Electronic Supplementary Material (ESI) for RSC Advances.

Highly diastereo-/enantioselective Cu-catalyzed propargylic alkylations of propargyl acetates with cyclic enamines

Cheng Zhang, Yun-Ze Hui, De-Yang Zhang and Xiang-Ping Hu*

Department of Drug Discovery and Biomedical Sciences, South Carolina College of Pharmacy, Medical University of South Carolina, 280 Calhoun Street MSC140 QF307, Charleston, South Carolina 29425, USA, and Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 116023, China, and Faculty of Engineering and Built Environment, University of Newcastle, Callaghan, NSW 2308, Australia

xiangping@dicp.ac.cn; xiangping1974@163.com

Supporting Information

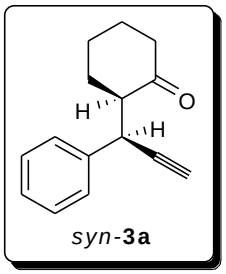
General Information

All reactions were carried out under a nitrogen atmosphere. Solvents were purified by standard procedure before use. Commercial reagents were used without further purification. Flash chromatography was performed on silica gel 60 (40-63μm, 60Å). Thin layer chromatography (TLC) was performed on glass plates coated with silica gel 60 with F254 indicator. Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded on a Bruker 400 MHz spectrometer. Chemical shifts for protons are reported in parts per million downfield from tetramethylsilane and are referenced to residual protium in the NMR solvent ($CHCl_3$ = δ 7.28). Carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded on a Bruker 100 MHz spectrometer. Chemical shifts for carbon are reported in parts per million downfield from tetramethylsilane and are referenced to the carbon resonances of the solvent ($CDCl_3$ = δ 77.07). Data are represented as follows: chemical shift, multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants in Hertz (Hz), integration. Enantiomeric ratios were determined by chiral HPLC with hexane and 2-PrOH as eluents. Optical rotations were recorded on a JASCO P-1020 polarimeter. Ligands (*S*)-**L$_1$**,[1] (R_c,S_p)-**L$_2$**[2] and (*R*)- or (*S*)-**L$_3$**[2] were prepared according to literatures. Propargylic esters[3] and cyclic enamines[4] were synthesized according to reported procedures. Racemic products were prepared from propargylic acetates with enamines according to the general procedure by the catalysis of a combination of $Cu(OAc)_2{\cdot}H_2O$ and racemic (±)-**L$_3$**.

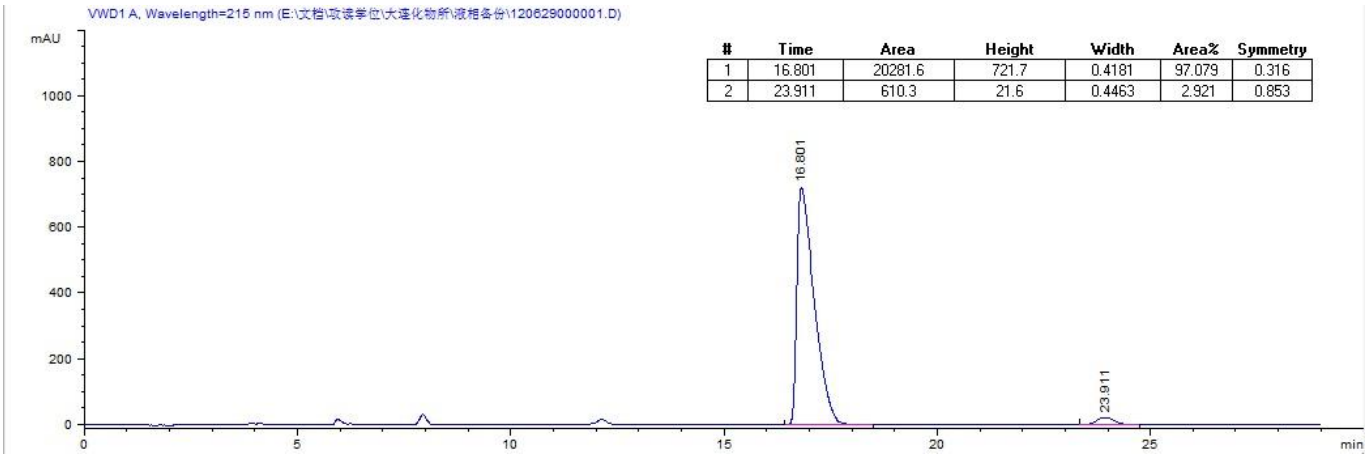
General procedure for copper-catalyzed asymmetric propargylic alkylation of propargylic acetates with cyclic enamines.

$Cu(OAc)_2{\cdot}H_2O$ (0.015 mmol) and (*R*)-**L$_3$** (0.0165 mmol) were stirred at room temperature in 1 mL of anhydrous methanol under nitrogen atmosphere for 1 h. After being cooled to 0 ^{o}C, a solution of propargylic acetate **1** (0.3 mmol), cyclic enamine **2** (0.36 mmol) and ^{i}Pr$_2$NEt (0.36 mmol) in 1 mL of anhydrous methanol was added. The mixture was stirred at room temperature for 10 h. The reaction was quenched by 1 mL of a buffer of NaOAc/AcOH, and extracted with EtOAc (5 mL x 2). The combined extracts were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under vaccum. The residue was then purified by silica gel chromatography (hexanes/AcOEt, 40/1) to afford the alkylation product **3**.

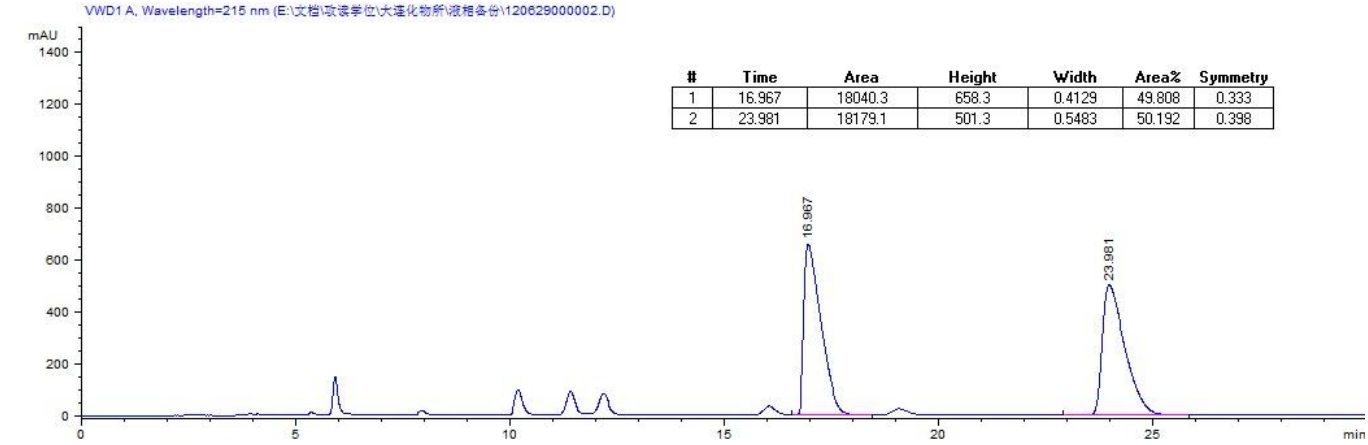
(*R*)-2-[(*S*)-1-phenylprop-2-ynyl]cyclohexanone (*syn*-3a):[2] colorless oil, 82% yield, 94% ee. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 16.8 min; minor enantiomer: t_2 = 23.9 min. $[\alpha]_D^{20}$ = 42 (*c* 0.8, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35-7.40 (m, 2H), 7.28-7.34 (m, 2H), 7.20-7.25 (m, 1H), 4.47 (s, 1H), 2.45-3.55 (m, 2H), 2.22-2.28 (m, 2H), 1.97-2.11 (m, 2H), 1.52-1.90 (m, 4H).



syn-**3a**

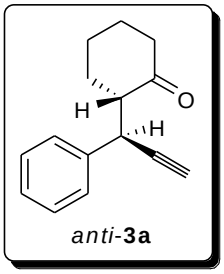


#	Time	Area	Height	Width	Area%	Symmetry
1	16.801	20281.6	721.7	0.4181	97.079	0.316
2	23.911	610.3	21.6	0.4463	2.921	0.853



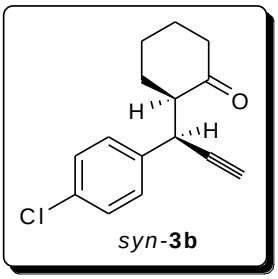
#	Time	Area	Height	Width	Area%	Symmetry
1	16.967	18040.3	658.3	0.4129	49.808	0.333
2	23.981	18179.1	501.3	0.5483	50.192	0.398

(*S*)-2-[(*S*)-1-phenylprop-2-ynyl]cyclohexanone (*anti*-3a): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35-7.38 (m, 2H), 7.29-7.32 (m, 2H), 7.24-7.26 (m, 1H), 4.11 (dd, *J* = 7.2, 2.4 Hz, 1H), 2.77-2.84 (m, 1H), 2.43-2.48 (m, 1H), 2.31-2.39 (m, 1H), 2.21 (d, *J* = 2.4 Hz, 1H), 1.98-2.04 (m, 1H), 1.78-1.83 (m, 2H), 1.56-1.65 (m, 2H), 1.21-1.28 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.2, 138.5, 128.7, 128.3, 127.1, 85.7, 70.4, 57.0, 42.2, 36.4, 31.2, 27.9, 24.7. HRMS calc. for $C_{15}H_{16}O$ $[M]^+$: 212.1201, found: 212.1198.

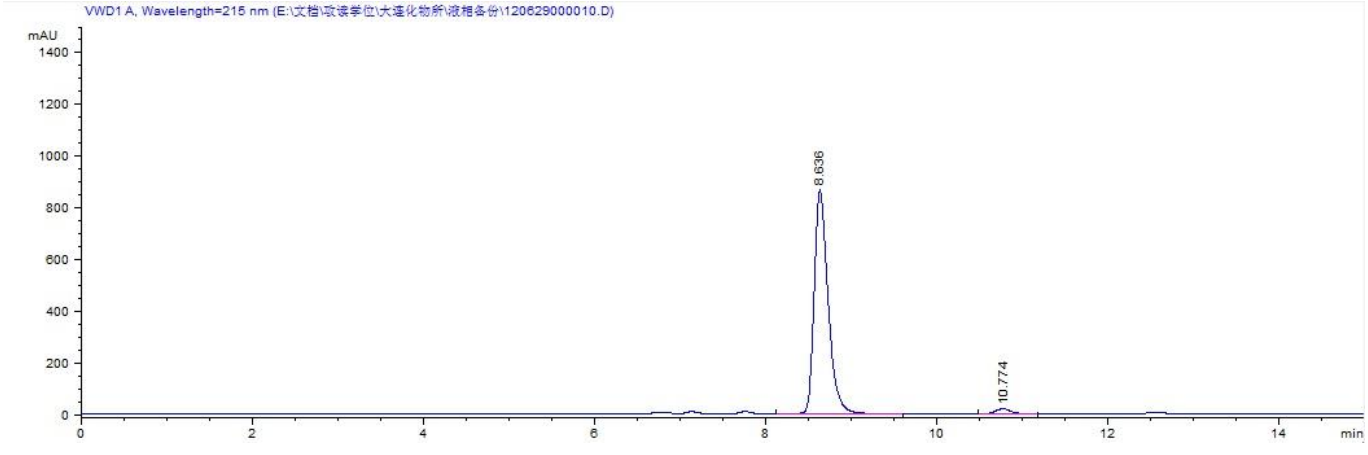


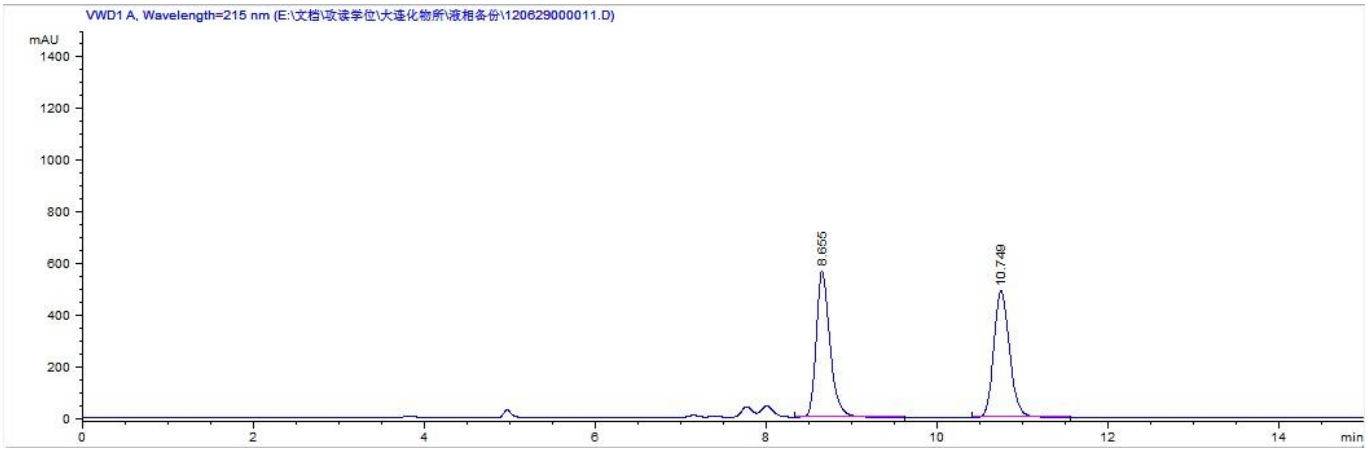
anti-**3a**

(*R*)-2-[(*S*)-1-(4-chlorophenyl)prop-2-ynyl]cyclohexanone (*syn*-3b): colorless oil, 80% yield, 95% ee. HPLC conditions: chiralcel OJ-H, 40 °C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 8.6 min; minor enantiomer: t_2 = 10.8 min. $[\alpha]_D^{20}$ = 35 (*c* 0.7, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25-7.31 (m, 4H), 4.38-4.40 (m, 1H), 2.43-2.51 (m, 2H), 2.22-2.28 (m, 2H), 2.04-2.06 (m, 2H), 1.87-1.91 (m, 1H), 1.53-1.77 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.5, 138.4, 132.7, 129.4, 128.5, 82.8, 72.9, 56.3, 42.0, 35.8, 29.0, 27.2, 24.8. HRMS calc. for $C_{15}H_{15}OCl$ $[M]^+$: 246.0811, found: 246.0816.

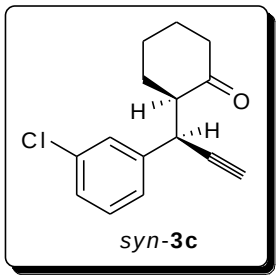


syn-**3b**

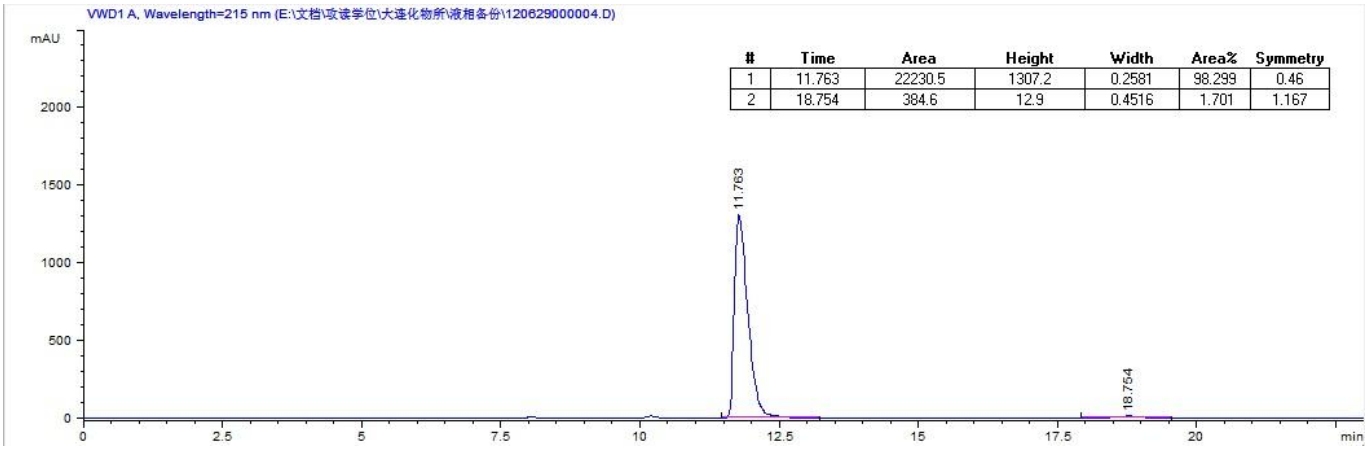




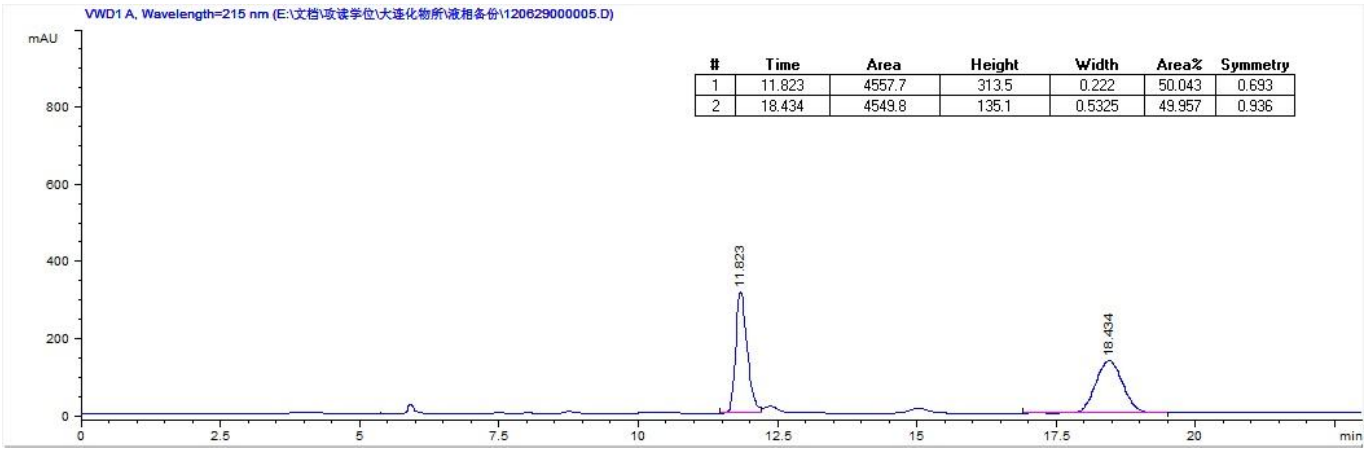
(*R*)-2-[(*S*)-1-(3-chlorophenyl)prop-2-ynyl]cyclohexanone (*syn*-3c): colorless oil, 85% yield, 97% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 11.8 min; minor enantiomer: t_2 = 18.8 min. $[\alpha]_D^{20}$ = 36 (*c* 0.5, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37 (s, 1H), 7.20-7.25 (m, 3H), 4.41-4.43 (m, 1H), 2.44-2.53 (m, 2H), 2.23-2.30 (m, 2H), 2.03-2.06 (m, 2H), 1.88-1.91 (m, 1H), 1.54-1.82 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.3, 142.0, 134.2, 129.6, 128.1, 127.1, 126.2, 82.5, 73.2, 56.2, 42.0, 36.0, 28.9, 27.2, 24.7. HRMS calc. for $C_{15}H_{15}OCl$ $[M]^+$: 246.0811, found: 246.0812.

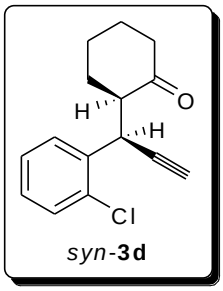


#	Time	Area	Height	Width	Area%	Symmetry
1	11.763	22230.5	1307.2	0.2581	98.299	0.46
2	18.754	384.6	12.9	0.4516	1.701	1.167

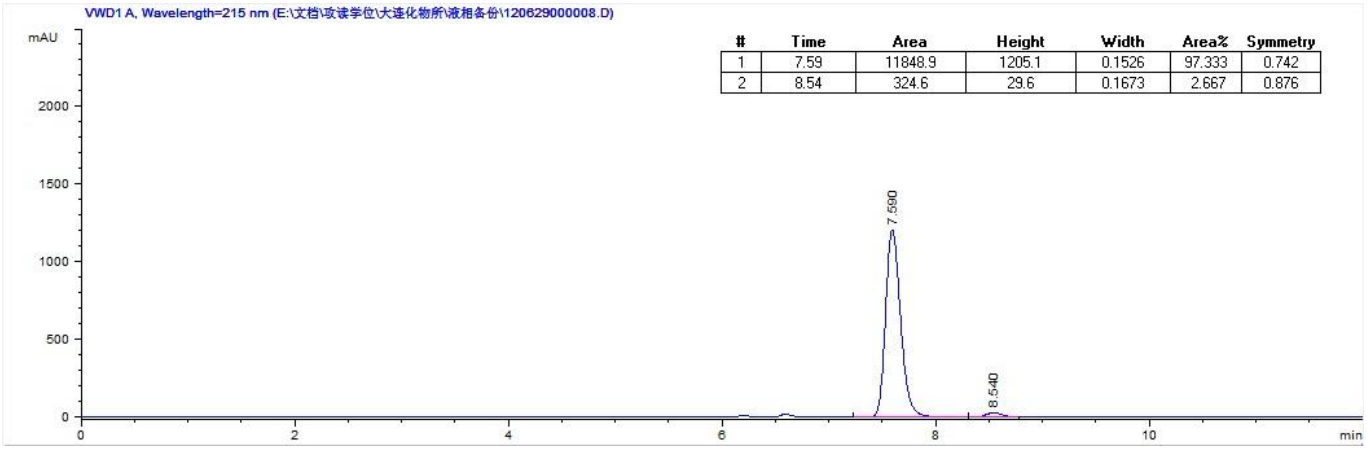


#	Time	Area	Height	Width	Area%	Symmetry
1	11.823	4557.7	313.5	0.222	50.043	0.693
2	18.434	4549.8	135.1	0.5325	49.957	0.936

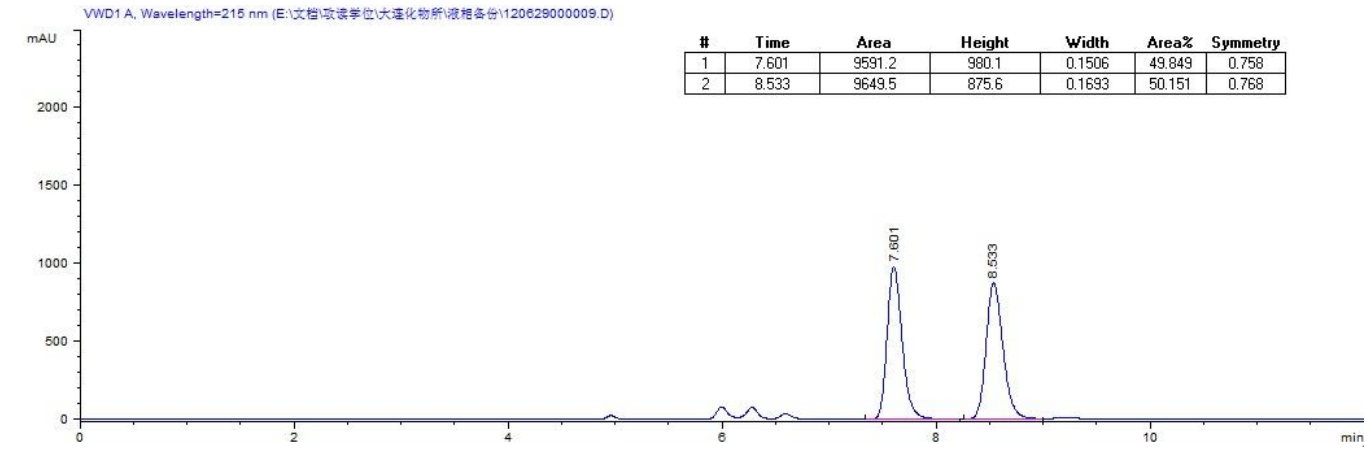
(*R*)-2-[(*S*)-1-(2-chlorophenyl)prop-2-ynyl]cyclohexanone (*syn*-3d): colorless oil, 88% yield, 95% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 7.6 min; minor enantiomer: t_2 = 8.5 min. $[\alpha]_D^{20}$ = 36 (*c* 0.4, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63 (d, *J* = 7.6 Hz, 1H), 7.33 (d, *J* = 8.0 Hz, 1H), 7.24-7.27 (m, 1H), 7.17-7.21 (m, 1H), 4.94-4.95 (m, 1H), 2.59-2.63 (m, 1H), 2.48-2.51 (m, 1H), 2.33-2.27 (m, 2H), 2.03-2.05 (m, 1H), 1.87-1.89 (m, 3H), 1.63-1.71 (m, 1H), 1.51-1.55 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.0, 136.9, 132.6, 130.4, 129.6, 128.3, 126.7, 82.5, 72.8, 52.9, 41.8, 33.6, 27.7, 26.8, 24.6. HRMS calc. for $C_{15}H_{15}OCl$ $[M]^+$: 246.0811, found: 246.0813.

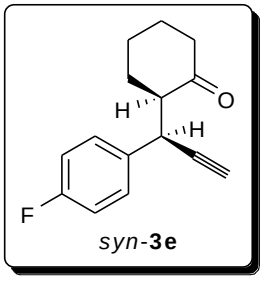


#	Time	Area	Height	Width	Area%	Symmetry
1	7.59	11848.9	1205.1	0.1526	97.333	0.742
2	8.54	324.6	29.6	0.1673	2.667	0.876

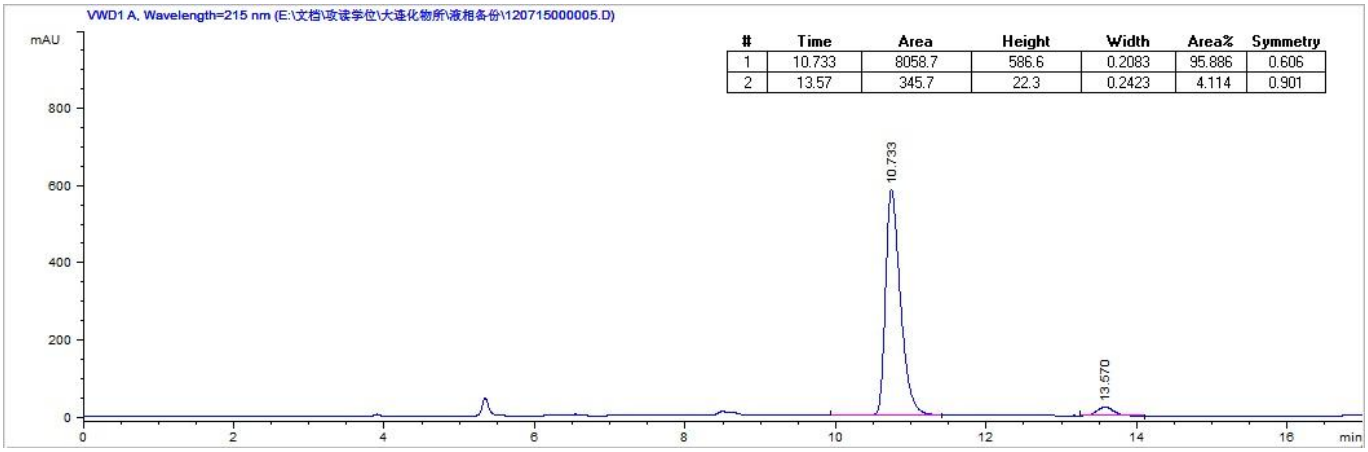


#	Time	Area	Height	Width	Area%	Symmetry
1	7.601	9591.2	980.1	0.1506	49.849	0.758
2	8.533	9649.5	875.6	0.1693	50.151	0.768

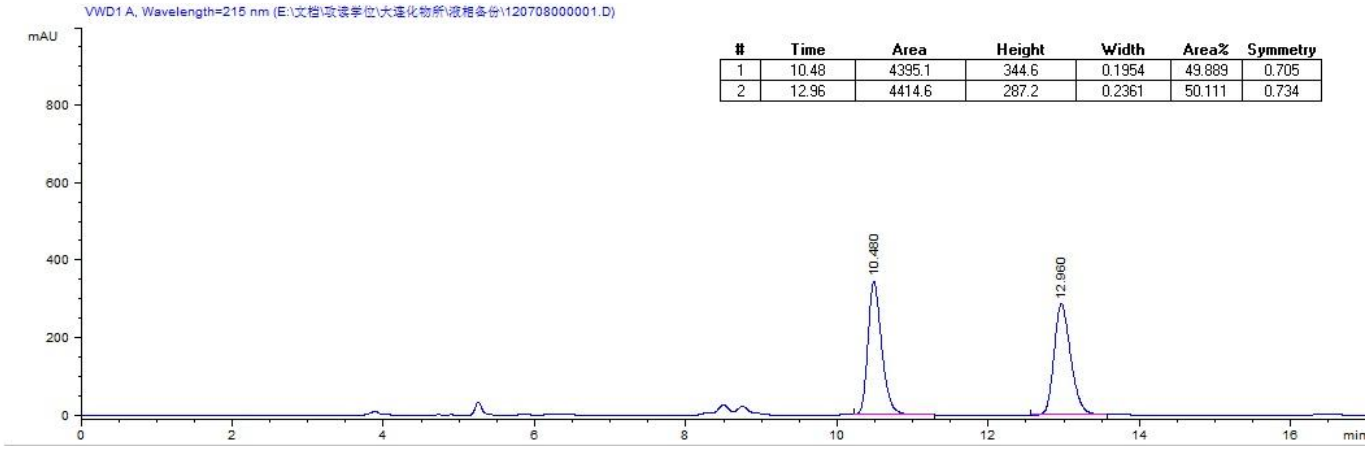
(*R*)-2-[(*S*)-1-(4-fluorophenyl)prop-2-ynyl]cyclohexanone (*syn*-3e): colorless oil, 88% yield, 92% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 10.7 min; minor enantiomer: t_2 = 13.6 min. $[\alpha]_D^{20}$ = 37 (*c* 0.5, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32-7.34 (m, 2H), 6.97-7.01 (m, 2H), 4.41-4.42 (m, 1H), 2.44-2.52 (m, 2H), 2.22-2.28 (m, 2H), 2.06-2.08 (m, 2H), 2.89-2.92 (m, 1H), 1.54-1.82 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.7, 161.7 (d, *J* = 243 Hz), 135.5 (d, *J* = 3 Hz), 129.4 (d, *J* = 8 Hz), 115.2 (d, *J* = 21 Hz), 83.1, 72.8, 56.5, 42.0, 35.6, 29.0, 27.3, 24.8; HRMS calc. for $C_{15}H_{15}OF$ $[M]^+$: 230.1107, found: 230.1114.

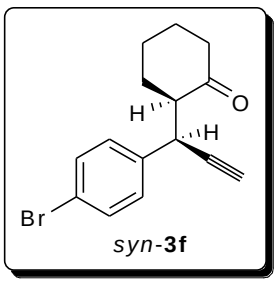


#	Time	Area	Height	Width	Area%	Symmetry
1	10.733	8058.7	586.6	0.2083	95.886	0.606
2	13.57	345.7	22.3	0.2423	4.114	0.901

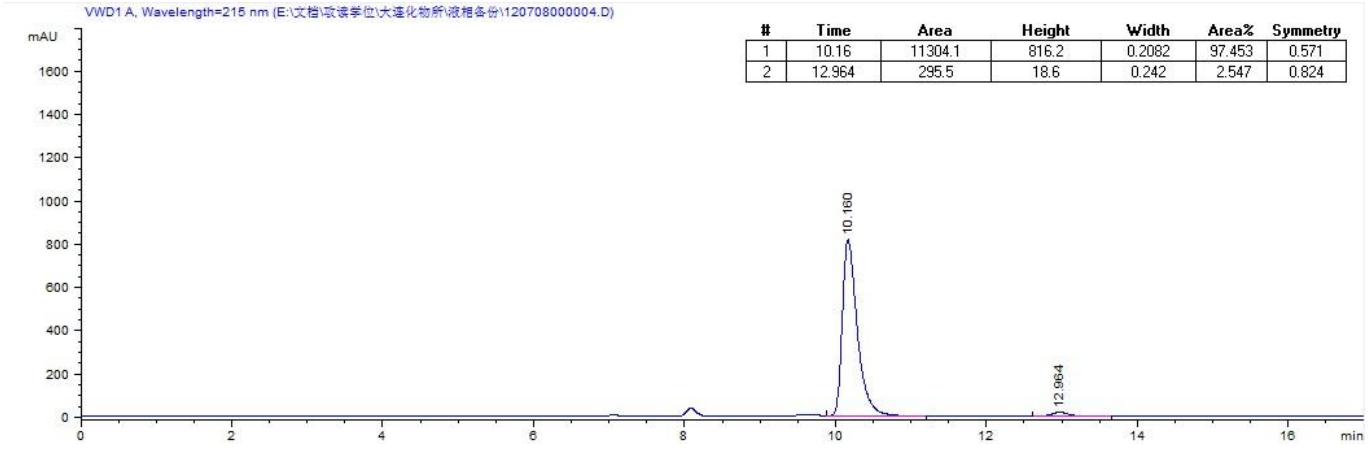


#	Time	Area	Height	Width	Area%	Symmetry
1	10.48	4395.1	344.6	0.1954	49.889	0.705
2	12.96	4414.6	287.2	0.2361	50.111	0.734

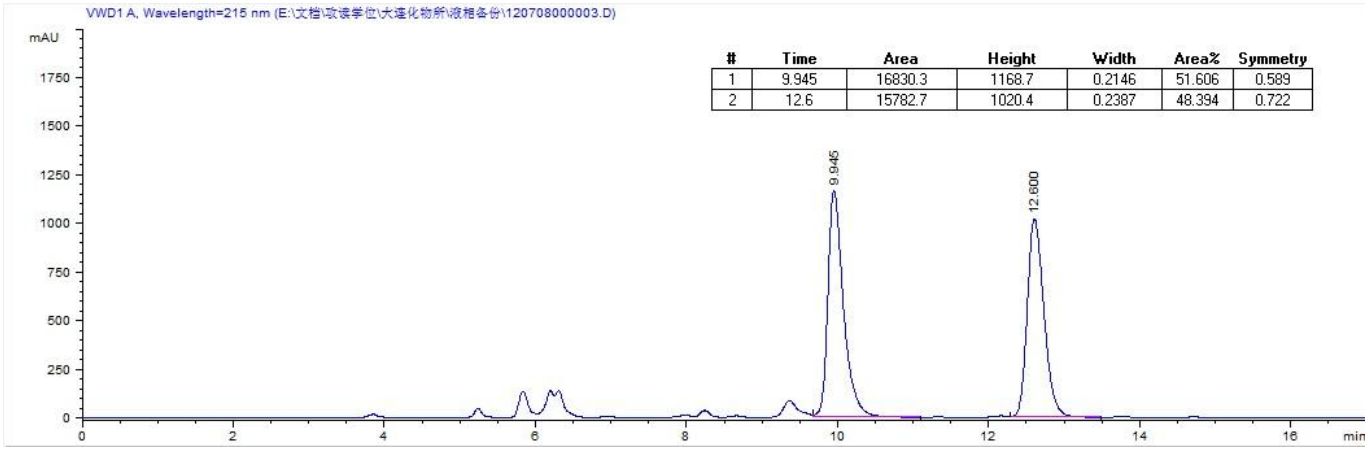
(*R*)-2-[(*S*)-1-(4-bromophenyl)prop-2-ynyl]cyclohexanone (*syn*-3f): colorless oil, 90% yield, 95% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 10.2 min; minor enantiomer: t_2 = 13.0 min. $[\alpha]_D^{20}$ = 32 (*c* 0.9, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8 Hz, 2H), 7.25 (d, *J* = 8 Hz, 2H), 4.39-4.40 (m, 1H), 2.44-2.51 (m, 2H), 2.22-2.29 (m, 2H), 2.06-2.08 (m, 2H), 1.89-1.92 (m, 1H), 1.51-1.81 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.5, 139.0, 131.4, 129.7, 120.8, 82.7, 73.0, 56.3, 42.0, 35.8, 29.0, 27.2, 24.8. HRMS calc. for $C_{15}H_{15}OBr[M]^+$: 292.0306, found: 292.0304.

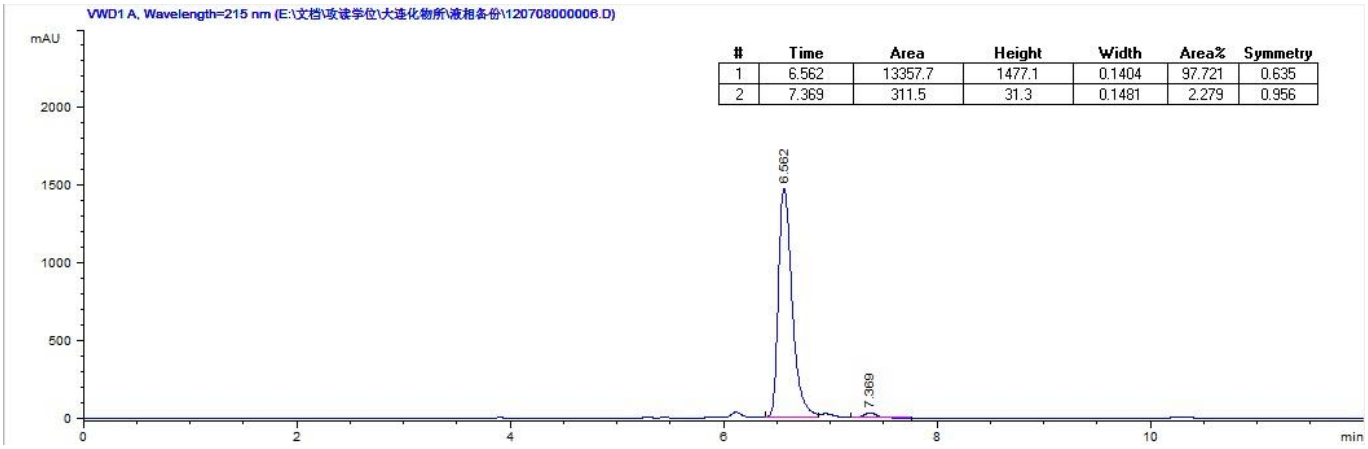


#	Time	Area	Height	Width	Area%	Symmetry
1	10.16	11304.1	816.2	0.2082	97.453	0.571
2	12.964	295.5	18.6	0.242	2.547	0.824

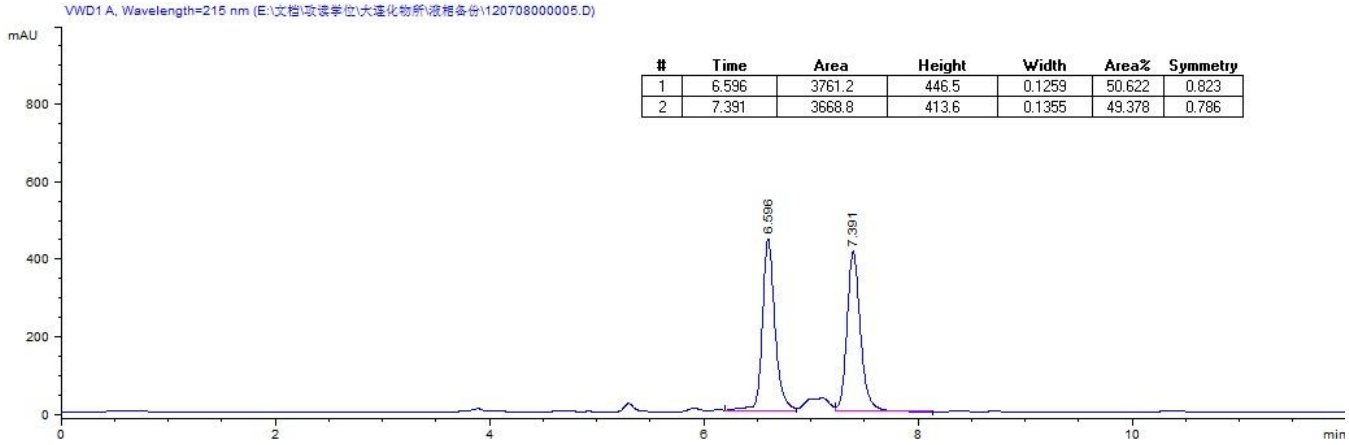


#	Time	Area	Height	Width	Area%	Symmetry
1	9.945	16830.3	1168.7	0.2146	51.606	0.589
2	12.6	15782.7	1020.4	0.2387	48.394	0.722

(*R*)-2-[(*S*)-1-(4-trifluoromethylphenyl)prop-2-ynyl]cyclohexanone (*syn*-3g): colorless oil, 84% yield, 95% ee. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 6.6 min; minor enantiomer: t_2 = 7.4 min. $[\alpha]_D^{20}$ = 55 (*c* 0.1, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 7.6 Hz, 2H), 4.48-4.49 (m, 1H), 2.53-2.57 (m, 1H), 2.45-2.49 (m, 1H), 2.23-2.31 (m, 2H), 2.07-2.09 (m, 2H), 1.90-1.93 (m, 1H), 1.55-1.83 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.2, 144.1, 129.2 (q, *J* = 32 Hz), 128.4, 125.3 (q, *J* = 4 Hz), 124.1 (q, *J* = 270 Hz), 82.4, 73.2, 56.2, 42.0, 36.3, 29.2, 27.2, 24.8. HRMS calc. for $C_{16}H_{15}OF_3$ $[M]^+$: 280.1075, found: 280.1073.

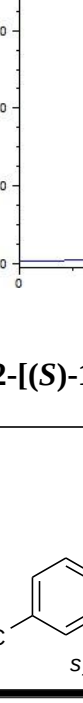


#	Time	Area	Height	Width	Area%	Symmetry
1	6.562	13357.7	1477.1	0.1404	97.721	0.635
2	7.369	311.5	31.3	0.1481	2.279	0.956

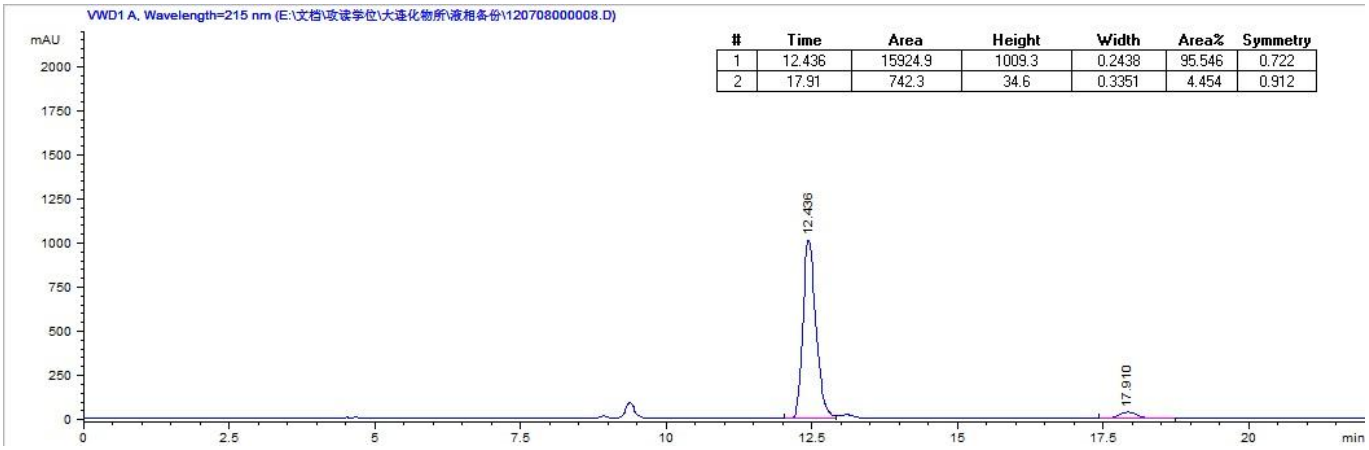


#	Time	Area	Height	Width	Area%	Symmetry
1	6.596	3761.2	446.5	0.1259	50.622	0.823
2	7.391	3668.8	413.6	0.1355	49.378	0.786

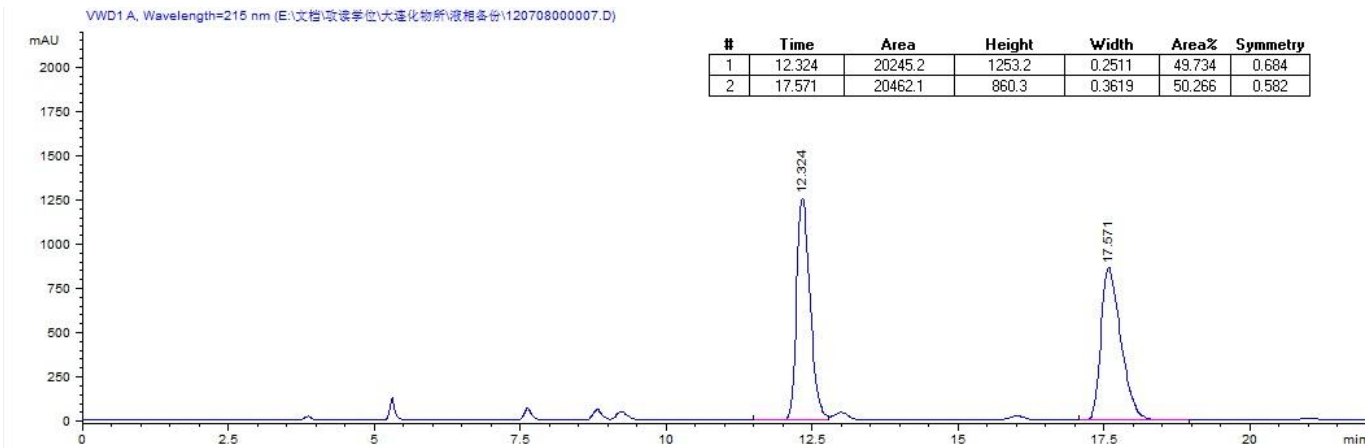
(*R*)-2-[(*S*)-1-(4-methylphenyl)prop-2-ynyl]cyclohexanone (*syn*-3h): colorless oil, 92% yield, 91% ee. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 12.4 min; minor enantiomer: t_2 = 17.9 min. $[\alpha]_D^{20}$ = 42 (*c* 0.7, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25 (d, *J* = 6.8 Hz, 2H), 7.12 (d, *J* = 6.8 Hz, 2H), 4.42-4.43 (m, 1H), 2.45-2.54 (m, 2H), 2.33 (s, 3H), 2.22-2.29 (m, 2H), 2.03-2.10 (m, 2H), 1.49-1.91 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.9, 136.8, 136.4, 129.1, 127.8, 83.5, 72.4, 56.5, 42.0, 35.8, 28.8, 27.2, 24.7, 21.0. HRMS calc. for $C_{16}H_{18}O$ $[M]^+$: 226.1358, found: 226.1365.



syn-**3h**

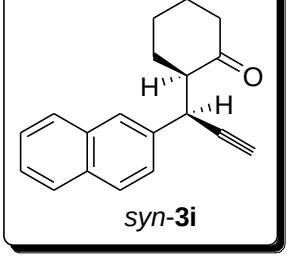


#	Time	Area	Height	Width	Area%	Symmetry
1	12.436	15924.9	1009.3	0.2438	95.546	0.722
2	17.91	742.3	34.6	0.3351	4.454	0.912

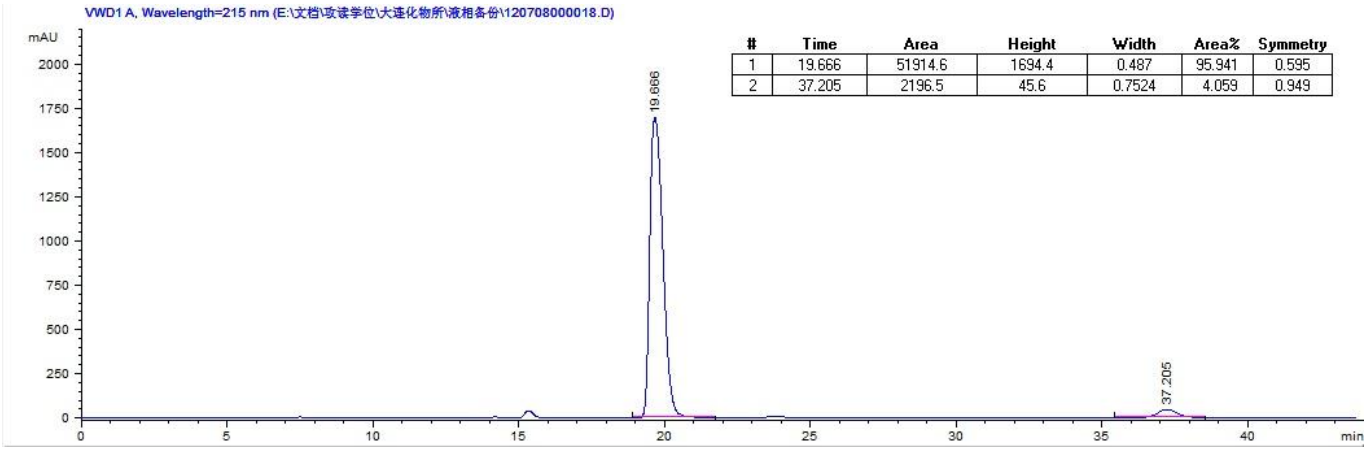


#	Time	Area	Height	Width	Area%	Symmetry
1	12.324	20245.2	1253.2	0.2511	49.734	0.684
2	17.571	20462.1	860.3	0.3619	50.266	0.582

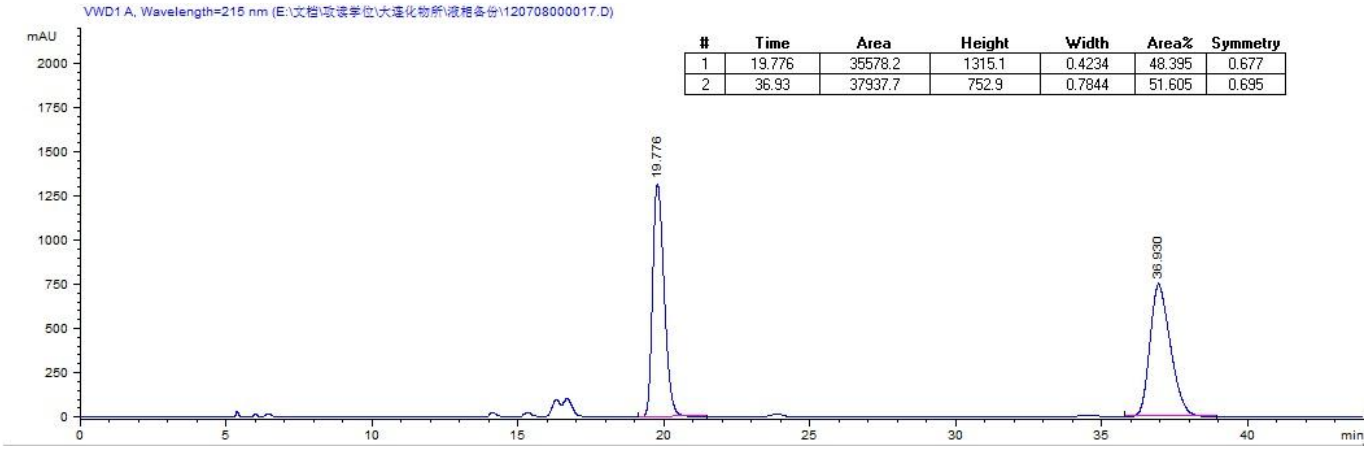
(*R*)-2-[(*S*)-1-naphthylprop-2-ynyl]cyclohexanone (*syn*-3i): colorless oil, 88% yield, 92% ee. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 19.7 min; minor enantiomer: t_2 = 37.2 min. $[\alpha]_D^{20}$ = 36 (*c* 0.6, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (s, 1H), 7.80-7.84 (m, 3H), 7.44-7.46 (m, 3H), 4.66 (s, 1H), 2.64-2.67 (m, 1H), 2.48-2.52 (m, 1H), 2.38 (s, 1H), 2.24-2.32 (m, 1H), 2.03-2.11 (m, 2H), 1.82-1.91 (m, 2H), 1.66-1.76 (m, 1H), 1.51-1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.7, 137.2, 133.3, 132.4, 128.1, 127.8, 127.6, 126.8, 126.2, 126.0, 125.8, 83.2, 73.0, 56.3, 42.0, 36.4, 28.8, 27.2, 24.8. HRMS calc. for $C_{19}H_{18}O$ $[M]^+$: 262.1358, found: 262.1368.



syn-**3i**

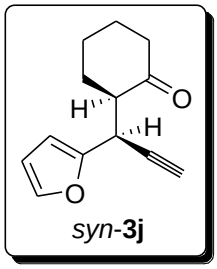


#	Time	Area	Height	Width	Area%	Symmetry
1	19.666	51914.6	1694.4	0.487	95.941	0.595
2	37.205	2196.5	45.6	0.7524	4.059	0.949

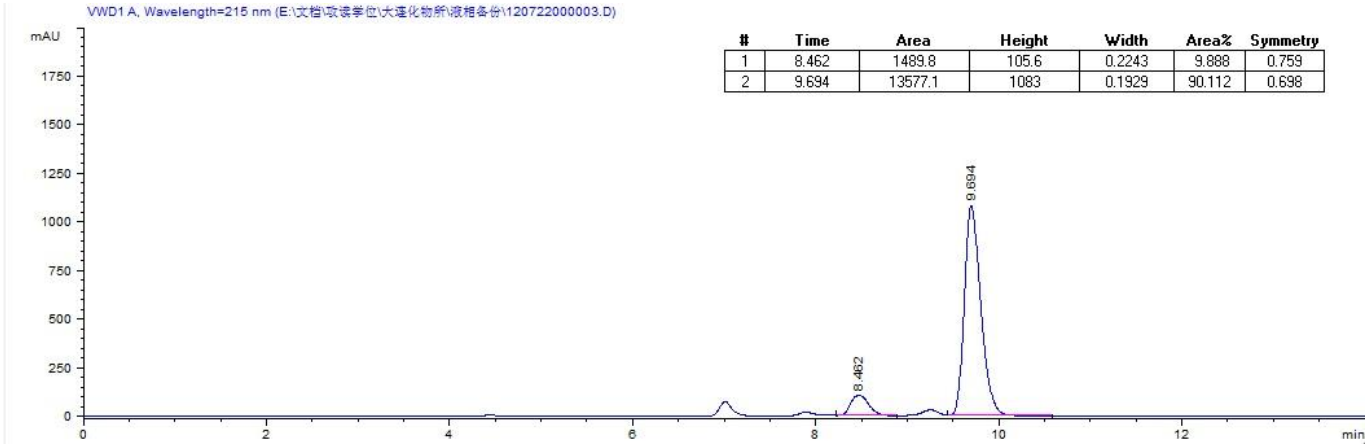


#	Time	Area	Height	Width	Area%	Symmetry
1	19.776	35578.2	1315.1	0.4234	48.395	0.677
2	36.93	37937.7	752.9	0.7844	51.605	0.695

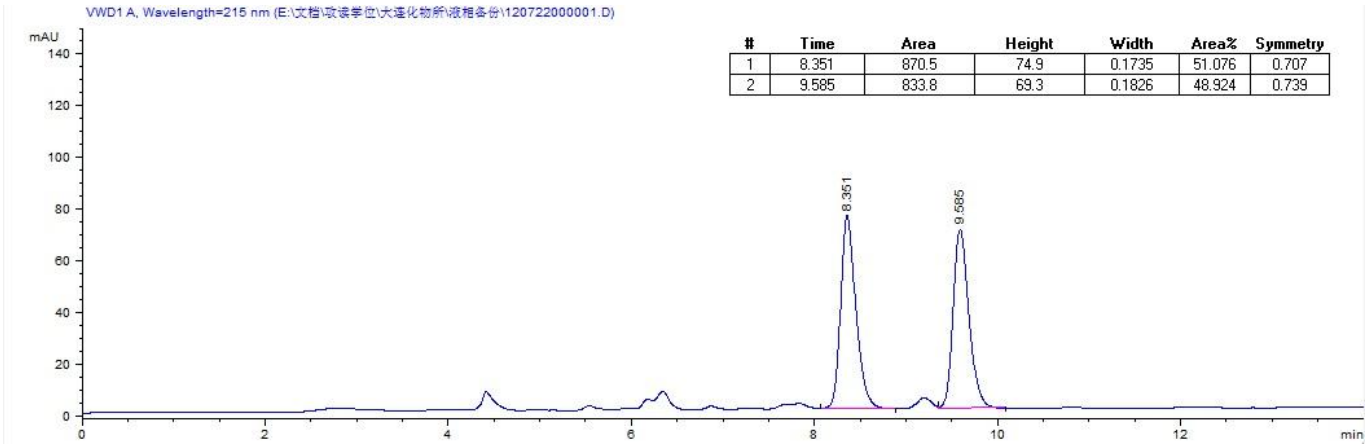
(*R*)-2-[(*S*)-1-furylprop-2-ynyl]cyclohexanone (*syn*-3j): colorless oil, 90% yield, 80% ee. HPLC conditions: chiralpak OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 9.7 min; minor enantiomer: t_2 = 8.5 min. $[\alpha]_D^{20}$ = 15 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 (s, 1H), 6.28-6.30 (m, 2H), 4.50-4.51 (m, 1H), 2.77-2.80 (m, 1H), 2.47-2.50 (m, 1H), 2.26-2.33 (m, 1H), 2.22 (s, 1H), 2.05-2.06 (m, 2H), 1.90-1.93 (m, 1H), 1.61-1.84 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.2, 152.4, 141.7, 110.3, 107.2, 80.8, 71.8, 52.7, 41.9, 30.6, 29.0, 27.1, 24.7. HRMS calc. for $C_{13}H_{14}O_2$ $[M]^+$: 202.0994, found: 202.0998.



syn-**3j**

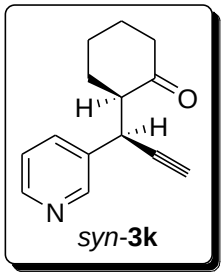


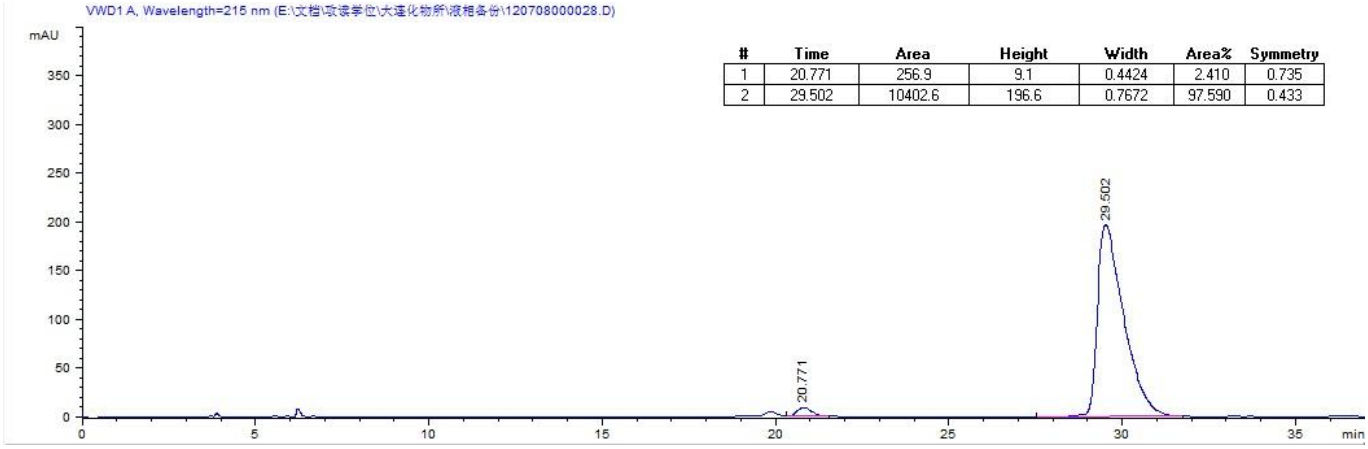
#	Time	Area	Height	Width	Area%	Symmetry
1	8.462	1489.8	105.6	0.2243	9.888	0.759
2	9.694	13577.1	1083	0.1929	90.112	0.698



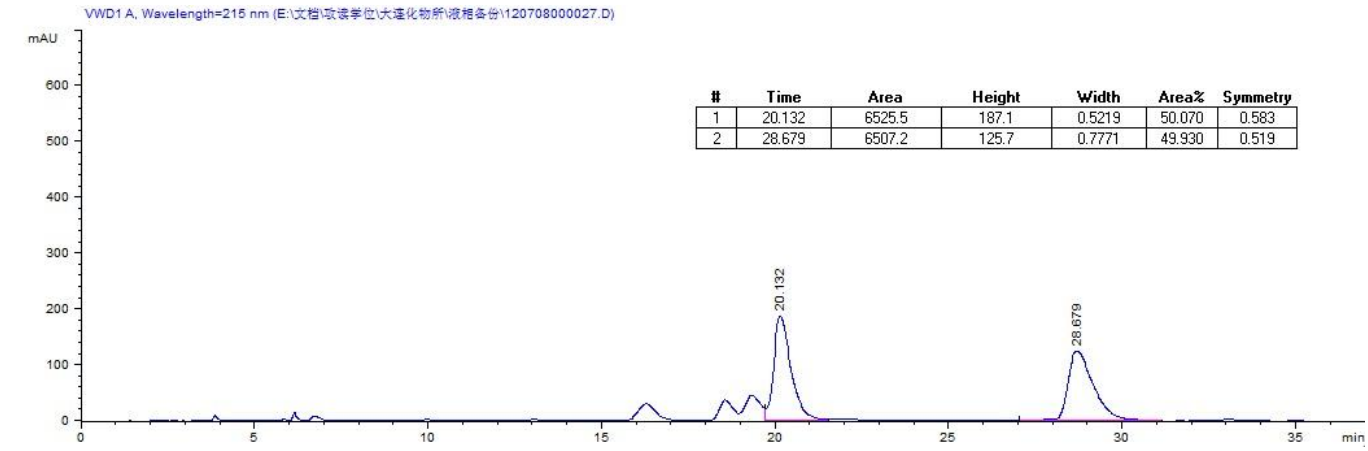
#	Time	Area	Height	Width	Area%	Symmetry
1	8.351	870.5	74.9	0.1735	51.076	0.707
2	9.585	833.8	69.3	0.1826	48.924	0.739

(*R*)-2-[(*S*)-1-(3-pyridinyl)prop-2-ynyl]cyclohexanone (*syn*-3k): colorless oil, 86% yield, 95% ee. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 29.5 min; minor enantiomer: t_2 = 20.8 min. $[\alpha]_D^{20}$ = 35 (*c* 0.2, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.61 (s, 1H), 8.48 (s, 1H), 7.74-7.76 (m, 1H), 7.26 (s, 1H), 4.40-4.41 (m, 1H), 2.54-2.56 (m, 1H), 2.43-2.47 (m, 1H), 2.22-2.30 (m, 2H), 2.05-2.15 (m, 2H), 1.90-1.93 (m, 1H), 1.52-1.80 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.2, 149.1, 147.8, 136.1, 135.9, 123.3, 82.0, 73.3, 56.1, 42.0, 34.2, 29.4, 27.3, 24.8. HRMS calc. for $C_{14}H_{15}NO$ $[M]^+$: 213.1154, found: 213.1158.



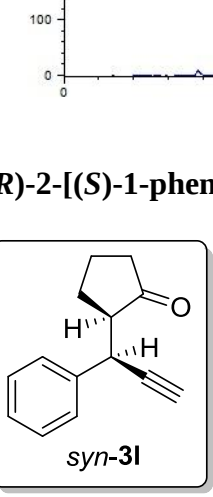


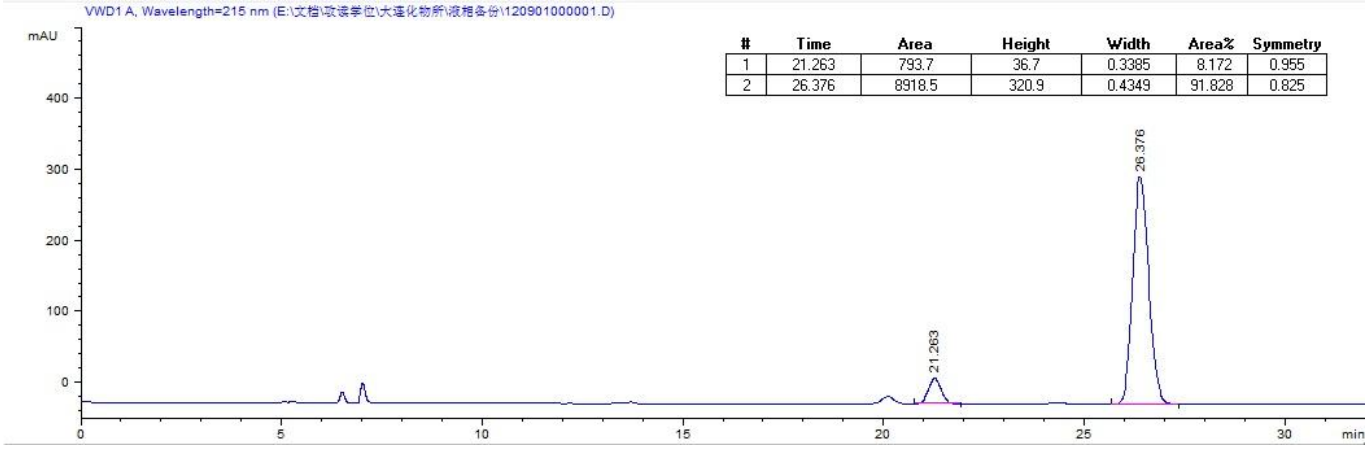
#	Time	Area	Height	Width	Area%	Symmetry
1	20.771	256.9	9.1	0.4424	2.410	0.735
2	29.502	10402.6	196.6	0.7672	97.590	0.433



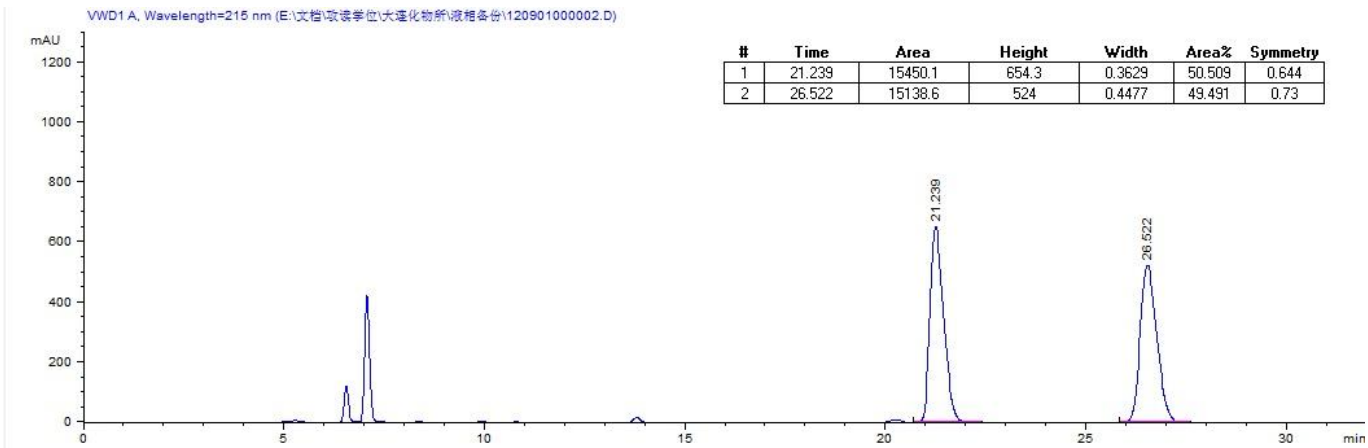
#	Time	Area	Height	Width	Area%	Symmetry
1	20.132	6525.5	187.1	0.5219	50.070	0.583
2	28.679	6507.2	125.7	0.7771	49.930	0.519

(*R*)-2-[(*S*)-1-phenylprop-2-ynyl]cyclopentanone (*syn*-3l): colorless oil, 84% yield, -84% ee [(*S*)-**L$_3$** was used as the ligand]. HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 26.4 min; minor enantiomer: t_2 = 21.3 min. $[\alpha]_D^{20}$ = 180 (*c* 1.2, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37-7.39 (m, 2H), 7.31-7.34 (m, 2H), 7.23-7.26 (m, 1H), 4.41 (s, 1H), 2.34-2.43 (m, 2H), 2.27 (s, 1H), 2.03-2.22 (m, 3H), 1.86-1.91 (m, 1H), 1.61-1.74 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 217.8, 139.3, 128.6, 127.4, 127.0, 82.2, 72.9, 55.4, 38.6, 36.9, 24.8, 20.3. HRMS calc. for $C_{14}H_{14}O$ $[M]^+$: 198.1045, found: 198.1045.



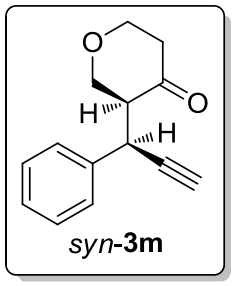


#	Time	Area	Height	Width	Area%	Symmetry
1	21.263	793.7	36.7	0.3385	8.172	0.955
2	26.376	8918.5	320.9	0.4349	91.828	0.825

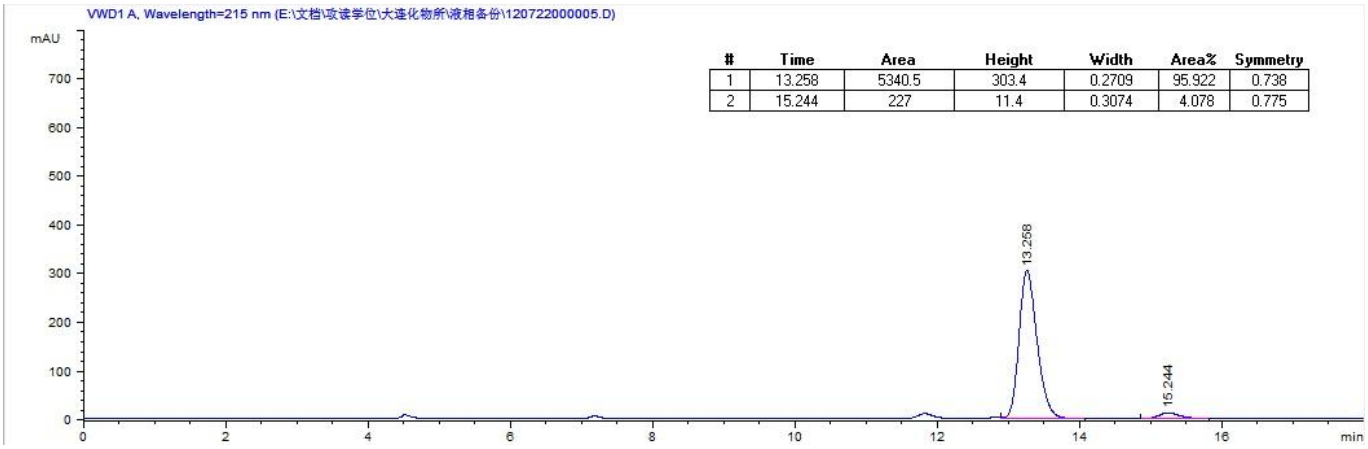


#	Time	Area	Height	Width	Area%	Symmetry
1	21.239	15450.1	654.3	0.3629	50.509	0.644
2	26.522	15138.6	524	0.4477	49.491	0.73

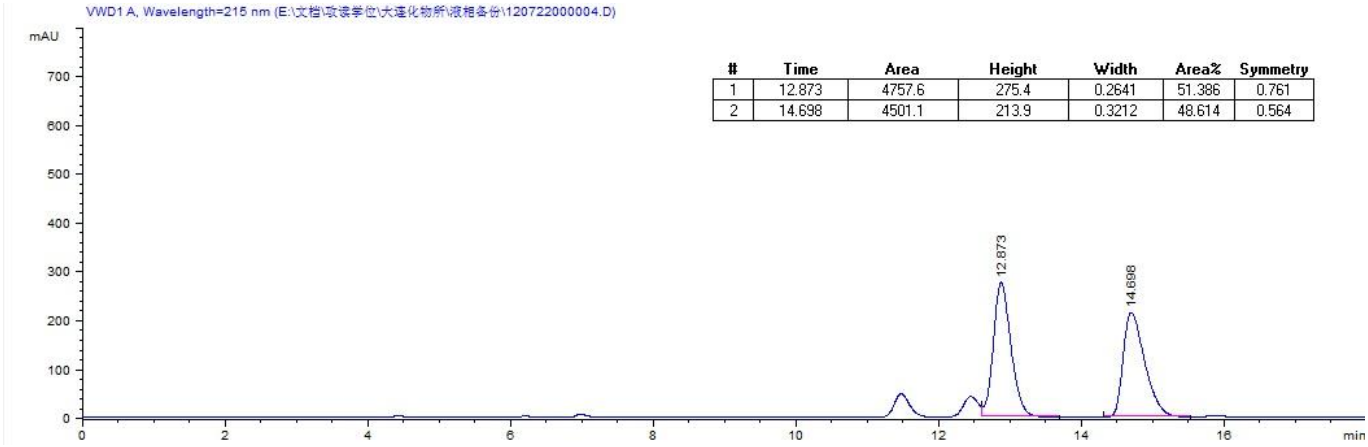
(*R*)-2-[(*S*)-1-phenylprop-2-ynyl]-4-oxacyclohexanone (*syn*-3m): colorless oil, 80% yield, 92% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 13.3 min; minor enantiomer: t_2 = 15.2 min. $[\alpha]_D^{20}$ = 30 (*c* 0.9, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32-7.37 (m, 4H), 7.24-7.26 (m, 1H), 4.48 (s, 1H), 4.14-4.19 (m, 2H), 3.86-3.91 (m, 1H), 3.73-3.79 (m, 1H), 2.81-2.84 (m, 1H), 2.53-2.61 (m, 1H), 2.44-2.48 (m, 1H), 2.33 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 205.2, 138.5, 128.6, 127.6, 127.3, 82.1, 73.3, 69.5, 68.1, 58.2, 42.4, 33.7. HRMS calc. for $C_{14}H_{14}O_2$ $[M]^+$: 214.0994, found: 214.1002.

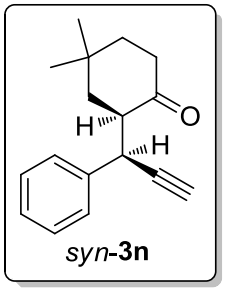


#	Time	Area	Height	Width	Area%	Symmetry
1	13.258	5340.5	303.4	0.2709	95.922	0.738
2	15.244	227	11.4	0.3074	4.078	0.775

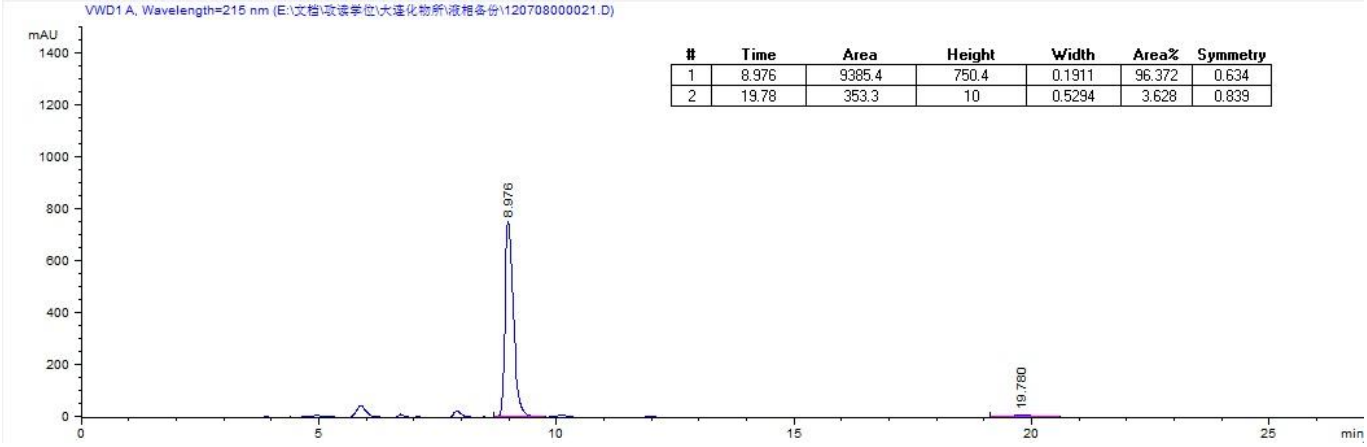


#	Time	Area	Height	Width	Area%	Symmetry
1	12.873	4757.6	275.4	0.2641	51.386	0.761
2	14.698	4501.1	213.9	0.3212	48.614	0.564

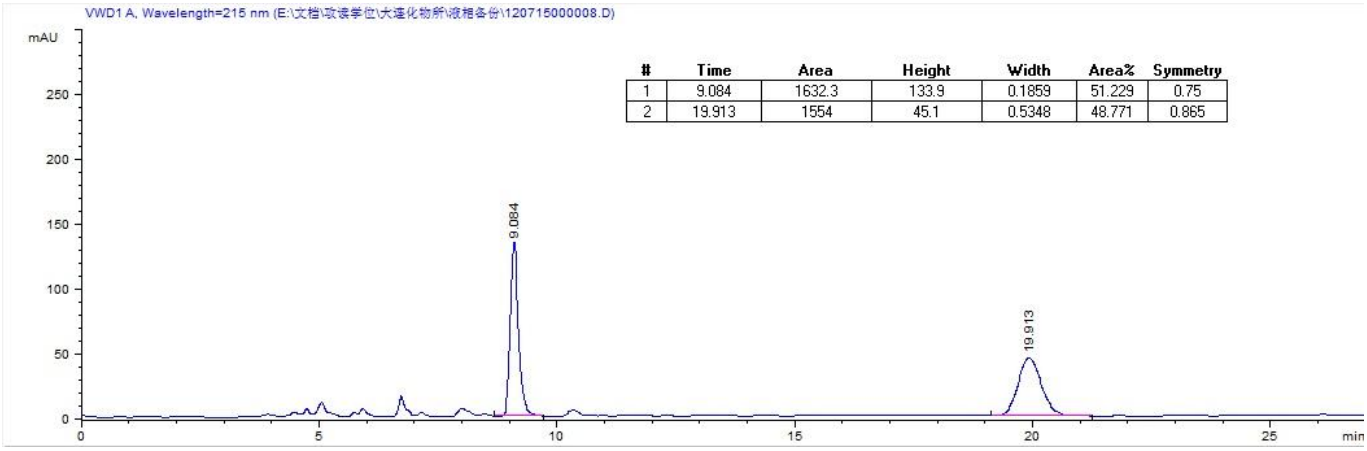
(*R*)-2-[(*S*)-1-phenylprop-2-ynyl]-4,4-dimethylcyclohexanone (*syn*-3n): colorless oil, 88% yield, 93% ee.



HPLC conditions: chiralcel OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 9.0 min; minor enantiomer: t_2 = 19.8 min. $[\alpha]_D^{20}$ = 53 (*c* 0.2, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30-7.38 (m, 4H), 7.24-7.26 (m, 1H), 4.50 (s, 1H), 2.65-2.68 (m, 1H), 2.33-2.46 (m, 2H), 2.28 (s, 1H), 1.60-1.81 (m, 4H), 1.05 (s, 3H), 1.01 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.2, 139.6, 128.4, 127.8, 126.8, 83.1, 72.7, 52.1, 40.7, 39.1, 38.0, 36.0, 31.5, 30.4, 24.3. HRMS calc. for $C_{17}H_{20}O$ $[M]^+$: 240.1514, found: 240.1507.

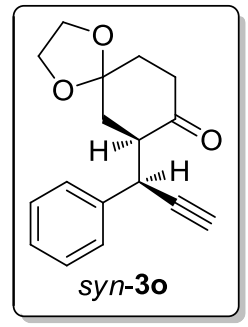


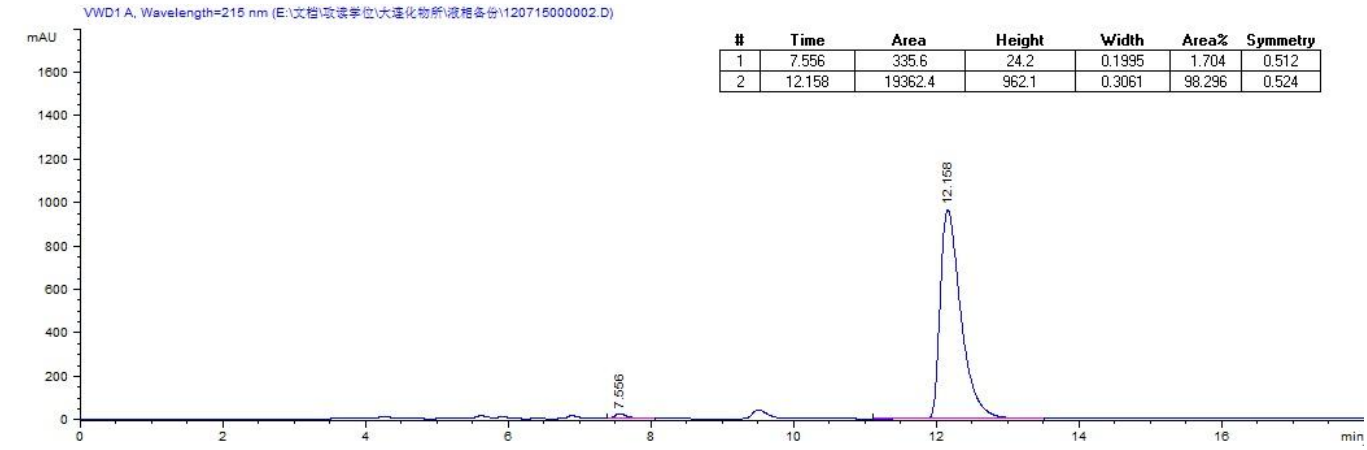
#	Time	Area	Height	Width	Area%	Symmetry
1	8.976	9385.4	750.4	0.1911	96.372	0.634
2	19.78	353.3	10	0.5294	3.628	0.839



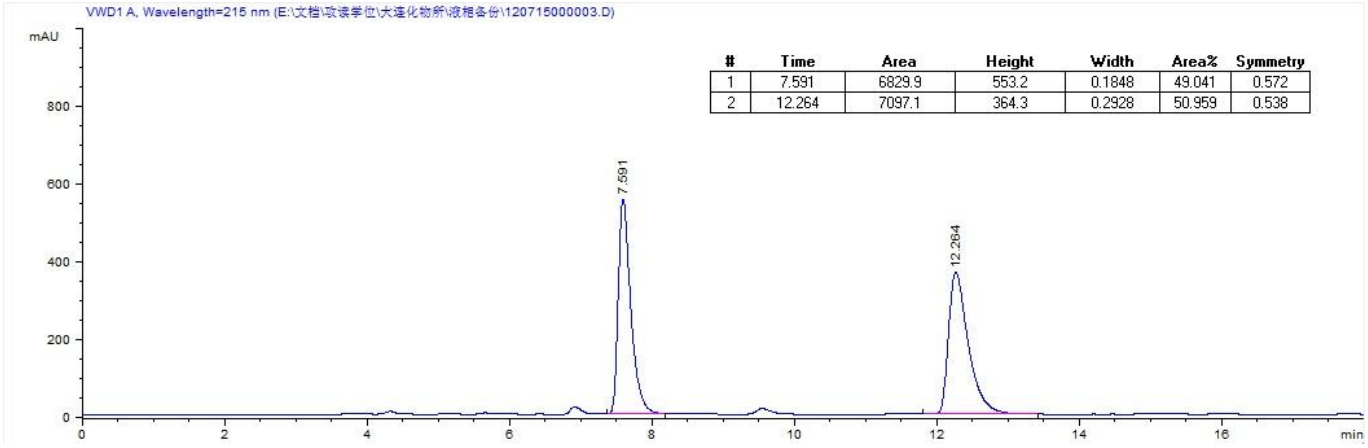
#	Time	Area	Height	Width	Area%	Symmetry
1	9.084	1632.3	133.9	0.1859	51.229	0.75
2	19.913	1554	45.1	0.5348	48.771	0.865

Spiro[(*R*)-2-[(*S*)-1-phenyl)prop-2-ynyl]cyclopentanone-4,2'-[1,3]-dioxolane] (*syn*-3o): White solid, 80% yield, 97% ee. HPLC conditions: chiralcel OJ-H, 40 °C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 12.2 min; minor enantiomer: t_2 = 7.6 min. $[\alpha]_D^{20}$ = 40 (*c* 0.2, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30-7.40 (m, 4H), 7.24-7.26 (m, 1H), 4.53 (s, 1H), 3.86-3.94 (m, 4H), 2.86-2.90 (m, 1H), 2.59-2.68 (m, 1H), 2.45-2.49 (m, 1H), 2.29 (s, 1H), 2.16-2.23 (m, 1H), 2.00-2.03 (m, 2H), 1.91-1.94 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 208.0, 139.0, 128.4, 127.8, 126.9, 107.5, 82.6, 73.0, 64.6, 64.4, 52.5, 38.0, 35.9, 35.4, 33.9. HRMS calc. for $C_{17}H_{18}O_3$ $[M]^+$: 270.1256, found: 270.1260.



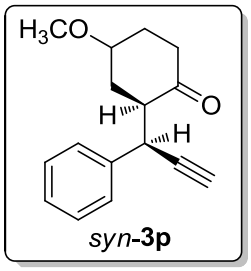


#	Time	Area	Height	Width	Area%	Symmetry
1	7.556	335.6	24.2	0.1995	1.704	0.512
2	12.158	19362.4	962.1	0.3061	98.296	0.524

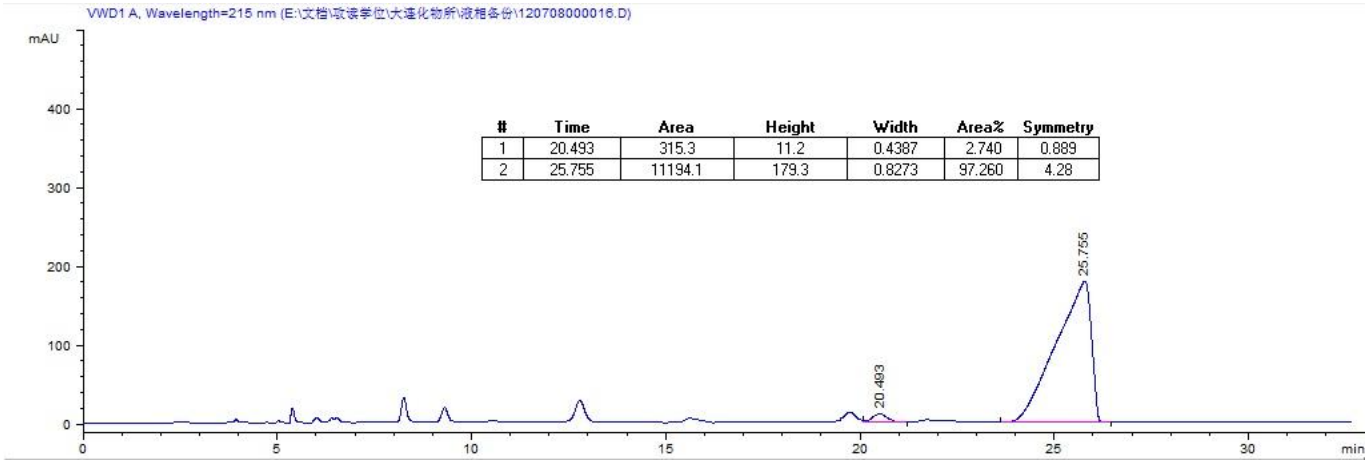


#	Time	Area	Height	Width	Area%	Symmetry
1	7.591	6829.9	553.2	0.1848	49.041	0.572
2	12.264	7097.1	364.3	0.2928	50.959	0.538

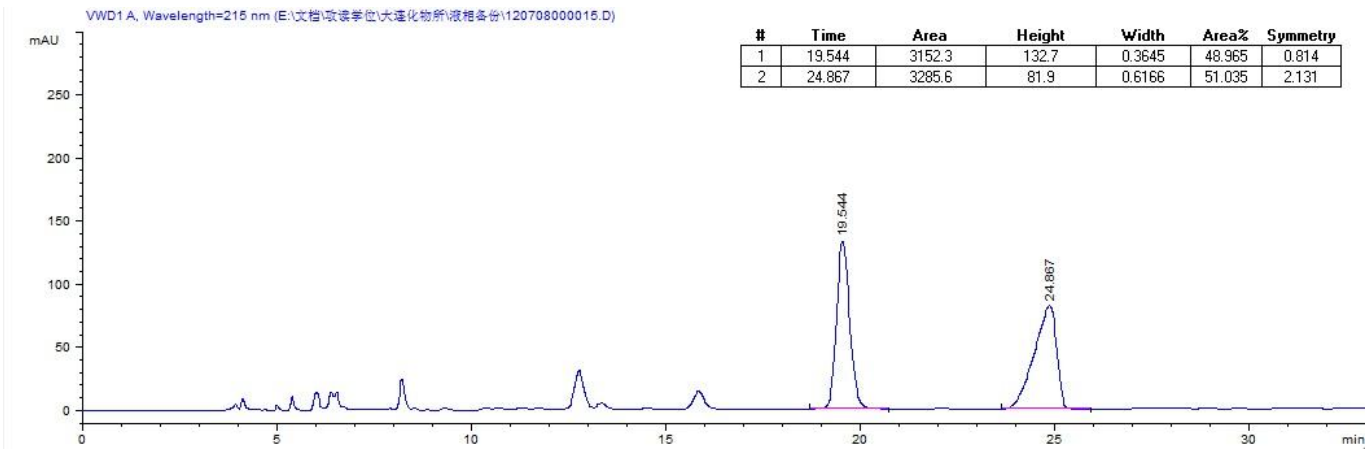
(*R*)-2-[(*S*)-1-phenylprop-2-ynyl]-4-methoxylcyclohexanone (*syn*-3p): colorless oil, 82% yield, 95% ee.



HPLC conditions: chiralpak OJ-H, 40 ^{o}C, 215 nm, *n*-hexane/2-propanol = 95/5, flow rate = 0.8 mL/min, major enantiomer: t_1 = 25.8 min; minor enantiomer: t_2 = 20.5 min. $[\alpha]_D^{20}$ = 49 (*c* 0.4, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36-7.38 (m, 2H), 7.30-7.33 (m, 2H), 7.22-7.25 (m, 1H), 4.52 (s, 1H), 3.65 (s, 1H), 3.20 (s, 3H), 2.89-2.93 (m, 1H), 2.58-2.65 (m, 1H), 2.21-2.33 (m, 4H), 1.71-1.93 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.4, 139.3, 128.4, 127.8, 126.9, 83.0, 73.4, 72.8, 55.7, 50.6, 36.5, 35.7, 31.3, 29.9. HRMS calc. for $C_{16}H_{18}O_2$ $[M]^+$: 242.1307, found: 242.1300.

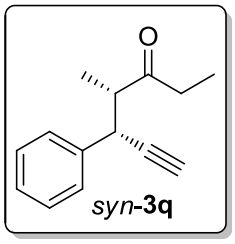


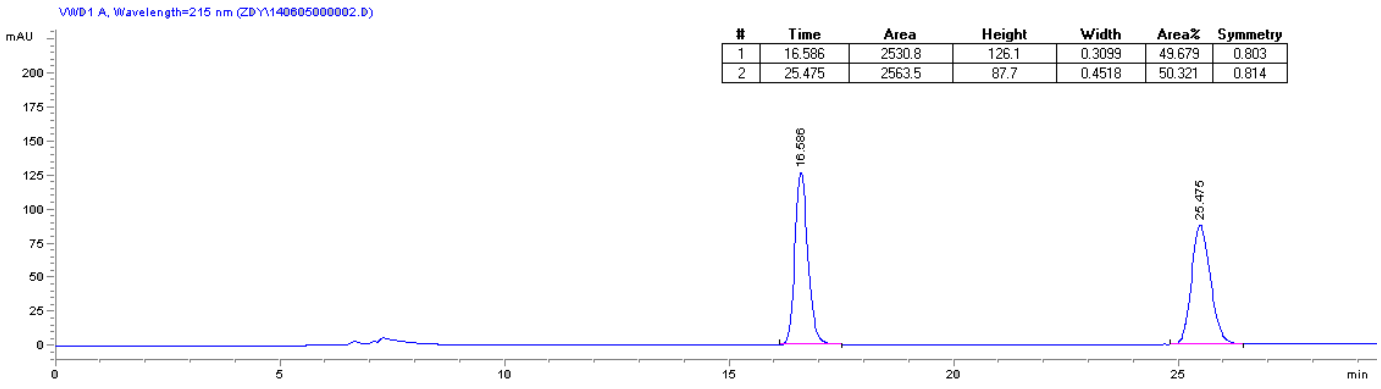
#	Time	Area	Height	Width	Area%	Symmetry
1	20.493	315.3	11.2	0.4387	2.740	0.889
2	25.755	11194.1	179.3	0.8273	97.260	4.28



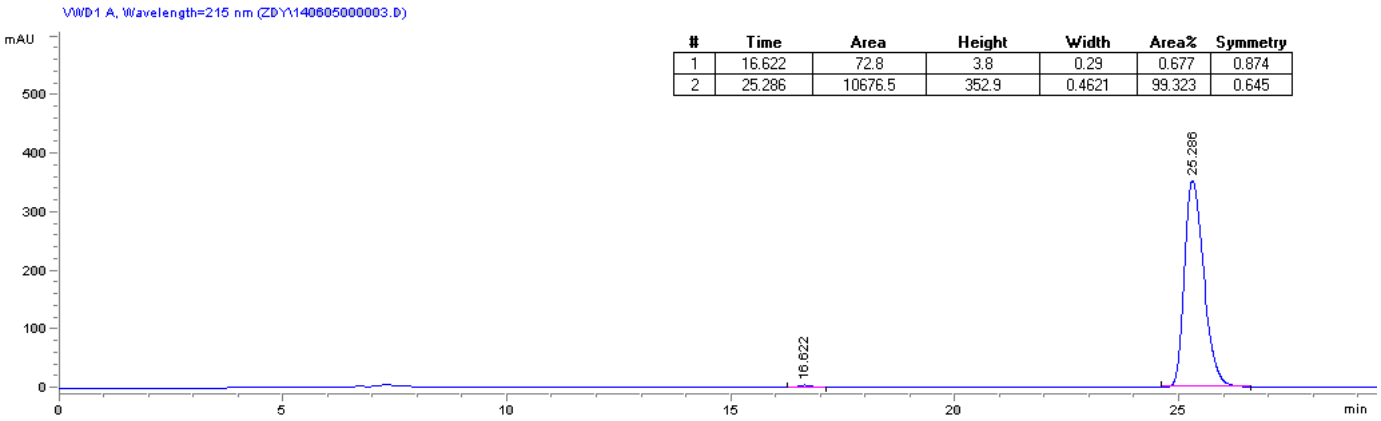
#	Time	Area	Height	Width	Area%	Symmetry
1	19.544	3152.3	132.7	0.3645	48.965	0.814
2	24.867	3285.6	81.9	0.6166	51.035	2.131

(2*S*,3*R*)-4-Methyl-5-phenylhept-6-yn-3-one (*syn*-3q). Obtained with (*S*)-**L**$_1$, 60% yield. Colorless oil was obtained after purification with column chromatography on silica gel (petroleum ether/Et_2O, 150:1 to 110:1). 99% ee was determined by chiral HPLC (Chiralcel OJ-H, *n*-hexane/*i*-PrOH = 98/2, 0.5 mL/min, 215 nm, 40 ^oC): t_R (minor) = 16.6 min, t_R (major) = 25.3 min. [ ]$_D^{28}$ = 94.2 (*c* 0.88, CH_2Cl_2). ^1H NMR (400 MHz, $CDCl_3$): δ 7.33–7.26 (m, 4H), 7.24–7.20 (m, 1H), 4.00 (dd, *J* = 8.4, 2.5 Hz, 1H), 2.90–2.83 (m, 1H), 2.40–2.32 (m, 1H), 2.30 (d, *J* = 2.5 Hz, 1H), 2.06–1.95 (m, 1H), 1.26 (d, *J* = 7.0 Hz, 3H), 0.85 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 212.9, 139.8, 128.7, 128.2, 127.4, 83.9, 72.7, 52.7, 40.5, 36.1, 14.9, 7.5. HRMS calc. for $C_{14}H_{16}O$ $[M+H]^+$: 201.1279, found: 201.1273.





#	Time	Area	Height	Width	Area%	Symmetry
1	16.586	2530.8	126.1	0.3099	49.679	0.803
2	25.475	2563.5	87.7	0.4518	50.321	0.814



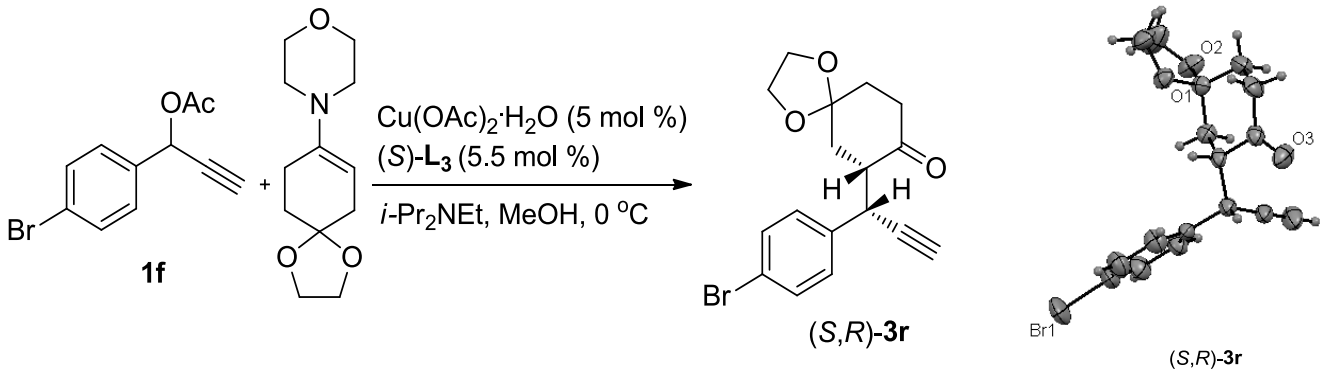
#	Time	Area	Height	Width	Area%	Symmetry
1	16.622	72.8	3.8	0.29	0.677	0.874
2	25.286	10676.5	352.9	0.4621	99.323	0.645

Reference

1. F.-L. Zhu, Y. Zou, D.-Y. Zhang, Y.-H. Wang, X.-H. Hu, S. Chen, J. Xu and X.-P. Hu, *Angew. Chem. Int. Ed.*, 2014, **53**, 1410.
2. C. Zhang, X.-H. Hu, Y.-H. Wang, Z. Zheng, J. Xu and X.-P. Hu, *J. Am. Chem. Soc.*, 2012, **134**, 9585.
3. a) R. J. Detz, M. M. E. Delville, H. Hiemstra and J. H. van Maarseveen, *Angew. Chem. Int. Ed.*, 2008, **47**, 3777; b) G. Hattori, H. Matsuzawa, Y. Miyake and Y. Nishibayashi, *Angew. Chem. Int. Ed.*, 2008, **47**, 3781.
4. a) S. Hünig, E. Lücke and W. Brenninger, *Org. Synth.*, **1961**, *41*, 65; b) G. L. May and J. T. Pinhey,

Aust. J. Chem., **1982**, *35*, 1859; c) T. Mikie, H. Asahara, K. Nagao, N. Ikuma, K. Kokubo and T. Oshima, *Org. Lett.*, **2011**, *13*, 4244; d) L. Anzalone and J. A. Hirsch, *J. Org. Chem.*, **1985**, *50*, 2607; e) S. Kaiser, S. P. Smidt and A. Pfaltz, *Angew. Chem. Int. Ed.*, **2006**, *45*, 5194; f) J.-J. Chanot and C. Plessis, US 2012165557, **2012**; g) E. J. Hicken, K. W. Hunt, M. E. Rodriguez, T. P. Tang and S. Michael, WO 2013148851, **2013**.

Single crystal of (*S*,*R*)-3r

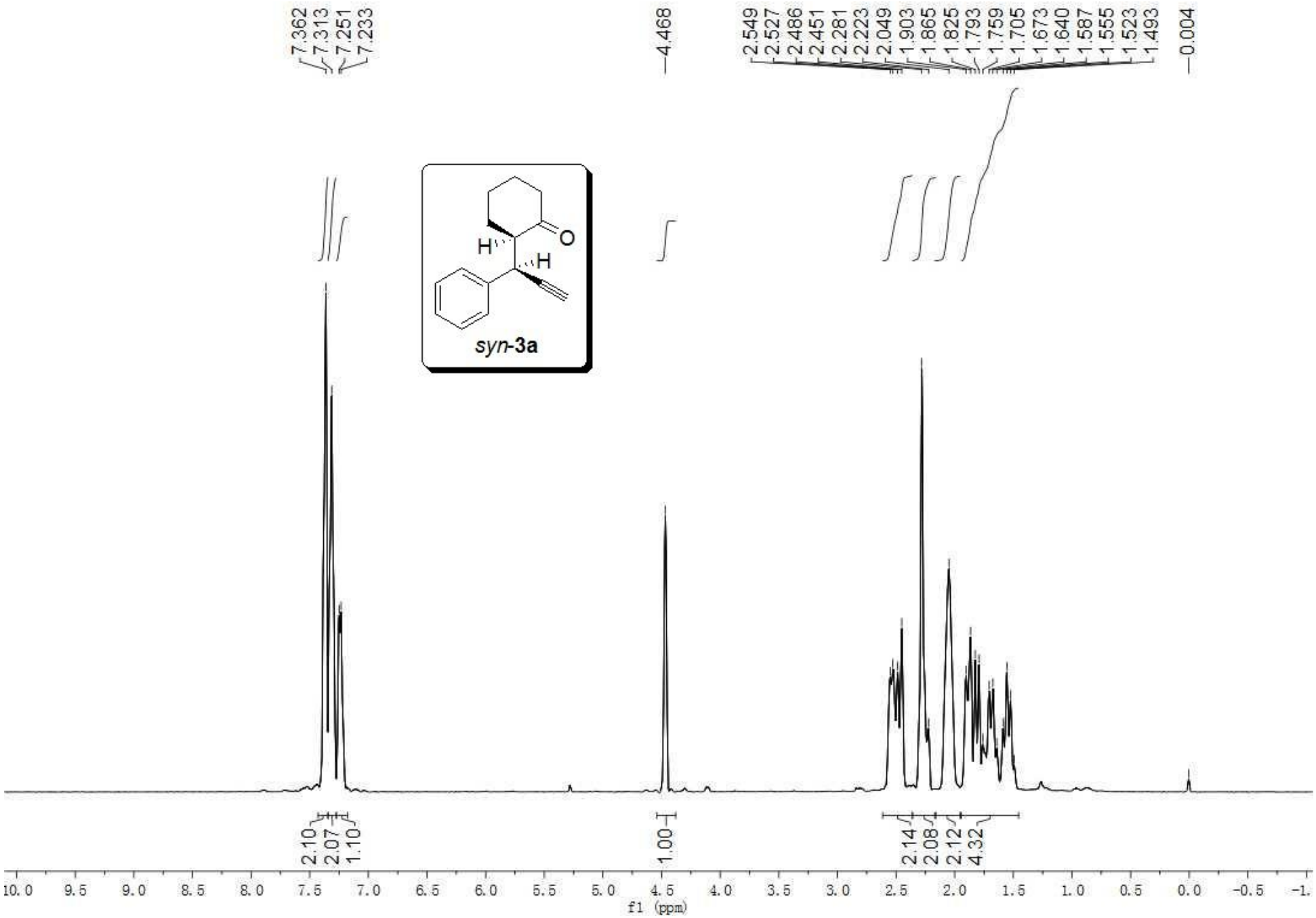


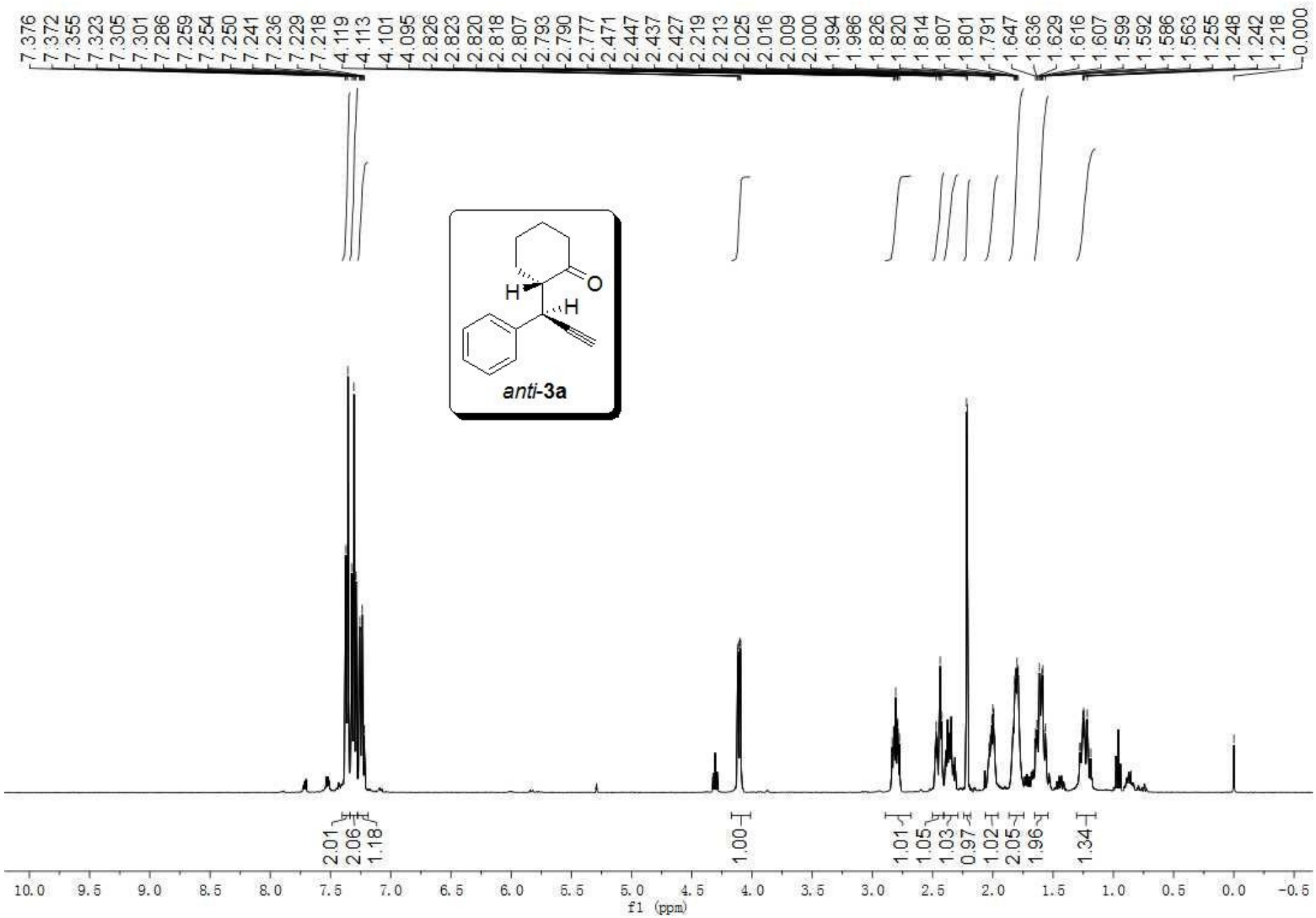
Procedures of preparation of (*S*,*R*)-**3r** are the same as other asymmetric substitution reactions except with (*S*)-$\mathbf{L_3}$ instead of (*R*)-$\mathbf{L_3}$. Single crystal of (*S*,*R*)-**3r** are grew in Methanol by slow evaporating of the solvent. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.43 (d, 2H), 7.23 (d, 2H), 4.45 (m, 1H), 3.92-3.94 (m, 4H), 2.82-2.84 (m, 1H), 2.57-2.63 (m, 1H), 2.43-2.47 (m, 1H), 2.30 (s, 1H), 2.12-2.18 (m, 1H), 1.96-2.03 (m, 2H), 1.86-1.89 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 207.9, 138.1, 131.5, 129.6, 120.9, 107.4, 82.0, 73.5, 64.7, 64.5, 52.4, 38.0, 35.5, 35.5, 33.9.

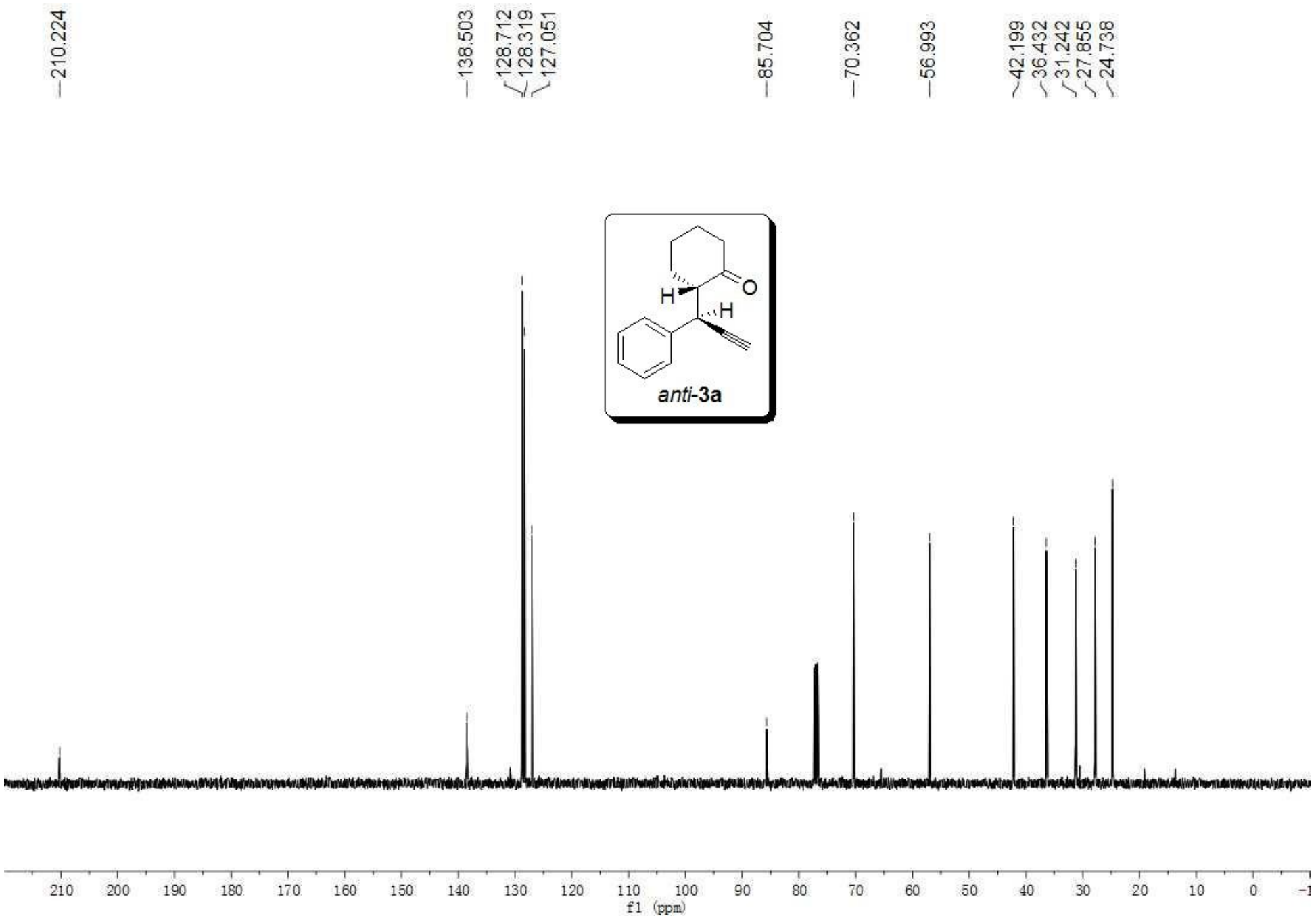
Crystal data

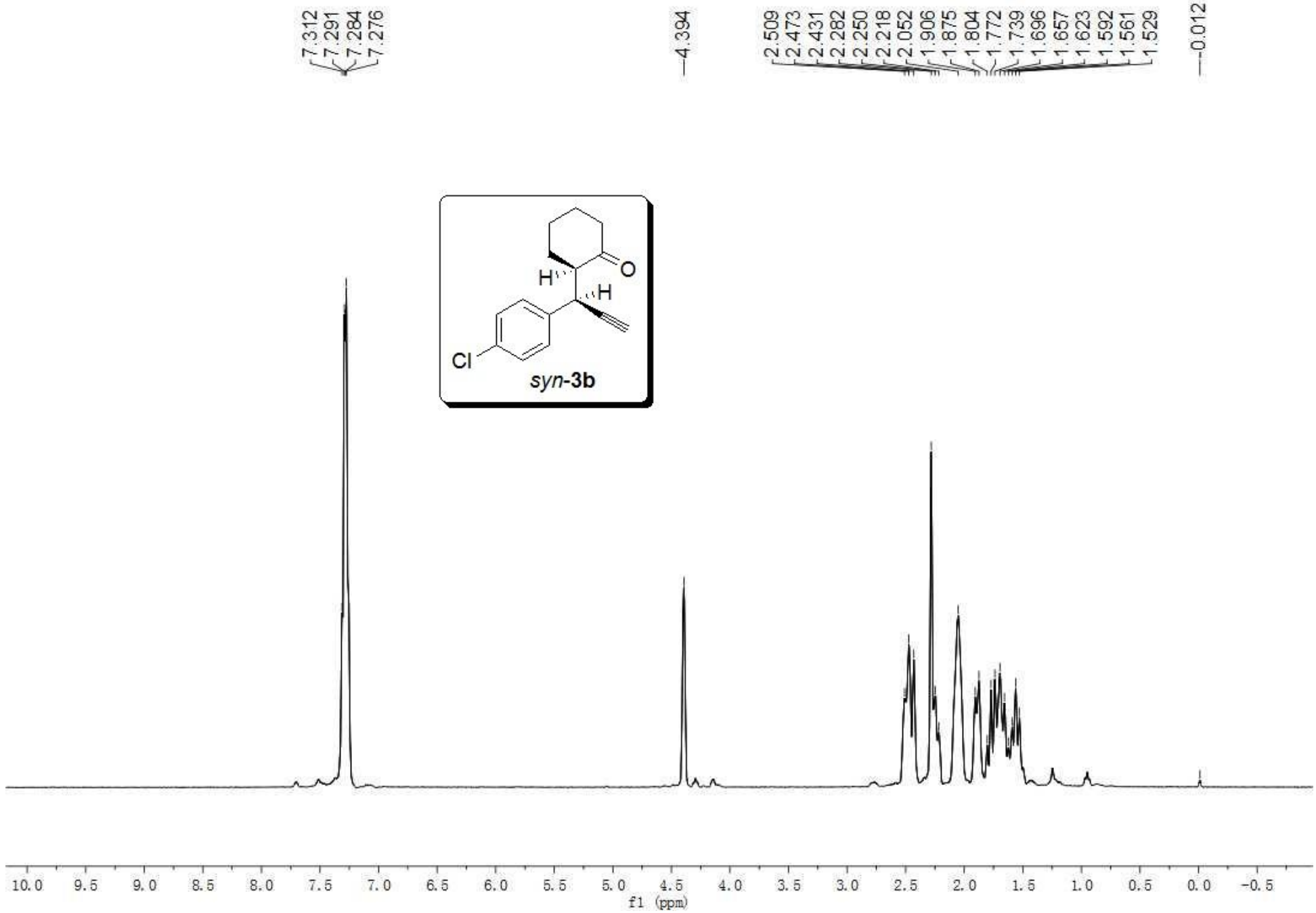
Identification code	120927a_0m
Empirical formula	C17 H17 Br O3
Formula weight	349.22
Temperature	293(2) K
Wavelength	0.71073 A
Crystal system, space group	Monoclinic, P21/c
Unit cell dimensions	a = 5.776(3) A alpha = 90 deg b = 32.024(16) A beta = 115.031(13) deg c = 9.608(4) A gamma = 90 deg.
Volume	1610.3(13) A^3
Z, Calculated density	4, 1.440 Mg/m^3
Absorption coefficient	2.559 mm^-1
F(000)	712
Crystal size	0.15 x 0.13 x 0.12 mm
Theta range for data collection	2.42 to 27.80 deg.
Limiting indices	-7<=h<=7, -41<=k<=41, -12<=l<=11
Reflections collected / unique	13713 / 3749 [R(int) = 0.0563]
Completeness to theta = 27.80	98.0 %

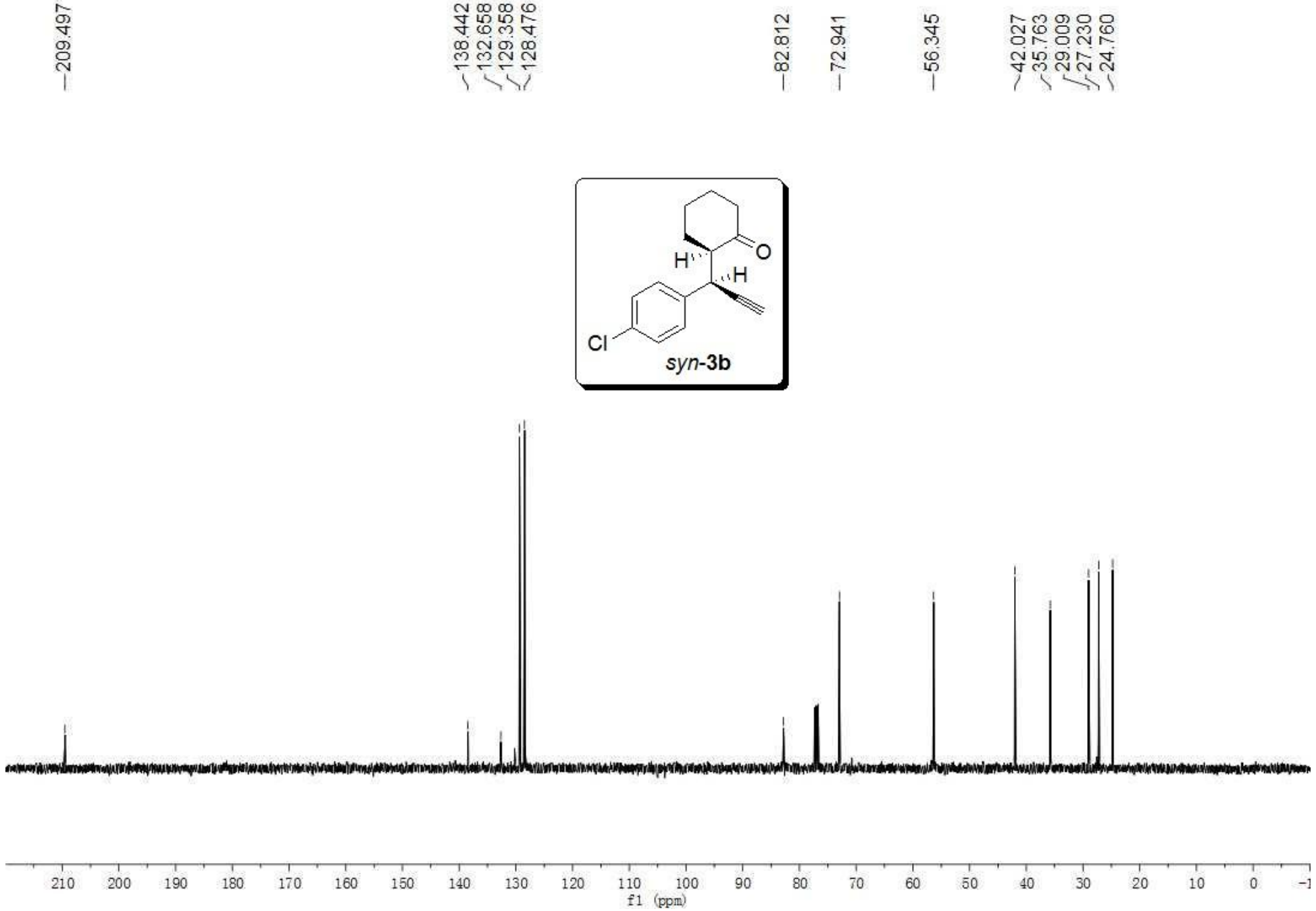
Absorption correction	None
Max. and min. transmission	0.7487 and 0.7001
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3749 / 0 / 190
Goodness-of-fit on F^2	1.066
Final R indices [I>2sigma(I)]	R1 = 0.0938, wR2 = 0.2529
R indices (all data)	R1 = 0.1427, wR2 = 0.2839
Largest diff. peak and hole	1.971 and -0.539 e.A

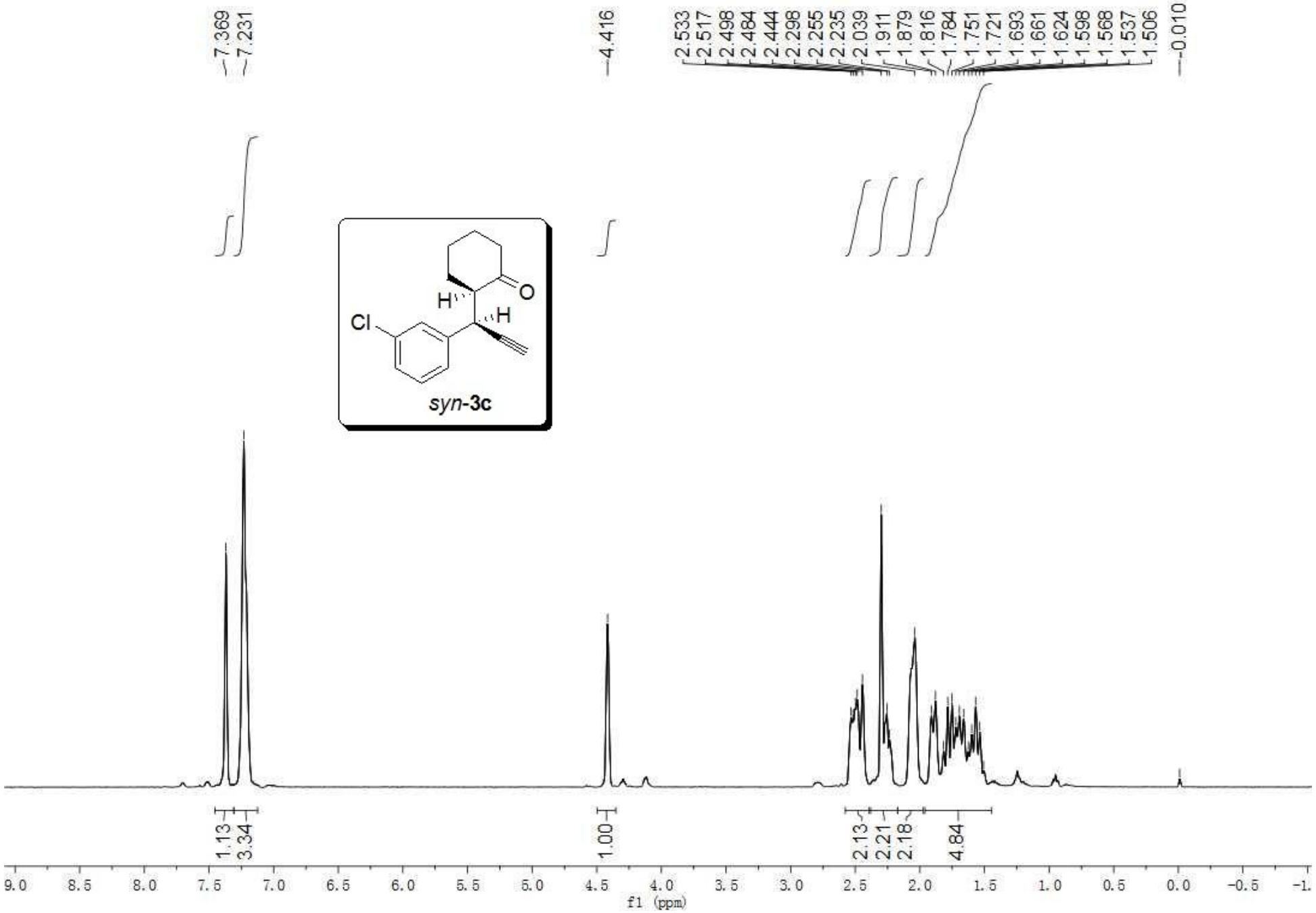

7.362
7.313
7.251
7.233
4.468
2.549
2.527
2.486
2.451
2.281
2.223
2.049
1.903
1.865
1.825
1.793
1.759
1.705
1.673
1.640
1.587
1.555
1.523
1.493
0.004
H
O
H
syn-3a
2.10
2.07
1.10
1.00
2.14
2.08
2.12
4.32
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.
f1 (ppm)


7.376
7.372
7.355
7.323
7.305
7.301
7.286
7.259
7.254
7.250
7.241
7.236
7.229
7.218
4.119
4.113
4.101
4.095
2.826
2.823
2.820
2.818
2.807
2.793
2.790
2.777
2.471
2.447
2.437
2.427
2.219
2.213
2.025
2.016
2.009
2.000
1.994
1.986
1.826
1.820
1.814
1.807
1.801
1.791
1.647
1.636
1.629
1.616
1.607
1.599
1.592
1.586
1.563
1.255
1.248
1.242
1.218
0.000
H
O
H
anti-3a
2.01
2.06
1.18
1.00
1.01
1.05
1.03
0.97
1.02
2.05
1.96
1.34
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


210.224
138.503
128.712
128.319
127.051
85.704
70.362
56.993
42.199
36.432
31.242
27.855
24.738
H
O
H
anti-3a
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.312
7.291
7.284
7.276
4.394
2.509
2.473
2.431
2.282
2.250
2.218
2.052
1.906
1.875
1.804
1.772
1.739
1.696
1.657
1.623
1.592
1.561
1.529
0.012
H
O
H
Cl
syn-3b
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


209.497
138.442
132.658
129.358
128.476
82.812
72.941
56.345
42.027
35.763
29.009
27.230
24.760
H
O
H
Cl
syn-3b
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.369
7.231
4.416
2.533
2.517
2.498
2.484
2.444
2.298
2.255
2.235
2.039
1.911
1.879
1.816
1.784
1.751
1.721
1.693
1.661
1.624
1.598
1.568
1.537
1.506
0.010
H
O
H
Cl
syn-3c
1.13
3.34
1.00
2.13
2.21
2.18
4.84
f1 (ppm)

209.347

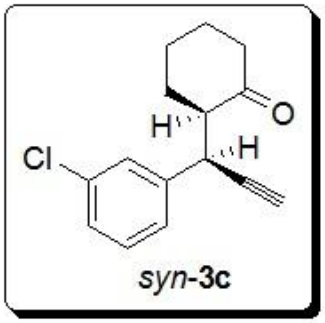
141.978
134.200
129.597
128.107
127.082
126.214

82.469

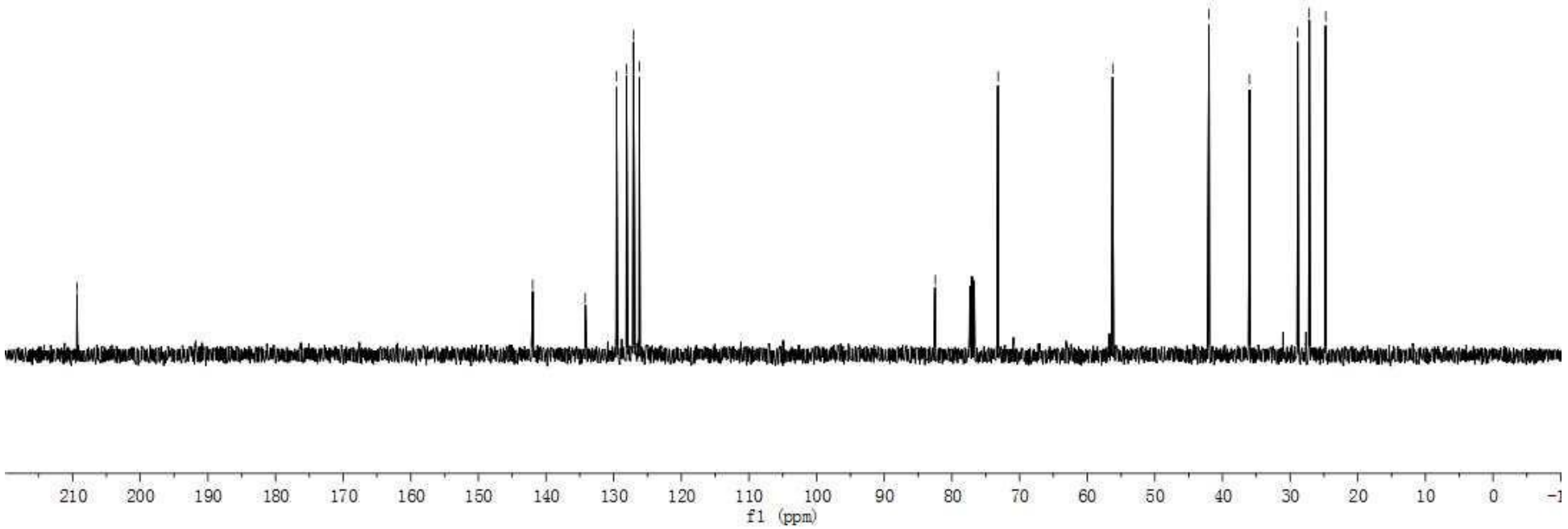
73.171

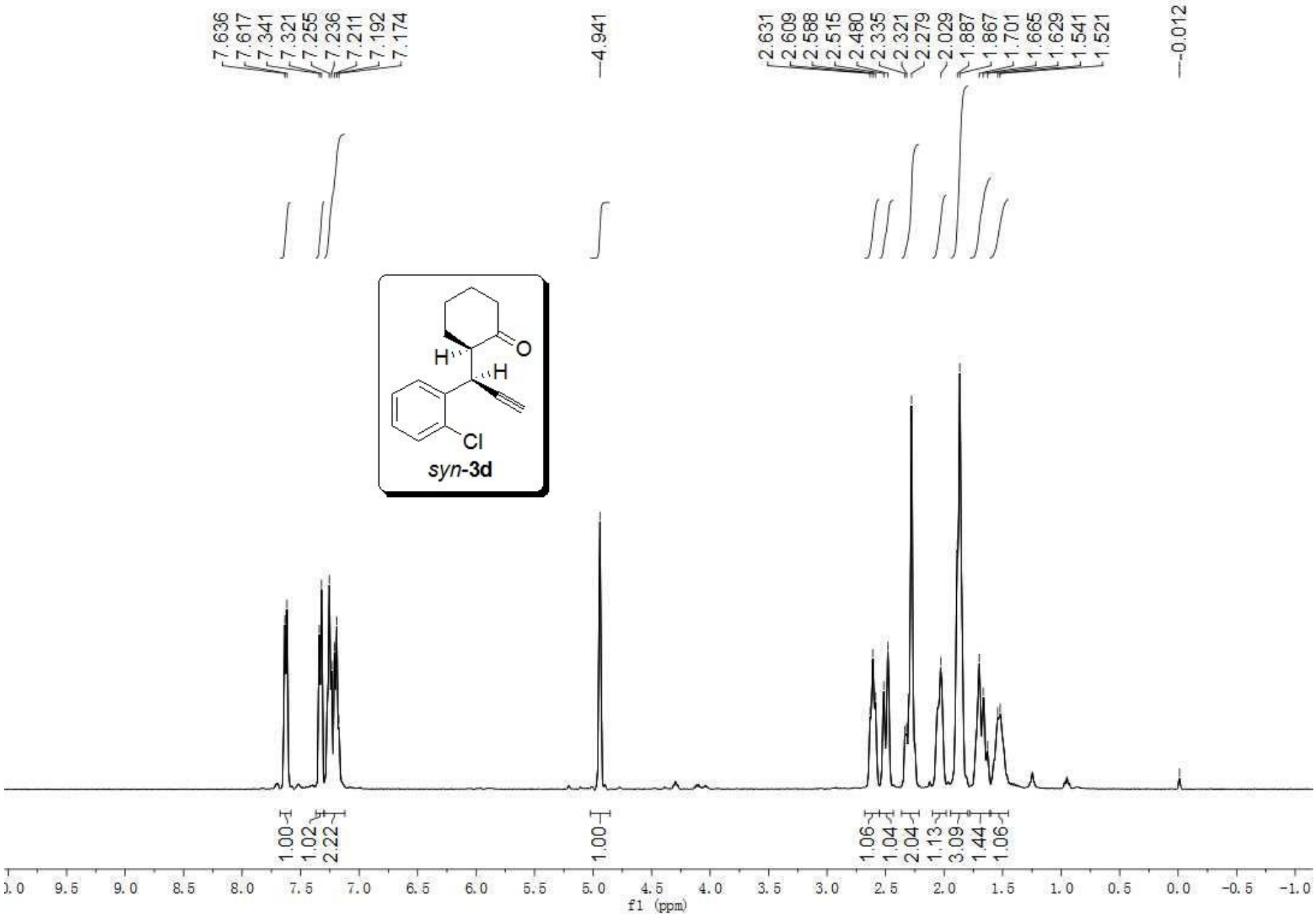
56.230

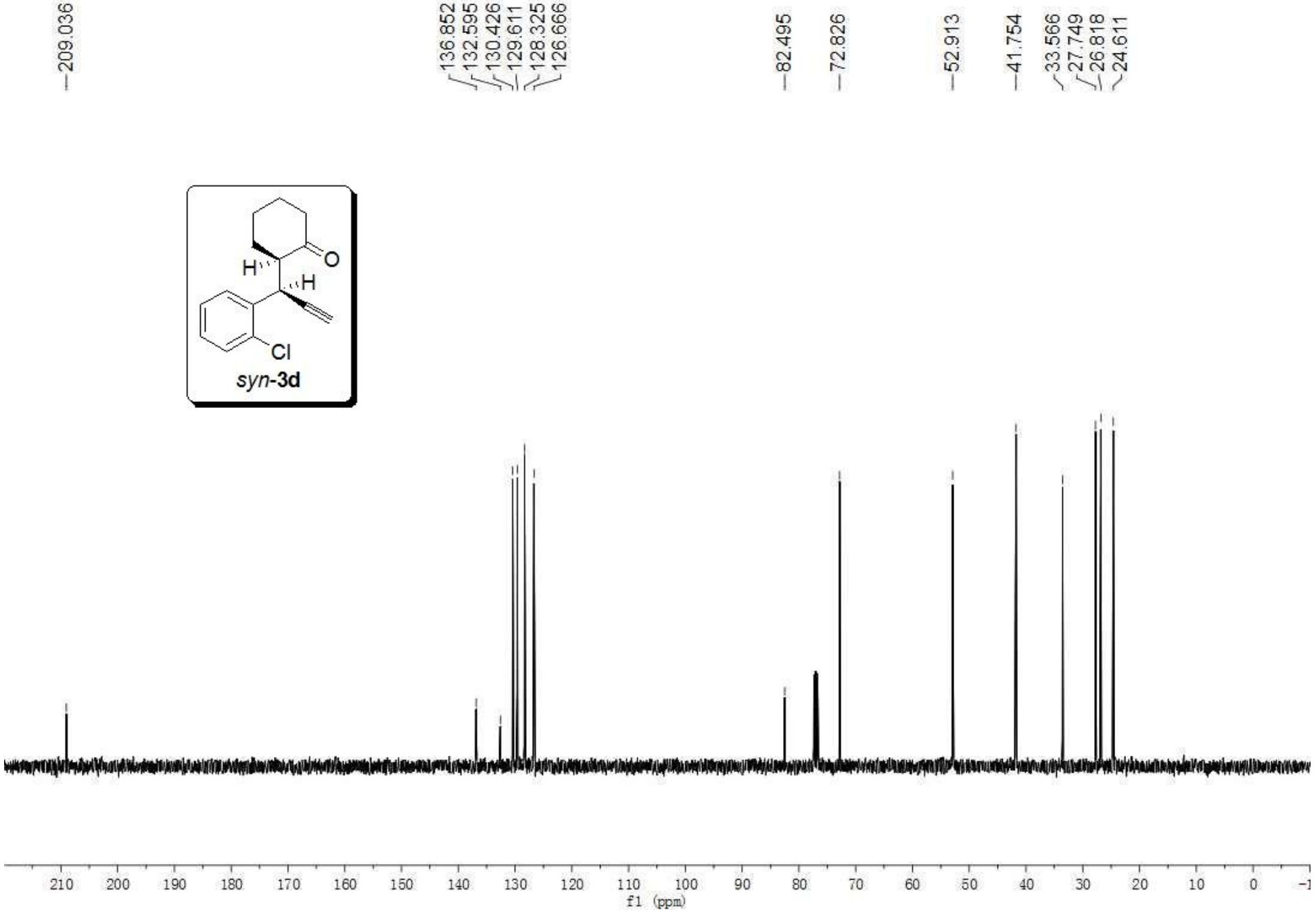
41.995
36.003
28.865
27.163
24.736

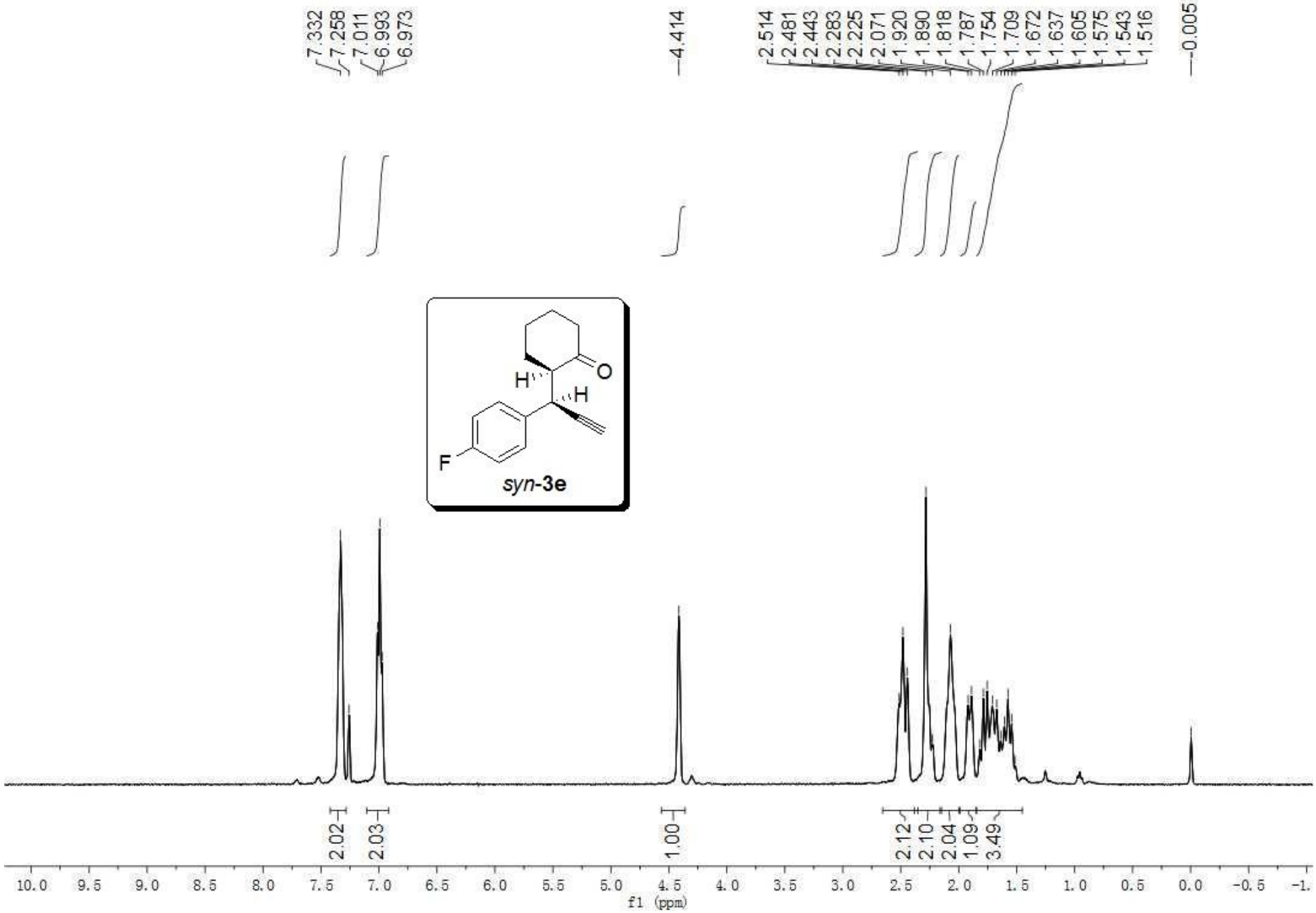


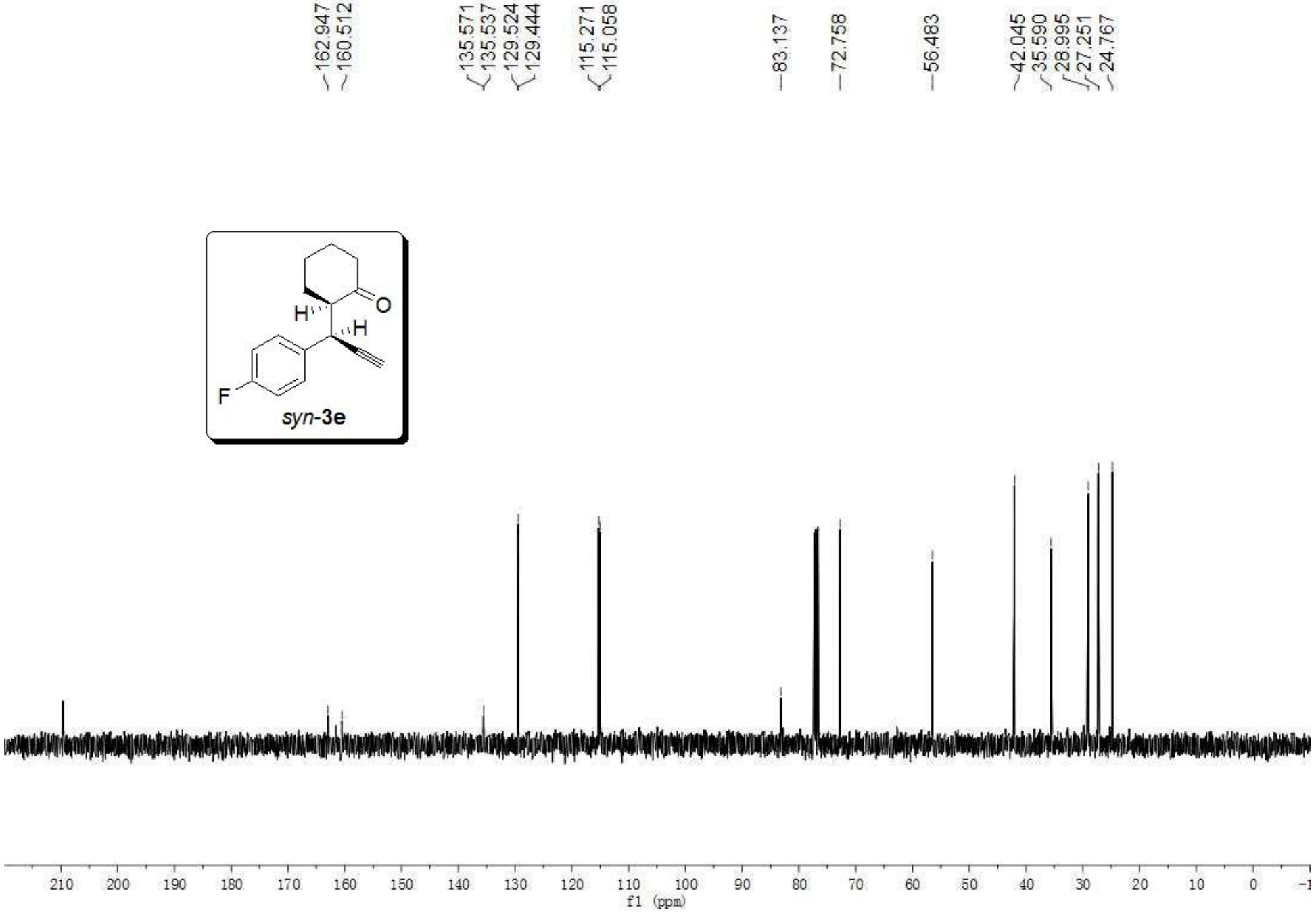
syn-**3c**

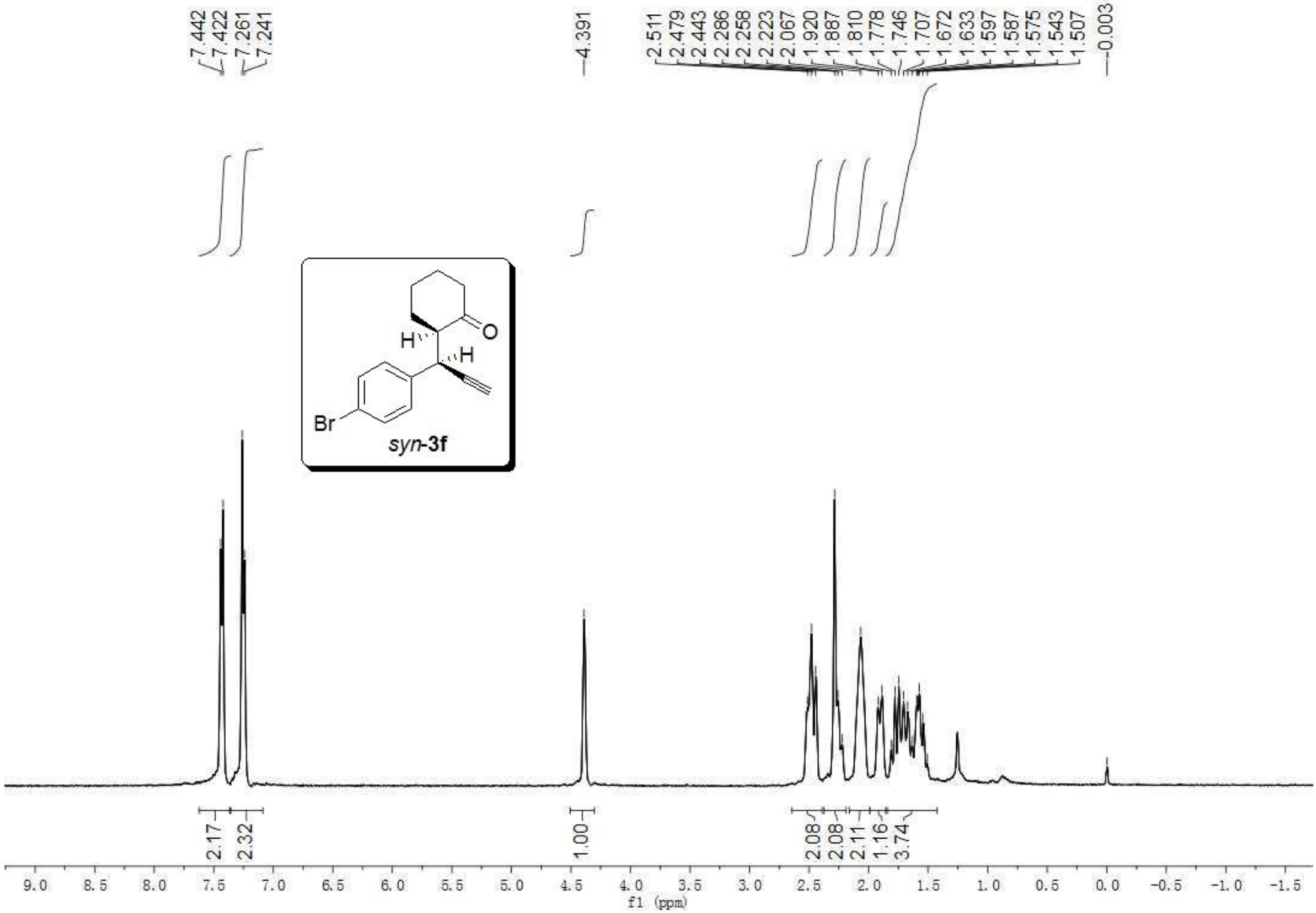


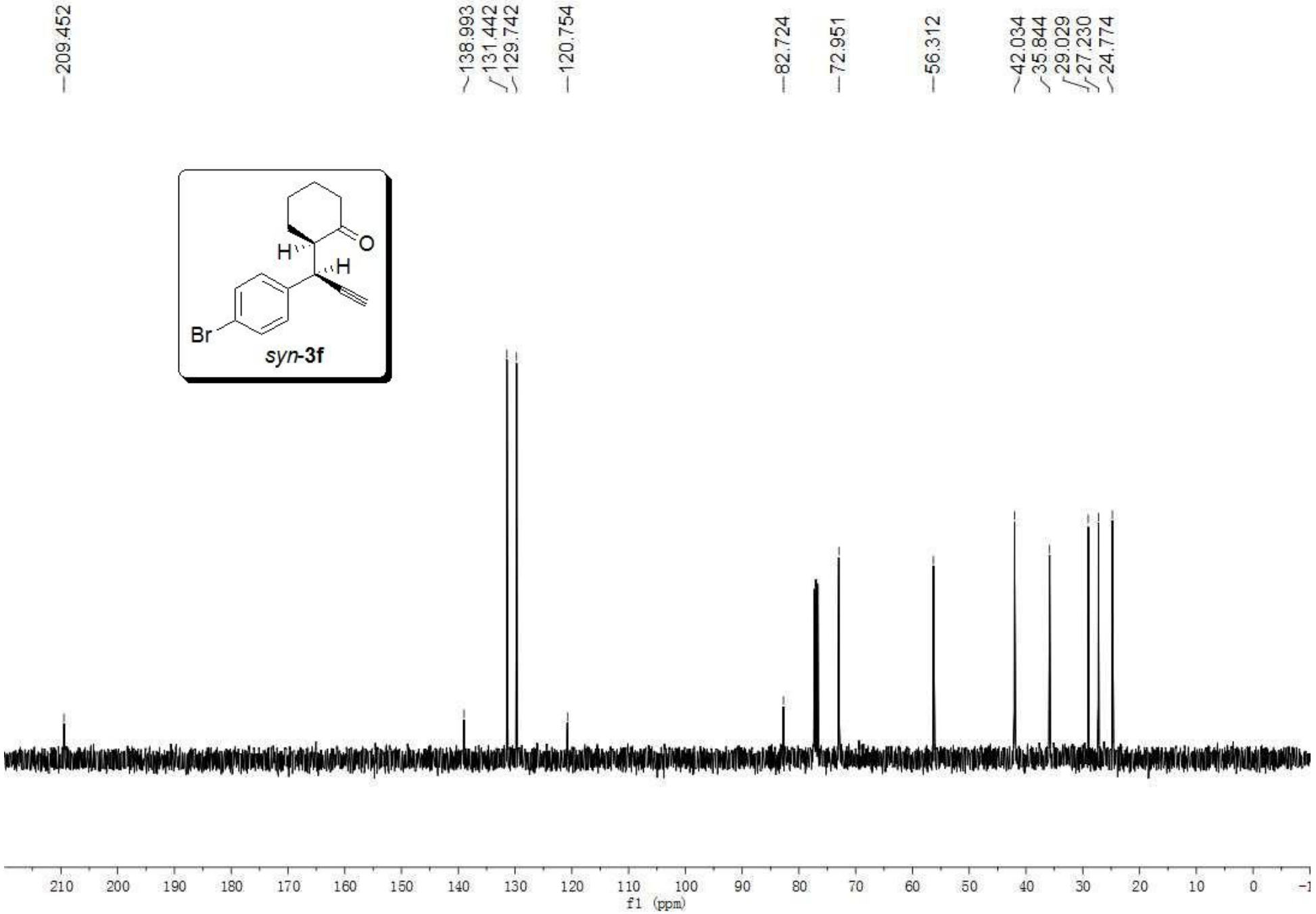

7.636
7.617
7.341
7.321
7.255
7.236
7.211
7.192
7.174
4.941
2.631
2.609
2.588
2.515
2.480
2.335
2.321
2.279
2.029
1.887
1.867
1.701
1.665
1.629
1.541
1.521
0.012
H
O
H
Cl
syn-3d
1.00
1.02
2.22
1.00
1.06
1.04
2.04
1.13
3.09
1.44
1.06
f1 (ppm)

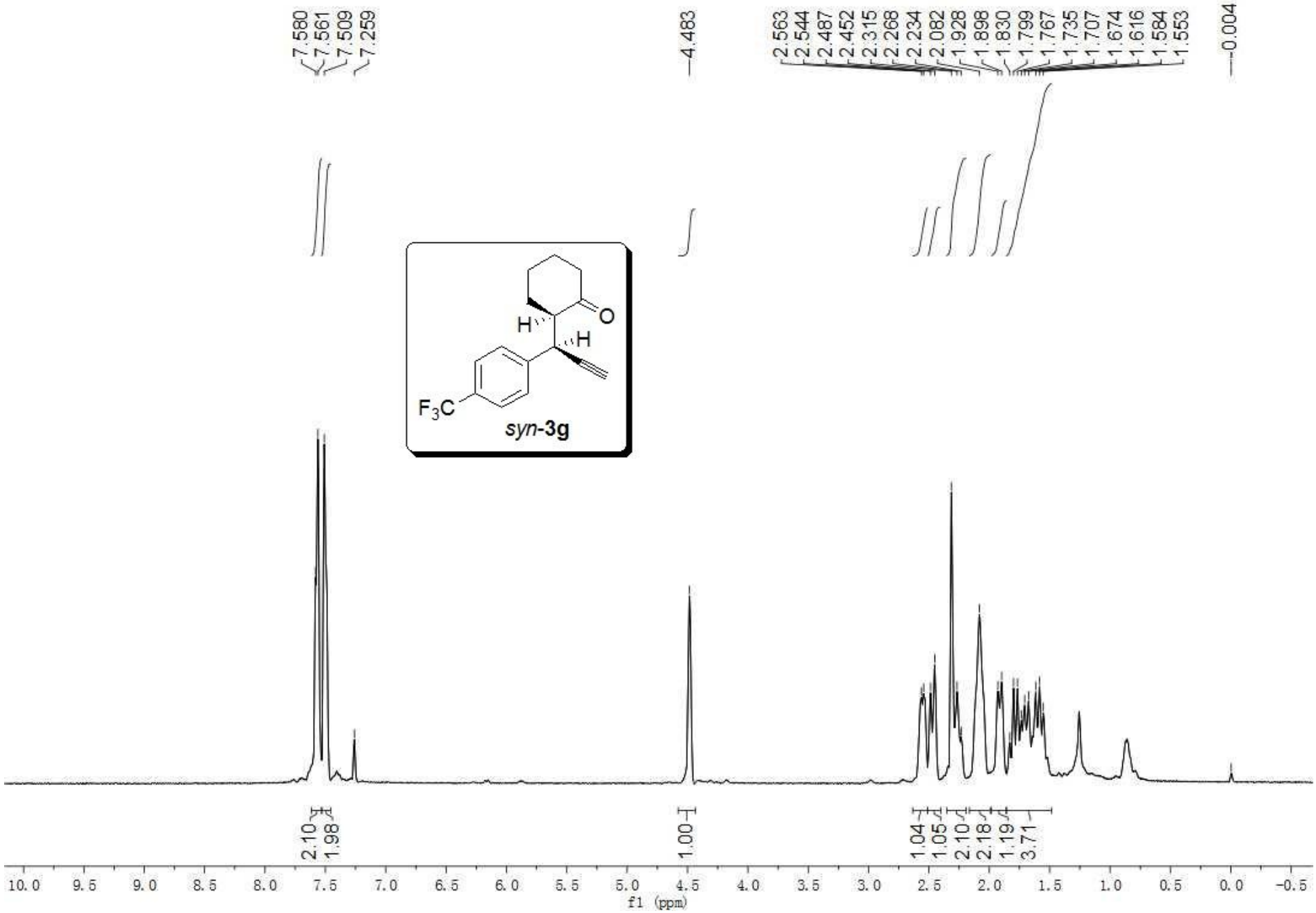

209.036
136.852
132.595
130.426
129.611
128.325
126.666
82.495
72.826
52.913
41.754
33.566
27.749
26.818
24.611
O
H
H
Cl
syn-3d
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

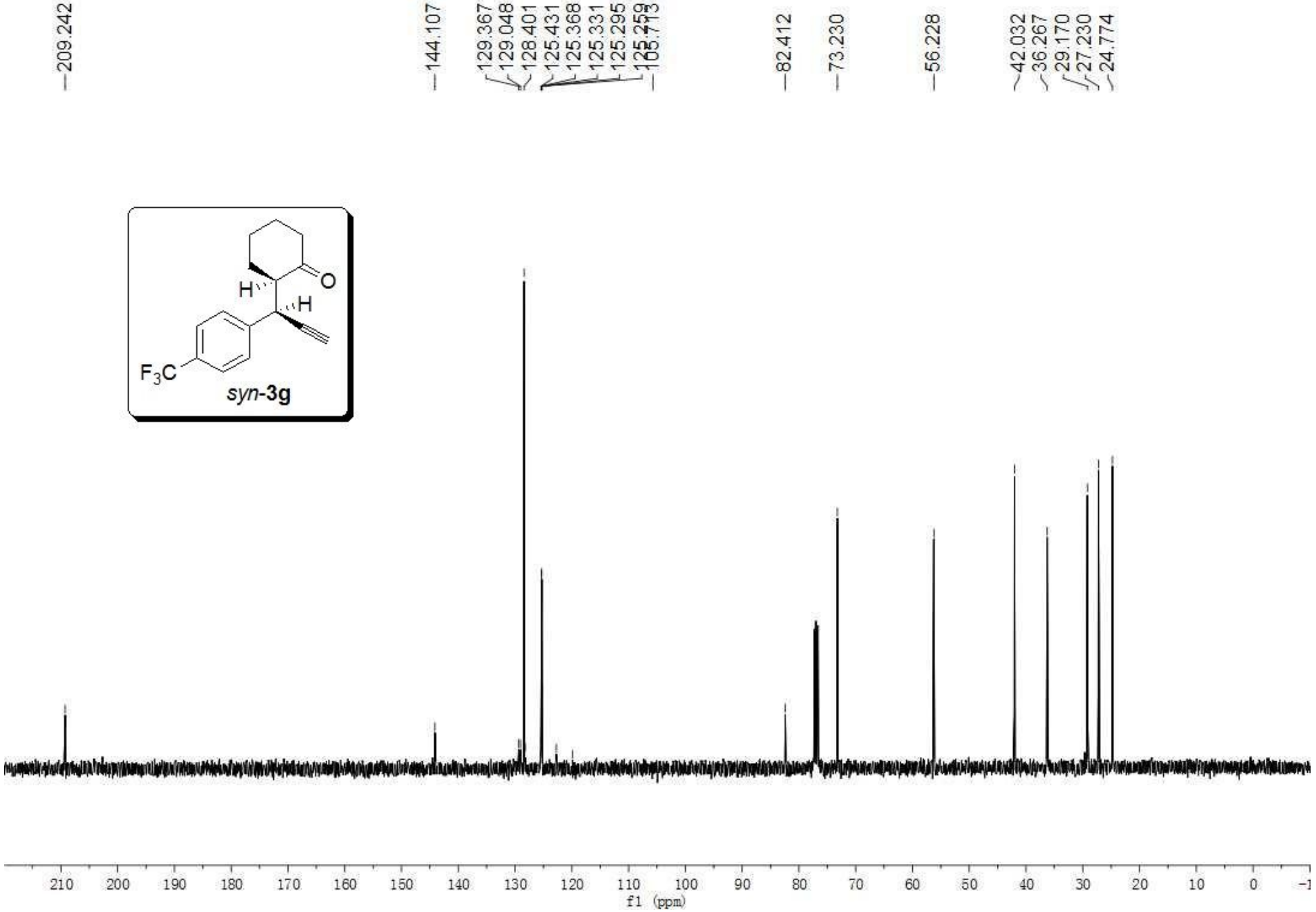

7.332
7.258
7.011
6.993
6.973
4.414
2.514
2.481
2.443
2.283
2.225
2.071
1.920
1.890
1.818
1.787
1.754
1.709
1.672
1.637
1.605
1.575
1.543
1.516
0.005
H
O
H
F
syn-3e
2.02
2.03
1.00
2.12
2.10
2.04
1.09
3.49
f1 (ppm)

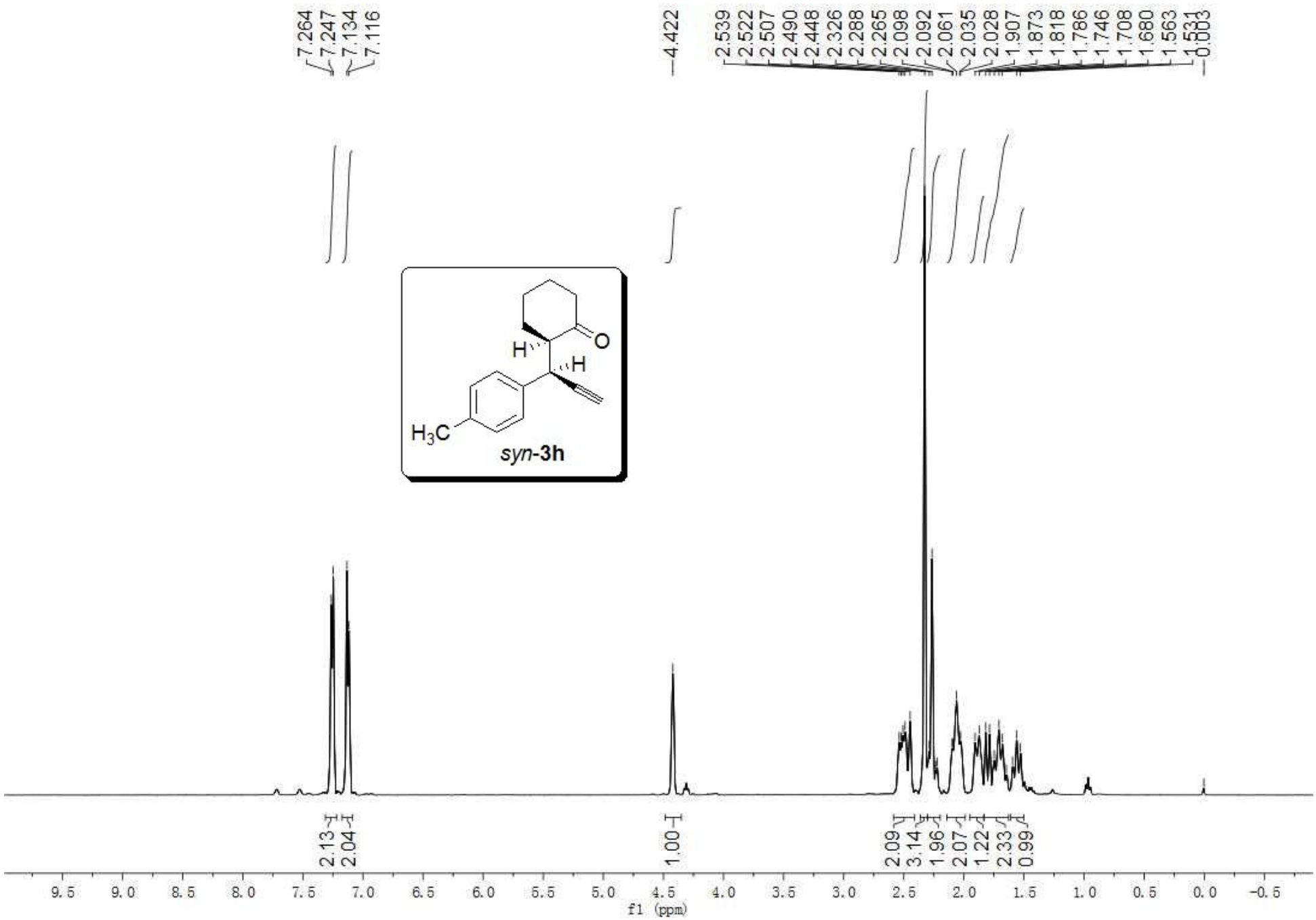

162.947
160.512
135.571
135.537
129.524
129.444
115.271
115.058
83.137
72.758
56.483
42.045
35.590
28.995
27.251
24.767
O
H
H
F
syn-3e
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

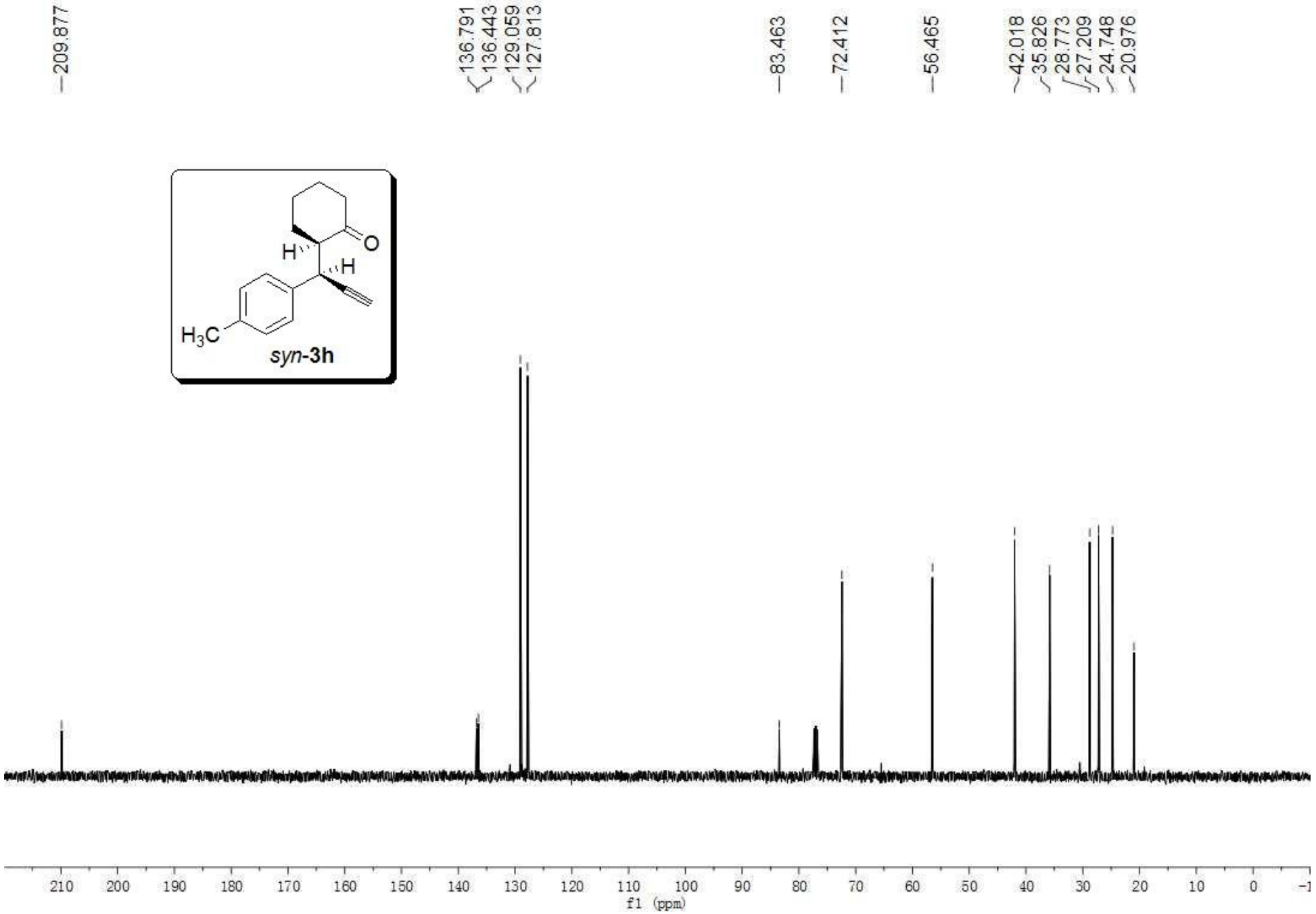

7.442
7.422
7.261
7.241
4.391
2.511
2.479
2.443
2.286
2.258
2.223
2.067
1.920
1.887
1.810
1.778
1.746
1.707
1.672
1.633
1.597
1.587
1.575
1.543
1.507
0.003
H
O
H
Br
syn-3f
2.17
2.32
1.00
2.08
2.08
2.11
1.16
3.74
f1 (ppm)

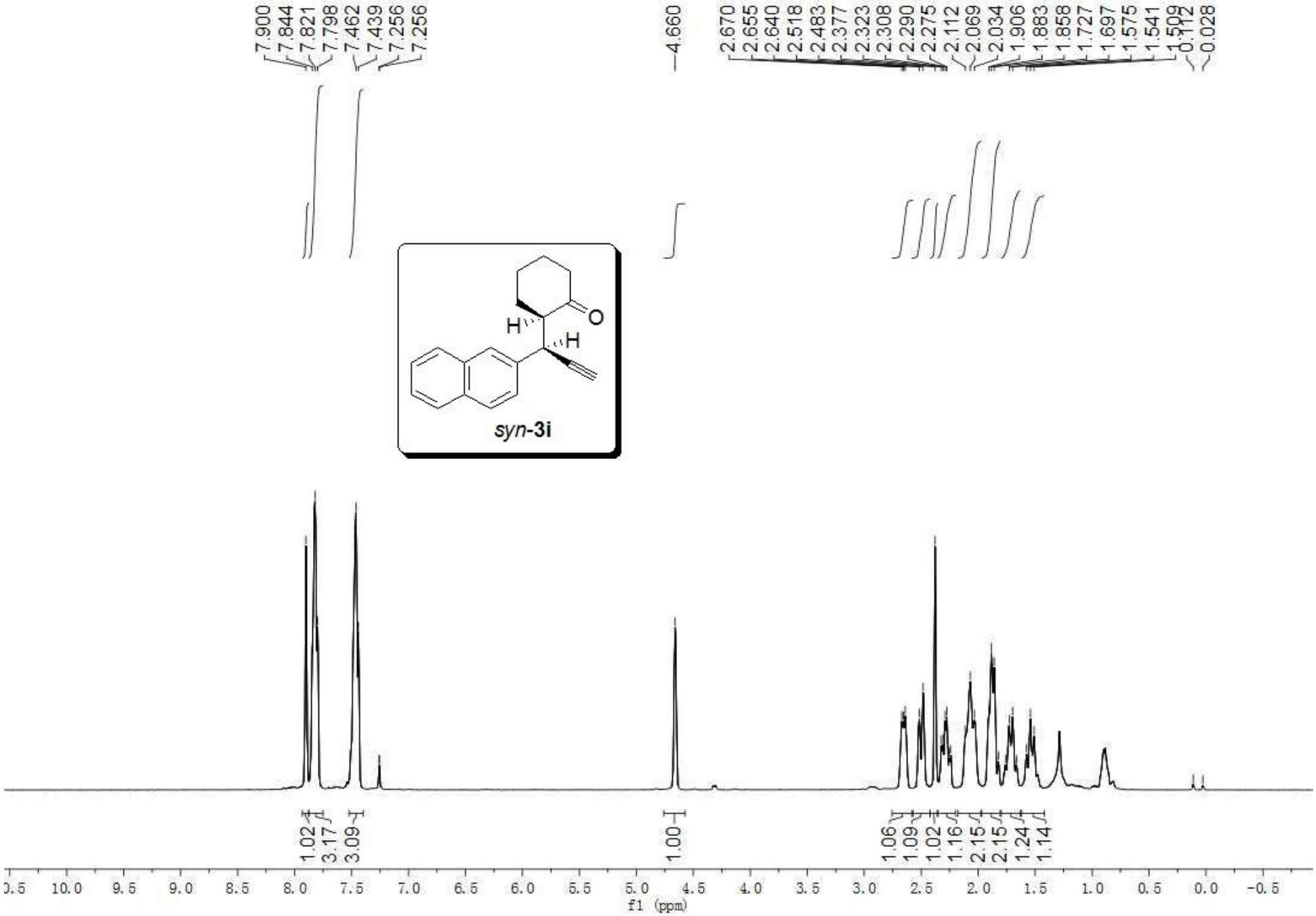

209.452
138.993
131.442
129.742
120.754
82.724
72.951
56.312
42.034
35.844
29.029
27.230
24.774
H
O
H
Br
syn-3f
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.580
7.561
7.509
7.259
4.483
2.563
2.544
2.487
2.452
2.315
2.268
2.234
2.082
1.928
1.898
1.830
1.799
1.767
1.735
1.707
1.674
1.616
1.584
1.553
0.004
H
O
H
F3C
syn-3g
2.10
1.98
1.00
1.04
1.05
2.10
2.18
1.19
3.71
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


209.242
144.107
129.367
129.048
128.401
125.431
125.368
125.331
125.295
82.412
73.230
56.228
42.032
36.267
29.170
27.230
24.774
H
O
H
F3C
syn-3g
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.264
7.247
7.134
7.116
4.422
2.539
2.522
2.507
2.490
2.448
2.326
2.288
2.265
2.098
2.092
2.061
2.035
2.028
1.907
1.873
1.818
1.786
1.746
1.708
1.680
1.563
1.531
0.883
H
O
H
H3C
syn-3h
2.13
2.04
1.00
2.09
3.14
1.96
2.07
1.22
2.33
0.99
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


209.877
136.791
136.443
129.059
127.813
83.463
72.412
56.465
42.018
35.826
28.773
27.209
24.748
20.976
H
O
H
H3C
syn-3h
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.900
7.844
7.821
7.798
7.462
7.439
7.256
7.256
4.660
2.670
2.655
2.640
2.518
2.483
2.377
2.323
2.308
2.290
2.275
2.112
2.069
2.034
1.906
1.883
1.858
1.727
1.697
1.575
1.541
1.509
0.112
0.028
H
O
H
syn-3i
1.02
3.17
3.09
1.00
1.06
1.09
1.02
1.16
2.15
2.15
1.24
1.14
f1 (ppm)

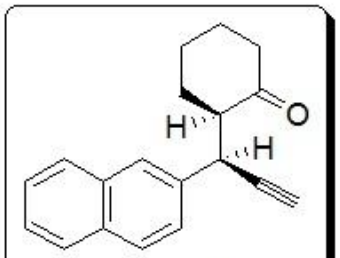
209.651

137.193
133.297
132.435
128.124
127.782
127.573
126.784
126.161
126.047
125.771

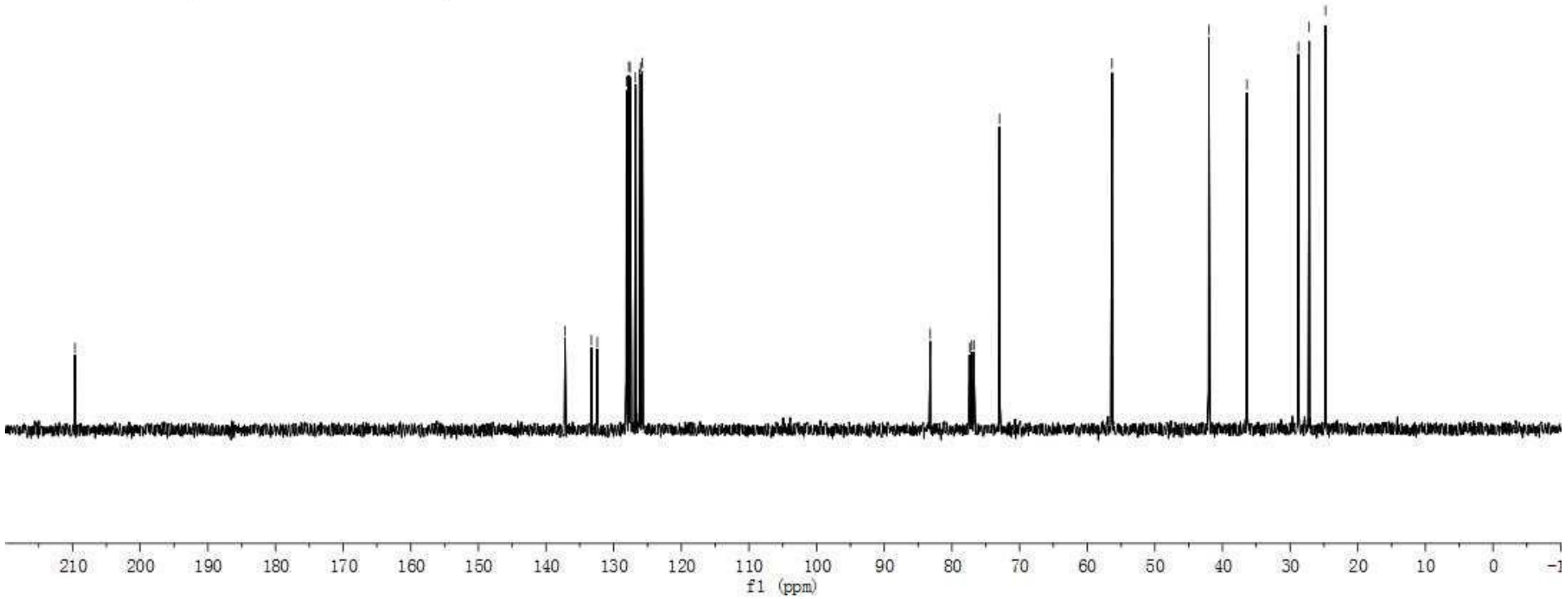
83.205
77.387
77.069
76.750
72.961

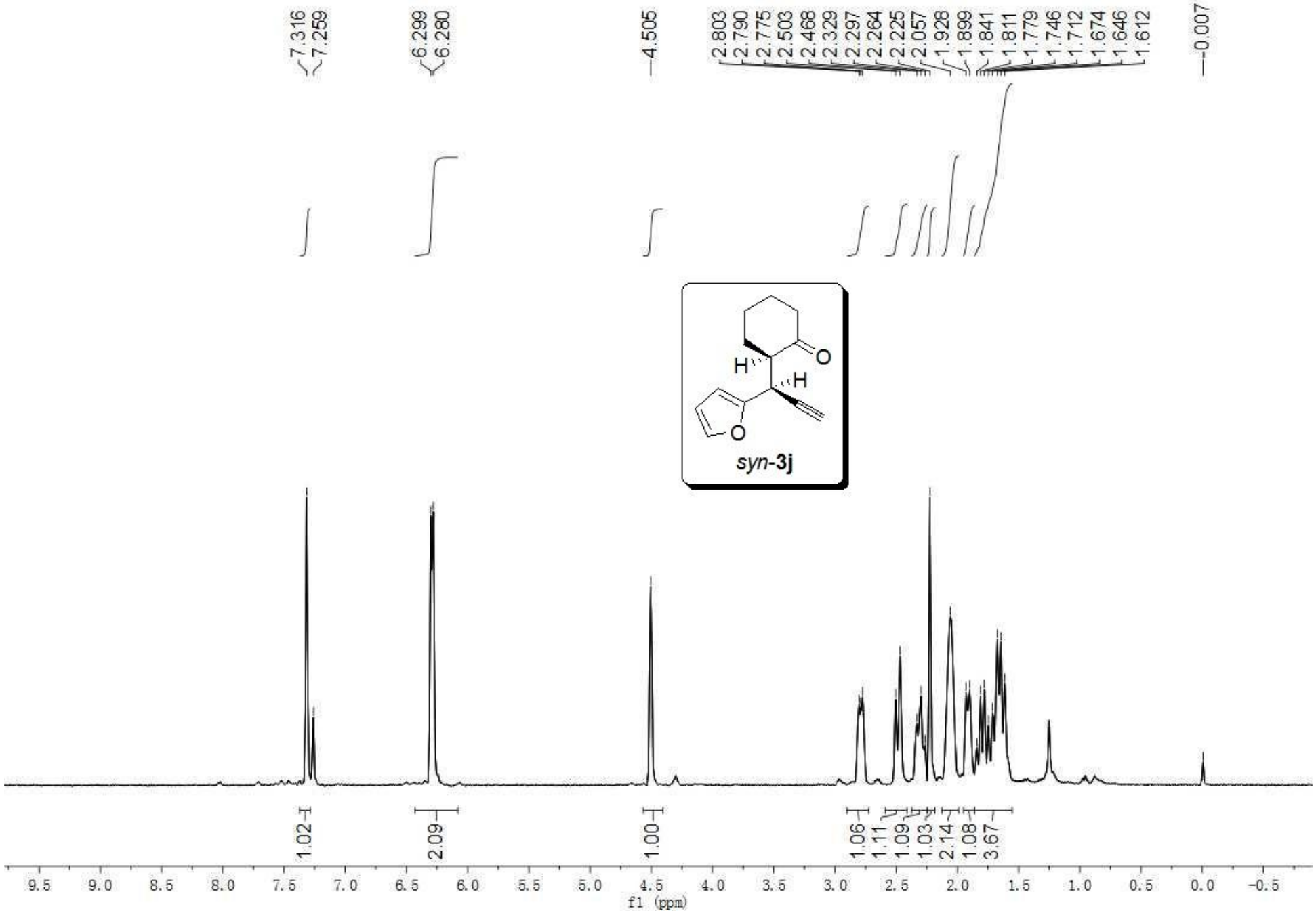
56.324

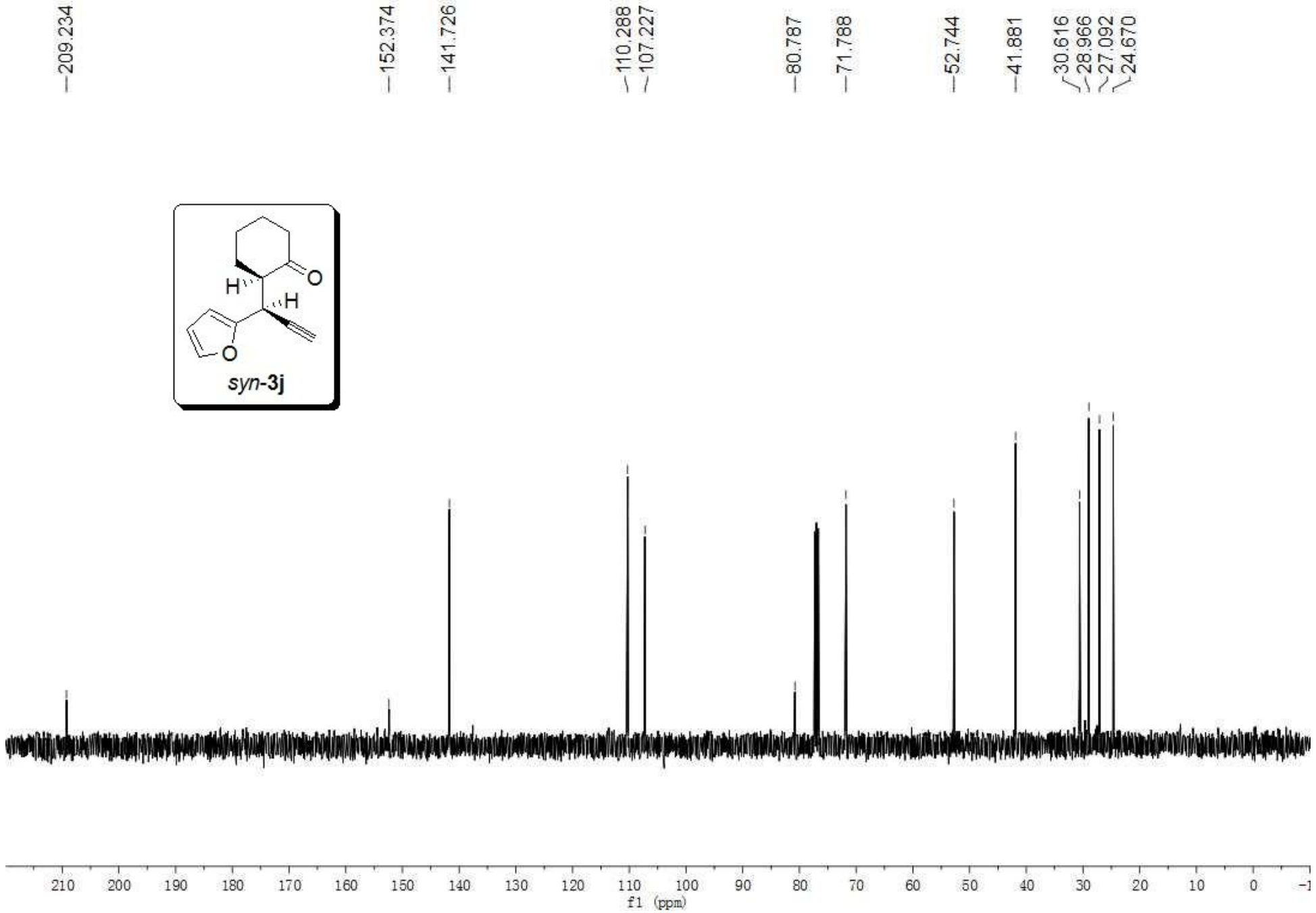
42.028
36.378
28.768
27.169
24.754

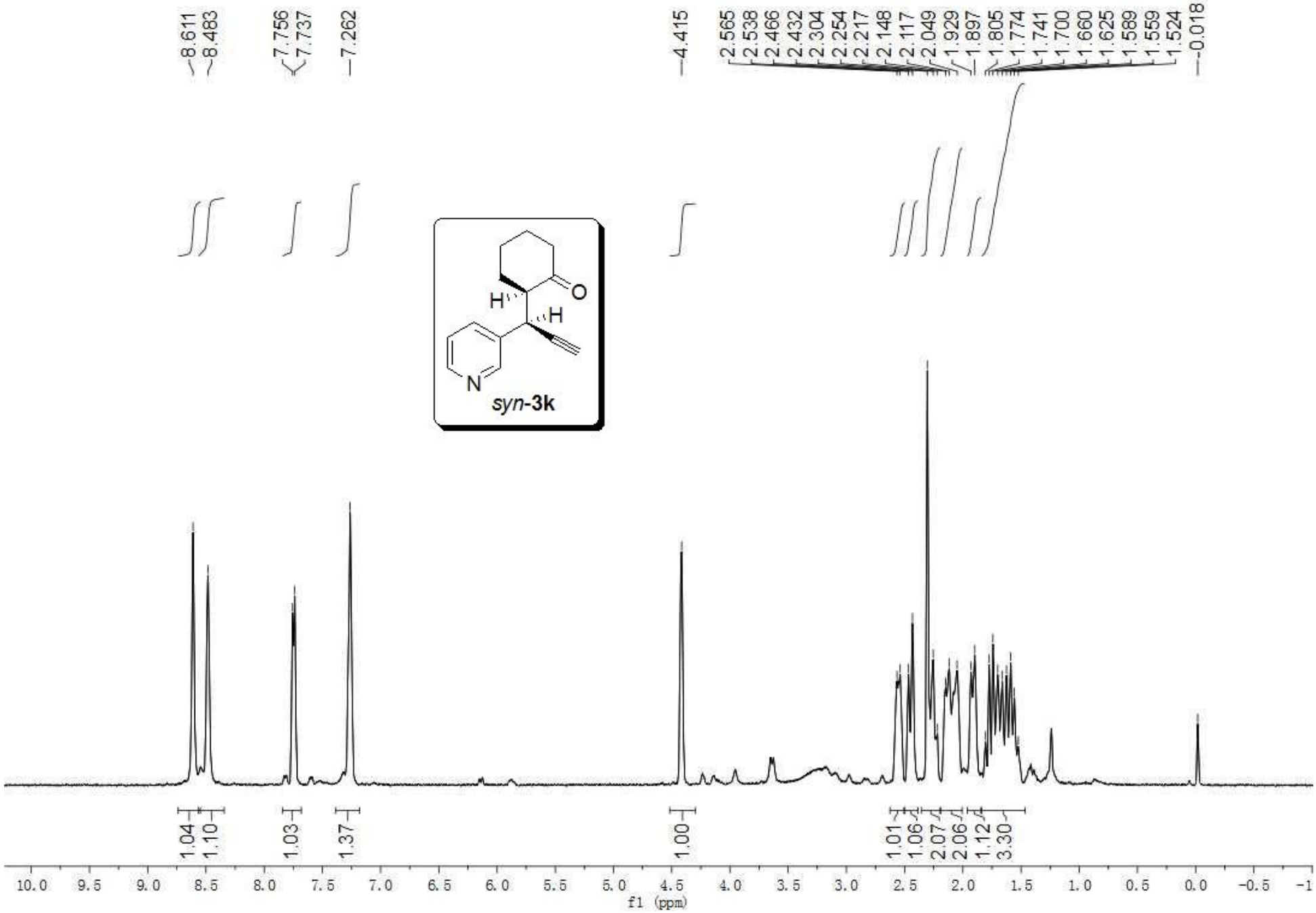


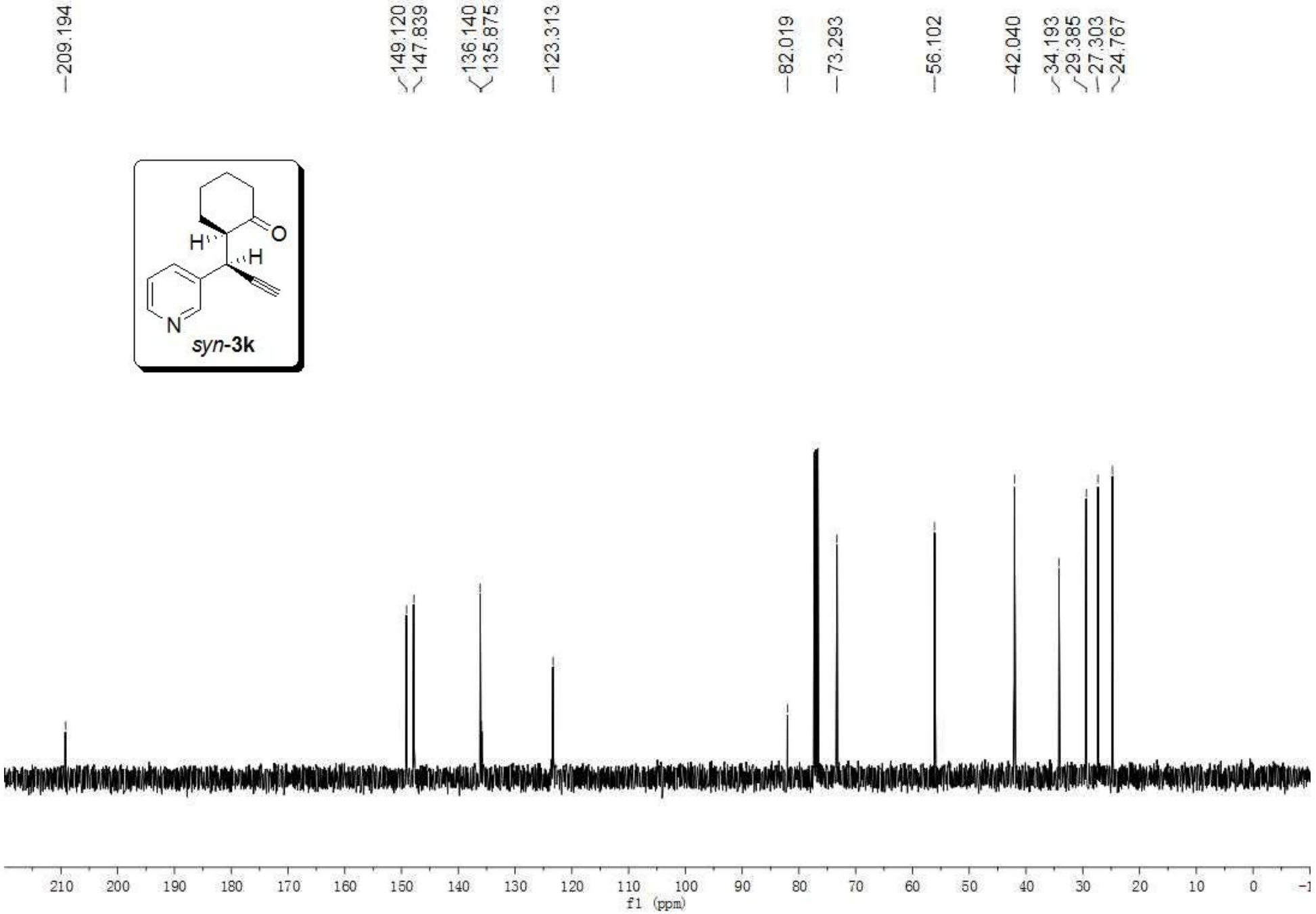
syn-**3i**

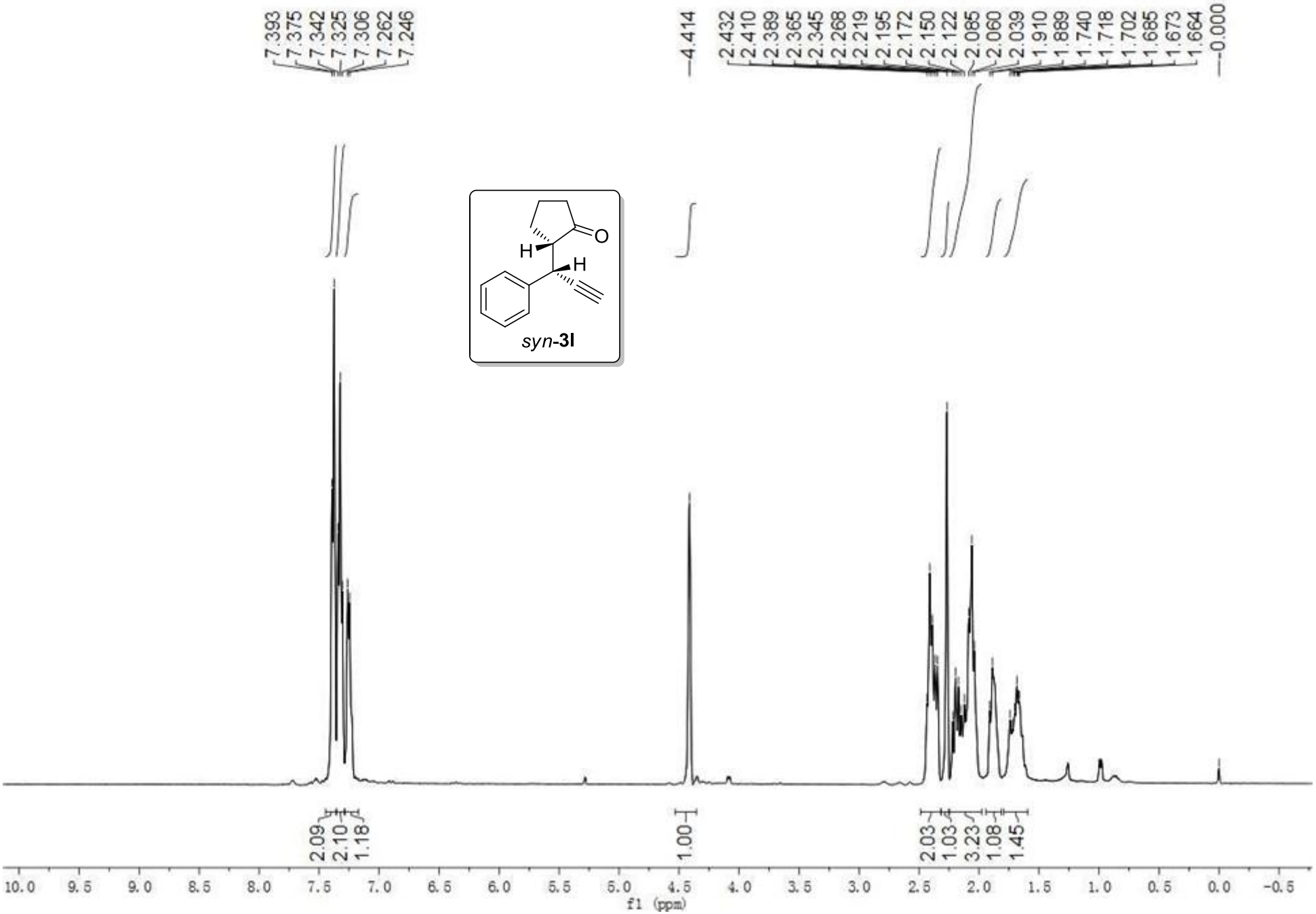


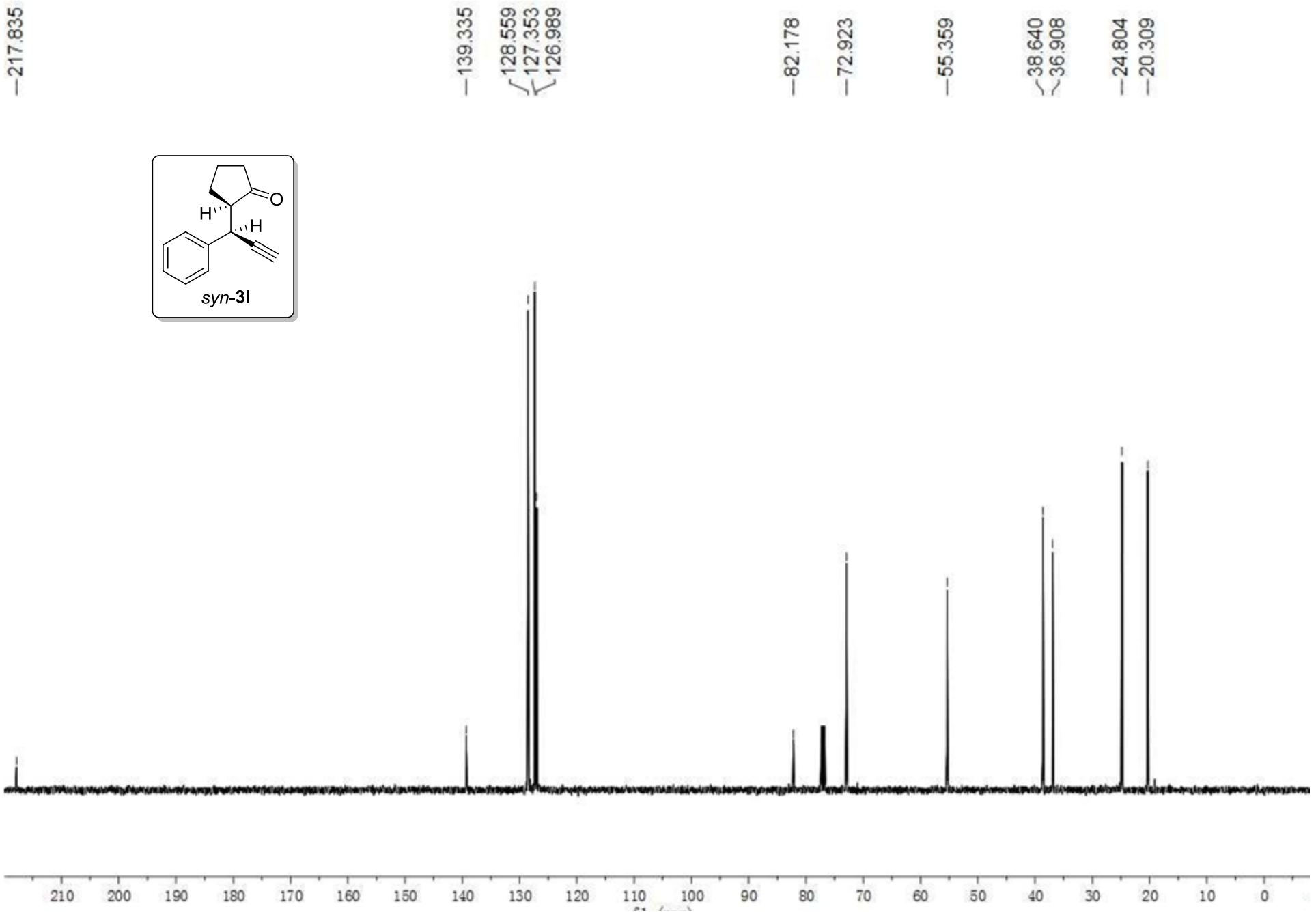

7.316
7.259
6.299
6.280
4.505
2.803
2.790
2.775
2.503
2.468
2.329
2.297
2.264
2.225
2.057
1.928
1.899
1.841
1.811
1.779
1.746
1.712
1.674
1.646
1.612
0.007
H
H
O
O
syn-3j
1.02
2.09
1.00
1.06
1.11
1.09
1.03
2.14
1.08
3.67
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

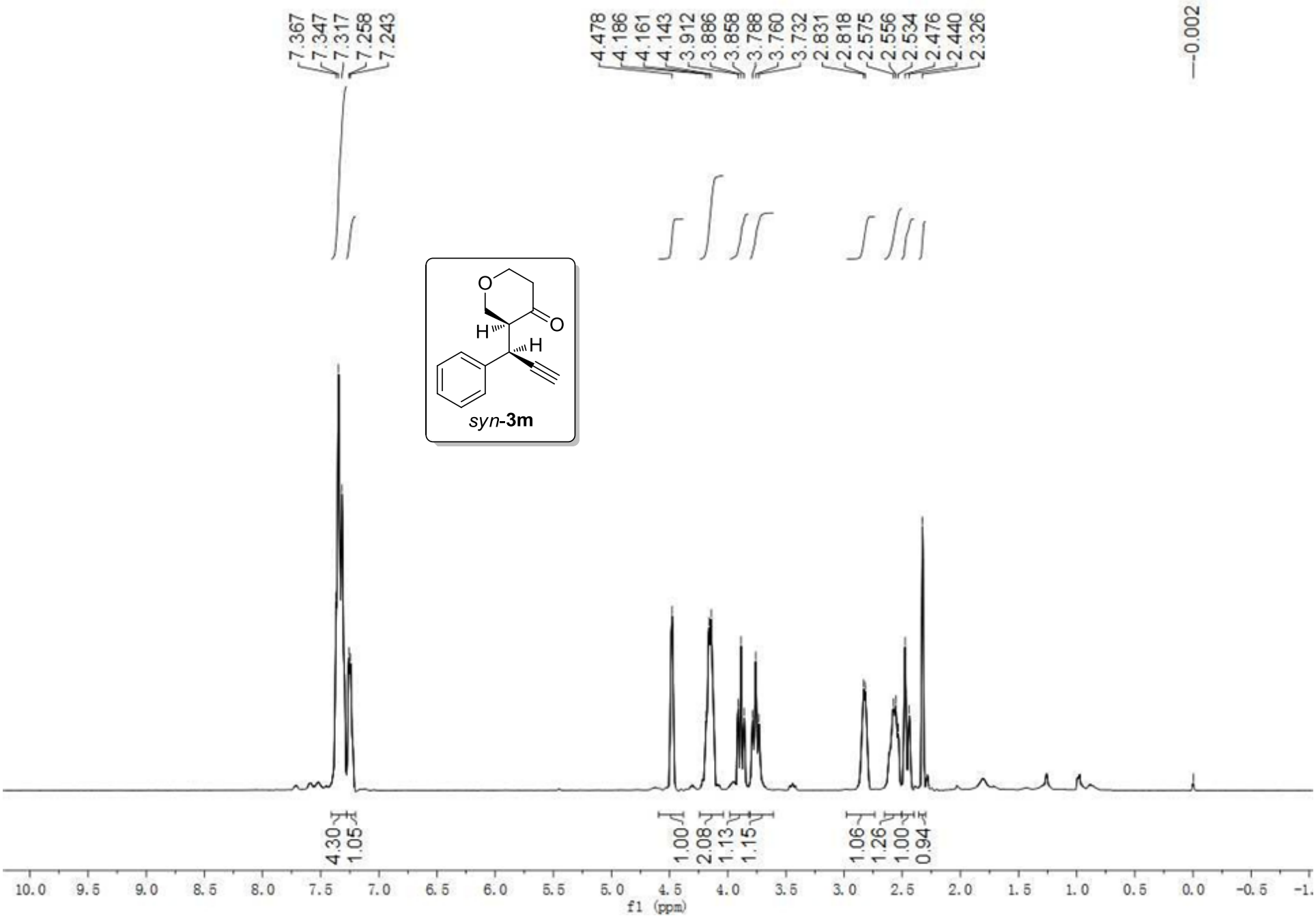

209.234
152.374
141.726
110.288
107.227
80.787
71.788
52.744
41.881
30.616
28.966
27.092
24.670
H
H
O
O
syn-3j
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

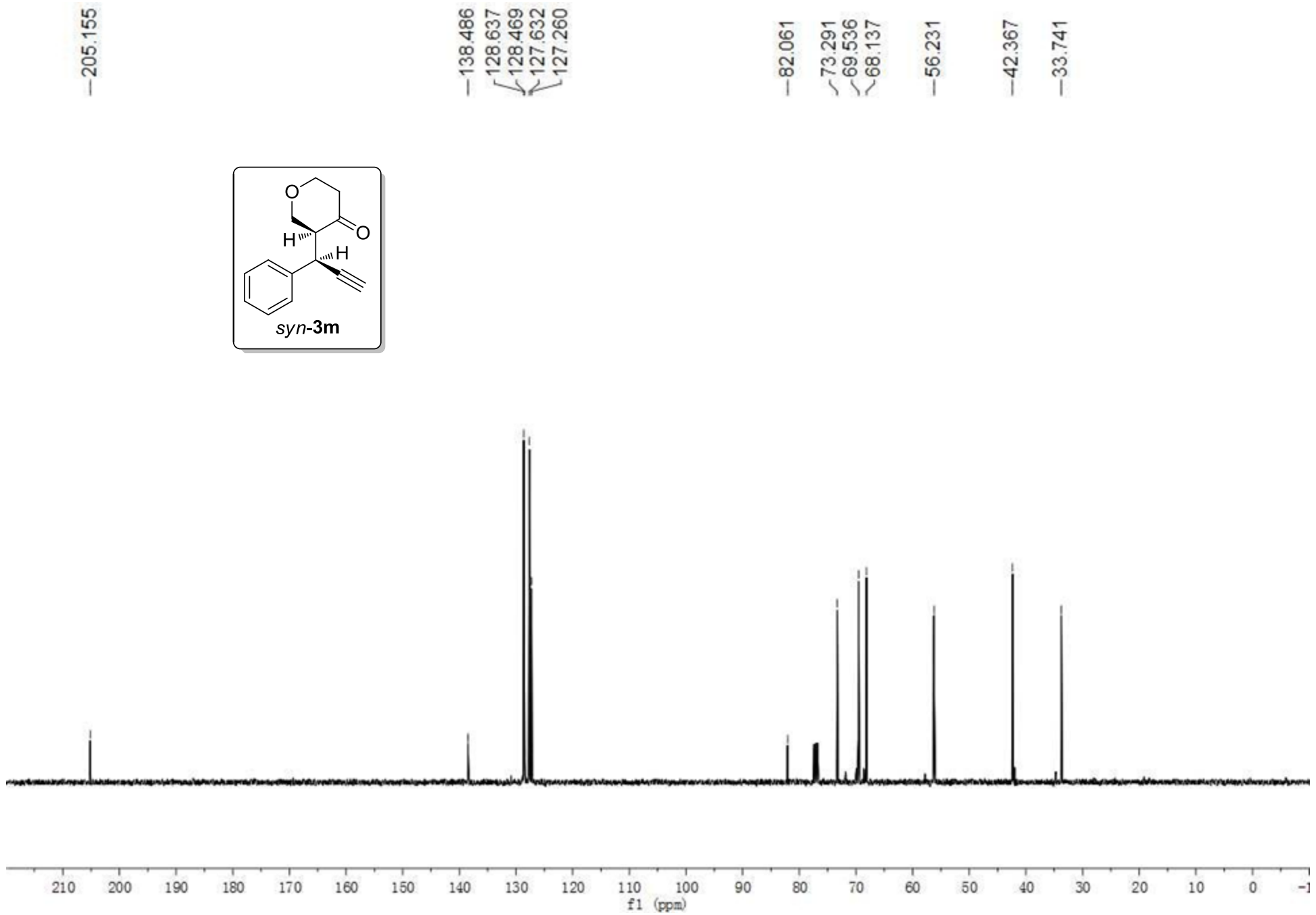

8.611
8.483
7.756
7.737
7.262
4.415
2.565
2.538
2.466
2.432
2.304
2.254
2.217
2.148
2.117
2.049
1.929
1.897
1.805
1.774
1.741
1.700
1.660
1.625
1.589
1.559
1.524
0.018
H
O
H
N
syn-3k
1.04
1.10
1.03
1.37
1.00
1.01
1.06
2.07
2.06
1.12
3.30
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1
f1 (ppm)

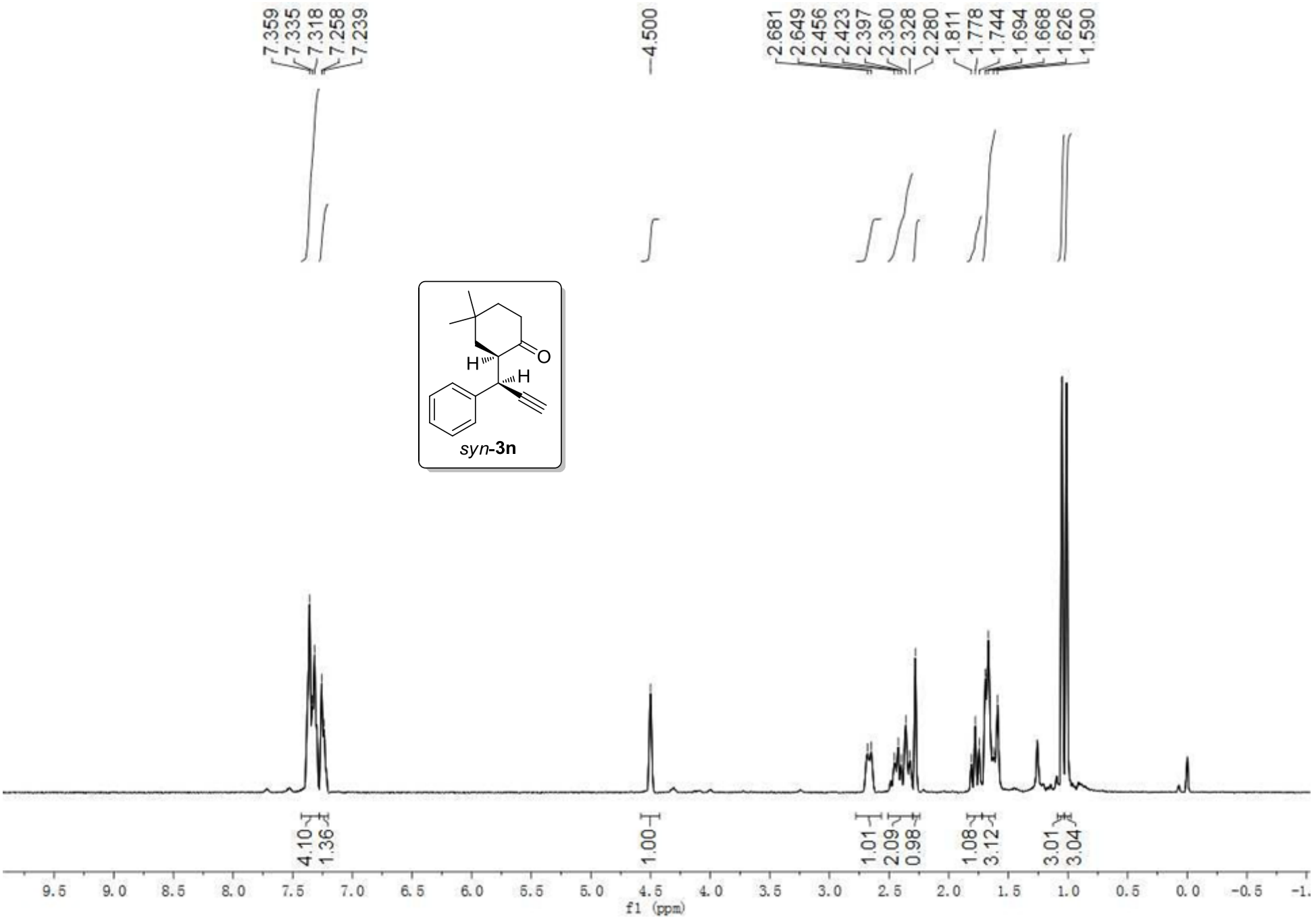

209.194
149.120
147.839
136.140
135.875
123.313
82.019
73.293
56.102
42.040
34.193
29.385
27.303
24.767
O
H
H
N
syn-3k
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

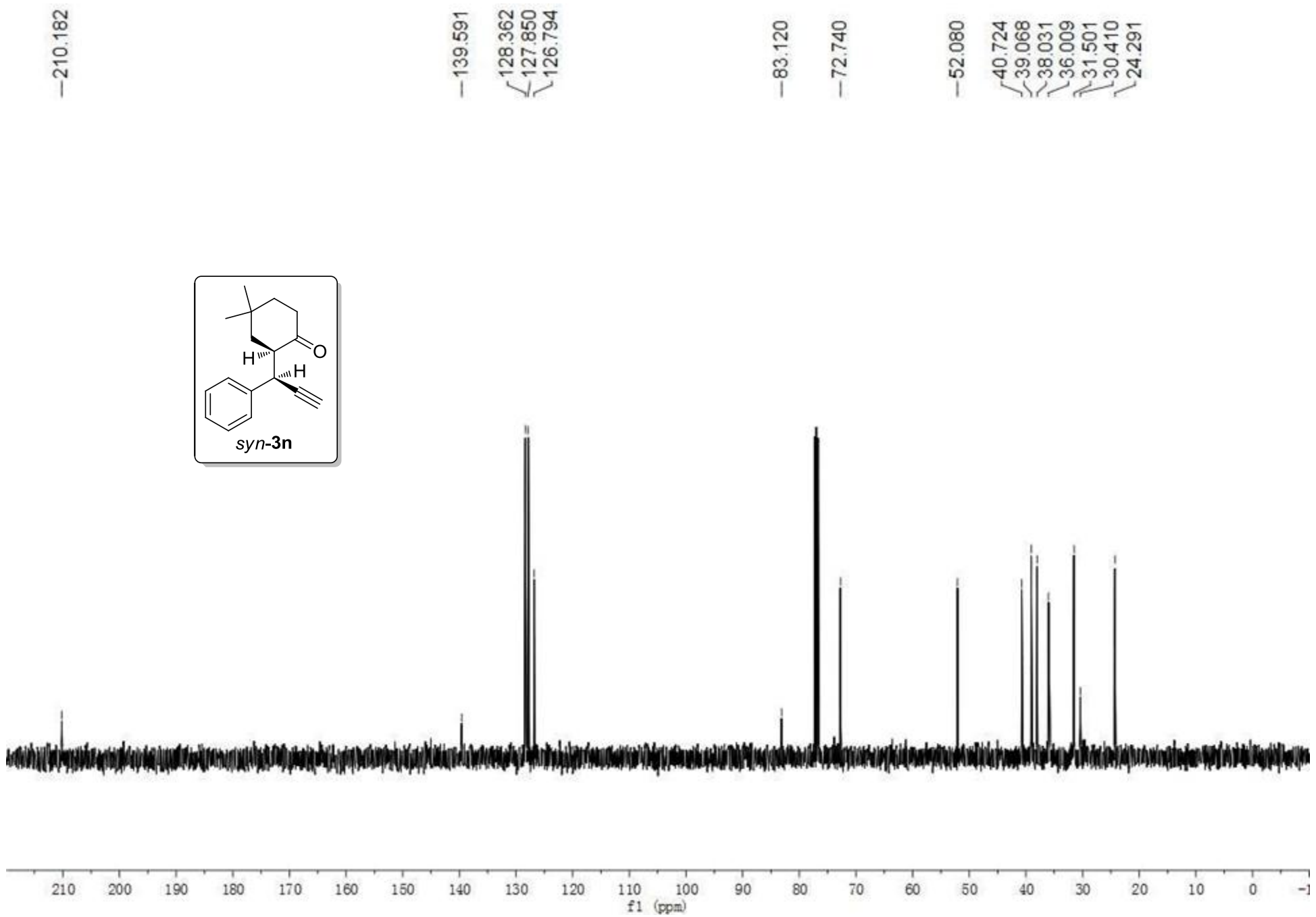

7.393
7.375
7.342
7.325
7.306
7.262
7.246
4.414
2.432
2.410
2.389
2.365
2.345
2.268
2.219
2.195
2.172
2.150
2.122
2.085
2.060
2.039
1.910
1.889
1.740
1.718
1.702
1.685
1.673
1.664
0.000
O
H
H
syn-3l
2.09
2.10
1.18
1.00
2.03
1.03
3.23
1.08
1.45
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

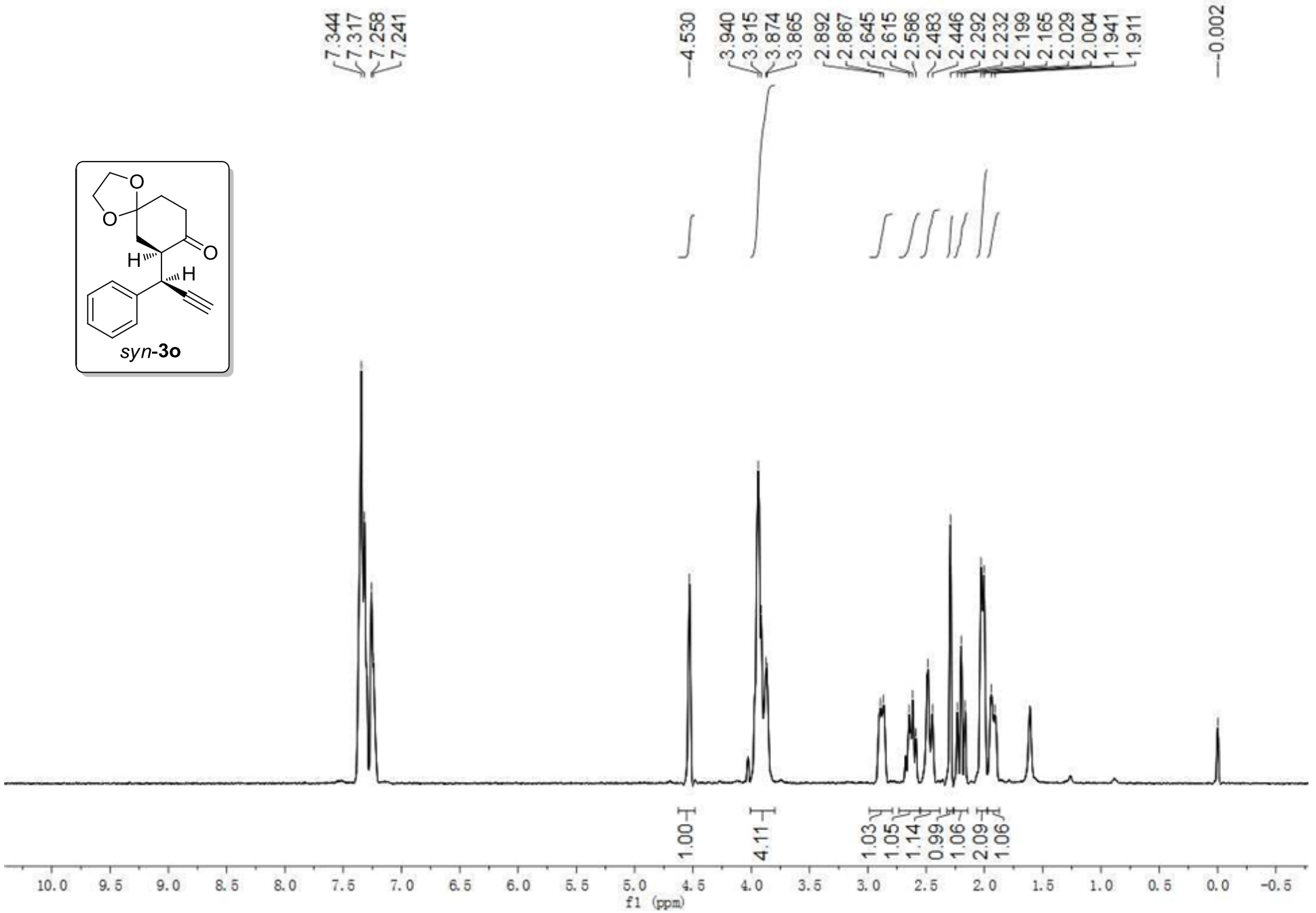

217.835
139.335
128.559
127.353
126.989
82.178
72.923
55.359
38.640
36.908
24.804
20.309
O
H
H
syn-3l
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

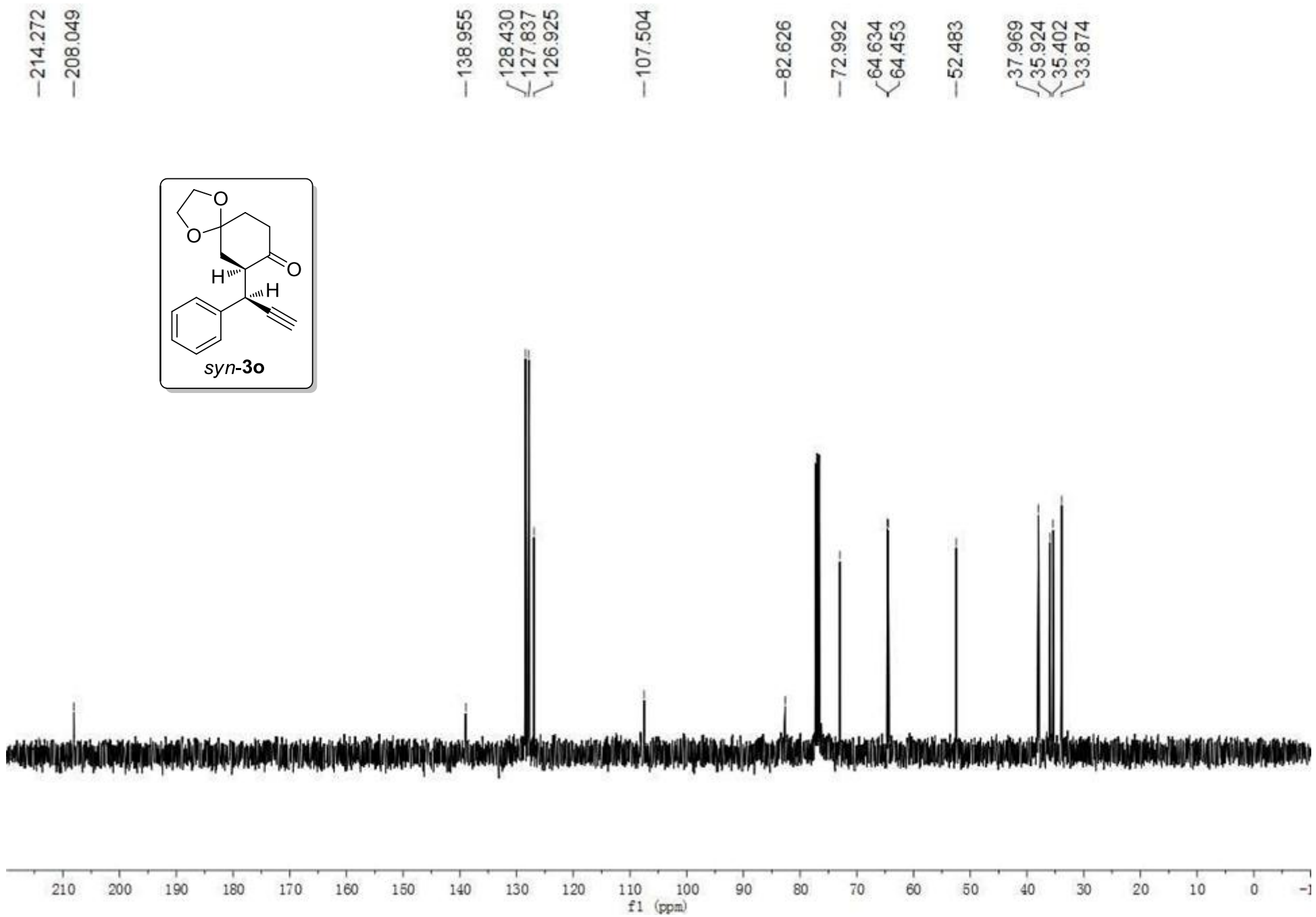

7.367
7.347
7.317
7.258
7.243
4.478
4.186
4.161
4.143
3.912
3.886
3.858
3.788
3.760
3.732
2.831
2.818
2.575
2.556
2.534
2.476
2.440
2.326
0.002
O
O
H
H
syn-3m
4.30
1.05
1.00
2.08
1.13
1.15
1.06
1.26
1.00
0.94
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

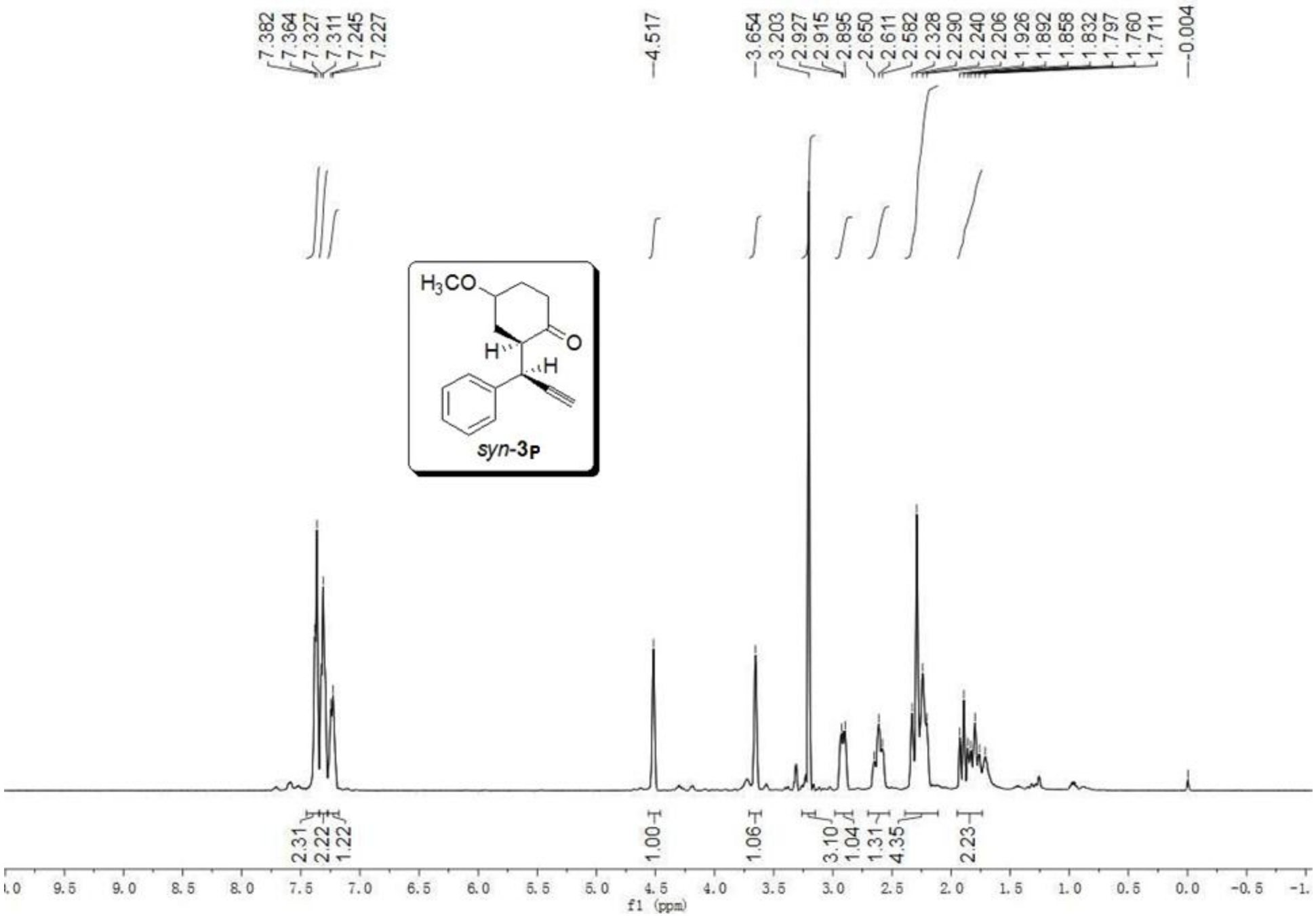

205.155
138.486
128.637
128.469
127.632
127.260
82.061
73.291
69.536
68.137
56.231
42.367
33.741
O
H
H
O
syn-3m
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

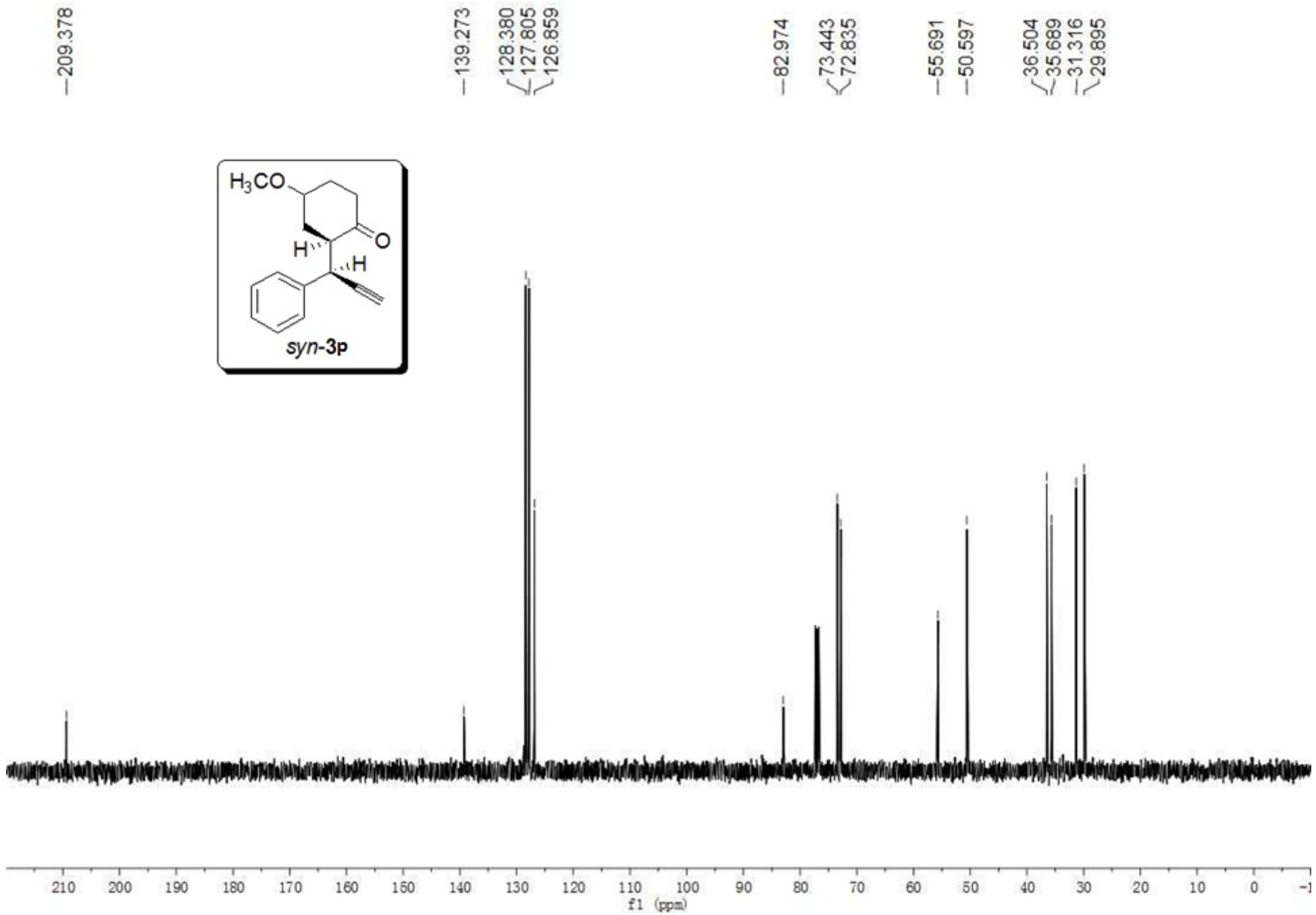

7.359
7.335
7.318
7.258
7.239
4.500
2.681
2.649
2.456
2.423
2.397
2.360
2.328
2.280
1.811
1.778
1.744
1.694
1.668
1.626
1.590
O
H
H
syn-3n
4.10
1.36
1.00
1.01
2.09
0.98
1.08
3.12
3.01
3.04
f1 (ppm)

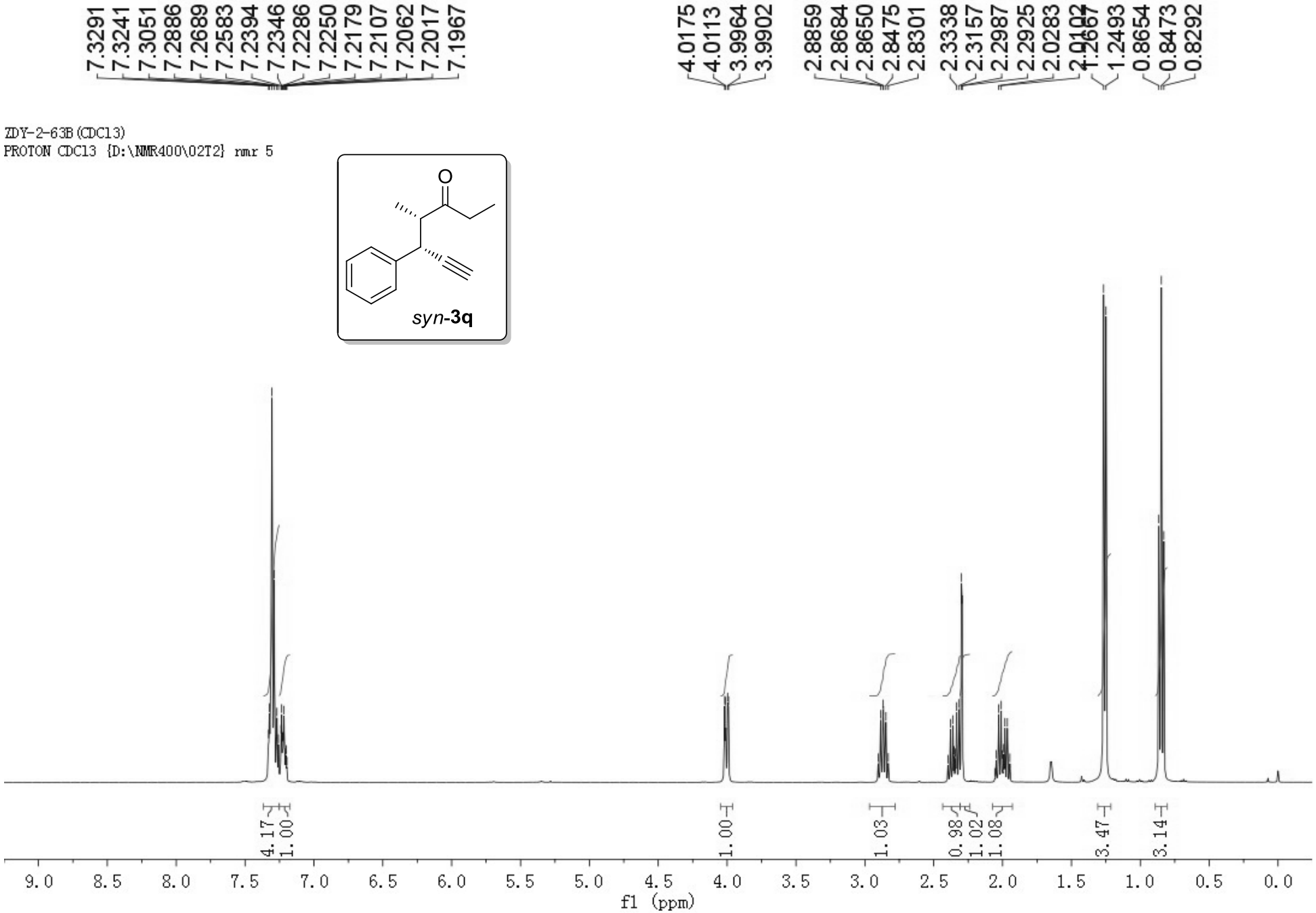

210.182
139.591
128.362
127.850
126.794
83.120
72.740
52.080
40.724
39.068
38.031
36.009
31.501
30.410
24.291
O
H
H
syn-3n
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.344
7.317
7.258
7.241
4.530
3.940
3.915
3.874
3.865
2.892
2.867
2.645
2.615
2.586
2.483
2.446
2.292
2.232
2.199
2.165
2.029
2.004
1.941
1.911
0.002
O
O
O
H
H
syn-3o
1.00
4.11
1.03
1.05
1.14
0.99
1.06
2.09
1.06
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


214.272
208.049
138.955
128.430
127.837
126.925
107.504
82.626
72.992
64.634
64.453
52.483
37.969
35.924
35.402
33.874
O
O
O
H
H
syn-3o
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

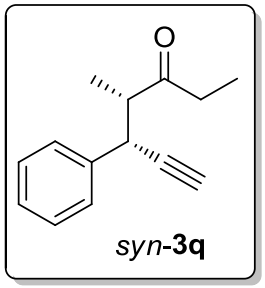

7.382
7.364
7.327
7.311
7.245
7.227
4.517
3.654
3.203
2.927
2.915
2.895
2.650
2.611
2.582
2.328
2.290
2.240
2.206
1.926
1.892
1.858
1.832
1.797
1.760
1.711
0.004
H3CO
O
H
H
syn-3P
2.31
2.22
1.22
1.00
1.06
3.10
1.04
1.31
4.35
2.23
f1 (ppm)


209.378
139.273
128.380
127.805
126.859
82.974
73.443
72.835
55.691
50.597
36.504
35.689
31.316
29.895
H3CO
O
H
H
syn-3p
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

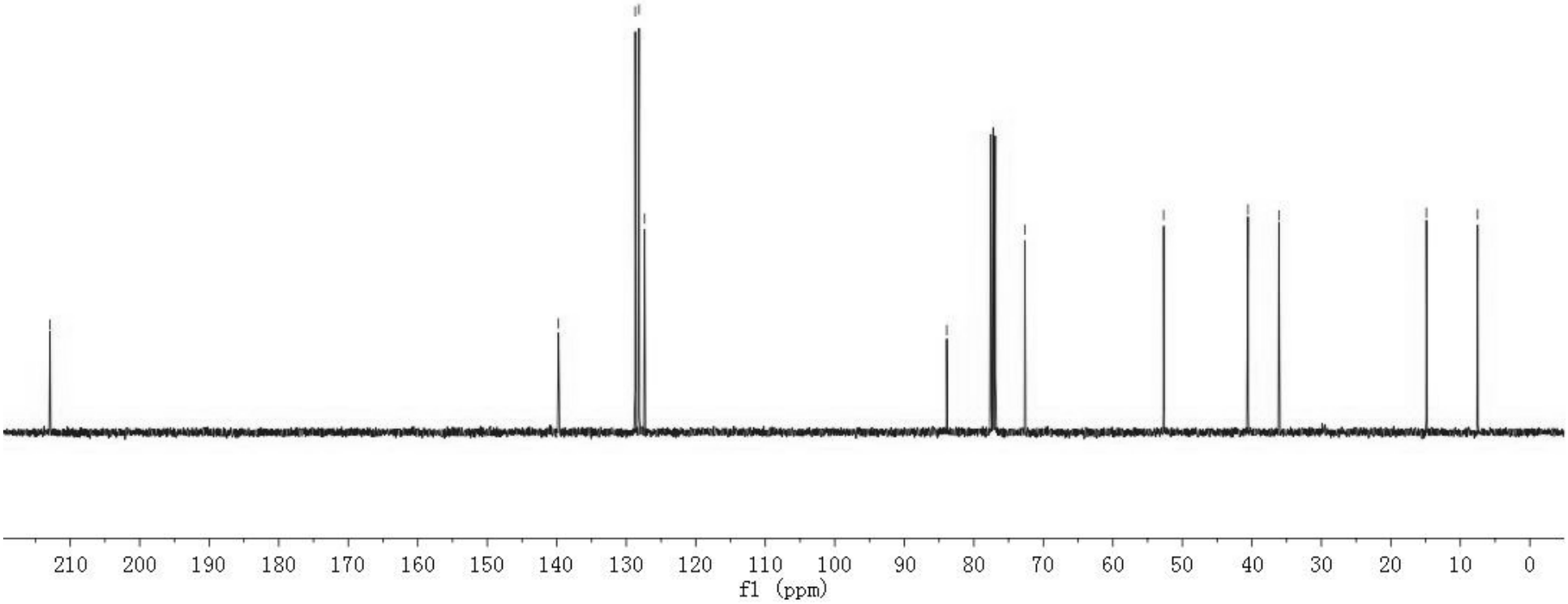

7.3291
7.3241
7.3051
7.2886
7.2689
7.2583
7.2394
7.2346
7.2286
7.2250
7.2179
7.2107
7.2062
7.2017
7.1967
4.0175
4.0113
3.9964
3.9902
2.8859
2.8684
2.8650
2.8475
2.8301
2.3338
2.3157
2.2987
2.2925
2.0283
1.2493
0.8654
0.8473
0.8292
ZDY-2-63B(CDCl3)
PROTON CDCl3 {D:\NMR400\02T2} rmr 5
O
syn-3q
4.17
1.00
1.00
1.03
0.98
1.02
1.08
3.47
3.14
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

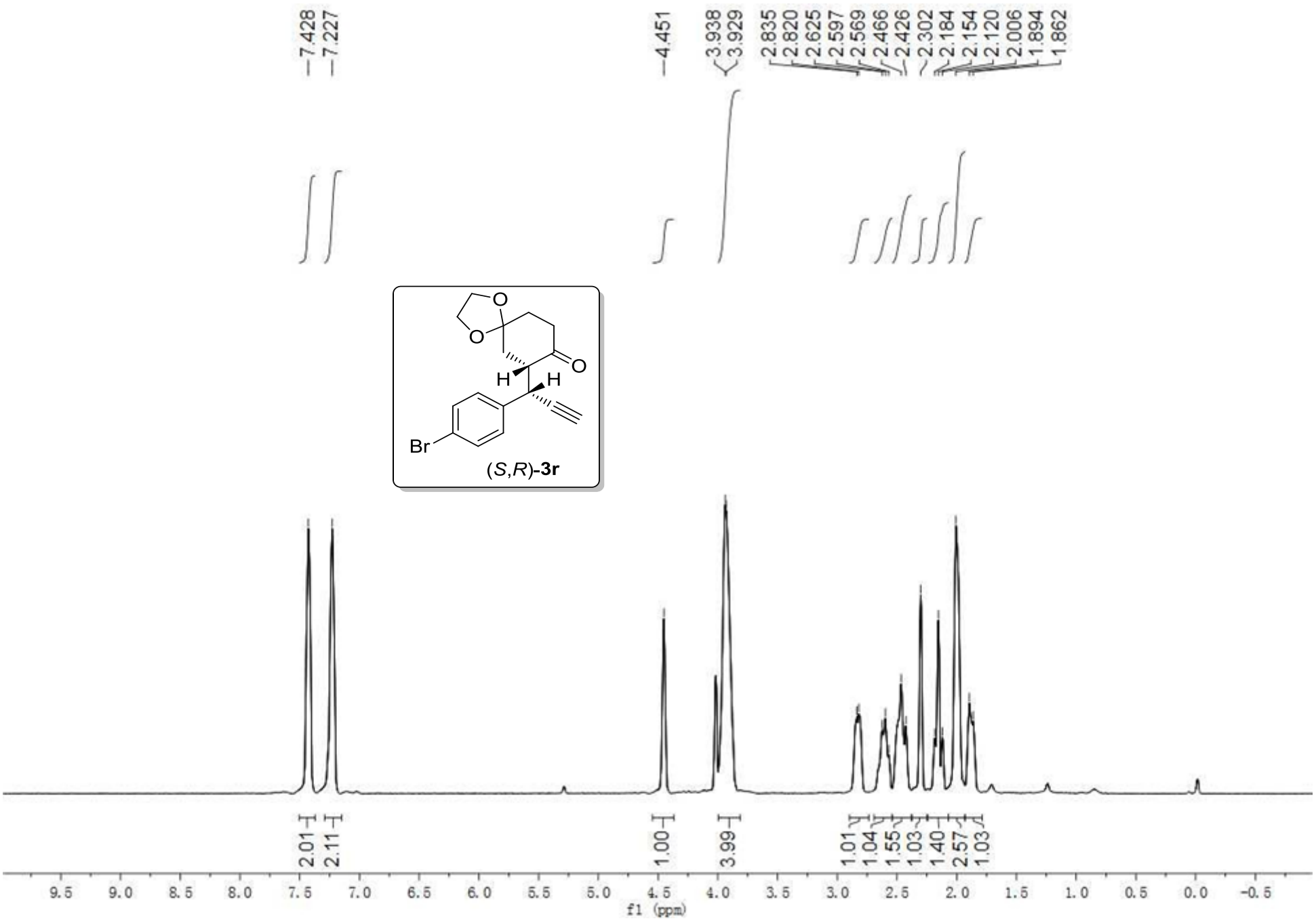
212.91
139.75
128.72
128.15
127.36
83.90
72.65
52.69
40.54
36.11
14.88
7.51

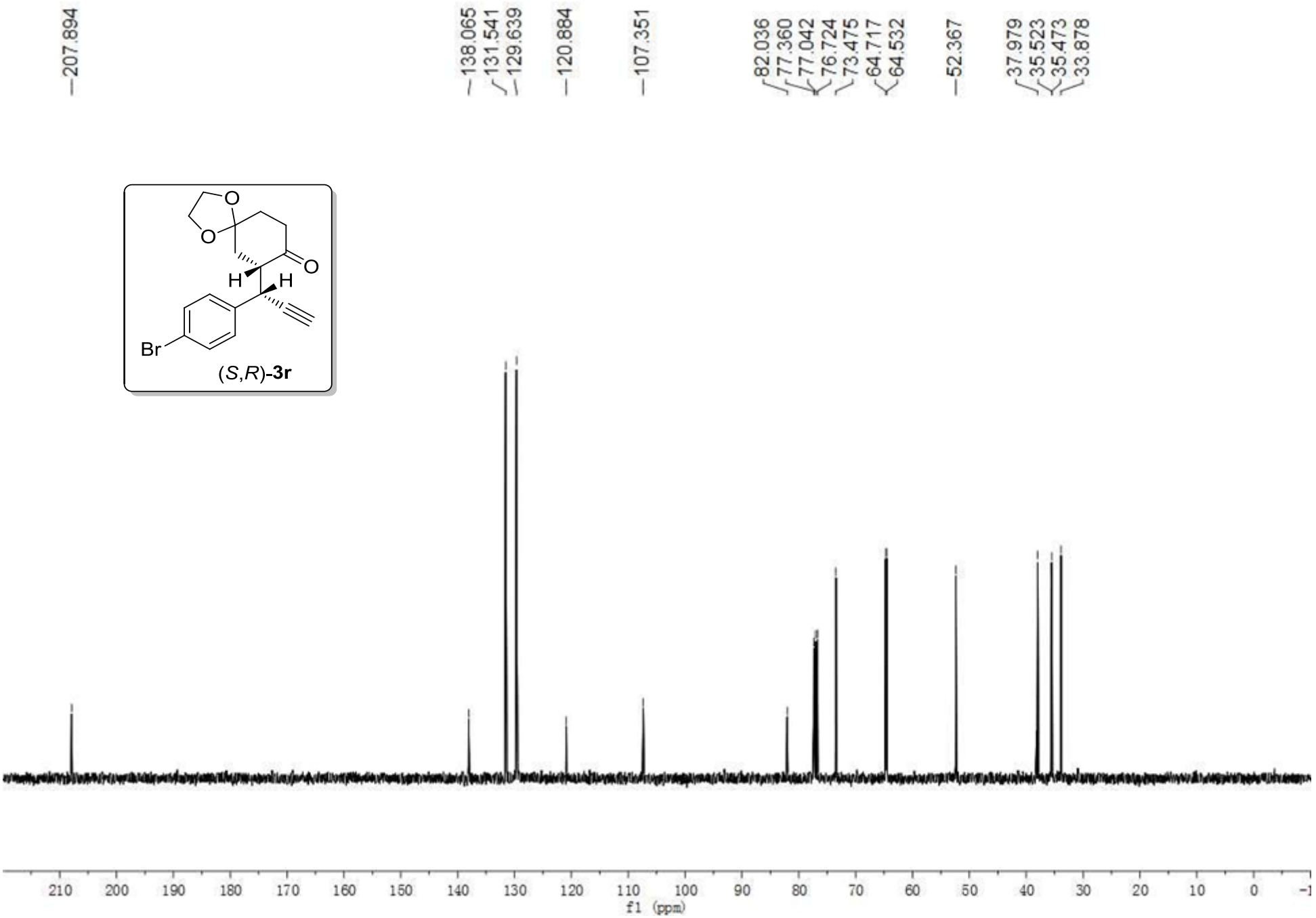
ZDY-2-63B(CDCl3)
C13CPD CDCl3 {D:\NMR400\02T2} rmr 5



syn-**3q**




7.428
7.227
4.451
3.938
3.929
2.835
2.820
2.625
2.597
2.569
2.466
2.426
2.302
2.184
2.154
2.120
2.006
1.894
1.862
O
O
O
H
H
Br
(S,R)-3r
2.01
2.11
1.00
3.99
1.01
1.04
1.55
1.03
1.40
2.57
1.03
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


207.894
138.065
131.541
129.639
120.884
107.351
82.036
77.360
77.042
76.724
73.475
64.717
64.532
52.367
37.979
35.523
35.473
33.878
O
O
O
H
H
Br
(S,R)-3r
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)