Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

Supporting Information

A photocatalytic decarboxylative/defluorinative [4+3] annulation of *o*-hydroxyphenylacetic acids and trifluoromethyl alkenes: synthesis of fluorinated dihydrobenzoxepines

*Haoguo Chen, Yuwei He and Lei Zhou**

School of Chemistry and Chemical Engineering, Sun Yat-Sen University, 135 Xingang West Road, Guangzhou 510275, China

E-mail: zhoul39@mail.sysu.edu.cn

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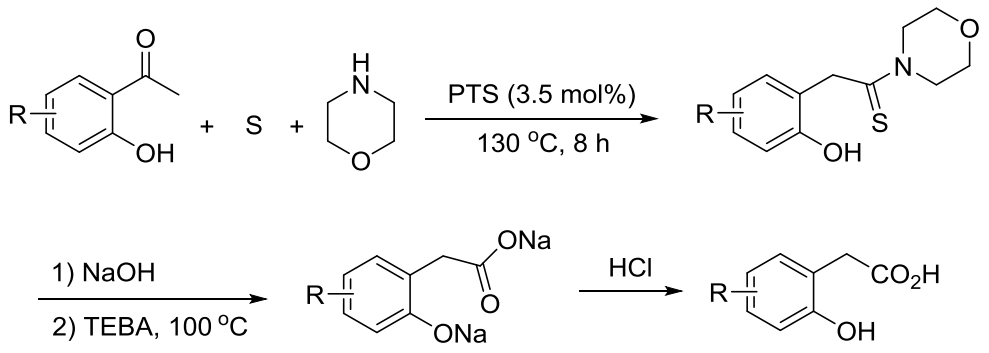
General

Unless otherwise noted, all reactions were performed in a 10 mL test tube at room temperature. Photo-irradiation was carried out with a 5 W blue LED. For chromatography, 200-300 mesh silica gel (Qingdao, China) was employed. ^{1}H NMR and ^{13}C NMR spectra were measured in $CDCl_3$ and recorded on Brucker ARX 400 spectrometer. Chemical shifts (δ) were given in ppm, referenced to the residual proton resonance of $CDCl_3$ (7.26), to the carbon resonance of $CDCl_3$ (77.16). Coupling constants (J) were given in Hertz (Hz). The term m, q, t, d, s referred to multiplet, quartet, triplet, doublet, singlet. Exact masses (HRMS) were recorded on a highresolution magnetic mass spectrometer using electron impact ionization techniques or an ESI-Q-TQF mass spectrometer. α-CF_3 alkenes were prepared according to previous reported procedures.[1] Materials obtained from commercial suppliers were used without further purification.

Synthesis of o-hydroxyphenylacetic acids 1b-k.

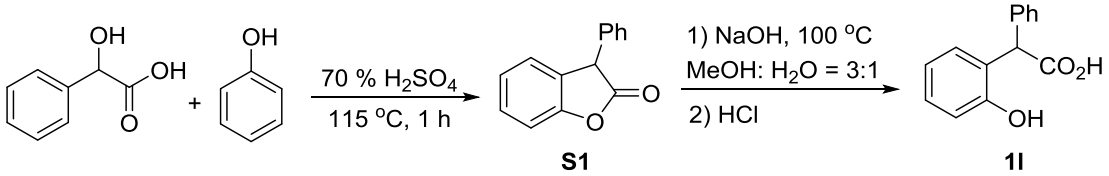
o-Hydroxyphenylacetic acids **1b-k** were prepared *via* Willgerodt-Kindler reaction according to Adapa's procedure with slight modification.[2]



To a 100 mL round flask was added 2-hydroxyacetophenone (2.72 g, 20 mmol), sulfur (1.28 g, 40 mmol), morpholine (6 mL, 60 mmol) and *p*-toluene sulphonic acid (0.12 g, 0.7 mmol). Then the solution was heated under constant stirring in an oil bath at 130 ^{o}C for 8 h. After completion of the reaction as monitored by TLC, the reaction mixture was allowed to cool and 20% NaOH and triethyl benzyl ammonium chloride

(TEBA) (114 mg, 0.05 mmol) were added. The reaction mixture continued hydrolysis at 100 ^{o}C for additional 8 h. After cooling to the room temperature, the precipitate was filtered off. To obtain the pure product, additional filter was performed after the filtrate was acidified with HCl to pH 6. Then, the aqueous filtrate was poured into 20% NaOH solution and washed with ethyl acetate (3x30 mL). Remove the organic layer, and the aqueous layer was acidified with HCl to pH 2. Extract the desired product by washing with ethyl acetate (3x30 mL). The organic layer was washed with brine, dried over anhydrous Na_2SO_4 and evaporated under reduced pressure. Pure *o*-hydroxyphenylacetic acids were obtained in almost quantitative yields, which could be used directly for the next step of reaction.

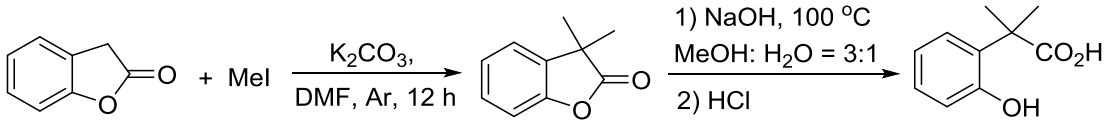
Synthesis of α-phenyl o-hydroxyphenylacetic acids 1l.[3]



To a solution of DL-mandelic acid (20 mmol, 1.0 equiv) in 70 % H_2SO_4 (7.8 mL, 2.6 M), was added phenol (27 mmol, 1.4 equiv) slowly at 0 ^{o}C. The reaction mixture was allowed to stir at 115 ^{o}C. After 1 h, the reaction was quenched by cool water, followed by the addion of sat. $NaHCO_3$ and extraction with EtOAc (3x30 mL). The organic layer was dried over Na_2SO_4 and evaporated under reduced pressure. The residue was purified by column chromatography (R_f = 0.2, petroleum ether/EtOAc = 50:1) to give **S1** as a white solid (1.176 g, 28% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.43 – 7.29 (m, 4H), 7.28 – 7.15 (m, 5H), 4.90 (s, 1H).

1.176 gram of **S1** (5.6 mmol) was dissolved in 30 mL solvent (MeOH : H_2O = 3 : 1), and then 2.0 equiv NaOH (11.2 mmol, 0.448 g) was added. The reaction mixture was stirred at 100 ^{o}C until the reaction completion. Acidified of cool reaction mixture with HCl to PH = 2, and extracted with ethyl acetate (3x30 mL). The organic layer was washed with brine, dried over anhydrous Na_2SO_4 and evaporated under reduced pressure to give pure **1l** as a yellow solid (1.12 g, 88% yield).

Synthesis of α,α-dimethyl o-hydroxyphenylacetic acids 1m.[4]



S2 **1m**

In a dry round flask, 2-coumaranone (4.87 g, 36.3 mmol) and dry K_2CO_3 (242 mmol, 6.7 equiv) were dissolved in dry DMF under argon atmosphere. 8.34 mL MeI (134 mmol, 3.7 equiv) were added at 0 °C. The reaction mixture was allowed to stir at room temperature for 12 h. After completion of the reaction, the mixture was filtered and 2 M HCl was added to the filtrate. The aqueous phase was extracted two times with ethyl acetate. The combined organic phases were died over Na_2SO_4 and the solvent was removed. Purification by column-chromatography (R_f = 0.18, petroleum ether/EtOAc = 40:1) to give **S2** as a yellow oil (3.82 g, 65% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.30 – 7.27 (m, 1H), 7.22 – 7.20 (m, 1H), 7.17 – 7.15 (m, 1H), 7.13 – 7.10 (m, 1H), 1.50 (s, 6H).

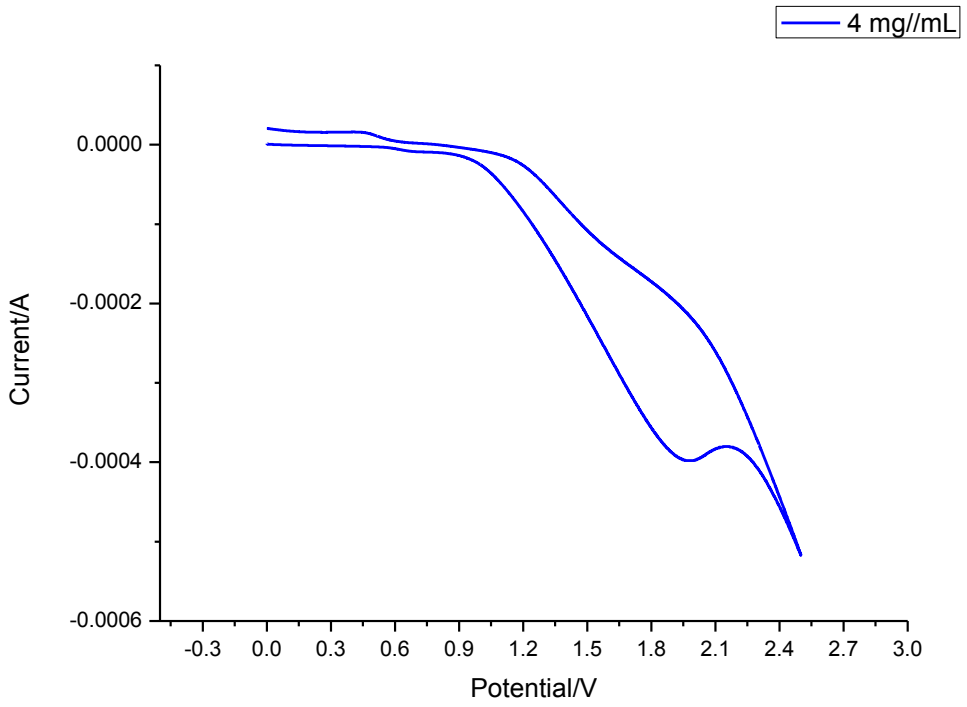
The hydrolysis of **S2** was performed in 5 mmol scale using the same method as described above, which gave 1m as a yellow soild in 80% yield (0.72 g).

Typical procedure for the synthesis of fluorinated dihydrobenzoxepine 3a

To a 10 mL test tube equipped with a magnetic stir bar was charged with *o*-hydroxyphenylacetic acid **1a** (0.39 mmol, 45.6 mg), α-trifluoromethyl styrene **2a** (0.3 mmol, 51.6 mg), 4DPAIPN (5 mol %, 10 mg), $CsCO_3$ (1.5 mmol, 488.7 mg) and 3 mL of solvent (DMSO/H_2O = 20 : 1). The solution was stirred at room temperature with the irradiation of a 5 W blue LED under argon. Upon completion of the reaction, the reaction was quenched by adding excess amount of H_2O, followed by extraction with ethyl acetate. The organic phase was washed with brine, and then dried over anhydrous Na_2SO_4. After the solution was filtered and the solvent was evaporated

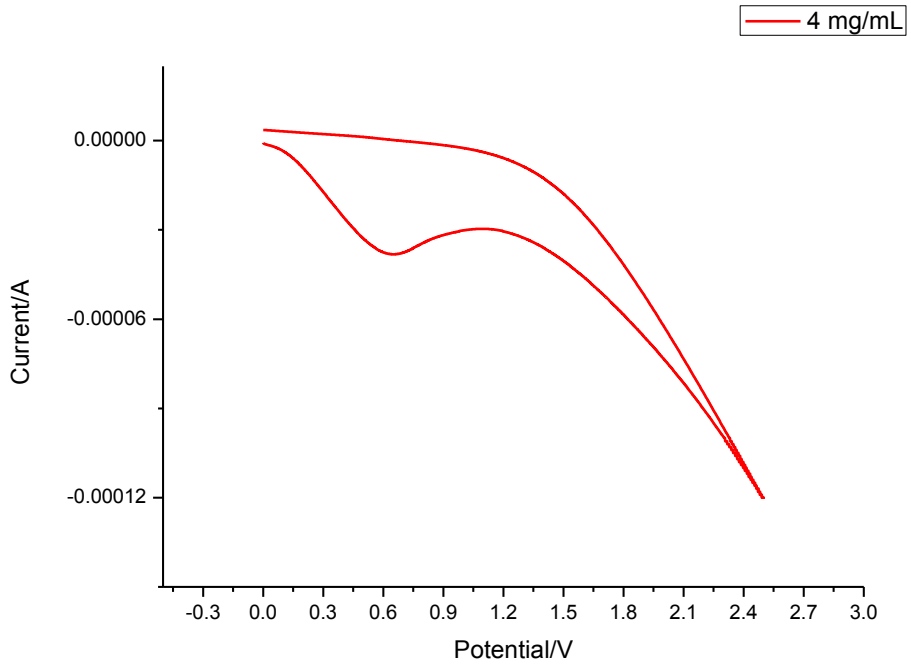
under vacuum, the crude product was purified by flash column chromatography on silica gel with hexane as the eluent, giving the product **3a** as colorless oil (62.9 mg, 87% yield).

Figure S1. Cyclic Voltammograms of 1a



Cyclic voltammogram was recorded on a CHI750E Electrochemical Analyzer using a three-electrode cell at room temperature. The reference electrode was the saturated Ag/AgCl. A glassy carbon electrode was used as the working electrode and a platinum wire as the auxiliary electrode. Tetrabutylammonium hexafluorophosphate (0.1 mmol in DMF) was used as the supporting electrolyte. Voltammogram was taken in a solution of *o*-hydroxyphenylacetic acid **1a** in DMF (4 mg/mL), which was purged with Ar. The peak potential for the irreversible oxidation of **1a** was measured as 1.964 V vs. Ag/AgCl. The potentials measured were then referred to SCE (E = +1.92 V) by applying the equation: E(vs SCE) = E(vs Ag/AgCl; sat's KCl) − 45 mV.

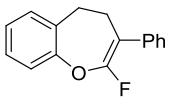
Figure S2. Cyclic Voltammograms of 1a⁻



Cyclic voltammograms were taken using the same method as described in Figure S1. Before the voltammograms were recored, the DMF solution of *o*-hydroxyphenylacetic acid **1a** (4 mg/mL) and ^{t}BuOLi was stirred for 5 min and then purged with Ar. Only one wave of **1a**$^{-}$ was observed, which was measured as 0.6570 V vs. Ag/AgCl (0.612 V vs. SCE).

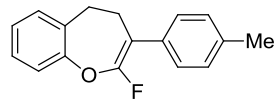
Compound characterization data:

2-fluoro-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3a)



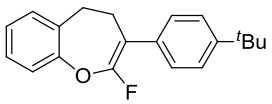
Colorless oil (62.64 mg, 87% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.37 – 7.31 (m, 4H), 7.28 – 7.23 (m, 3H), 7.20 – 7.15 (m, 2H), 3.15 – 3.12 (m, 2H), 2.74 – 2.69 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.67 (s). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1, 154.1 (d, $^{1}J_{CF}$ = 263.4 Hz), 137.6 (d, $^{3}J_{CF}$ = 2.2 Hz), 133.3 (d, $^{4}J_{CF}$ = 3.1 Hz), 129.8, 128.4 (d, $^{4}J_{CF}$ = 3.4 Hz), 128.3, 127.6, 126.9, 125.7, 120.1, 95.6 (d, $^{2}J_{CF}$ = 25.0 Hz), 31.0 (d, $^{3}J_{CF}$ = 1.9 Hz), 29.9. **HRMS (EI)** calcd for $C_{16}H_{13}FO$ $[M+H]^{+}$ 241.1023, found 241.1021.

2-fluoro-3-(p-tolyl)-4,5-dihydrobenzo[*b*]oxepine (3b)



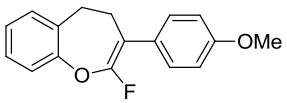
Colorless oil (67.06 mg, 88% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.26 – 7.19 (m, 4H), 7.18 – 7.13 (m, 4H), 3.13 – 3.10 (m, 2H), 2.70 – 2.66 (m, 2H), 2.34 (s, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -81.06. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.2, 154.0 (d, $^{1}J_{CF}$ = 263.0 Hz), 136.6, 134.6 (d, $^{3}J_{CF}$ = 2.0 Hz), 133.4 (d, $^{4}J_{CF}$ = 3.1 Hz), 129.8, 129.1, 128.2 (d, $^{4}J_{CF}$ = 3.1 Hz), 127.6, 125.6, 120.1, 95.5 (d, $^{2}J_{CF}$ = 25.1 Hz), 31.1 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.9, 21.2. **HRMS (EI)** calcd for $C_{17}H_{15}FO$ $[M+Na]^+$ 277.0999, found 277.0993.

3-(4-(tert-butyl)phenyl)-2-fluoro-4,5-dihydrobenzo[*b*]oxepine (3c)



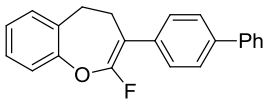
Colorless oil (75.48 mg, 85% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.37 – 7.35 (m, 2H), 7.26 – 7.21 (m, 4H), 7.19 – 7.16 (m, 2H), 3.14 – 3.11 (m, 2H), 2.73 – 2.69 (m, 2H), 1.34 (s, 9H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.99. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1, 154.1 (d, $^{1}J_{CF}$ = 263.6 Hz), 149.7, 134.5 (d, $^{3}J_{CF}$ = 2.3 Hz), 133.3 (d, $^{4}J_{CF}$ = 3.0 Hz), 129.8, 127.9 (d, $^{4}J_{CF}$ = 3.3 Hz), 127.6, 125.6, 125.2, 120.1, 95.5 (d, $^{2}J_{CF}$ = 24.8 Hz), 34.6, 31.5, 30.9 (d, $^{3}J_{CF}$ = 2.1 Hz), 29.9. **HRMS (EI)** calcd for $C_{20}H_{21}FO$ $[M+Na]^+$ 319.1469, found 319.1473.

2-fluoro-3-(4-methoxyphenyl)-4,5-dihydrobenzo[*b*]oxepine (3d)



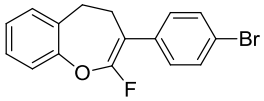
Colorless oil (65.61 mg, 81% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.26 – 7.21 (m, 4H), 7.19 – 7.14 (m, 2H), 6.89 – 6.87 (m, 2H), 3.81 (s, 3H), 3.13 – 3.10 (m, 2H), 2.70 – 2.65 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -81.44. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.4, 156.2, 154.0 (d, $^{1}J_{CF}$ = 262.8 Hz), 133.4 (d, $^{4}J_{CF}$ = 3.1 Hz), 129.8 (d, $^{3}J_{CF}$ = 2.1 Hz), 129.7, 129.4 (d, $^{4}J_{CF}$ = 3.3 Hz), 127.6, 125.6, 120.1, 113.8, 95.1 (d, $^{2}J_{CF}$ = 25.0 Hz), 55.3, 31.1 (d, $^{3}J_{CF}$ = 1.9 Hz), 29.9. **HRMS (ESI)** calcd for $C_{17}H_{15}FO_2$ $[M+H]^+$ 271.11288, found 271.1128.

3-([1,1'-biphenyl]-4-yl)-2-fluoro-4,5-dihydrobenzo[*b*]oxepine (3e)



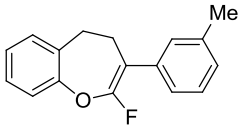
White solid (81.53 mg, 86% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.62 – 7.57 (m, 4H), 7.47 – 7.35 (m, 5H), 7.26 – 7.18 (m, 4H), 3.17 – 3.14 (m, 2H), 2.77 – 2.73 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.13. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1, 154.3 (d, $^{1}J_{CF}$ = 263.9 Hz), 140.9, 139.7, 136.5 (d, $^{3}J_{CF}$ = 2.3 Hz), 133.3 (d, $^{4}J_{CF}$ = 3.0 Hz), 129.8, 128.9, 128.7 (d, $^{4}J_{CF}$ = 3.4 Hz), 127.7, 127.4, 127.1, 127.0, 125.7, 120.1, 95.3 (d, $^{2}J_{CF}$ = 24.6 Hz), 30.9 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.9. **HRMS (EI)** calcd for $C_{22}H_{17}FO$ $[M+Na]^+$ 339.1156, found 339.1151.

3-(4-bromophenyl)-2-fluoro-4,5-dihydrobenzo[*b*]oxepine (3f)



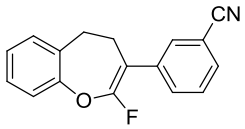
Colorless oil (80.14 mg, 84% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.45 – 7.43 (m, 2H), 7.27 – 7.20 (m, 2H), 7.18 – 7.14 (m, 4H), 3.12 – 3.09 (m, 2H), 2.68 – 2.63 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -79.60. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.0, 154.2 (d, $^{1}J_{CF}$ = 263.9 Hz), 136.5 (d, $^{3}J_{CF}$ = 2.3 Hz), 133.2 (d, $^{4}J_{CF}$ = 3.0 Hz), 131.5, 130.1 (d, $^{4}J_{CF}$ = 3.5 Hz), 129.8, 127.7, 125.8, 120.7, 120.1, 94.6 (d, $^{2}J_{CF}$ = 24.8 Hz), 30.9 (d, $^{3}J_{CF}$ = 1.7 Hz), 29.8. **HRMS (EI)** calcd for $C_{16}H_{12}BrFO$ $[M+H]^+$ 319.0128, found 319.0126.

2-fluoro-3-(m-tolyl)-4,5-dihydrobenzo[*b*]oxepine (3g)



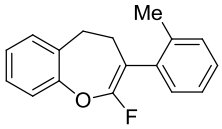
Colorless oil (67.82 mg, 89% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.26 – 7.21 (m, 3H), 7.19 – 7.16 (m, 2H), 7.13 – 7.10 (m, 2H), 7.08 – 7.06 (m, 1H), 3.14 – 3.11 (m, 2H), 2.72 – 2.67 (m, 2H), 2.36 (s, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.75. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.2, 154.0 (d, $^{1}J_{CF}$ = 263.2 Hz), 137.9, 137.5 (d, $^{3}J_{CF}$ = 1.9 Hz), 133.4 (d, $^{4}J_{CF}$ = 3.0 Hz), 129.8, 129.1 (d, $^{4}J_{CF}$ = 3.0 Hz), 128.2, 127.7, 127.6, 125.6, 125.5 (d, $^{4}J_{CF}$ = 3.1 Hz), 120.1, 95.7 (d, $^{2}J_{CF}$ = 25.1 Hz), 31.1 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.9, 21.6. **HRMS (EI)** calcd for $C_{17}H_{15}FO$ $[M+Na]^+$ 277.0999, found 277.0991.

3-(2-fluoro-4,5-dihydrobenzo[*b*]oxepin-3-yl)benzonitrile (3h)



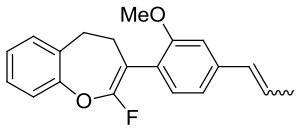
Colorless oil (62.01 mg, 78% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.58 (s, 1H), 7.55 – 7.49 (m, 2H), 7.43 – 7.40 (m, 1H), 7.25 – 7.15 (m, 4H), 3.14 – 3.11 (m, 2H), 2.69 – 2.65 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -78.41. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.0, 154.6 (d, $^{1}J_{CF}$ = 253.2 Hz), 139.0 (d, $^{3}J_{CF}$ = 2.3 Hz), 133.0, 132.9 (d, $^{4}J_{CF}$ = 3.9 Hz), 132.0 (d, $^{4}J_{CF}$ = 3.6 Hz), 130.4, 129.8, 129.2, 127.9, 126.0, 120.1, 118.9, 112.6, 93.8 (d, $^{2}J_{CF}$ = 24.5 Hz), 30.8 (d, $^{3}J_{CF}$ = 1.5 Hz), 29.7. **HRMS (ESI)** calcd for $C_{17}H_{12}FNO$ $[M+H]^+$ 266.09757, found 266.09744.

2-fluoro-3-(o-tolyl)-4,5-dihydrobenzo[*b*]oxepine (3i)



Colorless oil (70.10 mg, 92% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.28 – 7.24 (m, 2H), 7.21 – 7.18 (m, 3H), 7.17 – 7.14 (m, 2H), 7.12 – 7.09 (m, 1H), 3.14 – 3.11 (m, 2H), 2.54 – 2.49 (m, 2H), 2.25 (s, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -79.17. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.4, 153.1 (d, $^{1}J_{CF}$ = 257.3 Hz), 136.9, 136.4, 133.6 (d, $^{4}J_{CF}$ = 2.9 Hz), 130.2, 129.7, 129.3, 127.7, 127.5, 126.0, 125.7, 120.0, 94.2 (d, $^{2}J_{CF}$ = 29.7 Hz), 32.0 (d, $^{3}J_{CF}$ = 2.1 Hz), 30.1, 19.3. **HRMS (EI)** calcd for $C_{17}H_{15}FO$ $[M+Na]^+$ 277.0999, found 277.0991.

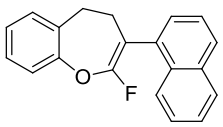
2-fluoro-3-(2-methoxy-4-(prop-1-en-1-yl)phenyl)-4,5-dihydrobenzo[*b*]oxepine (3j)



Yellow oil (79.98 mg, 86% yield). 2:1 mixture of E/Z isomers. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.26 – 7.21 (m, 1H), 7.19 – 7.14 (m, 3H), 7.12 - 7.04 (m, 1H), 6.91 – 6.83 (m, 2H), 6.43– 6.37 (m, 1H), 6.28 – 6.19 (m, 0.66H), 5.84 – 5.76 (m, 0.33H), 3.82 (s, 3H), 3.12 – 3.09 (m, 2H), 2.60 – 2.58 (m, 2H), 1.94 (d, *J* = 7.2 Hz, 1H), 1.89 (d, *J* = 6.5 Hz, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -79.76, -79.77. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.2, 156.9, 156.0, 153.6 (d, $^{1}J_{CF}$ = 258.6 Hz), 153.6 (d, $^{1}J_{CF}$ = 258.6 Hz), 138.7, 138.3, 133.6 (d, $^{4}J_{CF}$ = 2.8 Hz), 131.0, 131.0 (d, $^{3}J_{CF}$ = 2.1 Hz), 130.6 (d, $^{3}J_{CF}$ = 2.0 Hz), 129.9, 127.5, 127.0, 126.0, 125.4, 125.0, 124.6, 121.2, 120.1, 118.3, 111.9, 108.6, 92.7 (d, $^{2}J_{CF}$ = 27.5 Hz), 92.7 (d, $^{2}J_{CF}$ = 27.5 Hz), 55.6, 30.5 (d, $^{3}J_{CF}$ = 1.2 Hz), 18.6,

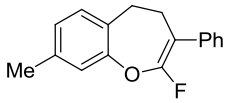
14.9. **HRMS (ESI)** calcd for $C_{20}H_{19}FO_2$ $[M+H]^+$ 311.14418, found 311.14417.

2-fluoro-3-(naphthalen-1-yl)-4,5-dihydrobenzo[*b*]oxepine (3k)



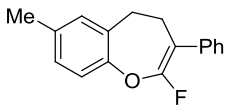
Colorless oil (76.56 mg, 88% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.89 – 7.86 (m, 2H), 7.81 (d, *J* = 8.2 Hz, 1H), 7.51 – 7.43 (m, 3H), 7.34 – 7.21 (m, 5H), 3.31 – 3.12 (m, 2H), 2.73 – 2.62 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -77.34. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.3, 153.8 (d, $^1J_{CF}$ = 258.0 Hz), 135.3, 134.0, 133.6 (d, $^4J_{CF}$ = 2.9 Hz), 131.4, 129.9, 128.6, 127.8, 127.8, 126.8, 126.3, 125.9, 125.8, 125.7, 125.0, 120.2, 93.2 (d, $^2J_{CF}$ = 29.4 Hz), 32.6 (d, $^3J_{CF}$ = 1.9 Hz), 30.3. **HRMS (EI)** calcd for $C_{20}H_{15}FO$ $[M+H]^+$ 291.1180, found 291.1185.

2-fluoro-8-methyl-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3l)



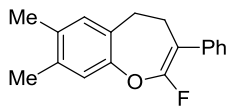
Colorless oil (59.44 mg, 78% yield). **^{1}H NMR** (400 MHz, CDCl3) δ 7.36 – 7.29 (m, 4H), 7.26 – 7.22 (m, 1H), 7.11 (d, J = 7.6 Hz, 1H), 7.09 – 6.97 (m, 2H), 3.10 – 3.07 (m, 2H), 2.71 – 2.66 (m, 2H), 2.37 (s, 3H). **^{19}F NMR** (376 MHz, CDCl3) δ -80.67. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.9, 154.1 (d, $^1J_{CF}$ = 263.2 Hz), 137.8, 137.7 (d, $^3J_{CF}$ = 1.9 Hz), 130.0 (d, $^4J_{CF}$ = 3.0 Hz), 129.5, 128.4 (d, $^4J_{CF}$ = 3.2 Hz), 128.3, 126.8, 126.2, 120.6, 95.6 (d, $^2J_{CF}$ = 25.1 Hz), 31.2 (d, $^3J_{CF}$ = 1.9 Hz), 29.5, 21.0. **HRMS (EI)** calcd for $C_{17}H_{15}FO$ $[M+Na]^+$ 277.0999, found 277.1004.

2-fluoro-7-methyl-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3m)



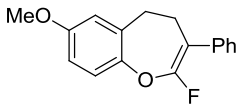
Colorless oil (70.10 mg, 92% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.26 (m, 4H), 7.24 – 7.20 (m, 1H), 7.06 – 7.00 (m, 3H), 3.08 – 3.05 (m, 2H), 2.69 – 2.65 (m, 2H), 2.33 (s, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.72. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.6, 153.5 (d, $^1J_{CF}$ = 262.6 Hz), 137.7 (d, $^3J_{CF}$ = 1.7 Hz), 135.3, 132.9 (d, $^4J_{CF}$ = 3.0 Hz), 130.2, 128.4 (d, $^4J_{CF}$ = 3.2 Hz), 128.3, 128.0, 126.8, 119.8, 95.4 (d, $^2J_{CF}$ = 25.3 Hz), 31.1 (d, $^3J_{CF}$ = 2.3 Hz), 29.9, 20.9. **HRMS (EI)** calcd for $C_{17}H_{15}FO$ $[M+Na]^+$ 277.0999, found 278.1006.

2-fluoro-7,8-dimethyl-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3n)



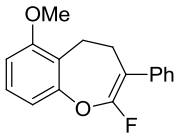
Colorless oil (70.56 mg, 89% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33 – 7.27 (m, 4H), 7.26 – 7.19 (m, 1H), 6.96 (s, 2H), 3.05 – 3.02 (m, 2H), 2.68 – 2.64 (m, 2H), 2.24 (d, *J* = 3.6 Hz, 6H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.76. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.4 (d, $^{1}J_{CF}$ = 262.9 Hz), 153.9, 137.8 (d, $^{3}J_{CF}$ = 2.0 Hz), 135.9, 133.7, 130.7, 130.0 (d, $^{4}J_{CF}$ = 2.9 Hz), 128.4 (d, $^{4}J_{CF}$ = 3.2 Hz), 128.3, 126.8, 121.0, 95.4 (d, $^{2}J_{CF}$ = 25.2 Hz), 31.3 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.5, 19.5, 19.2. **HRMS (EI)** calcd for $C_{18}H_{17}OF$ $[M+H]^+$ 269.1336, found 269.1333.

2-fluoro-7-methoxy-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3o)



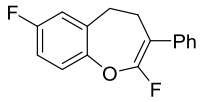
Yellow oil (48.60 mg, 60% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.27 (m, 4H), 7.25 – 7.21 (m, 1H), 7.10 – 7.08 (m, 1H), 6.75 – 6.69 (m, 2H), 3.80 (s, 3H), 3.06 – 3.03 (m, 2H), 2.68 – 2.64 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.92. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.1, 156.5, 154.0 (d, $^{1}J_{CF}$ = 263.2 Hz), 137.6 (d, $^{3}J_{CF}$ = 2.1 Hz), 130.2, 128.4 (d, $^{4}J_{CF}$ = 3.1 Hz), 128.3, 126.9, 125.0 (d, $^{4}J_{CF}$ = 2.8 Hz), 111.6, 105.8, 95.9 (d, $^{2}J_{CF}$ = 24.8 Hz), 55.7, 31.3 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.2. **HRMS (ESI)** calcd for $C_{17}H_{15}FO_2$ $[M+H]^+$ 271.1128, found 271.11300.

2-fluoro-6-methoxy-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3p)



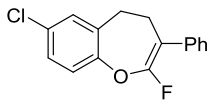
Yellow oil (75.33 mg, 93% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 4.7 Hz, 4H), 7.27 – 7.23 (m, 1H), 7.20 – 7.16 (m, 1H), 6.84 (d, *J* = 8.2 Hz, 1H), 6.75 (d, *J* = 8.1 Hz, 1H), 3.86 (s, 3H), 3.17 – 3.14 (m, 2H), 2.73 – 2.68 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -81.08. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.8, 157.1, 154.4 (d, $^{1}J_{CF}$ = 267.9 Hz), 137.3 (d, $^{3}J_{CF}$ = 2.8 Hz), 128.3, 128.2 (d, $^{4}J_{CF}$ = 3.5 Hz), 127.1, 126.8, 121.7 (d, $^{4}J_{CF}$ = 3.4 Hz), 112.7, 107.5, 96.9 (d, $^{2}J_{CF}$ = 23.7 Hz), 56.0, 29.7 (d, $^{3}J_{CF}$ = 1.9 Hz), 21.6. **HRMS (ESI)** calcd for $C_{17}H_{15}FO_2$ $[M+H]^+$ 271.11300, found 271.11288.

2,7-difluoro-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3q)



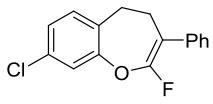
Colorless oil (47.21 mg, 61% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.38 – 7.31 (m, 4H), 7.29 – 7.25 (m, 1H), 7.18 – 7.12 (m, 1H), 6.96 – 6.91 (m, 2H), 3.13 – 3.10 (m, 2H), 2.74 – 2.69 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.87, -117.35. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.8 (d, $^{1}J_{CF}$ = 244.0 Hz), 154.2 (d, $^{1}J_{CF}$ = 264.9 Hz), 152.2 (d, $^{4}J_{CF}$ = 2.6 Hz), 137.2 (d, $^{3}J_{CF}$ = 2.2 Hz), 135.2 (dd, *J* = 8.0, 3.2 Hz), 128.4, 128.3 (d, $^{4}J_{CF}$ = 3.2 Hz), 127.0, 121.3 (d, $^{3}J_{CF}$ = 8.8 Hz), 116.1 (d, $^{2}J_{CF}$ = 23.3 Hz), 113.9 (d, $^{2}J_{CF}$ = 23.3 Hz), 95.7 (d, $^{2}J_{CF}$ = 25.0 Hz), 30.7 (d, $^{3}J_{CF}$ = 1.8 Hz), 29.8. **HRMS (EI)** calcd for $C_{16}H_{12}F_2O$ $[M+Na]^+$ 281.0748, found 281.0752.

7-chloro-2-fluoro-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3r)



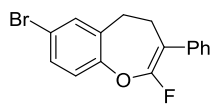
Colorless oil (71.51 mg, 87% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.36 – 7.30 (m, 2H), 7.29 – 7.24 (m, 3H), 7.21 – 7.19 (m, 2H), 7.12 – 7.09 (m, 1H), 3.10 – 3.07 (m, 2H), 2.71 – 2.67 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -81.00. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.6, 153.9 (d, $^{1}J_{CF}$ = 264.7 Hz), 137.2 (d, $^{3}J_{CF}$ = 2.2 Hz), 135.0 (d, $^{4}J_{CF}$ = 3.1 Hz), 130.6, 129.6, 128.4, 128.3 (d, $^{4}J_{CF}$ = 3.2 Hz), 127.5, 127.1, 121.5, 95.9 (d, $^{2}J_{CF}$ = 24.8 Hz), 30.6 (d, $^{3}J_{CF}$ = 1.7 Hz), 29.7. **HRMS (EI)** calcd for $C_{16}H_{12}ClFO$ $[M+H]^+$ 275.0633, found 275.0636.

8-chloro-2-fluoro-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3s)



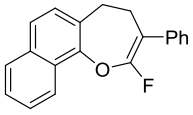
Colorless oil (63.29 mg, 77% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33 – 7.26 (m, 4H), 7.25 – 7.22 (m, 1H), 7.19 (s, 1H), 7.13 (d, *J* = 1.2 Hz, 2H), 3.09 – 3.06 (m, 2H), 2.69 – 2.65 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -81.19. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.3, 153.5 (d, $^{1}J_{CF}$ = 262.9 Hz), 135.9 (d, $^{3}J_{CF}$ = 2.3 Hz), 132.5 (d, $^{4}J_{CF}$ = 3.0 Hz), 130.8, 129.4 (d, $^{4}J_{CF}$ = 3.5 Hz), 129.1, 127.1, 125.1, 120.0, 119.4, 93.9 (d, $^{2}J_{CF}$ = 24.8 Hz), 30.2 (d, $^{3}J_{CF}$ = 1.7 Hz), 29.1. **HRMS (EI)** calcd for $C_{16}H_{12}ClFO$ $[M+H]^+$ 275.0633, found 275.0634.

7-bromo-2-fluoro-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3t)



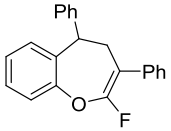
Colorless oil (77.27 mg, 81% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 – 7.29 (m, 4H), 7.27 – 7.21 (m, 3H), 7.19 – 7.16 (m, 1H), 3.14 – 3.11 (m, 2H), 2.72 – 2.68 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.71. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1, 154.1 (d, $^{1}J_{CF}$ = 263.5 Hz), 137.6 (d, $^{3}J_{CF}$ = 2.1 Hz), 133.3 (d, $^{4}J_{CF}$ = 3.0 Hz), 129.8, 128.4 (d, $^{4}J_{CF}$ = 3.4 Hz), 128.3, 127.6, 126.9, 125.7, 120.1, 95.6 (d, $^{2}J_{CF}$ = 25.0 Hz), 31.0 (d, $^{3}J_{CF}$ = 2.0 Hz), 29.9. **HRMS (EI)** calcd for $C_{16}H_{12}BrFO$ $[M+H]^+$ 319.0128, found 319.0122.

2-fluoro-3-phenyl-4,5-dihydronaphtho[*1,2-b*]oxepine (3u)



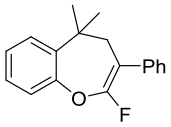
Colorless oil (65.25 mg, 75% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.30 – 8.28 (m, 1H), 7.86 – 7.84 (m, 1H), 7.66 (d, *J* = 8.3 Hz, 1H), 7.57 – 7.54 (m, 1H), 7.52 – 7.50 (m, 1H), 7.33 – 7.26 (m, 5H), 7.24 – 7.23 (m, 1H), 3.29 – 3.26 (m, 2H), 2.81 – 2.76 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -80.94. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.5 (d, $^{1}J_{CF}$ = 266.4 Hz), 151.3, 137.4 (d, $^{3}J_{CF}$ = 2.3 Hz), 133.4, 128.5 (d, $^{4}J_{CF}$ = 3.3 Hz), 128.4, 128.3, 127.6, 127.5, 126.9, 126.8, 126.5, 126.2, 125.2, 121.5, 96.4 (d, $^{2}J_{CF}$ = 24.4 Hz), 30.9 (d, $^{3}J_{CF}$ = 1.5 Hz), 29.9. **HRMS (EI)** calcd for $C_{20}H_{15}FO$ $[M+H]^+$ 291.1180, found 291.1182.

2-fluoro-3,5-diphenyl-4,5-dihydrobenzo[*b*]oxepine (3v)



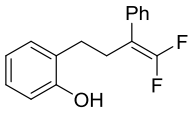
Colorless oil (67.31 mg, 71% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.30 (m, 2H), 7.28 – 7.23 (m, 5H), 7.22 – 7.16 (m, 5H), 7.05 – 7.01 (m, 1H), 6.82 (d, *J* = 7.7 Hz, 1H), 4.66 (dd, *J* = 10.0, 3.6 Hz, 1H), 3.12 – 2.94 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -82.16. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.1, 154.6 (d, $^{1}J_{CF}$ = 269.2 Hz), 142.8, 136.9 (d, $^{3}J_{CF}$ = 2.9 Hz), 135.1 (d, $^{4}J_{CF}$ = 2.9 Hz), 130.4, 128.8, 128.4, 128.4, 128.3 (d, $^{4}J_{CF}$ = 3.6 Hz), 127.9, 127.0, 127.0, 125.5, 120.5, 95.6 (d, $^{2}J_{CF}$ = 23.9 Hz), 44.7, 36.4 (d, $^{3}J_{CF}$ = 2.1 Hz). **HRMS (ESI)** calcd for $C_{22}H_{17}FO$ $[M-H]^+$ 315.11907, found 315.11896.

2-fluoro-5,5-dimethyl-3-phenyl-4,5-dihydrobenzo[*b*]oxepine (3w)



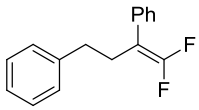
Colorless oil (73.16 mg, 91% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.41 – 7.37 (m, 5H), 7.28 – 7.17 (m, 4H), 2.73 (d, *J* = 4.7 Hz, 2H), 1.50 (s, 6H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -85.00. **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.2 (d, $^{1}J_{CF}$ = 270.0 Hz), 154.0, 138.3 (d, $^{3}J_{CF}$ = 2.8 Hz), 137.3 (d, $^{4}J_{CF}$ = 3.5 Hz), 128.4, 128.3 (d, $^{4}J_{CF}$ = 8.7 Hz), 128.2, 127.6, 126.8, 125.3, 121.3, 95.6 (d, $^{2}J_{CF}$ = 22.5 Hz), 43.7 (d, $^{3}J_{CF}$ = 2.2 Hz), 36.8, 30.0. **HRMS (EI)** calcd for $C_{18}H_{17}FO$ $[M+H]^+$ 269.1336, found 269.1331.

2-(4,4-difluoro-3-phenylbut-3-en-1-yl)phenol (4)



Colorless oil (33.54 mg, 43% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.39 – 7.38 (m, 4H), 7.31 – 7.28 (m, 1H), 7.11 – 7.05 (m, 2H), 6.88 – 6.85 (m, 1H), 6.73 (d, *J* = 8.0 Hz, 1H), 4.78 (s, 1H), 2.75 – 2.68 (m, 4H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -91.07 (dd, *J* = 165.1, 42.3 Hz). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.0 (dd, *J* = 291.4, 287.0 Hz), 153.7, 130.5, 128.6, 128.4, 128.4, 128.4, 127.6, 127.4, 121.0, 115.4, 92.2 (dd, *J* = 21.7, 12.9 Hz), 28.9, 27.9. **HRMS (ESI)** calcd for $C_{16}H_{14}F_2O$ $[M-H]^+$ 259.09407, found 259.09399

(4,4-difluorobut-3-ene-1,3-diyl)dibenzene (7)



Colorless oil (27.08 mg, 37% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.42 – 7.38 (m, 2H), 7.35 – 7.28 (m, 5H), 7.24 – 7.20 (m, 1H), 7.17 – 7.15 (m, 2H), 2.77 – 2.72 (m, 2H), 2.70 – 2.66 (m, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -91.30 (dd, *J* = 154.9, 42.6 Hz). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.4 (dd, *J* = 295.7, 291.9 Hz), 140.1, 132.4 (dd, *J* = 9.9, 4.6 Hz), 131.7, 130.2, 129.9, 128.5, 128.0, 123.0, 95.6 (dd, *J* = 19.2, 17.3 Hz), 35.1, 34.9. **HRMS (EI)** calcd for $C_{16}H_{14}F_2$ $[M+H]^+$ 244.1058, found 244.1055.

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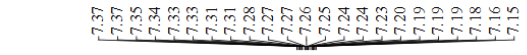
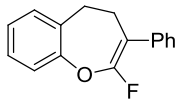
2. M. M. Alam and S. R. Adapa, *Synth. Commun.* 2003**, 33**, 59-63.

3. T. Tanaka, T. Tanaka, T. Tsuji, R. Yazaki and T. Ohshima, *Org. Lett*. 2018, **20**, 3541-3544.

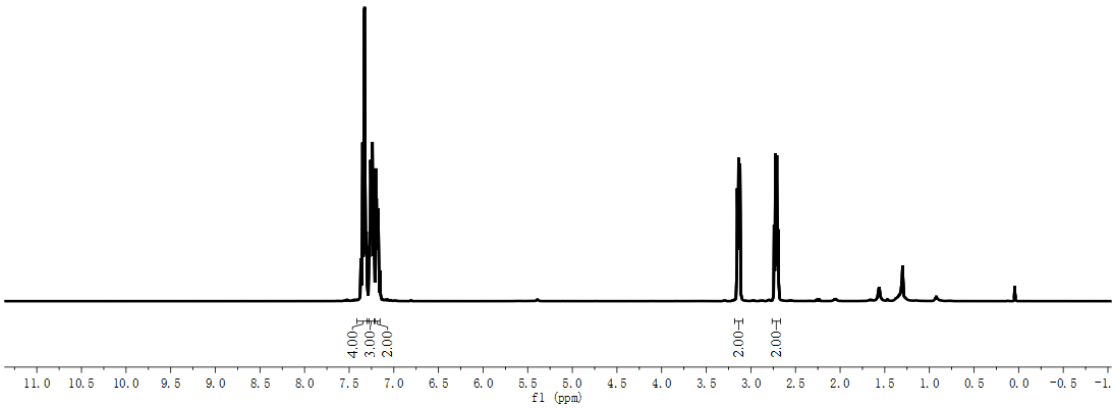
4. J. Schlueter, M. Blazejak and L. Hintermann, *ChemCatChem*, 2013, **5**, 3309-3315.

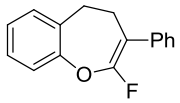
^{1}H NMR, ^{19}F NMR and ^{13}C NMR spectra





3a





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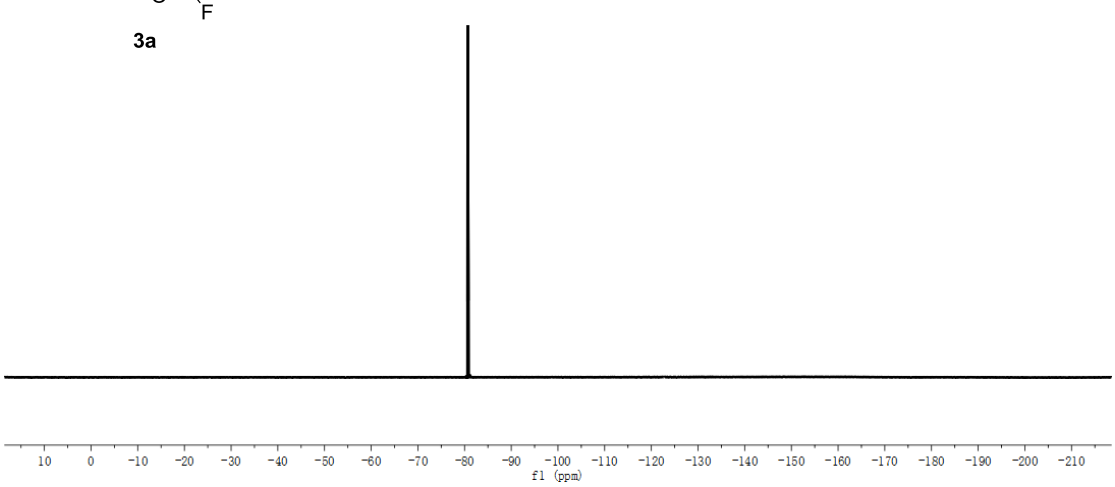

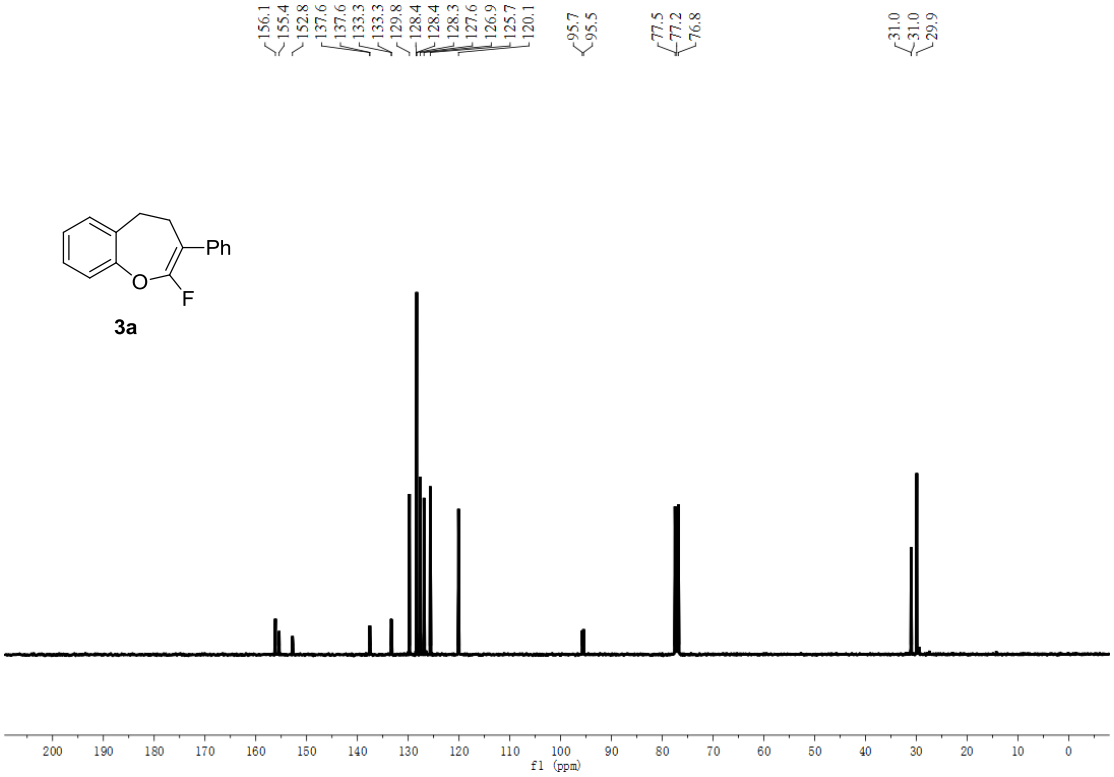
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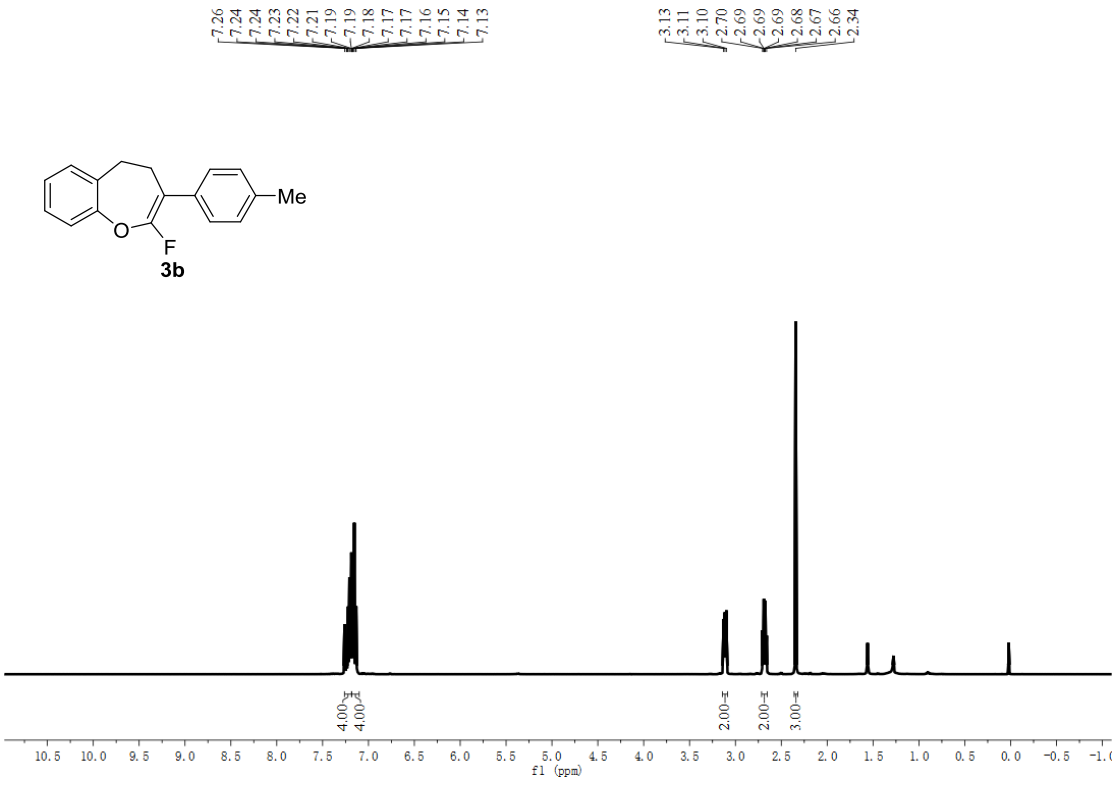
137.6
133.3
133.3
129.8
128.4
128.4
128.3
127.6
126.9
125.7
120.1
95.7
95.5
77.5
77.2
76.8
31.0
31.0
29.9
Ph
O
F
3a
f1 (ppm)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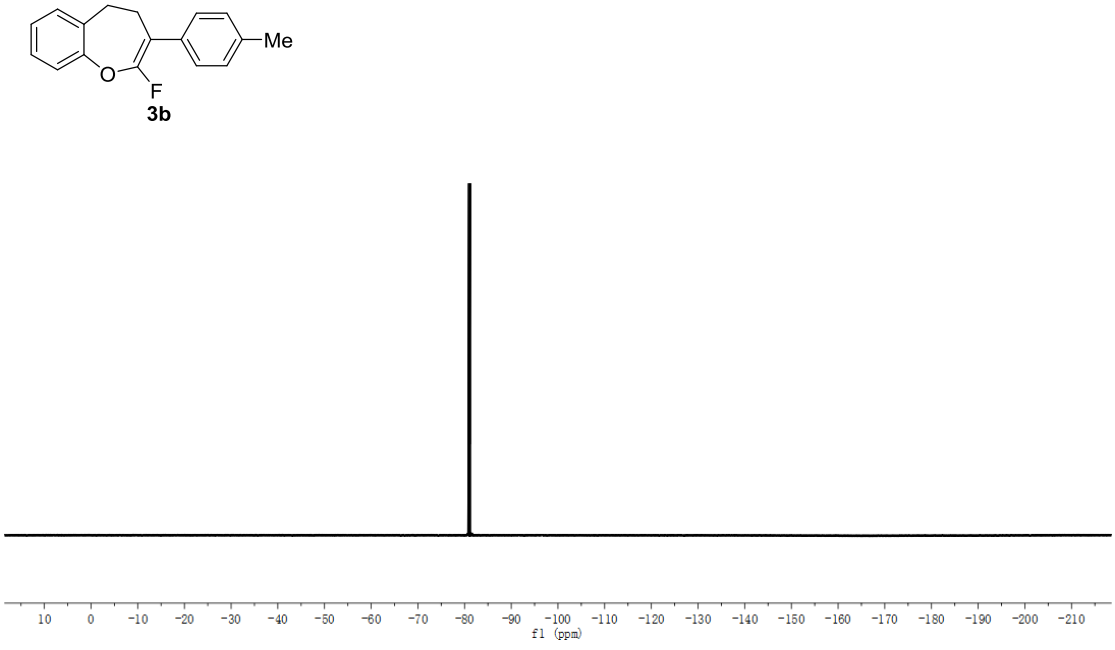
7.15
7.14
7.13
3.13
3.11
3.10
2.70
2.69
2.69
2.68
2.67
2.66
2.34
Me
O
F
3b
4.00
4.00
2.00
2.00
3.00
f1 (ppm)


-81.06
Me
O
F
3b
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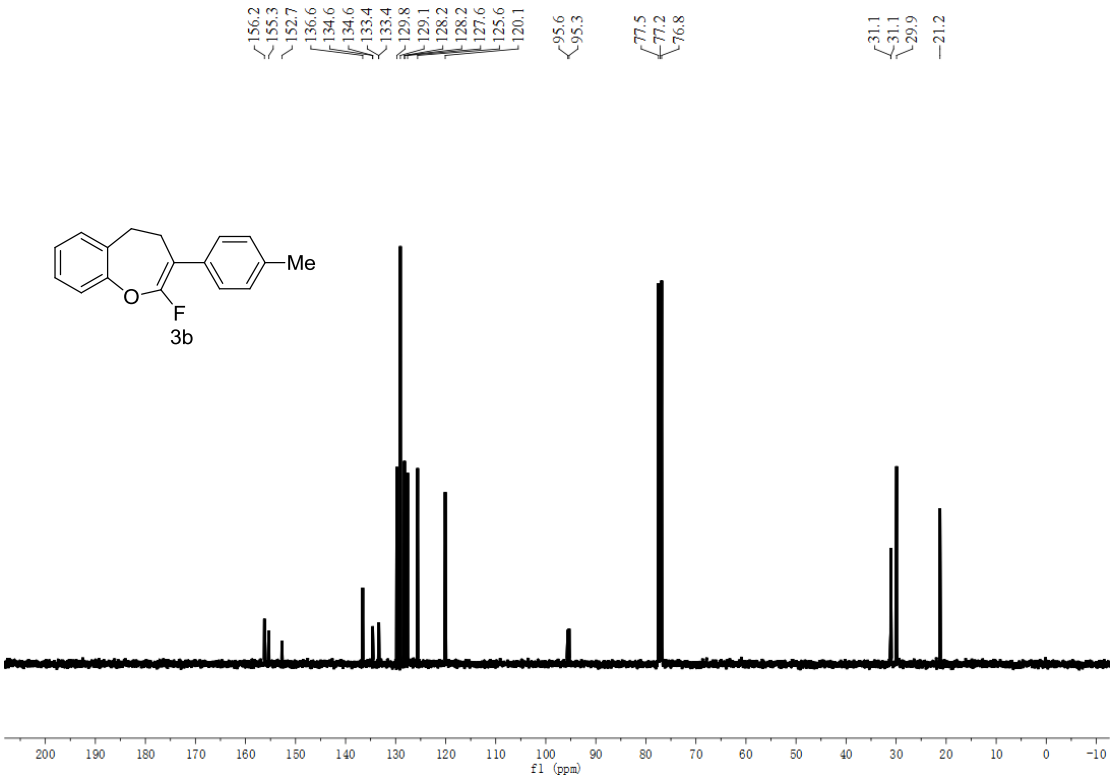
f1 (ppm)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133.4
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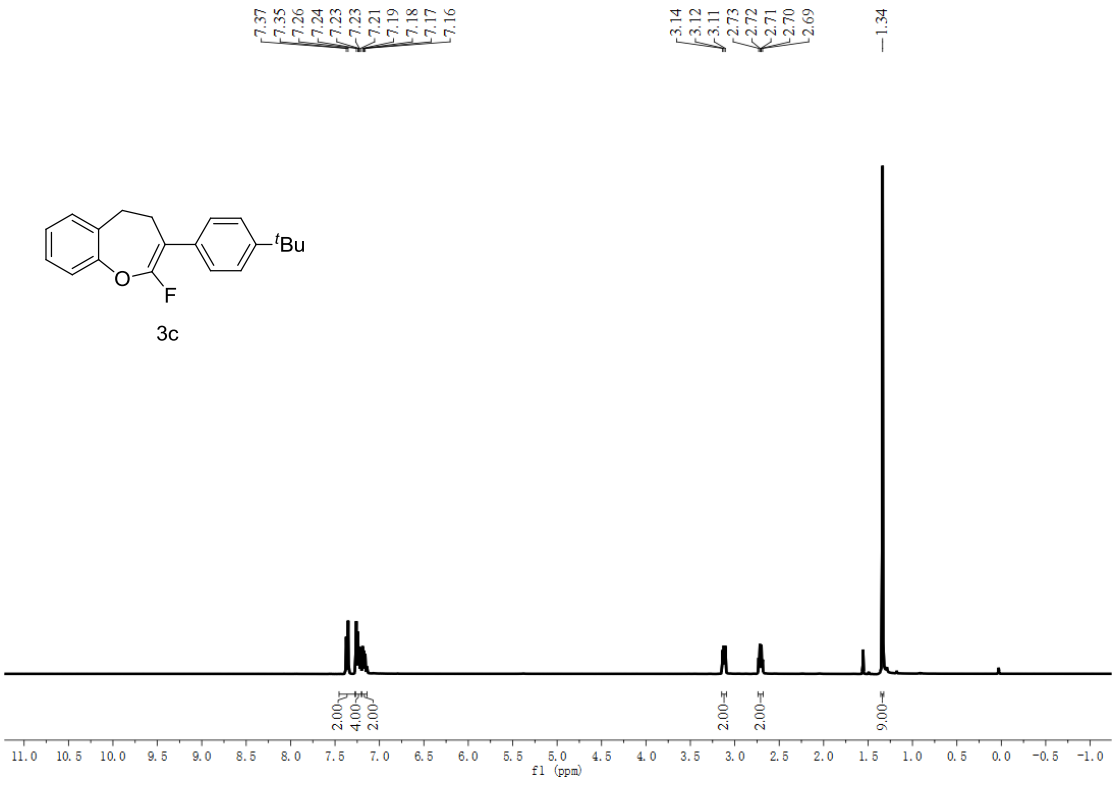
129.1
128.2
128.2
127.6
125.6
120.1
95.6
95.3
77.5
77.2
76.8
31.1
31.1
29.9
21.2
Me
O
F
3b
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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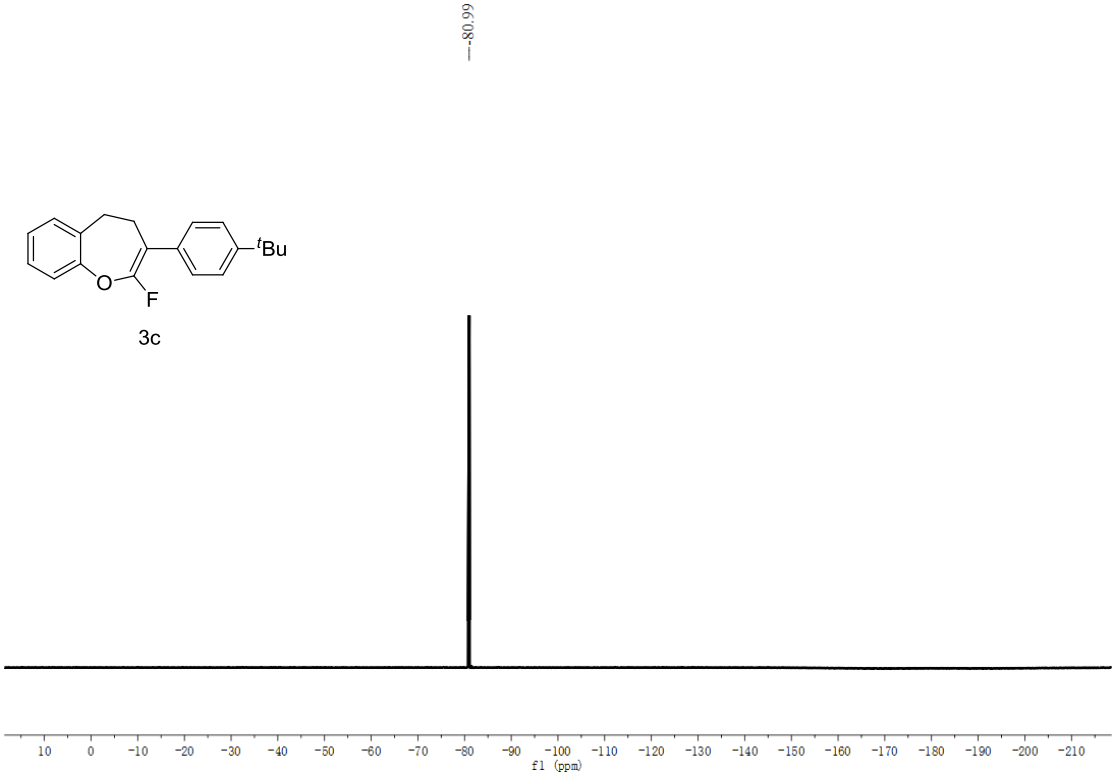
7.21
7.19
7.18
7.17
7.16
3.14
3.12
3.11
2.73
2.72
2.71
2.70
2.69
1.34
tBu
O
F
2.00
4.00
2.00
2.00
2.00
9.00
f1 (ppm)

3c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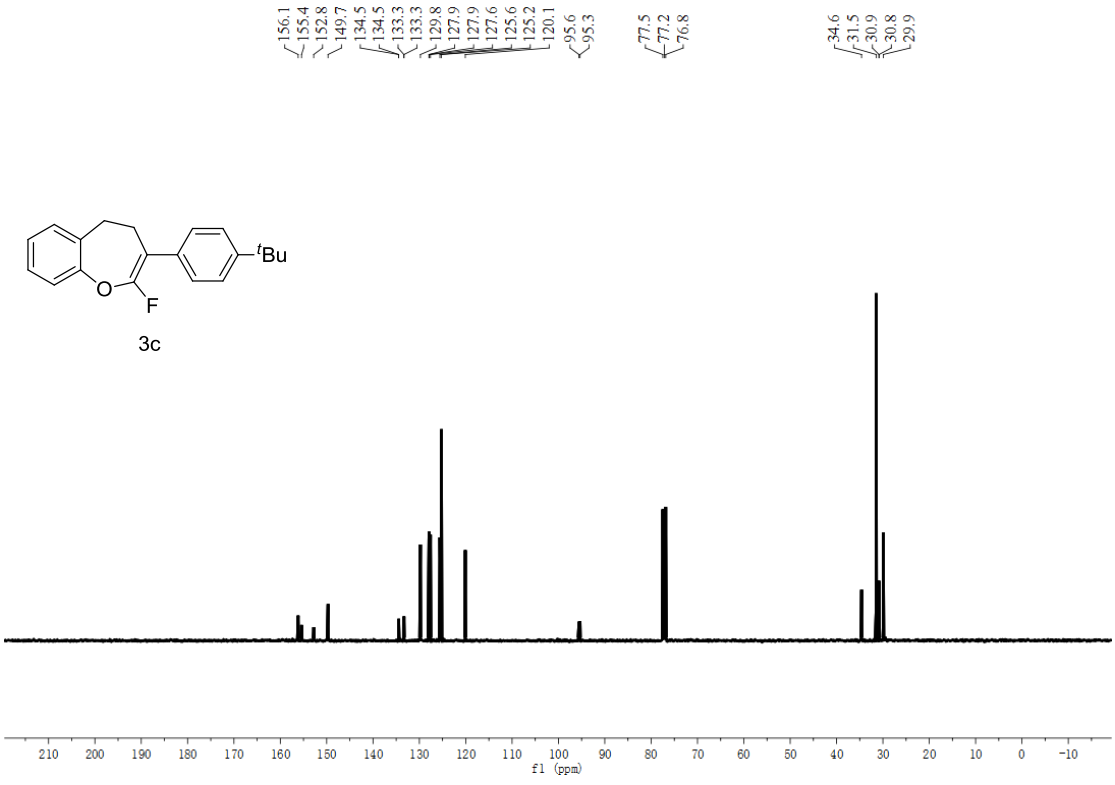
tBu
O
F
f1 (ppm)

3c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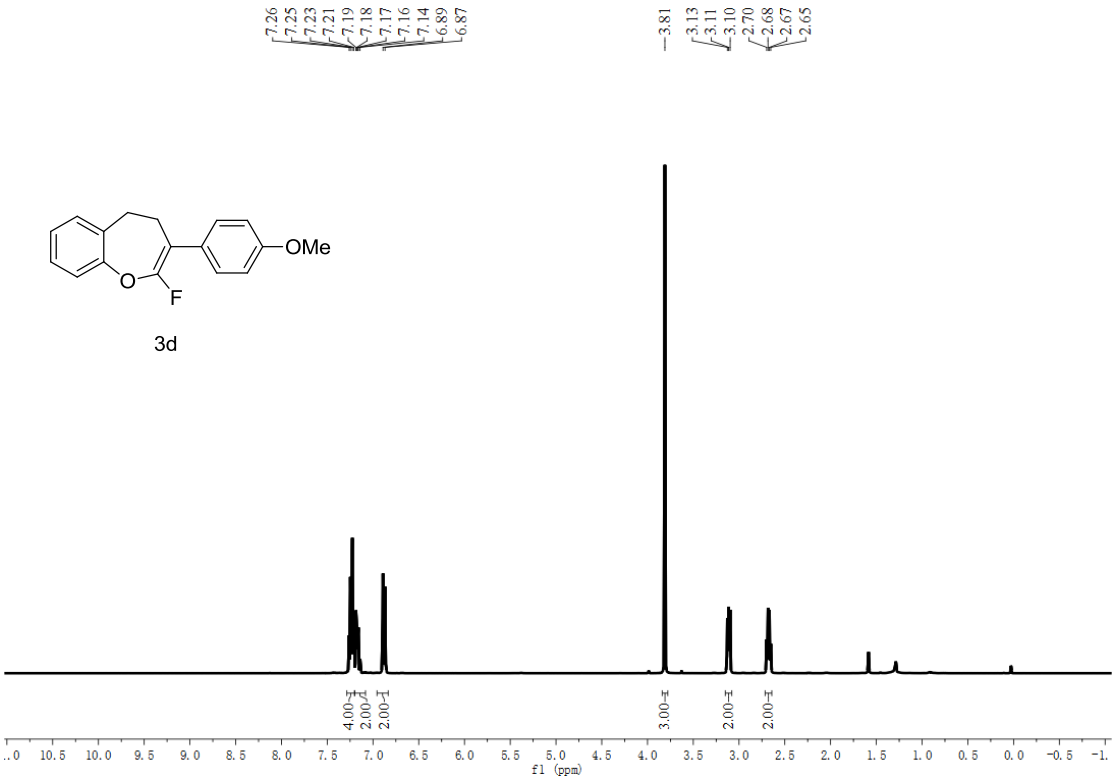
133.3
133.3
129.8
127.9
127.9
127.6
125.6
125.2
120.1
95.6
95.3
77.5
77.2
76.8
34.6
31.5
30.9
30.8
29.9
tBu
O
F
3c
f1 (ppm)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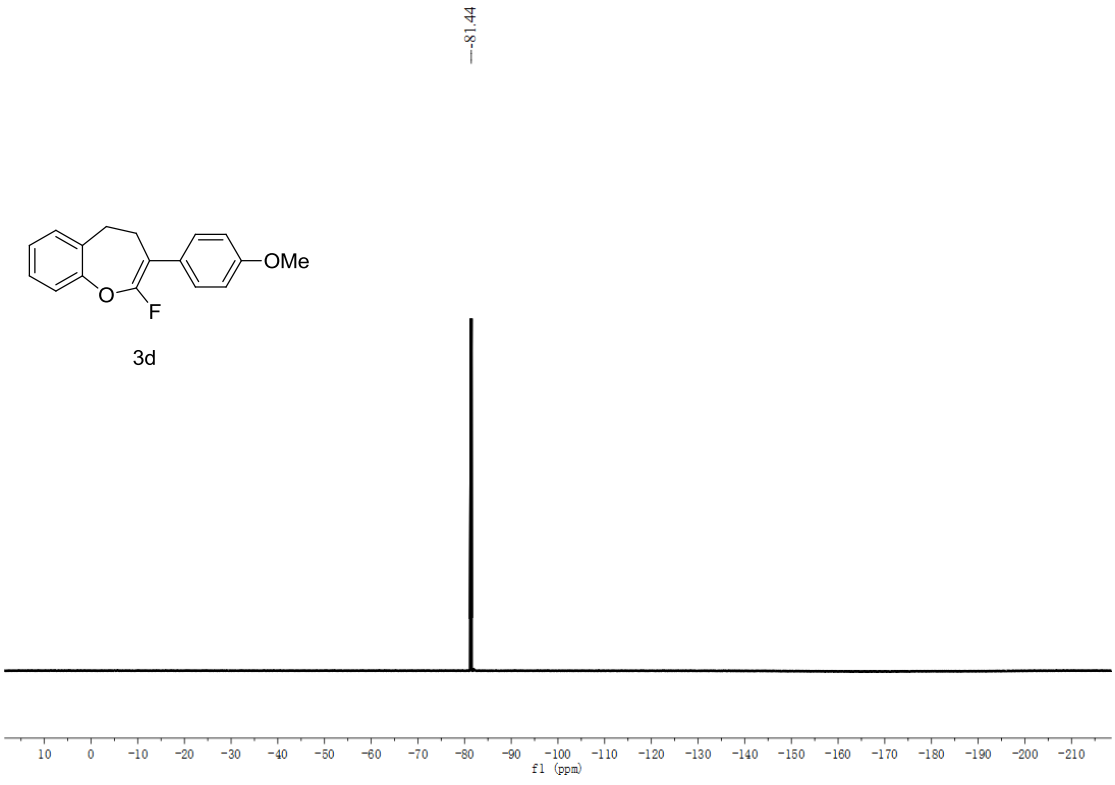
7.14
6.89
6.87
3.81
3.13
3.11
3.10
2.70
2.68
2.67
2.65
OMe
O
F
3d
4.00
2.00
2.00
3.00
2.00
2.00
f1 (ppm)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OMe
O
F
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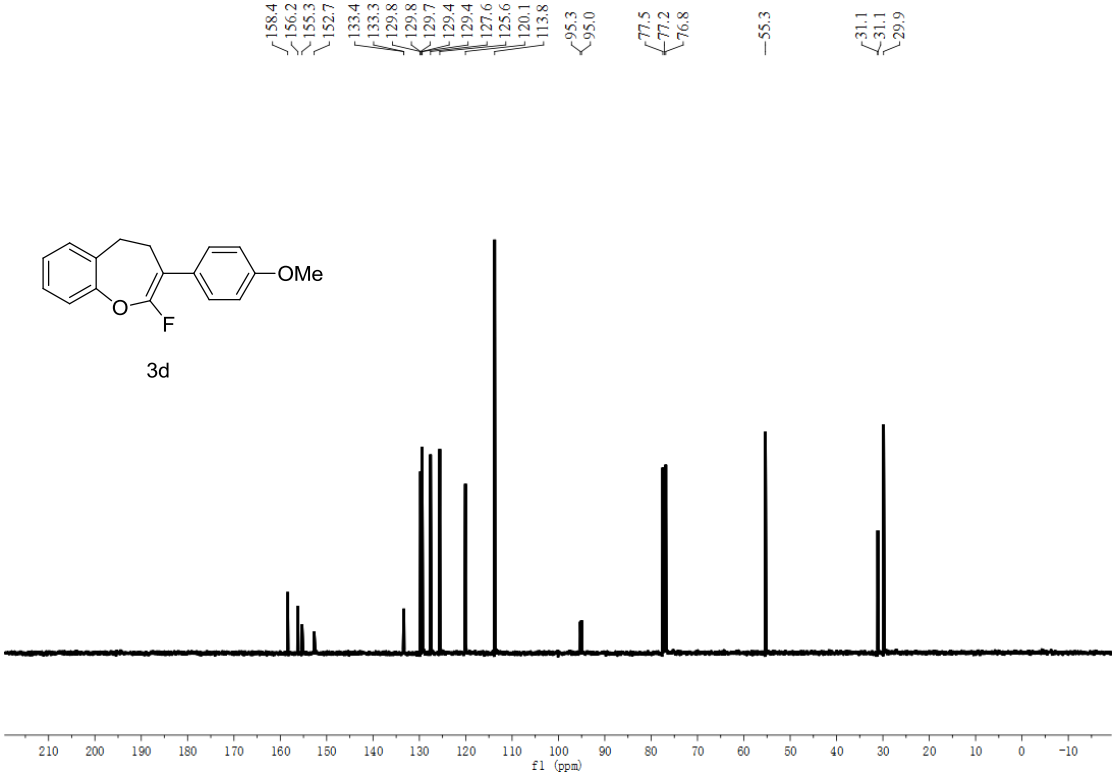
f1 (ppm)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129.8
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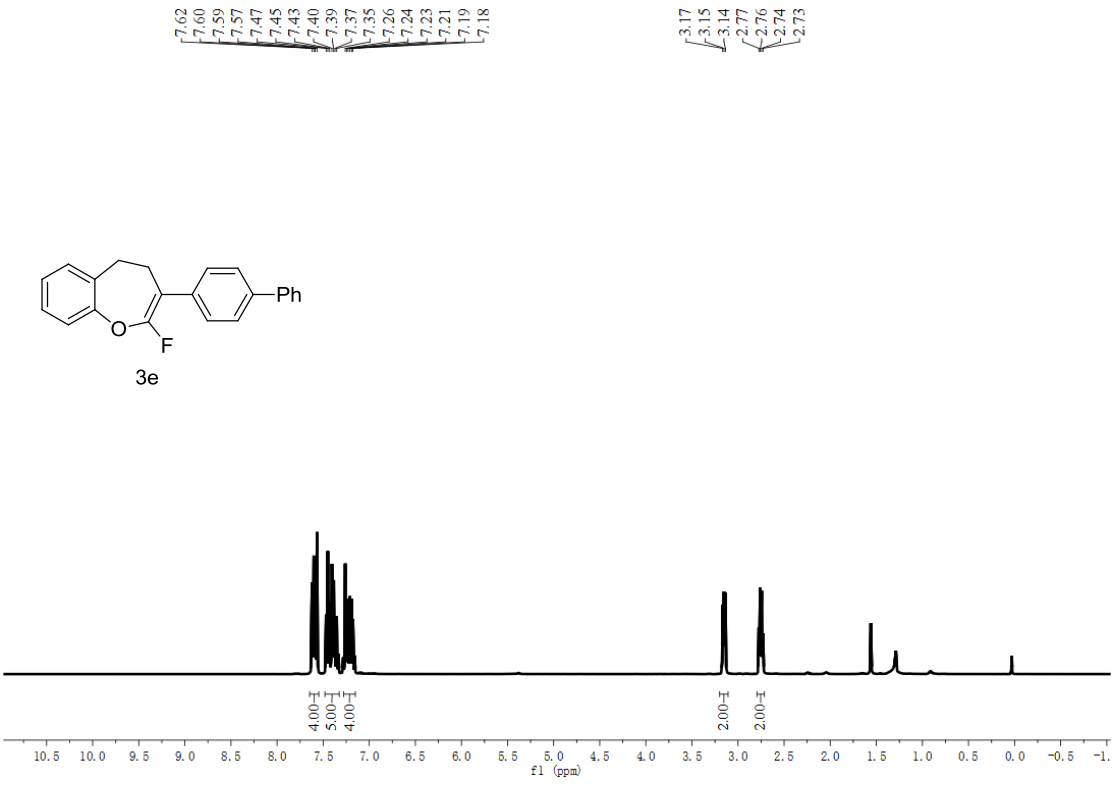
129.4
129.4
127.6
125.6
120.1
113.8
95.3
95.0
77.5
77.2
76.8
55.3
31.1
31.1
29.9
OMe
O
F
3d
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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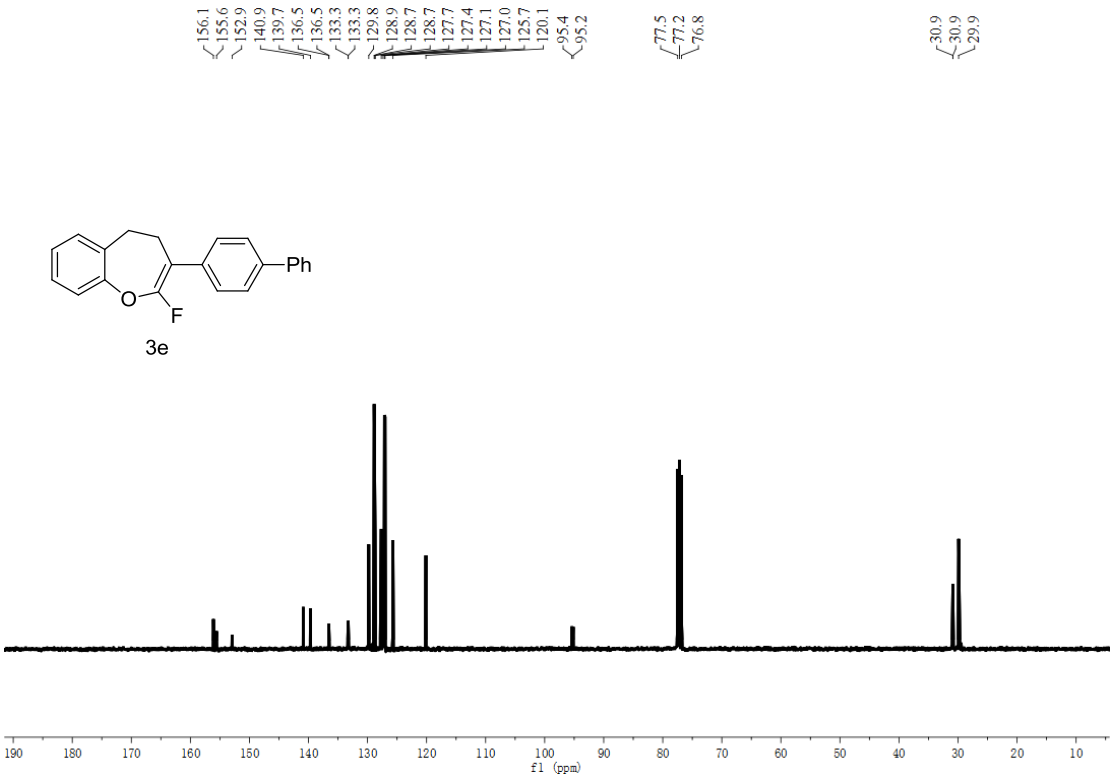
7.24
7.23
7.21
7.19
7.18
3.17
3.15
3.14
2.77
2.76
2.74
2.73
Ph
O
F
3e
4.00
5.00
4.00
2.00
2.00
f1 (ppm)


-80.13
Ph
O
F
3e
f1 (ppm)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136.5
133.3
133.3
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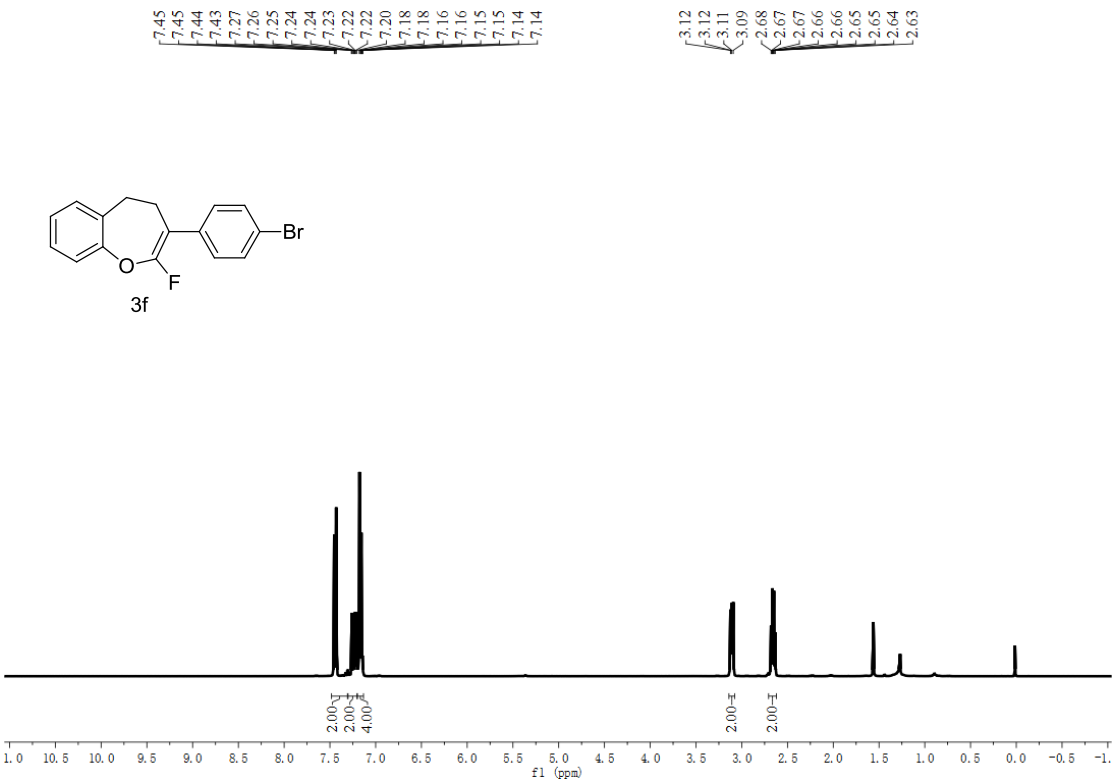
128.9
128.8
128.7
127.7
127.4
127.1
127.0
125.7
120.1
95.4
95.2
77.5
77.2
76.8
30.9
30.9
29.9
Ph
O
F
3e
f1 (ppm)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7.18
7.16
7.16
7.15
7.15
7.14
7.14
3.12
3.12
3.11
3.09
2.68
2.67
2.67
2.66
2.66
2.65
2.65
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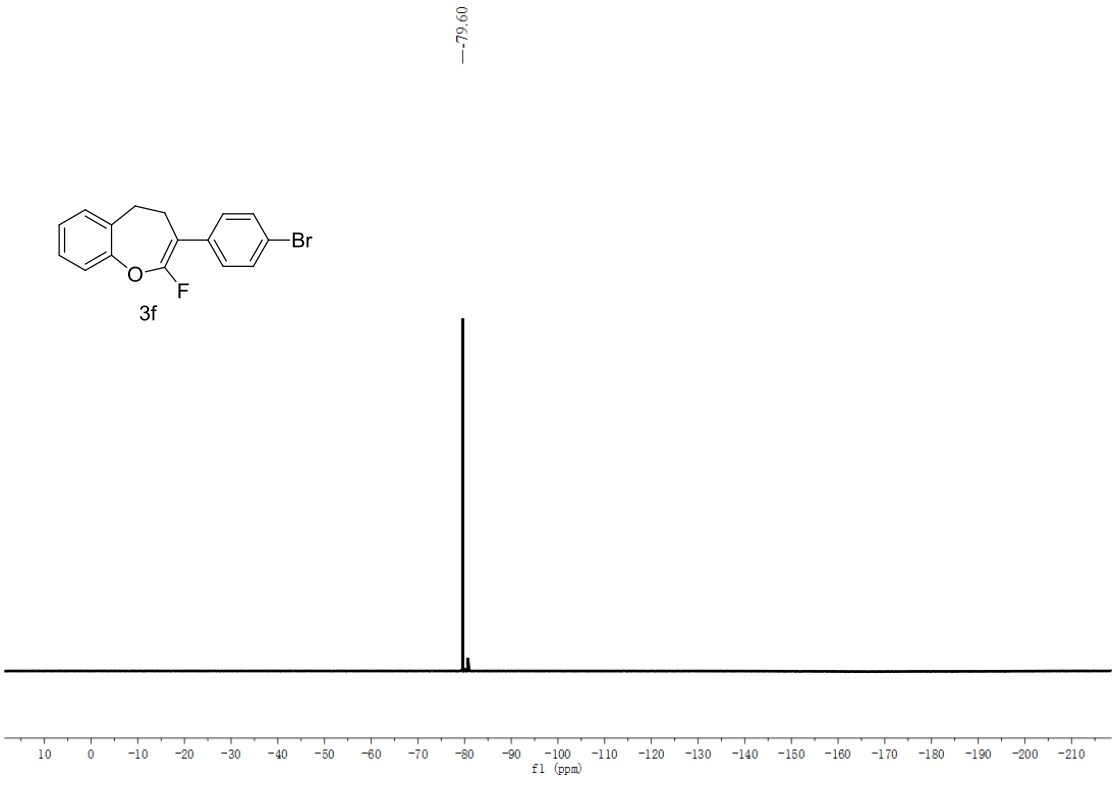
2.63
Br
O
F
3f
2.00
2.00
4.00
2.00
2.00
f1 (ppm)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Br
O
F
3f
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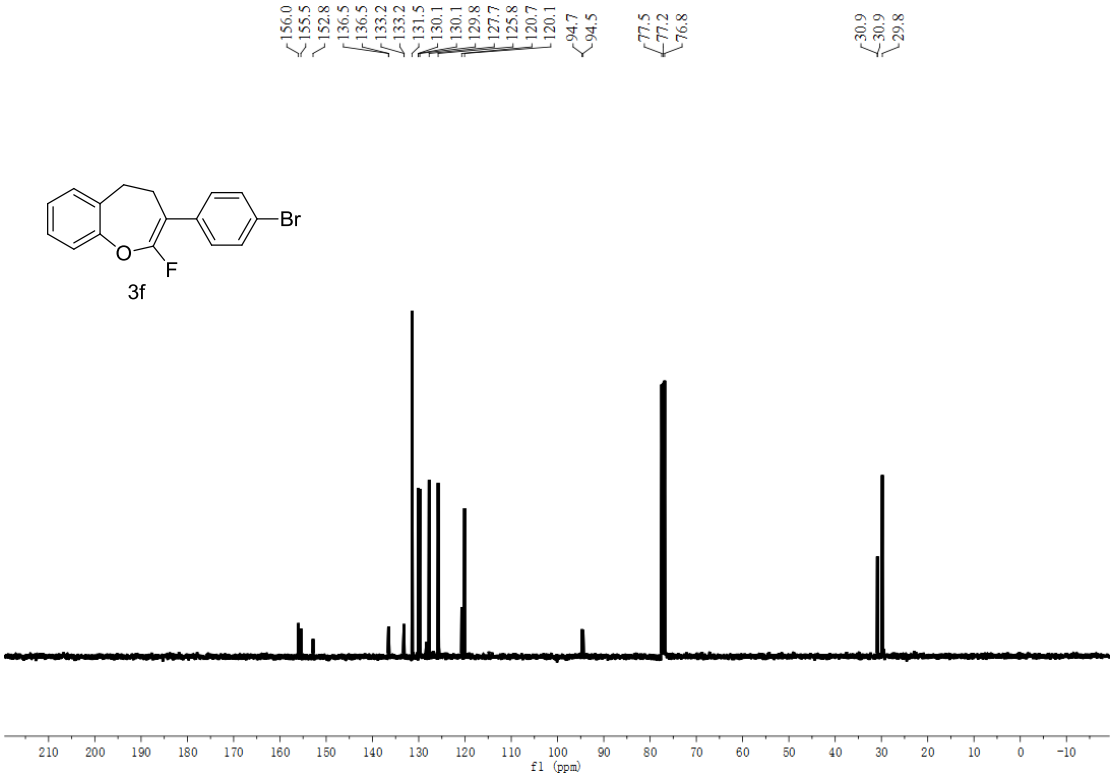
f1 (ppm)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133.2
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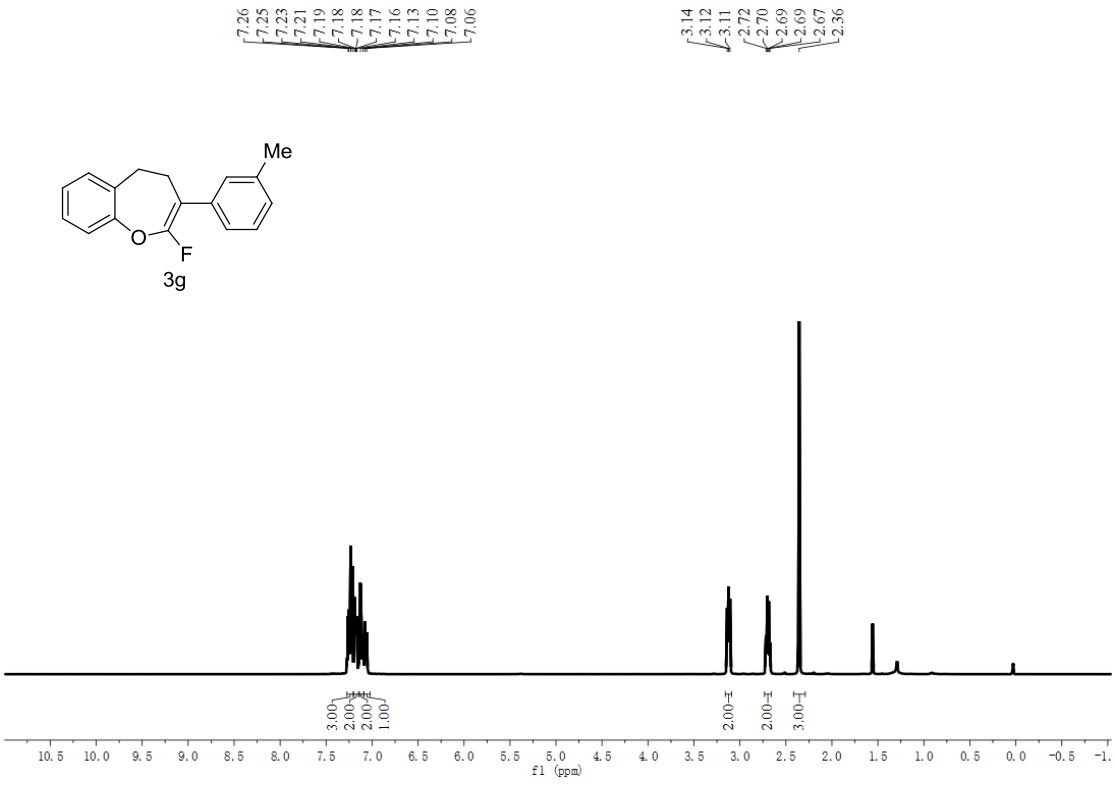
130.1
130.1
129.8
127.7
125.8
120.7
120.1
94.7
94.5
77.5
77.2
76.8
30.9
30.9
29.8
Br
O
F
3f
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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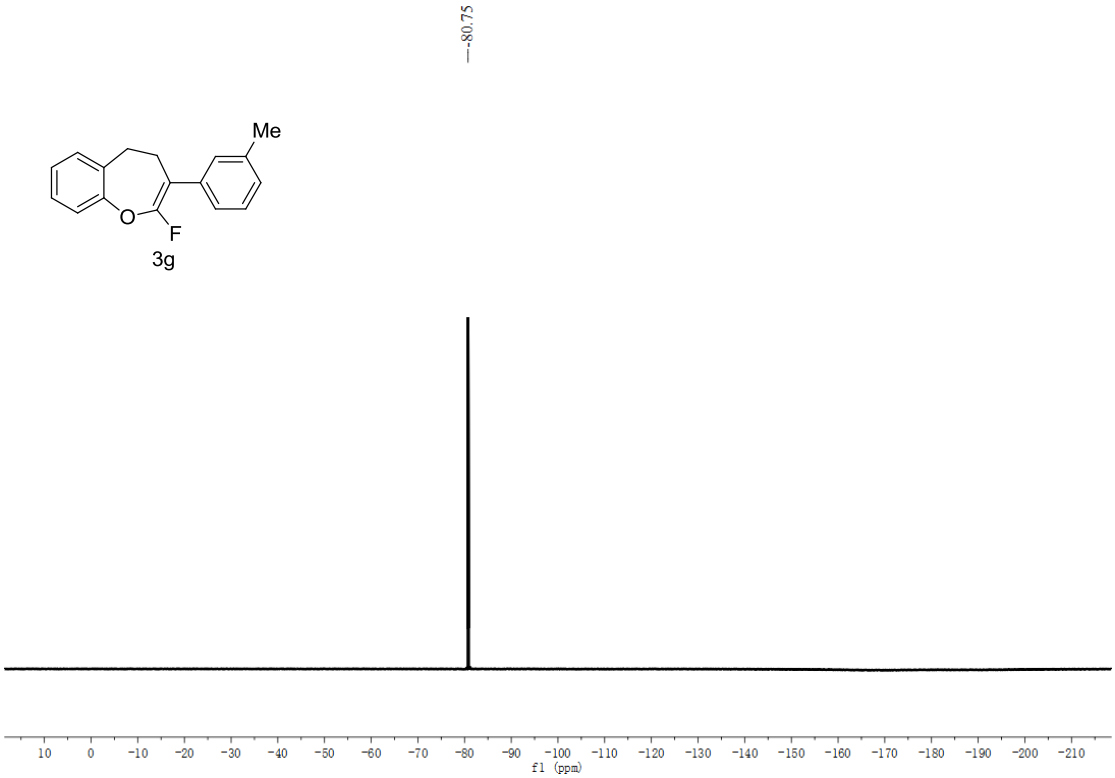
7.18
7.17
7.16
7.13
7.10
7.08
7.06
3.14
3.12
3.11
2.72
2.70
2.69
2.69
2.67
2.36
Me
O
F
3g
3.00
2.00
2.00
1.00
2.00
2.00
3.00
f1 (ppm)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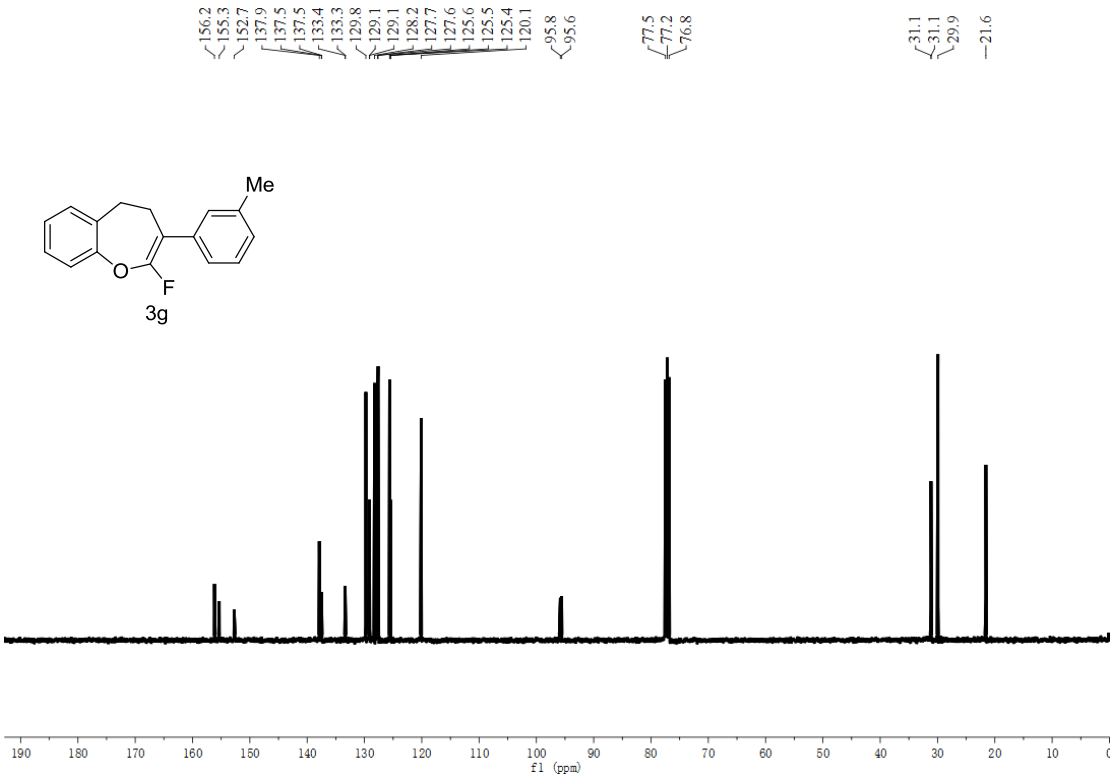
Me
O
F
3g
f1 (ppm)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129.1
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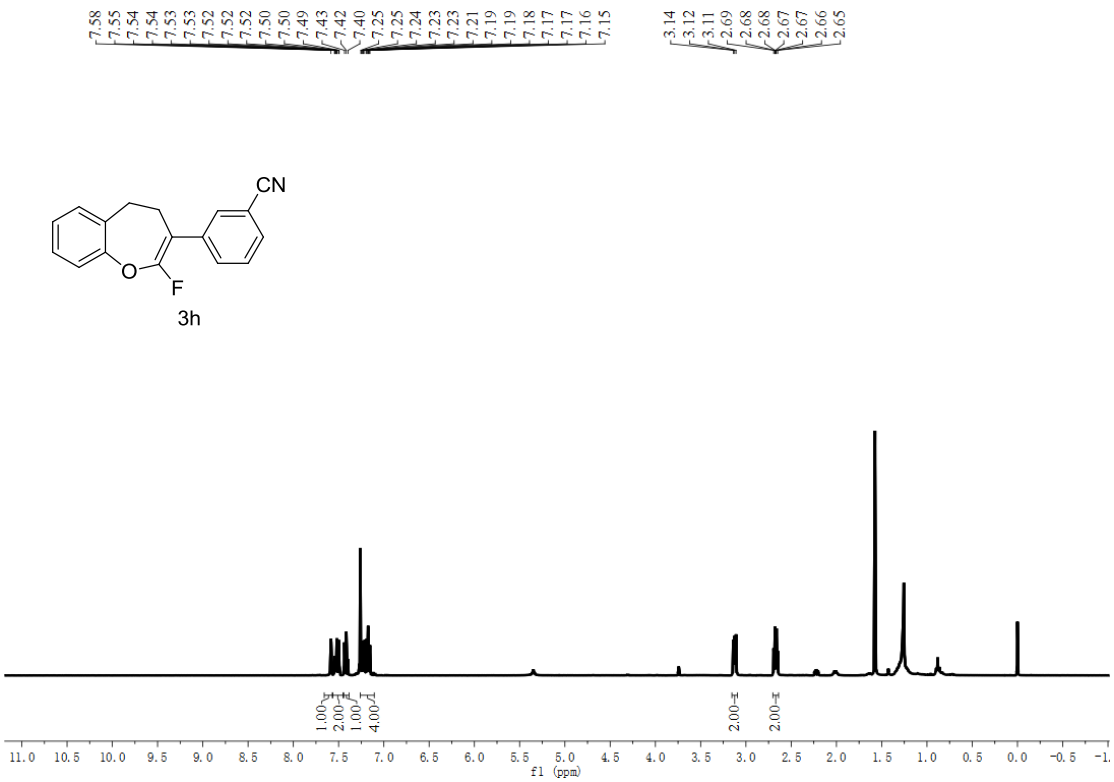
128.2
127.7
127.6
125.6
125.5
125.4
120.1
95.8
95.6
77.5
77.2
76.8
31.1
31.1
29.9
21.6
Me
O
F
3g
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)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7.17
7.17
7.16
7.15
3.14
3.12
3.11
2.69
2.68
2.68
2.67
2.67
2.66
2.65
CN
O
F
3h
1.00
2.00
1.00
4.00
2.00
2.00
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
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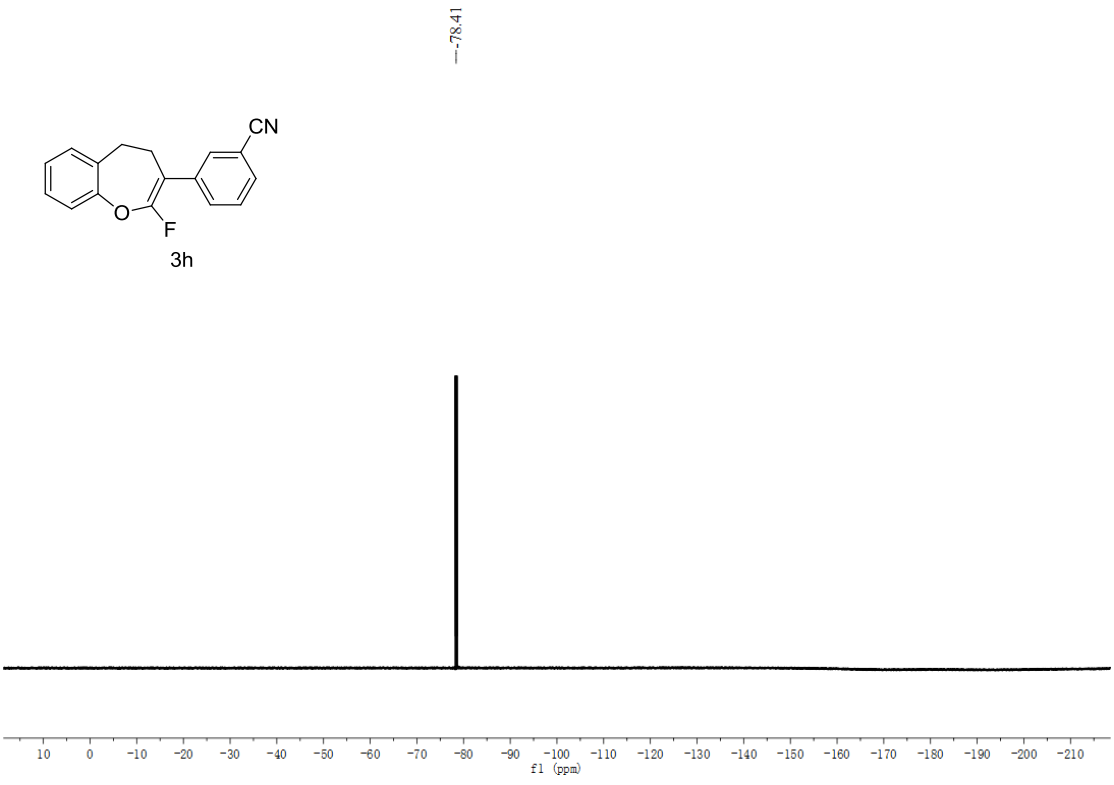
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)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CN
O
F
3h
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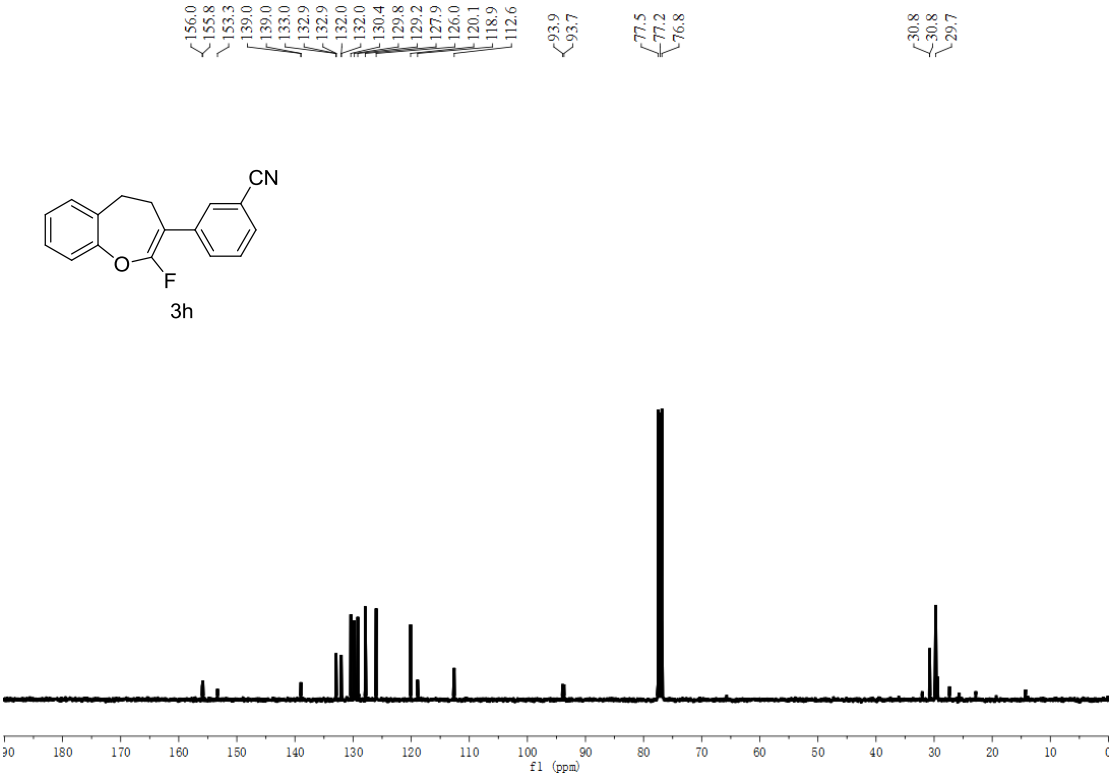
f1 (ppm)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133.0
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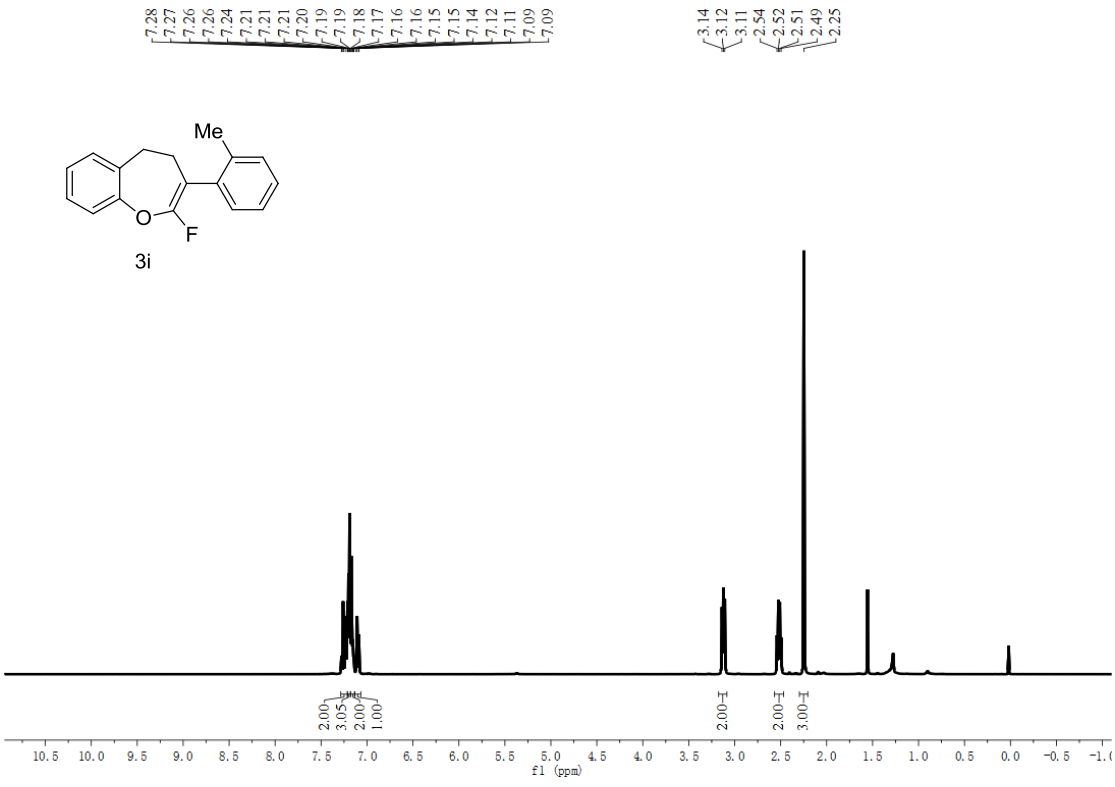
132.9
132.0
132.0
130.4
129.8
129.2
127.9
126.0
120.1
118.9
112.6
93.9
93.7
77.5
77.2
76.8
30.8
30.8
29.7
CN
O
F
3h
90 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)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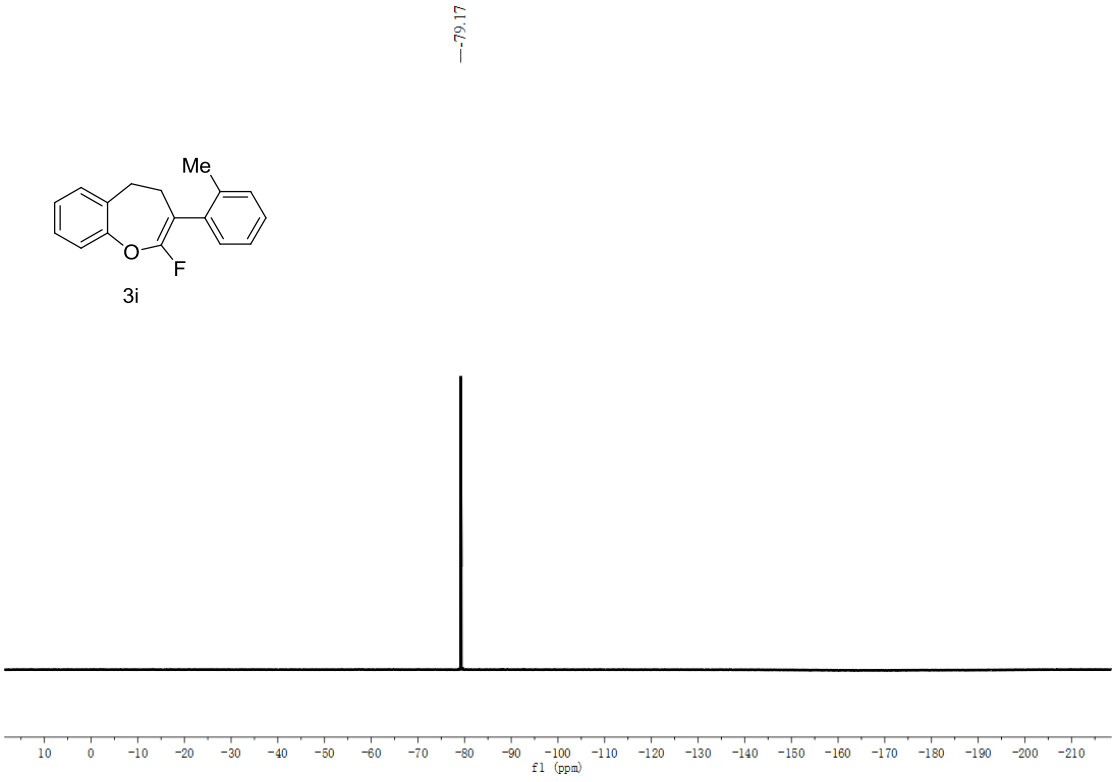
7.14
7.12
7.11
7.09
7.09
3.14
3.12
3.11
2.54
2.52
2.51
2.49
2.25
Me
O
F
3i
2.00
3.05
2.00
1.00
2.00
2.00
3.00
f1 (ppm)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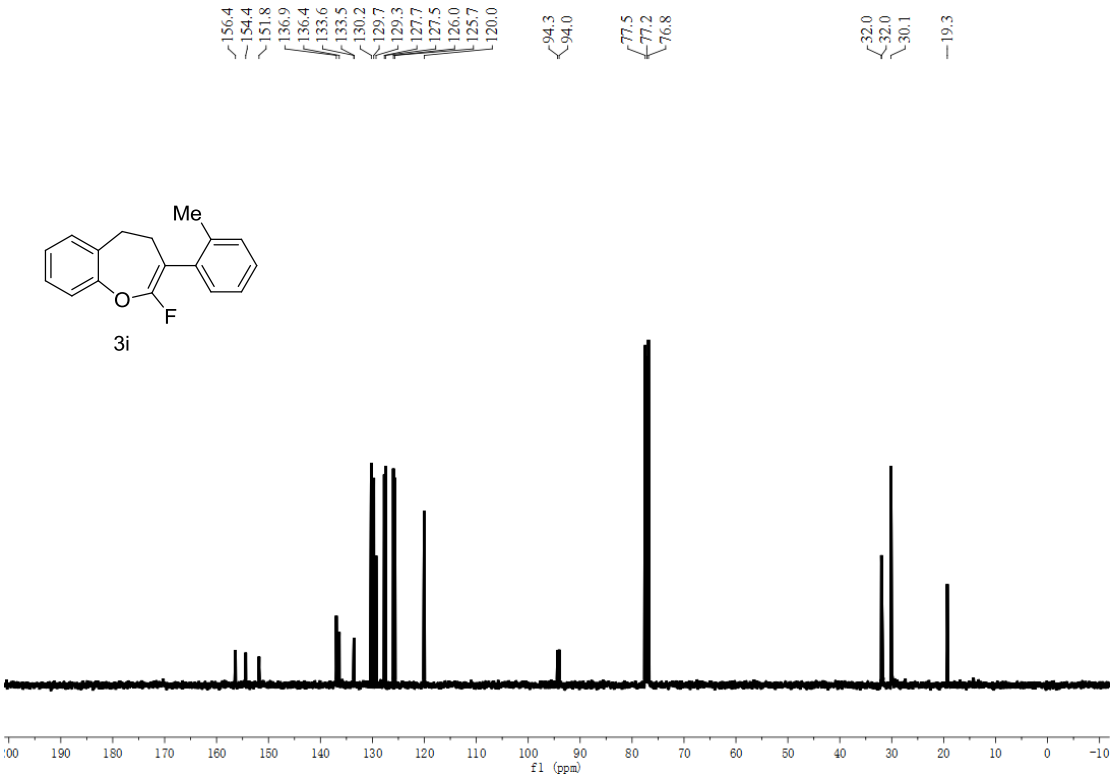
O
F
3i
f1 (ppm)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127.5
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125.7
120.0
94.3
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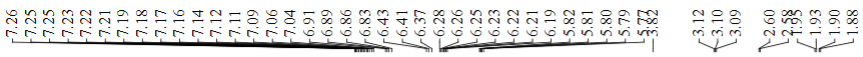
30.1
19.3
Me
O
F
3i
f1 (ppm)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7.09
7.06
7.04
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5.77
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3.10
3.09
2.60
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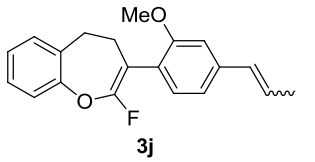
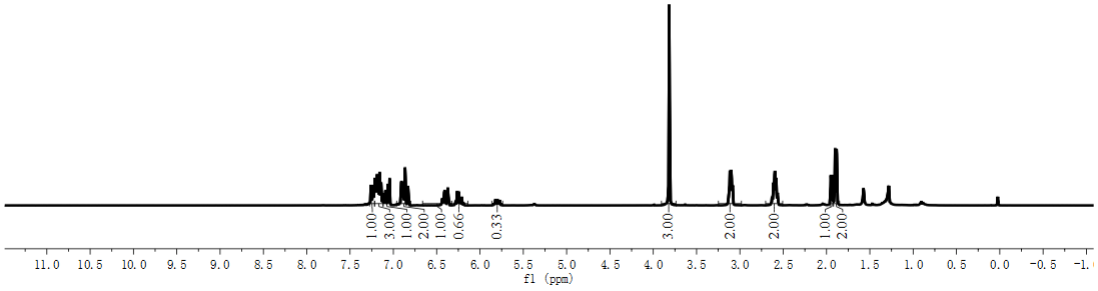
1.90
1.88


MeO
O
F

3j


1.00
3.00
1.00
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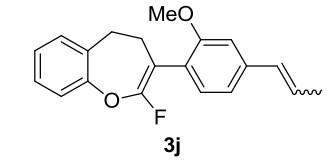
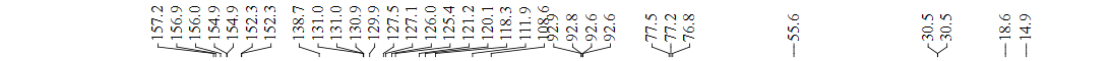
1.00
0.66
0.33
3.00
2.00
2.00
1.00
2.00
f1 (ppm)


MeO
O
F

3j

-79.76
-79.77
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)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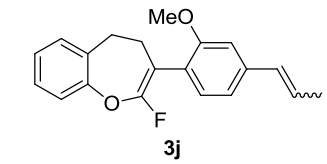
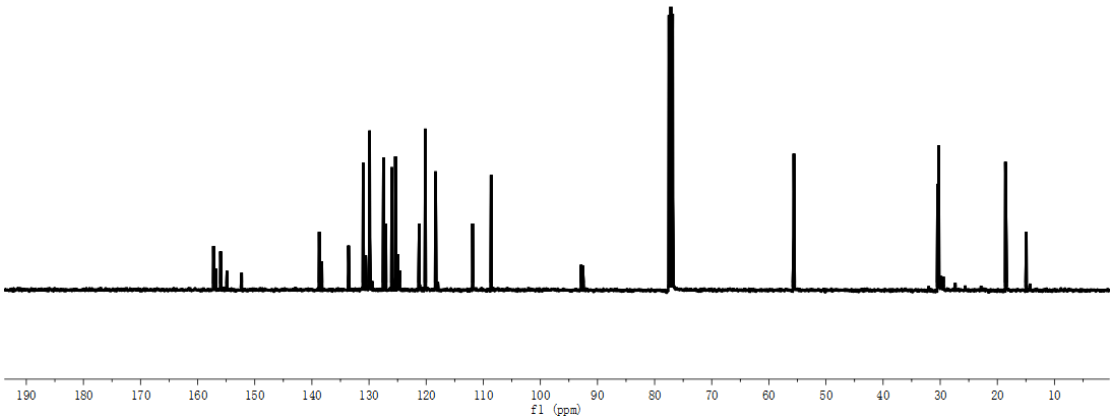
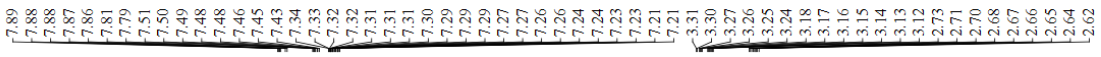
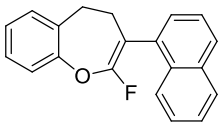
156.0
154.9
154.9
152.3
152.3
138.7
131.0
131.0
130.9
129.9
127.5
127.1
126.0
125.4
121.2
120.1
118.3
111.9
108.6
92.9
92.8
92.6
92.6
77.5
77.2
76.8
55.6
30.5
30.5
18.6
14.9


MeO
O
F

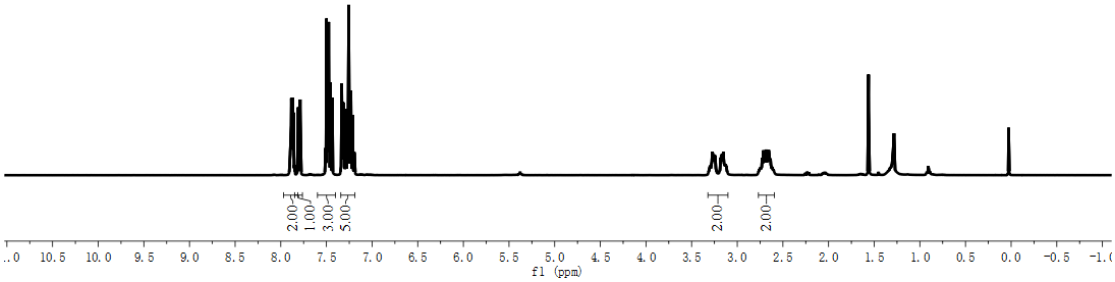
3j


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

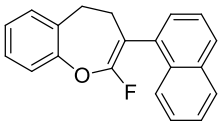

7.89
7.88
7.88
7.87
7.86
7.81
7.79
7.51
7.50
7.49
7.48
7.48
7.46
7.45
7.43
7.34
7.33
7.32
7.32
7.31
7.31
7.31
7.30
7.29
7.29
7.29
7.27
7.27
7.26
7.26
7.24
7.24
7.23
7.23
7.21
7.21
3.31
3.30
3.27
3.26
3.25
3.24
3.18
3.17
3.16
3.15
3.14
3.13
3.12
2.73
2.71
2.70
2.68
2.67
2.66
2.65
2.64
2.62


O
F

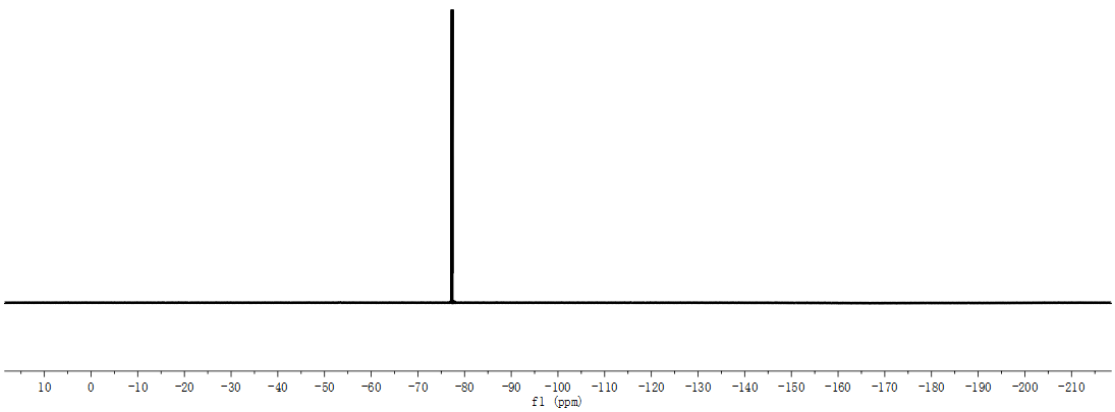
3k

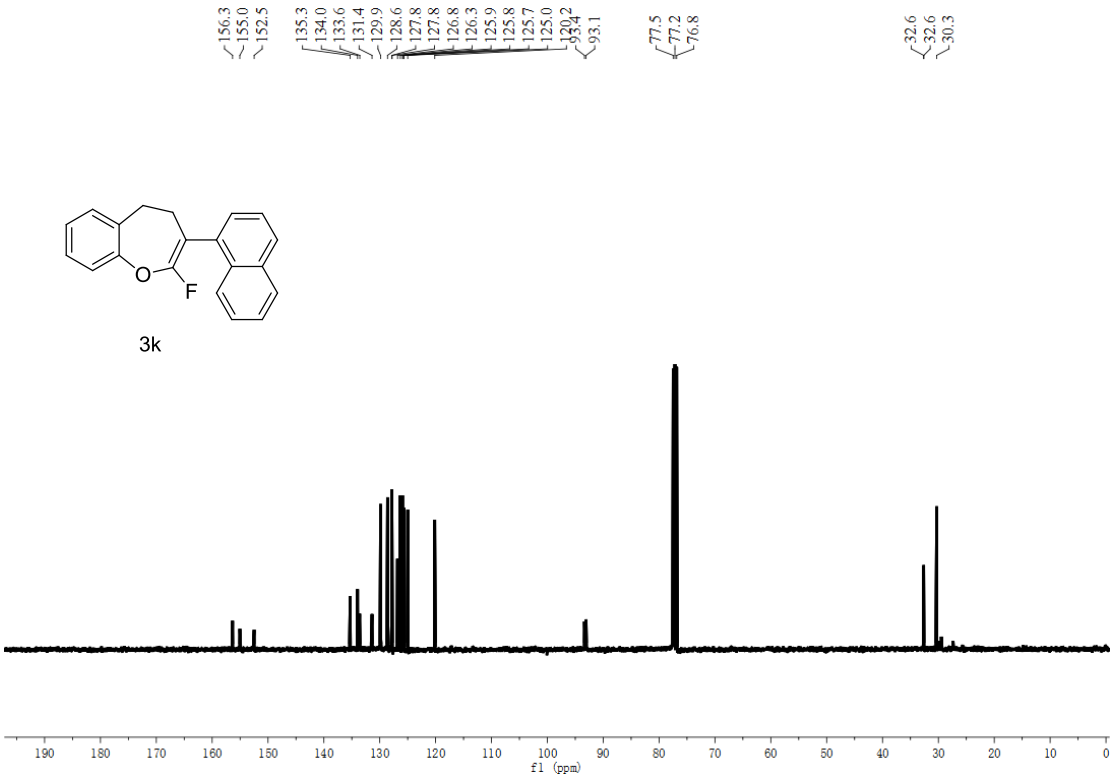

2.00
1.00
3.00
5.00
2.00
2.00
f1 (ppm)


77.34


O
F

3k


f1 (ppm)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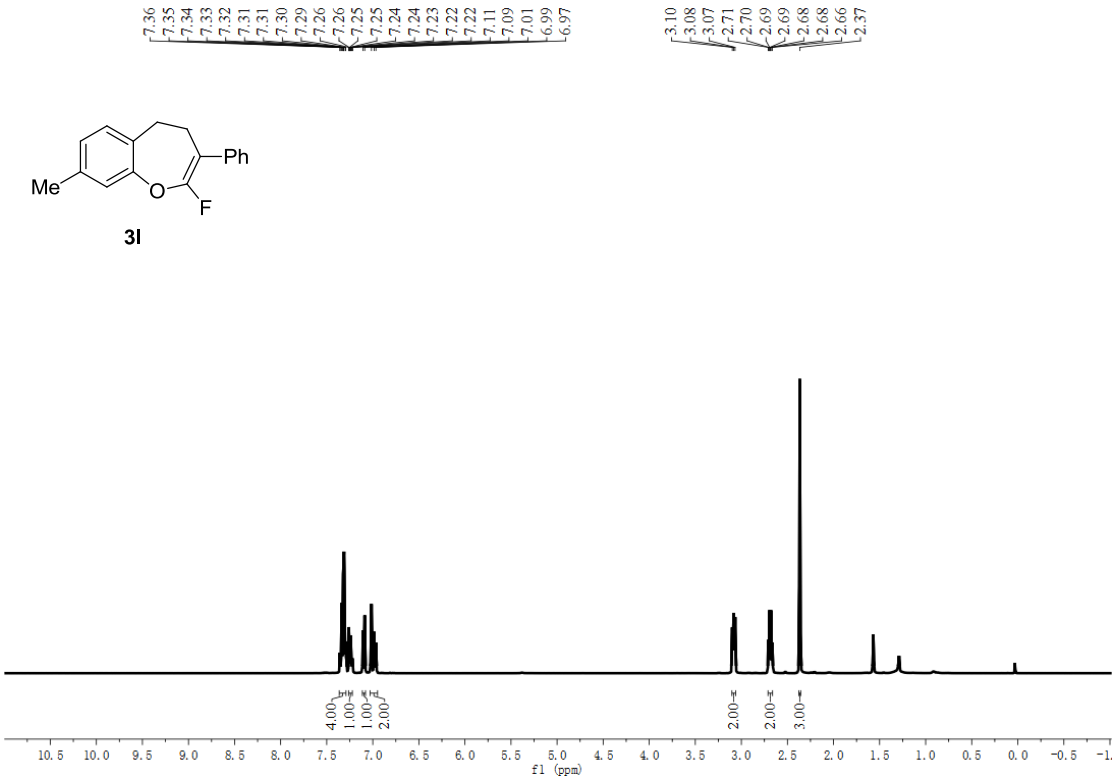
152.5
135.3
134.0
133.6
131.4
129.9
128.6
127.8
127.8
126.8
126.3
125.9
125.8
125.7
125.0
120.2
93.4
93.1
77.5
77.2
76.8
32.6
32.6
30.3
O
F
3k
f1 (ppm)


7.36
7.35
7.34
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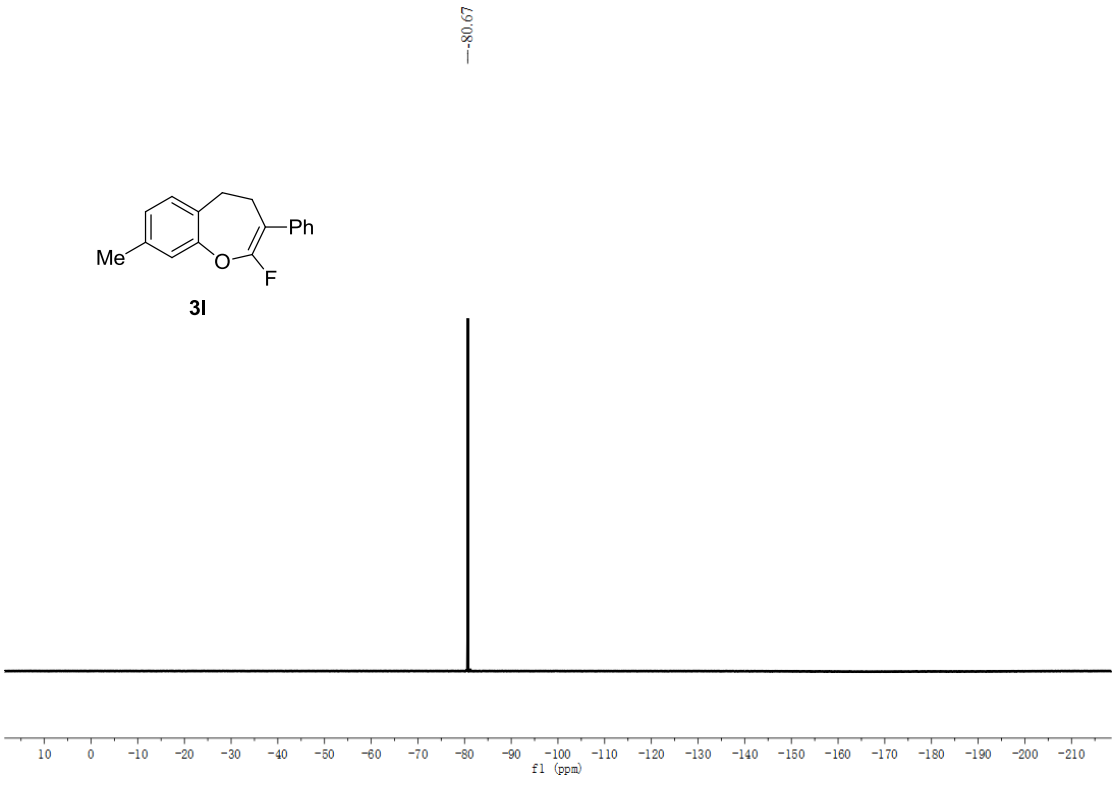
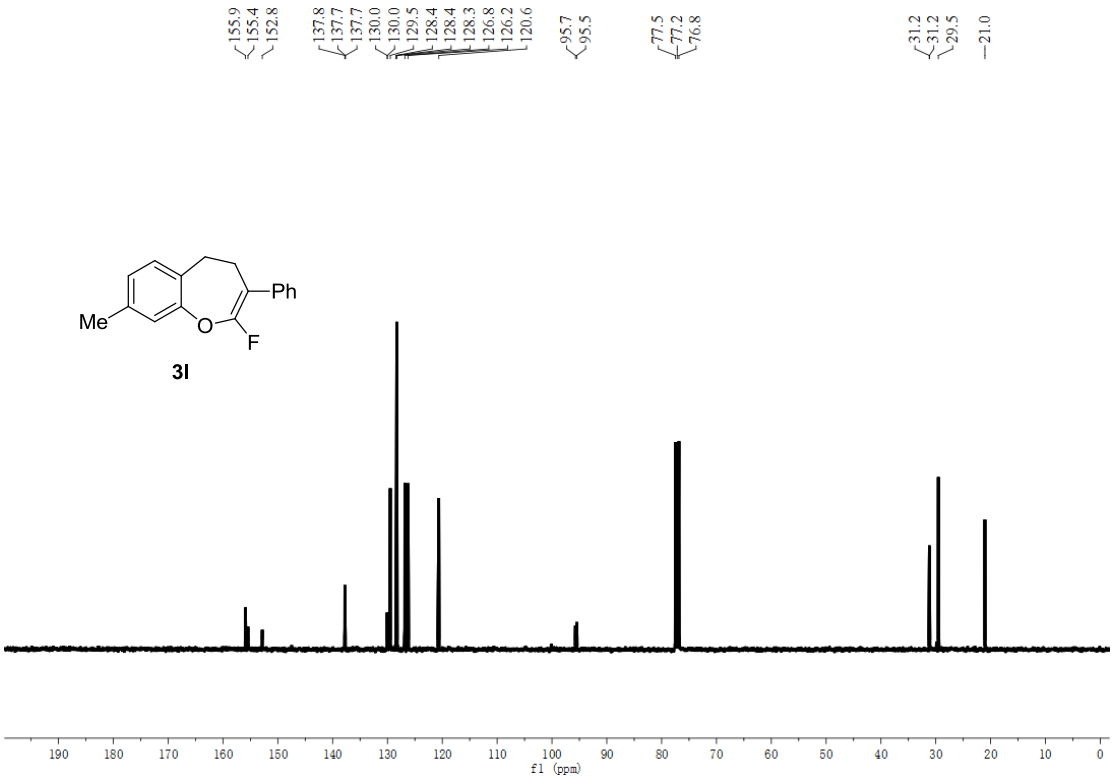
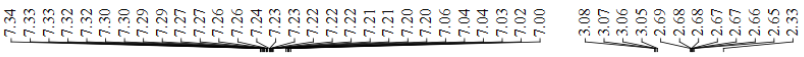
7.32
7.31
7.31
7.30
7.29
7.26
7.26
7.25
7.25
7.24
7.24
7.23
7.22
7.22
7.11
7.09
7.01
6.99
6.97
3.10
3.08
3.07
2.71
2.70
2.69
2.69
2.68
2.68
2.66
2.37
Me
O
F
Ph
3l
4.00
1.00
1.00
2.00
2.00
2.00
3.00
f1 (ppm)


-80.67
Me
O
F
Ph
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

3l


155.9
155.4
152.8
137.8
137.7
137.7
130.0
130.0
129.5
128.4
128.4
128.3
126.8
126.2
120.6
95.7
95.5
77.5
77.2
76.8
31.2
31.2
29.5
21.0
Me
O
F
Ph
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

3l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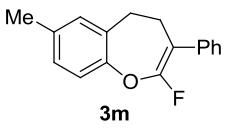
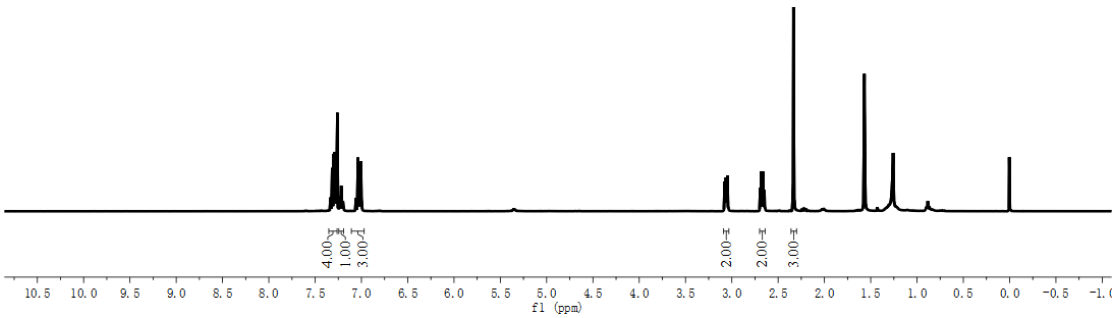
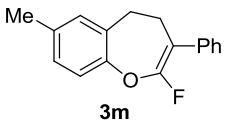
7.33
7.33
7.32
7.32
7.30
7.30
7.29
7.29
7.27
7.27
7.26
7.26
7.24
7.23
7.23
7.22
7.22
7.22
7.21
7.21
7.20
7.20
7.06
7.04
7.04
7.03
7.02
7.00
3.08
3.07
3.06
3.05
2.69
2.68
2.68
2.67
2.67
2.66
2.65
2.33


Me
Ph
O
F

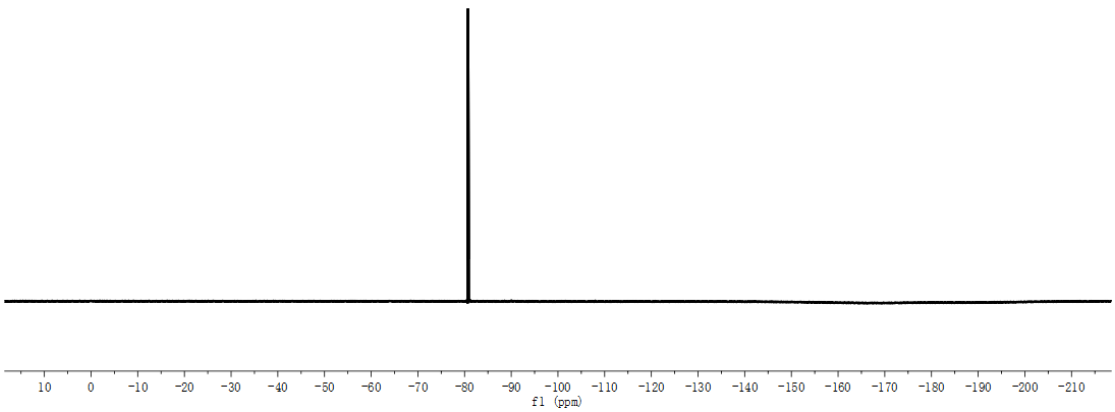
3m

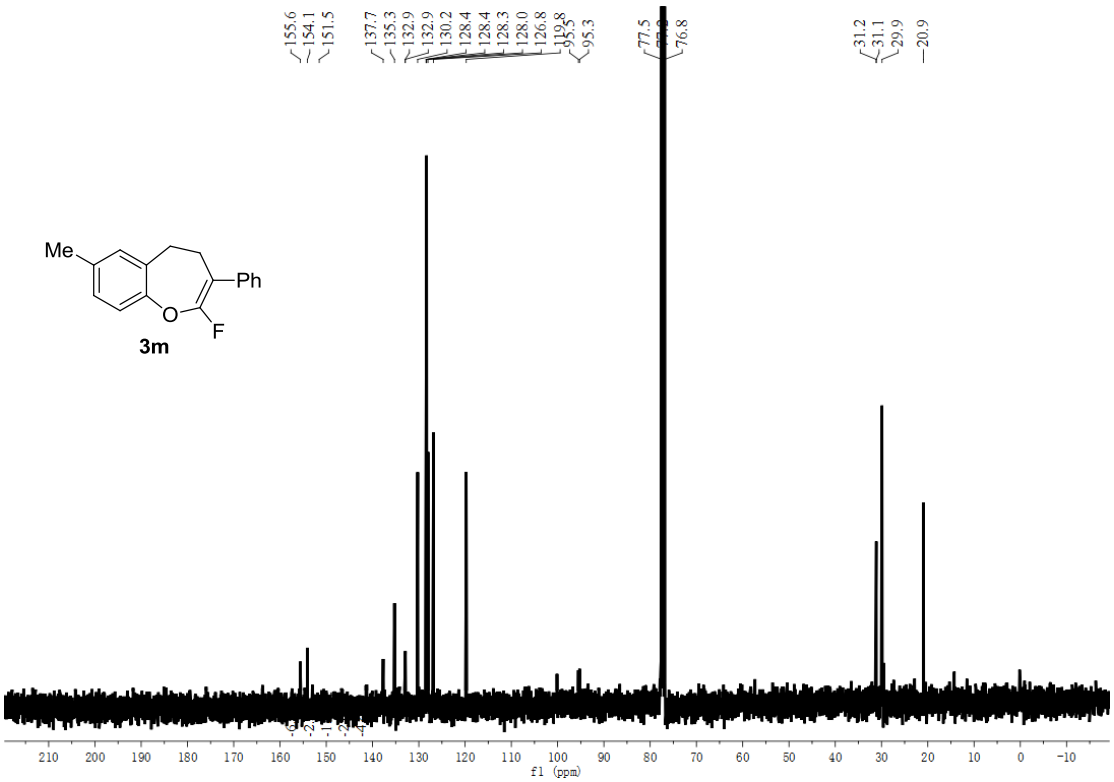

4.00
1.00
3.00
2.00
2.00
3.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

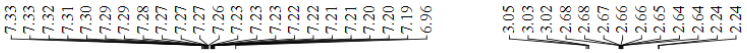

-80.72


Me
Ph
O
F

3m


10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


155.6
154.1
151.5
137.7
135.3
132.9
132.9
130.2
128.4
128.4
128.3
128.0
126.8
119.8
95.5
95.3
77.5
76.8
31.2
31.1
29.9
20.9
Me
Ph
O
F
3m
f1 (ppm)


7.33
7.33
7.32
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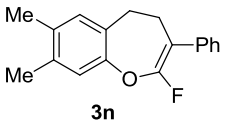
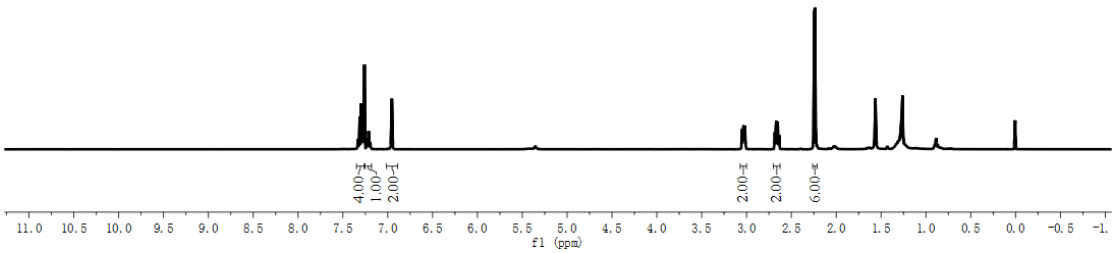
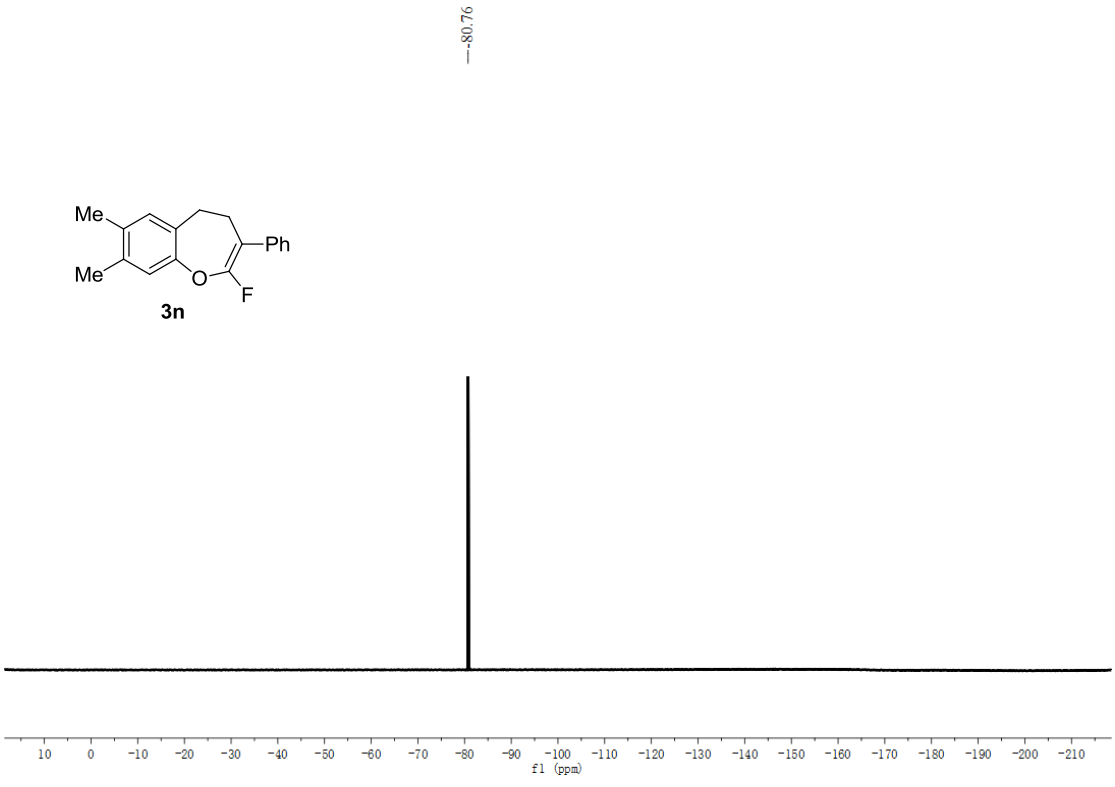
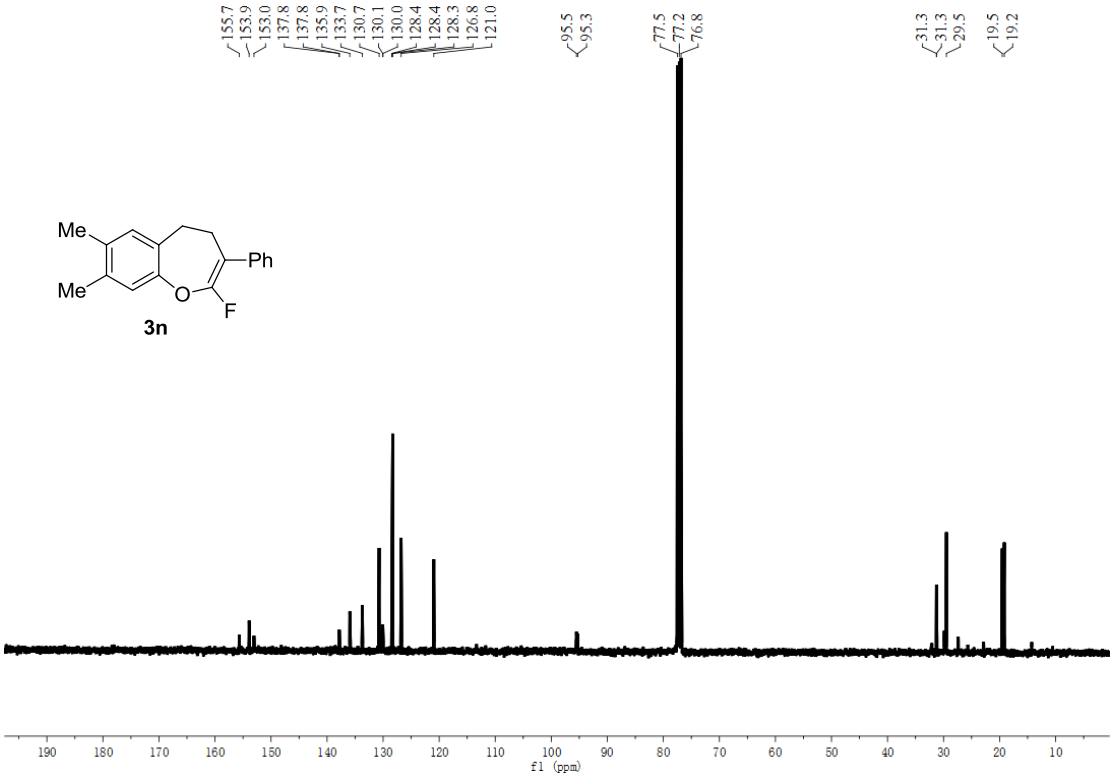
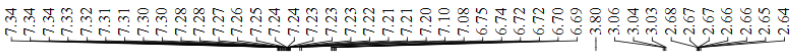
7.29
7.29
7.28
7.27
7.27
7.27
7.26
7.23
7.23
7.23
7.22
7.22
7.21
7.21
7.20
7.20
7.19
6.96
3.05
3.03
3.02
2.68
2.68
2.67
2.66
2.66
2.65
2.64
2.64
2.24
2.24


Me
Me
Ph
O
F
3n


4.00
1.00
2.00
2.00
2.00
6.00
f1 (ppm)


-80.76
Me
Me
Ph
O
F
3n
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


155.7
153.9
153.0
137.8
137.8
135.9
133.7
130.7
130.1
130.0
128.4
128.4
128.3
126.8
121.0
95.5
95.3
77.5
77.2
76.8
31.3
31.3
29.5
19.5
19.2
Me
Me
Ph
O
F
3n
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)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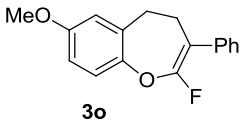
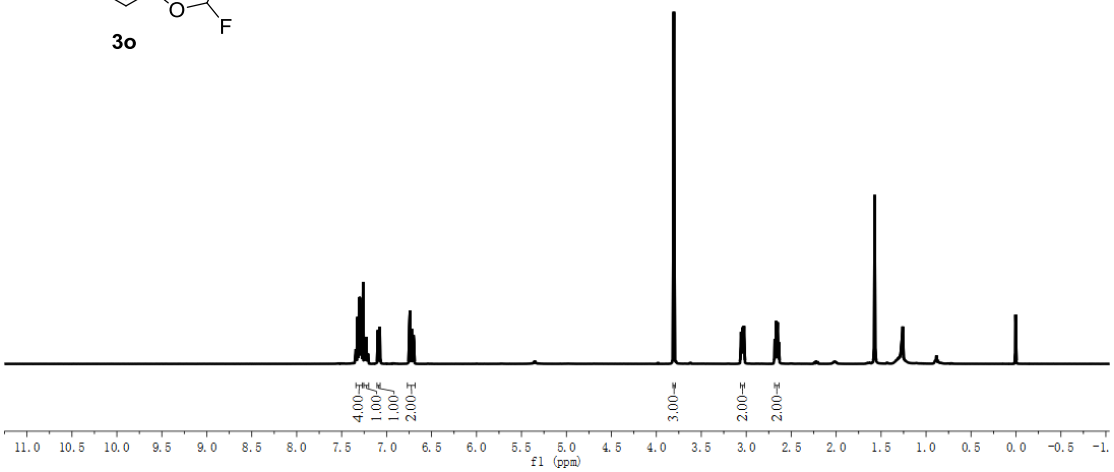
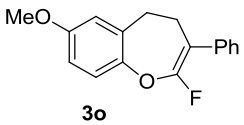
7.34
7.33
7.32
7.31
7.31
7.30
7.30
7.28
7.28
7.27
7.26
7.25
7.24
7.24
7.23
7.23
7.23
7.22
7.21
7.21
7.20
7.10
7.08
6.75
6.74
6.72
6.72
6.70
6.69
3.80
3.06
3.04
3.03
2.68
2.67
2.67
2.66
2.66
2.65
2.64


MeO
Ph
O
F

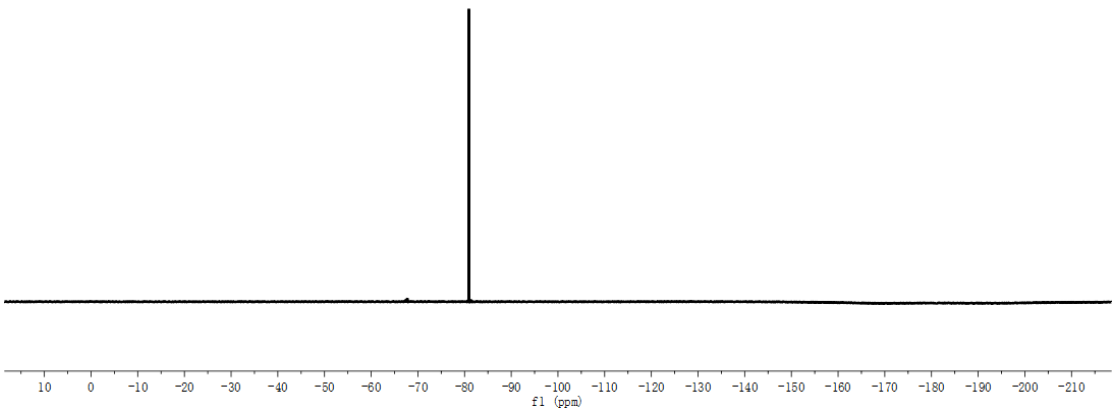
3o

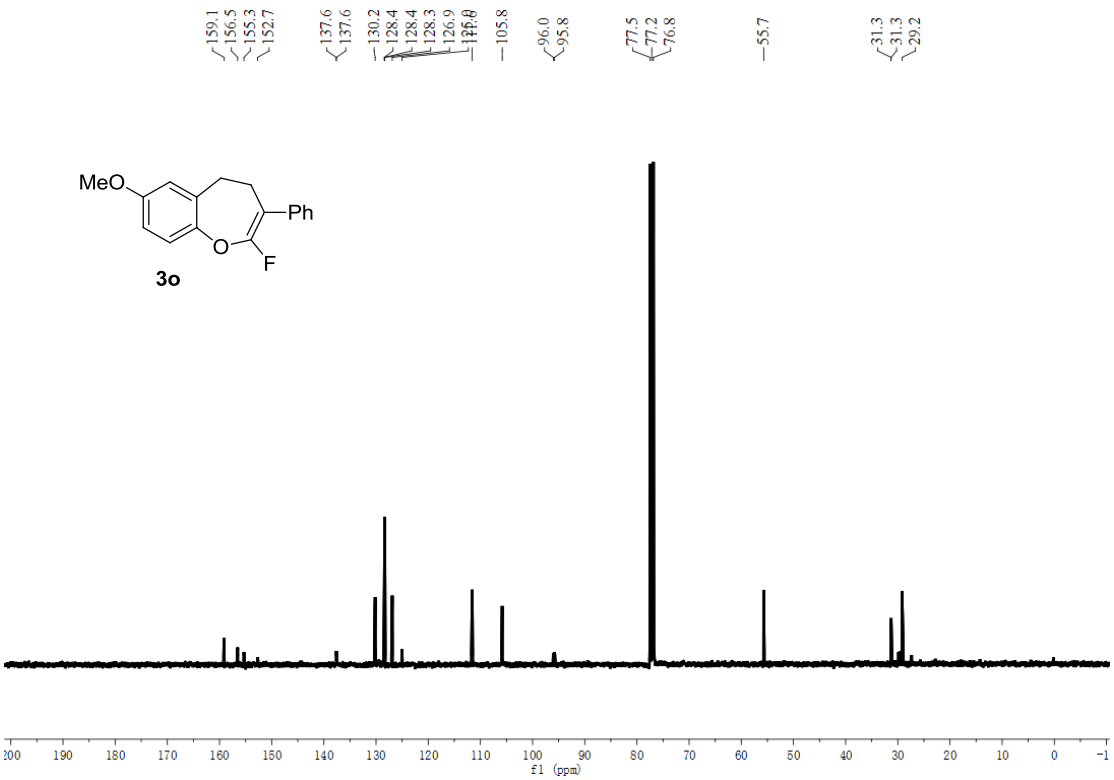

4.00
1.00
1.00
2.00
3.00
2.00
2.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

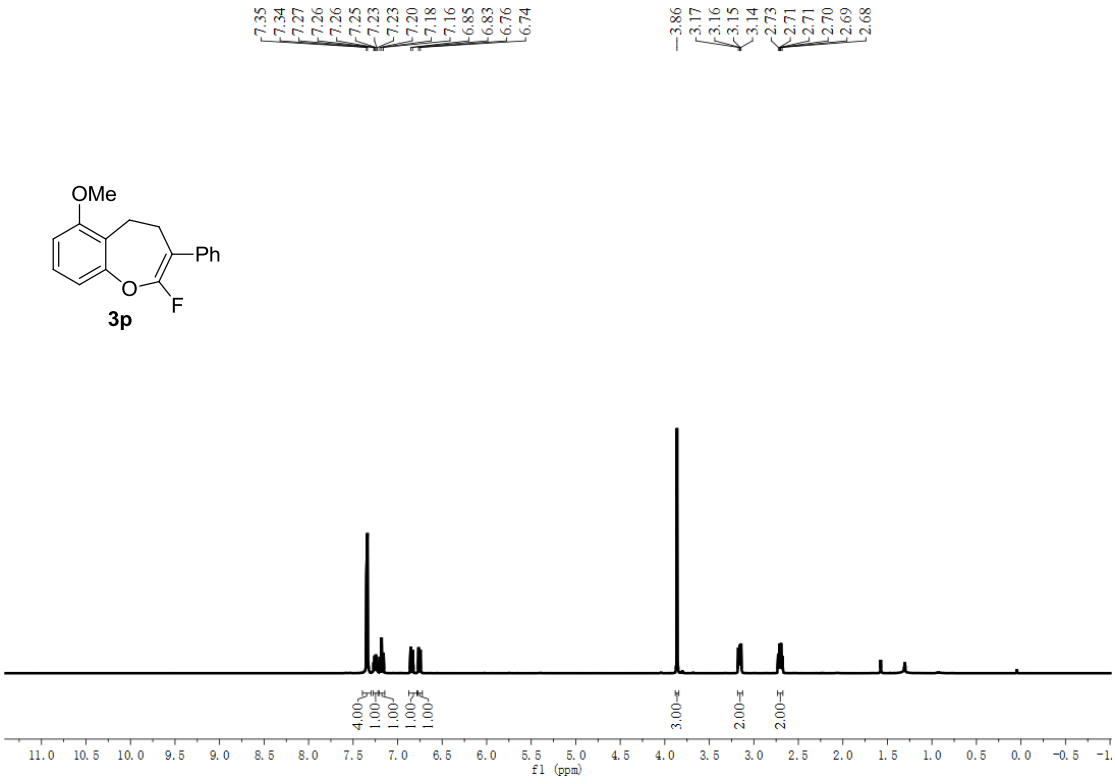

-80.92

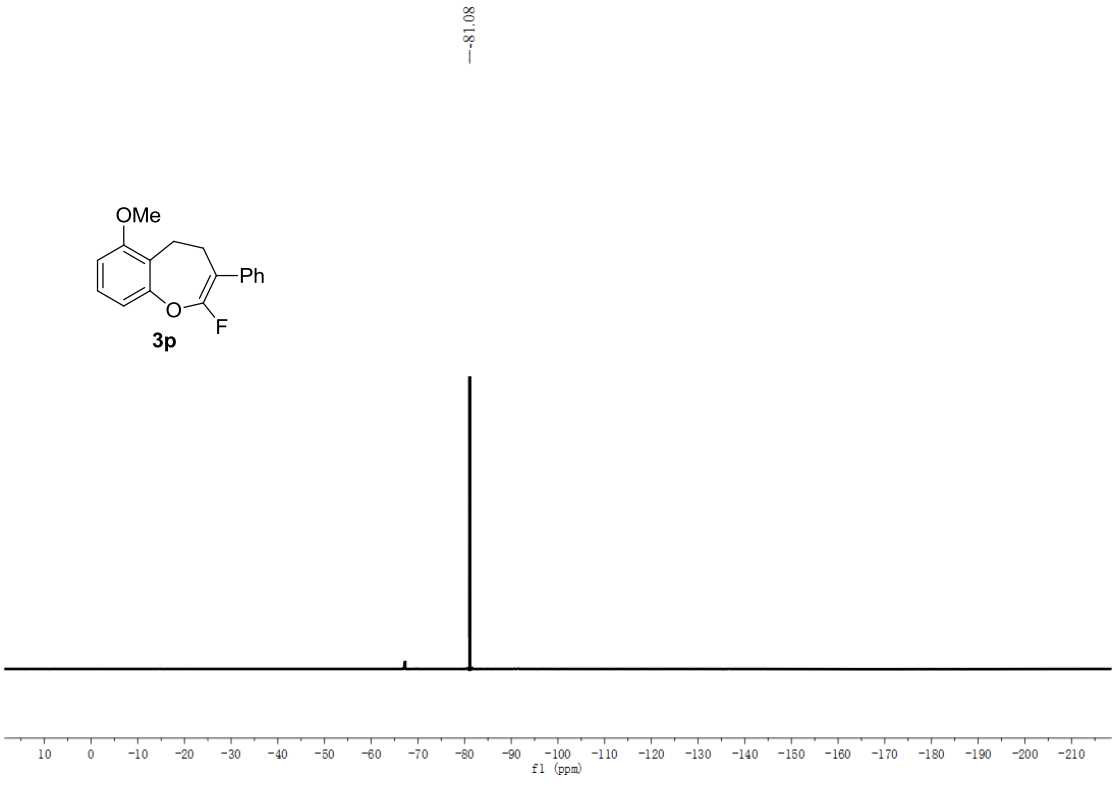

MeO
Ph
O
F

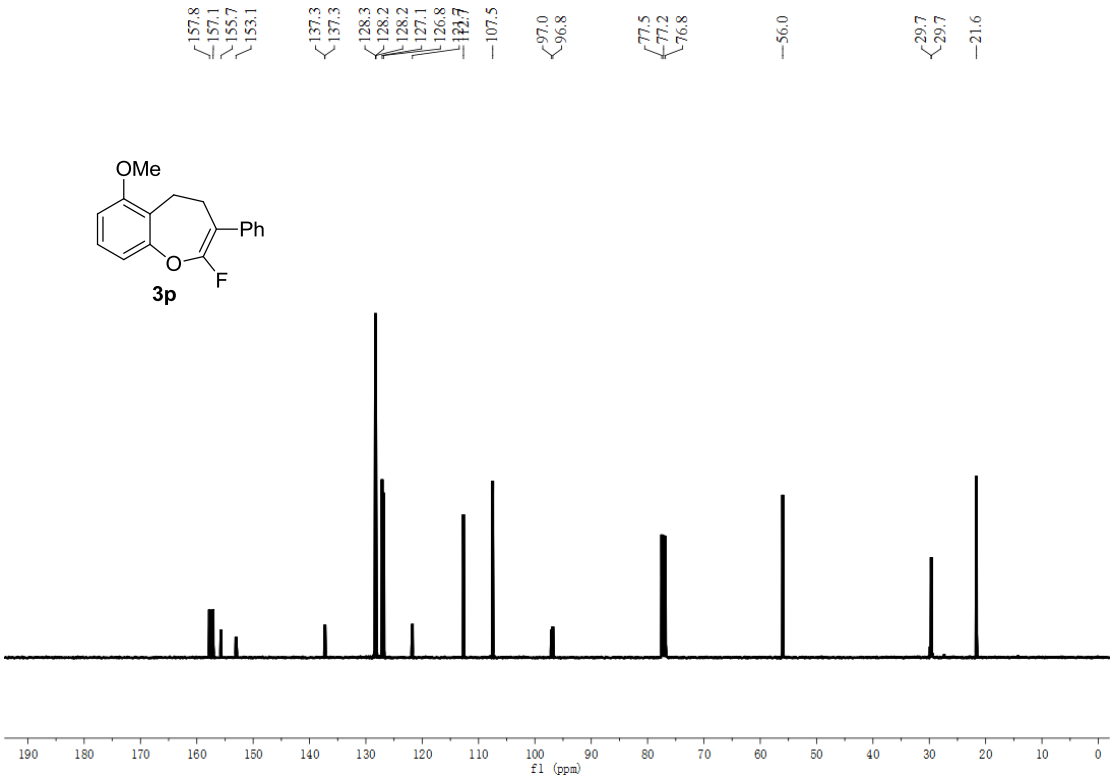
3o

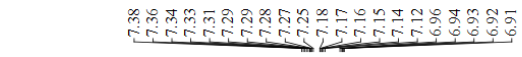

10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


159.1
156.5
155.3
152.7
137.6
137.6
130.2
128.4
128.4
128.3
126.9
105.8
96.0
95.8
77.5
77.2
76.8
55.7
31.3
31.3
29.2
MeO
Ph
O
F
3o
f1 (ppm)


7.35
7.34
7.27
7.26
7.26
7.25
7.23
7.23
7.20
7.18
7.16
6.85
6.83
6.76
6.74
3.86
3.17
3.16
3.15
3.14
2.73
2.71
2.71
2.70
2.69
2.68
OMe
Ph
O
F
3p
4.00
1.00
1.00
1.00
1.00
3.00
2.00
2.00
f1 (ppm)


-81.08
OMe
Ph
O
F
3p
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


157.8
157.1
155.7
153.1
137.3
137.3
128.3
128.2
128.2
127.1
126.8
107.5
97.0
96.8
77.5
77.2
76.8
56.0
29.7
29.7
21.6
OMe
Ph
O
F
3p
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


7.38
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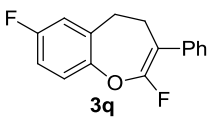
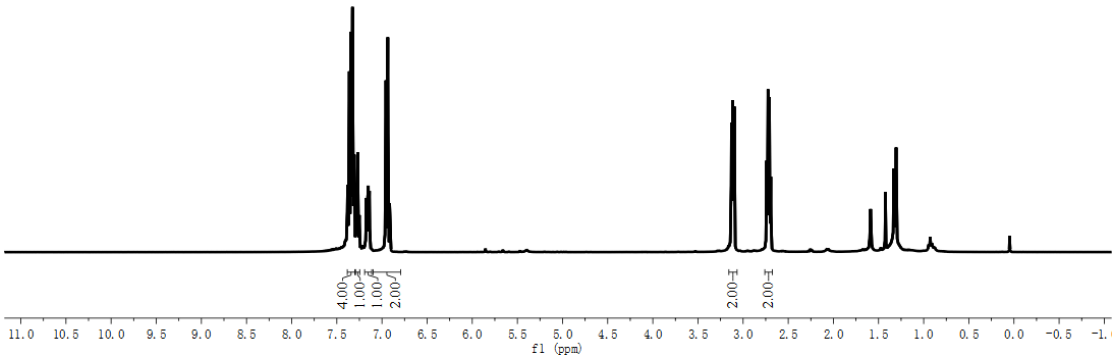
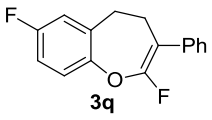
7.28
7.27
7.25
7.18
7.17
7.16
7.15
7.14
7.12
6.96
6.94
6.93
6.92
6.91
3.13
3.11
3.10
2.74
2.73
2.72
2.71
2.71
2.69


F
Ph
O
F

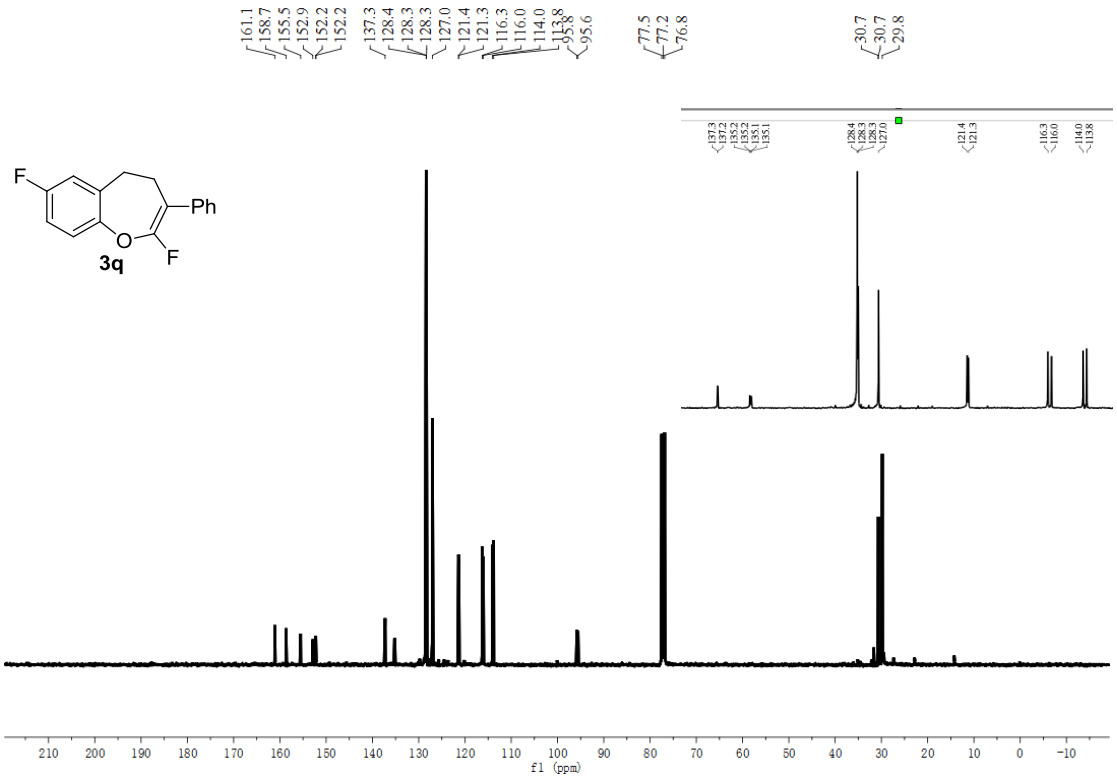
3q

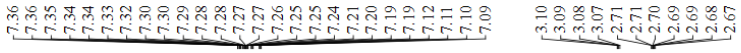

4.00
1.00
1.00
2.00
2.00
2.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

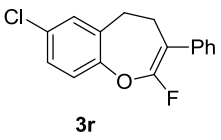

F
Ph
O
F

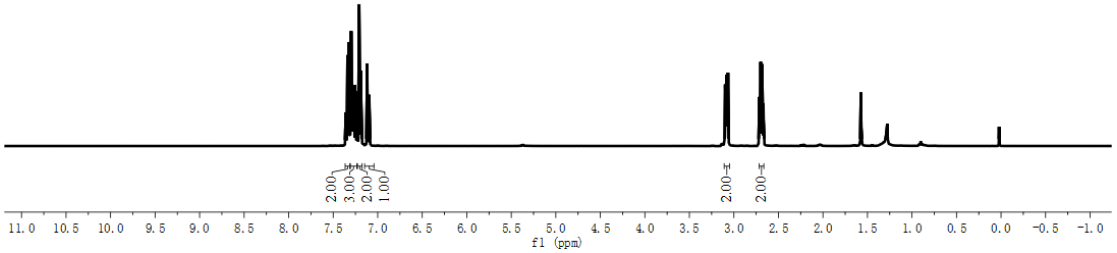
3q

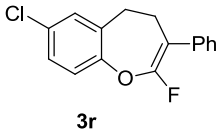
-80.87
-117.35
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


161.1
158.7
155.5
152.9
152.2
152.2
137.3
128.4
128.3
128.3
127.0
121.4
121.3
116.3
116.0
114.0
113.8
95.8
95.6
77.5
77.2
76.8
30.7
30.7
29.8
F
Ph
O
F
3q
f1 (ppm)


7.36
7.36
7.35
7.34
7.34
7.33
7.32
7.30
7.30
7.29
7.28
7.28
7.27
7.27
7.26
7.25
7.25
7.24
7.21
7.20
7.19
7.19
7.12
7.11
7.10
7.09
3.10
3.09
3.08
3.07
2.71
2.71
2.70
2.69
2.69
2.68
2.67

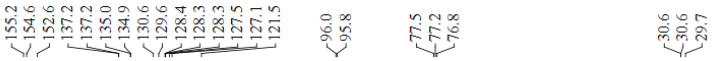

Cl
Ph
O
F
3r

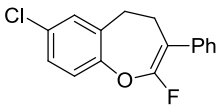

2.00
3.00
2.00
1.00
2.00
2.00
f1 (ppm)


Cl
Ph
O
F

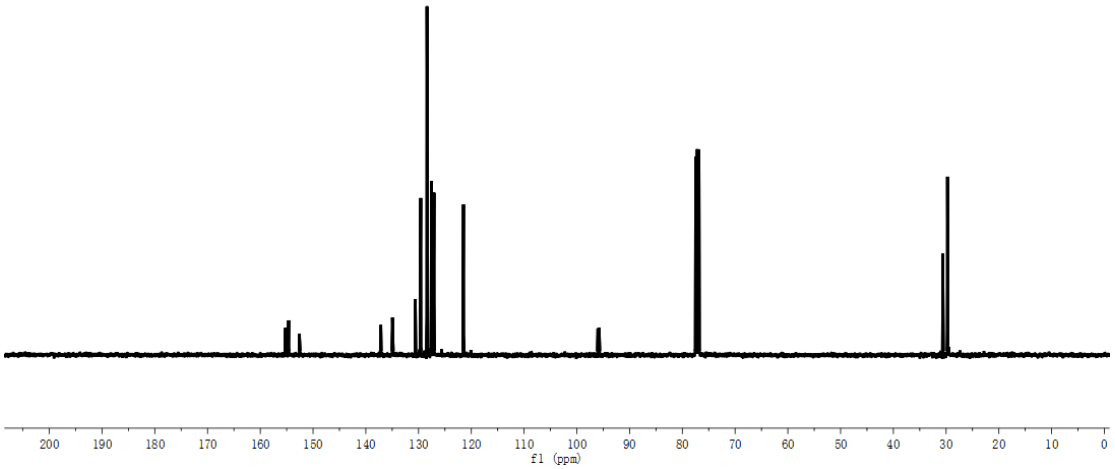
3r

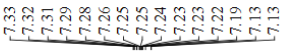
-81.00
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

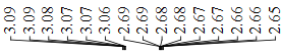

155.2
154.6
152.6
137.2
137.2
135.0
134.9
130.6
129.6
128.4
128.3
128.3
127.5
127.1
121.5
96.0
95.8
77.5
77.2
76.8
30.6
30.6
29.7

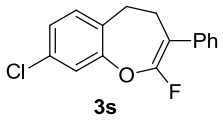

Cl
Ph
O
F

3r

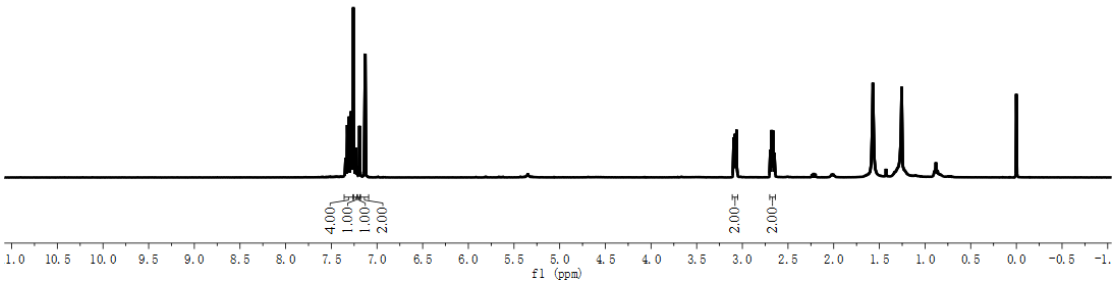

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


7.33
7.32
7.31
7.29
7.28
7.26
7.25
7.25
7.24
7.23
7.23
7.22
7.19
7.13
7.13

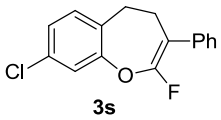

3.09
3.09
3.08
3.07
3.07
3.06
2.69
2.69
2.68
2.68
2.67
2.67
2.66
2.66
2.65


Ph
Cl
O
F

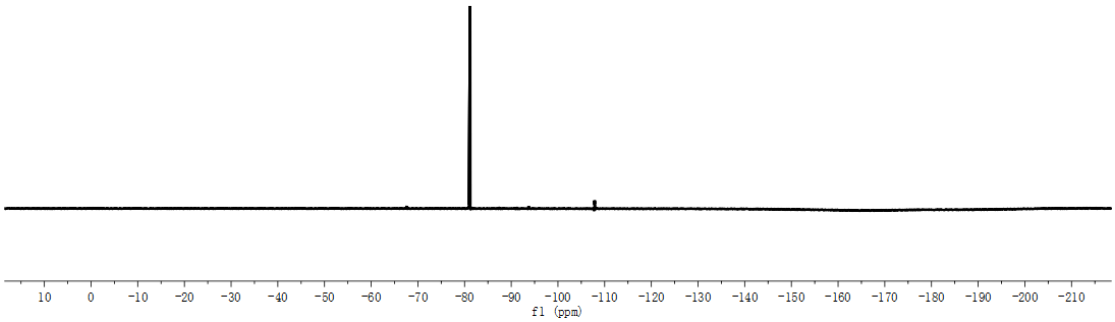
3s

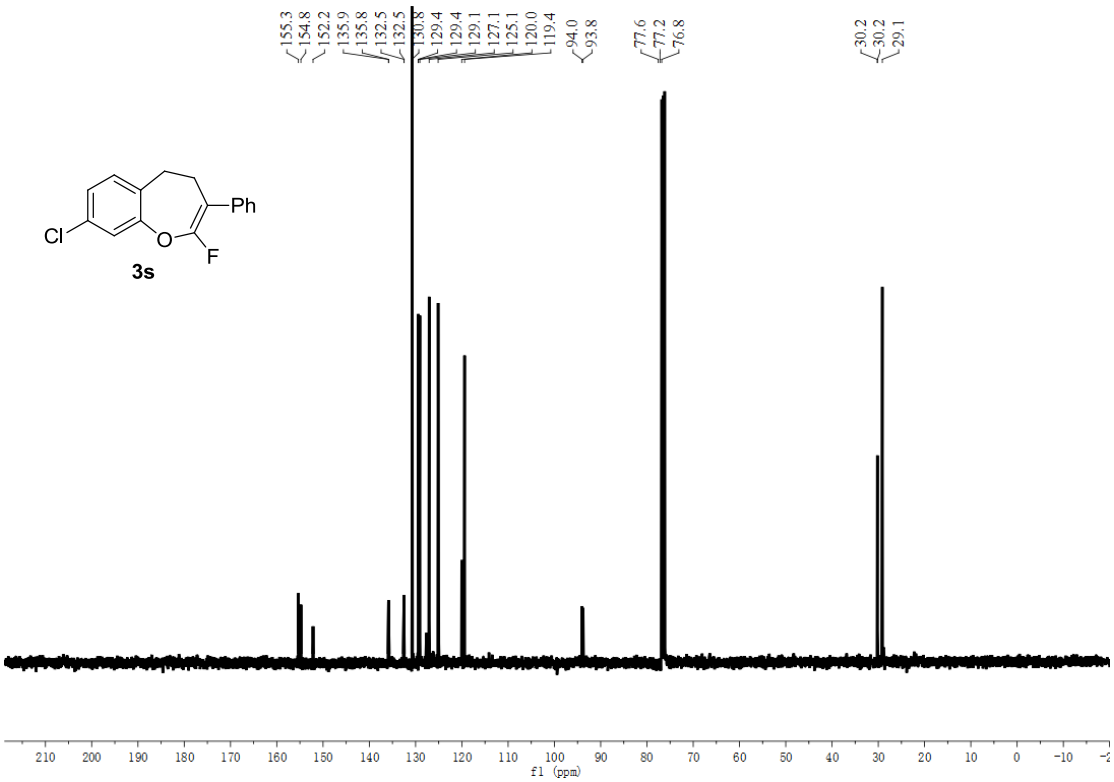

4.00
1.00
1.00
2.00
2.00
2.00
1.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

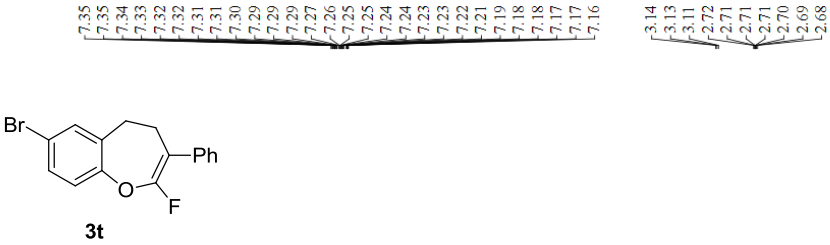

-81.19


Ph
Cl
O
F

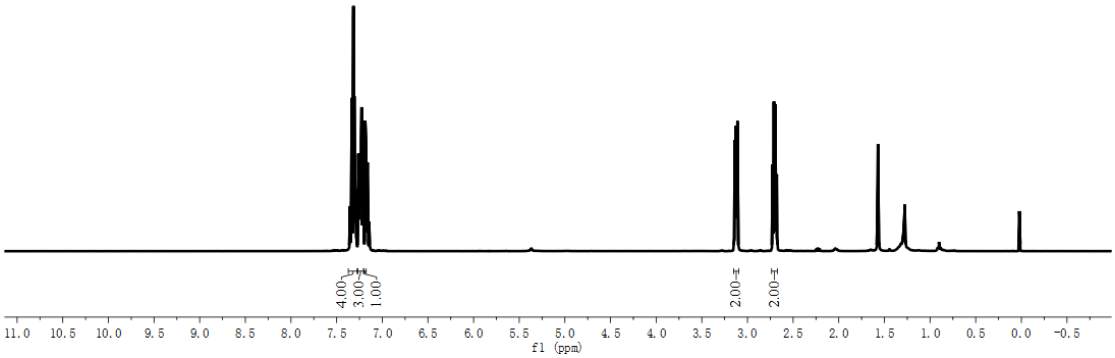
3s

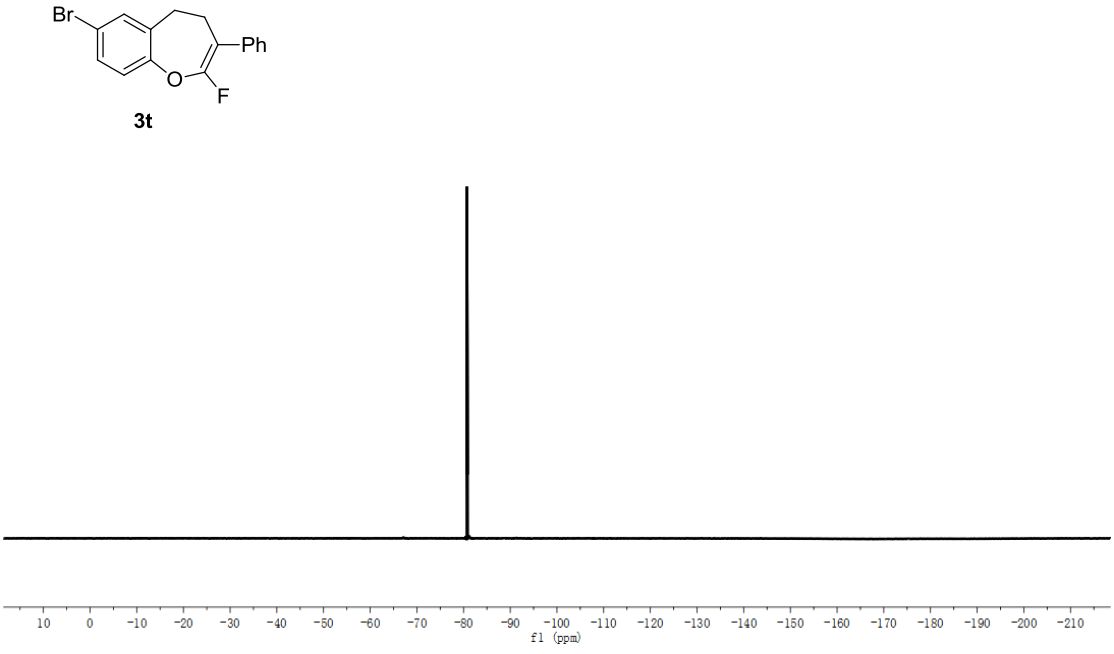

10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

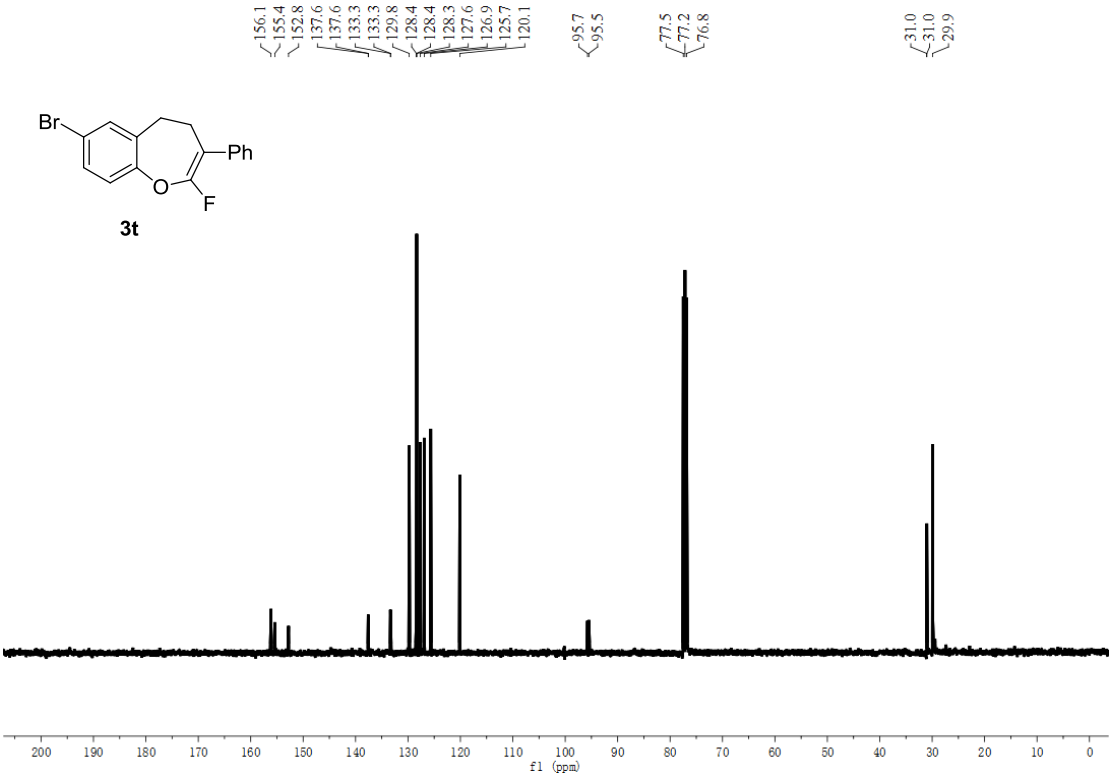

155.3
154.8
152.2
135.9
135.8
132.5
132.5
130.8
129.4
129.4
129.1
127.1
125.1
120.0
119.4
94.0
93.8
77.6
77.2
76.8
30.2
30.2
29.1
Cl
O
Ph
F
3s
f1 (ppm)

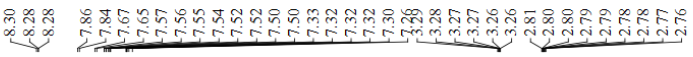

7.35
7.35
7.34
7.33
7.32
7.32
7.31
7.31
7.30
7.29
7.29
7.29
7.27
7.26
7.25
7.25
7.24
7.24
7.23
7.23
7.22
7.21
7.19
7.18
7.18
7.17
7.17
7.16
3.14
3.13
3.11
2.72
2.71
2.71
2.71
2.70
2.69
2.68

Br
O
Ph
F
3t


4.00
3.00
1.00
2.00
2.00
f1 (ppm)


-80.71
Br
Ph
O
F
3t
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


156.1
155.4
152.8
137.6
137.6
133.3
133.3
129.8
128.4
128.4
128.3
127.6
126.9
125.7
120.1
95.7
95.5
77.5
77.2
76.8
31.0
31.0
29.9
Br
Ph
O
F
3t
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


8.30
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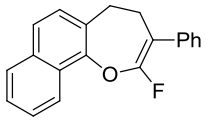
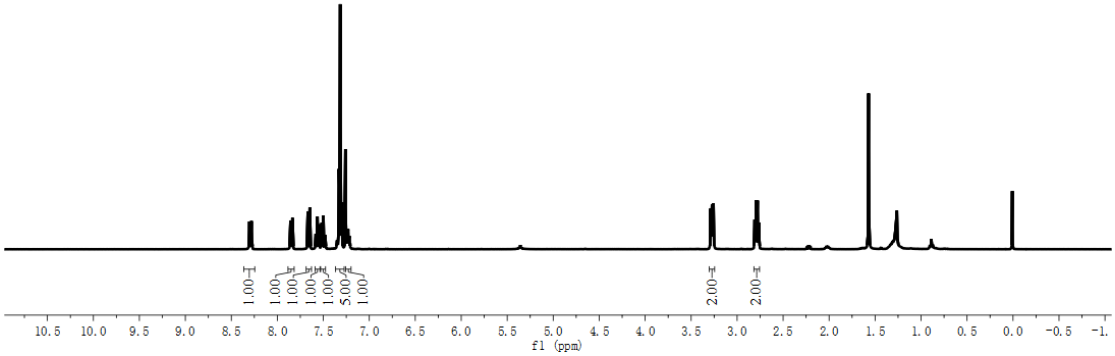
8.28
7.86
7.84
7.67
7.65
7.57
7.56
7.55
7.54
7.52
7.52
7.50
7.50
7.33
7.32
7.32
7.30
3.28
3.27
3.27
3.26
3.26
2.81
2.80
2.80
2.79
2.79
2.78
2.78
2.77
2.76


Ph
O
F

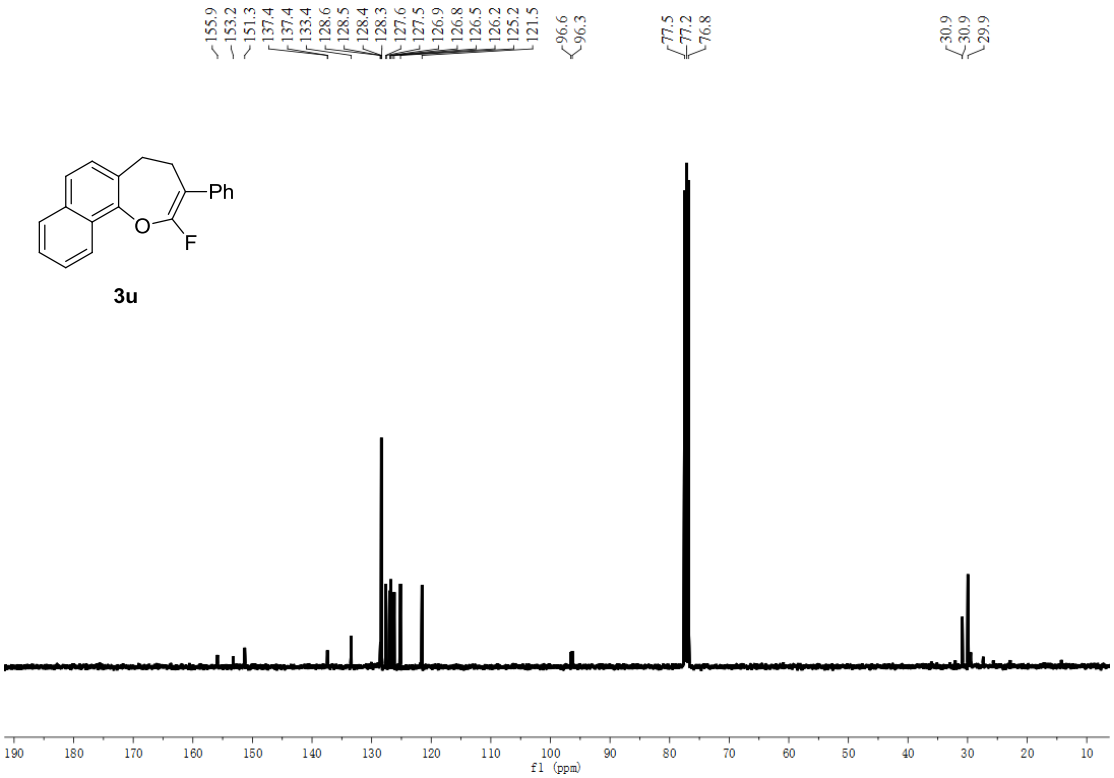
3u


1.00
1.00
1.00
1.00
5.00
1.00
2.00
2.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

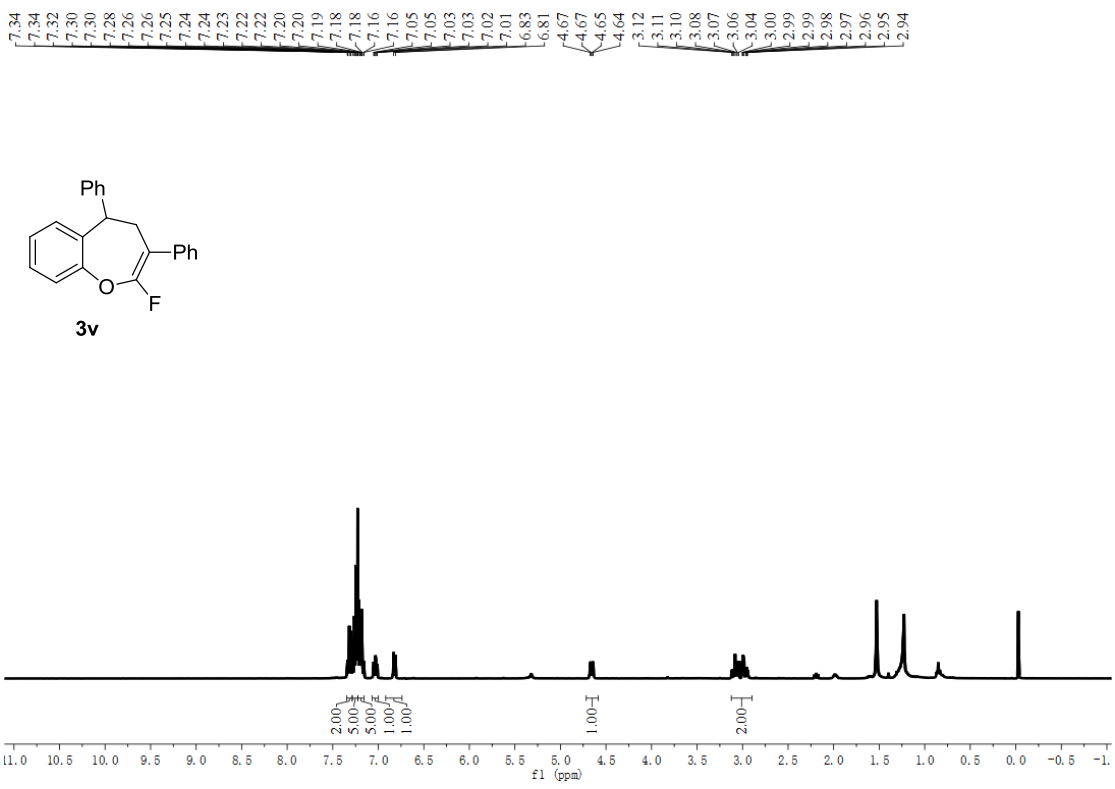

-80.94
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

Ph
O
F

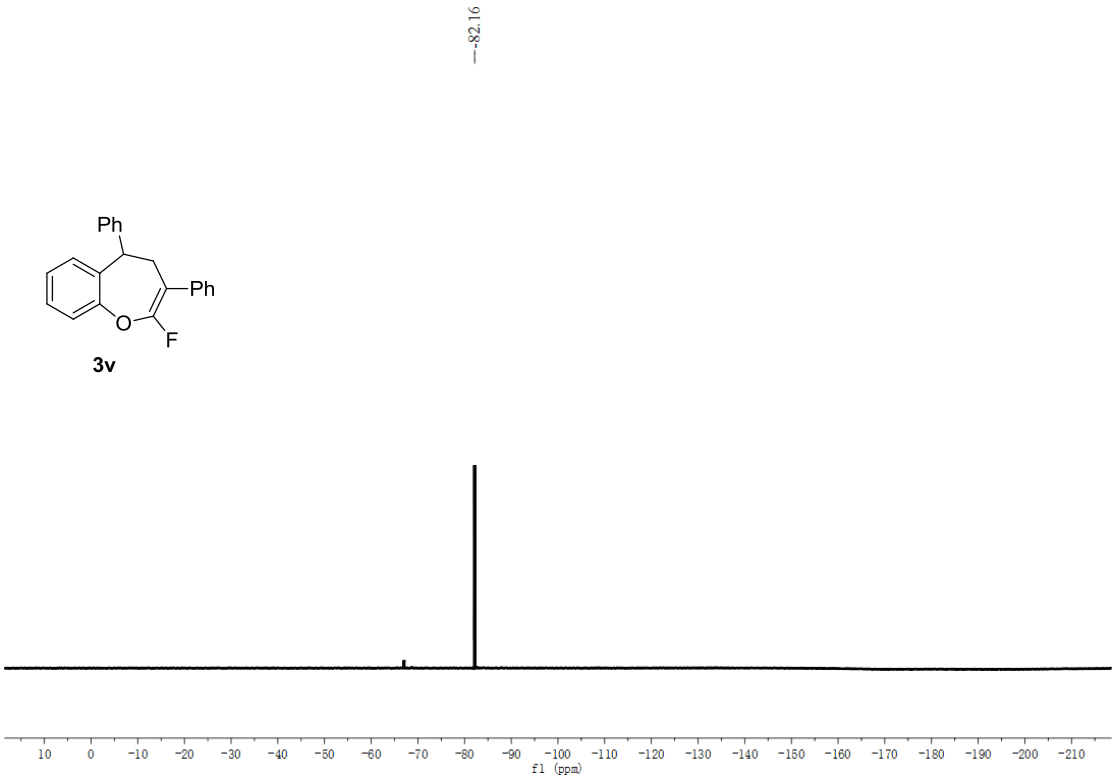
3u

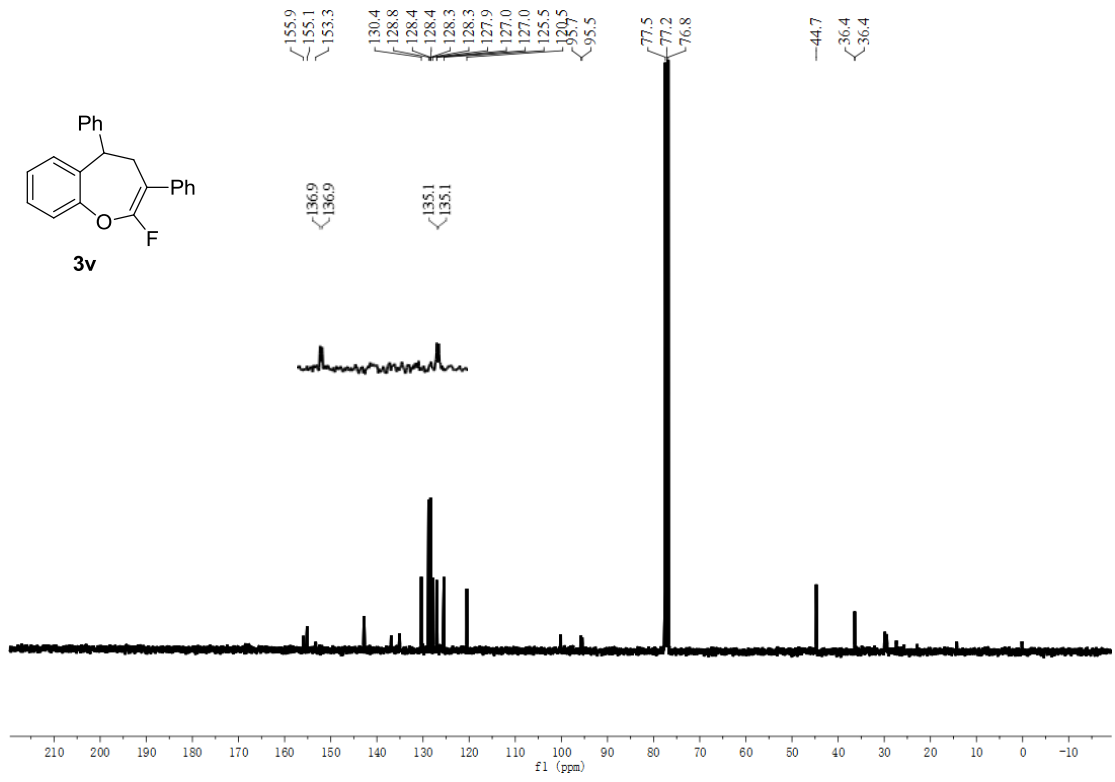

155.9
153.2
151.3
137.4
137.4
133.4
128.6
128.5
128.4
128.3
127.6
127.5
126.9
126.8
126.5
126.2
125.2
121.5
96.6
96.3
77.5
77.2
76.8
30.9
30.9
29.9
Ph
O
F
f1 (ppm)

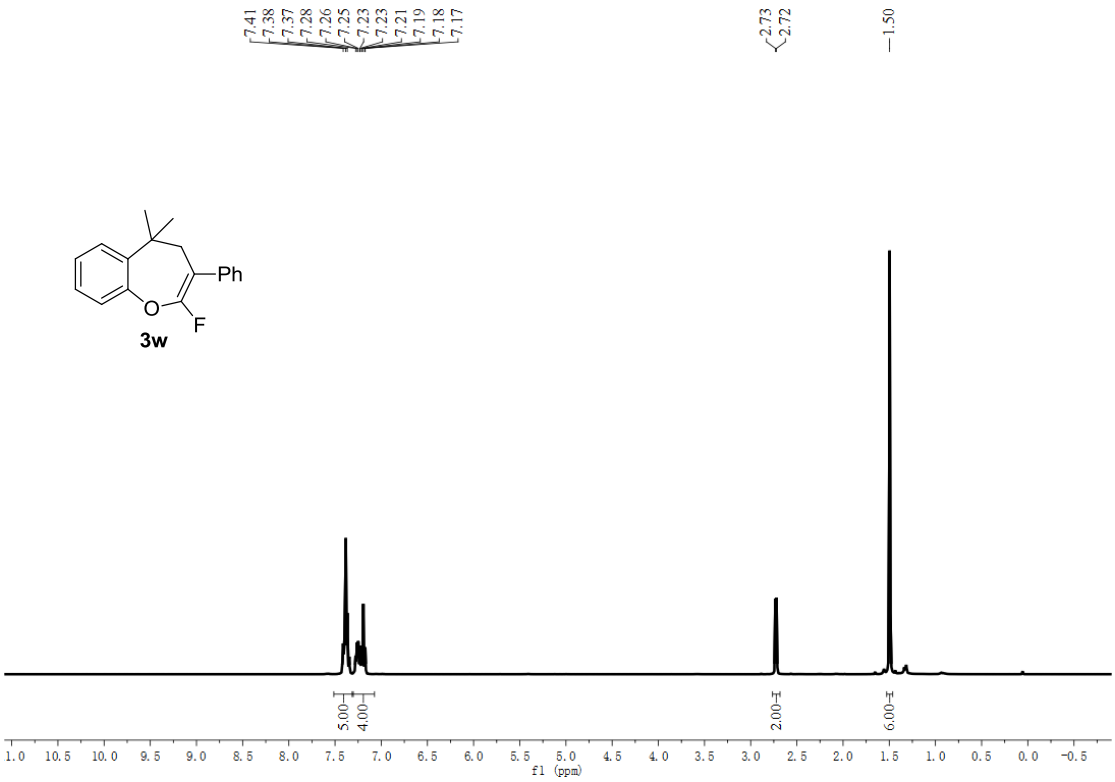
3u

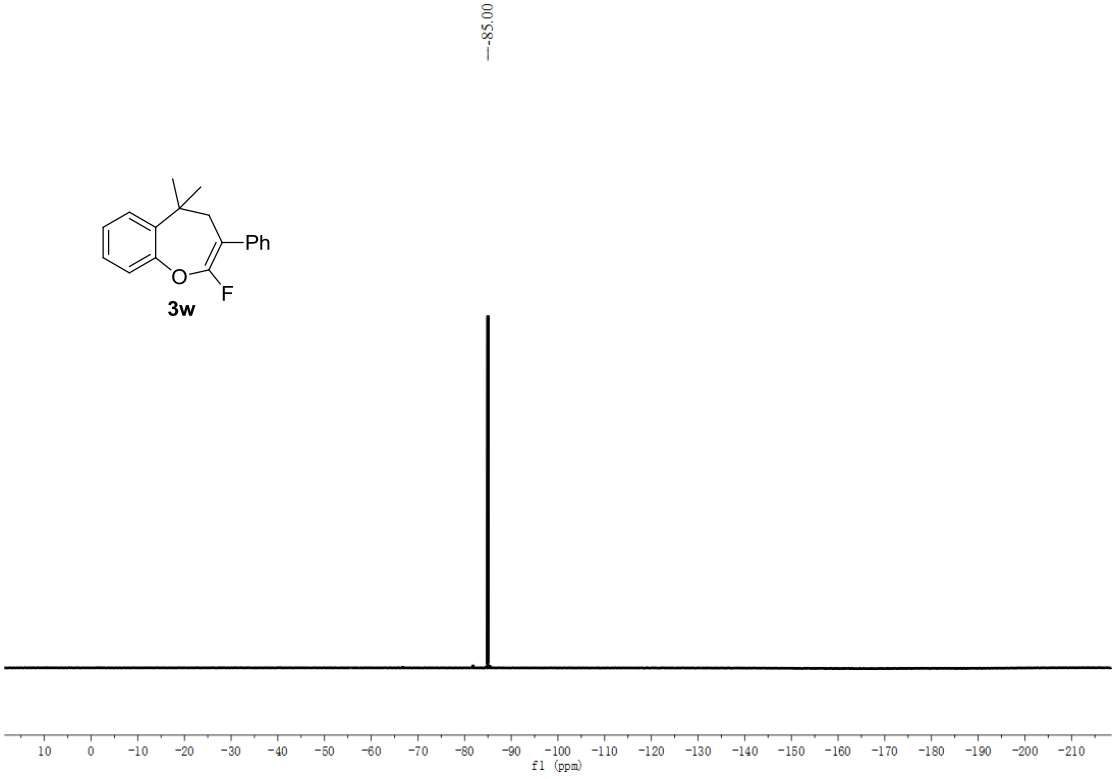

7.34
7.34
7.32
7.30
7.30
7.28
7.26
7.26
7.25
7.24
7.24
7.23
7.22
7.22
7.20
7.20
7.19
7.18
7.18
7.16
7.16
7.05
7.05
7.03
7.03
7.02
7.01
6.83
6.81
4.67
4.67
4.65
4.64
3.12
3.11
3.10
3.08
3.07
3.06
3.04
3.00
2.99
2.99
2.98
2.97
2.96
2.95
2.94
Ph
Ph
O
F
2.00
5.00
5.00
1.00
1.00
1.00
2.00
f1 (ppm)

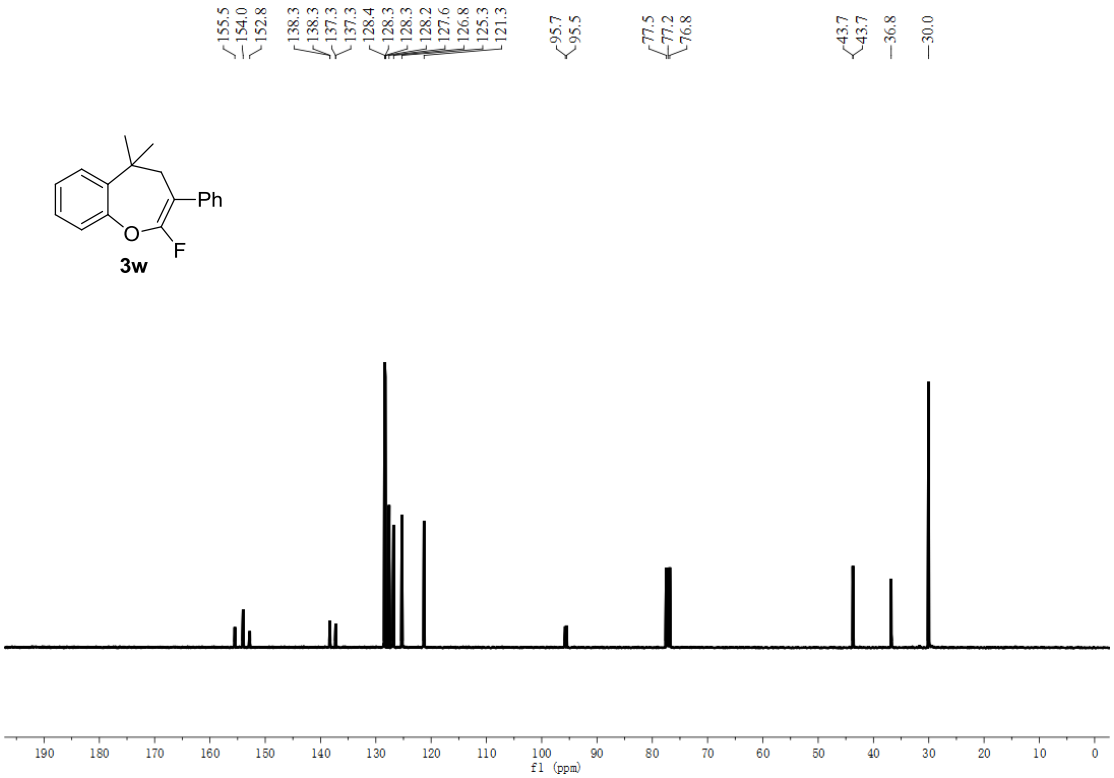
3v

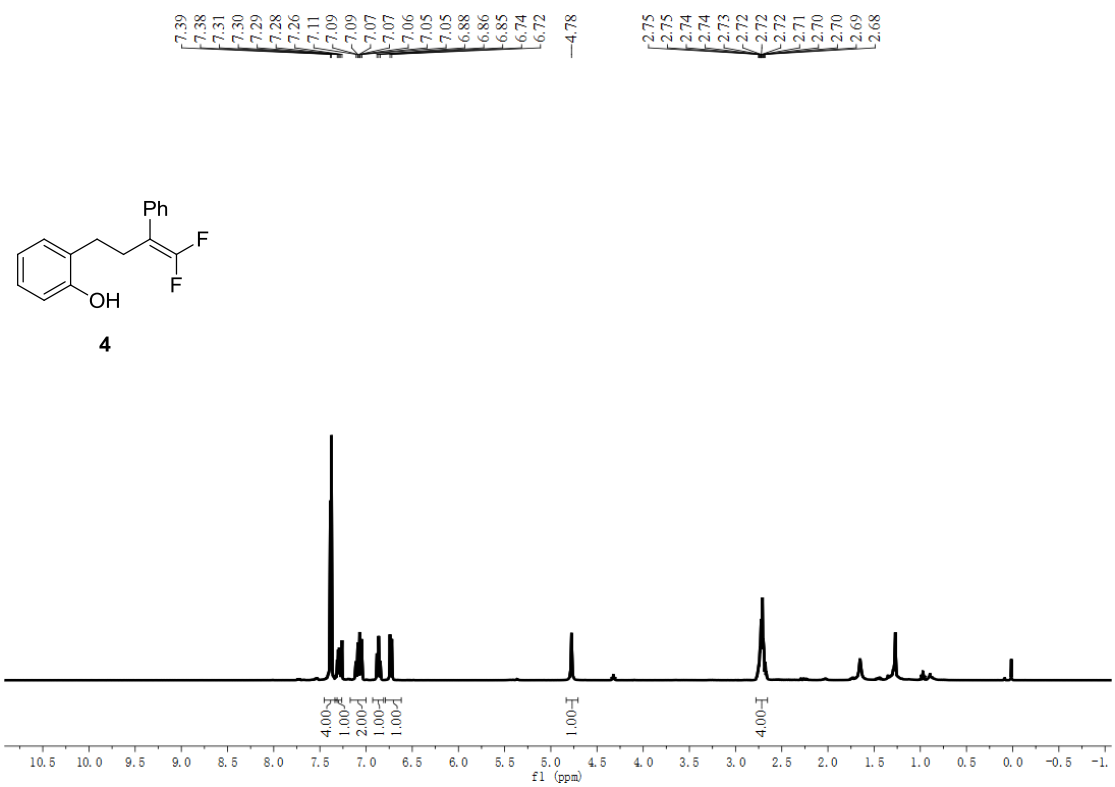

-82.16
Ph
Ph
O
F
3v
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

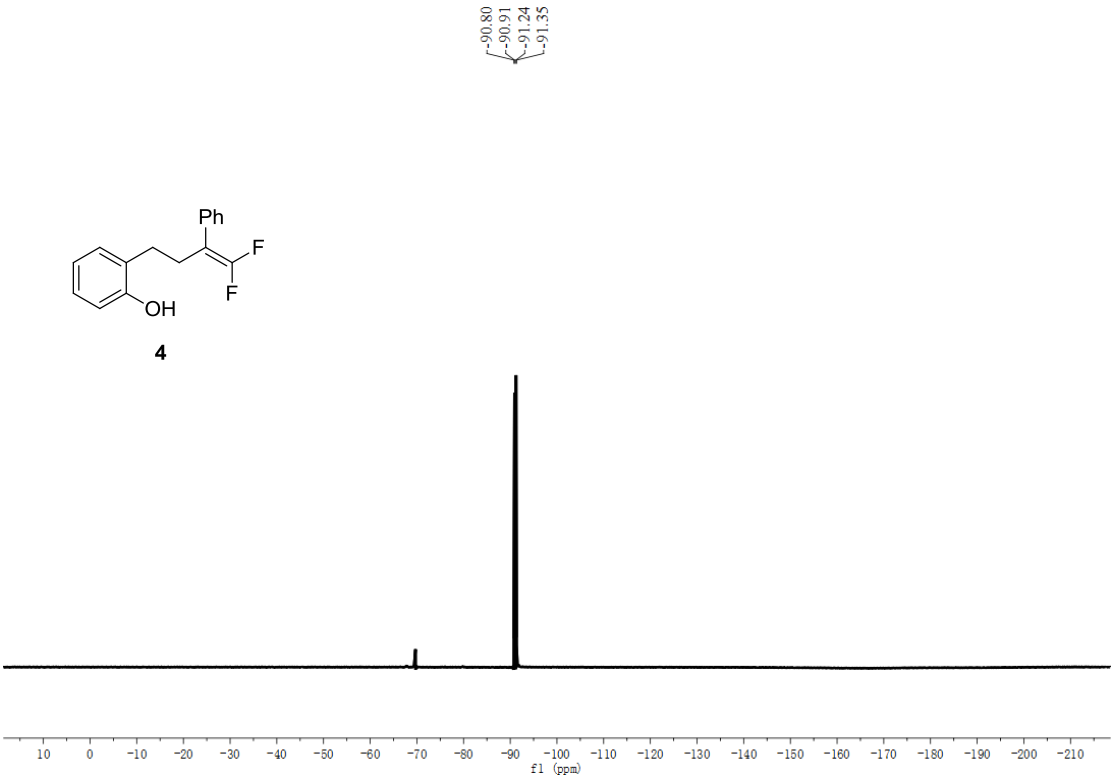

155.9
155.1
153.3
130.4
128.8
128.4
128.4
128.3
128.3
127.9
127.0
127.0
125.5
120.5
95.7
95.5
77.5
77.2
76.8
44.7
36.4
36.4
136.9
136.9
135.1
135.1
Ph
Ph
O
F
3v
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


7.41
7.38
7.37
7.28
7.26
7.25
7.23
7.23
7.21
7.19
7.18
7.17
2.73
2.72
1.50
Ph
O
F
3w
5.00
4.00
2.00
6.00
f1 (ppm)

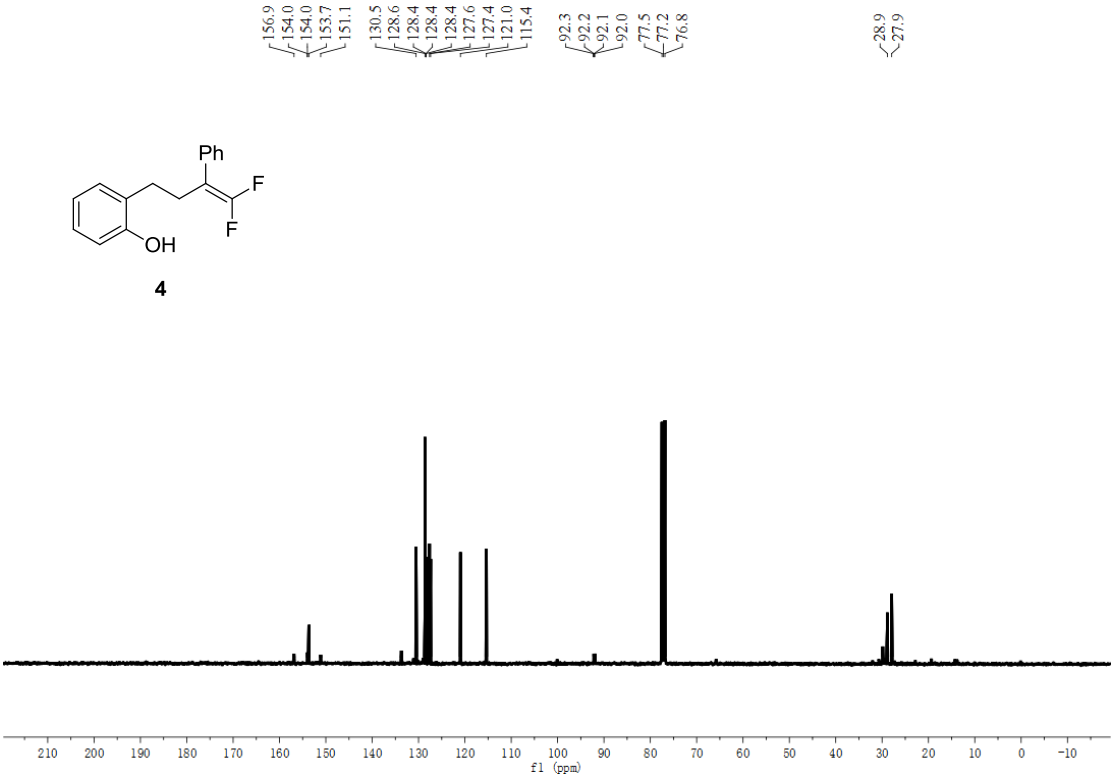

-85.00
Ph
O
F
3w
f1 (ppm)


155.5
154.0
152.8
138.3
138.3
137.3
137.3
128.4
128.3
128.3
128.2
127.6
126.8
125.3
121.3
95.7
95.5
77.5
77.2
76.8
43.7
43.7
36.8
30.0
Ph
O
F
3w
f1 (ppm)

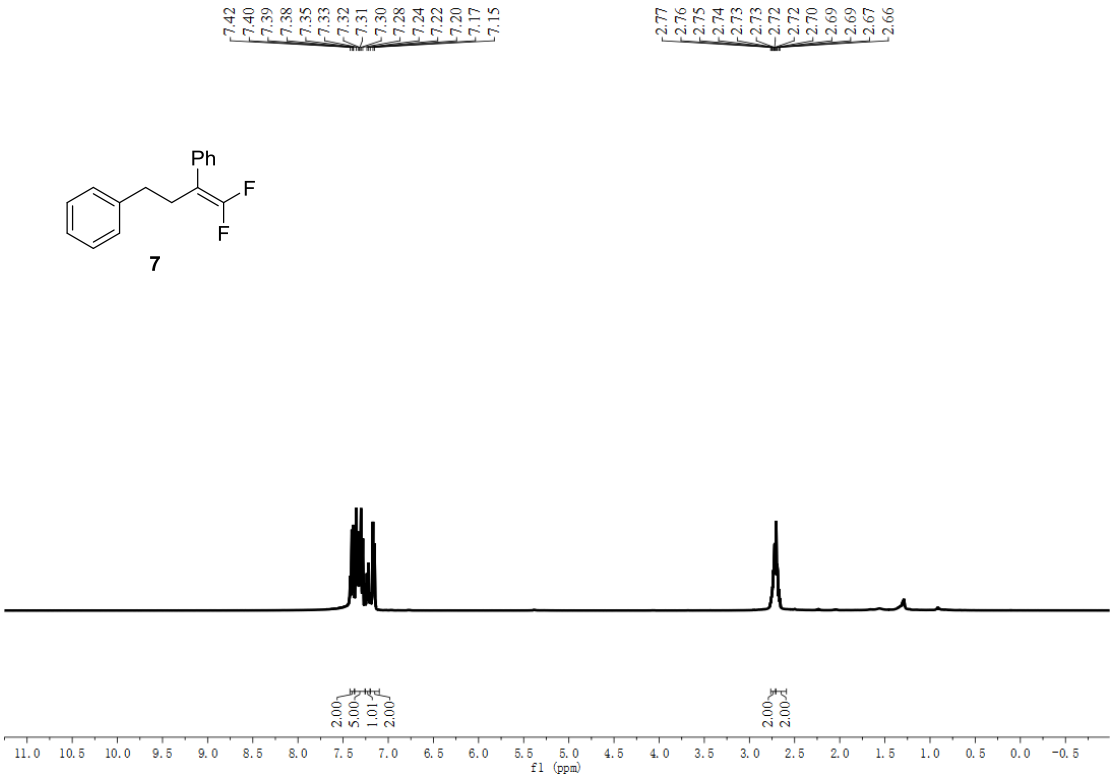

7.39
7.38
7.31
7.30
7.29
7.28
7.26
7.11
7.09
7.09
7.07
7.07
7.06
7.05
7.05
6.88
6.86
6.85
6.74
6.72
4.78
2.75
2.75
2.74
2.74
2.73
2.72
2.72
2.72
2.72
2.71
2.70
2.70
2.69
2.68
Ph
F
F
OH
4
4.00
1.00
2.00
1.00
1.00
1.00
4.00
f1 (ppm)

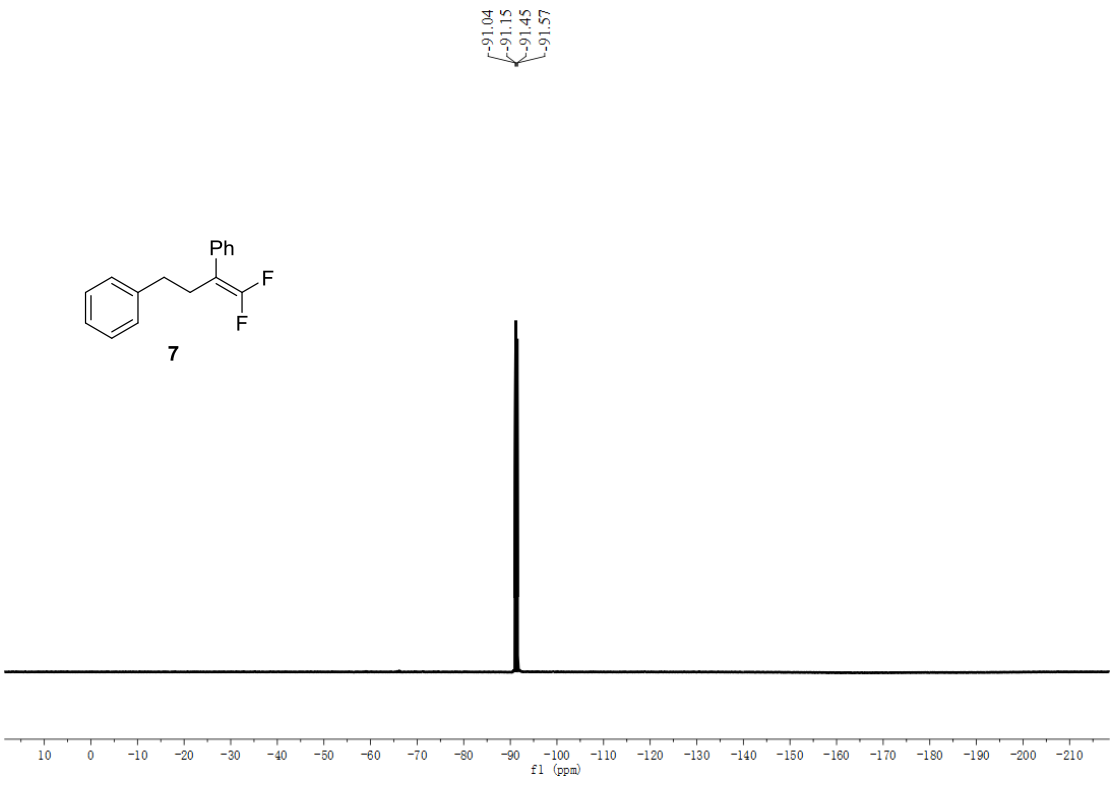

-90.80
-90.91
-91.24
-91.35
Ph
F
F
OH
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

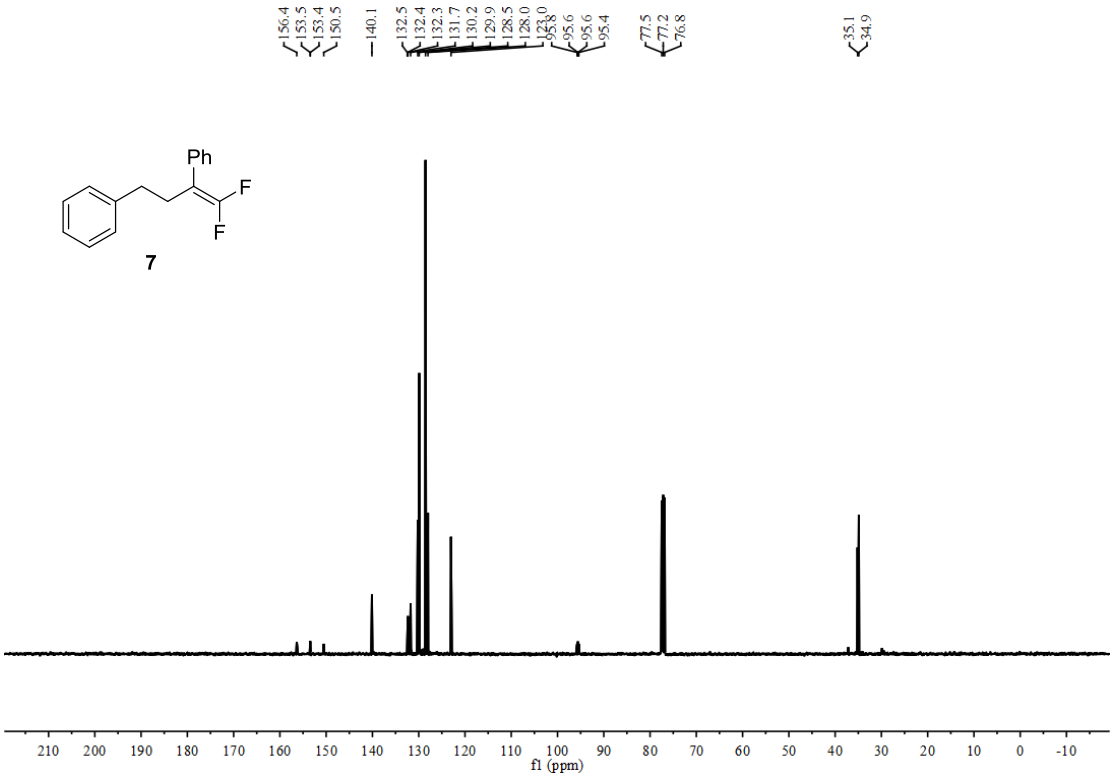
4


156.9
154.0
154.0
153.7
151.1
130.5
128.6
128.4
128.4
128.4
127.6
127.4
121.0
115.4
92.3
92.2
92.1
92.0
77.5
77.2
76.8
28.9
27.9
Ph
F
F
OH
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

4


7.42
7.40
7.39
7.38
7.35
7.33
7.32
7.31
7.30
7.28
7.24
7.22
7.20
7.17
7.15
2.77
2.76
2.75
2.74
2.73
2.73
2.72
2.72
2.70
2.69
2.69
2.67
2.66
Ph
F
F
7
2.00
5.00
1.01
2.00
2.00
2.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


-91.04
-91.15
-91.45
-91.57
Ph
F
F
7
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


156.4
153.5
153.4
150.5
140.1
132.5
132.4
132.3
131.7
130.2
129.9
128.5
128.0
123.0
95.8
95.6
95.6
95.4
77.5
77.2
76.8
35.1
34.9
Ph
F
F
7
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)