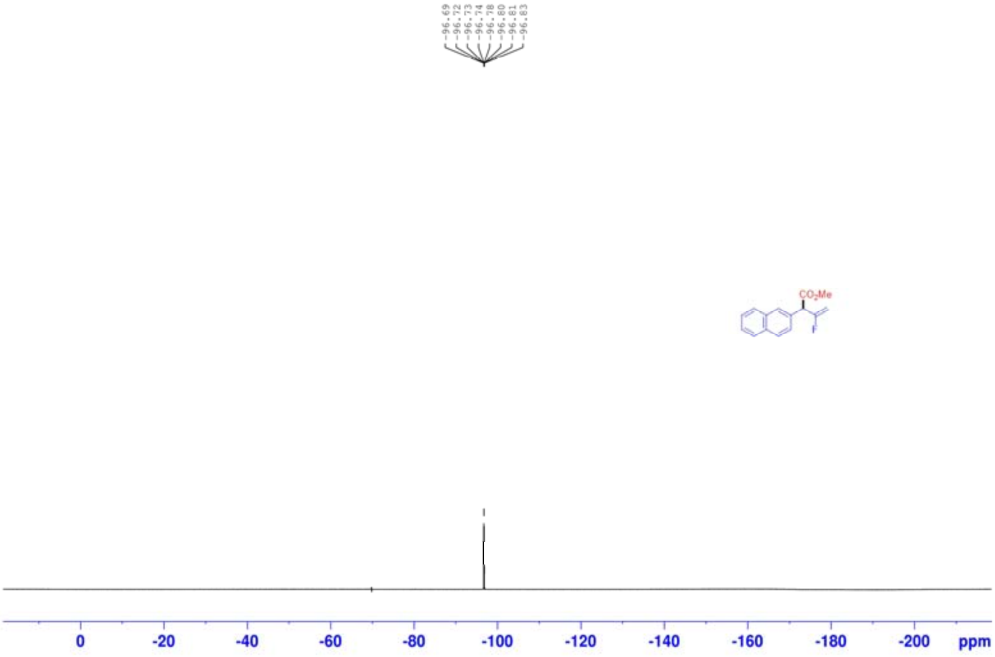
54.77
54.58
52.77
CO2Me
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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CO2Me
F
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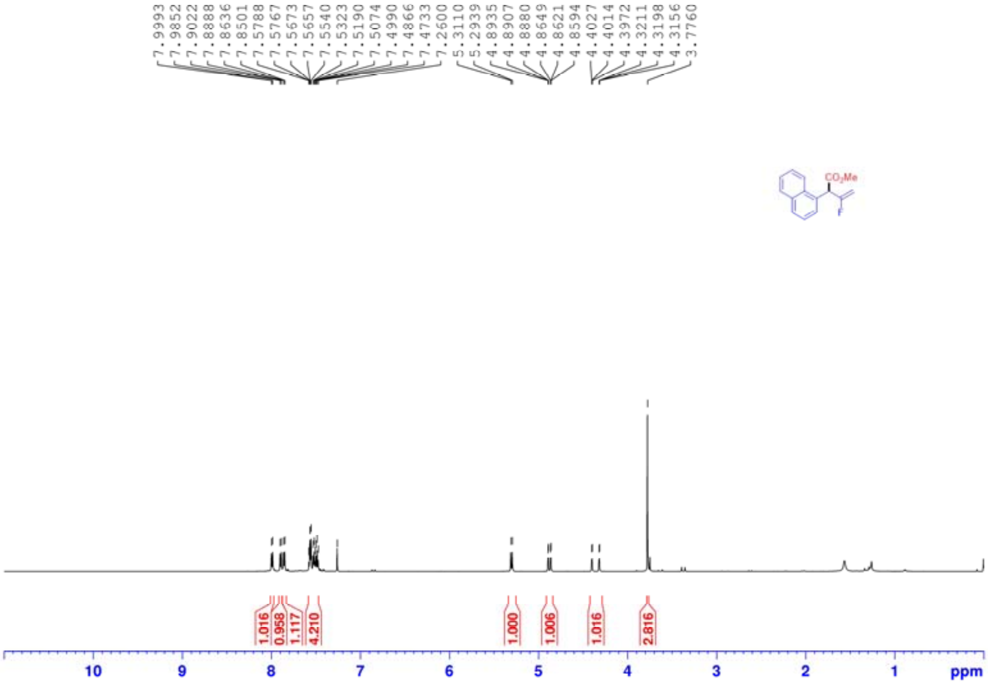
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7.5540
7.5323
7.5190
7.5074
7.4990
7.4866
7.4733
7.2600
5.3110
5.2939
4.8935
4.8907
4.8880
4.8649
4.8621
4.8594
4.4027
4.4014
4.3972
4.3211
4.3198
4.3156
3.7760
CO_2Me
F
1.016
0.958
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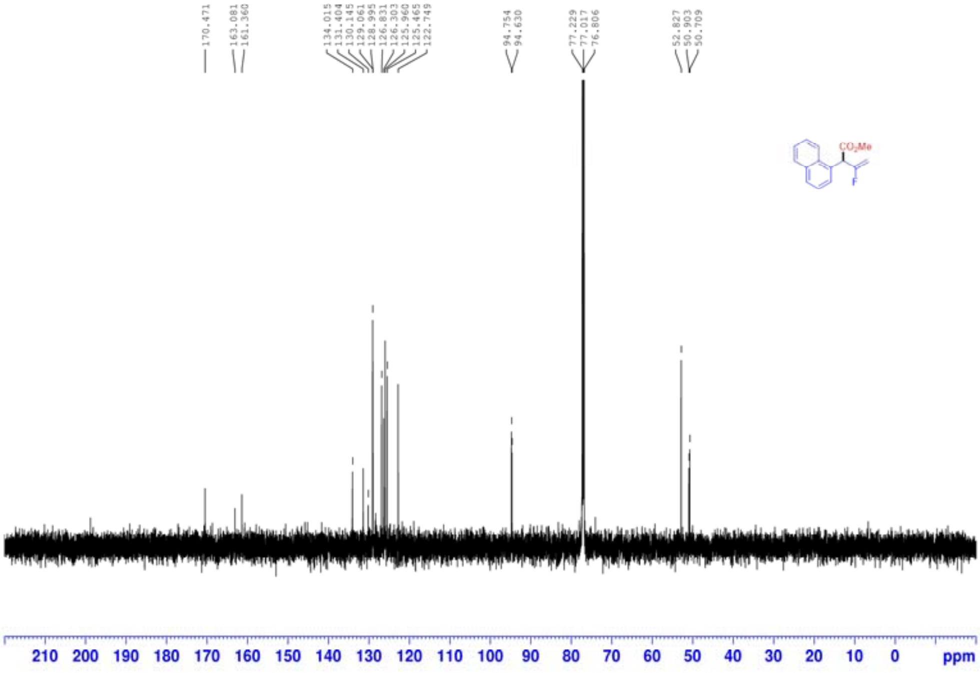
1.006
1.016
2.816
10
9
8
7
6
5
4
3
2
1
ppm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122.749
94.754
94.630
77.229
77.017
76.806
52.827
50.903
50.709
CO_2Me
F
210
200
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180
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160
150
140
130
120
110
100
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80
70
60
50
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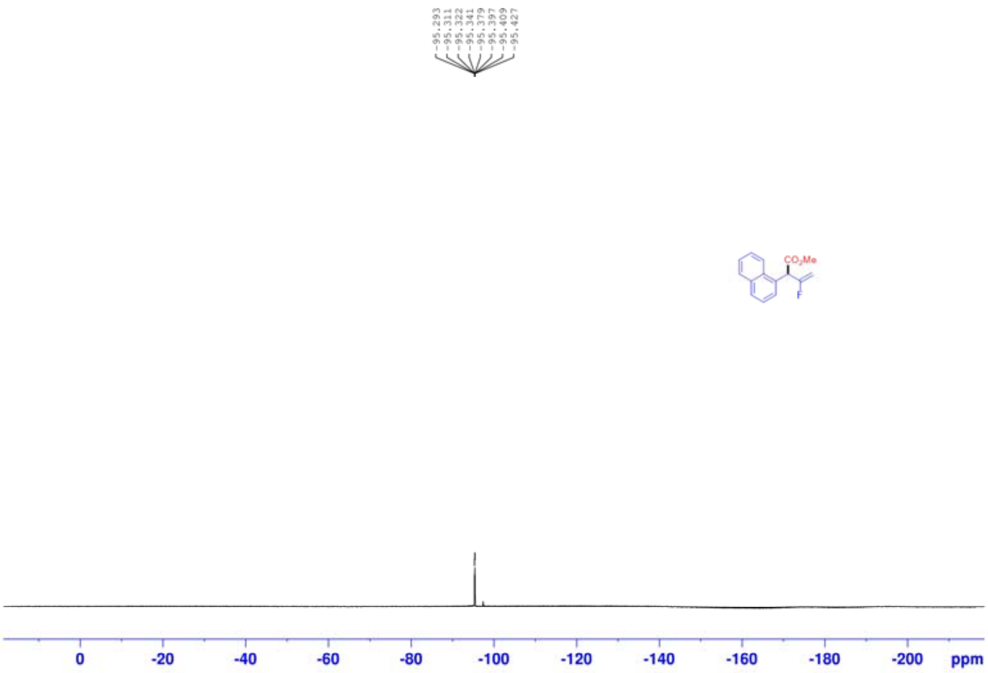
30
20
10
0
ppm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-95.379
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-95.409
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CO2Me
F
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-40
-60
-80
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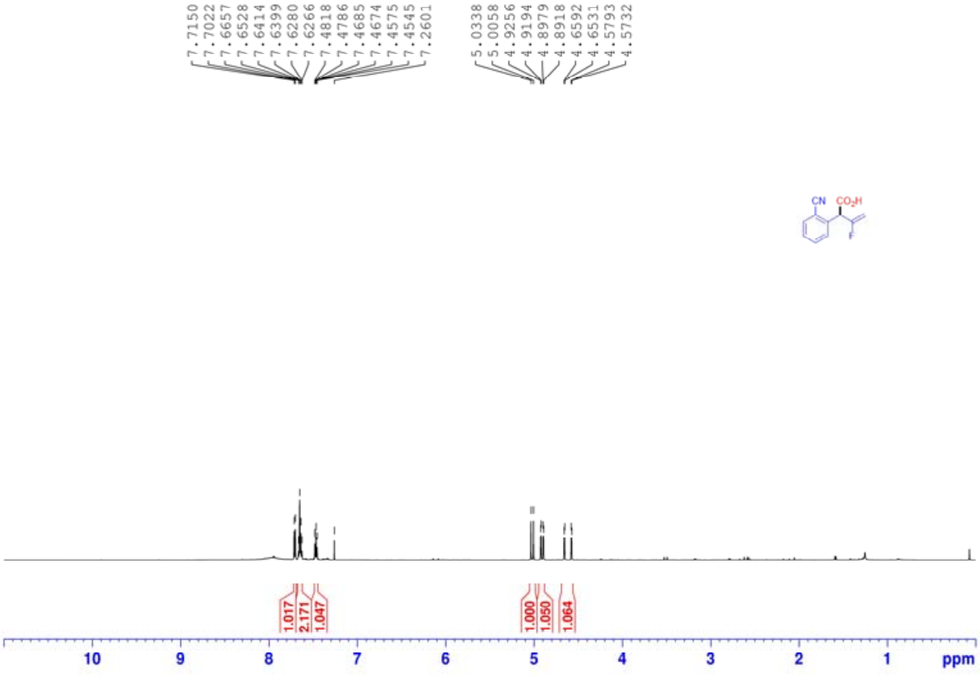
-120
-140
-160
-180
-200
ppm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7.6280
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7.4685
7.4674
7.4575
7.4545
7.2601
5.0338
5.0058
4.9256
4.9194
4.8979
4.8918
4.6592
4.6531
4.5793
4.5732
CN
CO2H
F
1.017
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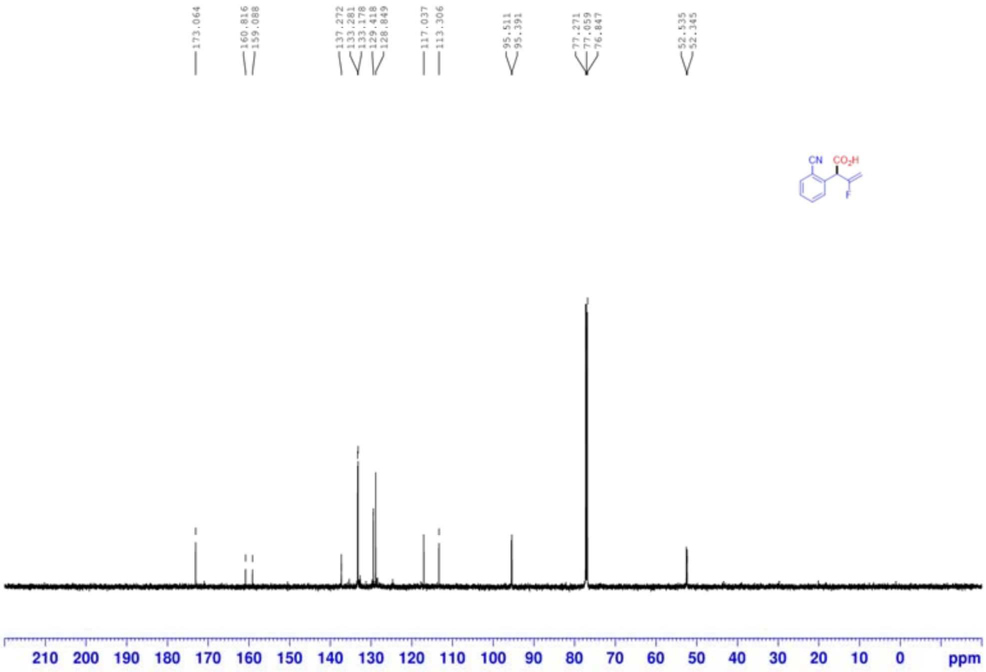
1.047
1.000
1.050
1.064
10
9
8
7
6
5
4
3
2
1
ppm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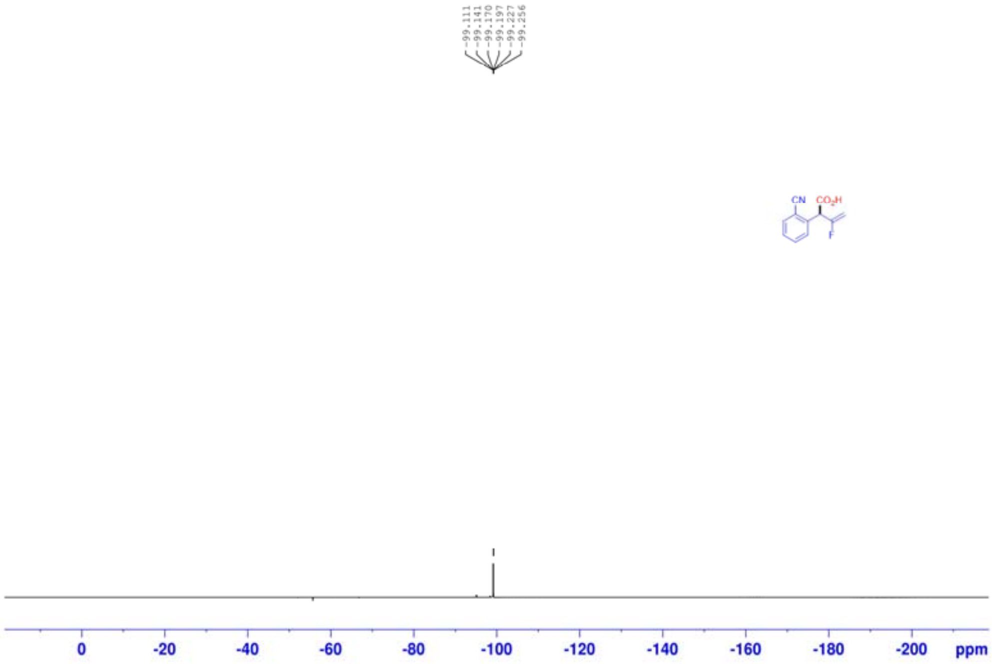
159.088
137.272
133.281
133.178
129.418
128.849
117.037
113.306
95.511
95.391
77.271
77.059
76.847
52.535
52.345
CN
CO2H
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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-99.141
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-99.227
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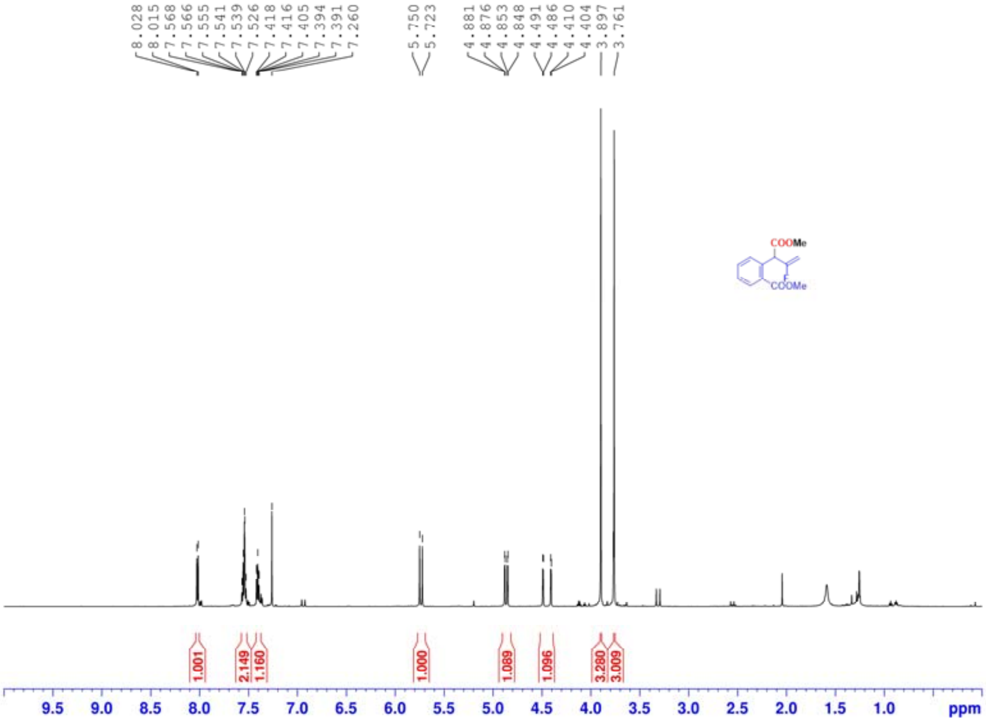
CN
CO2H
F
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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7.541
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7.526
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7.416
7.405
7.394
7.391
7.260
5.750
5.723
4.881
4.876
4.853
4.848
4.491
4.486
4.410
4.404
3.897
3.761
COOMe
F
COOMe
1.001
2.149
1.160
1.000
1.089
1.096
3.280
3.009
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
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5.0
4.5
4.0
3.5
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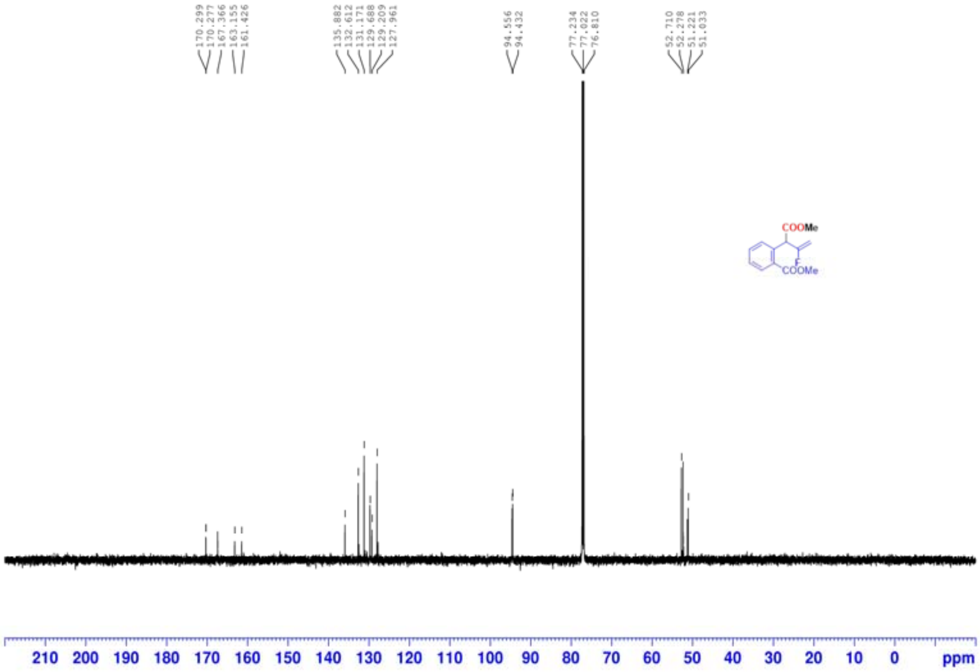
2.5
2.0
1.5
1.0
ppm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129.209
127.961
94.556
94.432
77.234
77.022
76.810
52.710
52.278
51.221
51.033
COOMe
F
COOMe
210
200
190
180
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60
50
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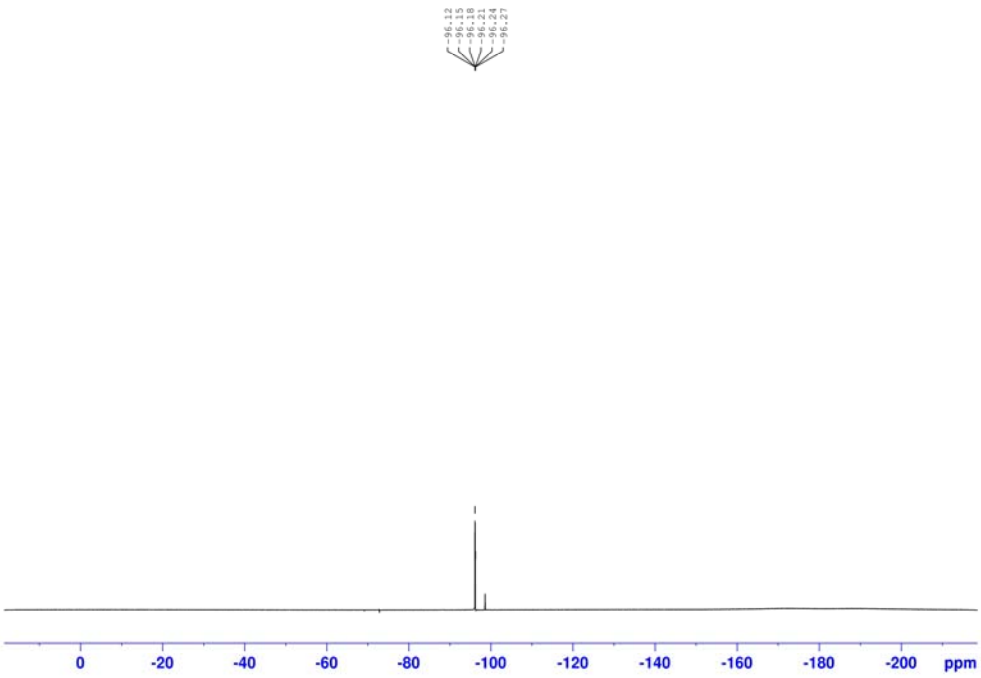
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-20
-40
-60
-80
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-120
-140
-160
-180
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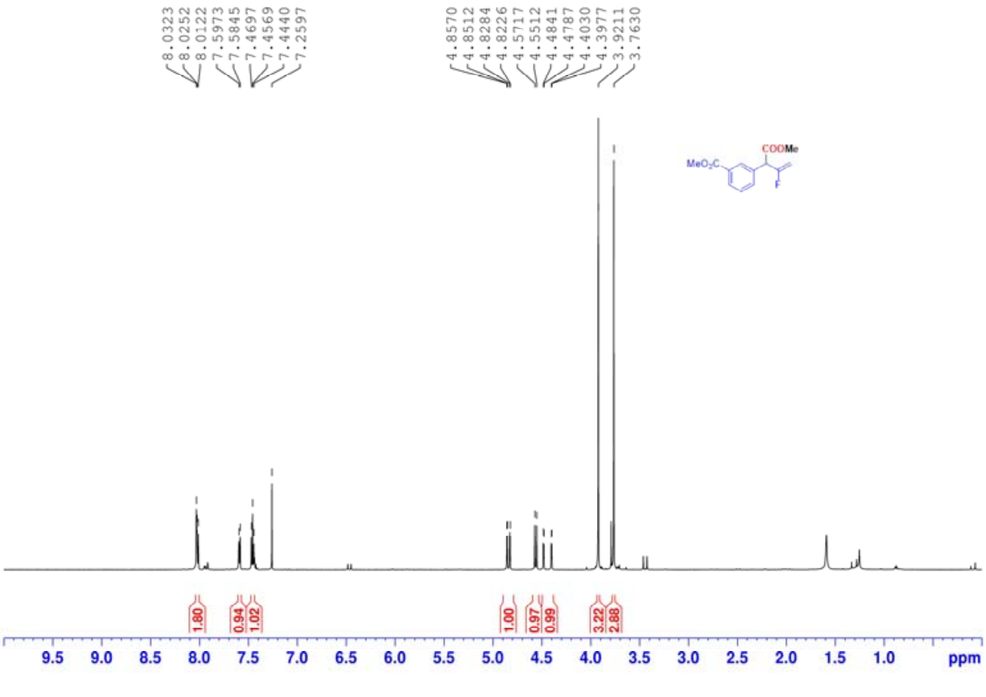
ppm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7.4569
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4.8512
4.8284
4.8226
4.5717
4.5512
4.4841
4.4787
4.4030
4.3977
3.9211
3.7630
MeO2C
COOMe
F
1.80
0.94
1.02
1.00
0.97
0.99
3.22
2.88
9.5
9.0
8.5
8.0
7.5
7.0
6.5
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5.0
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4.0
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2.5
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1.5
1.0
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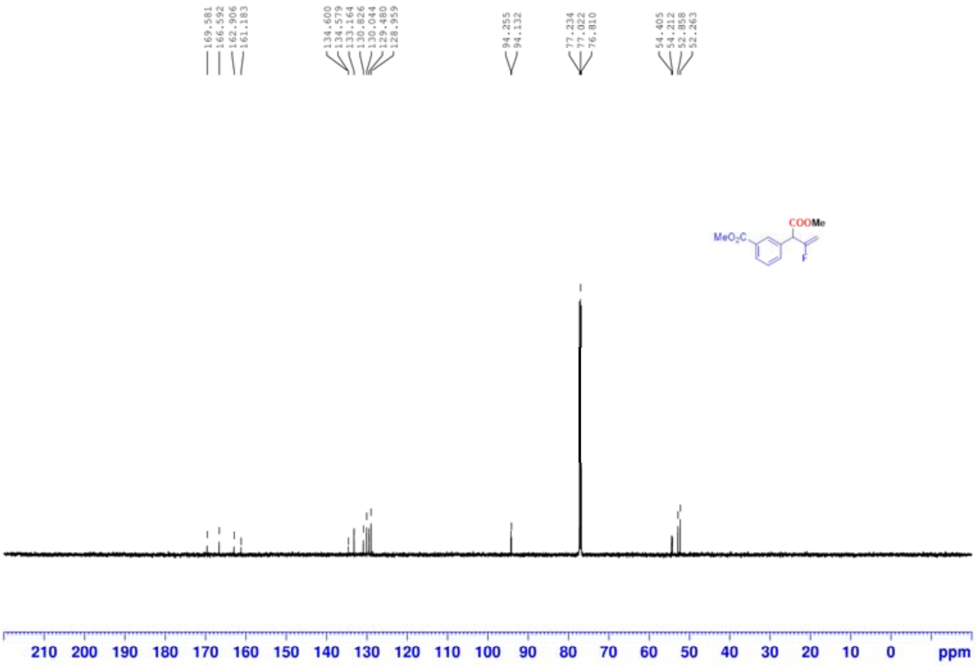
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161.183
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133.164
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130.044
129.480
128.959
94.255
94.132
77.234
77.022
76.810
54.405
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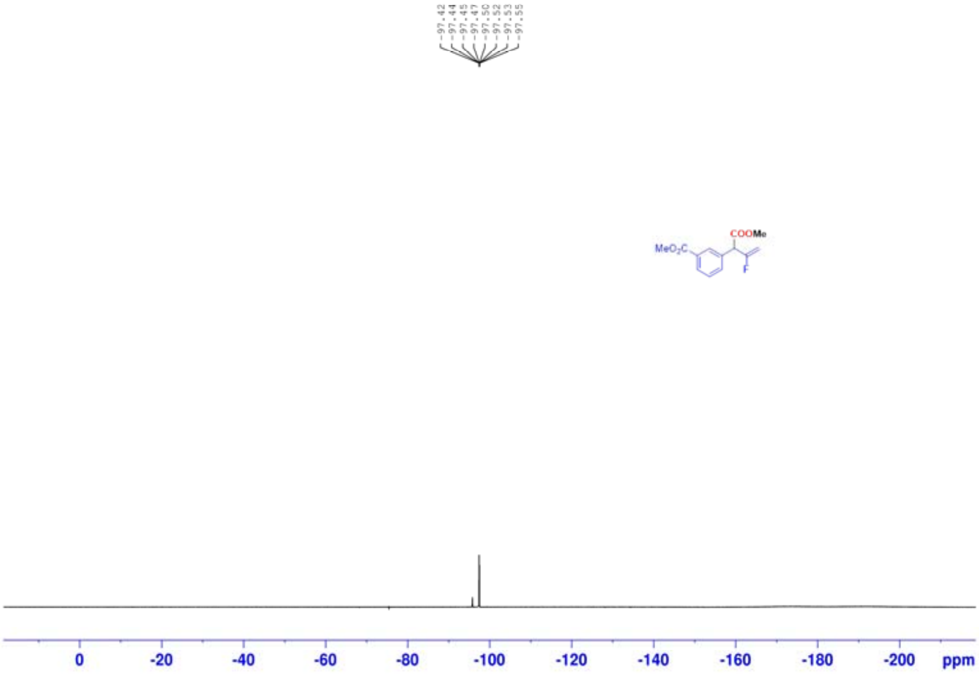
52.858
52.263
COOMe
MeO2C
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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-97.53
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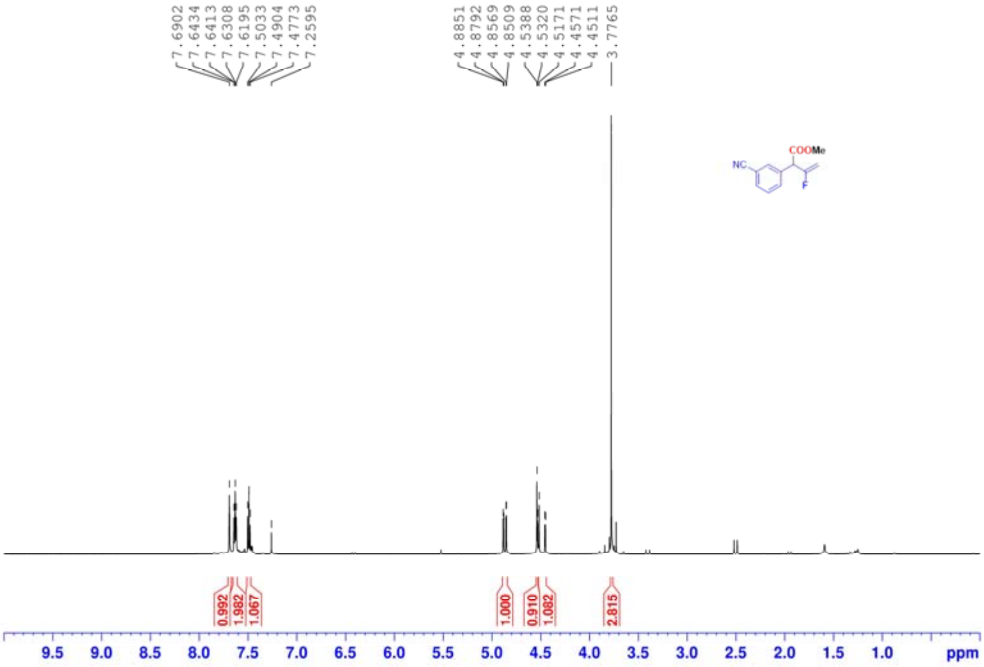
COOMe
MeO2C
F
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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7.6413
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7.6195
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7.4904
7.4773
7.2595
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4.8792
4.8569
4.8509
4.5388
4.5320
4.5171
4.4571
4.4511
3.7765
NC
COOMe
F
0.992
1.982
1.067
1.000
0.910
1.082
2.815
9.5
9.0
8.5
8.0
7.5
7.0
6.5
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5.0
4.5
4.0
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1.5
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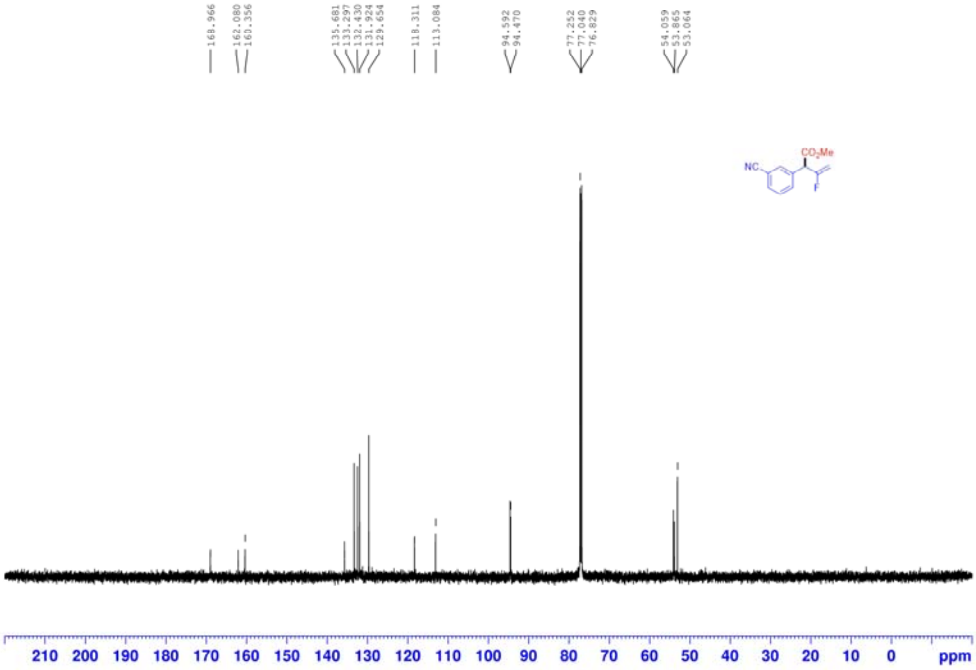
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129.654
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94.470
77.252
77.040
76.829
54.059
53.865
53.064
NC
CO2Me
F
210
200
190
180
170
160
150
140
130
120
110
100
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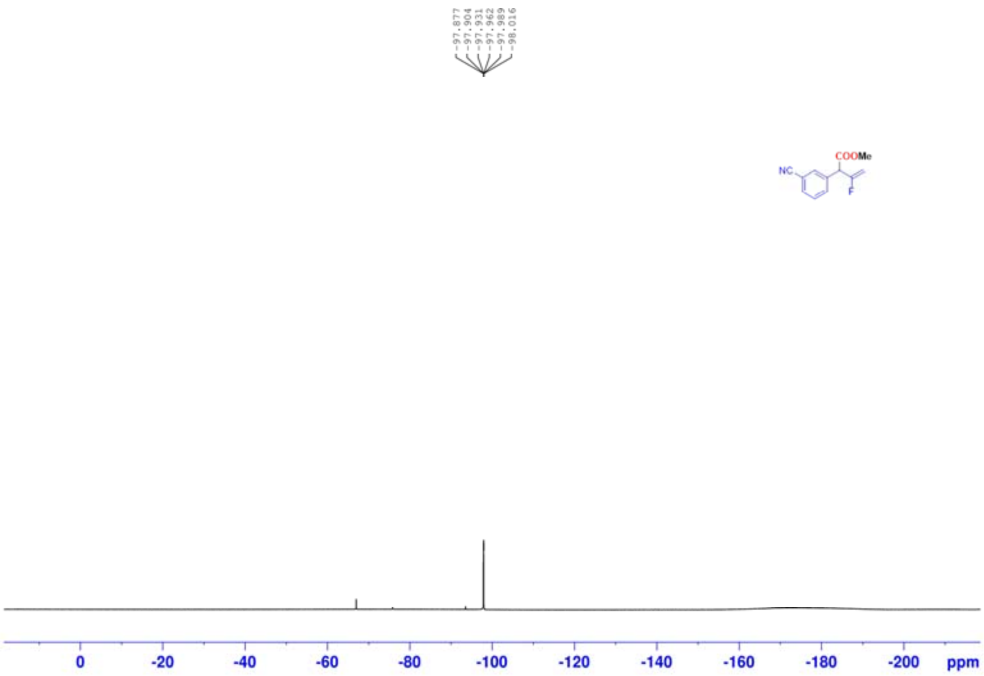
80
70
60
50
40
30
20
10
0
ppm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F
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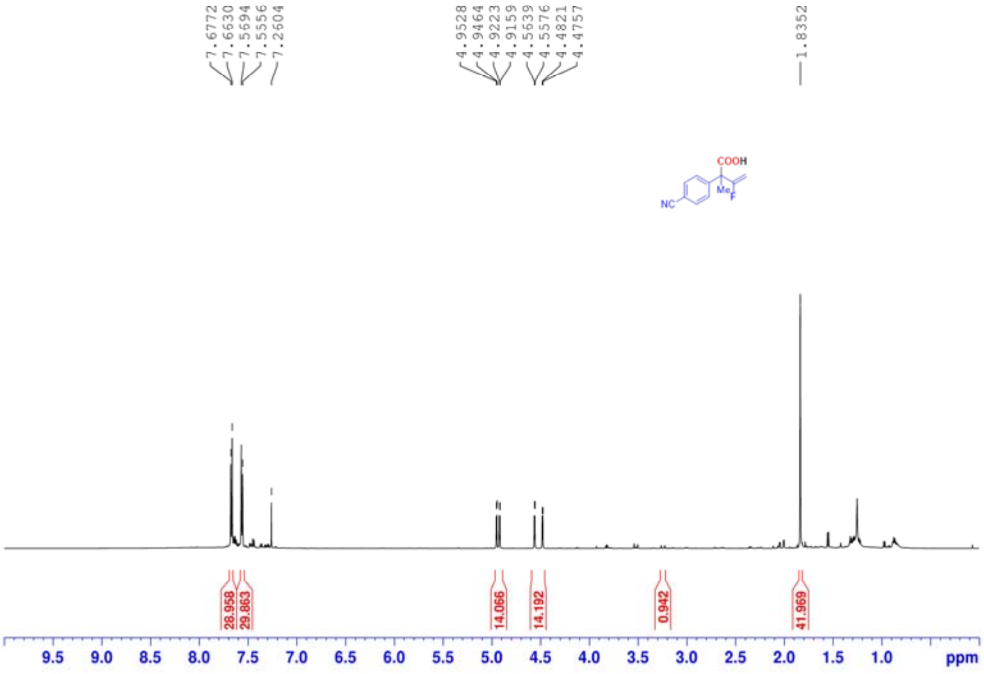
ppm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7.5556
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4.9464
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4.9159
4.5639
4.5576
4.4821
4.4757
1.8352
COOH
Me
F
NC
28.958
29.863
14.066
14.192
0.942
41.969
9.5
9.0
8.5
8.0
7.5
7.0
6.5
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5.0
4.5
4.0
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2.5
2.0
1.5
1.0
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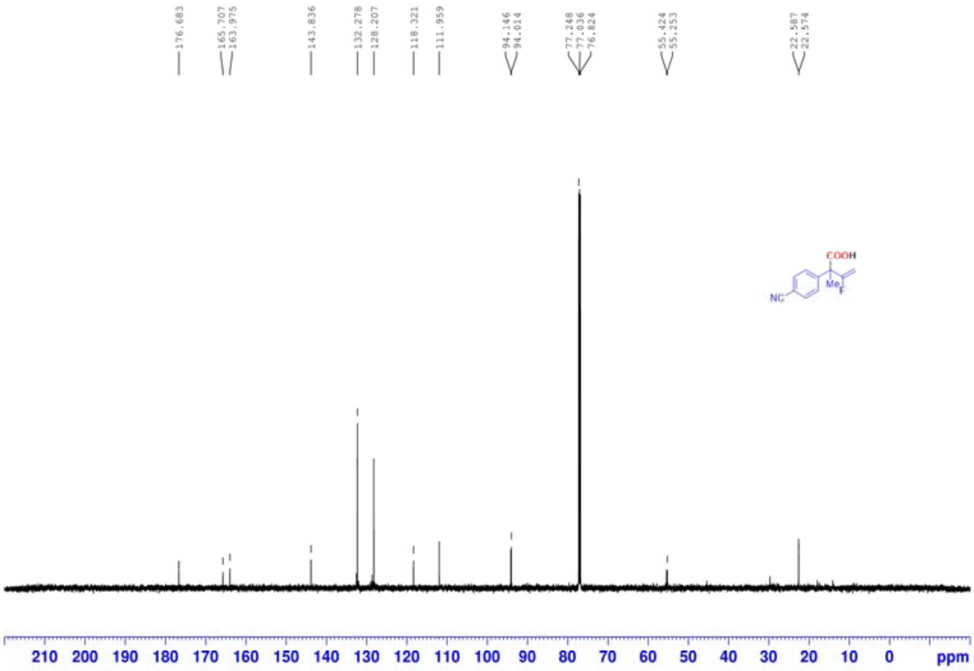
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94.014
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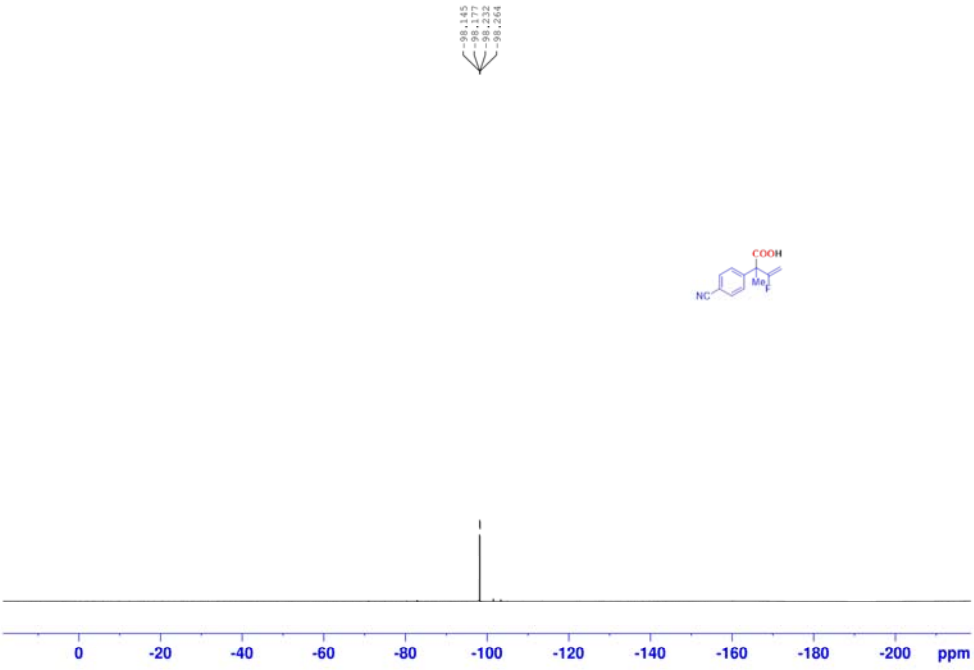
77.036
76.824
55.424
55.253
22.587
22.574
COOH
Me
F
NC
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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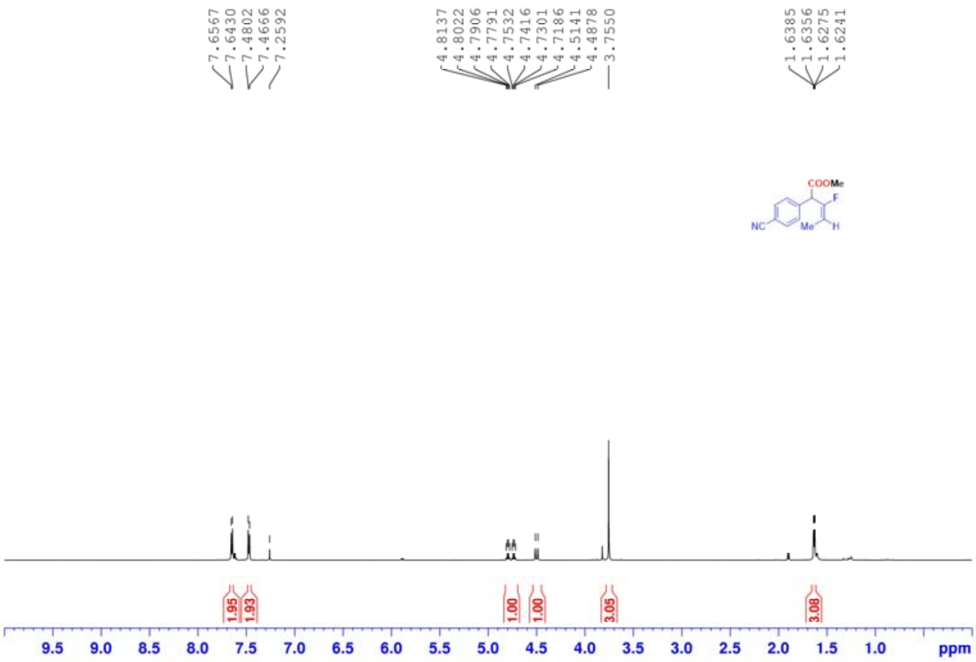
COOH
Me
F
NC
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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7.4802
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7.2592
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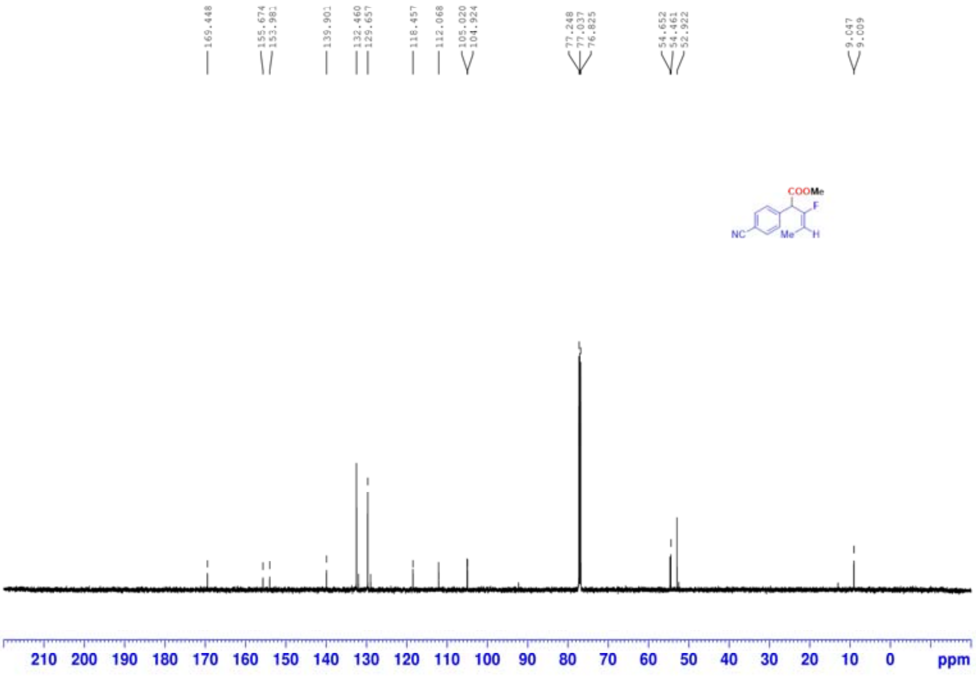
4.7791
4.7532
4.7416
4.7301
4.7186
4.5141
4.4878
3.7550
1.6385
1.6356
1.6275
1.6241
COOMe
F
NC
Me
H
1.95
1.93
1.00
1.00
3.05
3.08
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm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129.657
118.457
112.068
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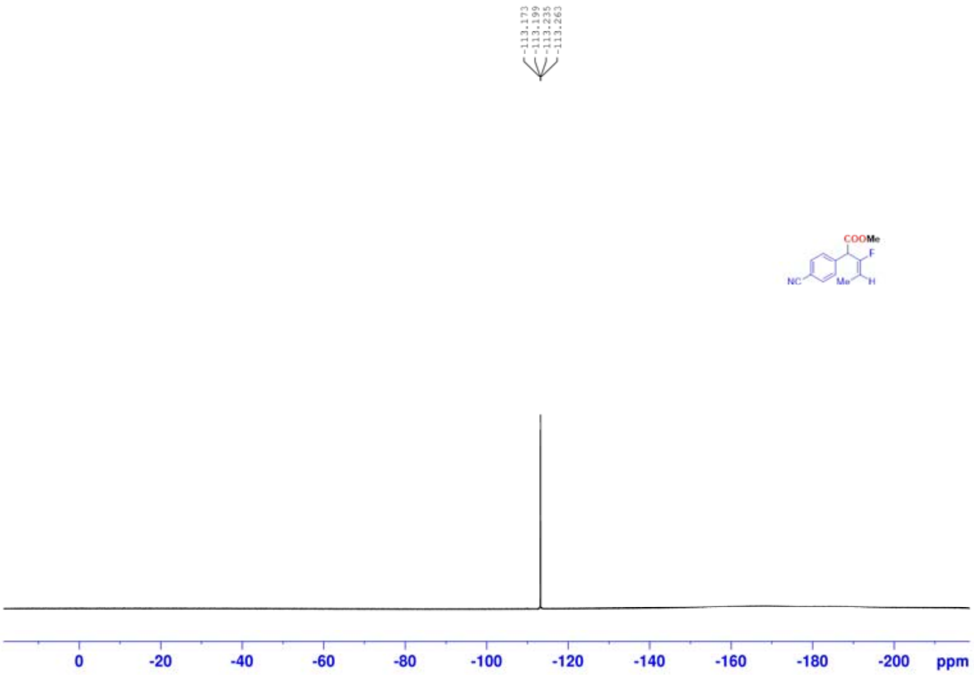
104.924
77.248
77.037
76.825
54.652
54.461
52.922
9.047
9.009
COOMe
F
NC
Me
H
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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-113.235
-113.263
COOMe
F
NC
Me
H
0
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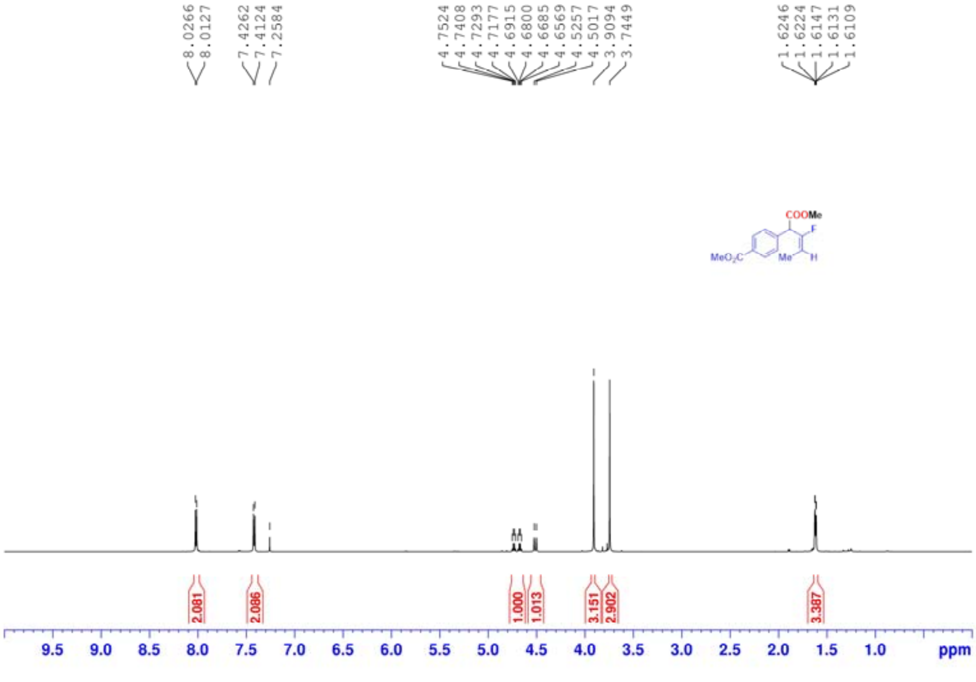
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm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8.0127
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7.4124
7.2584
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4.7177
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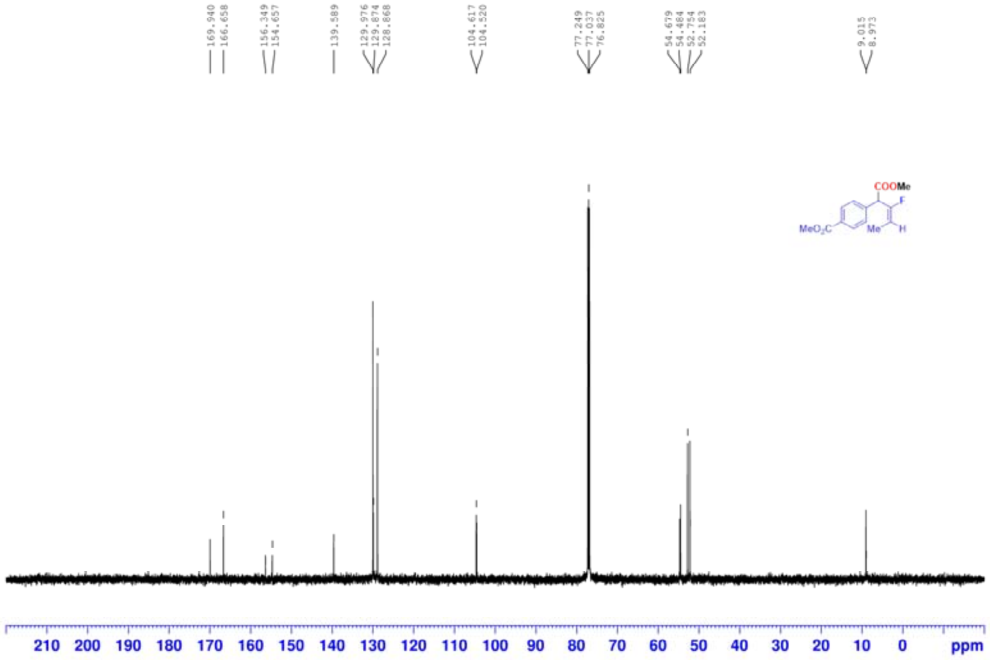
4.6800
4.6685
4.6569
4.5257
4.5017
3.9094
3.7449
1.6246
1.6224
1.6147
1.6131
1.6109
COOMe
F
MeO_2C
Me
H
2.081
2.086
1.000
1.013
3.151
2.902
3.387
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm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129.874
128.868
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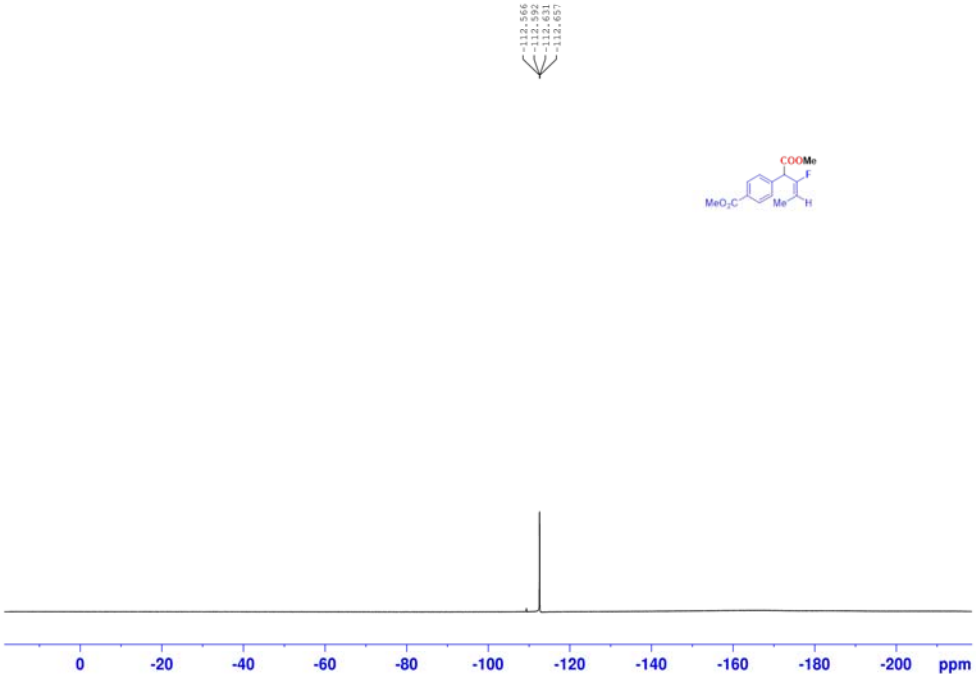
104.520
77.249
77.037
76.825
54.679
54.884
52.754
52.183
9.015
8.973
COOMe
F
MeO2C
Me
H
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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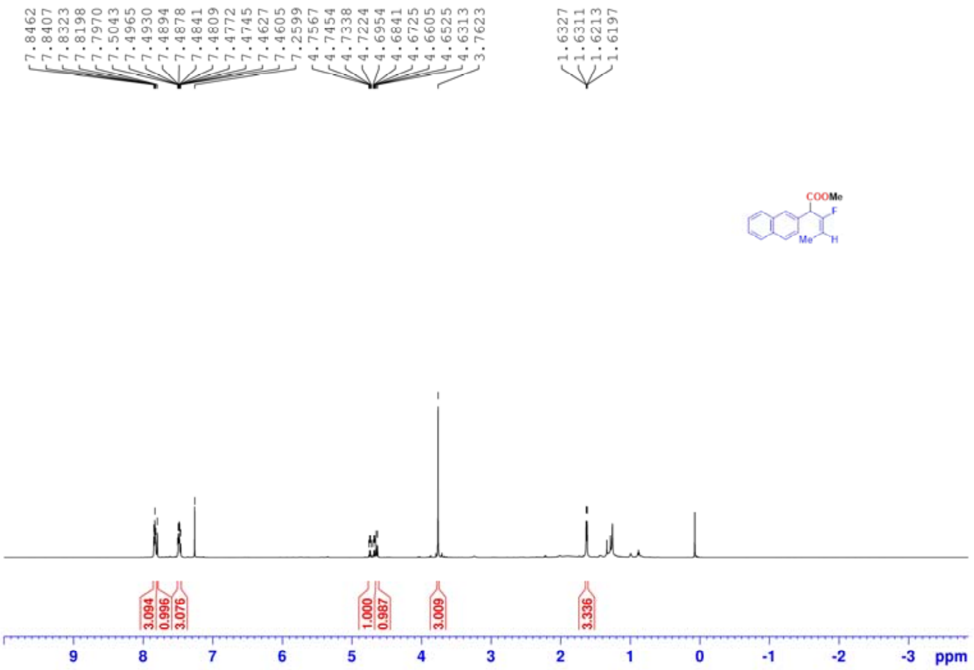
-112.657
COOMe
F
MeO2C
Me
H
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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7.8323
7.8198
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7.4965
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7.4841
7.4809
7.4772
7.4745
7.4627
7.4605
7.2599
4.7567
4.7454
4.7338
4.7224
4.6954
4.6841
4.6725
4.6605
4.6525
4.6313
3.7623
1.6327
1.6311
1.6213
1.6197
COOMe
F
Me
H
3.094
0.996
3.076
1.000
0.987
3.009
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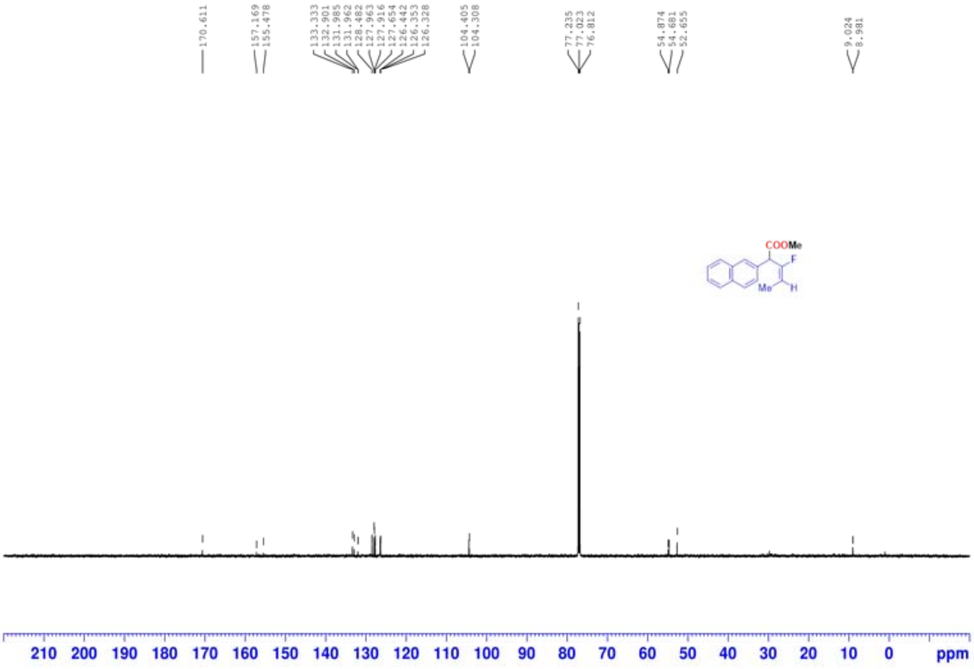
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
ppm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127.916
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126.442
126.353
126.328
104.405
104.308
77.235
77.023
76.812
54.874
54.681
52.655
9.024
8.981
COOMe
F
Me
H
210
200
190
180
170
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150
140
130
120
110
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60
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20
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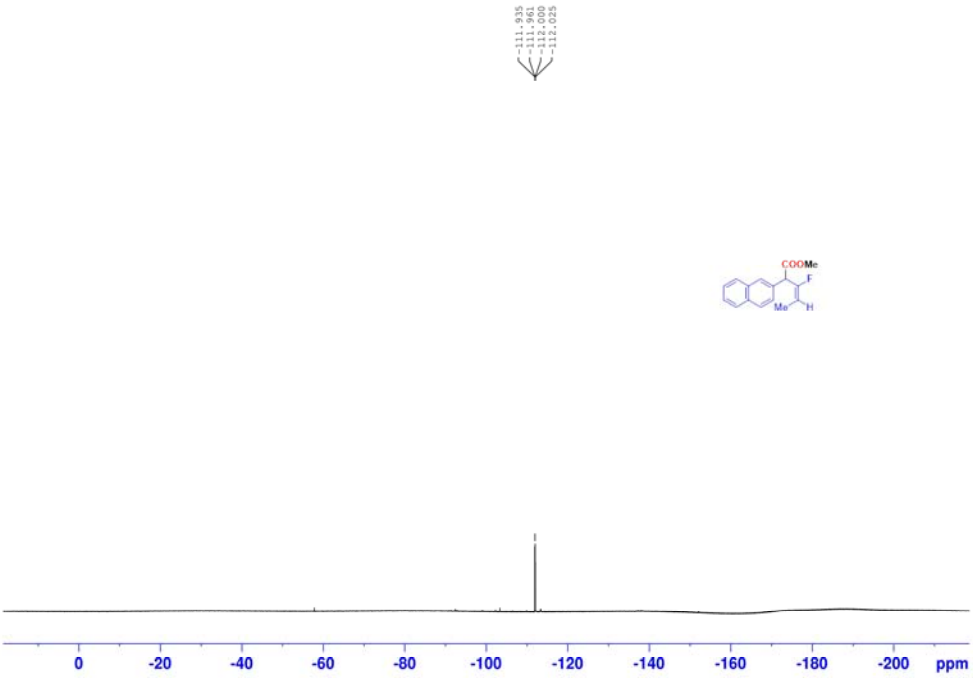
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F
Me
H
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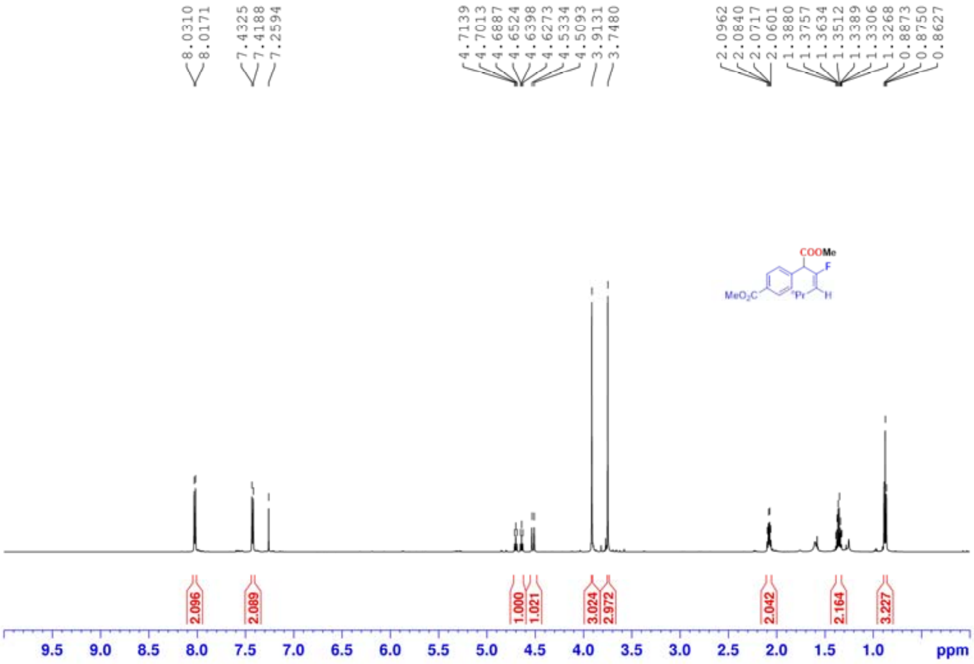
-160
-180
-200
ppm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4.7013
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4.6273
4.5334
4.5093
3.9131
3.7480
2.0962
2.0840
2.0717
2.0601
1.3880
1.3757
1.3634
1.3512
1.3389
1.3306
1.3268
0.8873
0.8750
0.8627
COOMe
F
MeO2C
nPr
H
2.096
2.089
1.000
1.021
3.024
2.972
2.042
2.164
3.227
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
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5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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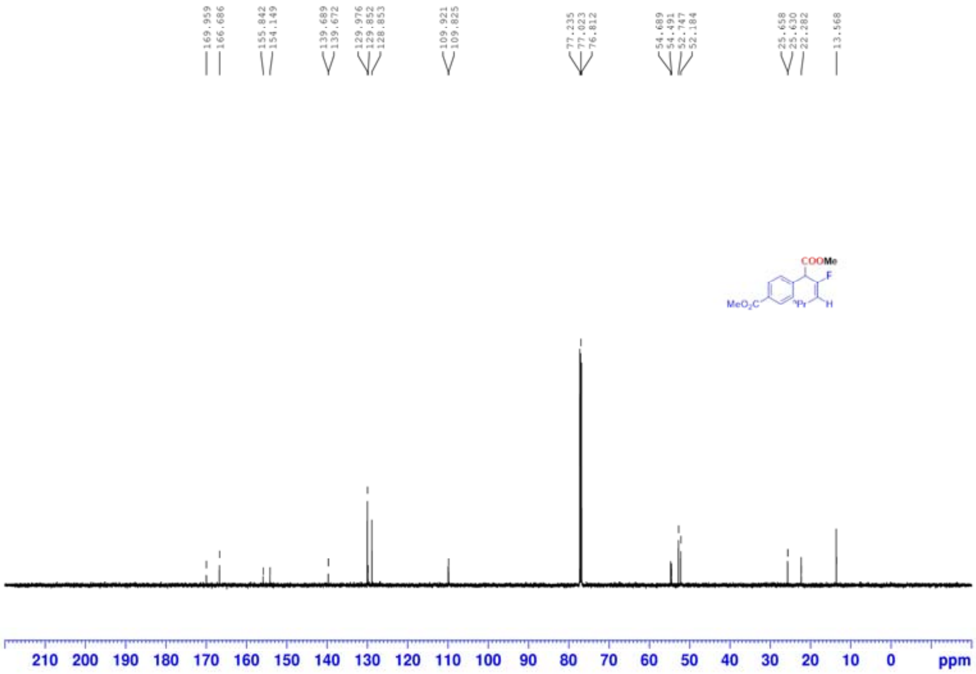
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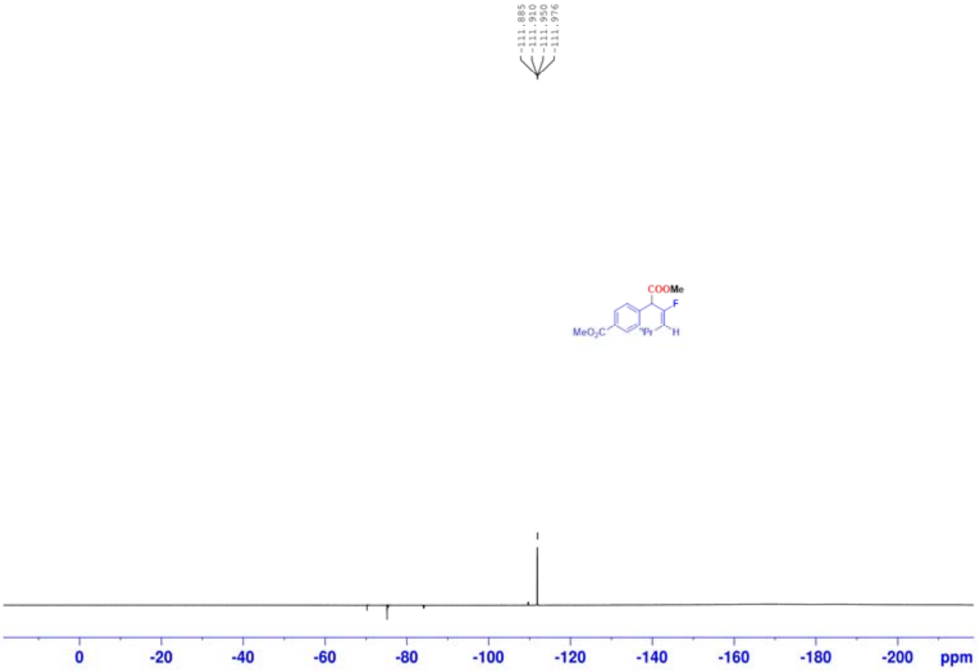
109.921
109.825
77.235
77.023
76.812
54.689
54.491
52.747
52.184
25.658
25.630
22.282
13.568
COOMe
F
MeO$_2$C
^{n}Pr
H
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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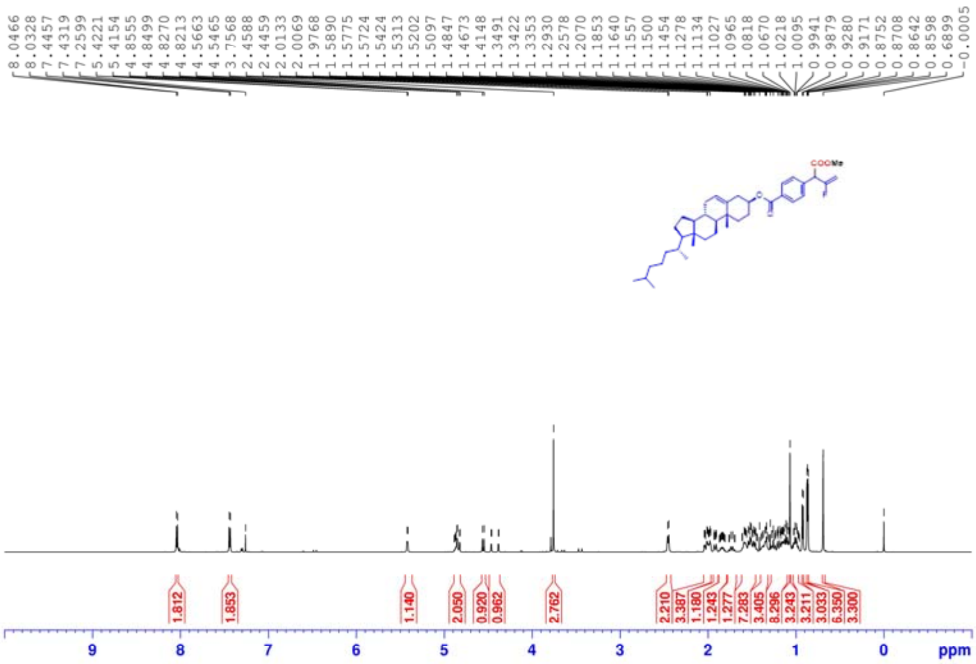
F
MeO$_2$C
^{n}Pr
H
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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4.8213
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4.5465
3.7568
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2.4459
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1.3422
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1.2578
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1.1853
1.1640
1.1557
1.1500
1.1454
1.1278
1.1134
1.1027
1.0965
1.0818
1.0670
1.0218
1.0095
0.9941
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0.9280
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0.8642
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0.6899
-0.0005
COOMe
1.812
1.853
1.140
2.050
0.920
0.962
2.762
2.210
3.387
1.180
1.243
1.277
7.283
3.405
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6
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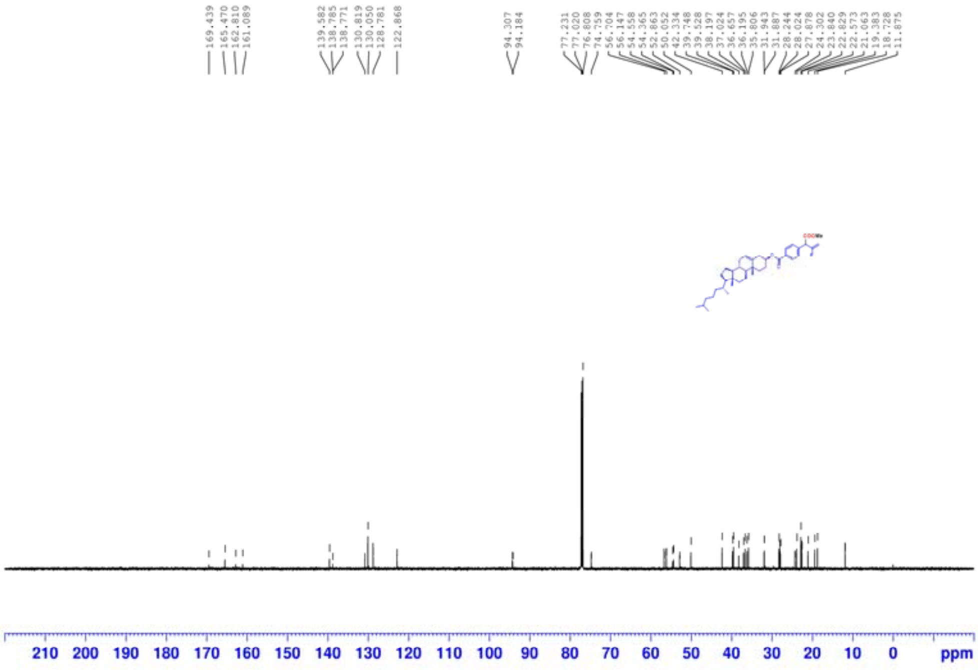
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94.184
77.231
77.020
76.808
74.759
56.704
56.147
54.558
54.365
52.863
50.052
42.334
39.748
39.528
38.197
37.024
36.657
36.195
35.806
31.943
31.887
28.244
28.024
27.878
24.302
23.840
22.829
22.573
21.063
19.383
18.728
11.875
COOMe
210
200
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110
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80
70
60
50
40
30
20
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0
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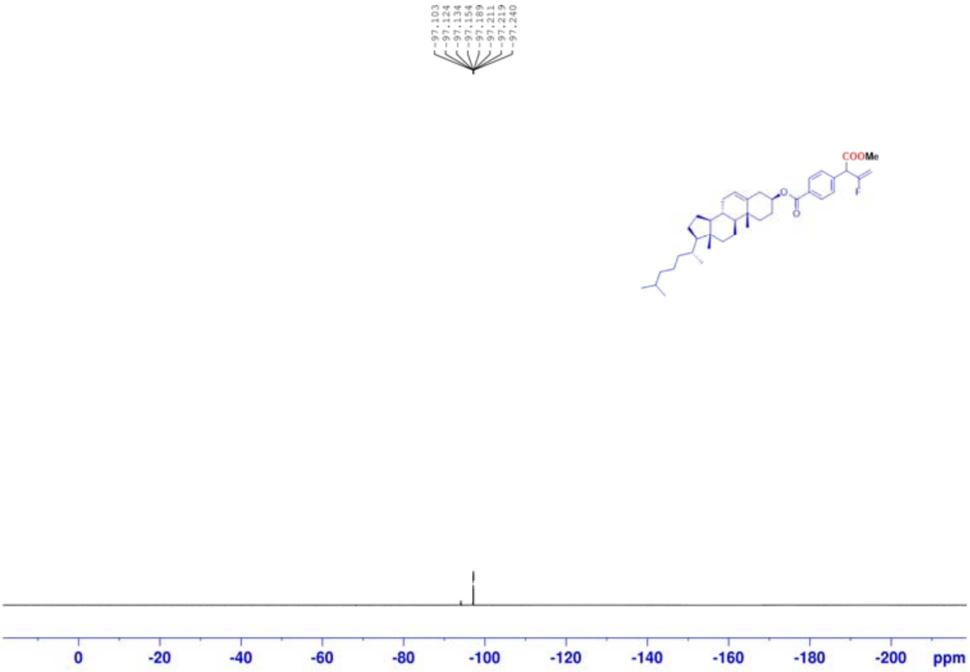
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COOMe
O
F
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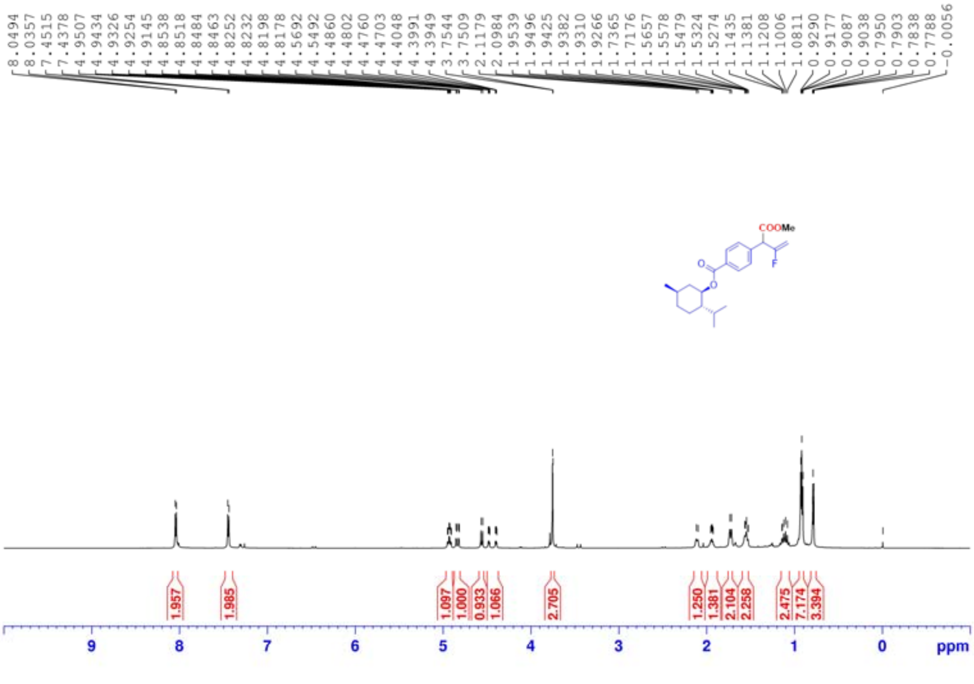
-120
-140
-160
-180
-200
ppm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4.8518
4.8484
4.8463
4.8252
4.8232
4.8198
4.8178
4.5692
4.5492
4.4860
4.4802
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4.4703
4.4048
4.3991
4.3949
3.7544
3.7509
2.1179
2.0984
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1.9496
1.9425
1.9382
1.9310
1.9266
1.7365
1.7176
1.5657
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1.5479
1.5324
1.5274
1.1435
1.1381
1.1208
1.1006
1.0811
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0.9177
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0.7950
0.7903
0.7838
0.7788
-0.0056
COOMe
O
F
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1.985
1.097
1.000
0.933
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2.705
1.250
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2.475
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6
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2
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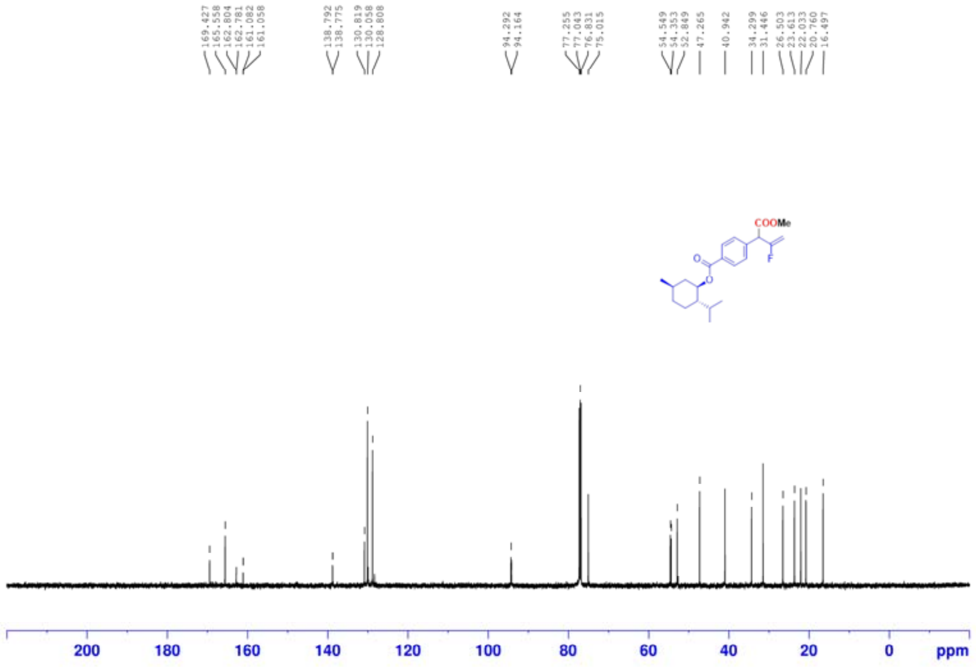
0
ppm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94.164
77.255
77.043
76.831
75.015
54.549
54.353
52.849
47.265
40.942
34.299
31.446
26.503
23.613
22.033
20.760
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COOMe
O
O
F
200
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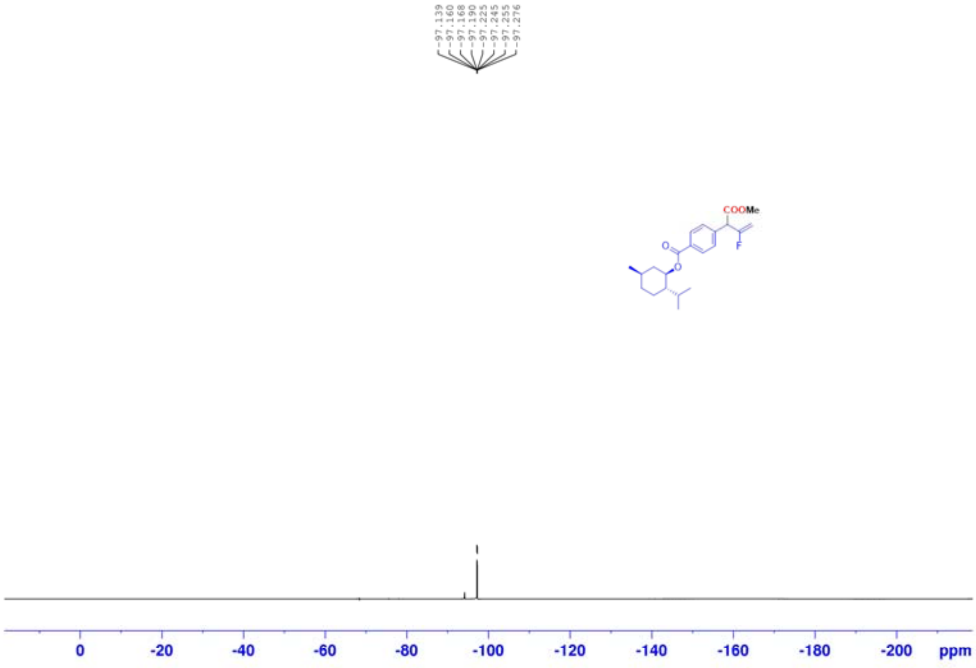
120
100
80
60
40
20
0
ppm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COOMe
O
O
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
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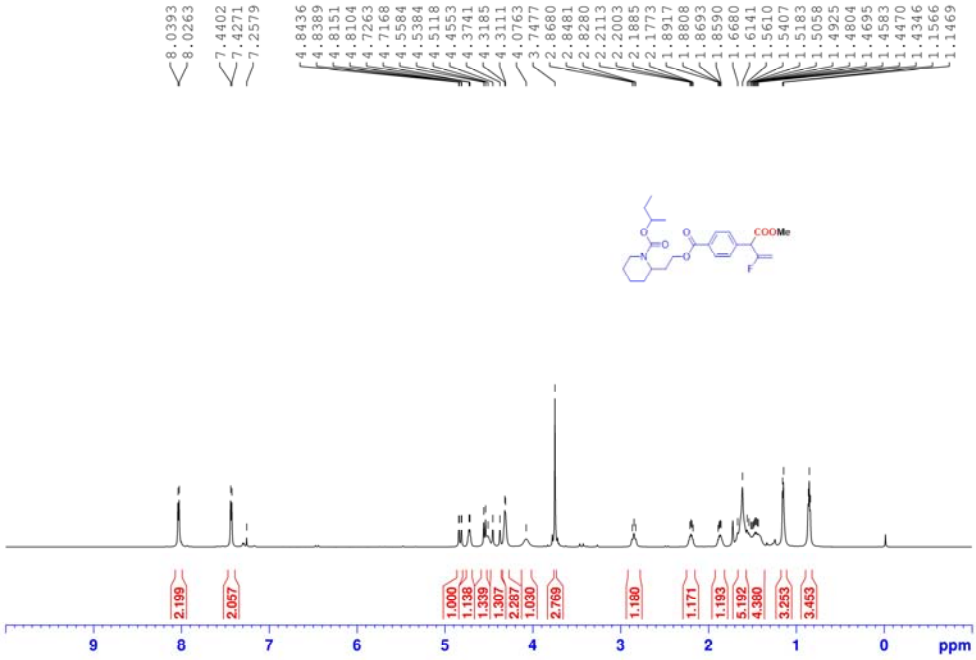
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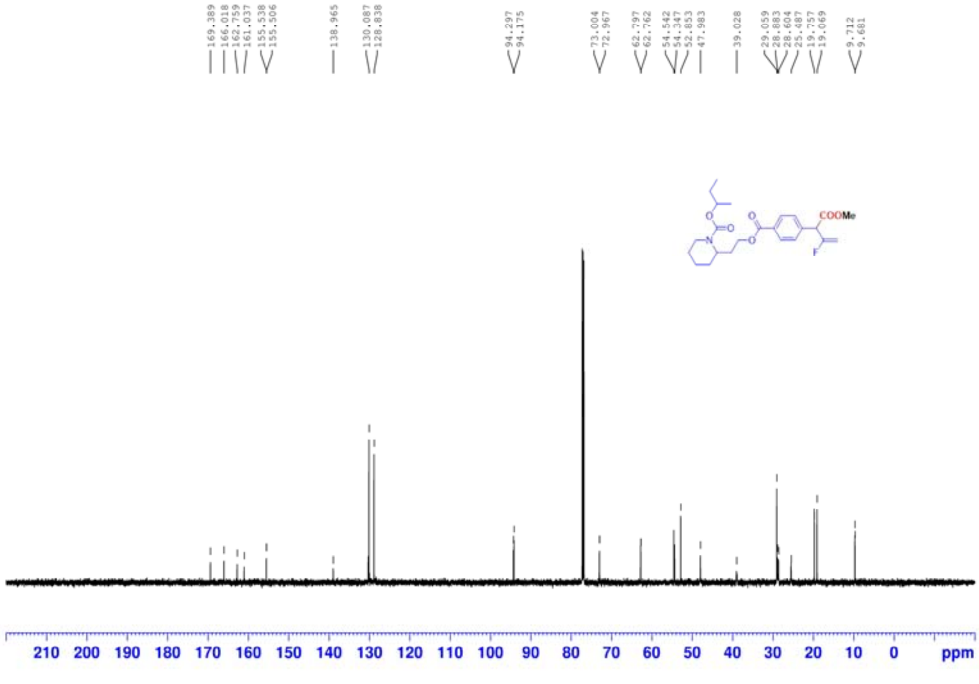
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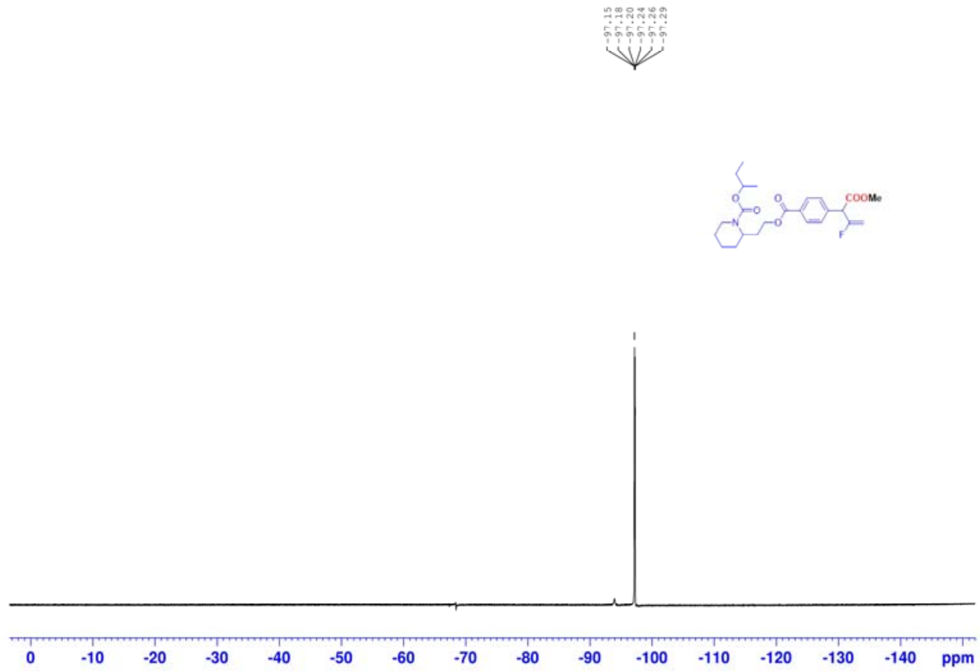
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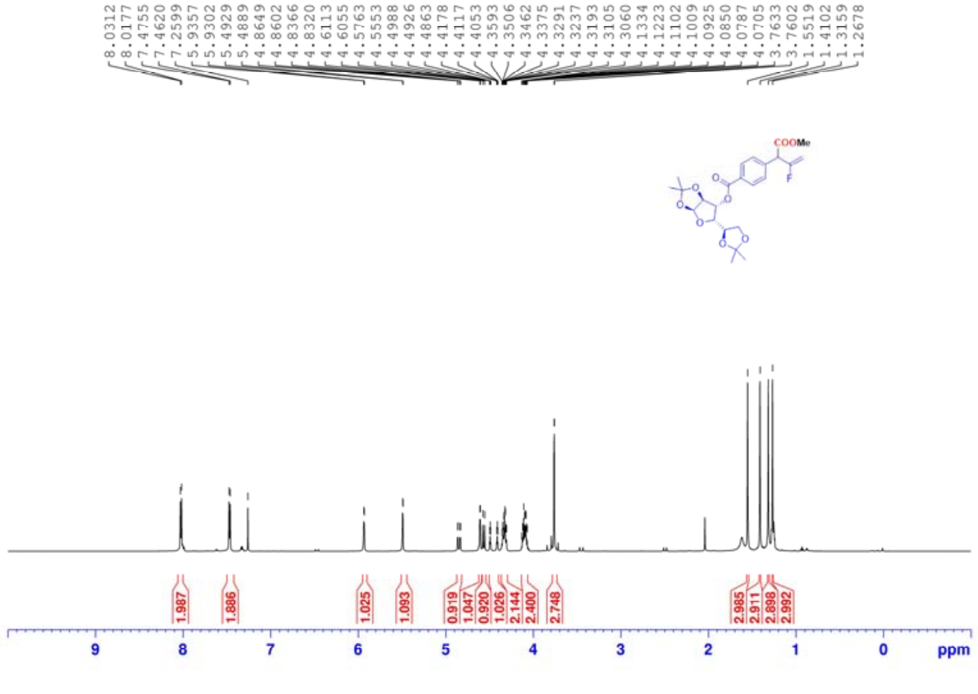
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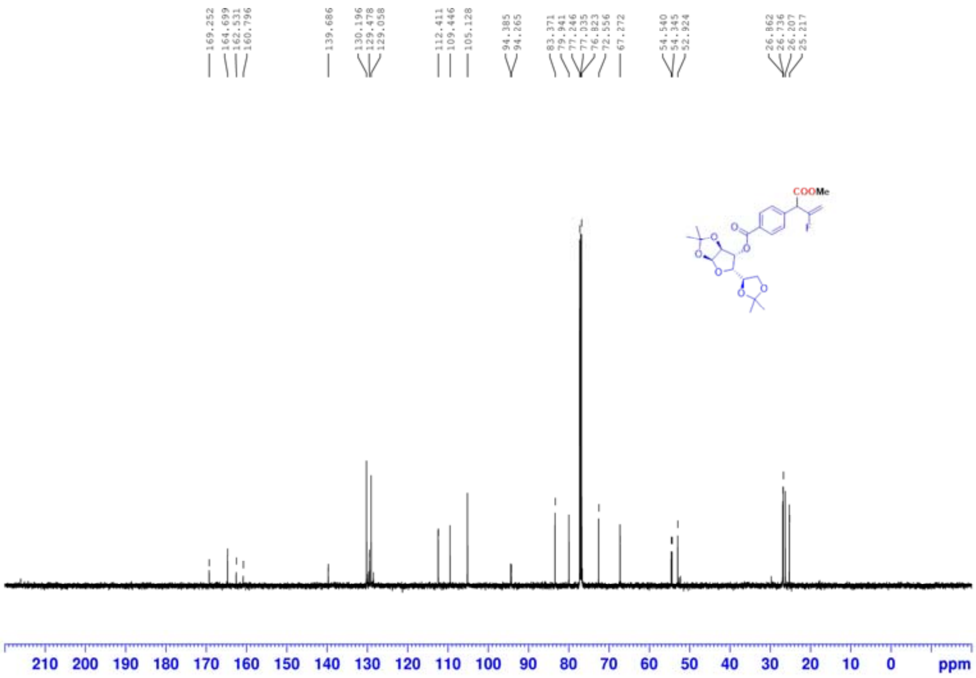
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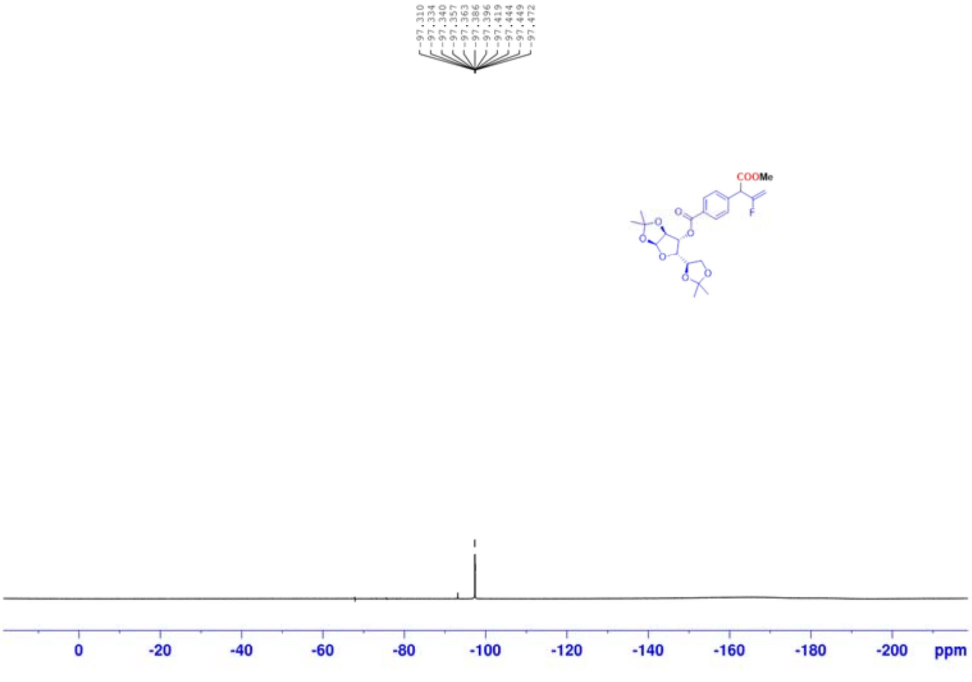
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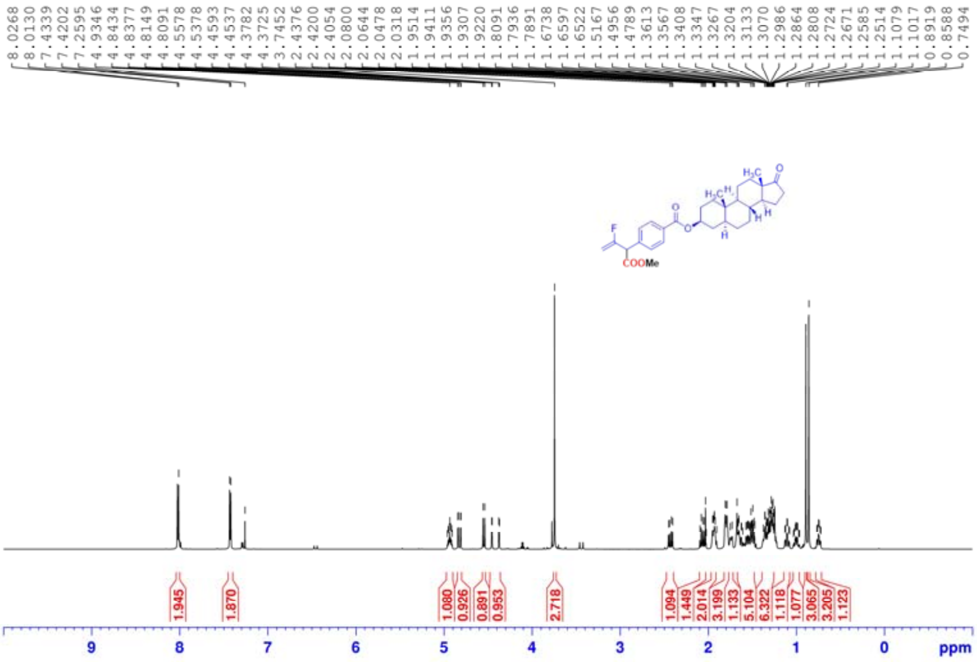
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4.4593
4.4537
4.3782
4.3725
3.7452
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2.4200
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2.0800
2.0644
2.0478
2.0318
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0.8588
0.7494
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O
H3C
H
H
H
H3C
O
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1.080
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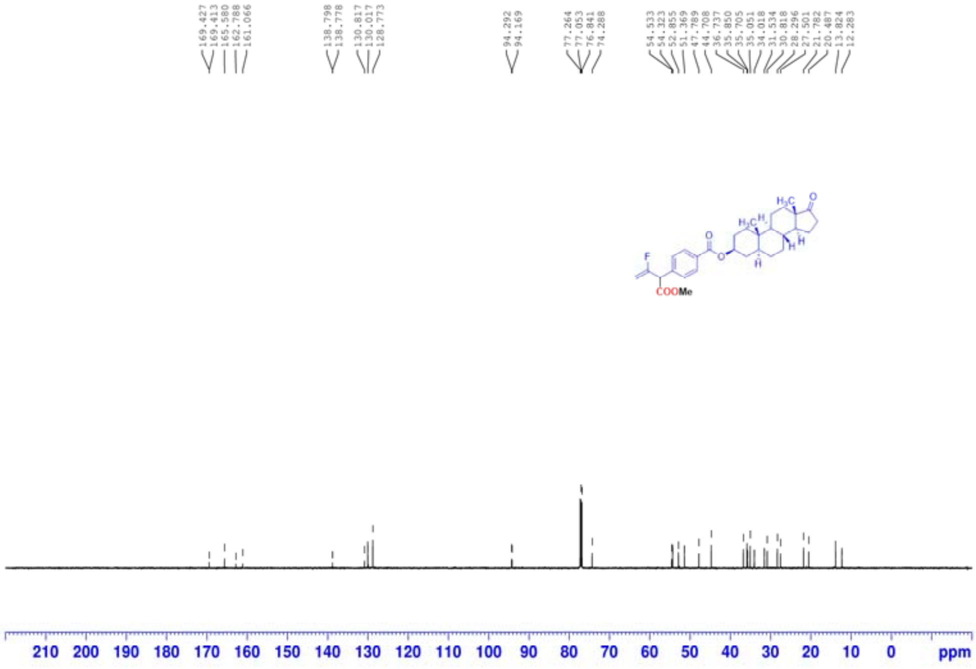
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COOMe
O
H3C
H
H
H
H3C
O
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200
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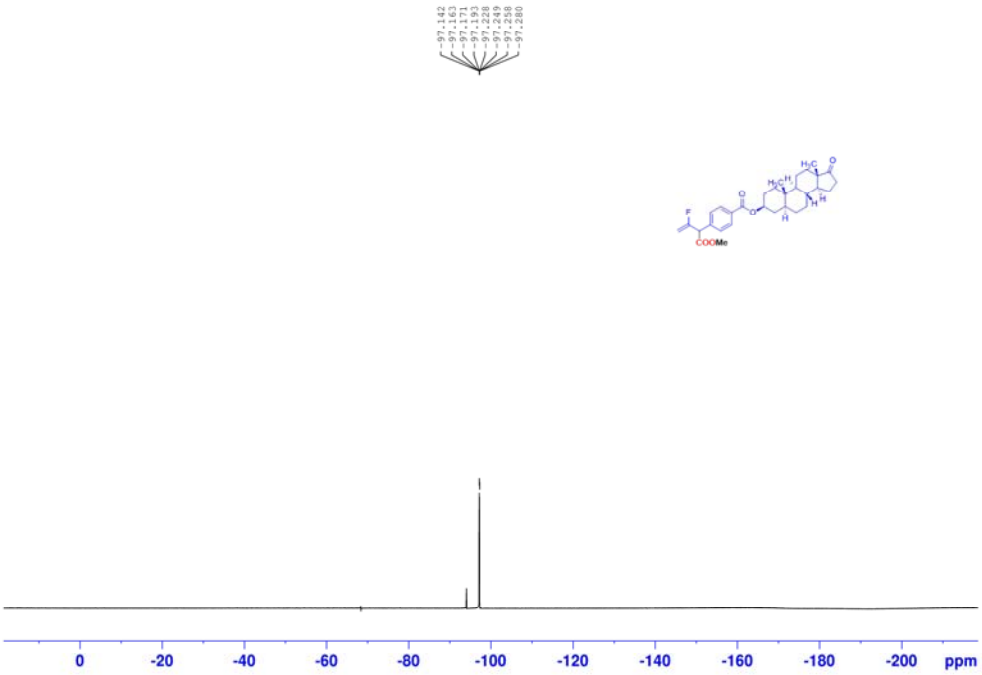
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H3C
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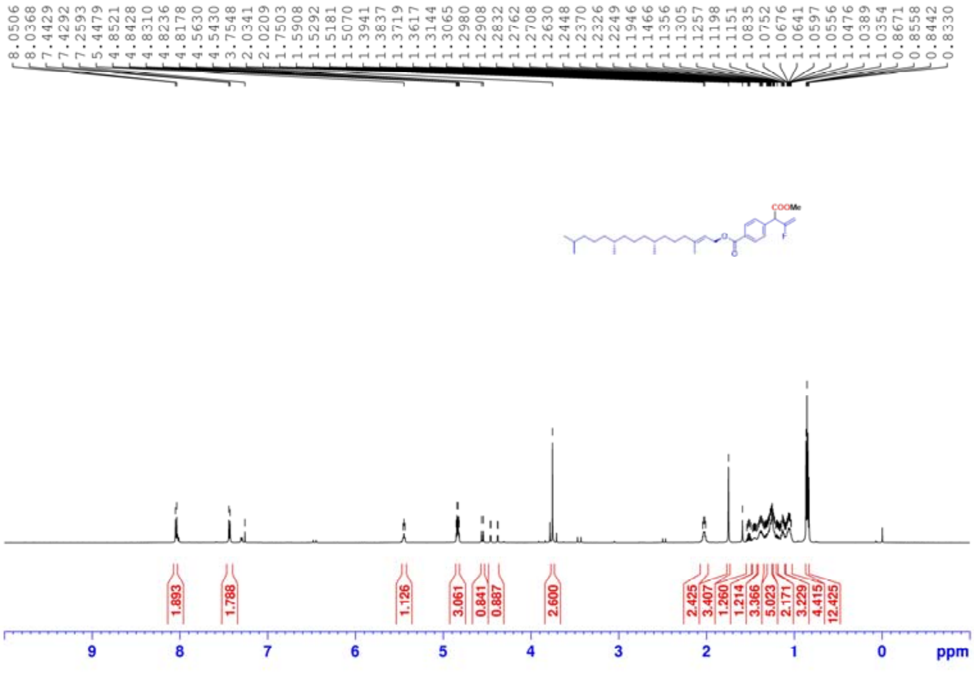
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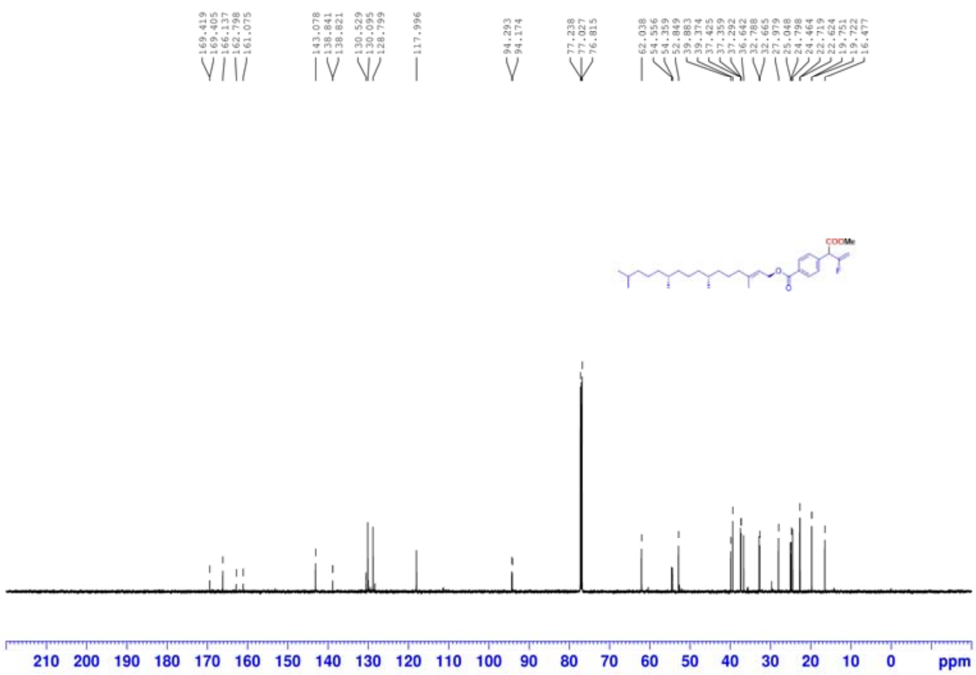
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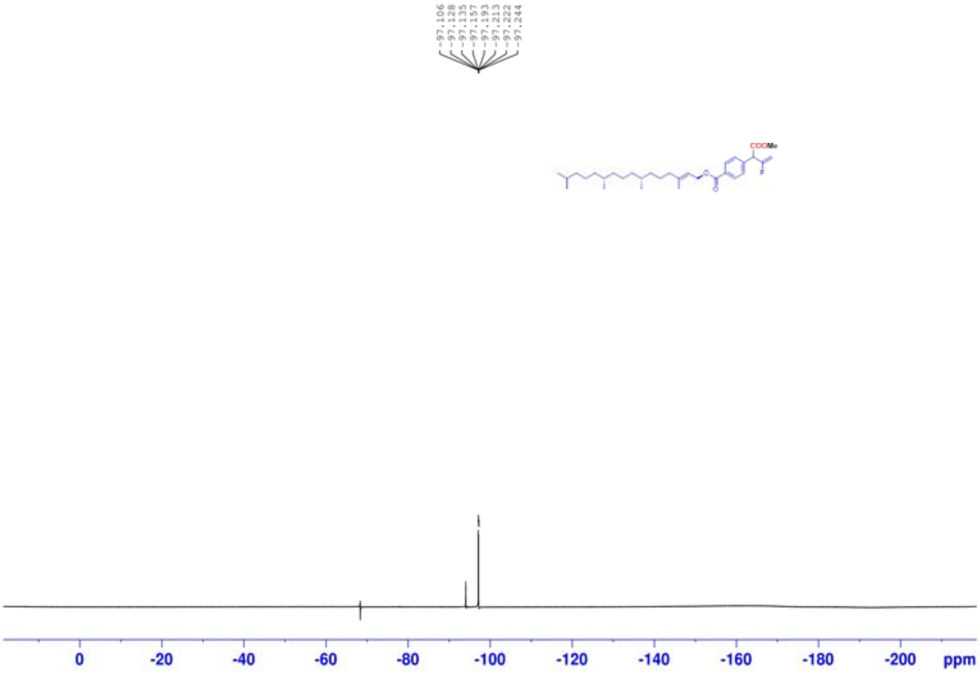
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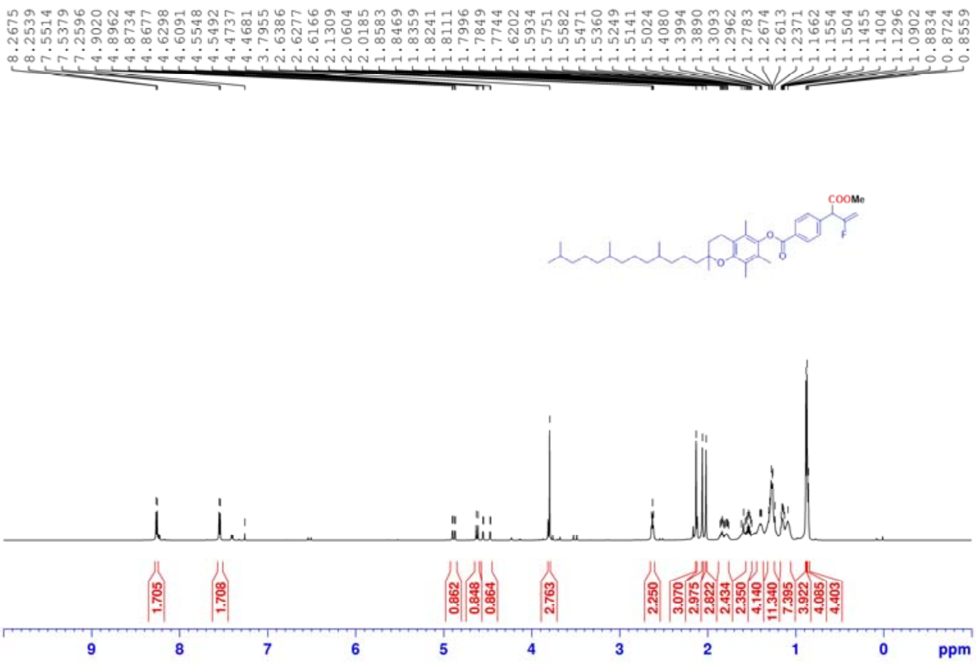
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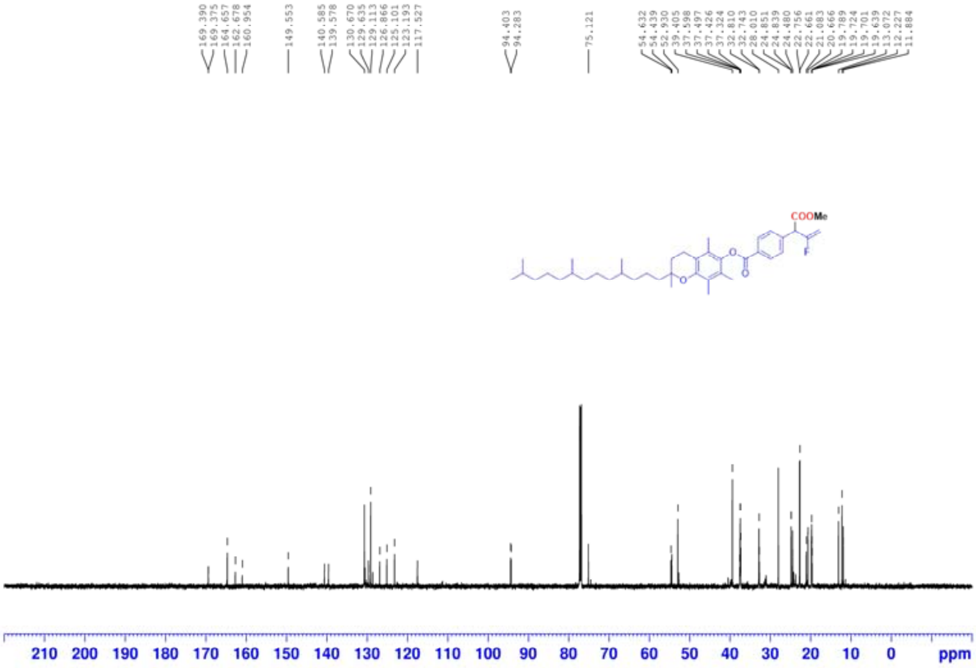
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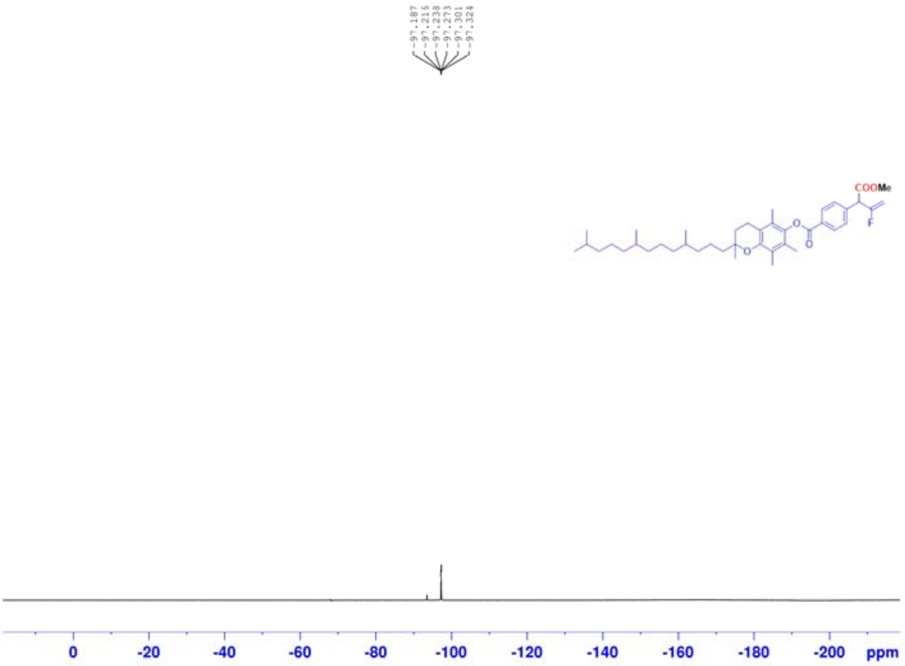
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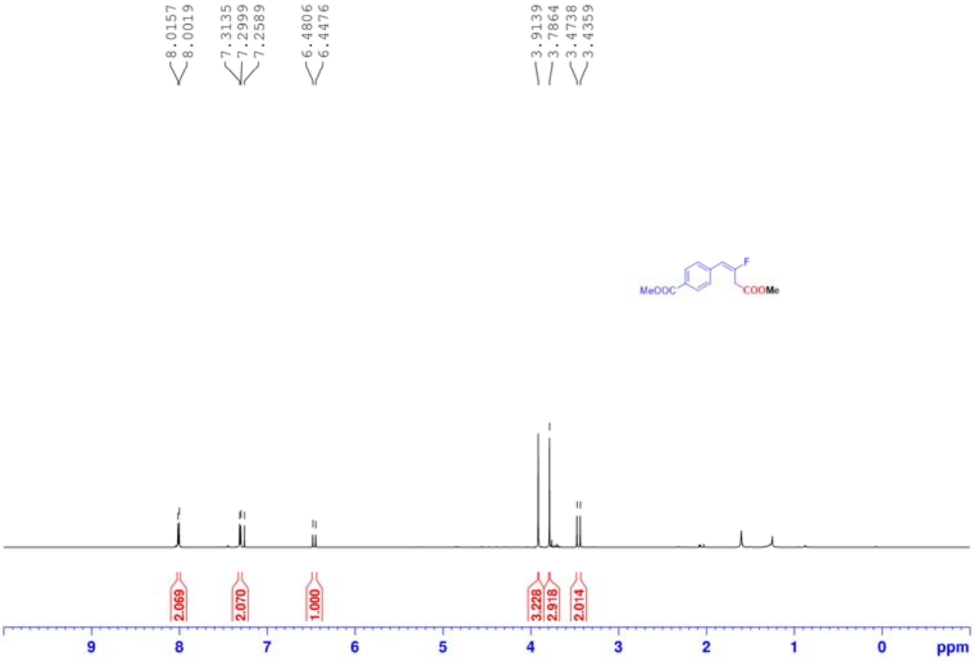
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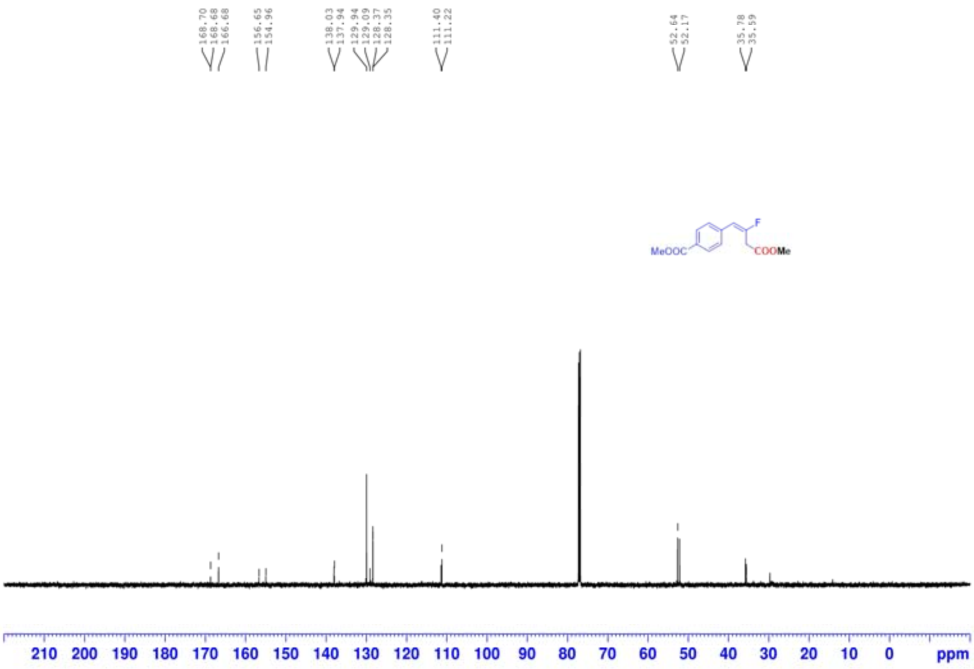
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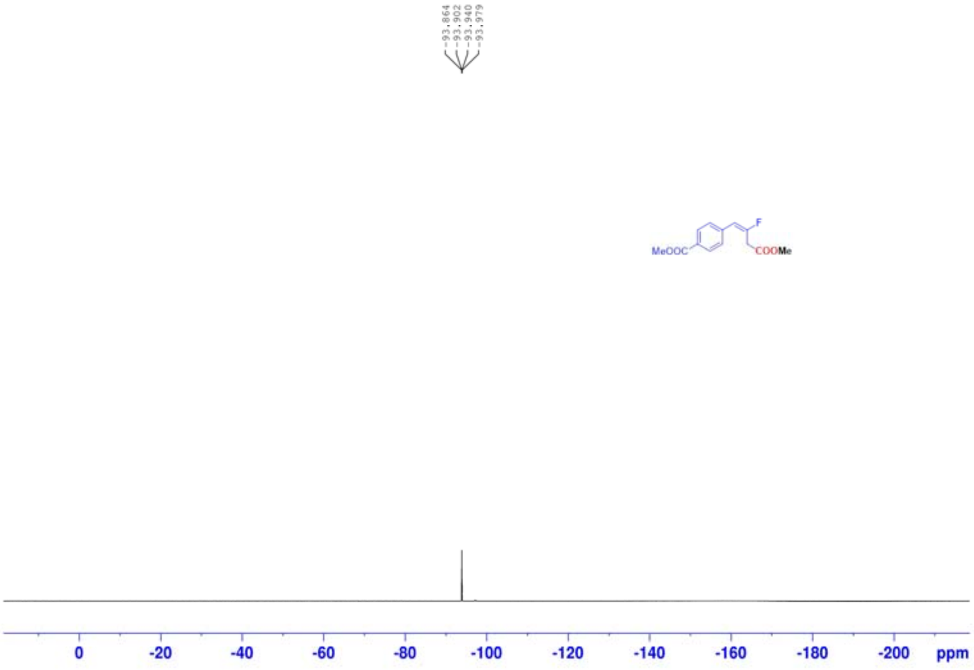
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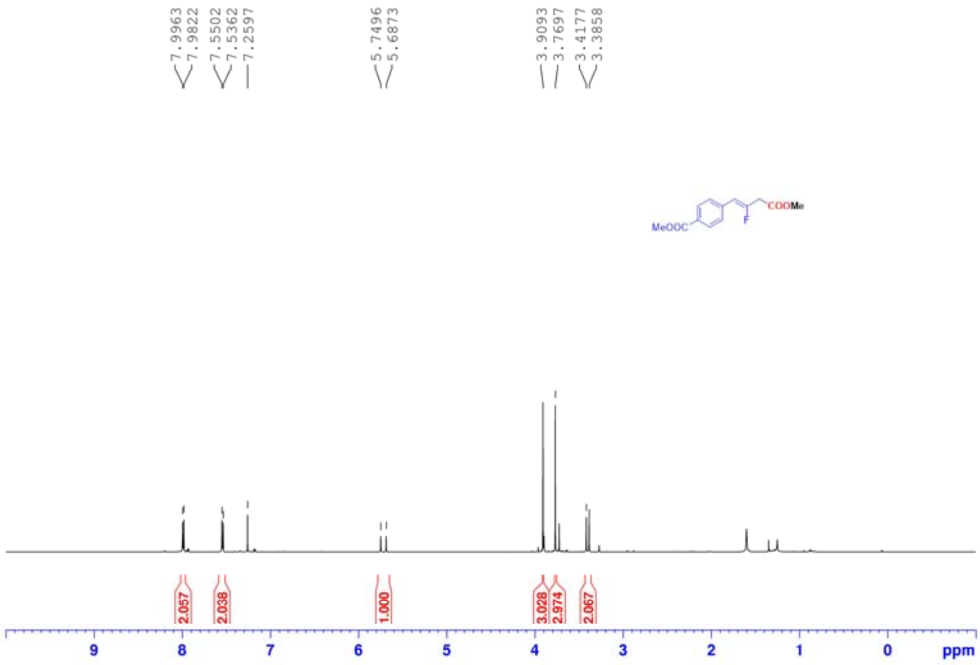
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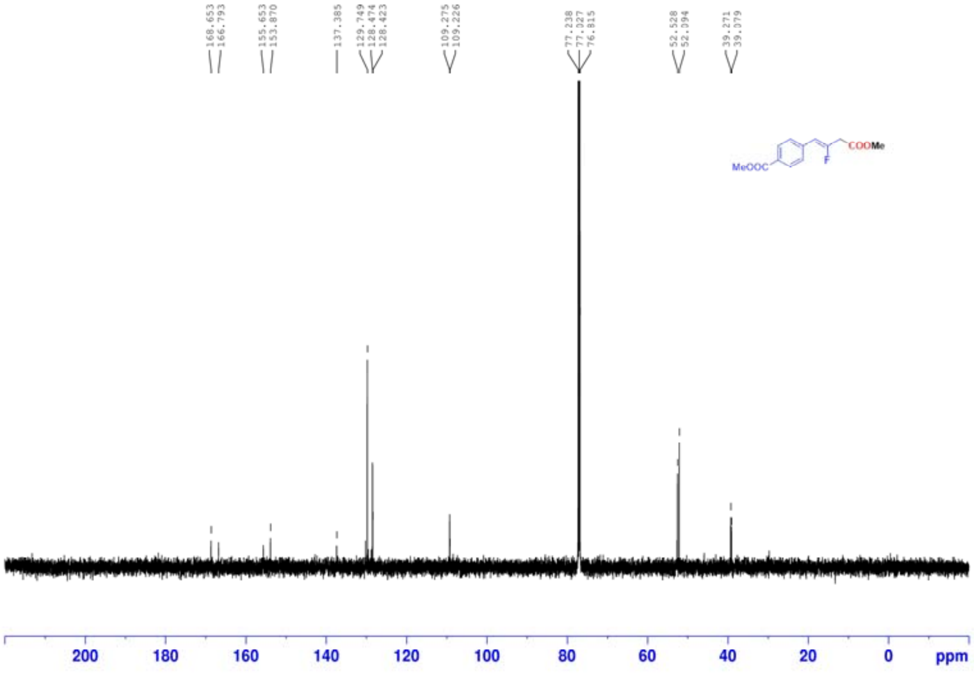
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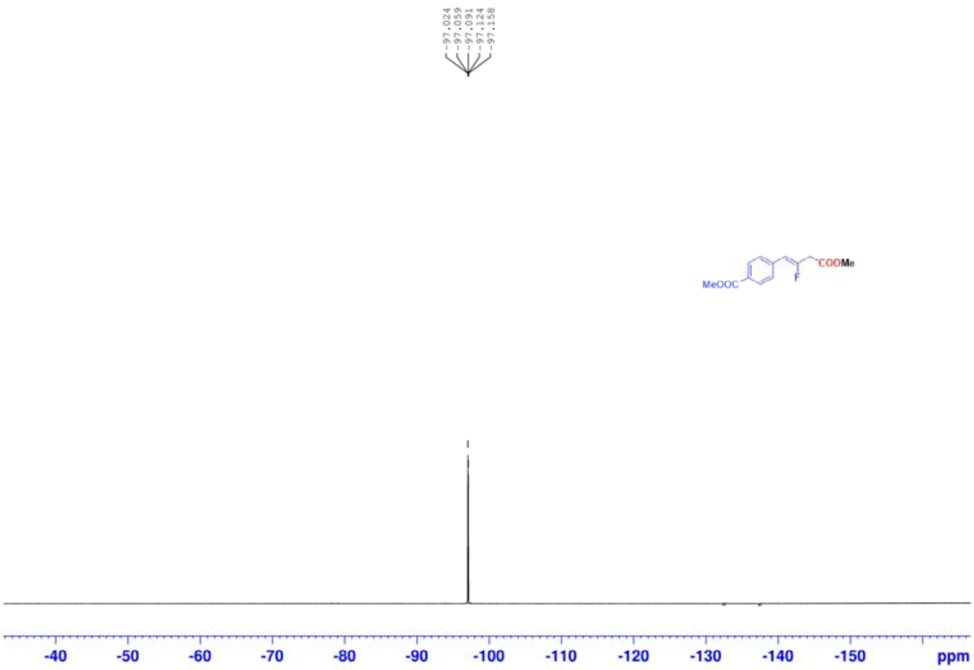
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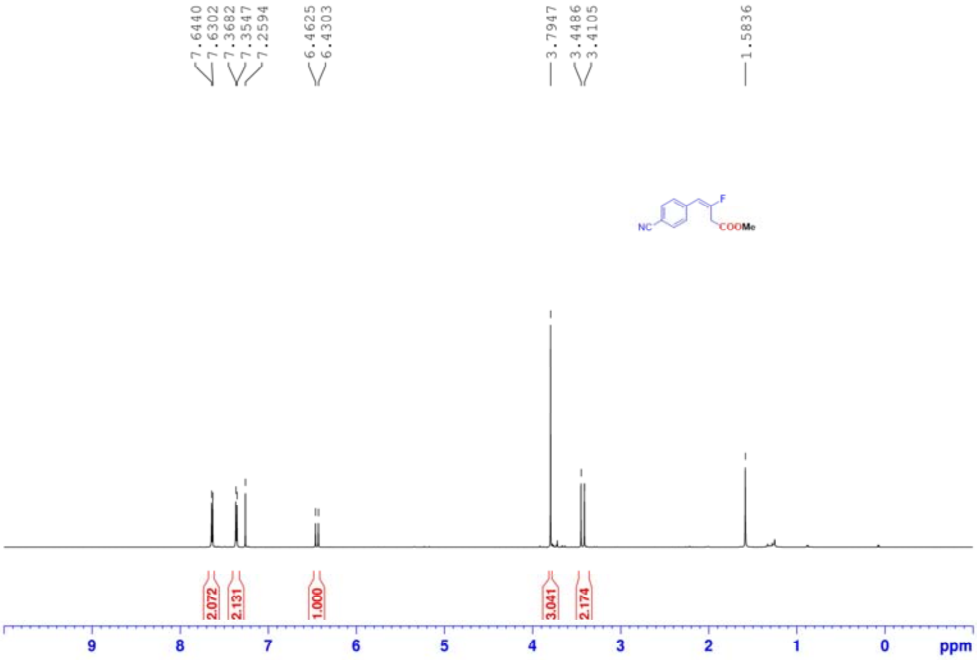
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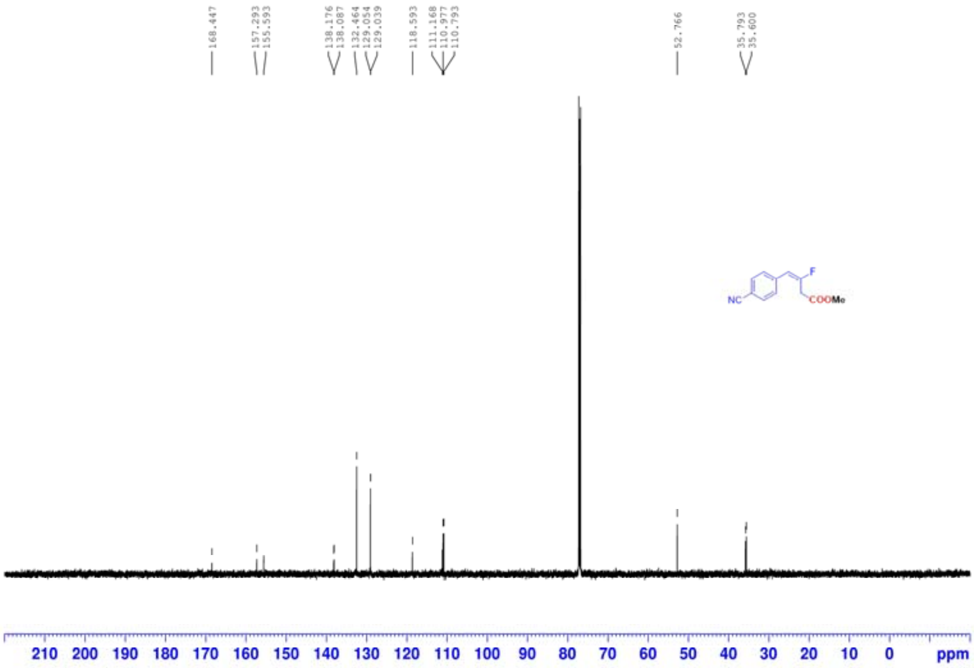
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NC
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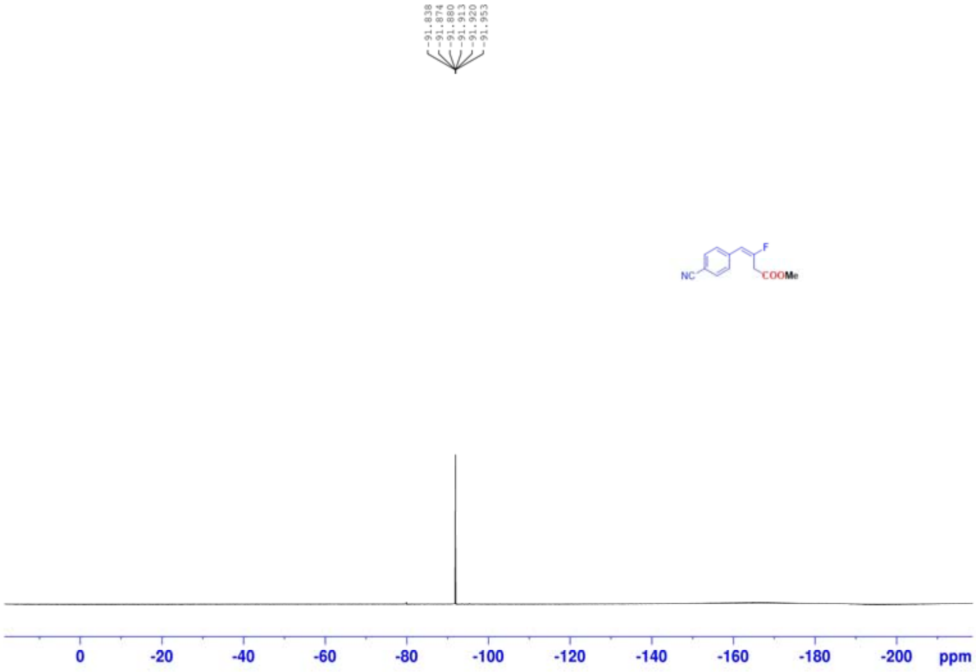
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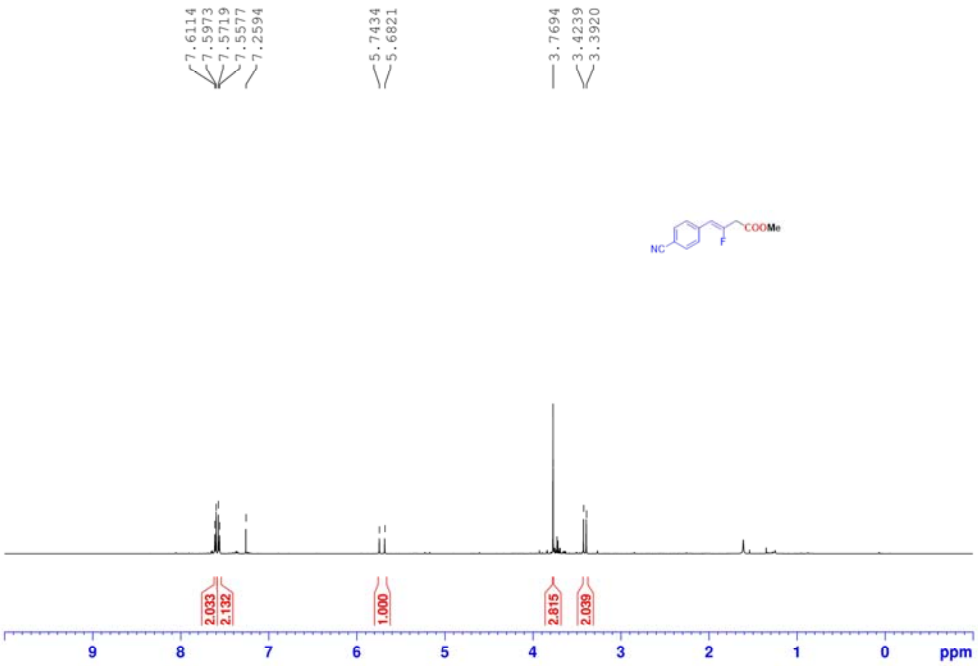
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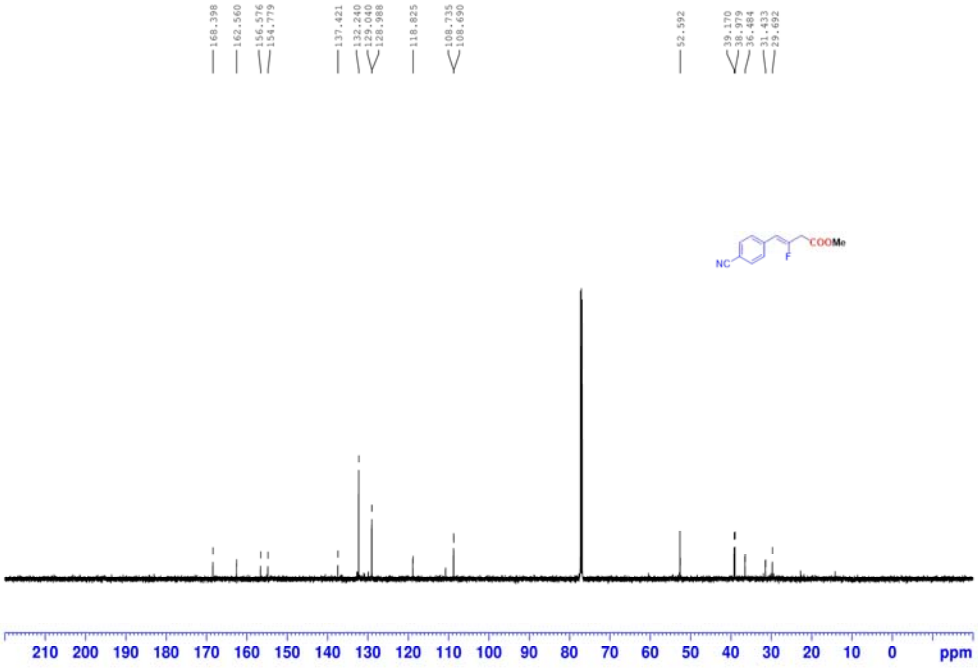
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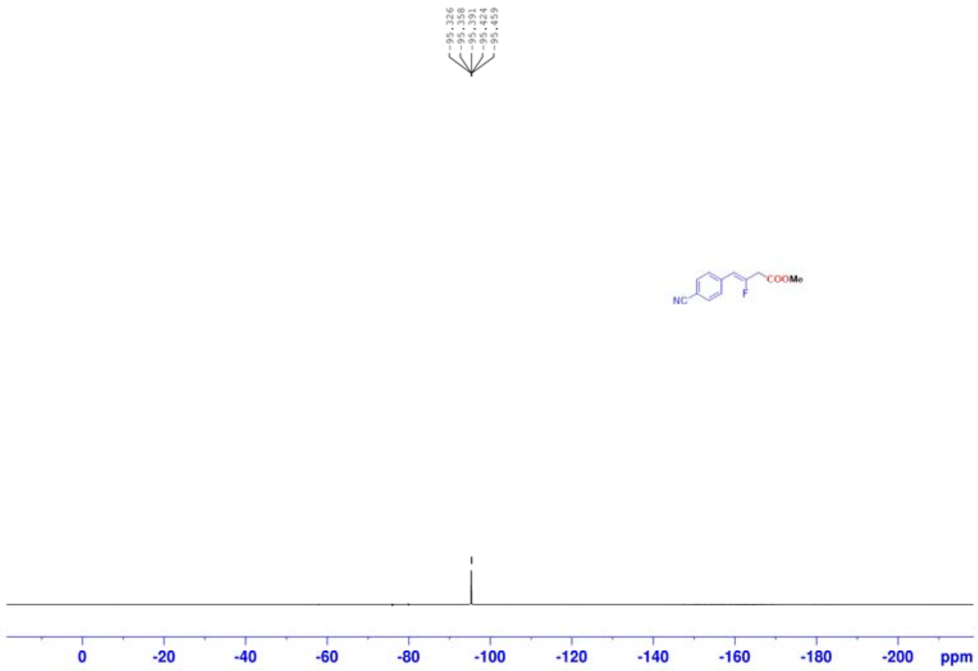
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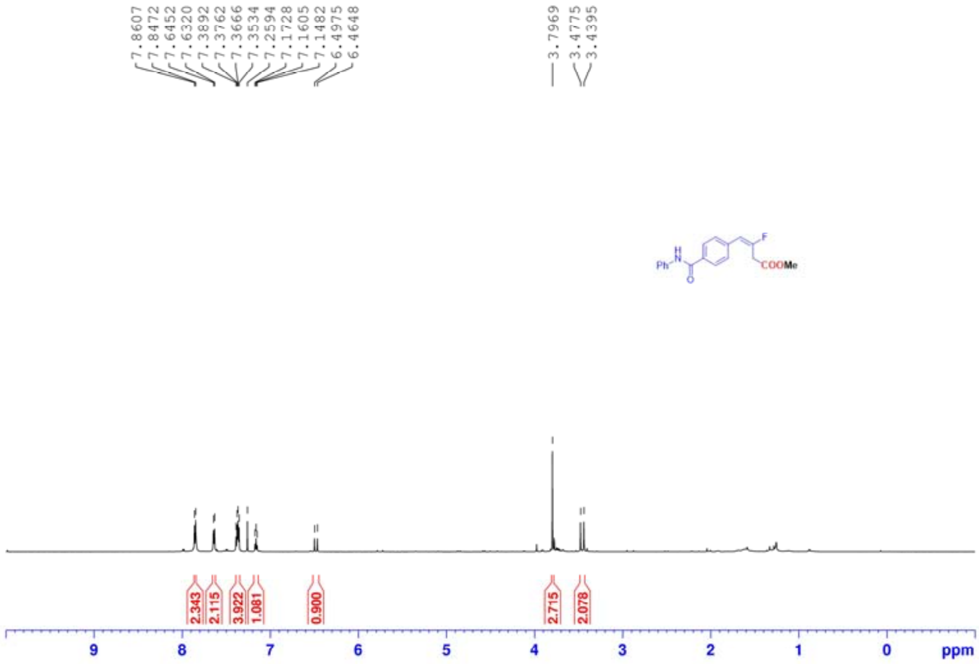
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7.1482
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6.4648
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Ph
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H
O
F
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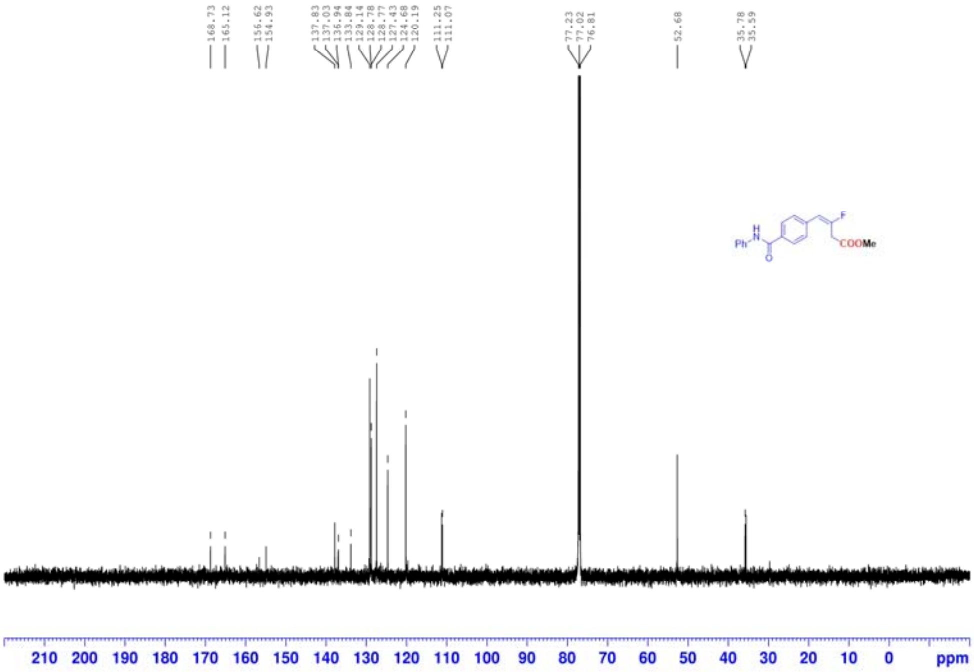
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120.19
111.25
111.07
77.23
77.02
76.81
52.68
35.78
35.59
Ph
H
N
O
F
COOMe
210
200
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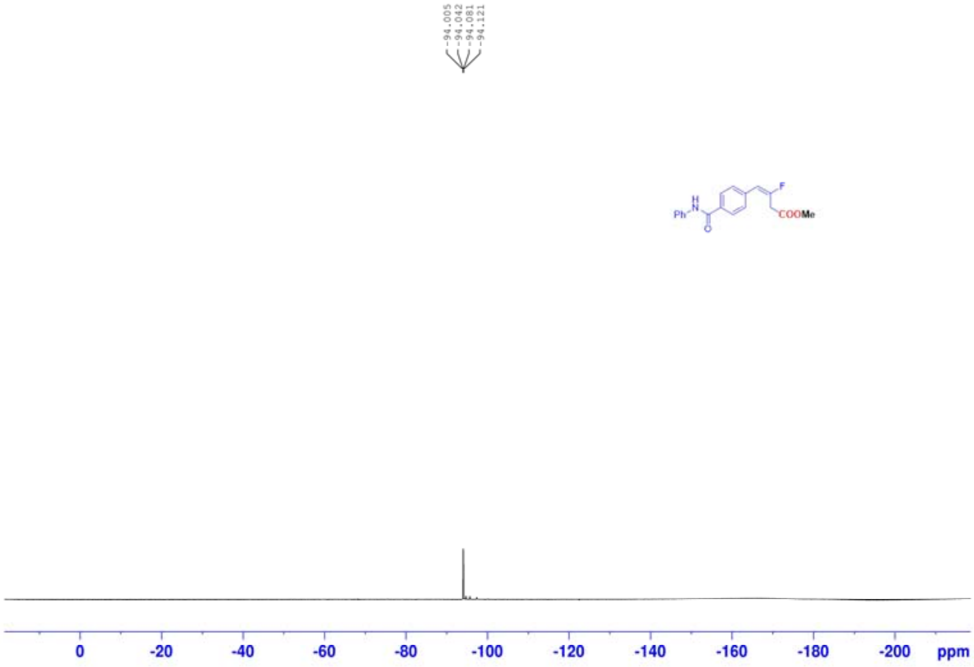
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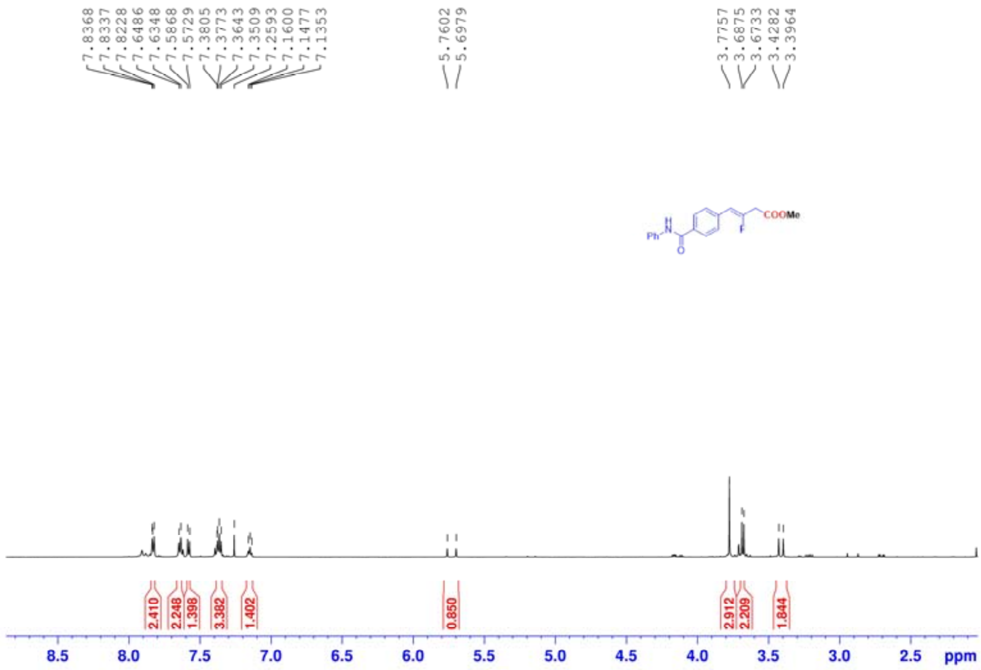
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7.2593
7.1600
7.1477
7.1353
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3.7757
3.6875
3.6733
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3.3964
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H
O
F
COOMe
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1.402
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2.209
1.844
8.5
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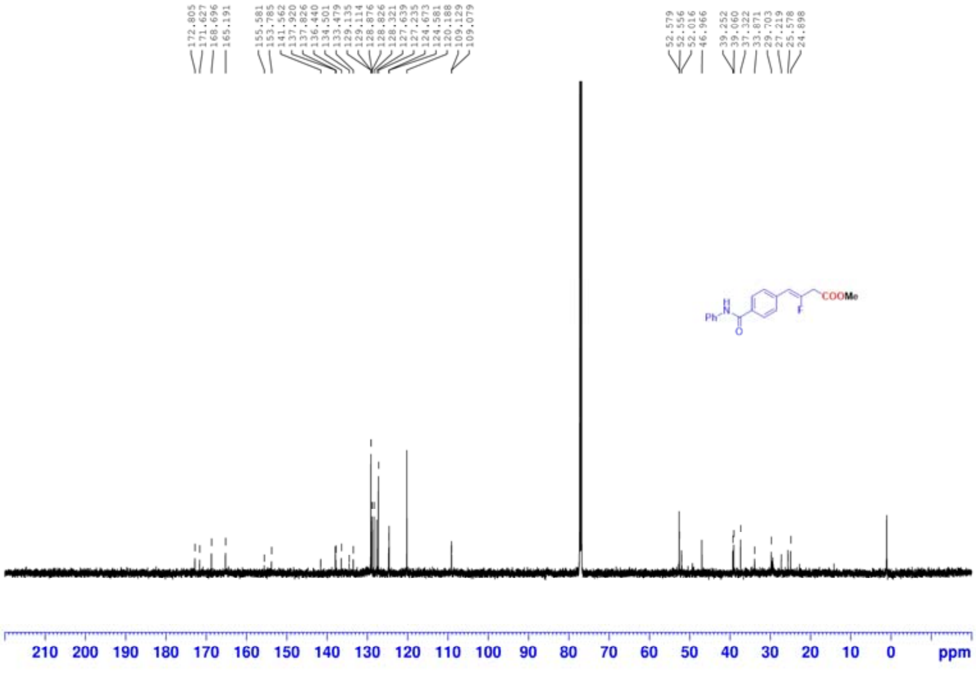
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129.114
128.876
128.826
128.321
127.639
127.235
124.673
124.581
120.188
109.129
109.079
52.579
52.556
52.016
46.966
39.252
39.060
37.322
33.871
29.703
27.219
25.578
24.898
Ph
N
H
O
F
COOMe
210
200
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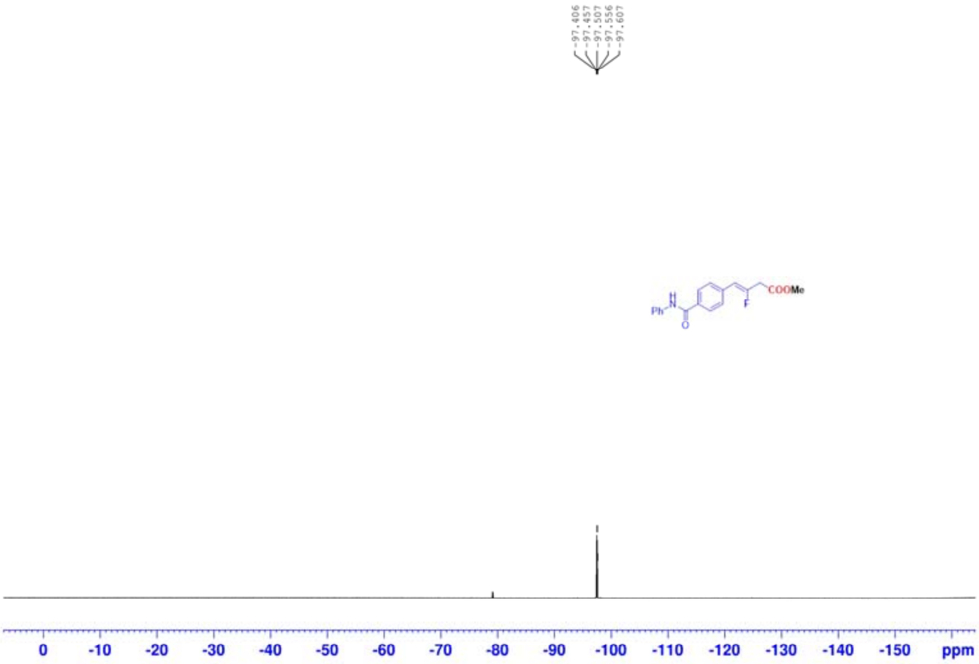
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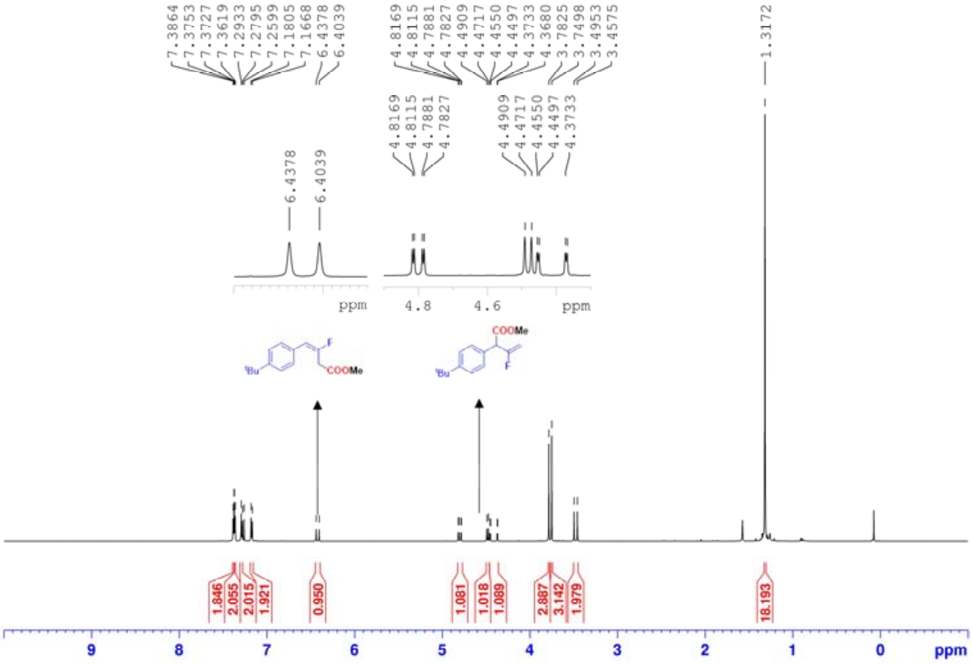
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6.4039
4.8169
4.8115
4.7881
4.7827
4.4909
4.4717
4.4550
4.4497
4.3733
4.3680
3.7825
3.7498
3.4953
3.4575
1.3172
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6.4039
ppm
4.8169
4.8115
4.7881
4.7827
4.4909
4.4717
4.4550
4.4497
4.3733
4.8
4.6
ppm
tBu
F
COOMe
COOMe
tBu
F
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2.055
2.015
1.921
0.950
1.081
1.018
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3.142
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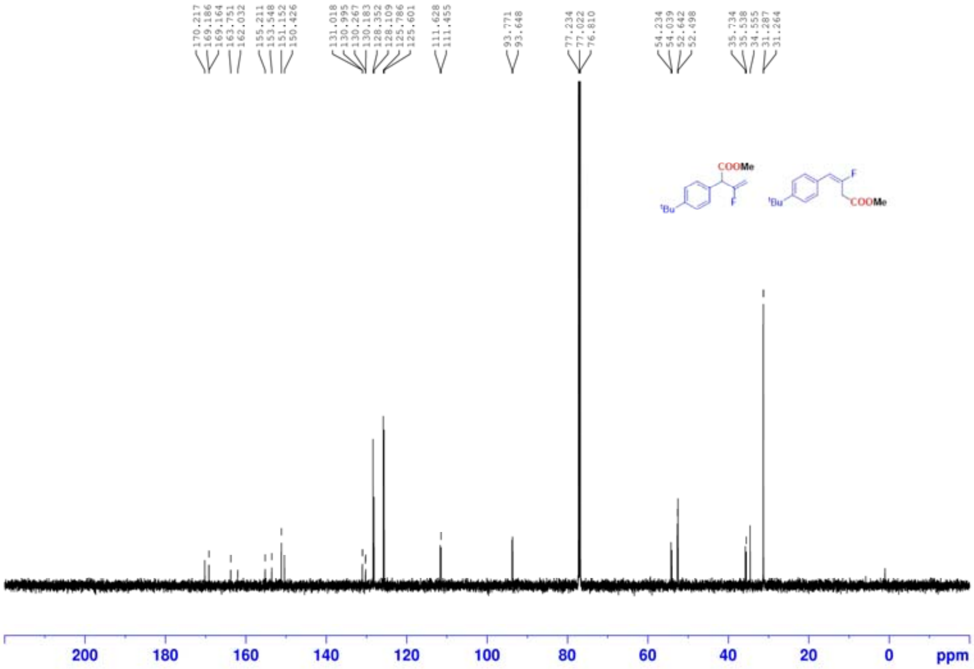
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128.352
128.109
125.786
125.601
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93.771
93.648
77.234
77.022
76.810
54.234
54.039
52.642
52.498
35.734
35.538
34.555
31.287
31.264
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F
tBu
COOMe
200
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120
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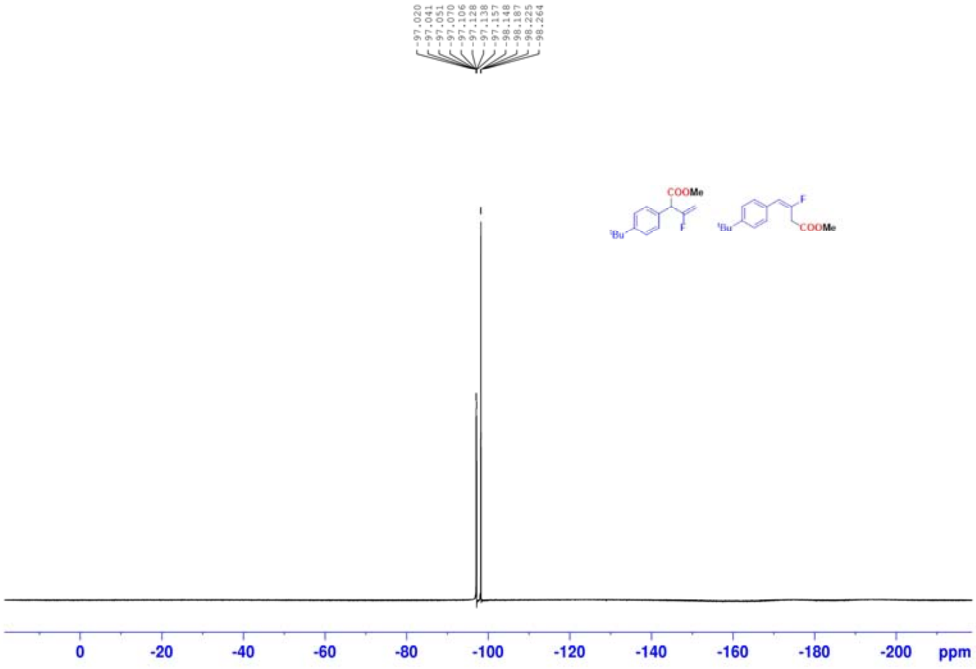
60
40
20
0
ppm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-98.264
COOMe
F
tBu
F
tBu
COOMe
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-180
-200
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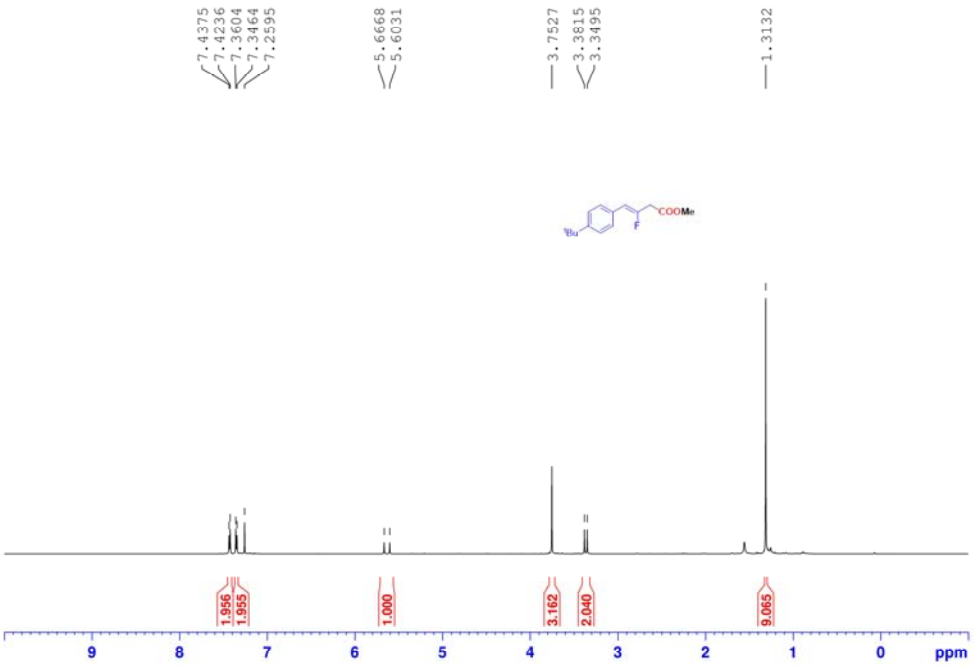
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1.3132
tBu
F
COOMe
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2.040
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8
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6
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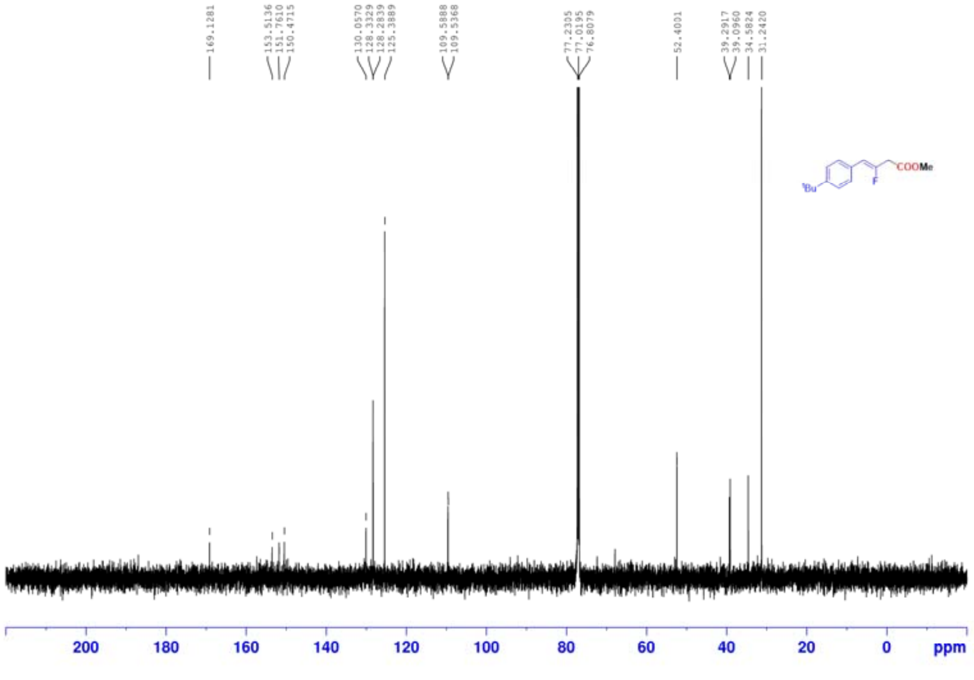
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77.0195
76.8079
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39.0960
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tBu
F
COOMe
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120
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40
20
0
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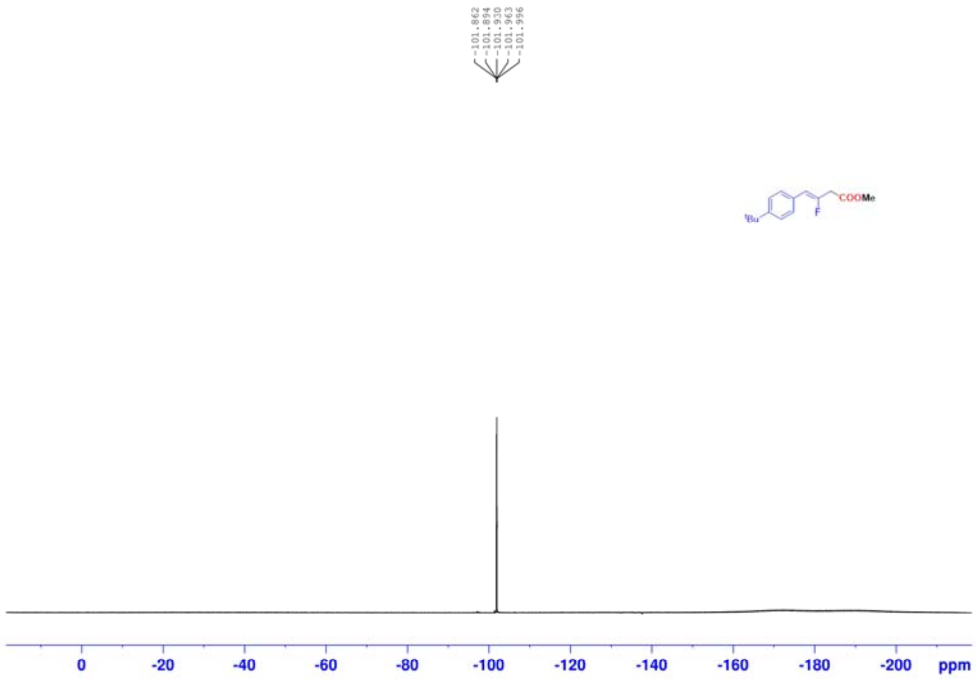
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F
COOMe
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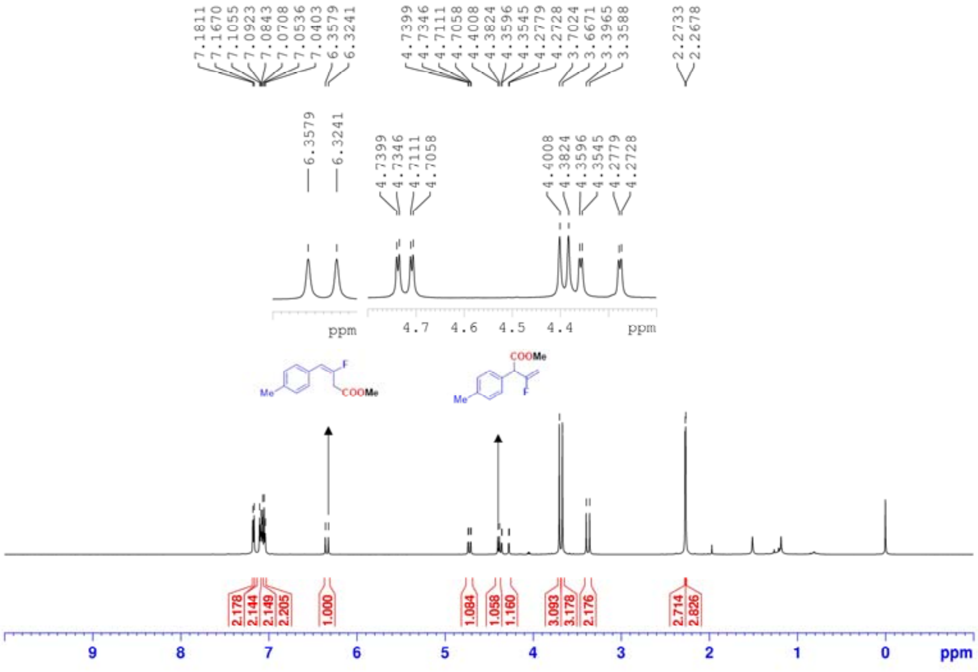
ppm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6.3579
6.3241
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4.7346
4.7111
4.7058
4.4008
4.3824
4.3596
4.3545
4.2779
4.2728
3.7024
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3.3965
3.3588
2.2733
2.2678
ppm
4.7
4.6
4.5
4.4
ppm
Me
F
COOMe
COOMe
Me
F
2.178
2.144
2.149
2.205
1.000
1.084
1.058
1.160
3.093
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2.176
2.714
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9
8
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6
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2
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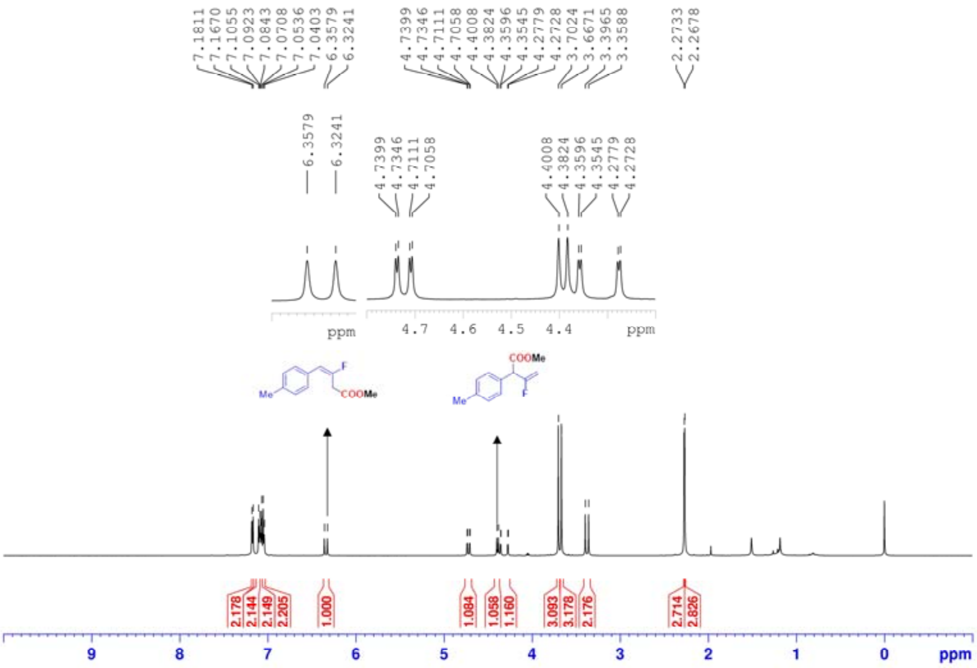
0
ppm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4.7399
4.7346
4.7111
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ppm
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4.4008
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4.3545
4.2779
4.2728
4.7
4.6
4.5
4.4
ppm
F
Me
COOMe
COOMe
Me
F
2.178
2.144
2.149
2.205
1.000
1.084
1.058
1.160
3.093
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2.176
2.714
2.826
9
8
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6
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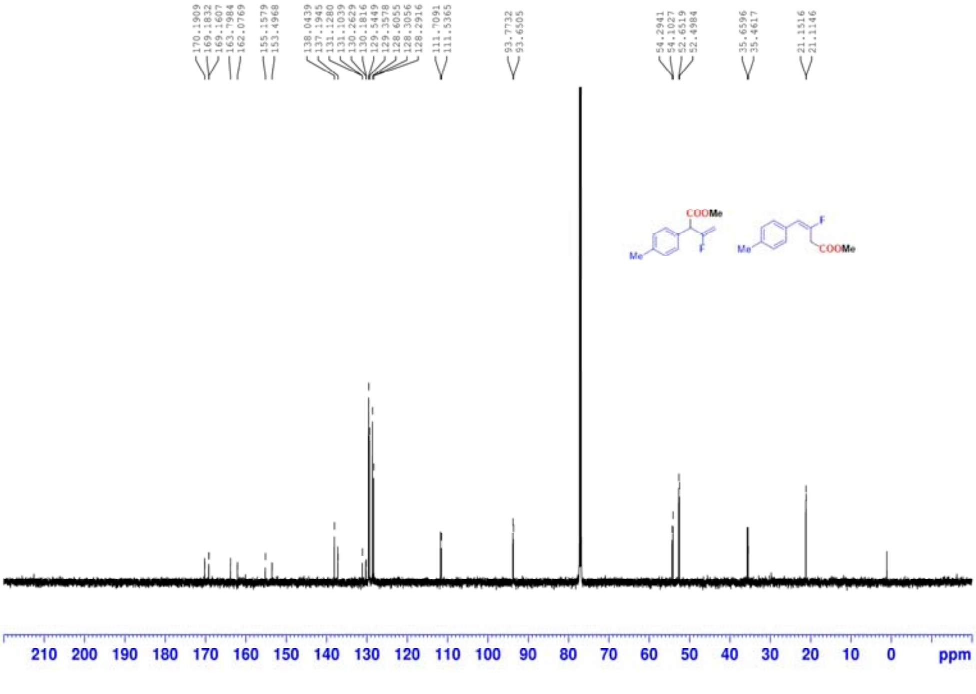
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129.5449
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128.3056
128.2916
111.7091
111.5365
93.7732
93.6505
54.2941
54.1027
52.6519
52.4984
35.6596
35.4617
21.1516
21.1146
COOMe
Me
F
Me
F
COOMe
210
200
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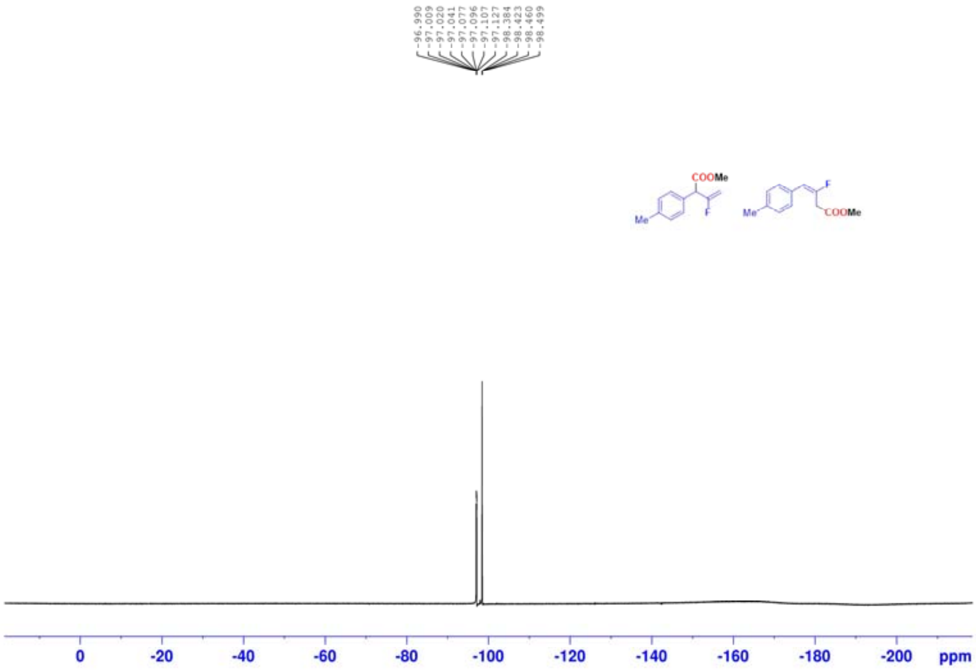
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COOMe
F
Me
Me
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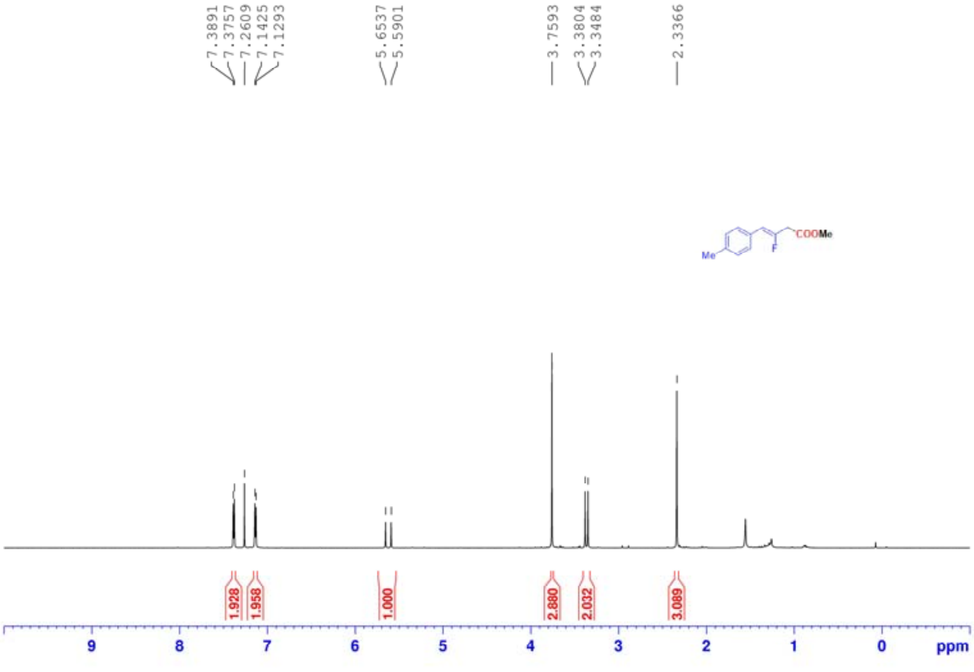
-180
-200
ppm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Me
F
COOMe
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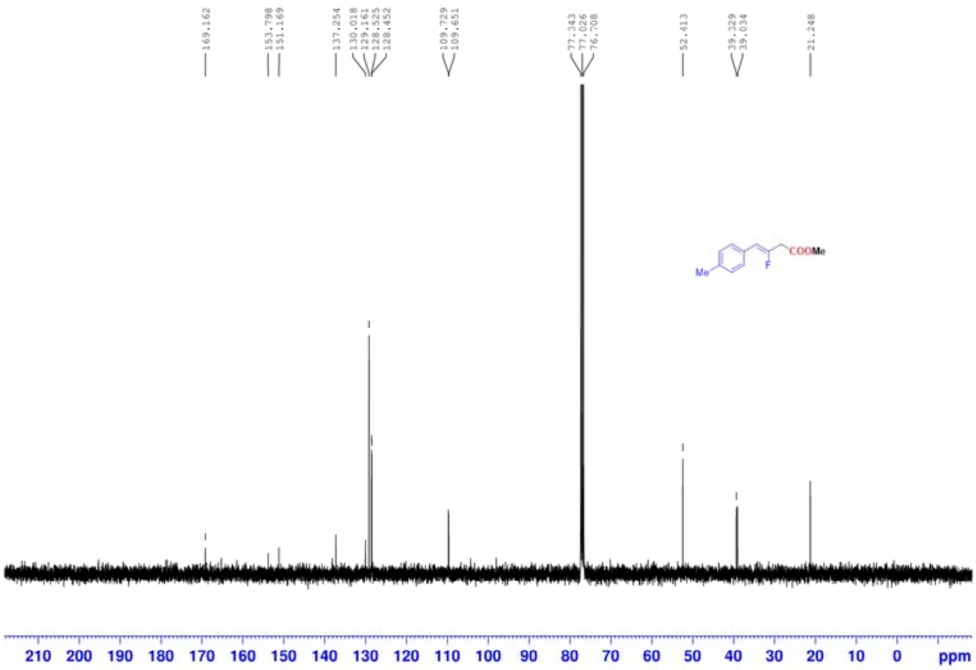
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109.651
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39.034
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Me
F
COOMe
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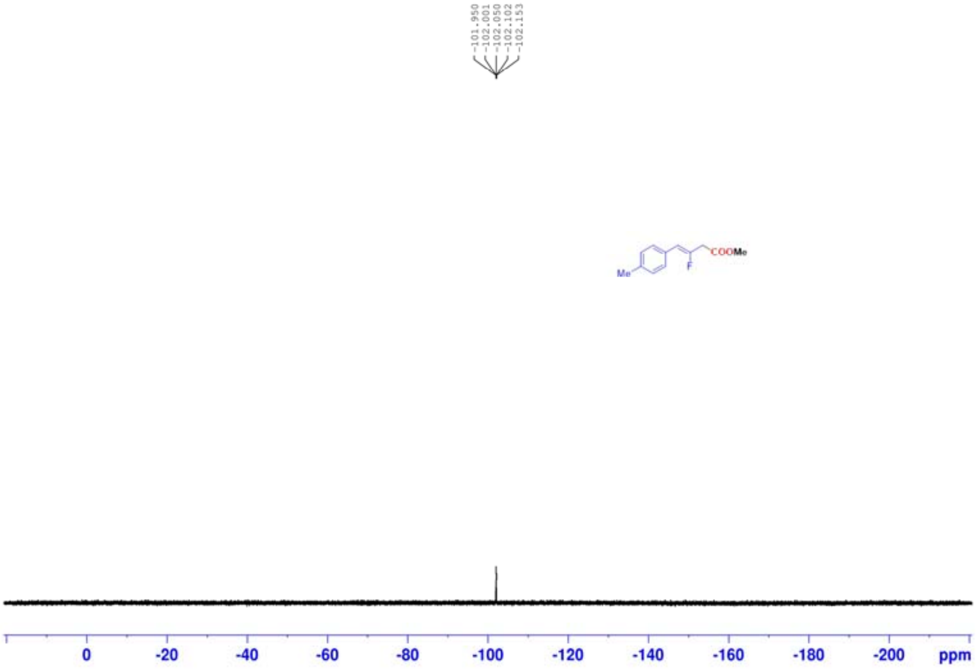
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F
COOMe
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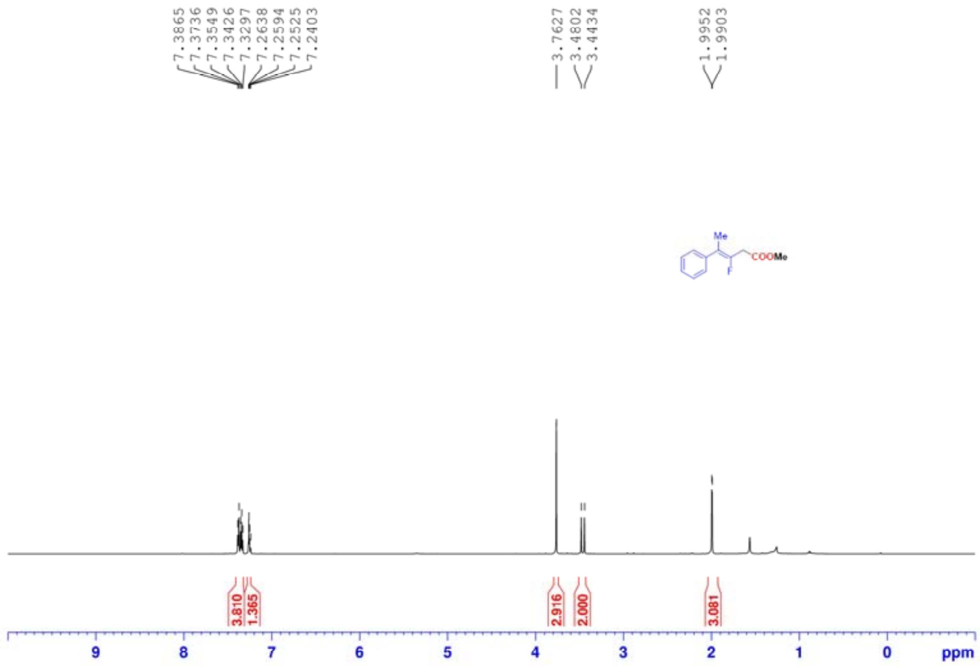
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7.2403
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3.4802
3.4434
1.9952
1.9903
Me
COOMe
F
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2.000
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6
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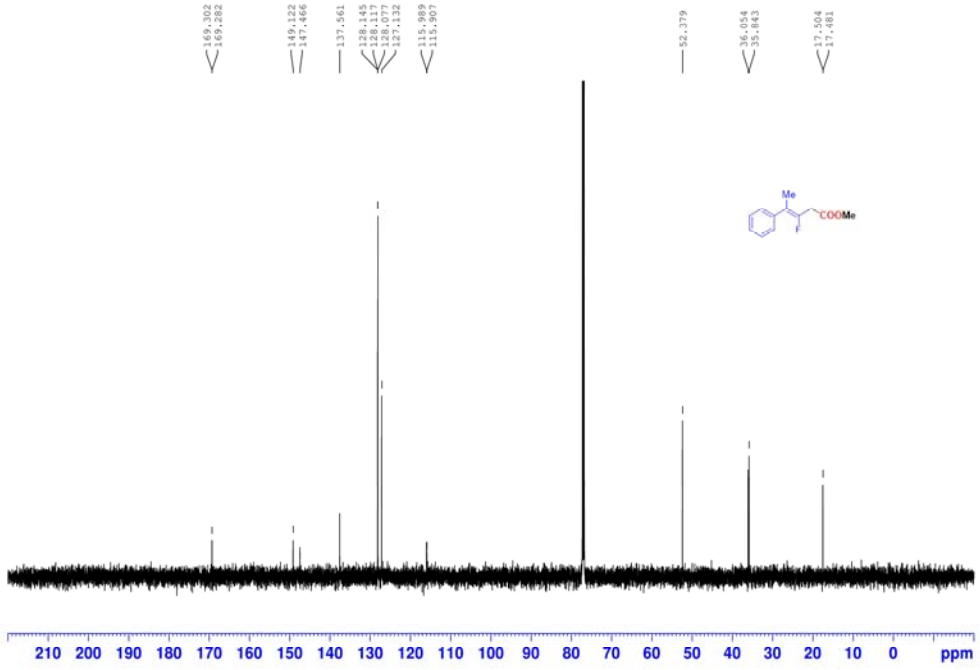
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17.481
Me
COOMe
F
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200
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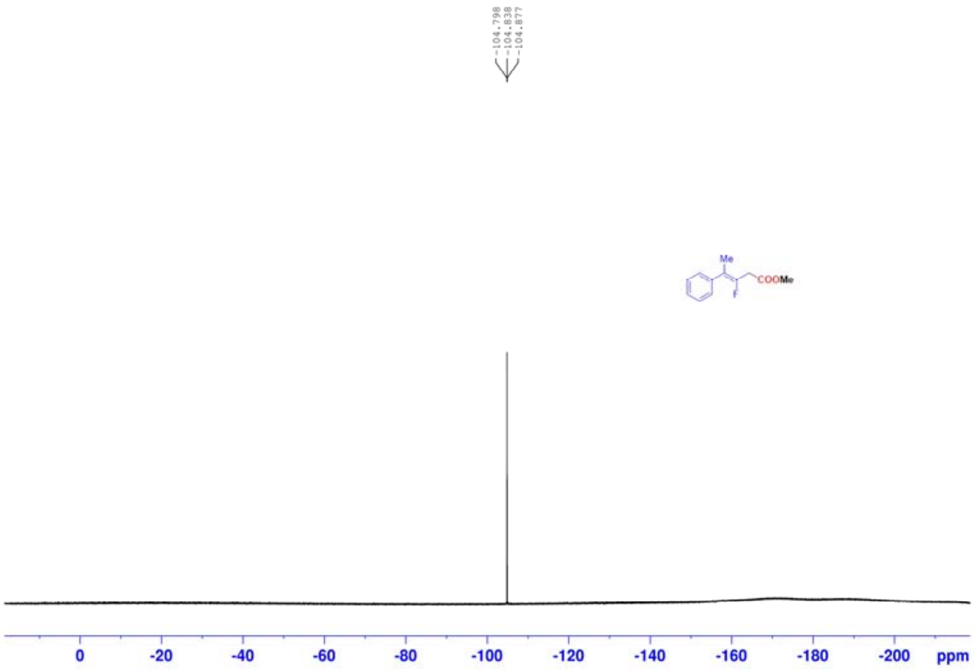

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Me
COOMe
F
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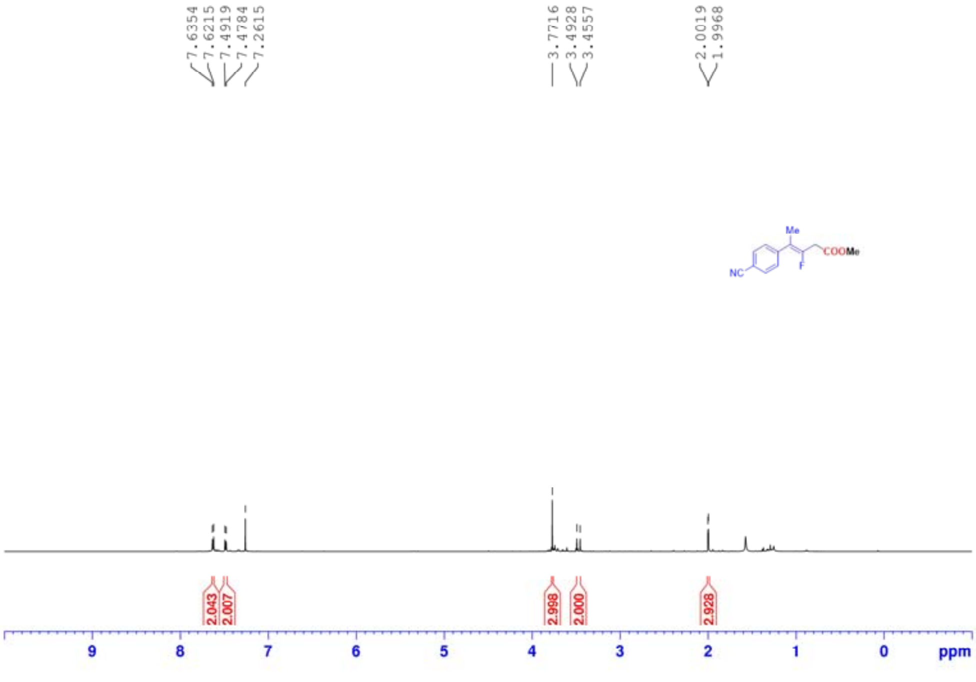
-180
-200
ppm



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Me
COOMe
NC
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2.000
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0
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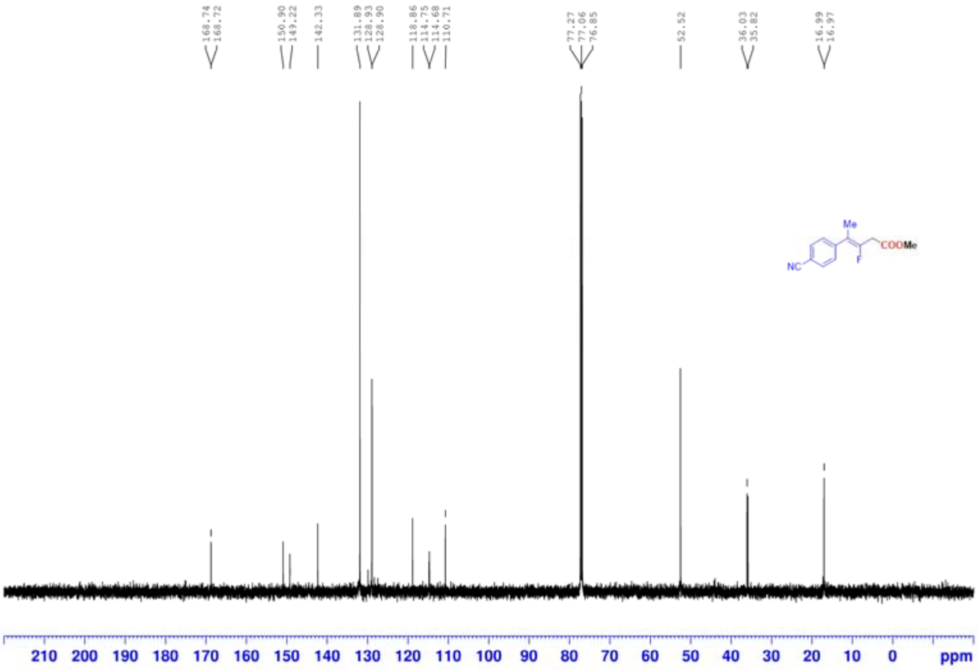
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77.27
77.06
76.85
52.52
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16.99
16.97
Me
COOMe
NC
F
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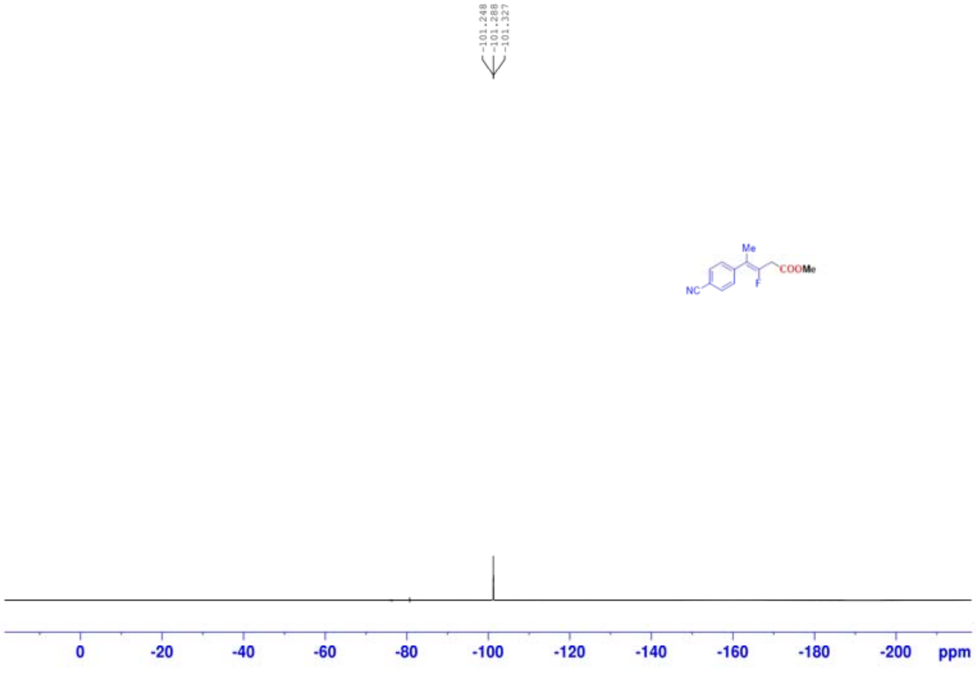
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NC
F
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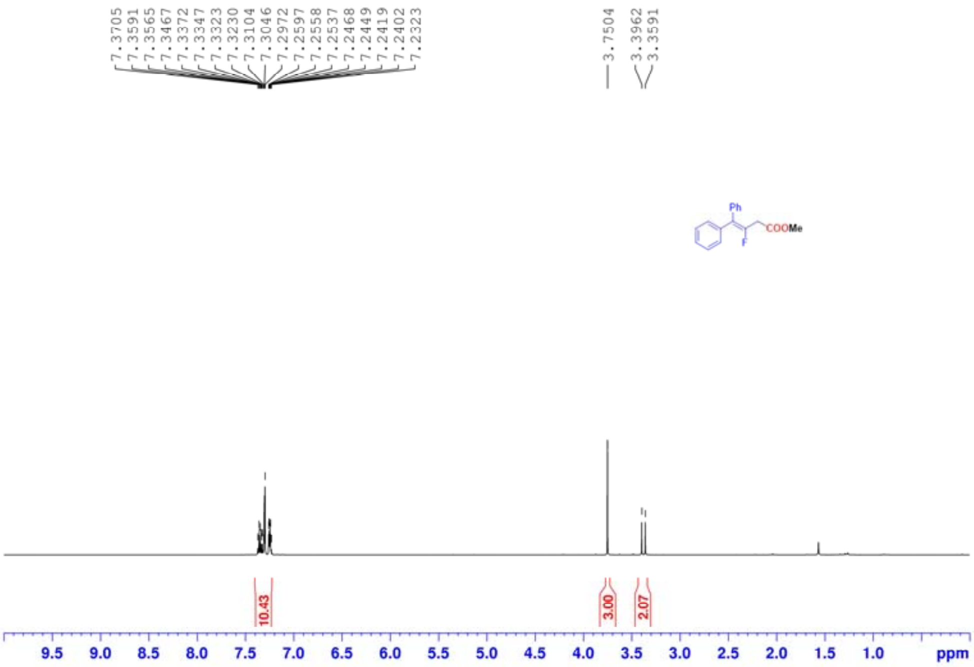
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7.2419
7.2402
7.2323
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3.3962
3.3591
Ph
COOMe
F
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9.0
8.5
8.0
7.5
7.0
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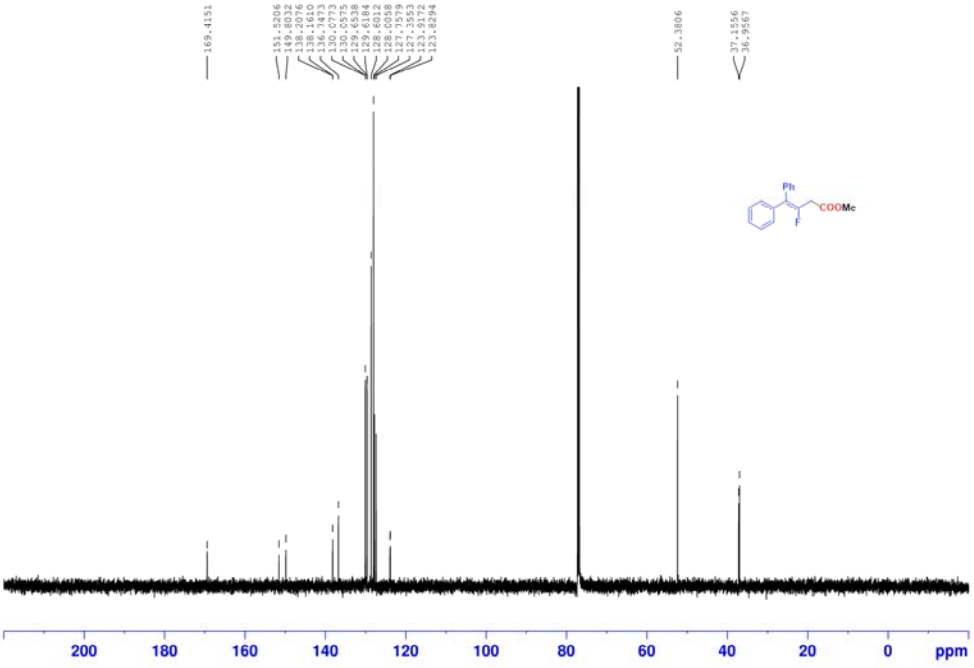
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123.8294
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Ph
COOMe
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120
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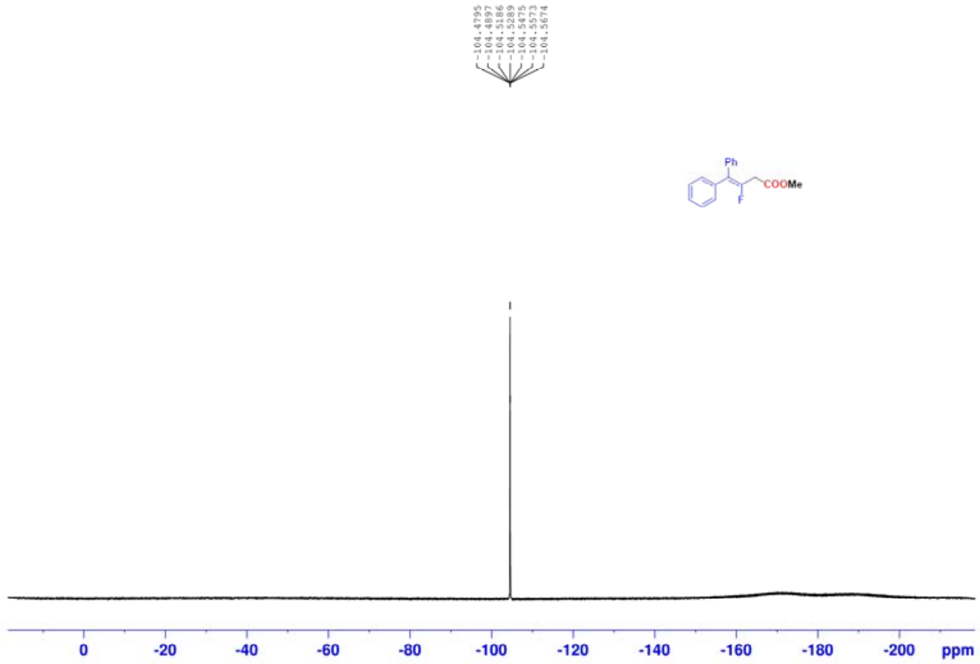

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Ph
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COOMe
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-60
-80
-100
-120
-140
-160
-180
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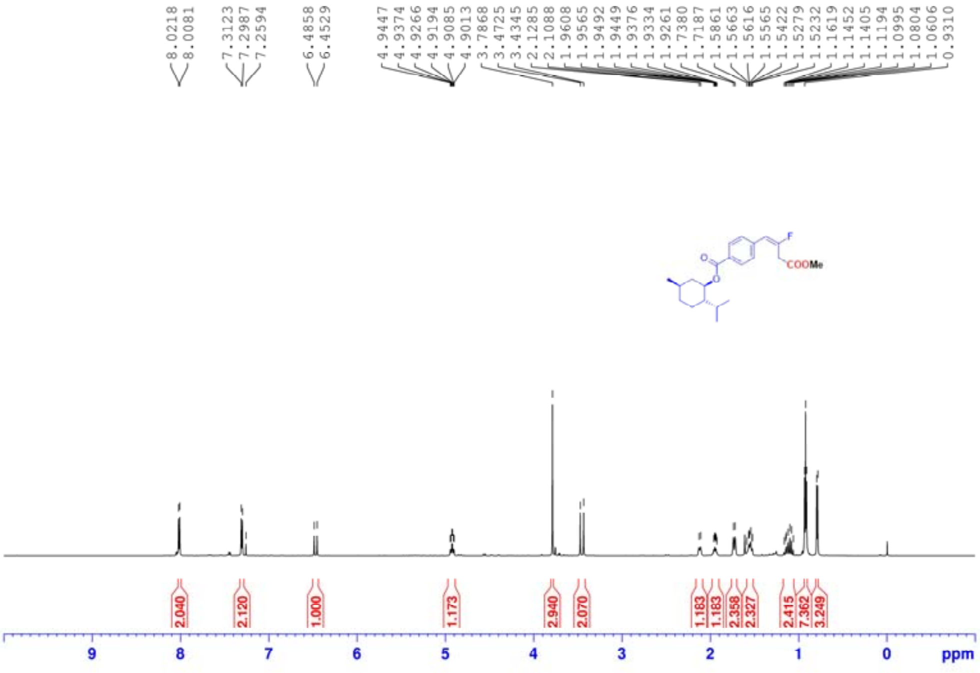
ppm



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4.9085
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3.4725
3.4345
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2.1088
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1.9334
1.9261
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1.1619
1.1452
1.1405
1.1194
1.0995
1.0804
1.0606
0.9310
O
F
COOMe
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2.940
2.070
1.183
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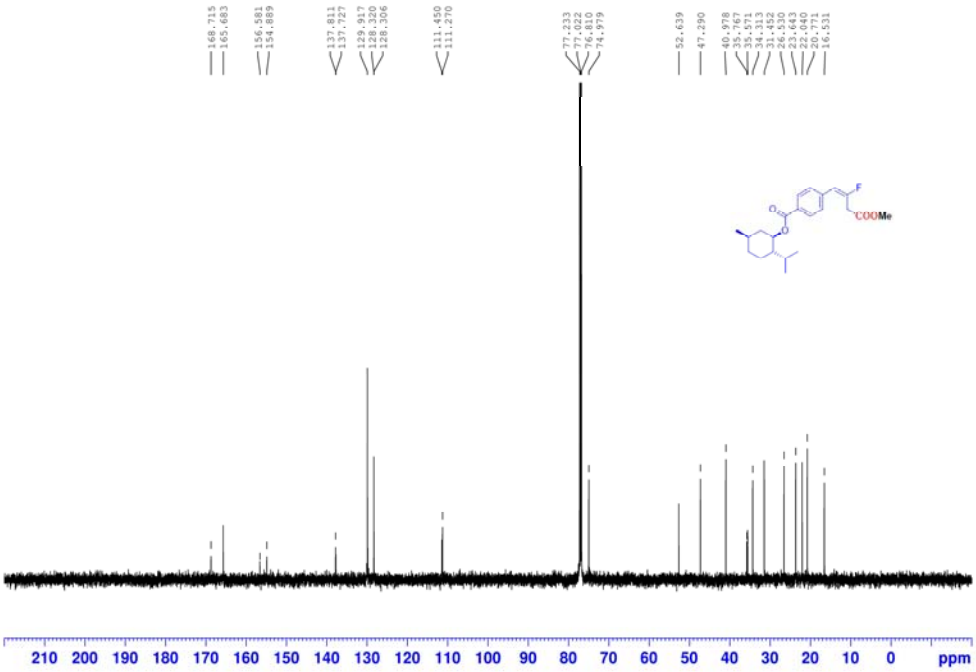
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77.022
76.810
74.979
52.639
47.290
40.978
35.767
35.571
34.313
31.452
26.530
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20.771
16.531
F
COOMe
O
O
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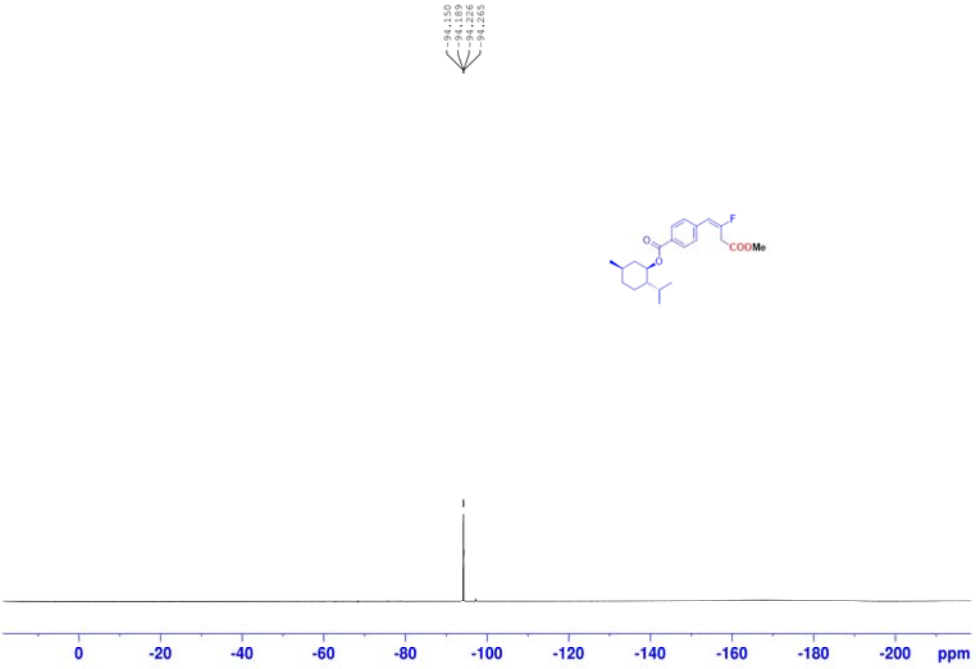
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O
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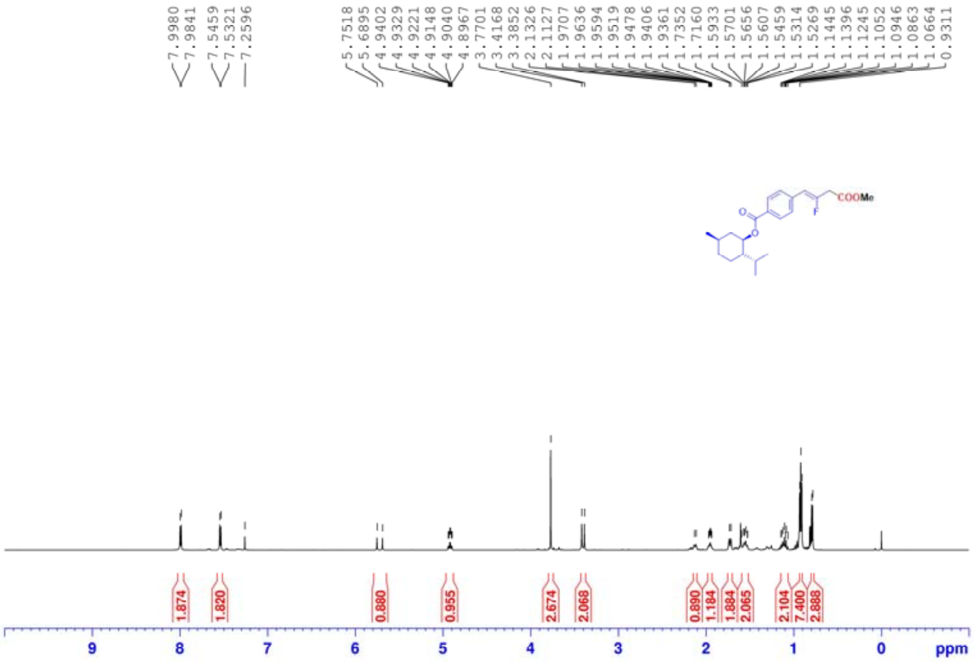
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3.3852
2.1326
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1.9519
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1.7352
1.7160
1.5933
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1.5656
1.5607
1.5459
1.5314
1.5269
1.1445
1.1396
1.1245
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1.0946
1.0863
1.0664
0.9311
COOMe
O
O
F
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0.880
0.955
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0.890
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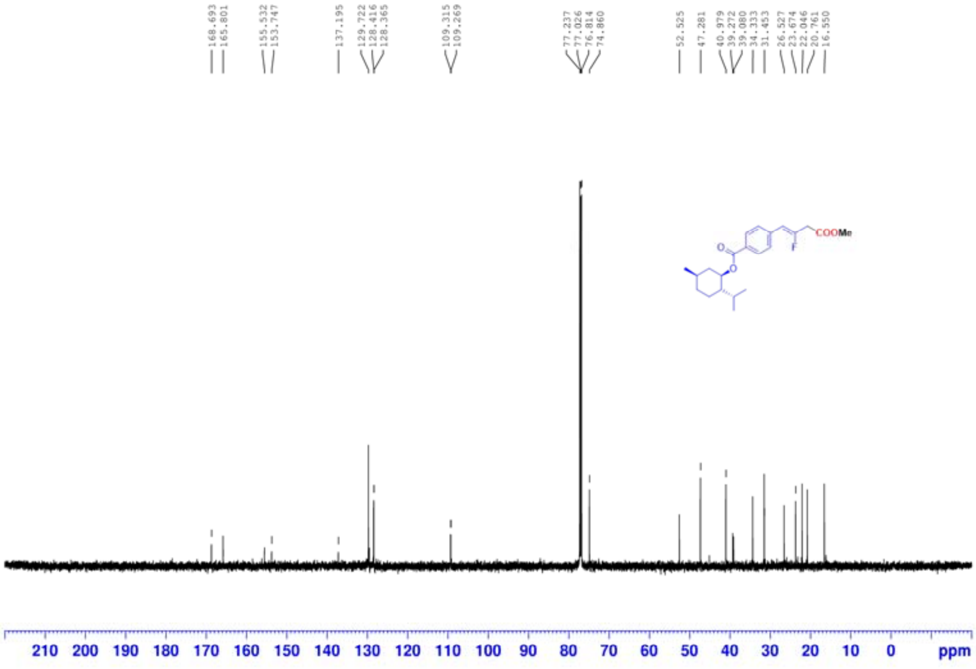
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76.814
74.860
52.525
47.281
40.979
39.272
39.080
34.333
31.453
26.527
23.674
22.046
20.761
16.550
COOMe
O
O
F
210
200
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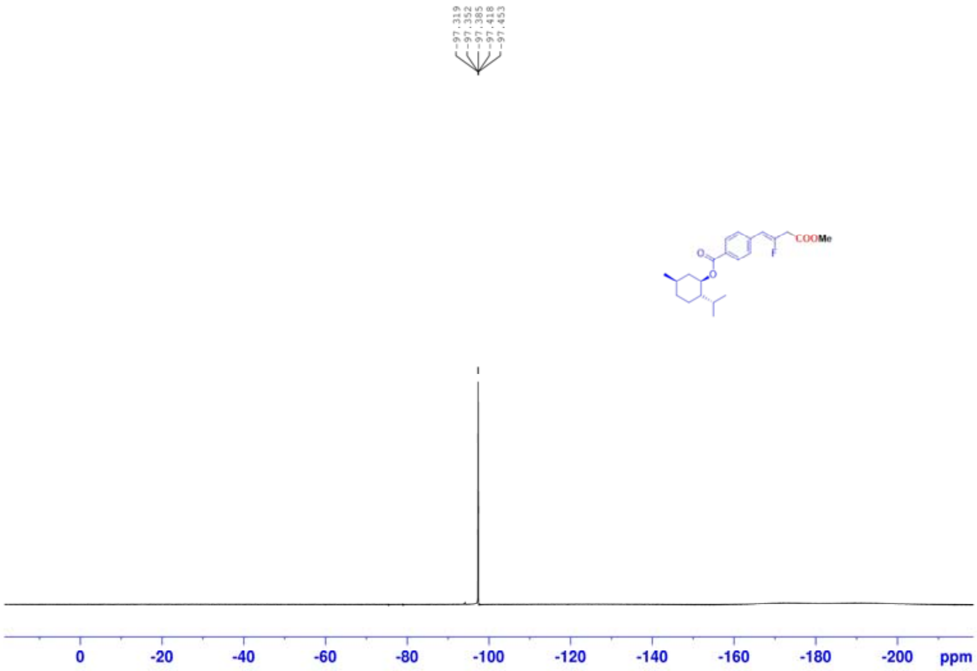
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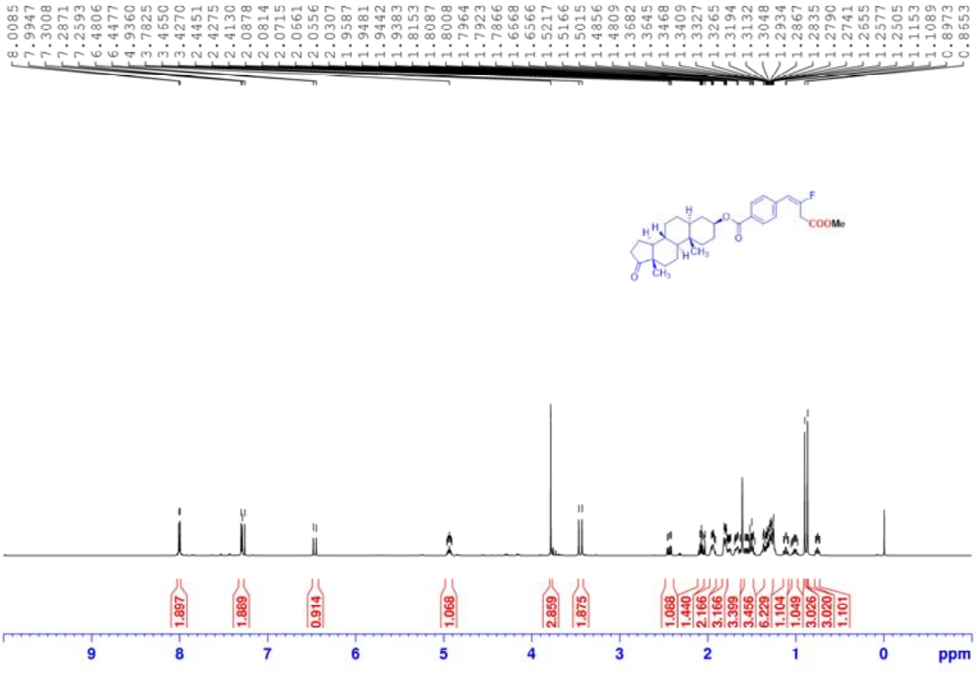
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3.4270
2.4451
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2.4130
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2.0715
2.0661
2.0556
2.0307
1.9587
1.9481
1.9442
1.9383
1.8153
1.8087
1.8008
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1.7923
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1.6566
1.5217
1.5166
1.5015
1.4856
1.4809
1.3682
1.3645
1.3468
1.3409
1.3327
1.3265
1.3194
1.3132
1.3048
1.2934
1.2867
1.2835
1.2790
1.2741
1.2655
1.2577
1.2505
1.1153
1.1089
0.8973
0.8653
F
H
O
COOMe
CH3
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1.889
0.914
1.068
2.859
1.875
1.088
1.440
2.166
3.166
3.399
3.456
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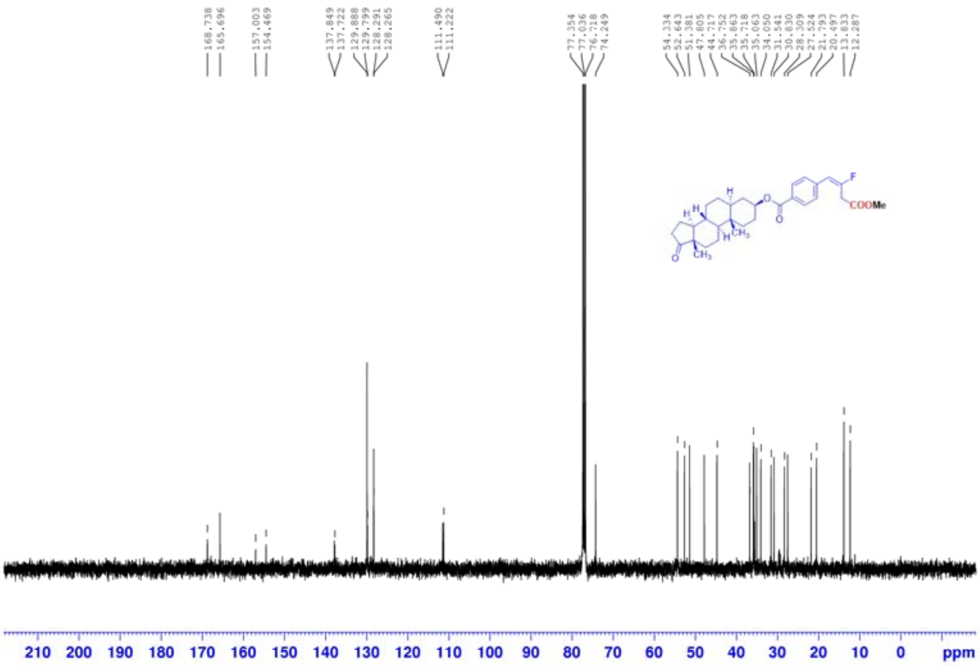
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129.799
128.291
128.265
111.490
111.222
77.354
77.036
76.718
74.249
54.334
52.643
51.381
47.805
44.717
36.752
35.863
35.718
35.063
34.050
31.541
30.830
28.309
27.524
21.793
20.497
13.833
12.287
H
H
H
H
CH3
O
CH3
O
O
F
COOMe
210
200
190
180
170
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150
140
130
120
110
100
90
80
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60
50
40
30
20
10
0
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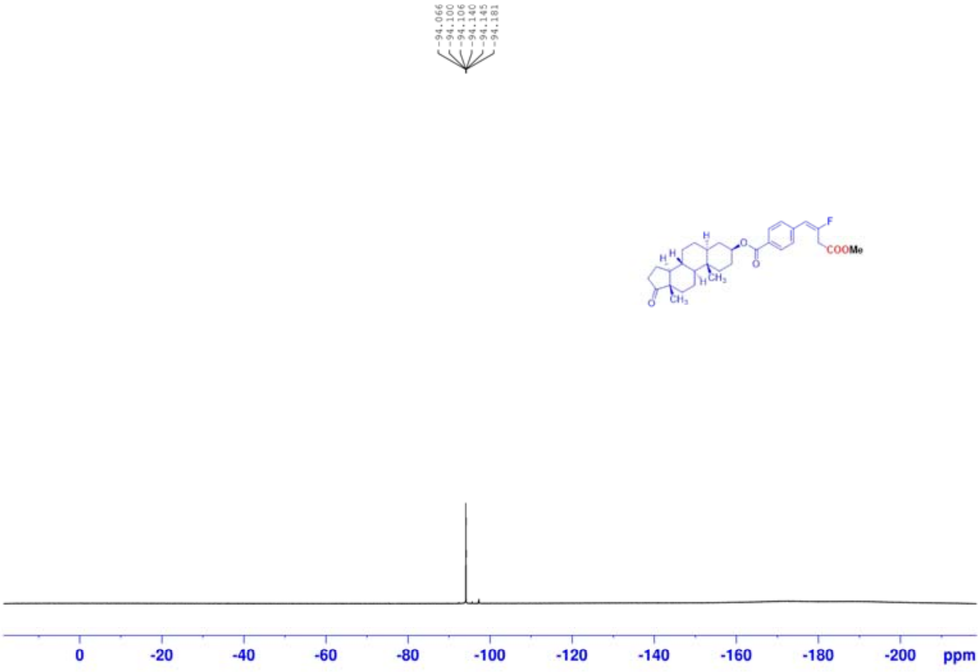
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H
H
H
CH3
O
CH3
O
O
F
COOMe
0
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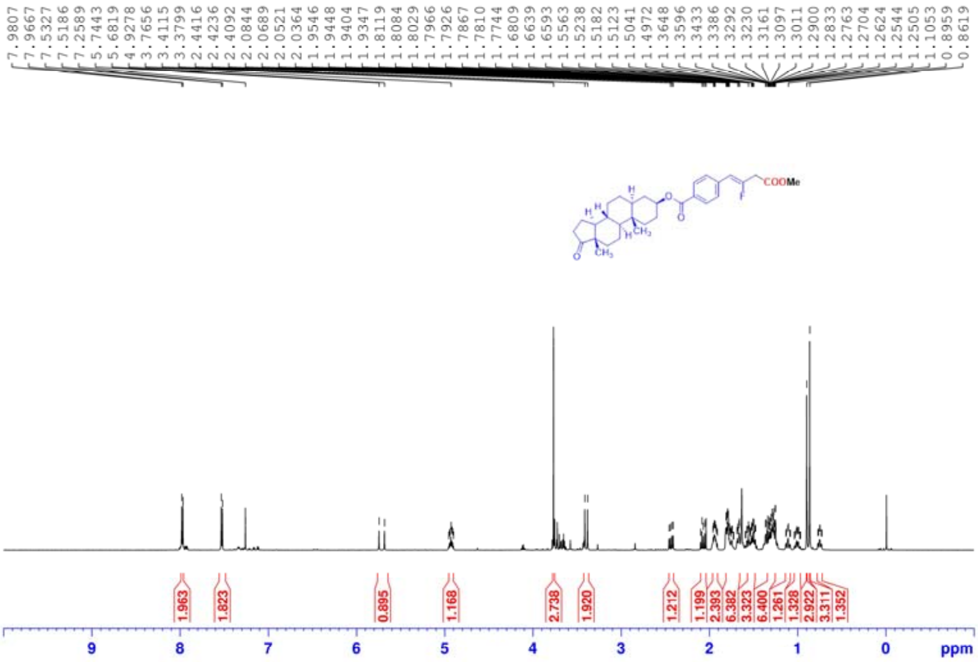
-180
-200
ppm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2.4236
2.4092
2.0844
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2.0364
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1.9404
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1.7744
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1.2900
1.2833
1.2763
1.2704
1.2624
1.2544
1.2505
1.1053
0.8959
0.8619
H
H
H
H
CH3
CH3
O
O
O
F
COOMe
1.963
1.823
0.895
1.168
2.738
1.920
1.212
1.199
2.393
6.382
3.323
6.400
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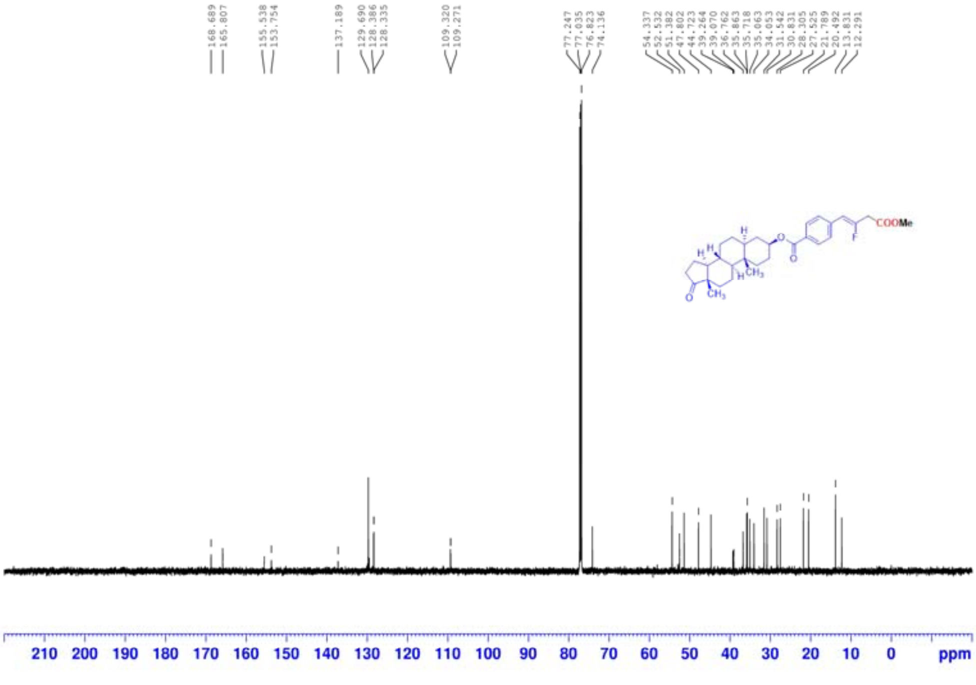
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52.532
51.382
47.802
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39.070
36.762
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35.718
35.063
34.053
31.542
30.831
28.305
27.525
21.789
20.492
13.831
12.291
H
H
H
H
CH3
CH3
O
O
O
F
COOMe
210
200
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160
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140
130
120
110
100
90
80
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60
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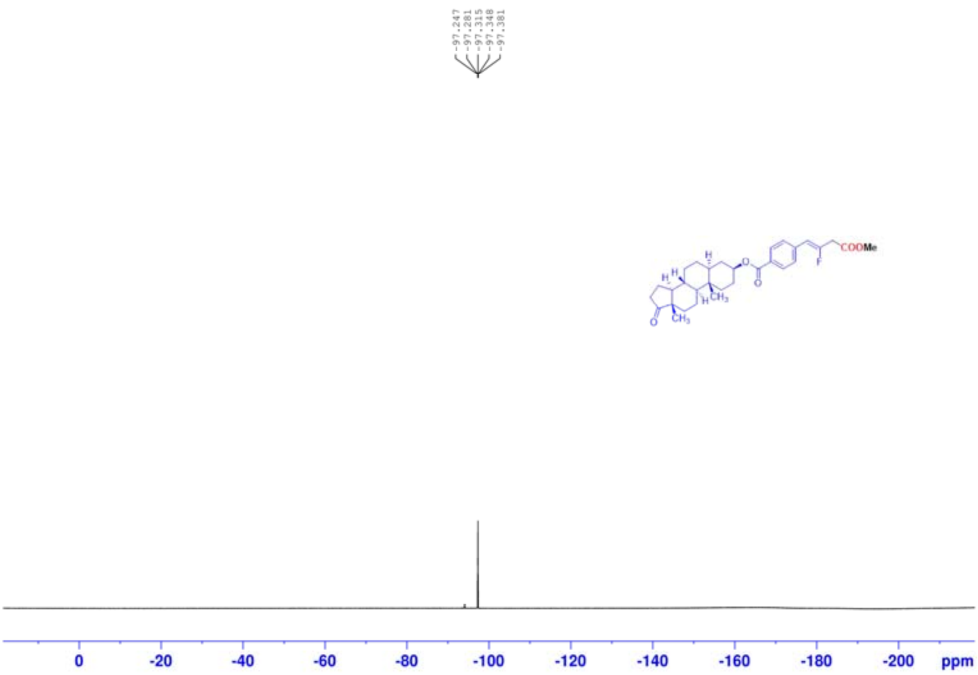
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H
H
H
CH3
CH3
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O
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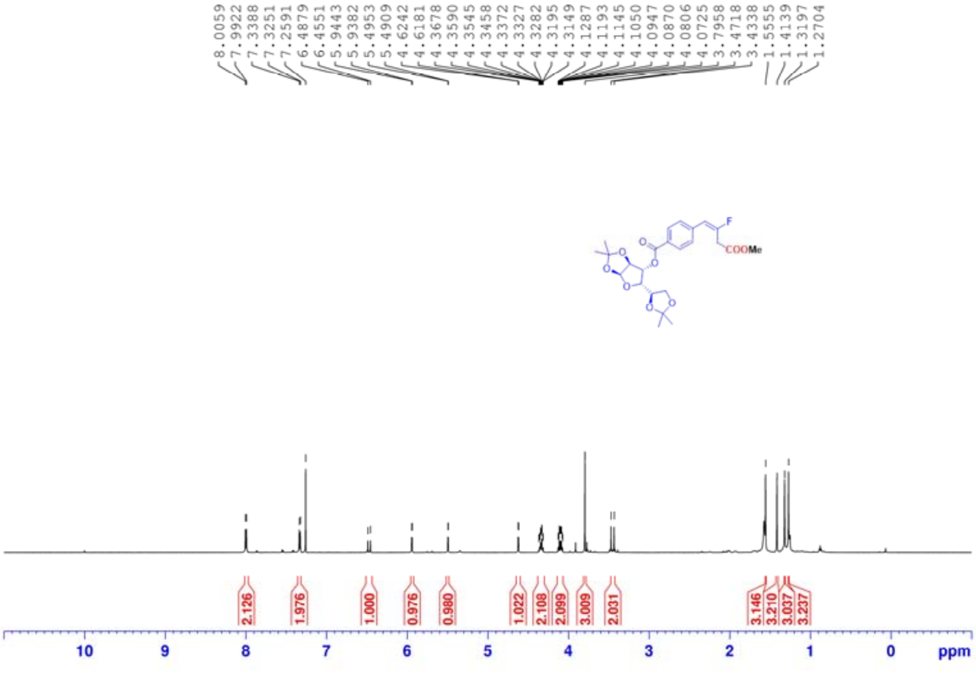
-180
-200
ppm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4.6242
4.6181
4.3678
4.3590
4.3545
4.3458
4.3372
4.3327
4.3282
4.3195
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4.1287
4.1193
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4.0947
4.0870
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4.0725
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3.4718
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1.2704
O
O
O
O
O
O
O
F
COOMe
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1.000
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0.980
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2.108
2.099
3.009
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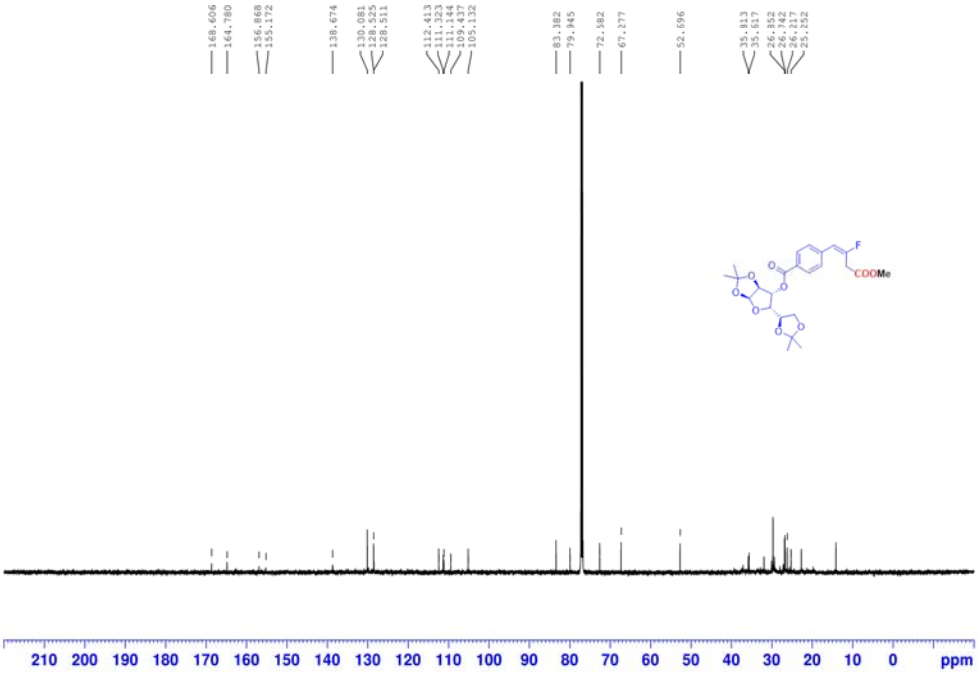
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79.945
72.582
67.277
52.696
35.813
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26.217
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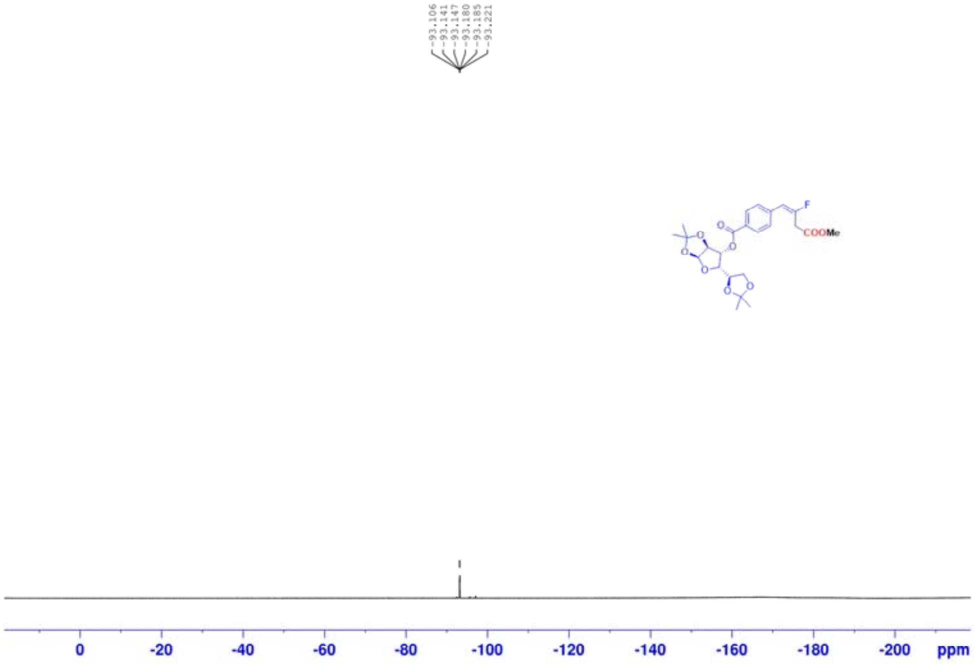
F
COOMe
O
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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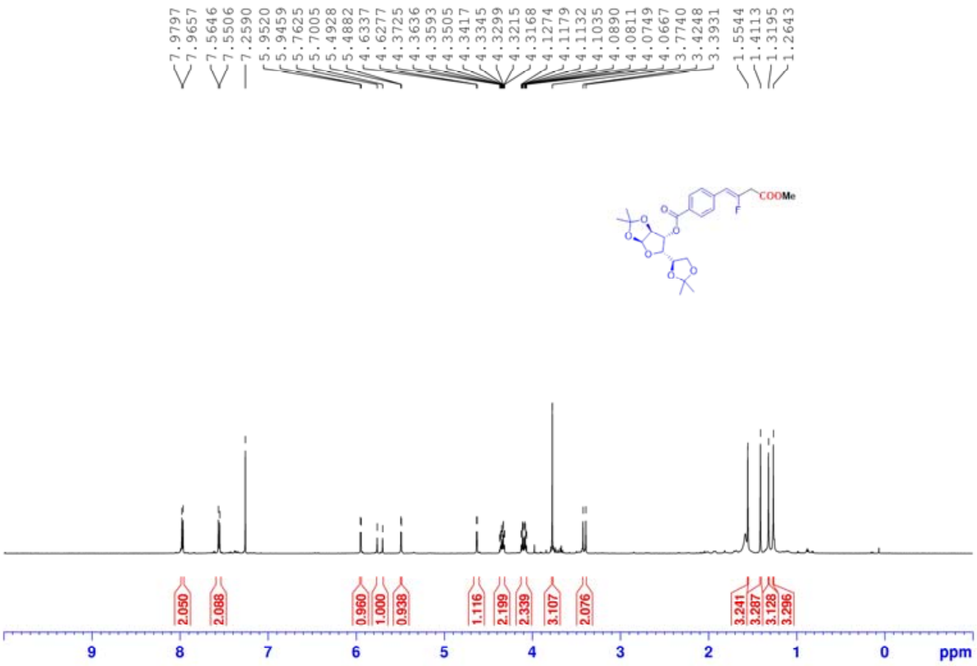
O
0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 ppm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4.3725
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4.3505
4.3417
4.3345
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4.3215
4.3168
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4.1132
4.1035
4.0890
4.0811
4.0749
4.0667
3.7740
3.4248
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1.4113
1.3195
1.2643
COOMe
F
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2
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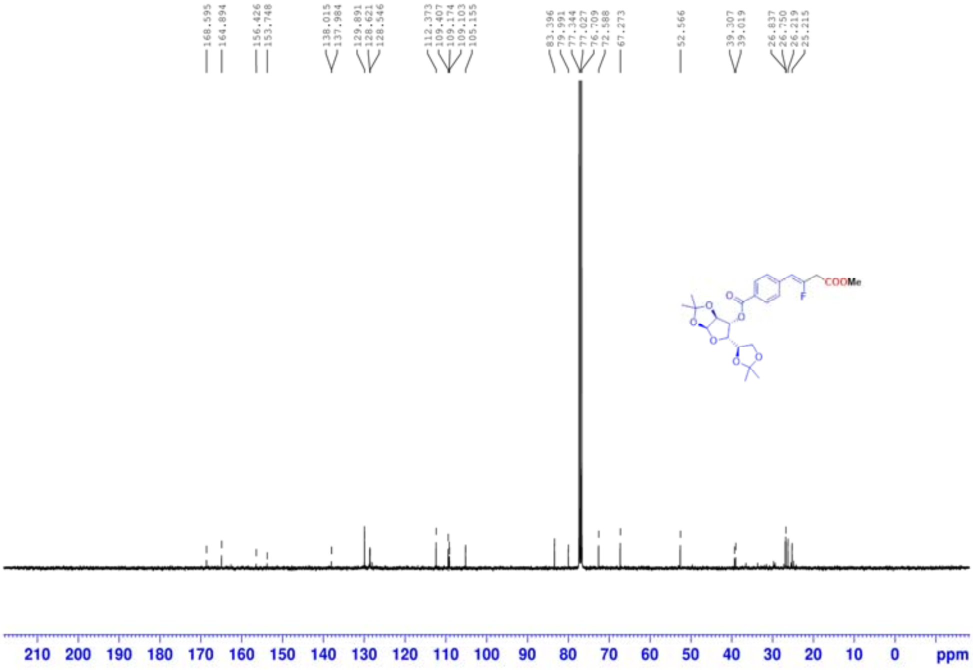
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77.027
76.709
72.588
67.273
52.566
39.307
39.019
26.837
26.750
26.219
25.215
COOMe
F
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200
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130
120
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60
50
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20
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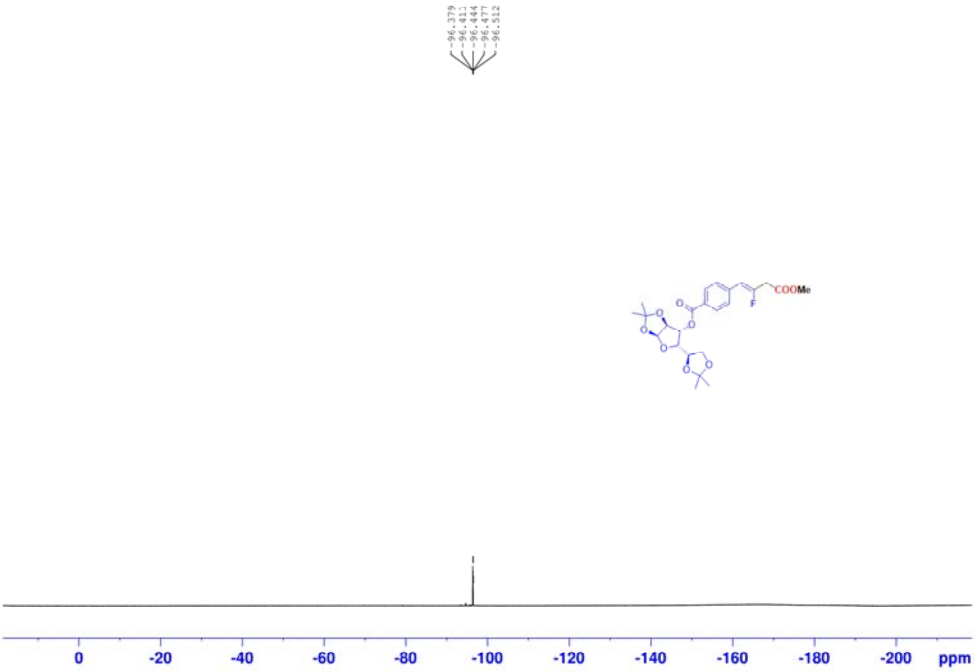
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O
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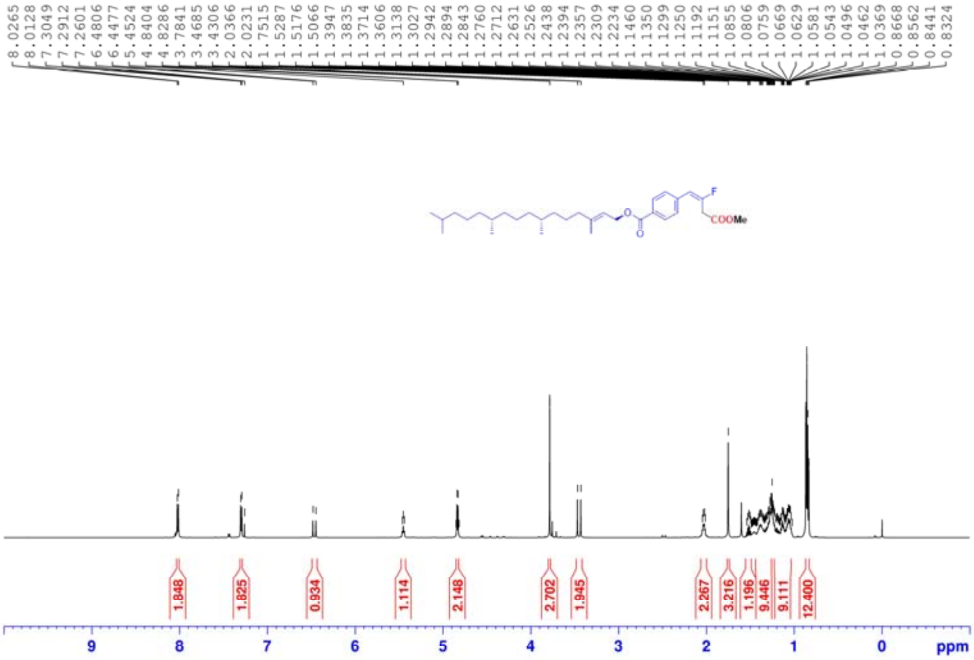
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1.2942
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O
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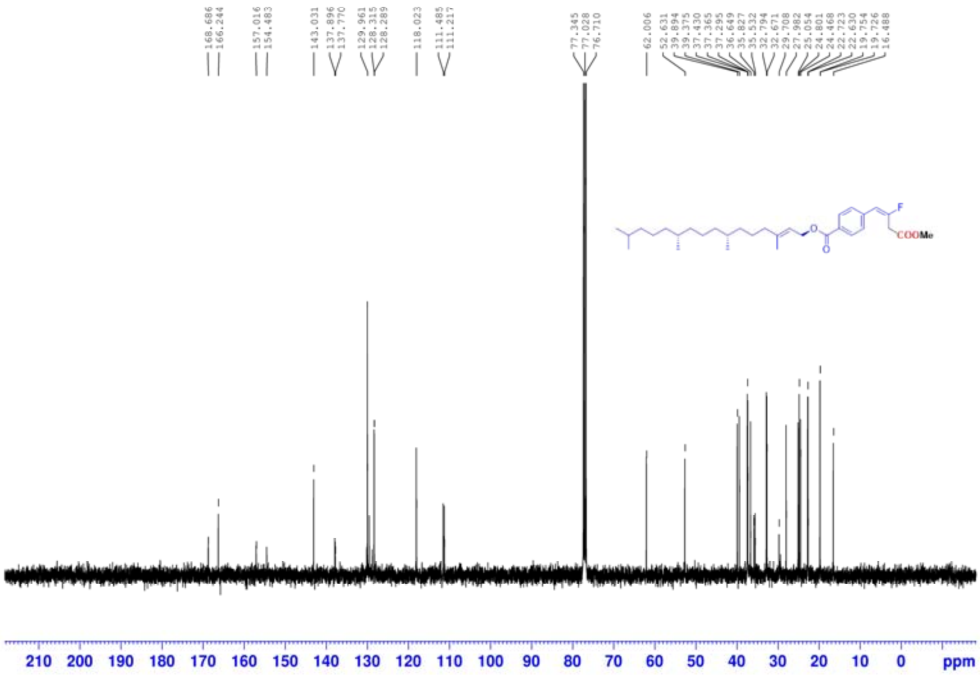
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76.710
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39.894
39.375
37.430
37.365
37.295
36.649
35.827
35.532
32.794
32.671
29.708
27.982
25.054
24.801
24.468
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19.754
19.726
16.488
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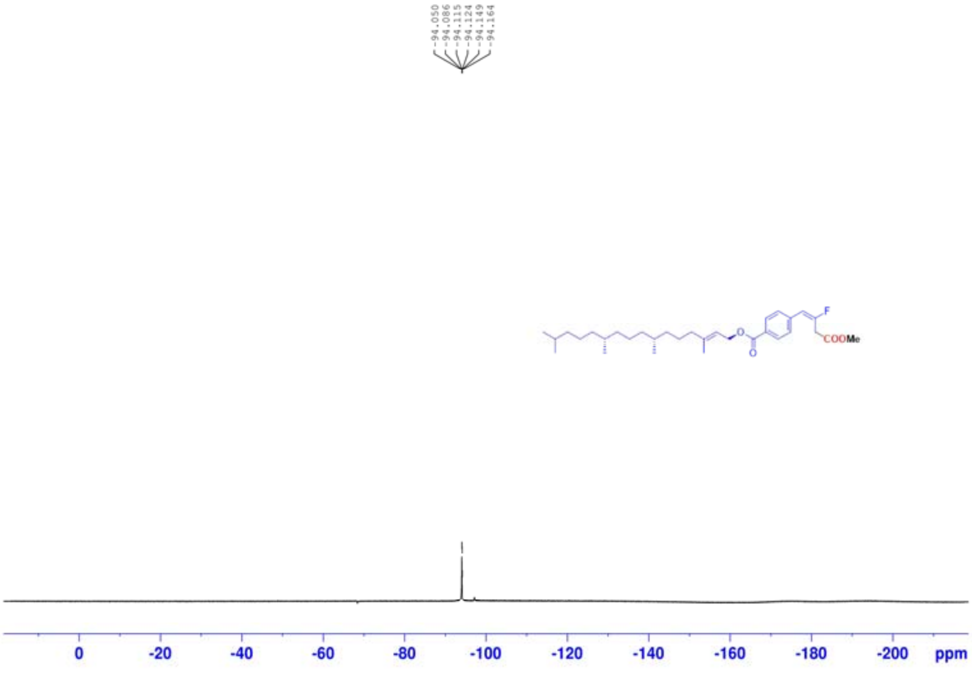
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COOMe
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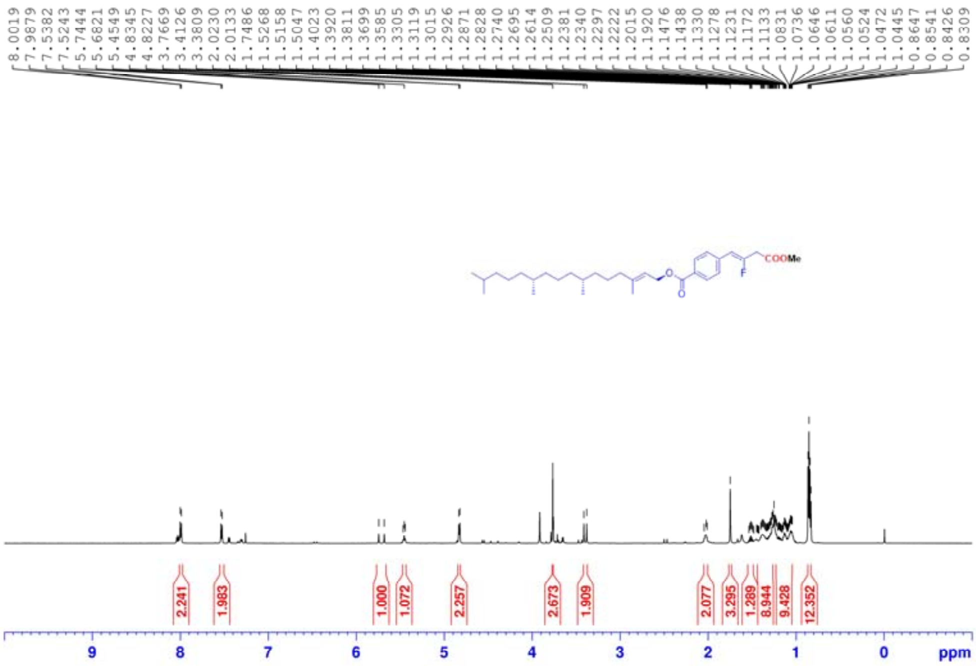
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1.2614
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O
O
F
COOMe
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2.257
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1.909
2.077
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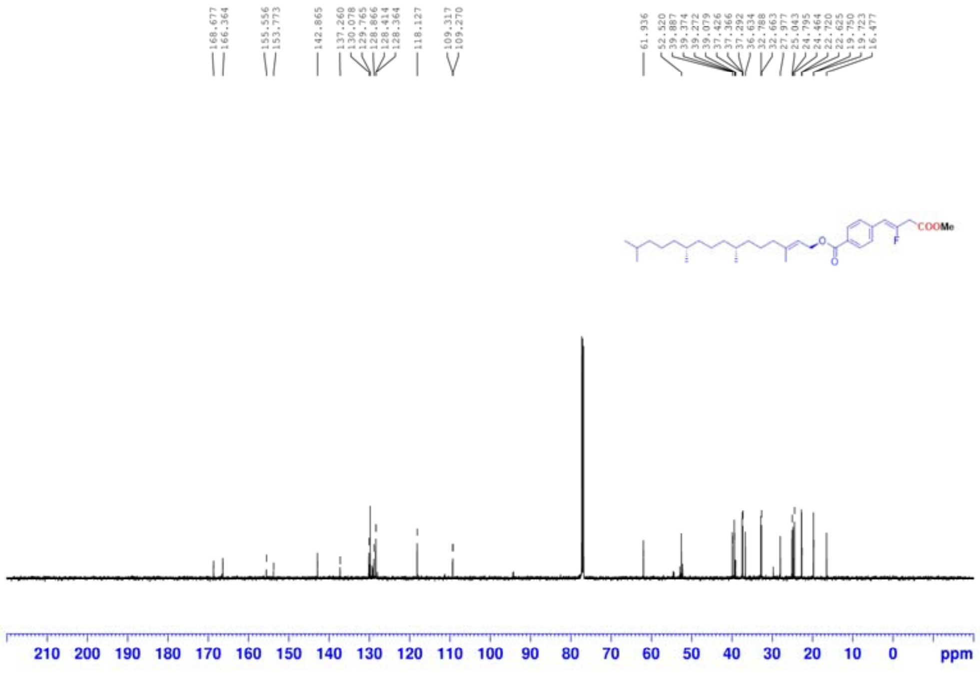
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39.272
39.079
37.426
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37.292
36.634
32.788
32.663
27.977
25.043
24.795
24.464
22.720
22.625
19.750
19.723
16.477
O
O
F
COOMe
210
200
190
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150
140
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80
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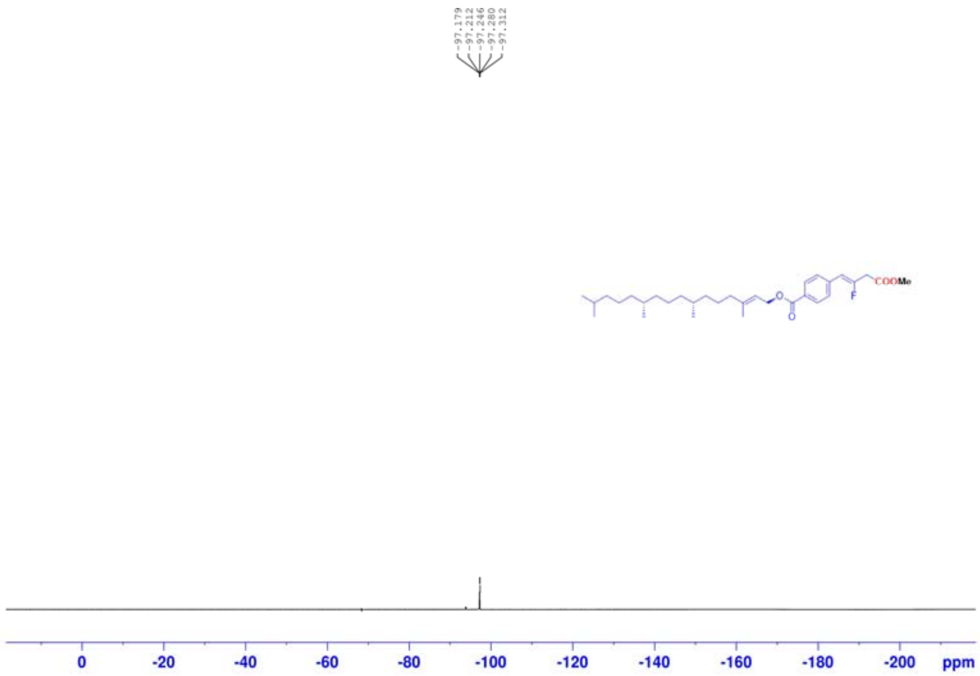
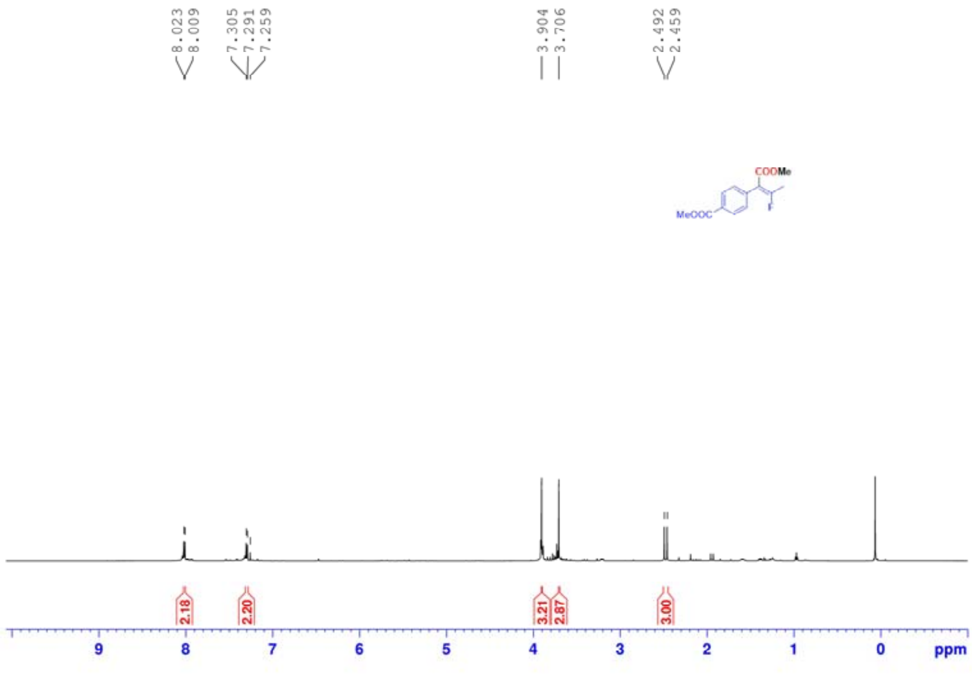
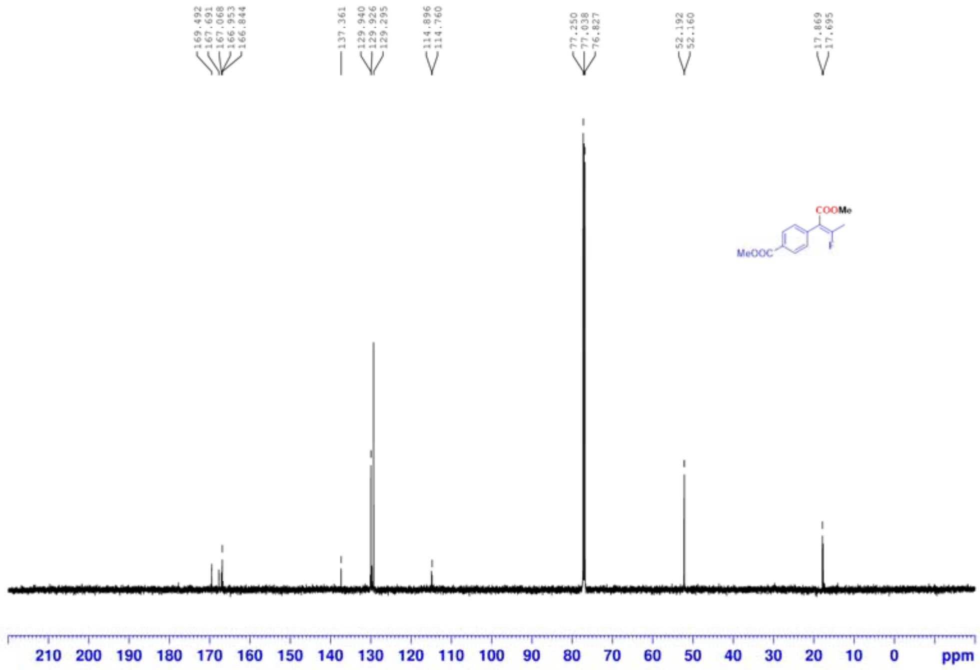
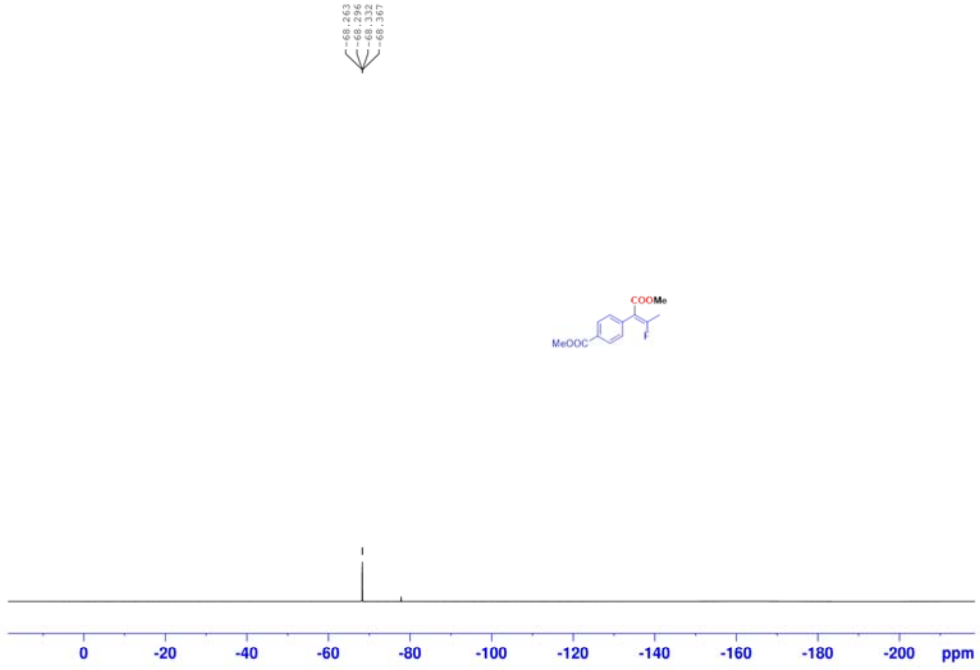
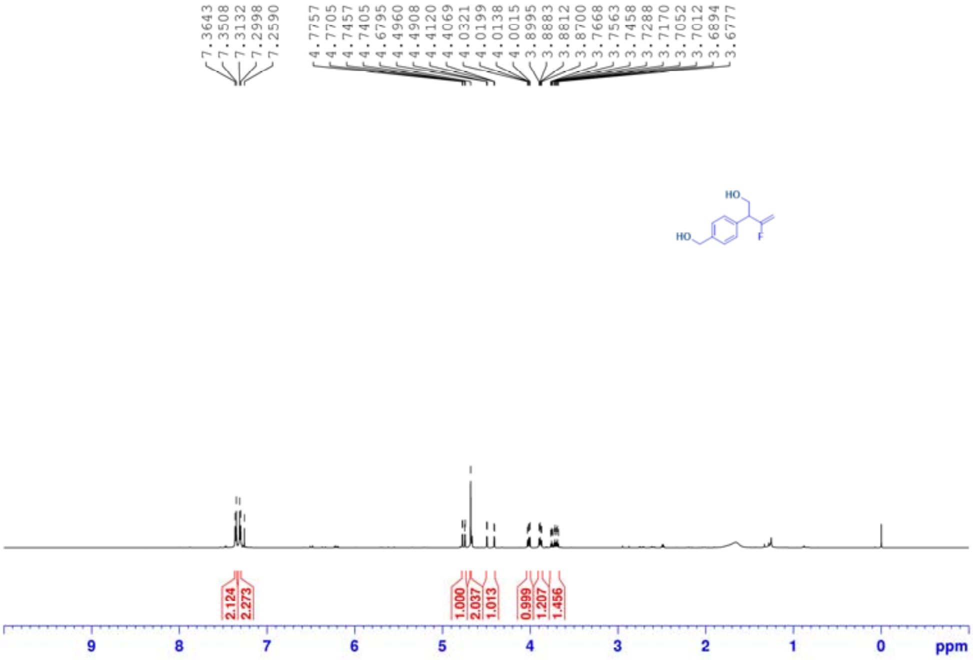
30
20
10
0
ppm

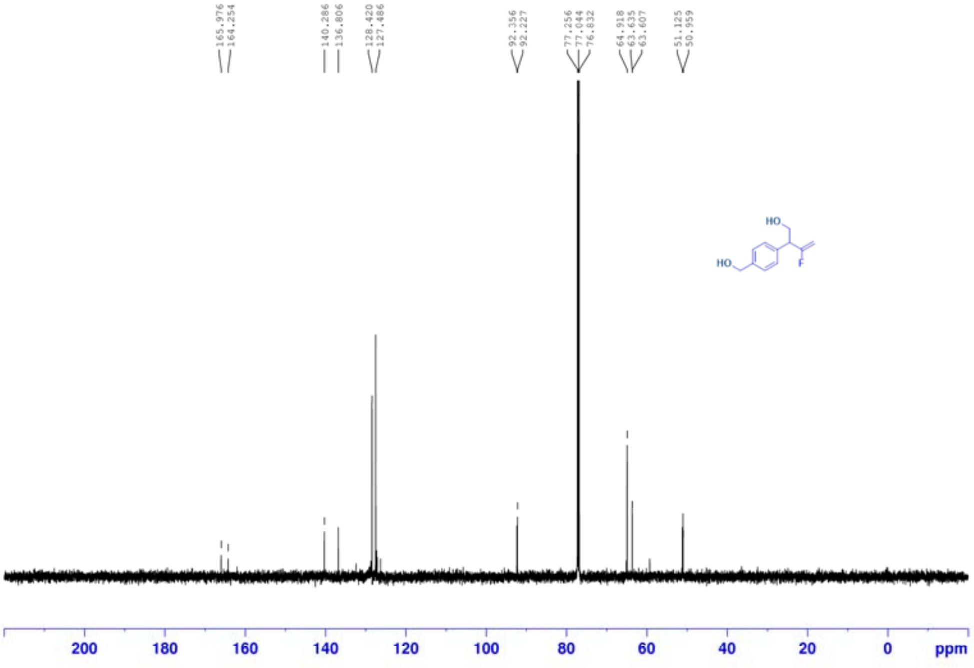

-97.179
-97.212
-97.246
-97.280
-97.312
O
O
F
COOMe
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm

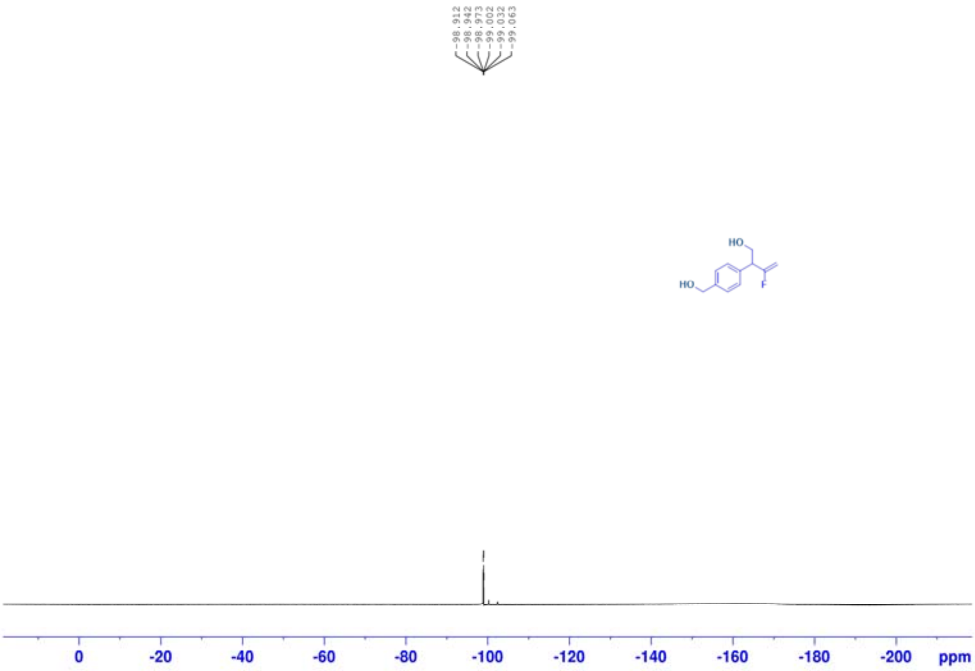

8.023
8.009
7.305
7.291
7.259
3.904
3.706
2.492
2.459
COOMe
MeOOC
F
2.18
2.20
3.21
2.87
3.00
9
8
7
6
5
4
3
2
1
0
ppm

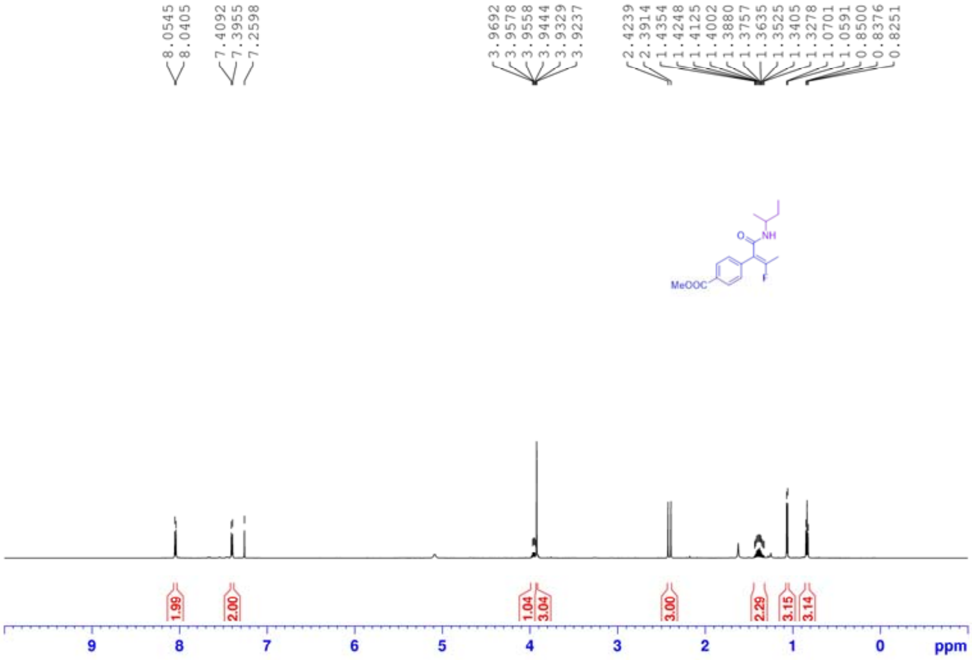

169.492
167.691
167.068
166.953
166.844
137.361
129.940
129.926
129.295
114.896
114.760
77.250
77.038
76.827
52.192
52.160
17.869
17.695
COOMe
MeOOC
F
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

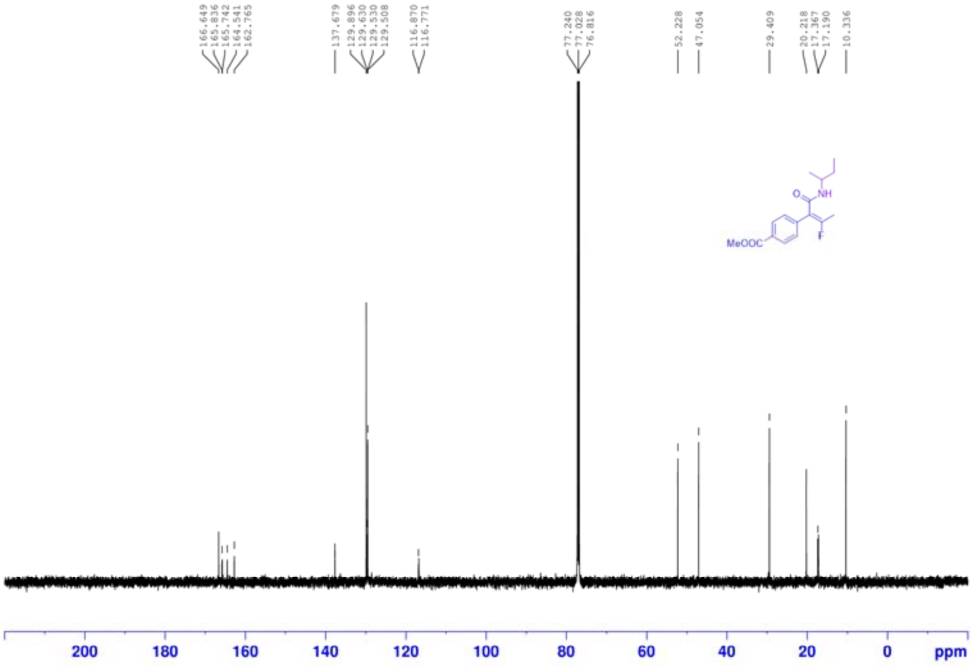

-68.263
-68.296
-68.332
-68.367
COOMe
MeOOC
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm

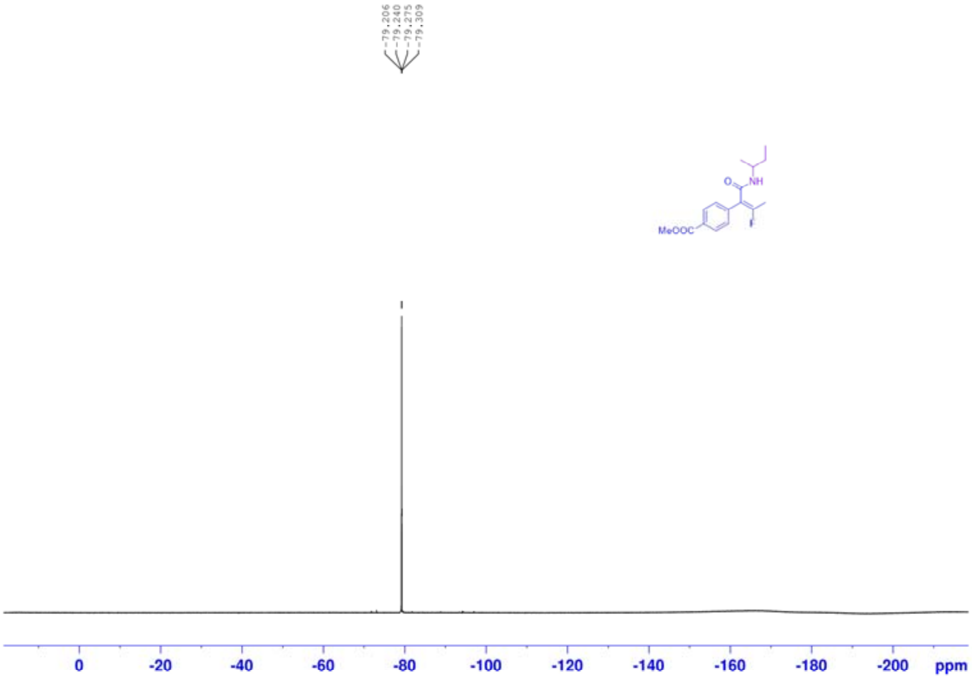

7.3643
7.3508
7.3132
7.2998
7.2590
4.7757
4.7705
4.7457
4.7405
4.6795
4.4960
4.4908
4.4120
4.4069
4.0321
4.0199
4.0138
4.0015
3.8995
3.8883
3.8812
3.8700
3.7668
3.7563
3.7458
3.7288
3.7170
3.7052
3.7012
3.6894
3.6777
HO
HO
F
2.124
2.273
1.000
2.037
1.013
0.999
1.207
1.456
9
8
7
6
5
4
3
2
1
0
ppm


165.976
164.254
140.286
136.806
128.420
127.486
92.356
92.227
77.256
77.044
76.832
64.918
63.635
63.607
51.125
50.959
HO
HO
F
200
180
160
140
120
100
80
60
40
20
0
ppm

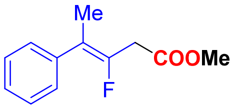

-98.912
-98.942
-98.973
-99.002
-99.032
-99.063
HO
HO
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm


8.0545
8.0405
7.4092
7.3955
7.2598
3.9692
3.9578
3.9558
3.9444
3.9329
3.9237
2.4239
2.3914
1.4354
1.4248
1.4125
1.4002
1.3880
1.3757
1.3635
1.3525
1.3405
1.3278
1.0701
1.0591
0.8500
0.8376
0.8251
O
NH
MeOOC
F
1.99
2.00
1.04
3.04
3.00
2.29
3.15
3.14
9
8
7
6
5
4
3
2
1
0
ppm

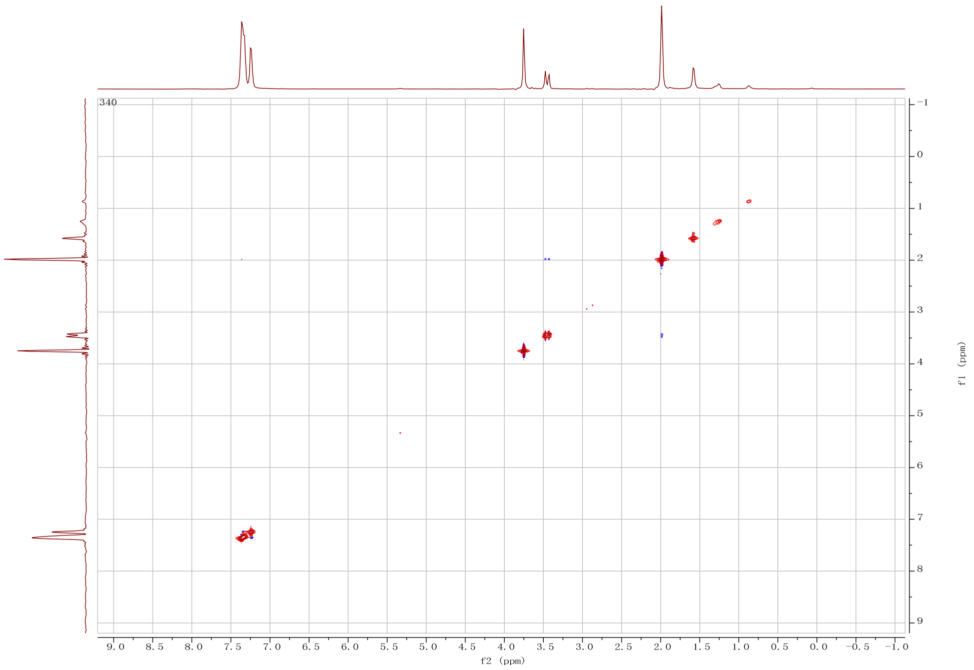

166.649
165.836
165.742
164.541
162.765
137.679
129.896
129.630
129.530
129.508
116.870
116.771
77.240
77.028
76.816
52.228
47.054
29.409
20.218
17.367
17.190
10.336
O
NH
MeOOC
F
200
180
160
140
120
100
80
60
40
20
0
ppm

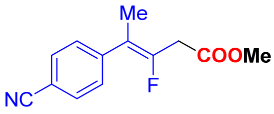

-79.206
-79.240
-79.275
-79.309
O
NH
MeOOC
F
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm

11. 2D 1H-1H NOESY experiment

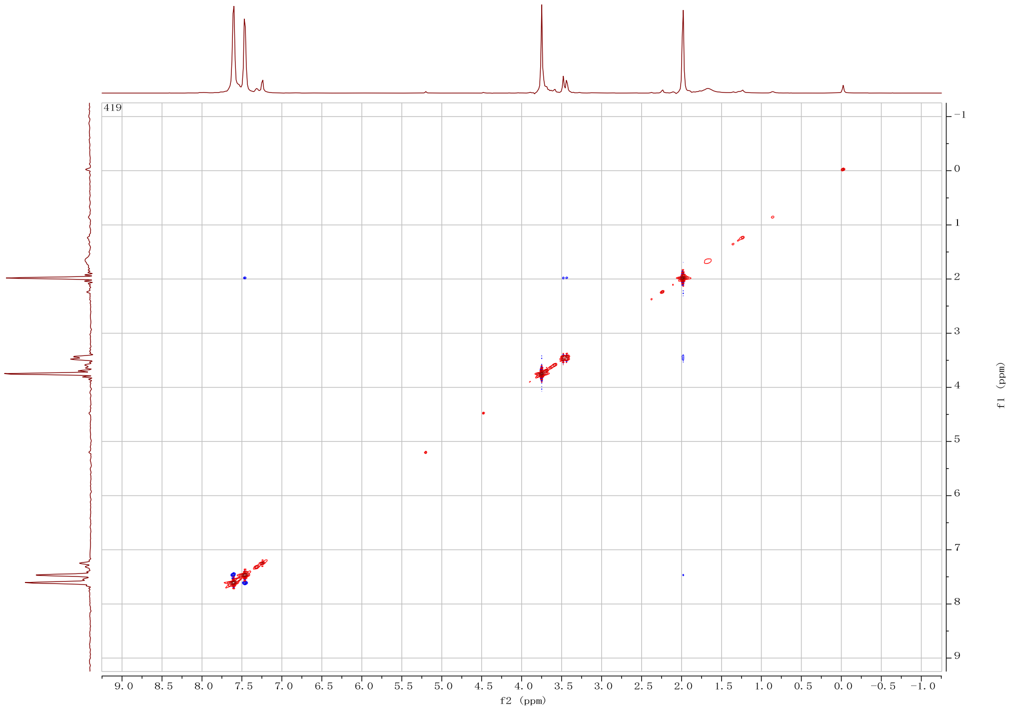


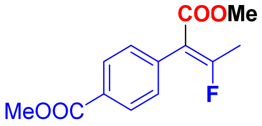
Methyl (Z)-3-fluoro-4-phenylpent-3-enoate (3ad).



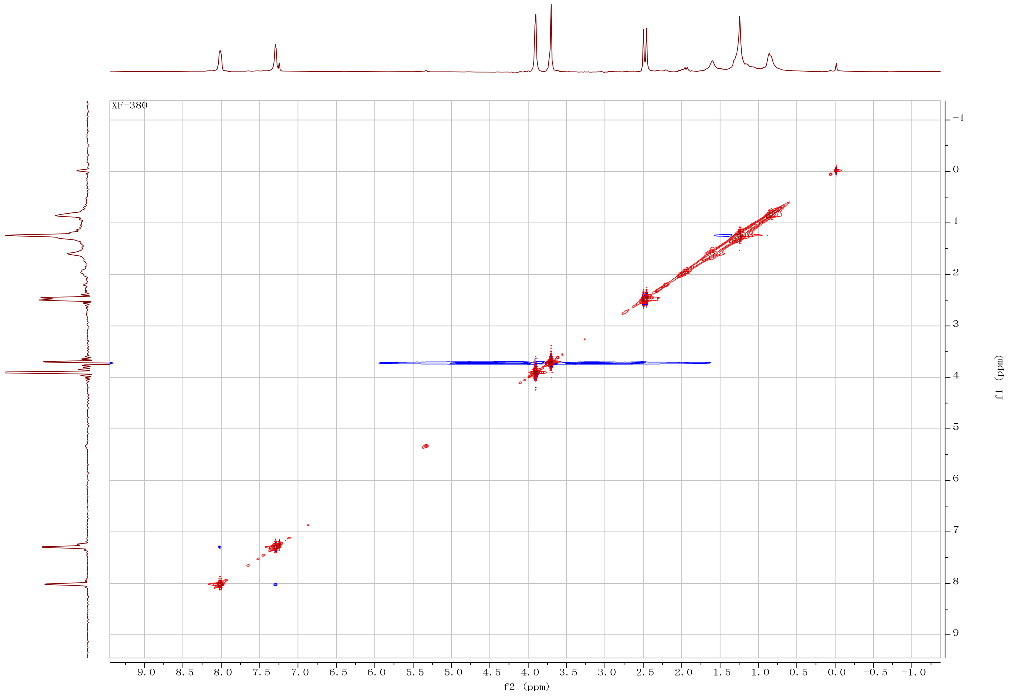


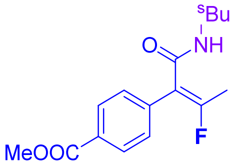
Methyl (Z)-4-(4-cyanophenyl)-3-fluoropent-3-enoate (3m).





Methyl (E)-4-(3-fluoro-1-methoxy-1-oxobut-2-en-2-yl)benzoate (4).





Methyl (E)-4-(1-(sec-butylamino)-3-fluoro-1-oxobut-2-en-2-yl)benzoate (5).