Supporting Information

Highly Efficient and Enantioselective Synthesis of Chiral Lactones via Ir-Catalysed Asymmetric Hydrogenation of Ketoesters

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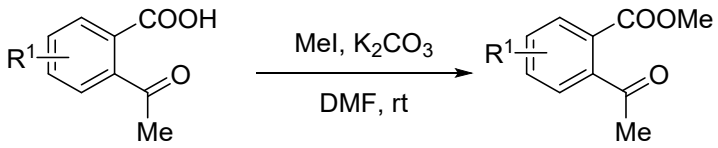
Content

1. General Information

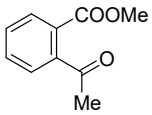
Unless otherwise mentioned, all experiments and manipulations which are sensitive to moisture or air were carried out under an atmosphere of argon in a glovebox or using standard Schlenk techniques. Solvents were dried with standard procedures and degassed with N_2. Flash column chromatography was performed using Tsingdao silica gel (60, particle size 200-300 mesh). NMR spectra were recorded on a Bruker DPX 400 spectrometer at 400 MHz for ^1H NMR, 101 MHz for ^{13}C NMR in $CDCl_3$ with tetramethylsilane (TMS) as internal standard. Date is reported as: multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet) and chemical shifts are reported in ppm and coupling constants are given in Hz. Chemical shifts were reported relative to TMS (0.00 ppm) or $CHCl_3$ (7.26 ppm) for ^1H NMR and relative to $CDCl_3$ (77.0 ppm) for ^{13}C NMR. Optical rotations $[\alpha]_D$ were determined using a PERKIN ELMER polarimeter 343 instrument. HPLC analyses were performed using Daicel chiral column on an Agilent 1260 Series HPLC instrument.

2. General procedure for synthesis of benzo-fused ketoesters

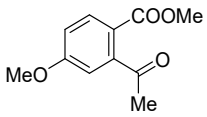


1e and benzo-fused ketoacids were prepared as described in the literature. The relevant data see the literature.[1]

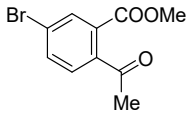
Others were prepared with the following steps. MeI (3.0 equiv) was added to the stirred solution of benzo-fused ketoacids (1.0 equiv) and K_2CO_3 (1.5 equiv) in DMF. The resulting reaction mixture was stirred in room temperature for 6 hours. After completion of the reaction, extracted with DCM and washed with water for 3 times. Organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on silica gel to afford **1a**, **1b**, **1c** and **1d** in 90% - 99% yield.



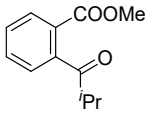
Methyl 2-acetylbenzoate (1a) [1]: **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.86 (dd, *J* = 7.7, 1.3 Hz, 1H), 7.57 (td, *J* = 7.5, 1.3 Hz, 1H), 7.51 (td, *J* = 7.6, 1.3 Hz, 1H), 7.43 (dd, *J* = 7.6, 1.3 Hz, 1H), 3.90 (s, 3H), 2.55 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.91, 167.48, 142.71, 132.05, 130.09, 129.72, 128.86, 126.51, 52.58, 29.98.



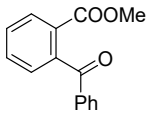
Methyl 2-acetyl-4-methoxybenzoate (1b) [1]: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.90 (d, *J* = 8.7 Hz, 1H), 6.93 (dd, *J* = 8.7, 2.6 Hz, 1H), 6.76 (d, *J* = 2.6 Hz, 1H), 3.86 (s, 6H), 2.50 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 204.01, 166.31, 162.88, 146.58, 132.29, 119.48, 114.48, 111.32, 55.68, 52.24, 30.69.



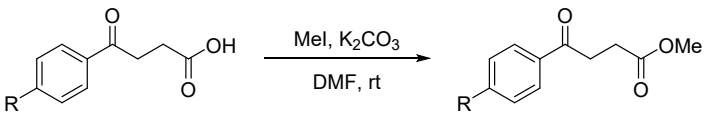
Methyl 2-acetyl-5-bromobenzoate (1c) [1]: **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.97 (s, 1H), 7.70 (d, *J* = 8.2 Hz, 1H), 7.32 (d, *J* = 8.2 Hz, 1H), 3.91 (s, 3H), 2.53 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 201.52, 166.26, 141.01, 134.91, 132.68, 130.87, 128.20, 124.45, 52.89, 29.78.



Methyl 2-isobutyrylbenzoate (1d) [1]: **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.93 (t, *J* = 6.5 Hz, 1H), 7.56 (t, *J* = 6.8 Hz, 1H), 7.49 (t, *J* = 6.7 Hz, 1H), 7.31 (t, *J* = 7.0 Hz, 1H), 3.88 (s, 3H), 3.12 – 3.01 (m, 1H), 1.23 – 1.16 (m, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 210.17, 166.98, 143.12, 132.16, 130.10, 129.49, 128.39, 126.81, 52.56, 40.73, 18.52.

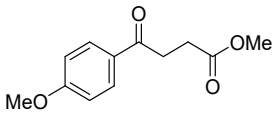


Methyl 2-benzoylbenzoate (1f) [1]: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.05 (dd, J = 7.6, 1.1 Hz, 1H), 7.75 (dd, J = 8.4, 1.4 Hz, 2H), 7.65 (td, J = 7.5, 1.4 Hz, 1H), 7.60 – 7.53 (m, 2H), 7.47 – 7.39 (m, 3H), 3.61 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.17, 166.54, 141.82, 137.33, 133.21, 132.55, 130.23, 129.77, 129.39, 128.65, 127.94, 52.31.

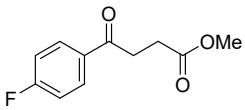


Compound **1g** was commercially available. Others are prepared with the following steps. MeI (3.0 equiv) was added to the stirred solution of γ-ketoacids (1.0 equiv) and K_2CO_3 (1.5 equiv) in DMF. The resulting reaction mixture was stirred in room temperature for 6 hours. After completion of the reaction, extracted with DCM and washed with water for 3 times. Organic layer was dried over anhydrous Na_2SO_4

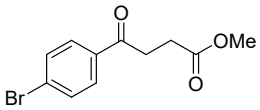
and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on silica gel to afford **1h**, **1i** and **1j** in 92% - 99% yield.



Methyl 4-(4-methoxyphenyl)-4-oxobutanoate (1h) [2]**: ^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.93 (d, *J* = 8.9 Hz, 2H), 6.90 (d, *J* = 8.9 Hz, 2H), 3.83 (s, 3H), 3.67 (s, 3H), 3.24 (t, *J* = 6.7 Hz, 2H), 2.72 (t, *J* = 6.7 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 196.56, 173.50, 163.58, 130.28, 129.62, 113.74, 55.46, 51.78, 33.00, 28.10.

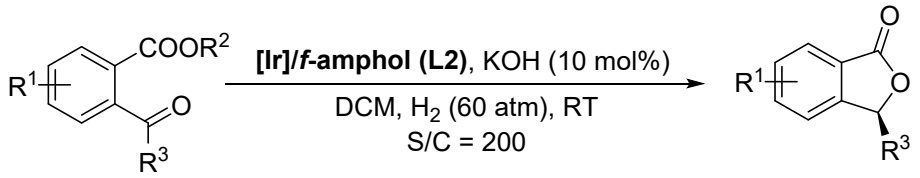


Methyl 4-(4-fluorophenyl)-4-oxobutanoate (1i) [2]**: ^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.97 (dd, *J* = 8.7, 5.6 Hz, 2H), 7.09 (t, *J* = 8.6 Hz, 2H), 3.66 (s, 3H), 3.25 (t, *J* = 6.6 Hz, 2H), 2.72 (t, *J* = 6.6 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 196.46, 173.27, 167.06, 164.53, 132.99, 132.96, 130.70, 130.61, 115.80, 115.58, 51.81, 33.25, 27.93.



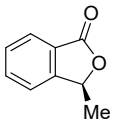
Methyl 4-(4-bromophenyl)-4-oxobutanoate (1j) [2]**: ^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 8.6 Hz, 2H), 7.60 (d, *J* = 8.6 Hz, 2H), 3.69 (s, 3H), 3.26 (t, *J* = 6.6 Hz, 2H), 2.75 (t, *J* = 6.6 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.08, 173.23, 135.25, 131.96, 129.57, 128.44, 51.90, 33.34, 27.92.

3. General procedure for asymmetric hydrogenation of benzo-fused ketoesters



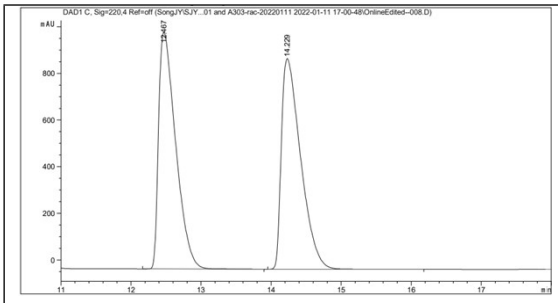
1a-1f **2a-2f**

To a 4.0 mL vial was added the catalyst precursor $[Ir(COD)Cl]_2$ (6.72 mg, 1.0×10^{-2} mmol), ligand (R_C,S_C,R_C,S_{FC})-*f*-amphol (16.9 mg, 2.2×10^{-2} mmol) and anhydrous DCM (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2.0 h at 25 °C giving orange solution. And then 0.1 mmol of benzo-fused ketoesters, KOH (0.56 mg, 0.01 mmol) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous DCM was added as solvent and a solution of Ir/(R_C,S_C,R_C,S_{FC})-*f*-amphol in anhydrous DCM (50 μL) was added via an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from glovebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 60 atm H_2. The reaction solution was stirred at room temperature (25 °C - 30 °C) until for 24 h, then released pressure carefully. DCM was removed under reduced pressure. The solution of reaction mixture was purified by a flash chromatography on a silica gel with ethyl acetate and the solvent was removed under reduced pressure. The ee value were determined by chiral HPLC analysis of the hydrogenation product chiral lactones directly. The absolute configurations of chiral lactones were assigned by analogy.



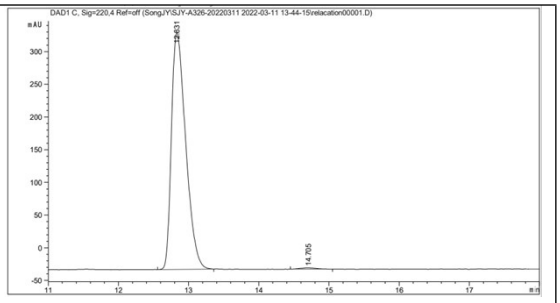
(*S*)-3-methylisobenzofuran-1(3*H*)-one (2a) [1]**:** 99% yield, 98% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.90 (d, *J* = 7.7 Hz, 1H), 7.68 (t, *J* = 7.5 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.44 (d, *J* = 7.6 Hz, 1H), 5.57 (q, *J* = 6.7 Hz, 1H), 1.64 (d, *J* = 6.7 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 170.49, 151.20, 134.05, 129.08, 125.82, 125.73, 121.54,

77.75, 20.41. **Optical Rotation**: $[\alpha]_D^{22}$ = -8.2 (c = 0.73, MeOH). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 12.83 min; (minor) = 14.71 min.



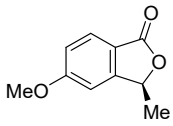
Signal 1: DAD1 C, Sig=220,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.467	BB	0.2591	1.71505e4	1015.28760	49.9073
2	14.229	BB	0.2904	1.72142e4	902.90576	50.0927

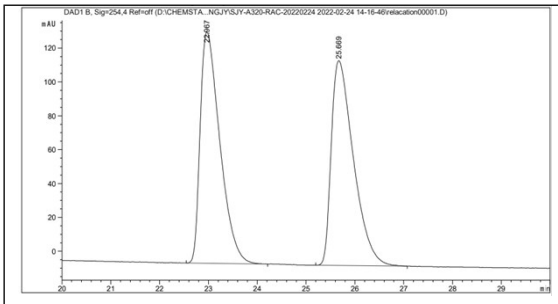


Signal 1: DAD1 C, Sig=220,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.831	BB	0.2190	5121.25879	362.12415	99.2893
2	14.705	BB	0.2033	36.65837	2.18965	0.7107

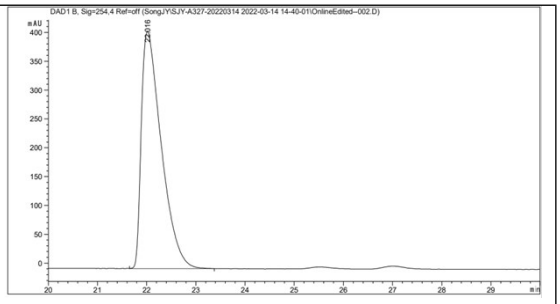


(*S*)-5-methoxy-3-methylisobenzofuran-1(3*H*)-one (2b) [1]**:** 71% yield, 99% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.5 Hz, 1H), 7.02 (d, *J* = 8.4 Hz, 1H), 6.84 (s, 1H), 5.47 (q, *J* = 7.4, 6.1 Hz, 1H), 3.90 (s, 3H), 1.61 (d, *J* = 6.7 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 170.32, 164.86, 154.11, 127.37, 118.23, 116.40, 105.78, 77.14, 55.98, 20.56. **Optical Rotation**: $[\alpha]_D^{22}$ = -52.0 (c = 0.40, MeOH). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 254 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 22.02 min.



Signal 1: DAD1 B, Sig=254,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.967	BB	0.4287	3825.72827	136.63116	50.0217
2	25.669	BB	0.4785	3822.40137	121.00867	49.9783



Signal 1: DAD1 B, Sig=254,4 Ref=off

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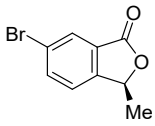
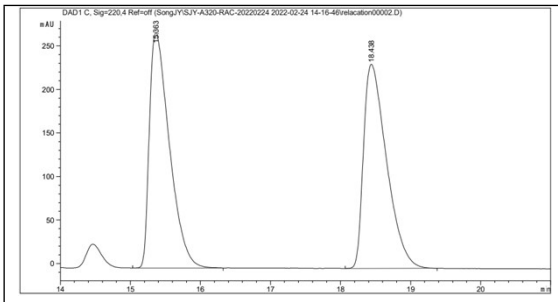
1	22.016	BB	0.4206	1.15676e4	410.71616	100.0000



(*S*)-6-bromo-3-methylisobenzofuran-1(3*H*)-one (2c) [1]**:** 95% yield, 98% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 1.8 Hz, 1H), 7.79 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.32 (d, *J* = 8.1 Hz, 1H), 5.53 (q, *J* = 6.7 Hz, 1H), 1.63 (d, *J* = 6.7 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.83, 149.79, 137.12, 128.73, 127.96, 123.18, 123.07, 77.69, 20.27.

Optical Rotation: $[\alpha]_D^{22}$ = -74.0 (c = 0.40, MeOH). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 15.17 min; (minor) = 18.80 min.

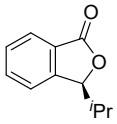


Signal 1: DAD1 C, Sig=220,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.363	BB	0.3032	5363.03662	270.64423	50.0461
2	18.438	BB	0.3461	5353.14795	234.68814	49.9539

Signal 1: DAD1 C, Sig=220,4 Ref=off

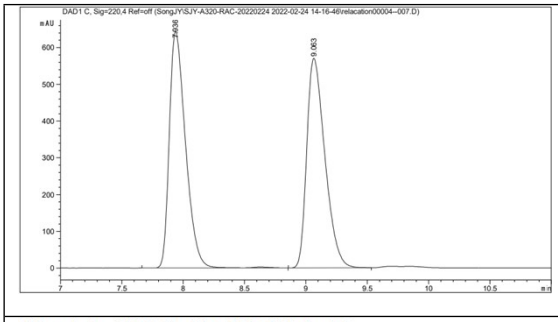
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.172	BB	0.2978	1.13081e4	564.21313	99.1858
2	18.796	BB	0.2528	92.82758	4.65161	0.8142



(*S*)-3-isopropylisobenzofuran-1(3*H*)-one (2d) [1]**:** 91% yield, 99% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.90 (d, J = 7.6 Hz, 1H), 7.66 (t, J = 8.1 Hz, 1H), 7.52 (t, J = 7.1 Hz, 1H), 7.44 (d, J = 7.7 Hz, 1H), 5.37 (d, J = 3.7 Hz, 1H), 2.28 (pd, J = 6.9, 3.7 Hz, 1H), 1.13 (d, J = 6.9 Hz, 3H), 0.81 (d, J = 6.9 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 170.97, 149.02, 133.96, 129.19, 126.92, 125.84, 122.23, 85.79, 32.52, 18.83, 15.81.

Optical Rotation: $[\alpha]_D^{22}$ = -2.9 (c = 0.60, MeOH). The enantiomeric excess was

determined by HPLC on Chiral OJ-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 7.87 min.



Signal 1: DAD1 C, Sig=220,4 Ref=off

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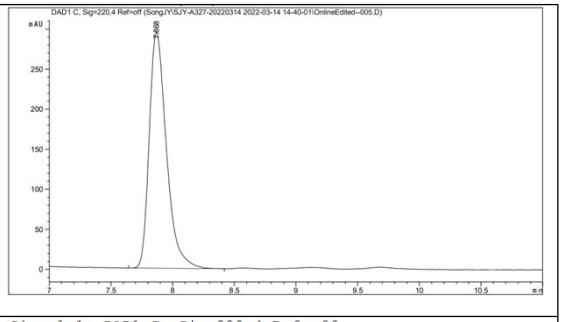
2	9.063	BB	0.1579	5860.63281	570.46741	49.7778



Signal 1: DAD1 C, Sig=220,4 Ref=off

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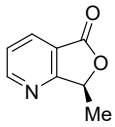
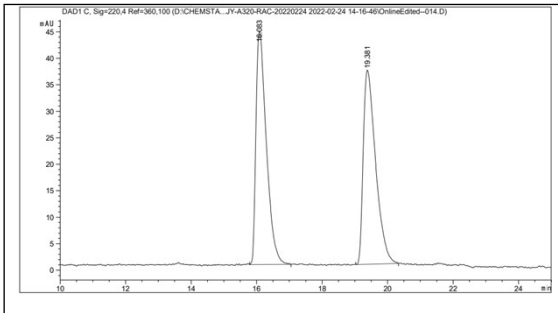
1	7.868	BB	0.1491	2854.02222	294.52060	100.0000

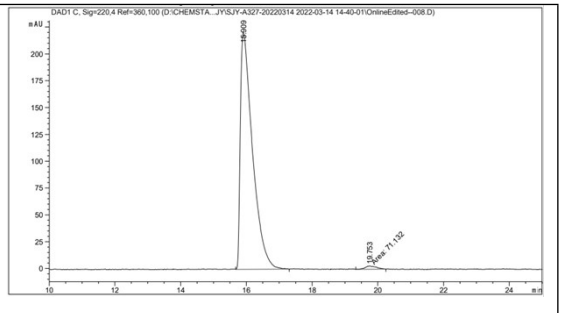


(*S*)-7-methylfuro[3,4-b]pyridin-5(7*H*)-one (2e) [1]**:** 99% yield, 97% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.89 (d, *J* = 4.6 Hz, 1H), 7.86 (d, *J* = 7.8 Hz, 1H), 7.57 (dd, *J* = 8.1, 4.5 Hz, 1H), 5.62 (q, *J* = 6.7 Hz, 1H), 1.68 (d, *J* = 6.7 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 166.92, 151.55, 143.82, 143.50, 129.34, 126.20, 74.83, 19.18. **Optical Rotation**: $[\alpha]_D^{22}$ = -22.1 (c = 1.00, MeOH). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 75:25; flow 1.0 mL/min; t_R (major) = 15.91 min; (minor) = 19.75 min.



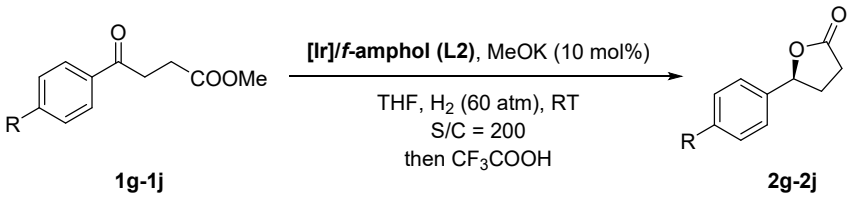
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.083	BB	0.3366	967.30981	43.98272	50.1340
2	19.381	BB	0.3884	962.13800	36.63009	49.8660



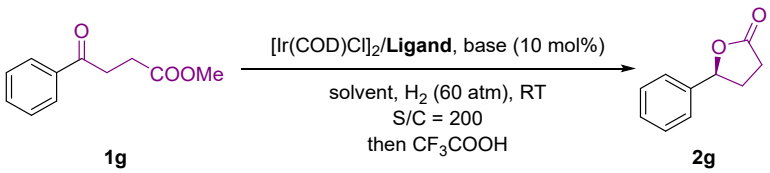
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.909	BV R	0.3798	5677.11914	220.93015	98.7625
2	19.753	MM	0.3947	71.13204	3.00360	1.2375



To a 4.0 mL vial was added the catalyst precursor $[Ir(COD)Cl]_2$ (6.72 mg, 1.0×10^{-2} mmol), ligand (R_C,S_C,R_C,S_{FC})-*f*-amphol (16.9 mg, 2.2×10^{-2} mmol) and anhydrous IPA (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2.0 h at 25 °C giving orange red solution. And then 0.1 mmol of γ-ketoesters, MeOK (0.70 mg, 0.01 mmol) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous THF was added as solvent and a solution of Ir/(R_C,S_C,R_C,S_{FC})-*f*-amphol in anhydrous IPA (50 μL) was added via an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from glovebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 60 atm H_2. The reaction solution was stirred at room temperature (25 °C - 30 °C) until for 24 h, then released pressure carefully. THF was removed under reduced pressure. CF_3COOH was added and the resulting reaction mixture was stirred in room temperature for 2 hours. Then, the solution of reaction mixture was purified by a flash chromatography on a silica gel with ethyl acetate and the solvent was removed under reduced pressure. The ee value were determined by chiral HPLC analysis of the hydrogenation product chiral lactones directly. The absolute configurations of chiral lactones were assigned by analogy.

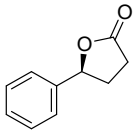
Table 1 Screening of reaction conditions for reducing methyl 4-oxo-4-phenylbutanoate (**1g**)[a]



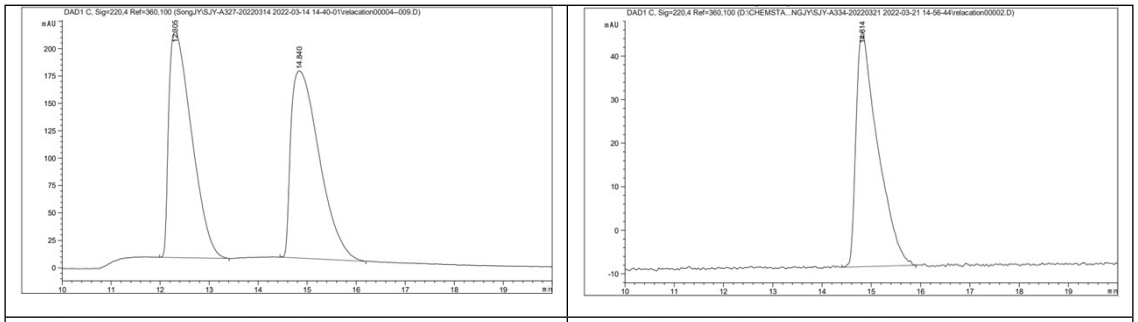
Entry	Ligand	Solvent	Base	Conv. (%)[b]	ee (%)[c]
1[d]	**L1**	DCM	Cs_2CO_3	6%	98%
2[d]	**L2**	DCM	Cs_2CO_3	33%	98%
3[d]	**L3**	DCM	Cs_2CO_3	NR	--
4	**L2**	EtOH	Cs_2CO_3	98%	99%

5	**L2**	^{i}PrOH	Cs_2CO_3	57%	99%
6	**L2**	toluene	Cs_2CO_3	72%	99%
7	**L2**	THF	Cs_2CO_3	99%	99%
8	**L2**	THF	MeOK	99%	99%
9	**L2**	THF	KOH	99%	99%
10	**L2**	THF	^{t}BuOK	99%	99%

[a]Reaction conditions: **1g** (0.10 mmol), $[Ir(COD)Cl]_2$ (0.0025 mmol), ligand (0.005 mmol), base (0.01 mmol), solvent (1 mL), H_2 (60 atm), RT, 24 h; [b]Determined by ^{1}H NMR analysis of the crude reaction mixture; [c]Determined by HPLC analysis using a chiral stationary phase; [d]S/C = 500.



(*S*)-5-phenyldihydrofuran-2(3*H*)-one (2g) [1]**:** 99% yield, 99% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 – 7.26 (m, 5H), 5.52 (t, *J* = 7.0 Hz, 1H), 2.66 (d, *J* = 4.7 Hz, 3H), 2.20 (ddd, *J* = 12.5, 8.5, 4.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 177.15, 139.34, 128.80, 128.49, 125.30, 81.36, 30.97, 29.00. **Optical Rotation**: $[\alpha]_D^{24}$ = -20.2 (c = 0.60, MeOH). The enantiomeric excess was determined by HPLC on Chiral AS-H column, 220 nm, 25 °C, *n*-hexane: *i*-PrOH = 80:20; flow 1.0 mL/min; t_R (major) = 14.81 min.

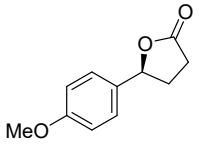


Signal 1: DAD1 C, Sig=220,4 Ref=360,100

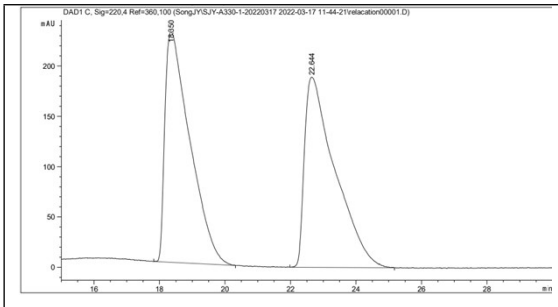
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.305	BB	0.4540	6636.75928	205.90250	49.0665
2	14.840	BB	0.5586	6889.28711	170.78127	50.9335

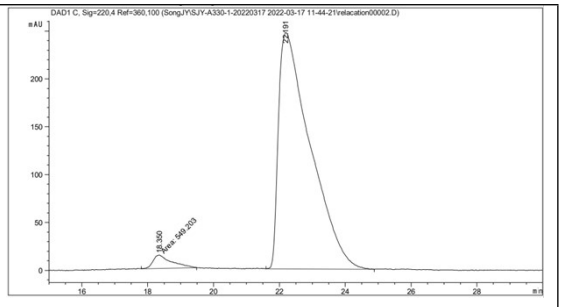
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.814	BV R	0.4238	1647.21948	53.71539	100.0000



(*S*)-5-(4-methoxyphenyl)dihydrofuran-2(3*H*)-one (2h) [1]**:** 99% yield, 94% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.30 – 7.22 (m, 2H), 6.91 (d, J = 8.7 Hz, 2H), 5.46 (dd, J = 8.4, 6.0 Hz, 1H), 3.81 (s, 3H), 2.69 – 2.55 (m, 3H), 2.26 – 2.13 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 177.06, 159.79, 131.15, 126.97, 114.15, 81.41, 55.36, 30.90, 29.24. **Optical Rotation**: $[\alpha]_D^{24}$ = -0.6 (c = 1.00, MeOH). The enantiomeric excess was determined by HPLC on Chiral AS-H column, 220 nm, 25 °C, *n*-hexane: *i*-PrOH = 75:25; flow 1.0 mL/min; t_R (major) = 22.19 min; (minor) = 18.35 min.



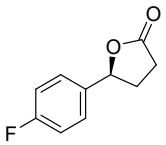


Signal 1: DAD1 C, Sig=220,4 Ref=360,100

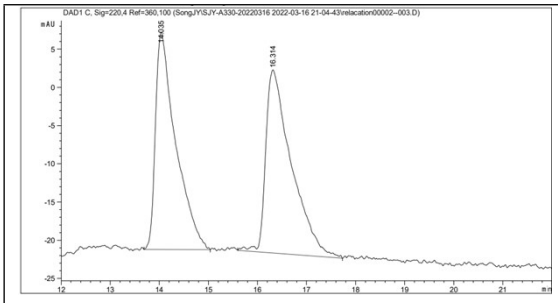
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.350	VB R	0.6987	1.21421e4	228.96072	49.8268
2	22.644	BV R	0.8413	1.22265e4	188.85535	50.1732

Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.350	MM	0.6528	549.20264	14.02069	3.2136
2	22.191	BV R	0.8694	1.65405e4	246.95361	96.7864

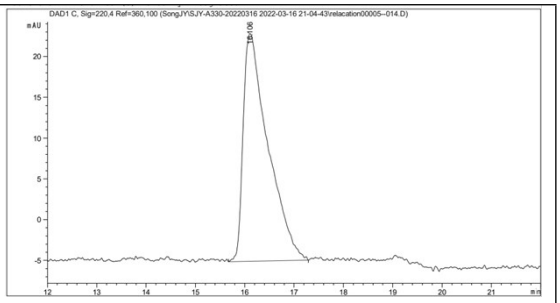


(*S*)-5-(4-fluorophenyl)dihydrofuran-2(3*H*)-one (2i) [1]**:** 99% yield, 99% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 (dd, *J* = 8.7, 5.1 Hz, 2H), 7.08 (t, *J* = 8.6 Hz, 2H), 5.49 (dd, *J* = 8.4, 5.8 Hz, 1H), 2.73 – 2.59 (m, 3H), 2.25 – 2.10 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 176.64, 163.92, 161.47, 135.11, 135.08, 127.25, 127.17, 115.87, 115.66, 80.67, 31.05, 29.02. **Optical Rotation**: $[\alpha]_D^{24}$ = -5.4 (c = 0.30, MeOH). The enantiomeric excess was determined by HPLC on Chiral AS-H column, 220 nm, 25 °C, *n*-hexane: *i*-PrOH = 80:20; flow 1.0 mL/min; t_R (major) = 16.11 min.



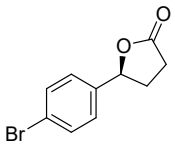
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.035	BB	0.3867	815.43951	28.42631	48.3692
2	16.314	VV R	0.4878	870.42578	23.96121	51.6308

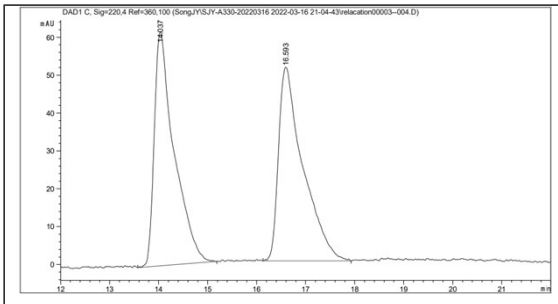


Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.106	BV R	0.4860	975.80823	27.90480	100.0000

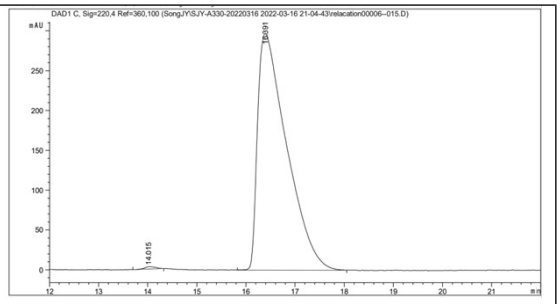


(*S*)-5-(4-bromophenyl)dihydrofuran-2(3*H*)-one (2j) [1]**:** 99% yield, 99% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 (d, J = 8.5 Hz, 2H), 7.21 (d, J = 8.4 Hz, 2H), 5.53 – 5.40 (m, 1H), 2.70 – 2.61 (m, 3H), 2.19 – 2.10 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) 13C NMR (101 MHz, CDCl3) δ 176.80, 138.37, 131.96, 126.98, 122.45, 80.57, 30.91, 28.89. **Optical Rotation**: $[\alpha]_D^{24}$ = -8.3 (c = 1.00, MeOH). The enantiomeric excess was determined by HPLC on Chiral AS-H column, 220 nm, 25 °C, *n*-hexane: *i*-PrOH = 80:20; flow 1.0 mL/min; t_R (major) = 16.39 min; (minor) = 14.02 min.



Signal 1: DAD1 C, Sig=220,4 Ref=360,100

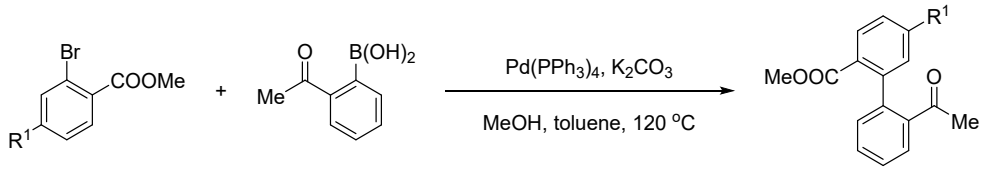
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.037	BB	0.4008	1740.67493	61.77277	49.5518
2	16.593	BV R	0.4805	1772.16614	51.11333	50.4482



Signal 1: DAD1 C, Sig=220,4 Ref=360,100

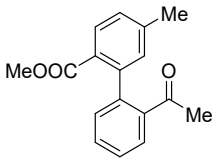
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.015	BB	0.1984	47.12843	2.98094	0.3852
2	16.391	VB R	0.5569	1.21889e4	296.96063	99.6148

4. General procedure for synthesis of biaryl bridged ketoesters

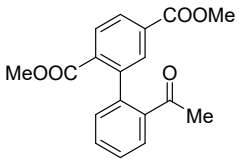


Compound **3b** and **3i** are prepared with the following steps. Others were prepared as described in the literature. The relevant data see the literature.[3]

To a solution of methyl 2-bromobenzoate (1.0 equiv) and arylboronic acid (1.0 equiv) in toluene (6 mL) and MeOH (3 mL), aqueous K_2CO_3 (c = 0.276 g/mL, 2 mL) was added. The mixture was degassed by bubbling with Ar for 20 min. $Pd(PPh_3)_4$ (0.05 equiv) was then added and the resulted mixture was allowed to stir at 120 °C for 8 h. The reaction mixture was then cool to room temperature and filtered through a thin pad of celite (eluted with EA). The filtrate was washed with saturated aqueous $NaHCO_3$ and the organic layers were combined and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure and the crude product was purified by column chromatography (eluent: PE/EA = 10/1 to 4/1).

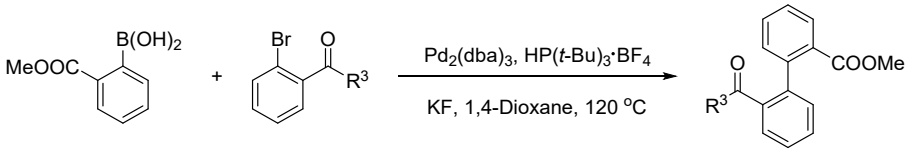


Methyl 2'-acetyl-5-methyl-[1,1'-biphenyl]-2-carboxylate (3b) [3]: ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.90 (d, *J* = 8.0 Hz, 1H), 7.71 (d, *J* = 8.5 Hz, 1H), 7.48 – 7.39 (m, 2H), 7.23 (d, *J* = 8.0 Hz, 1H), 7.15 (d, *J* = 7.5 Hz, 1H), 7.01 (s, 1H), 3.63 (s, 3H), 2.39 (s, 3H), 2.18 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 201.86, 167.37, 142.97, 142.34, 141.15, 138.70, 131.64, 130.73, 130.47, 130.12, 128.34, 128.15, 127.27, 126.70, 51.81, 29.38, 21.48.

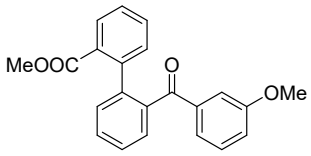


Dimethyl 2'-acetyl-[1,1'-biphenyl]-2,5-dicarboxylate (3i) [3]**: ^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.07 (dd, *J* = 8.1, 1.7 Hz, 1H), 8.02 (d, *J* = 8.2 Hz, 1H), 7.87 (d, *J* = 1.3 Hz, 1H), 7.79 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.48 (dtd, *J* = 33.1, 7.5, 1.4 Hz, 2H), 7.17 (dd, *J* = 7.7, 1.2 Hz, 1H), 3.90 (s, 3H), 3.64 (s, 3H), 2.30 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 200.50, 166.72, 166.06, 143.29, 140.29, 137.73, 133.33, 132.70, 131.52, 131.22, 130.34, 130.09, 128.68, 128.34, 127.73, 52.42, 52.17, 28.98.

3o, **3p** and **3q** are prepared with the following steps.

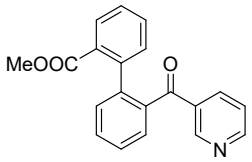


An oven-dried 25 mL Schlenk tube was charged with arylboronic acid (1.1 euqiv), 2'-bromoacetophenone (1.0 equiv), Pd_2dba_3 (0.01 equiv), HP(*t*-Bu)$_3$·BF_4 (0.024 equiv) and KF (3.3 equiv). The Schlenk tube was capped with a rubber stopper and then evacuated and backfilled with argon for two times. 1,4-Dioxane (5.0 mL) was added via syringe and the reaction mixture was heated to 120 °C for 24 h. The resulted mixture was then cool to room temperature and filtered through a thin pad of celite (eluted with EA. The filtrate was washed with saturated aqueous $NaHCO_3$ and the organic layer was separated. The aqueous layer was extracted with EA (2 × 15 mL) and then the organic layers were combined and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure and the crude product was purified by column chromatography (eluent: PE/EA = 10/1 to 4/1).

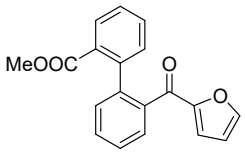


Methyl 2'-(3-methoxybenzoyl)-[1,1'-biphenyl]-2-carboxylate (3o) [3]**: ^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.74 (dd, *J* = 7.8, 1.4 Hz, 1H), 7.69 (dd, *J* = 7.9, 1.4 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 1H), 7.35 – 7.32 (m, 1H), 7.28 – 7.25 (m, 2H), 7.24 (d, *J* = 5.5 Hz, 1H), 7.23 – 7.21 (m, 1H), 7.19 (dd, *J* = 7.9, 1.4 Hz, 1H), 7.08 (dd, *J* = 8.5, 2.7 Hz, 1H),

7.04 (d, *J* = 2.6 Hz, 1H), 3.86 (s, 3H), 3.65 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 167.65, 158.36, 139.40, 137.44, 133.19, 132.68, 131.97, 131.44, 131.20, 130.10, 130.07, 127.89, 127.14, 115.86, 113.98, 55.48, 51.91.

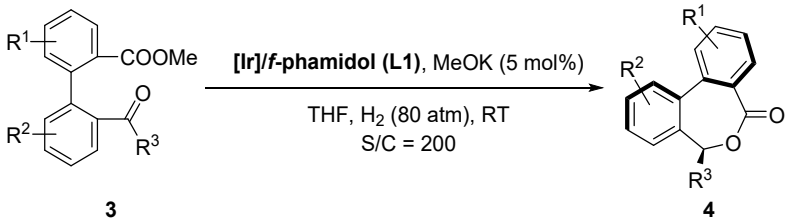


Methyl 2'-nicotinoyl-[1,1'-biphenyl]-2-carboxylate (3p): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.83 (d, J = 2.1 Hz, 1H), 8.60 (dd, J = 4.9, 1.8 Hz, 1H), 7.97 (dt, J = 7.9, 2.0 Hz, 1H), 7.80 (d, J = 7.1 Hz, 1H), 7.58 (dd, J = 14.4, 6.9 Hz, 2H), 7.52 – 7.47 (m, 1H), 7.40 (t, J = 7.6 Hz, 1H), 7.34 (d, J = 7.8 Hz, 1H), 7.30 – 7.26 (m, 1H), 7.24 – 7.18 (m, 2H), 3.65 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 196.67, 167.46, 152.93, 151.31, 141.30, 137.57, 137.02, 133.32, 131.73, 131.62, 130.91, 130.46, 130.39, 129.81, 129.14, 127.79, 127.33, 123.00, 52.17. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{20}H_{16}NO_3^+$ 318.1125; Found 318.1125.



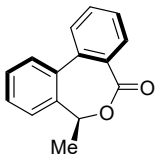
Methyl 2'-(furan-2-carbonyl)-[1,1'-biphenyl]-2-carboxylate (3q): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (dd, J = 7.8, 1.5 Hz, 1H), 7.84 – 7.79 (m, 1H), 7.58 (dd, J = 7.5, 1.5 Hz, 1H), 7.52 (td, J = 7.5, 1.5 Hz, 1H), 7.44 (tdd, J = 7.5, 3.1, 1.4 Hz, 2H), 7.33 (td, J = 7.6, 1.4 Hz, 1H), 7.30 (t, J = 1.7 Hz, 1H), 7.28 (dd, J = 7.5, 1.3 Hz, 1H), 7.26 – 7.23 (m, 1H), 6.69 (dd, J = 2.0, 0.8 Hz, 1H), 3.64 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 191.15, 167.80, 150.28, 143.83, 141.48, 140.35, 139.15, 131.55, 131.50, 130.42, 130.25, 130.14, 129.94, 128.19, 127.87, 127.57, 127.14, 109.38, 52.00. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{19}H_{15}O_4^+$ 307.0965; Found 307.0964.

5. General procedure for asymmetric hydrogenation of bibenzoic-fused ketoesters



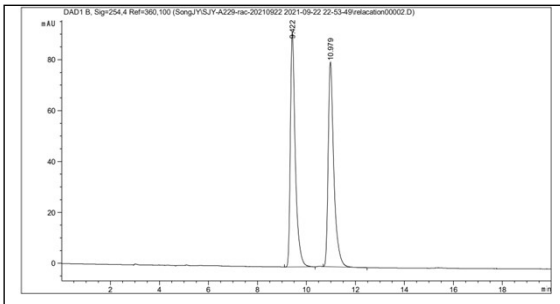
3 **4**

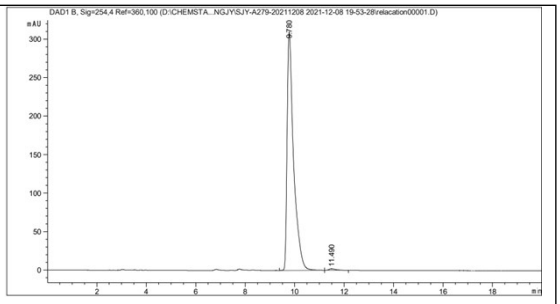
To a 4.0 mL vial was added the catalyst precursor $[Ir(COD)Cl]_2$ (6.72 mg, 1.0×10^{-2} mmol), ligand (R_C,S_C,R_C,S_{FC})-*f*-amphol (16.9 mg, 2.2×10^{-2} mmol) and anhydrous IPA (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2.0 h at 25 °C giving orange solution. And then 0.1 mmol of biaryl ketoesters, MeOK (0.35 mg, 0.01 mmol) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous DCM was added as solvent and a solution of Ir/(R_C,S_C,R_C,S_{FC})-*f*-amphol in anhydrous IPA (50 μL) was added via an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from glovebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 80 atm H_2. The reaction solution was stirred at room temperature (25 °C - 30 °C) until for 24 h, then released pressure carefully. DCM was removed under reduced pressure. The solution of reaction mixture was purified by a flash chromatography on a silica gel with ethyl acetate and the solvent was removed under reduced pressure. The ee value were determined by chiral HPLC analysis of the hydrogenation product chiral lactones directly. The absolute configurations of chiral lactones were assigned by analogy.



(*S*)-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4a): 99% yield, 99% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.98 (d, *J* = 7.7 Hz, 1H), 7.66 (t, *J* = 7.6 Hz, 1H), 7.60 (t, *J* = 9.0 Hz, 2H), 7.53 (dt, *J* = 15.3, 7.7 Hz, 3H), 7.47 (t, *J* = 7.5 Hz, 1H), 5.29 (q, *J* = 6.7 Hz, 1H), 1.85 (d, *J* = 6.6 Hz, 3H).**^{13}C NMR** (151 MHz, $CDCl_3$) δ 170.01, 138.71, 137.58,

137.38, 132.54, 131.35, 130.93, 129.61, 128.99, 128.83, 128.59, 128.40, 123.97, 73.14, 29.72, 16.90. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{15}H_{13}O_2^+$ 225.0910; Found 225.0907. **Optical Rotation**: $[\alpha]_D^{23}$ = +91.5 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 9.46 min, t_R (minor) = 11.07 min



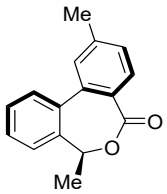


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

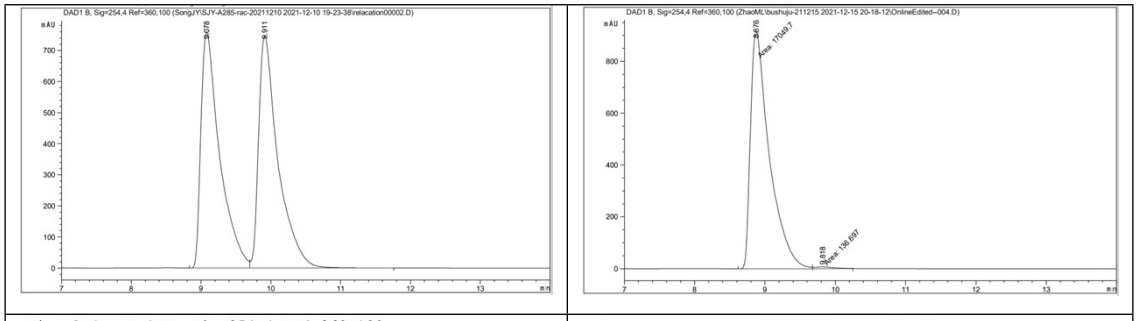
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.422	BB	0.2076	1295.53809	92.37437	50.1085
2	10.979	BB	0.2414	1289.92981	80.30387	49.8915

Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.780	BB	0.2669	5652.45801	309.75967	99.3455
2	11.490	BB	0.2789	37.23831	1.89829	0.6545



(*S*)-2,7-dimethyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4b): 99% yield, 98% ee. **^{1}H NMR** (400 MHz, CDCl3) δ 7.88 (d, *J* = 7.9 Hz, 1H), 7.60 (d, *J* = 7.4 Hz, 1H), 7.56 – 7.43 (m, 3H), 7.39 (s, 1H), 7.33 (d, *J* = 8.0 Hz, 1H), 5.27 (q, *J* = 6.6 Hz, 1H), 2.49 (s, 3H), 1.84 (d, *J* = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl3) δ 170.14, 143.13, 138.81, 137.64, 137.38, 131.51, 129.50, 129.41, 129.26, 128.93, 128.47, 128.18, 123.91, 73.05, 21.67, 16.92. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{16}H_{15}O_2^+$ 239.1067; Found 239.1062. **Optical Rotation**: $[\alpha]_D^{23}$ = +110.0 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 8.88 min, t_R (minor) = 9.82 min.

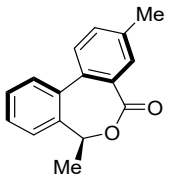


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

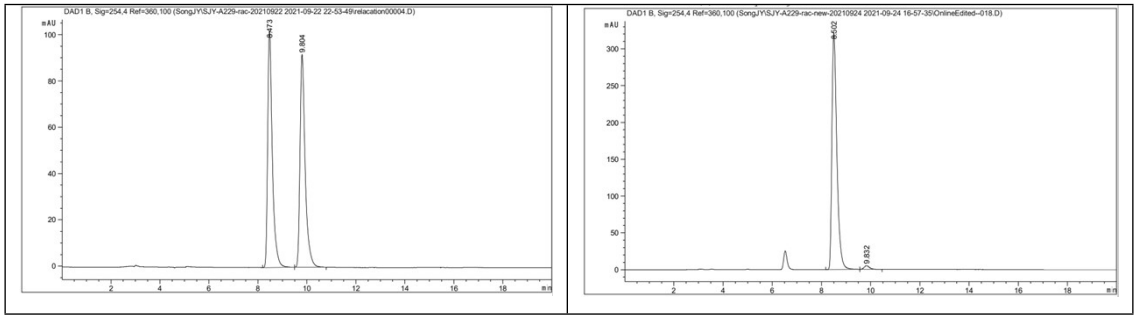
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.078	BV	0.2716	1.41292e4	757.46240	49.5743
2	9.911	VB	0.2809	1.43718e4	745.47681	50.4257

Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.876	MF	0.3108	1.70497e4	914.41327	99.2046
2	9.818	MF	0.3257	136.69688	6.99569	0.7954



(*S*)-3,7-dimethyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4c): 99% yield, 97% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 (s, 1H), 7.59 (dd, J = 7.5, 1.5 Hz, 1H), 7.57 – 7.38 (m, 5H), 5.30 – 5.22 (m, 1H), 2.46 (s, 3H), 1.85 (d, J = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 170.36, 138.84, 138.70, 137.54, 134.75, 133.59, 131.78, 130.78, 129.65, 128.91, 128.38, 124.05, 73.29, 21.13, 17.04. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{16}H_{15}O_2^+$ 239.1067; Found 239.1062. **Optical Rotation**: $[\alpha]_D^{23}$ = +144.3 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 8.50 min, t_R (minor) = 9.83 min.

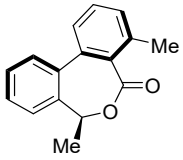


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

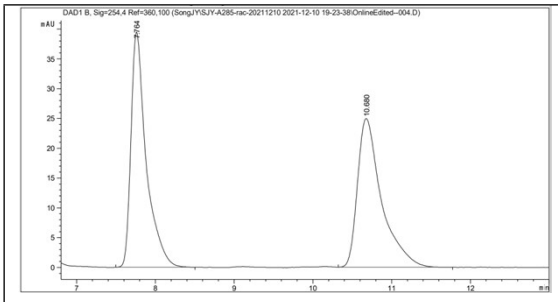
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.473	BB	0.1959	1345.63965	102.03900	50.0411
2	9.804	BB	0.2186	1343.42822	91.86837	49.9589

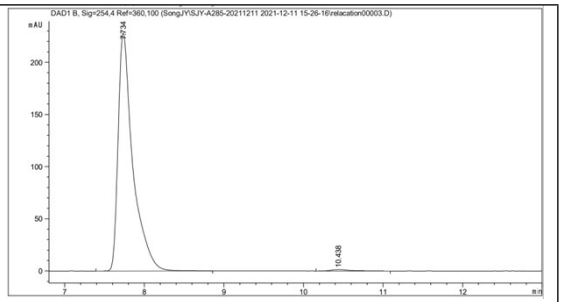
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.502	BB	0.2109	4488.01025	321.38776	98.3733
2	9.832	BB	0.2298	74.21227	4.92580	1.6267



(*S*)-4,7-dimethyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4d): 99% yield, 98% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.61 (dd, J = 7.6, 1.4 Hz, 1H), 7.53 – 7.43 (m, 4H), 7.37 – 7.33 (m, 2H), 5.25 (q, J = 6.5 Hz, 1H), 2.58 (s, 3H), 1.83 (d, J = 6.5 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 168.82, 139.23, 138.85, 138.03, 137.44, 131.02, 130.97, 130.71, 129.63, 129.09, 128.48, 126.59, 123.89, 72.77, 21.38, 16.71. **Optical Rotation**: $[\alpha]_D^{23}$ = +254.2 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 7.73 min, t_R (minor) = 10.44 min.



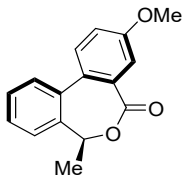


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.764	BB	0.1967	529.73920	39.43867	50.1608
2	10.680	BB	0.3102	526.34210	24.93945	49.8392

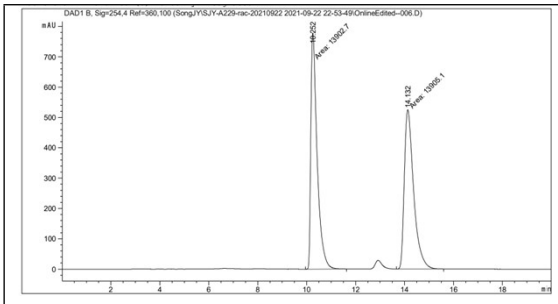
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.734	BB	0.1876	2925.59082	228.08517	99.2100
2	10.438	BB	0.2481	23.29769	1.31907	0.7900



(*S*)-3-methoxy-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4e): 71% yield, 91% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.58 – 7.46 (m, 5H), 7.42 (t, *J* = 7.3 Hz, 1H), 7.21 (d, *J* =

8.6 Hz, 1H), 5.27 (q, *J* = 7.0, 6.5 Hz, 1H), 3.90 (s, 3H), 1.85 (d, *J* = 6.6 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 169.90, 159.57, 138.58, 137.19, 131.95, 130.43, 130.17, 129.60, 128.69, 128.01, 123.99, 120.12, 114.69, 73.42, 55.76, 17.01. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{16}H_{15}O_3^+$ 255.1016; Found 255.1012. **Optical Rotation**: $[\alpha]_D^{23}$ = +27.4 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 10.26 min, t_R (minor) = 14.46 min.

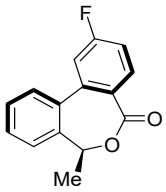


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

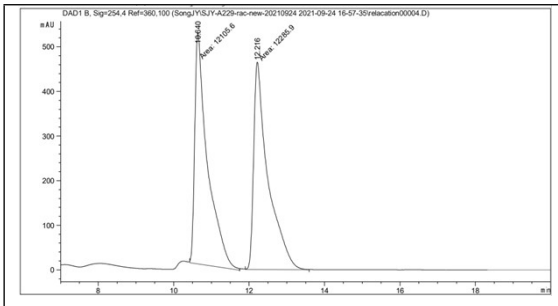
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.252	MF	0.2979	1.39027e4	777.87018	49.9958
2	14.132	MF	0.4413	1.39051e4	525.09717	50.0042

Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.260	BB	0.2996	1.10390e4	537.55865	95.6215
2	14.460	BB	0.3397	505.47205	23.06104	4.3785

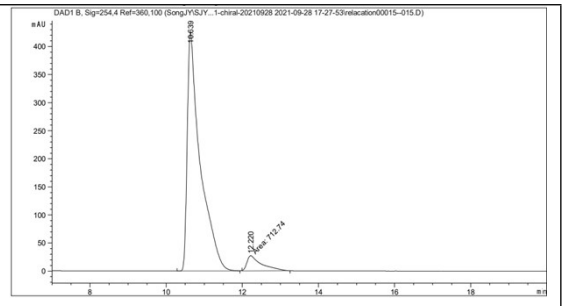


(*S*)-2-fluoro-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4f): 68% yield, 87% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.02 (dd, J = 8.7, 5.8 Hz, 1H), 7.61 – 7.48 (m, 4H), 7.29 (dd, J = 9.6, 2.6 Hz, 1H), 7.21 (td, J = 8.2, 2.6 Hz, 1H), 5.29 (q, J = 6.6 Hz, 1H), 1.86 (d, J = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 169.21, 166.28, 163.76, 140.39, 140.30, 137.77, 137.65, 134.50, 134.40, 129.90, 129.34, 129.08, 127.30, 124.29, 116.03, 115.81, 115.72, 115.49, 73.28, 17.03. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{15}H_{12}FO_2^+$ 243.0816; Found 243.0813. **Optical Rotation**: $[\alpha]_D^{23}$ = +73.4 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 10.64 min, t_R (minor) = 12.22 min.



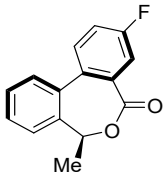
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.640	MM	0.3895	1.21056e4	518.00616	49.6303
2	12.216	MF	0.4404	1.22859e4	464.99701	50.3697

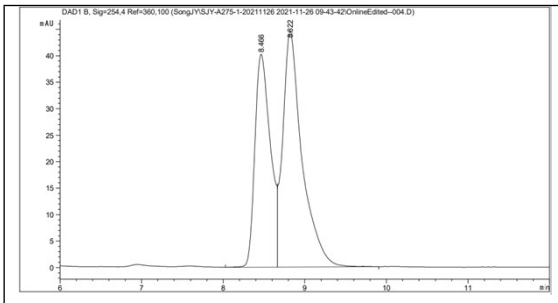


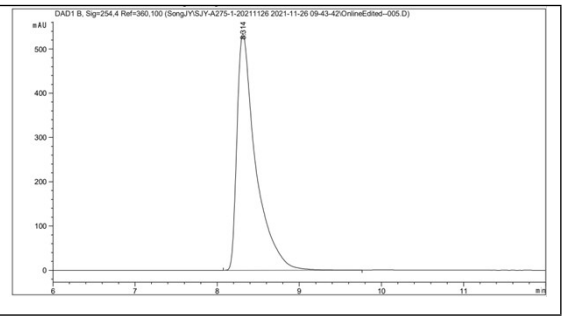
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.639	BV	0.3235	1.01057e4	424.83453	93.4118
2	12.220	MM	0.4399	712.73981	27.00331	6.5882



(*S*)-3-fluoro-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4g): 89% yield, 99% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.69 (dd, J = 8.8, 2.8 Hz, 1H), 7.65 – 7.44 (m, 5H), 7.38 (td, J = 8.2, 2.8 Hz, 1H), 5.29 (q, J = 6.4 Hz, 1H), 1.87 (d, J = 6.7 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 168.74, 163.19, 161.53, 137.89, 137.37, 133.76, 132.79, 131.13, 131.08, 129.87, 129.02, 128.79, 124.24, 120.19, 120.05, 118.13, 117.98, 73.56, 17.02. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{15}H_{12}FO_2^+$ 243.0816; Found 243.0813. **Optical Rotation**: $[\alpha]_D^{23}$ = +1.6 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 8.31 min.



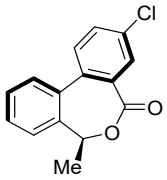


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

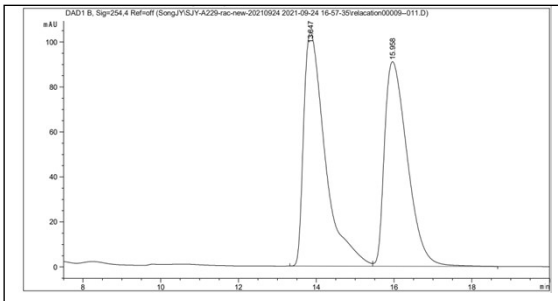
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.466	BV	0.1993	528.49121	40.21690	41.8912
2	8.822	VB	0.2343	733.08832	44.47321	58.1088

Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.314	BB	0.2283	8451.03125	535.11279	100.0000

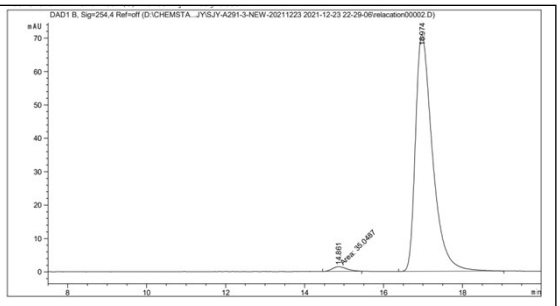


(*S*)-3-chloro-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4h): 77% yield, 97% ee (S/C = 100). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.97 (d, J = 2.3 Hz, 1H), 7.65 – 7.47 (m, 6H), 5.28 (q, J = 6.6 Hz, 1H), 1.86 (d, J = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.75, 137.76, 137.45, 135.88, 134.74, 132.79, 132.36, 131.24, 130.40, 129.92, 129.06, 128.97, 124.30, 73.49, 17.00. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{15}H_{12}ClO_2^+$ 259.0520; Found 259.0517. **Optical Rotation**: $[\alpha]_D^{23}$ = +11.8 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 16.97 min, t_R (minor) = 14.86 min.



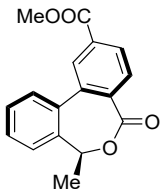
Signal 1: DAD1 B, Sig=254,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.847	BV	0.5932	3998.48779	103.85080	51.9495
2	15.958	VB	0.6384	3698.38940	90.95216	48.0505

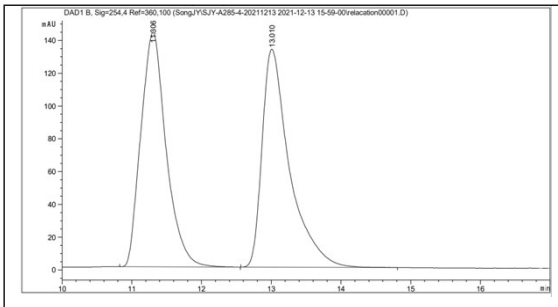


Signal 1: DAD1 B, Sig=254,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.861	MM	0.4219	35.04873	1.38465	1.6253
2	16.974	BB	0.4530	2121.35156	70.90452	98.3747

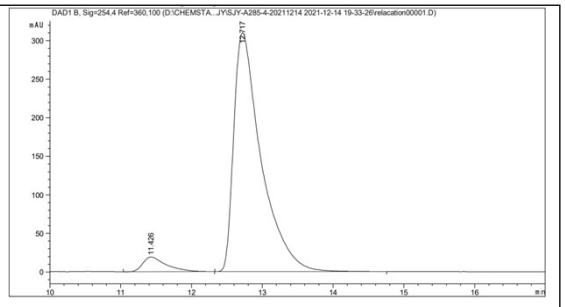


Methyl (*S*)-7-methyl-5-oxo-5,7-dihydrodibenzo[*c*,*e*]oxepine-2-carboxylate (4i): 87% yield, 90% ee. **^{1}H NMR** (400 MHz, CDCl3) δ 8.27 (dd, *J* = 8.6, 1.7 Hz, 1H), 8.15 (dd, *J* = 8.1, 1.6 Hz, 1H), 8.05 (d, *J* = 8.1 Hz, 1H), 7.69 (d, *J* = 7.6 Hz, 1H), 7.60 – 7.48 (m, 3H), 5.27 (t, *J* = 6.6 Hz, 1H), 3.99 (s, 3H), 1.87 (d, *J* = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, CDCl3) δ 168.10, 164.92, 136.84, 136.51, 136.37, 133.51, 132.66, 130.56, 129.05, 128.83, 128.11, 128.05, 127.89, 123.10, 72.30, 51.63, 15.83. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.28 (d, *J* = 1.6 Hz, 1H), 8.15 (dd, *J* = 8.1, 1.7 Hz, 1H), 8.05 (d, *J* = 8.1 Hz, 1H), 7.69 (dd, *J* = 7.9, 1.5 Hz, 1H), 7.60 – 7.47 (m, 3H), 5.28 (q, *J* = 6.5 Hz, 1H), 3.99 (s, 3H), 1.87 (d, *J* = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 169.29, 166.08, 137.98, 137.66, 137.50, 134.64, 133.80, 131.72, 130.21, 129.99, 129.27, 129.21, 129.05, 124.26, 73.47, 52.80, 17.00. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}O_4^+$ 283.0965; Found 283.0962. **Optical Rotation**: $[\alpha]_D^{23}$ = +34.5 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 12.72 min, t_R (minor) = 11.43 min.



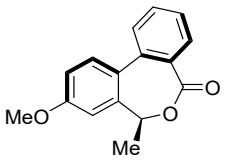
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.306	BB	0.4019	3604.33350	143.09613	49.8409
2	13.010	BB	0.4021	3627.34131	133.03943	50.1591

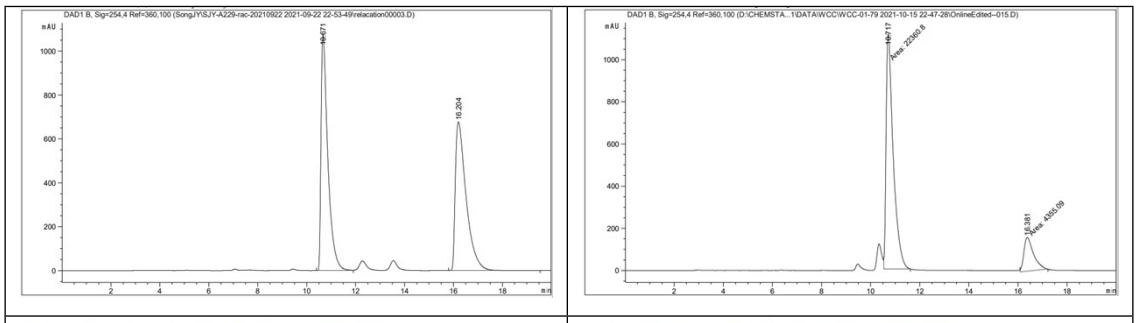


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.426	BB	0.3317	433.94830	19.05422	4.9654
2	12.717	BB	0.3929	8305.50391	309.66132	95.0346



(*S*)-9-methoxy-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4j): 92% yield, 77% ee (S/C = 100). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.97 (d, J = 7.8 Hz, 1H), 7.64 (t, J = 7.6 Hz, 1H), 7.54 (dd, J = 8.2, 3.6 Hz, 2H), 7.47 (t, J = 7.6 Hz, 1H), 7.13 – 6.98 (m, 2H), 5.27 (q, J = 6.6 Hz, 1H), 3.90 (s, 3H), 1.83 (d, J = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.06, 139.17, 137.45, 132.63, 131.57, 130.42, 128.63, 127.88, 114.49, 110.39, 73.14, 55.67, 17.00. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{16}H_{15}O_3^+$ 255.1016; Found 255.1012. **Optical Rotation**: $[\alpha]_D^{23}$ = +34.5 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 11.07 min, t_R (minor) = 16.75 min.

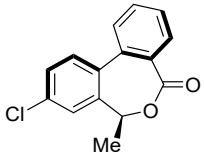


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.671	BV	0.2858	2.08079e4	1075.27612	50.0721
2	16.204	BB	0.4571	2.07480e4	677.76428	49.9279

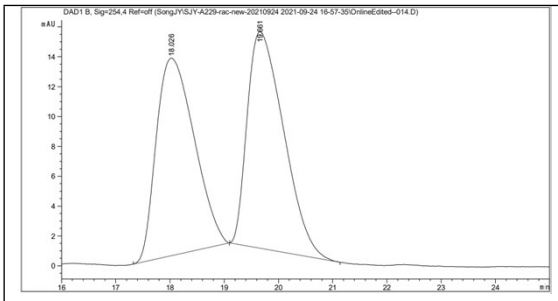
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.067	FM	0.3829	6144.16113	267.46948	88.6647
2	16.751	BB	0.4670	785.49933	24.43992	11.3353



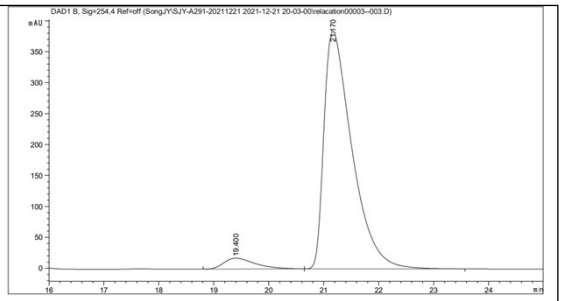
(*S*)-9-chloro-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4k): 96% yield, 90% ee (S/C = 100). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (d, J = 8.1 Hz, 1H), 7.70 – 7.64 (m, 1H), 7.58 – 7.48 (m, 5H), 5.25 (q, J = 6.6 Hz, 1H), 1.84 (d, J = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 139.35, 137.21, 136.41, 134.95, 132.84, 131.71, 130.84, 130.44, 129.85, 128.89, 128.80, 124.66, 72.72, 16.97. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for

$C_{15}H_{12}ClO_2^+$ 259.0520; Found 259.0517. **Optical Rotation**: $[\alpha]_D^{23}$ = +6.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OJ-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 21.17 min, t_R (minor) = 19.40 min.



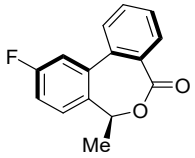
Signal 1: DAD1 B, Sig=254,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.026	BB	0.7248	643.06134	13.23754	48.6744
2	19.661	BB	0.6936	678.08801	14.49863	51.3256

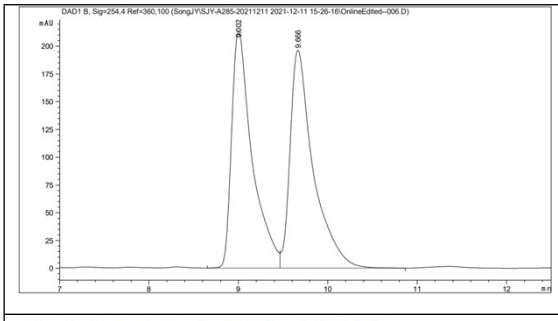


Signal 1: DAD1 B, Sig=254,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	19.400	BB	0.5583	696.04883	17.64241	4.8725
2	21.170	BB	0.5310	1.35892e4	383.89026	95.1275

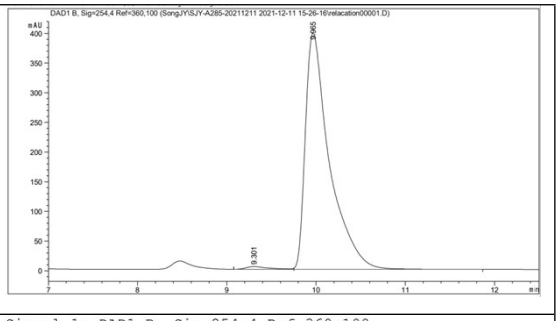


(*S*)-10-fluoro-7-methyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4l): 91% yield, 98% ee (S/C = 100). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (d, *J* = 6.6 Hz, 1H), 7.72 – 7.65 (m, 1H), 7.56 (d, *J* = 7.5 Hz, 3H), 7.31 (dd, *J* = 9.4, 2.7 Hz, 1H), 7.16 (td, *J* = 8.4, 2.7 Hz, 1H), 5.24 (q, *J* = 6.6 Hz, 1H), 1.84 (d, *J* = 6.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 169.78, 164.54, 162.07, 141.00, 140.91, 136.31, 136.29, 133.77, 132.83, 131.64, 131.05, 129.10, 128.82, 126.29, 126.20, 116.01, 115.79, 115.50, 115.28, 72.65, 17.22. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{15}H_{12}FO_2^+$ 243.0816; Found 243.0812. **Optical Rotation**: $[\alpha]_D^{23}$ = +122.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 9.97 min, t_R (minor) = 9.30 min.



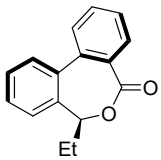
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.002	BV	0.2319	3399.30688	213.33772	49.0599
2	9.666	VB	0.2618	3529.58984	196.28122	50.9401

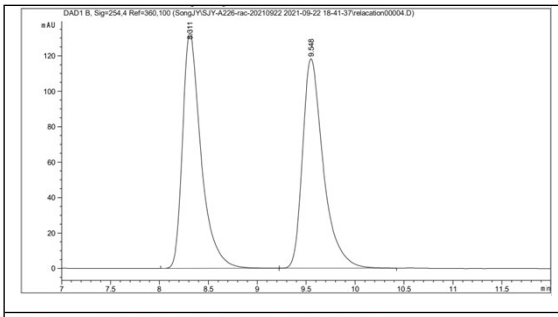


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.301	VV E	0.2485	80.54048	4.63949	1.0693
2	9.965	VB R	0.2724	7451.23145	398.03427	98.9307

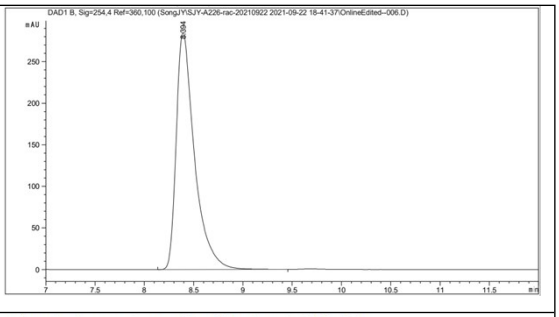


(*S*)-7-ethyldibenzo[*c*,*e*]oxepin-5(7*H*)-one (4m): 99% yield, 99% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (d, *J* = 7.8 Hz, 1H), 7.67 (t, *J* = 7.6 Hz, 1H), 7.60 (d, *J* = 6.7 Hz, 2H), 7.56 – 7.43 (m, 4H), 4.94 (dd, *J* = 8.8, 5.1 Hz, 1H), 2.35 (tt, *J* = 14.6, 7.6 Hz, 1H), 2.26 – 2.13 (m, 1H), 1.15 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 170.28, 139.05, 137.50, 136.97, 132.60, 131.37, 131.05, 129.55, 129.18, 128.82, 128.63, 128.48, 124.34, 78.56, 23.97, 10.82. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{16}H_{15}O_2^+$ 239.1067; Found 239.1063. **Optical Rotation**: $[\alpha]_D^{23}$ = +30.0 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 8.39 min.



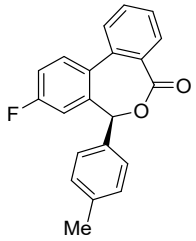
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.311	BB	0.1975	1747.96777	132.88623	50.0413
2	9.548	BB	0.2222	1745.07983	118.20672	49.9587

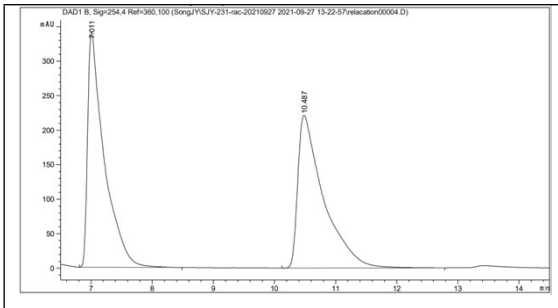


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.394	BB	0.1919	3662.35352	285.06937	100.0000



(*S*)-9-fluoro-7-(*p*-tolyl)dibenzo[*c*,*e*]oxepin-5(7*H*)-one (4n): 99% yield, 98% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.73 (t, *J* = 8.4 Hz, 1H), 7.66 – 7.53 (m, 3H), 7.38 (d, *J* = 7.8 Hz, 2H), 7.28 (d, *J* = 8.0 Hz, 2H), 7.18 (td, *J* = 8.3, 2.7 Hz, 1H), 6.53 (dd, *J* = 9.5, 2.7 Hz, 1H), 6.16 (s, 1H), 2.42 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 169.41, 163.96, 138.80, 136.61, 134.61, 132.93, 132.23, 131.78, 130.75, 129.57, 128.94, 128.76, 127.35, 116.80, 116.59, 114.65, 114.42, 78.65, 21.42. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{21}H_{16}FO_2^+$ 319.1129; Found 319.1125. **Optical Rotation**: $[\alpha]_D^{23}$ = -62.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 7.13 min, t_R (minor) = 10.69 min.

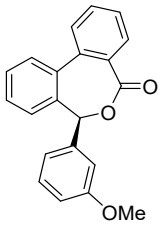


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.011	VB	0.2531	6403.12842	340.97980	49.8962
2	10.487	BB	0.3987	6429.77490	221.46747	50.1038

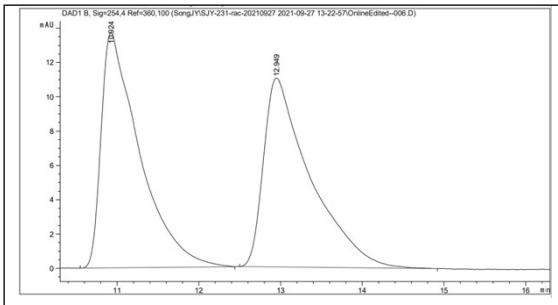
Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.129	BV R	0.1648	2.76595e4	2502.74512	98.9665
2	10.688	BB	0.2444	288.83829	17.69437	1.0335



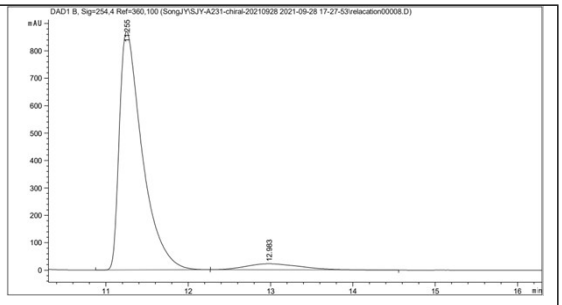
(*S*)-7-(3-methoxyphenyl)dibenzo[*c*,*e*]oxepin-5(7*H*)-one (4o): 99% yield, 89% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.00 (d, J = 7.8 Hz, 1H), 7.70 (t, J = 7.6 Hz, 1H), 7.61

(dd, J = 15.5, 8.2 Hz, 2H), 7.55 – 7.38 (m, 6H), 7.01 (d, J = 8.6 Hz, 1H), 6.32 (s, 1H), 6.22 (s, 1H), 3.69 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 169.74, 159.83, 140.25, 137.42, 135.78, 132.83, 131.73, 131.17, 130.42, 130.29, 128.76, 128.71, 128.07, 127.53, 114.49, 113.46, 79.09, 55.44. **HRMS (ESI)** m/z: $[M+H]^+$ Calcd for $C_{21}H_{17}O_3^+$ 317.1172; Found 317.1168. **Optical Rotation**: $[\alpha]_D^{23}$ = -20.8 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 254 nm, 25 °C, *n*-hexane: *i*-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 11.26 min, t_R (minor) = 12.98 min.



Signal 1: DAD1 B, Sig=254,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.924	BB	0.4387	446.96893	13.69578	50.6220
2	12.949	BB	0.5402	435.98462	11.00538	49.3780

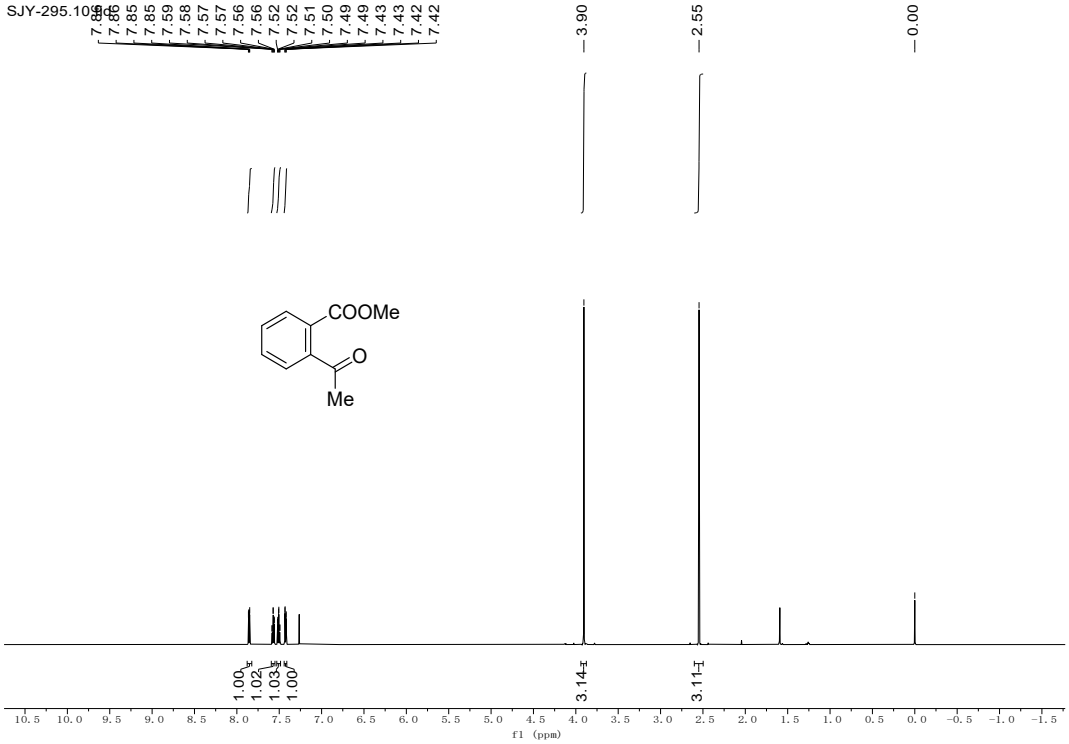


Signal 1: DAD1 B, Sig=254,4 Ref=360,100

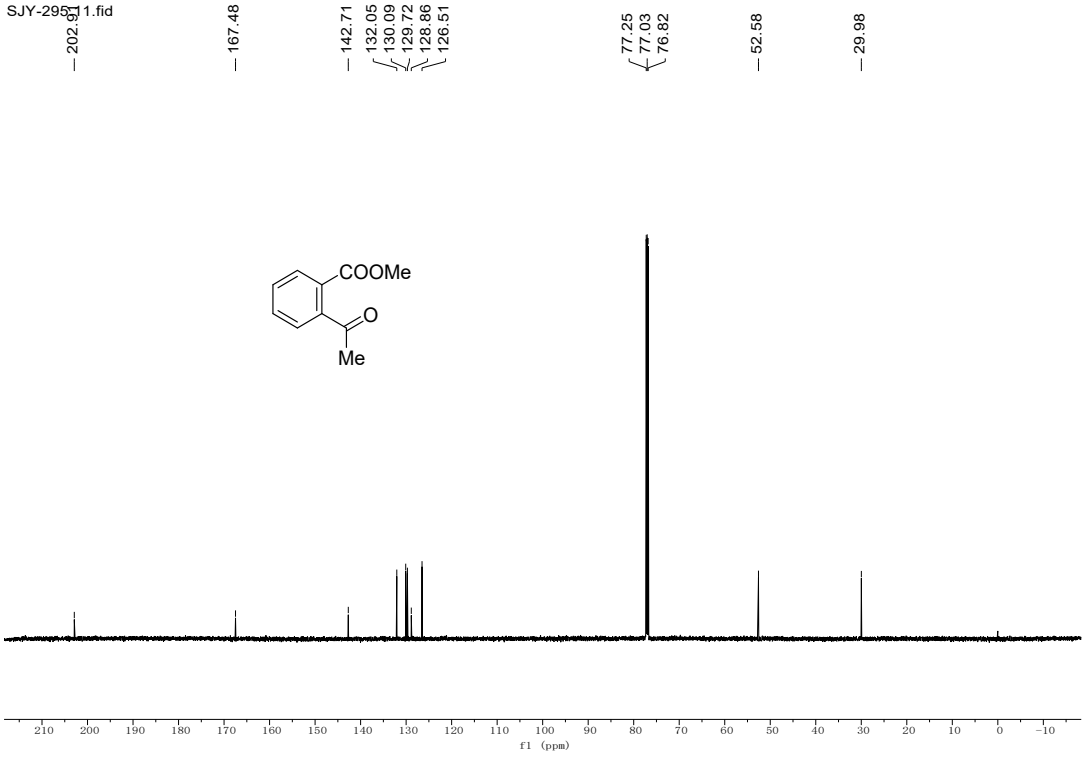
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.255	BB	0.2871	1.67899e4	870.12225	94.2874
2	12.983	BB	0.6796	1017.25061	21.91379	5.7126

6. NMR Spectra

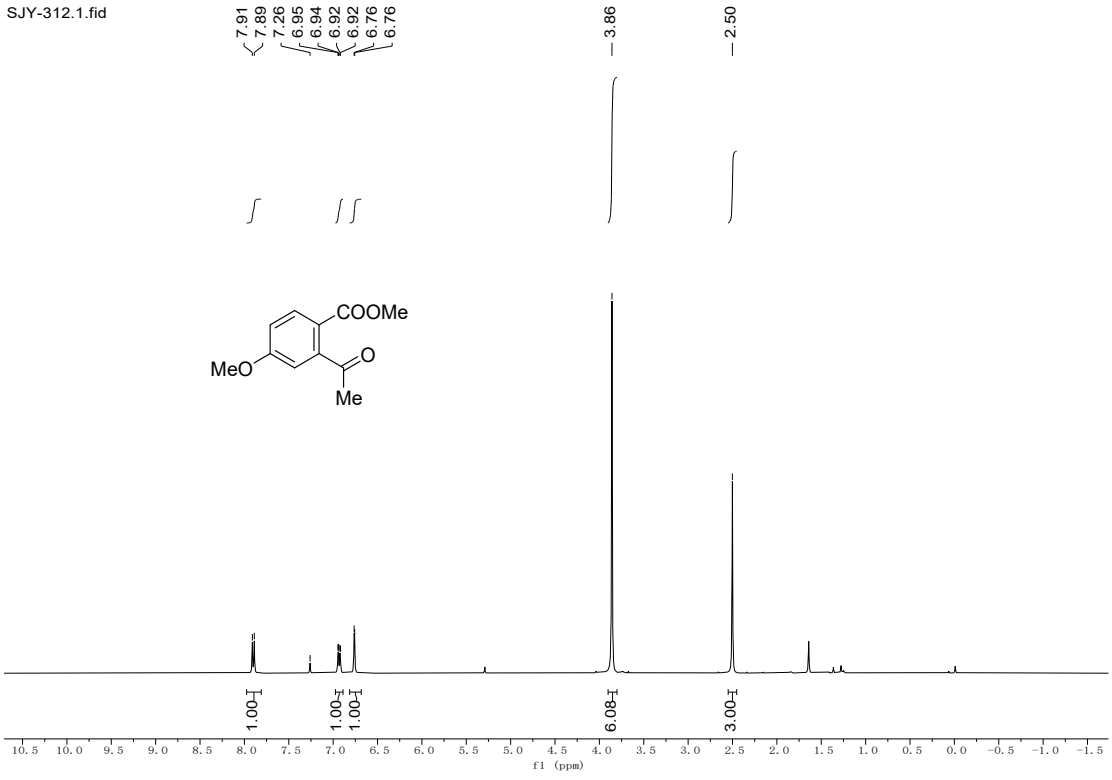
^{1}H NMR (600 MHz, $CDCl_3$) of compound **1a**



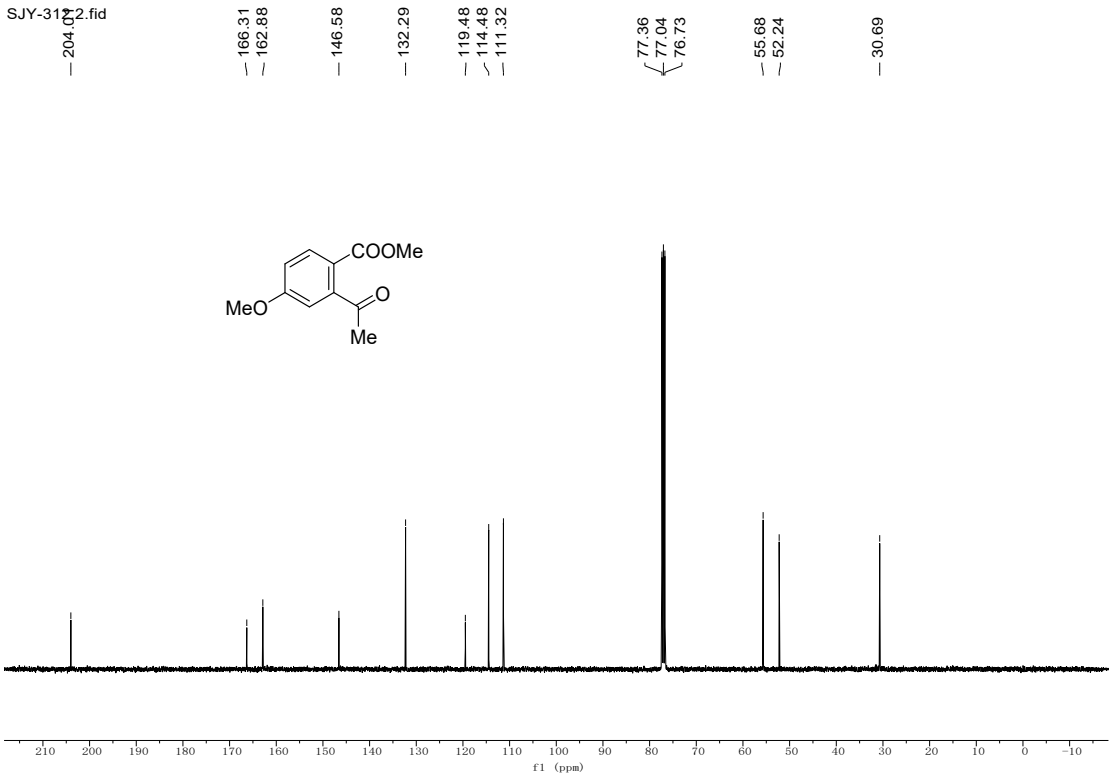
^{13}C NMR (151 MHz, $CDCl_3$) of compound **1a**



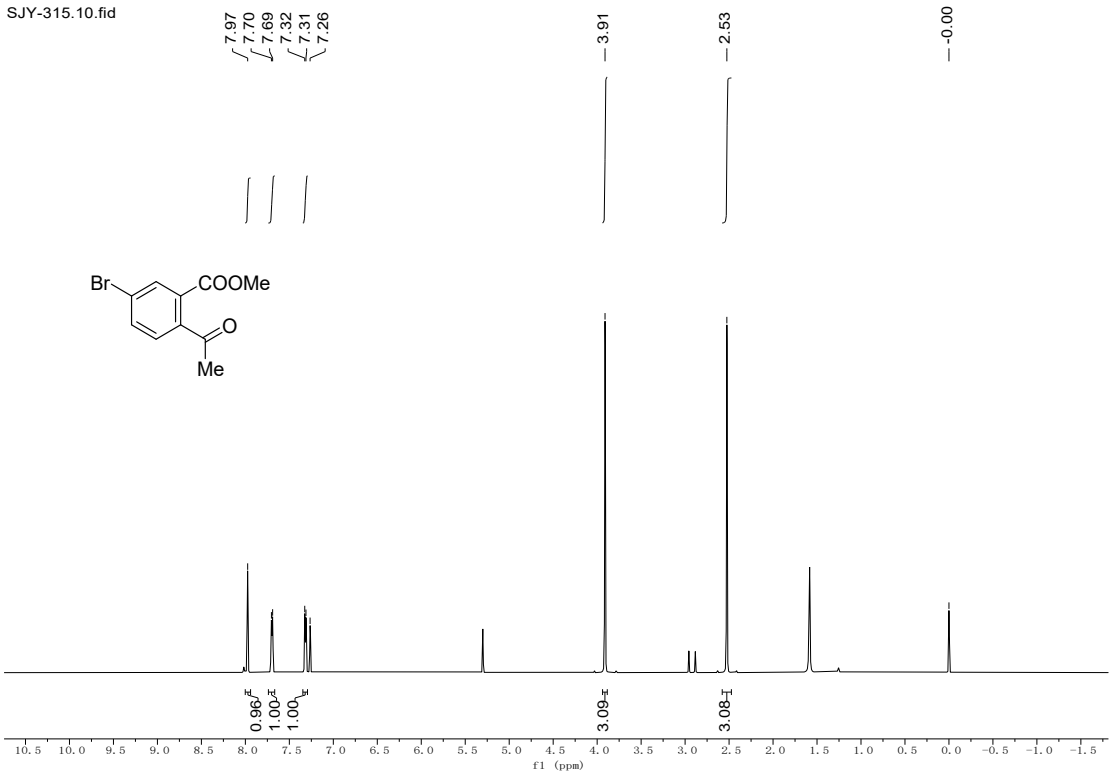
^{1}H NMR (400 MHz, $CDCl_3$) of compound **1b**



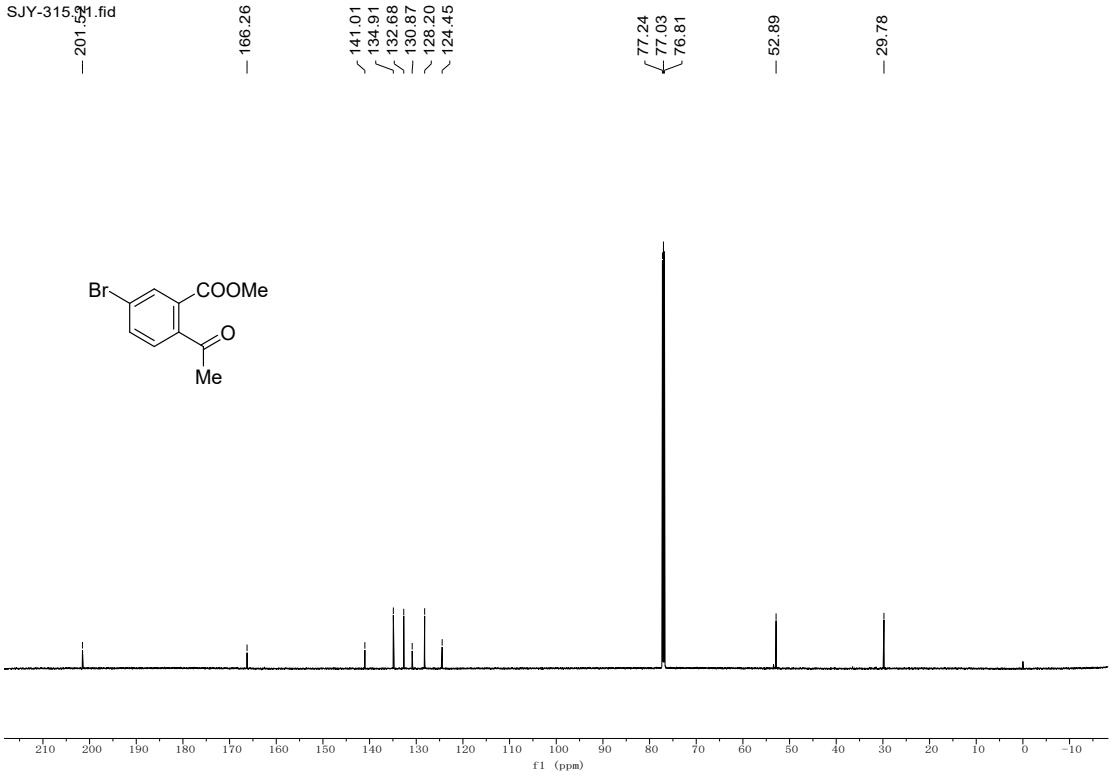
^{13}C NMR (101 MHz, $CDCl_3$) of compound **1b**



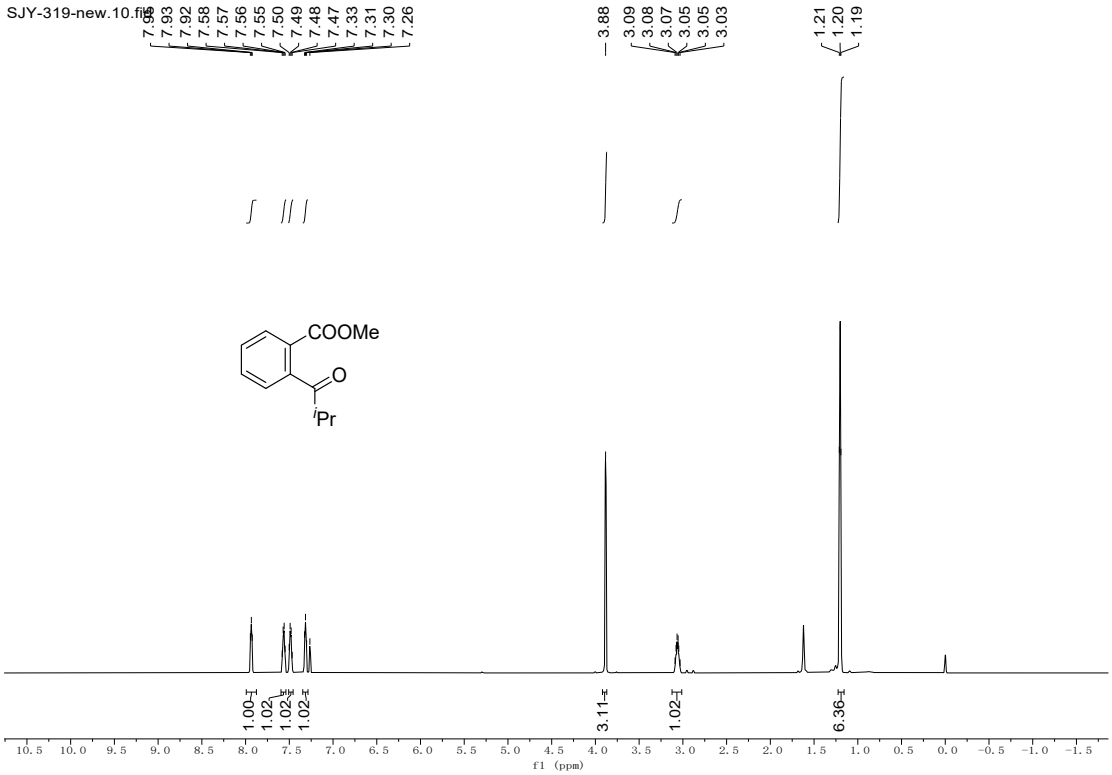
^{1}H NMR (600 MHz, $CDCl_3$) of compound **1c**



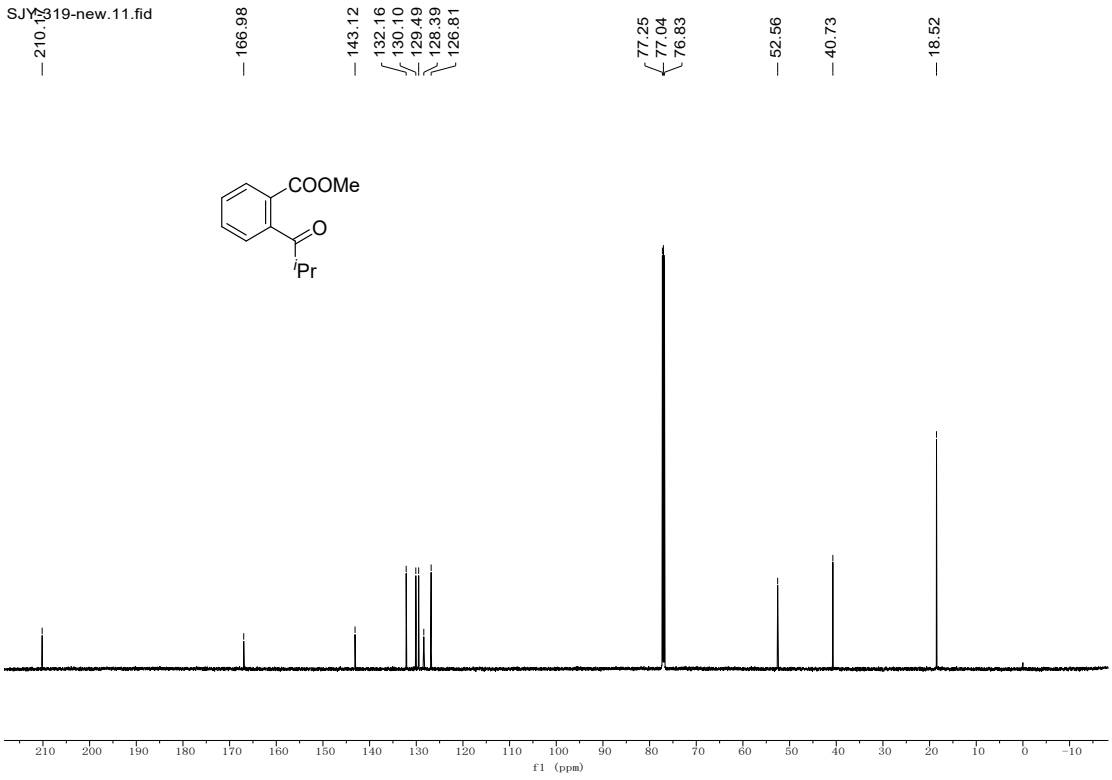
^{13}C NMR (151 MHz, $CDCl_3$) of compound **1c**



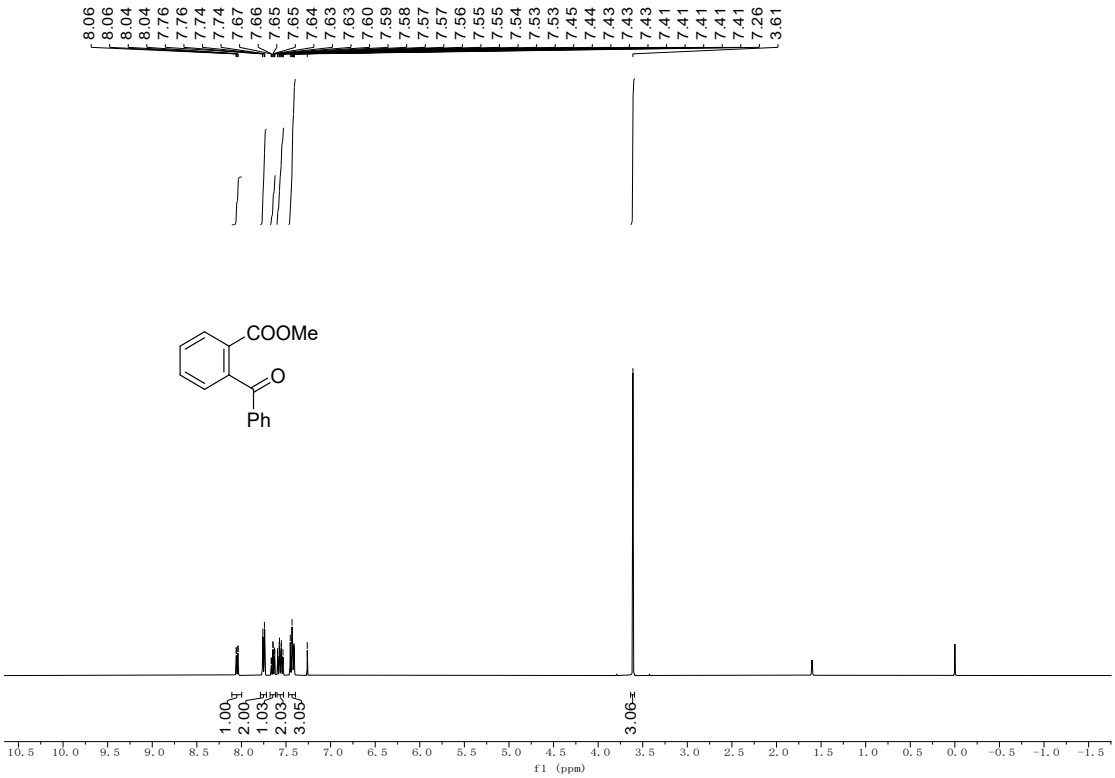
^{1}H NMR (600 MHz, $CDCl_3$) of compound **1d**



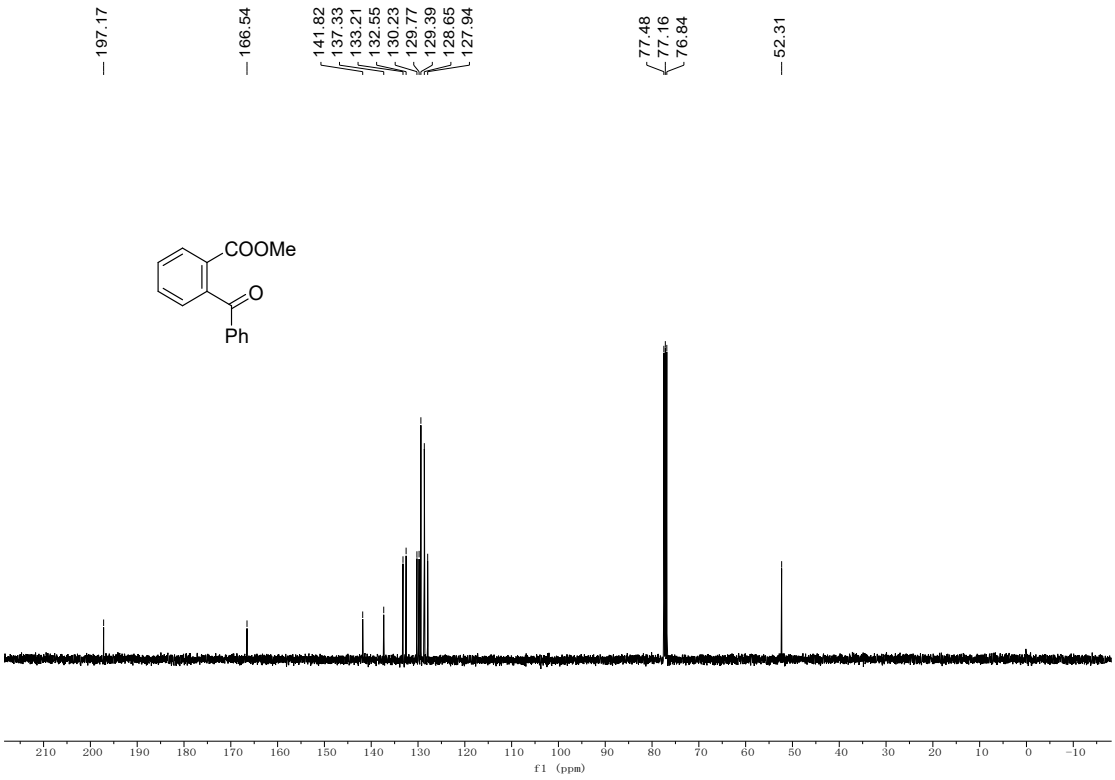
^{13}C NMR (151 MHz, $CDCl_3$) of compound **1d**



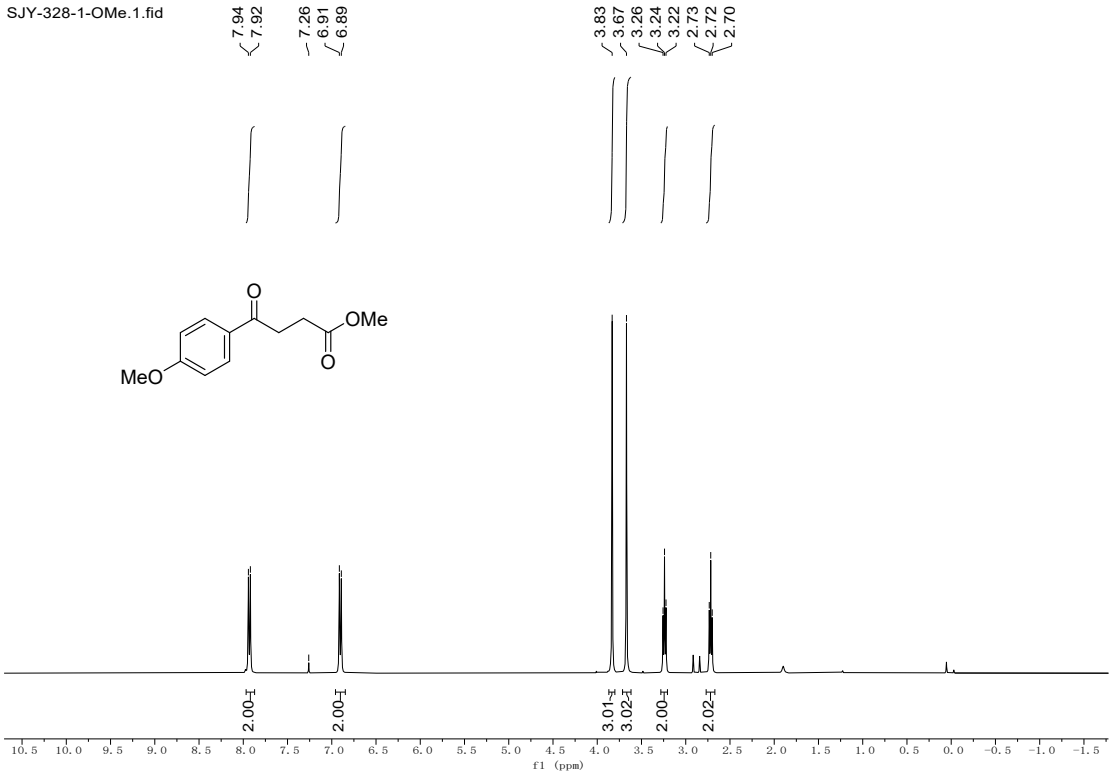
^{1}H NMR (400 MHz, $CDCl_3$) of compound **1f**



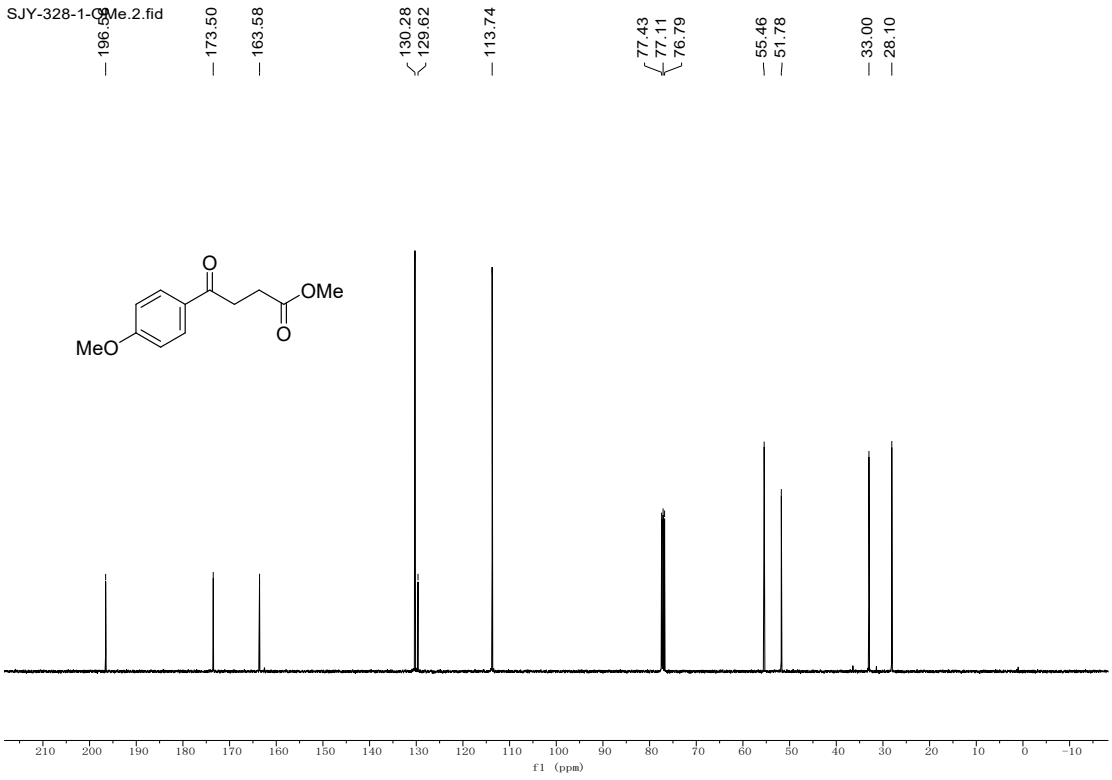
^{13}C NMR (101 MHz, $CDCl_3$) of compound **1f**



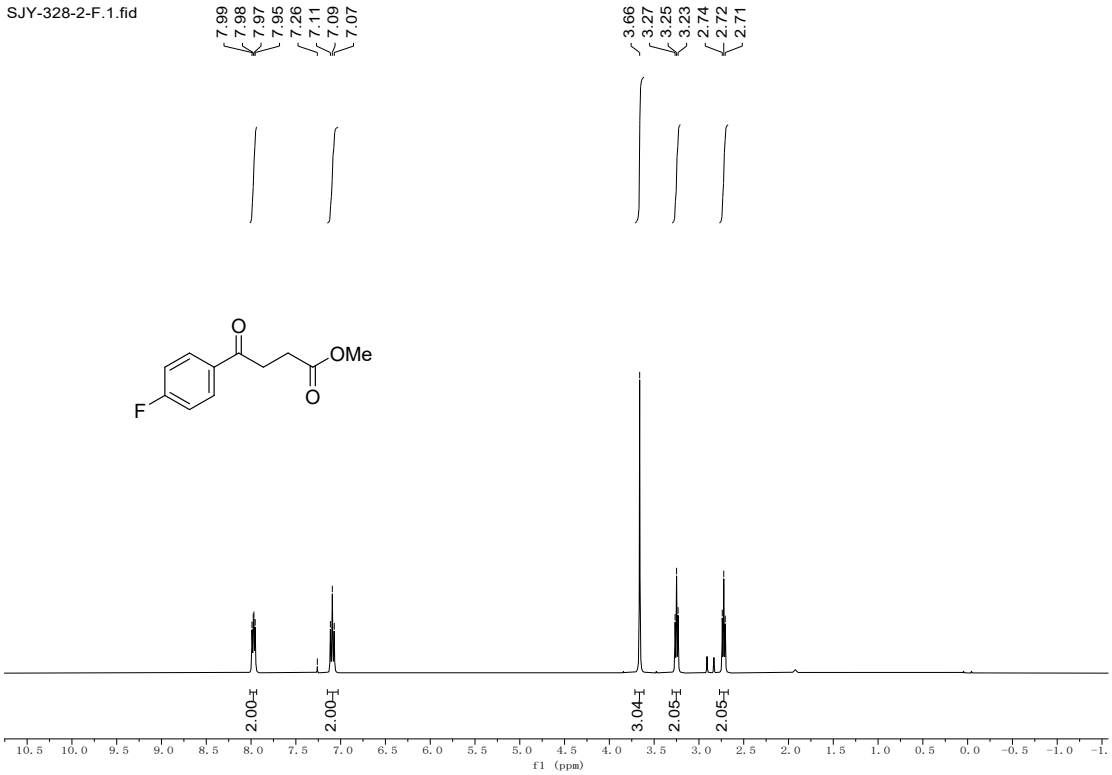
^{1}H NMR (400 MHz, $CDCl_3$) of compound **1h**



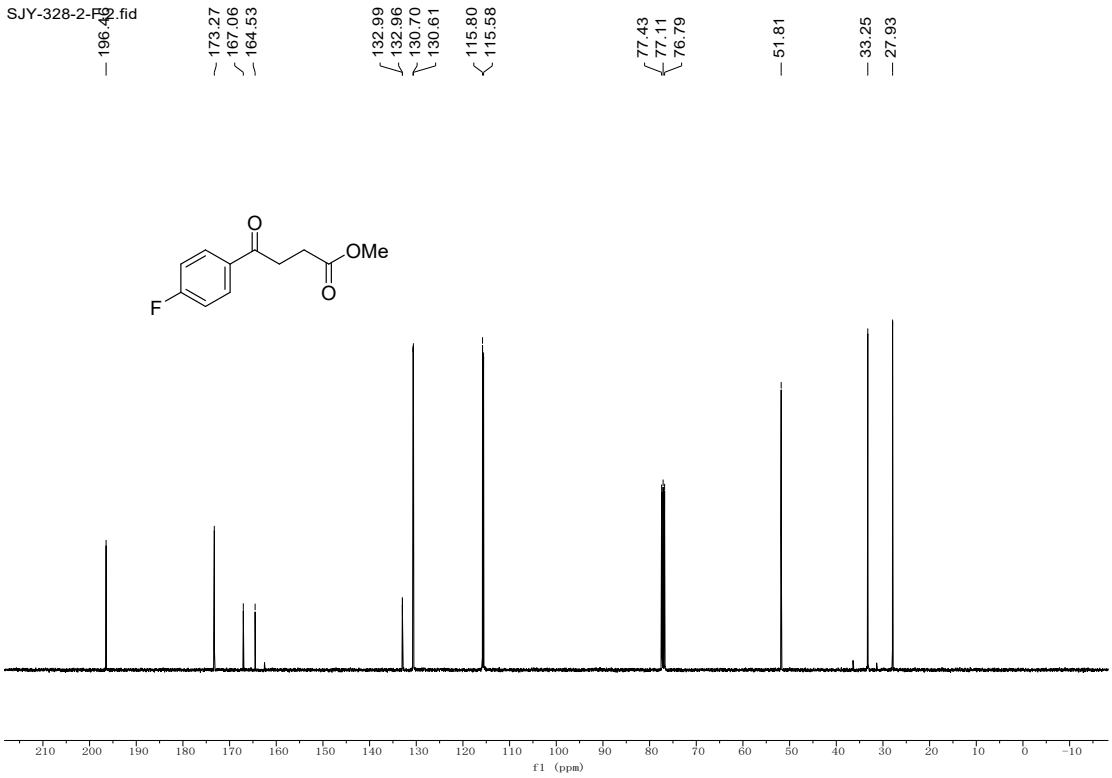
^{13}C NMR (101 MHz, $CDCl_3$) of compound **1h**



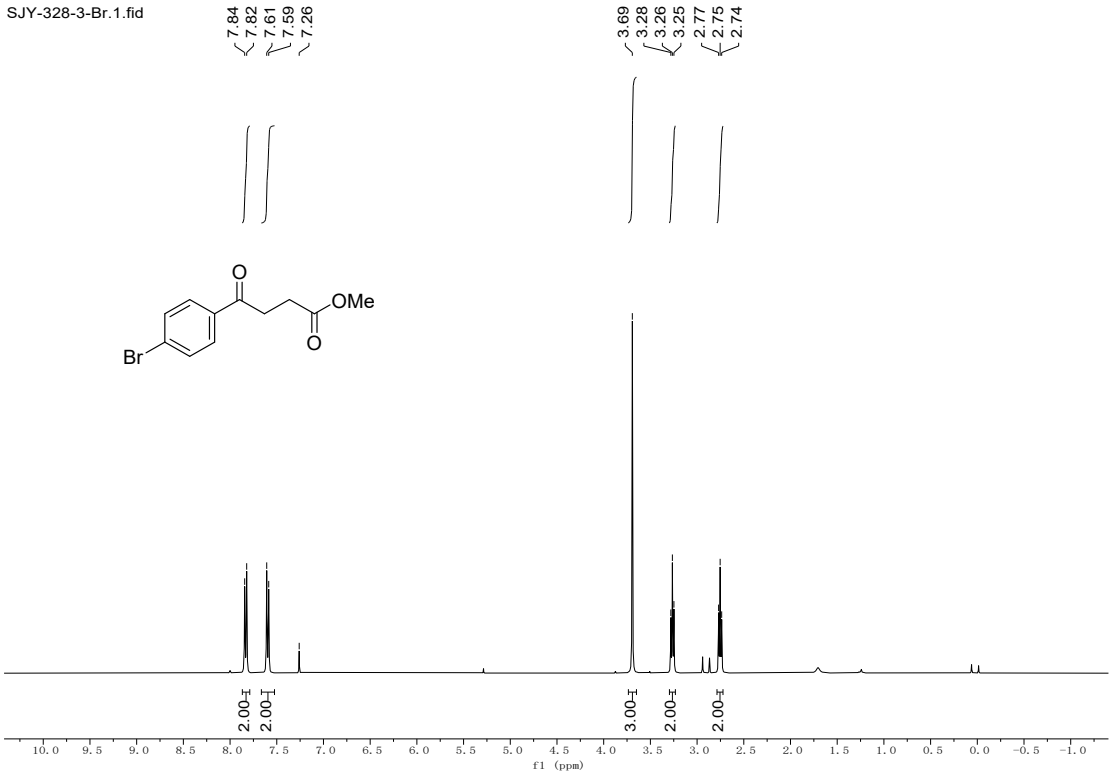
^{1}H NMR (400 MHz, $CDCl_3$) of compound **1i**



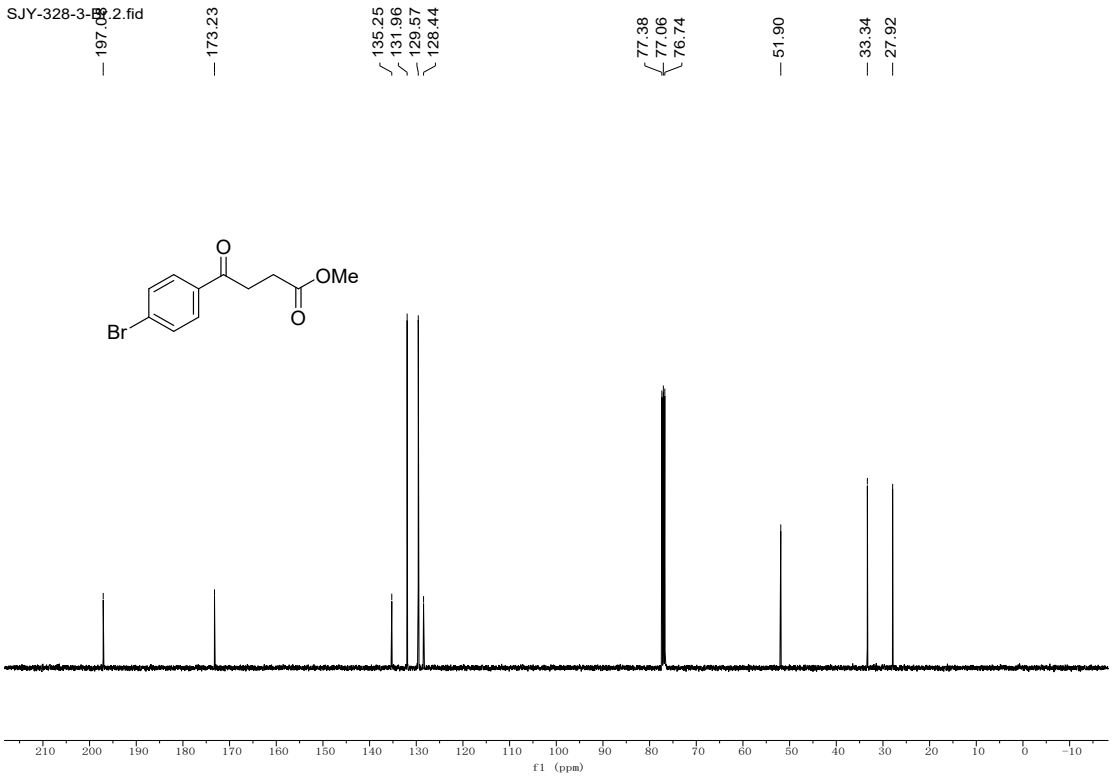
^{13}C NMR (101 MHz, $CDCl_3$) of compound **1i**



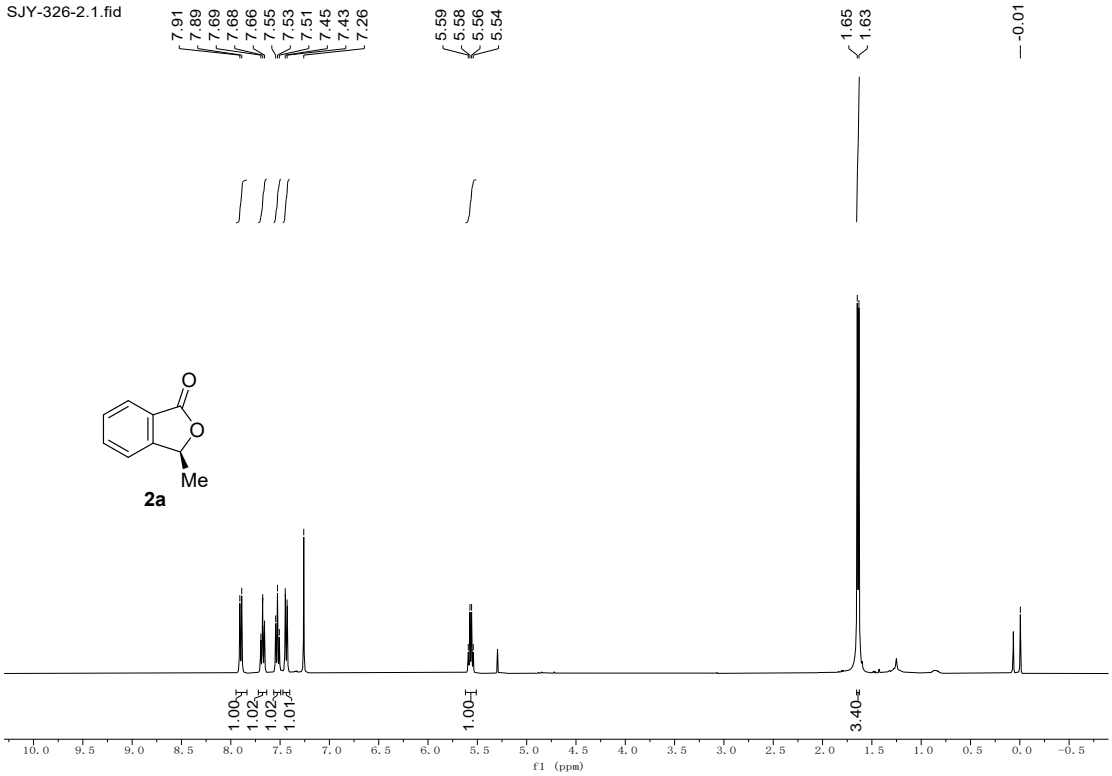
^{1}H NMR (400 MHz, $CDCl_3$) of compound **1j**



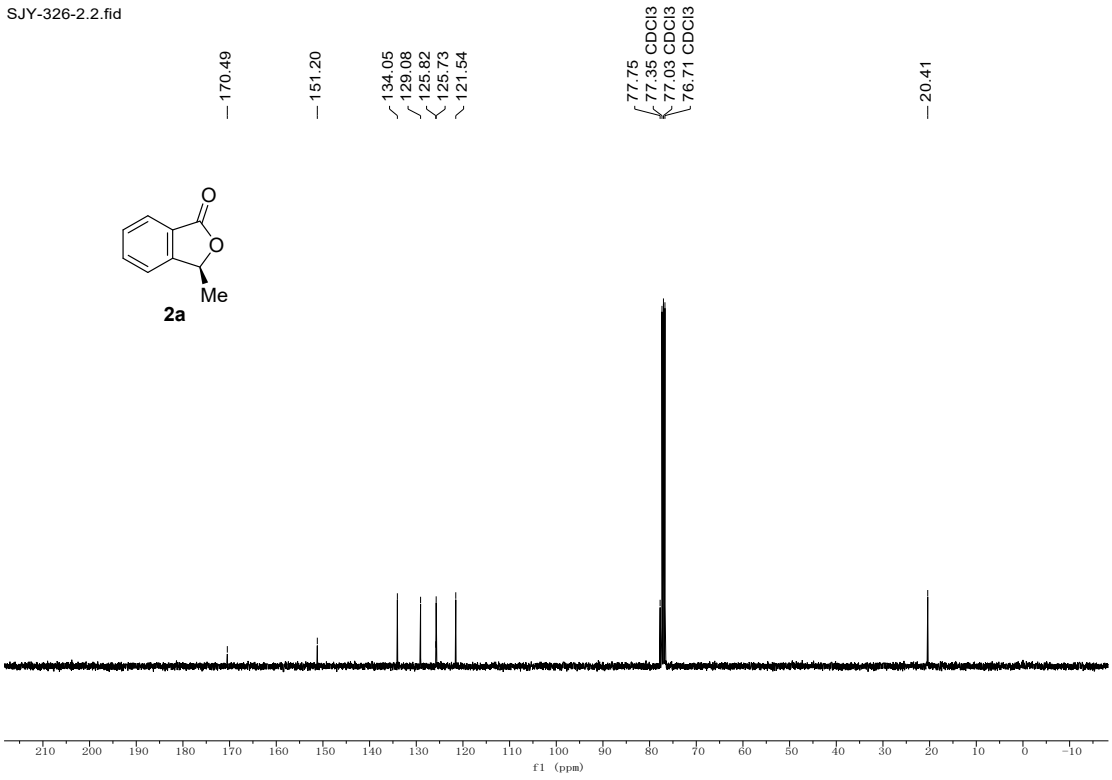
^{13}C NMR (101 MHz, $CDCl_3$) of compound **1j**



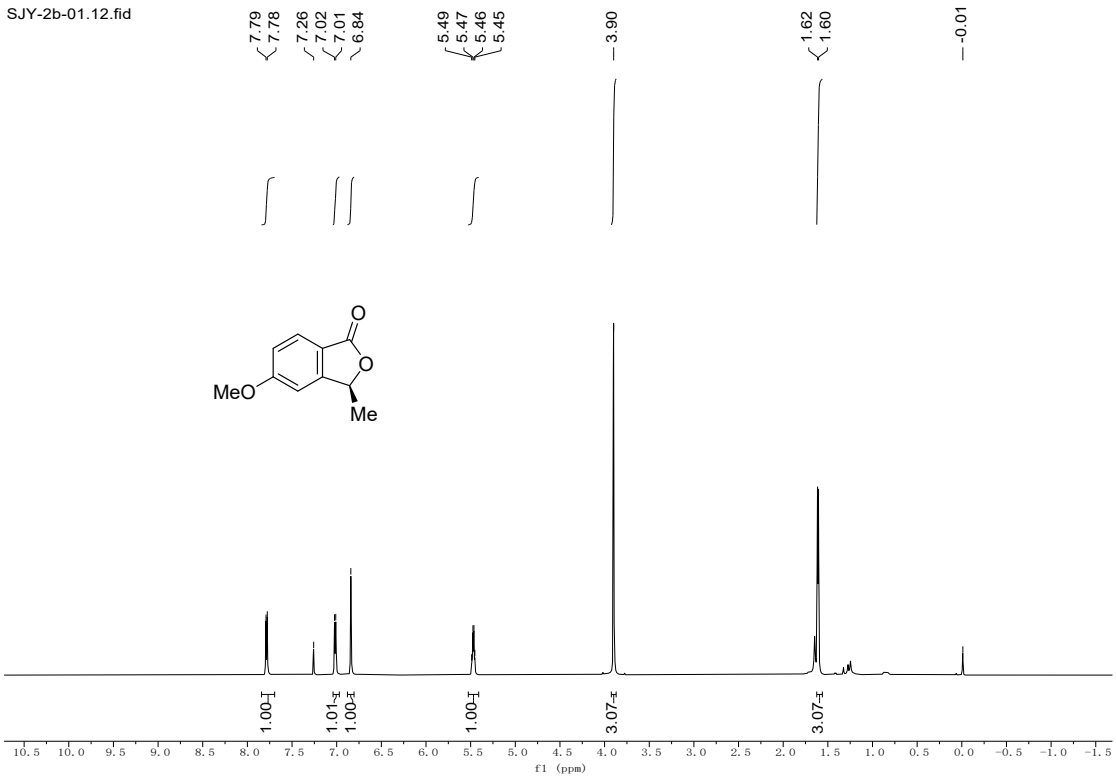
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2a**



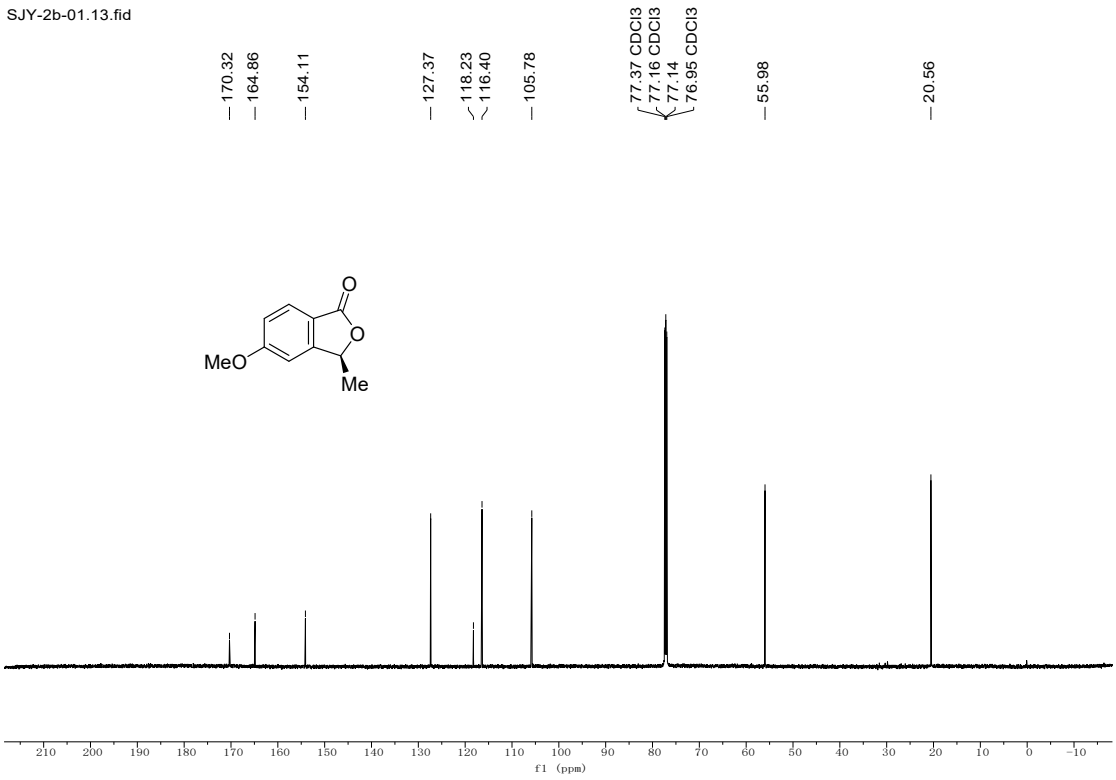
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2a**



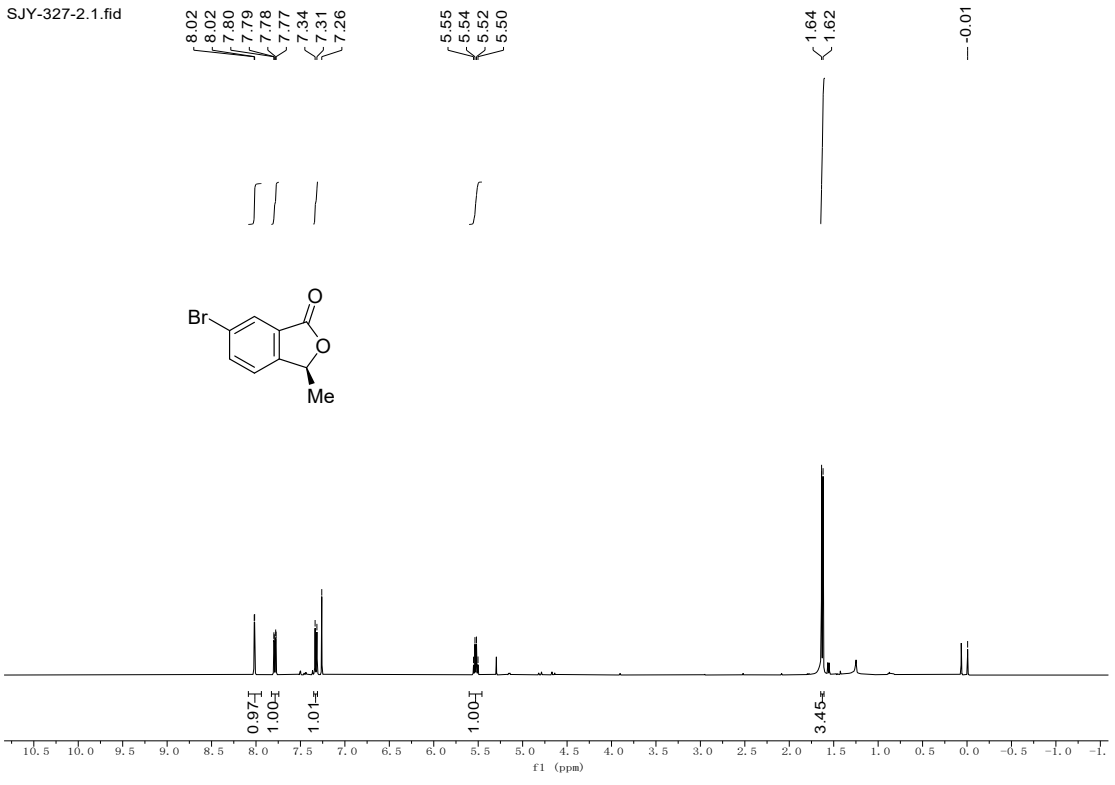
^{1}H NMR (600 MHz, $CDCl_3$) of compound **2b**



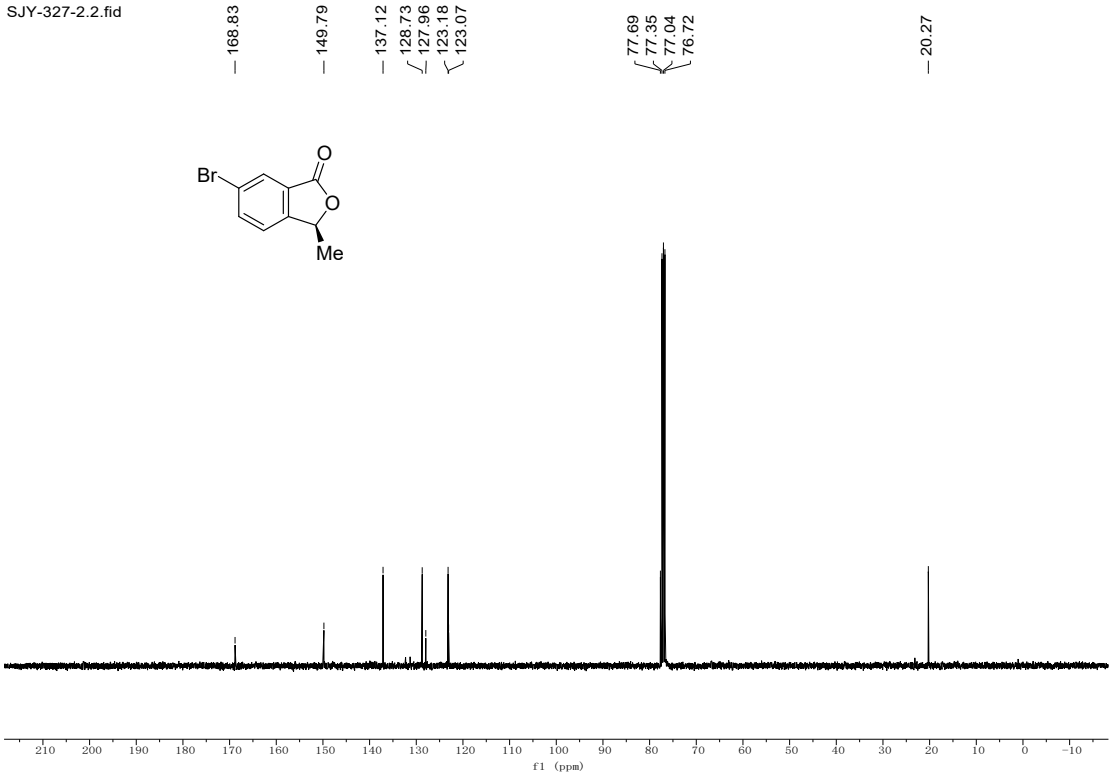
^{13}C NMR (151 MHz, $CDCl_3$) of compound **2b**



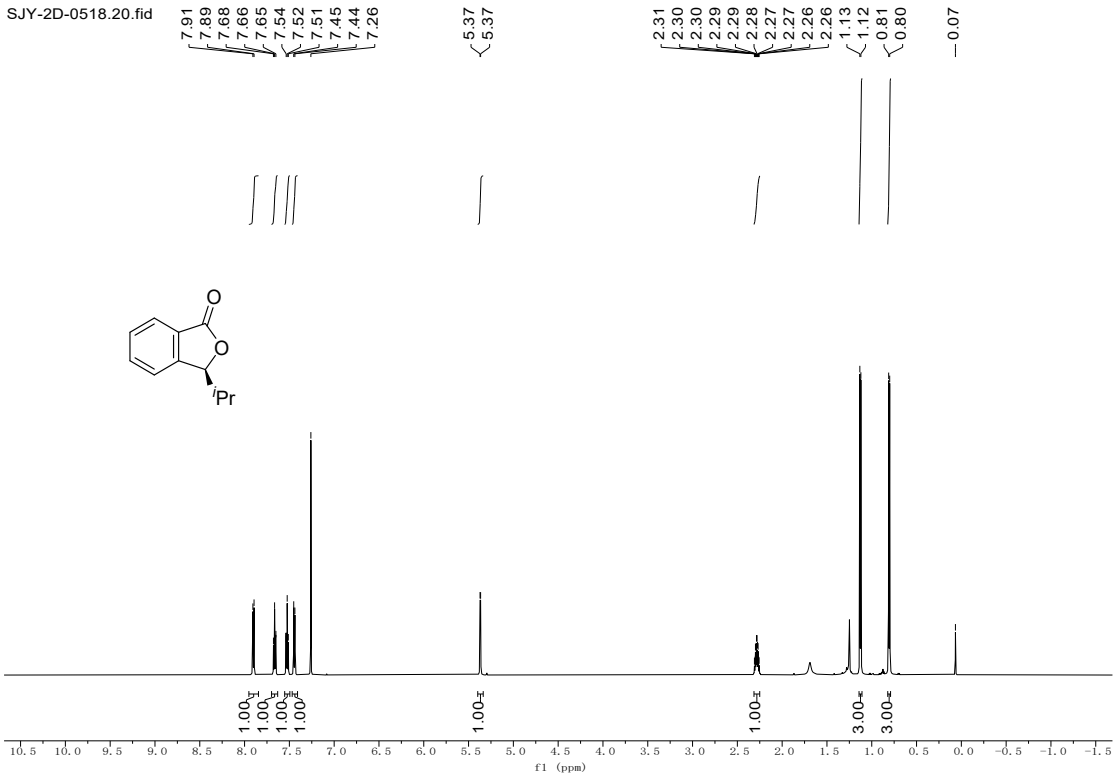
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2c**



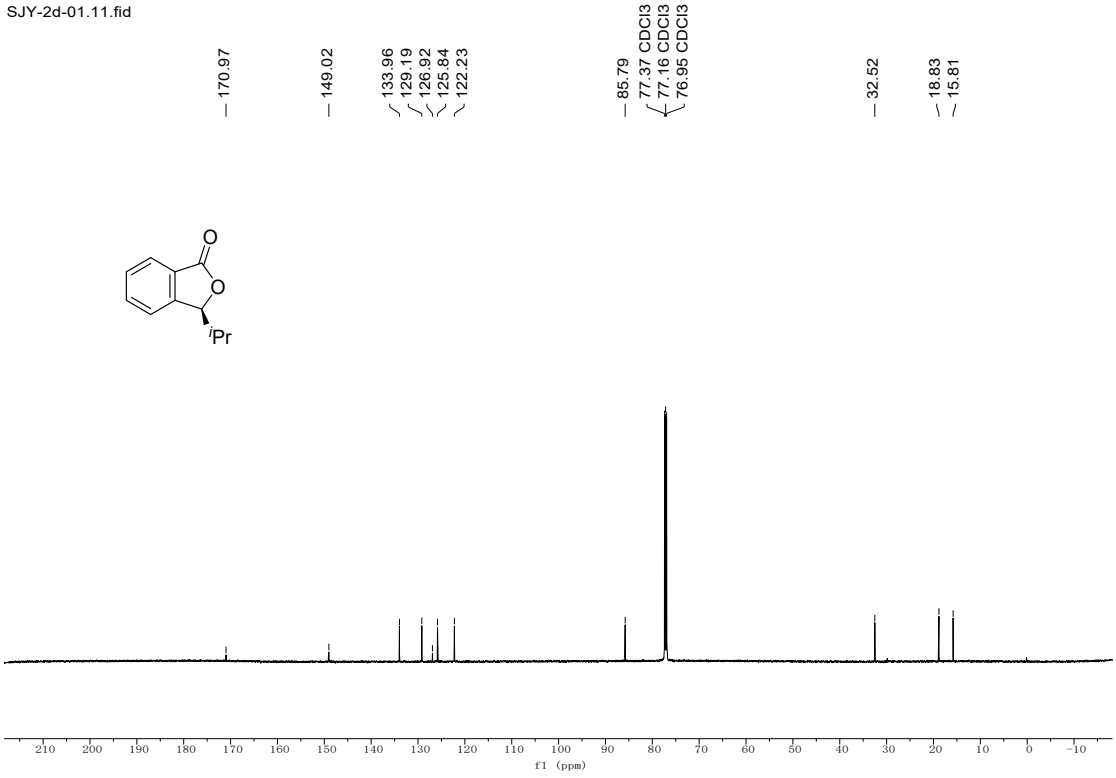
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2c**



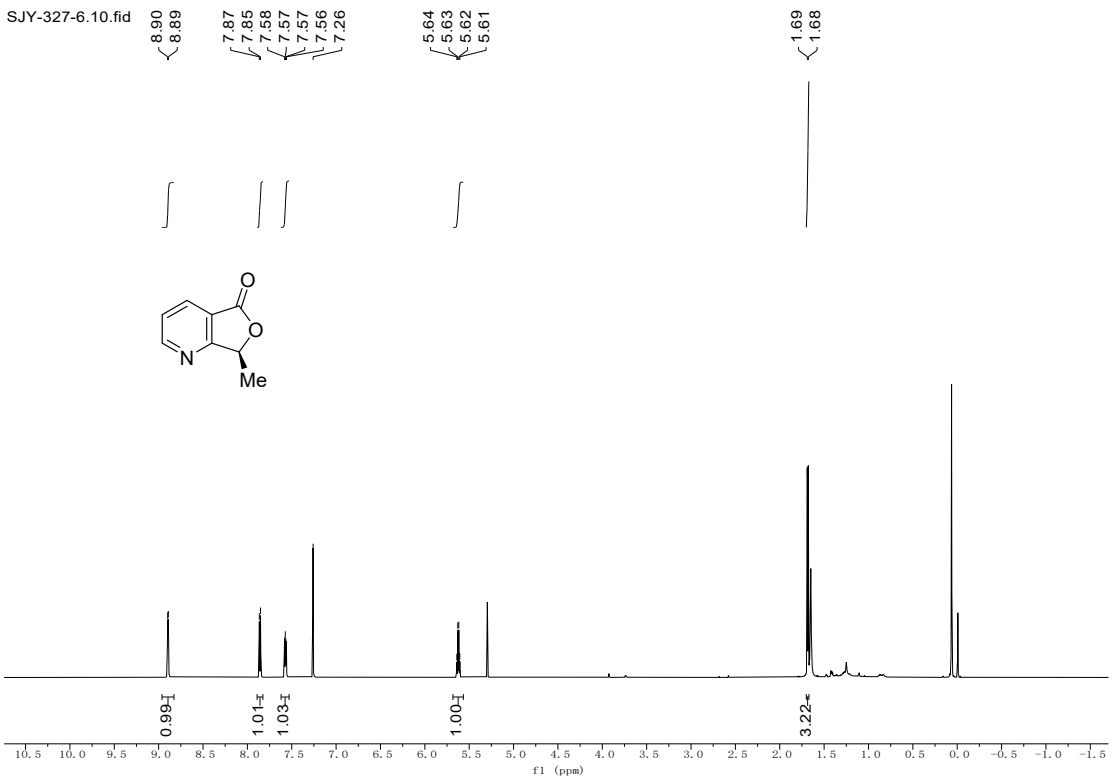
^{1}H NMR (600 MHz, $CDCl_3$) of compound **2d**



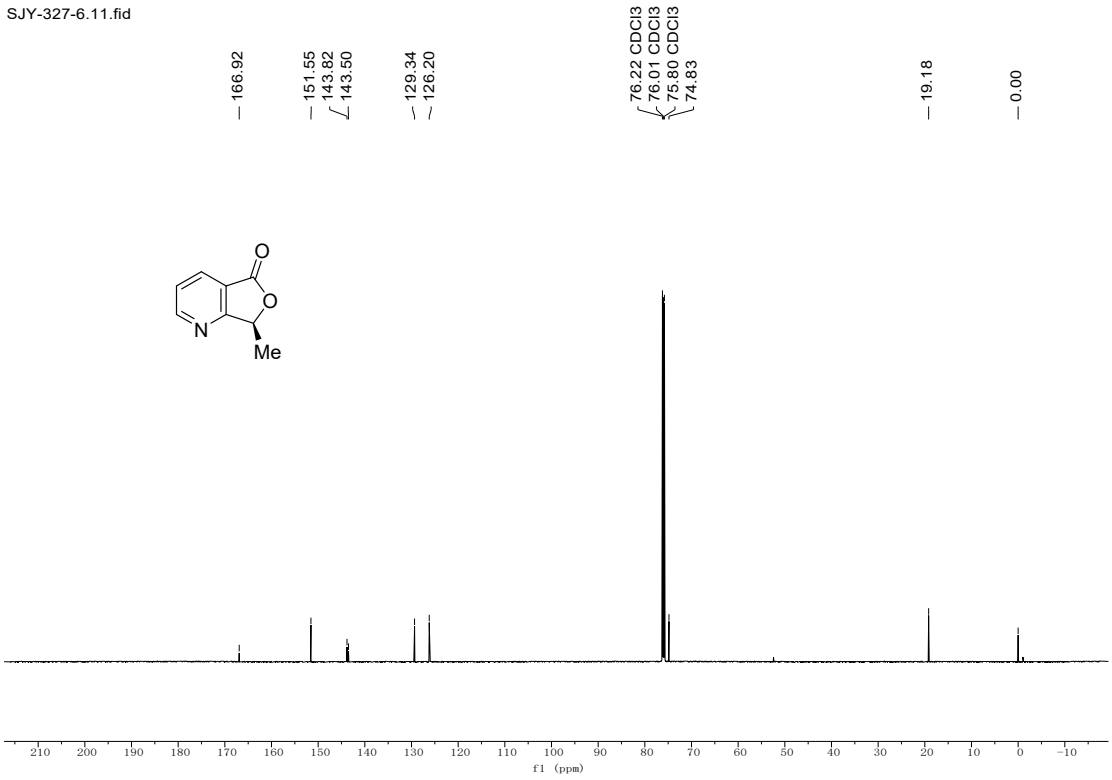
^{13}C NMR (151 MHz, $CDCl_3$) of compound **2d**



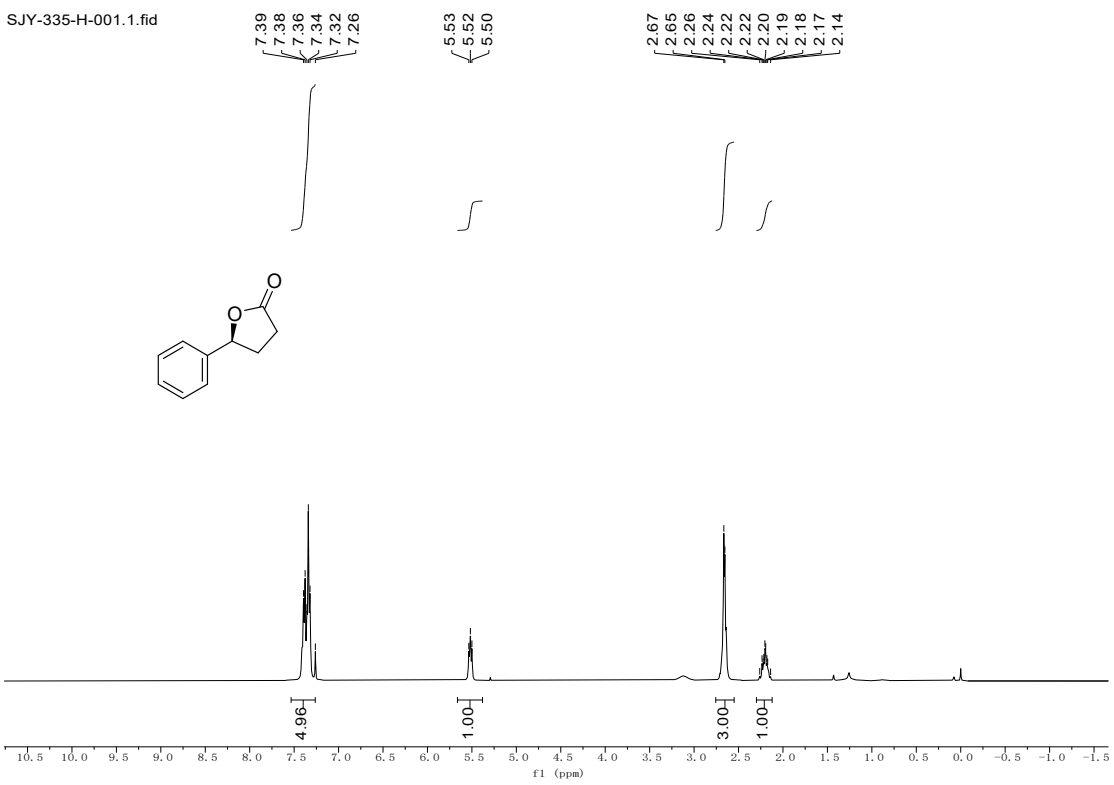
^{1}H NMR (600 MHz, $CDCl_3$) of compound **2e**



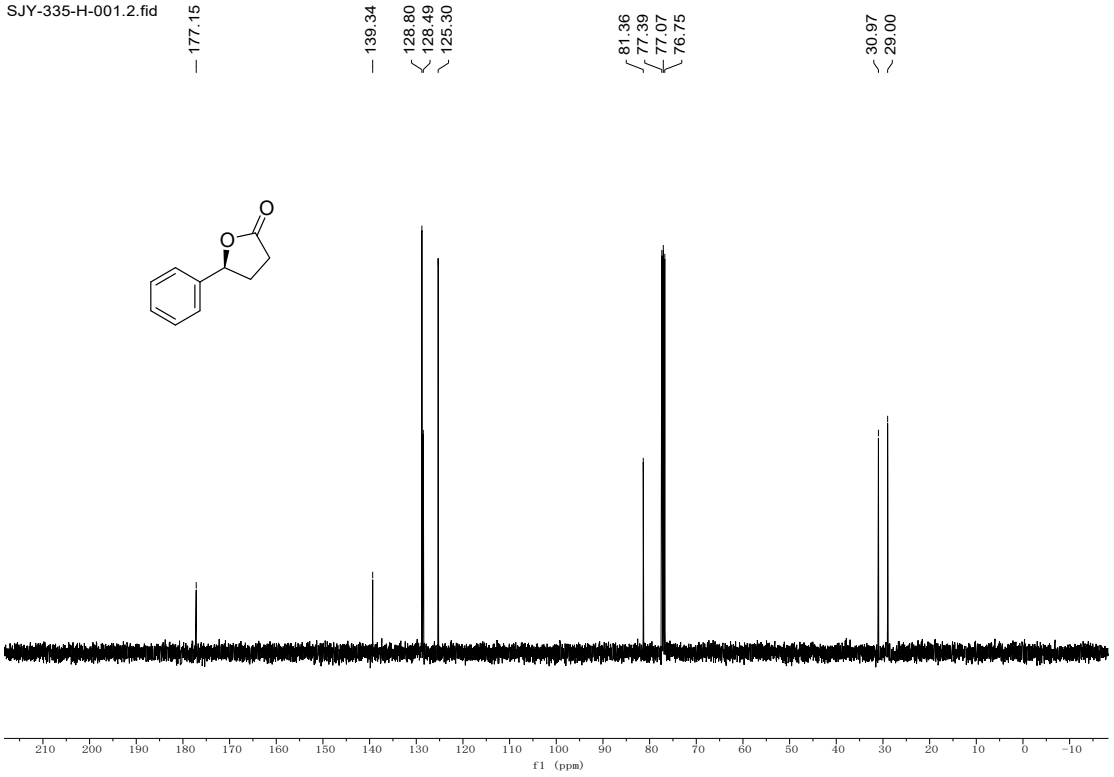
^{13}C NMR (151 MHz, $CDCl_3$) of compound **2e**



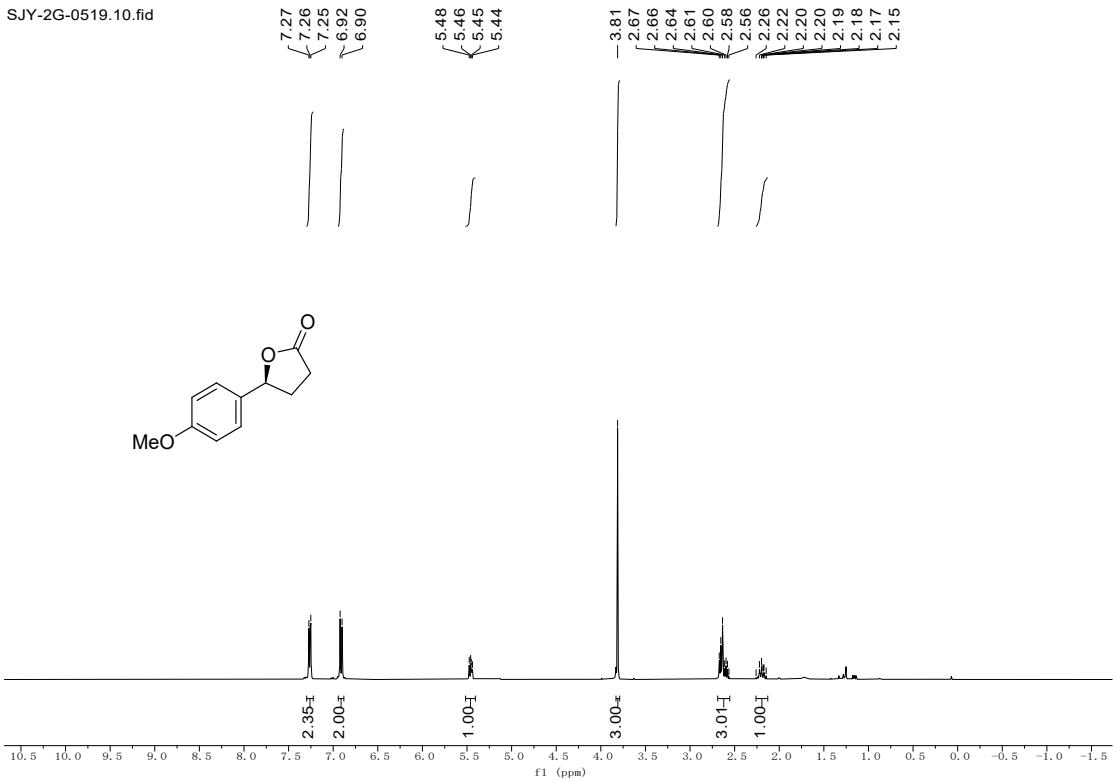
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2g**



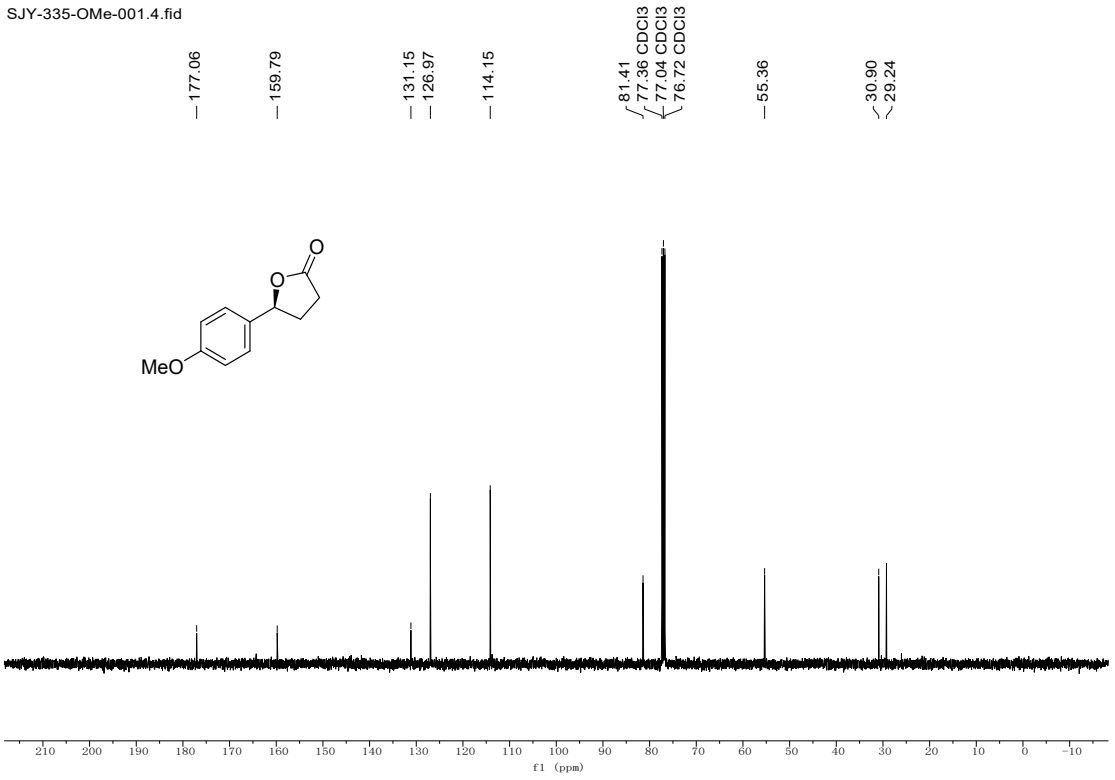
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2g**



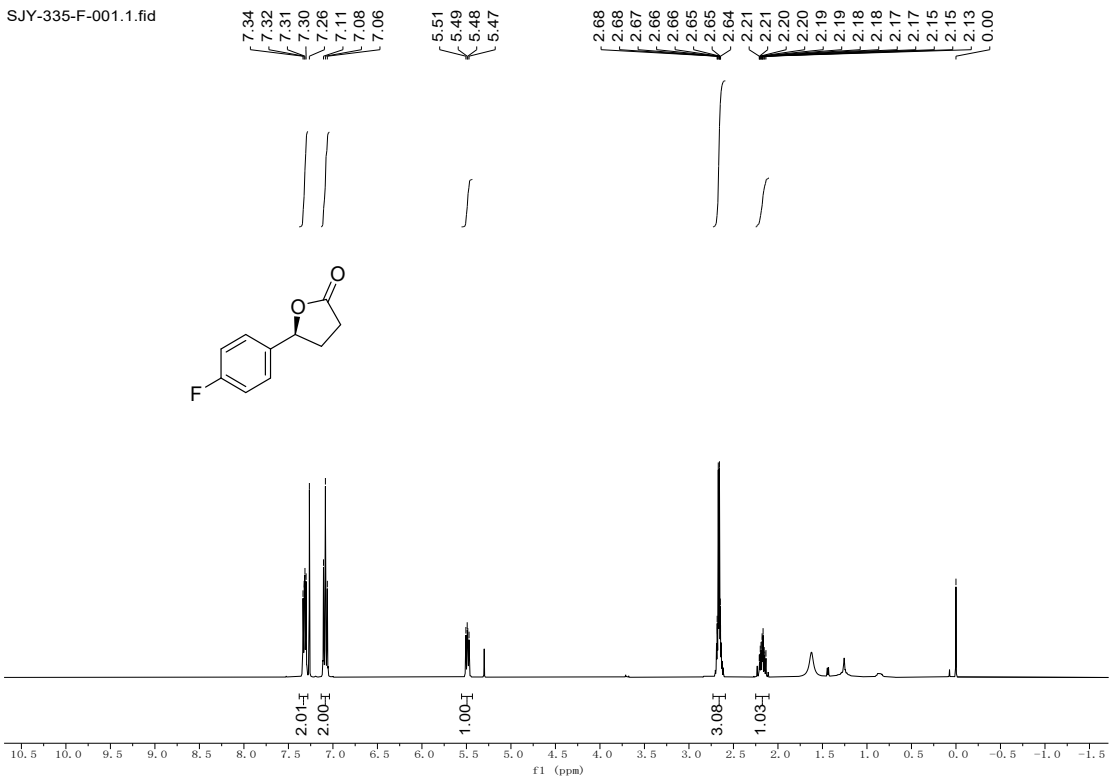
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2h**



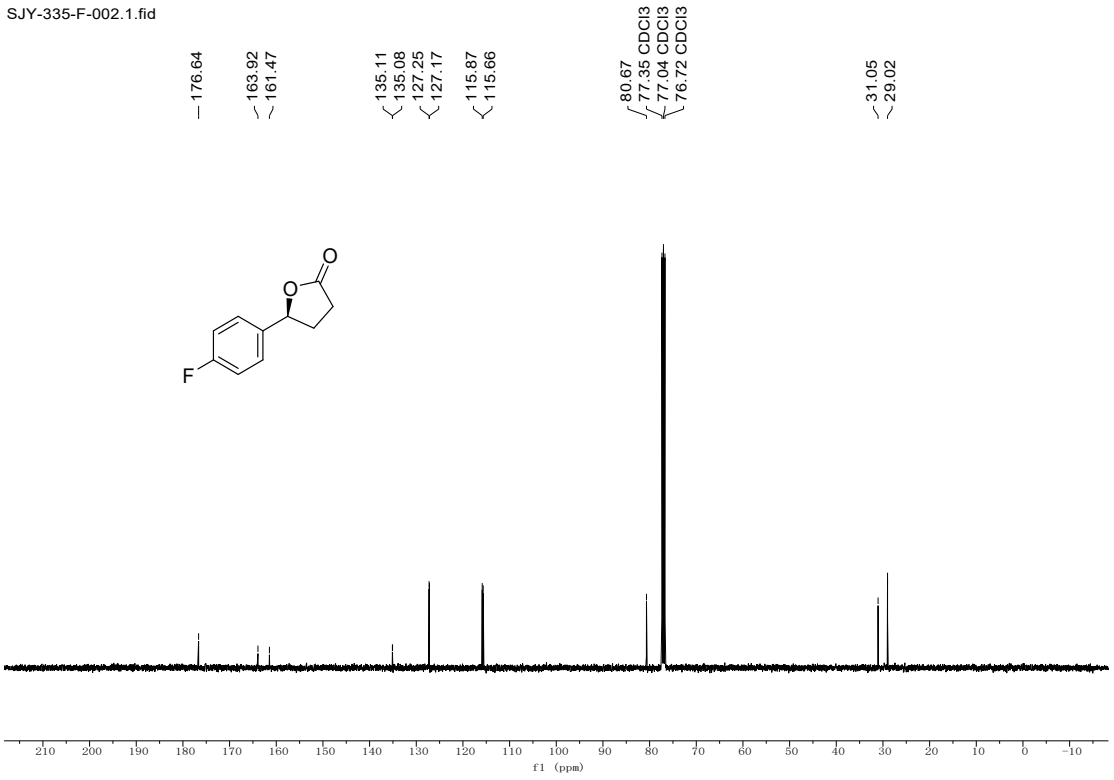
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2h**



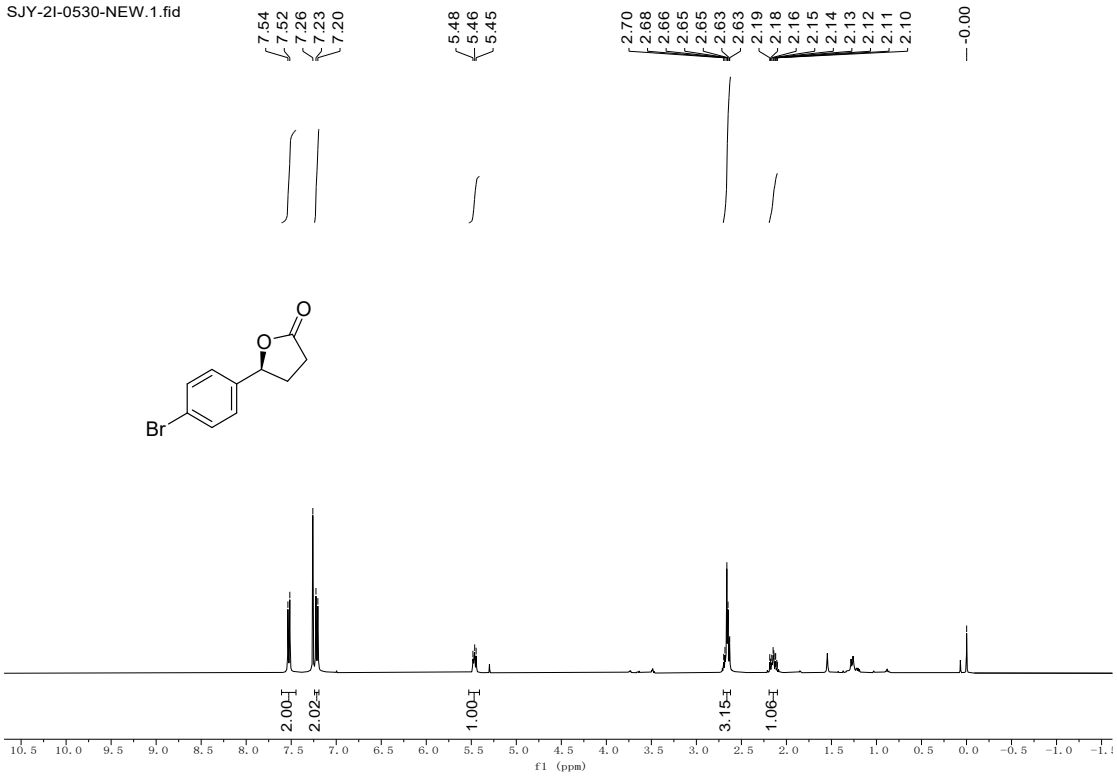
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2i**



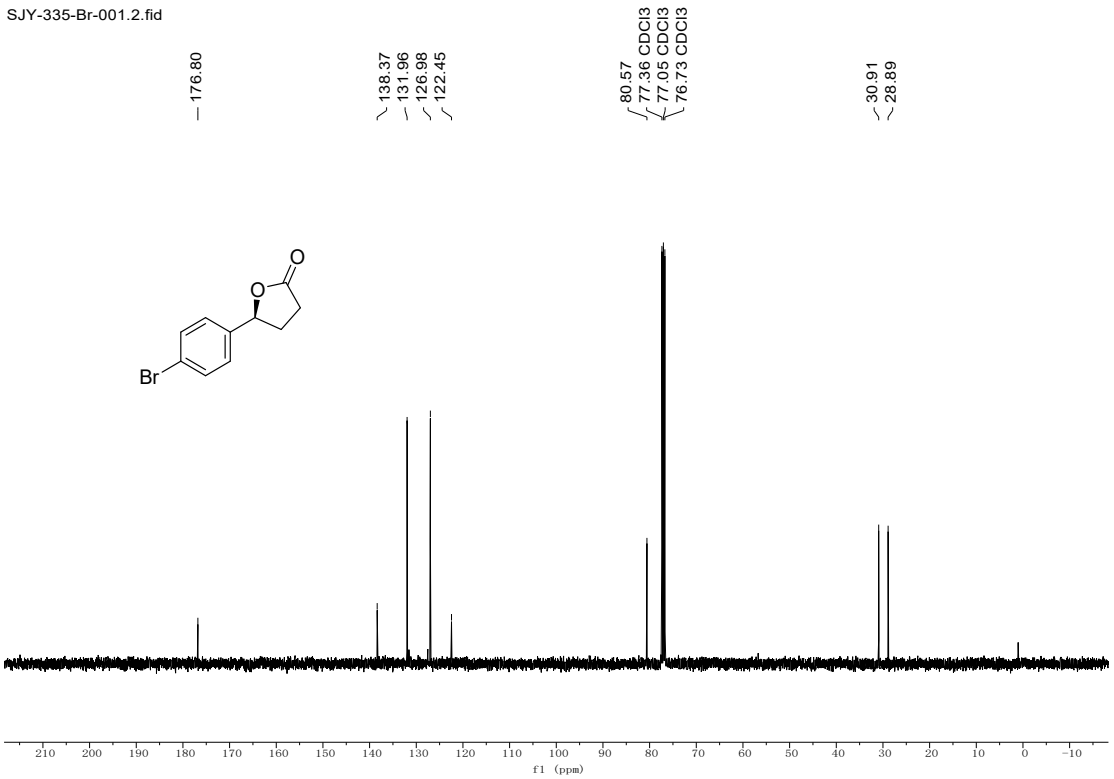
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2i**



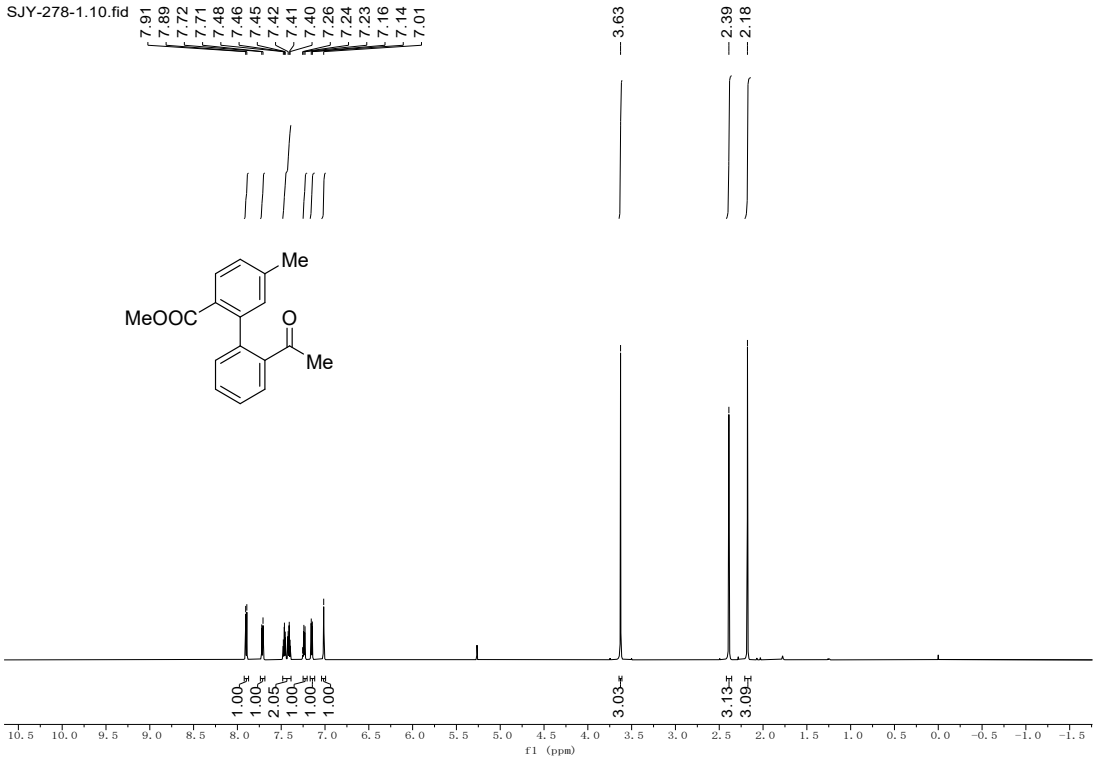
^{1}H NMR (400 MHz, $CDCl_3$) of compound **2j**



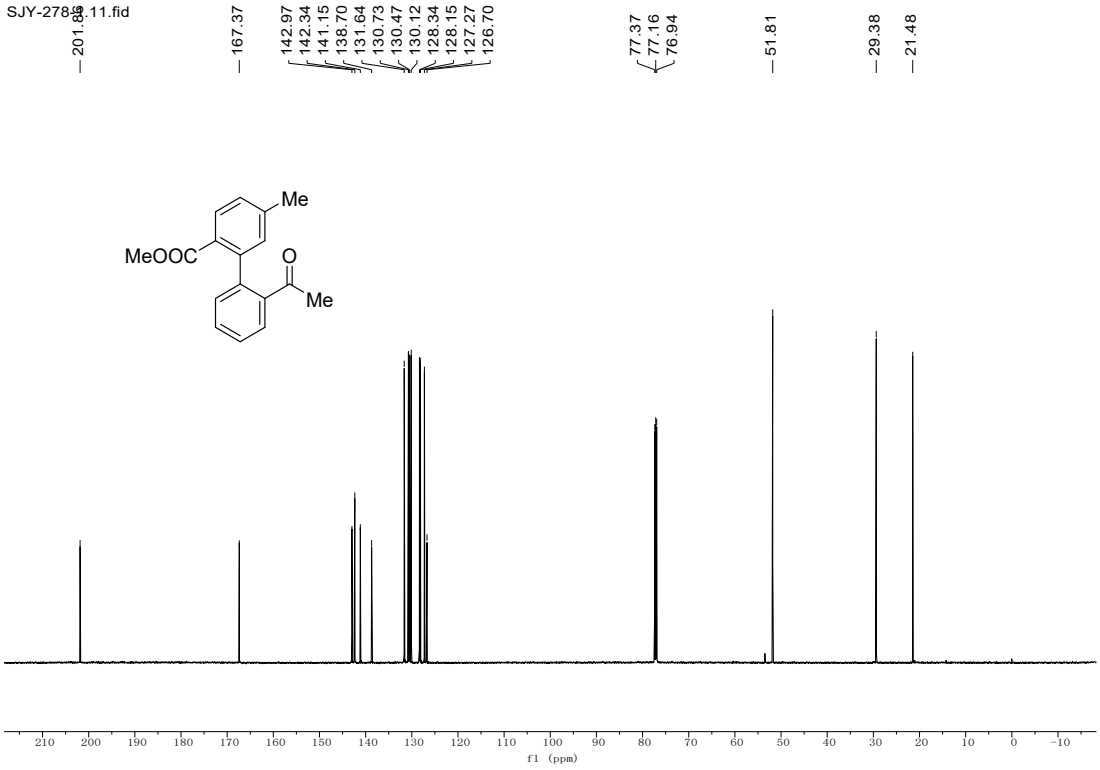
^{13}C NMR (101 MHz, $CDCl_3$) of compound **2j**



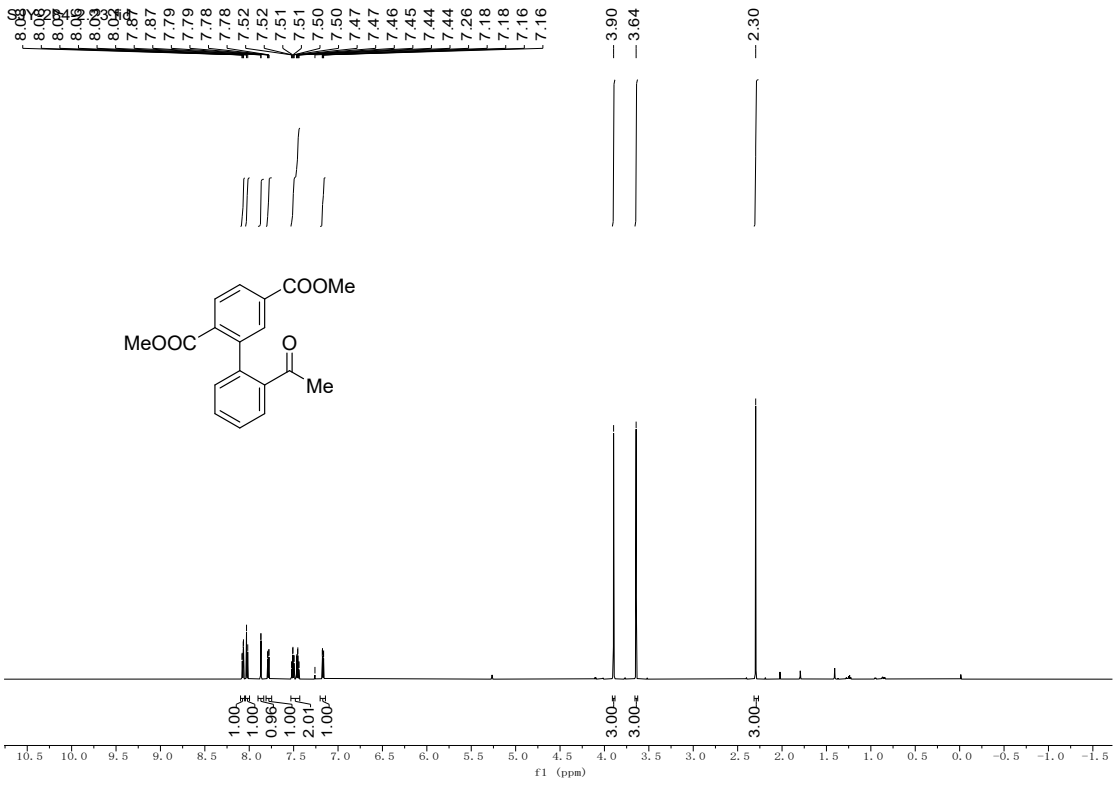
^{1}H NMR (600 MHz, $CDCl_3$) of compound **3b**



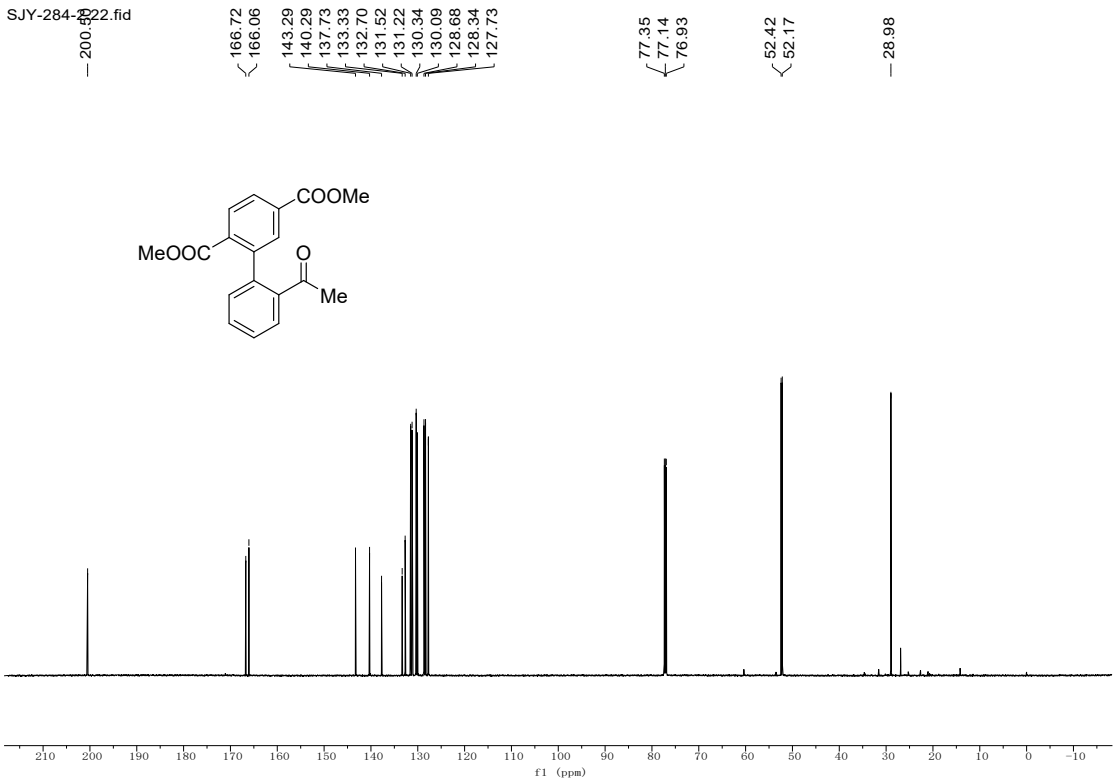
^{13}C NMR (151 MHz, $CDCl_3$) of compound **3b**



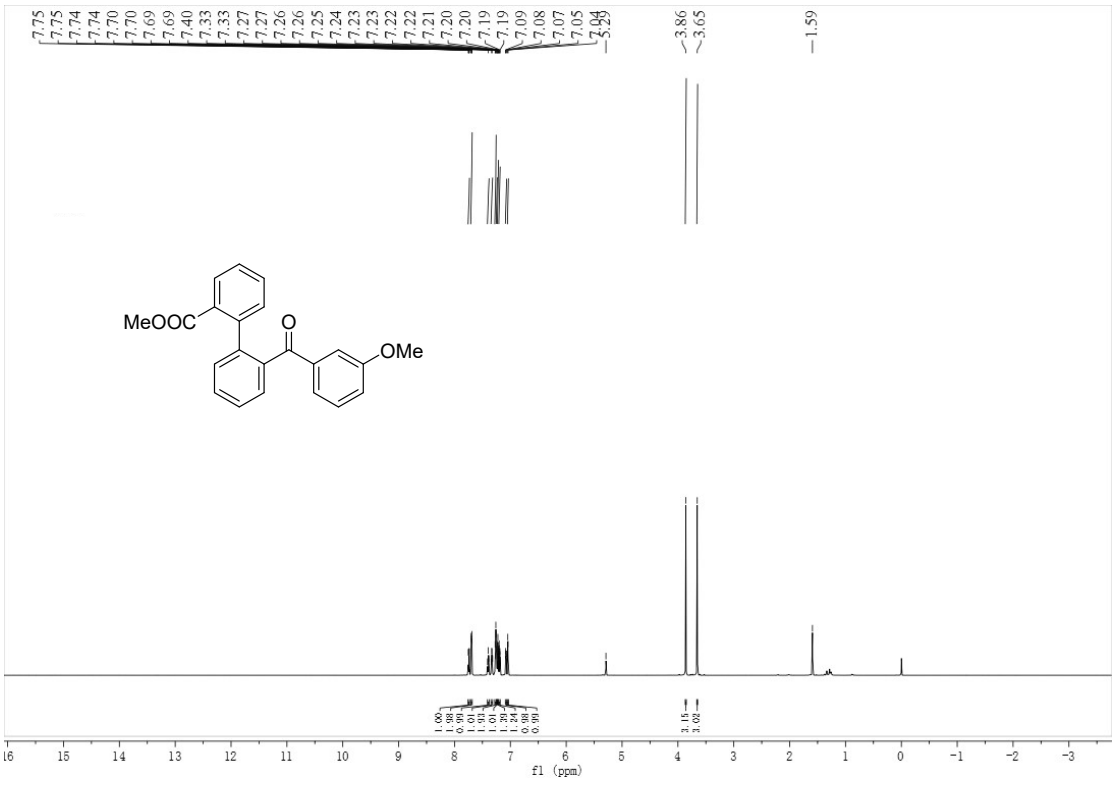
^{1}H NMR (600 MHz, $CDCl_3$) of compound **3i**



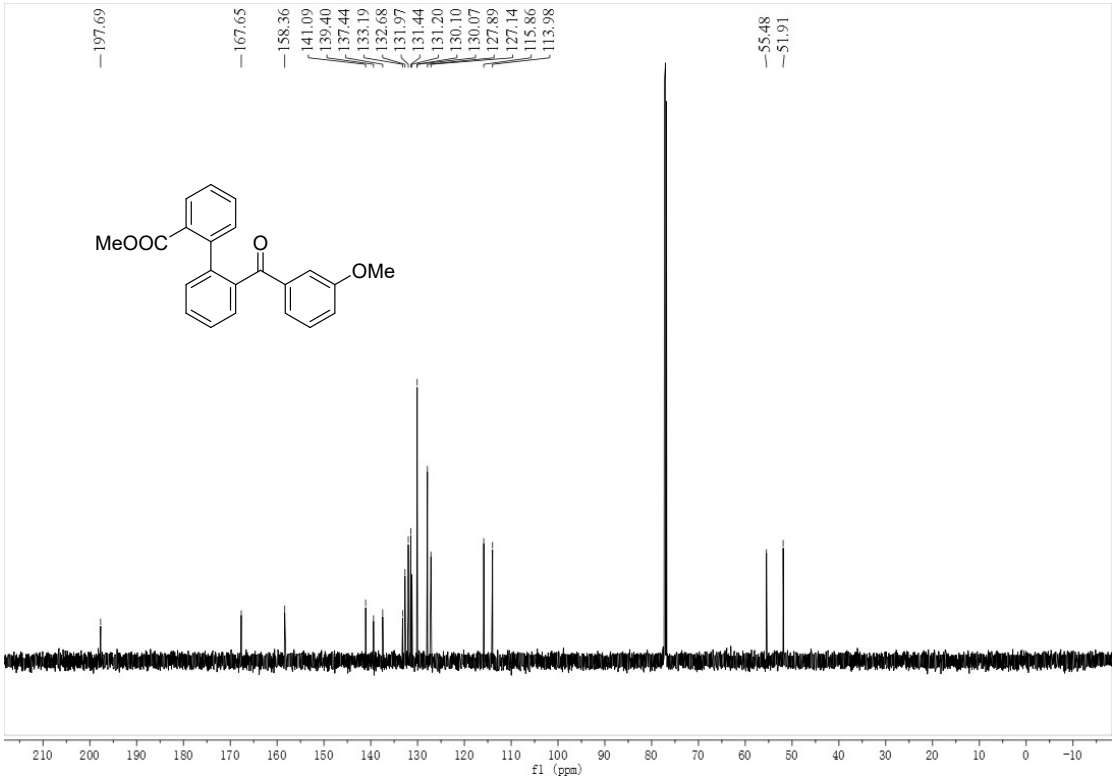
^{13}C NMR (151 MHz, $CDCl_3$) of compound **3i**



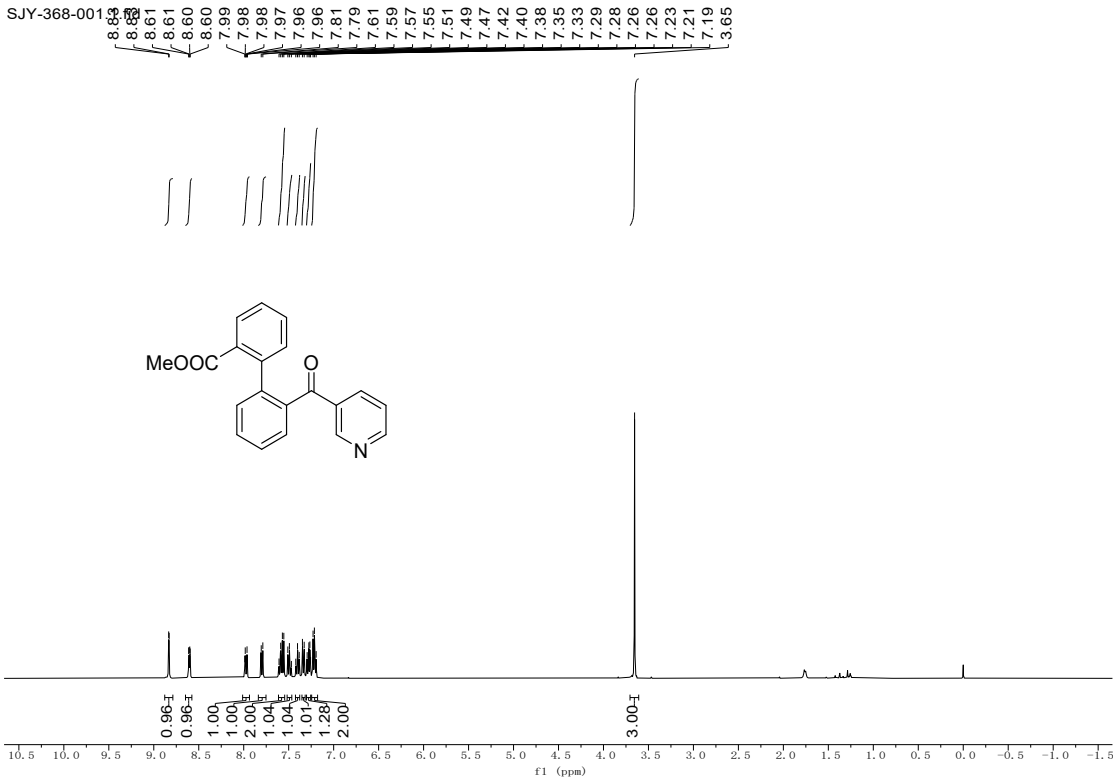
^{1}H NMR (600 MHz, $CDCl_3$) of compound **3o**



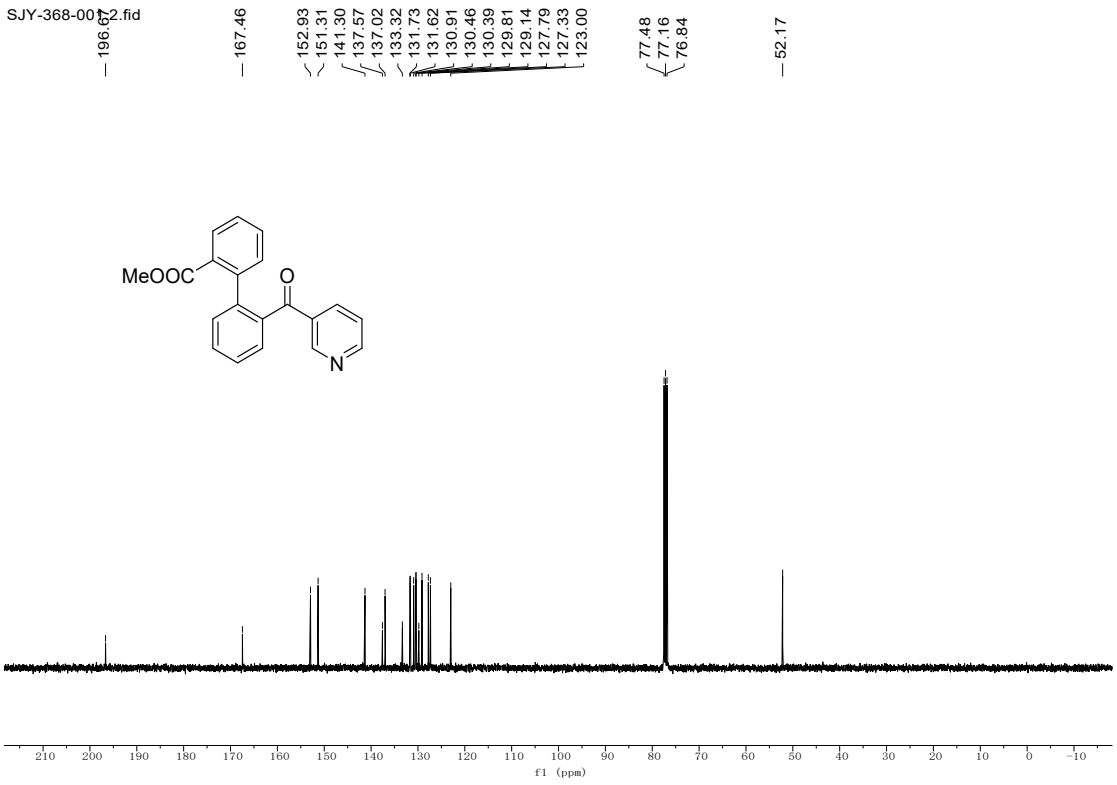
^{13}C NMR (151 MHz, $CDCl_3$) of compound **3o**



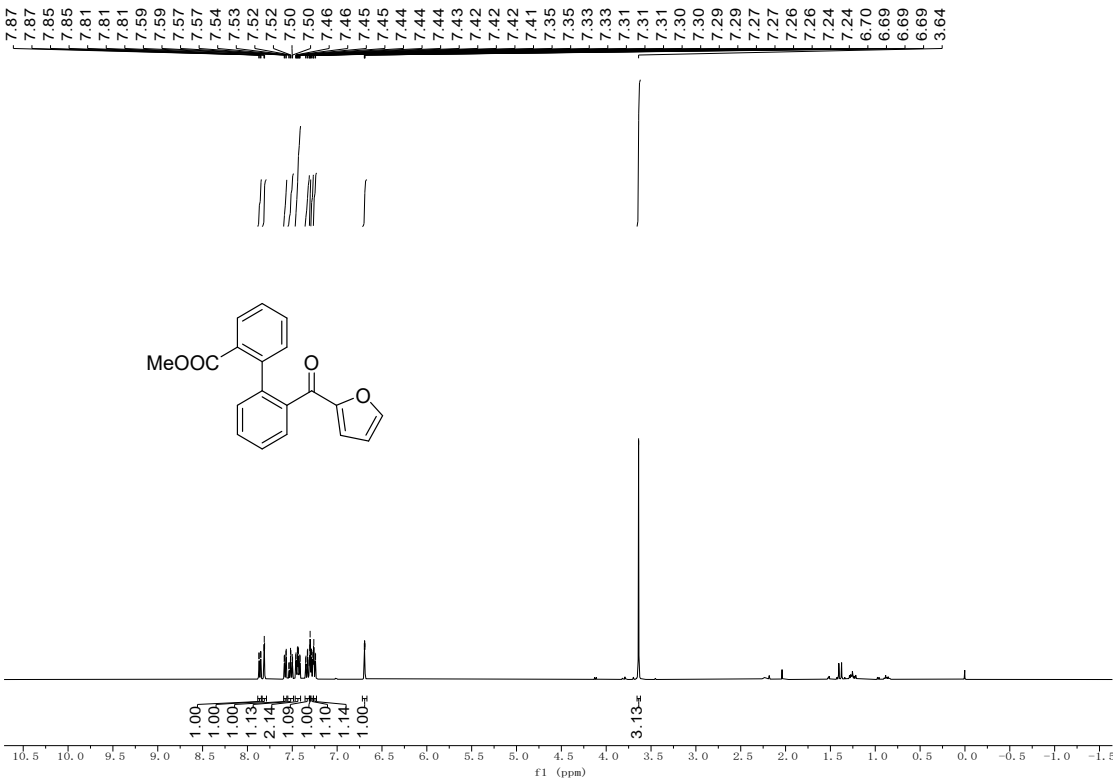
^{1}H NMR (400 MHz, $CDCl_3$) of compound **3p**



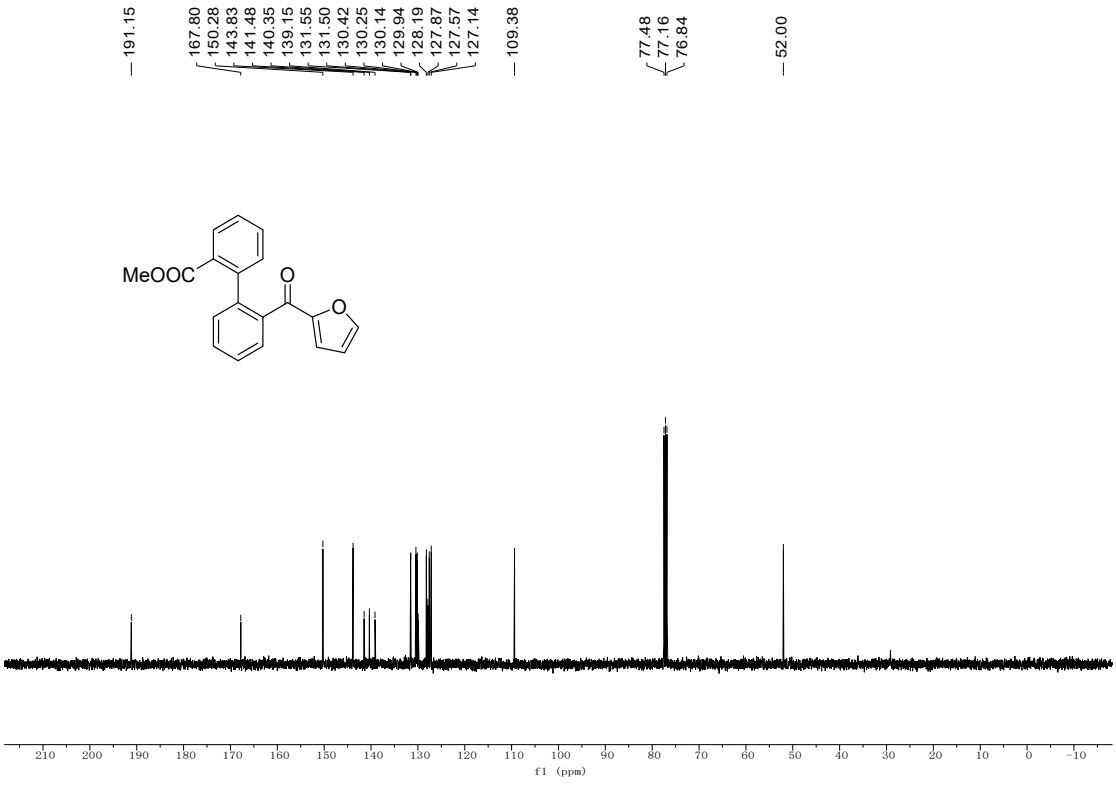
^{13}C NMR (101 MHz, $CDCl_3$) of compound **3p**



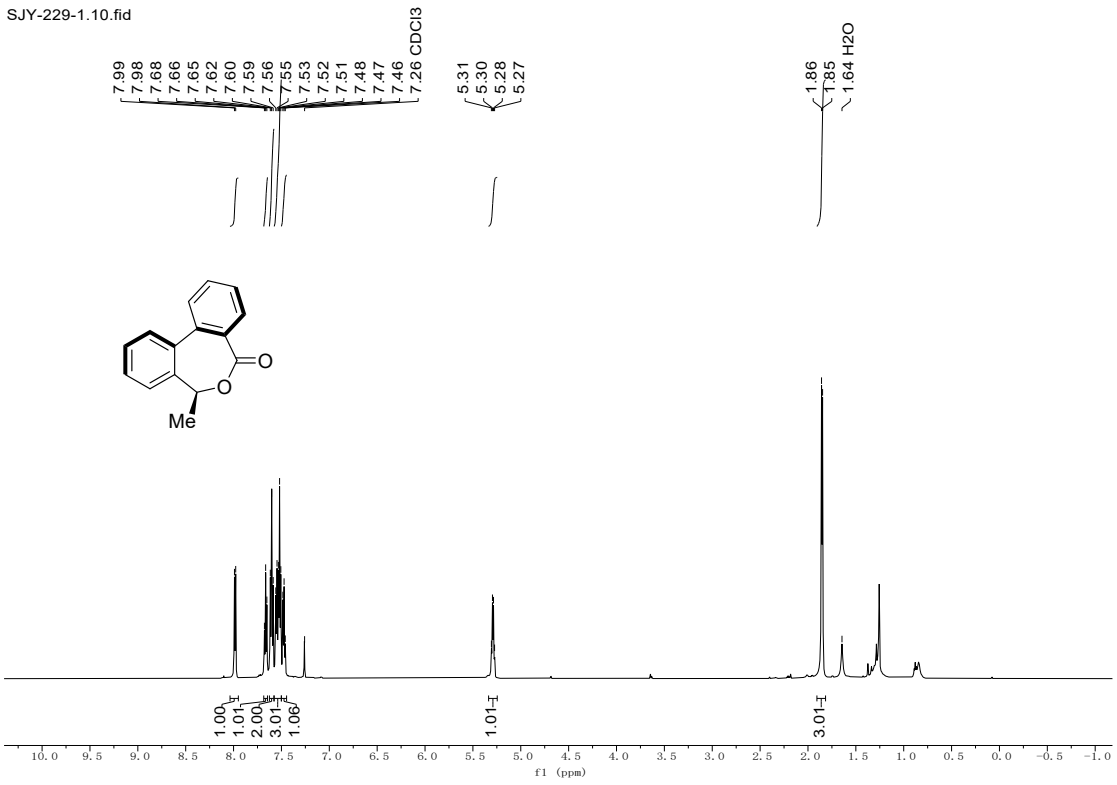
^{1}H NMR (400 MHz, $CDCl_3$) of compound **3q**



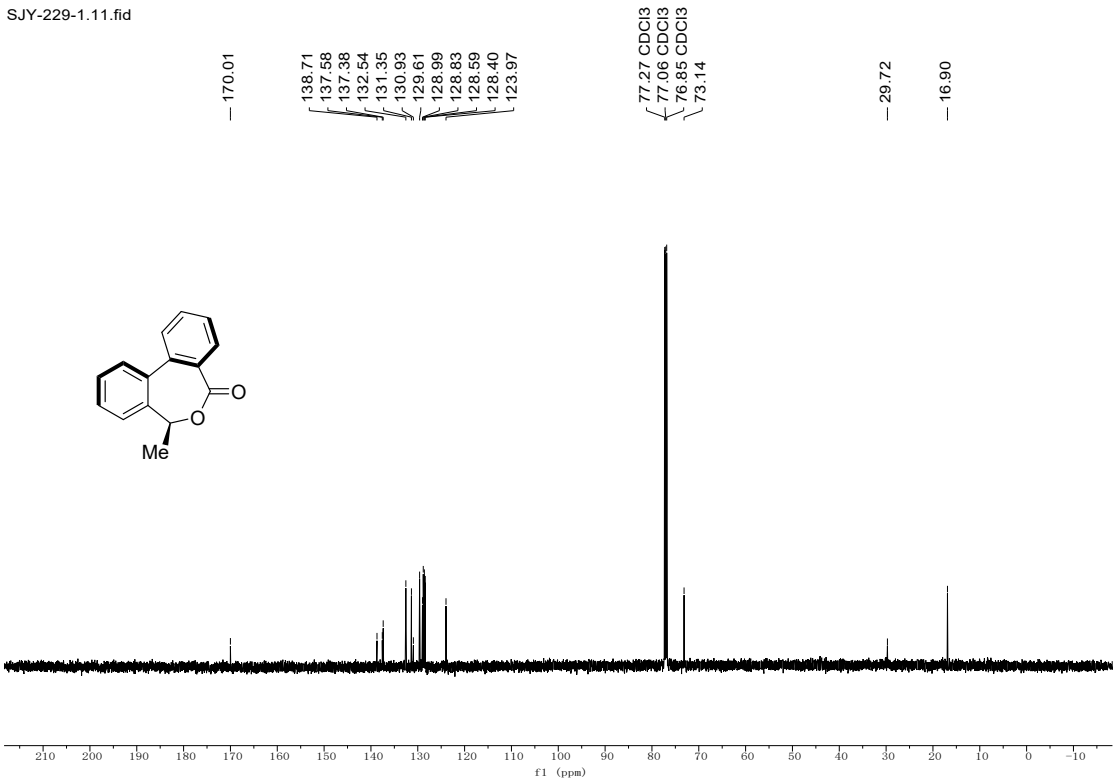
^{13}C NMR (101 MHz, $CDCl_3$) of compound **3q**



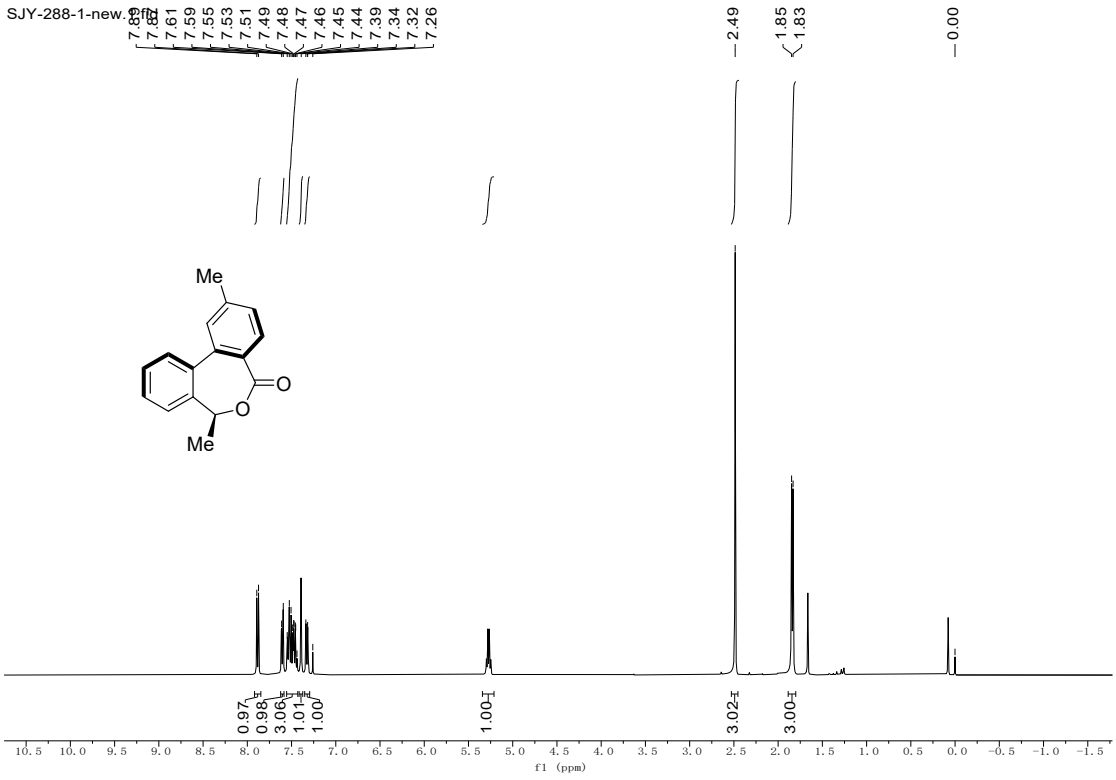
^{1}H NMR (600 MHz, $CDCl_3$) of compound **4a**



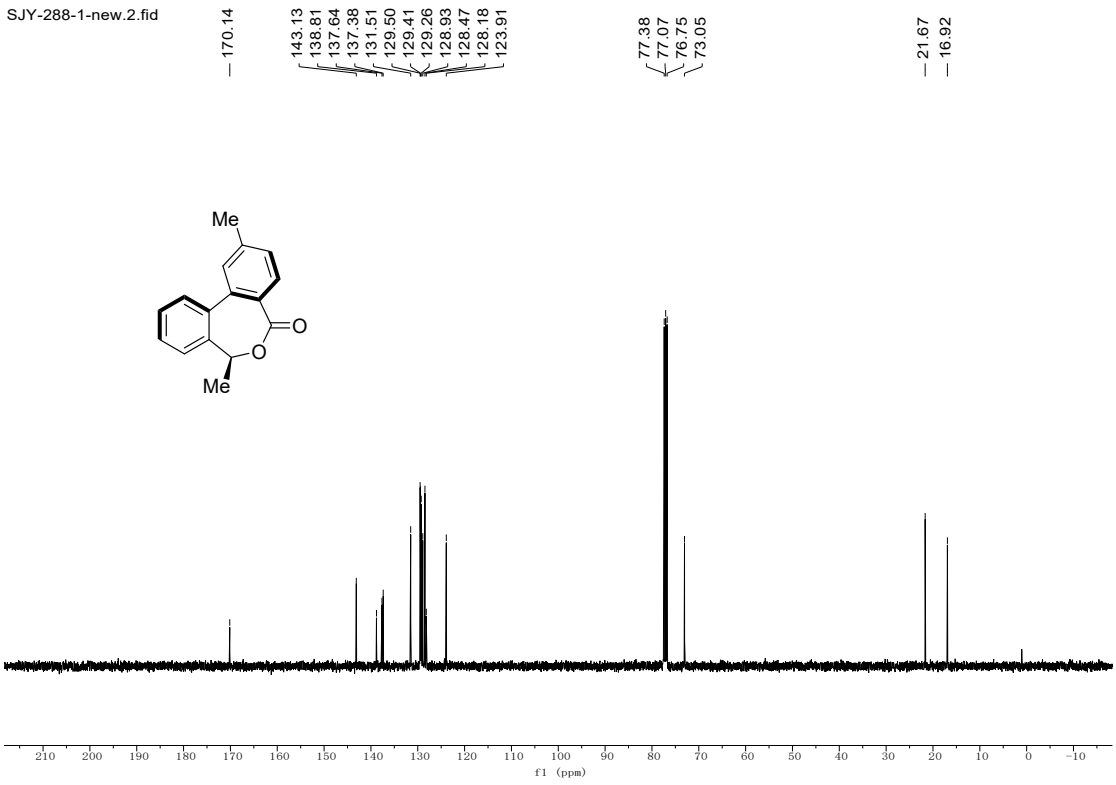
^{13}C NMR (151 MHz, $CDCl_3$) of compound **4a**



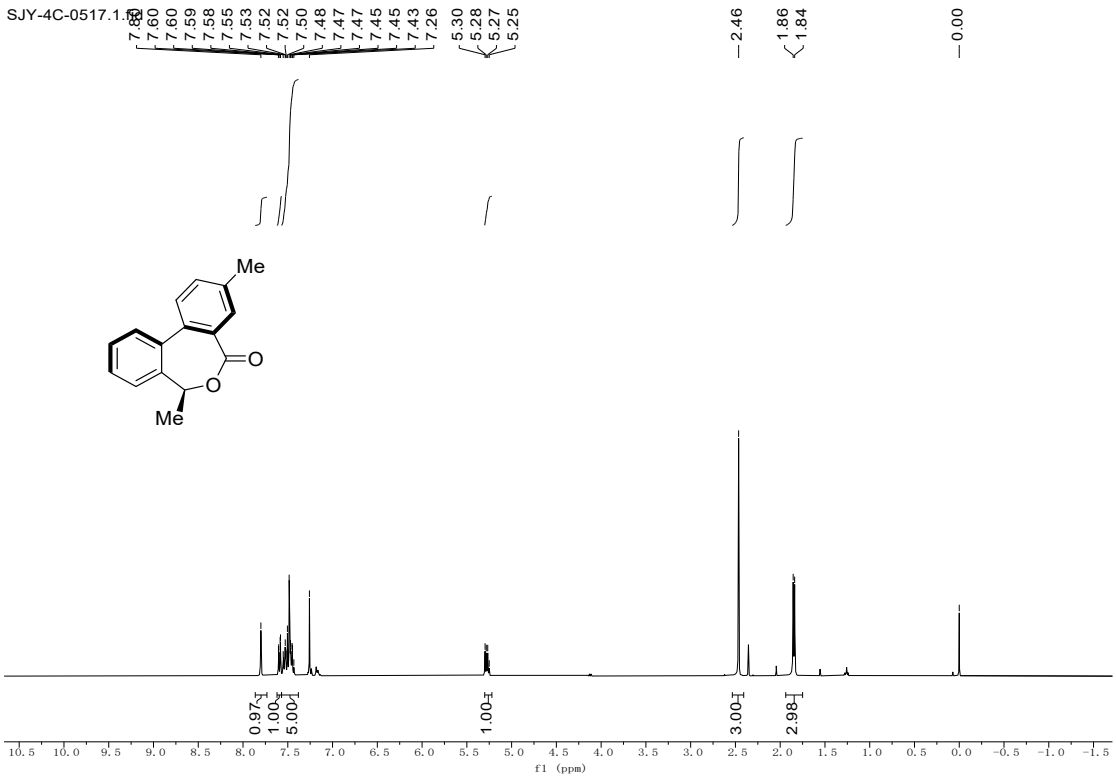
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4b**



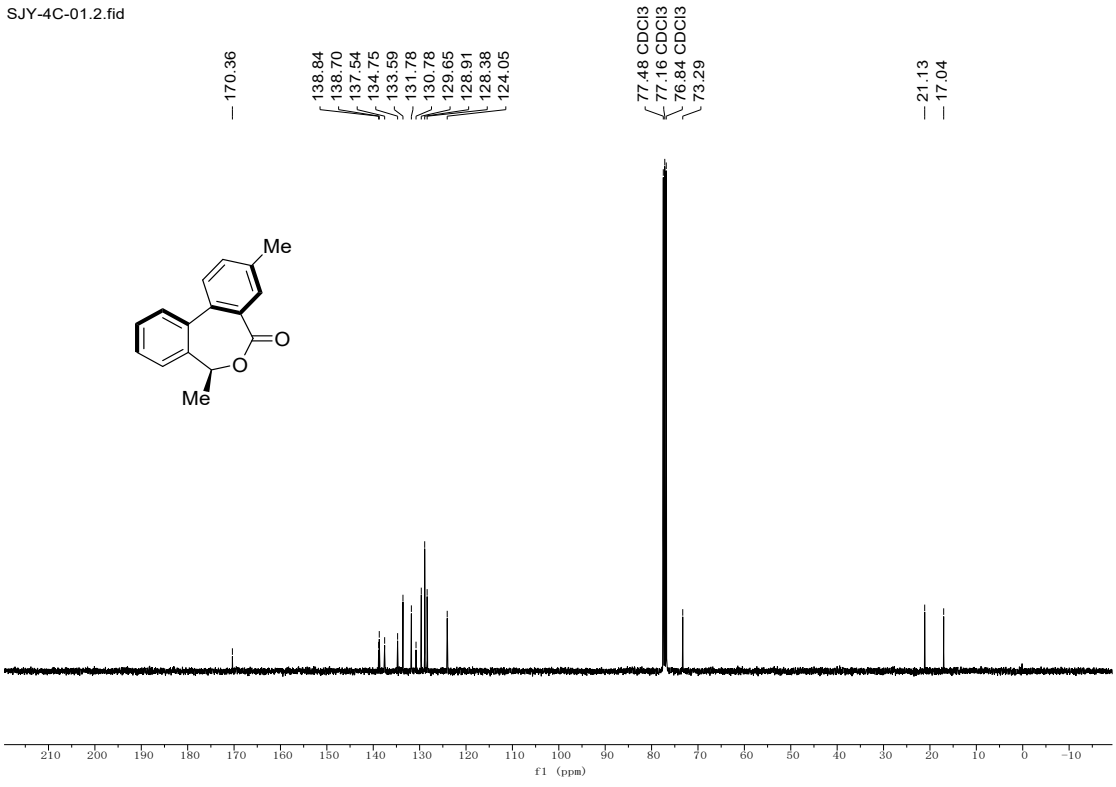
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4b**



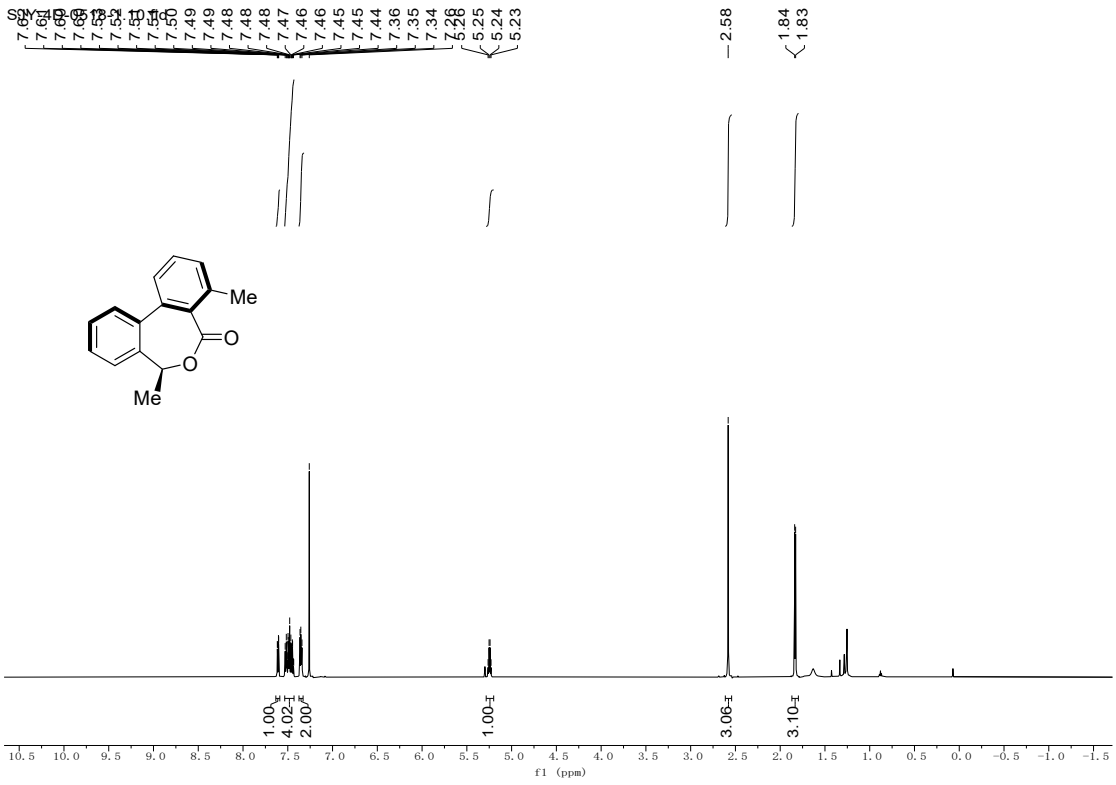
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4c**



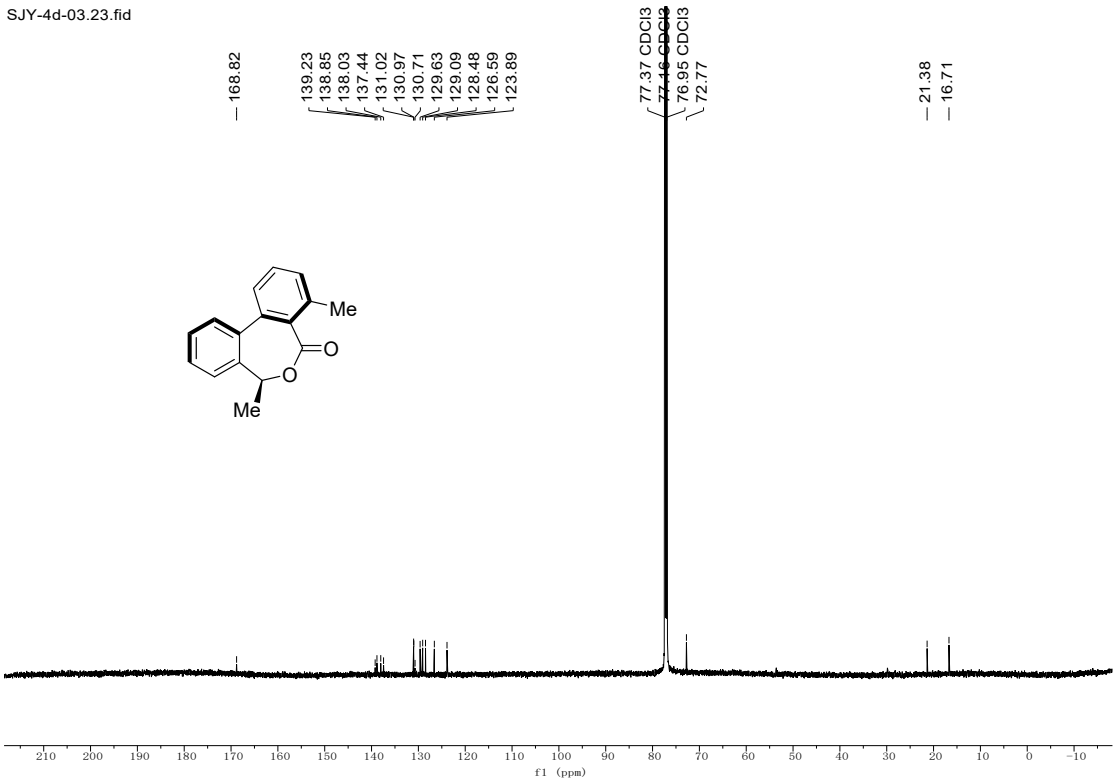
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4c**



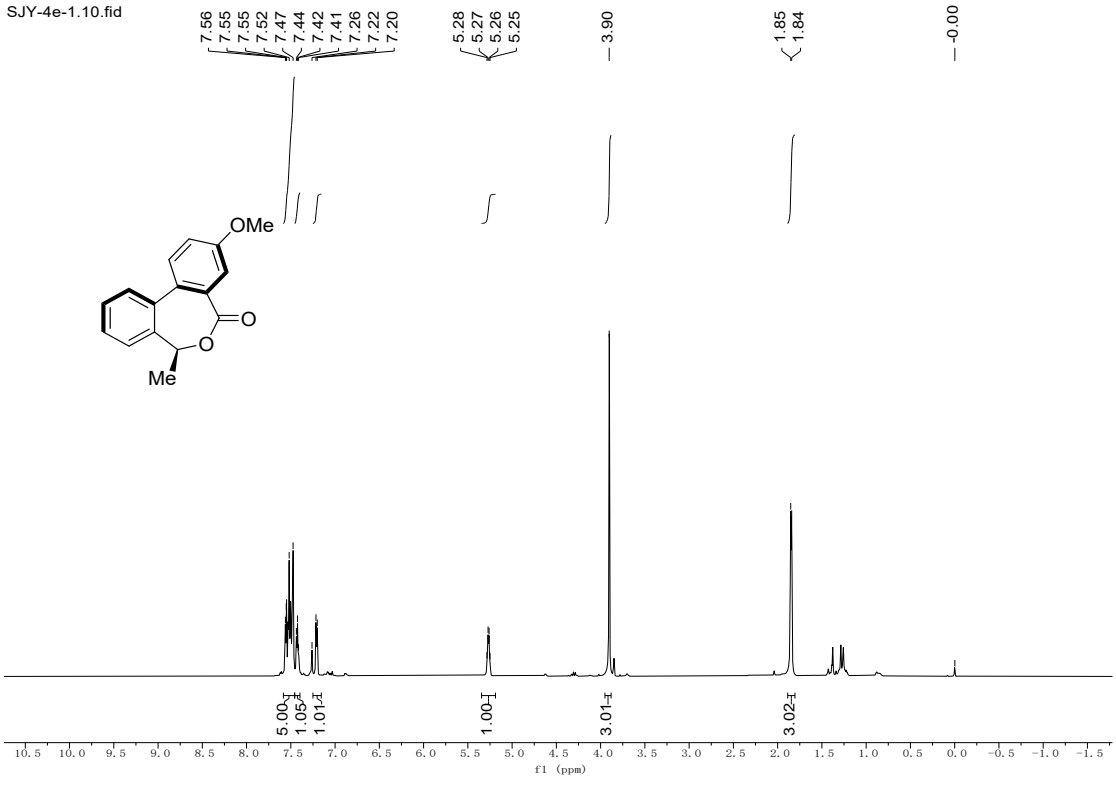
^{1}H NMR (600 MHz, $CDCl_3$) of compound **4d**



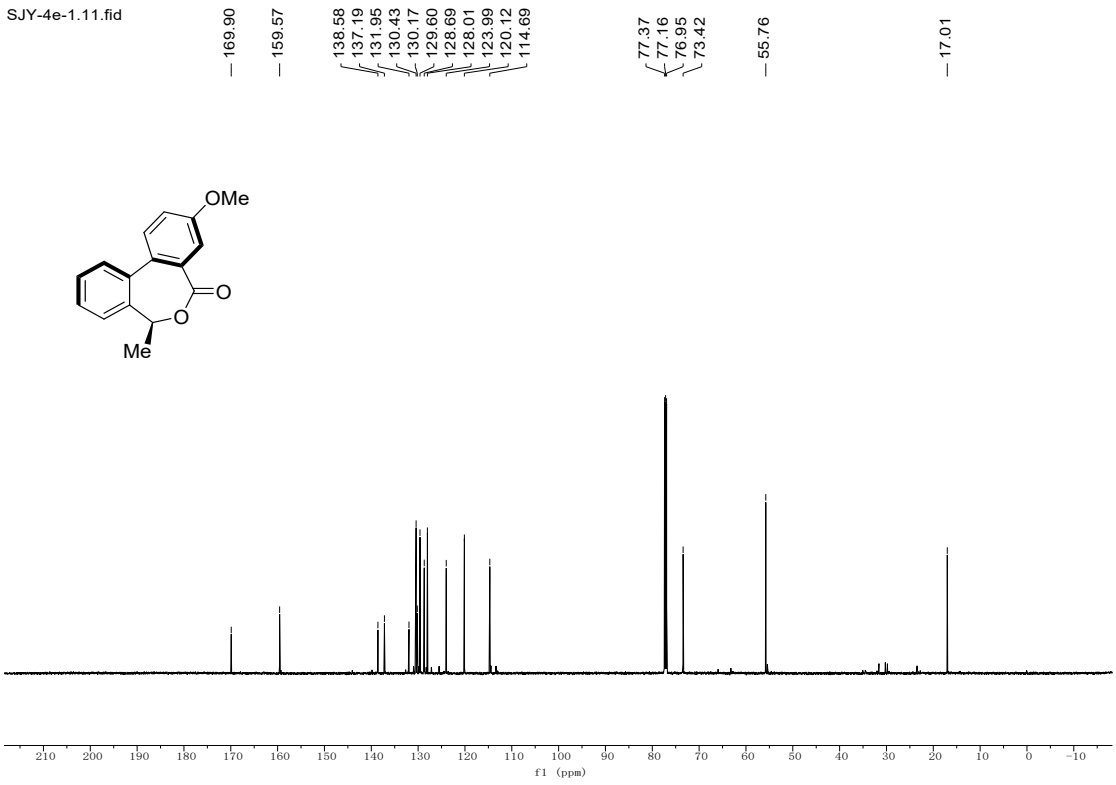
^{13}C NMR (151 MHz, $CDCl_3$) of compound **4d**



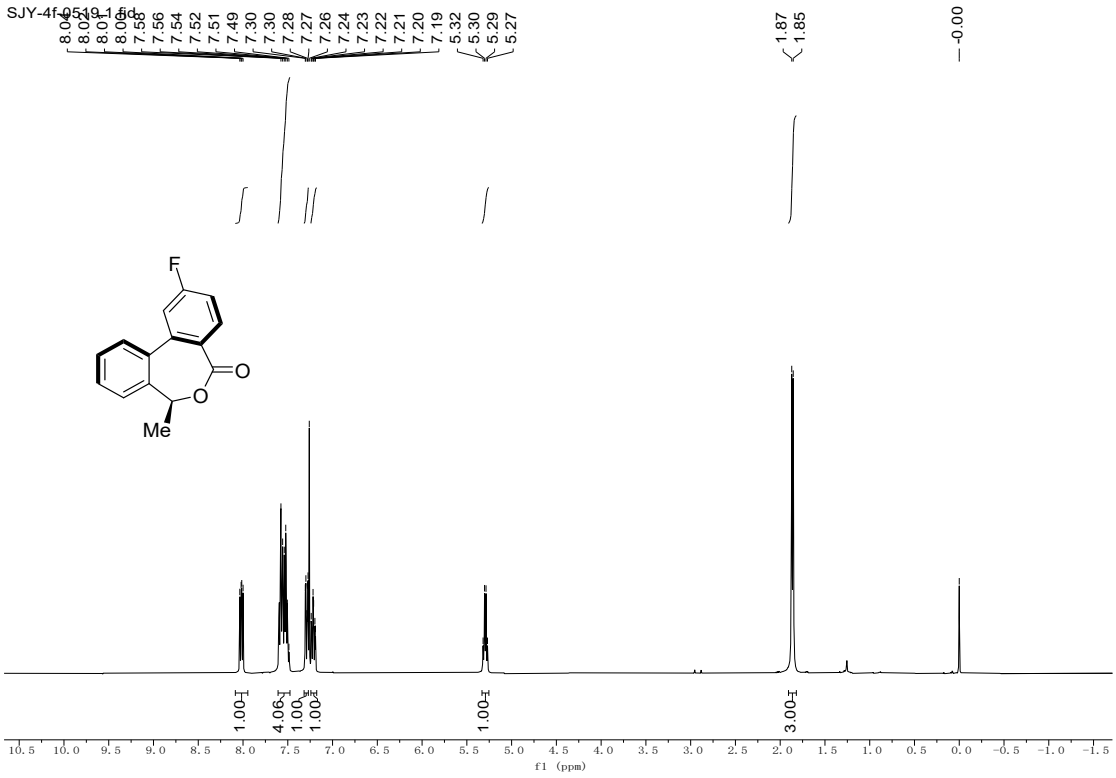
^{1}H NMR (600 MHz, $CDCl_3$) of compound **4e**



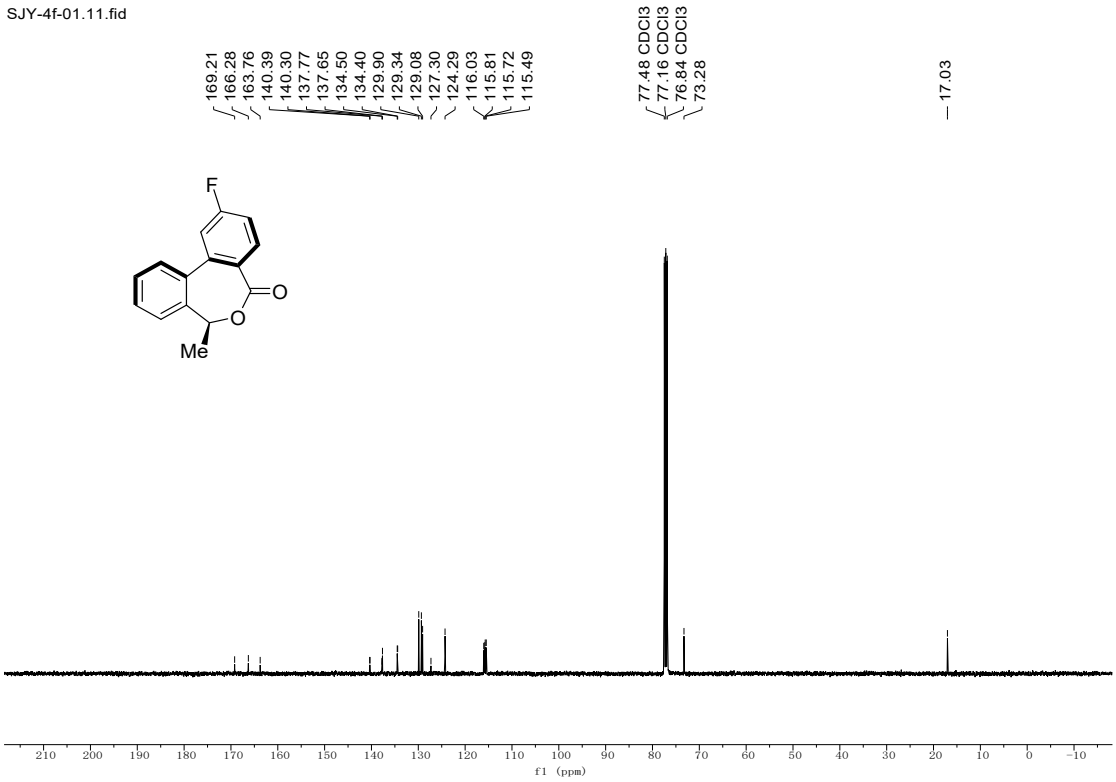
^{13}C NMR (151 MHz, $CDCl_3$) of compound **4e**



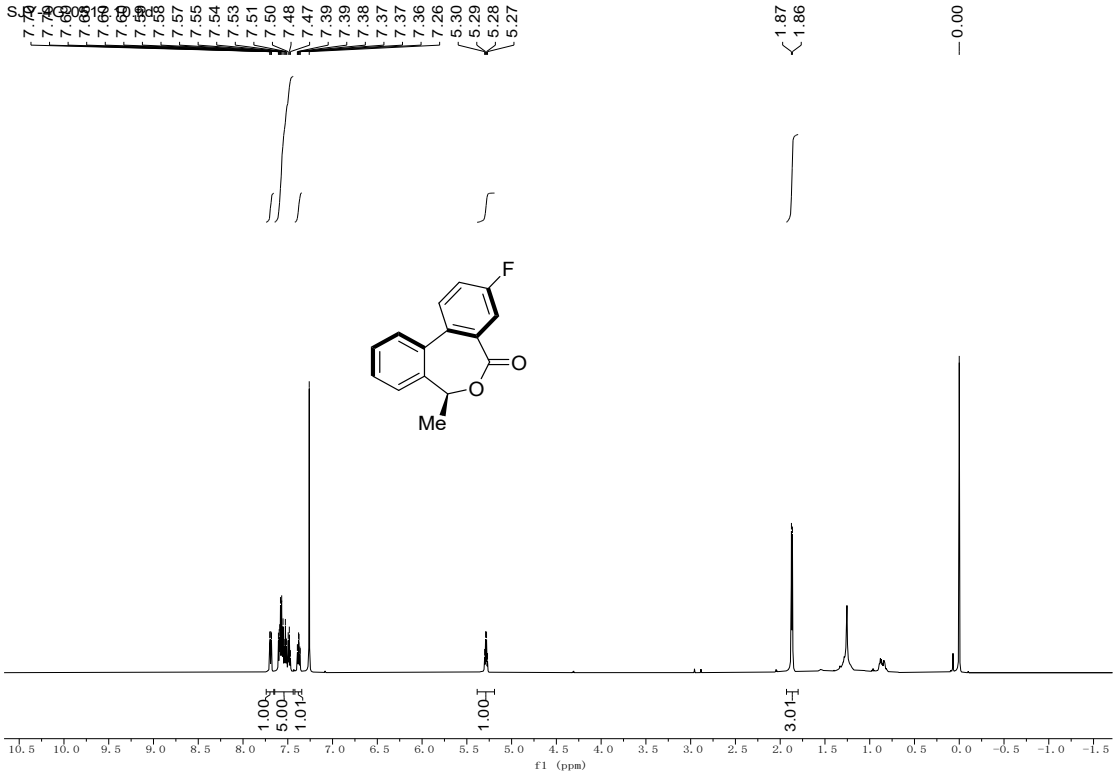
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4f**



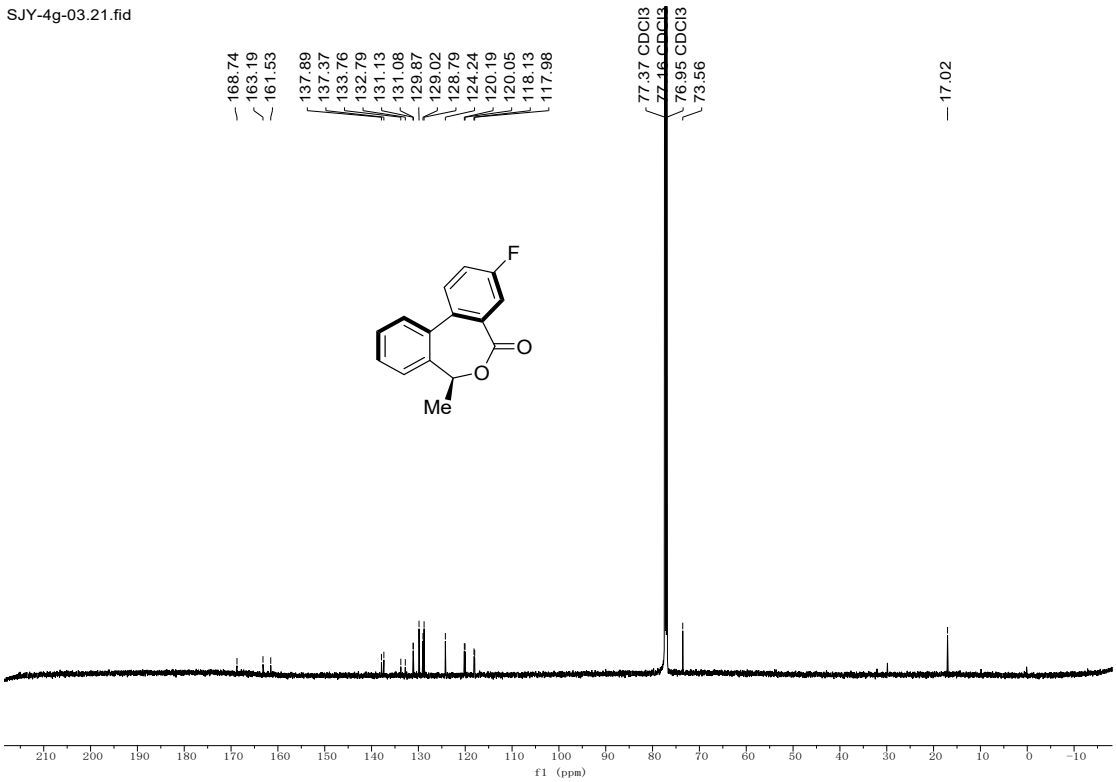
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4f**



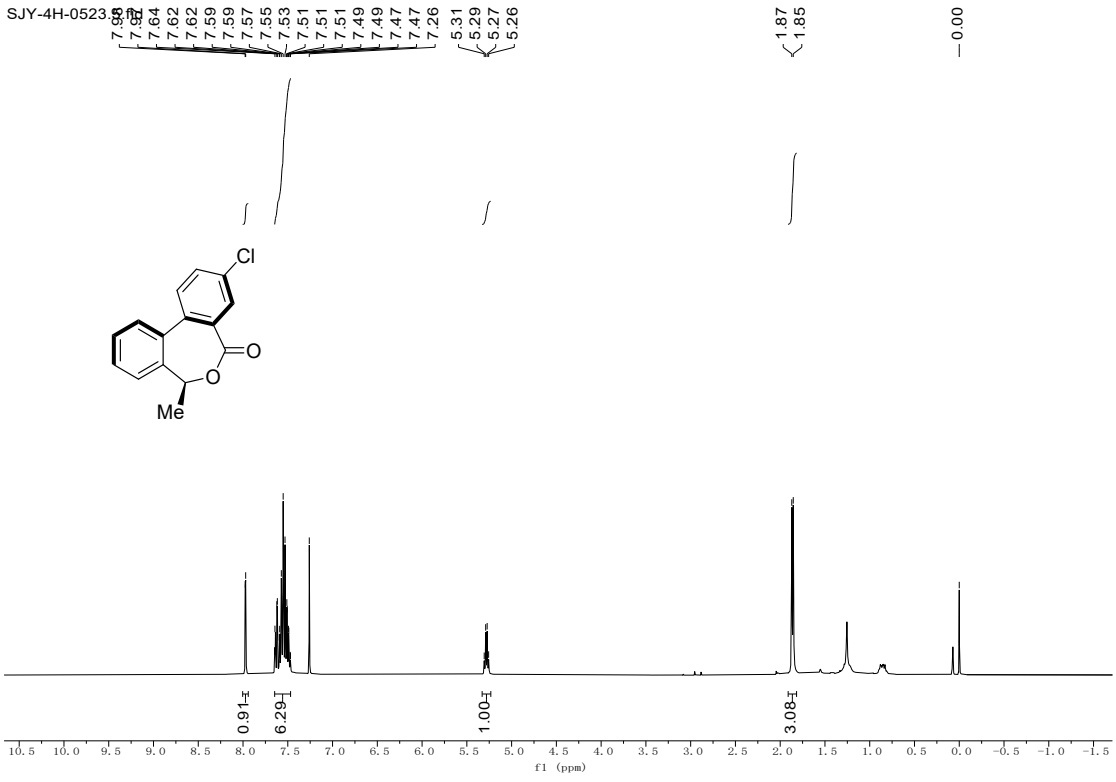
^{1}H NMR (600 MHz, $CDCl_3$) of compound **4g**



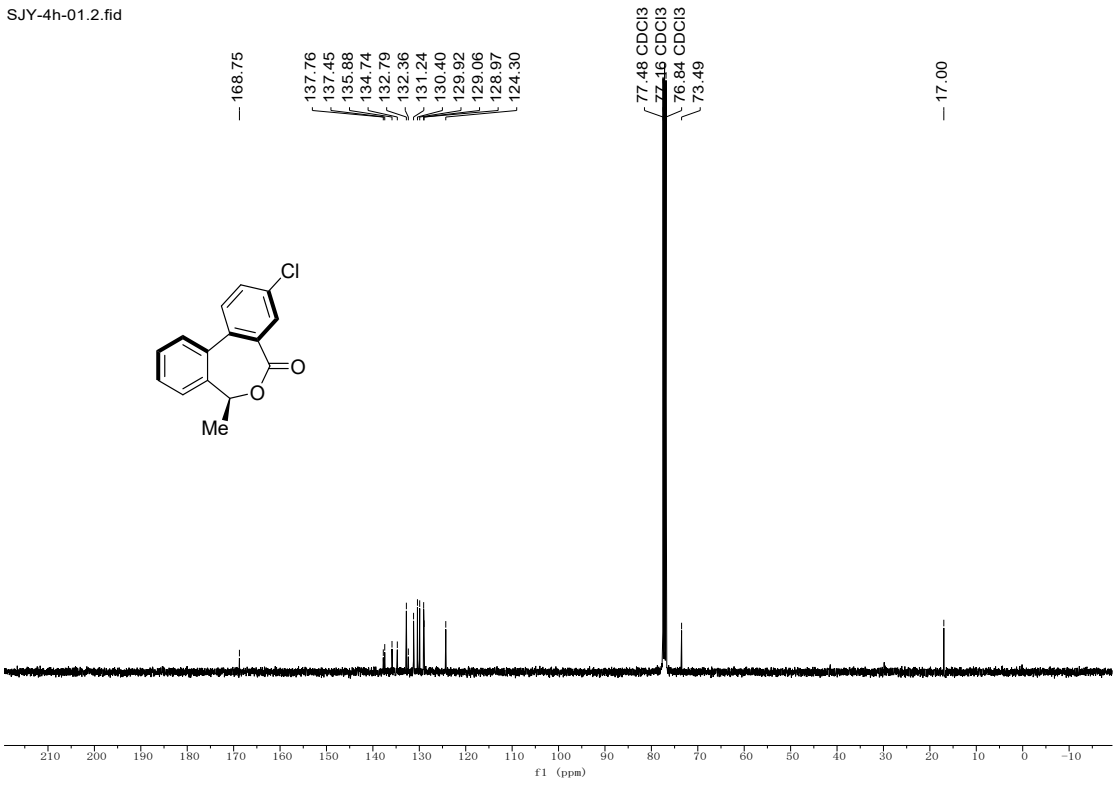
^{13}C NMR (151 MHz, $CDCl_3$) of compound **4g**



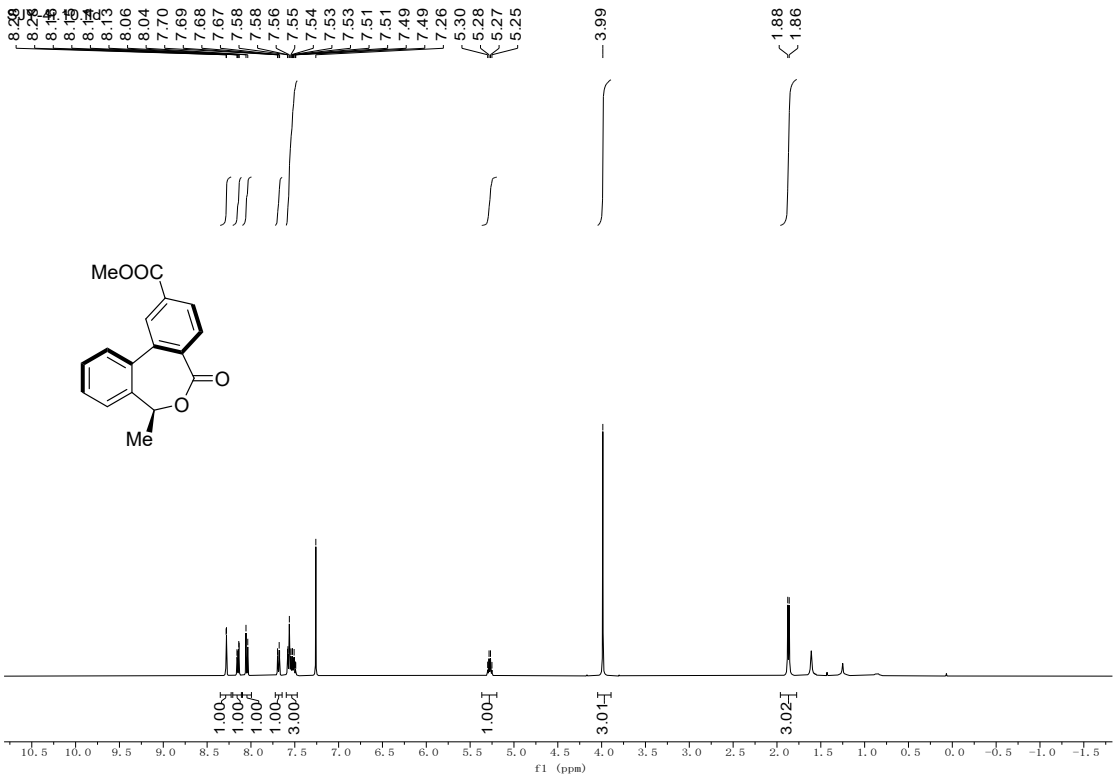
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4h**



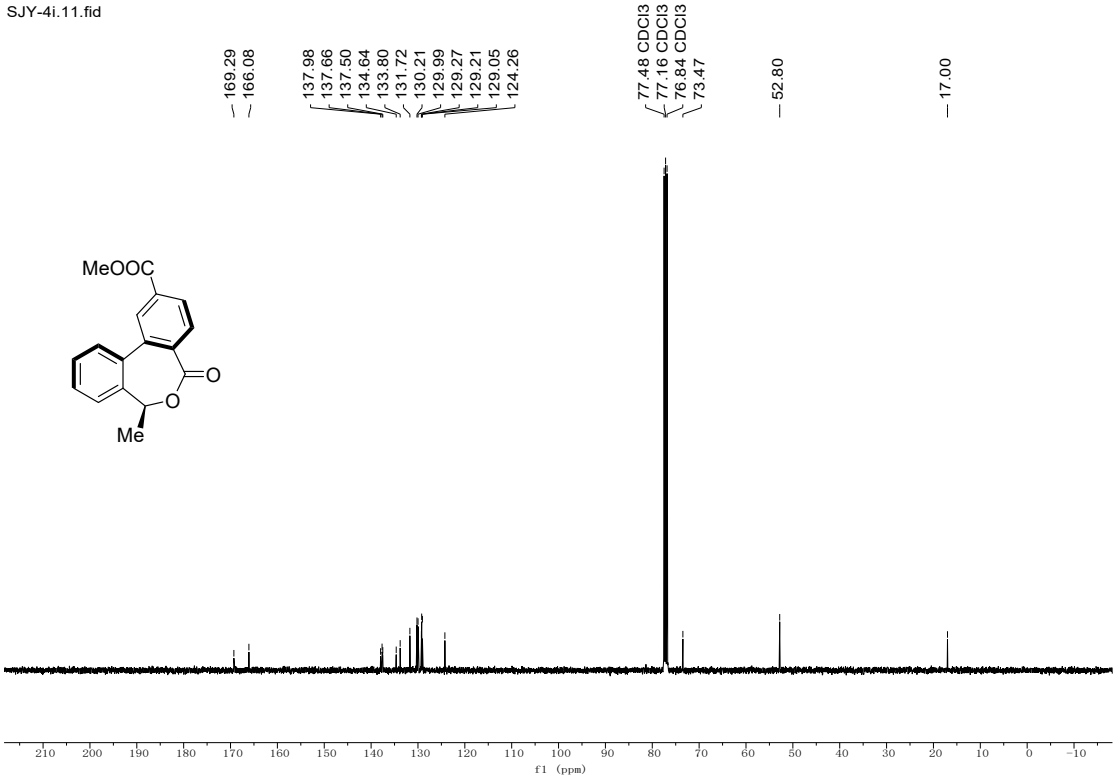
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4h**



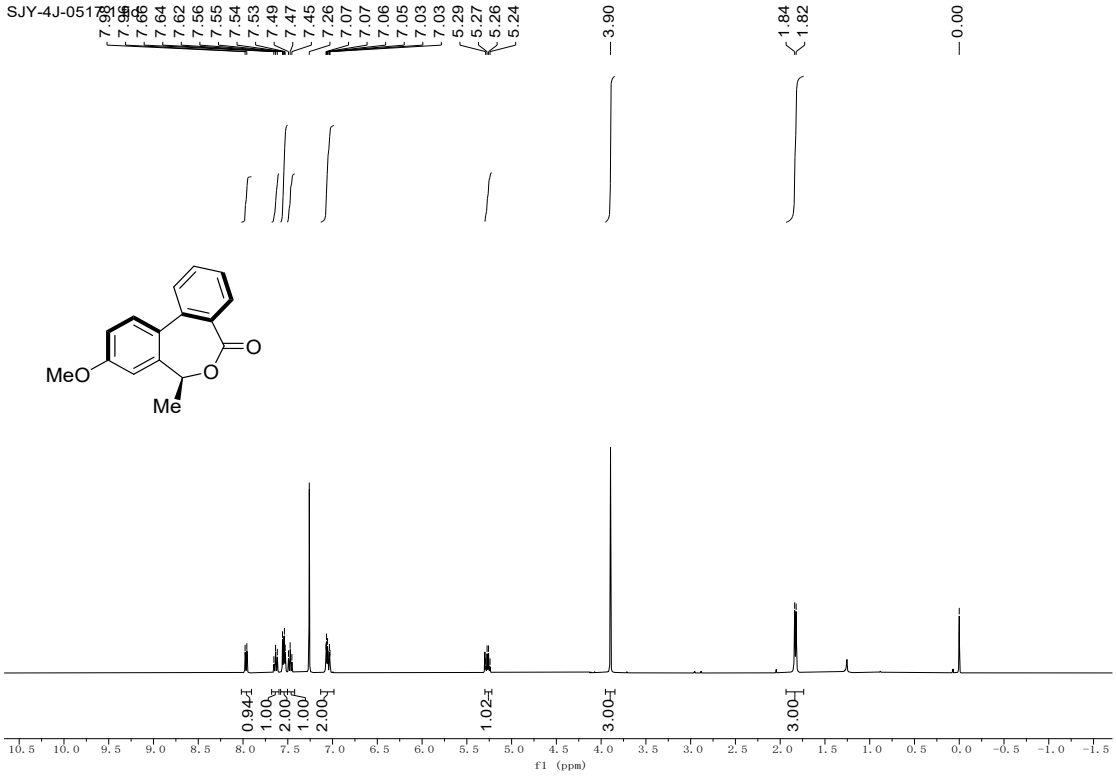
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4i**



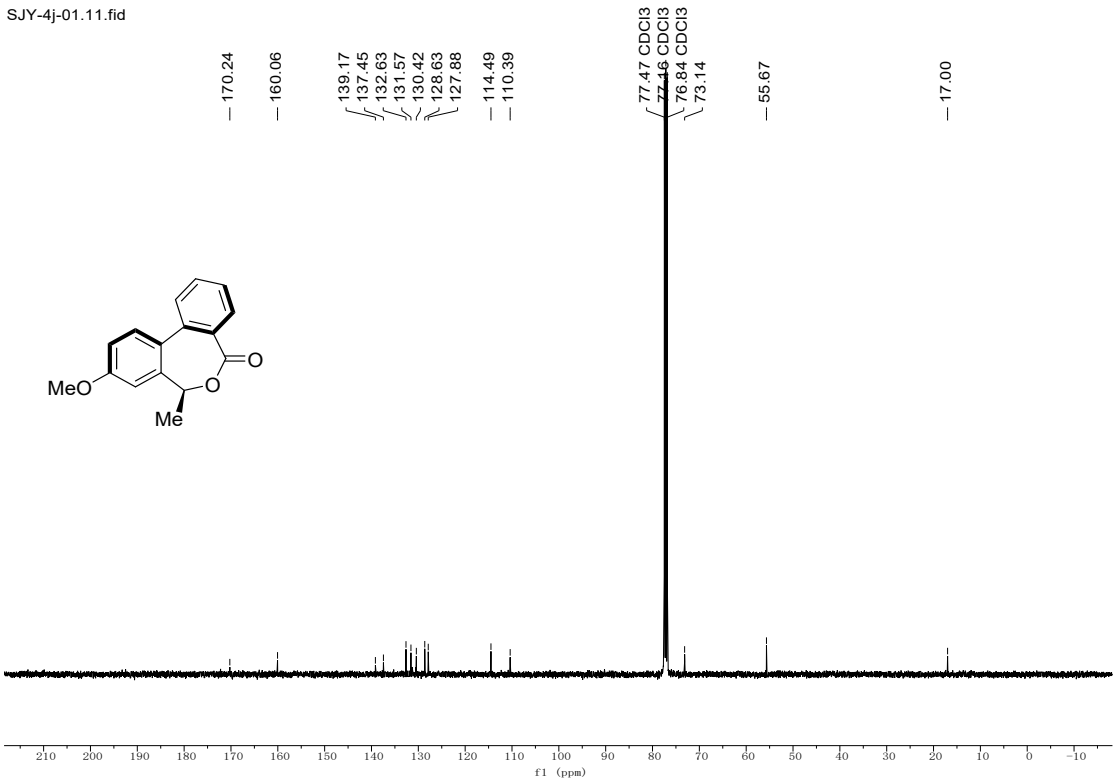
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4i**



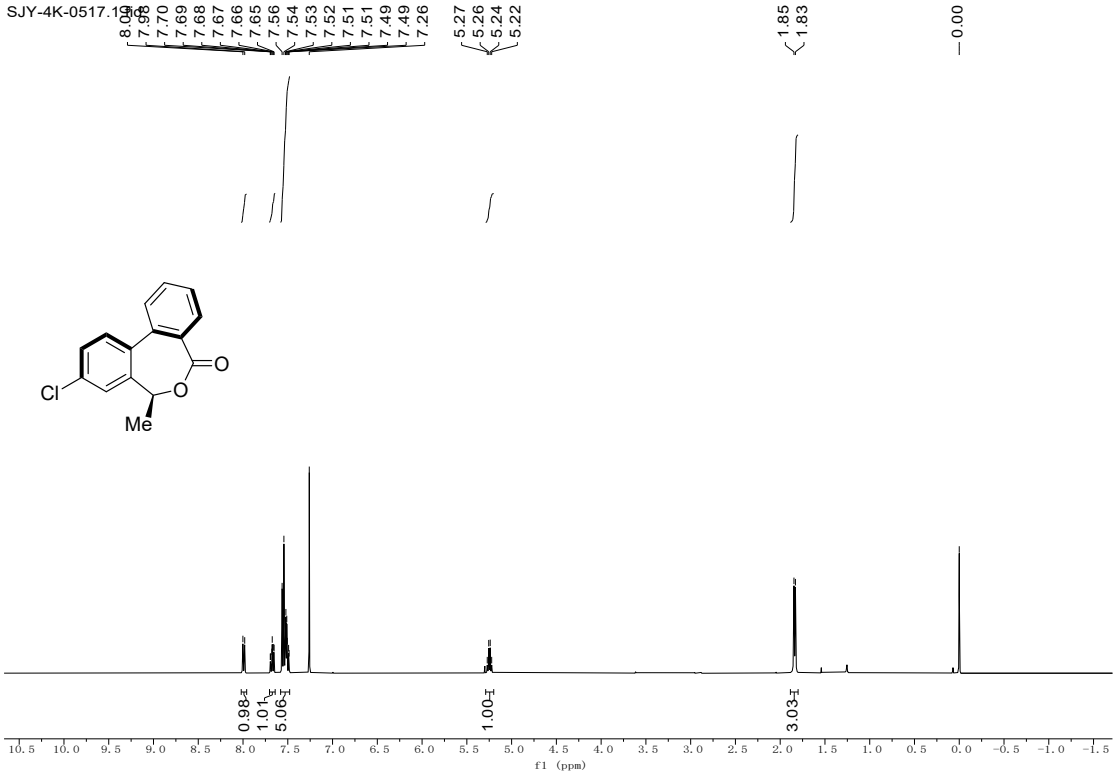
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4j**



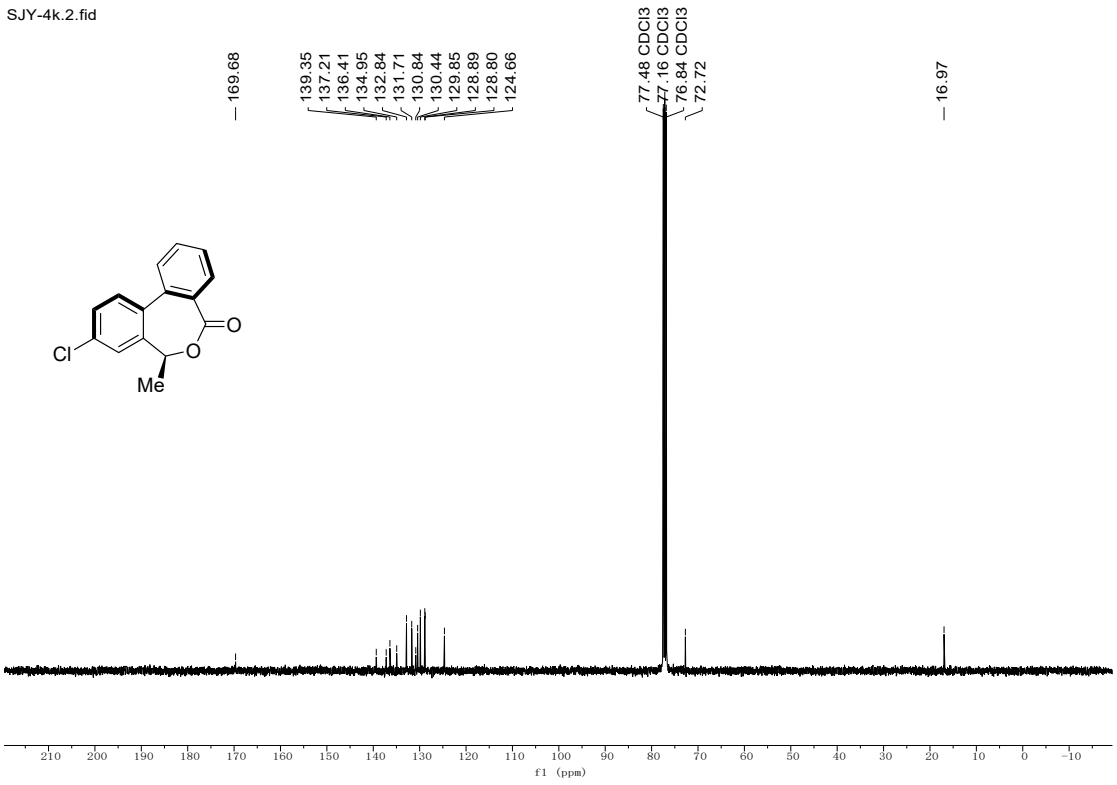
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4j**



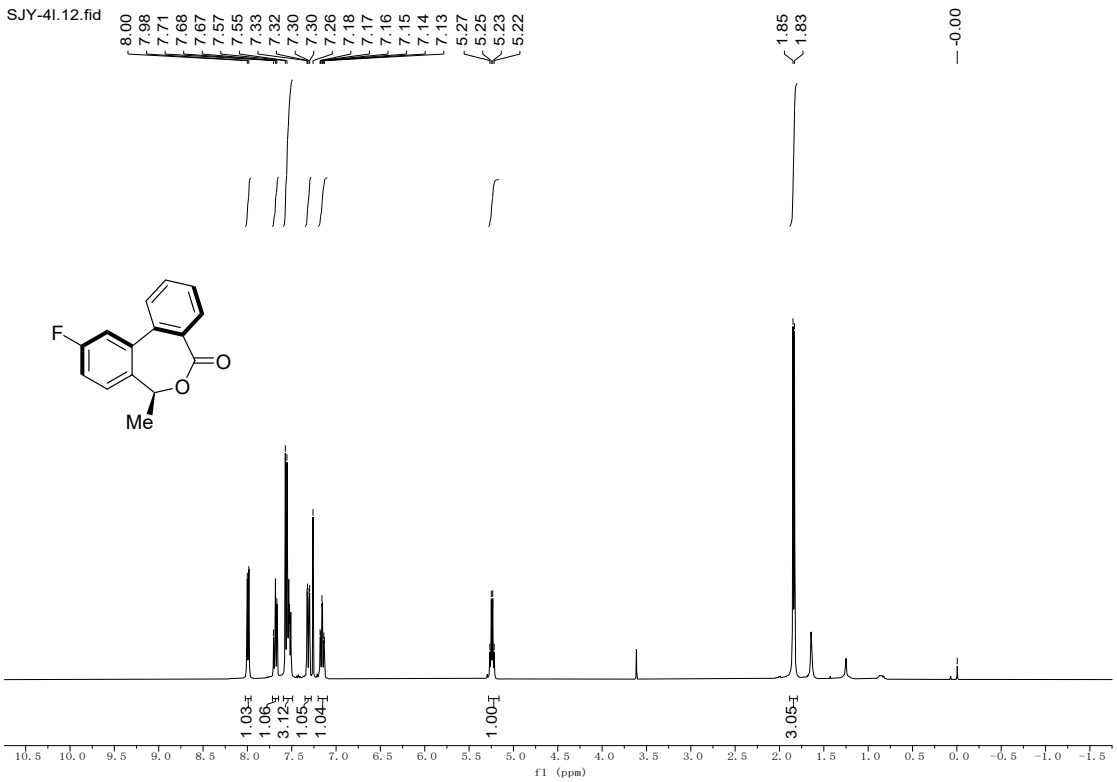
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4k**



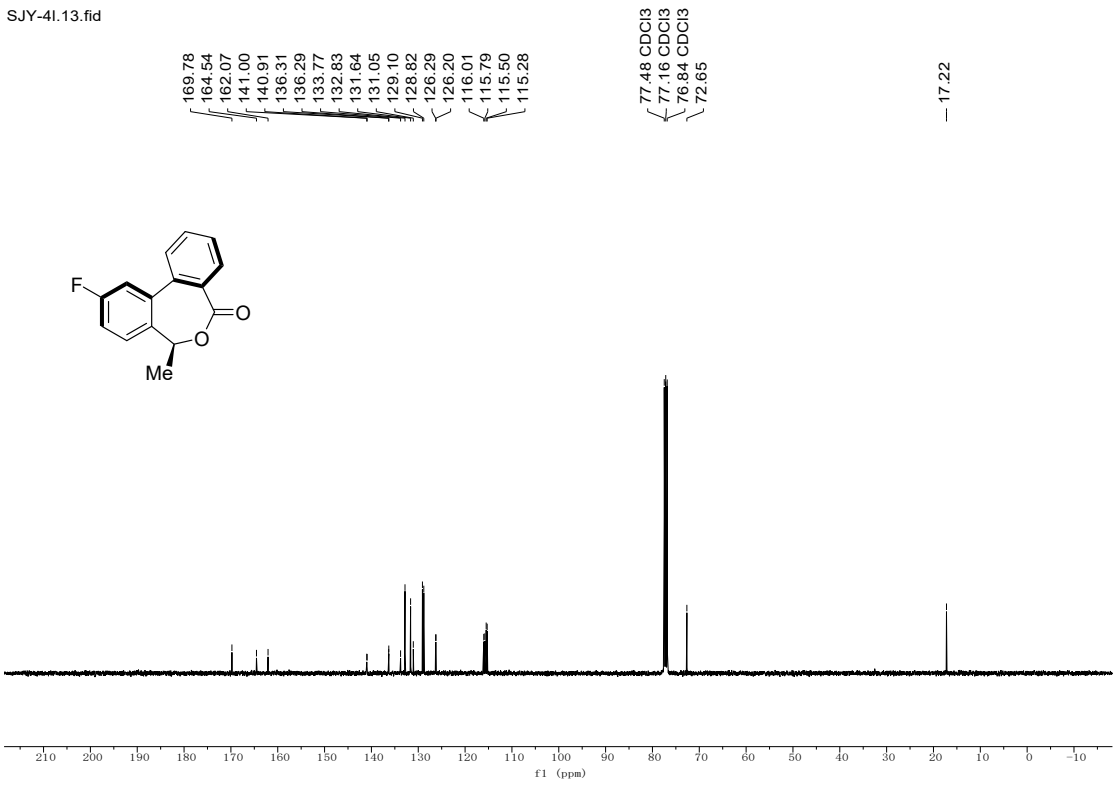
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4k**



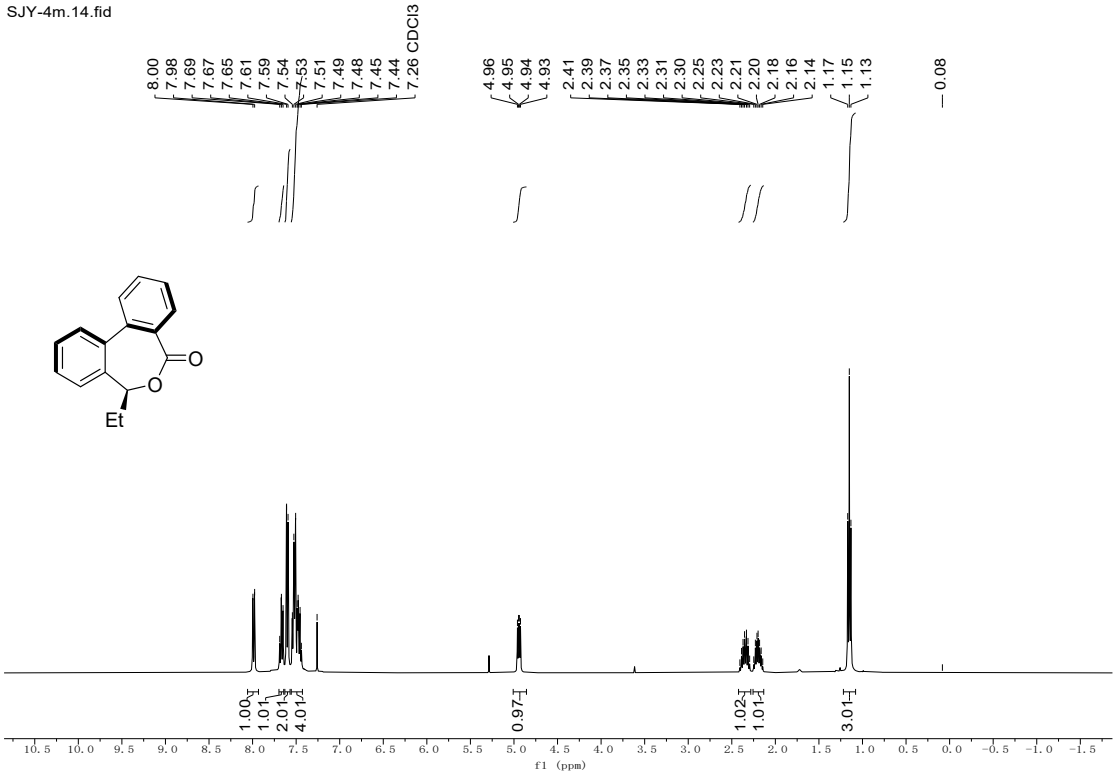
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4l**



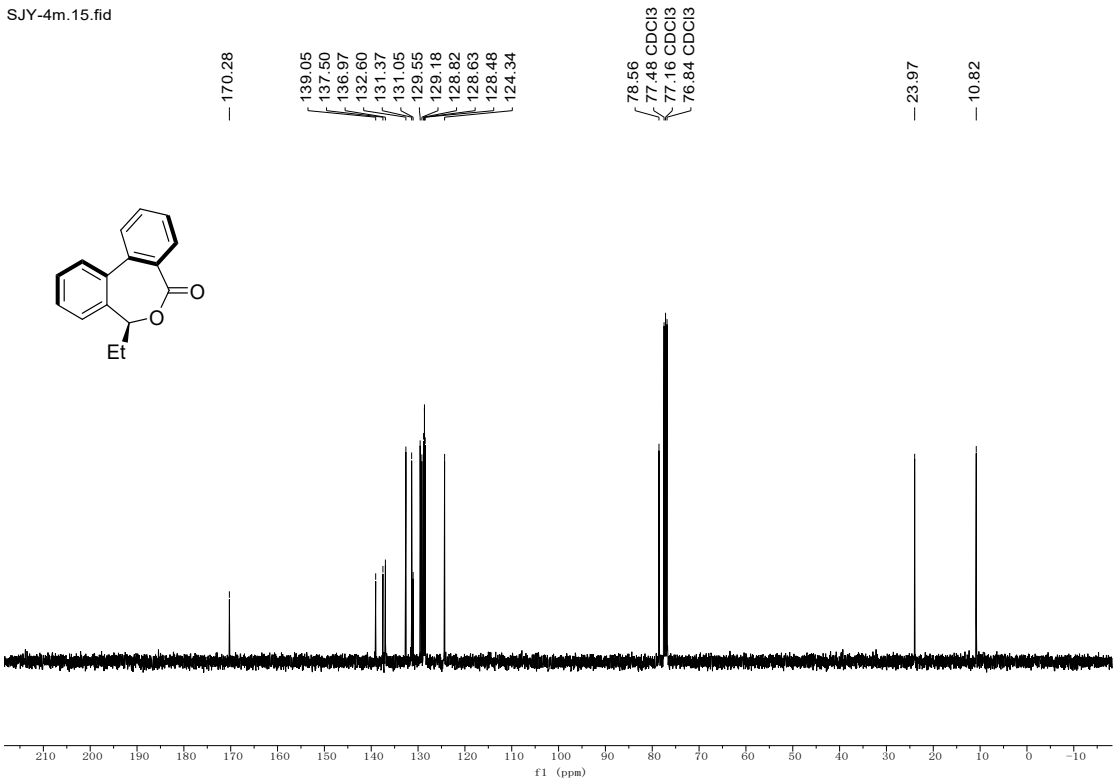
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4l**



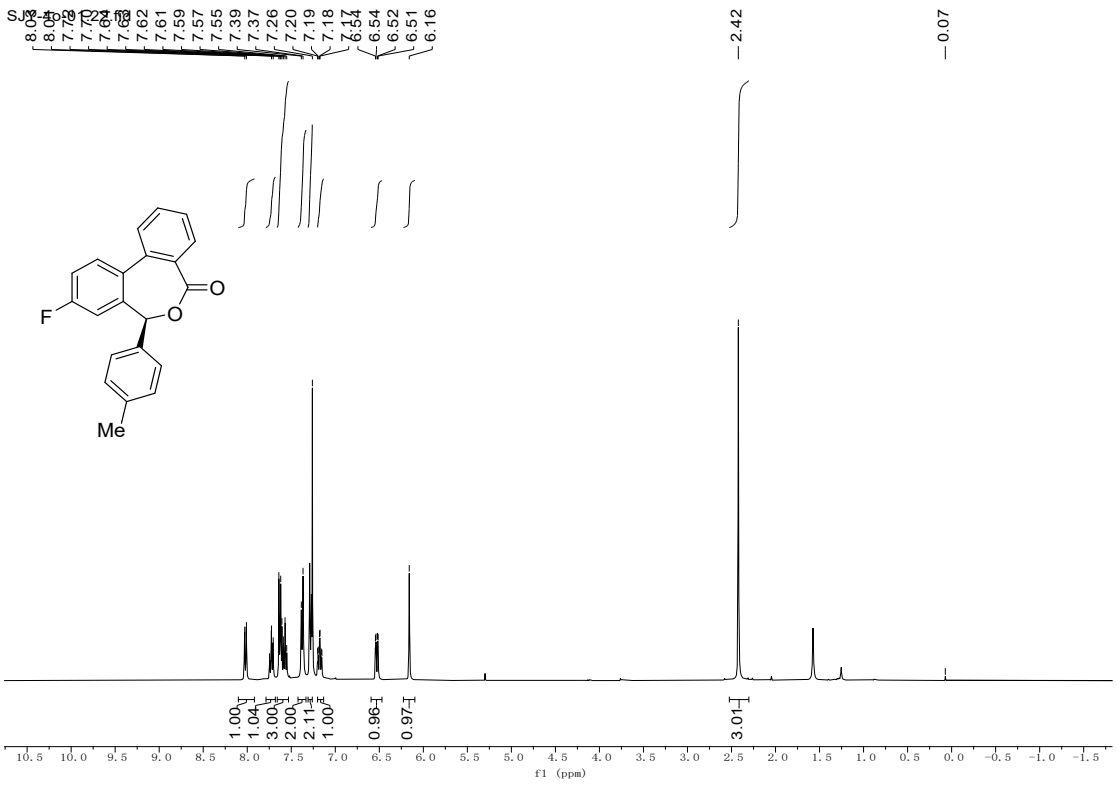
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4m**



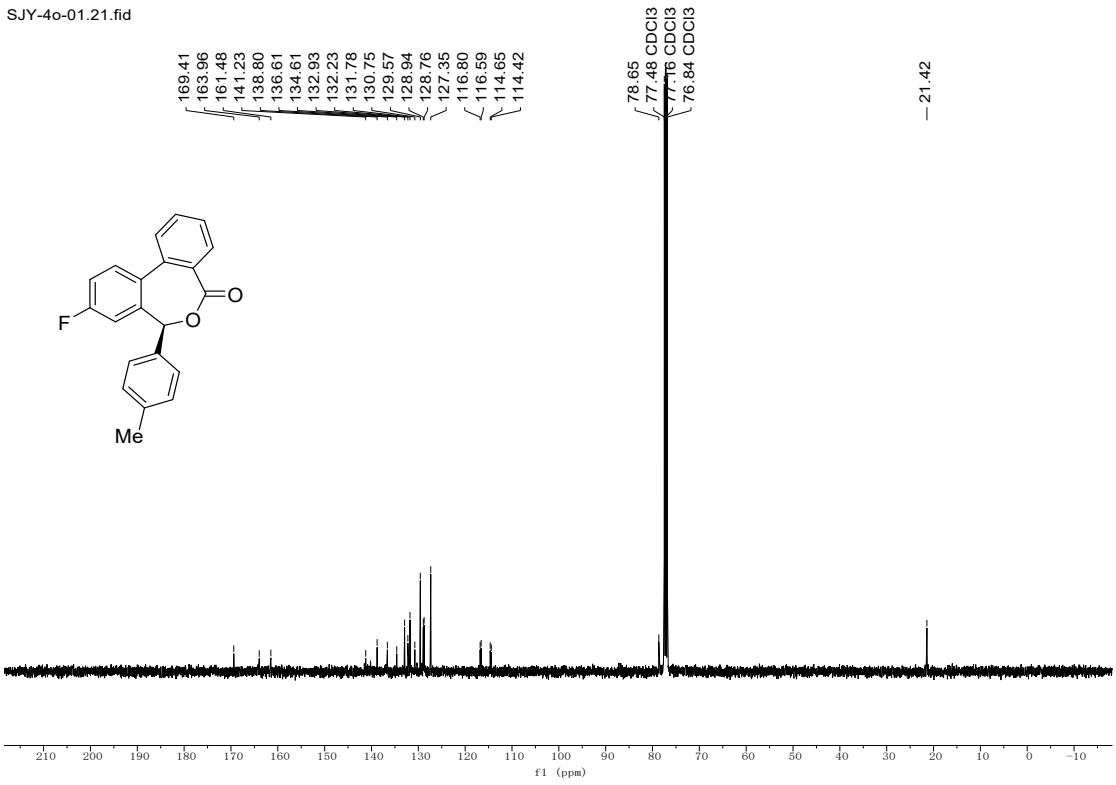
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4m**



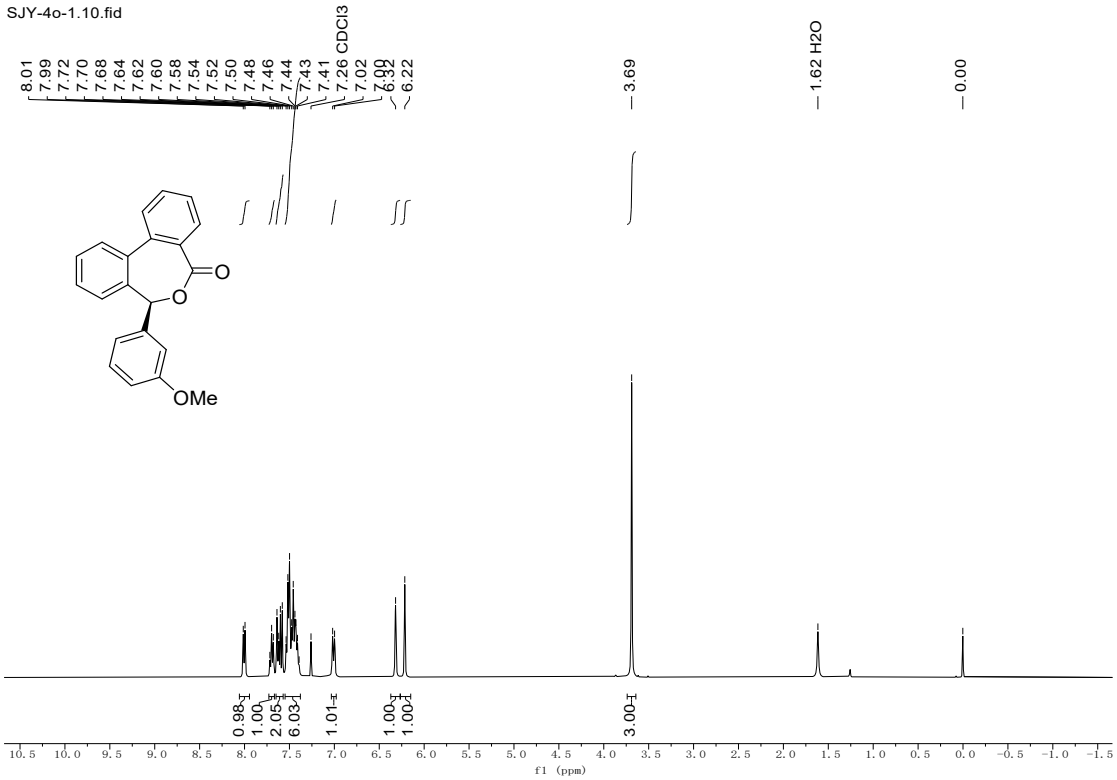
^{1}H NMR (400 MHz, $CDCl_3$) of compound **4n**



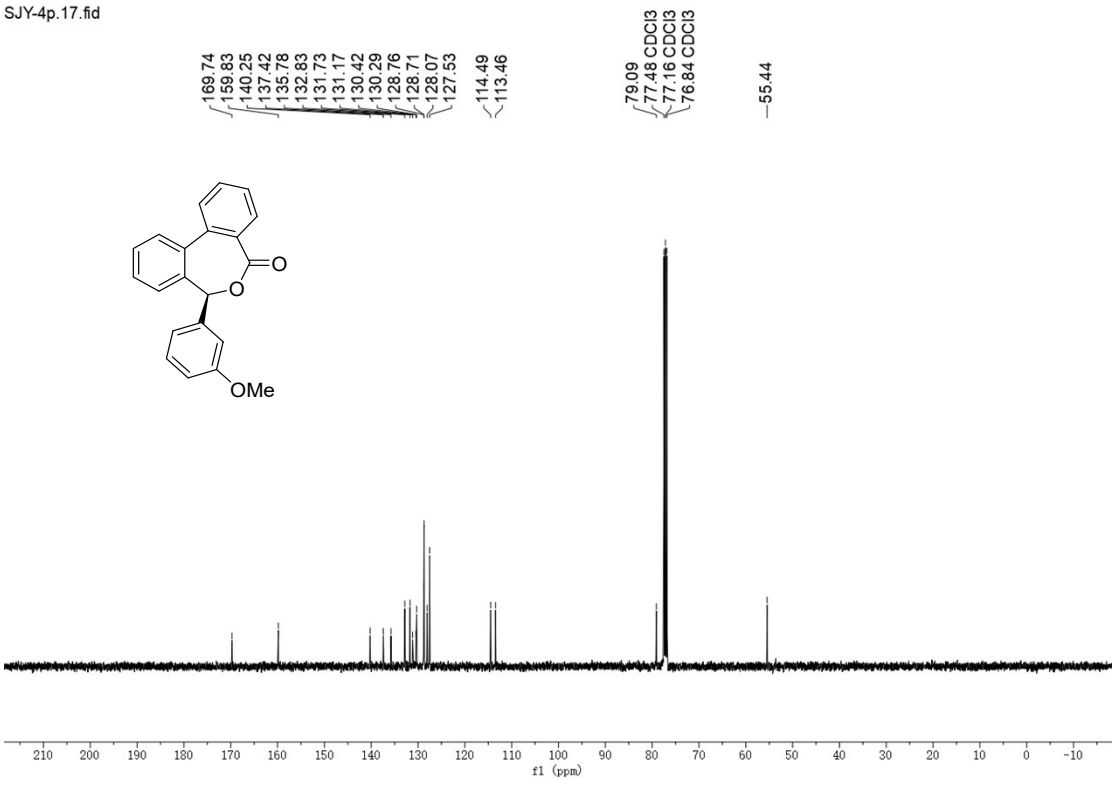
^{13}C NMR (101 MHz, $CDCl_3$) of compound **4n**



^{1}H NMR (400 MHz, $CDCl_3$) of compound **4o**



^{13}C NMR (101 MHz, $CDCl_3$) of compound **4o**



7. References

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2. P. Borowiecki, N. Telatycka, M. Tataruch, A. Żądło-Dobrowolska, T. Reiter, K. Schühle, J. Heider, M. Szaleniec and W. Kroutil, *Adv. Synth. Catal.*, 2020, **362**, 2012-2029.

3. Y. Zhang, Y. Q. Liu, L. Hu, X. Zhang and Q. Yin, *Org Lett,* 2020, **22**, 6479-6483.