Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Supporting Materials to

Iron-catalyzed domino Knoevenagel-hetero-Diels-Alder reaction: a facile access to oxabicyclo[3.3.1]nonene derivatives

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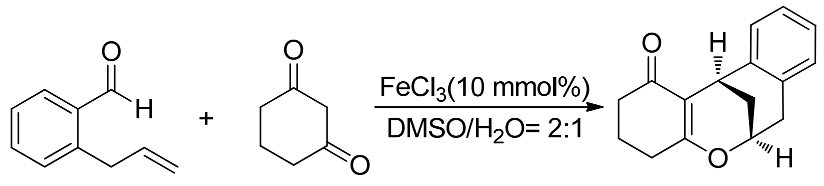
Experimental

General

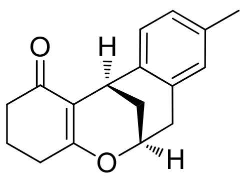
Melting points reported here were measured by a melting point instrument and were uncorrected. ^{1}H, ^{13}C, and ^{19}F NMR spectra were measured on a 600 MHz NMR spectrometers with $CDCl_3$ as the solvent with tetramethylsilane (TMS) as the internal standard. High-resolution mass spectra (HRMS) analyses were run with a TOF MS instrument using an ESI source. The products were purified by column chromatography using silica gel (300−400 mesh) with a mixture of petroleum ether and EtOAc as the eluent.

The starting materials **1**[1] are prepared according to previously reported literature.

Genaral procedure for Iron-catalyzed domino Knoevenagel-hetero-Diels-Alder reaction

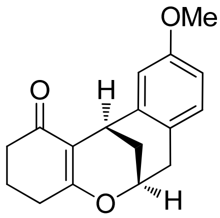


To a solution of **1a** (36.5 mg, 0.25 mmol) and **2a** (56.0 mg, 0.5 mmol) in 4.5 mL of dimethyl sulfoxide and H_2O (DMSO/H_2O=2:1) was added $FeCl_3$ (4.0 mg, 0.025 mmol) under a nitrogen atmosphere. The sealed tube was then stirred at 80 °C for 10 hours. After completion (monitored by TLC), the reaction solution was concentrated in vacuo, and the residue was purified by silica gel column chromatography (petroleum ether/EtOAc) to gave 50 mg (yield: 83%) of **3aa** as a yellow solid, mp: 117–119 °C; IR(neat) 2934, 1637, 1602, 1486, 1383, 1225; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.51–7.45 (m, 1H), 7.14–7.07 (m, 3H), 5.03 (s, 1H), 4.14 (s, 1H), 3.30–3.27 (m, 1H), 3.18–3.15 (m, 1H), 2.43–2.32 (m, 3H), 2.30–3.25 (m, 1H), 2.07–1.99 (m, 2H), 1.96–1.87 (m, 2H); ^{13}C NMR (151 MHz, CDCl$_3$) δ 195.8, 169.9, 141.2, 131.4, 128.6, 128.5, 125.9, 125.8, 116.2, 71.6, 37.1, 36.5, 28.3, 26.9, 26.5, 20.8; HRMS (ESI) calcd for $C_{16}H_{16}NaO_2$ $(M+Na)^+$ 263.1043, found 263.1043.



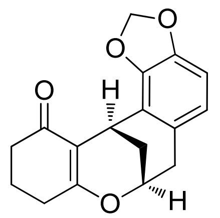
3ba

*Compound **3ba***: 49 mg, 77% yield, yellow solid, mp: 122–124 °C; IR(neat) 2933, 1638, 1602, 1486, 1383, 1226; ^{1}H NMR (600 MHz, CDCl$_3$) δ 7.37 (d, J = 8.3 Hz, 1H), 6.94 (d, J = 7.1 Hz, 2H), 5.02 (s, 1H), 4.11 (s, 1H), 3.27–3.23 (m, 1H), 3.14–3.11 (m, 1H), 2.42–2.33 (m, 3H), 2.29 (s, 3H), 2.29–2.24 (m, 1H), 2.03–1.87 (m, 4H); ^{13}C NMR (151 MHz, CDCl$_3$) δ 195.9, 169.9, 138.3, 135.4, 131.2, 129.2, 128.4, 126.6, 116.5, 71.7, 37.1, 36.5, 28.4, 27.1, 26.1, 21.0, 20.8; HRMS (ESI) calcd for $C_{17}H_{18}NaO_2$ $(M+Na)^+$ 277.1199, found 277.1199.



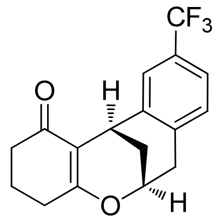
3ca

*Compound **3ca***: 57 mg, 85% yield, yellow solid, mp: 127–129 °C; IR(neat) 2938, 1637, 1601, 1486, 1384, 1226; ^{1}H NMR (600 MHz, CDCl$_3$) δ 7.05–6.92 (m, 2H), 6.67–6.65 (m, 1H), 4.99 (s, 1H), 4.06 (s, 1H), 3.77 (s, 3H), 3.20–3.16 (m, 1H), 3.07–3.04 (m, 1H), 2.39–2.24 (m, 4H), 2.02–1.84 (m, 4H); ^{13}C NMR (151 MHz, CDCl$_3$) δ 195.8, 170.2, 157.5, 142.3, 129.5, 123.0, 116.0, 112.9, 112.5, 71.8, 55.2, 36.5, 36.4, 28.4, 26.9, 26.8, 20.8; HRMS (ESI) calcd for $C_{17}H_{18}NaO_3$ $(M+Na)^+$ 293.1148, found 293.1149.



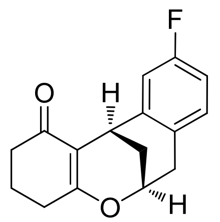
3da

Compound ***3da***: 57 mg, 80% yield, yellow solid, mp: 146–148 °C; IR(neat) 2943, 1638, 1602, 1486, 1383, 1223; ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.60–6.58 (m, 1H), 6.56–6.55 (m, 1H), 6.01 (d, J = 1.4 Hz, 1H), 5.89 (d, J = 1.4 Hz, 1H), 4.95 (s, 1H), 4.34 (s, 1H), 3.20–3.19 (m, 1H), 3.13–3.09 (m, 1H), 2.39–2.30 (m, 4H), 1.95–1.85 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.3, 170.5, 145.3, 144.0, 125.3, 123.2, 121.2, 115.2, 106.1, 100.8, 71.2, 36.7, 36.5, 28.5, 26.8, 20.4, 20.3; HRMS (ESI) calcd for $C_{17}H_{16}NaO_4$ $(M+Na)^+$ 307.0941, found 307.0946.



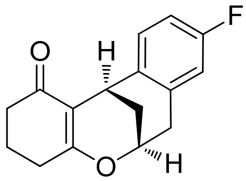
3ea

Compound ***3ea***: 68 mg, 89% yield, yellow solid, mp: 123–125 °C; IR(neat) 2943, 1638, 1602, 1486, 1383, 1223; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.73 (s, 1H), 7.36–7.32 (m, 1H), 7.20 (d, J = 8.0 Hz, 1H), 5.05 (s, 1H), 4.17 (s, 1H), 3.33–3.29(m, 1H), 3.20–3.17 (m, 1H), 2.42–2.32 (m, 3H), 2.30–3.25 (m, 1H), 2.05– 1.99 (m, 2H), 1.96–1.86 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.6, 169.9, 141.9, 135.7 (d, J = 1.1 Hz), 129.00, 128.4 (q, J = 96.6 Hz), 125.3 (q, J = 10.6 Hz), 122.6 (q, J = 12.8 Hz), 115.5, 71.0, 37.2, 36.4, 28.3, 26.7, 26.5, 20.7; ^{19}F NMR (565 MHz, $CDCl_3$) δ -62.16; HRMS (ESI) calcd for $C_{17}H_{15}F_3NaO_2$ $(M+Na)^+$ 331.0916, found 331.0916.



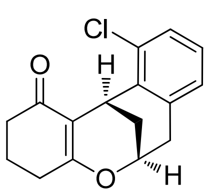
3fa

Compound ***3fa***: 65 mg, 77% yield, yellow solid, mp: 117–119 °C; IR(neat) 2934, 1636, 1601, 1486, 1386, 1224; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.15 (dd, J = 9.4, 2.5 Hz, 1H), 7.02 (dd, J = 8.0, 5.9 Hz, 1H), 6.79-6.76 (m, 1H), 5.00 (s, 1H), 4.06 (s, 1H), 3.22-3.18 (m, 1H), 3.10-3.07 (m, 1H), 2.40–2.24 (m, 4H), 1.99–1.83 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.7, 170.2, 161.6 (d, J_{C-F} = 224.6 Hz), 143.2 (d, J_{C-F} = 7.4 Hz), 129.9 (d, J_{C-F} = 7.9 Hz), 126.7 (d, J_{C-F} = 3.1 Hz) , 115.7 (d, J_{C-F} = 108.7 Hz), 114.9, 113.0 (d, J_{C-F} = 21.1 Hz), 71.5, 36.5, 36.4, 28.3, 26.6, 26.6, 20.8; ^{19}F NMR (565 MHz, $CDCl_3$) δ -116.87; HRMS (ESI) calcd for $C_{16}H_{15}FNaO_2$ $(M+Na)^+$ 281.0948, found 281.0950.



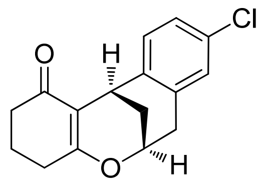
3ga

Compound ***3ga***: 48 mg, 75% yield, yellow solid, mp: 116–118 °C; IR(neat) 2933, 1637, 1602, 1486, 1383, 1226; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42–7.38 (m, 1H), 6.81–6.73 (m, 2H), 4.99 (s, 1H), 4.08 (s, 1H), 3.26–3.20 (m, 1H), 3.13–3.08 (m, 1H), 2.38–2.20 (m, 4H), 1.99 (t, J = 2.6 Hz, 2H), 1.92–1.84 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.9, 169.8, 161.8 (d, J_{C-F} = 241.6 Hz), 136.9 (d, J_{C-F} = 2.8 Hz), 133.4 (d, J_{C-F} = 7.6 Hz), 129.9 (d, J_{C-F} = 8.0 Hz), 116.2, 115.0 (d, J_{C-F} = 21.1 Hz), 112.9 (d, J_{C-F} = 21.1 Hz), 71.1, 37.2, 36.5, 28.3, 26.9, 25.9, 20.8; ^{19}F NMR (565 MHz, $CDCl_3$) δ -117.2; HRMS (ESI) calcd for $C_{16}H_{15}FNaO_2$ $(M+Na)^+$ 281.0948, found 281.0950.



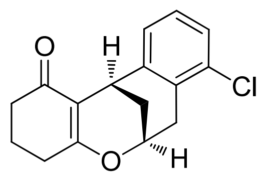
3ha

Compound ***3ha***: 66 mg, 96% yield, yellow solid, mp: 119–121 °C; IR(neat) 2933, 1637, 1602, 1486, 1384, 1227; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19–7.15 (m, 1H), 7.04–6.96 (m, 2H), 4.94 (s, 1H), 4.68 (s, 1H), 3.29–3.22 (m, 1H), 3.18–3.13 (m, 1H), 2.37 (t, J = 6.3 Hz, 2H), 2.34–2.23 (m, 2H), 2.02–1.81 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.3, 170.5, 138.7, 134.7, 133.2, 127.5, 127.2, 126.7, 115.13, 70.6, 37.9, 36.8, 28.8, 27.6, 23.7, 20.2; HRMS (ESI) calcd for $C_{16}H_{15}ClNaO_2$ $(M+Na)^+$ 297.0653, found 297.0654.



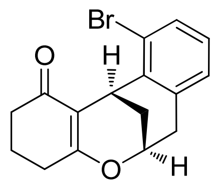
3ia

*Compound **3ia***: 51 mg, 75% yield, yellow solid, mp: 119–121 °C; IR(neat) 2936, 1636, 1604, 1487, 1383, 1225; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 (d, J = 2.1 Hz, 1H), 7.06–7.04(m, 1H), 7.00–6.99 (m, 1H), 4.99 (s, 1H), 4.06 (s, 1H), 3.22–3.18 (m, 1H), 3.10–3.07 (m, 1H), 2.39–2.26 (m, 4H), 1.98 (t, J = 2.5 Hz, 2H), 1.94–1.84 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.7, 170.1, 142.9, 131.4, 129.9, 129.8, 128.3, 126.1, 115.7, 71.3, 36.7, 36.5, 28.3, 26.6, 26.4, 20.8; HRMS (ESI) calcd for $C_{16}H_{15}ClNaO_2$ $(M+Na)^+$ 297.0653, found 297.0654.



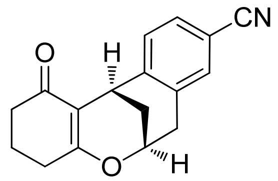
3ja

*Compound **3ja***: 50 mg, 73% yield, yellow solid, mp: 118–120 °C; IR(neat) 2936, 1635, 1604, 1486, 1383, 1224; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.40 (d, J = 7.5 Hz, 1H), 7.17–7.16 (m, 1H), 7.06 (t, J = 7.8 Hz, 1H), 5.08 (s, 1H), 4.14 (s, 1H), 3.21–3.11 (m, 2H), 2.42–2.31 (m, 3H), 2.28–2.23 (m, 1H), 2.00 (d, J = 2.9 Hz, 2H), 1.96–1.86 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.8, 170.1, 143.3, 134.1, 129.6, 127.0, 126.9, 126.6, 115.7, 70.9, 36.5, 36.1, 28.3, 26.6, 26.4, 20.7; HRMS (ESI) calcd for $C_{16}H_{15}ClNaO_2$ $(M+Na)^+$ 297.0653, found 297.0654.



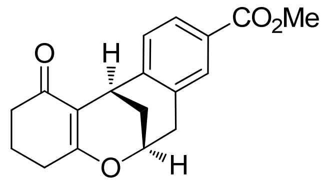
3ka

*Compound **3ka***: 74 mg, 93% yield, yellow solid, mp: 157–159 °C; IR(neat) 2932, 1632, 1602, 1476, 1386, 1228; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, J = 7.8 Hz, 1H), 7.02 (d, J = 7.4 Hz, 1H), 6.94 (t, J = 7.7 Hz, 1H), 4.92 (s, 1H), 4.62 (s, 1H), 3.31–3.25 (m, 1H), 3.17–3.12 (m, 1H), 2.37 (t, J = 6.3 Hz, 2H), 2.34–2.23 (m, 2H), 2.01–1.82 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.4, 170.3, 140.5, 135.1, 131.1, 127.8, 127.1, 123.5, 115.1, 70.6, 38.1, 36.8, 28.9, 27.9, 26.6, 20.2; HRMS (ESI) calcd for $C_{16}H_{15}BrNaO$ $(M+Na)^+$ 341.0148, found 341.0150.



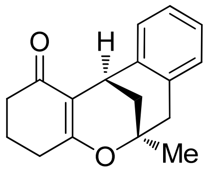
3la

*Compound **3la***: 40 mg, 60% yield, yellow solid, mp: 134–136 °C; IR(neat) 2936, 1635, 1601, 1487, 1384, 1226; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (d, J = 7.7 Hz, 1H), 7.36 (d, J = 8.5 Hz, 2H), 5.03 (s, 1H), 4.15 (s, 1H), 3.30-3.24 (m, 1H), 3.15 (d, J = 18.9 Hz, 1H), 2.41–2.20 (m, 4H), 2.04–1.84 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.7, 170.4, 146.5, 133.0, 132.4, 129.7, 129.3, 119.0, 115.1, 109.7, 70.8, 36.8, 36.4, 28.4, 26.8, 26.3, 20.7; HRMS (ESI) calcd for $C_{17}H_{15}NNaO_2$ $(M+Na)^+$ 288.0995, found 288.0996.



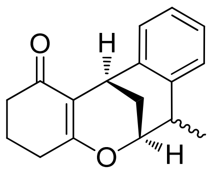
3ma

*Compound **3ma***: 58 mg, 78% yield, yellow solid, mp: 140–142 °C; IR(neat) 2930, 1635, 1602, 1469, 1383, 1228; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.77 (s, 1H), 7.73 (d, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 1H), 5.03 (s, 1H), 4.16 (s, 1H), 3.87 (s, 3H), 3.30–3.26 (m, 1H), 3.19–3.16 (m, 1H), 2.42–2.30 (m, 3H), 2.26–2.20 (m, 1H), 2.02 (s, 2H), 1.94–1.81 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.7, 170.3, 166.9, 146.2, 131.6, 129.9, 128.4, 127.6, 127.0, 115.3, 71.2, 51.8, 36.9, 36.3, 28.3, 26.6, 26.4, 20.6; HRMS (ESI) calcd for $C_{18}H_{18}NaO_4$ $(M+Na)^+$ 321.1097, found 321.1099.



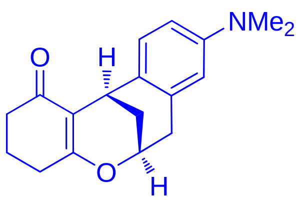
3na

*Compound **3na***: 44 mg, 70% yield, white solid, mp: 123–125 °C; IR(neat) 2937, 1646, 1612, 1487, 1389, 1249; ^{1}H NMR (600 MHz, CDCl$_3$) δ 7.47–7.46 (m, 1H), 7.12–7.08 (m, 2H), 7.08–7.05 (m, 1H), 4.16 (t, J = 2.8 Hz, 1H), 3.18 (d, J = 18.5 Hz, 1H), 3.11 (d, J = 18.5 Hz, 1H), 2.39–2.31 (m, 3H), 2.29–2.24 (m, 1H), 2.07–2.04 (m, 1H), 1.95–1.85 (m, 3H), 1.61 (s, 3H); ^{13}C NMR (151 MHz, CDCl$_3$) δ 195.9, 170.3, 140.9, 132.3, 128.3, 128.3, 125.8, 125.8, 115.7, 77.3, 43.3, 36.5, 34.2, 28.9, 28.9, 28.6, 20.9; HRMS (ESI) calcd for $C_{17}H_{18}NaO_2$ $(M+Na)^+$ 277.1199, found 277.1199.



3oa

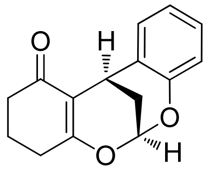
*Compound **3oa***: 44mg, 69% yield, white solid, mp: 124–126 °C, dr = 3:2; IR(neat) 2938, 1646, 1611, 1486, 1389, 1248; ^{1}H NMR (600 MHz, CDCl$_3$) δ 7.47 –7.42(m, 1H), 7.29–7.27 (m, 1H), 7.19–7.09 (m, 2H), 4.84–4.66 (m, 1H), 4.14–4.10 (m, 1H), 3.30–3.20 (m, 1H), 2.47–2.19 (m, 5H), 2.11–2.03 (m, 1H), 1.95–1.86 (m, 2H), 1.44–1.35 (m, 3H); ^{13}C NMR (151 MHz, CDCl$_3$) δ 195.8, 169.9, 141.1, 136.9, 129.0, 128.3, 126.1, 125.9, 116.9, 77.8, 40.3, 36.5, 28.3, 27.7, 26.5, 22.2, 20.8; HRMS (ESI) calcd for $C_{17}H_{18}NaO_2$ $(M+Na)^+$ 277.1199, found 277.1199.



3pa

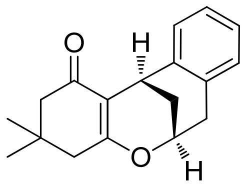
*Compound **3pa***: 50 mg, 72% yield, yellow solid, mp: 134–136 °C; IR(neat) 2934, 1637, 1602, 1486, 1383, 1225; ^{1}H NMR (600 MHz, CDCl$_3$) δ 7.33 (d, J = 8.4 Hz, 1H), 6.56–6.55 (m, 1H), 6.49 (s, 1H), 5.01 (s, 1H), 4.05 (s, 1H), 3.27–3.23 (m, 1H), 3.14–3.11 (m, 1H), 2.91 (s, 6H), 2.38–2.24 (m, 4H), 2.04–1.88 (m, 4H); ^{13}C NMR

(151 MHz, $CDCl_3$) δ 195.9, 169.5, 149.0, 131.9, 130.0, 129.1, 117.0, 112.5, 111.1, 71.9, 40.8, 37.6, 36.5, 28.4, 27.5, 25.5, 20.9; HRMS (ESI) calcd for $C_{20}H_{22}NaO_2$ $(M+Na)^+$ 306.1465, found 306.1465.



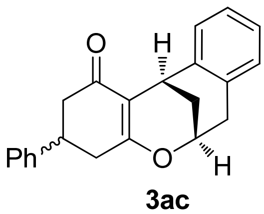
3qa

*Compound **3qa***: 34 mg, 57% yield, yellow solid, mp: 121–123 °C; IR(neat) 2941, 1635, 1488, 1389, 1224; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.37–7.35 (m, 1H), 7.14–7.11 (m, 1H), 6.93–6.88 (m, 2H), 6.11–6.10 (m, 1H), 4.13 (s, 1H), 2.44 (t, J = 6.3 Hz, 2H), 2.40–2.36 (m, 1H), 2.32–2.27 (m, 1H), 2.13–2.10 (m, 1H), 2.01–1.91 (m, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.9, 168.5, 150.4, 128.3, 127.5, 126.6, 121.3, 116.8, 115.8, 92.6, 36.3, 27.5, 25.3, 22.3, 20.6; HRMS (ESI) calcd for $C_{15}H_{14}NaO_3$ $(M+Na)^+$ 265.0835, found 265.0833.



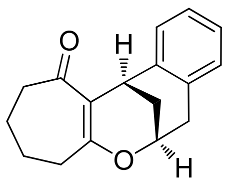
3ab

*Compound **3ab***: 57 mg, 85% yield, yellow solid, mp: 127–129 °C; IR(neat) 2946, 1631, 1602, 1467, 1387, 1234; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.47–7.41 (m, 1H), 7.13–7.06 (m, 3H), 5.04 (s, 1H), 4.13 (s, 1H), 3.30–3.26 (m, 1H), 3.16–3.13 (m, 1H), 2.27–2.13 (m, 4H), 2.07–2.00 (m, 2H), 1.06 (s, 3H), 0.91 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 195.5, 168.2, 141.1, 131.2, 128.6, 128.3, 125.8, 125.8, 115.0, 71.7, 50.4, 42.1, 37.2, 32.3, 28.9, 27.6, 26.9, 26.4; HRMS (ESI) calcd for $C_{18}H_{20}NaO_2$ $(M+H)^+$ 291.1356, found 291.1357.



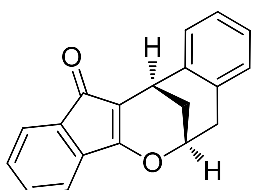
3ac

*Compound **3ac***: 51 mg, 65% yield, white solid, mp: 170–172 °C; dr = 2:1; IR(neat) 2934, 1637, 1601, 1486, 1383, 1226; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.56–7.49 (m, 1H), 7.37–7.31 (m, 2H), 7.27 (t, J = 6.9 Hz, 1H), 7.22–7.19 (m, 2H), 7.18–7.12 (m, 3H), 5.13–5.05 (m, 1H), 4.24–4.17 (m, 1H), 3.41–3.16 (m, 3H), 2.68–2.56 (m, 3H), 2.16–2.06 (m, 2H), 1.32–1.29 (m, 1H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 194.9, 169.2, 142.9, 141.1, 131.4, 128.8, 128.6, 128.5, 126.8, 126.6, 126.0, 125.8, 116.0, 72.0, 43.6, 39.7, 37.2, 35.8, 26.9, 26.6; HRMS (ESI) calcd for $C_{22}H_{20}NaO_2$ $(M+Na)^+$ 339.1356, found 339.1352.



3ad

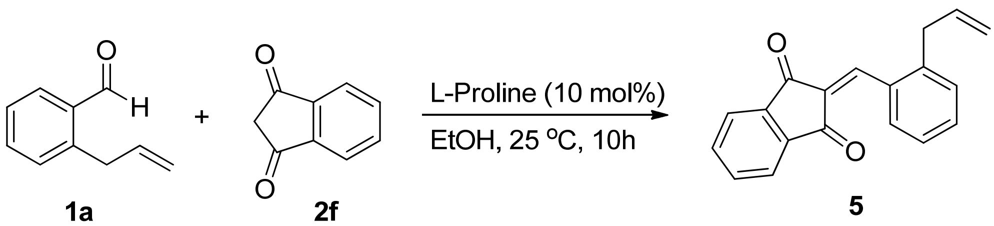
*Compound **3ad***: 32mg, 51% yield, white solid, mp: 126–128 °C; IR(neat) 2935, 1637, 1603, 1487, 1383, 1226; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.48–7.43 (m, 1H), 7.14–7.06 (m, 3H), 5.02–4.96 (m, 1H), 4.25–4.24 (m, 1H), 3.27–3.23 (m, 1H), 3.15–3.12 (m, 1H), 2.58–2.47 (m, 4H), 2.02–2.01 (m, 1H), 2.00–1.99 (m, 1H), 1.81–1.65 (m, 4H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 199.4, 169.9, 141.6, 131.4, 128.5, 128.3, 125.8, 125.8, 118.5, 71.3, 41.4, 37.3, 32.3, 28.5, 26.5, 23.2, 20.8; HRMS (ESI) calcd for $C_{17}H_{18}NaO_2$ $(M+Na)^+$ 277.1199, found 277.1199.



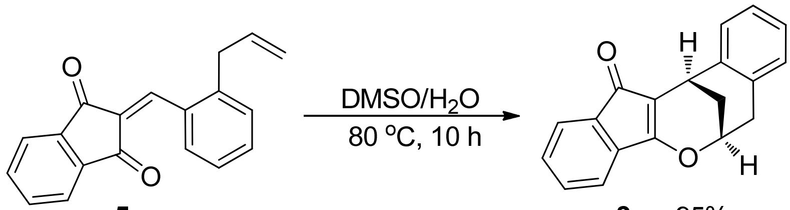
3ae

*Compound **3ae***: 41 mg, 60% yield, white solid, mp: 151–153 °C; IR(neat) 2957, 1687, 1598, 1487, 1407, 1383, 1225; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39–7.36 (m, 1H), 7.34 (d, J = 7.0 Hz, 1H), 7.29–7.26 (m, 1H), 7.22 (t, J = 7.3 Hz, 1H), 7.15–7.13 (m, 3H), 7.10 (d, J = 7.1 Hz, 1H), 5.35 (s, 1H), 3.91 (d, J = 1.3 Hz, 1H), 3.48–3.44 (m, 1H), 3.31–3.28 (m, 1H), 2.23 (d, J = 13.2 Hz, 1H), 2.16 (d, J = 13.2 Hz, 1H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 191.1, 172.6, 140.3, 137.7, 133.6, 131.6, 131.3 129.8, 129.0, 127.8, 126.4, 126.3, 121.0, 117.6, 113.1, 74.4, 37.1, 27.9, 27.2; HRMS (ESI) calcd for $C_{19}H_{14}NaO_2$ (M+Na)$^+$ 297.0886, found 297.0883.

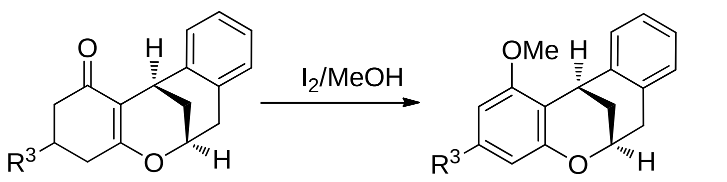
Mechanistic Studies:



To a solution of **1a** (36.5 mg, 0.25 mmol) and **2f** (36.5 mg, 0.25 mmol) in 2 mL of EtOH was added L-Proline (2.8 mg, 0.025 mmol) under a air atmosphere. The sealed tube was then stirred at 25 °C for 12 hours.[2] After completion (monitored by TLC), the reaction solution was concentrated in vacuo, and the residue was purified by silica gel column chromatography (petroleum ether/EtOAc) to gave 55 mg (yield: 80%) of **5** as a yellow oil; IR(neat) 3089, 1689, 1619, 1610, 1434, 1411, 978; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.53–8.51 (m, 1H), 8.24 (s, 1H), 8.02–7.97 (m, 2H), 7.81–7.91 (m, 2H), 7.49–7.44 (m, 1H), 7.40–7.35 (m, 1H), 7.31–7.28 (m, 1H), 6.02–5.92 (m, 1H), 5.11–5.01 (m, 2H), 3.63 (d, J = 6.2 Hz, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 190.0, 188.6, 144.3, 142.4, 142.1, 140.0, 136.4, 135.3, 135.2, 132.7, 132.6, 131.2, 130.0, 129.2, 126.3, 123.3, 123.2, 116.7, 38.1; HRMS (ESI) calcd for $C_{19}H_{14}NaO_2$ (M+Na)$^+$ 297.0886, found 297.0883.



To a solution of **5** (68.5 mg, 0.25 mmol) in 4.5 mL of dimethyl sulfoxide and H_2O (DMSO/H_2O=2:1) under a air atmosphere. The sealed tube was then stirred at 80 °C for 10 hours. After completion (monitored by TLC), the reaction solution was concentrated in vacuo, and the residue was purified by silica gel column chromatography (petroleum ether/EtOAc) to gave 65 mg (yield: 95%) of **3ae**.

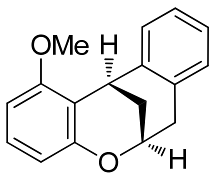


3 **4**

R^3 = H, **3aa**, dr > 98:2 **4a**, 89%, dr > 98:2

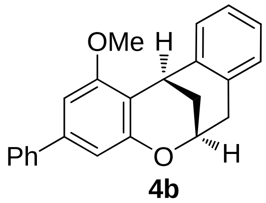
R^3 = Ph, **3ac,** dr = 2:1 **4b**, 80%, dr > 98:2

To a solution of **3** (0.25 mmol) in 10 mL of MeOH was added I_2 (126.5 mg, 0. 5 mmol) under a air atmosphere.[3] The sealed tube was then stirred at 80 °C for 16 hours. After completion (monitored by TLC), the reaction solution was concentrated in vacuo, and the residue was purified by silica gel column chromatography (petroleum ether/EtOAc) to gave **4**.



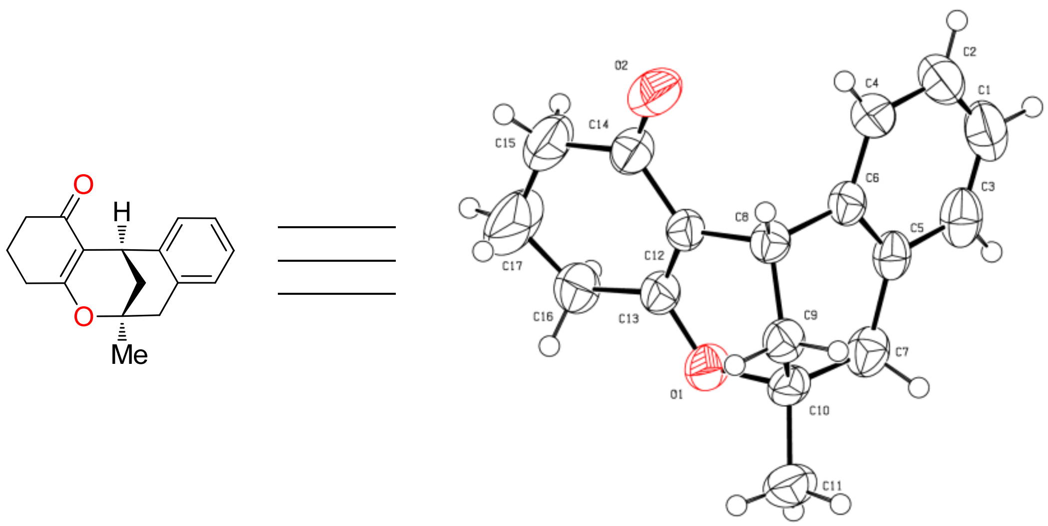
4a

*Compound **4a***: 56 mg, 89% yield, white solid, mp: 150-152 ^{o}C; IR(neat) 2936, 2834, 1734, 1591, 1465, 1094; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (d, J = 6.3 Hz, 1H), 7.30–7.13 (m, 3H), 7.15 (t, J = 8.2 Hz, 1H), 6.67 (d, J = 8.1 Hz, 1H), 6.51 (d, J = 8.0 Hz, 1H), 5.13 (s, 1H), 4.61 (s, 1H), 4.01 (s, 3H), 3.45–3.31 (m, 2H), 2.34–2.27 (m, 1H), 2.23–2.18 (m, 1H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 156.2, 153.2, 141.2, 132.7, 128.8, 128.0, 126.9, 125.8, 125.5, 115.4, 109.2, 101.5, 68.9, 55.3, 37.4, 28.1, 26.6; HRMS (ESI) calcd for $C_{17}H_{17}O_2$ $(M+H)^+$ 253.1223, found 253.1216.



4b

*Compound **4b***: 65 mg, 80% yield, white solid, mp: 167–169 ^{o}C; IR(neat) 2937, 2836, 1734, 1591, 1462, 1094; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60–7.57 (m, 3H), 7.46 (t, J = 7.5 Hz, 2H), 7.38 (t, J = 7.3 Hz, 1H), 7.22–7.16 (m, 3H), 6.79 (d, J = 1.1 Hz, 1H), 6.65 (d, J = 1.2 Hz, 1H), 5.10 (s, 1H), 4.53 (s, 1H), 4.01 (s, 3H), 3.42–3.26 (m, 2H), 2.31–2.15 (m, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 156.6, 153.4, 141.4, 141.2, 140.5, 132.8, 129.0, 128.5, 128.1, 127.1, 127.0, 126.0, 125.7, 114.6, 108.2, 101.1, 69.2, 55.5, 37.5, 28.2, 26.9; HRMS (ESI) calcd for $C_{23}H_{21}O_2$ $(M+H)^+$ 329.1536, found 329.1529.



The X-ray structure of **3na**

CCDC 1909224 (**3na**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Table 1. Crystal data and structure refinement for 3na.

Identification code	3na
Empirical formula	$C_{17}H_{18}O_2$
Formula weight	254.31

Temperature	296(2) K
Wavelength	0.71073 A
Crystal system	Monoclinic
space group	C2/c
Unit cell dimensions	a = 13.7694(4) A a= 90 deg.
	b = 12.6853(4) A b = 107.839(3) deg.
	c = 16.4364(5) A g = 90 deg.
Volume	2732.90(14) A^3
Z, Calculated density	8, 1.236 Mg/m^3
Absorption coefficient	0.080 mm^{-1}
F(000)	1088
Crystal size	0.31 x 0.29 x 0.17mm
Theta range for data collection	2.23 to 27.54 deg.
Limiting indices	-17<=h<=17, -16<=k<=16, -21<=l<=21
Reflections collected / unique	48432 / 3140 [R(int) = 0.0658]
Completeness to theta = 27.54	99.7 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3140 / 0 / 172
Goodness-of-fit on F^2	1.879
Final R indices [I>2sigma(I)]	R1 = 0.0743, wR2 = 0.2455
R indices (all data)	R1 = 0.1042, wR2 = 0.2738
Largest diff. peak and hole	0.820 and -0.609 $e.A^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters (A^2 x 10^3) for 3na. U(eq) is defined as one third of the trace of the orthogonalized Uij tensor.

Atom	x	y	z	U（eq）
C(1)	2715(2)	2053(3)	8125(2)	71(1)
C(2)	2684(2)	3121(3)	7967(2)	72(1)
C(3)	1977(2)	1409(2)	7607(2)	60(1)
C(4)	1906(2)	3538(2)	7301(2)	60(1)
C(5)	1197(2)	1803(2)	6923(1)	45(1)
C(6)	1160(2)	2889(2)	6768(1)	43(1)
C(7)	384(2)	1074(2)	6377(2)	53(1)
C(8)	333(2)	3340(2)	6017(1)	41(1)
C(9)	-638(2)	2687(2)	5839(2)	45(1)
C(10)	-408(2)	1573(2)	5627(2)	46(1)
C(11)	-1356(2)	893(2)	5322(2)	66(1)

C(12)	667(2)	3313(2)	5224(1)	42(1)
C(13)	470(2)	2449(2)	4721(1)	45(1)
C(14)	1204(2)	4209(2)	5014(2)	56(1)
C(15)	1521(3)	4136(3)	4218(2)	80(1)
C(16)	758(2)	2340(2)	3915(2)	61(1)
C(17)	973(5)	3412(4)	3608(3)	148(2)
O(1)	-16(1)	1586(1)	4883(1)	53(1)
O(2)	1411(2)	4992(2)	5475(1)	76(1)

Table 3. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (A^2 x 10^3) for 3na.

Atom	x	y	z	U（eq）
H(1A)	3231	1770	8578	85
H(2A)	3186	3560	8308	87
H(3A)	2002	689	7719	72
H(4A)	1878	4262	7206	72
H(7A)	720	516	6162	64
H(7B)	33	748	6742	64
H(8A)	192	4070	6142	49
H(9A)	-875	2686	6337	54
H(9B)	-1169	2988	5363	54
H(11A)	-1169	196	5198	99
H(11B)	-1817	1196	4815	99
H(11C)	-1682	857	5761	99
H(15A)	1451	4828	3955	96
H(15B)	2238	3948	4382	96
H(16A)	207	2005	3478	73
H(16B)	1360	1899	4022	73
H(17A)	1343	3307	3199	178
H(17B)	324	3732	3303	178

Table 4. Anisotropic displacement parameters (A^2 x 10^3) for 3na. The anisotropic displacement factor exponent takes the form: -2 pi^2 [h^2 a^{*2} U11 + ... + 2 h k a* b* U12]

Atom	U11	U22	U33	U23	U13	U12
C(1)	50(2)	117(3)	44(1)	14(2)	13(1)	12(2)

C(2)	57(2)	113(3)	43(2)	-2(2)	9(1)	-17(2)
C(3)	62(2)	74(2)	49(1)	12(1)	27(1)	17(1)
C(4)	60(2)	73(2)	45(1)	-2(1)	14(1)	-18(1)
C(5)	48(1)	54(1)	37(1)	4(1)	22(1)	6(1)
C(6)	46(1)	51(1)	35(1)	0(1)	17(1)	-1(1)
C(7)	74(2)	40(1)	51(1)	1(1)	26(1)	0(1)
C(8)	46(1)	38(1)	40(1)	0(1)	16(1)	1(1)
C(9)	41(1)	54(1)	43(1)	0(1)	19(1)	1(1)
C(10)	50(1)	52(1)	44(1)	-7(1)	26(1)	-13(1)
C(11)	67(2)	74(2)	66(2)	-15(1)	34(1)	-27(1)
C(12)	36(1)	50(1)	38(1)	7(1)	10(1)	0(1)
C(13)	41(1)	57(1)	39(1)	3(1)	16(1)	-4(1)
C(14)	54(2)	59(2)	54(2)	12(1)	16(1)	-6(1)
C(15)	98(2)	84(2)	73(2)	8(2)	48(2)	-22(2)
C(16)	59(2)	83(2)	48(1)	-5(1)	27(1)	-9(1)
C(17)	226(5)	175(5)	85(3)	-39(3)	107(3)	-111(4)
O(1)	65(1)	58(1)	46(1)	-11(1)	31(1)	-11(1)
O(2)	91(2)	63(1)	77(1)	0(1)	33(1)	-27(1)

Table 5. Bond lengths [A] and angles [deg] for 3na.

C(1)-C(3)	1.376(4)	C(4)-C(2)-H(2A)	120.1
C(1)-C(2)	1.377(5)	C(1)-C(2)-H(2A)	120.1
C(1)-H(1A)	0.9300	C(1)-C(3)-C(5)	121.9(3)
C(2)-C(4)	1.382(4)	C(1)-C(3)-H(3A)	119.0
C(2)-H(2A)	0.9300	C(5)-C(3)-H(3A)	119.0
C(3)-C(5)	1.389(3)	C(2)-C(4)-C(6)	120.9(3)
C(3)-H(3A)	0.9300	C(2)-C(4)-H(4A)	119.5
C(4)-C(6)	1.396(3)	C(6)-C(4)-H(4A)	119.5
C(4)-H(4A)	0.9300	C(3)-C(5)-C(6)	118.5(2)
C(5)-C(6)	1.400(3)	C(3)-C(5)-C(7)	120.5(2)
C(5)-C(7)	1.516(3)	C(6)-C(5)-C(7)	120.9(2)
C(6)-C(8)	1.511(3)	C(5)-C(6)-C(4)	119.2(2)
C(7)-C(10)	1.512(3)	C(5)-C(6)-C(8)	119.8(19)
C(7)-H(7A)	0.9700	C(4)-C(6)-C(8)	120.9(2)
C(7)-H(7B)	0.9700	C(10)-C(7)-C(5)	116.4(19)
C(8)-C(12)	1.509(3)	C(10)-C(7)-H(7A)	108.2
C(8)-C(9)	1.523(3)	C(5)-C(7)-H(7A)	108.2
C(8)-H(8A)	0.9800	C(10)-C(7)-H(7B)	108.2
C(9)-C(10)	1.513(3)	C(5)-C(7)-H(7B)	108.2
C(9)-H(9A)	0.9700	H(7A)-C(7)-H(7B)	107.3
C(9)-H(9B)	0.9700	C(6)-C(8)-C(12)	110.1(17)
C(10)-O(1)	1.480(3)	C(6)-C(8)-C(9)	110.3(18)
C(10)-C(11)	1.516(3)	C(12)-C(8)-C(9)	107.6(17)
C(11)-H(11A)	0.9600	C(6)-C(8)-H(8A)	109.6
C(11)-H(11B)	0.9600	C(12)-C(8)-H(8A)	109.6
C(11)-H(11C)	0.9600	C(9)-C(8)-H(8A)	109.6
C(12)-C(13)	1.350(3)	C(10)-C(9)-C(8)	108.6(18)
C(12)-C(14)	1.455(3)	C(10)-C(9)-H(9A)	110.0
C(13)-O(1)	1.351(3)	C(8)-C(9)-H(9A)	110.0
C(13)-C(16)	1.500(3)	C(10)-C(9)-H(9B)	110.0
C(14)-O(2)	1.229(3)	C(8)-C(9)-H(9B)	110.0
C(14)-C(15)	1.503(4)	H(9A)-C(9)-H(9B)	108.4
C(15)-C(17)	1.398(5)	O(1)-C(10)-C(7)	108.9(19)
C(15)-H(15A)	0.9700	O(1)-C(10)-C(9)	109.5(17)
C(15)-H(15B)	0.9700	C(7)-C(10)-C(9)	110.6(19)
C(16)-C(17)	1.511(5)	O(1)-C(10)-C(11)	103.2(18)
C(16)-H(16A)	0.9700	C(7)-C(10)-C(11)	111.4(2)
C(16)-H(16B)	0.9700	C(9)-C(10)-C(11)	112.8(2)
C(17)-H(17A)	0.9700	C(10)-C(11)-H(11A)	109.5
C(17)-H(17B)	0.9700	C(10)-C(11)-H(11B)	109.5
C(3)-C(1)-C(2)	119.5(3)	H(11A)-C(11)-H(11B)	109.5
C(3)-C(1)-H(1A)	120.2	C(10)-C(11)-H(11C)	109.5
C(2)-C(1)-H(1A)	120.2	H(11A)-C(11)-H(11C)	109.5
C(4)-C(2)-C(1)	119.9(3)	H(11B)-C(11)-H(11C)	109.5

C(13)-C(12)-C(14)	120.7(2)	H(15A)-C(15)-H(15B)	107.5
C(13)-C(12)-C(8)	119.4(19)	C(13)-C(16)-C(17)	110.1(2)
C(14)-C(12)-C(8)	119.9(2)	C(13)-C(16)-H(16A)	109.6
O(1)-C(13)-C(12)	123.7(2)	C(17)-C(16)-H(16A)	109.6
O(1)-C(13)-C(16)	112.4(2)	C(13)-C(16)-H(16B)	109.6
C(12)-C(13)-C(16)	123.9(2)	C(17)-C(16)-H(16B)	109.6
O(2)-C(14)-C(12)	121.6(2)	H(16A)-C(16)-H(16B)	108.2
O(2)-C(14)-C(15)	120.8(2)	C(15)-C(17)-C(16)	118.0(3)
C(12)-C(14)-C(15)	117.6(2)	C(15)-C(17)-H(17A)	107.8
C(17)-C(15)-C(14)	115.3(3)	C(16)-C(17)-H(17A)	107.8
C(17)-C(15)-H(15A)	108.4	C(15)-C(17)-H(17B)	107.8
C(14)-C(15)-H(15A)	108.4	C(16)-C(17)-H(17B)	107.8
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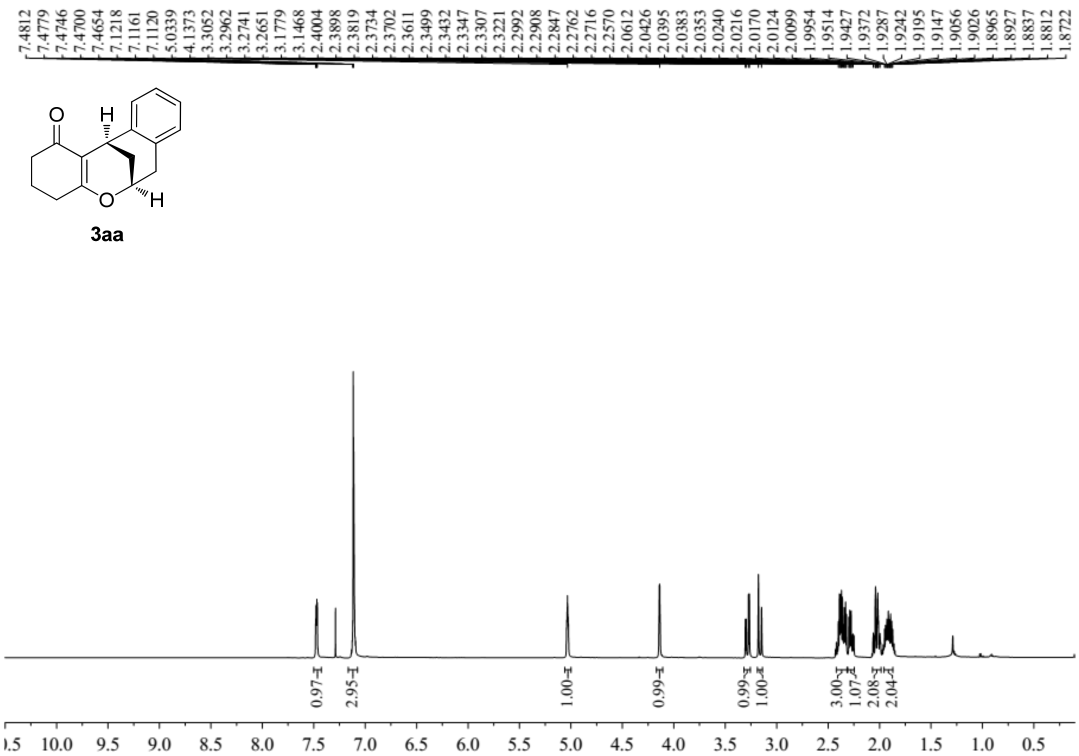
C(14)-C(15)-H(15B)	108.4	C(13)-O(1)-C(10)	120.0(16)

References

[1] D. Lu, Y. Wan and L. Kong, G. Zhu. *Org. Lett.,* 2017, **19**, 2929.

[2] P. Goswami and B. Das. *Tetrahedron Lett*., 2009, **50**, 897.

[3] H. Bonacorso, J. Navarini, C. Wiethan, A. Junges, S. Cavinatto, R. Andrighetto, M. Martins and N. Zanatta. *J. Fluorine Chem.*, 2012, **142**, 90.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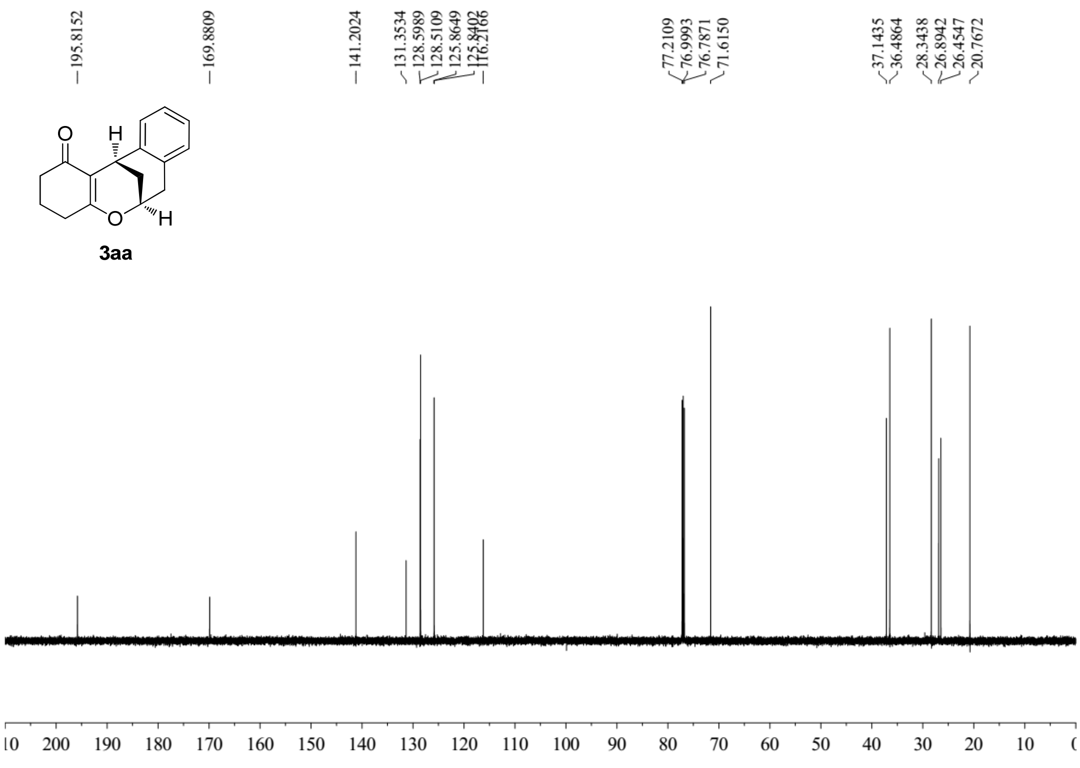
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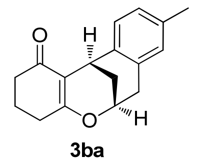
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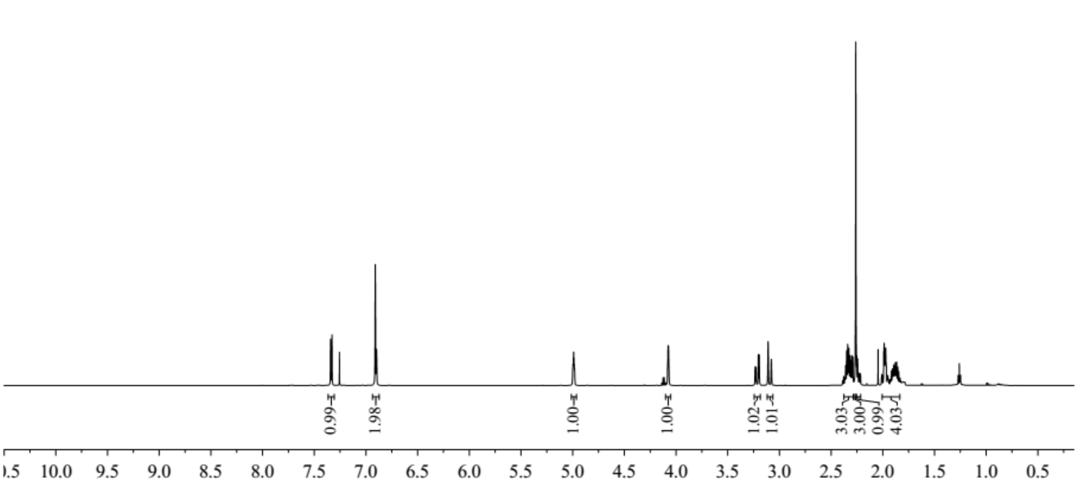
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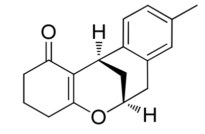
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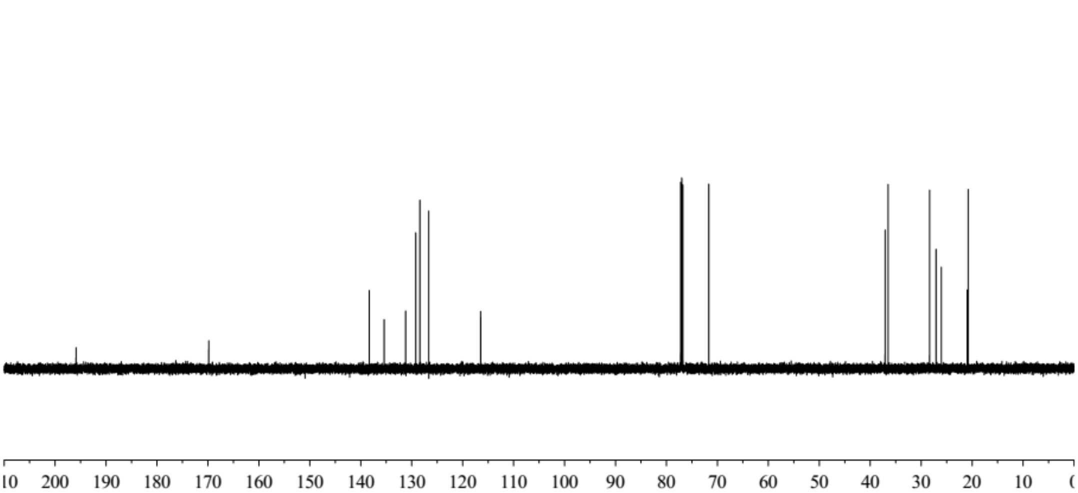
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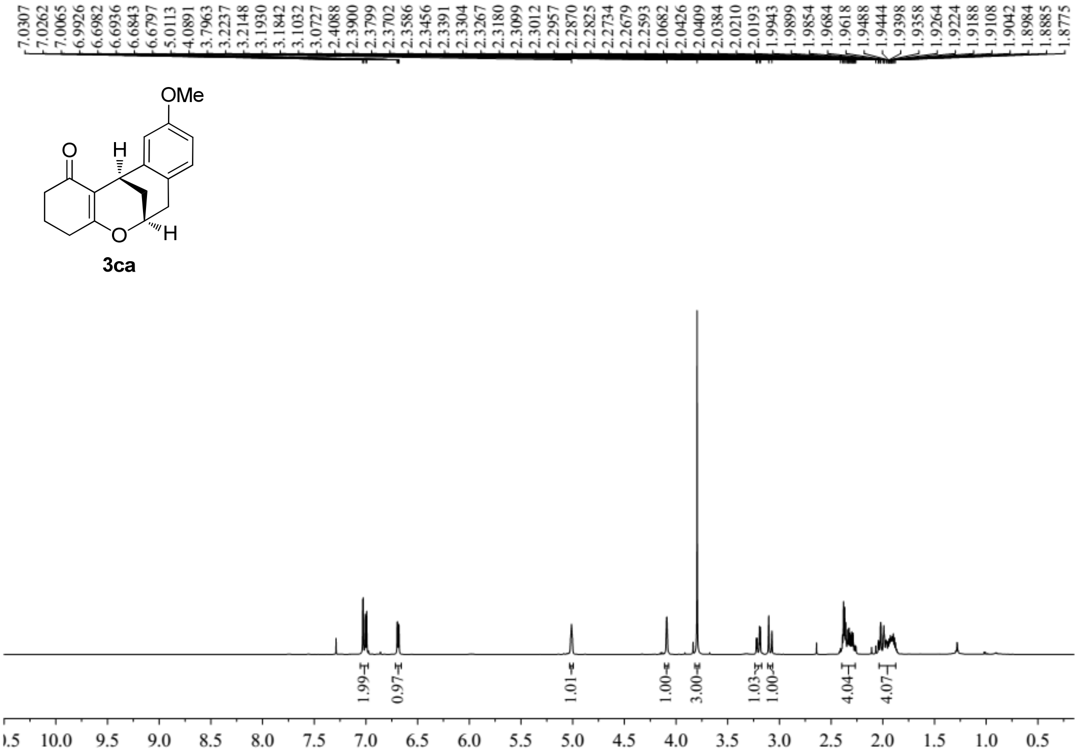
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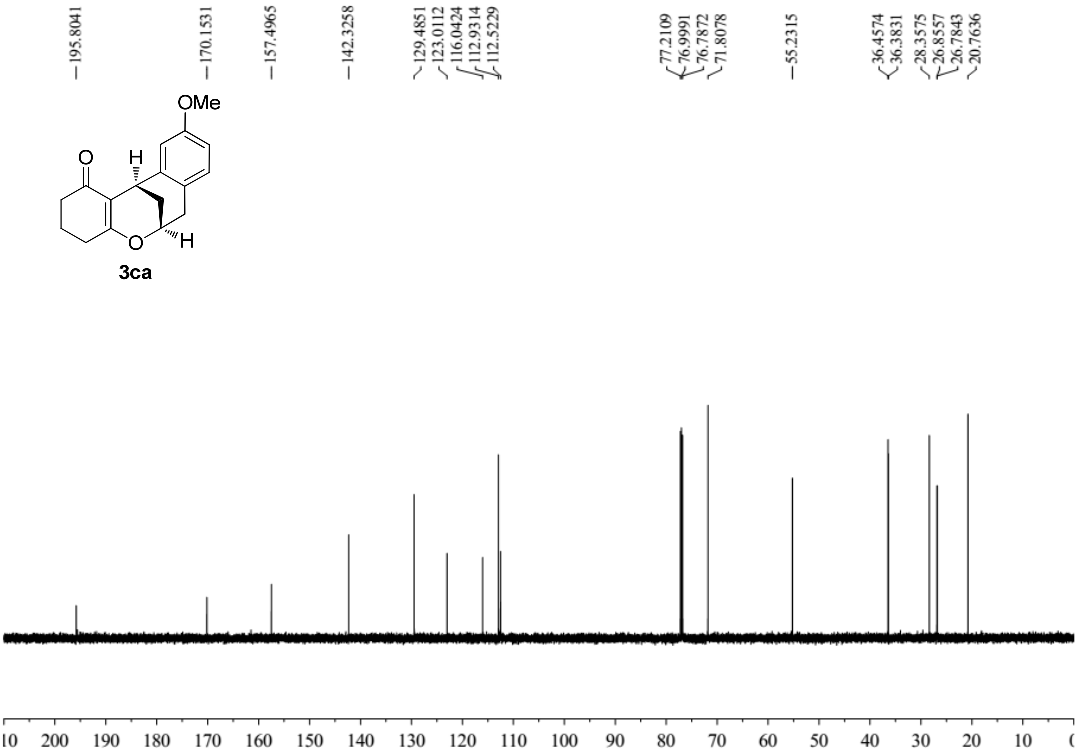
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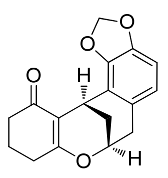

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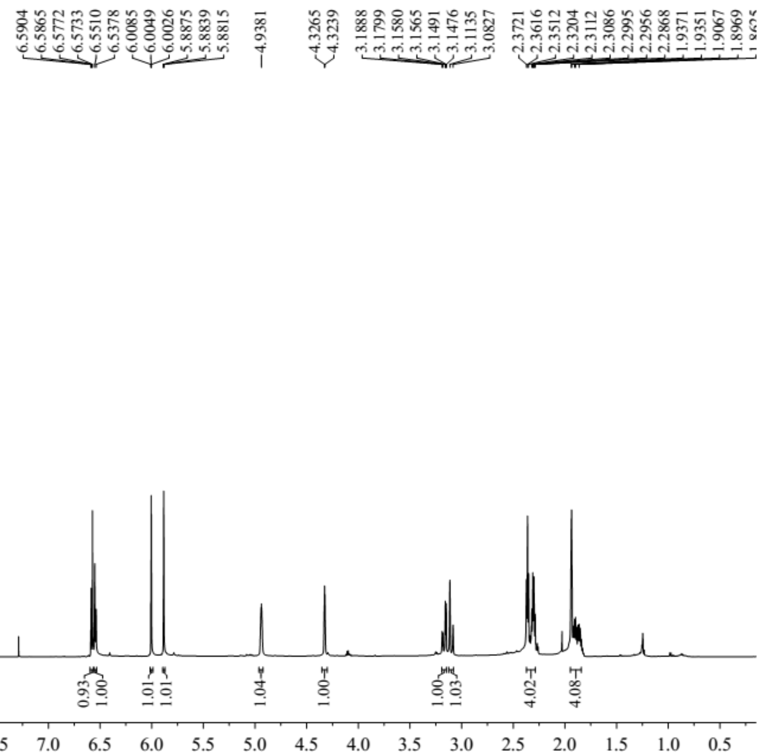
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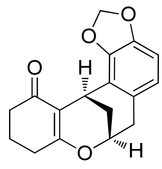

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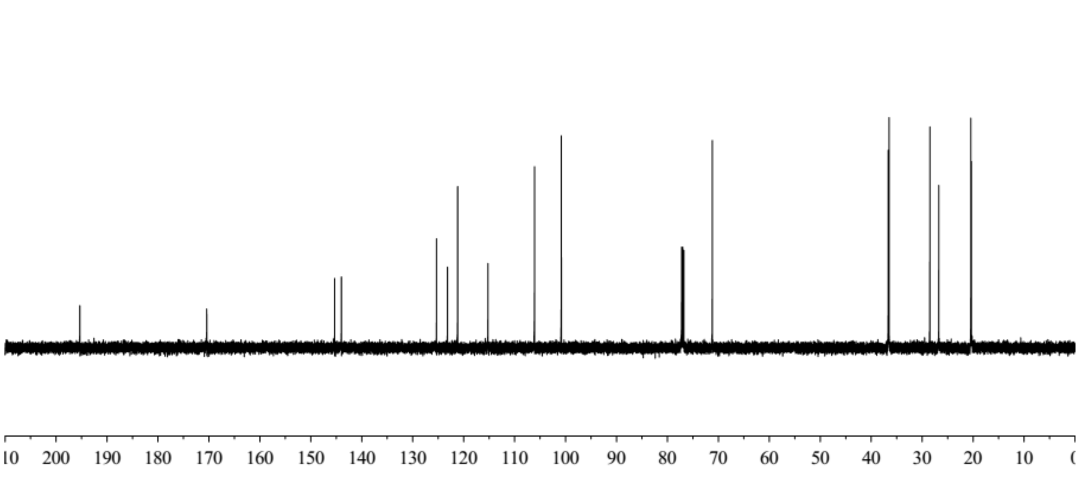
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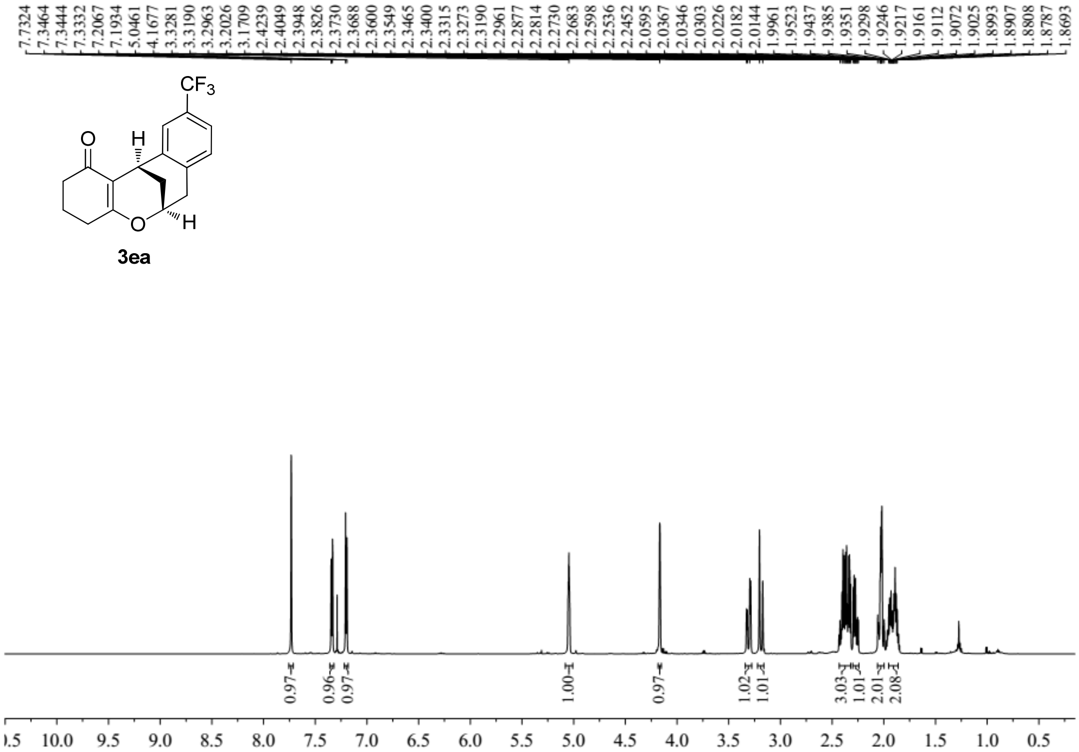

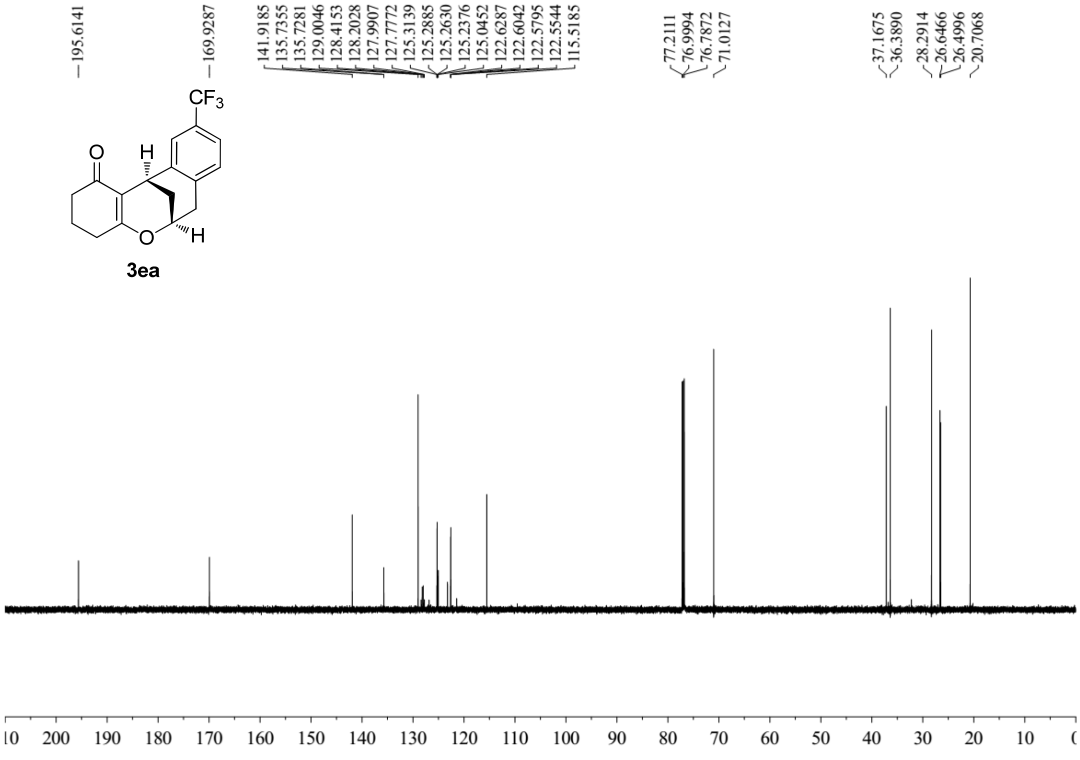

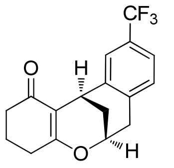

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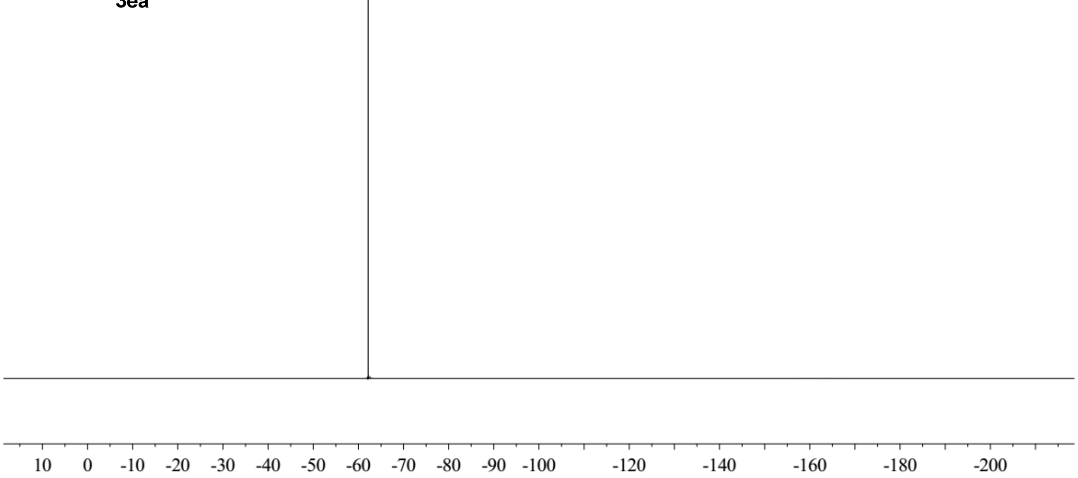
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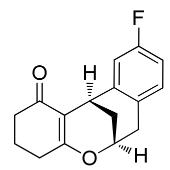

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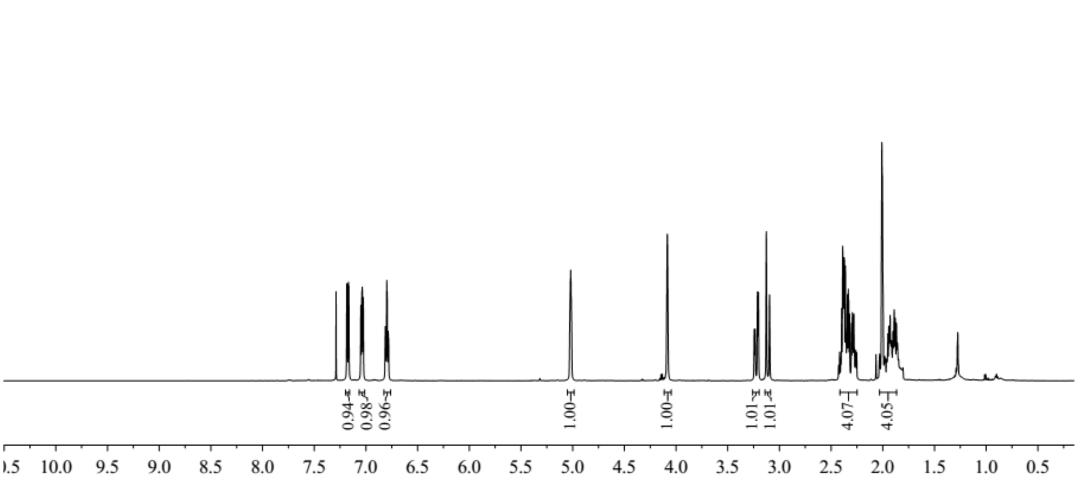
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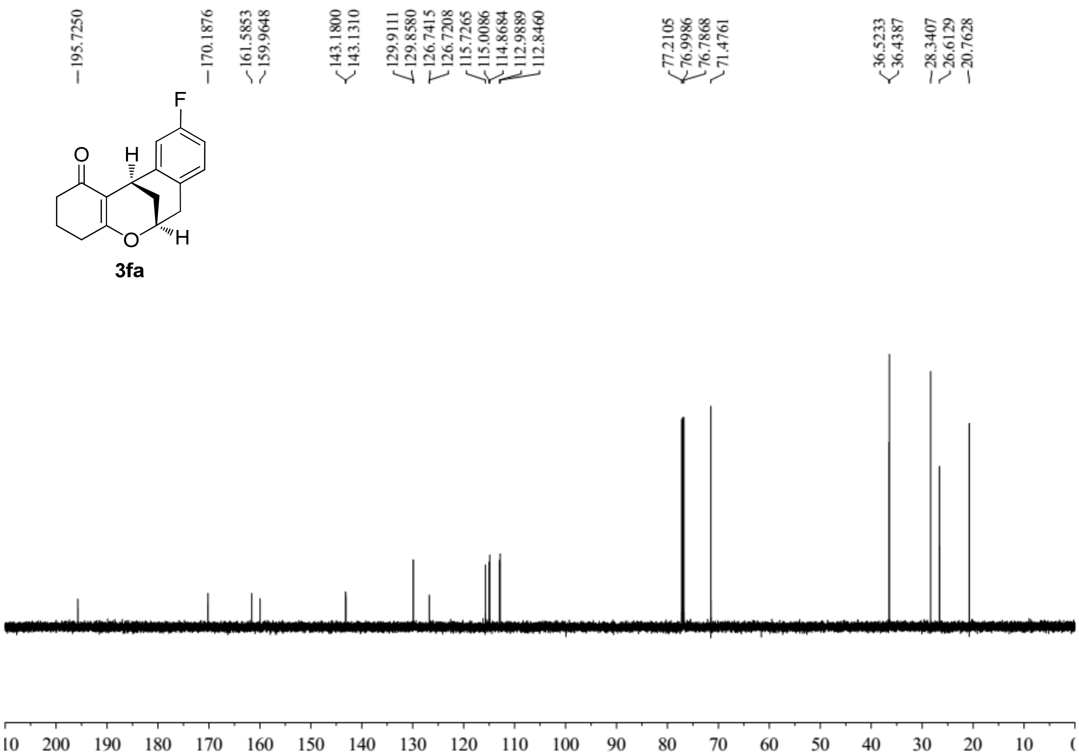
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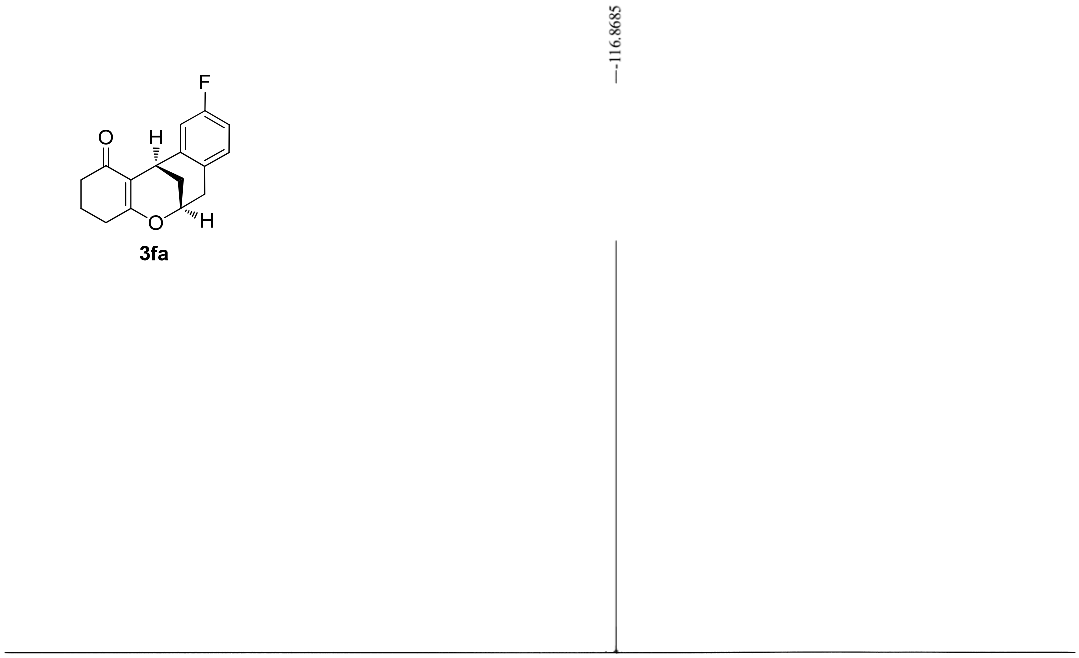
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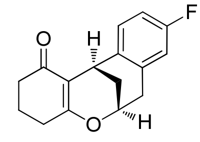

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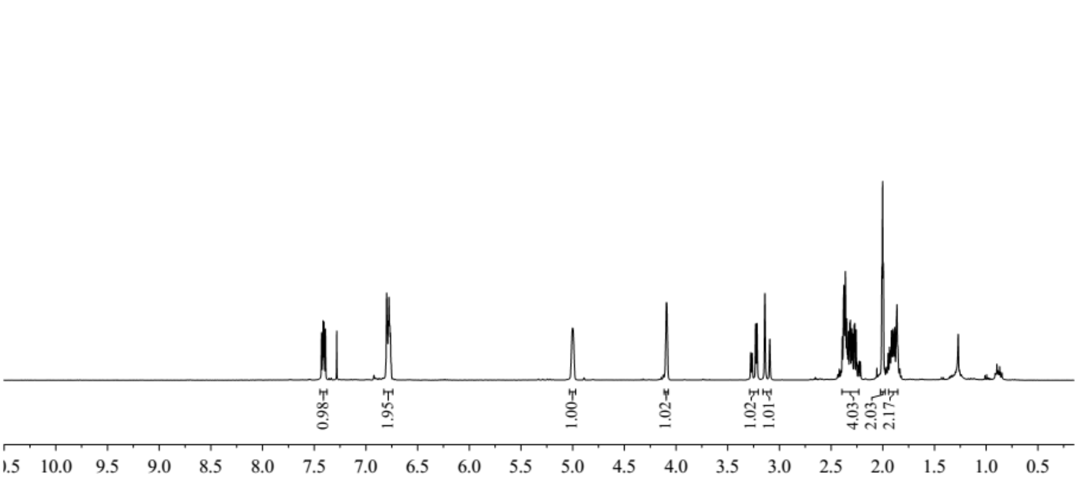
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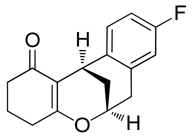

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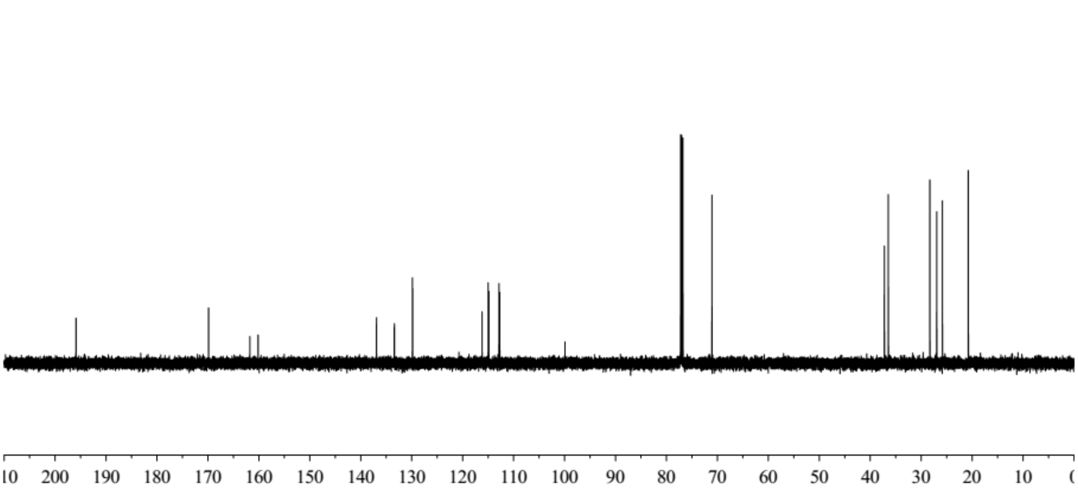
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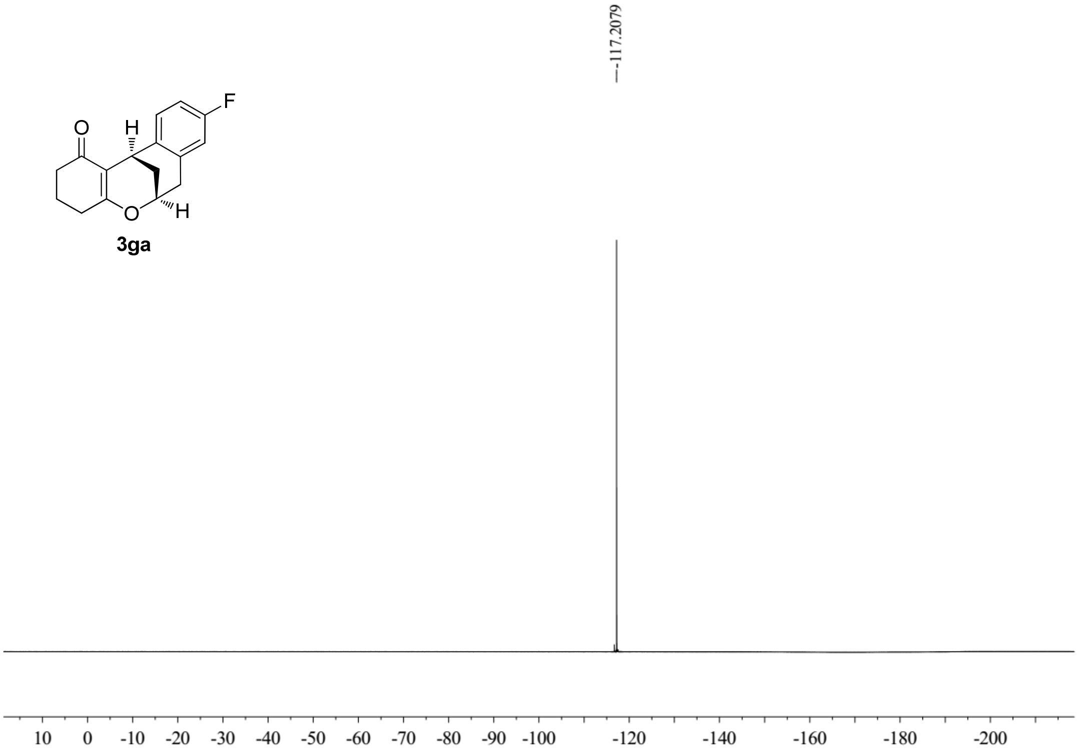

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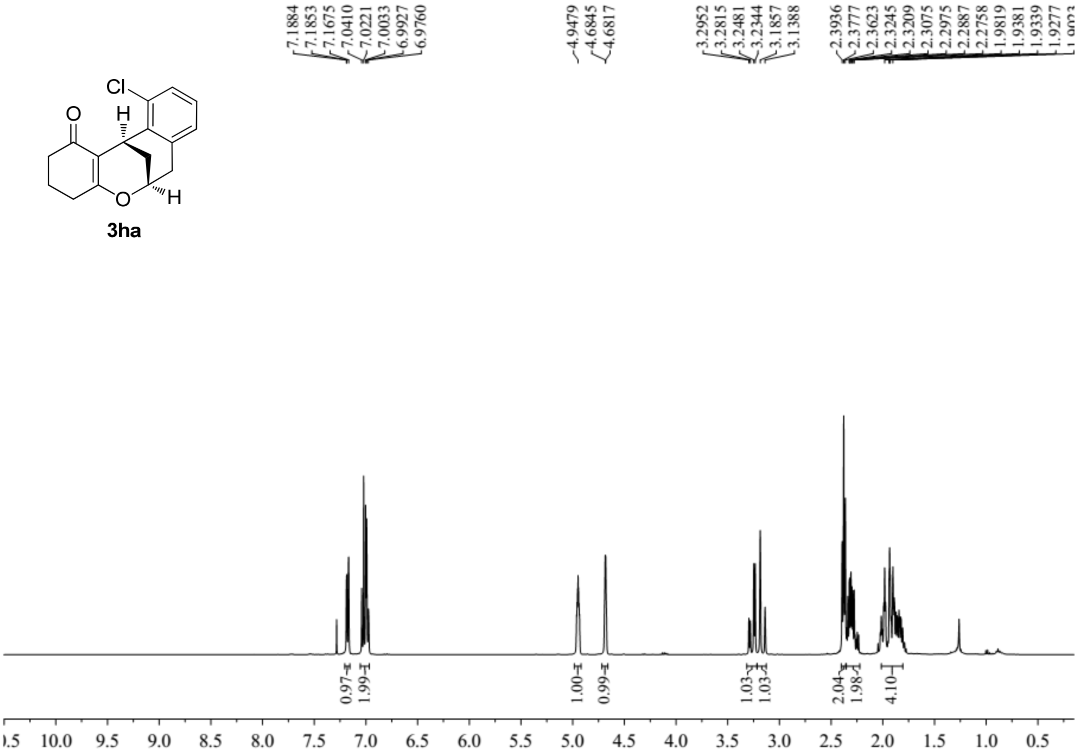

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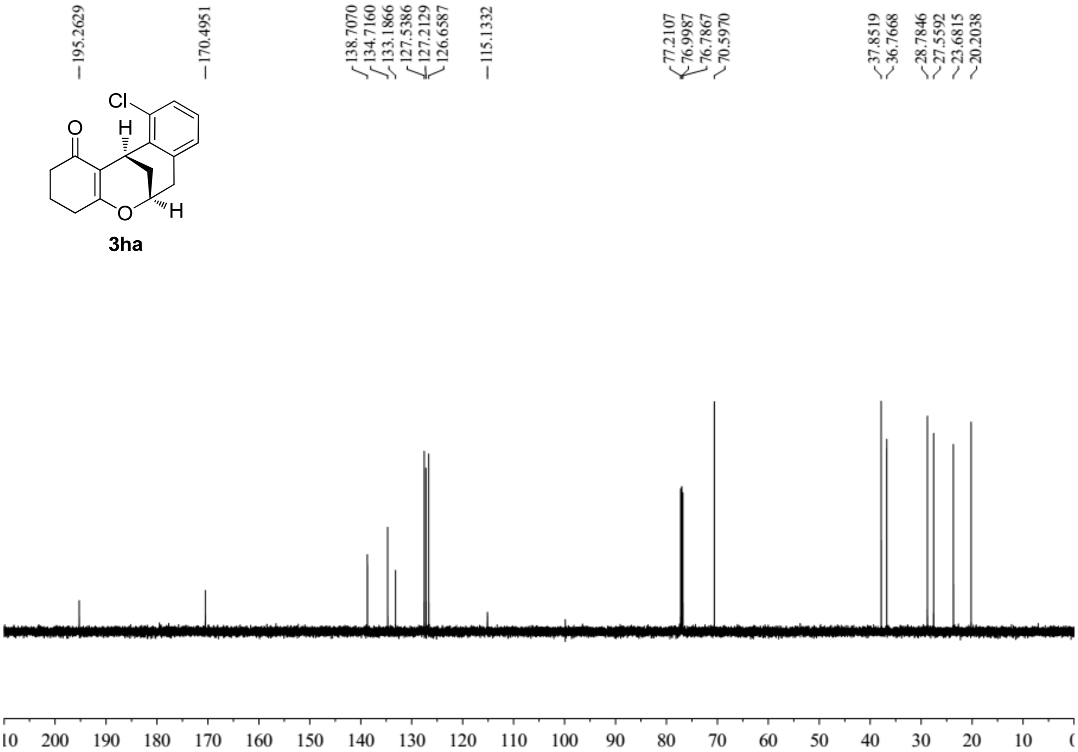
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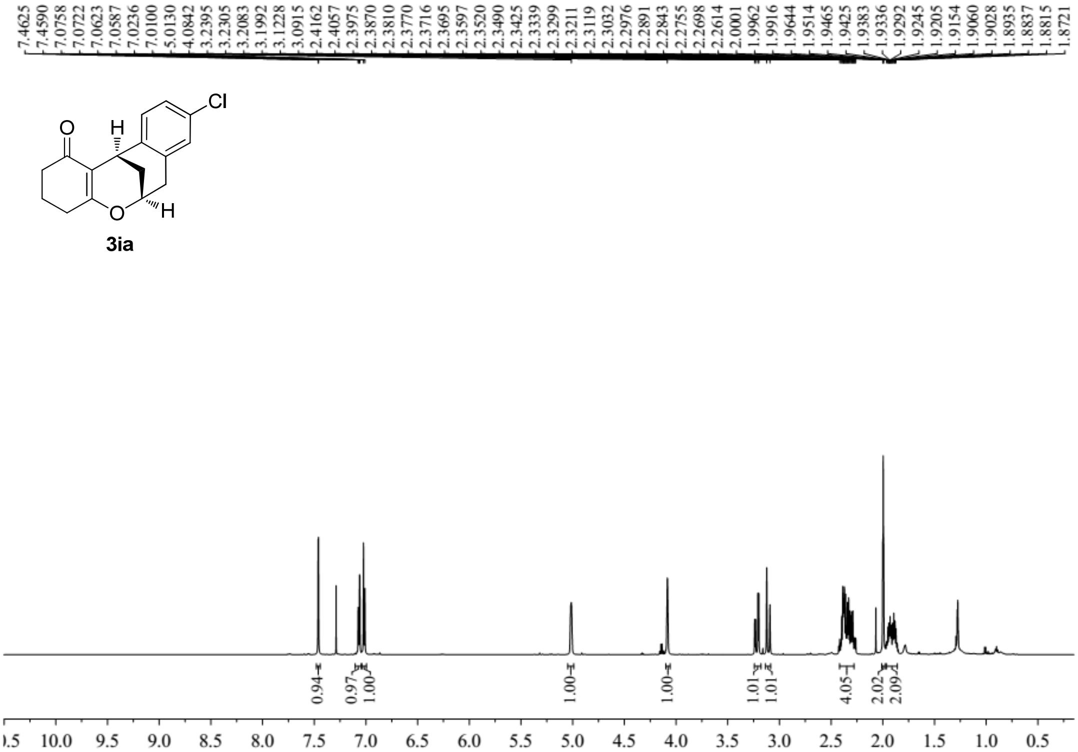
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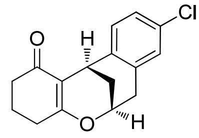

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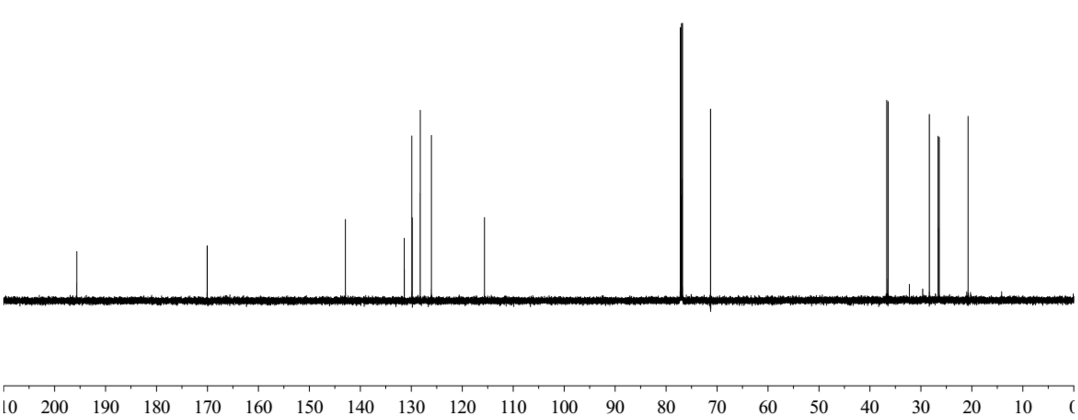
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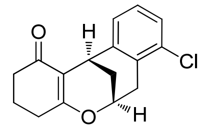

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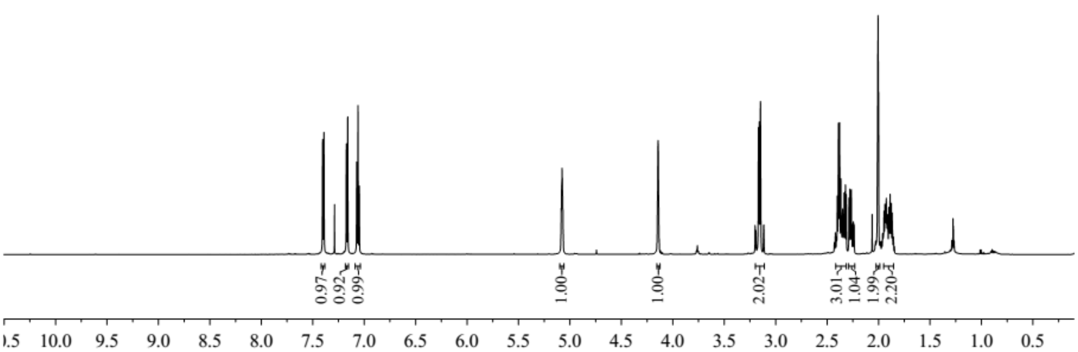
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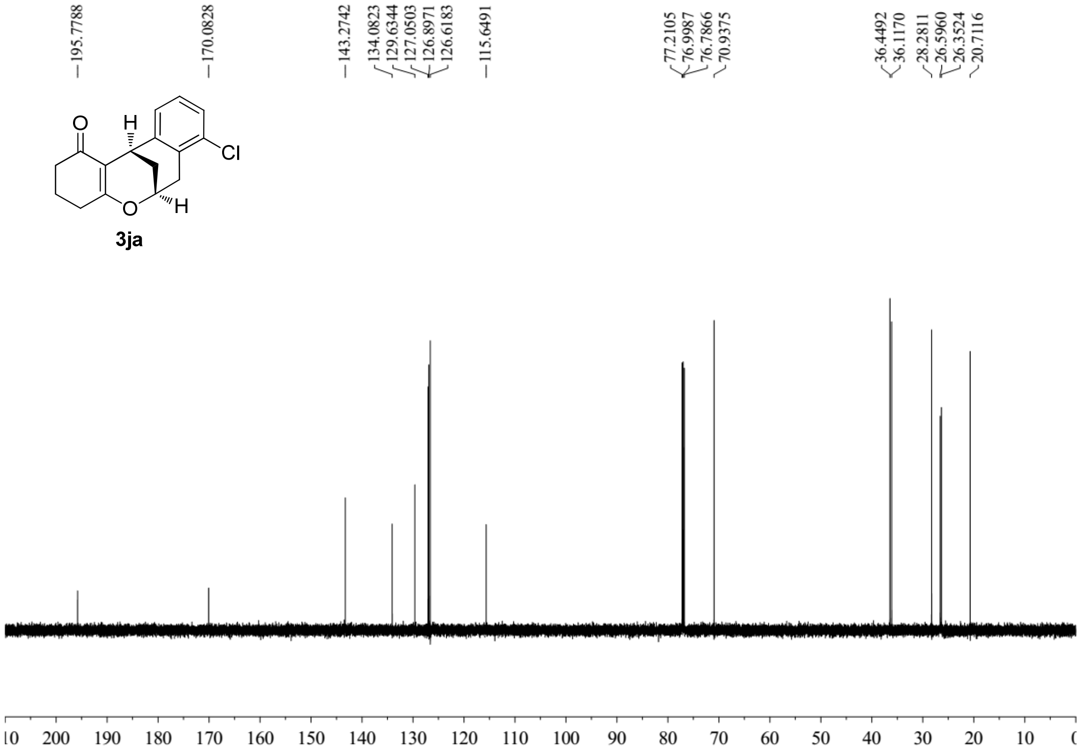
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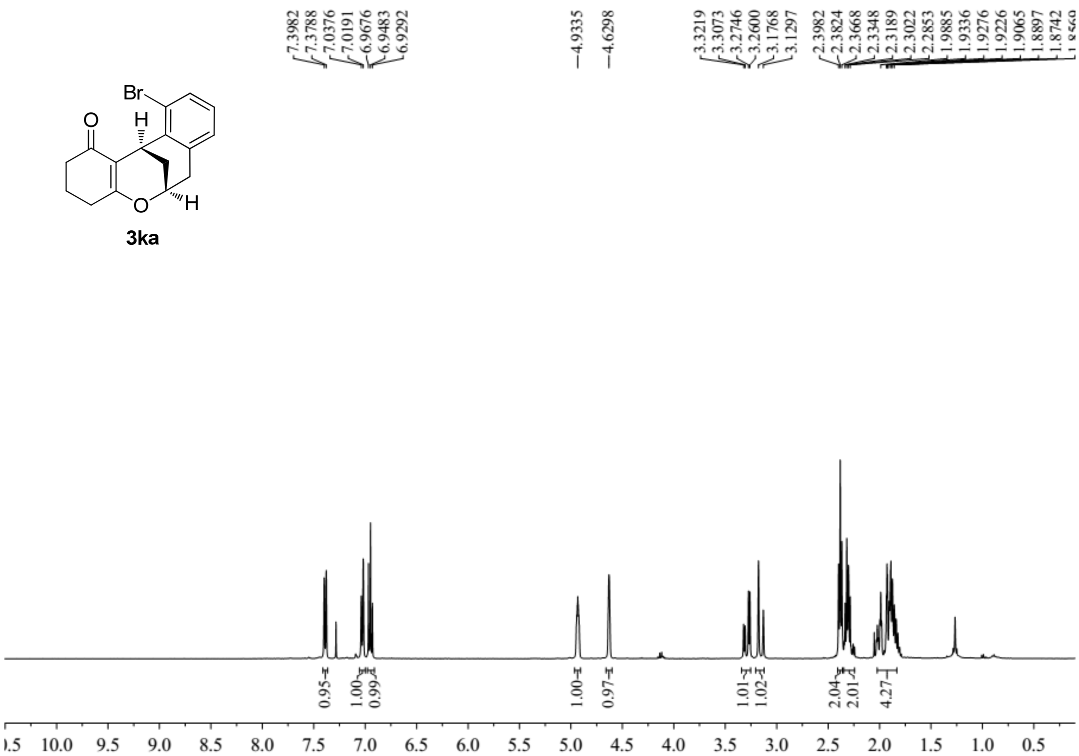
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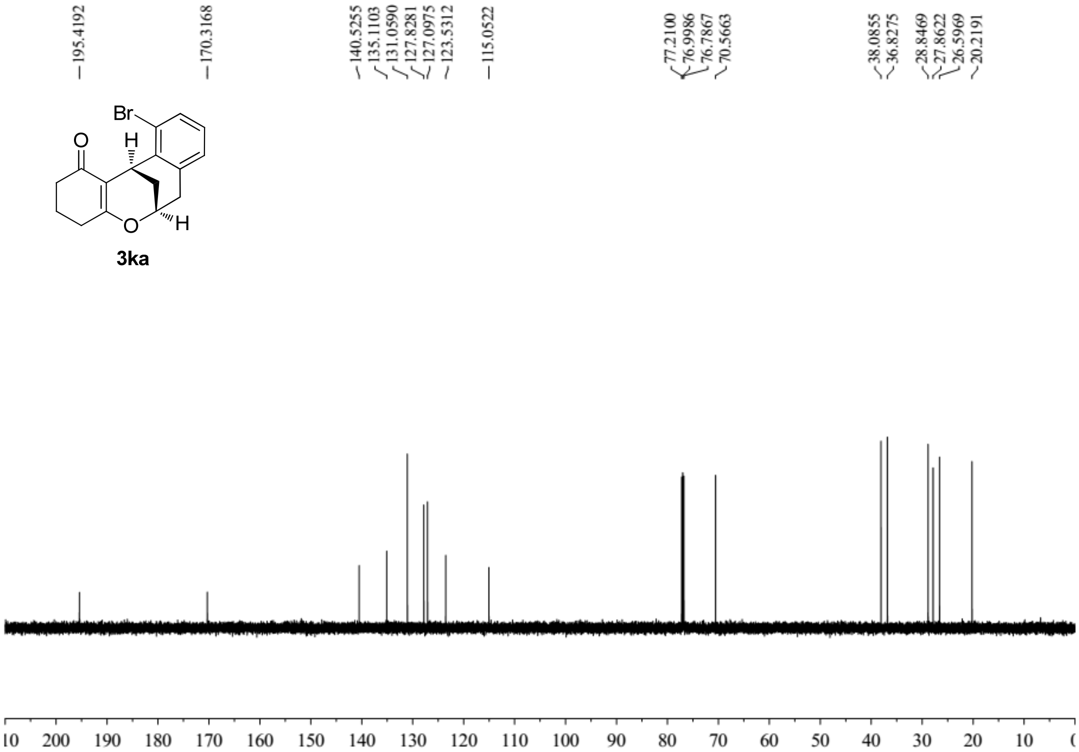

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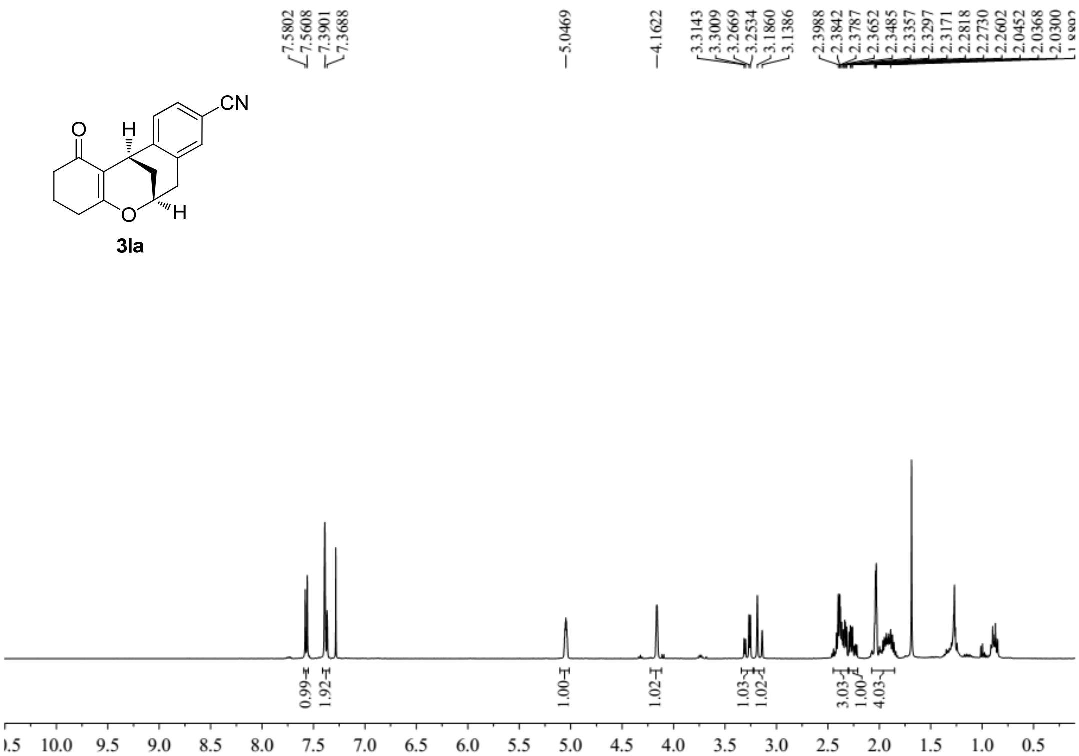

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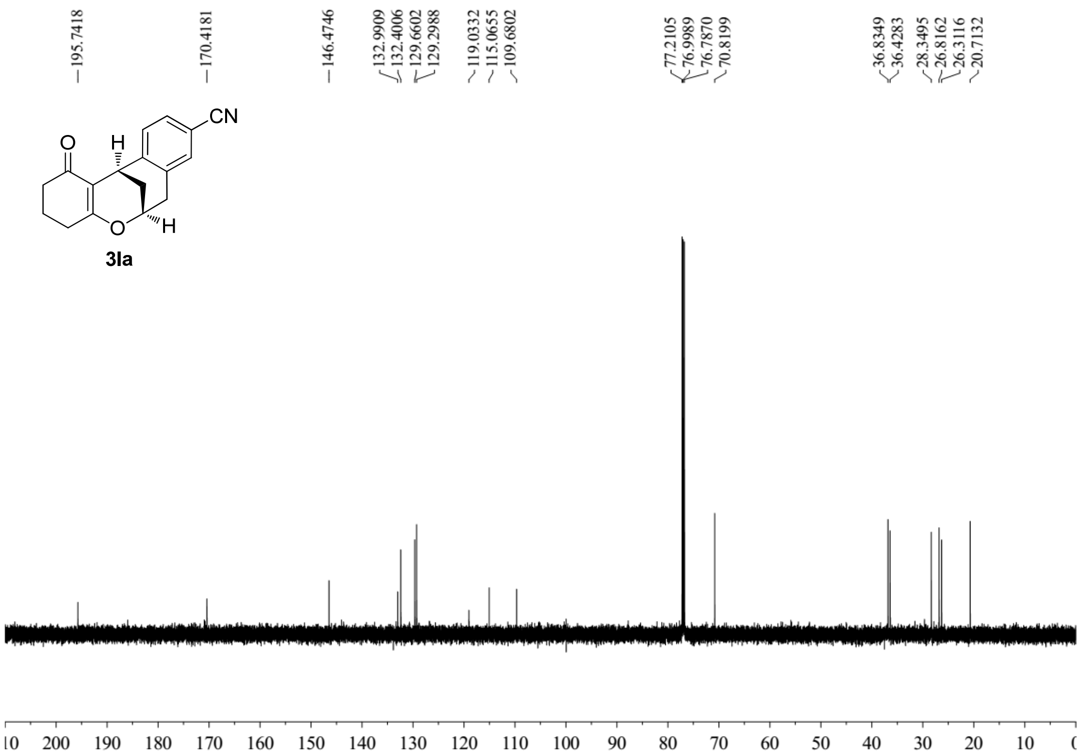
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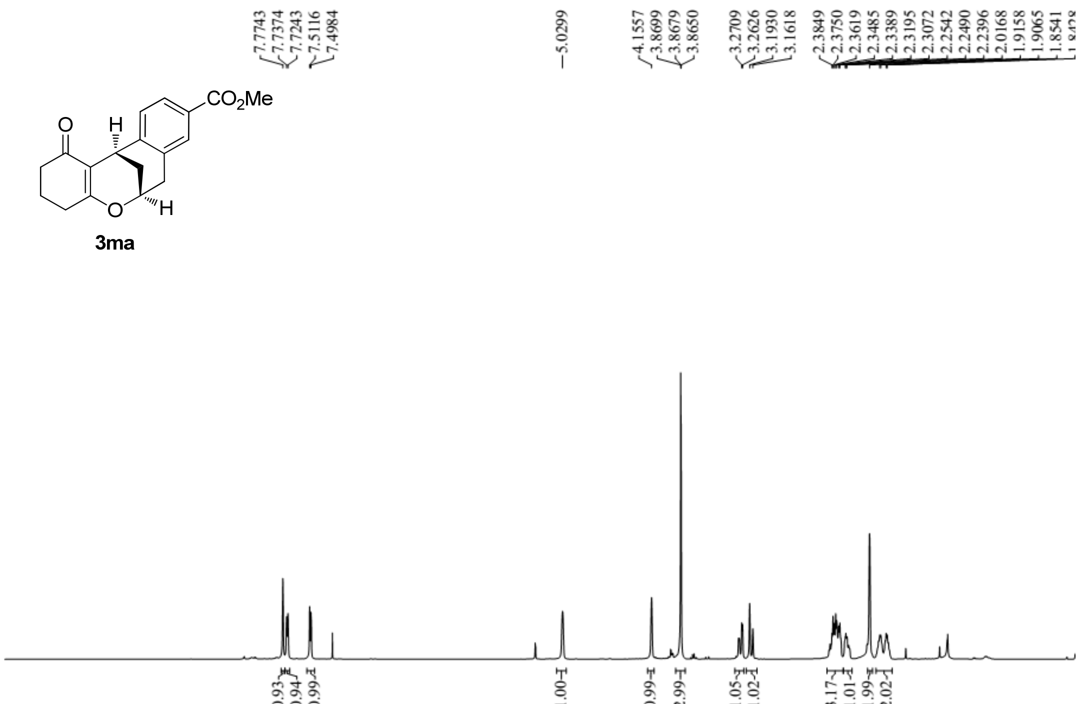
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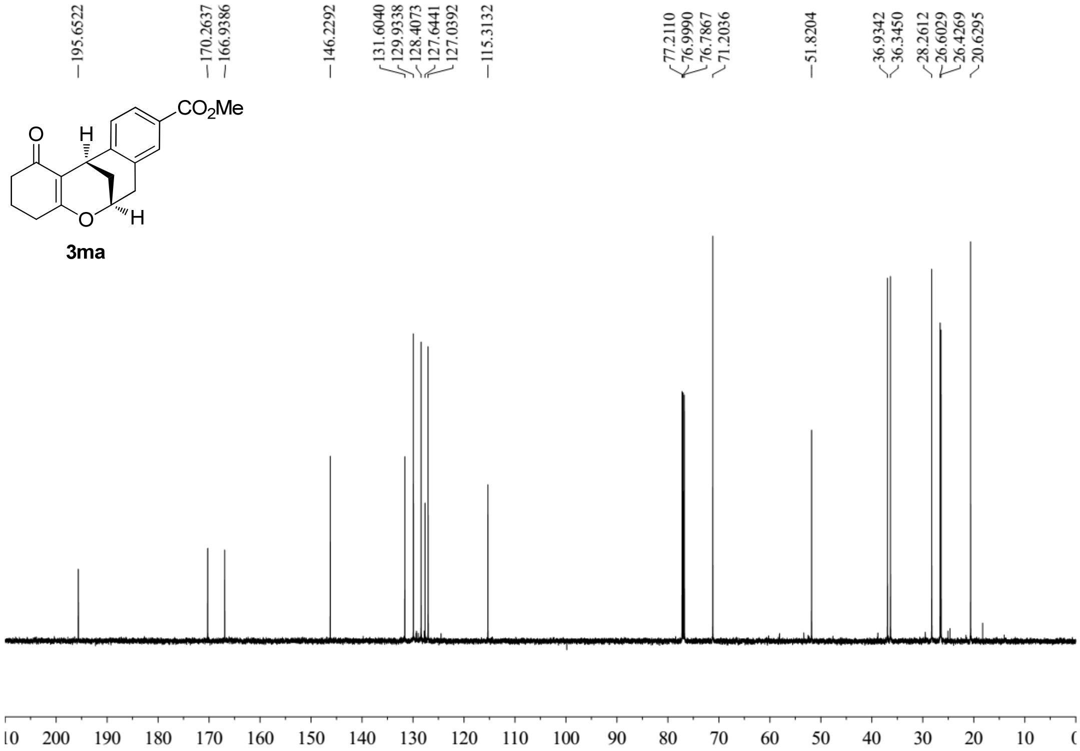
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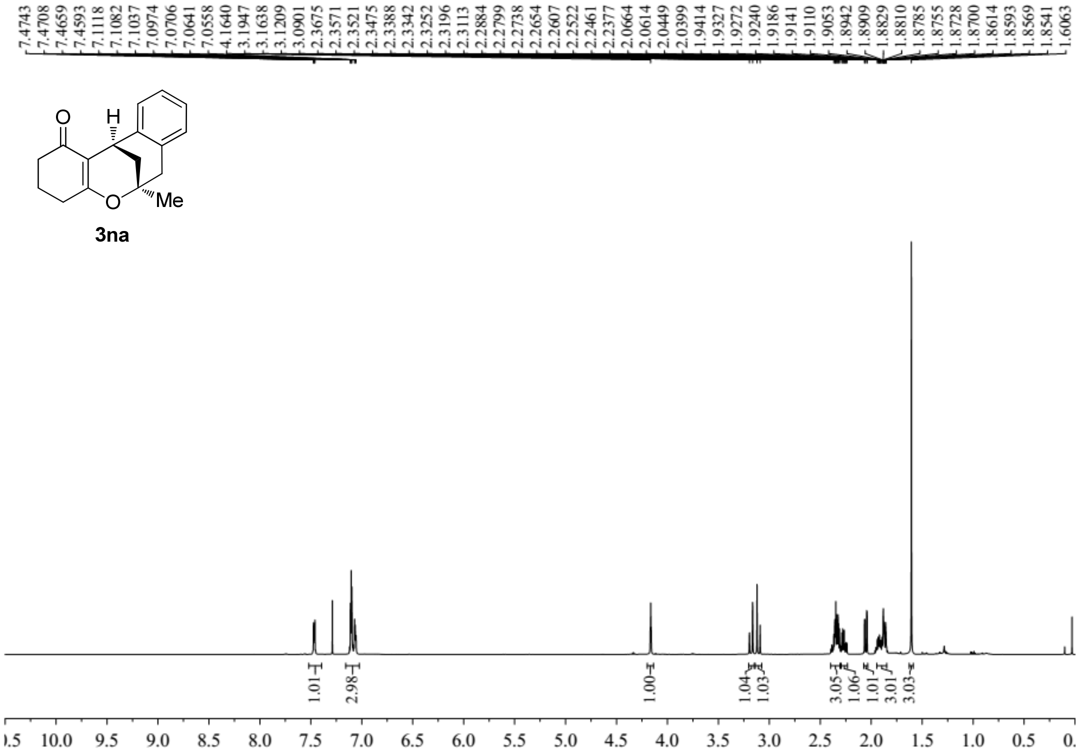
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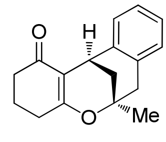
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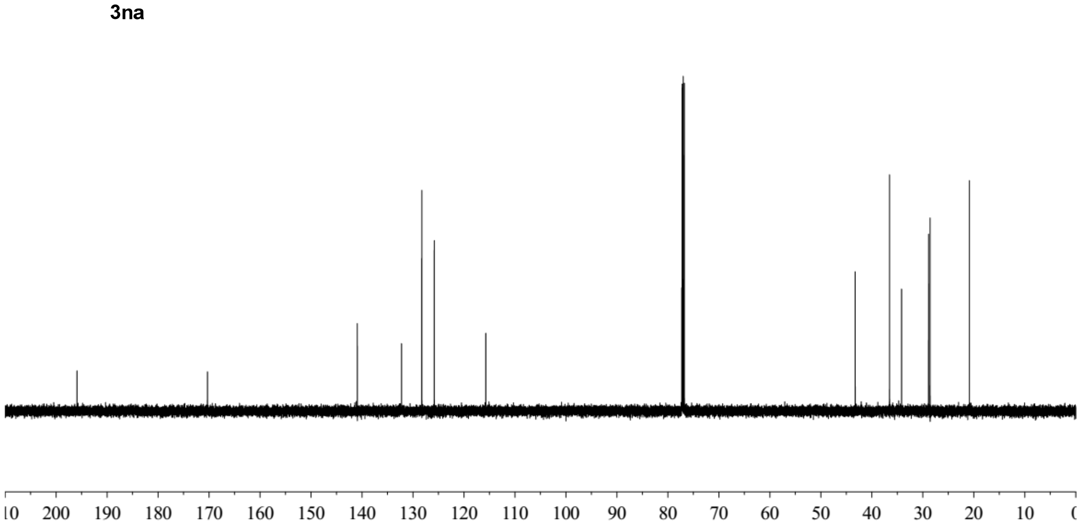
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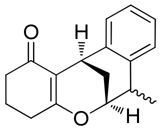
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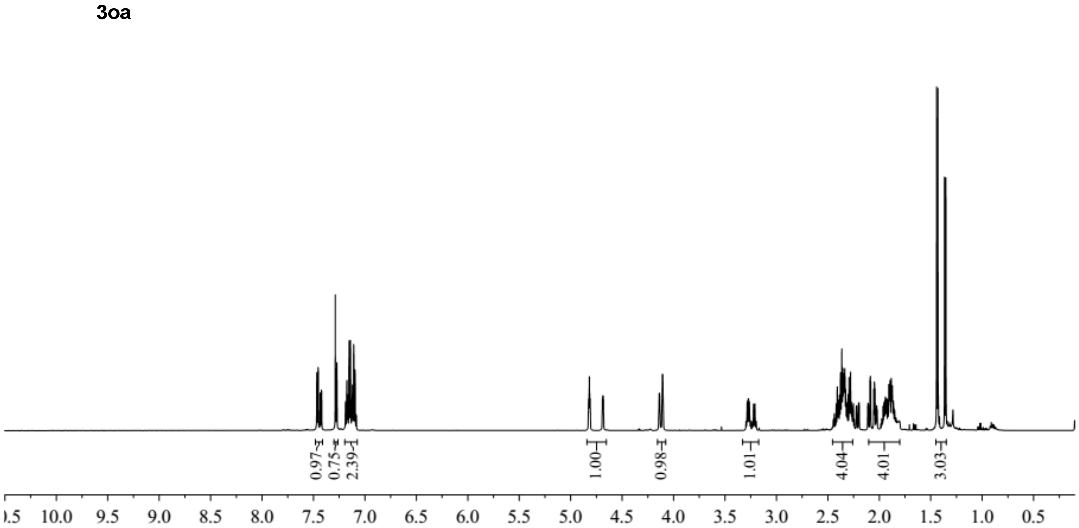
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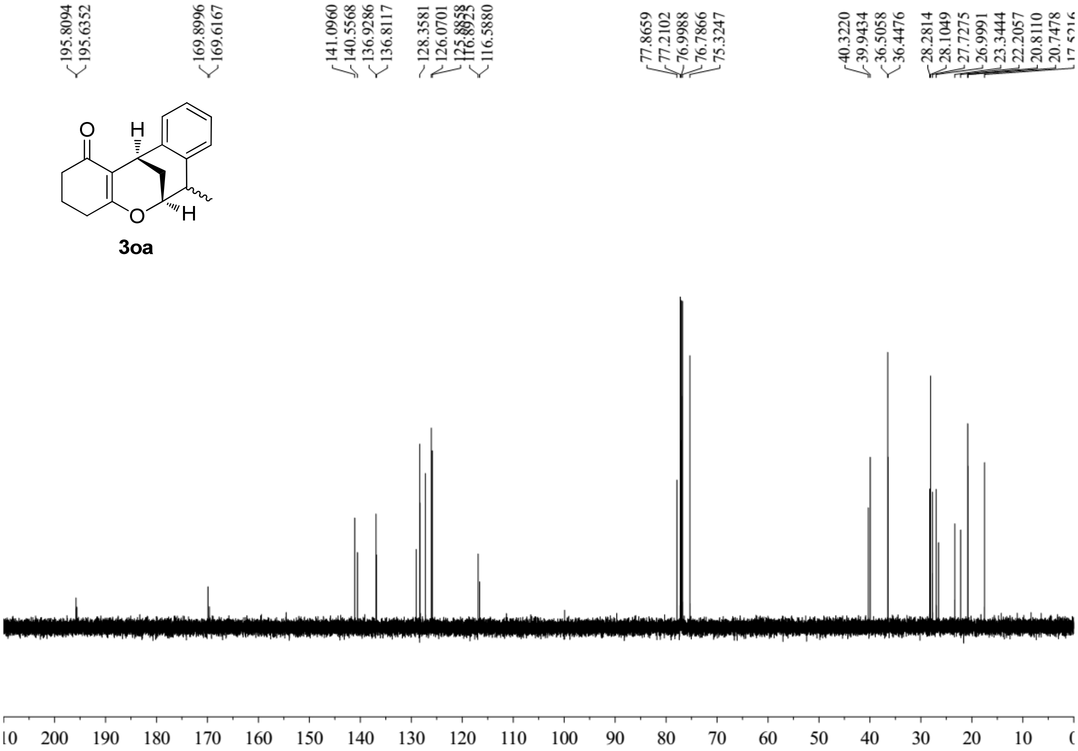
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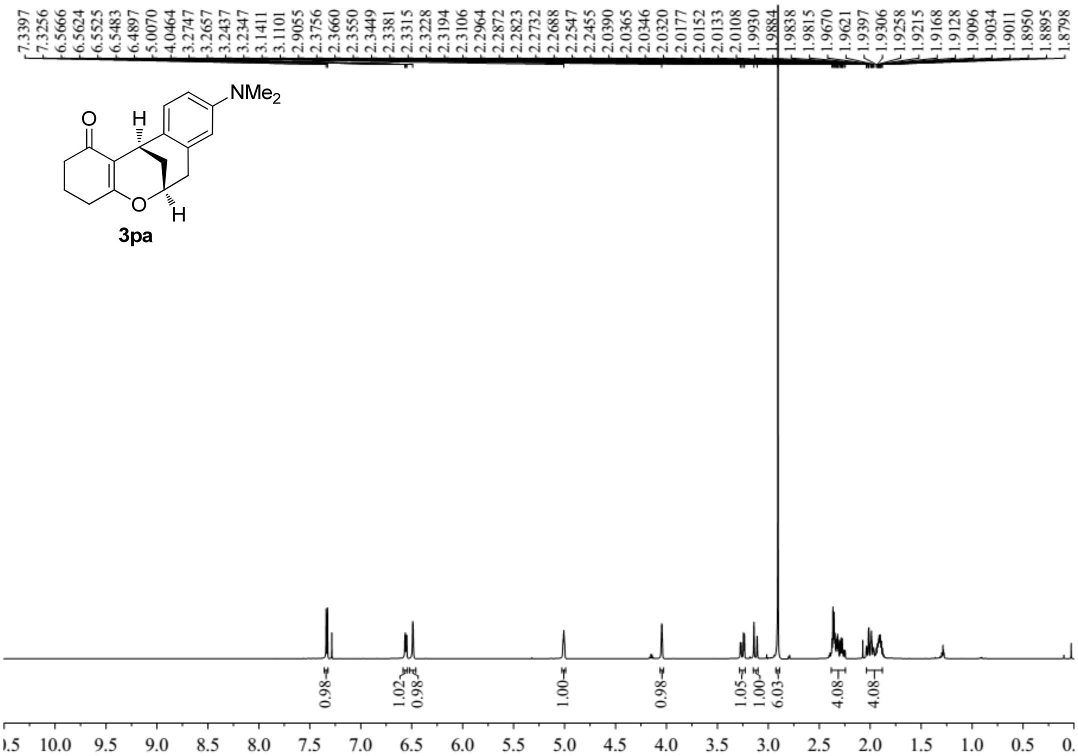
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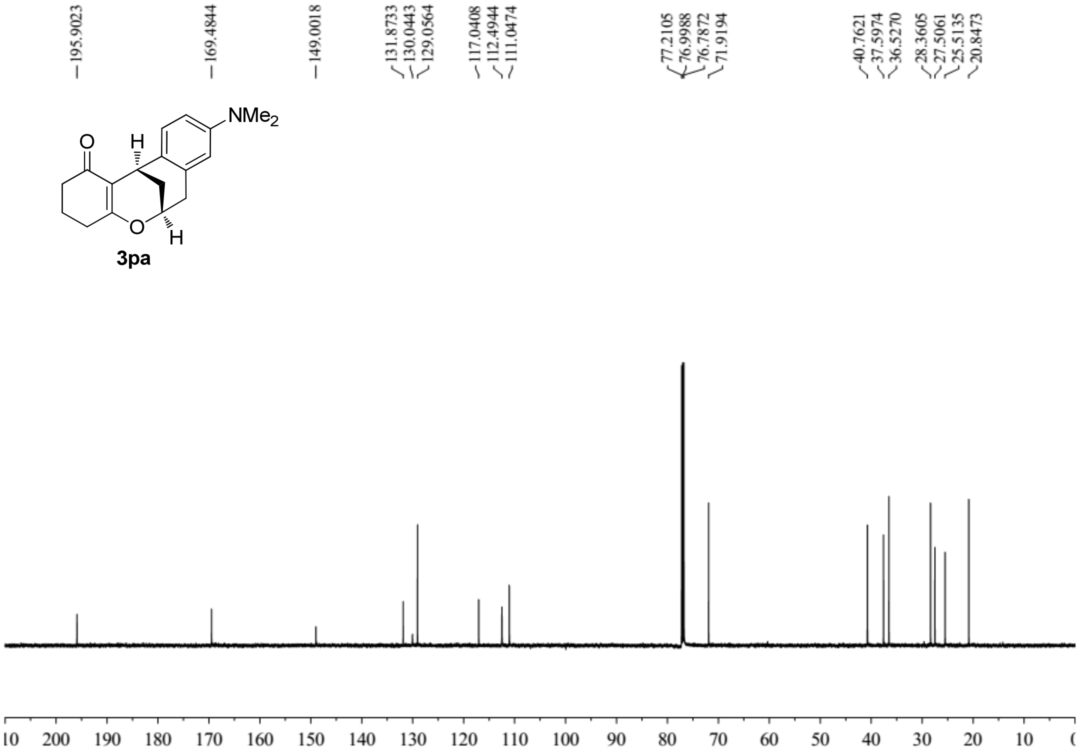
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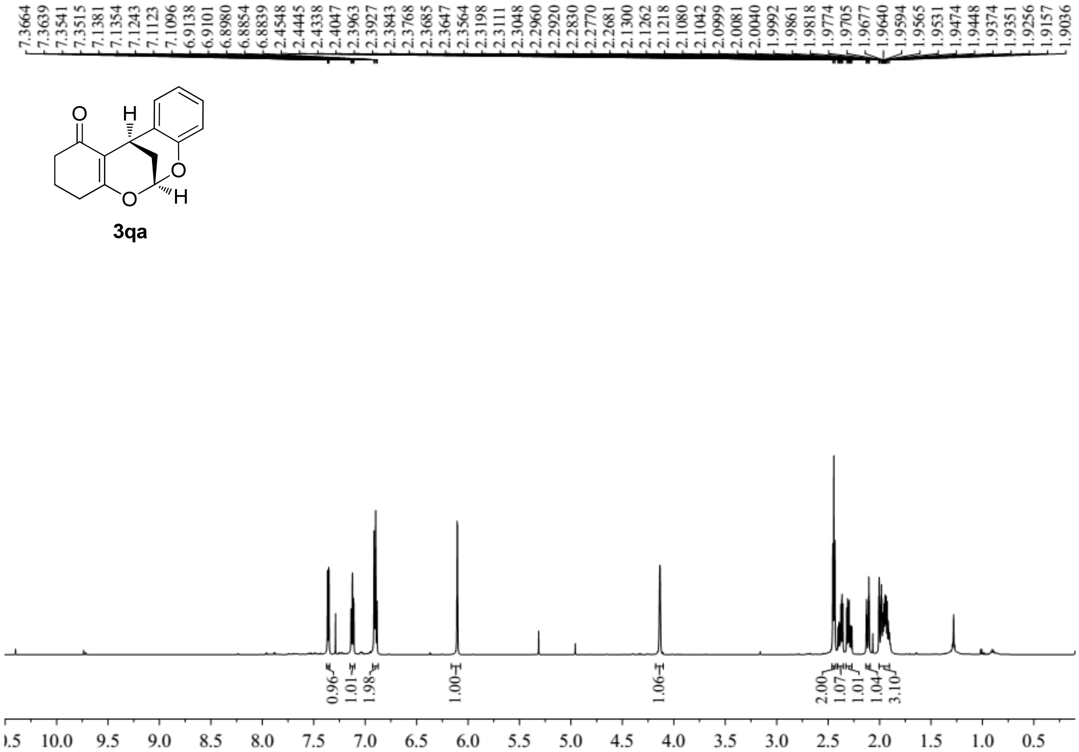
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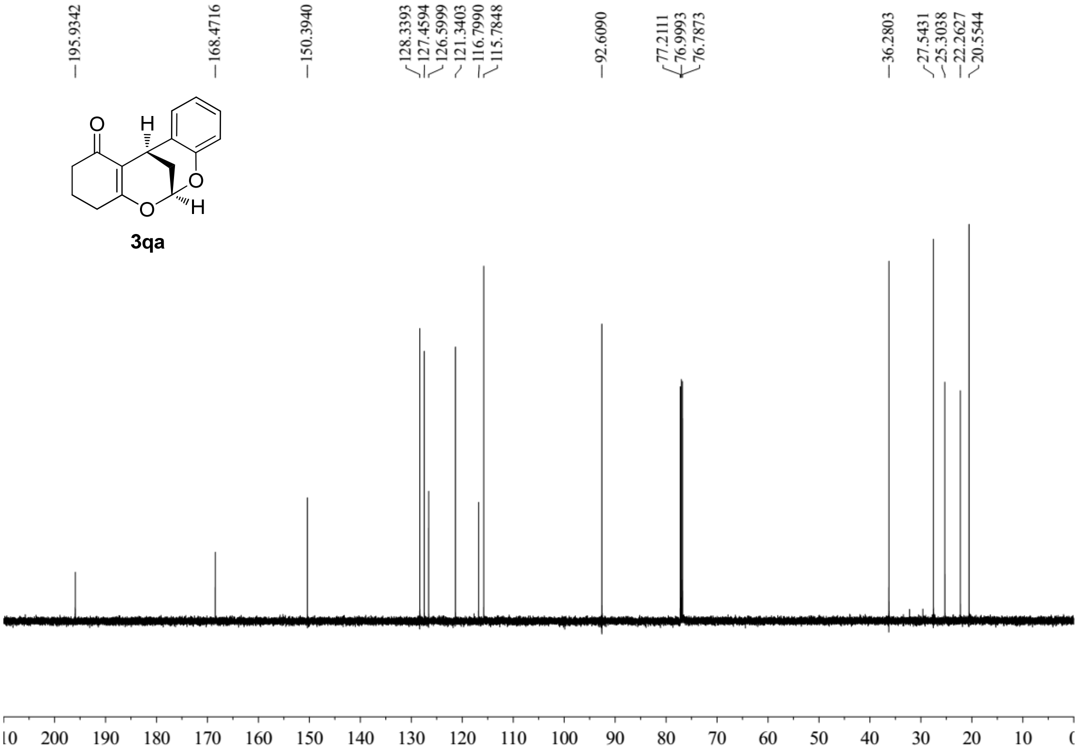
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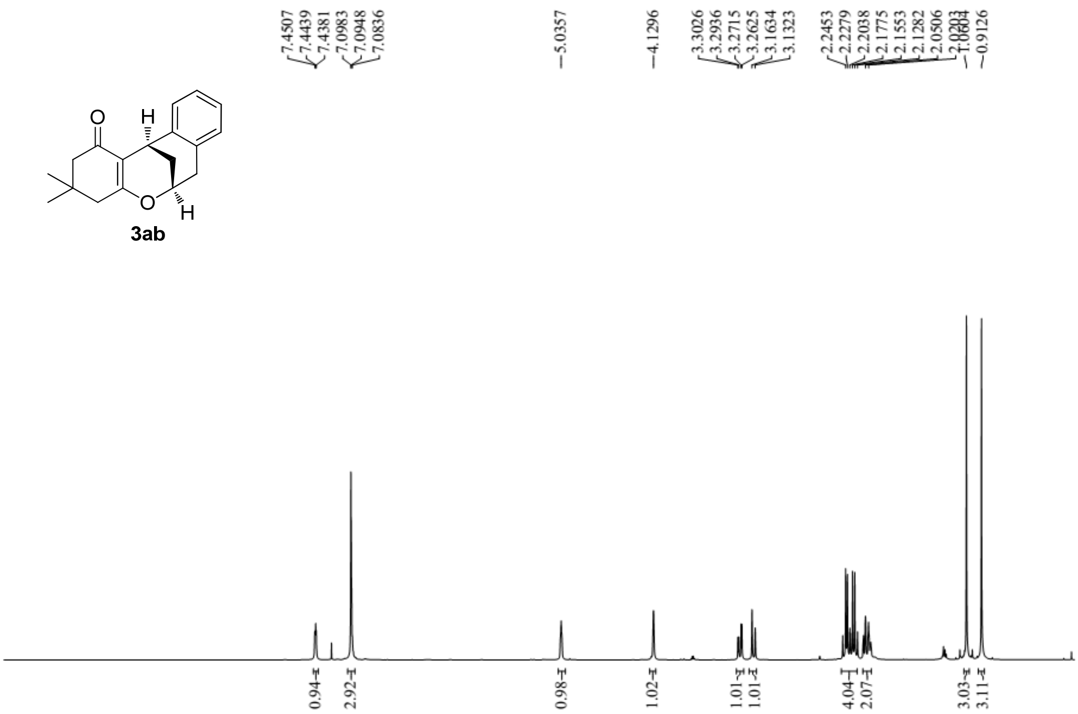
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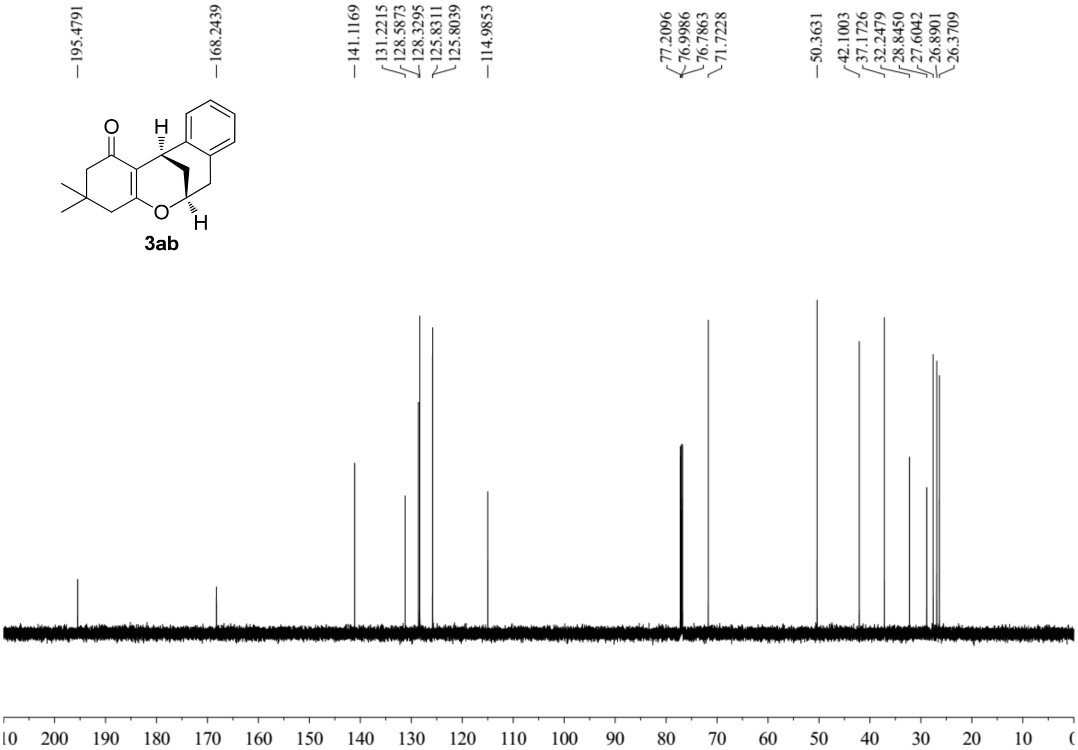
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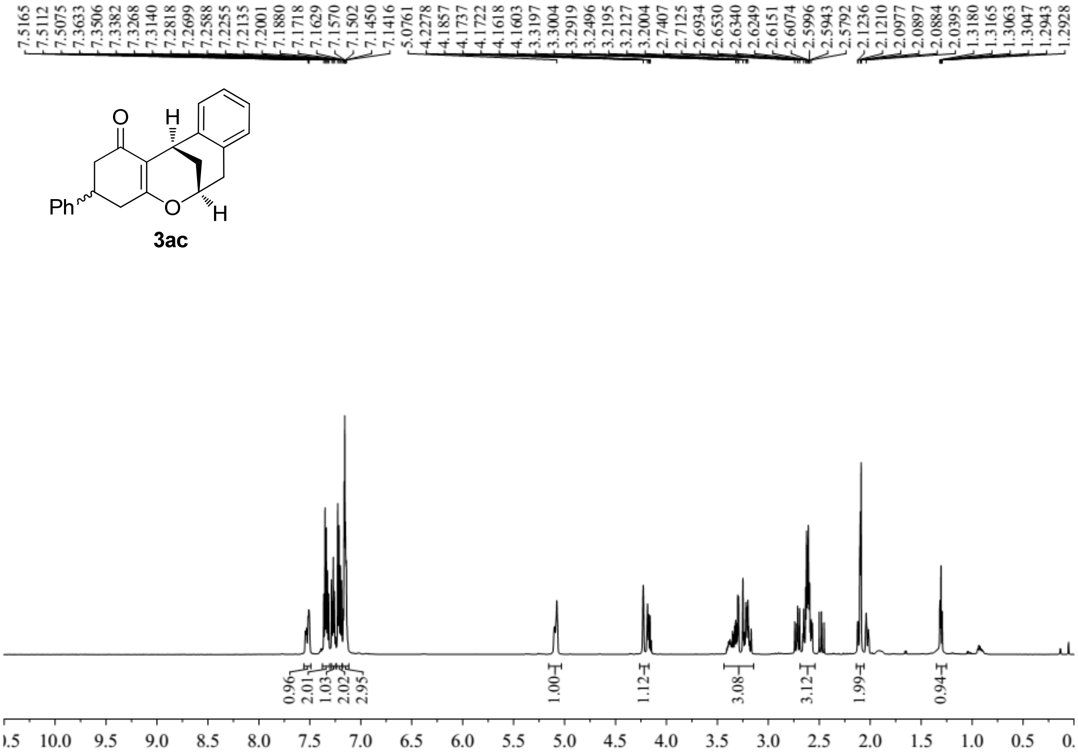
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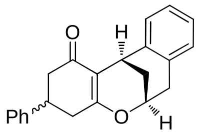
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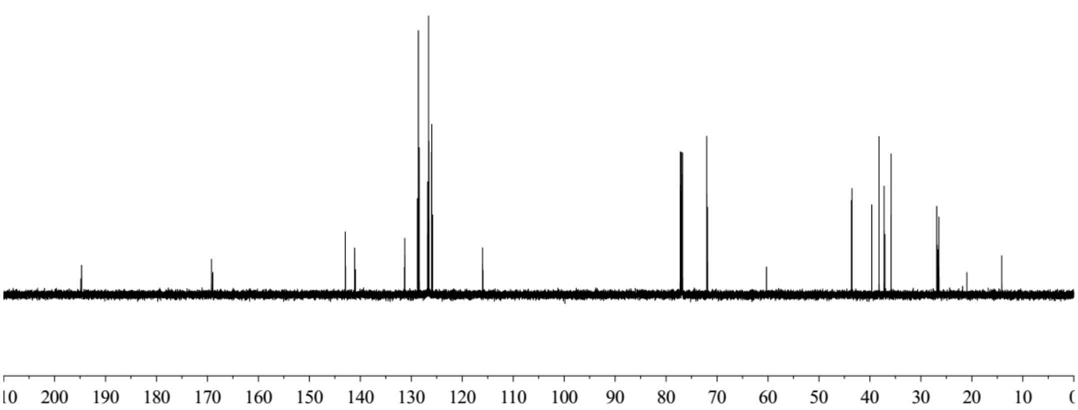
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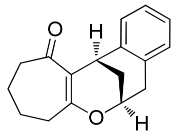
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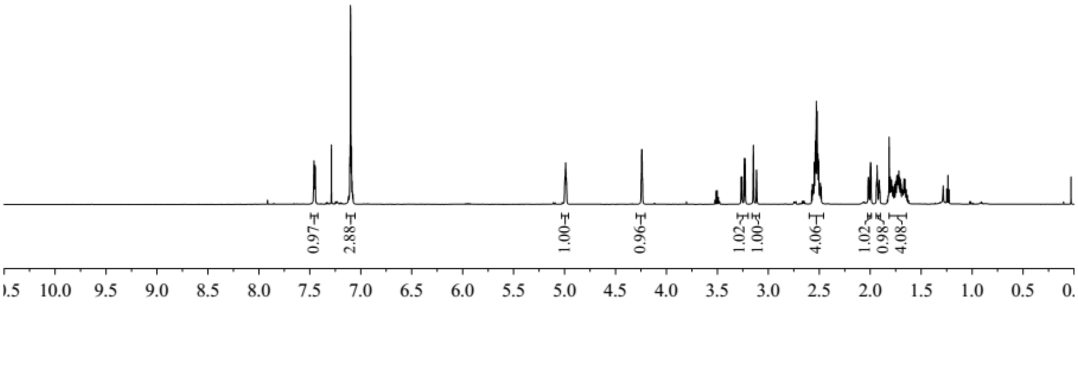
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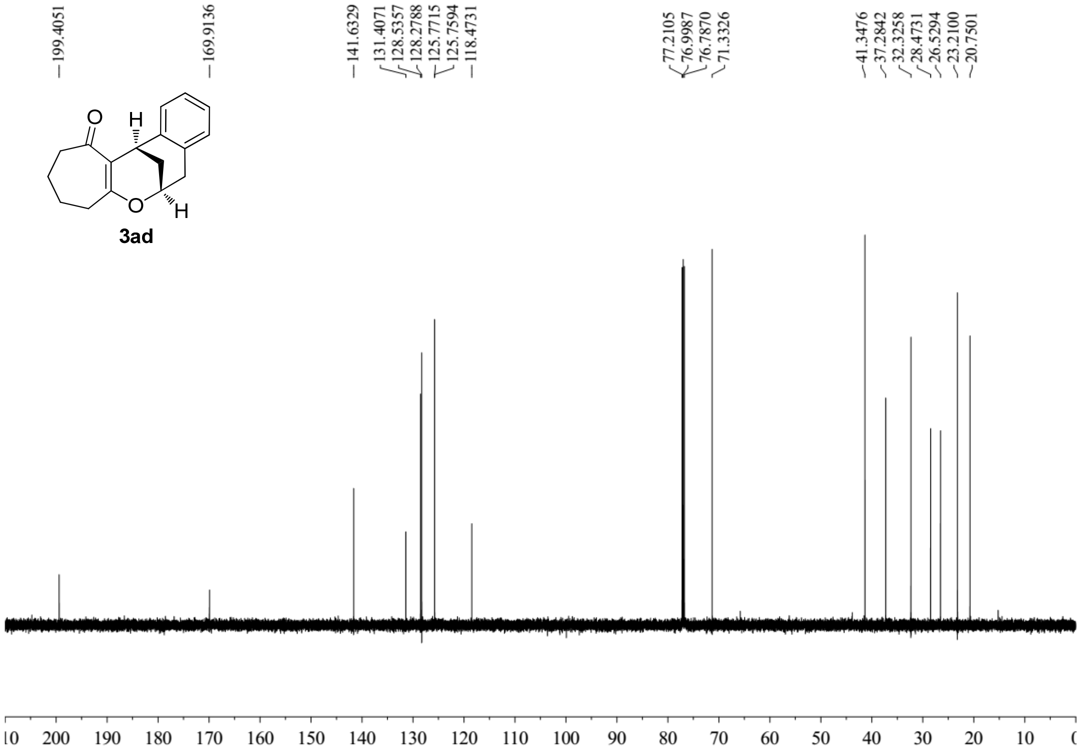
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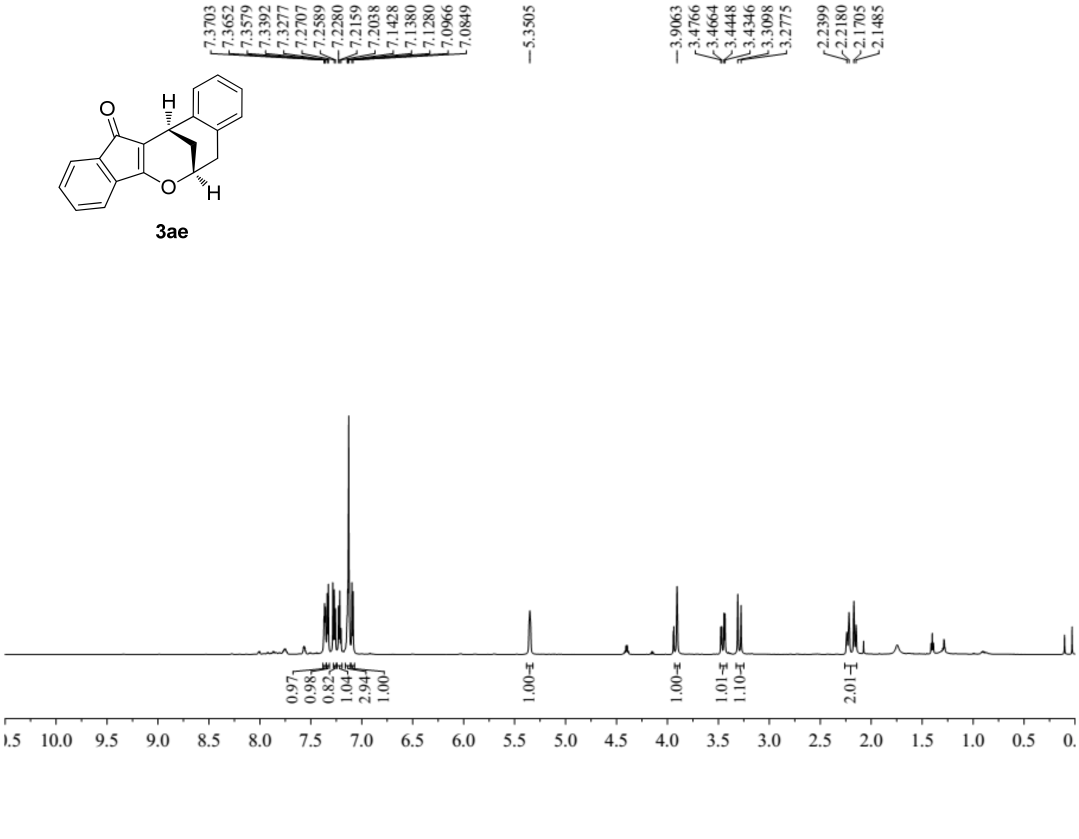
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3ae
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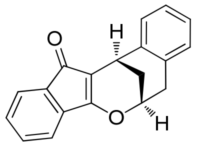

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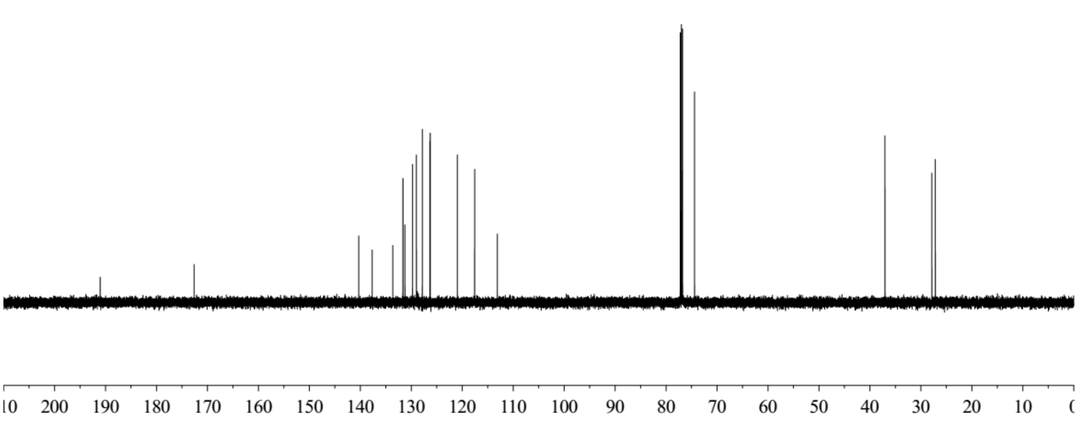
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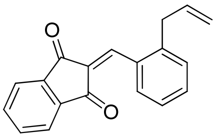

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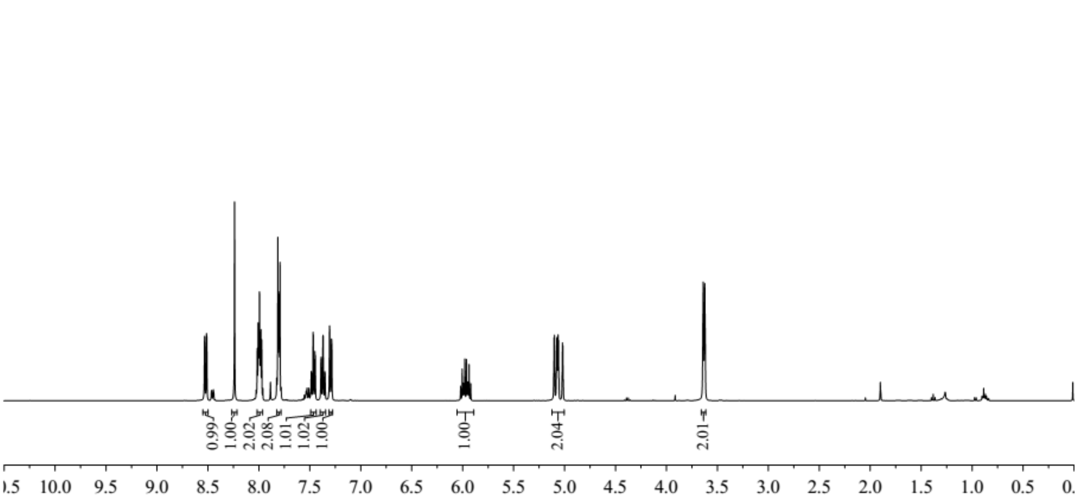
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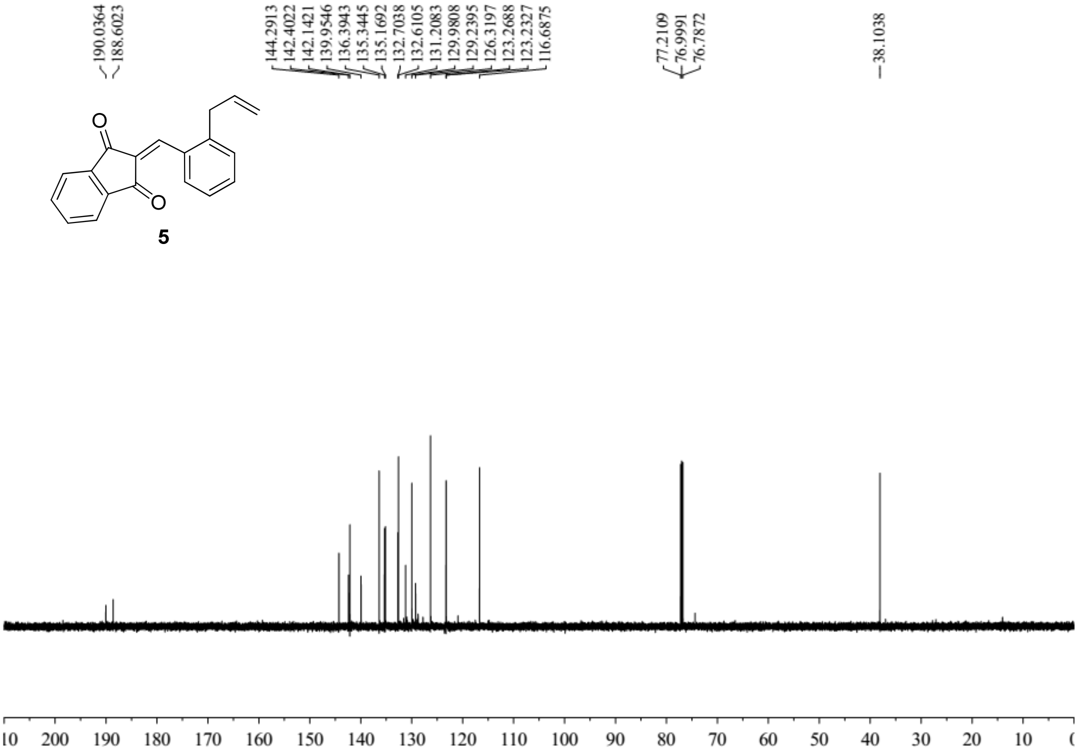
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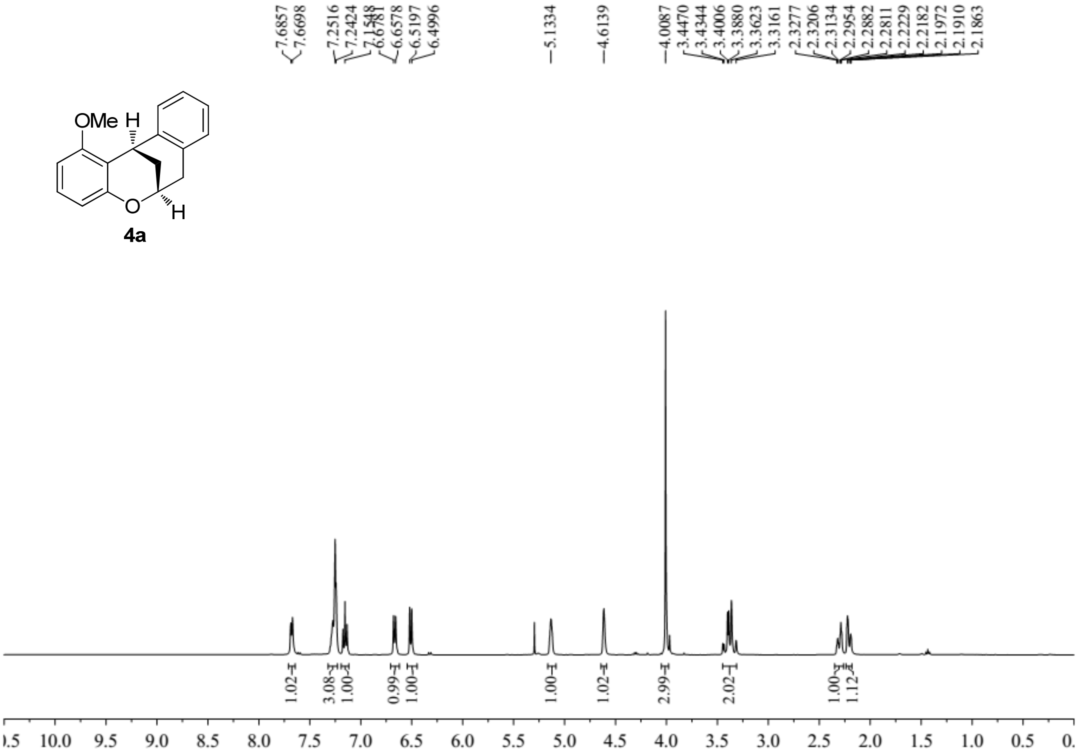
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2.1910
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OMe H
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3.08
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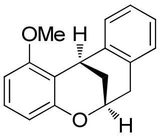

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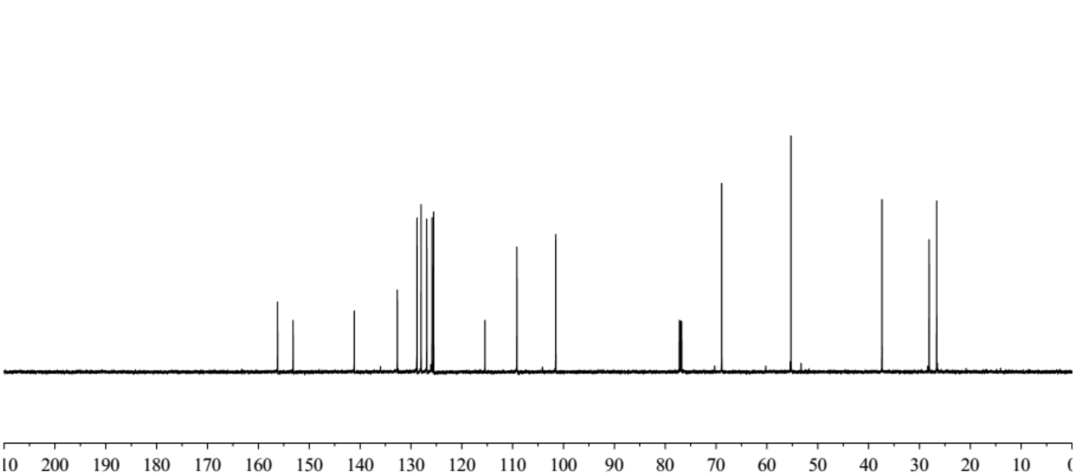
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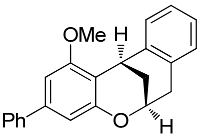

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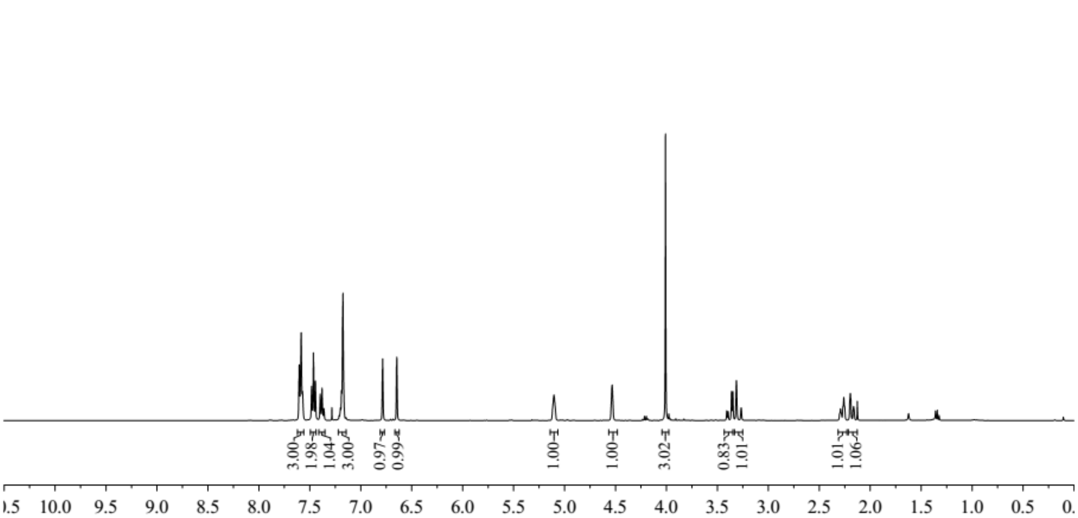
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1.01
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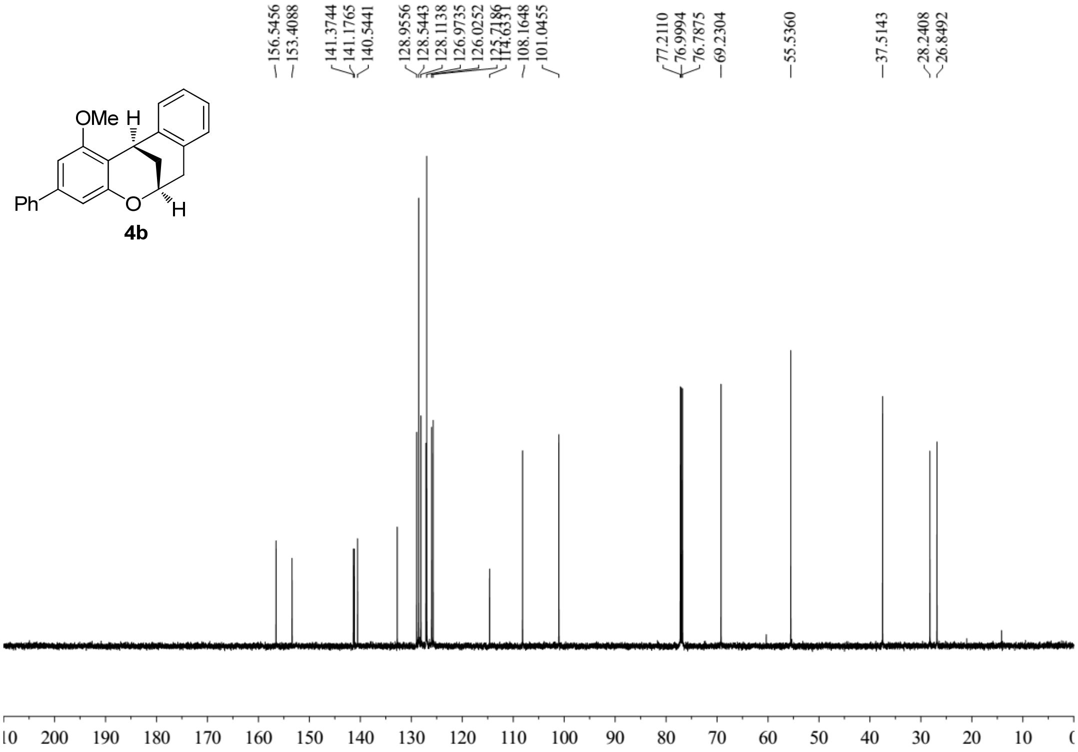
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