Electronic Supplementary Material (ESI) for ChemComm.

Supporting Information for

Ru-catalysed C(sp^2)–H vinylation/annulation of benzoic acids and alkynes: rapid access to medium-sized lactones

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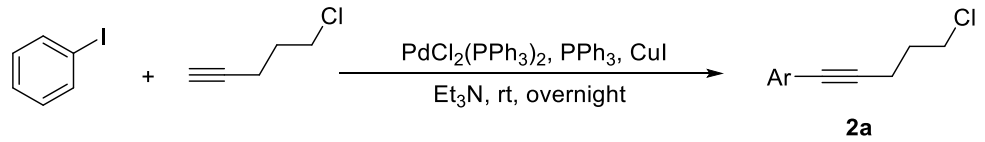
Table of Contents

1. General Information

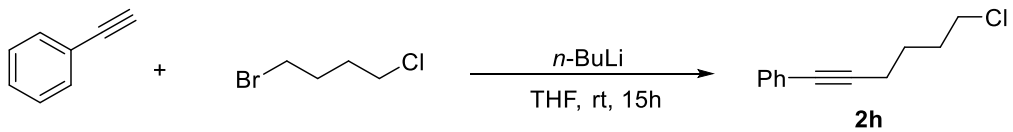
Unless otherwise noted, materials were purchased from commercial suppliers and used without further purification. The solvents used were purified by distillation over the drying agents. All reactions were monitored by thin-layer chromatography (TLC) on silica gel plates using UV light as visualizing agent (if applicable). Flash column chromatography was performed using 200-300 mesh silica gel. ^{1}H NMR spectra were recorded on 400/600 MHz spectrophotometers. Chemical shifts are reported in delta (δ (ppm)) units in parts per million (ppm) relative to the singlet (0 ppm) for tetramethylsilane (TMS). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, m = multiplet), coupling constants (Hz) and integration. ^{13}C NMR spectra were recorded on Varian Mercury 400 (100 MHz) with complete proton decoupling spectrophotometers ($CDCl_3$: 77.0 ppm).

2. Preparation of Substrates



2a

CuI (18 mg, 1 mol%), $PdCl_2(PPh_3)_2$ (36 mg, 5 mol%.) and PPh_3 (18 mg, 7 mol%) were added into a 100 mL flask. Then Et_3N (50 mL), iodobenzene (2.0 g, 10 mmol) and 5-chloro-1-pentyne (1.0 g, 10 mmol) was added into the flask. The resultant mixture was stirred at room temperature until the reaction was completed, as monitored by TLC. Then, H_2O (20 mL) was added and the resulting mixture was extracted with EtOAc (3×20 mL). The combined organic layers were washed with brine (20 mL), dried over $NaSO_4$, filtered, and the volatiles were removed under reduced pressure. The residue was purified by column chromatography to give the compound **2a** in 82% yield as a yellow oil. Other alkynes (**2b-2g**) were prepared according to the above procedure. The alkynes **(2b-2e, 2g)** are known compounds.



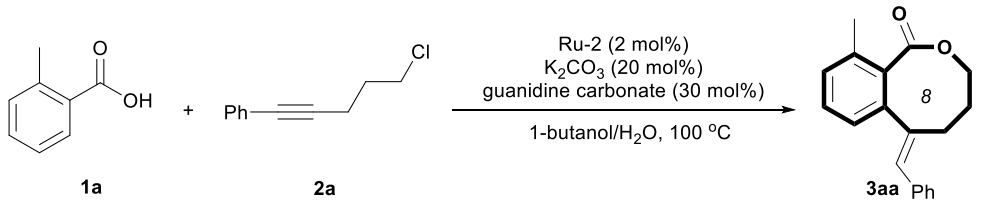
2h

To around-bottom flask were added Phenylacetylene (1.0 g, 10 mmol), 1-Bromo-4-chlorobutane (2.4 g, 14 mmol) and THF (40 mL). The solution was cooled to -78 ^{o}C, *n*-BuLi (4.8 mL, 12 mmol) was slowly

added into the reaction mixture. The mixture was heated 80 °C (reflux) for 15 hours. Then, H_2O (20 mL) was added and the resulting mixture was extracted with EtOAc (3×20 mL). The combined organic layers were washed with brine (20 mL), dried over $NaSO_4$, filtered, and the volatiles were removed under reduced pressure. The residue was purified by column chromatography to give the compound **2h** in 65% yield as a yellow oil.

3. General Procedure and Spectral Data of the Products

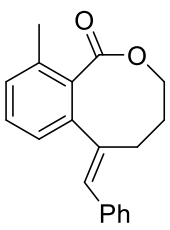
3.1 General procedure for the synthesis of 3aa-sa, 3ab-3ag, 3dh, 3di



1a (68.0 mg, 0.5 mmol), **2a** (133.6 mg, 0.75 mmol), $[RuI_2(p\text{-cymene})]_2$ (2 mol%), K_2CO_3 (13.7 mg, 0.1 mmol) and guanidine carbonate (27.0 mg, 0.15 mmol) were dissolved in 1-butanol/H_2O (1.0 mL, 9/1). Then, the mixture was stirred at 100 °C for 16 h, as monitored by TLC analysis. The crude product was purified by flash chromatography on silica gel (petroleum ether/ethyl acetate = 4:1) directly to give the desired product **3aa** in 78% isolated yield as a white solid. Other products **3aa-sa, 3ab-ag, 3ah, 3dh, 3di** were prepared according to the above procedure.

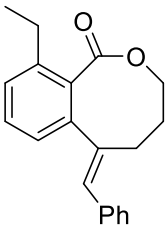
3.2 Spectral data of the products 3aa-sa, 3ab-ag, 3ah, 3dh, 3di

Product 3aa



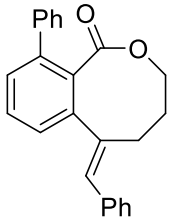
Yield of **3aa**: 108.5 mg, 78% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.31 – 7.26 (m, 1H), 7.25 – 7.18 (m, 4H), 7.17 – 7.08 (m, 2H), 7.01 (d, *J* = 3.8 Hz, 1H), 6.41 (s, 1H), 4.18 (t, *J* = 5.0 Hz, 2H), 2.52 (t, *J* = 6.6 Hz, 2H), 2.33 (s, 3H), 2.04 – 1.94 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.9, 143.8, 140.3, 136.9, 136.2, 130.7, 130.5, 129.8, 129.5, 128.6, 128.8, 127.1, 125.3, 68.4, 30.2, 29.2, 19.9. M.P.: 118.0 – 118.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{18}O_2$: 279.1380; found: 279.1378.

Product 3ba



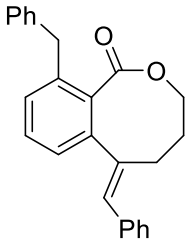
Yield of **3ba**: 124.2 mg, 85% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.36 – 7.27 (m, 2H), 7.25 – 7.14 (m, 5H), 7.03 (d, *J* = 7.6 Hz, 1H), 6.43 (s, 1H), 4.19 (t, *J* = 4.9 Hz, 2H), 2.68 (q, *J* = 7.6 Hz, 2H), 2.54 (t, *J* = 6.6 Hz, 2H), 2.07 – 1.95 (m, 2H), 1.16 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.9, 143.7, 142.5, 140.2, 136.9, 130.8, 130.6, 129.5, 128.6, 128.3, 128.1, 127.1, 125.4, 68.3, 30.2, 29.3, 26.7, 15.8. M.P.: 118.0 – 118.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{20}O_2$: 293.1536; found: 293.1534.

Product 3ca



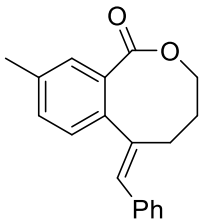
Yield of **3ca**: 137.8 mg, 81% as a white solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.45 (t, *J* = 7.6 Hz, 2H), 7.37 – 7.28 (m, 8H), 7.24 – 7.18 (m, 3H), 6.49 (s, 1H), 4.46 (t, *J* = 4.9 Hz, 2H), 2.61 (t, *J* = 6.5 Hz, 2H), 2.15 – 2.06 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.4, 144.1, 141.0, 140.0, 139.9, 136.9, 131.9, 130.9, 129.8, 129.3, 128.6, 128.4, 128.4, 127.8, 127.2, 127.0, 68.3, 30.5, 29.3. M.P.: 201.0 – 201.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{24}H_{20}O_2$: 341.1536; found: 341.1534.

Product 3da



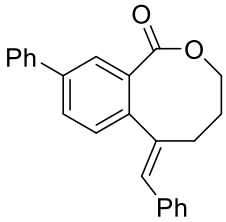
Yield of **3da**: 124.0 mg, 70% as a yellow oil. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.36 – 7.26 (m, 2H), 7.25 – 7.16 (m, 7H), 7.13 – 7.02 (m, 4H), 6.42 (s, 1H), 4.06 (s, 2H), 3.73 (t, *J* = 4.9 Hz, 2H), 2.46 (t, *J* = 6.6 Hz, 2H), 1.95 – 1.84 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.8, 144.1, 140.1, 139.9, 136.9, 130.8, 130.6, 130.2, 129.4, 129.3, 128.5, 128.5, 128.4, 127.1, 126.3, 125.9, 68.1, 39.3, 30.0, 29.3. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{25}H_{22}O_2$: 355.1693; found: 355.1695.

Product 3ea



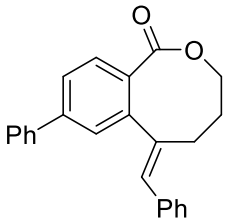
Yield of **3ea**: 69.5 mg, 50% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.31 (m, 2H), 7.26 (d, *J* = 2.6 Hz, 2H), 7.23 – 7.13 (m, 4H), 6.45 (s, 1H), 4.26 (t, *J* = 5.1 Hz, 2H), 2.57 (t, *J* = 6.4 Hz, 2H), 2.33 (s, 3H), 2.07 – 1.97 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) =172.5, 141.3, 140.5, 137.7, 137.1, 132.4, 130.6, 130.0, 129.2, 128.6, 128.4, 128.1, 127.8, 69.0, 30.3, 28.8, 20.9. M.P.: 90.0 – 90.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{18}O_2$: 279.1380; found: 279.1378.

Product 3fa



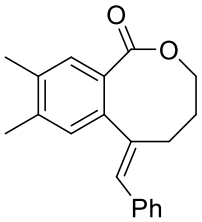
Yield of **3fa**: 105.4 mg, 62% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.74 (d, *J* = 2.0 Hz, 1H), 7.66 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.58 – 7.52 (m, 2H), 7.42 – 7.37 (m, 2H), 7.36 – 7.29 (m, 4H), 7.28 – 7.14 (m, 3H), 6.53 (s, 1H), 4.31 (t, *J* = 5.2 Hz, 2H), 2.62 (t, *J* = 6.3 Hz, 2H), 2.09 – 1.99 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 172.4, 143.0, 140.8, 140.4, 139.5, 137.0, 130.9, 130.7, 130.2, 129.0, 128.8, 128.6, 128.5, 127.9, 127.4, 127.2, 127.0, 69.2, 30.3, 28.8. M.P.: 148.0 – 148.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{24}H_{20}O_2$: 341.1536; found: 341.1538

Product 3ga



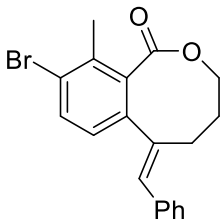
Yield of **3ga**: 95.2 mg, 56% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.72 (d, *J* = 2.0 Hz, 1H), 7.64 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.57 – 7.49 (m, 2H), 7.43 – 7.29 (m, 4H), 7.29 – 7.13 (m, 5H), 6.51 (s, 1H), 4.29 (t, *J* = 5.2 Hz, 2H), 2.6 1 (t, *J* = 6.3 Hz, 2H), 2.09 – 1.95 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 172.4, 143.0, 140.8, 140.4, 139.5, 137.0, 130.9, 130.7, 130.2, 129.0, 128.9, 128.6, 128.5, 128.0, 127.4, 127.2, 127.0, 69.2, 30.3, 28.8. M.P.: 145.5 – 146.0 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{24}H_{20}O_2$: 341.1536; found: 341.1535

Product 3ha



Yield of **3ha**: 87.6 mg, 60% as a white solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.33 – 7.27 (m, 2H), 7.26 – 7.20 (m, 3H), 7.19 (M, 1H), 7.02 (s, 1H), 6.43 (s, 1H), 4.25 (t, *J* = 5.1 Hz, 2H), 2.56 (t, *J* = 6.4 Hz, 2H), 2.24 (d, *J* = 5.8 Hz, 6H), 2.00 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 172.6, 141.8, 140.7, 137.2, 136.4, 130.3, 130.0, 129.4, 128.6, 128.4, 127.5, 127.0, 69.0, 30.3, 28.9, 19.9, 19.2. M.P.: 68.0 – 68.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{20}O_2$: 293.1536; found: 293.1537.

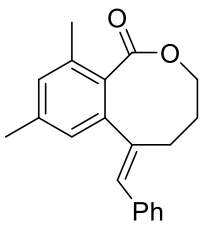
Product 3ia



Yield of **3ia**: 112.1 mg, 63% as a white solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.57 (d, *J* = 8.2 Hz, 1H), 7.30 (dt, *J* = 7.1, 1.3 Hz, 1H), 7.26 – 7.14 (m, 4H), 6.92 (d, *J* = 8.6 Hz, 1H), 6.43 (s, 1H), 4.21 (t, *J* = 5.0 Hz, 2H), 2.52 (t, *J* = 6.6 Hz, 2H), 2.39 (s,

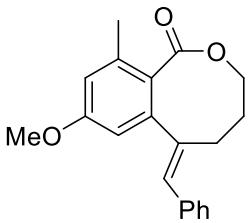
3H), 2.07 – 1.96 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) =170.0, 142.9, 139.2, 136.6, 135.7, 134.6, 131.9, 131.4, 128.5, 128.4, 127.3, 126.9, 125.0, 68.6, 30.2, 29.1, 20.5. M.P.: 80.0 – 80.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}BrO_2$: 357.0485; found: 357.0483.

Product 3ja



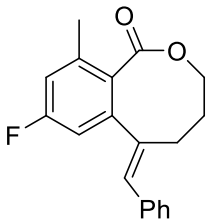
Yield of **3ja**: 124.2 mg, 85% as a white solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.32 – 7.26 (m, 1H), 7.25 – 7.13 (m, 4H), 6.90 (d, *J* = 28.0 Hz, 2H), 6.40 (s, 1H), 4.18 (t, *J* = 4.9 Hz, 2H), 2.53 (t, *J* = 6.6 Hz, 2H), 2.29 (d, *J* = 5.5 Hz, 6H), 2.06 – 1.93 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 171.2, 143.9, 140.6, 140.5, 137.0, 136.4, 130.4, 130.3, 128.6, 128.3, 127.0, 127.0, 125.9, 68.4, 30.2, 29.2, 21.3, 19.8. M.P.: 153.0 – 153.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{20}O_2$: 293.1536; found: 293.1534.

Product 3ka



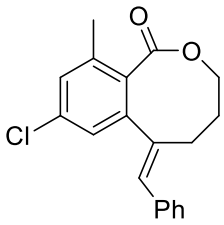
Yield of **3ka**: 110.9 mg, 72% as a white solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.33 – 7.27 (m, 1H), 7.25 (d, *J* = 2.4 Hz, 2H), 7.23 – 7.14 (m, 2H), 6.61 (dd, *J* = 29.5, 2.4 Hz, 2H), 6.42 (s, 1H), 4.20 (t, *J* = 5.0 Hz, 2H), 3.77 (s, 3H), 2.55 (t, *J* = 6.6 Hz, 2H), 2.34 (s, 3H), 2.06 – 1.96 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 171.0, 160.9, 146.0, 140.6, 139.0, 136.9, 130.4, 128.5, 128.4, 127.1, 122.3, 115.2, 110.7, 68.4, 55.4, 30.2, 29.2, 20.2. M.P.: 165.0 – 165.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{20}O_3$: 309.1485; found: 309.1485.

Product 3la



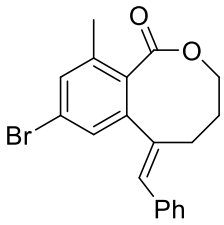
Yield of **3la**: 114.0 mg, 77% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.32-7.27 (m, 1H), 7.25 (d, *J* = 5.7 Hz, 2H), 7.23 – 7.15 (m, 2H), 6.85 (dd, *J* = 9.2, 2.2 Hz, 1H), 6.76 (dd, *J* = 8.9, 2.5 Hz, 1H), 6.43 (s, 1H), 4.20 (t, *J* = 5.0 Hz, 2H), 2.53 (t, *J* = 6.5 Hz, 2H), 2.34 (s, 3H), 2.06 – 1.96 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.3, 163.3 (d, *J* = 249.6 Hz), 146.4 (d, *J* = 8.4 Hz), 139.8 (d, *J* = 8.7 Hz), 139.4 (d, *J* = 1.7 Hz), 136.5, 131.1, 128.5, 128.4, 127.34, 126.1 (d, *J* = 3.0 Hz), 116.5 (d, *J* = 20.2 Hz), 112.5 (d, *J* = 21.4 Hz), 68.4, 30.2, 29.0, 20.3. ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) = -109.84 (s, 1F). M.P.: 65.0 – 65.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}FO2$: 297.1285; found: 297.1286.

Product 3ma



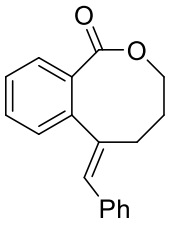
Yield of **3ma**: 101.4 mg, 65% as a brown solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.33 – 7.25 (m, 2H), 7.24 – 7.18 (m, 3H), 7.10 (ddd, *J* = 22.4, 2.0, 0.7 Hz, 2H), 6.43 (s, 1H), 4.20 (t, *J* = 5.0 Hz, 2H), 2.53 (t, *J* = 6.5 Hz, 2H), 2.32 (s, 3H), 2.06 – 1.97 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) =1 70.1, 145.5, 139.1, 138.6, 136.5, 136.1, 131.4, 129.5, 128.5, 128.4, 127.4, 125.6, 68.5, 30.2, 29.0, 19.8. M.P.: 152.0 – 152.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}ClO_2$: 313.0990; found: 313.0989.

Product 3na



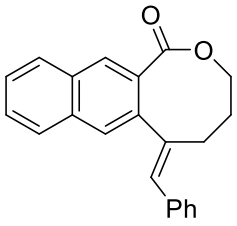
Yield of **3na**: 106.8 mg, 60% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.56 (d, *J* = 8.2 Hz, 1H), 7.32 – 7.27 (m, 1H), 7.26 – 7.21 (m, 3H), 7.20 – 7.16 (m, 1H), 6.92 (d, *J* = 8.2 Hz, 1H), 6.42 (s, 1H), 4.20 (t, *J* = 5.0 Hz, 2H), 2.51 (t, *J* = 6.6 Hz, 2H), 2.38 (s, 3H), 2.06 – 1.96 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.0, 143.0, 139.2, 136.6, 135.6, 134.6, 131.9, 131.3, 128.5, 128.4, 127.3, 126.9, 125.0, 68.6, 30.2, 29.1, 20.6. M.P.: 82.0 – 82.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}BrO_2$: 357.0485; found: 357.0483.

Product 3oa



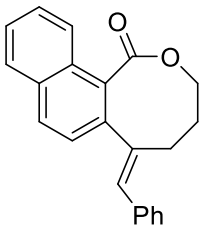
Yield of **3oa**: 68.7 mg, 52% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 7.51 (dd, *J* = 7.5, 1.3 Hz, 1H), 7.43 (dd, *J* = 7.5, 1.6 Hz, 1H), 7.37 – 7.28 (m, 3H), 7.27 – 7.18 (m, 4H), 6.46 (s, 1H), 4.26 (t, *J* = 5.1 Hz, 2H), 2.59 (t, *J* = 6.4 Hz, 2H), 2.04 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 172.2, 144.2, 140.6, 137.0, 131.7, 130.8, 130.2, 128.8, 128.6, 128.4, 128.3, 127.8, 127.2, 69.1, 30.2, 28.9. M.P.: 118.0 – 118.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{18}H_{16}O_2$: 265.1223; found: 265.1224.

Product 3pa



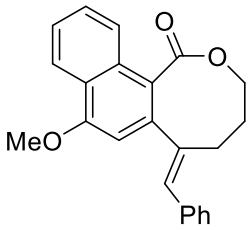
Yield of **3pa**: 73.8 mg, 47% as a yellow oil. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 8.08 (s, 1H), 7.89 – 7.76 (m, 3H), 7.72 (s, 1H), 7.55 – 7.43 (m, 3H), 7.31 (s, 1H), 7.26 – 7.17 (m, 2H), 6.55 (s, 1H), 4.30 (t, *J* = 5.2 Hz, 2H), 2.70 (t, *J* = 6.4 Hz, 2H), 2.06 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 172.3, 141.2, 141.0, 137.1, 134.7, 132.0, 131.0, 129.6, 129.0, 128.6, 128.5, 128.5, 128.1, 127.8, 127.2, 127.2, 126.8, 69.4, 30.2, 29.8. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{22}H_{18}O_2$: 315.1380; found: 315.1381

Product 3qa



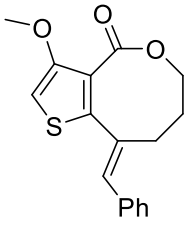
Yield of **3qa**: 84.8 mg, 54% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 8.03 – 7.96 (m, 1H), 7.90 (d, *J* = 8.4 Hz, 1H), 7.85 – 7.79 (m, 1H), 7.55 – 7.45 (m, 2H), 7.35 – 7.18 (m, 6H), 6.55 (s, 1H), 4.22 (t, *J* = 4.9 Hz, 2H), 2.63 (t, *J* = 6.6 Hz, 2H), 2.14 – 2.00 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 170.5, 141.6, 140.2, 136.8, 132.6, 131.3, 131.2, 129.8 128.6, 128.4, 128.2, 127.9, 127.3, 126.6, 126.4, 125.5, 125.5, 68.6, 30.3, 28.5. M.P.: 146.0 – 146.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{22}H_{18}O_2$: 315.1380; found: 315.1357.

Product 3ra



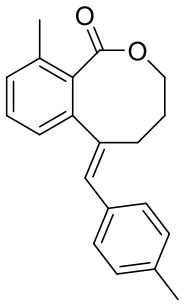
Yield of **3ra**: 82.6 mg, 48% as a yellow solid. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 8.97 (d, *J* = 8.2 Hz, 1H), 8.23 (d, *J* = 8.4 Hz, 1H), 8.17 (d, *J* = 8.3 Hz, 1H), 7.57 – 7.49 (m, 1H), 7.45 – 7.37 (m, 1H), 7.34 – 7.28 (m, 2H), 7.20 – 7.15 (m, 3H), 6.64 (d, *J* = 8.3 Hz, 1H), 4.45 (t, *J* = 6.3 Hz, 2H), 3.92 (s, 3H), 2.55 (t, *J* = 7.0 Hz, 2H), 1.98 – 2.09 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 167.2, 159.4, 132.9, 132.3, 131.6, 128.3, 128.2, 127.7, 125.8, 125.7, 125.5, 123.8, 122.3, 118.9, 102.5, 88.9, 81.4, 63.5, 55.8, 28.1, 16.6. M.P.: 43.0 – 43.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{23}H_{20}O_3$: 345.1485; found: 345.1482.

Product 3sa



Yield of **3sa**: 60.0 mg, 40% as a brown oil. ^{1}H NMR (250 MHz, $CDCl_3$) δ (ppm) = 8.05 (d, *J* = 3.6 Hz, 1H), 7.45 – 7.37 (m, 2H), 7.33 – 7.27 (m, 3H), 6.30 (d, *J* = 3.6 Hz, 1H), 4.45 (t, *J* = 6.2 Hz, 2H), 3.92 (s, 3H), 2.61 (t, *J* = 7.0 Hz, 2H), 1.91 – 2.02 (m, 2H). ^{13}C NMR (63 MHz, $CDCl_3$) δ (ppm) = 161.7, 157.7, 133.4, 131.6, 128.2, 127.7, 123.7, 123.4, 98.1, 88.8, 81.3, 63.2, 58.0, 28.0. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{17}H_{16}O_3S$: 301.0893; found: 301.0895.

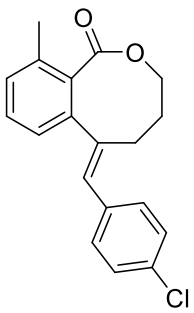
Product 3ab



Yield of **3ab**: 113.9 mg, 78% as a yellow solid. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 7.35 (t, *J* = 7.6 Hz, 1H), 7.22-7.20 (m, 3H), 7.16 (d, *J* = 7.9 Hz, 2H), 7.10 (d, *J* = 7.5 Hz, 1H), 6.46 (s, 1H), 4.27 (t, *J* = 4.9 Hz, 2H), 2.62 (t, *J* = 5.0 Hz, 2H), 2.42 (s, 3H), 2.36 (s,

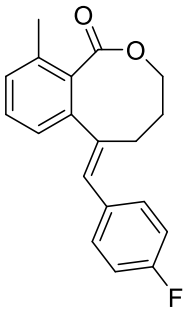
3H), 2.12 – 2.08 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) = 171.1, 144.0, 139.5, 136.9, 136.2, 134.0, 130.6, 130.5, 129.9, 129.4, 129.1, 128.5, 125.4, 68.5, 30.2, 29.3, 21.3, 19.9. M.P.: 60.0 – 60.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{20}O_2$: 293.1536; found: 293.1537.

Product 3ac



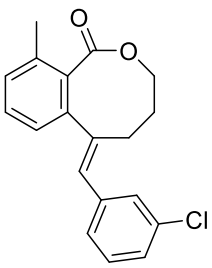
Yield of **3ac**: 98.3 mg, 63% as a red oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 7.36 (t, *J* = 7.6 Hz, 1H), 7.34 – 7.31 (m, 2H), 7.25 – 7.22 (m, 3H), 7.09 (d, *J* = 7.6 Hz, 1H), 6.44 (s, 1H), 4.27 (t, *J* = 4.9 Hz, 2H), 2.59 (t, *J* = 6.6 Hz, 2H), 2.42 (s, 3H), 2.11 – 2.04 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) = 170.8, 143.4, 141.0, 136.3, 135.3, 132.9, 130.5, 129.8, 129.6, 129.6, 129.5, 128.5, 125.1, 68.3, 30.07, 29.2, 19.8. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}ClO_2$: 313.0990; found: 313.0990.

Product 3ad



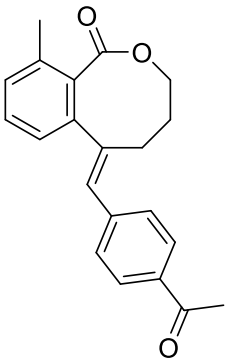
Yield of **3ad**: 93.2 mg, 63% as a yellow solid. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 7.36 (t, *J* = 7.6 Hz, 1H), 7.26 – 7.29 (m, 2H), 7.22 (d, *J* = 7.6 Hz, 1H), 7.10 (d, *J* = 7.6 Hz, 1H), 7.05 (t, *J* = 8.7 Hz, 2H), 6.45 (s, 1H), 4.28 – 4.26 (m, 2H), 2.59 (t, *J* = 6.6 Hz, 2H), 2.42 (s, 3H), 2.11 – 2.07 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) = 170.9, 161.8 (d, *J* = 245.3 Hz), 143.5, 140.3, 136.3, 132.9, 132.9, 130.5, 130.2 (d, *J* = 3.4 Hz), 129.8, 129.6 (d, *J* = 2.4 Hz), 125.2, 115.3 (d, *J* = 21.2 Hz), 68.4, 30.1, 29.2, 19.8. ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) = -114.80 (s, 1F). M.P.: 66.0 – 66.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}FO_2$: 297.1285; found: 297.1283.

Product 3ae



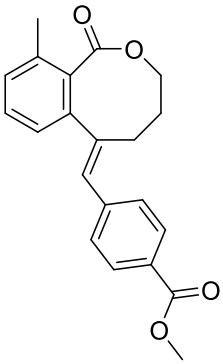
Yield of **3ae**: 95.2 mg, 61% as a yellow solid. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 7.36 (t, *J* = 7.6 Hz, 1H), 7.30 – 7.27 (m, 2H), 7.25 – 7.22 (m, 2H), 7.18 (d, *J* = 7.7 Hz, 1H), 7.09 (d, *J* = 7.6 Hz, 1H), 6.44 (s, 1H), 4.27 (t, *J* = 4.9 Hz, 2H), 2.60 (t, *J* = 6.3 Hz, 2H), 2.42 (s, 3H), 2.11 – 2.07 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) = 170.8, 143.3, 141.8, 138.6, 136.4, 134.2, 130.6, 129.7, 129.6, 129.4, 128.5, 127.2, 126.8, 125.2, 68.3, 30.2, 29.2, 19.9. M.P.: 100.0 – 100.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{19}H_{17}ClO_2$: 313.0990; found: 313.0990.

Product 3af



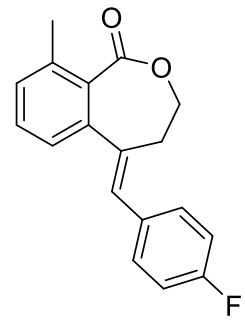
Yield of **3af**: 96.0 mg, 60% as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 7.96 (d, *J* = 6.3 Hz, 2H), 7.41 – 7.39 (m, 2H), 7.38 – 7.35 (m, 1H), 7.24 (d, *J* = 7.6 Hz, 1H), 7.11 (d, *J* = 7.5 Hz, 1H), 6.53 (s, 1H), 4.28 (t, *J* = 3.7 Hz, 2H), 2.64 – 2.60 (m, 5H), 2.43 (s, 3H), 2.12 – 2.08 (m, 2H). ^{13}C NMR (150MHz, $CDCl_3$) δ (ppm) = 197.7, 170.8, 143.4, 142.6, 141.7, 136.5, 135.6, 130.6, 129.8, 129.8, 129.5, 128.7, 128.5, 125.1, 68.3, 30.2, 29.4, 26.7, 19.9. M.P.: 139.0 – 139.5 °C. HRMS (EI): m/z $[M + H]^+$ calcd for $C_{21}H_{20}O_3$: 321.1485; found: 321.1487

Product 3ag



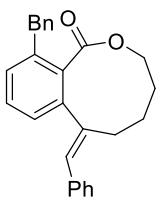
Yield of **3ag**: 107.6 mg, 64% as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) = 8.03 (d, *J* = 8.4 Hz, 2H), 7.39 – 7.36 (m, 3H), 7.24 (d, *J* = 7.7 Hz, 1H), 7.11 (d, *J* = 7.4 Hz, 1H), 6.52 (s, 1H), 4.28 (t, *J* = 4.9 Hz, 2H), 3.93 (s, 3H), 2.62 (t, *J* = 6.6 Hz, 2H), 2.43 (s, 3H), 2.12 – 2.08 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) = 170.8, 166.9, 143.4, 142.4, 141.5, 136.4, 130.6, 129.9, 129.7, 129.7, 129.6, 128.7, 128.5, 125.1, 68.3, 52.7, 30.2, 29.4, 19.9. M.P.: 106.0 – 106.5 °C. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{21}H_{20}O_4$: 337.1434; found: 337.1436.

Product 3ah



Yield of **3ah**: 98.2 mg, 69 % as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) =7.41 (t, *J* = 7.6 Hz, 1H), 7.31 – 7.26 (m, 2H), 7.26 – 7.23 (m, 1H), 7.15 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.08 – 7.03 (m, 2H), 6.58 (s, 1H), 4.29 (t, *J* = 5.6 Hz, 2H), 3.05 (t, *J* = 4.6 Hz, 2H), 2.49 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ (ppm) = 170.2, 161.9 (d, *J* = 246.1 Hz), 140.3, 138.5, 136.8, 132.5 (d, *J* = 3.3 Hz), 132.3, 131.6, 130.9 (d, *J* = 1.9 Hz), 130.7, 128.9, 126.3, 115.3 (d, *J* = 21.4 Hz), 65.3, 33.4, 20.6. M.P.: 152.0 – 153.1 °C. ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) = -113.91 (s, 1F).

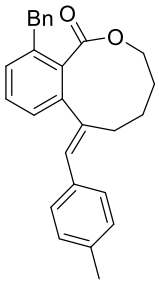
Product 3dh



Yield of **3dh**: 93.9 mg, 51% as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.42 (d, *J* = 7.6 Hz, 2H), 7.34 (m, 3H), 7.30 – 7.26 (m, 3H), 7.24 – 7.10 (m, 5H), 6.54 (s, 1H),

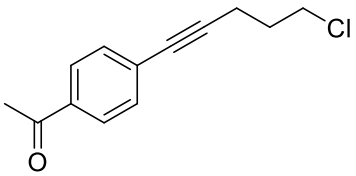
4.31 (t, *J* = 5.3 Hz, 2H), 4.25 (s, 2H), 2.75 (s, 2H), 1.77 – 1.63 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ (ppm) = 168.8, 147.6, 144.2, 140.8, 140.7, 138.3, 130.5, 129.6, 129.2, 128.9, 128.8, 128.6, 128.4, 128.3, 128.3, 126.6, 126.1, 66.9, 38.7, 32.8, 26.2, 25.1. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{26}H_{24}O_2$: 369.1849; found: 369.1846.

Product 3di



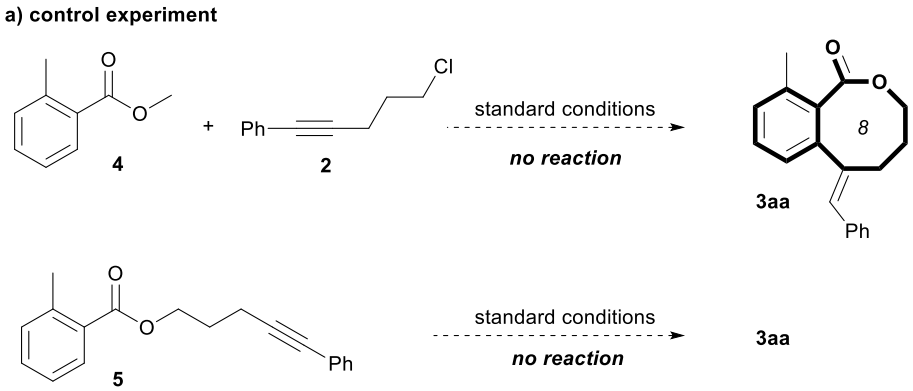
Yield of **3di**: 101.3 mg, 53% as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 77.33 – 7.25 (m, 6H), 7.21 (q, *J* = 7.5, 6.9 Hz, 3H), 7.17 – 7.10 (m, 3H), 6.50 (s, 1H), 4.31 (t, *J* = 5.2 Hz, 2H), 4.24 (s, 2H), 2.75 (t, *J* = 5.3 Hz, 2H), 2.36 (s, 3H), 1.76 – 1.67 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ (ppm) = 168.9, 147.7, 143.5, 140.8, 140.7, 136.4, 135.4, 130.5, 129.8, 129.6, 129.2, 129.0, 128.8, 128.6, 128.4, 128.3, 126.1, 66.9, 38.7, 32.9, 36.2, 25.2, 21.3. M.P.: 83.0 – 83.5 ºC. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{27}H_{26}O_2$: 383.2006; found: 383.2002.

Product 2f



Yield of **2f**: 935 mg, 85 % as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.65 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 3.51 (t, *J* = 6.4 Hz, 2H), 2.42 (t, *J* = 6.9 Hz, 2H), 2.35 (s, 3H), 1.85 (p, *J* = 6.6 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 196.8, 135.7, 131.5, 128.3, 128.0, 91.9, 80.9, 43.6, 31.2, 26.3, 16.8.

4. Mechanistic studies

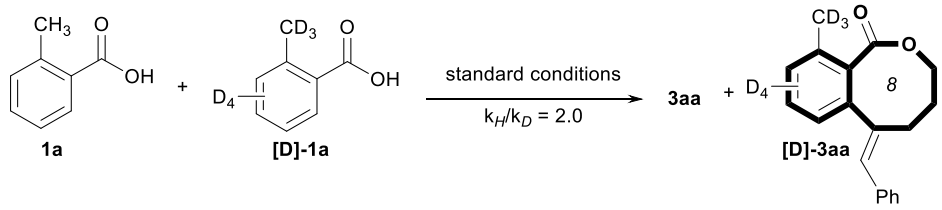


4 (75.0 mg, 0.5 mmol), **2a** (133.6 mg, 0.75 mmol), $[RuI_2(p\text{-cymene})]_2$ (2 mol%), K_2CO_3 (13.7 mg, 0.1 mmol) and guanidine carbonate (27.0 mg, 0.15 mmol) were dissolved in 1-butanol/H_2O (0 mL, 9/1). Then, the mixture was stirred at 100 ºC for 16 h, as monitored by TLC and GC analysis.

As a result, 2-methylbenzoate proved to be ineffective for this catalytic system, which demonstrated the importance of the carboxylate group in this reaction.

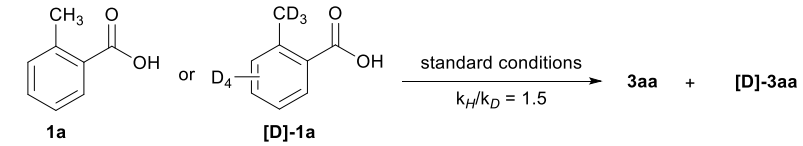
5 (139.0 mg, 0.5 mmol), $[RuI_2(p\text{-cymene})]_2$ (2 mol%), K_2CO_3 (13.7 mg, 0.1 mmol) and guanidine carbonate (27.0 mg, 0.15 mmol) were dissolved in 1-butanol/H_2O (0 mL, 9/1). Then, the mixture was stirred at 100 °C for 16 h, as monitored by TLC and GC analysis. ***No product can be detected, which indicated that compound 5 may not be the intermediate in this reaction.***

b) competitive experiment



1a (13.6 mg, 0.1 mmol), **[D]-1a** (14.3 mg, 0.1 mmol), and **2a** (53.4 mg, 0.3 mmol), $[RuI_2(p\text{-cymene})]_2$ (2 mol%), K_2CO_3 (5.5 mg, 0.04 mmol) and guanidine carbonate (8.1 mg, 0.06 mmol) were dissolved in 1-butanol/H_2O (0.4 mL, 9/1). Then, the mixture was stirred at 100 °C for 16 h. Yields determined by ^1H NMR spectroscopy using 1,3,5-trimethoxybenzene as the internal standard: k_H/k_D = 2.0:1.

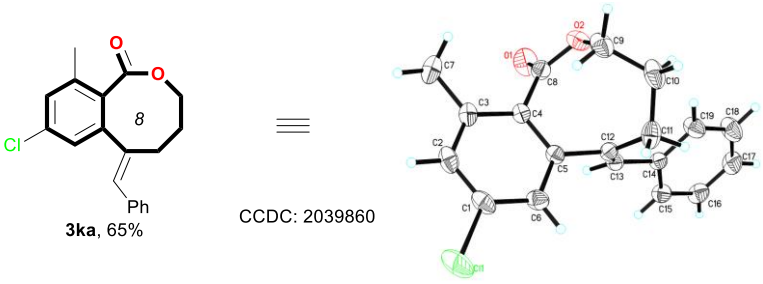
c) parallel experiment

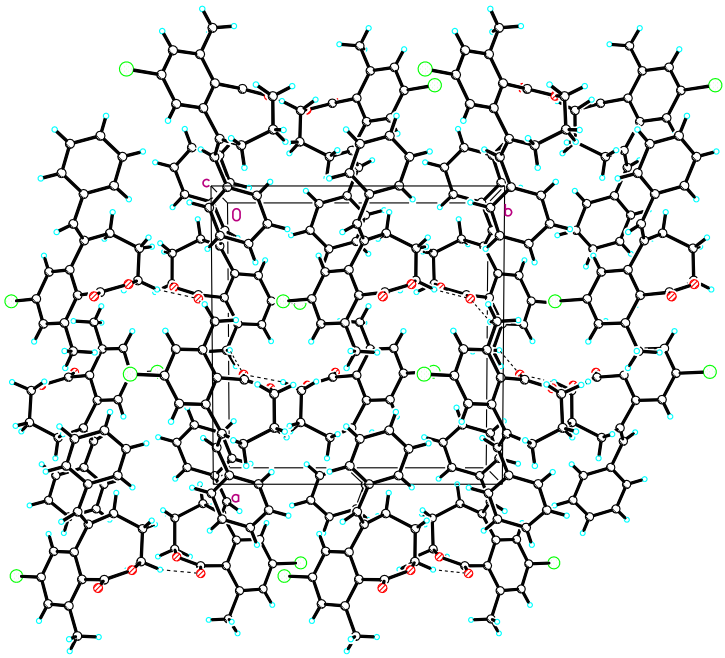


1a (27.2 mg, 0.2 mmol) or **[D]-1a** (28.6 mg, 0.2 mmol), and **2a** (106.8 mg, 0.6 mmol), $[RuI_2(p\text{-cymene})]_2$ (2 mol%), K_2CO_3 (10.9 mg, 0.08 mmol) and guanidine carbonate (21.6 mg, 0.12 mmol) were dissolved in 1-butanol/H_2O (0.4 mL, 9/1). Then, the mixture was stirred at 100 °C for 16 h. Yields determined by ^1H NMR spectroscopy using 1,3,5-trimethoxybenzene as the internal standard: k_H/k_D = 1.5:1.

The kinetic isotope effects (KIE) in both competitive (k_H/k_D = 2.0:1) and parallel (k_H/k_D = 1.5:1) reactions, indicating the ruthenium-catalyzed C−H bond activation may be the rate-determining step in this transformation.

5. X-Ray structure of 3ka

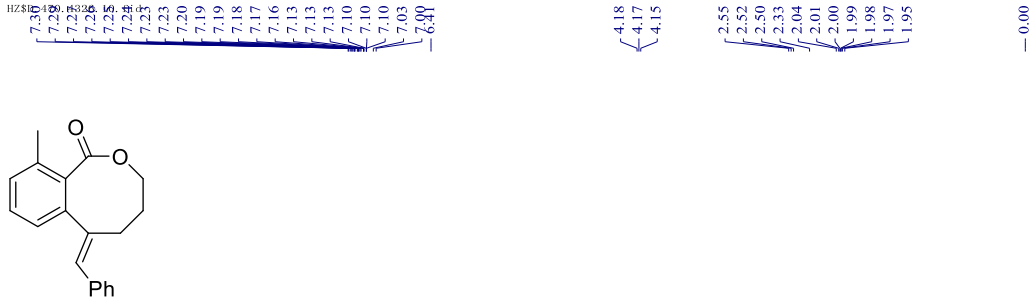


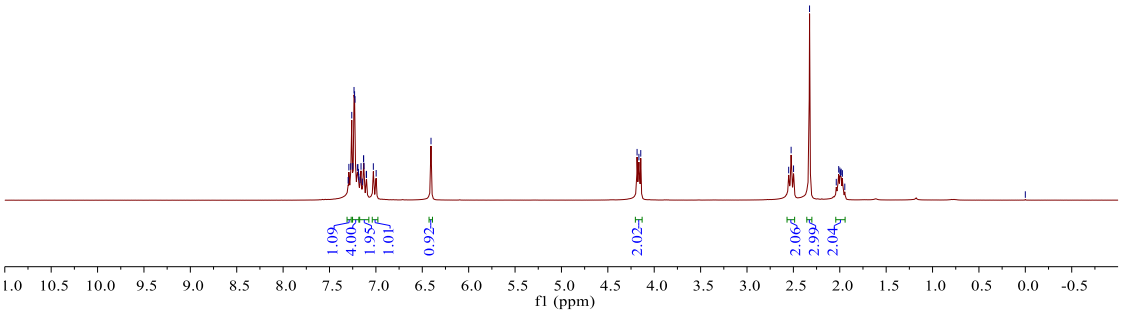


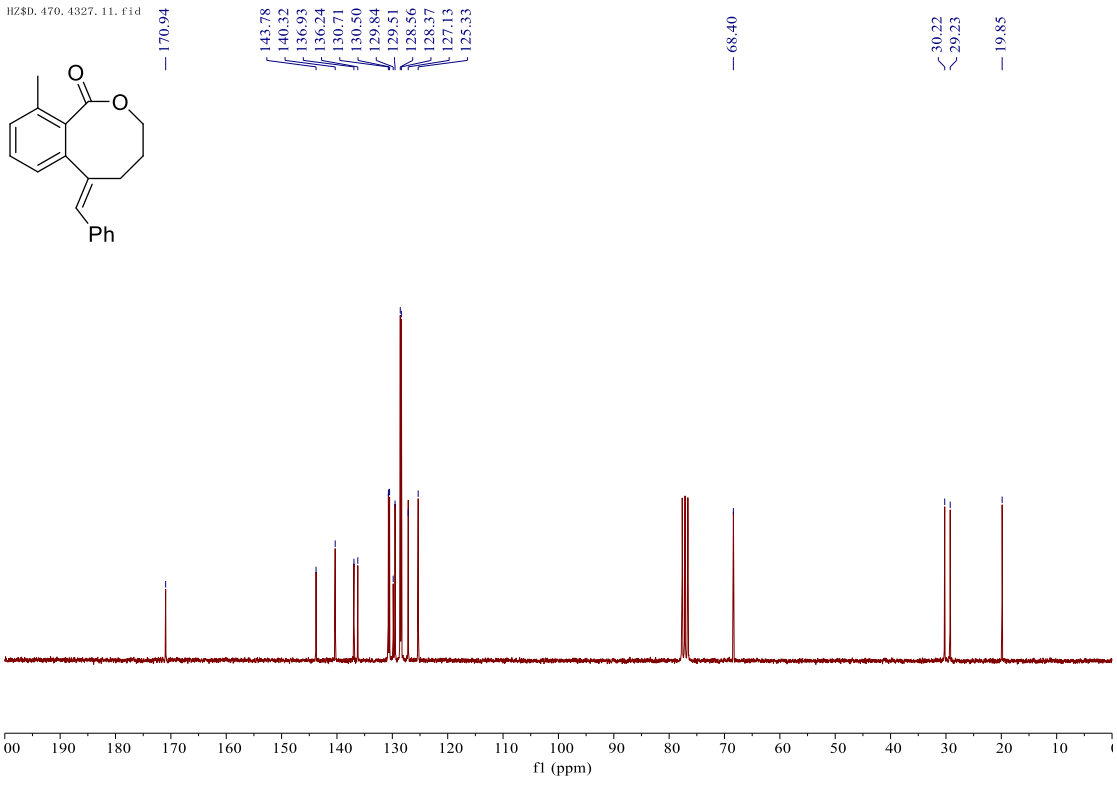
CCDC number: 2039860

6. NMR Spectra of products 3aa–3sa, 3ab–3ag, 3ah, 3dh, 3di and 2f

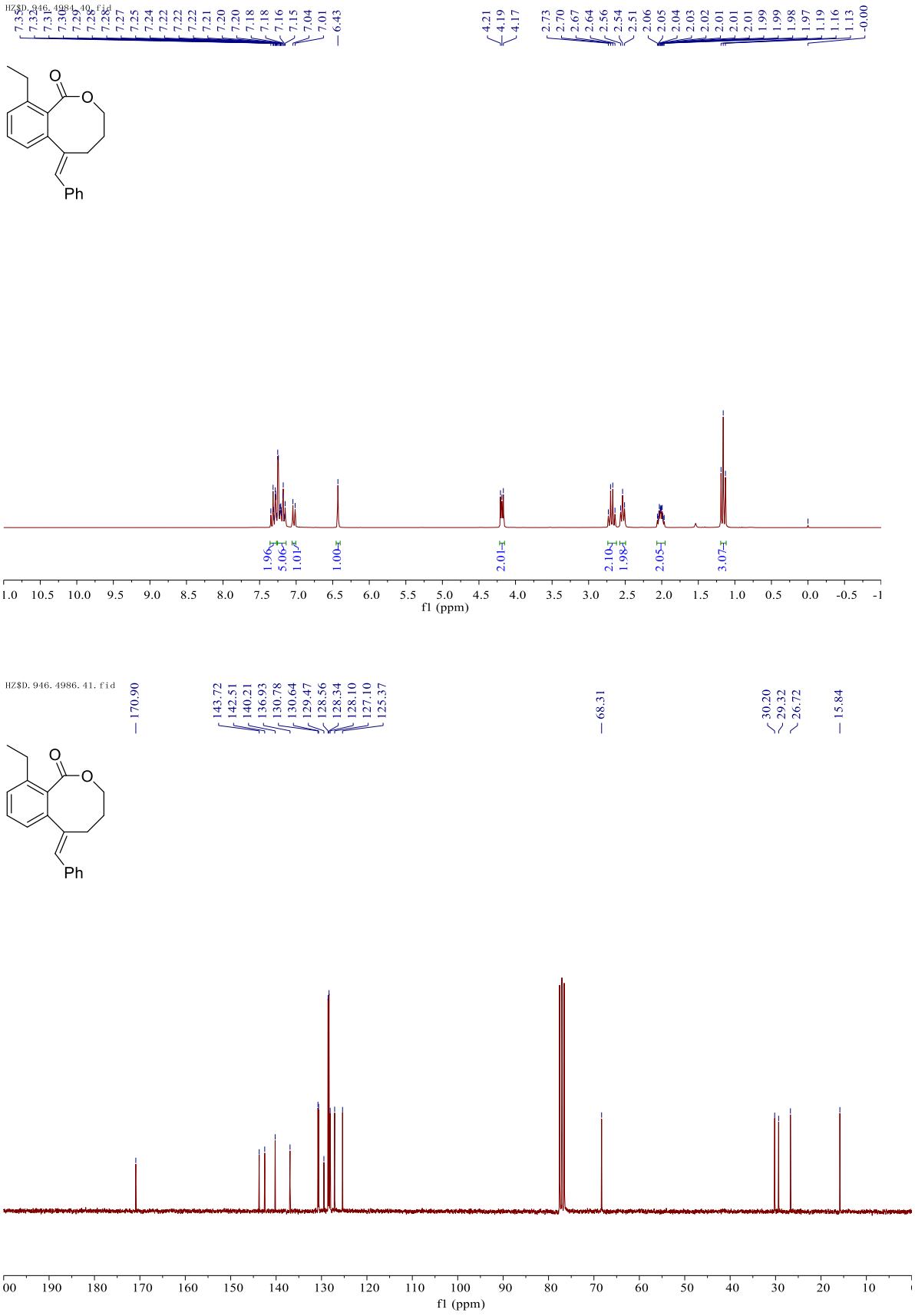
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3aa



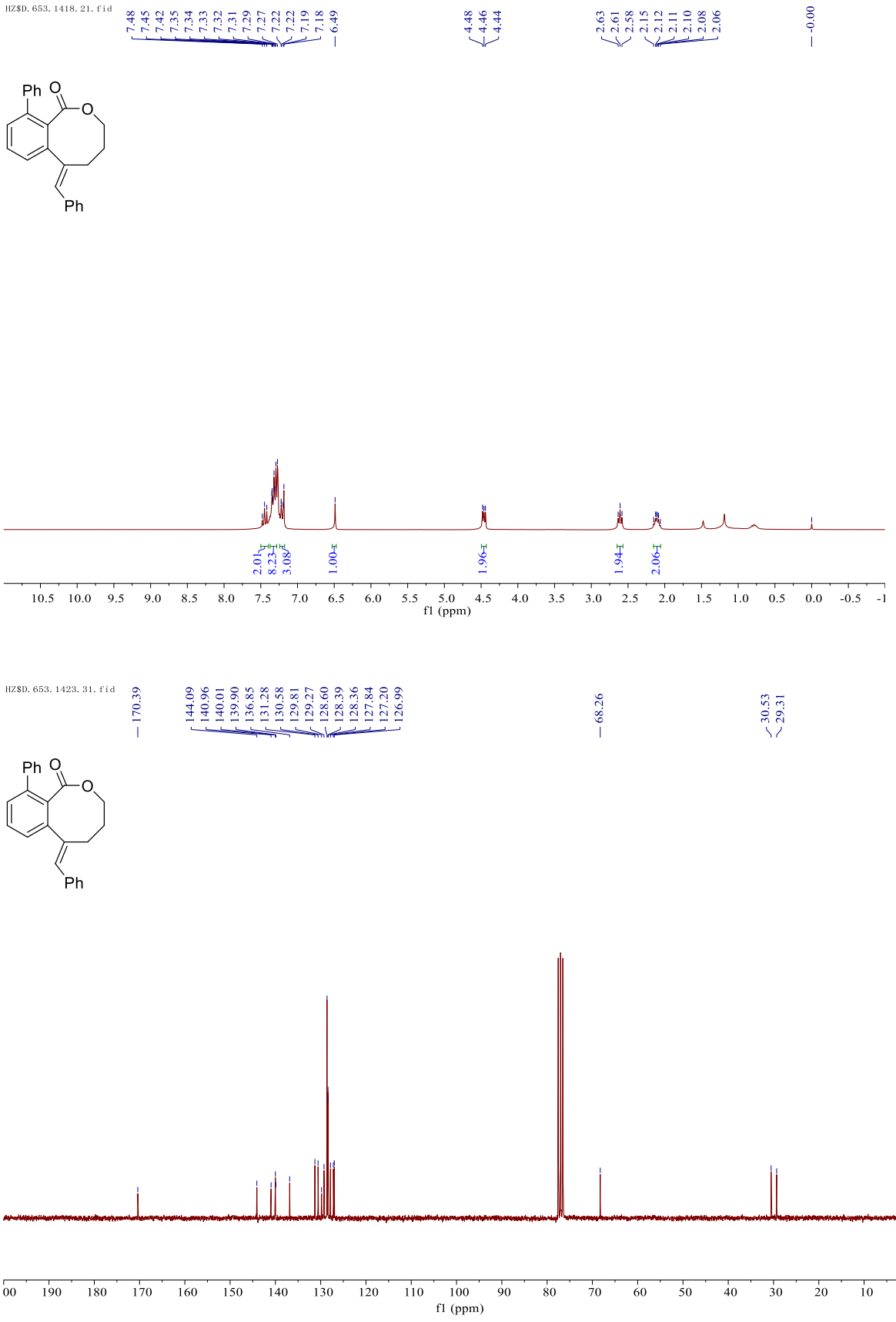




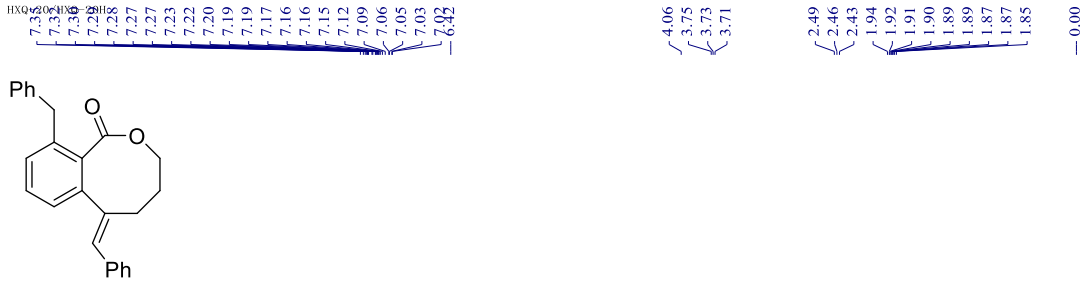
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ba

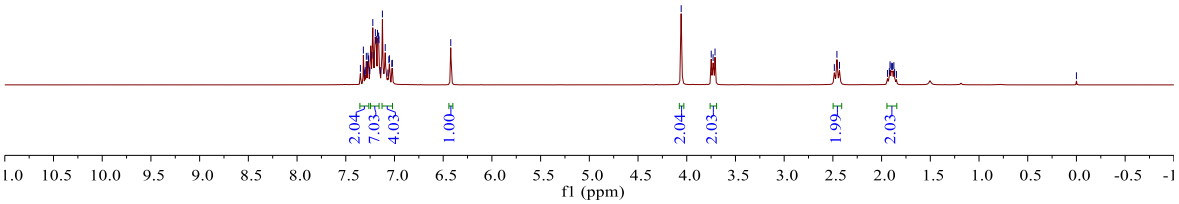


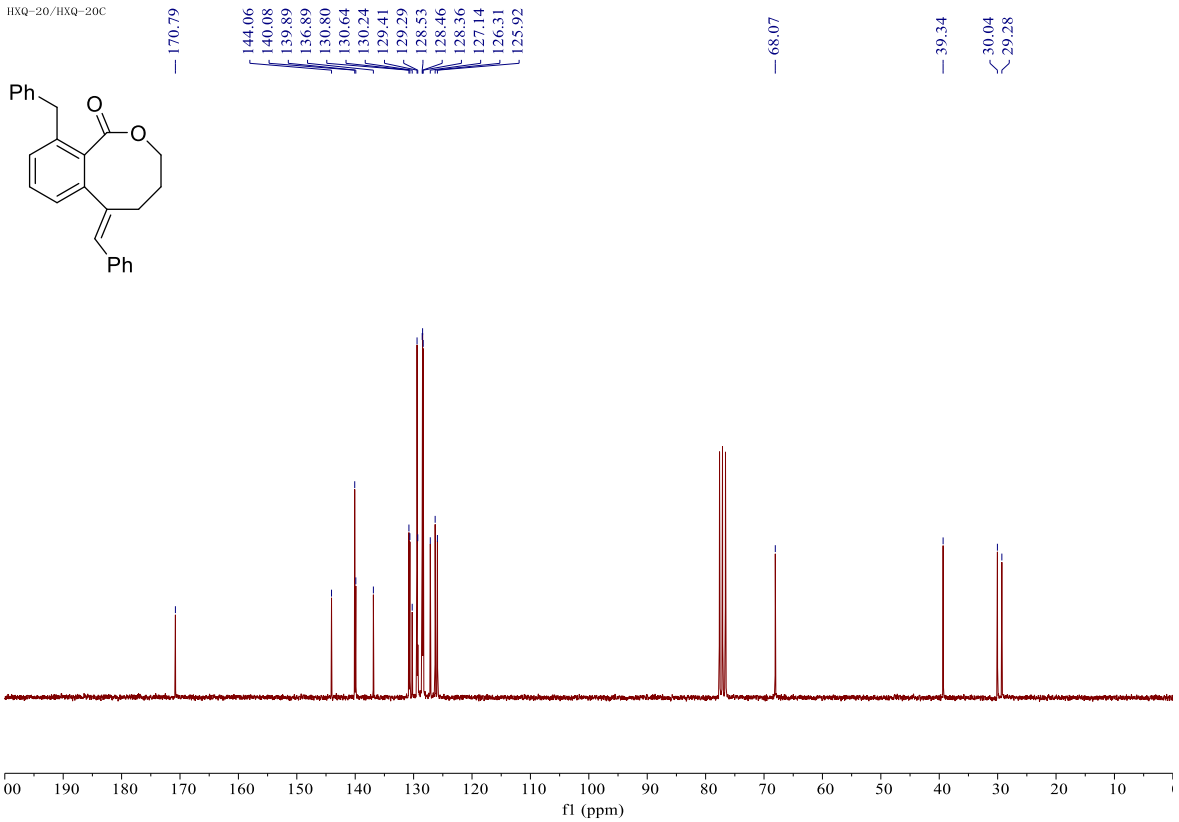
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ca



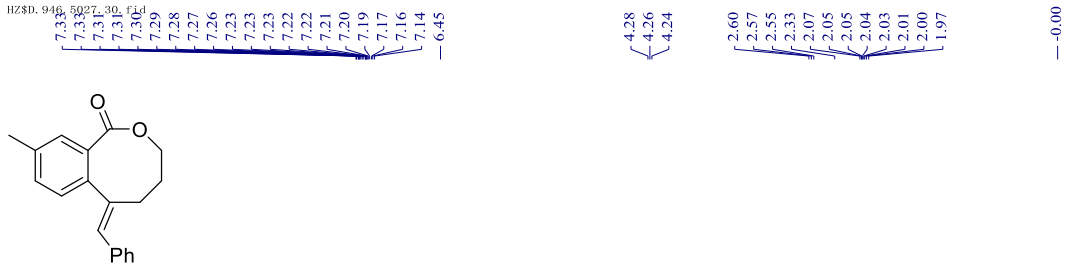
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3da

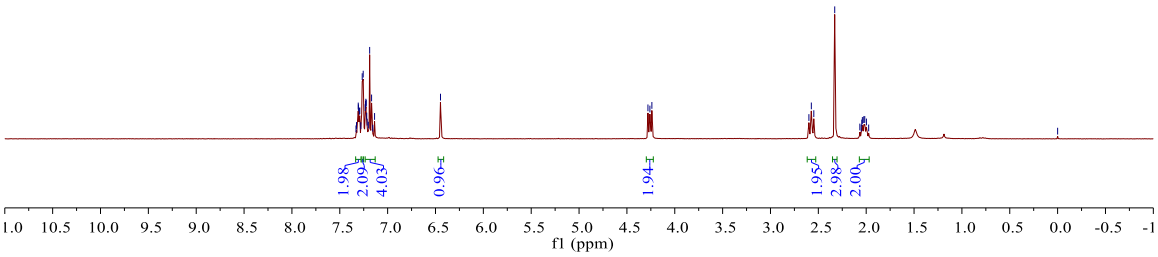


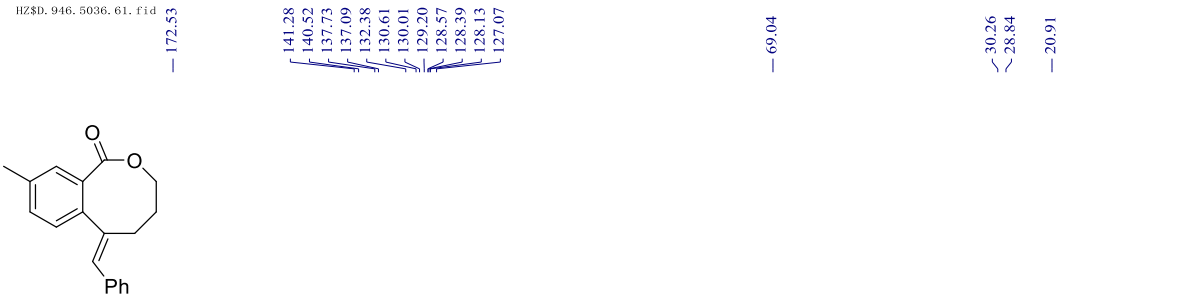


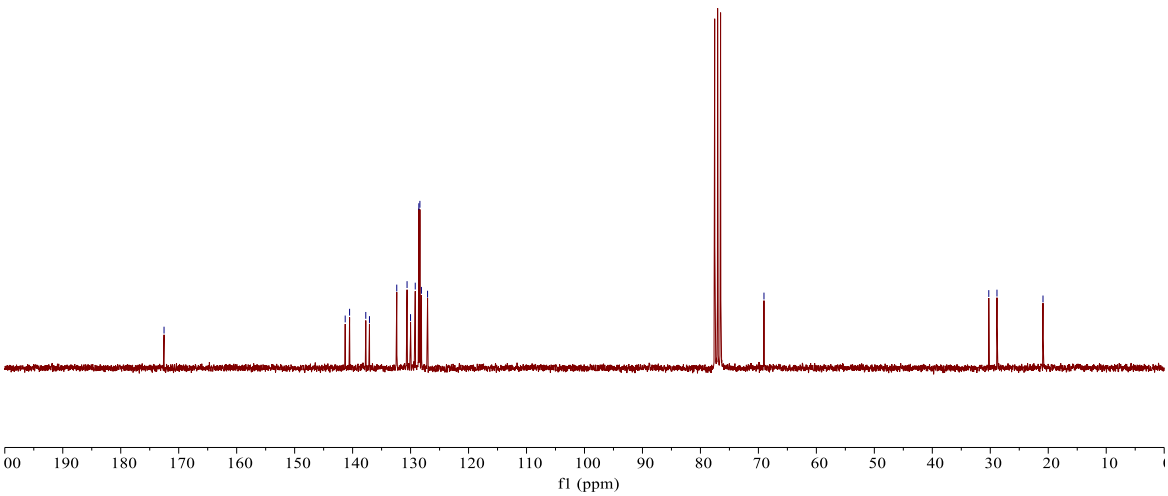


^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ea

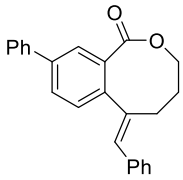


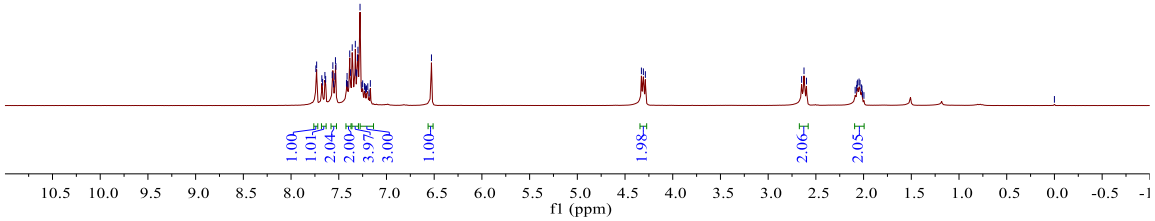


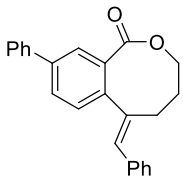


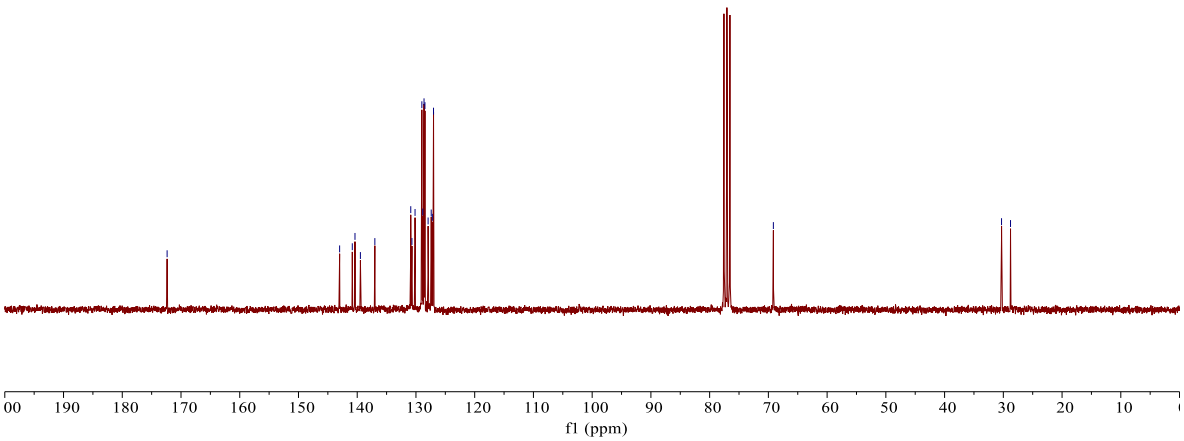


^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3fa

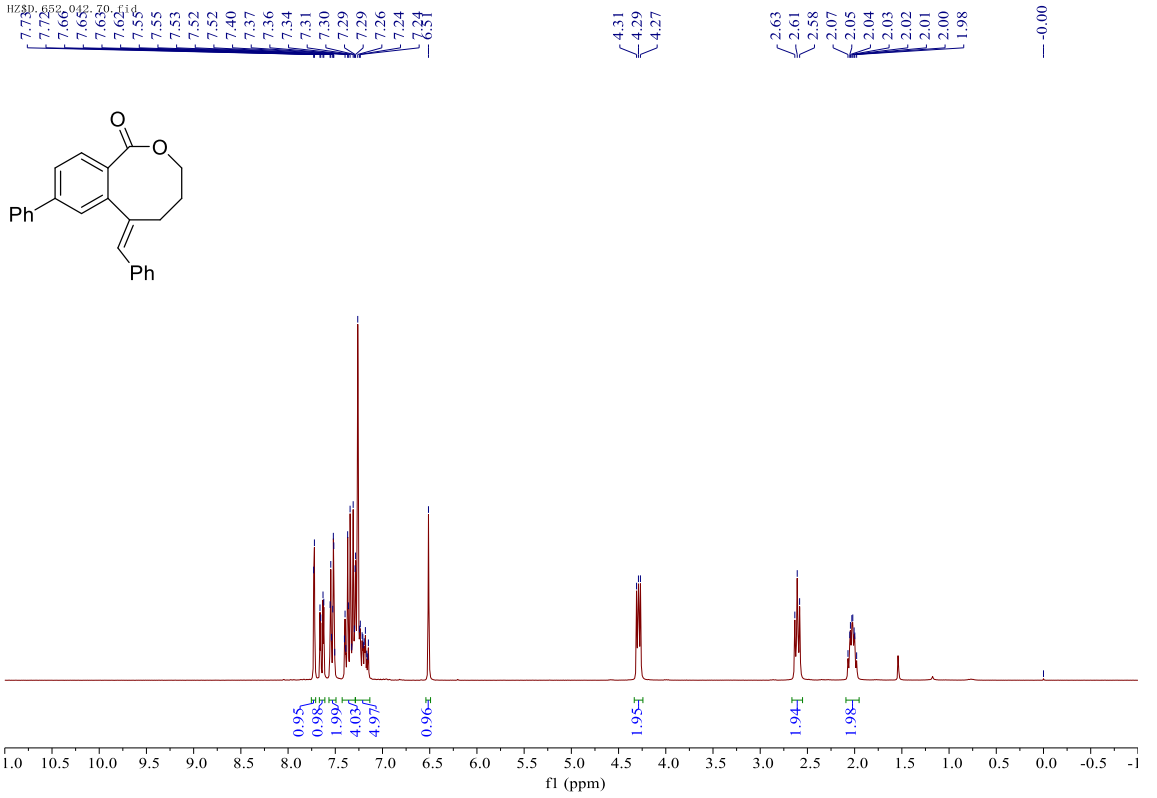


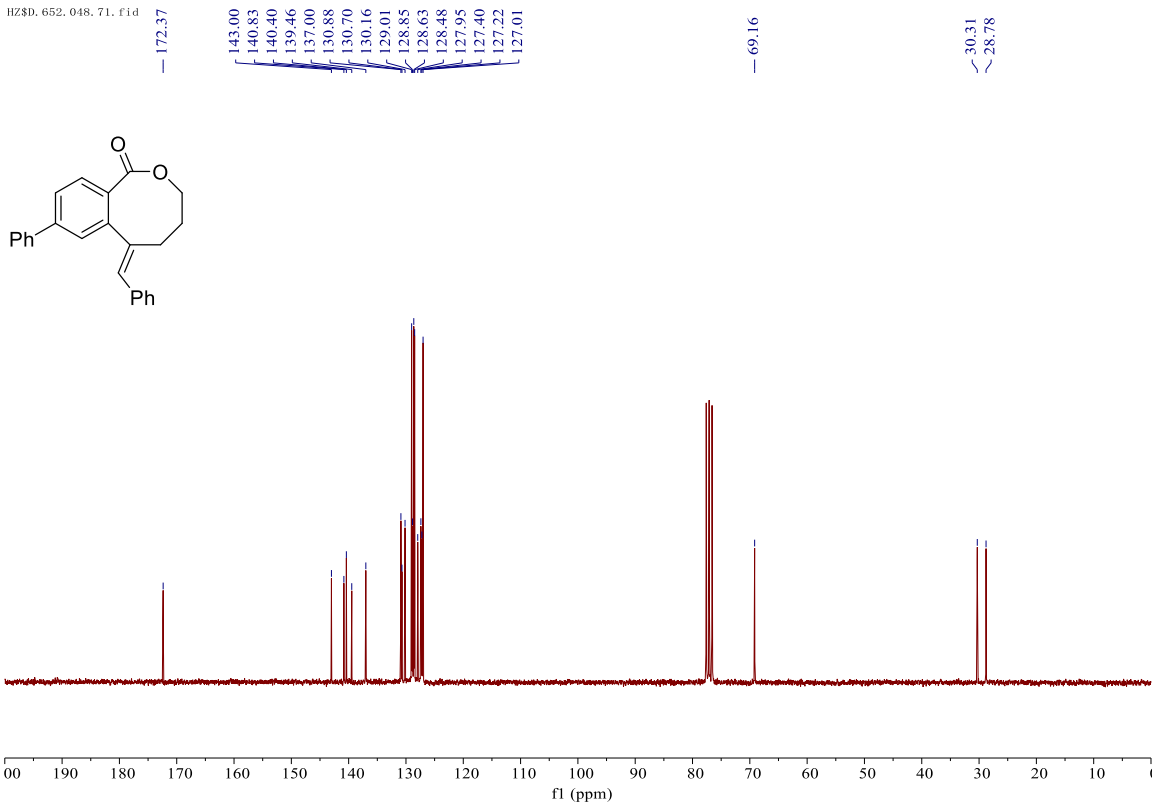




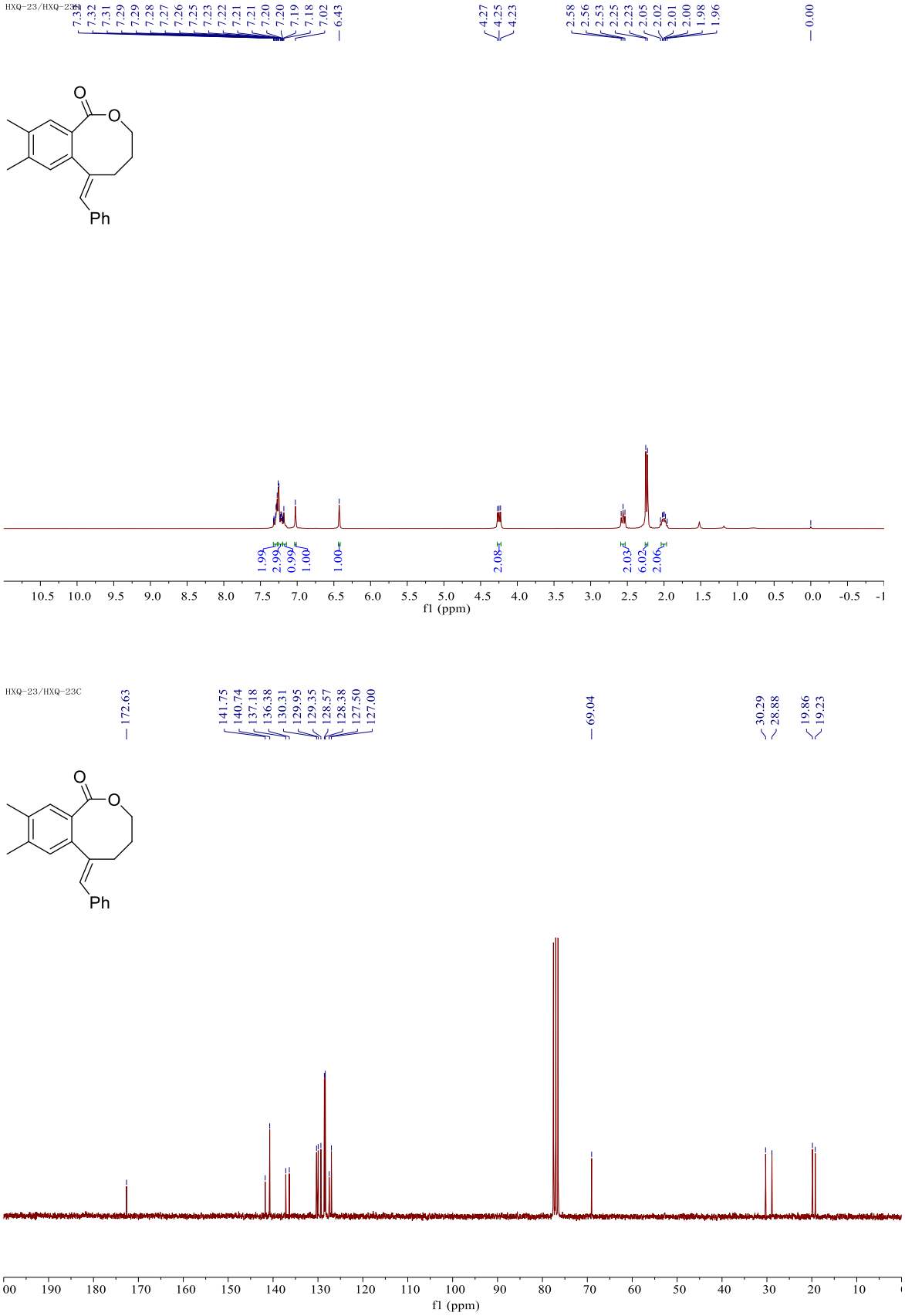


^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ga

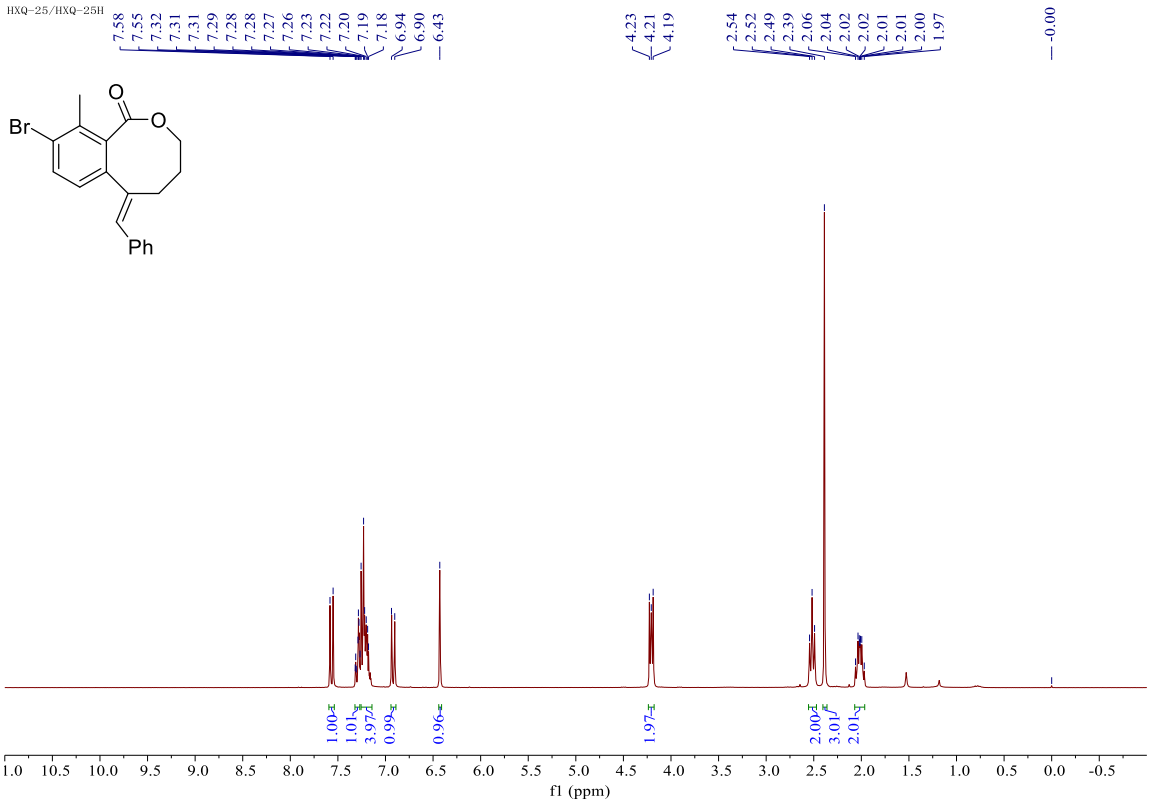


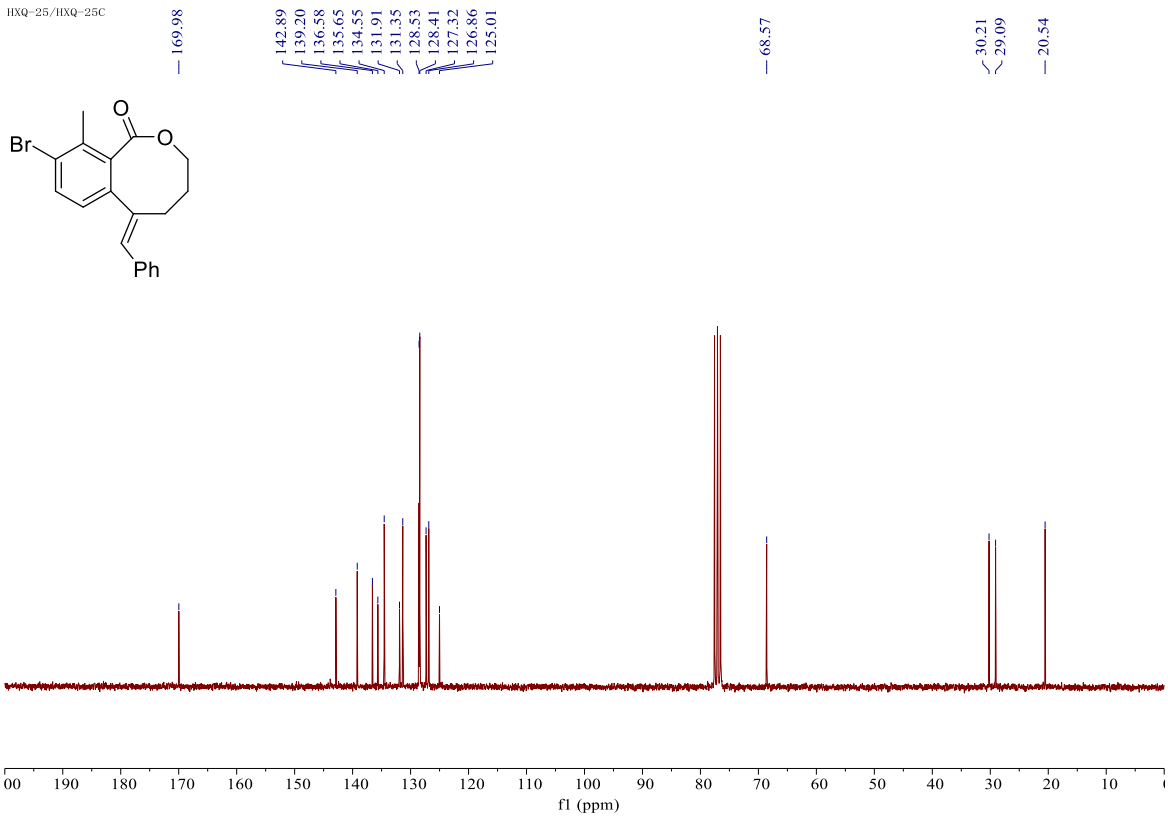


^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ha

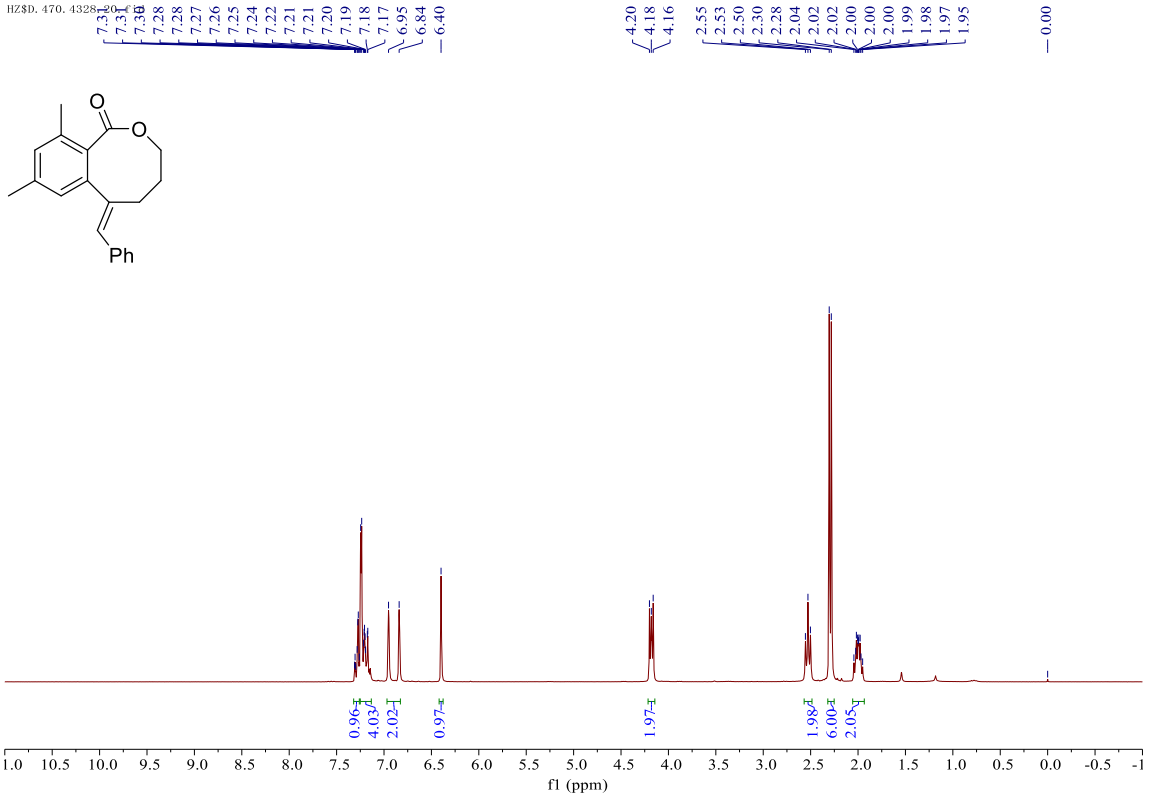


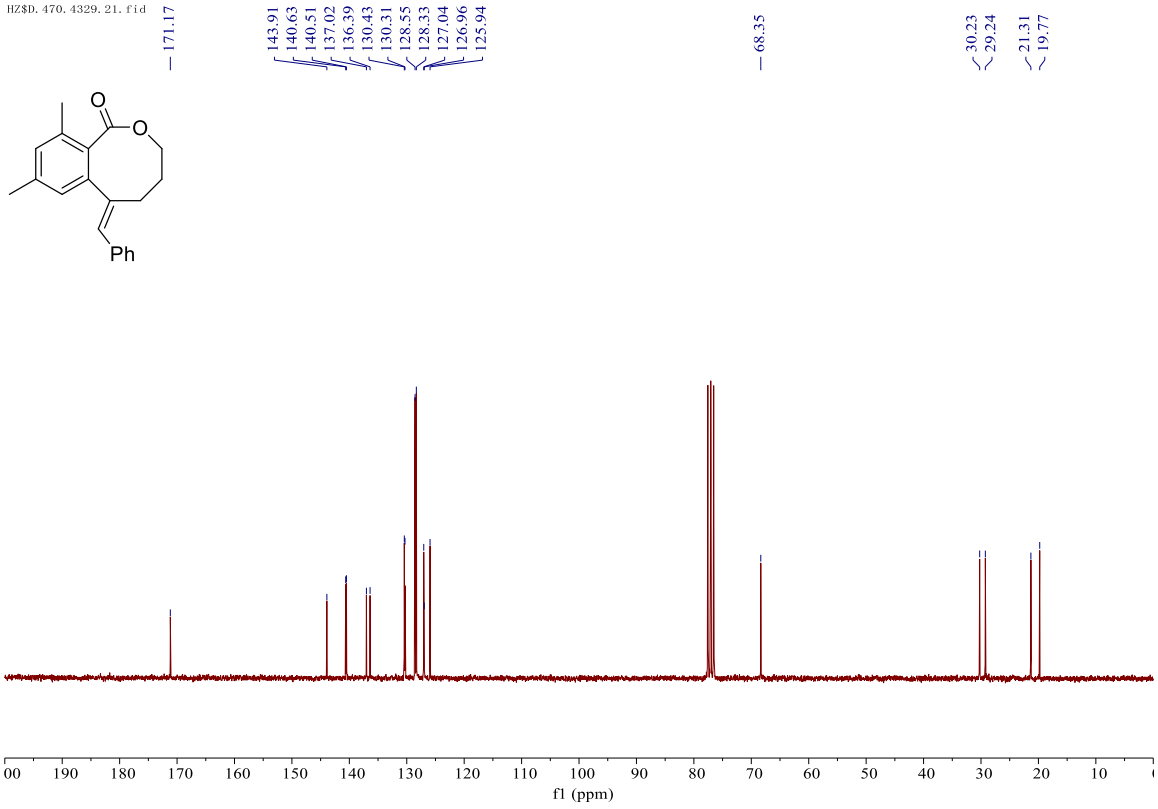
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ia



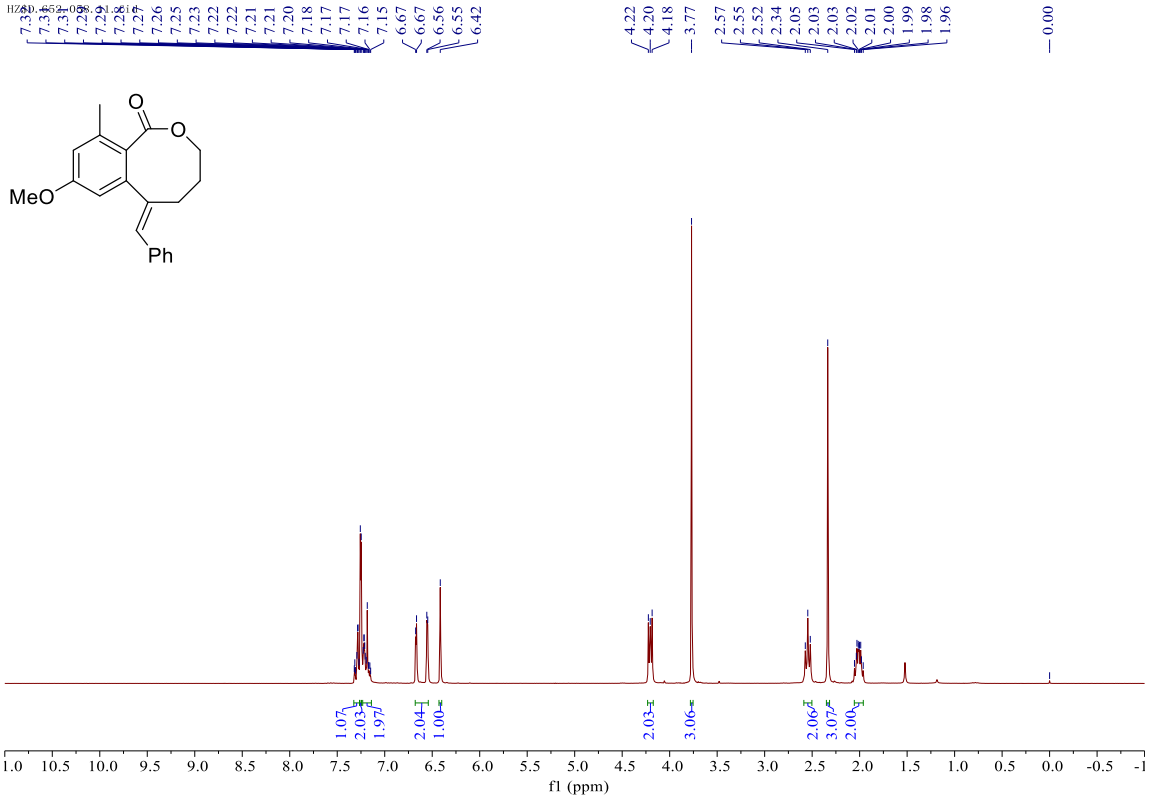


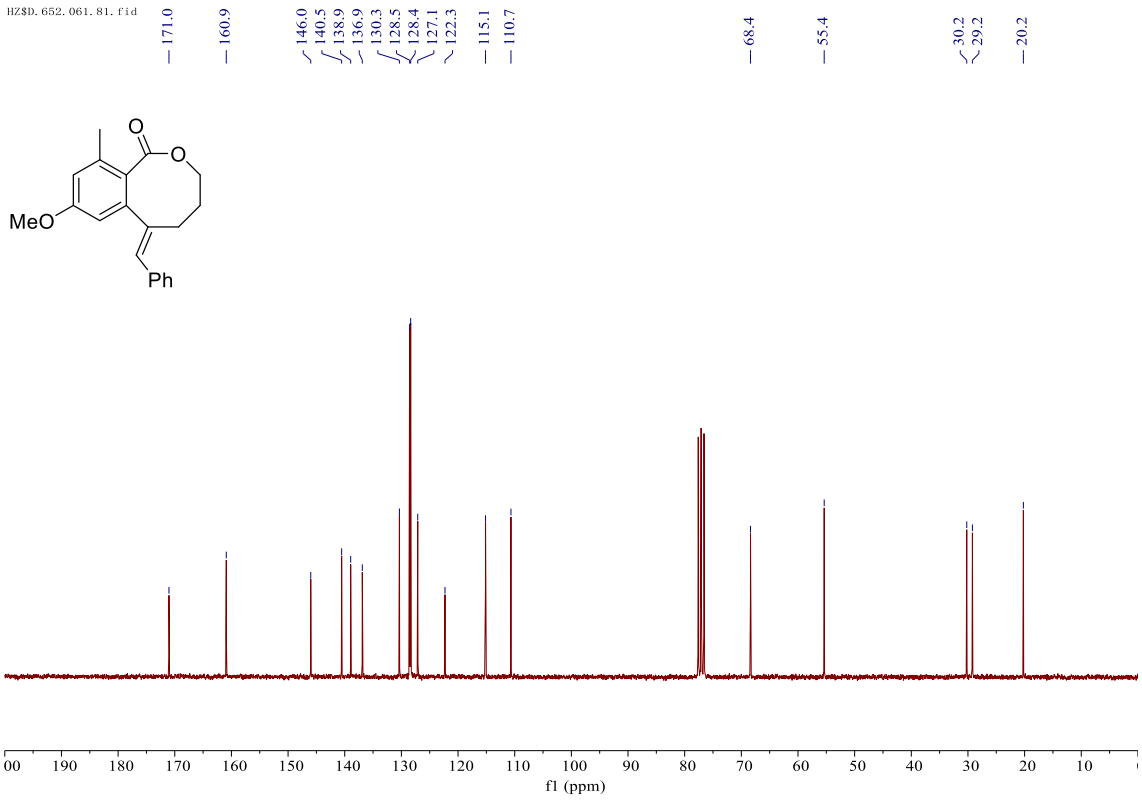
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ja



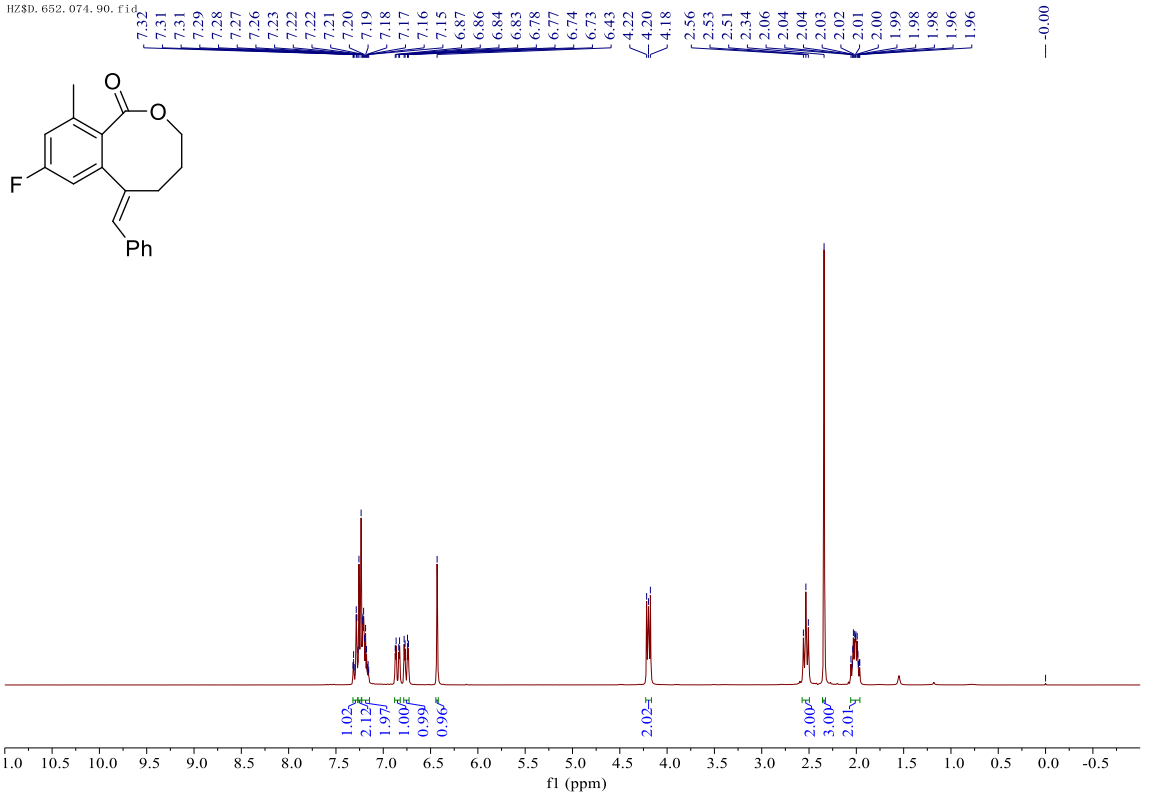


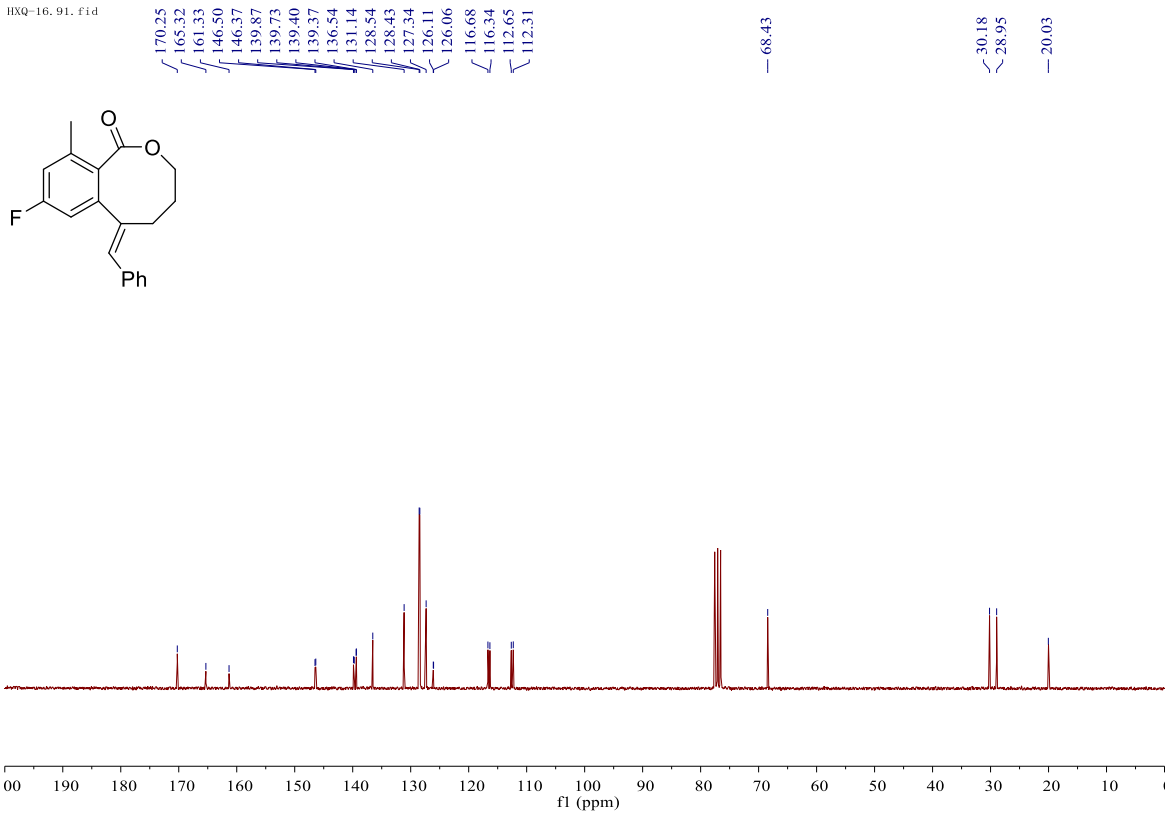
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ka



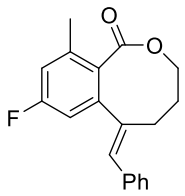


^{1}H NMR (250 MHz, $CDCl_3$), ^{13}C NMR (63 MHz, $CDCl_3$) and ^{19}F NMR (376 MHz, $CDCl_3$) spectra of product 3la

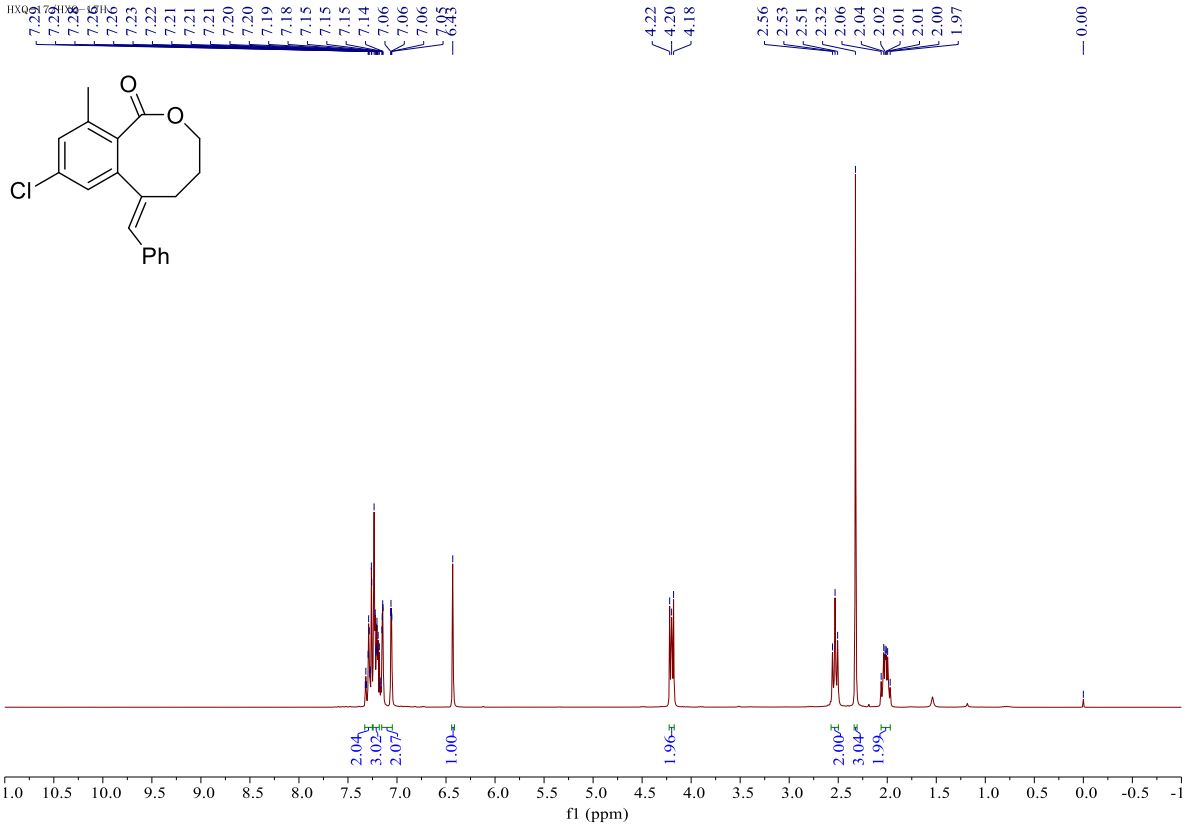


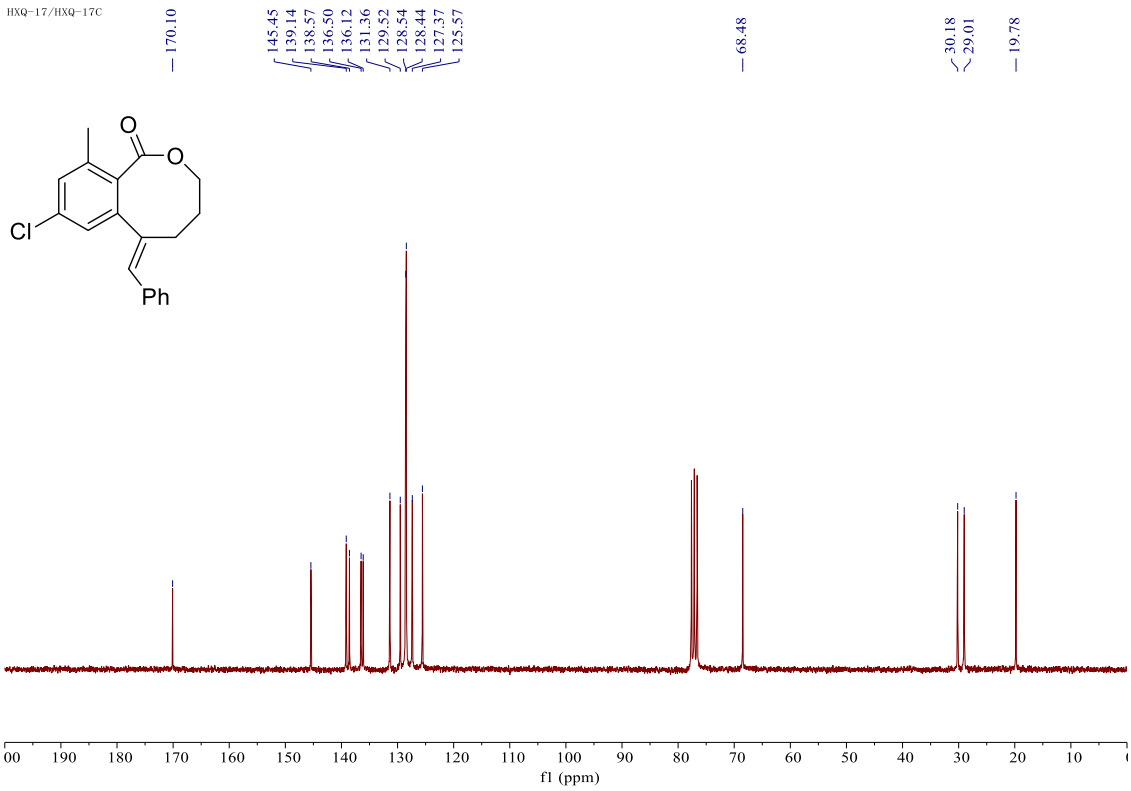


HXQ-16/HXQ-16F
F19
20.11.26 HXQ-16

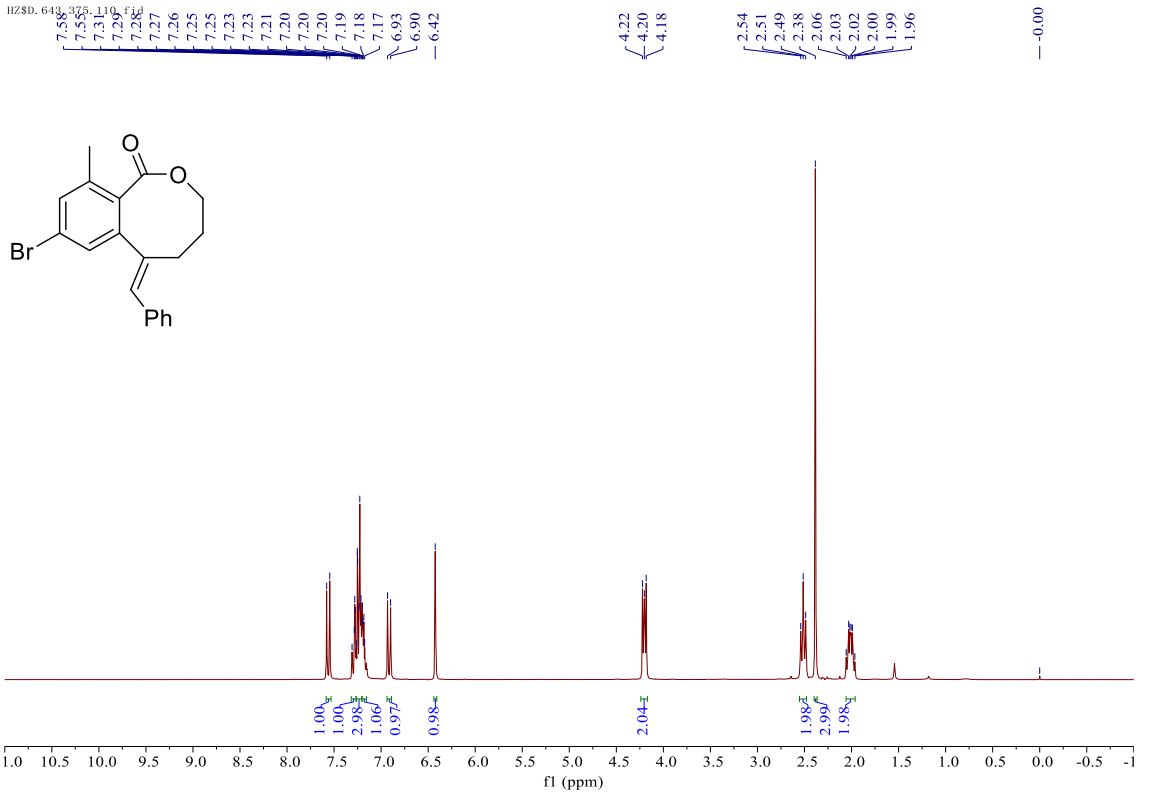


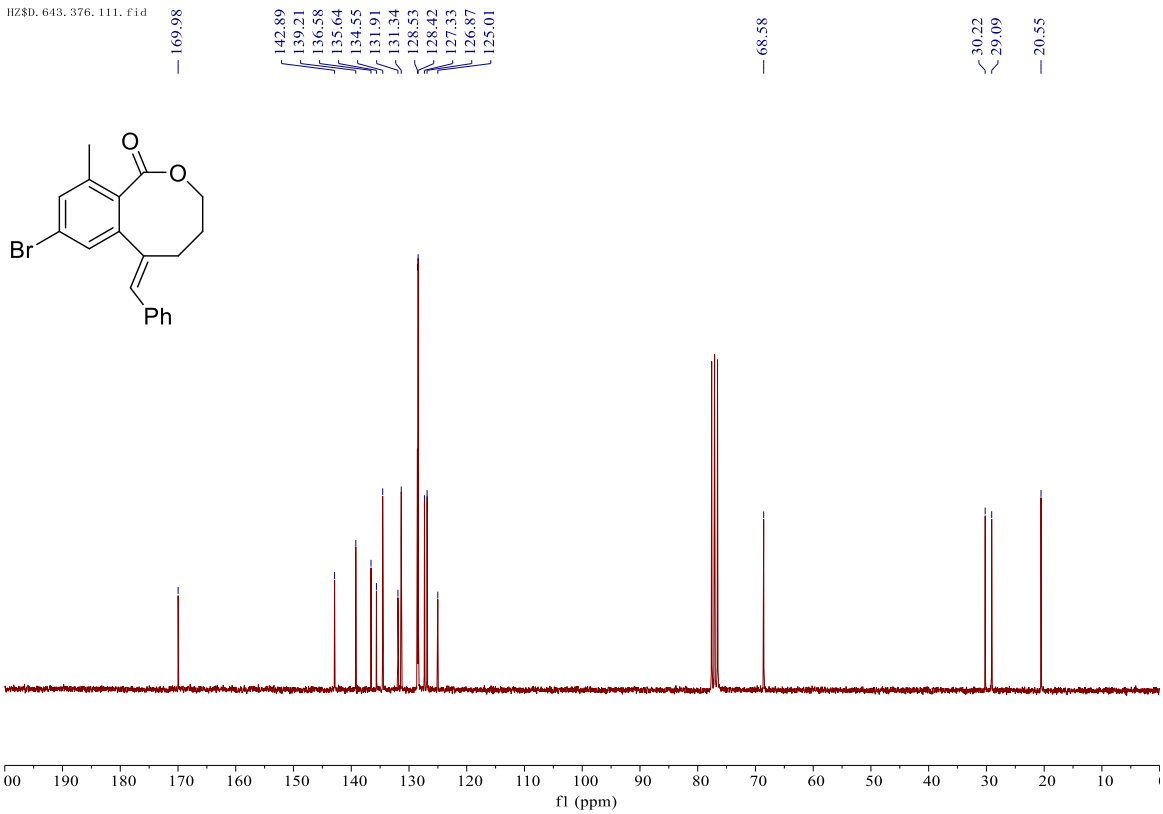
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ma



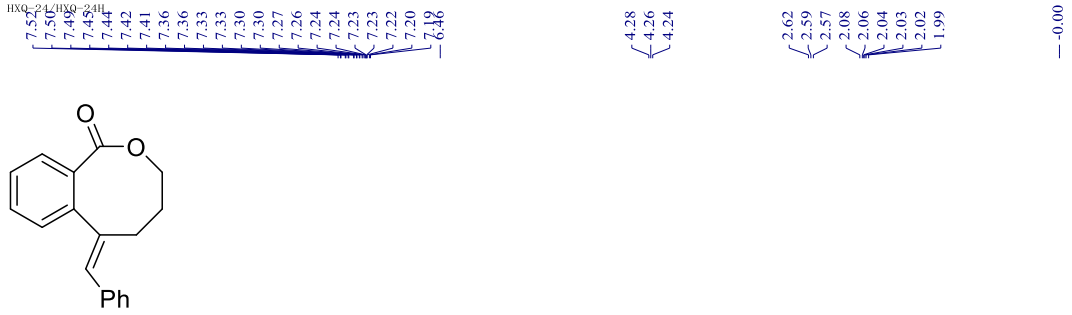


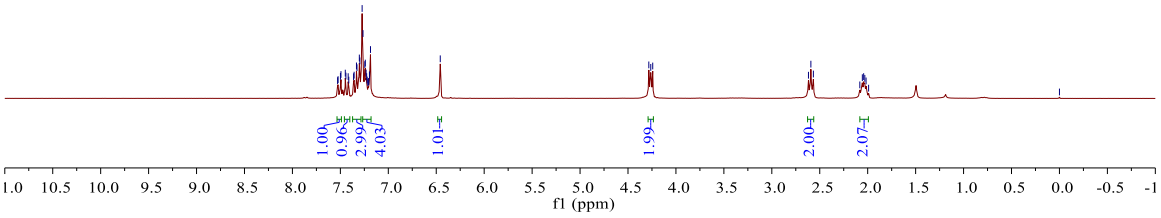
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3na

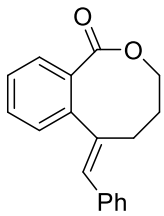


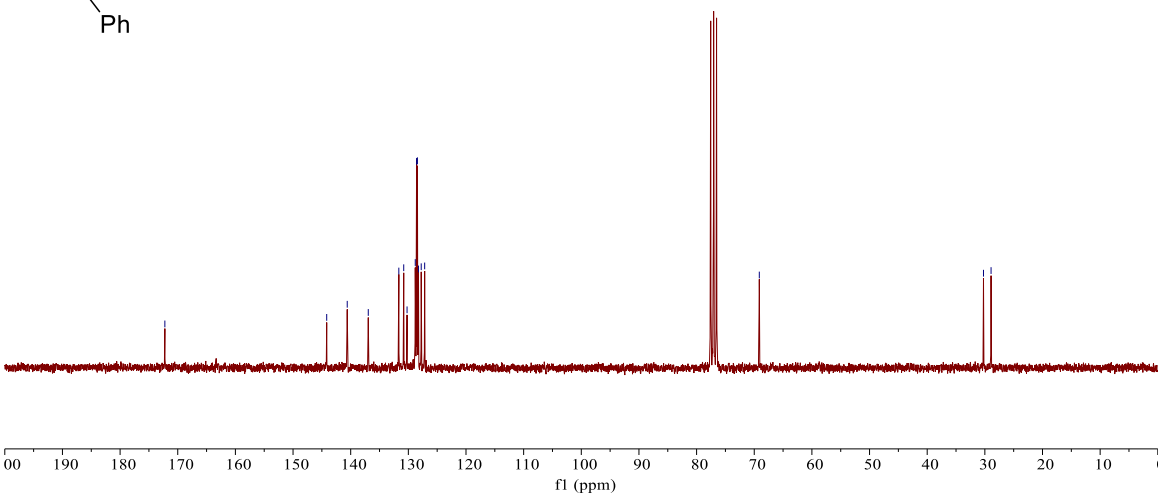


^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3oa



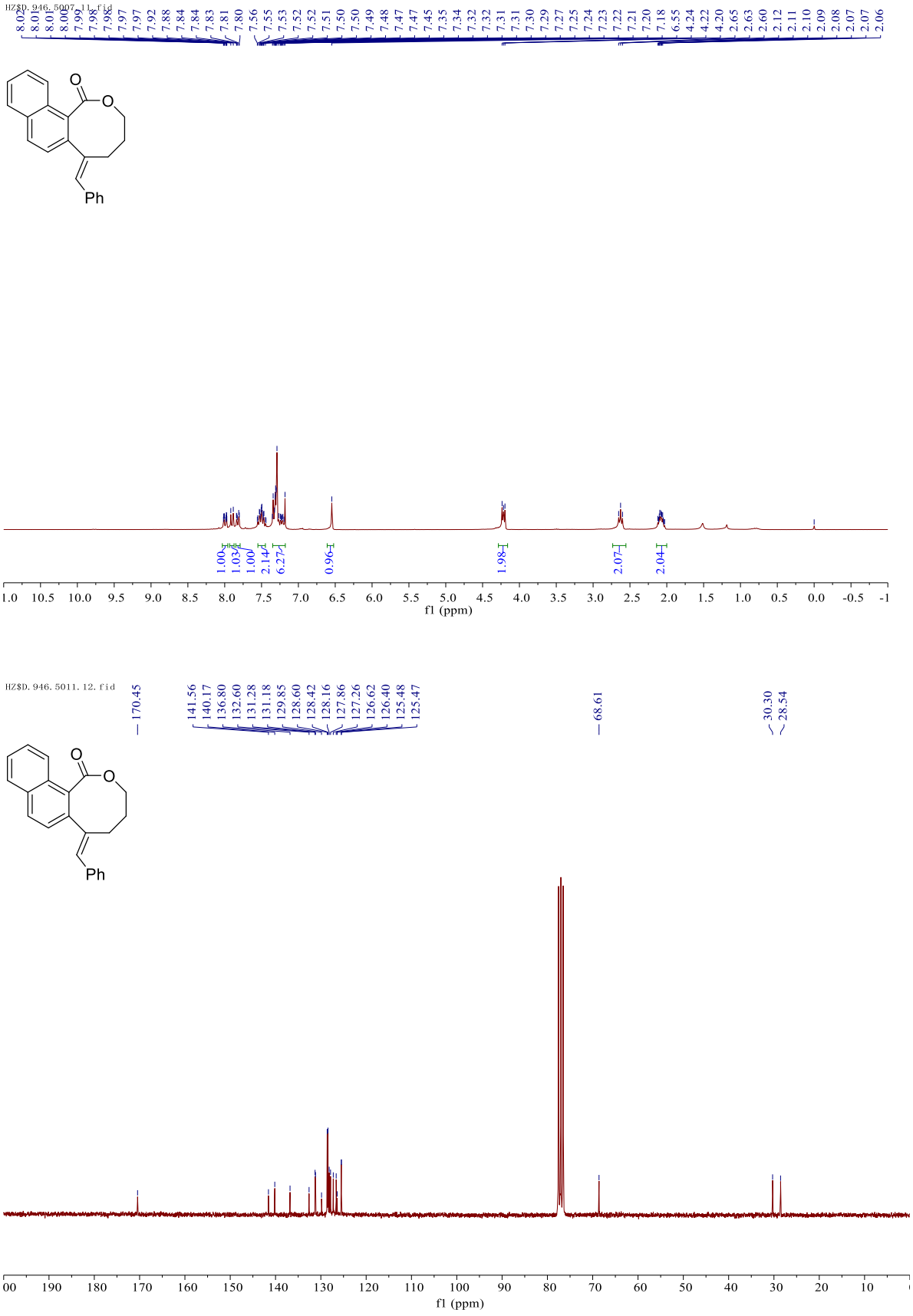




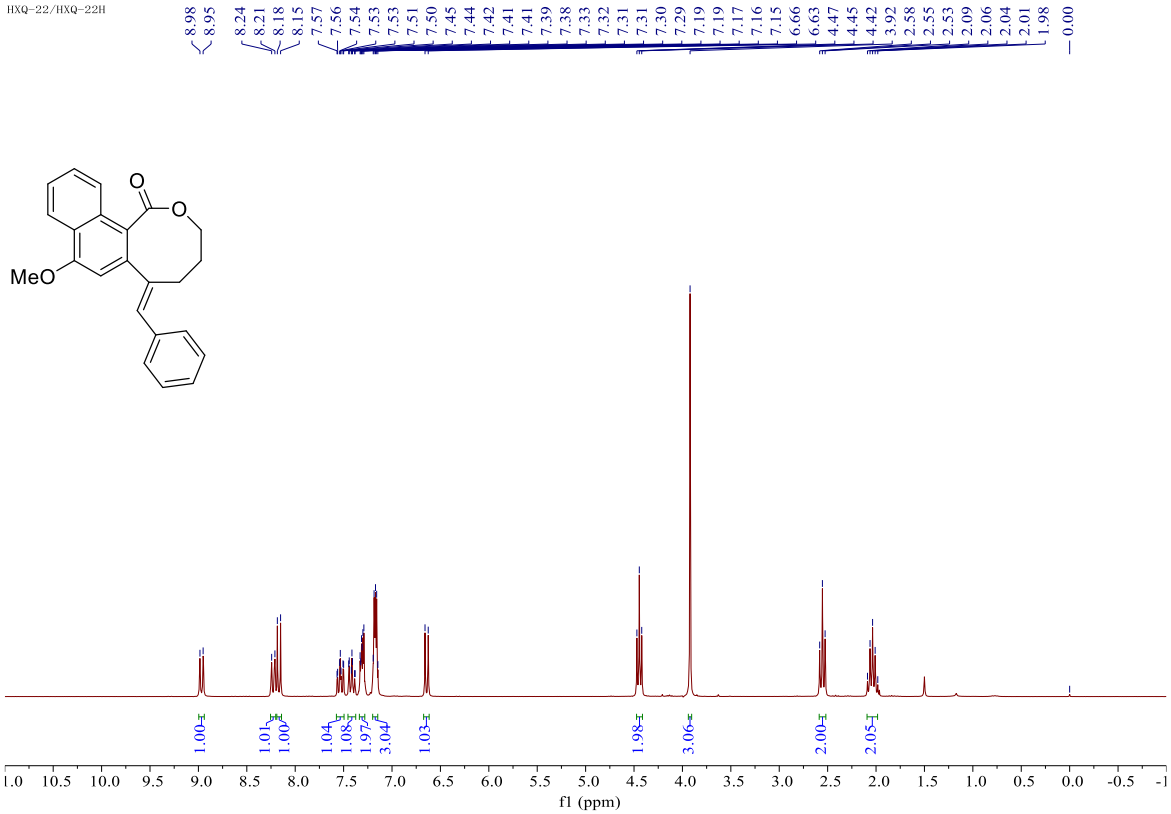


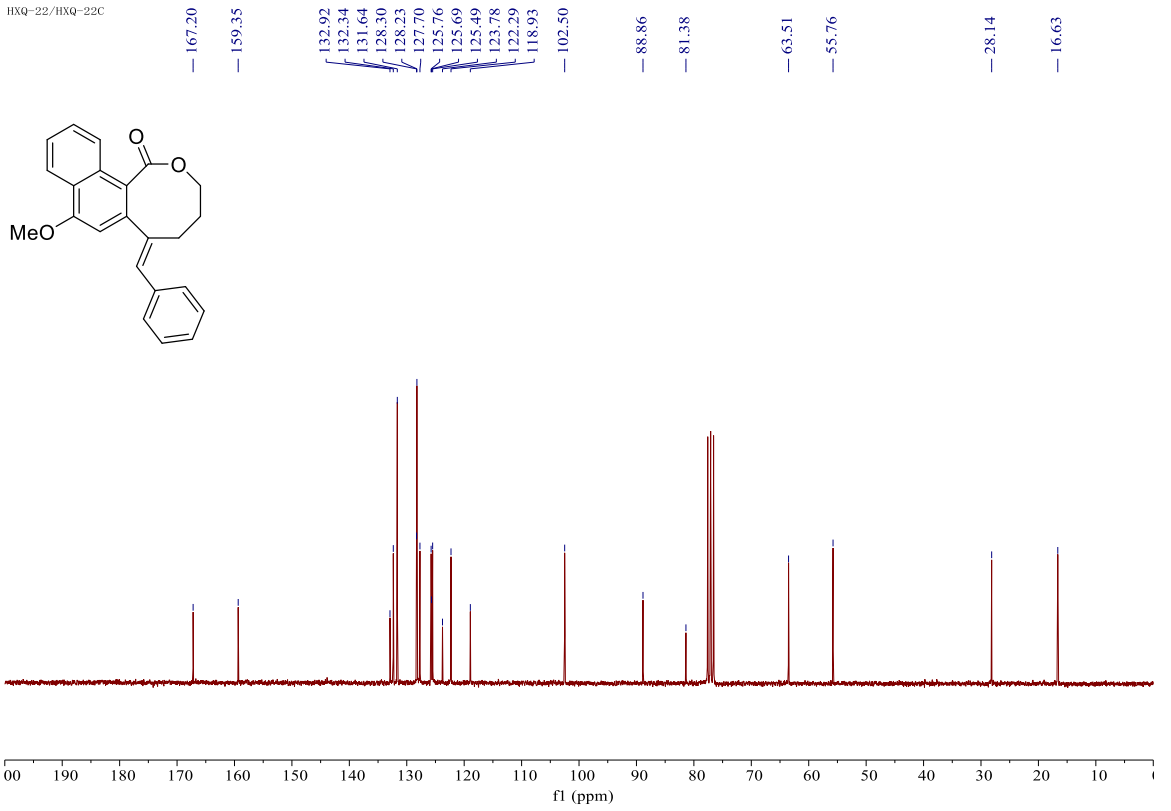
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3pa

^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3qa

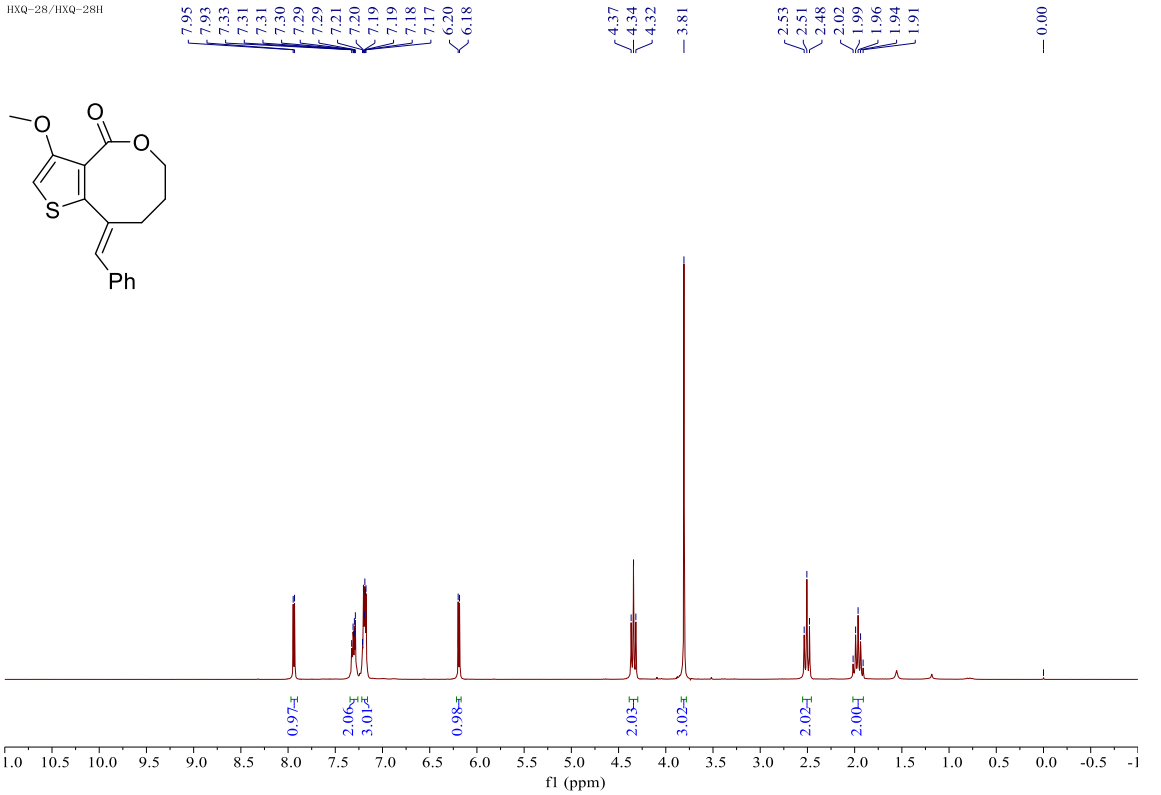


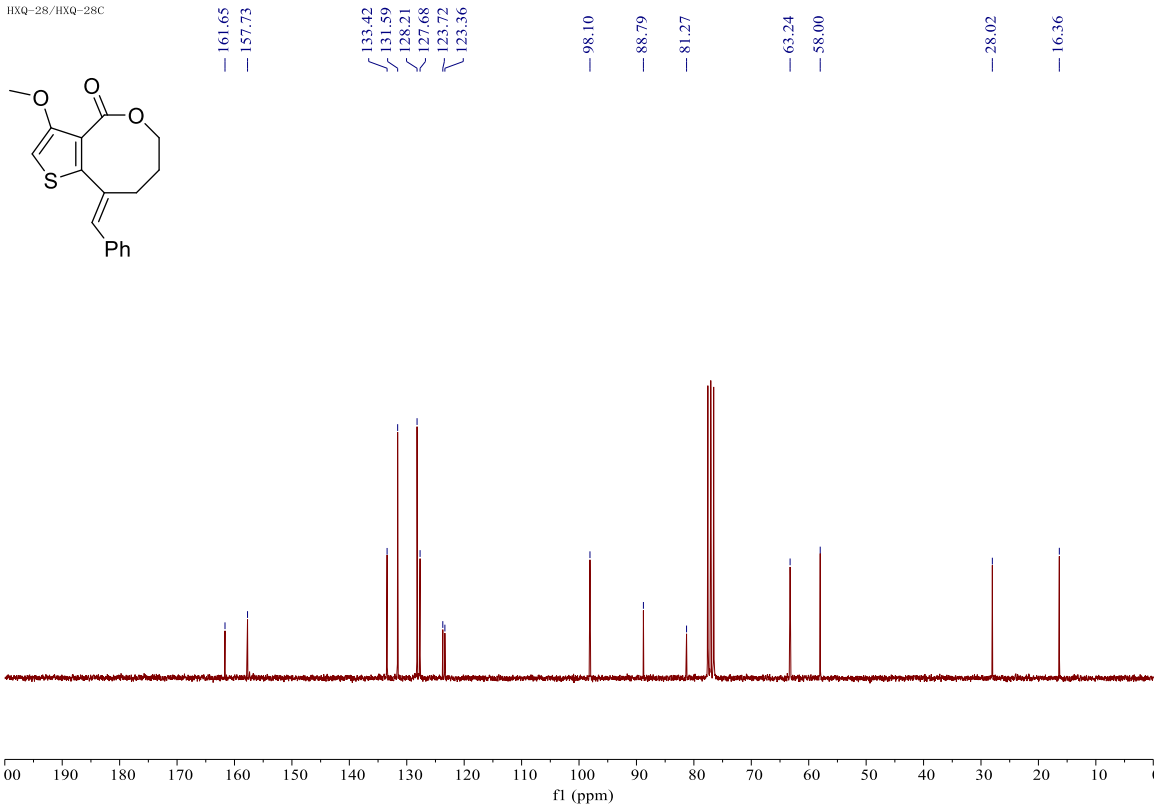
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3ra



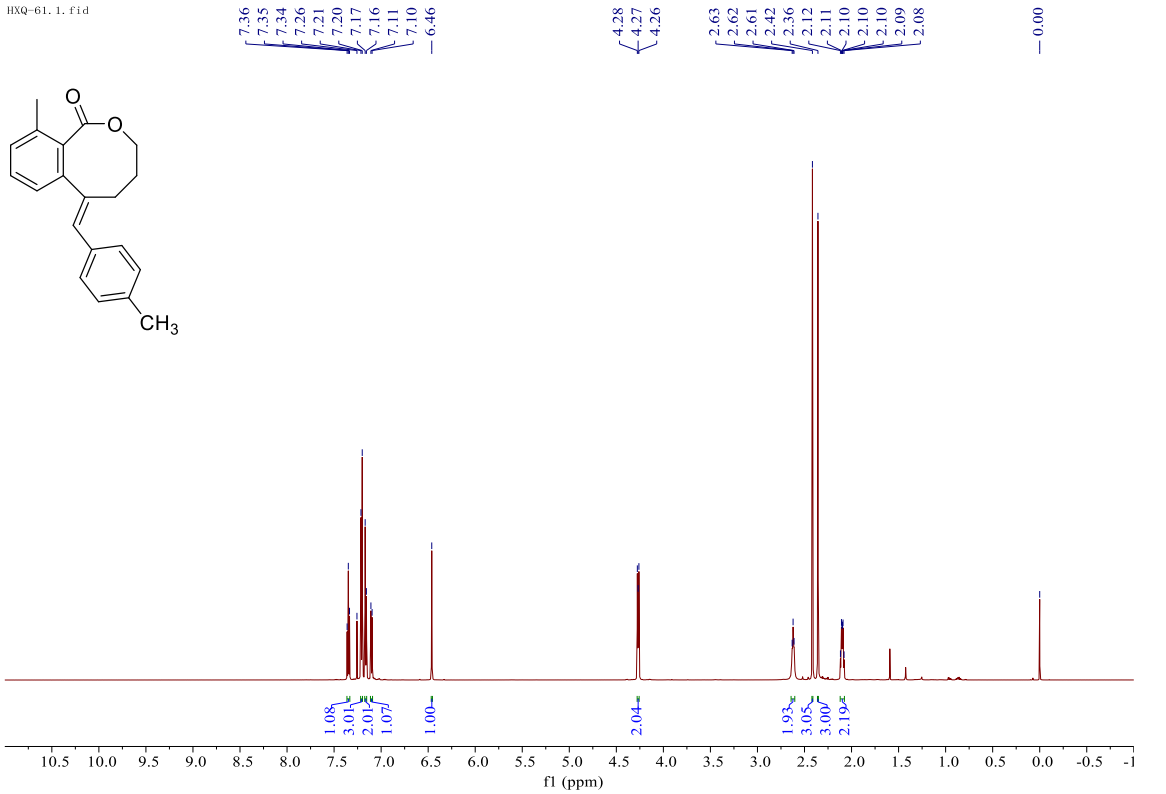


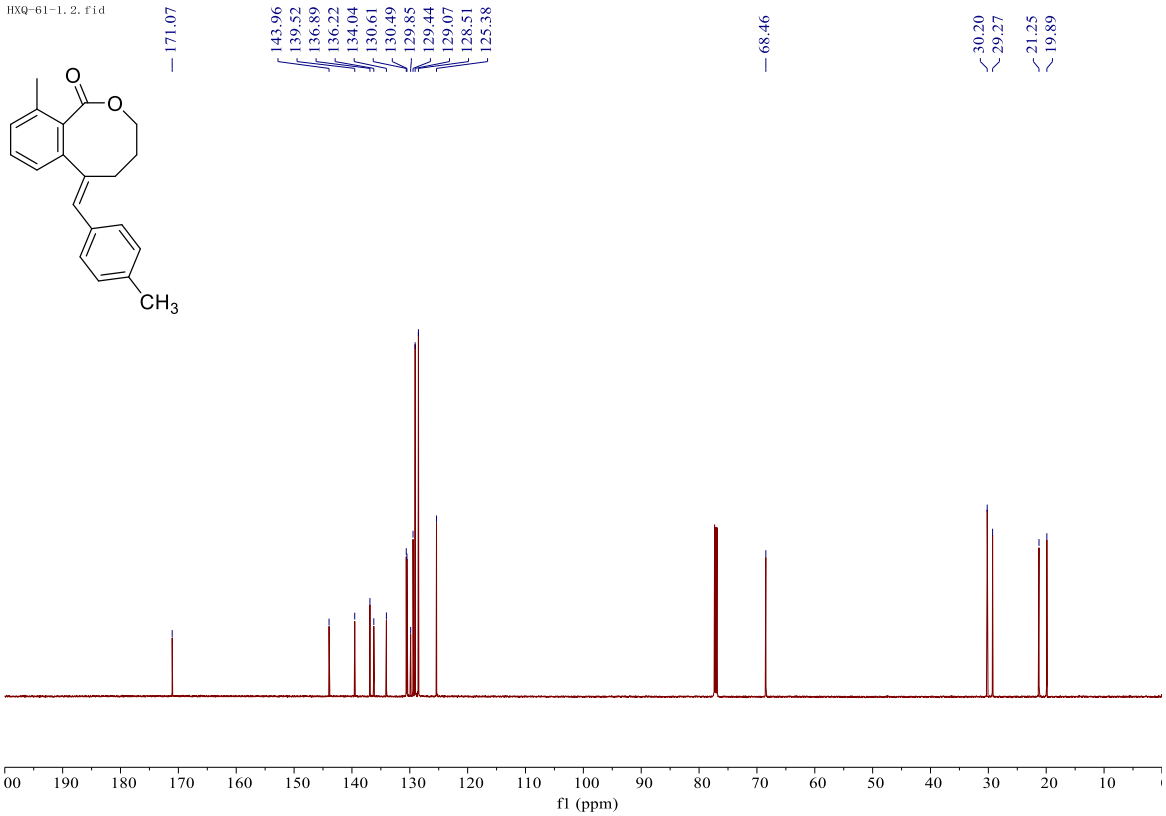
^{1}H NMR (250 MHz, $CDCl_3$) and ^{13}C NMR (63 MHz, $CDCl_3$) spectra of product 3sa



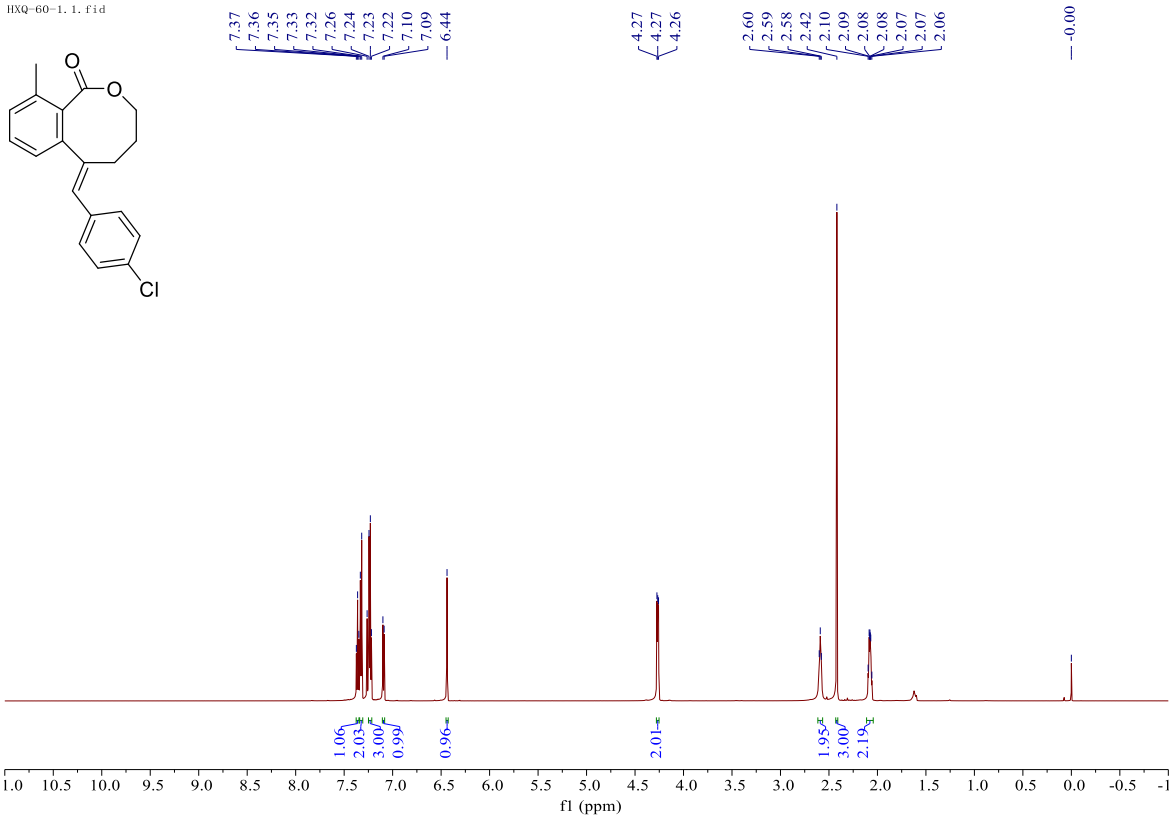


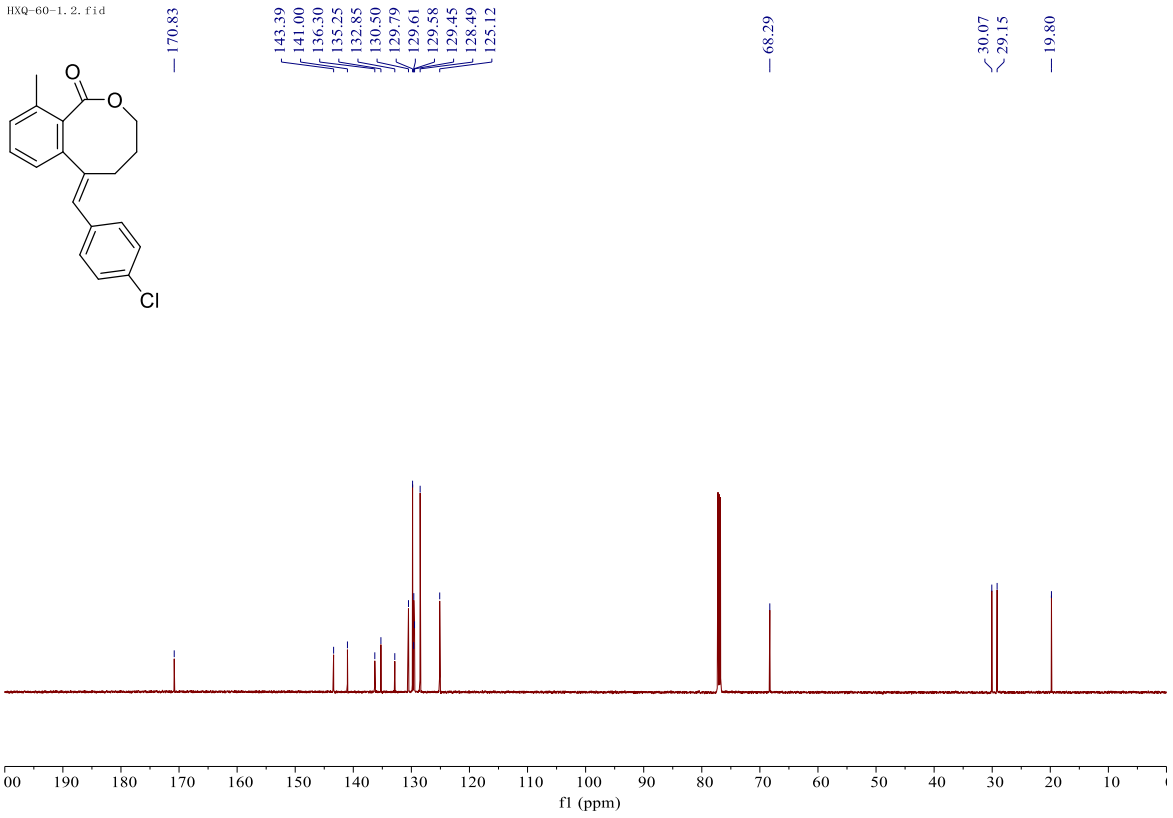
^{1}H NMR (600 MHz, $CDCl_3$) and ^{13}C NMR (150 MHz, $CDCl_3$) spectra of product 3ab



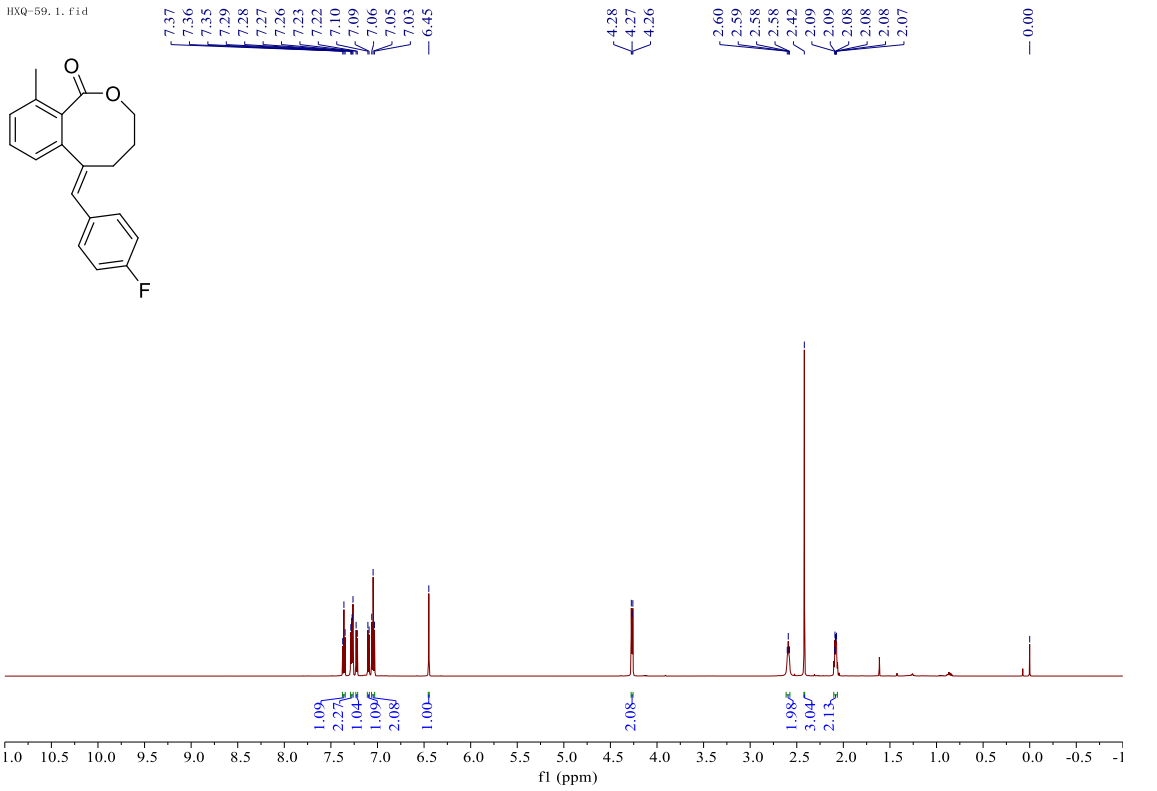


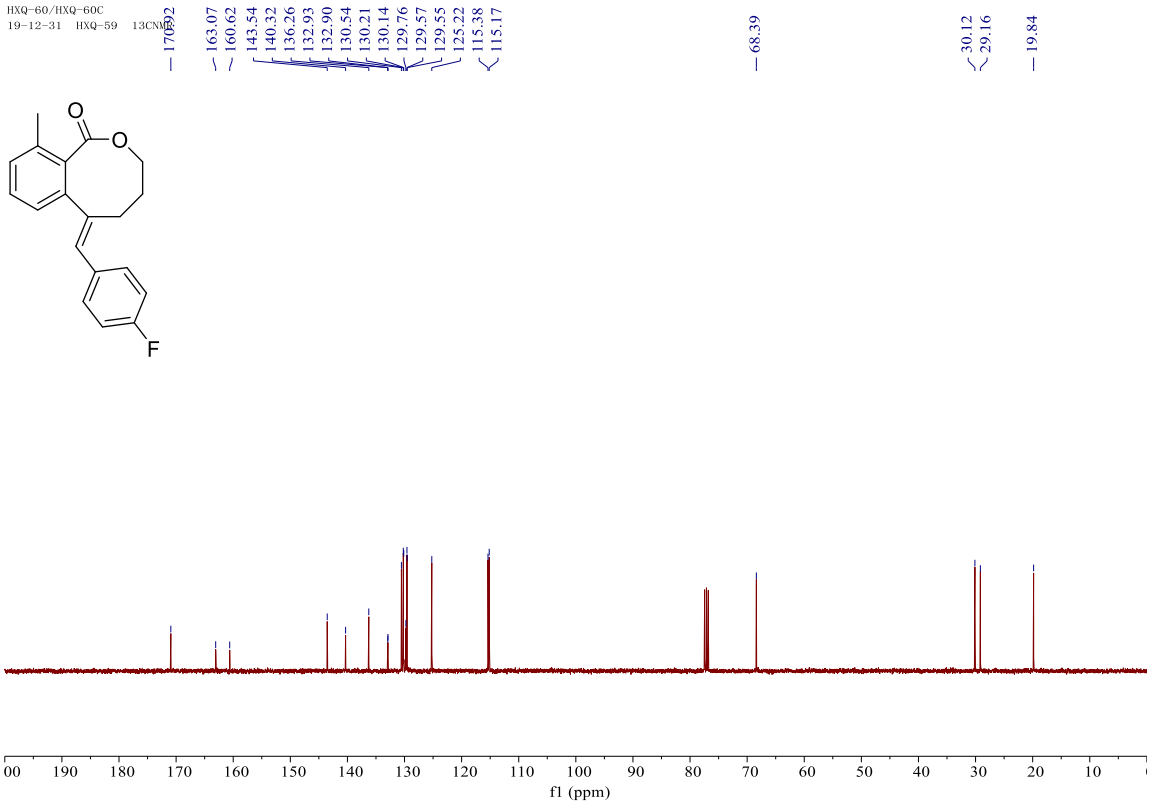
^{1}H NMR (600 MHz, $CDCl_3$) and ^{13}C NMR (150 MHz, $CDCl_3$) spectra of product 3ac

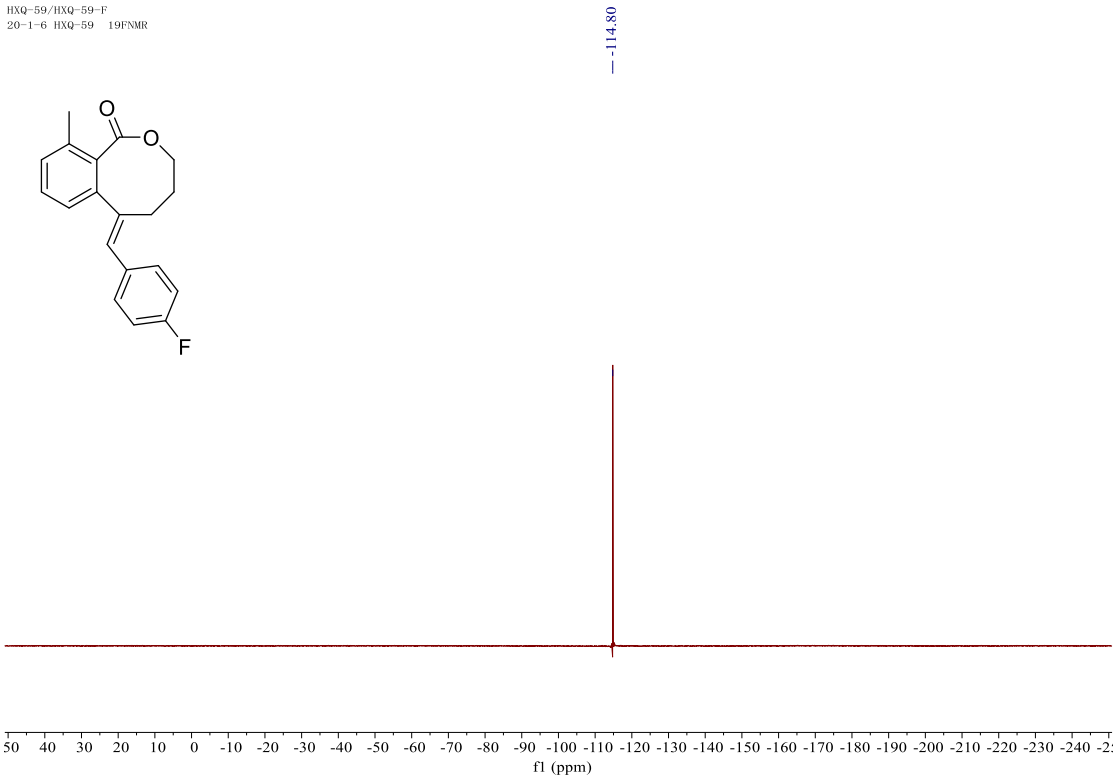




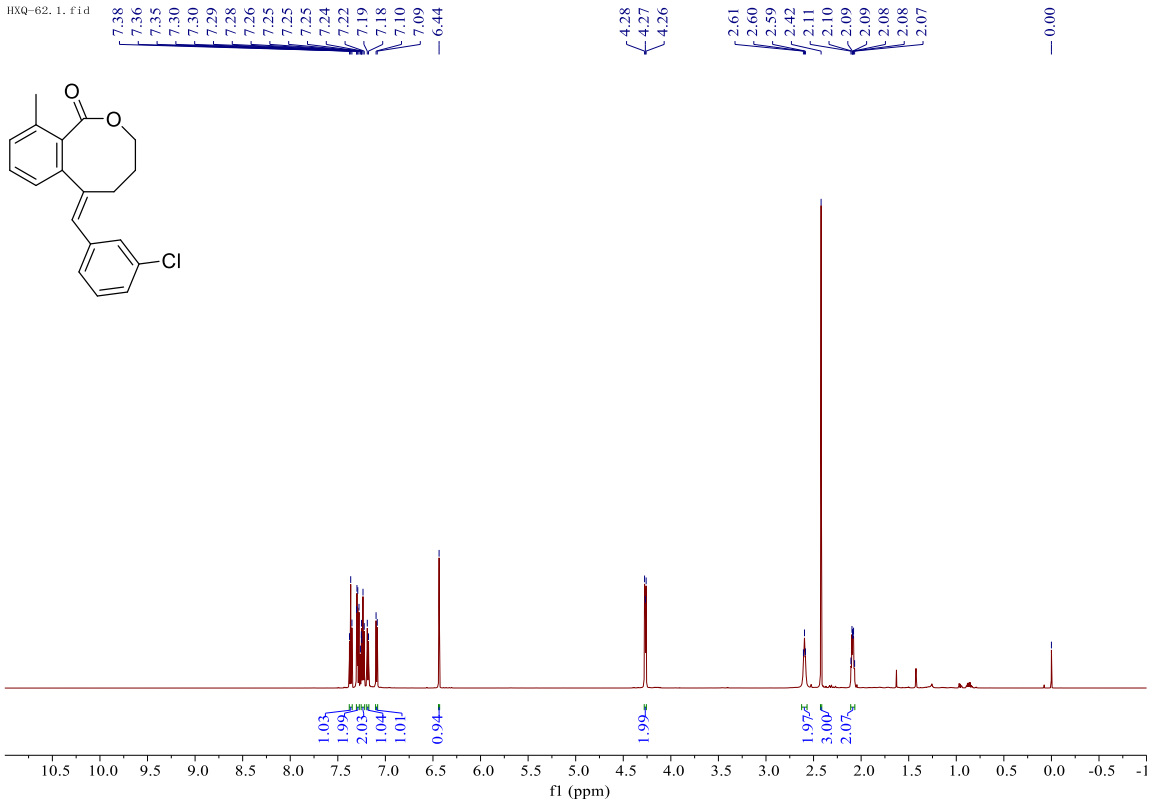
^{1}H NMR (600 MHz, $CDCl_3$), ^{13}C NMR (100 MHz, $CDCl_3$) and ^{19}F NMR (376 MHz, $CDCl_3$) spectra of product 3ad

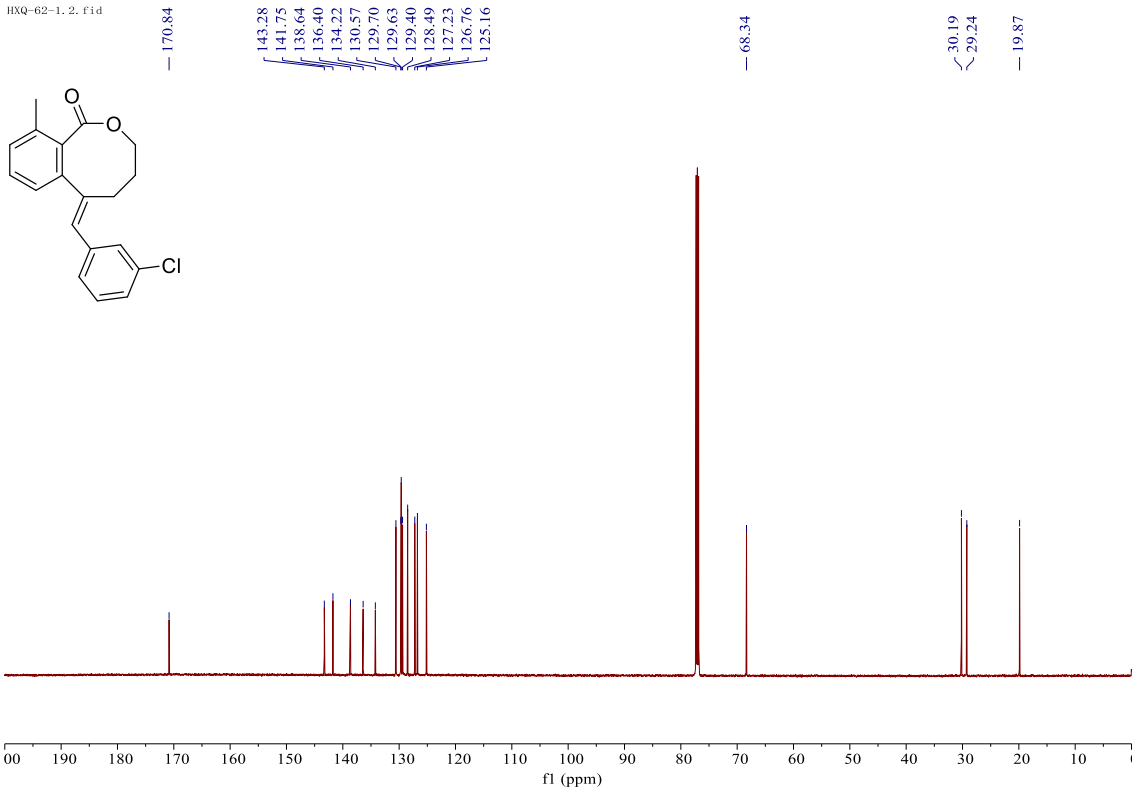




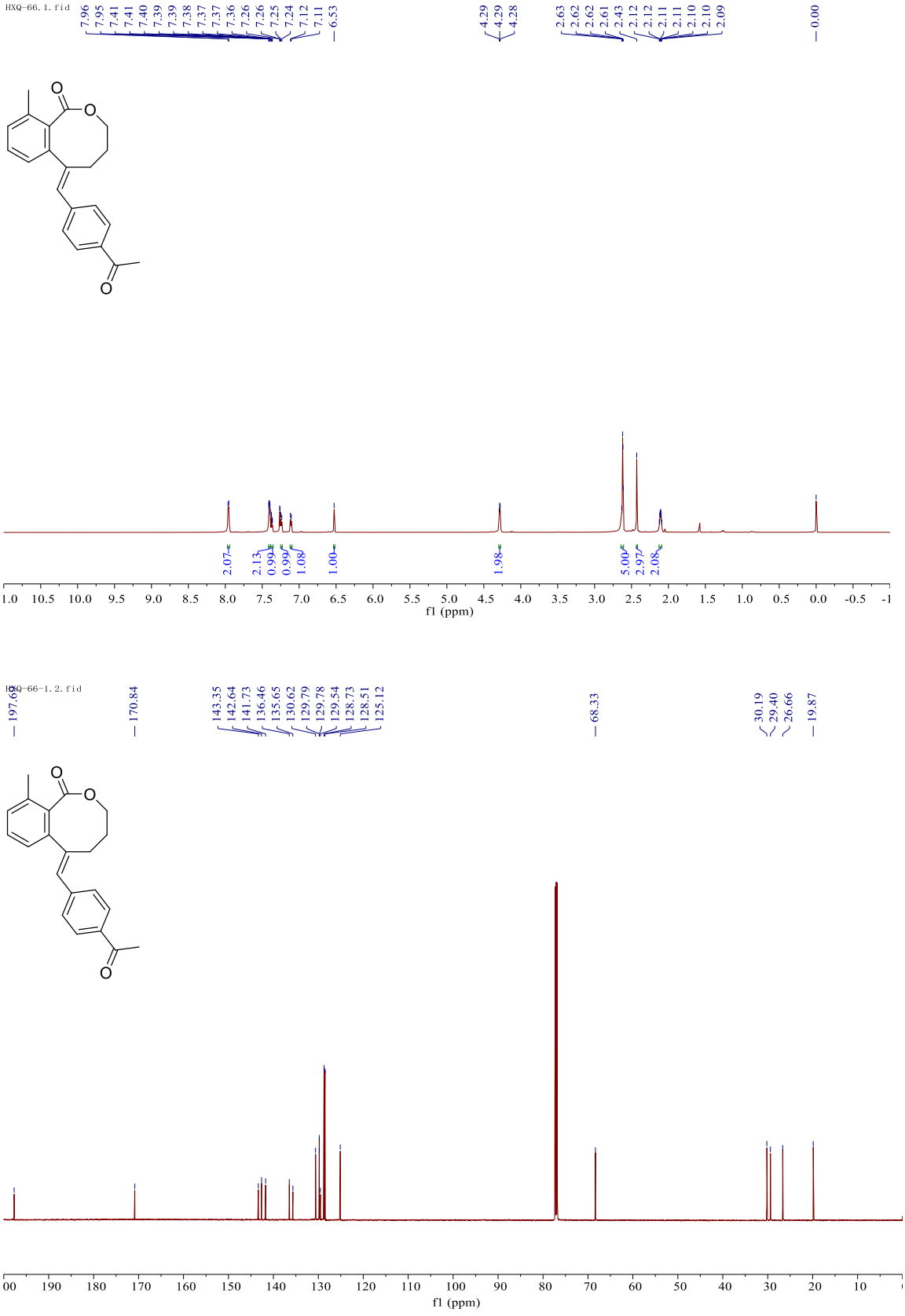

HXQ-59/HXQ-59-F
20-1-6 HXQ-59 19FNMR
-114.80
O
O
F
50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210 -220 -230 -240
f1 (ppm)

^{1}H NMR (600 MHz, $CDCl_3$) and ^{13}C NMR (150 MHz, $CDCl_3$) spectra of product 3ae

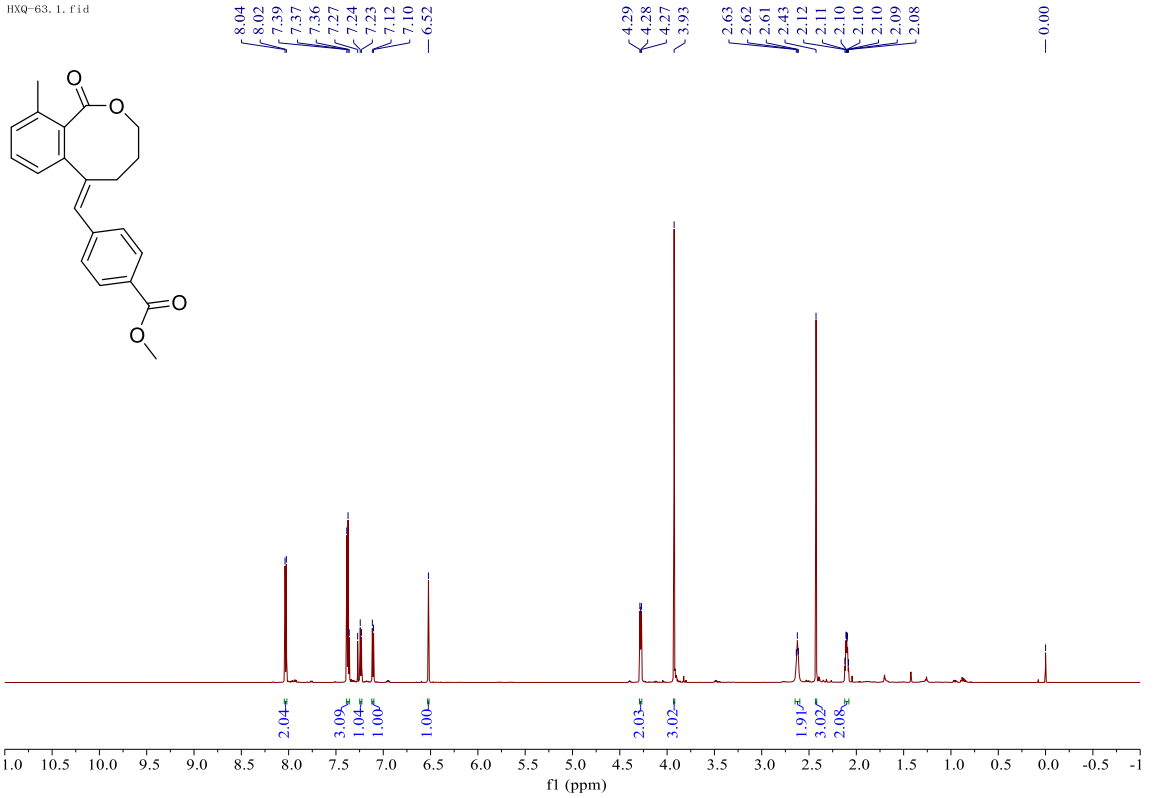


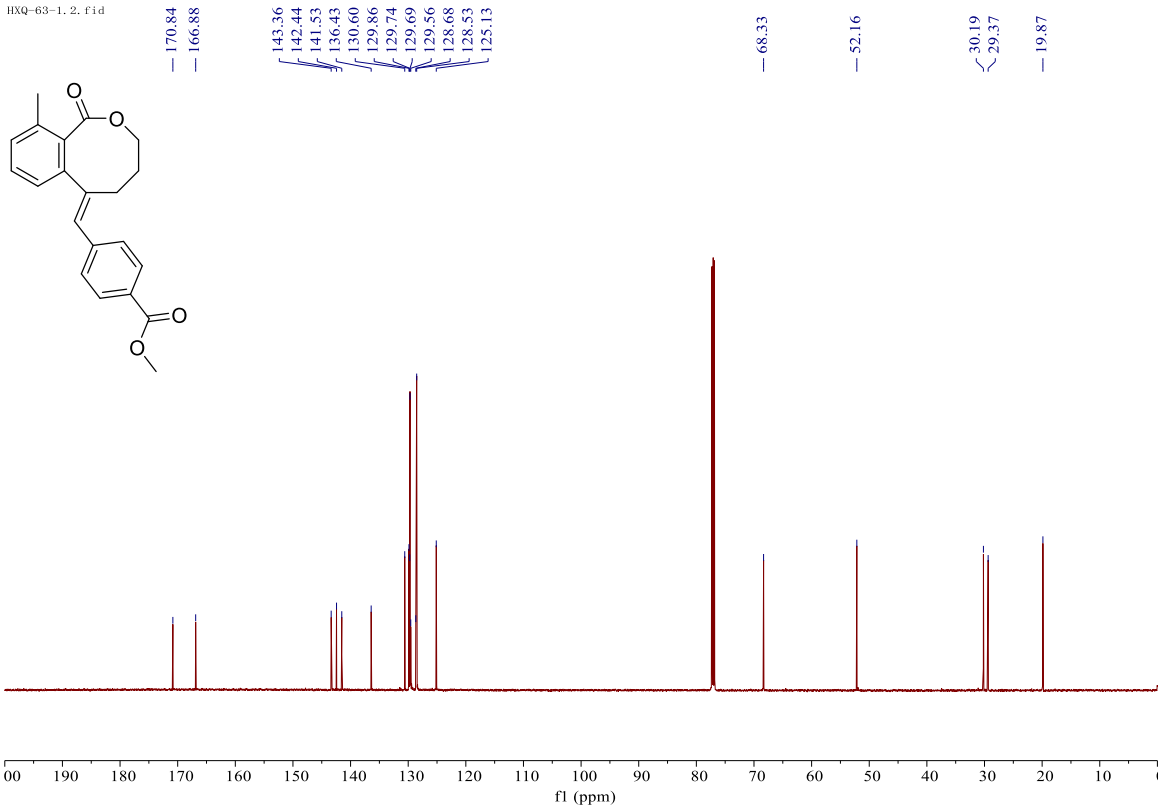


^{1}H NMR (600 MHz, $CDCl_3$) and ^{13}C NMR (150 MHz, $CDCl_3$) spectra of product 3af

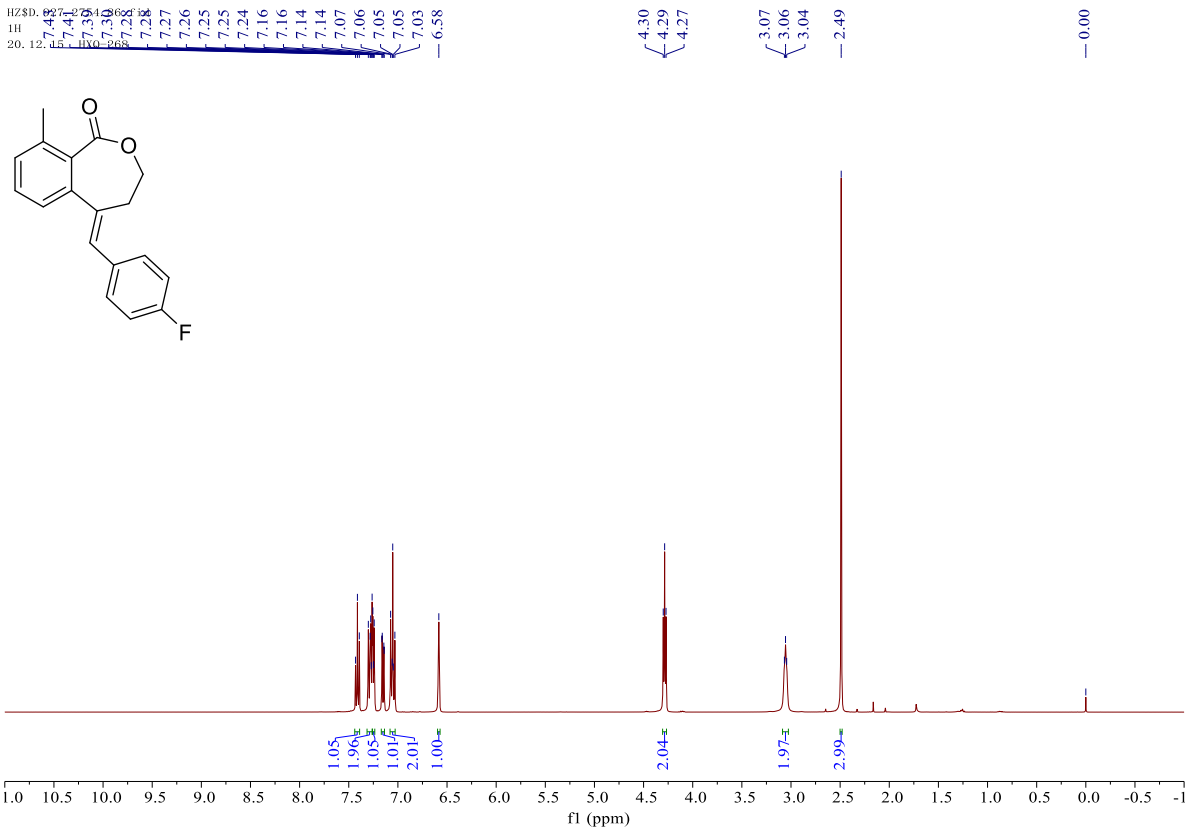


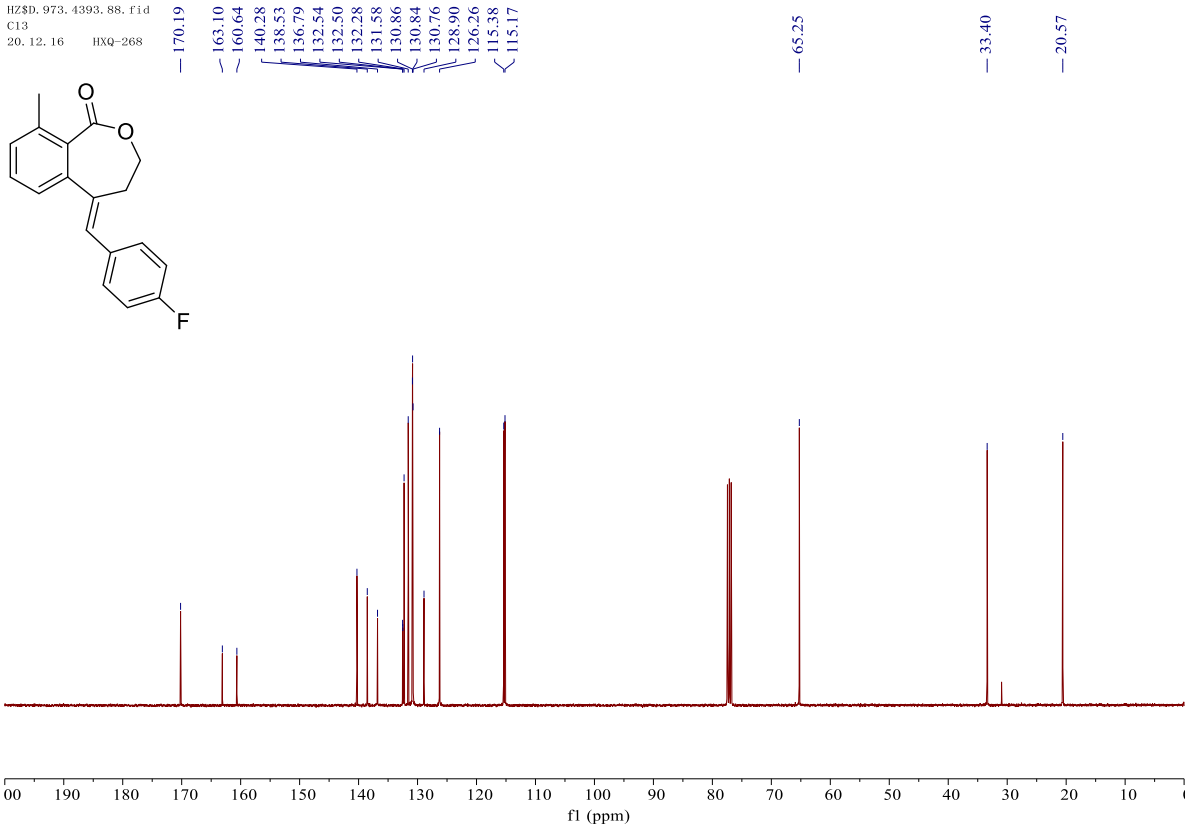
^{1}H NMR (600 MHz, $CDCl_3$) and ^{13}C NMR (150 MHz, $CDCl_3$) spectra of product 3ag



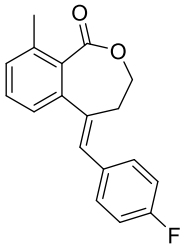


^{1}H NMR (400 MHz, $CDCl_3$), ^{13}C NMR (100 MHz, $CDCl_3$) and ^{19}F NMR (376 MHz, $CDCl_3$) spectra of product 3ah

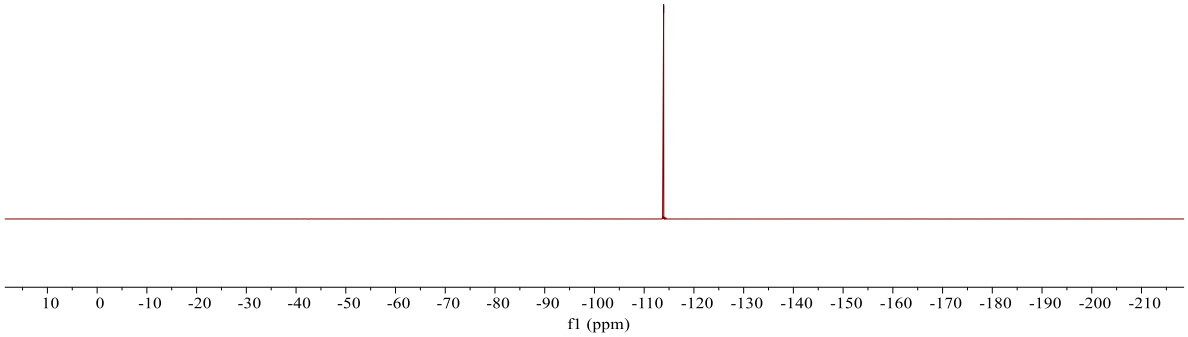




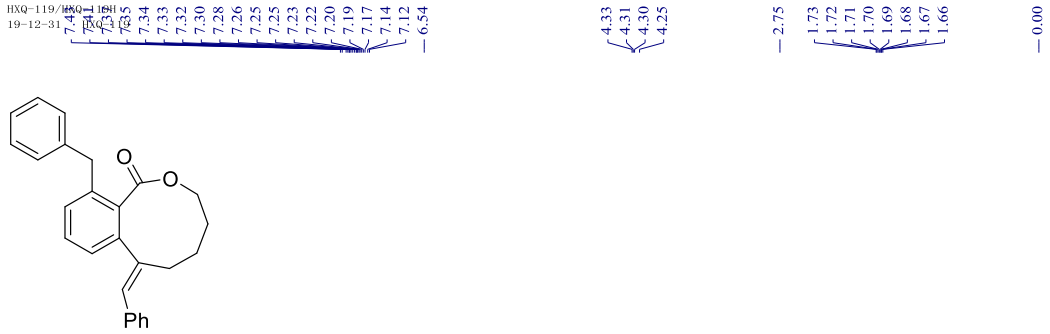
HZ$D.973.4395.87.fid
F19
20.12.16 HXQ-268

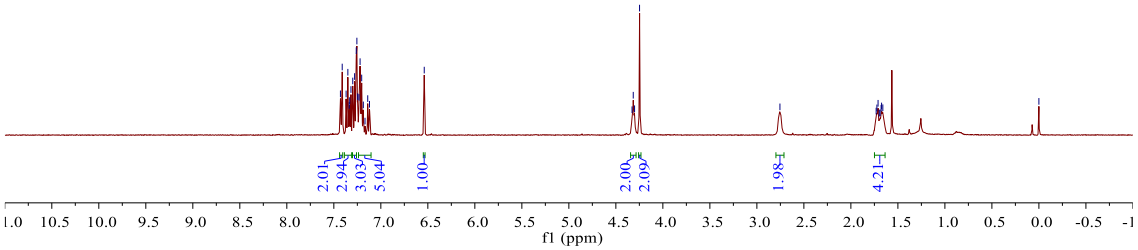


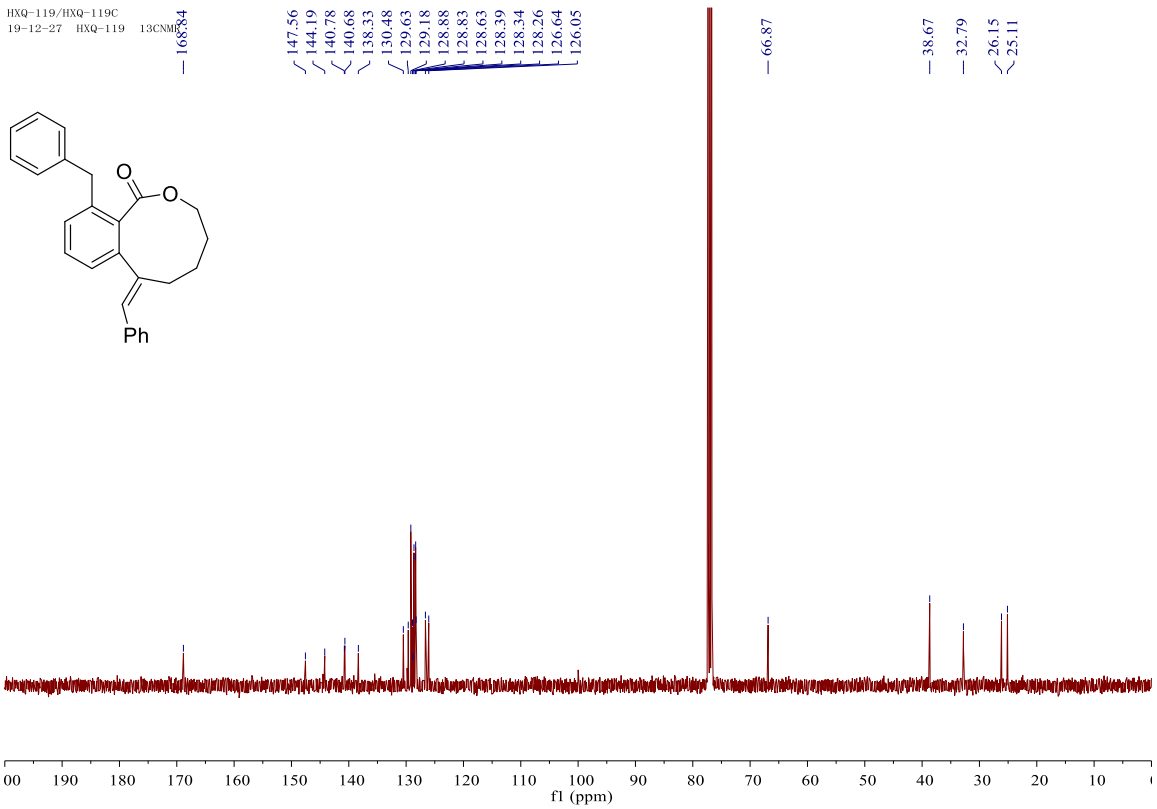
-113.91



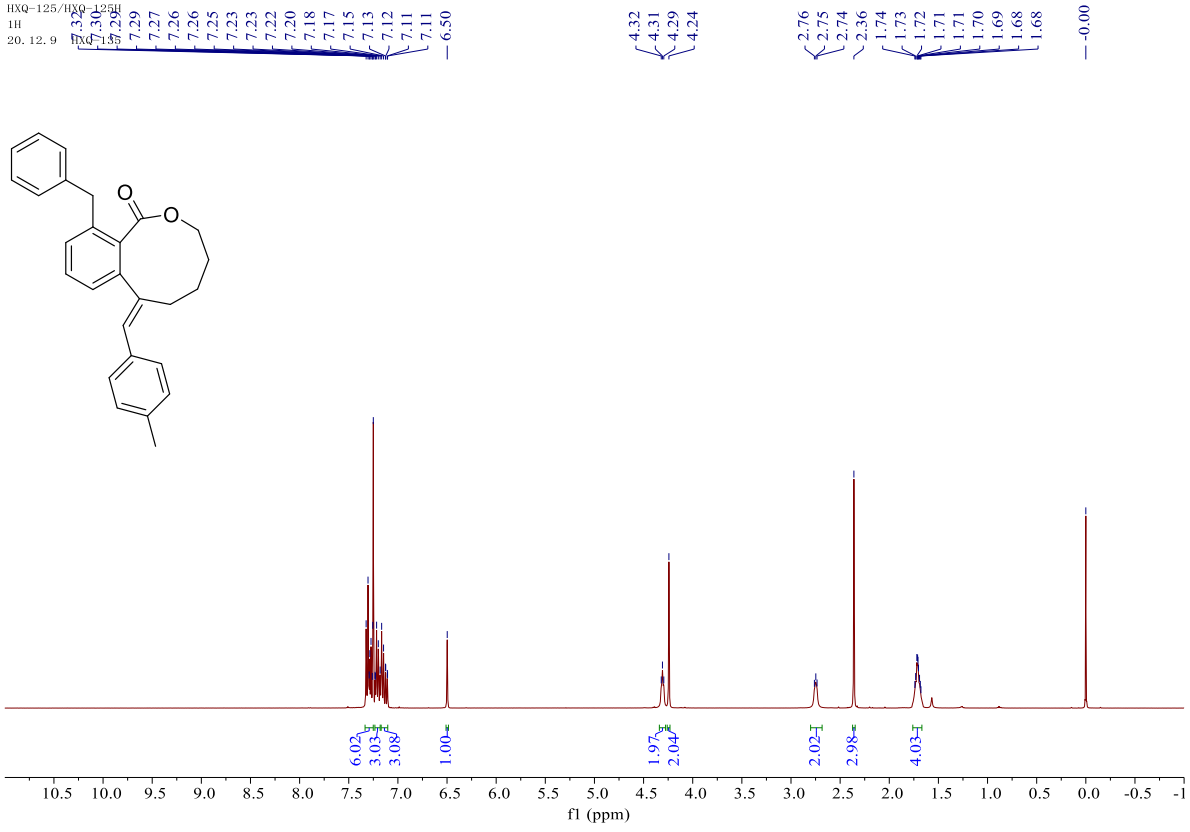
^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C NMR (100 MHz, $CDCl_3$) spectra of product 3dh

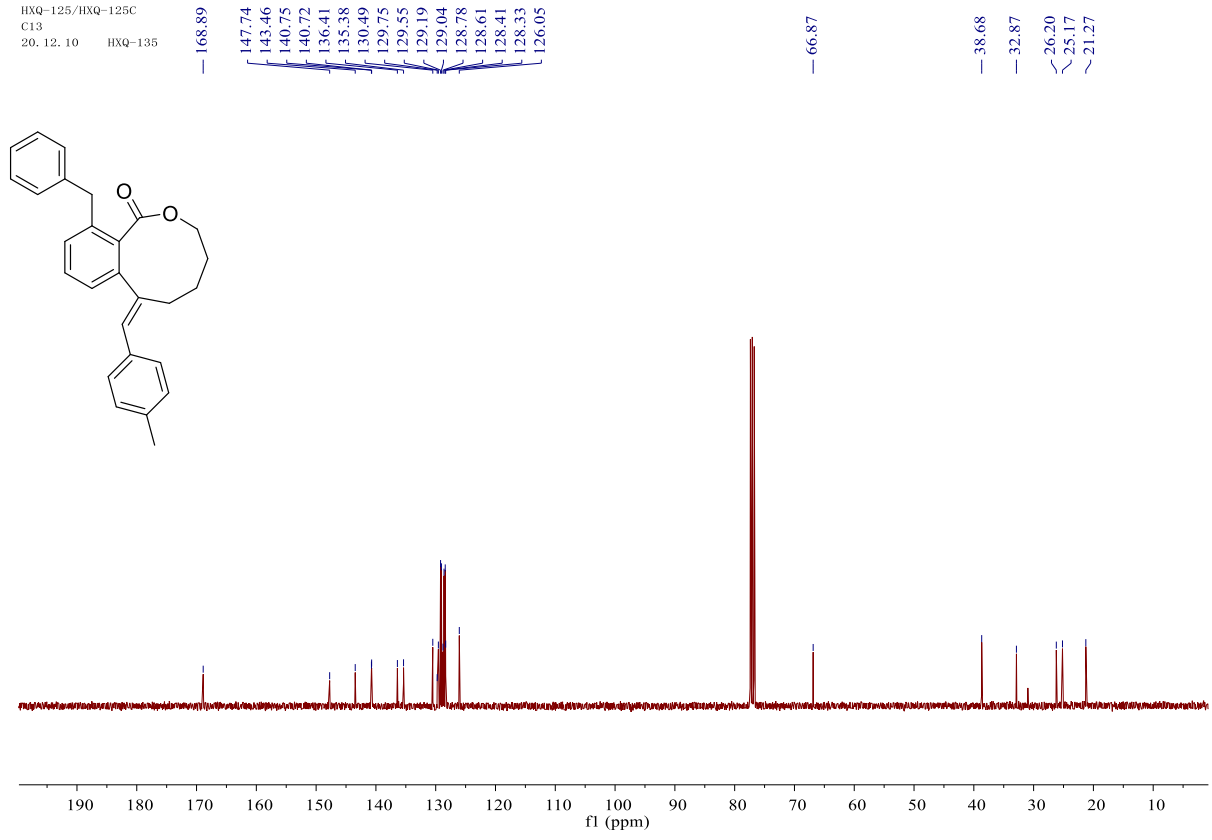






^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C NMR (100 MHz, $CDCl_3$) spectra of product 3di





^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C NMR (101 MHz, $CDCl_3$) spectra of product 2f