Electronic Supplementary Information

Asymmetric Hydrogenation of 1,4-Diketones: Facile Synthesis of Enantiopure 1,4-Diarylbutane-1,4-diols

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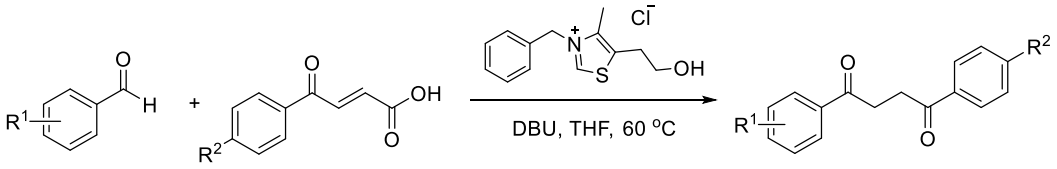
Content

1. General Information

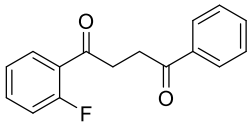
Unless otherwise mentioned, all experiments and manipulations which are sensitive to moisture or air were carried out under an atmosphere of argon in a glovebox or using standard Schlenk techniques. Solvents were dried with standard procedures and degassed with N_2. Flash column chromatography was performed using Tsingdao silica gel (60, particle size 200-300 mesh). NMR spectra were recorded on a Bruker DPX 400 spectrometer at 400 MHz for ^{1}H NMR, 101 MHz for ^{13}C NMR in $CDCl_3$ with tetramethylsilane (TMS) as internal standard. Date are 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 ^{1}H 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 1,4-diketones



5a, **5r**, **5s** were commercially available and used without further purification unless otherwise stated. Other substrates were prepared as described in literature.[1] DBU (0.4 equiv) was added to the stirred solution of benzaldehyde (1.5 equiv) and thiazolium salt (0.2 equiv) in THF. The resulting reaction mixture was stirred in room temperature for 10-15 minutes. After that 3-benzoylacrylic acid (1.0 equiv) was added at 60 °C for overnight and monitored by TLC. After completion of the reaction, reaction system was cooled to room temperature and washed with saturated solution of sodium bicarbonate and extracted with ethyl acetate, organic layer was dried over sodium sulphate and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on silica gel.

1-(2-fluorophenyl)-4-phenylbutane-1,4-dione (5b)



5b

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.0 Hz, 2H), 7.91 (td, *J* = 7.6, 1.9 Hz, 1H), 7.61 – 7.44 (m, 4H), 7.24 (td, *J* = 7.7, 1.3 Hz, 1H), 7.16 (dd, *J* = 11.3, 8.3 Hz, 1H), 3.46 (d, *J* = 1.9 Hz, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.52, 197.03, 196.99, 163.43, 160.89, 136.79, 134.66, 134.57, 133.14, 130.73, 130.70, 128.61, 128.14, 125.42, 125.01, 124.47, 124.43, 116.84, 116.61, 37.46, 37.38, 32.60, 32.58.

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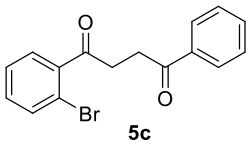
[1] A. R. S. Verma, M. Mishra, C. B. Pandey, S. Kumar and B. Tiwari. *J. Org. Chem.*, 2020, **85**, 8166−8175.

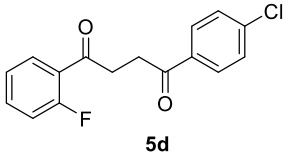
1-(2-bromophenyl)-4-phenylbutane-1,4-dione (5c)



5c

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (dd, *J* = 8.4, 1.4 Hz, 2H), 7.61 (dd, *J* = 18.3, 7.6 Hz, 3H), 7.49 (t, *J* = 7.6 Hz, 2H), 7.42 (td, *J* = 7.5, 1.2 Hz, 1H), 7.31 (td, *J* = 7.7, 1.7 Hz, 1H), 3.50 (t, *J* = 6.4 Hz, 2H), 3.37 (t, *J* = 6.0 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 202.69, 198.25, 141.57, 136.59, 133.65, 133.27, 131.63, 128.93, 128.65, 128.12, 127.52, 118.60, 36.56, 33.00.

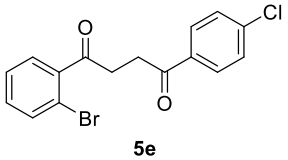
1-(4-chlorophenyl)-4-(2-fluorophenyl)butane-1,4-dione (5d)



5d

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, *J* = 8.6 Hz, 2H), 7.90 (td, *J* = 7.6, 1.9 Hz, 1H), 7.57 – 7.50 (m, 1H), 7.46 (d, *J* = 8.6 Hz, 2H), 7.25 – 7.12 (m, 2H), 3.49 – 3.38 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.34, 163.46, 139.57, 135.14, 134.75, 134.66, 130.72, 130.69, 129.56, 128.93, 125.40, 124.49, 124.46, 116.86, 116.62, 37.44, 37.36, 32.53, 32.51.

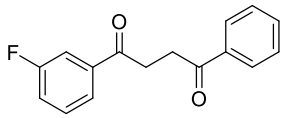
1-(2-bromophenyl)-4-(4-chlorophenyl)butane-1,4-dione (5e)



5e

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 8.5 Hz, 2H), 7.69 – 7.54 (m, 2H), 7.43 (dd, *J* = 23.0, 7.9 Hz, 3H), 7.31 (td, *J* = 7.7, 1.8 Hz, 1H), 3.49 – 3.32 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 202.52, 197.07, 141.41, 139.72, 134.92, 133.69, 131.70, 129.54, 128.98, 128.90, 127.52, 118.63, 36.49, 32.92.

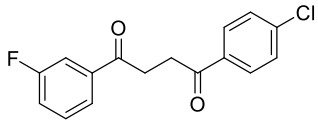
1-(3-fluorophenyl)-4-phenylbutane-1,4-dione (5f)



5f

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.0 Hz, 2H), 7.83 (d, *J* = 7.8 Hz, 1H), 7.71 (dd, *J* = 9.5, 1.0 Hz, 1H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.53 – 7.42 (m, 3H), 7.33 – 7.24 (m, 1H), 3.45 (dd, *J* = 12.1, 5.6 Hz, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.44, 197.50, 197.48, 164.12, 161.66, 138.91, 138.85, 136.67, 133.26, 130.35, 130.27, 128.65, 128.14, 123.94, 123.91, 120.28, 120.07, 114.99, 114.77, 32.71, 32.54.

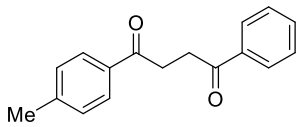
1-(4-chlorophenyl)-4-(3-fluorophenyl)butane-1,4-dione (5g)



5g

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, *J* = 8.5 Hz, 2H), 7.83 (dt, *J* = 7.8, 1.3 Hz, 1H), 7.70 (dd, *J* = 9.4, 1.1 Hz, 1H), 7.46 (d, *J* = 8.6 Hz, 3H), 7.30 (ddd, *J* = 8.3, 2.7, 0.9 Hz, 1H), 3.43 (s, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.33, 197.26, 164.13, 161.66, 139.72, 138.79, 138.73, 135.00, 130.38, 130.30, 129.56, 128.98, 123.92, 123.89, 120.38, 120.16, 115.00, 114.78, 32.67, 32.47.

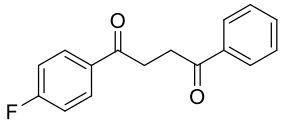
1-phenyl-4-(p-tolyl)butane-1,4-dione (5h)



5h

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 – 8.00 (m, 2H), 7.94 (d, *J* = 8.3 Hz, 2H), 7.58 (t, *J* = 7.3 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.28 (d, *J* = 8.0 Hz, 2H), 3.45 (s, 4H), 2.42 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.84, 198.35, 143.96, 136.83, 134.32, 133.15, 129.30, 128.61, 128.26, 128.15, 32.64, 32.50, 21.68.

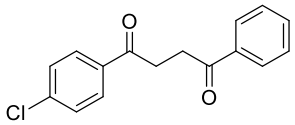
1-(4-fluorophenyl)-4-phenylbutane-1,4-dione (5i)



5i

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 – 8.00 (m, 4H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.51 – 7.44 (m, 2H), 7.15 (t, *J* = 8.6 Hz, 2H), 3.45 (ddd, *J* = 10.0, 4.4, 0.9 Hz, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.61, 197.13, 167.09, 164.56, 136.71, 133.23, 130.82, 130.73, 128.64, 128.14, 115.82, 115.60, 32.59, 32.46.

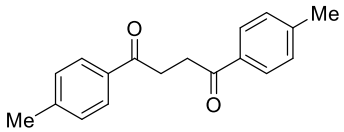
1-(4-chlorophenyl)-4-phenylbutane-1,4-dione (5j)



5j

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (dd, *J* = 20.7, 7.8 Hz, 4H), 7.59 (t, *J* = 7.3 Hz, 1H), 7.48 (dd, *J* = 14.2, 8.2 Hz, 4H), 3.50 – 3.40 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.52, 197.52, 139.61, 136.68, 135.13, 133.25, 129.56, 128.94, 128.64, 128.13, 32.56, 32.52.

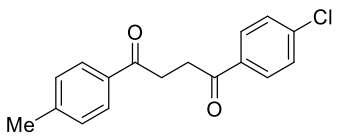
1,4-di-p-tolylbutane-1,4-dione (5k)



5k

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, J = 8.1 Hz, 4H), 7.28 (d, J = 8.1 Hz, 4H), 3.42 (s, 4H), 2.41 (s, 6H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.45, 143.90, 134.37, 129.28, 128.26, 32.54, 21.67.

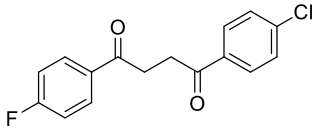
1-(4-chlorophenyl)-4-(p-tolyl)butane-1,4-dione (5l)



5l

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (dd, *J* = 19.9, 8.4 Hz, 4H), 7.45 (d, *J* = 8.6 Hz, 2H), 7.27 (d, *J* = 8.6 Hz, 2H), 3.47 – 3.38 (m, 4H), 2.42 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.15, 197.65, 144.05, 139.57, 135.18, 134.22, 129.57, 129.32, 128.93, 128.25, 32.56, 32.46, 21.68.

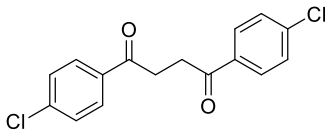
1-(4-chlorophenyl)-4-(4-fluorophenyl)butane-1,4-dione (5m)



5m

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (dd, *J* = 8.9, 5.4 Hz, 2H), 7.98 (d, *J* = 8.6 Hz, 2H), 7.46 (d, *J* = 8.6 Hz, 2H), 7.15 (t, *J* = 8.6 Hz, 2H), 3.42 (s, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.43, 196.94, 172.11, 167.13, 164.60, 139.68, 135.04, 133.15, 130.82, 130.73, 129.56, 128.97, 115.86, 115.64, 32.51, 32.43.

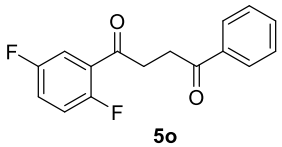
1,4-bis(4-chlorophenyl)butane-1,4-dione (5n)



5n

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 – 7.95 (m, 4H), 7.50 – 7.42 (m, 4H), 3.42 (s, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.34, 139.71, 135.01, 129.56, 128.98, 32.49.

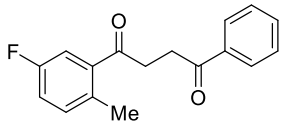
1-(2,5-difluorophenyl)-4-phenylbutane-1,4-dione (5o)



5o

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (dd, *J* = 8.3, 1.4 Hz, 2H), 7.64 – 7.54 (m, 2H), 7.48 (t, *J* = 7.5 Hz, 2H), 7.25 – 7.11 (m, 2H), 3.45 (s, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.29, 136.67, 133.22, 128.63, 128.13, 121.47, 121.37, 121.22, 121.13, 118.32, 118.13, 118.05, 116.71, 116.50, 37.32, 37.24, 32.58, 32.56.

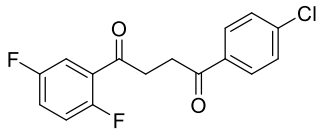
1-(5-fluoro-2-methylphenyl)-4-phenylbutane-1,4-dione (5p)



5p

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.0 Hz, 2H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.54 – 7.44 (m, 3H), 7.22 (dd, *J* = 8.5, 5.5 Hz, 1H), 7.09 (td, *J* = 8.3, 2.8 Hz, 1H), 3.50 – 3.43 (m, 2H), 3.34 – 3.27 (m, 2H), 2.45 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 201.63, 201.60, 198.39, 161.84, 159.41, 139.14, 139.08, 136.65, 133.53, 133.49, 133.30, 133.24, 133.22, 128.64, 128.11, 118.20, 117.99, 115.37, 115.15, 35.27, 32.83, 20.39.

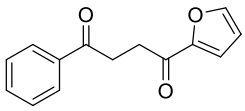
1-(4-chlorophenyl)-4-(2,5-difluorophenyl)butane-1,4-dione (5q)



5q

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 8.6 Hz, 2H), 7.57 (ddd, *J* = 8.6, 5.4, 3.2 Hz, 1H), 7.46 (d, *J* = 8.5 Hz, 2H), 7.26 – 7.11 (m, 2H), 3.42 (dd, *J* = 5.2, 3.4 Hz, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 197.11, 195.60, 195.56, 139.67, 135.01, 129.54, 128.96, 121.58, 121.48, 121.33, 121.24, 118.43, 118.35, 118.16, 118.08, 116.72, 116.69, 116.47, 116.44, 37.29, 37.21, 32.50, 32.48.

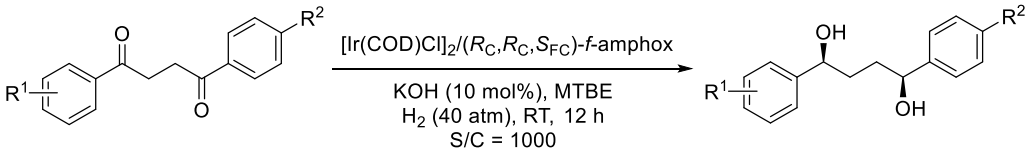
1-(furan-2-yl)-4-phenylbutane-1,4-dione (5t)



5t

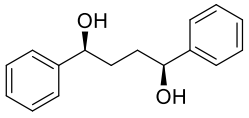
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.0 Hz, 2H), 7.69 – 7.53 (m, 2H), 7.47 (t, *J* = 7.6 Hz, 2H), 7.27 (d, *J* = 1.9 Hz, 1H), 6.55 (dd, *J* = 3.6, 1.7 Hz, 1H), 3.45 (t, *J* = 6.6 Hz, 2H), 3.31 (t, *J* = 6.3 Hz, 2H). **^{13}C NMR (101 MHz, CDCl3)** δ 198.39, 187.89, 152.56, 146.39, 136.64, 133.21, 128.62, 128.12, 117.15, 112.25, 32.28, 32.25.

3. General procedure for asymmetric hydrogenation of 1,4-diketones



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,R_C,S_{FC})-*f*-amphox (12.2 mg, 2.2×10^{-2} mmol) and anhydrous toluene (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2 h at 25 °C giving orange red solution. And then 0.1 mmol of 1,4-diketones, KOH (0.56 mg, 0.01 mmol) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous MTBE was added as solvent and a solution of Ir/(R_C,R_C,S_{FC})-*f*-amphox in anhydrous toluene (10 μL) was added *via* an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from golvebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 40 atm H_2. The reaction solution was stirred at room temperature (25 °C - 30 °C) until for 12 h, then released pressure carefully. The solution of reaction mixture was purified by flash chromatography on silica gel with ethyl acetate and the solvent was removed under reduced pressure. The ee value was determined by chiral HPLC analysis of the hydrogenation product chiral diol directly. The absolute configurations of 1,4-diols were assigned by analogy.

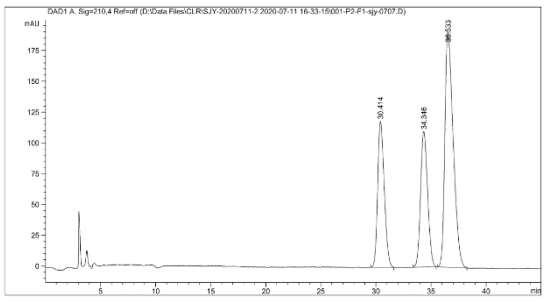
(1*S*,4*S*)-1,4-diphenylbutane-1,4-diol (6a)



6a

99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.40 – 7.23 (m, 10H), 4.85 – 4.52 (m, 2H), 2.87 (s, 2H), 1.98 – 1.76 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.64, 128.47, 127.53, 125.84, 74.61, 35.92.

Optical Rotation: $[\alpha]_D^{25}$ = -62.0 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OJ-H column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 33.68 min.



Signal 1: DAD1 A, Sig=210,4 Ref=off

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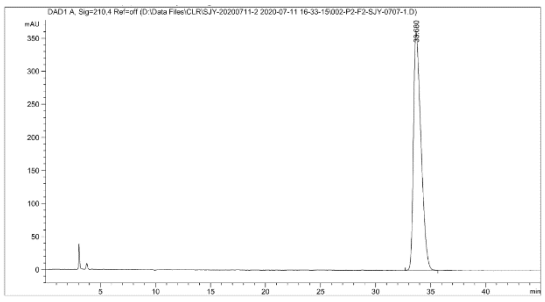
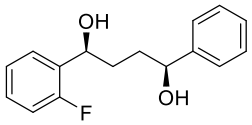
2	34.346	BB	0.6384	4869.43652	110.02171	24.6153
3	36.533	BB	0.7416	1.00146e4	191.03456	50.6246



Signal 1: DAD1 A, Sig=210,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	33.680	BV R	0.6728	1.71608e4	360.85788	100.0000

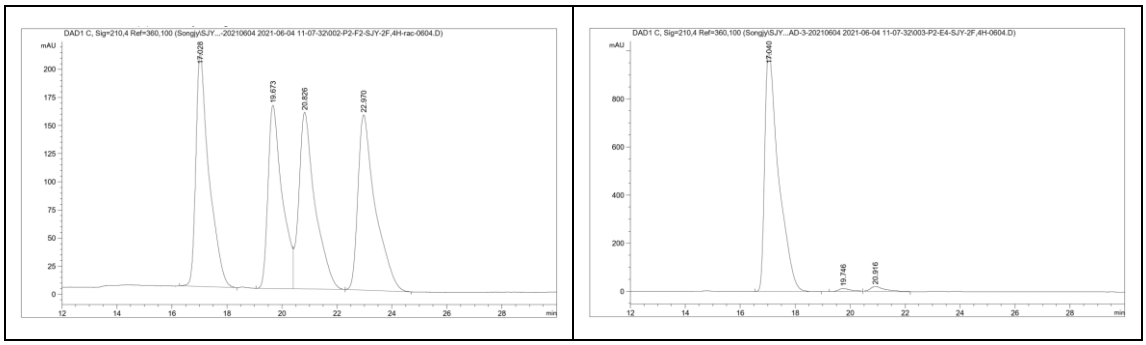
(1*S*,4*S*)-1-(2-fluorophenyl)-4-phenylbutane-1,4-diol (6b)



6b

99% yield, 33:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.46 (td, *J* = 7.5, 1.9 Hz, 1H), 7.33 (d, *J* = 3.8 Hz, 4H), 7.28 – 7.19 (m, 2H), 7.13 (t, *J* = 6.8 Hz, 1H), 7.04 – 6.95 (m, 1H), 5.02 (dd, *J* = 7.4, 4.1 Hz, 1H), 4.70 (dd, *J* = 7.8, 4.0 Hz, 1H), 3.01 (s, 2H), 1.97 – 1.82 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.89, 158.45, 144.52, 131.67, 131.53, 128.79, 128.71, 128.50, 127.58, 127.27, 127.22, 125.82, 124.29, 124.25, 115.35, 115.14, 74.61, 68.33, 68.31, 35.73, 34.85.

Optical Rotation: $[\alpha]_D^{25}$ = -25.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 17.04 min, t_R (minor) = 19.75 min, 20.92 min.



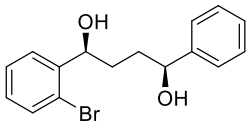
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.028	BB	0.4758	6887.20654	207.22250	26.4658
2	19.673	BV	0.5220	5864.97705	162.92426	22.5376
3	20.826	VB	0.5807	6415.82471	157.01456	24.6544
4	22.970	BB	0.6231	6855.07031	155.87086	26.3423

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.040	BB	0.5113	3.49621e4	991.82367	97.0627
2	19.746	BB	0.3912	344.38980	12.20428	0.9561
3	20.916	BB	0.4774	713.63147	20.33602	1.9812

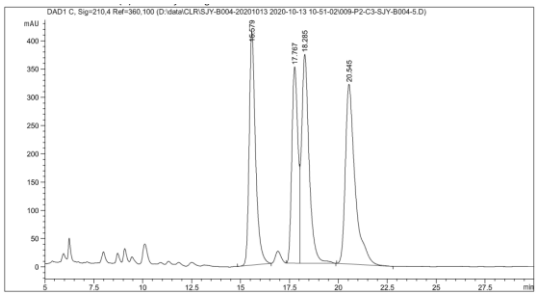
(1*S*,4*S*)-1-(2-bromophenyl)-4-phenylbutane-1,4-diol (6c)

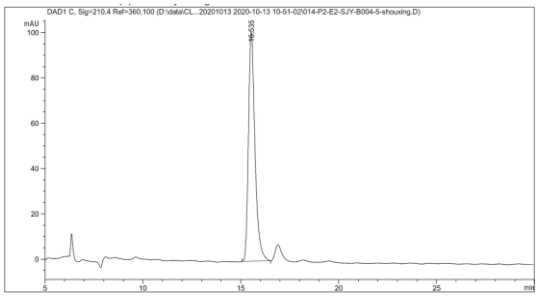


6c

99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.56 (dd, *J* = 7.8, 1.7 Hz, 1H), 7.50 (dd, *J* = 8.0, 1.3 Hz, 1H), 7.37 – 7.27 (m, 6H), 7.11 (td, *J* = 7.7, 1.8 Hz, 1H), 5.08 (dd, *J* = 8.7, 2.6 Hz, 1H), 4.73 (dd, *J* = 8.4, 3.7 Hz, 1H), 2.86 (s, 2H), 2.02 – 1.77 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.53, 143.60, 132.64, 128.75, 128.51, 127.72, 127.61, 127.29, 125.84, 121.90, 74.71, 73.13, 35.94, 34.58.

Optical Rotation: $[\alpha]_D^{25}$ = -39.5 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 15.54 min.





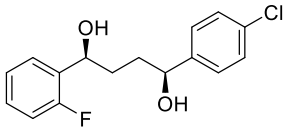
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.579	BB	0.3353	9307.54590	413.14755	24.7454
2	17.767	BV	0.3285	7441.59277	347.30875	19.7845
3	18.285	VB	0.3871	9951.56055	369.65997	26.4576
4	20.545	BB	0.4873	1.09125e4	318.07721	29.0125

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.535	BB	0.3300	2350.27490	101.36878	100.0000

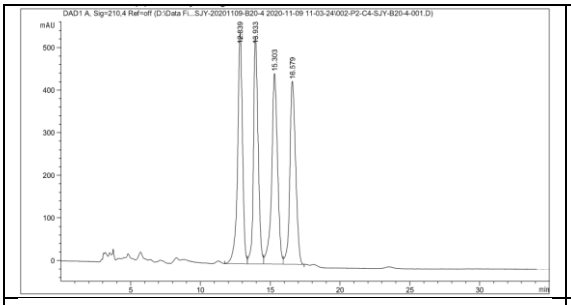
(1*S*,4*S*)-1-(4-chlorophenyl)-4-(2-fluorophenyl)butane-1,4-diol (6d)



6d

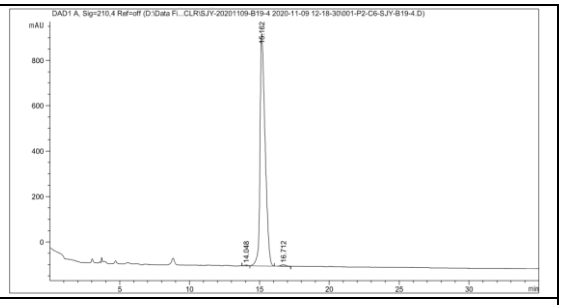
99% yield, >100:1 dr, 99.8% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.45 (td, *J* = 7.6, 1.9 Hz, 1H), 7.33 – 7.21 (m, 5H), 7.14 (td, *J* = 7.5, 1.2 Hz, 1H), 7.04 – 6.97 (m, 1H), 5.02 (dd, *J* = 7.8, 3.8 Hz, 1H), 4.75 – 4.61 (m, 1H), 3.14 (s, 2H), 1.95 – 1.79 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 171.29, 160.83, 158.40, 143.03, 133.12, 131.50, 131.37, 128.91, 128.83, 128.58, 127.19, 124.32, 124.29, 115.40, 115.18, 73.83, 68.29, 68.26, 35.84, 34.63.

Optical Rotation: $[\alpha]_D^{25}$ = -37.8 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OJ-H column, 210 nm, 30 °C, n-hexane: i-PrOH = 85:15; flow 1.0 mL/min; t_R (major) = 15.16 min, t_R (minor) = 14.05 min, 16.71 min.



Signal 1: DAD1 A, Sig=210,4 Ref=off

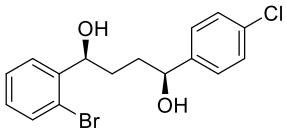
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.839	BV	0.3658	1.31619e4	541.12238	25.8074
2	13.933	VV	0.3535	1.24237e4	533.83685	24.3599
3	15.303	VV	0.4328	1.30618e4	447.11575	25.6110
4	16.579	VB	0.4275	1.23533e4	429.58118	24.2218



Signal 1: DAD1 A, Sig=210,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.048	BV E	0.2135	53.39716	3.15407	0.2043
2	15.162	VV R	0.3669	2.59091e4	1024.97583	99.1073
3	16.712	VB E	0.3350	179.98245	6.50186	0.6885

(1*S*,4*S*)-1-(2-bromophenyl)-4-(4-chlorophenyl)butane-1,4-diol (6e)

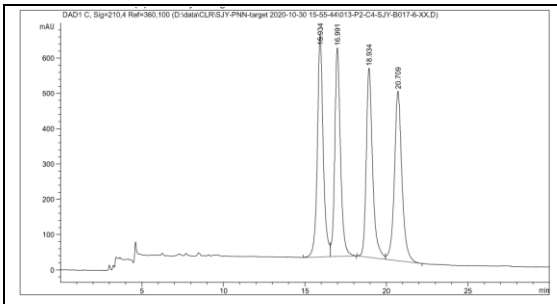


6e

99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 (ddd, *J* = 15.7, 7.9, 1.5 Hz, 2H), 7.28 (q, *J* = 8.6 Hz, 5H), 7.13 (td, *J* = 7.6, 1.7 Hz, 1H), 5.05 (dd, *J* =

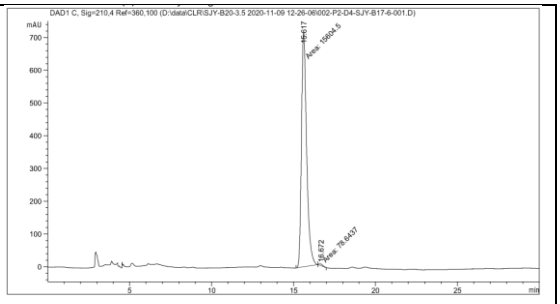
8.7, 2.7 Hz, 1H), 4.68 (dd, *J* = 7.7, 4.1 Hz, 1H), 3.51 (s, 2H), 1.96 – 1.71 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.42, 143.01, 133.10, 132.66, 128.83, 128.57, 127.74, 127.21, 127.18, 121.82, 73.90, 73.08, 36.14, 34.45.

Optical Rotation: $[\alpha]_D^{25}$ = -55.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 15.62min, t_R (minor) = 16.67 min.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

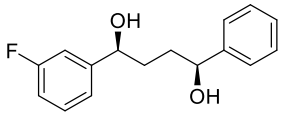
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.934	BV	0.3634	1.56739e4	629.59656	26.1671
2	16.991	VB	0.3550	1.43332e4	590.87982	23.9288
3	18.934	VV R	0.3829	1.44904e4	535.96271	24.1914
4	20.709	VB	0.4326	1.54017e4	480.37817	25.7127



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.617	MM	0.3641	1.56045e4	714.21509	99.4985
2	16.672	MM	0.2640	78.64367	4.96580	0.5015

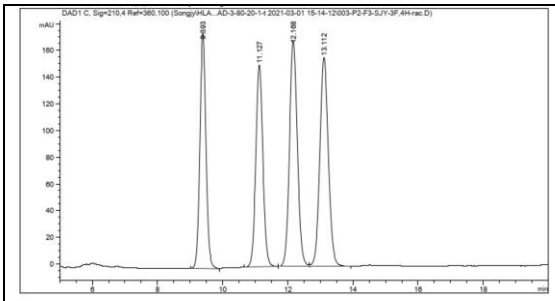
(1*S*,4*S*)-1-(3-fluorophenyl)-4-phenylbutane-1,4-diol (6f)



6f

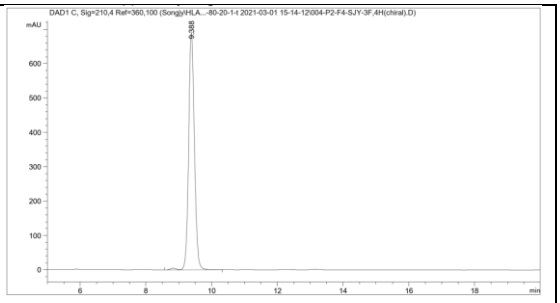
99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.32 (d, *J* = 18.3 Hz, 4H), 7.28 – 7.24 (m, 2H), 7.09 – 7.01 (m, 2H), 6.96 – 6.90 (m, 1H), 4.70 – 4.65 (m, 2H), 3.25 (s, 1H), 2.92 (s, 1H), 1.92 – 1.78 (m, 4H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 163.77, 162.14, 147.45, 147.41, 144.47, 129.93, 129.87, 128.52, 127.63, 125.79, 121.40, 121.38, 114.29, 114.15, 112.80, 112.66, 74.59, 73.88, 73.86, 36.00, 35.70.

Optical Rotation: $[\alpha]_D^{25}$ = -27.6 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 9.39 min.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

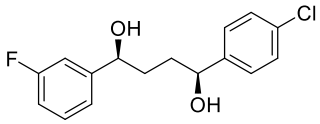
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.393	BB	0.1993	2295.19556	176.93823	22.3503
2	11.127	BB	0.2344	2285.68848	151.14558	22.2577
3	12.168	BV	0.2596	2835.83374	169.15118	27.6149
4	13.112	VB	0.2803	2852.49683	156.76355	27.7772



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.388	VB R	0.1882	8474.25293	690.84277	100.0000

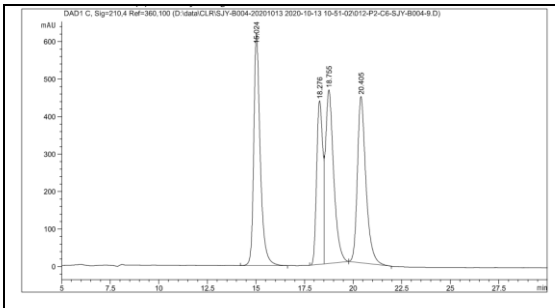
(1*S*,4*S*)-1-(4-chlorophenyl)-4-(3-fluorophenyl)butane-1,4-diol (6g)

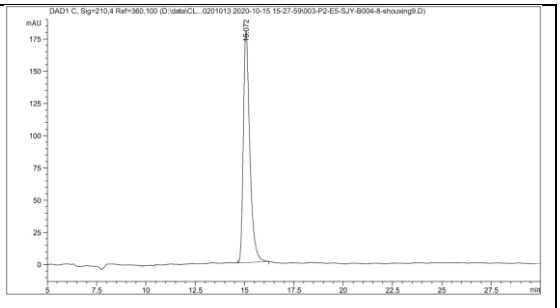


6g

99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.30 – 7.26 (m, 3H), 7.21 (d, *J* = 8.5 Hz, 2H), 7.03 (t, *J* = 8.3 Hz, 2H), 6.94 (td, *J* = 9.0, 8.4, 3.2 Hz, 1H), 4.63 (s, 2H), 3.33 (d, *J* = 12.6 Hz, 2H), 1.87 – 1.77 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 164.18, 161.73, 147.28, 147.21, 142.97, 133.16, 130.01, 129.93, 128.60, 127.16, 121.34, 121.32, 114.44, 114.23, 112.78, 112.56, 73.85, 73.82, 35.85.

Optical Rotation: $[\alpha]_D^{25}$ = -33.2 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 15.07 min.





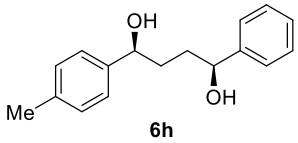
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.024	BB	0.3377	1.43575e4	619.83838	28.1372
2	18.276	BV	0.3347	9540.46484	436.20291	18.6971
3	18.755	VB	0.4213	1.36224e4	462.92474	26.6967
4	20.405	BB	0.4356	1.35062e4	443.79395	26.4690

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.072	BB	0.3393	4094.70142	179.41325	100.0000

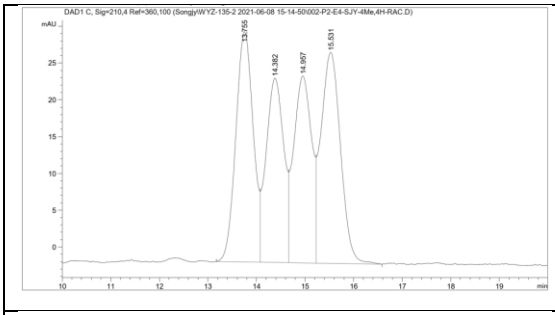
(1*S*,4*S*)-1-phenyl-4-(p-tolyl)butane-1,4-diol (6h)

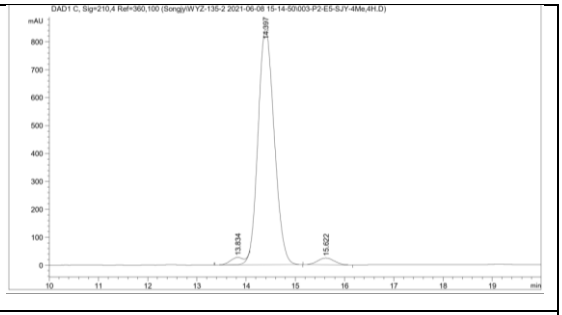


6h

99% yield, 19:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.36 – 7.24 (m, 5H), 7.21 (d, *J* = 8.2 Hz, 2H), 7.14 (d, *J* = 7.9 Hz, 2H), 4.66 (ddd, *J* = 11.7, 7.7, 4.3 Hz, 2H), 2.87 (d, *J* = 43.6 Hz, 2H), 2.34 (s, 3H), 1.93 – 1.75 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.71, 141.68, 137.18, 129.14, 128.44, 127.47, 125.86, 125.80, 74.60, 74.47, 36.00, 35.85, 21.12.

Optical Rotation: $[\alpha]_D^{25}$ = -35.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral IC column, 210 nm, 25 °C, n-hexane: i-PrOH = 88:12; flow 1.0 mL/min; t_R (major) = 14.40 min, t_R (minor) = 13.83 min, 15.62 min.





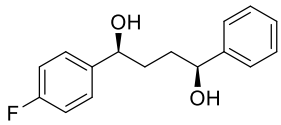
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.755	BV	0.3877	776.45502	31.27147	27.1225
2	14.382	VV	0.3780	630.79761	25.03446	22.0345
3	14.957	VV	0.3850	650.62225	25.38510	22.7270
4	15.531	VB	0.4178	804.89575	28.64261	28.1160

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.834	BV E	0.2710	457.86172	25.55935	2.2368
2	14.397	VB R	0.3580	1.94322e4	845.94733	94.9330
3	15.622	BB	0.3684	579.32166	24.62809	2.8302

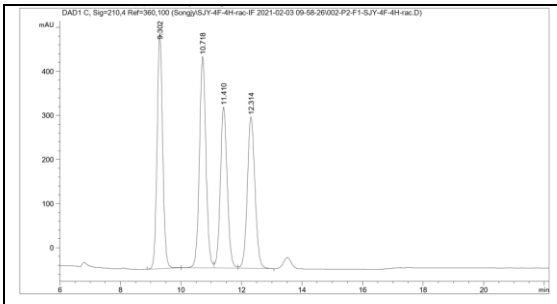
(1*S*,4*S*)-1-(4-fluorophenyl)-4-phenylbutane-1,4-diol (6i)



6i

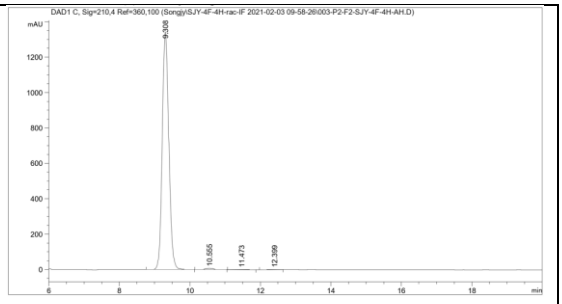
99% yield, >100:1 dr, 98.5% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.36 – 7.26 (m, 7H), 7.01 (t, *J* = 8.7 Hz, 2H), 4.75 – 4.65 (m, 2H), 2.77 (s, 2H), 1.95 – 1.75 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 163.35, 160.92, 144.53, 140.41, 140.38, 128.53, 127.64, 127.49, 127.41, 125.79, 115.35, 115.14, 74.65, 73.96, 36.06, 35.78.

Optical Rotation: $[\alpha]_D^{25}$ = -37.4 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral IF column, 210 nm, 25 ºC, n-hexane: i-PrOH = 88:12; flow 1.0 mL/min; t_R (major) = 9.31 min, t_R (minor) = 10.56 min, 11.47 min, 12.40 min.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

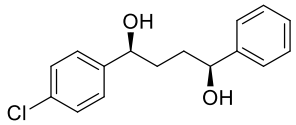
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.302	BB	0.1983	6891.18262	535.05841	26.5944
2	10.718	BV	0.2317	7218.99902	479.22189	27.8595
3	11.410	VV	0.2449	5789.41602	365.24149	22.3424



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.308	BB	0.2012	1.73925e4	1341.59192	98.8669
2	10.555	BB	0.2488	131.10847	8.10064	0.7453
3	11.473	BB	0.2357	43.19477	2.60145	0.2455
4	12.399	BB	0.2267	25.02999	1.69085	0.1423

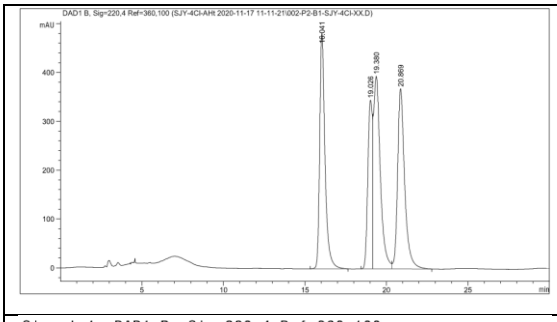
(1*S*,4*S*)-1-(4-chlorophenyl)-4-phenylbutane-1,4-diol (6j)



6j

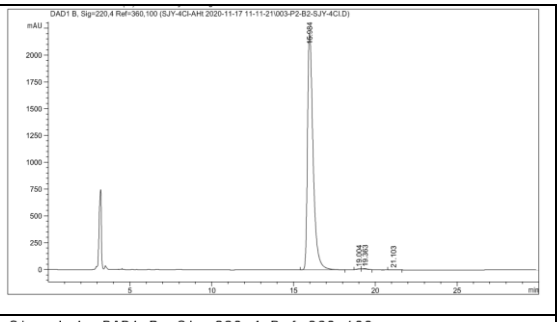
99% yield, >100:1 dr, 99.6% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.27 (d, *J* = 1.1 Hz, 1H), 7.25 – 7.22 (m, 3H), 7.22 – 7.17 (m, 5H), 4.62 (td, *J* = 7.6, 4.4 Hz, 2H), 2.65 (s, 2H), 1.86 – 1.70 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.46, 143.14, 133.09, 128.57, 128.54, 127.67, 127.22, 125.77, 74.64, 73.88, 36.02, 35.69.

Optical Rotation: $[\alpha]_D^{25}$ = -22.8 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 220 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 15.98 min, t_R (minor) = 19.00 min, 19.36 min, 21.10 min.



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

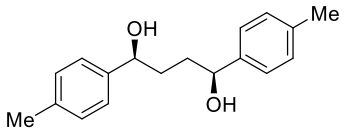
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.041	BB	0.3384	1.09353e4	482.51199	27.1868
2	19.026	BV	0.2962	6728.52588	345.55270	16.7281
3	19.380	VV	0.4197	1.14233e4	394.65350	28.4001
4	20.869	VB	0.4440	1.11357e4	369.09760	27.6850



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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.984	BB	0.3215	5.25661e4	2201.95215	99.6593
2	19.004	BB	0.1840	48.54292	3.12830	0.0920
3	19.363	BB	0.2231	94.09824	4.98872	0.1784
4	21.103	BB	0.2817	37.05931	1.55134	0.0703

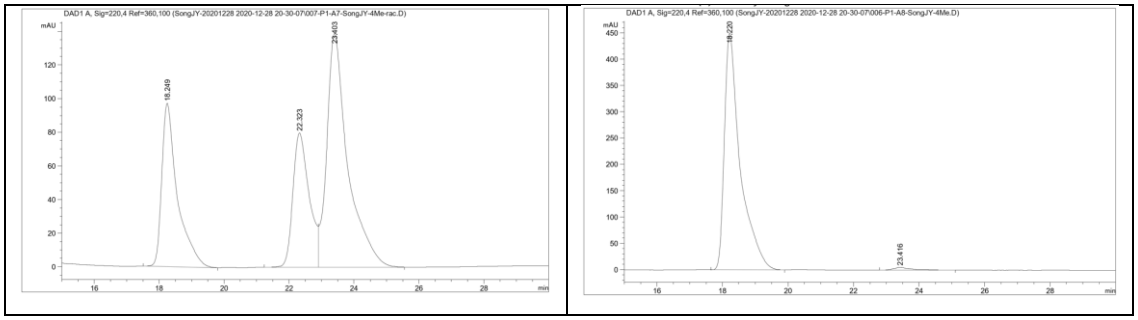
(1*S*,4*S*)-1,4-di-*p*-tolylbutane-1,4-diol (6k)



6k

99% yield, 76:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94 (d, *J* = 8.1 Hz, 4H), 7.28 (s, 4H), 3.42 (s, 4H), 2.41 (s, 6H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 198.45, 143.90, 134.37, 129.28, 128.26, 32.54, 21.67.

Optical Rotation: $[\alpha]_D^{25}$ = -49.6 (c = 0.50, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 220 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 18.22 min, t_R (minor) = 23.42 min.



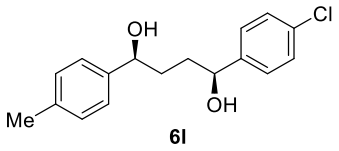
Signal 1: DAD1 A, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.249	BB	0.4777	3228.04712	97.13160	26.3898
2	22.323	BV	0.5166	2769.92554	79.87865	22.6446
3	23.403	VB	0.6388	6234.21875	139.10869	50.9657

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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.220	BB	0.4844	1.51410e4	450.19681	98.7098
2	23.416	BB	0.5606	197.89963	4.70646	1.2902

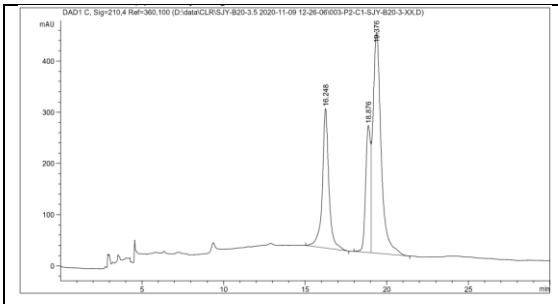
(1*S*,4*S*)-1-(4-chlorophenyl)-4-(*p*-tolyl)butane-1,4-diol (6l)

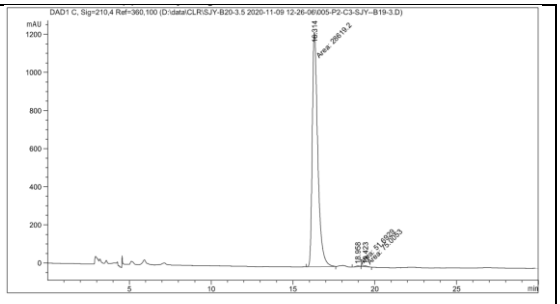


6l

99% yield, >100:1 dr, 99.6% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.30 (d, *J* = 8.5 Hz, 2H), 7.28 – 7.19 (m, 4H), 7.16 (d, *J* = 7.9 Hz, 2H), 4.66 (dt, *J* = 7.7, 3.6 Hz, 2H), 3.23 (s, 1H), 2.80 (s, 1H), 2.36 (s, 3H), 1.92 – 1.76 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.21, 141.50, 137.33, 133.00, 129.19, 128.52, 127.23, 125.73, 74.47, 73.85, 36.14, 35.69, 21.12.

Optical Rotation: $[\alpha]_D^{25}$ = -49.5 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 16.31 min, t_R (minor) = 18.96 min, 19.42 min.





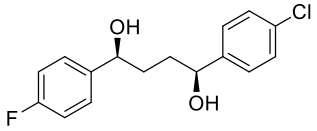
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.248	BB	0.3921	7578.68262	272.38766	27.2225
2	18.876	VV R	0.2929	5177.21289	248.19695	18.5964
3	19.376	VV R	0.4783	1.50839e4	431.55484	54.1811

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.314	MM	0.3875	2.86192e4	1230.81812	99.5592
2	18.958	MM	0.2583	51.69290	3.33579	0.1798
3	19.423	MM	0.3135	75.00529	3.98809	0.2609

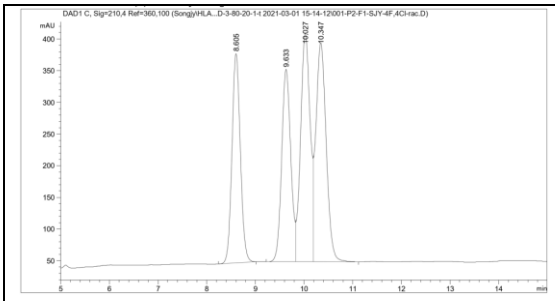
(1*S*,4*S*)-1-(4-chlorophenyl)-4-(4-fluorophenyl)butane-1,4-diol (6m)



6m

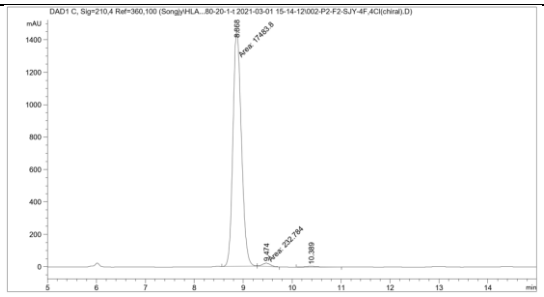
99% yield, >100:1 dr, 97.4% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.29 (d, *J* = 8.3 Hz, 3H), 7.23 (d, *J* = 8.6 Hz, 3H), 7.00 (t, *J* = 8.7 Hz, 2H), 4.65 (dd, *J* = 7.4, 3.4 Hz, 2H), 3.01 (d, *J* = 40.8 Hz, 2H), 1.93 – 1.72 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 163.39, 160.95, 143.03, 140.25, 140.21, 133.16, 128.60, 127.43, 127.35, 127.17, 115.41, 115.19, 73.93, 73.87, 35.96, 35.93.

Optical Rotation: $[\alpha]_D^{25}$ = -42.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral IF column, 210 nm, 30 °C, n-hexane: i-PrOH = 88:12; flow 1.0 mL/min; t_R (major) = 8.87 min, t_R (minor) = 9.47 min, 10.39 min.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

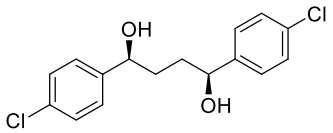
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.605	BB	0.1835	3949.93188	330.45813	22.0089
2	9.633	BV	0.1993	3944.08081	304.08475	21.9763
3	10.027	VV	0.2073	4927.01758	360.73349	27.4532
4	10.347	VB	0.2250	5125.90967	345.75763	28.5615



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.868	MM	0.2009	1.74838e4	1450.54077	98.2735
2	9.474	MM	0.1901	232.78407	20.41088	1.3084
3	10.389	BB	0.2248	74.38322	5.02274	0.4181

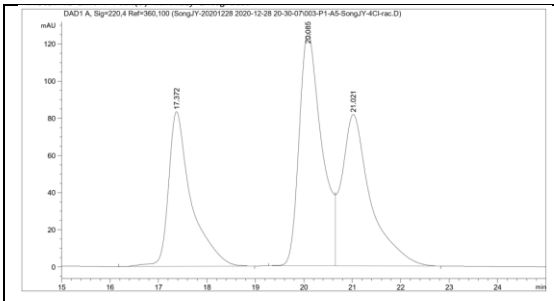
(1*S*,4*S*)-1,4-bis(4-chlorophenyl)butane-1,4-diol (6n)



6n

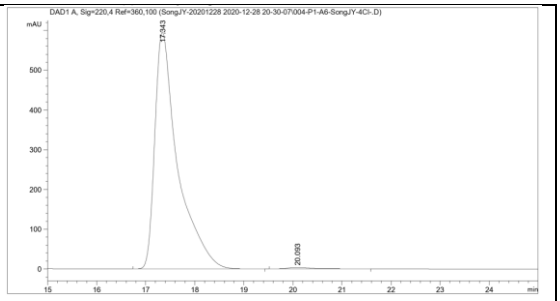
99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29 (d, *J* = 8.2 Hz, 4H), 7.23 (d, *J* = 8.1 Hz, 4H), 4.65 (d, *J* = 4.7 Hz, 2H), 2.92 (s, 2H), 1.88 – 1.73 (m, 4H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 141.93, 132.16, 127.58, 126.12, 72.82, 34.83.

Optical Rotation: $[\alpha]_D^{25}$ = -37.8 (c = 0.50, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 220 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 17.37 min, t_R (minor) = 20.09 min.



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

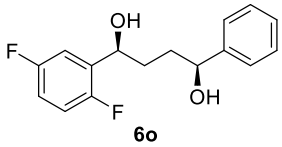
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.372	BB	0.4619	2695.90234	83.22778	26.6700
2	20.085	BV	0.4784	4040.48877	125.23609	39.9717
3	21.021	VB	0.5843	3371.97144	81.56603	33.3582



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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.343	BB	0.4677	1.92903e4	595.91565	99.2993
2	20.093	BB	0.5262	136.12195	3.64083	0.7007

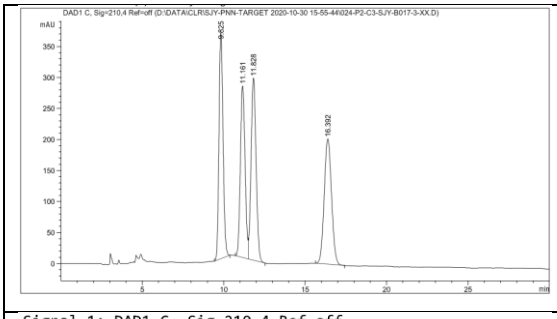
(1*S*,4*S*)-1-(2,5-difluorophenyl)-4-phenylbutane-1,4-diol (6o)



6o

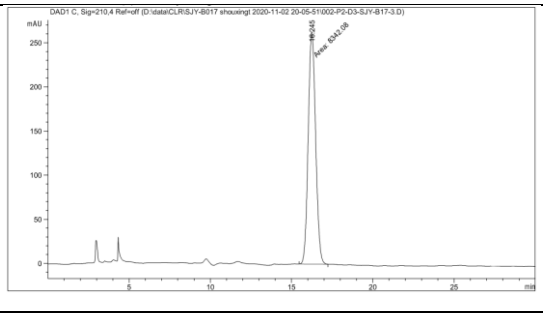
99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33 (d, *J* = 6.6 Hz, 4H), 7.29 – 7.26 (m, 1H), 7.22 – 7.15 (m, 1H), 6.99 – 6.83 (m, 2H), 4.97 (t, *J* = 5.7 Hz, 1H), 4.69 (dd, *J* = 7.9, 3.5 Hz, 1H), 3.04 (s, 2H), 1.96 – 1.80 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.18, 160.16, 157.77, 157.75, 156.53, 154.16, 154.14, 144.32, 133.76, 133.69, 133.60, 133.53, 128.54, 127.69, 125.78, 116.38, 116.30, 116.14, 116.05, 115.03, 114.95, 114.79, 114.70, 113.96, 113.91, 113.71, 113.66, 74.63, 67.89, 35.60, 34.91.

Optical Rotation: $[\alpha]_D^{25}$ = -40.7 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 210 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 16.25 min.



Signal 1: DAD1 C, Sig=210,4 Ref=off

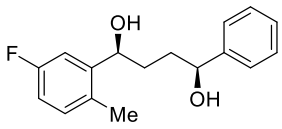
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.825	BB	0.2704	6320.35303	364.30667	25.8934
2	11.161	BV	0.3152	5527.04736	276.50348	22.6434
3	11.828	VB	0.3306	6260.48389	293.77255	25.6481
4	16.392	BB	0.4859	6301.22900	202.00610	25.8151



Signal 1: DAD1 C, Sig=210,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.245	MM	0.5281	8342.07813	263.29306	100.0000

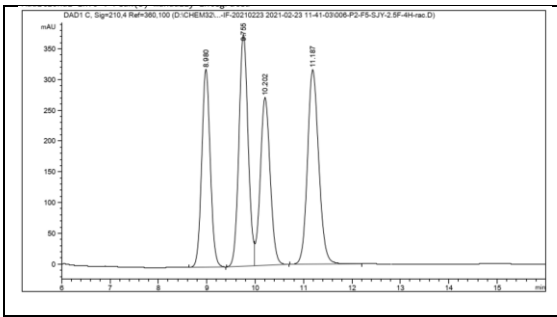
(1*S*,4*S*)-1-(5-fluoro-2-methylphenyl)-4-phenylbutane-1,4-diol (**6p**)

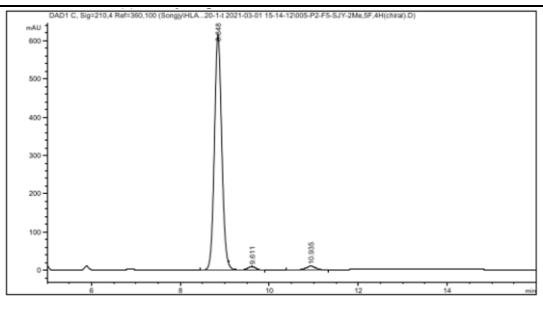


6p

99% yield, 25:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 4.4 Hz, 4H), 7.28 (d, *J* = 4.3 Hz, 1H), 7.20 (dd, *J* = 10.2, 2.9 Hz, 1H), 7.04 (dd, *J* = 8.4, 5.8 Hz, 1H), 6.83 (td, *J* = 8.3, 2.8 Hz, 1H), 4.88 (t, *J* = 6.2 Hz, 1H), 4.71 (dd, *J* = 8.2, 4.5 Hz, 1H), 3.04 (s, 2H), 2.20 (s, 3H), 2.00 – 1.86 (m, 2H), 1.78 (q, *J* = 7.0, 6.5 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.89, 160.47, 145.09, 145.03, 144.50, 131.60, 131.52, 129.51, 129.48, 128.53, 127.63, 125.79, 113.77, 113.57, 112.22, 112.00, 74.66, 70.60, 70.59, 36.01, 34.80, 18.24.

Optical Rotation: $[\alpha]_D^{25}$ = -60.4 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral IF column, 210 nm, 30 ºC, n-hexane: i-PrOH = 88:12; flow 1.0 mL/min; t_R (major) = 8.85 min, t_R (minor) = 9.61 min, 10.94 min.





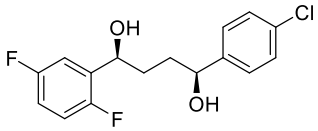
Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.980	BB	0.1912	3946.08789	321.43826	22.0150
2	9.755	BV	0.2045	4993.86279	377.05154	27.8605
3	10.202	VB	0.2193	3868.75366	272.99463	21.5836
4	11.187	BB	0.2488	5115.82129	316.20224	28.5409

Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.848	BV R	0.1763	7074.02197	614.70929	96.1588
2	9.611	VB E	0.2172	134.93028	9.19562	1.8341
3	10.935	BB	0.2378	147.65228	9.27228	2.0071

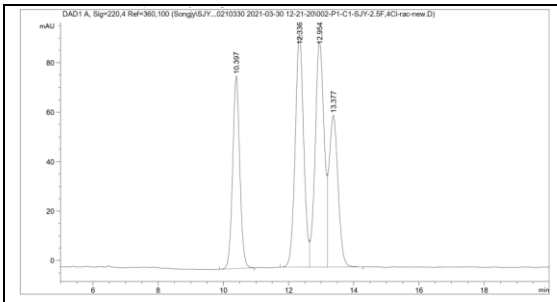
(1*S*,4*S*)-1-(4-chlorophenyl)-4-(2,5-difluorophenyl)butane-1,4-diol (6q)

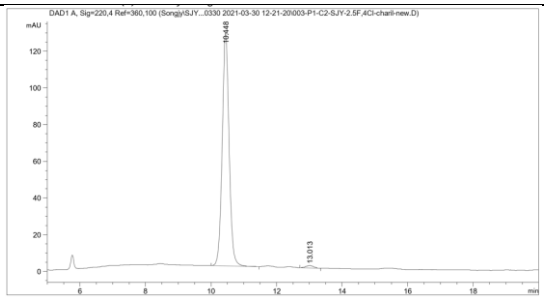


6q

99% yield, 82:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 – 7.24 (m, 5H), 7.20 (ddd, *J* = 8.9, 5.6, 3.1 Hz, 1H), 7.02 – 6.88 (m, 2H), 4.99 (s, 1H), 4.70 (s, 1H), 3.46 (d, *J* = 16.2 Hz, 1H), 3.09 (s, 1H), 1.95 – 1.81 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.18, 160.15, 157.77, 157.75, 156.48, 154.11, 154.09, 142.83, 133.58, 133.51, 133.42, 133.35, 133.27, 128.64, 127.14, 116.46, 116.37, 116.21, 116.12, 115.16, 115.08, 114.92, 114.83, 113.87, 113.82, 113.62, 113.58, 73.87, 67.83, 35.67, 34.67.

Optical Rotation: $[\alpha]_D^{25}$ = -43.3 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral IA column, 210 nm, 30 ºC, n-hexane: i-PrOH = 88:12; flow 1.0 mL/min; t_R (major) = 10.45 min, t_R (minor) = 13.01 min.





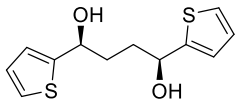
Signal 1: DAD1 A, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.397	BB	0.2314	1184.94568	77.93884	20.4087
2	12.336	BV	0.2793	1708.84241	94.35480	29.4319
3	12.954	VV	0.2873	1729.21204	91.16385	29.7827
4	13.377	VB	0.2904	1183.08630	61.50441	20.3767

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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.448	BB	0.2248	1857.26599	126.85838	98.7961
2	13.013	BB	0.2438	22.63145	1.32166	1.2039

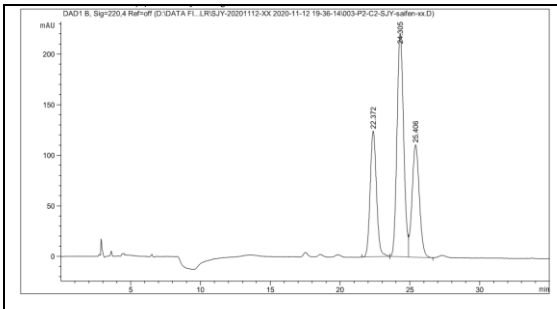
(1*S*,4*S*)-1,4-di(thiophen-2-yl)butane-1,4-diol (6r)



6r

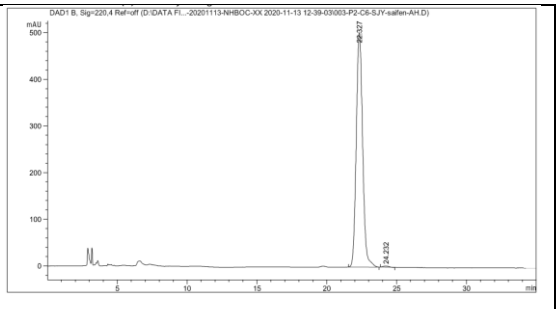
99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (400 MHz, DMSO-d6) δ 6.48 (d, *J* = 5.0 Hz, 2H), 6.11 – 5.98 (m, 4H), 4.67 (d, *J* = 4.7 Hz, 2H), 3.90 (q, *J* = 5.1 Hz, 2H), 0.98 – 0.72 (m, 4H). **^{13}C NMR** (101 MHz, DMSO-d6) δ 156.03, 131.63, 129.11, 127.96, 73.41, 40.93.

Optical Rotation: $[\alpha]_D^{25}$ = -18.1 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral AD-H column, 220 nm, 30 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 22.33 min, t_R (minor) = 24.23 min.



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

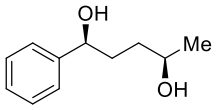
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.372	BB	0.4840	3903.26465	124.42773	25.6466
2	24.305	BV	0.5156	7300.44482	220.86026	47.9679
3	25.406	VB	0.5536	4015.71606	111.11474	26.3855



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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.327	BB	0.4931	1.58994e4	502.52542	99.5758
2	24.232	BB	0.3457	67.72499	2.38231	0.4242

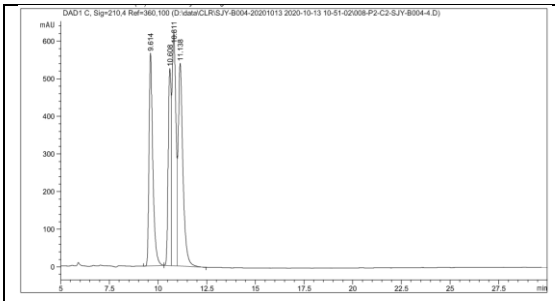
(1*S*,4*R*)-1-phenylpentane-1,4-dio (6s)



6s

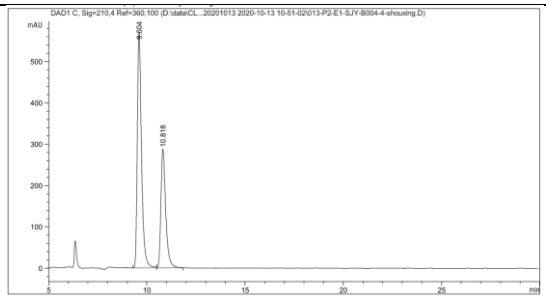
99% yield, 7:4 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.37 – 7.20 (m, 5H), 4.71 – 4.58 (m, 1H), 3.78 (dq, *J* = 24.2, 6.1 Hz, 1H), 1.87 – 1.74 (m, 2H), 1.59 – 1.39 (m, 2H), 1.19 – 1.09 (m, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 144.93, 144.75, 128.39, 127.39, 127.35, 125.86, 125.83, 74.66, 74.13, 68.22, 67.73, 36.19, 36.00, 35.06, 34.94, 23.62, 23.32.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 210 nm, 30 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 9.60 min, t_R (minor) = 10.82 min.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

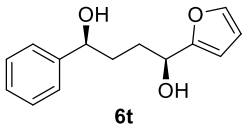
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.614	BB	0.2024	7672.43359	565.18958	24.8327
2	10.608	BV	0.1608	5494.70947	524.05963	17.7842
3	10.811	VV	0.2052	8632.20703	618.82953	27.9391
4	11.138	VB	0.2442	9097.20215	539.56232	29.4441



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.604	BV	0.2261	8474.96094	568.01208	63.5268
2	10.818	VB	0.2548	4865.80859	287.05173	36.4732

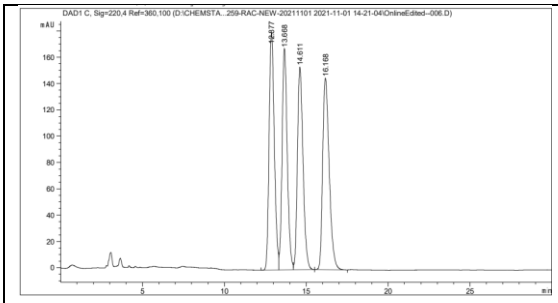
(1*S*,4*S*)-1-(furan-2-yl)-4-phenylbutane-1,4-diol (6t)



6t

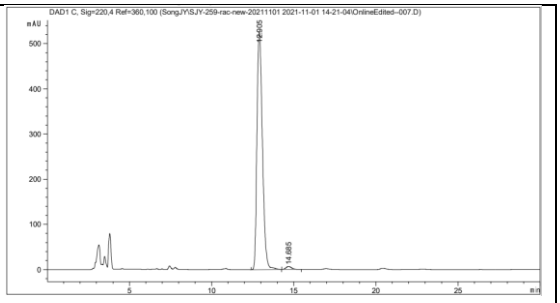
99% yield, 75:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, CDCl3) δ 7.34 (d, J = 4.4 Hz, 5H), 7.27 (q, J = 4.3 Hz, 1H), 6.34 – 6.29 (m, 1H), 6.21 (d, J = 3.2 Hz, 1H), 4.73 (dt, J = 8.0, 5.1 Hz, 2H), 2.58 (d, J = 113.7 Hz, 2H), 2.01 – 1.91 (m, 3H), 1.87 – 1.80 (m, 1H). **^{13}C NMR** (151 MHz, CDCl3) δ 156.61, 144.49, 141.91, 128.52, 127.63, 125.82, 110.16, 105.80, 74.45, 67.87, 35.41, 32.25.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral AS-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 12.91 min, t_R (minor) = 14.69 min.



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

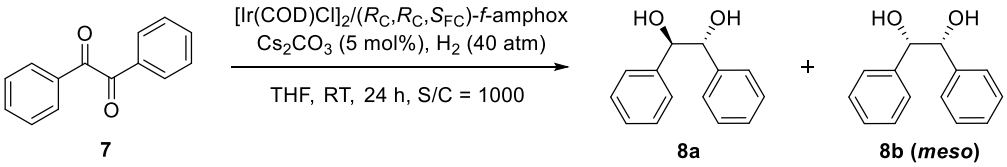
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.877	BV	0.3478	4011.55737	180.17473	26.0225
2	13.668	VV	0.3406	3694.20044	167.93747	23.9638
3	14.611	VB	0.3698	3668.17603	154.03580	23.7950
4	16.168	BB	0.4318	4041.80957	145.61195	26.2187



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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.905	BB	0.3640	1.21743e4	526.04846	98.7458
2	14.685	BB	0.3579	154.63133	6.53953	1.2542

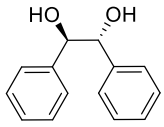
4. General procedure for asymmetric hydrogenation of benzil (7)



7 8a 8b (*meso*)

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,R_C,S_{FC})-*f*-amphox (12.2 mg, 2.2×10^{-2} mmol) and anhydrous THF (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 benzil **7** (0.1 mmol), Cs_2CO_3 (1.63 mg, 0.005 mmol), and anhydrous THF (1.0 mL) were added into a 5 mL hydrogenation vessel, and a solution of Ir/(R_C,R_C,S_{FC})-*f*-amphox in anhydrous THF (10 μL) was added *via* an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from golvebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 40 atm H_2. The reaction solution was stirred at room temperature (25 °C - 30 °C) until for 24 h, then released pressure carefully. The product was purified by flash chromatography on silica gel with ethyl acetate.

(1*R*,2*R*)-1,2-diphenylethane-1,2-diol (8a)



8a

99% yield, 7:3 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.30 (d, *J* = 6.2 Hz, 3H), 7.22 (t, *J* = 6.1 Hz, 5H), 7.10 (s, 2H), 4.80 (s, 1H), 4.67 (s, 1H), 3.10 (s, 1H), 2.44 (s, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 139.77, 128.21, 128.13, 128.08, 127.93, 127.13, 127.02, 79.02, 78.06.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral OJ-H column, 210 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 0.5 mL/min; t_R (major) = 31.73 min. The absolute configuration was assigned by comparing with literature data.[2]

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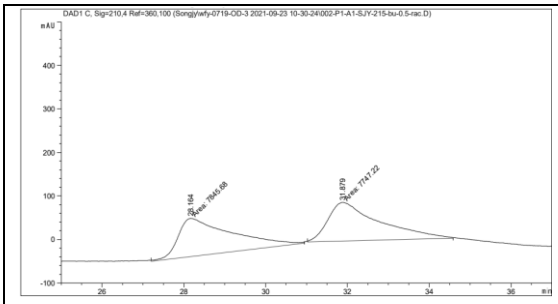
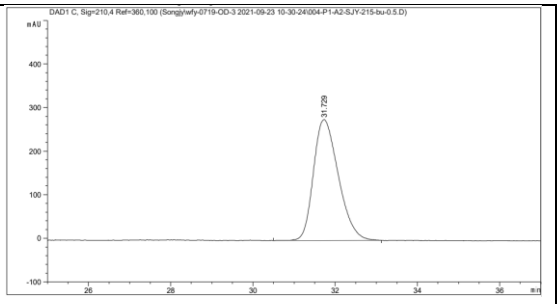
[2] T. Touge, T. Hakamata, H. Nara, T. Kobayashi, N. Sayo, T. Saito, Y. Kayaki, and T. Ikariya, *J. Am. Chem. Soc.*, 2011, **133 (38)**, 14960-14963.



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

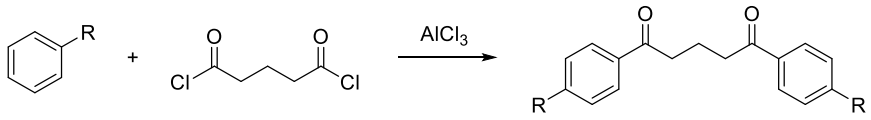
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	28.164	MM	1.4919	7845.67871	87.64993	50.3157
2	31.879	MM	1.4505	7747.21582	89.01520	49.6843



Signal 1: DAD1 C, Sig=210,4 Ref=360,100

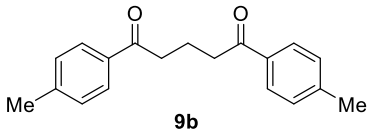
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	31.729	VB R	0.6045	1.16715e4	277.58972	100.0000

5. General procedure for synthesis of 1,5-diketones (9)



Aluminum chloride (1.33 g, 10 mmol) was added to the solution of glutaryl chloride (845 mg) in benzene (10 mL) at room temperature. The solution was stirred for 4 h at 25 °C. After completion of the reaction, add saturated ammonium chloride solution to the solution. Extracted with ethyl acetate, organic layer was dried over sodium sulphate and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on silica gel.

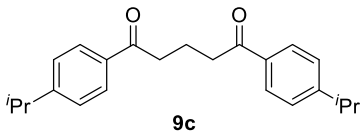
1,5-di-*p*-tolylpentane-1,5-dione (9b)



9b

65% yield. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.88 (d, J = 8.3 Hz, 4H), 7.25 (d, J = 8.0 Hz, 4H), 3.08 (t, J = 7.0 Hz, 4H), 2.40 (s, 6H), 2.18 (p, J = 6.9 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 199.61, 143.82, 134.43, 129.28, 128.22, 37.57, 21.64, 18.95.

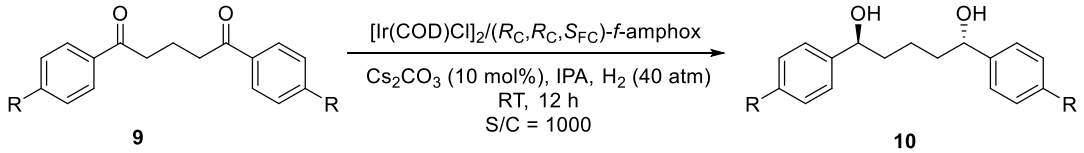
1,5-bis(4-isopropylphenyl)pentane-1,5-dione (9c)



9c

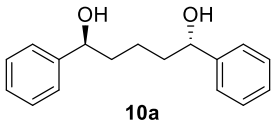
49% yield. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.92 (dd, J = 8.4, 1.9 Hz, 4H), 7.34 – 7.28 (m, 4H), 3.08 (t, J = 7.0 Hz, 4H), 2.96 (p, J = 6.9 Hz, 2H), 2.18 (p, J = 7.0 Hz, 2H), 1.26 (d, J = 7.0 Hz, 12H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 199.63, 154.55, 134.78, 128.36, 126.68, 37.59, 34.26, 23.69, 19.00.

6. General procedure for asymmetric hydrogenation of 1,5-diketones



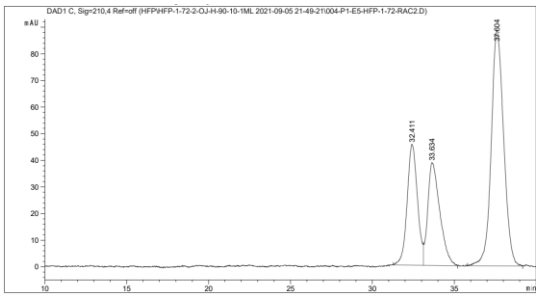
To a 4.0 mL vial was added the catalyst precursor $[Ir(COD)Cl]_2$ (6.72 mg, 1.0×10^{-2} mmol), ligand (R_C,R_C,S_{FC})-*f*-amphox (12.2 mg, 2.2×10^{-2} mmol) and anhydrous IPA (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2.0 h at 25 ºC giving orange red solution. And then 1,5-diketone **9** (0.1 mmol), Cs_2CO_3 (3.25 mg, 0.01 mmol.) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous IPA was added as solvent and a solution of Ir/(R_C,R_C,S_{FC})-*f*-amphox in anhydrous IPA (10 μL) was added via an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from golvebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 40 atm H_2. The reaction solution was stirred at room temperature (25 ºC - 30 ºC) until for 12 h, then released pressure carefully. The solution of reaction mixture was purified by flash chromatography on silica gel with ethyl acetate and the solvent was removed under reduced pressure. The ee value was determined by chiral HPLC analysis of the hydrogenation product chiral diol directly. The absolute configurations of 1,5-diol were assigned by analogy.

(1*S*,5*S*)-1,5-diphenylpentane-1,5-diol (10a)



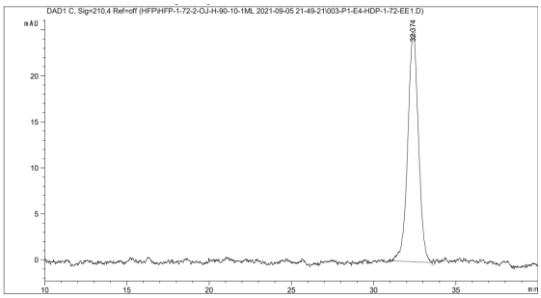
99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.36 – 7.29 (m, 8H), 7.29 – 7.25 (m, 2H), 4.66 (ddd, *J* = 8.2, 5.3, 3.0 Hz, 2H), 2.01 (d, *J* = 3.2 Hz, 2H), 1.88 – 1.79 (m, 2H), 1.76 – 1.68 (m, 2H), 1.48 (p, *J* = 7.8 Hz, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 144.78, 128.49, 127.57, 125.84, 74.46, 38.82, 22.29.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral OJ-H column, 210 nm, 25 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 32.37 min.



Signal 1: DAD1 C, Sig=210,4 Ref=off

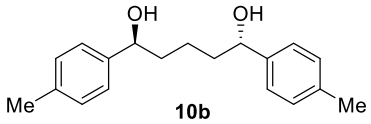
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	32.411	BV	0.5360	1986.82703	45.44917	22.9806
2	33.634	VV R	0.6221	1979.65430	38.61782	22.8976
3	37.604	VV R	0.6545	4679.18848	88.26025	54.1218



Signal 1: DAD1 C, Sig=210,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	32.374	VB R	0.5428	1127.38892	25.06358	100.0000

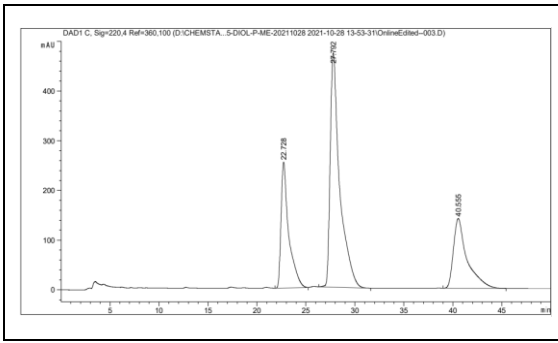
(1*S*,5*S*)-1,5- di-p-tolylpentane-1,5-diol (10b)

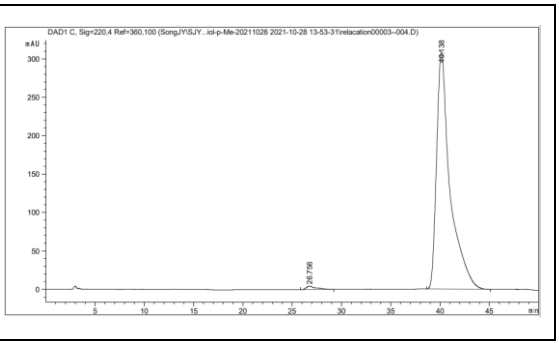


10b

99% yield, 92:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.20 (d, J = 7.7 Hz, 4H), 7.14 (d, J = 7.7 Hz, 4H), 4.63 – 4.57 (m, 2H), 2.34 (s, 6H), 2.13 (s, 2H), 1.81 (dq, J = 15.3, 7.8 Hz, 2H), 1.69 (td, J = 13.5, 7.9 Hz, 2H), 1.45 (p, J = 7.7 Hz, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 141.89, 137.17, 129.14, 125.82, 74.23, 38.78, 22.38, 21.13.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral AD-3 column, 220 nm, 25 ºC, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 40.14 min, t_R (minor) = 26.76 min.





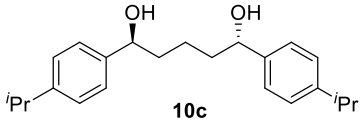
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.728	BB	0.7805	1.37752e4	253.30539	23.3546
2	27.792	BB	0.9635	3.17318e4	471.27997	53.7984
3	40.555	BB	1.3874	1.34757e4	140.20245	22.8469

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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	26.756	BB	0.8332	318.14532	4.59847	1.0747
2	40.138	BB	1.3651	2.92854e4	308.60568	98.9253

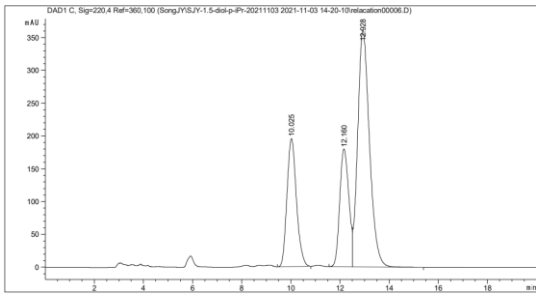
(1*S*,5*S*)-1,5-bis(4-isopropylphenyl)pentane-1,5-diol (10c)

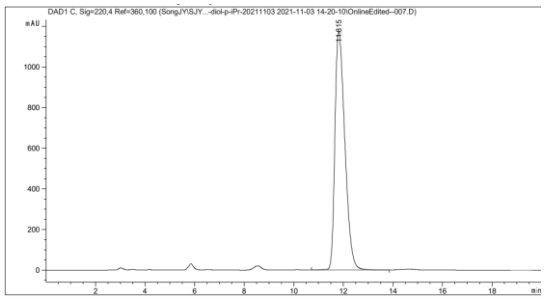


10c

99% yield, >100:1 dr, >99.9% ee. **^{1}H NMR** (600 MHz, CDCl3) δ 7.24 (d, J = 8.2 Hz, 4H), 7.19 (d, J = 8.3 Hz, 4H), 4.62 (dd, J = 8.0, 5.3 Hz, 2H), 2.90 (p, J = 6.9 Hz, 2H), 2.13 (s, 2H), 1.83 (dq, J = 15.1, 7.7 Hz, 2H), 1.71 (td, J = 13.4, 7.8 Hz, 2H), 1.49 (p, J = 7.7 Hz, 2H), 1.25 (d, J = 6.9 Hz, 12H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.15, 141.20, 125.46, 124.82, 73.23, 37.67, 32.77, 22.98, 21.42.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral OD-3 column, 220 nm, 25 °C, n-hexane: i-PrOH = 90:10; flow 1.0 mL/min; t_R (major) = 11.82 min.





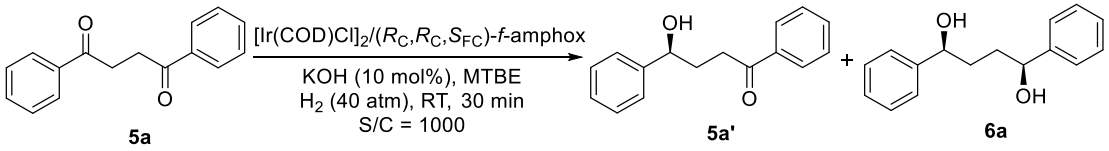
Signal 1: DAD1 C, Sig=220,4 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.025	BB	0.4155	5207.23877	195.03313	23.8300
2	12.160	BV	0.4036	4605.53125	179.37239	21.0764
3	12.928	VB	0.5078	1.20388e4	360.36252	55.0935

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

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.815	BB	0.4346	3.26600e4	1173.87292	100.0000

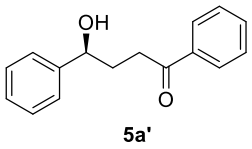
7. Mechanistic investigation



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,R_C,S_{FC})-*f*-amphox (12.2 mg, 2.2×10^{-2} mmol) and anhydrous toluene (2.0 mL) in the argon-filled glovebox. The mixture was stirred for 2 h at 25 ºC giving orange red solution. And then 0.1 mmol of 1,4-diphenylbutane-1,4-dione (**5a**), KOH (0.56 mg, 0.01 mmol) were added into a 5 mL hydrogenation vessel. 1.0 mL anhydrous MTBE was added as solvent and a solution of Ir/(R_C,R_C,S_{FC})-*f*-amphox in anhydrous toluene (10 μL) was added *via* an injection port. Then the vessel was placed in an autoclave, closed it and moved it out from golvebox. The autoclave quickly purged with hydrogen gas for three times, then pressurized to 40 atm H_2. The reaction solution was stirred at room temperature for 30 min, then released pressure carefully.

The reaction mixture was purified by flash chromatography on silica gel with ethyl acetate. The mono-reduced product (*S*)-4-hydroxy-1,4-diphenylbutan-1-one (**5a'**) could be obtained in 6.7% yield with 99% ee, and only a trace amount of **6a** was detected.

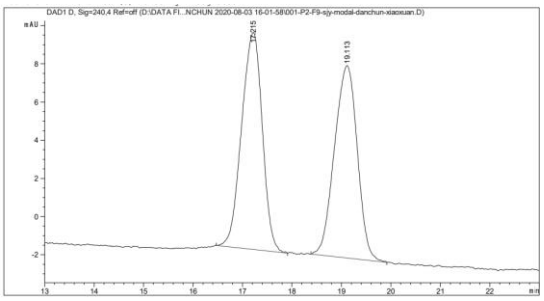
(*S*)-4-hydroxy-1,4-diphenylbutan-1-one (5a')



6.7% yield, 99% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94 (dd, *J* = 8.4, 1.4 Hz, 2H), 7.58 – 7.53 (m, 1H), 7.45 (t, *J* = 7.6 Hz, 2H), 7.40 – 7.33 (m, 4H), 7.30 – 7.26 (m, 1H), 4.83 (dd, *J* = 7.4, 5.3 Hz, 1H), 3.11 (t, *J* = 7.0 Hz, 2H), 2.50 (s, 1H), 2.26 – 2.16 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 200.59, 144.37, 136.85, 133.16, 128.61, 128.54, 128.12, 127.61, 125.78, 73.63, 34.79, 33.08.

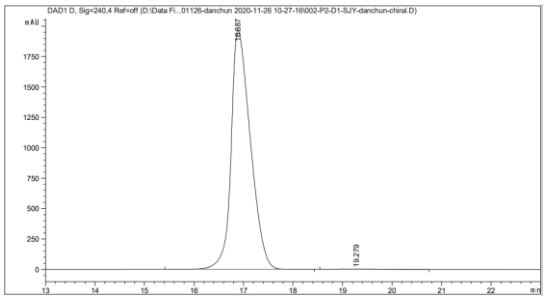
Optical Rotation: $[\alpha]_D^{22}$ = -23.8 (c = 1.00, $CHCl_3$). The enantiomeric excess was determined by HPLC on Chiral OJ-H column, 240 nm, 30 ºC, n-hexane: i-PrOH = 90:10;

flow 1.0 mL/min; t_R (major) = 16.89 min, t_R (minor) = 19.28 min. The absolute configuration of 1,4-diphenylbutane-1,4-diol **5a'** was assigned to be (*S*) by comparing the optical rotation with literature data.[3]



Signal 1: DAD1 D, Sig=240,4 Ref=off

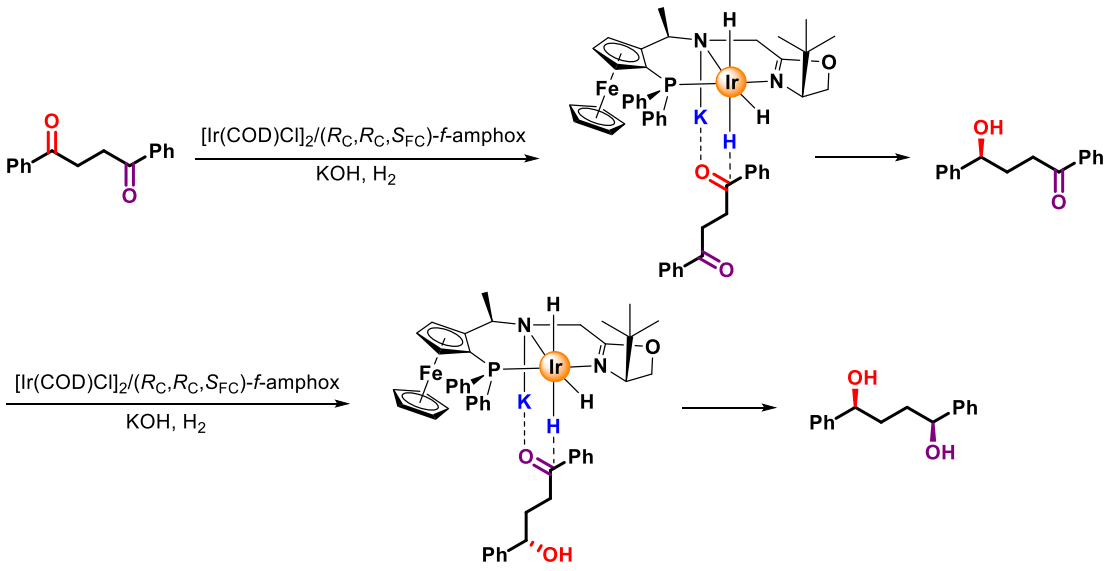
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.215	BB	0.4570	330.03091	11.35852	50.5578
2	19.113	BB	0.4536	322.74789	10.07849	49.4422



Signal 1: DAD1 D, Sig=240,4 Ref=off

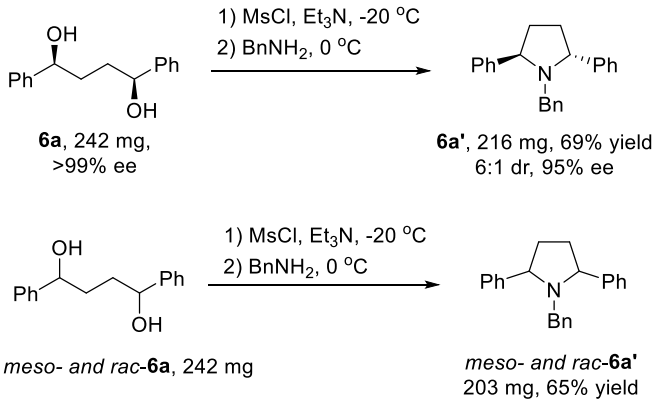
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.887	BB	0.4061	5.31897e4	1963.22437	99.6338
2	19.279	BB	0.6342	195.52222	3.68969	0.3662

The isolation of the intermediate revealed the nature of this stepwise transformation from 1,4-diketones to 1,4-diols.



[3] Y. Xia, L. Lin, F. Chang, X. Fu, X. Liu and X. Feng, *Angew. Chem. Int. Ed.* 2015, **54** ,13748-13752.

8. Synthesis of (2*R*,5*R*)-1-benzyl-2,5-diphenylpyrrolidine (6a')



(2*R*,5*R*)-1-benzyl-2,5-diphenylpyrrolidine (**6a'**) was prepared as described in literature.[4] To the solution of methanesulfonyl chloride (0.2 mL, 2.6 mmol) in CH_2Cl_2 (10 mL) at -20 °C was added a solution of (1*S*,4*S*)-1,4-diphenylbutane-1,4-diol (**6a**, 242 mg, 1.0 mmol, >99% ee) and Et_3N (0.42 mL, 3.0 mmol) in CH_2Cl_2 (10 mL). The reaction mixture was stirred for 2 h at -20 °C, then quenched with aq. sat. NH_4Cl (2 mL) and extracted with DCM. The organic layer was dried (Na_2SO_4), and concentrated to approximately 5 mL under reduced pressure, and immediately used for the next reaction without further purification.

Benzylamine (2 mL, 20 mmol) was added at 0 °C to the solution obtained in the previous step and the mixture was stirred at 0 °C for 12 h. Then, the mixture was extracted with DCM. The organic layer was dried (Na_2SO_4), and concentrated under reduced pressure.The obtained residue was purified by flash chromatography on silica gel.

Using the similar procedure, the corresponding racemic sample could be obtained. Unfortunately, after repeated purification, *rac*-**6a'** still could not be completely separated from *meso*-**6a'**.

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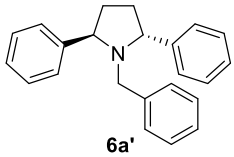
[4] M. Periasamy, M. Seenivasaperumal and V. D. Rao, *Synthesis*, 2003, **16**, 2507-2510.

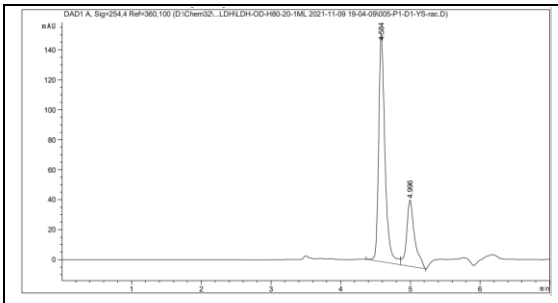
(2*R*,5*R*)-1-benzyl-2,5-diphenylpyrrolidine (6a')



6a'

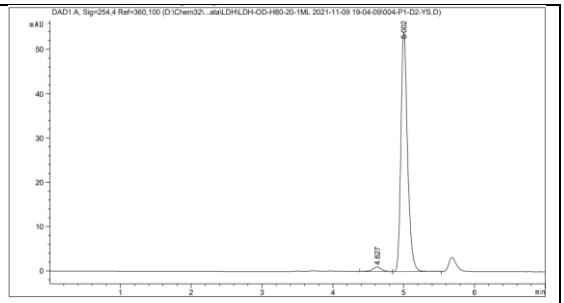
69% yield, 6:1 dr, 95% ee. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 – 7.26 (m, 9H), 7.25 – 7.16 (m, 4H), 7.11 (d, J = 7.2 Hz, 2H), 4.27 (t, J = 5.5 Hz, 2H), 3.57 (d, J = 14.1 Hz, 1H), 3.08 (d, J = 14.1 Hz, 1H), 2.63 – 2.48 (m, 2H), 2.04 – 1.91 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 142.86, 139.06, 127.26, 127.13, 127.05, 126.84, 125.84, 125.28, 64.16, 49.91, 32.20.

Optical Rotation: The enantiomeric excess was determined by HPLC on Chiral OD-H column, 254 nm, 25 ºC, n-hexane: i-PrOH = 98:2; flow 0.8 mL/min; t_R (major) = 5.00 min, t_R (minor) = 4.63 min.



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

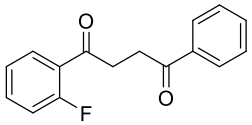
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.584	BV	0.0933	958.09088	152.41002	73.3328
2	4.996	VB	0.1142	348.40582	44.07001	26.6672



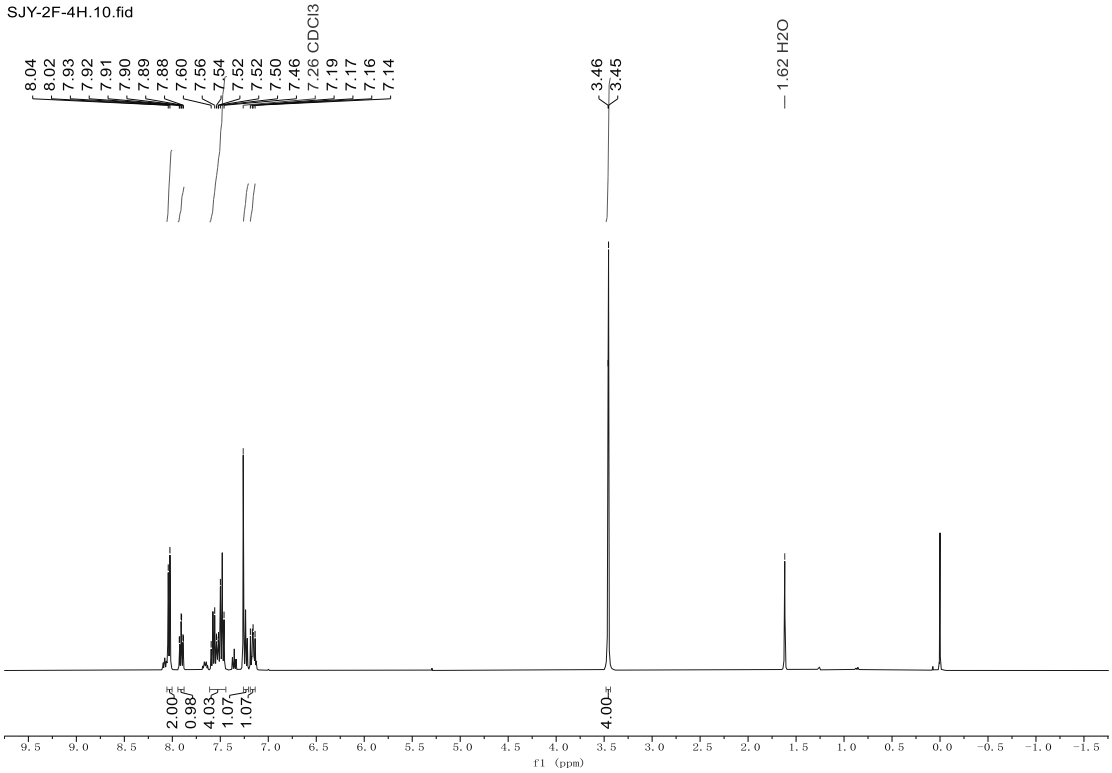
Signal 1: DAD1 A, Sig=254,4 Ref=360,100

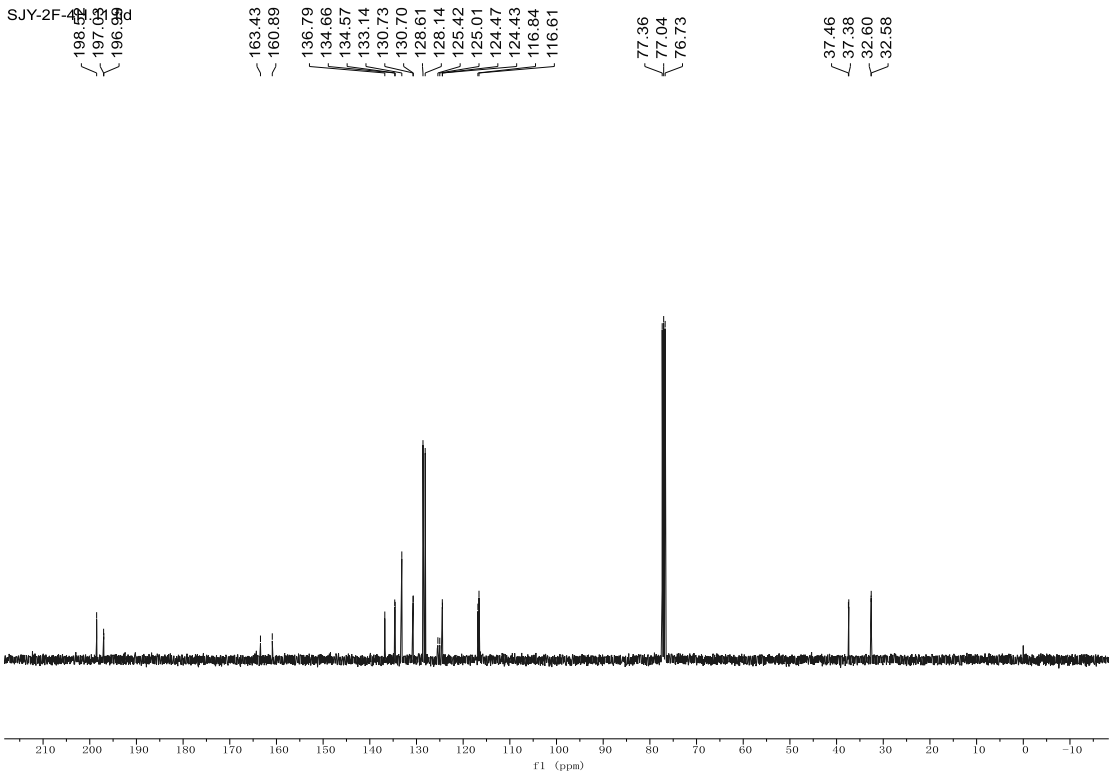
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.627	BB	0.1391	9.11846	1.01214	2.5306
2	5.002	BB	0.0998	351.20908	54.07738	97.4694

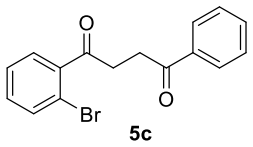
9. NMR Spectra



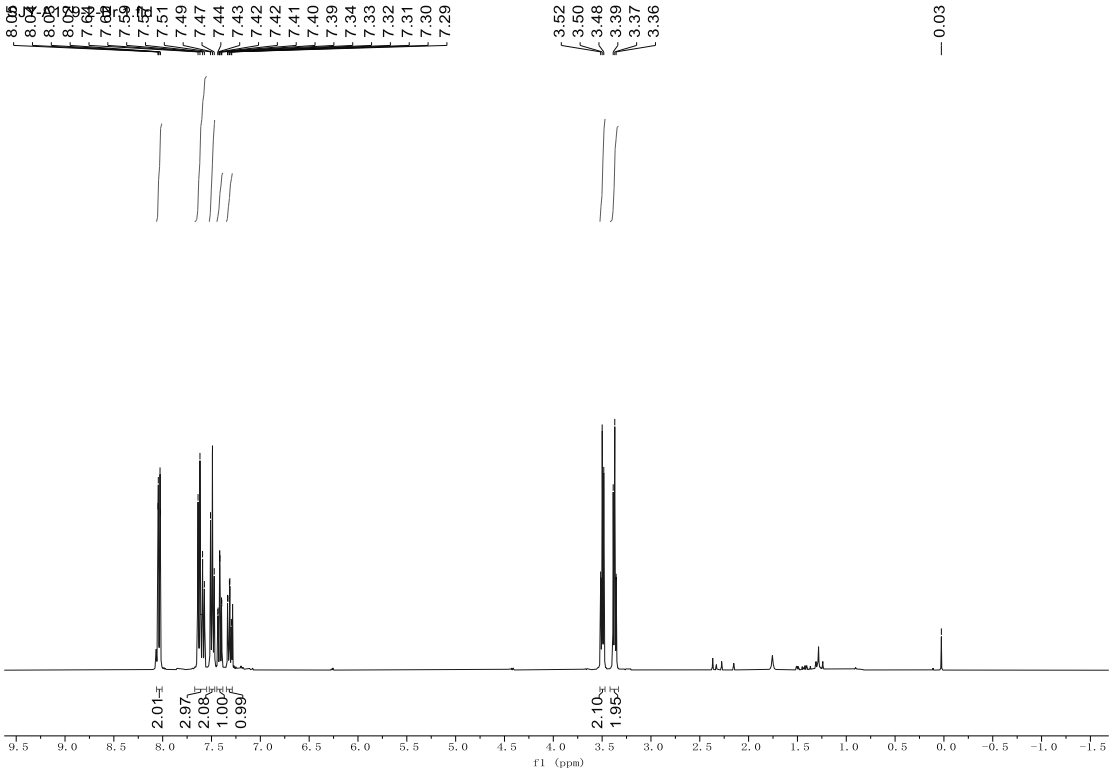
5b

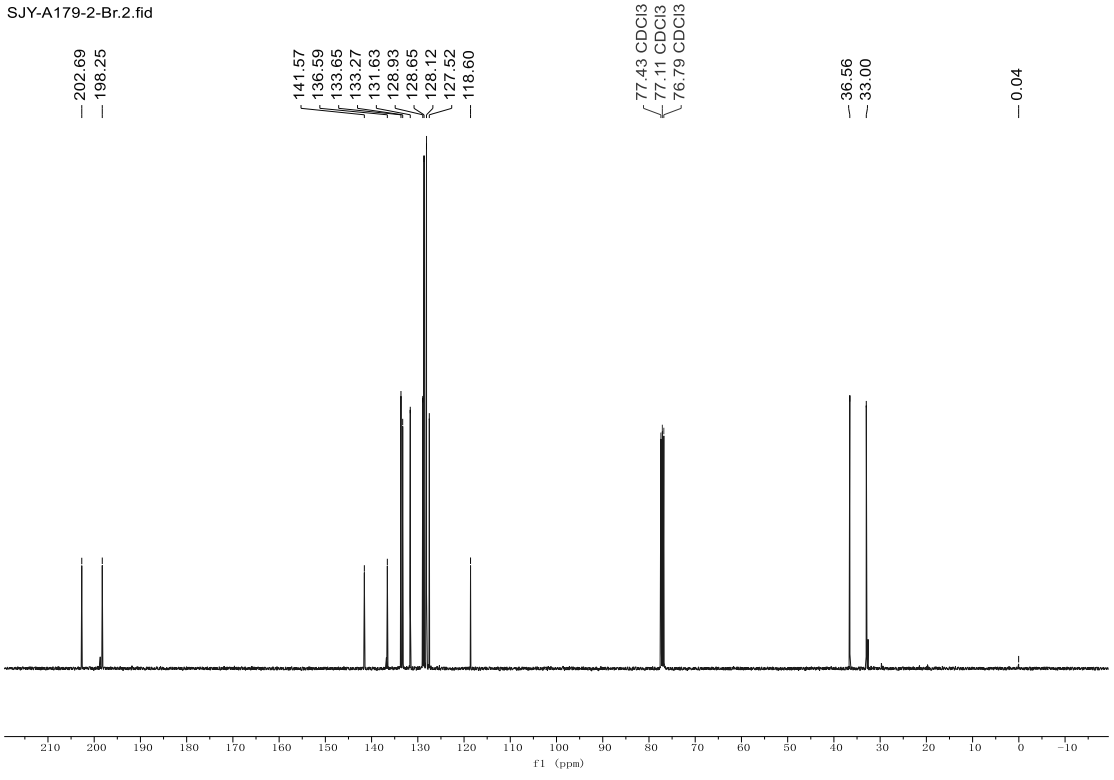


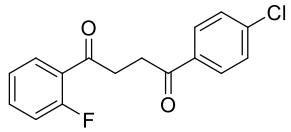



O
O
Br

5c

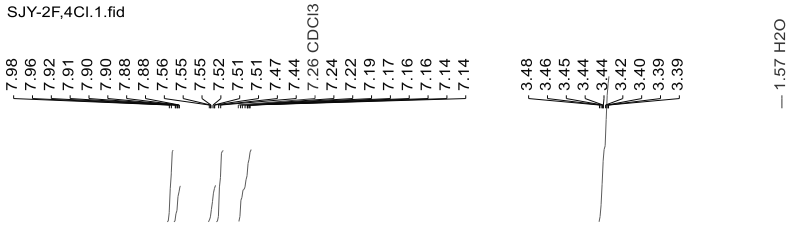

8.05
8.04
8.03
8.02
7.64
7.62
7.53
7.52
7.51
7.49
7.47
7.44
7.43
7.42
7.42
7.41
7.40
7.39
7.34
7.33
7.32
7.31
7.30
7.29
3.52
3.50
3.48
3.39
3.37
3.36
0.03
2.01
2.97
2.08
1.00
0.99
2.10
1.95
f1 (ppm)

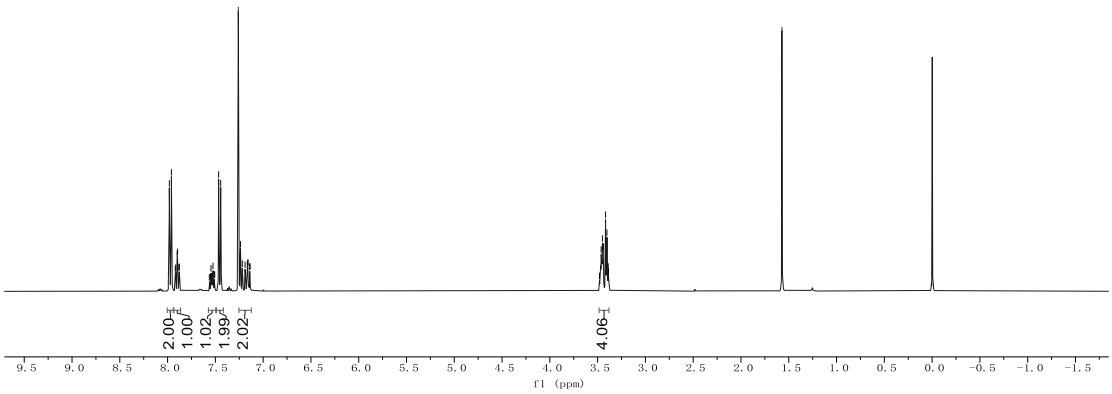

SJY-A179-2-Br.2.fid
202.69
198.25
141.57
136.59
133.65
133.27
131.63
128.93
128.65
128.12
127.52
118.60
77.43 CDCl3
77.11 CDCl3
76.79 CDCl3
36.56
33.00
0.04
f1 (ppm)



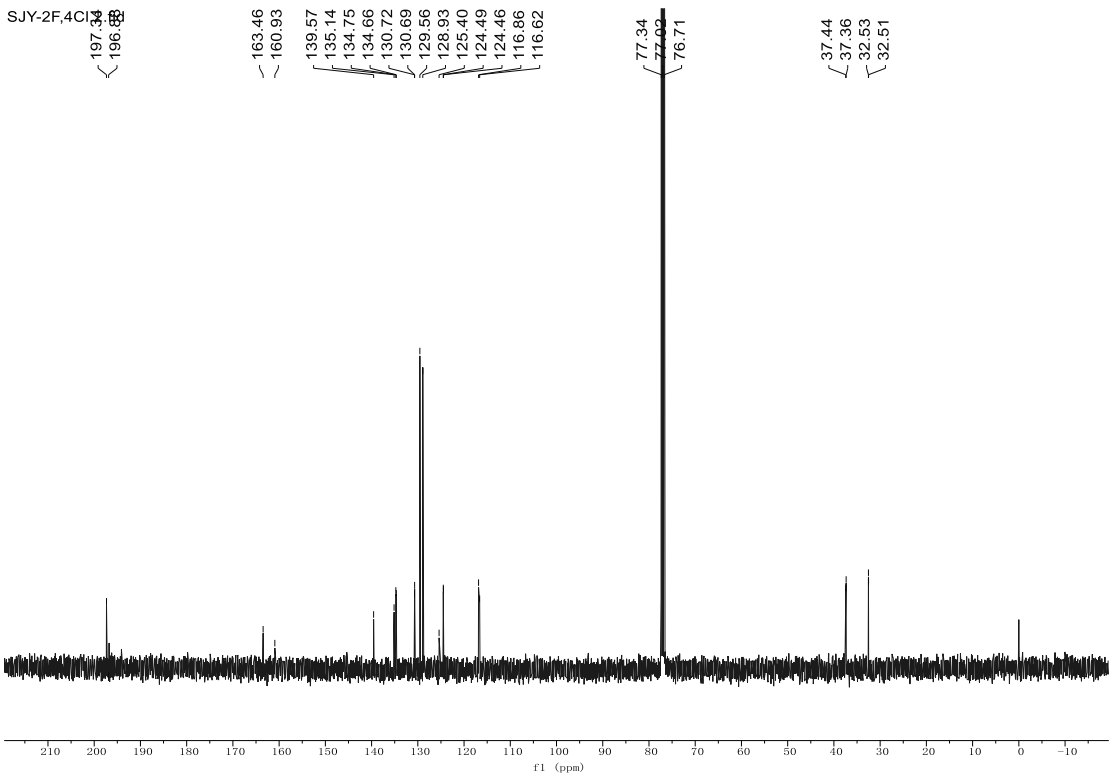
5d

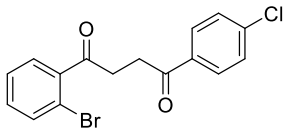
SJY-2F,4Cl.1.fid



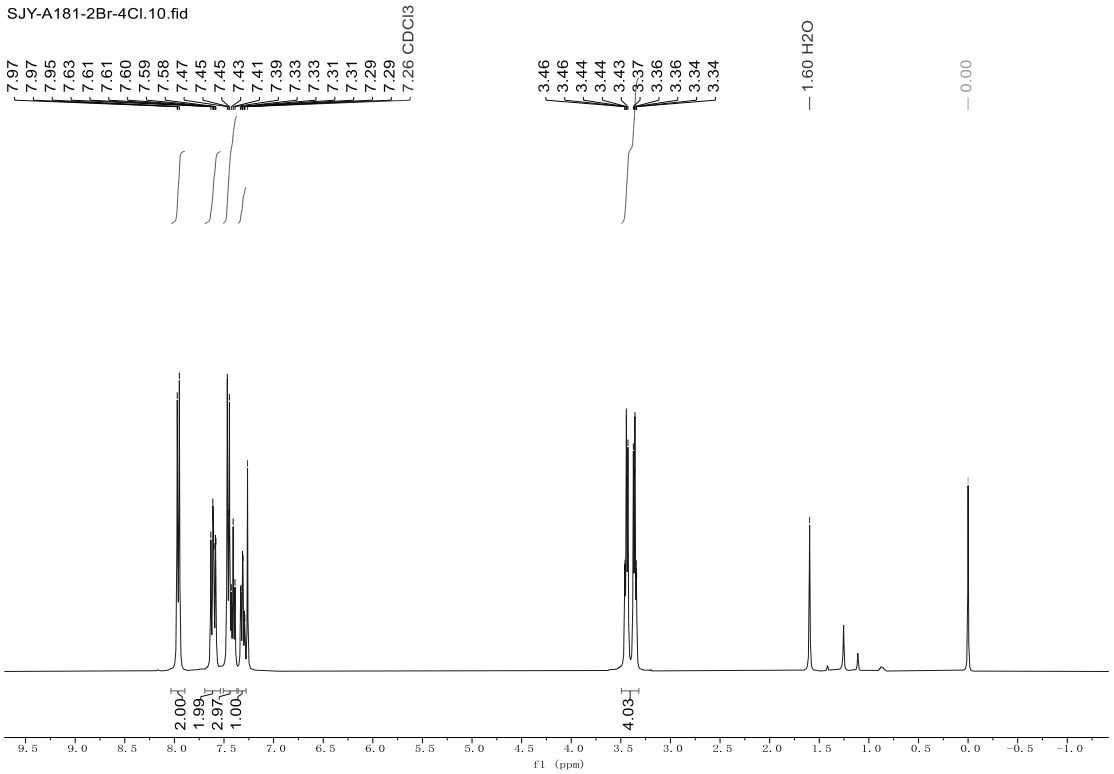


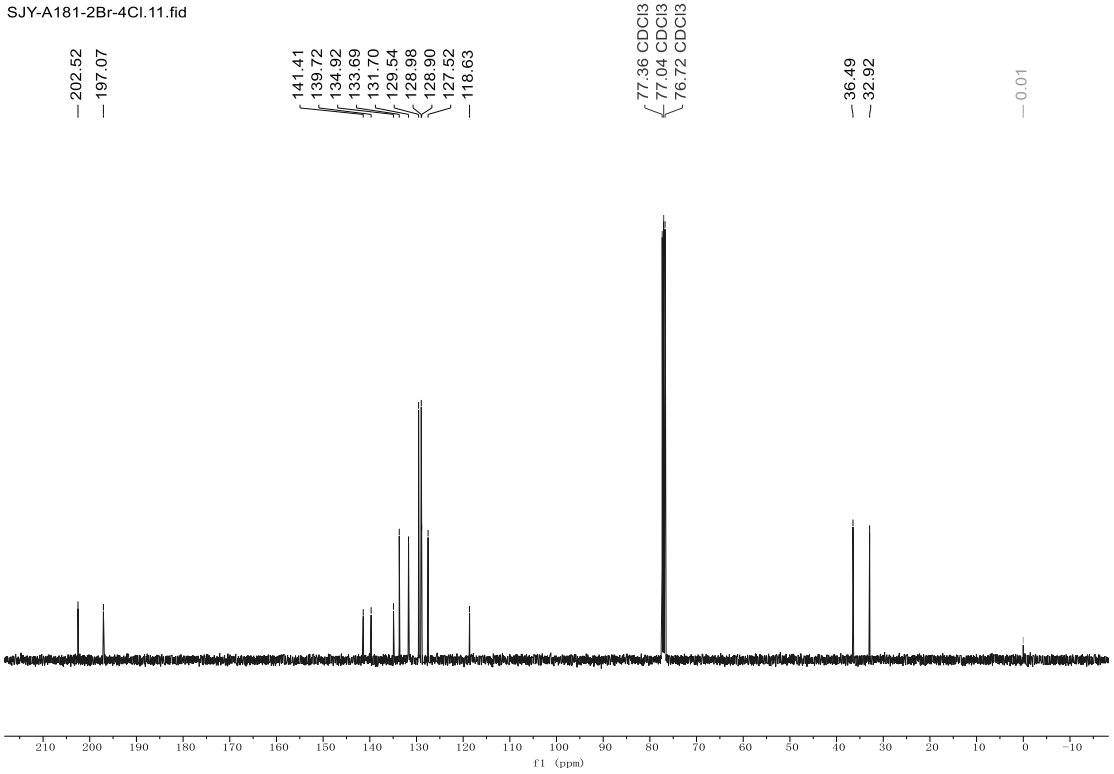
SJY-2F,4Cl.13.fid

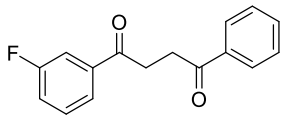



O
Cl
O
Br

5e

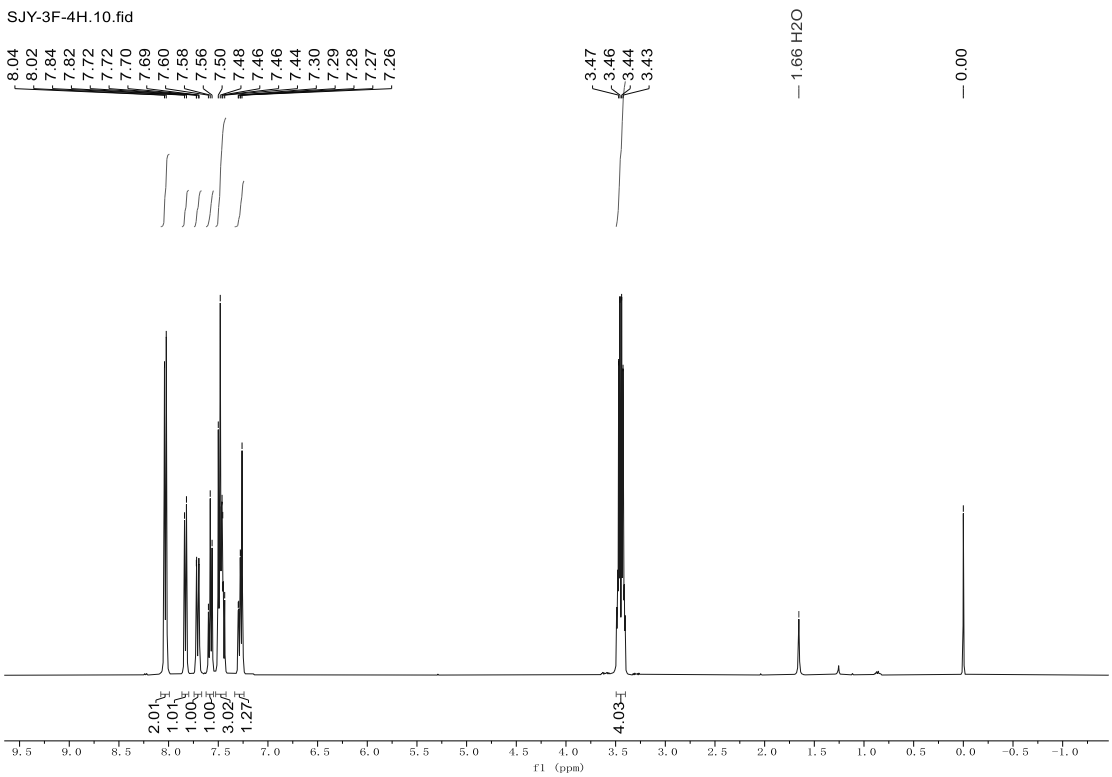

SJY-A181-2Br-4Cl.10.fid
7.97
7.97
7.95
7.63
7.61
7.61
7.60
7.59
7.58
7.47
7.45
7.45
7.43
7.41
7.39
7.33
7.33
7.31
7.31
7.29
7.29
7.26 CDCl3
3.46
3.46
3.44
3.44
3.43
3.37
3.36
3.36
3.34
3.34
1.60 H2O
0.00
2.00
1.99
2.97
1.00
4.03
f1 (ppm)


SJY-A181-2Br-4Cl.11.fid
202.52
197.07
141.41
139.72
134.92
133.69
131.70
129.54
128.98
128.90
127.52
118.63
77.36 CDCl3
77.04 CDCl3
76.72 CDCl3
36.49
32.92
0.01
f1 (ppm)

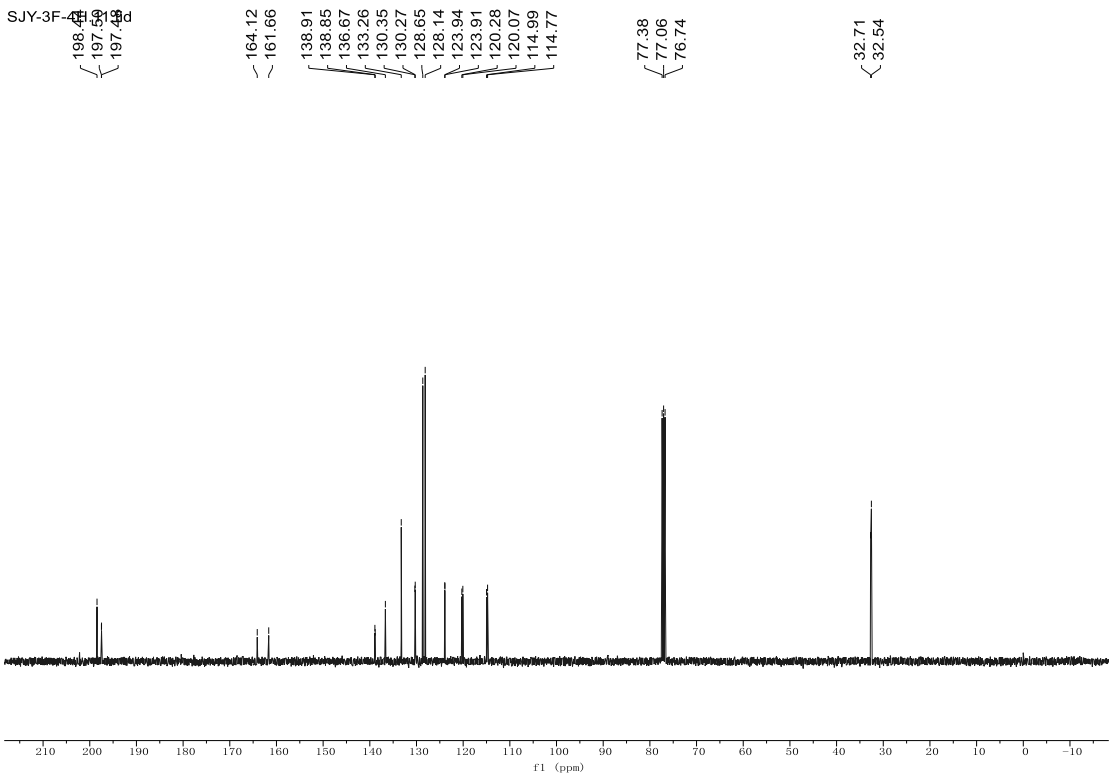


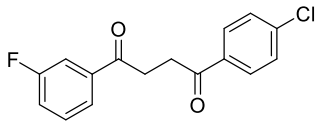
5f

SJY-3F-4H.10.fid

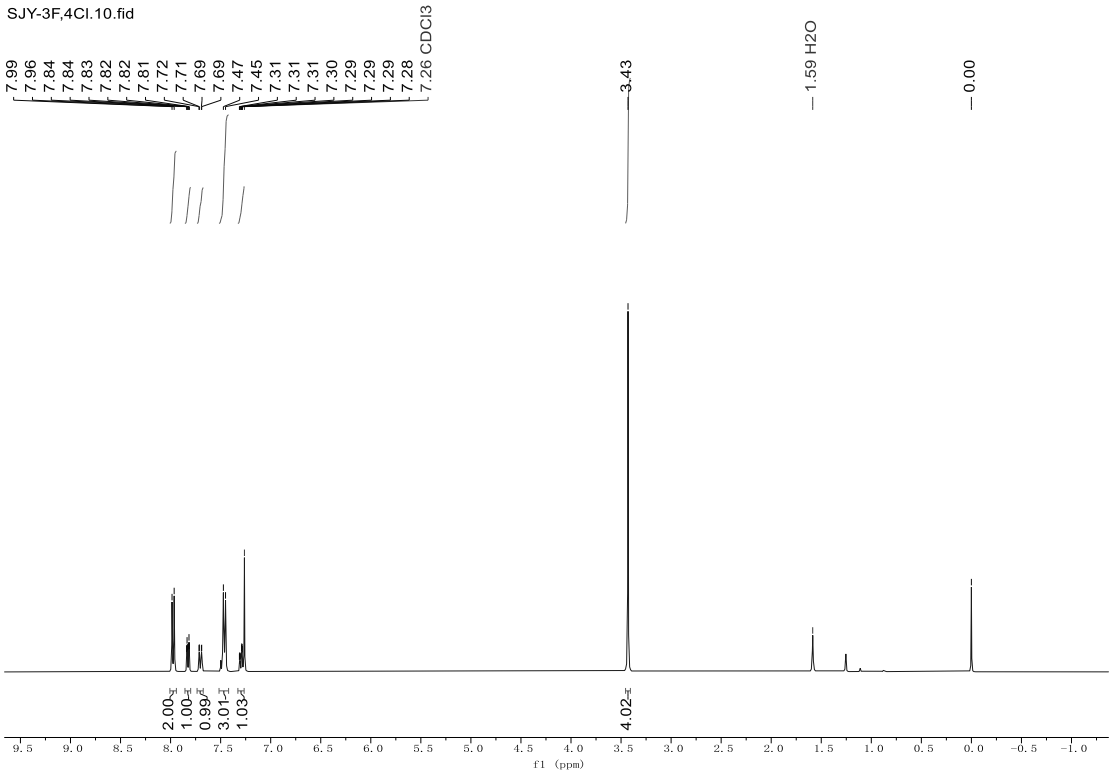


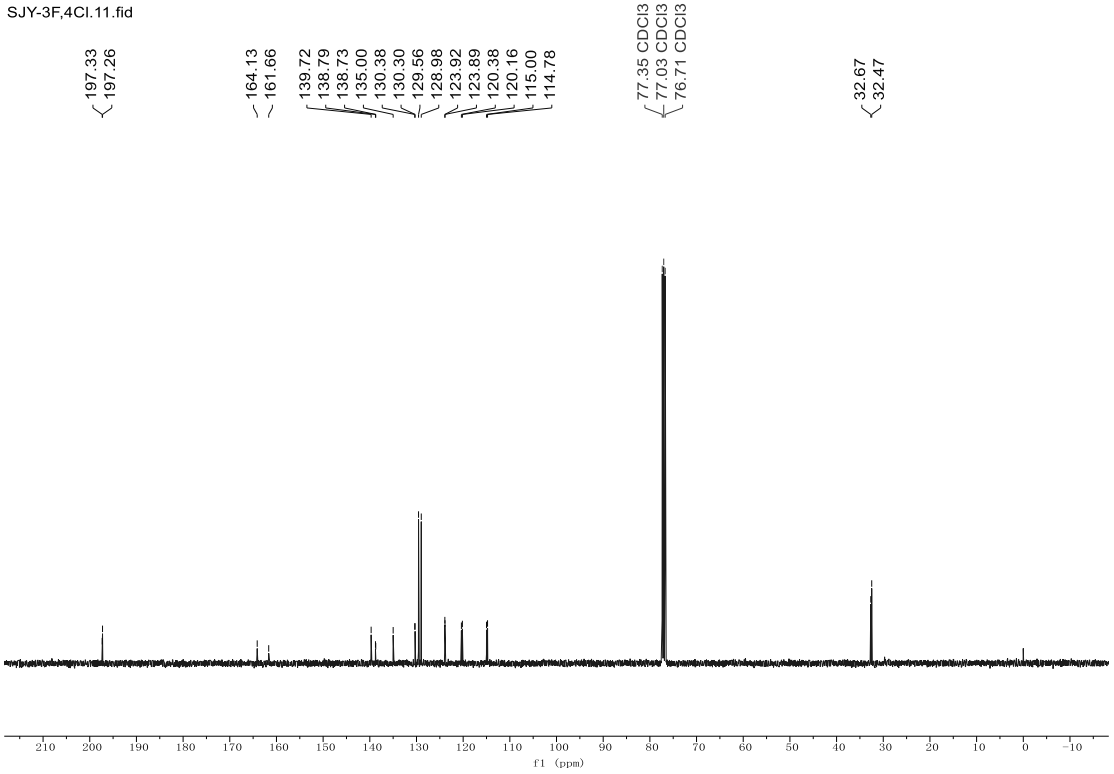
SJY-3F-4[illegible]

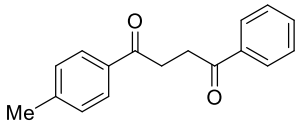



O
Cl
F
O

5g

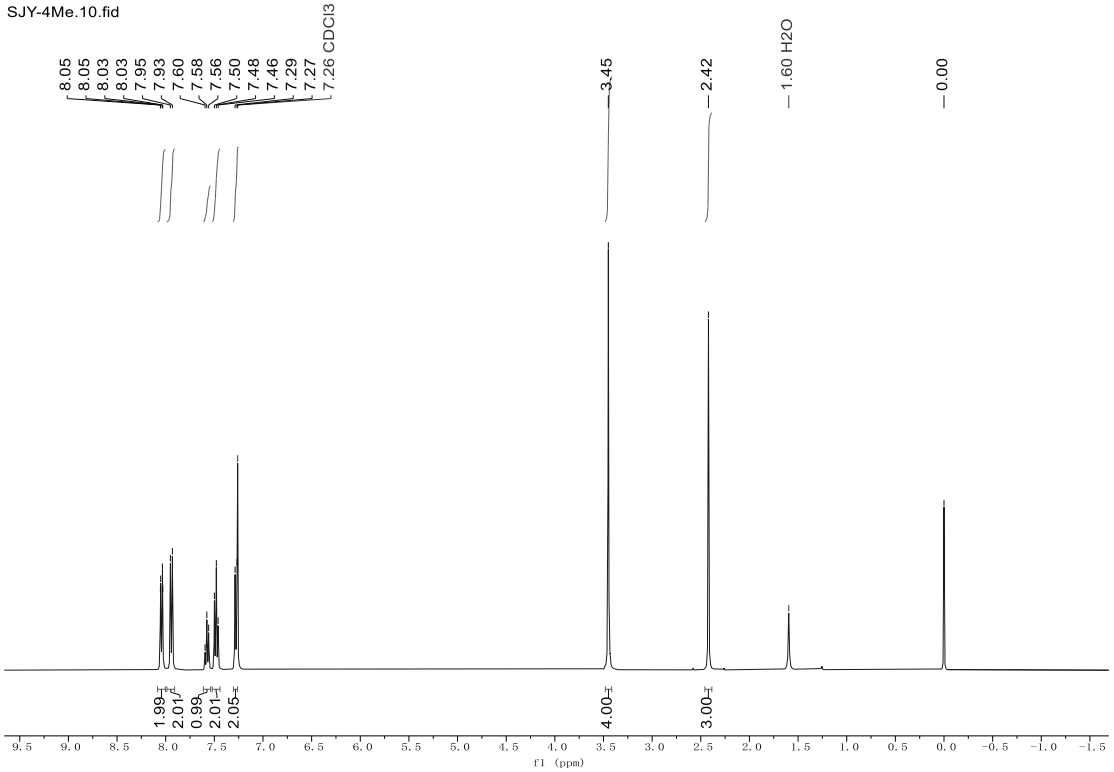

SJY-3F,4Cl.10.fid
7.99
7.96
7.84
7.84
7.83
7.82
7.82
7.81
7.72
7.71
7.69
7.69
7.47
7.45
7.31
7.31
7.30
7.29
7.29
7.28
7.26 CDCl3
3.43
1.59 H2O
0.00
2.00
1.00
0.99
3.01
1.03
4.02
f1 (ppm)


SJY-3F,4Cl.11.fid
197.33
197.26
164.13
161.66
139.72
138.79
138.73
135.00
130.38
130.30
129.56
128.98
123.92
123.89
120.38
120.16
115.00
114.78
77.35 CDCl3
77.03 CDCl3
76.71 CDCl3
32.67
32.47
f1 (ppm)

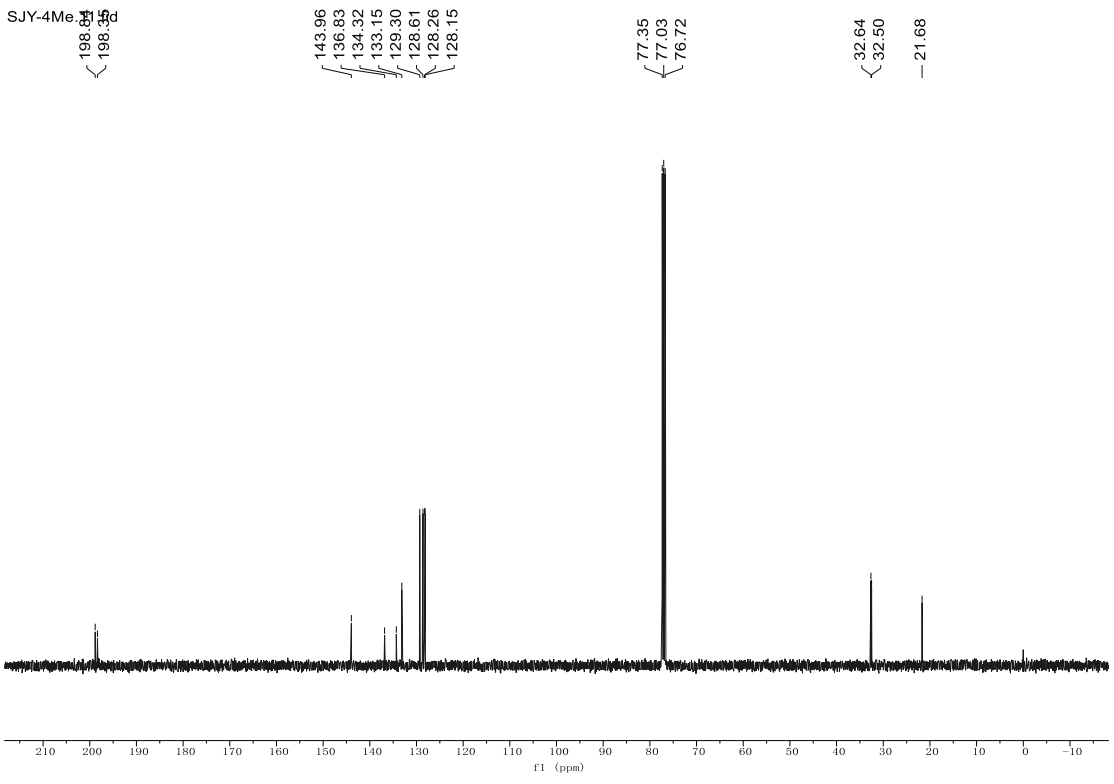


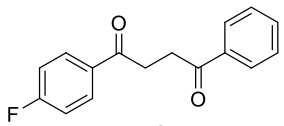
5h

SJY-4Me.10.fid

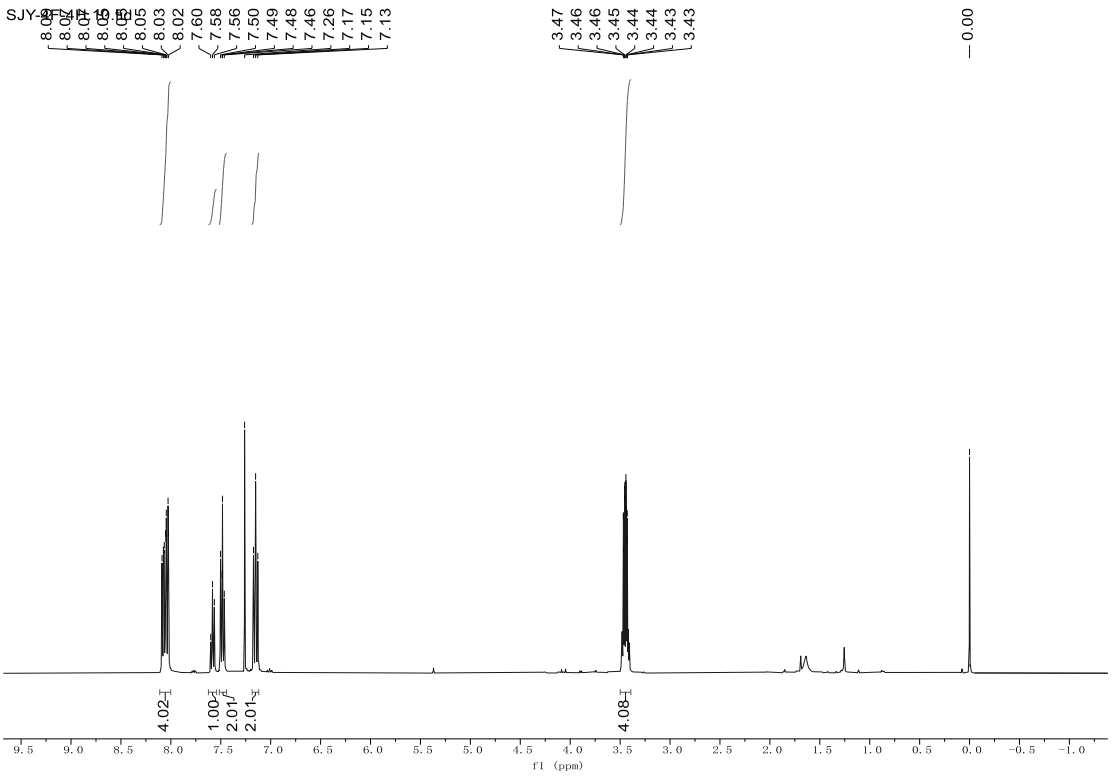


SJY-4Me.13.fid




O
O
F

5i


8.07
8.04
8.03
8.02
7.60
7.58
7.56
7.50
7.49
7.48
7.46
7.26
7.17
7.15
7.13
3.47
3.46
3.46
3.45
3.44
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3.43
3.43
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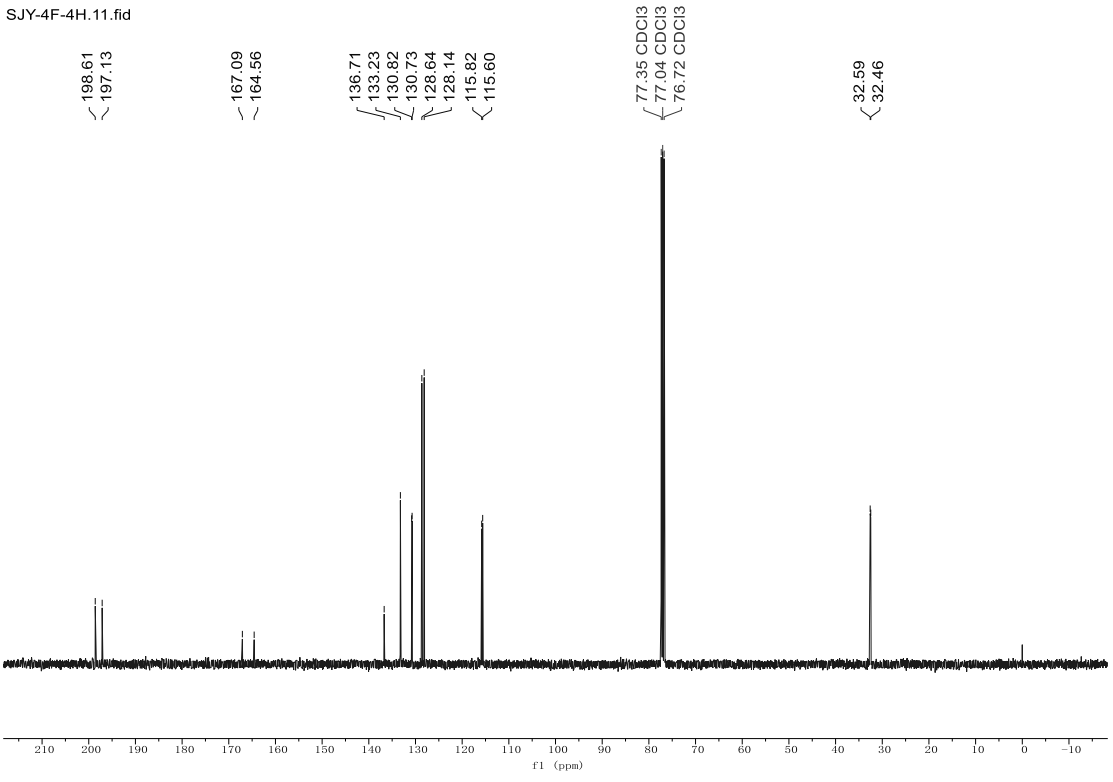
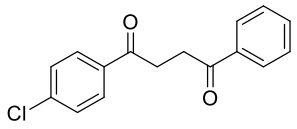
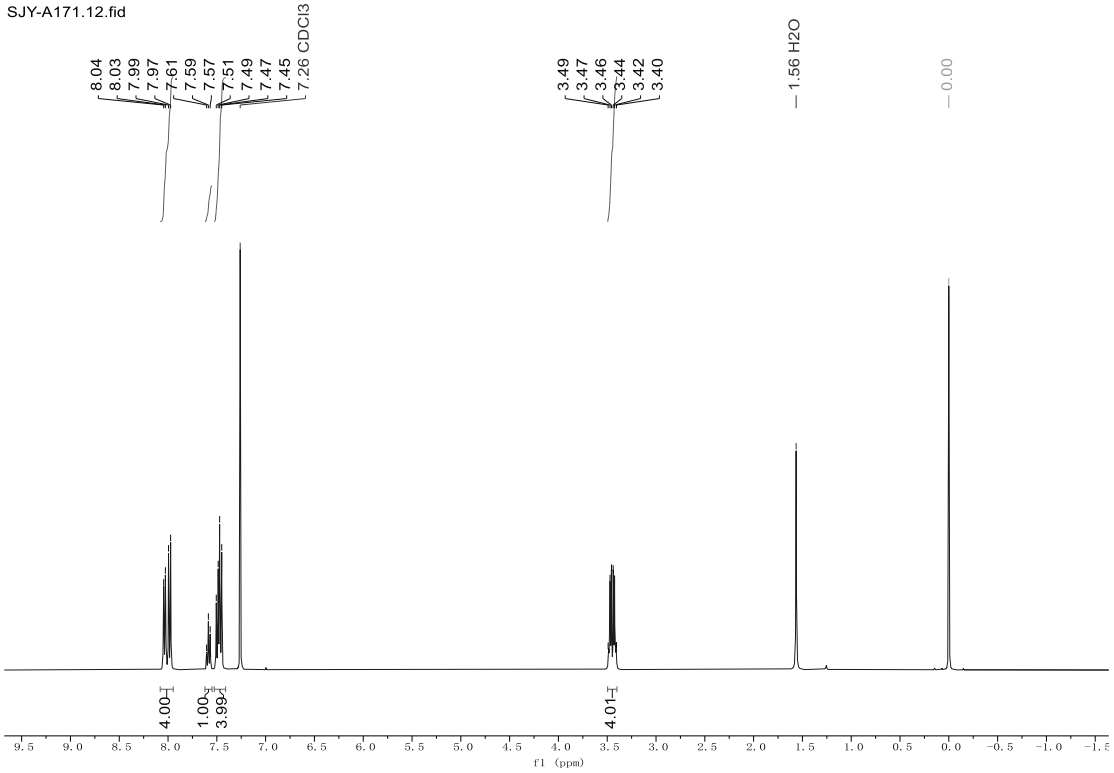
4.02
1.00
2.01
2.01
4.08
f1 (ppm)


SJY-4F-4H.11.fid
198.61
197.13
167.09
164.56
136.71
133.23
130.82
130.73
128.64
128.14
115.82
115.60
77.35 CDCl3
77.04 CDCl3
76.72 CDCl3
32.59
32.46
f1 (ppm)

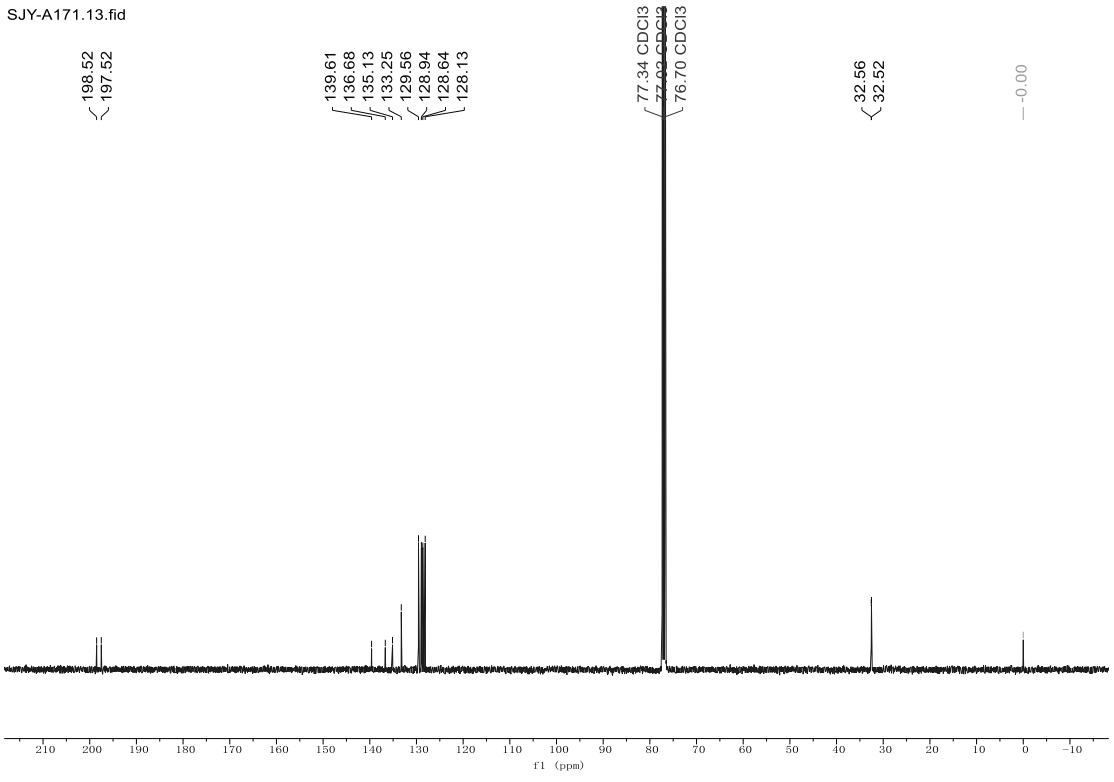


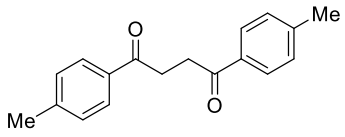
5j

SJY-A171.12.fid

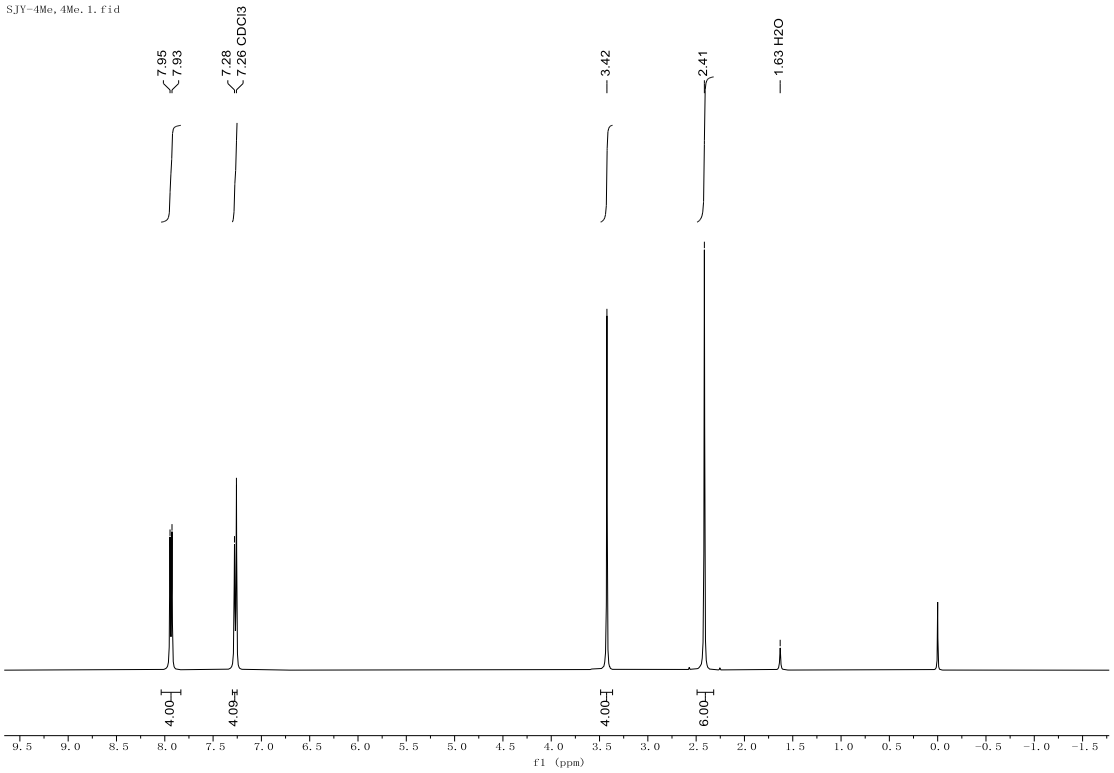


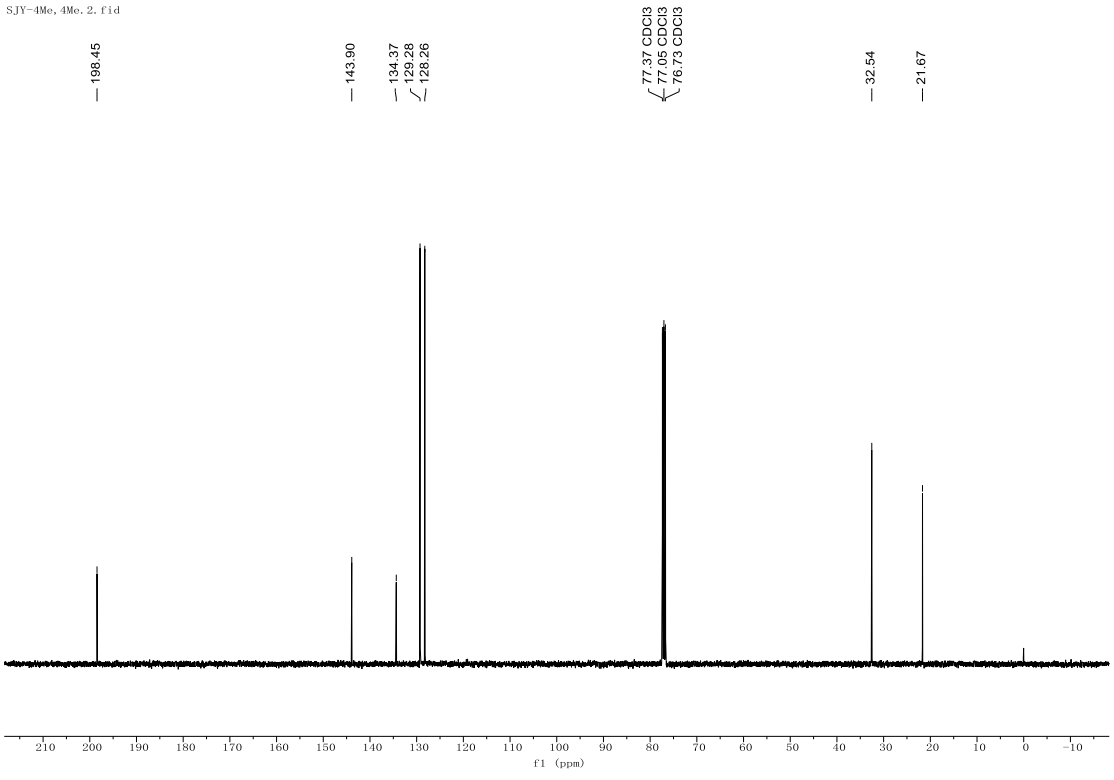
SJY-A171.13.fid

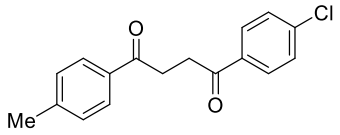



O
O
Me
Me

5k

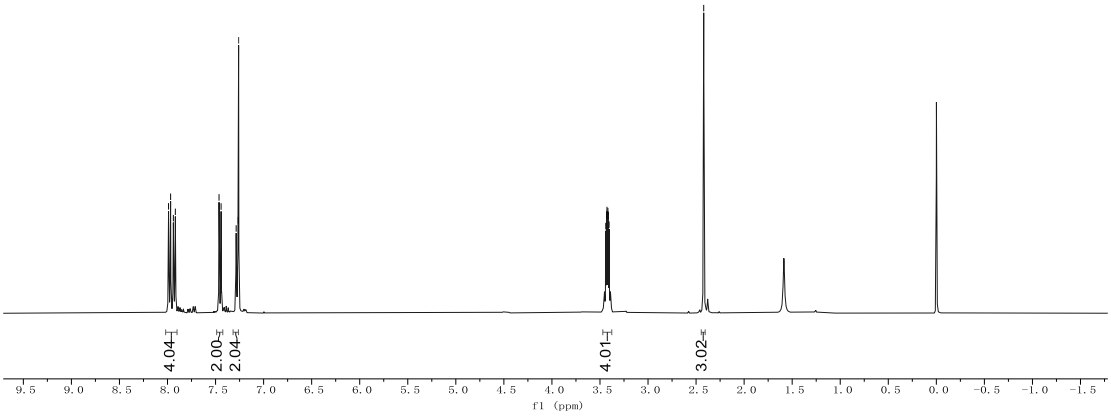

SJY-4Me,4Me.1.fid
7.95
7.93
7.28
7.26 CDCl3
3.42
2.41
1.63 H2O
4.00
4.09
4.00
6.00
f1 (ppm)


SJY-4Me,4Me.2.fid
198.45
143.90
134.37
129.28
128.26
77.37 CDCl3
77.05 CDCl3
76.73 CDCl3
32.54
21.67
f1 (ppm)

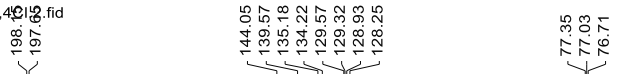


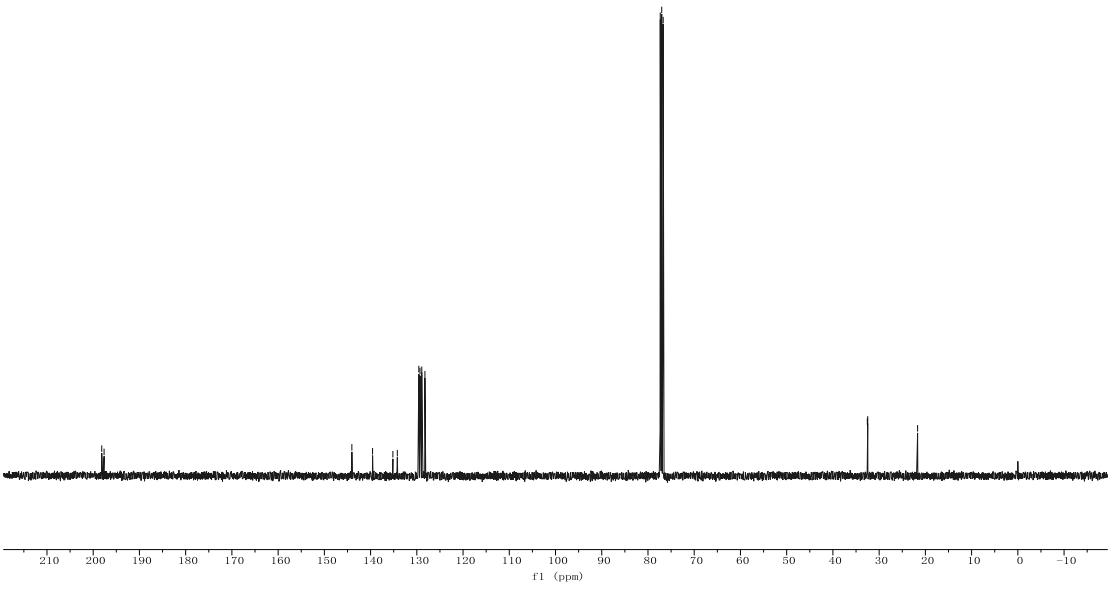
5l

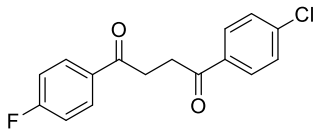
SJY-4Me,4Cl.1.fid



SJY-4Me,4Cl.5.fid

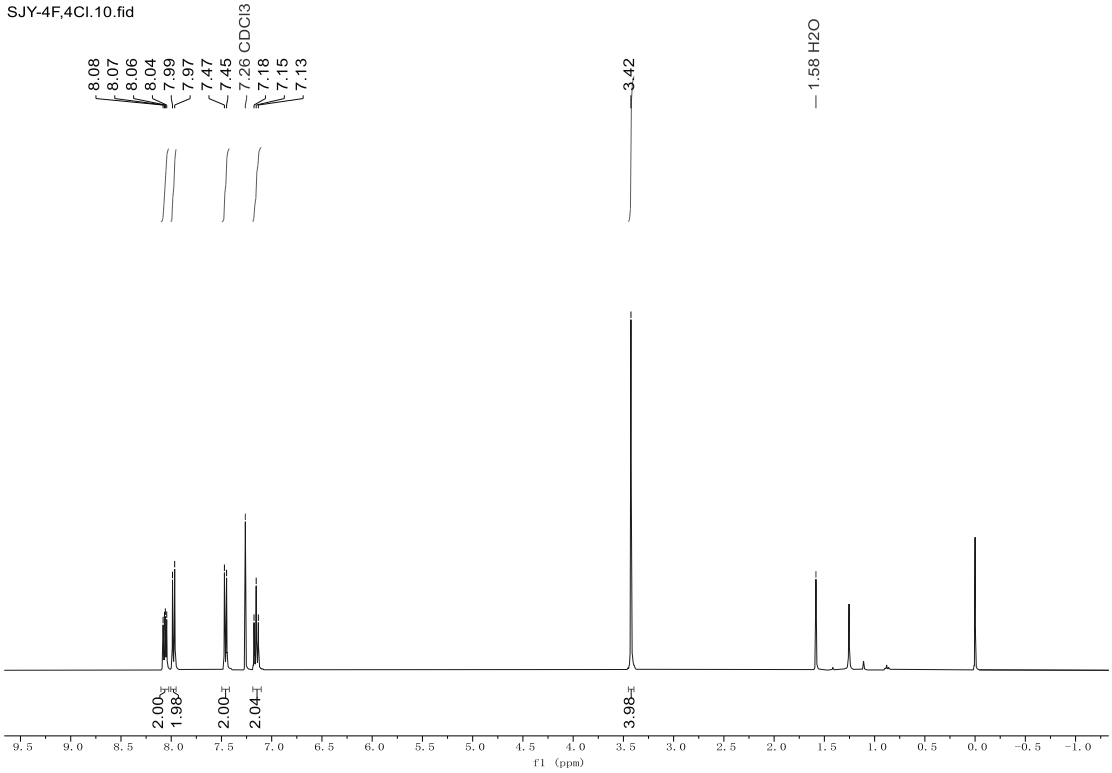




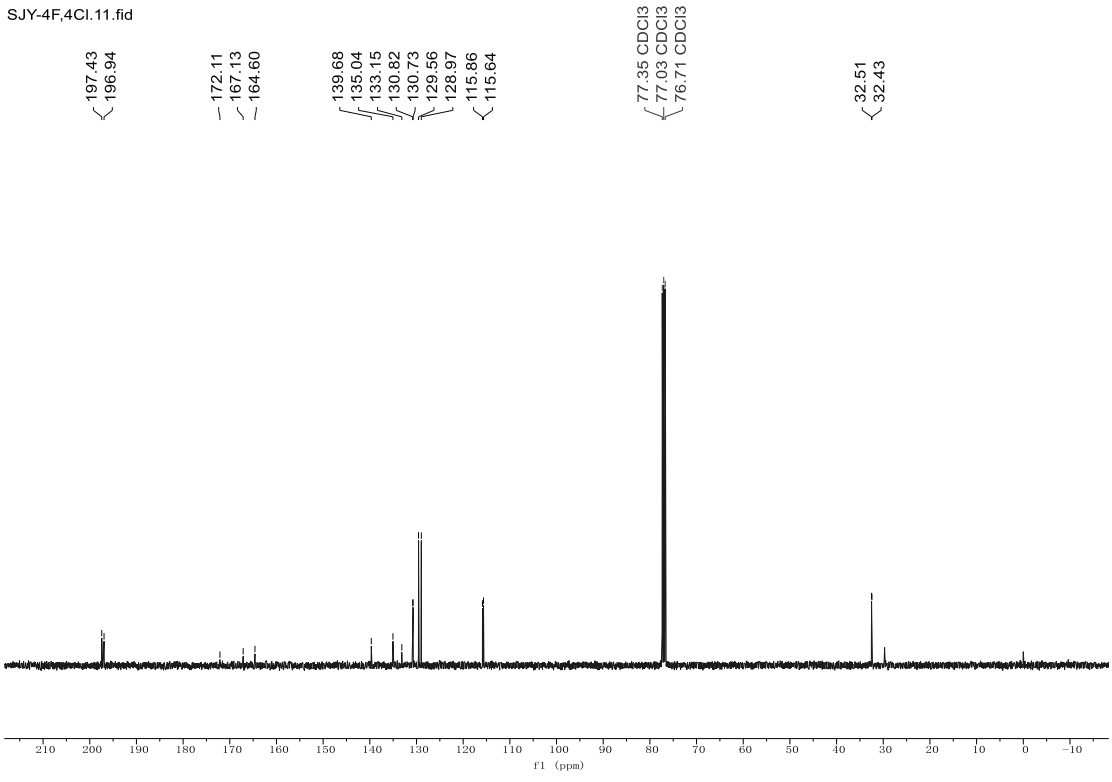


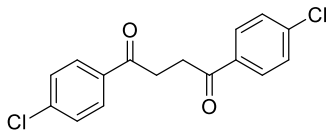
5m

SJY-4F,4Cl.10.fid

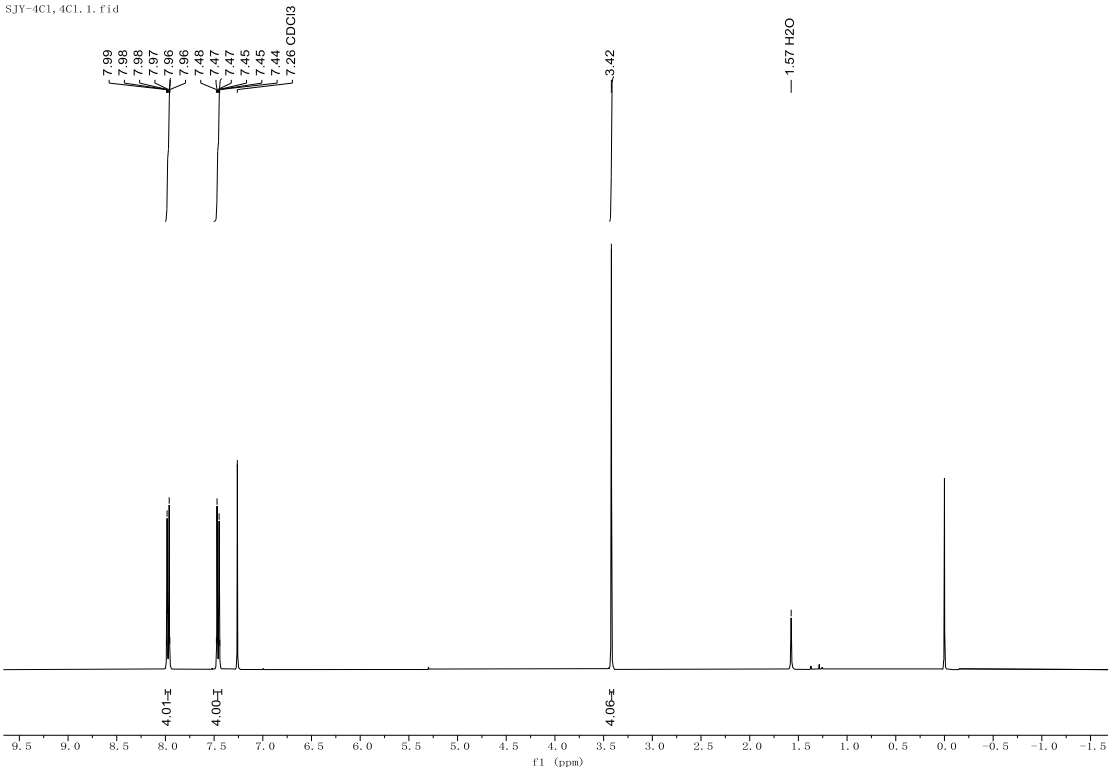


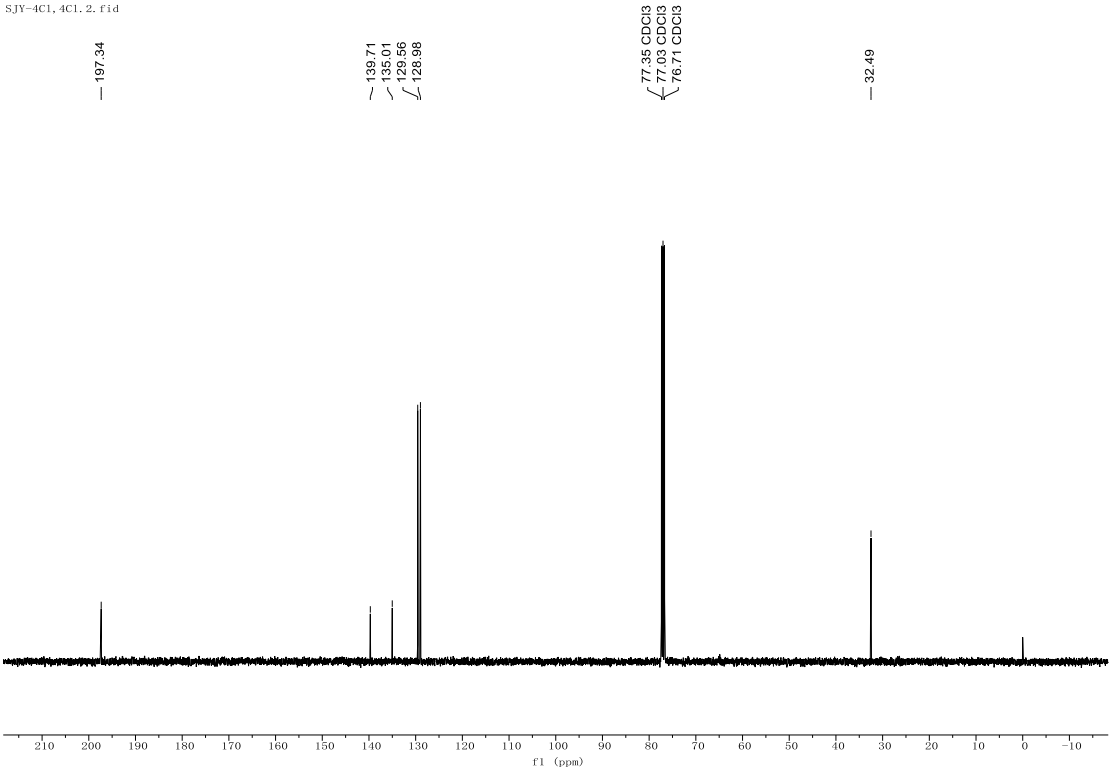
SJY-4F,4Cl.11.fid

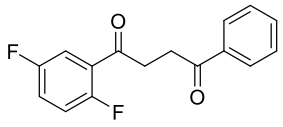



O
O
Cl
Cl

5n

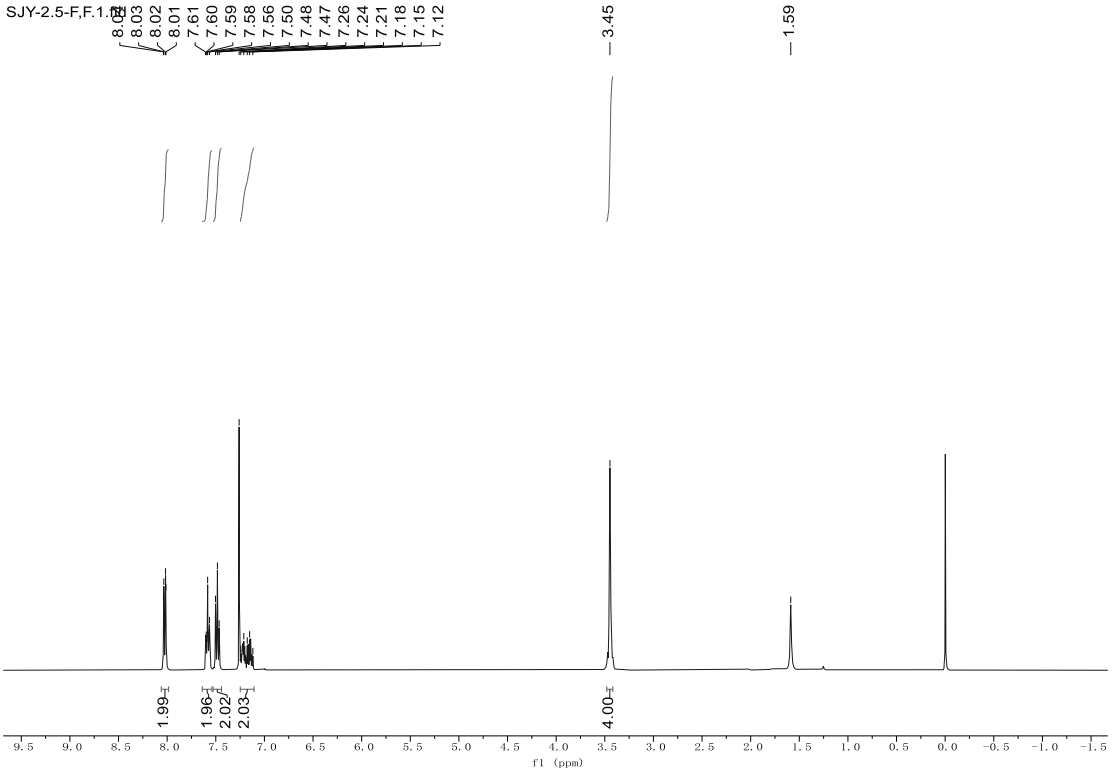

SJY-4Cl, 4Cl. 1. fid
7.99
7.98
7.98
7.97
7.96
7.96
7.48
7.47
7.47
7.45
7.45
7.44
7.26 CDCl3
3.42
1.57 H2O
4.01
4.00
4.06
f1 (ppm)


SJY-4Cl, 4Cl. 2. fid
197.34
139.71
135.01
129.56
128.98
77.35 CDCl3
77.03 CDCl3
76.71 CDCl3
32.49
f1 (ppm)

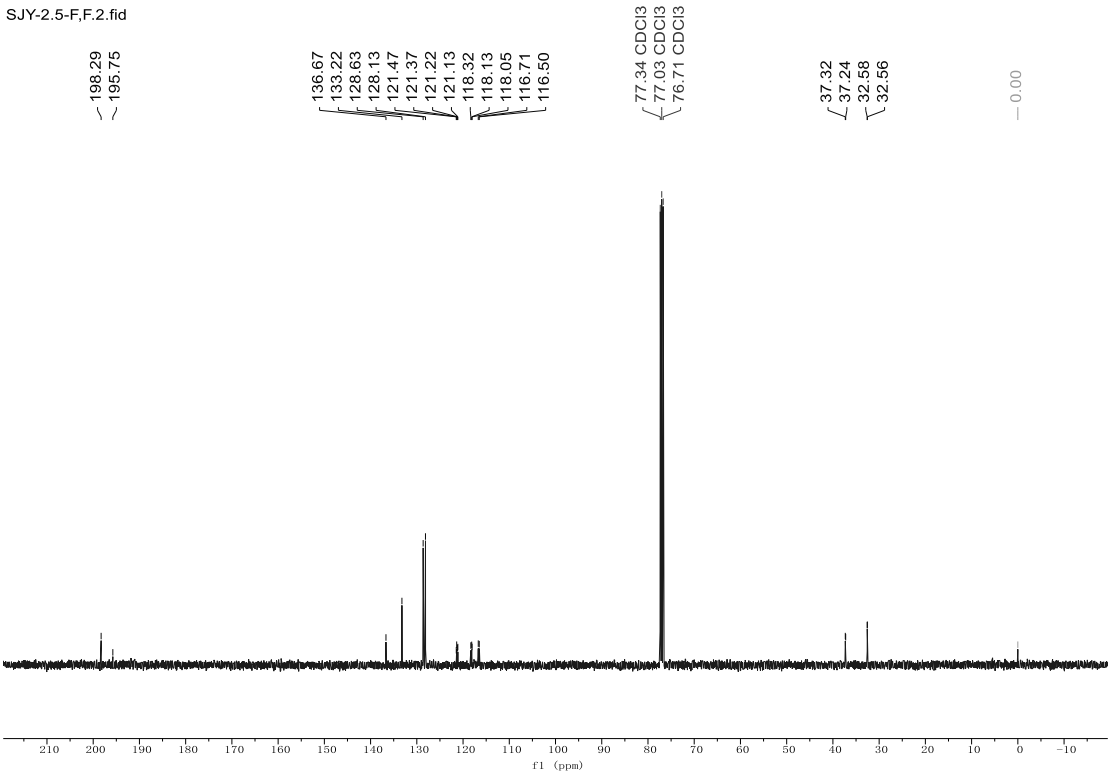


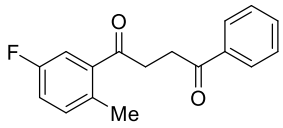
5o

SJY-2.5-F,F.1.fid



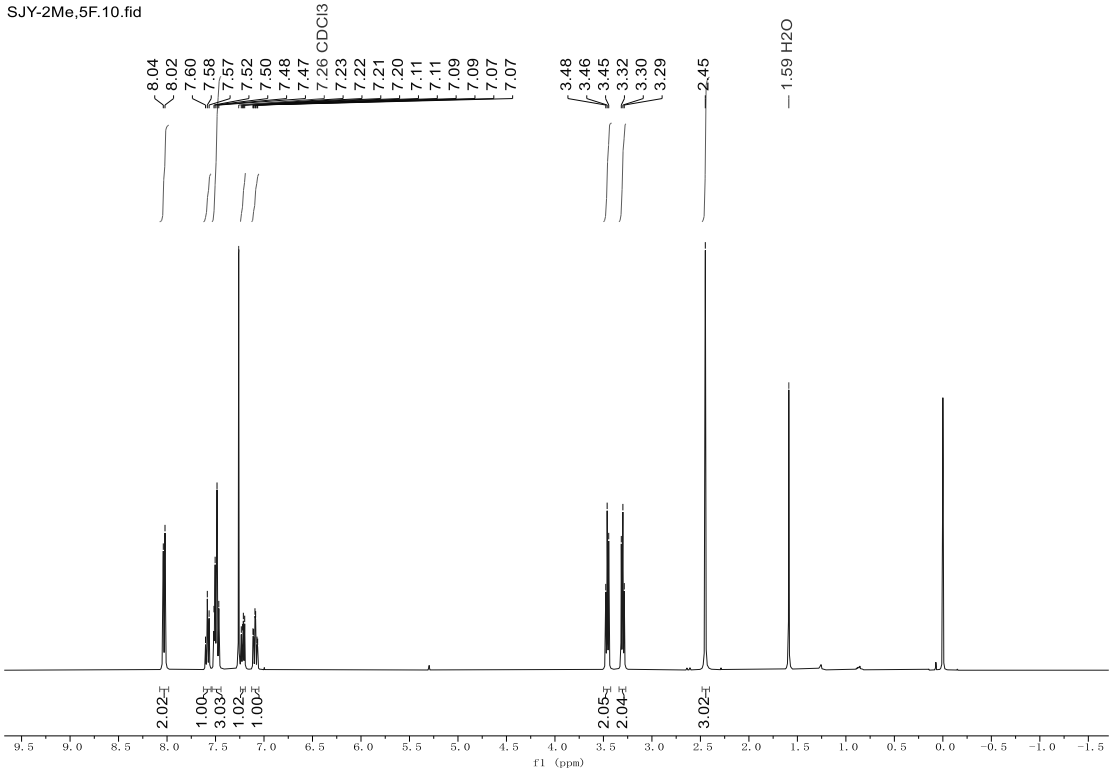
SJY-2.5-F,F.2.fid



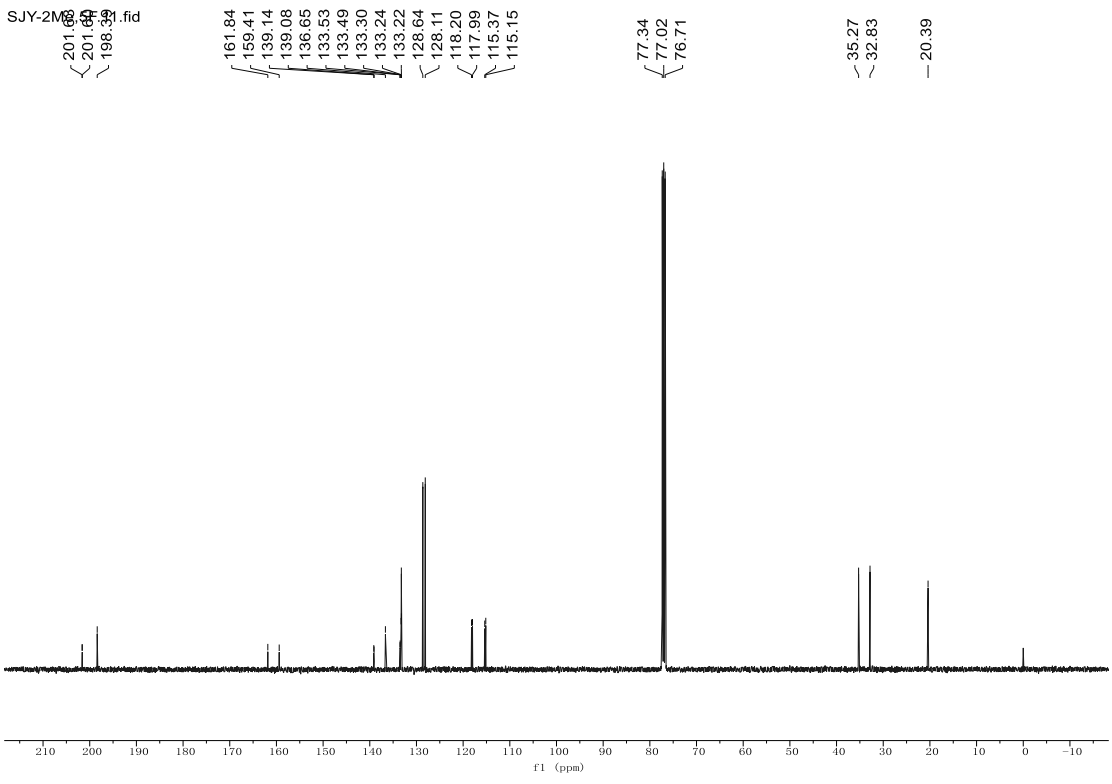


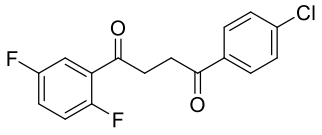
5p

SJY-2Me,5F.10.fid

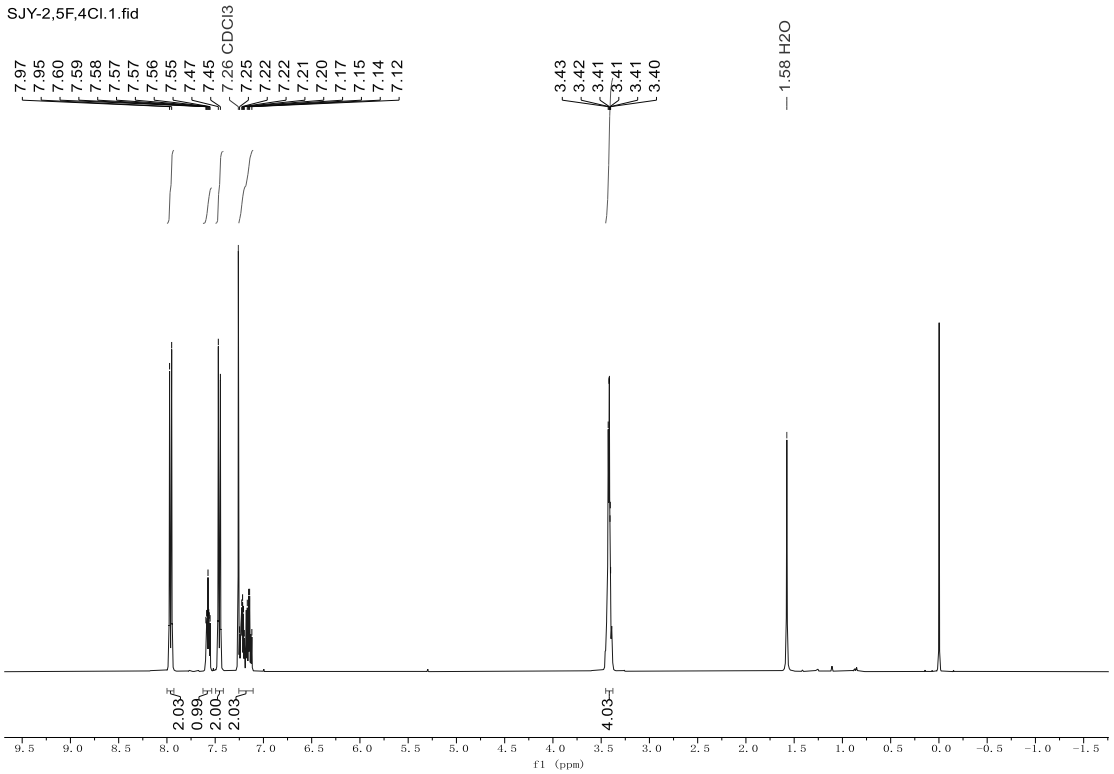


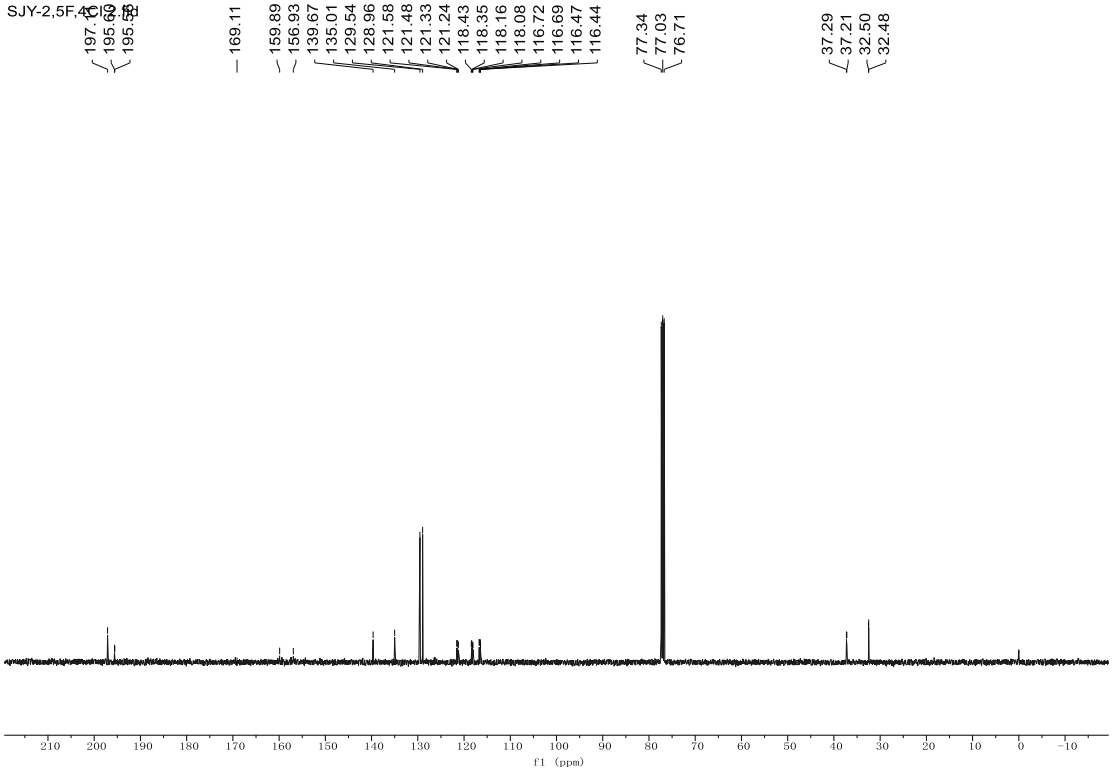
SJY-2Me,5F.11.fid

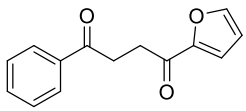



O
Cl
F
O
F

5q

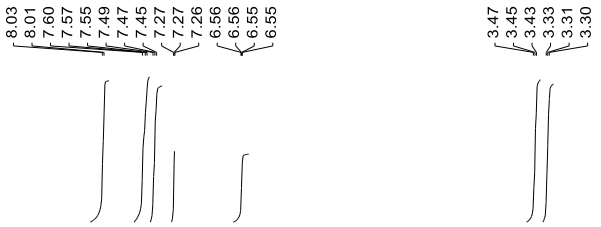

SJY-2,5F,4Cl.1.fid
7.97
7.95
7.60
7.59
7.58
7.57
7.57
7.56
7.55
7.47
7.45
7.26 CDCl3
7.25
7.22
7.22
7.21
7.20
7.17
7.15
7.14
7.12
3.43
3.42
3.41
3.41
3.41
3.40
1.58 H2O
2.03
0.99
2.00
2.03
4.03
f1 (ppm)

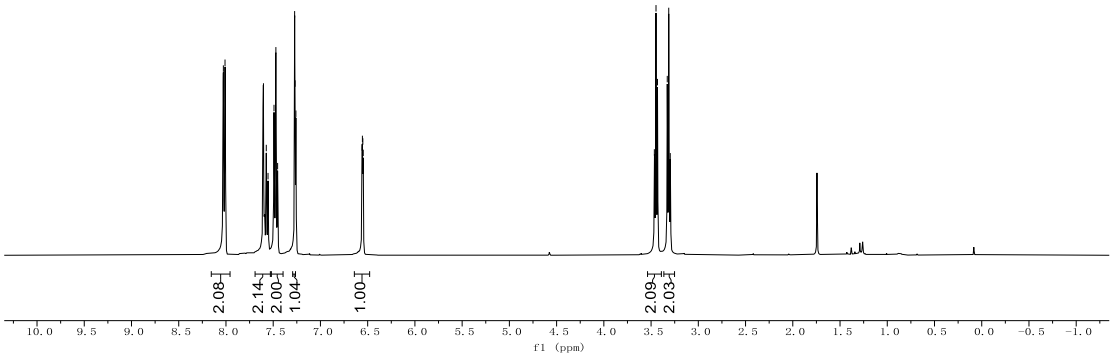

SJY-2,5F,4Cl.2.fid
197.42
195.62
195.38
169.11
159.89
156.93
139.67
135.01
129.54
128.96
121.58
121.48
121.33
121.24
118.43
118.35
118.16
118.08
116.72
116.69
116.47
116.44
77.34
77.03
76.71
37.29
37.21
32.50
32.48
f1 (ppm)



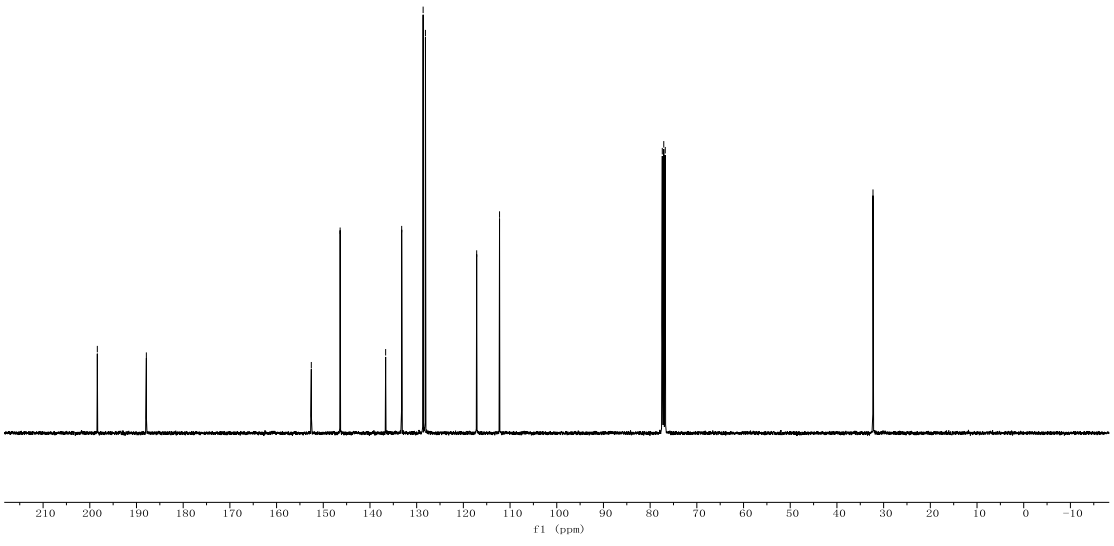
5t

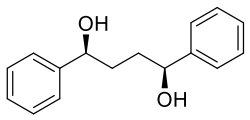
SJY-238.1.fid





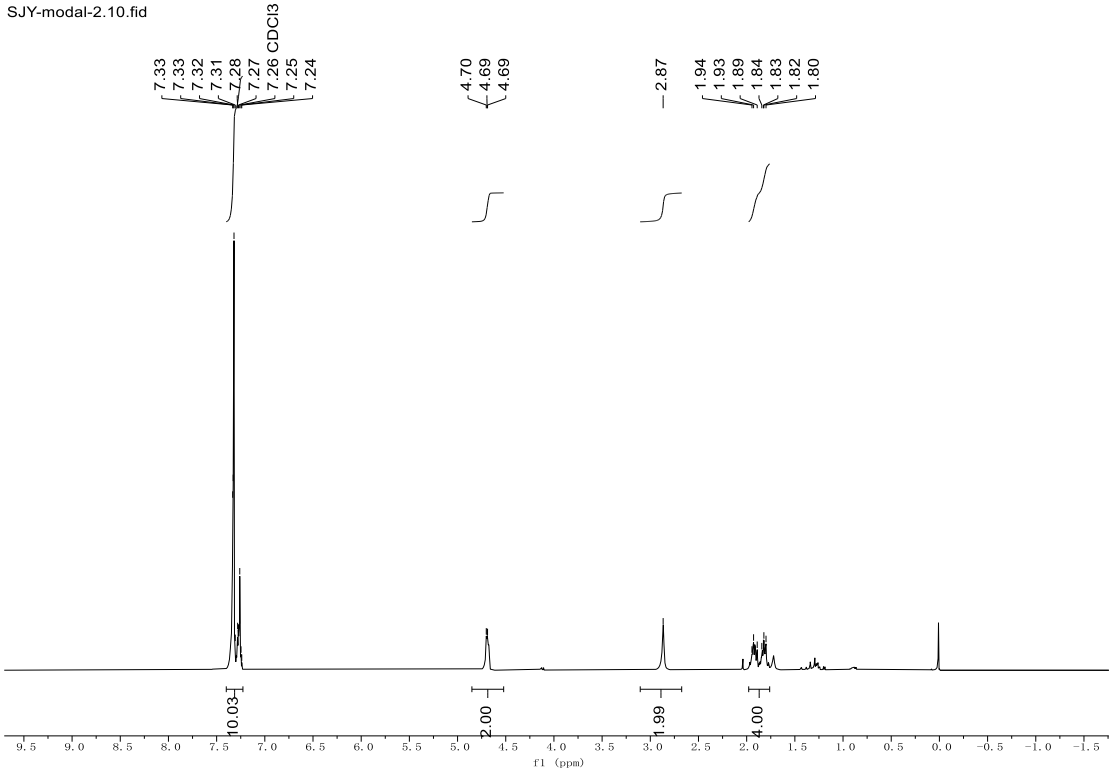
SJY-238.2.fid



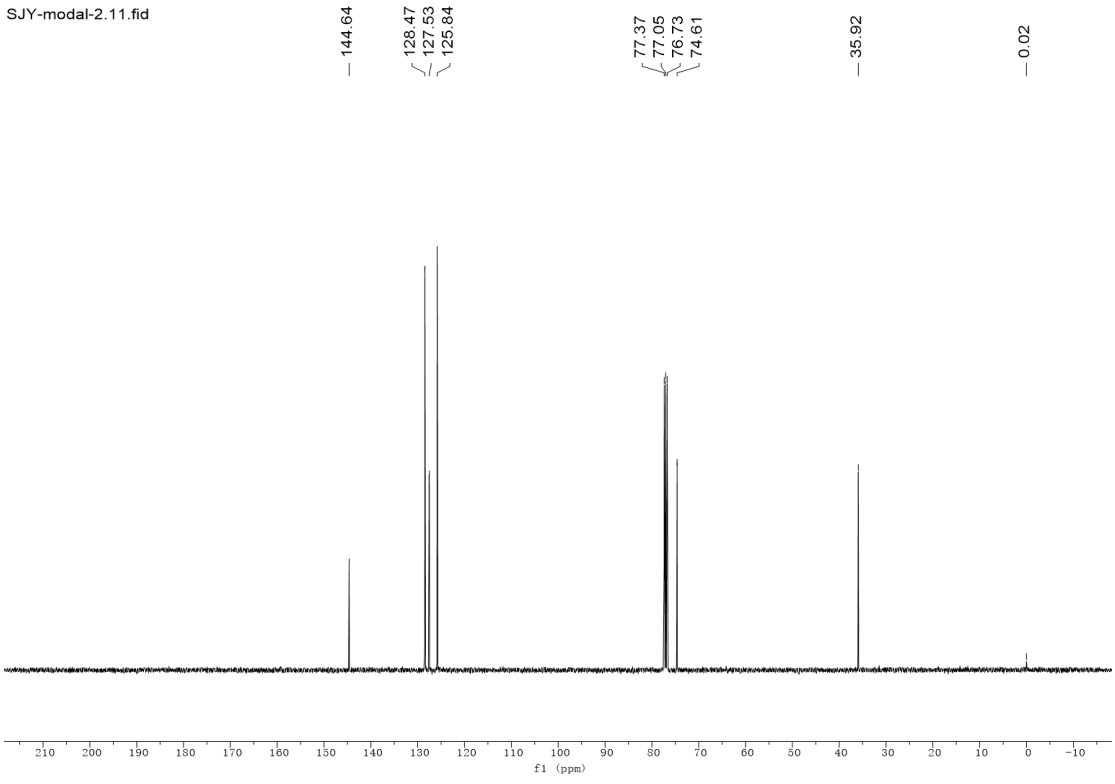


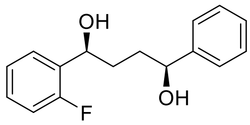
6a

SJY-modal-2.10.fid

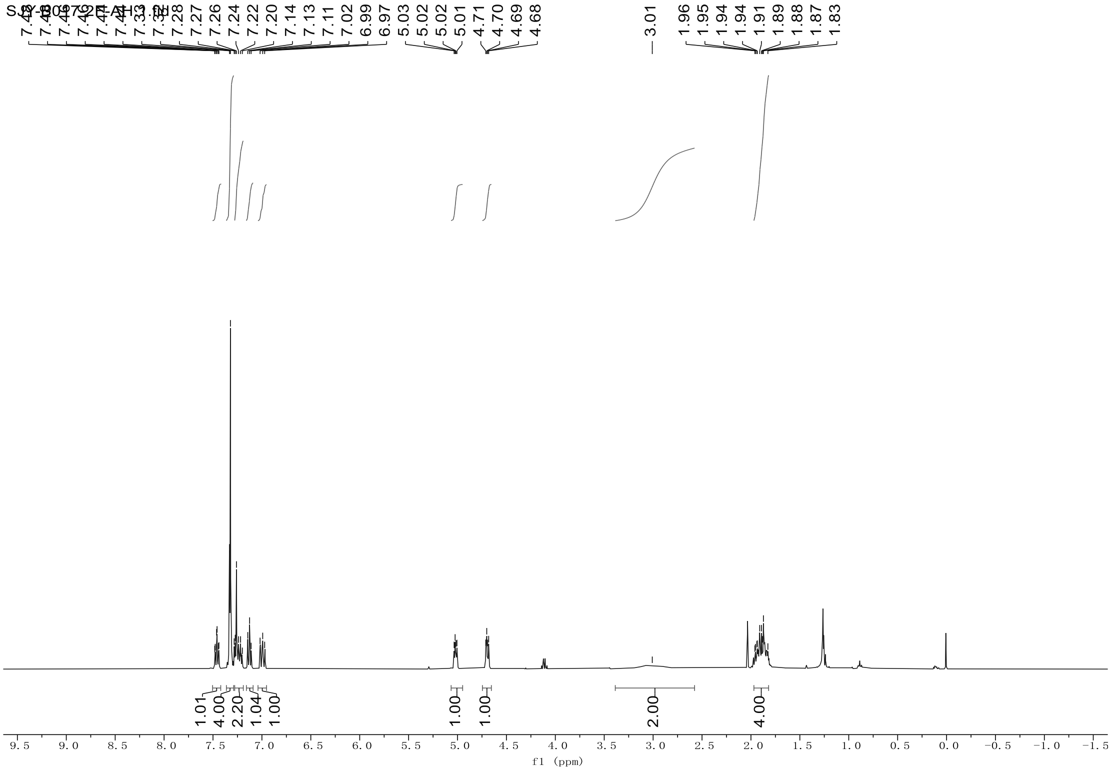


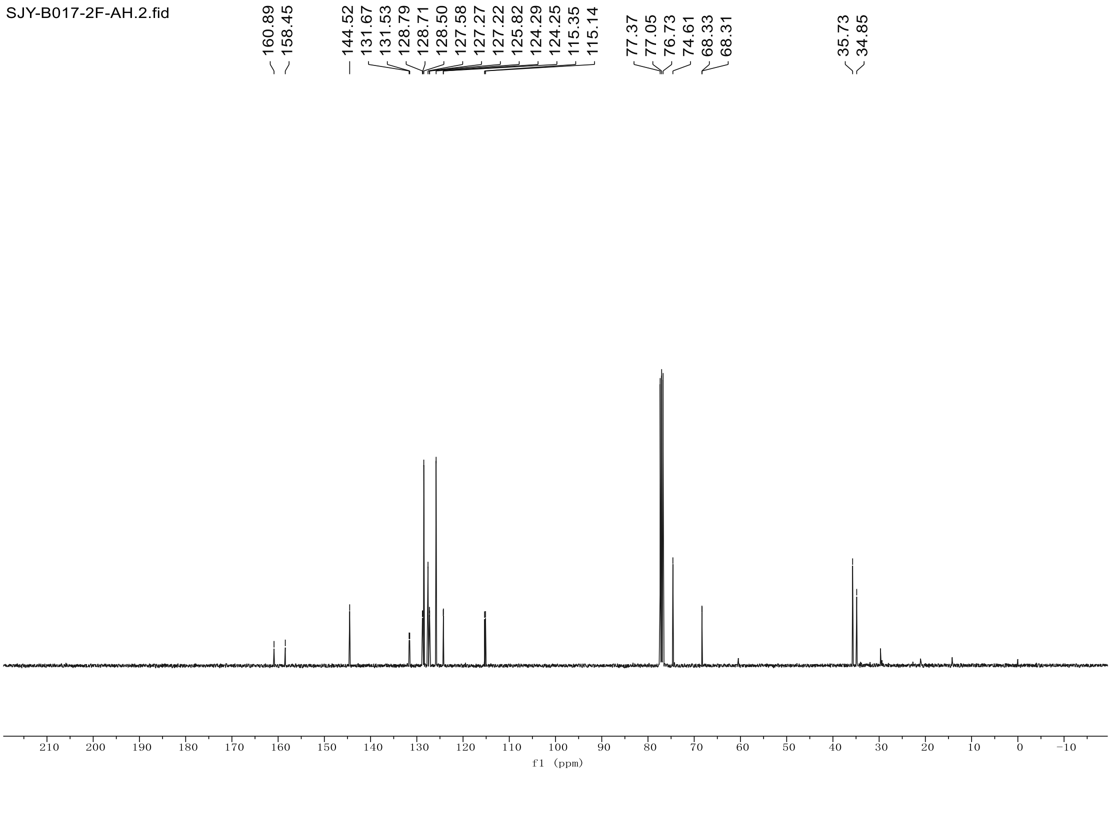
SJY-modal-2.11.fid

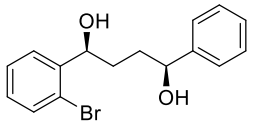



OH
F
OH

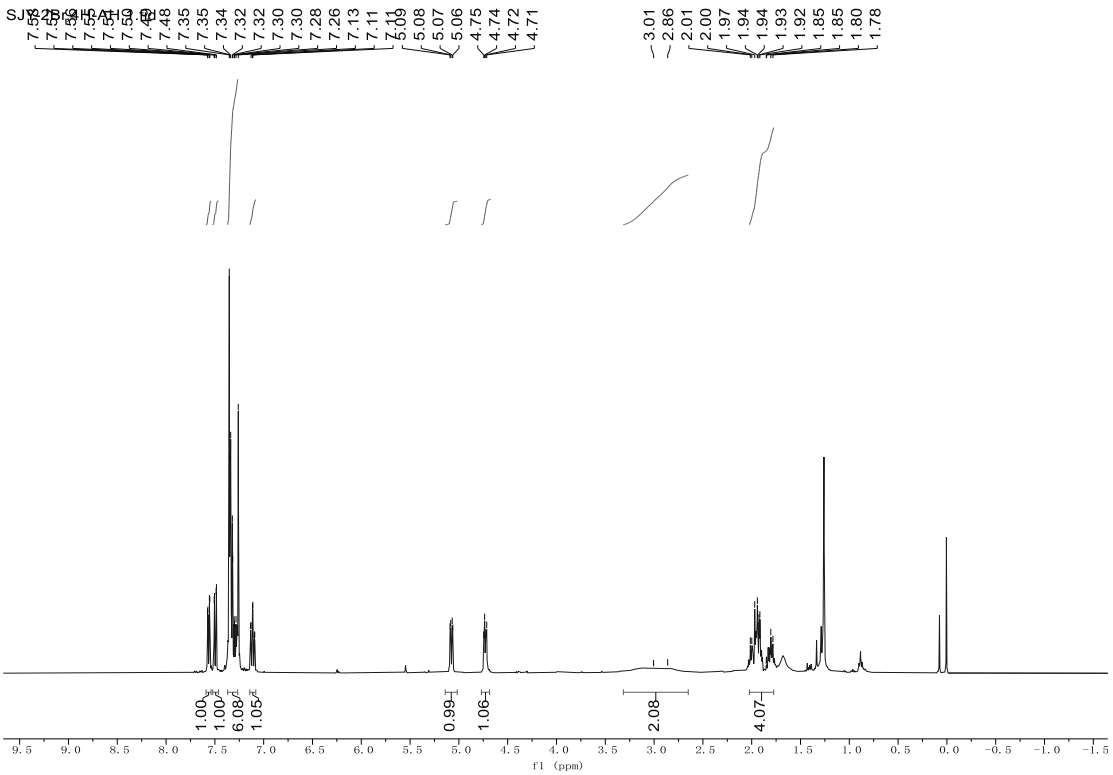
6b


7.4 7.42 7.41 7.41 7.33 7.32 7.28 7.27 7.26 7.24 7.22 7.20 7.14 7.13 7.11 7.02 6.99 6.97 5.03 5.02 5.02 5.01 4.71 4.70 4.69 4.68
3.01
1.96 1.95 1.94 1.94 1.91 1.89 1.88 1.87 1.83
1.01 4.00 2.20 1.04 1.00
1.00
1.00
2.00
4.00
f1 (ppm)

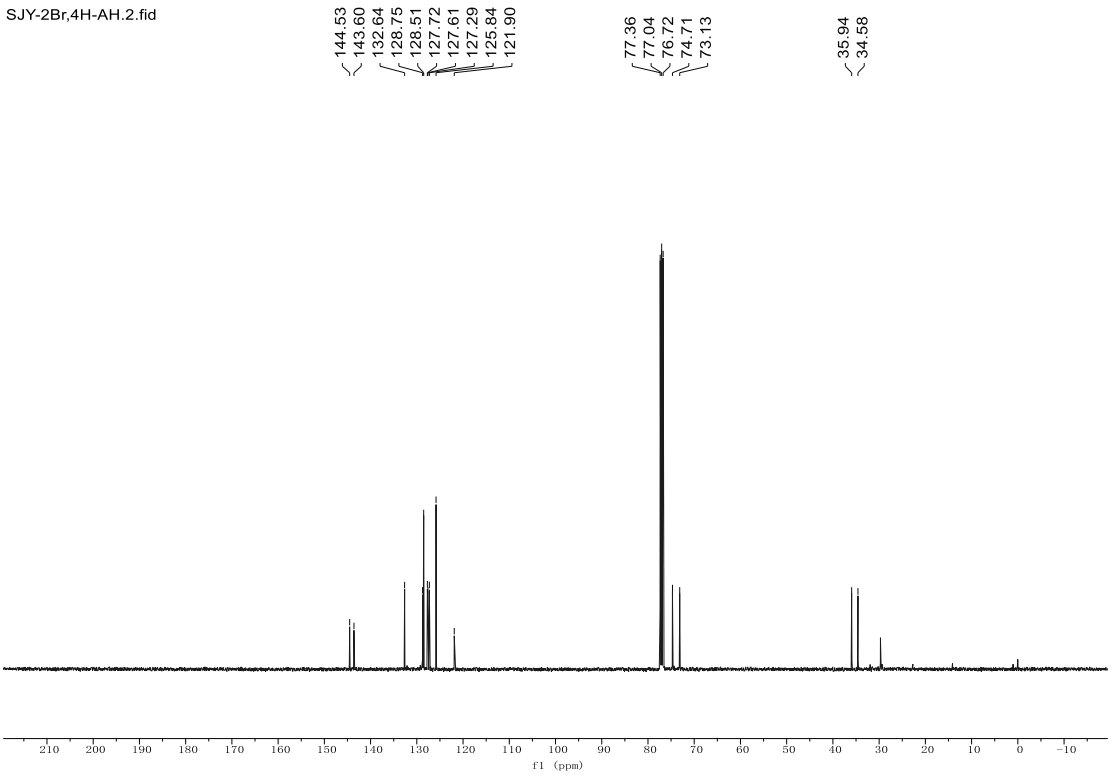

SJY-B017-2F-AH.2.fid
160.89 158.45
144.52 131.67 131.53 128.79 128.71 128.50 127.58 127.27 127.22 125.82 124.29 124.25 115.35 115.14
77.37 77.05 76.73 74.61 68.33 68.31
35.73 34.85
f1 (ppm)

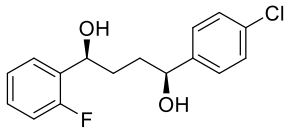


6c

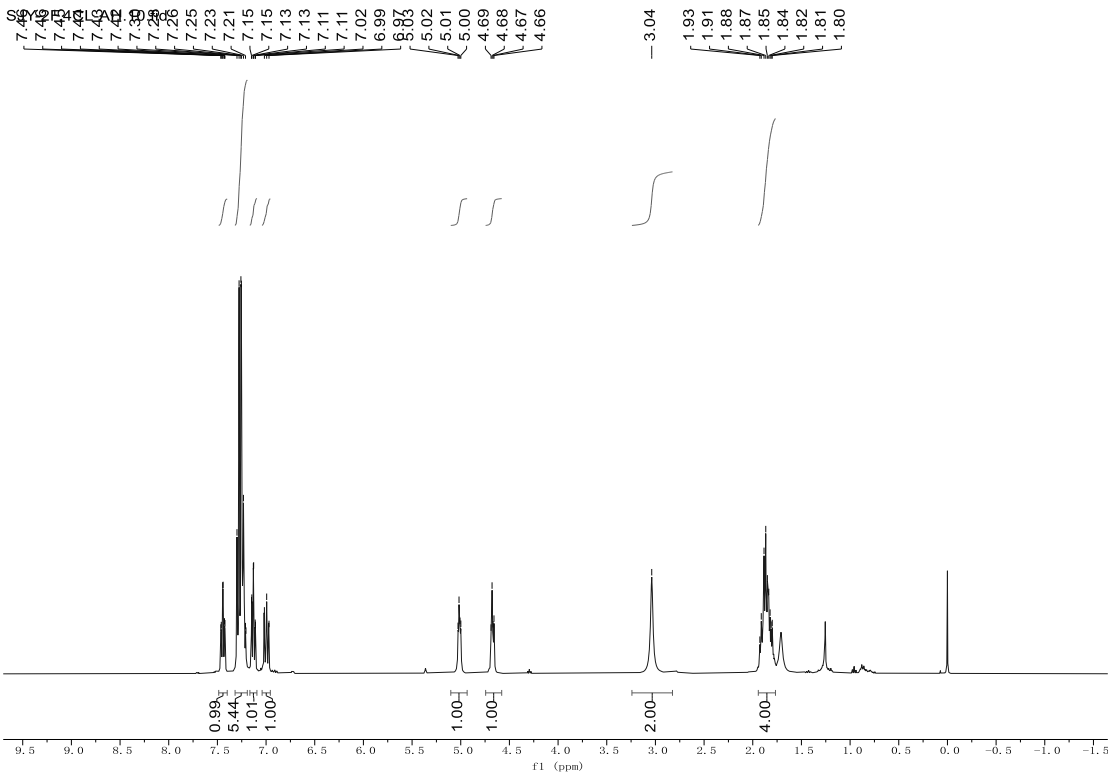


SJY-2Br,4H-AH.2.fid

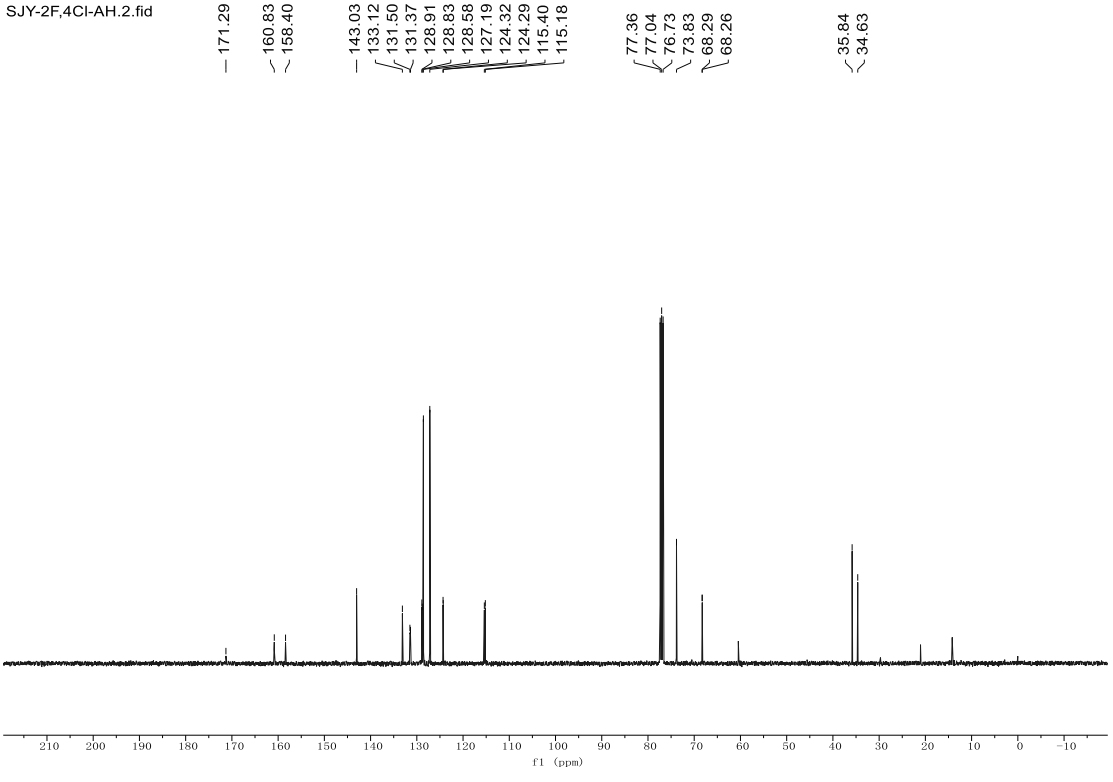


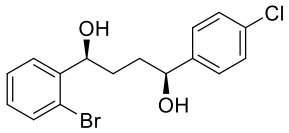


6d

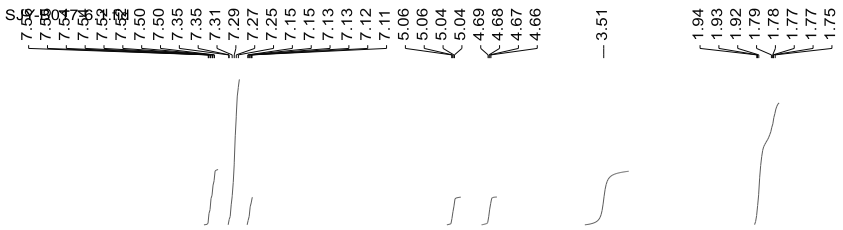


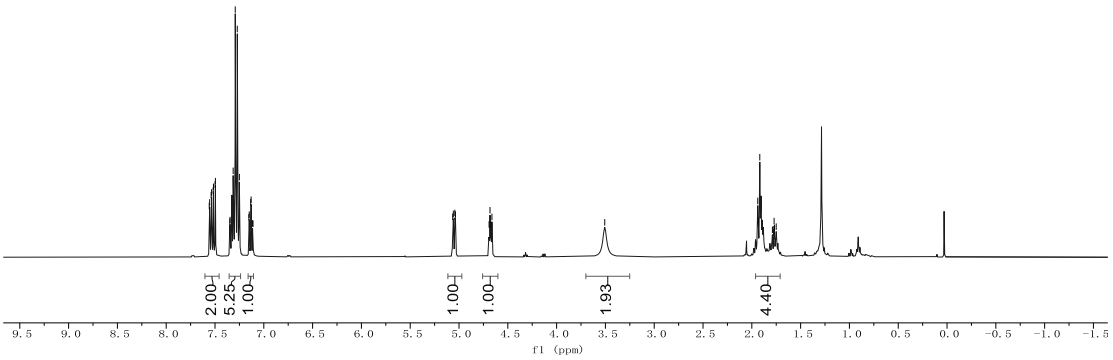
SJY-2F,4Cl-AH.2.fid



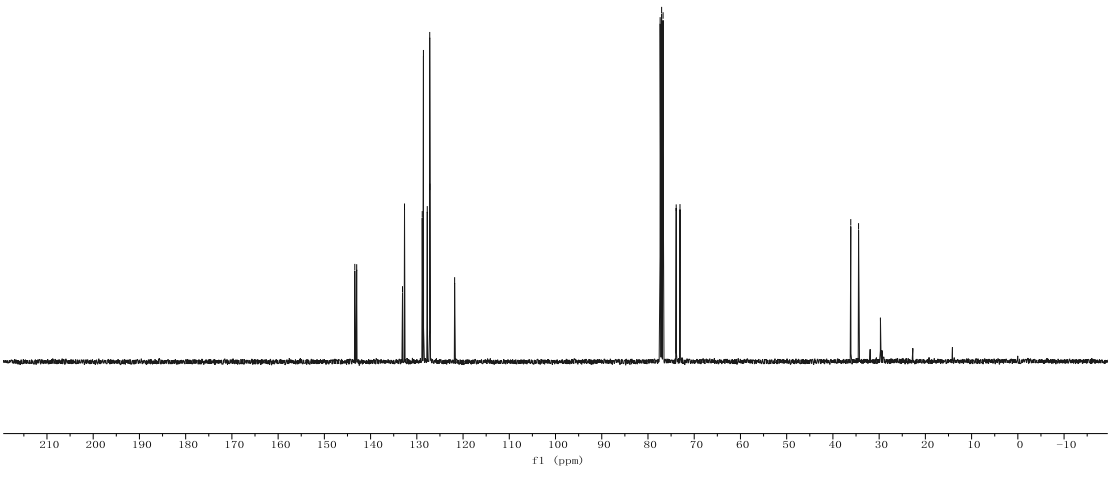


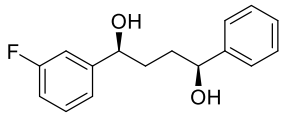
6e





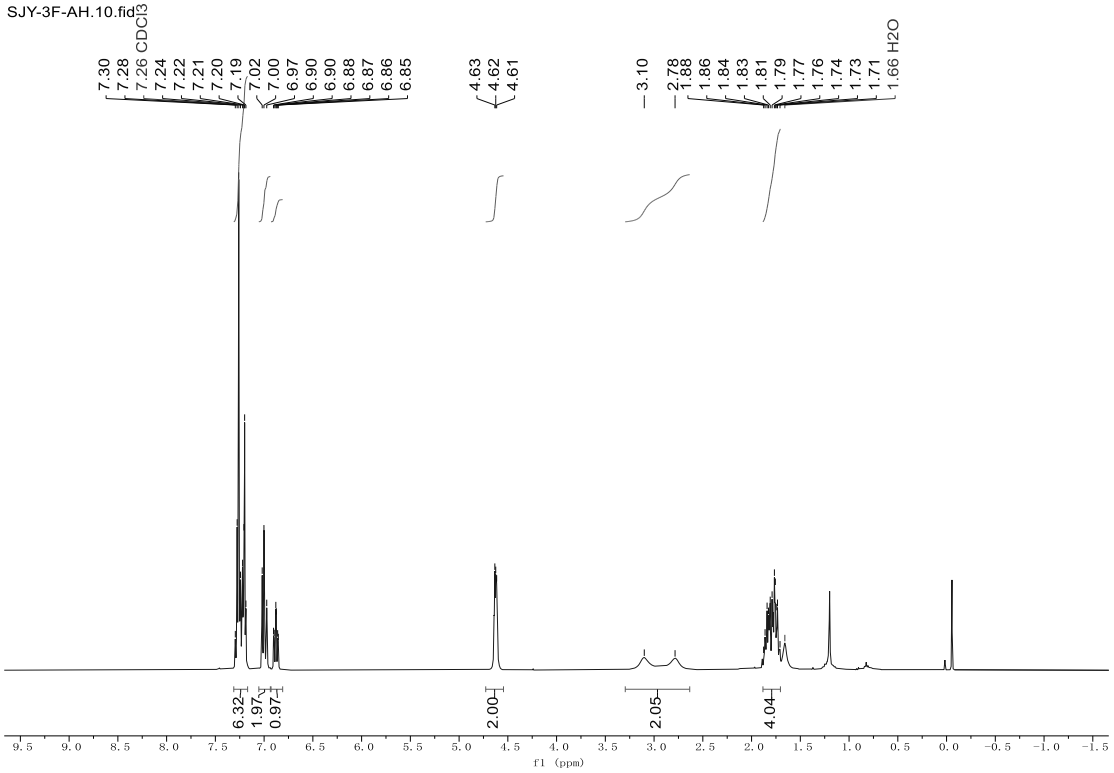
SJY-B017-6.2.fid



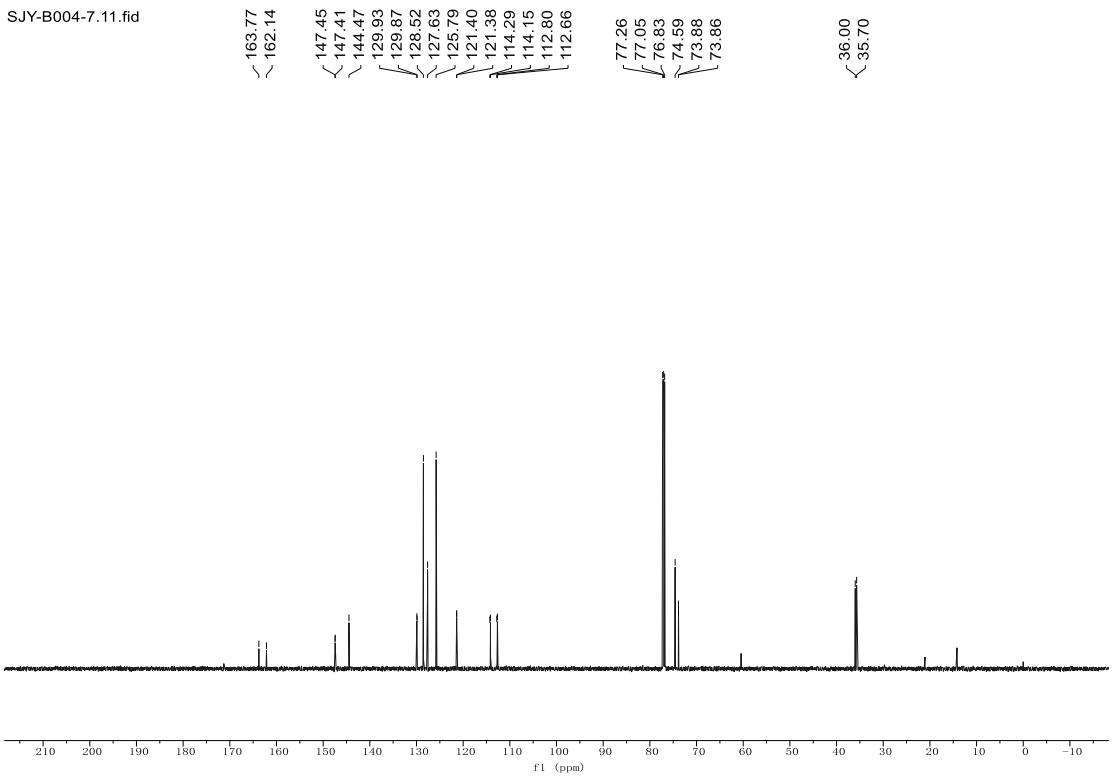


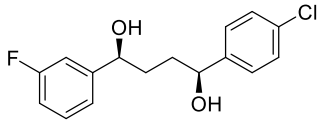
6f

SJY-3F-AH.10.fid



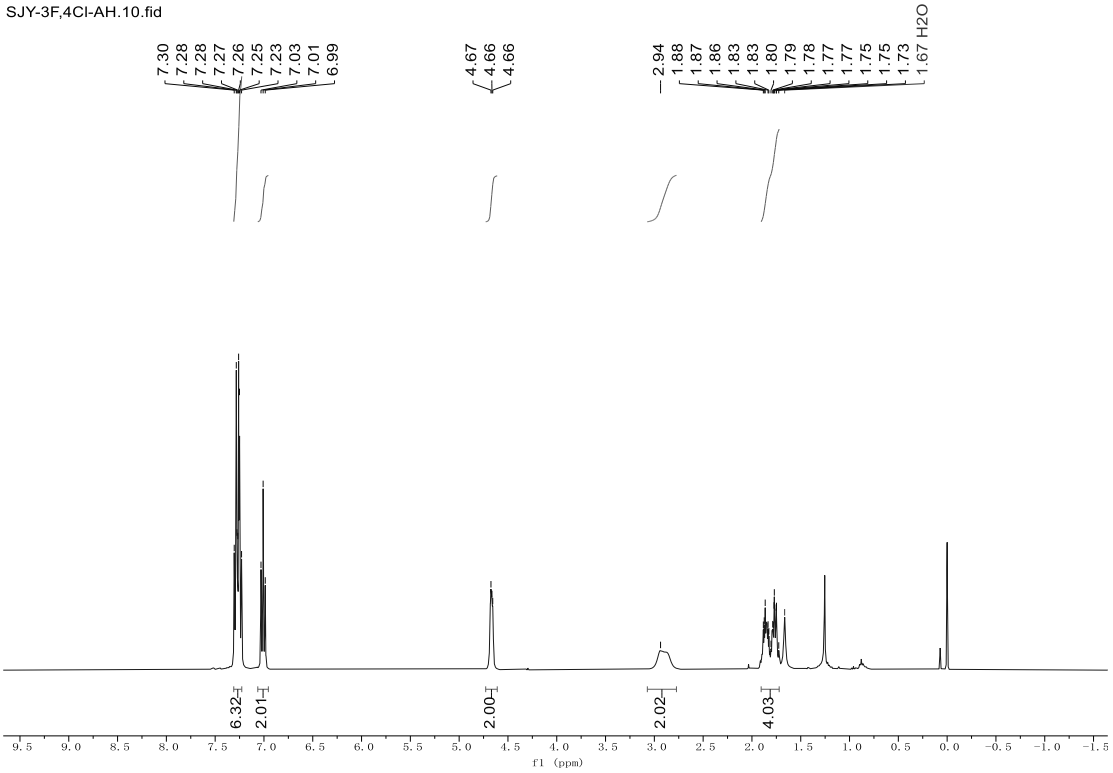
SJY-B004-7.11.fid



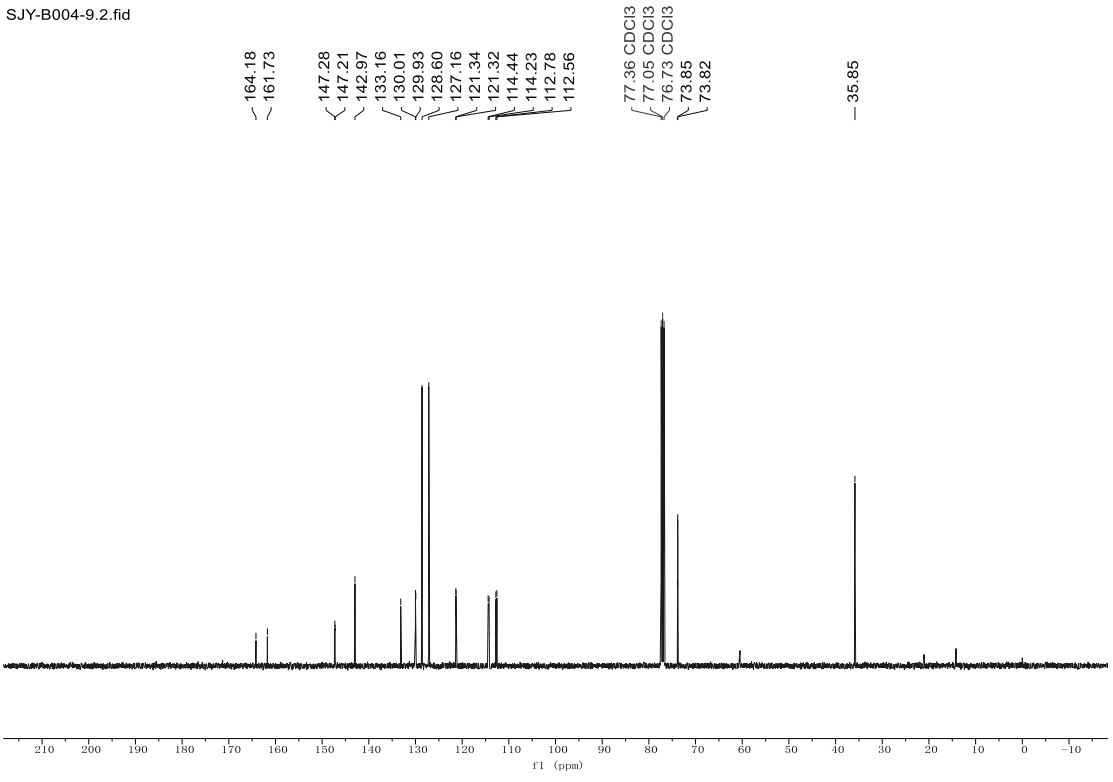


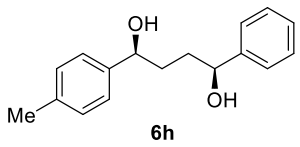
6g

SJY-3F,4Cl-AH.10.fid



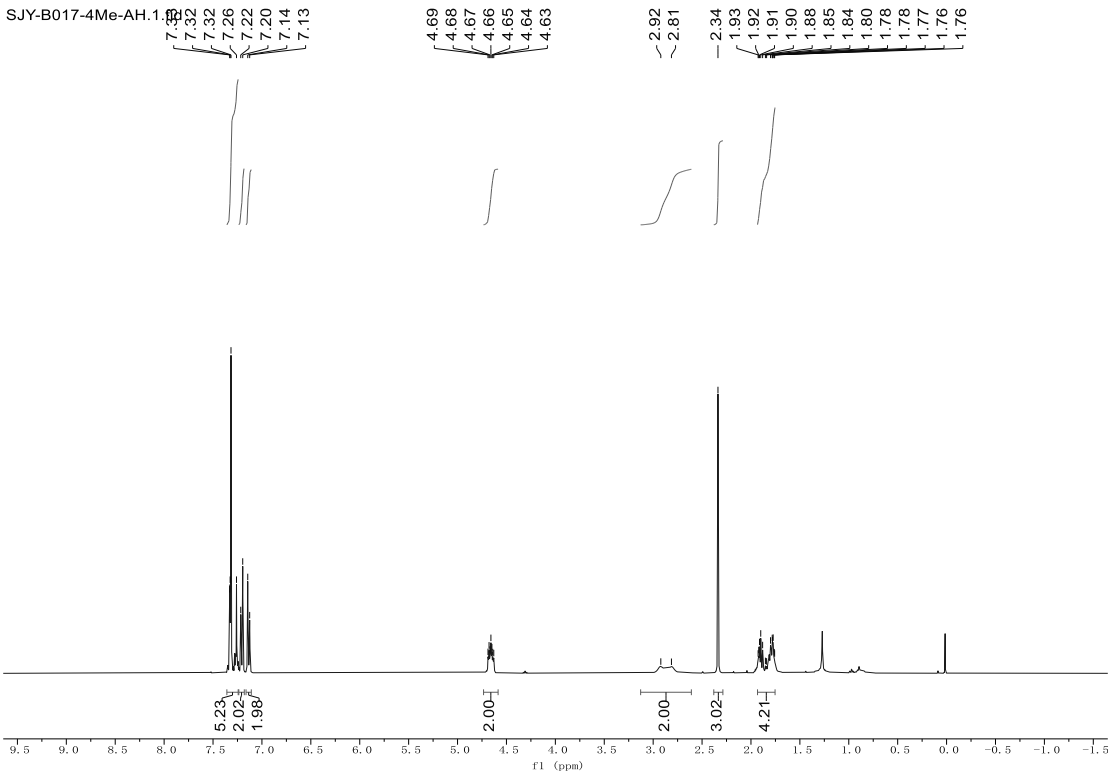
SJY-B004-9.2.fid



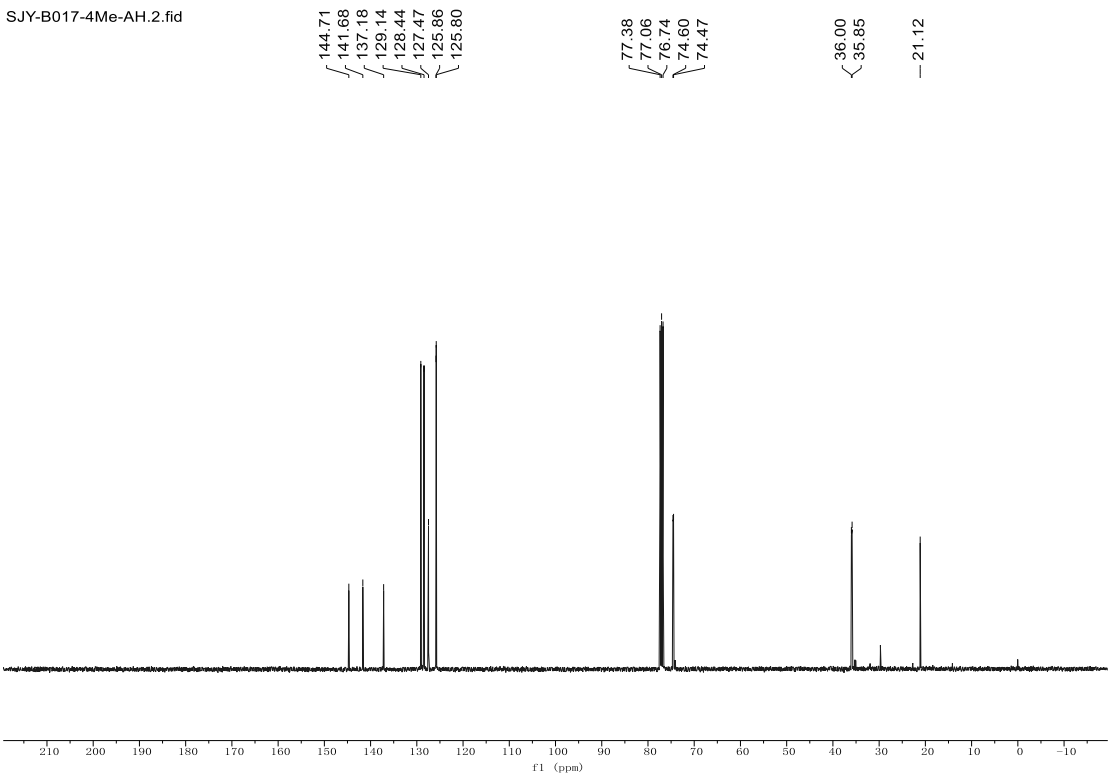


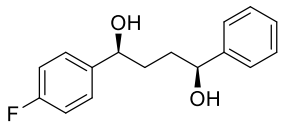
6h

SJY-B017-4Me-AH.1.fid



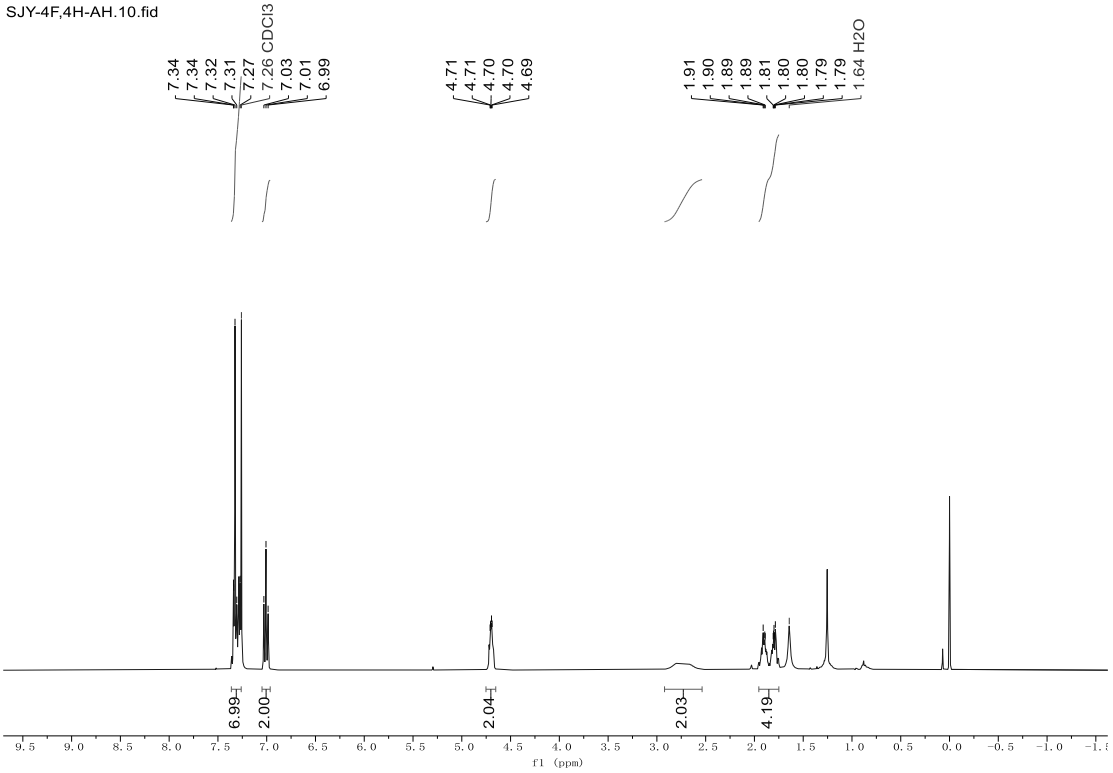
SJY-B017-4Me-AH.2.fid



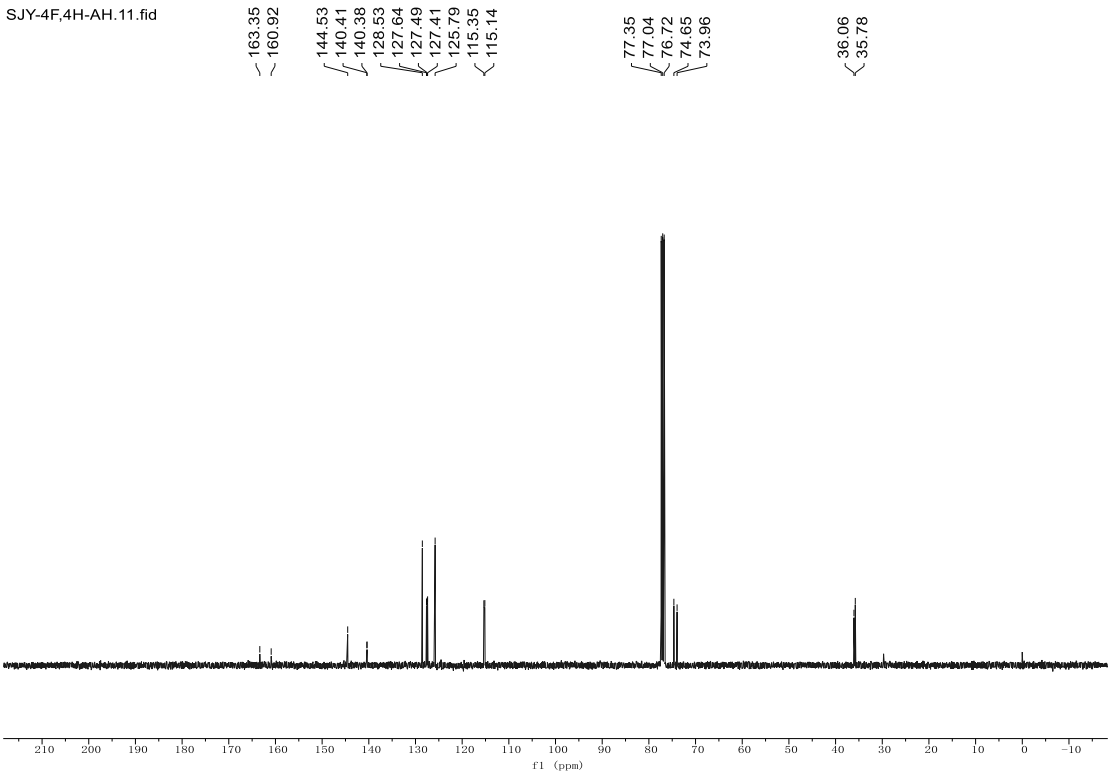


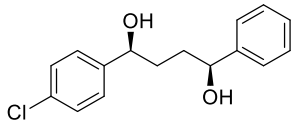
6i

SJY-4F,4H-AH.10.fid



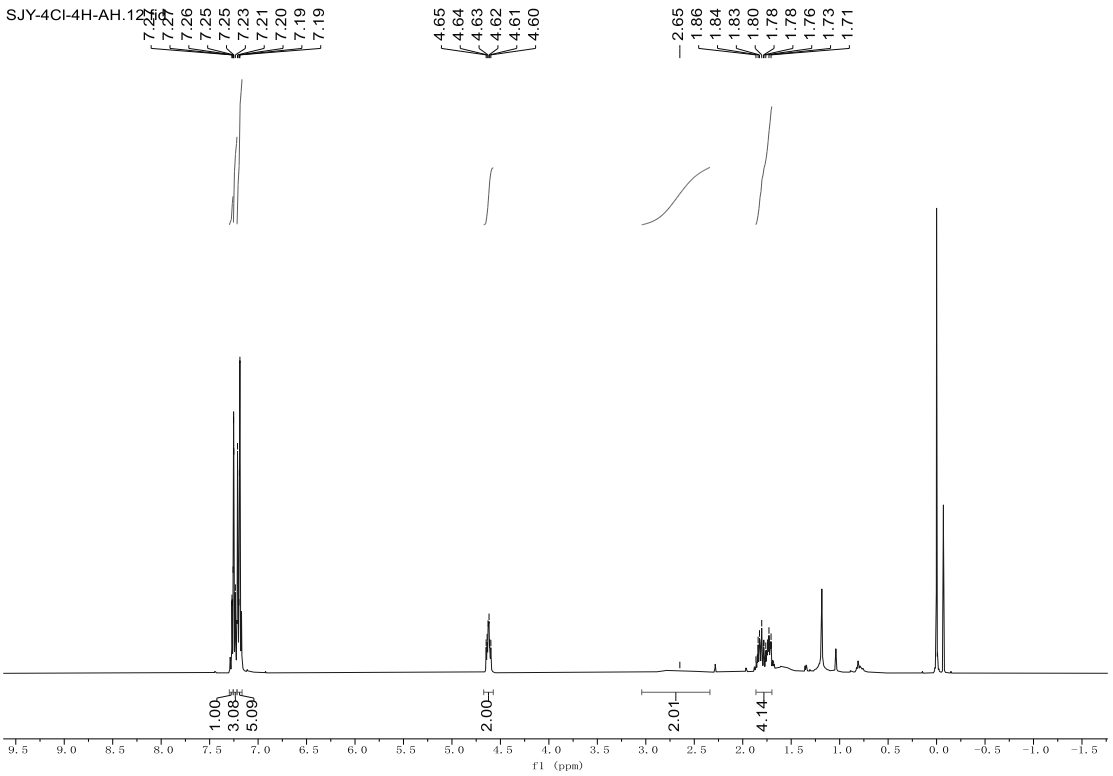
SJY-4F,4H-AH.11.fid



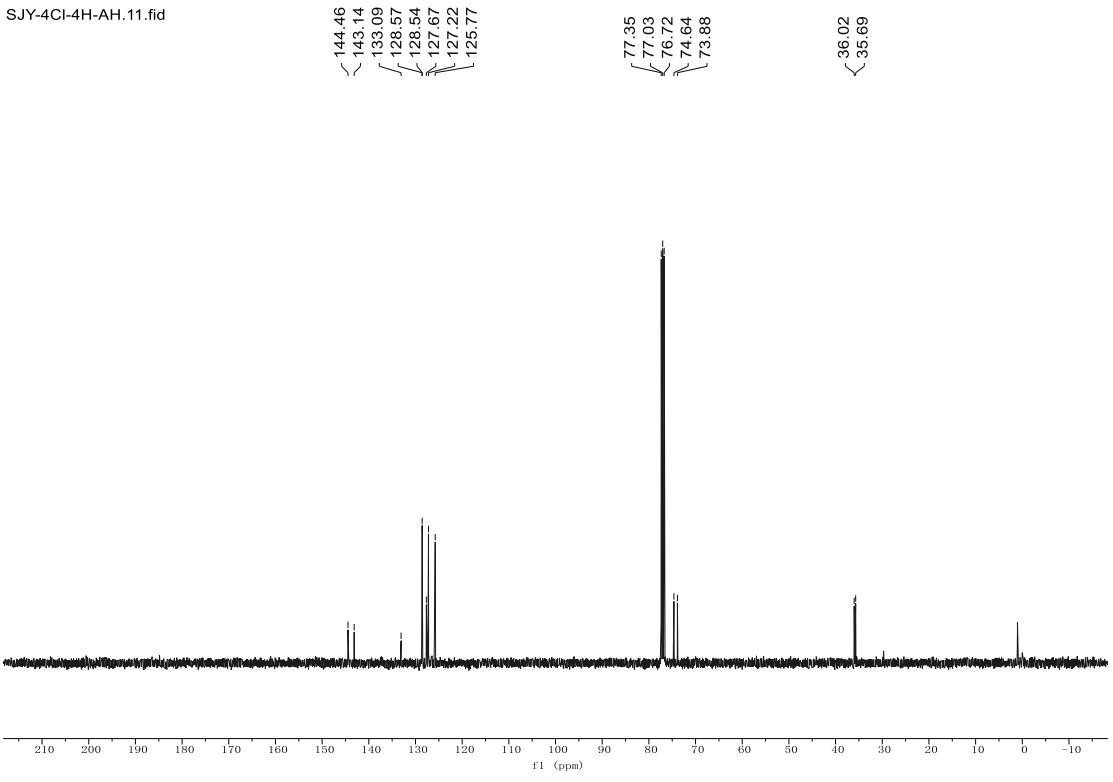


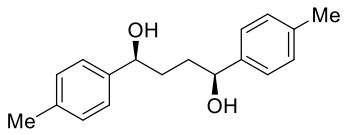
6j

SJY-4Cl-4H-AH.12.fid

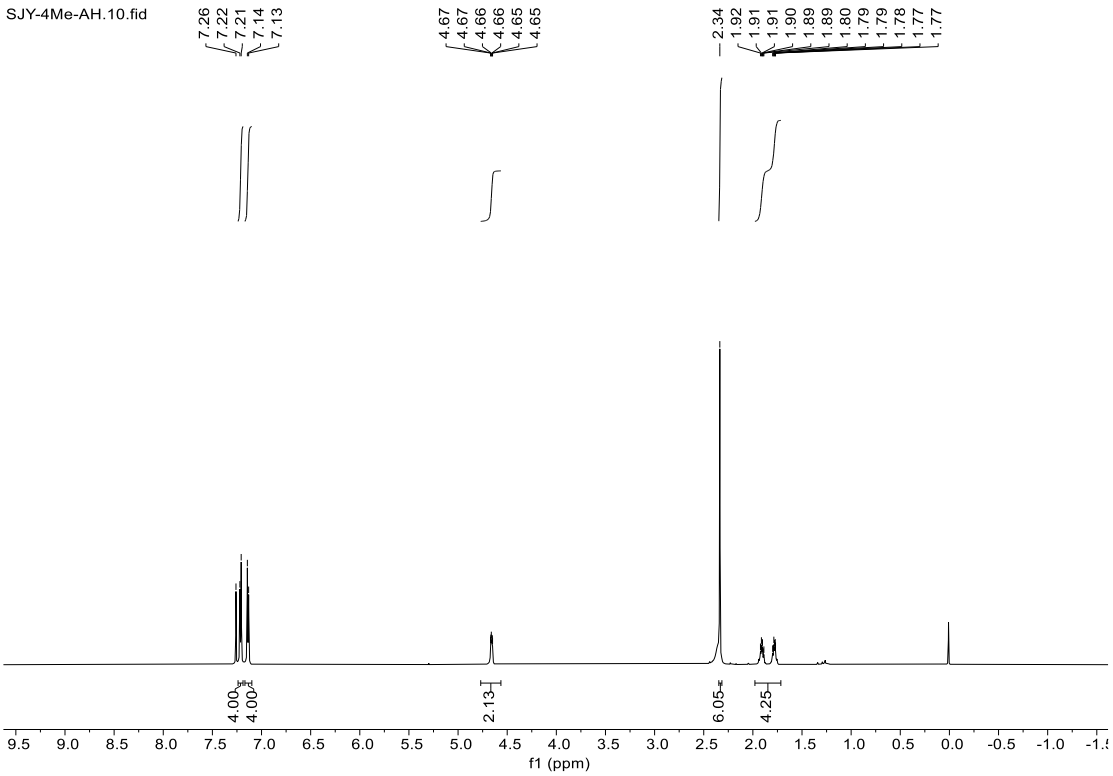


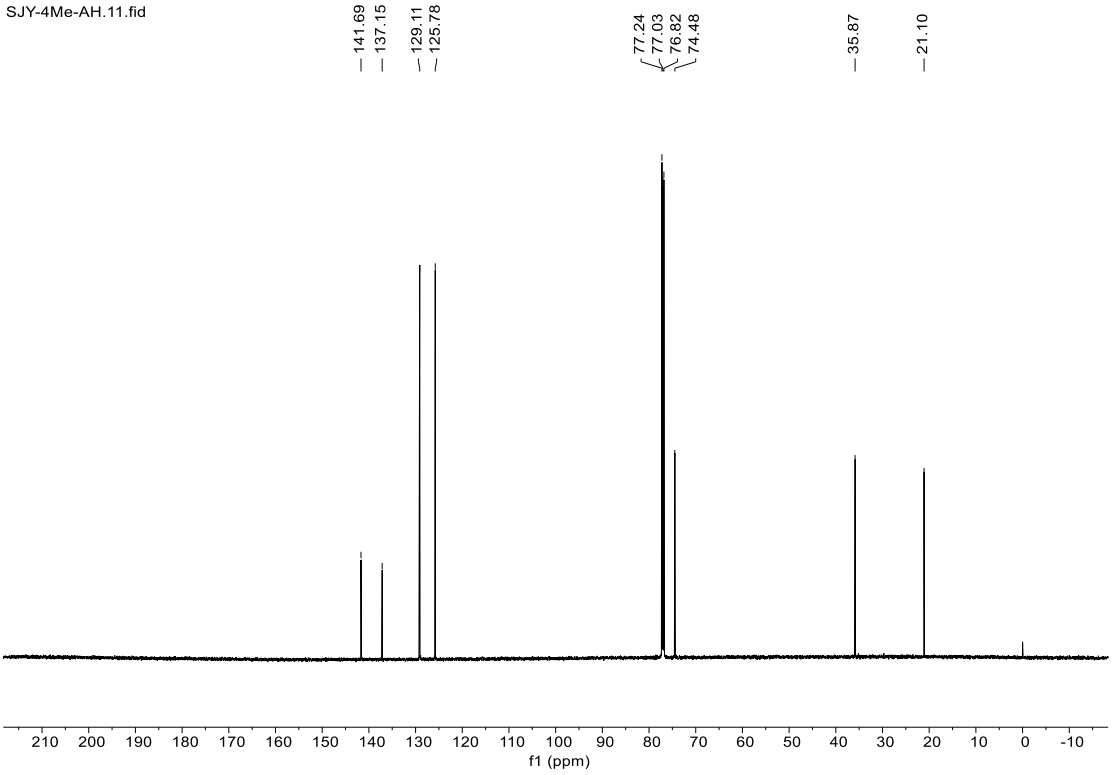
SJY-4Cl-4H-AH.11.fid

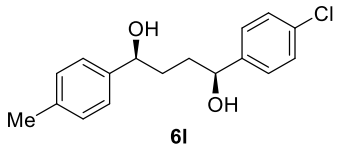



OH
Me
Me
OH

6k

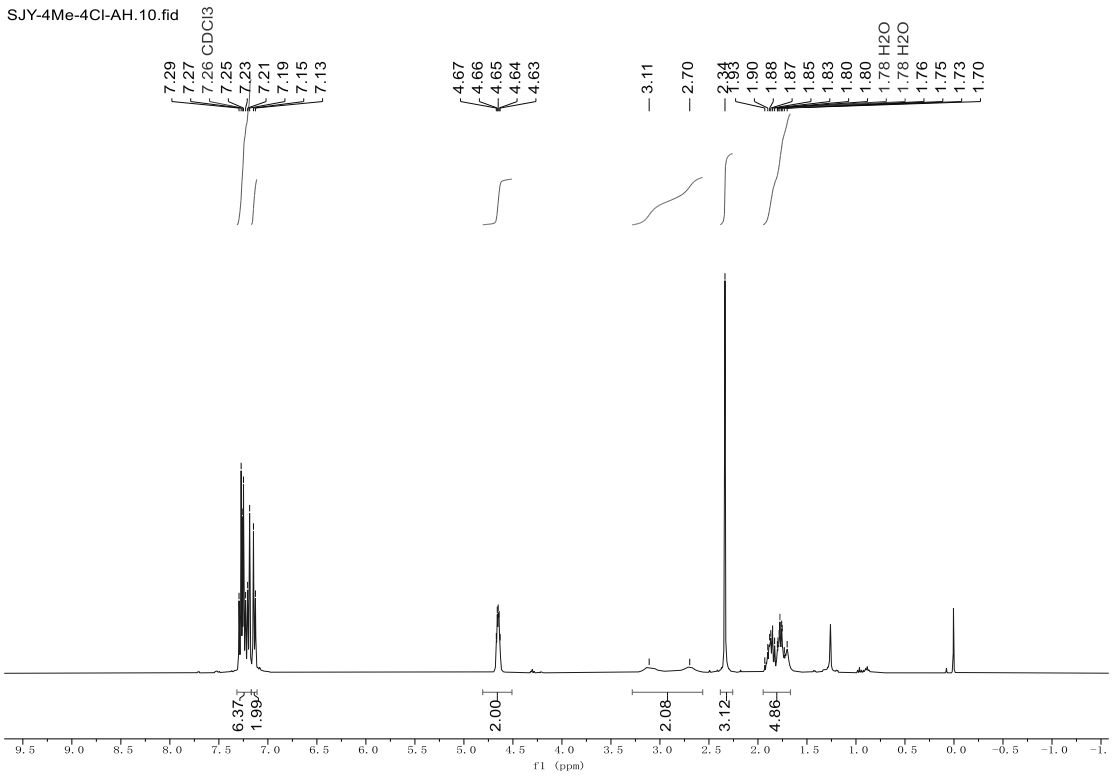

SJY-4Me-AH.10.fid
7.26
7.22
7.21
7.14
7.13
4.67
4.67
4.66
4.66
4.65
4.65
2.34
1.92
1.91
1.91
1.90
1.89
1.89
1.80
1.79
1.79
1.78
1.77
1.77
4.00
4.00
2.13
6.05
4.25
f1 (ppm)


SJY-4Me-AH.11.fid
141.69
137.15
129.11
125.78
77.24
77.03
76.82
74.48
35.87
21.10
f1 (ppm)

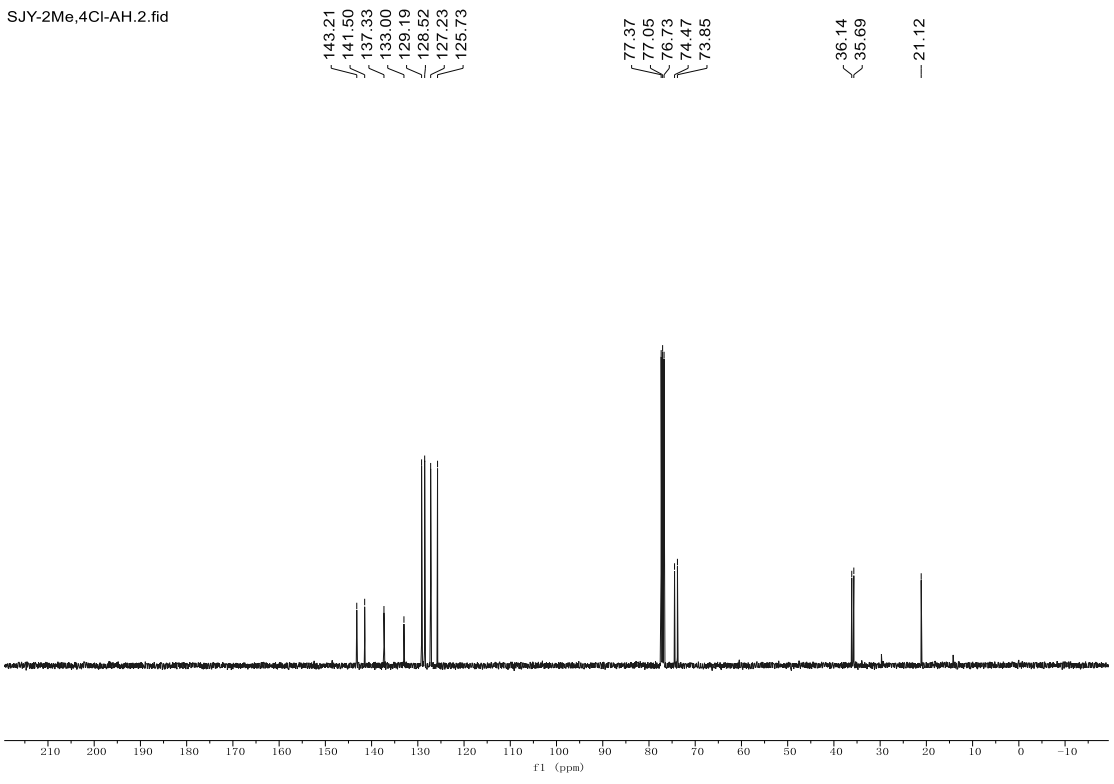


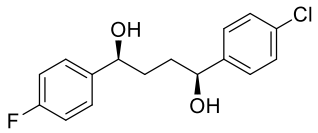
6l

SJY-4Me-4Cl-AH.10.fid



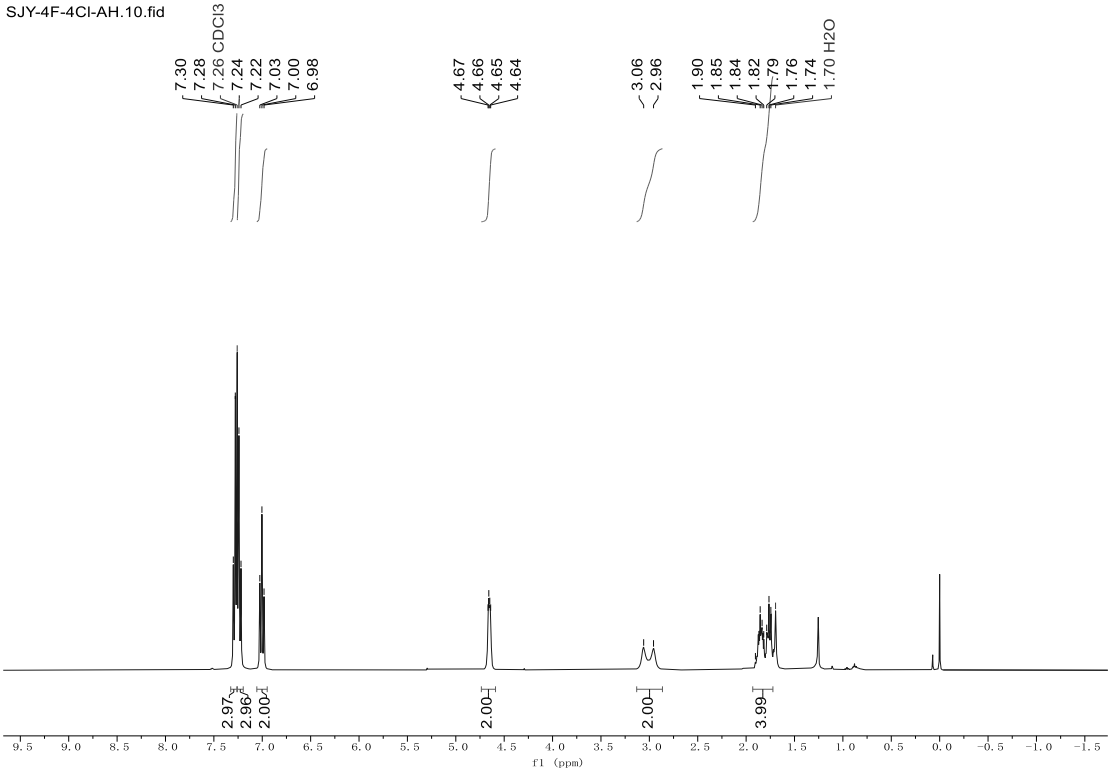
SJY-2Me,4Cl-AH.2.fid



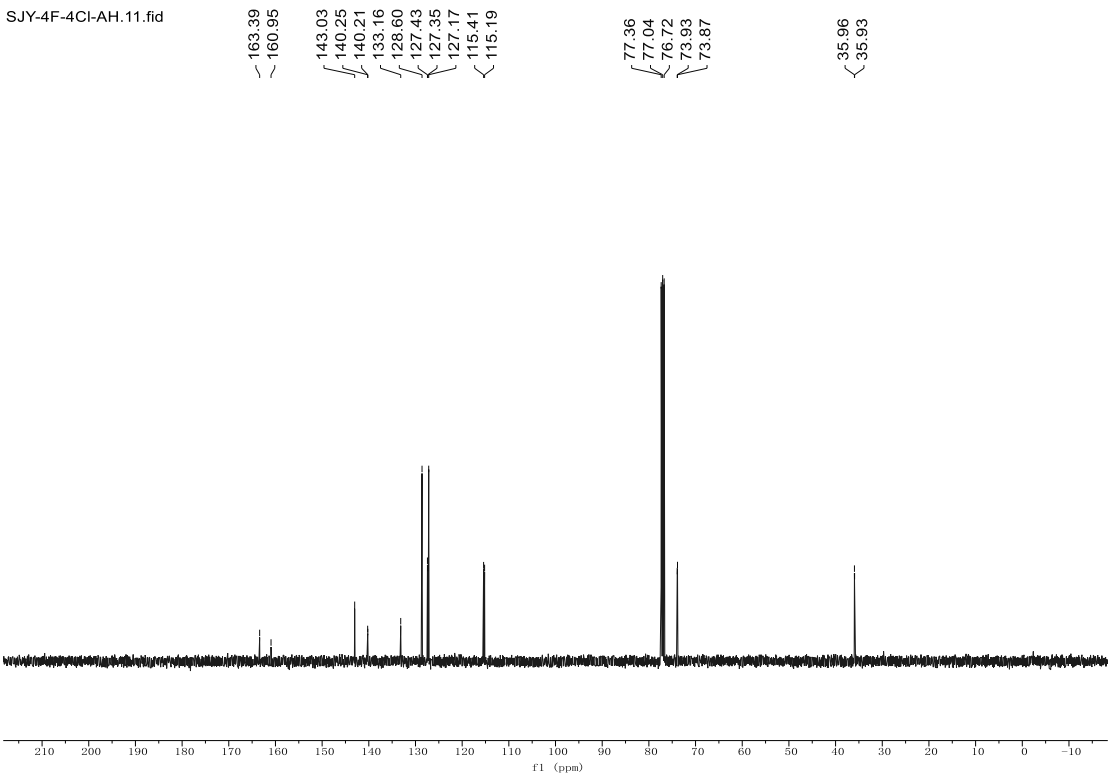


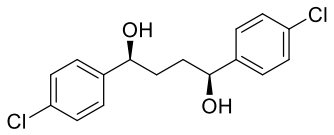
6m

SJY-4F-4Cl-AH.10.fid

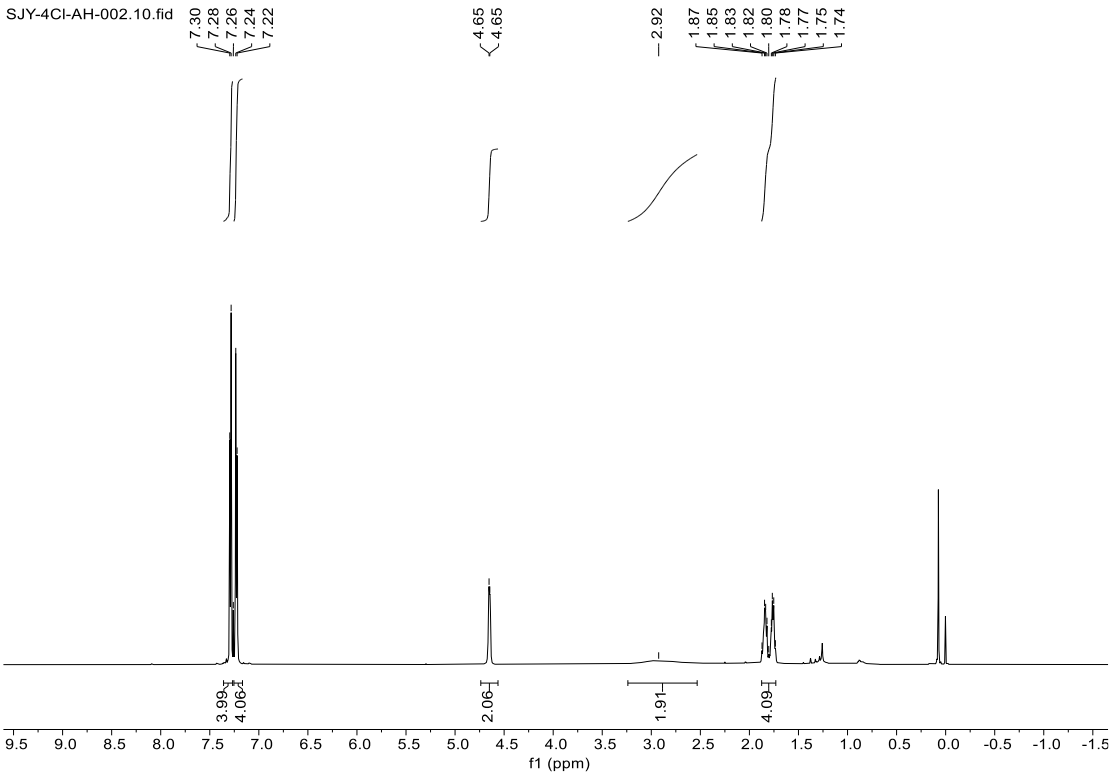


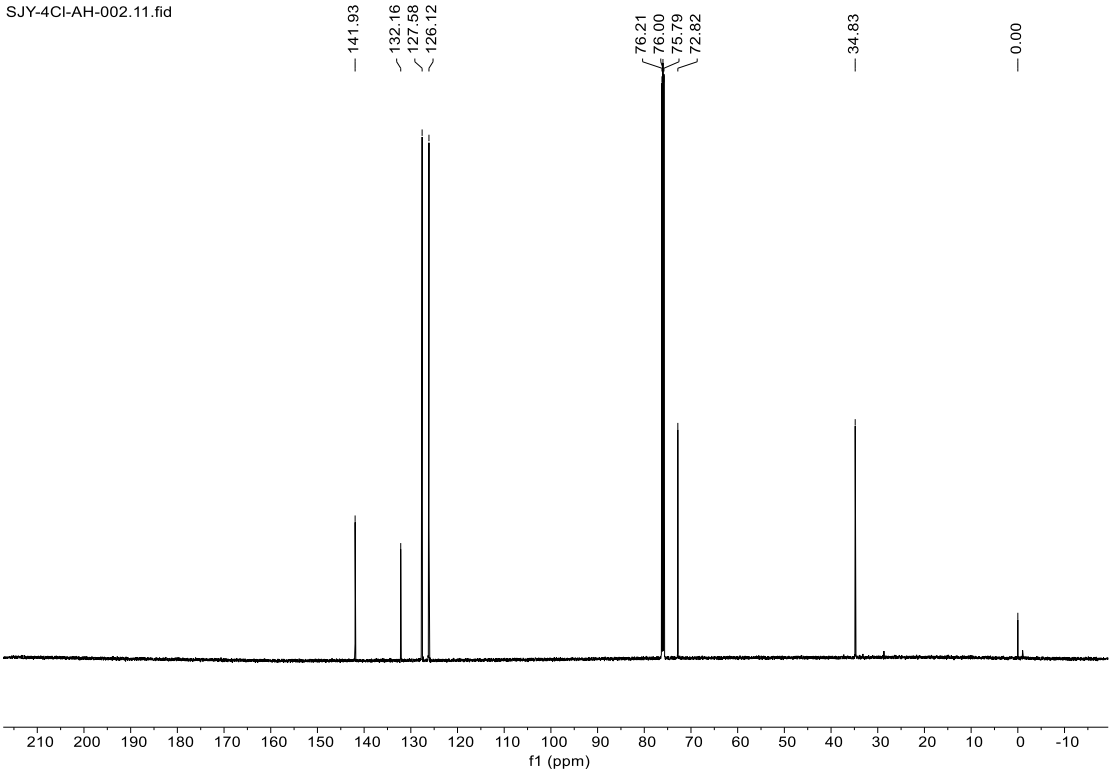
SJY-4F-4Cl-AH.11.fid

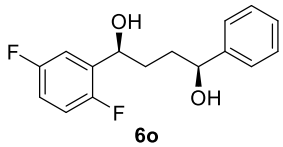



OH
Cl
Cl
OH

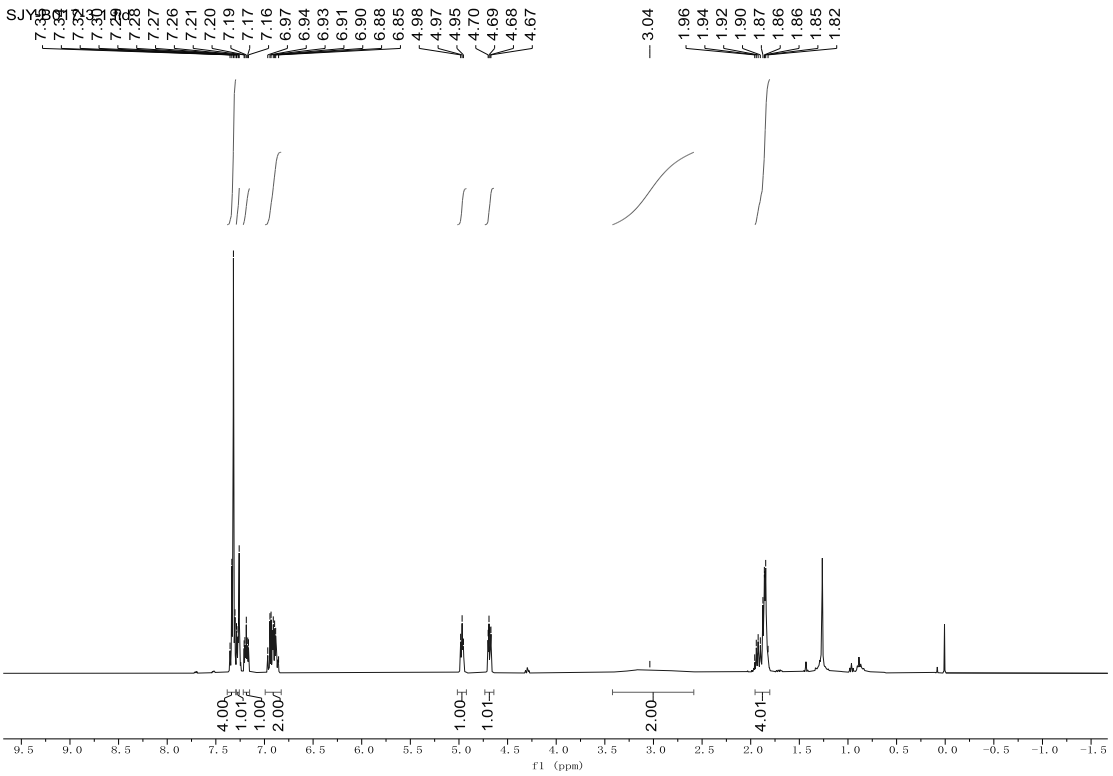
6n

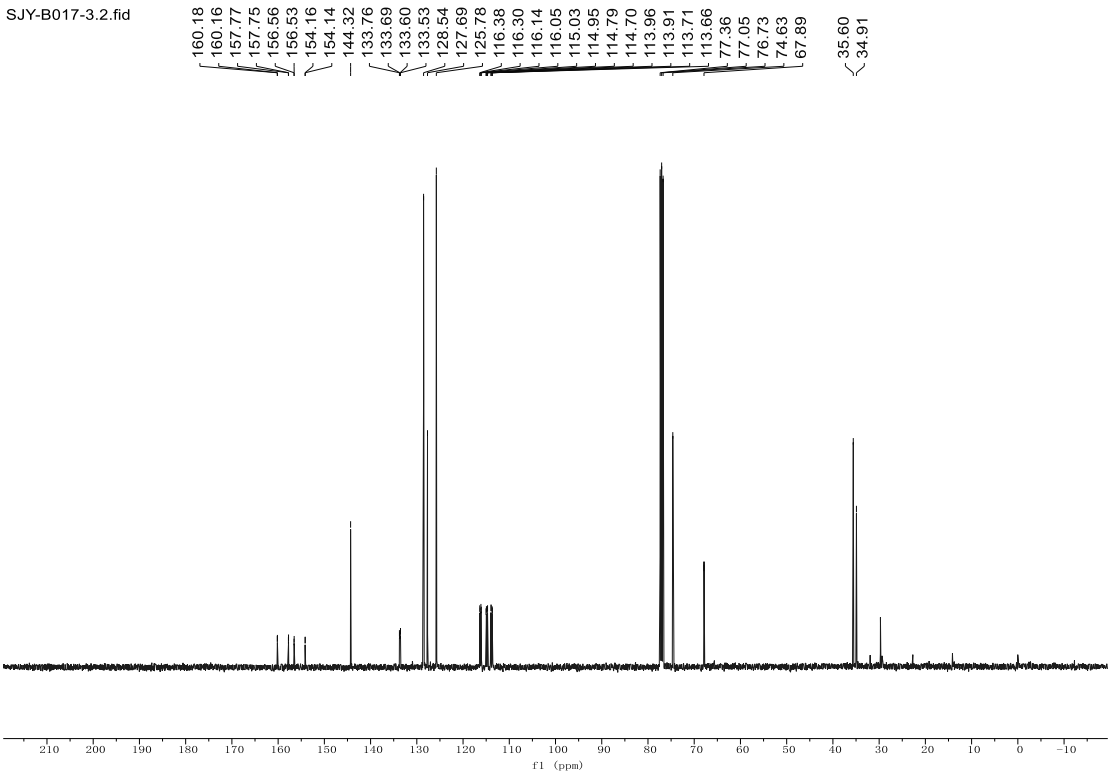

SJY-4Cl-AH-002.10.fid
7.30
7.28
7.26
7.24
7.22
4.65
4.65
2.92
1.87
1.85
1.83
1.82
1.80
1.78
1.77
1.75
1.74
3.99
4.06
2.06
1.91
4.09
f1 (ppm)

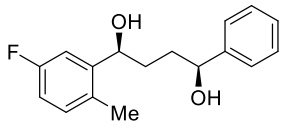

SJY-4Cl-AH-002.11.fid
141.93
132.16
127.58
126.12
76.21
76.00
75.79
72.82
34.83
0.00
f1 (ppm)


OH
F
OH
F

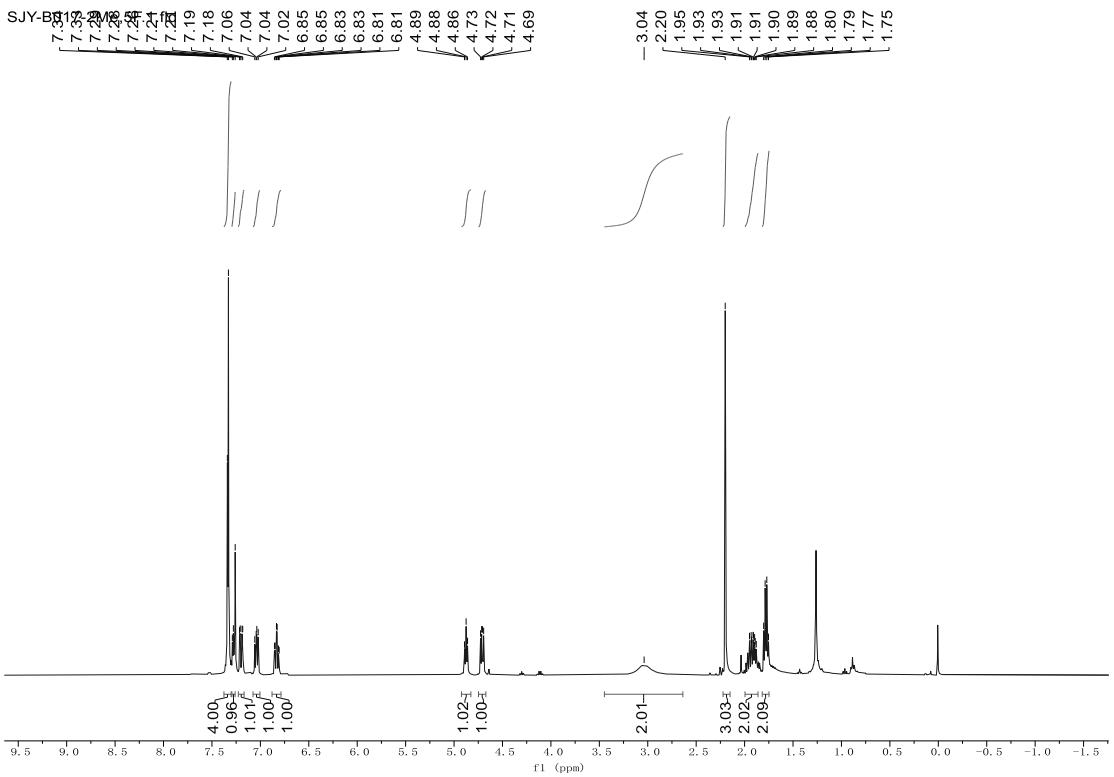
6o


7.35
7.34
7.33
7.32
7.31
7.30
7.28
7.27
7.26
7.21
7.20
7.19
7.17
7.16
6.97
6.94
6.93
6.91
6.90
6.88
6.85
4.98
4.97
4.95
4.70
4.69
4.68
4.67
3.04
1.96
1.94
1.92
1.90
1.87
1.86
1.86
1.85
1.82
4.00
1.01
1.00
2.00
1.00
1.01
2.00
4.01
f1 (ppm)

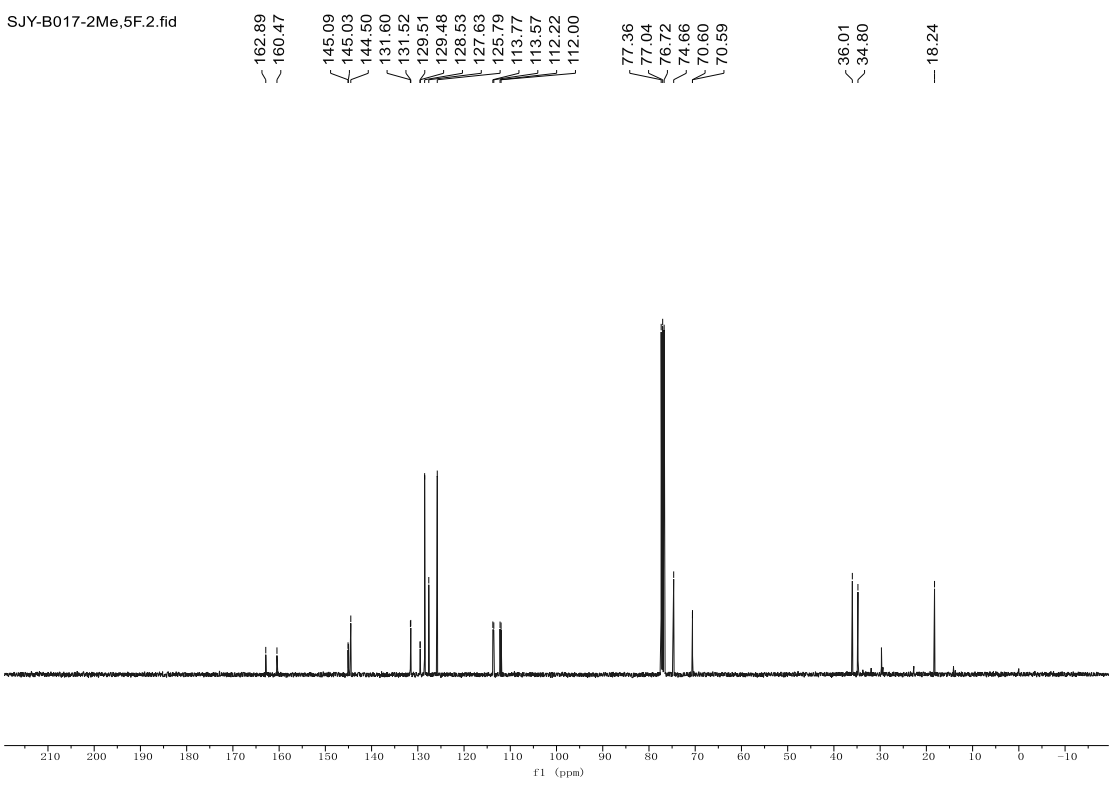

SJY-B017-3.2.fid
160.18
160.16
157.77
157.75
156.56
156.53
154.16
154.14
144.32
133.76
133.69
133.60
133.53
128.54
127.69
125.78
116.38
116.30
116.14
116.05
115.03
114.95
114.79
114.70
113.96
113.91
113.71
113.66
77.36
77.05
76.73
74.63
67.89
35.60
34.91
f1 (ppm)

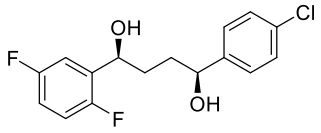


6p



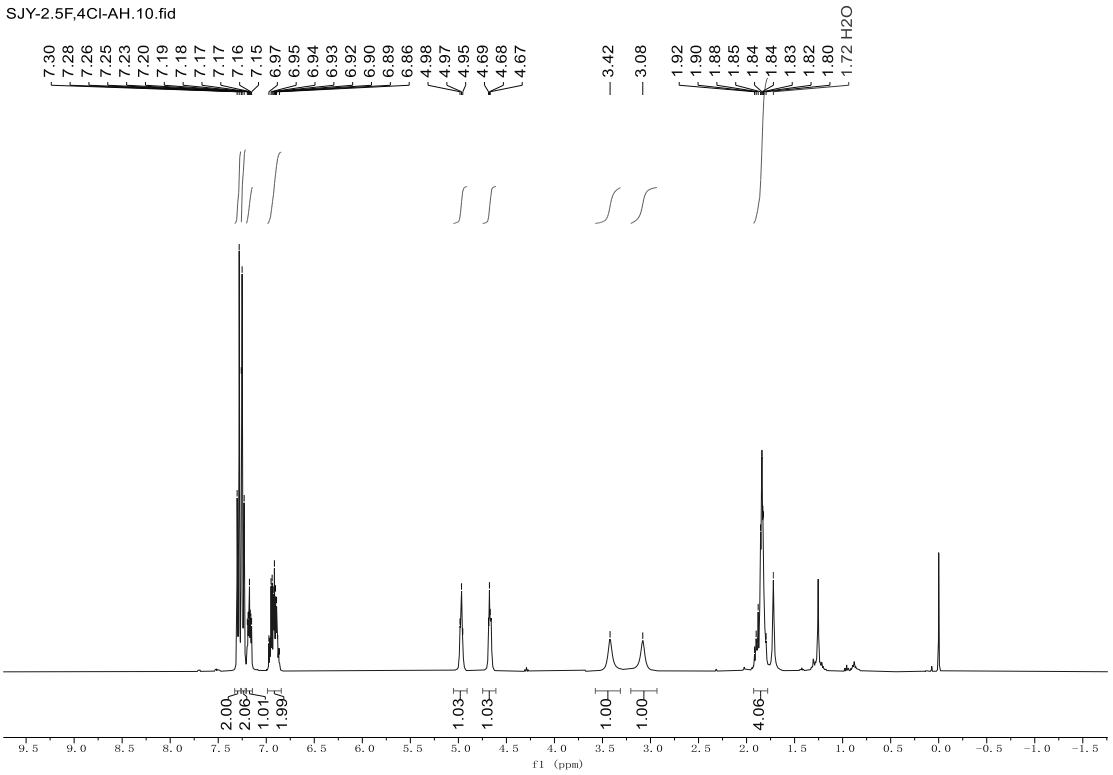
SJY-B017-2Me,5F.2.fid



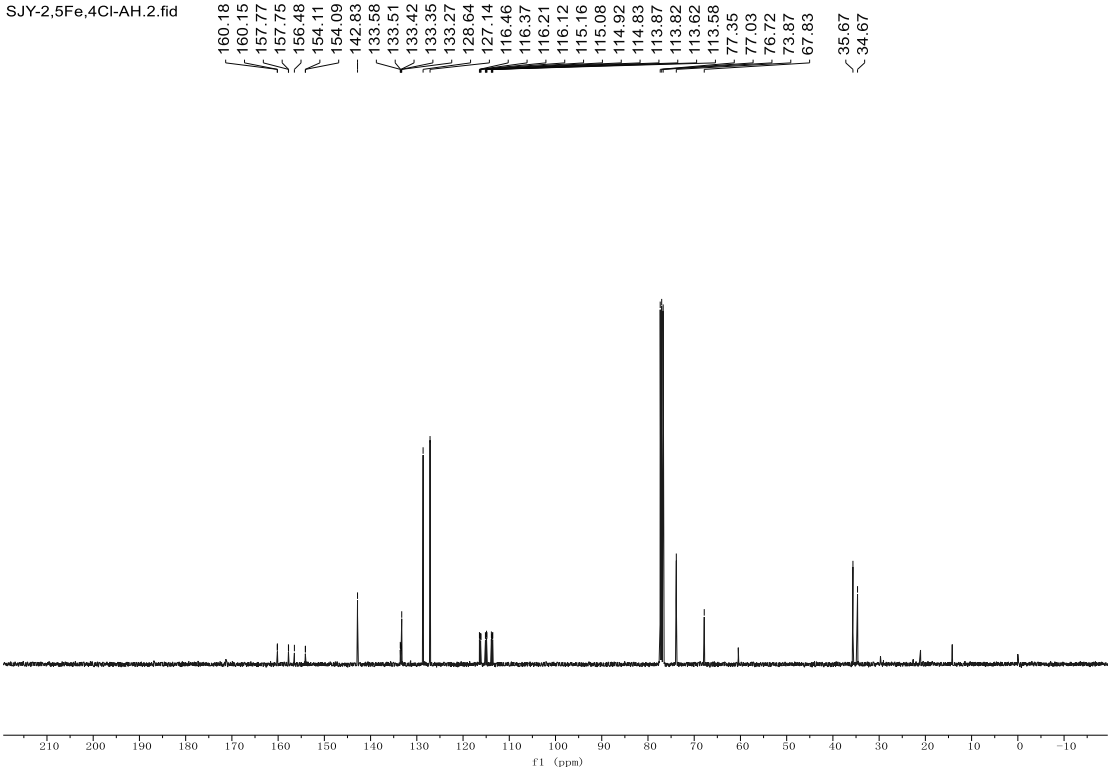


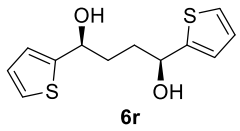
6q

SJY-2.5F,4Cl-AH.10.fid



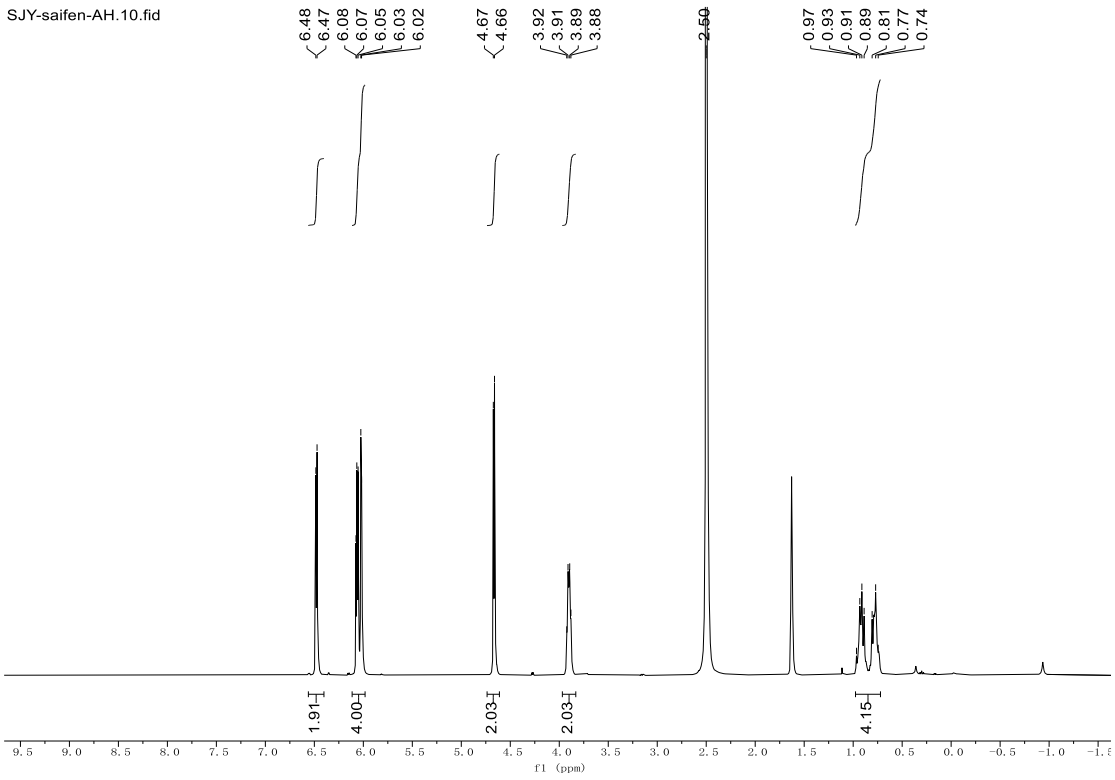
SJY-2,5Fe,4Cl-AH.2.fid

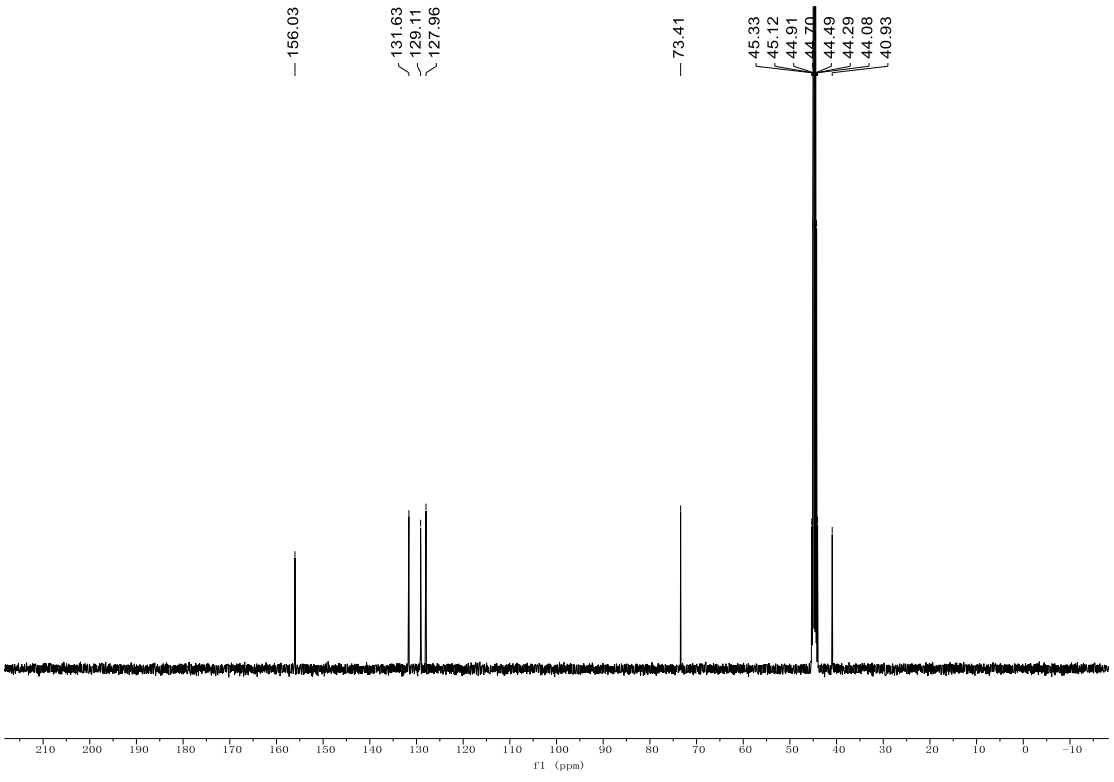


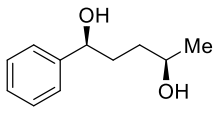


6r

SJY-saifen-AH.10.fid

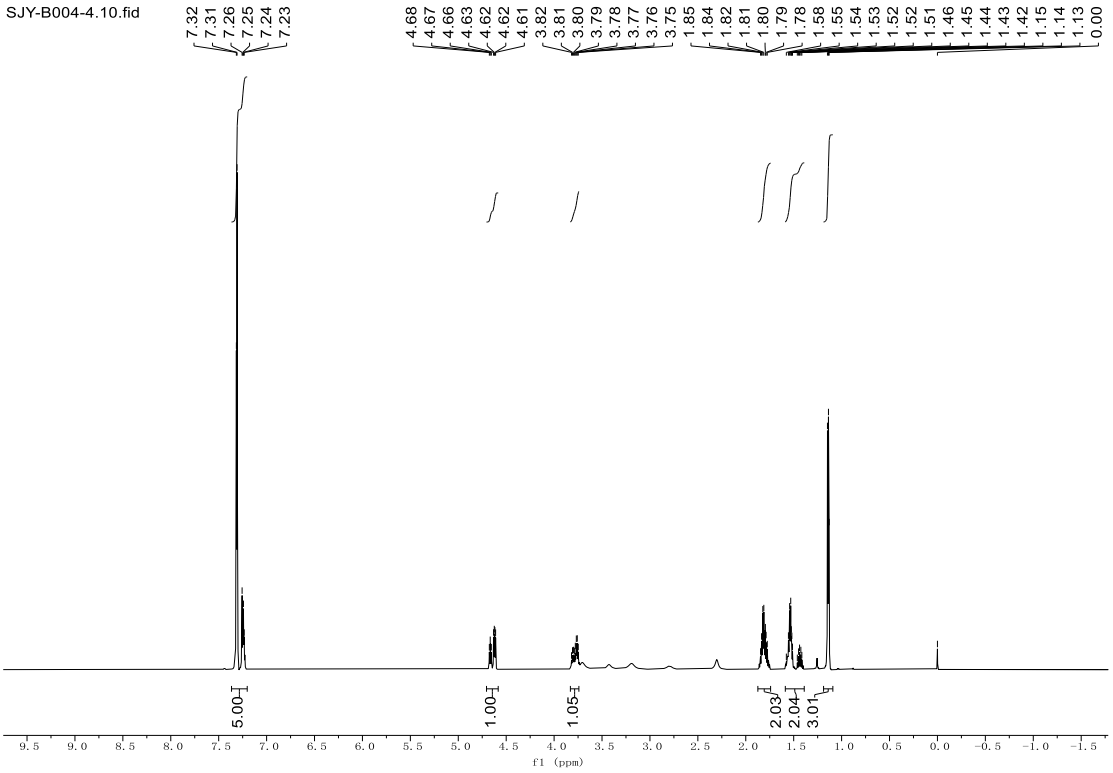




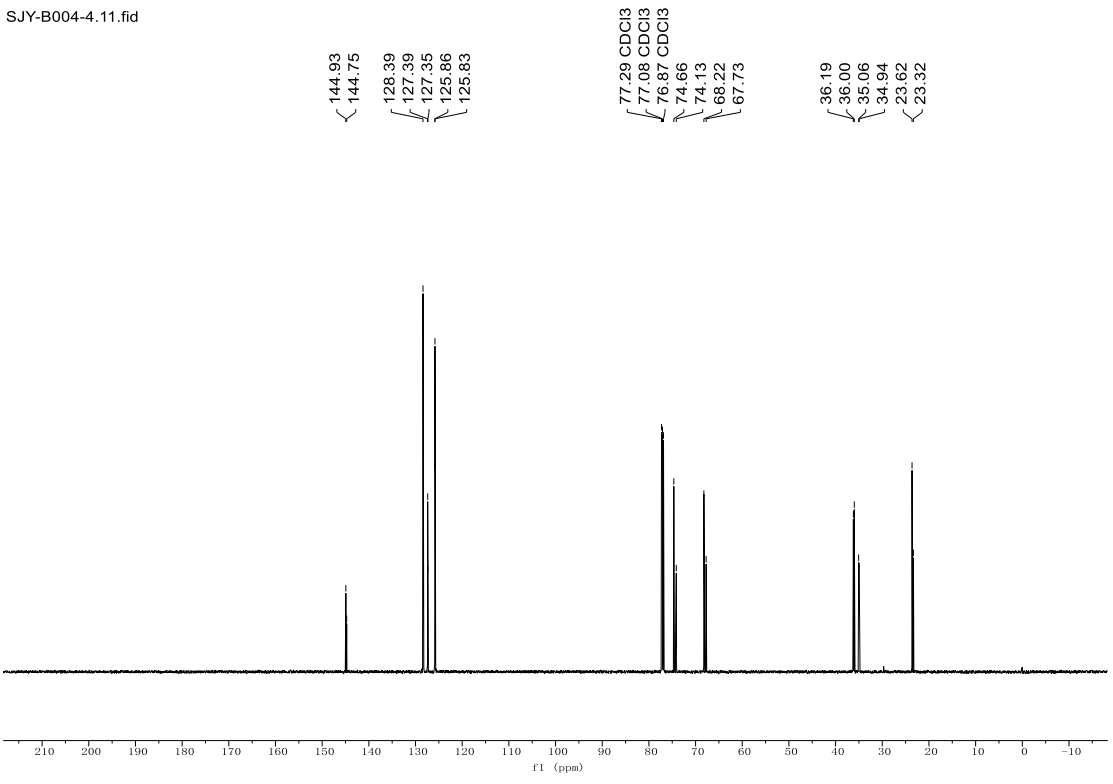


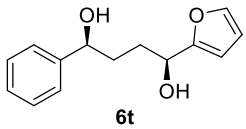
6s

SJY-B004-4.10.fid



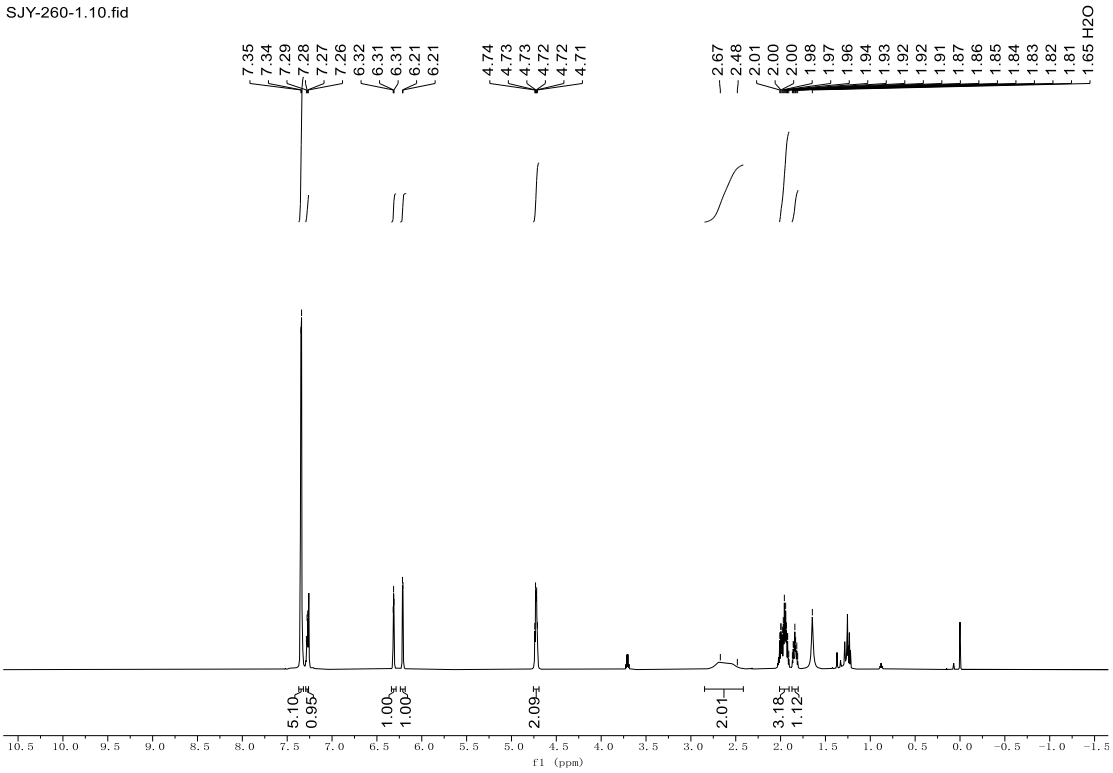
SJY-B004-4.11.fid



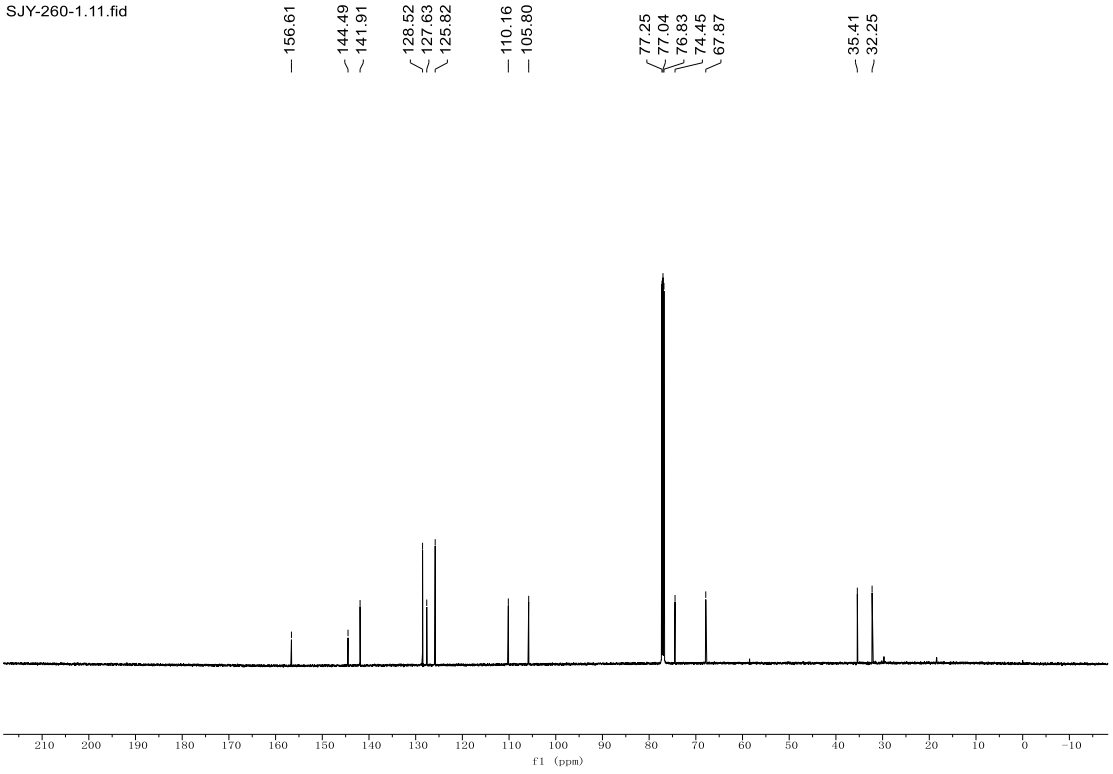


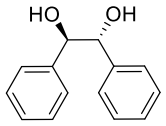
6t

SJY-260-1.10.fid



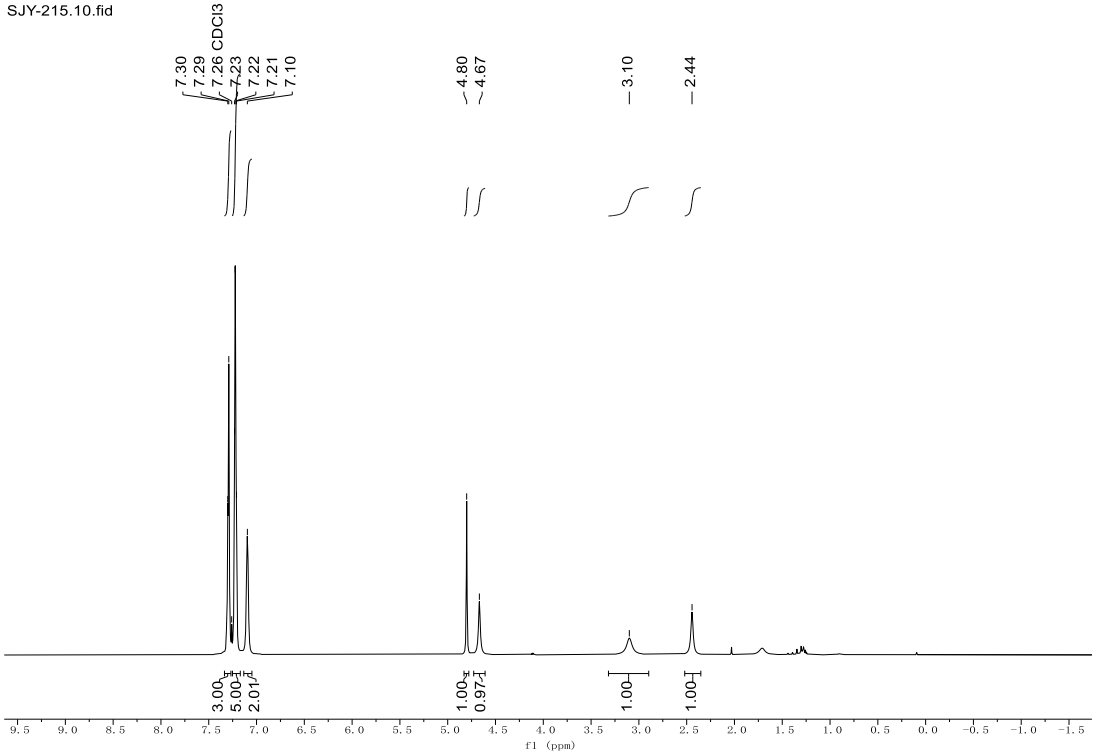
SJY-260-1.11.fid



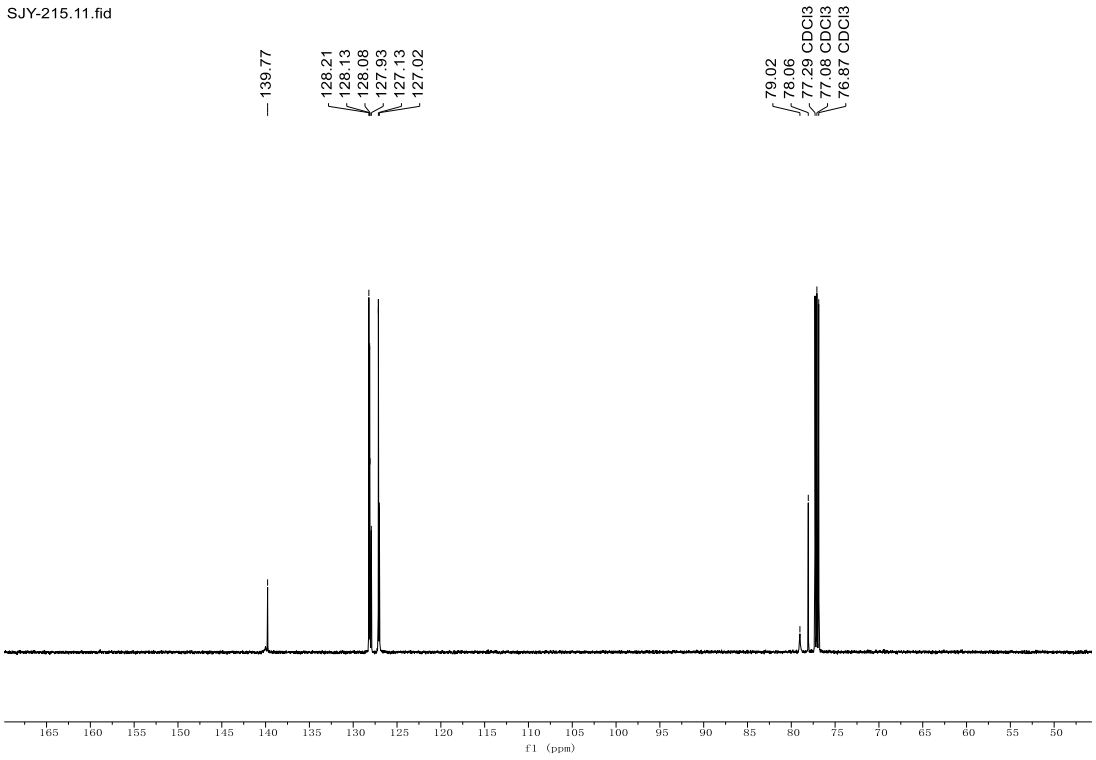


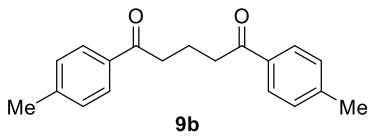
8a

SJY-215.10.fid



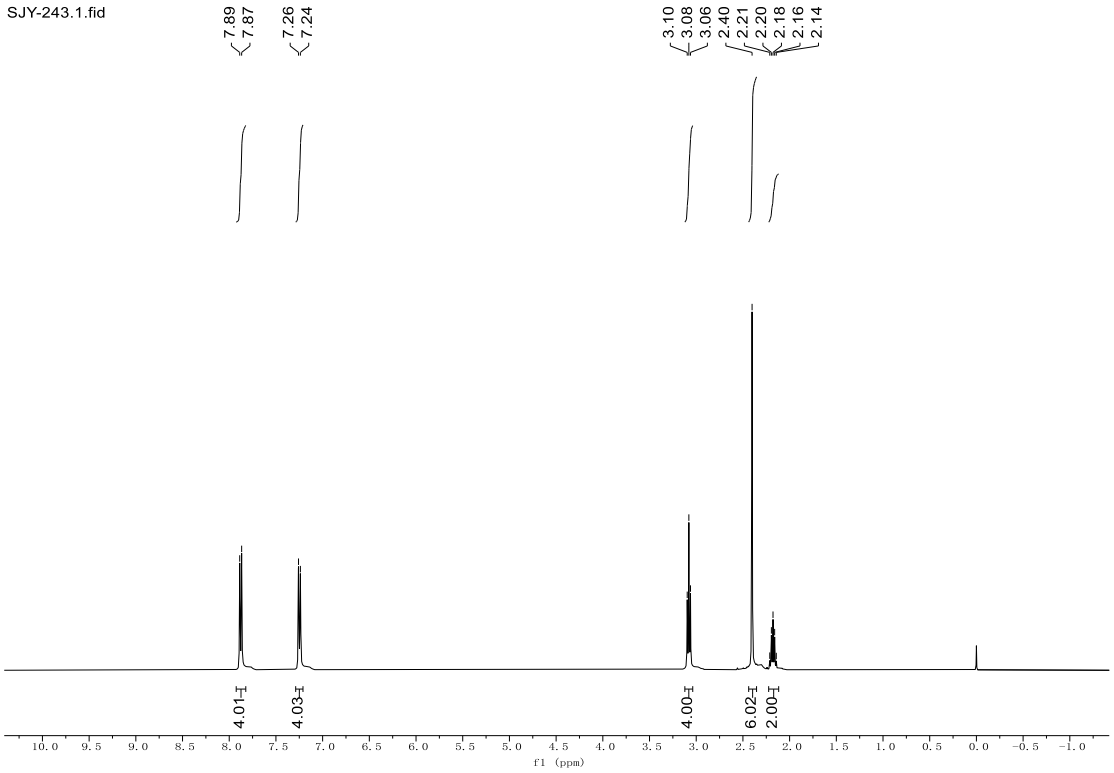
SJY-215.11.fid



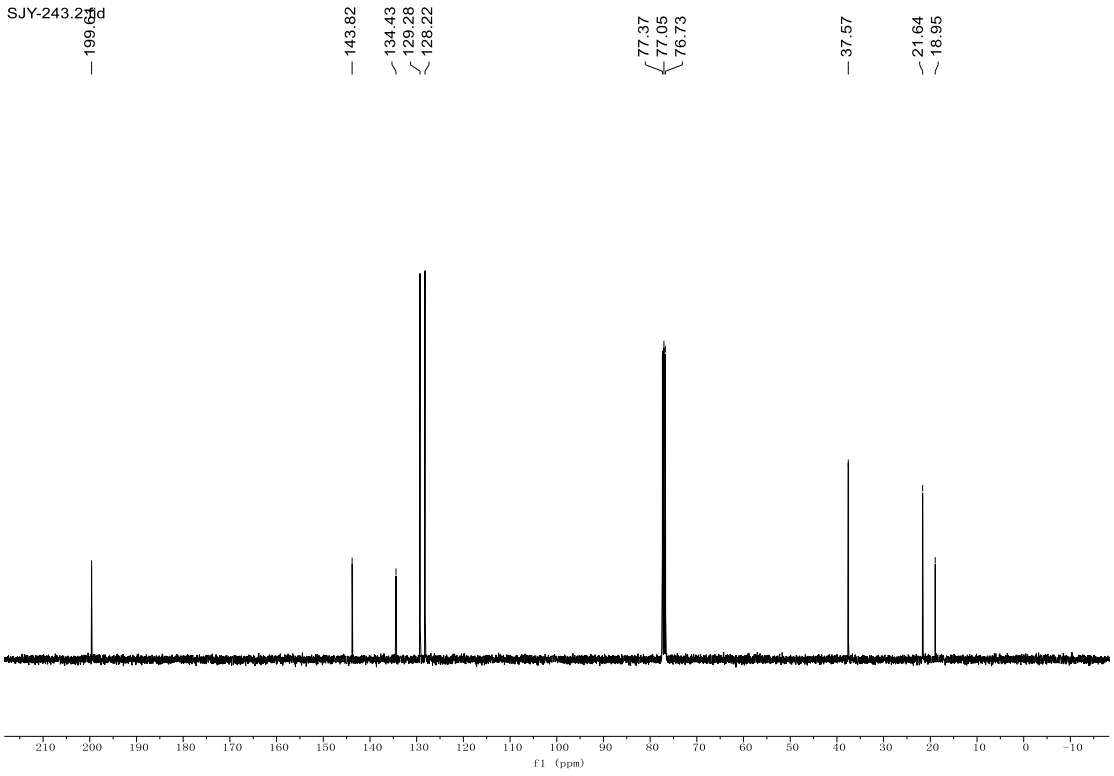


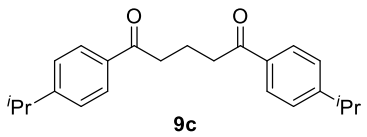
9b

SJY-243.1.fid



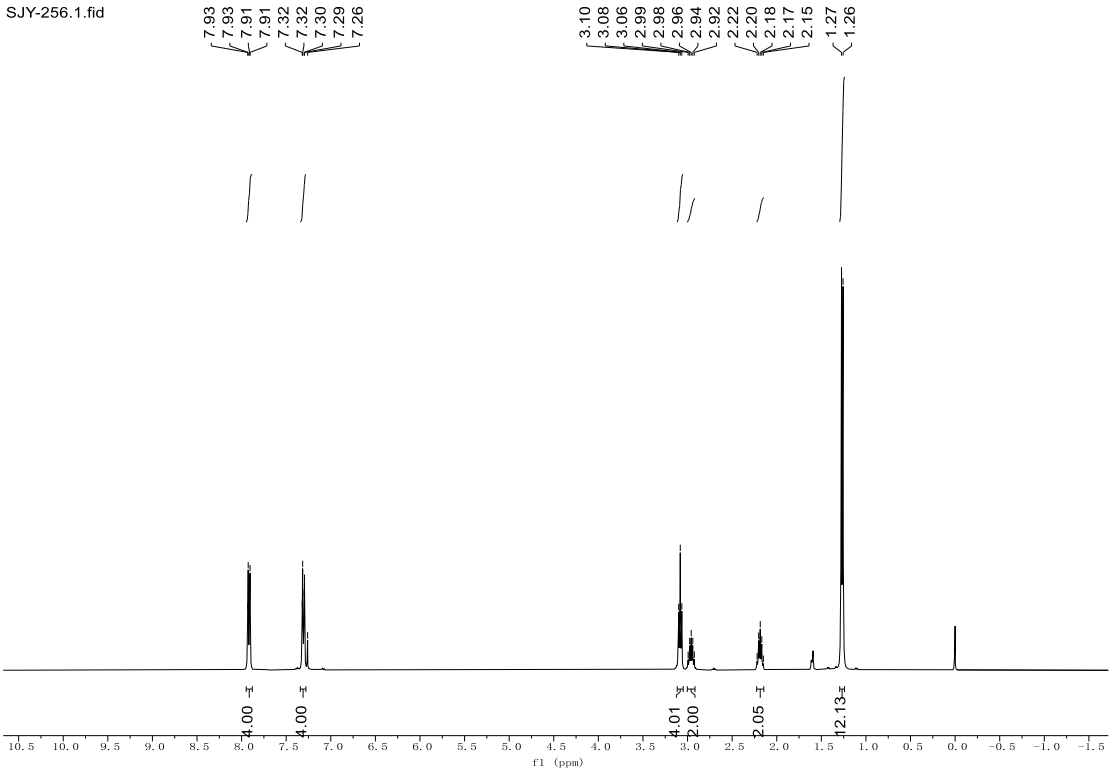
SJY-243.2.fid



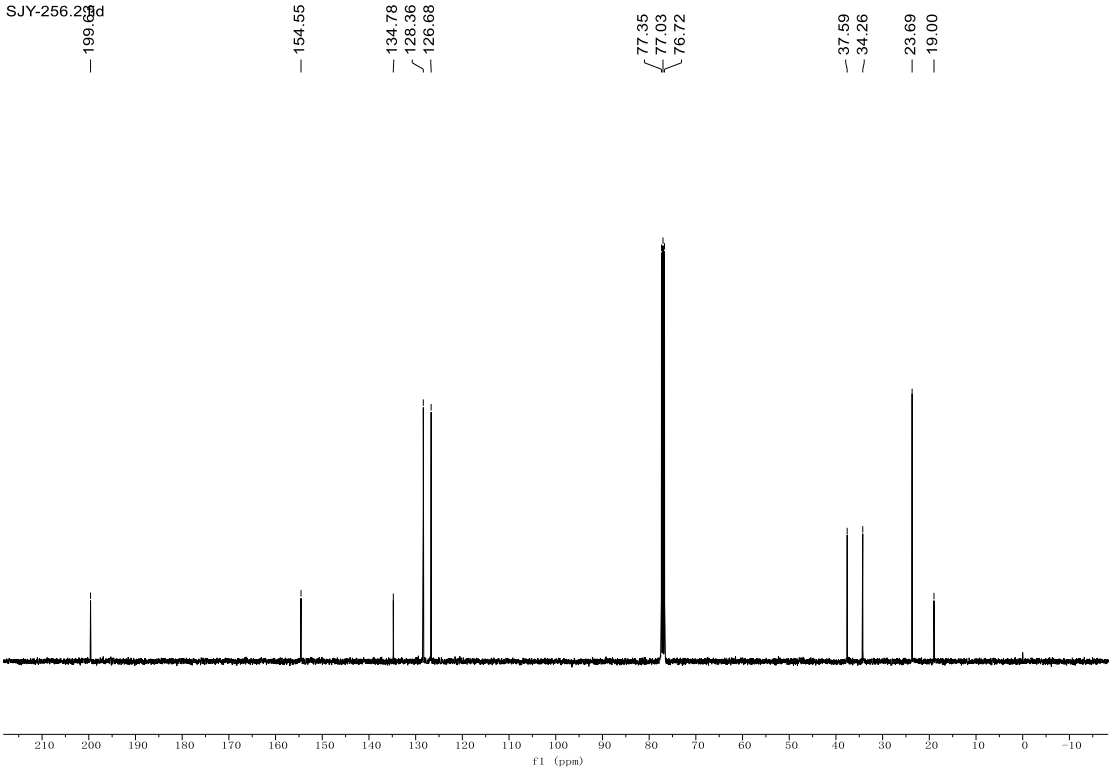


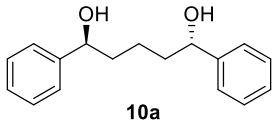
9c

SJY-256.1.fid



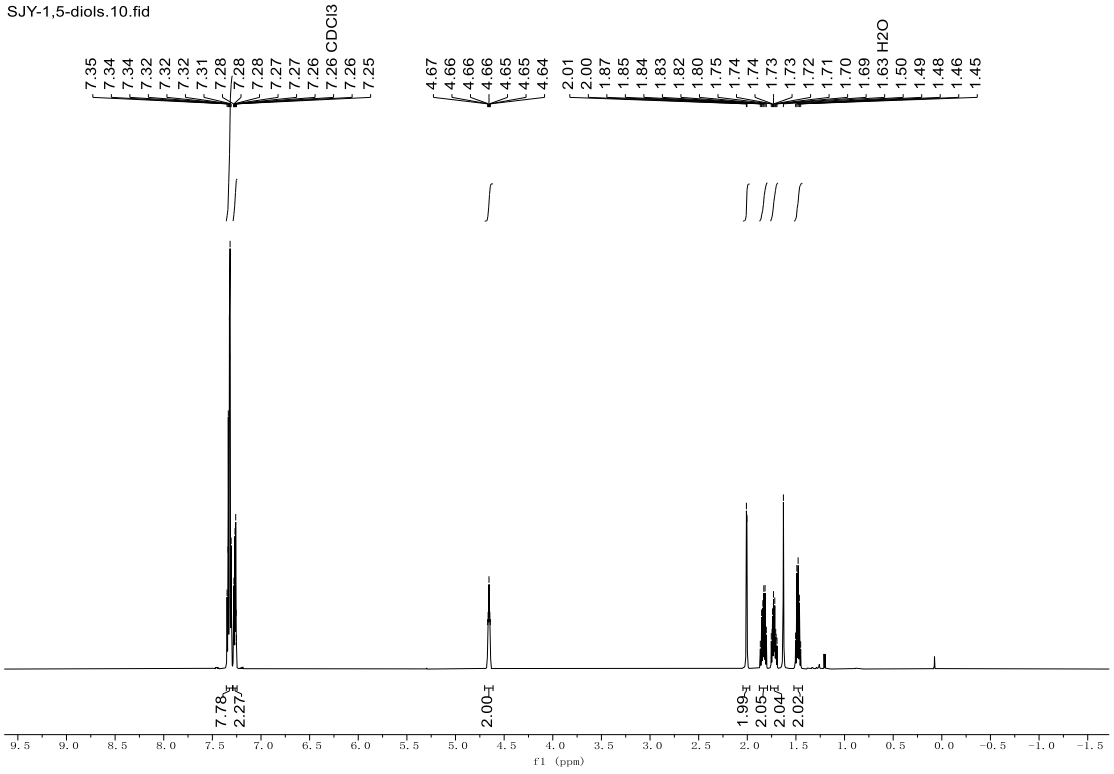
SJY-256.2.fid



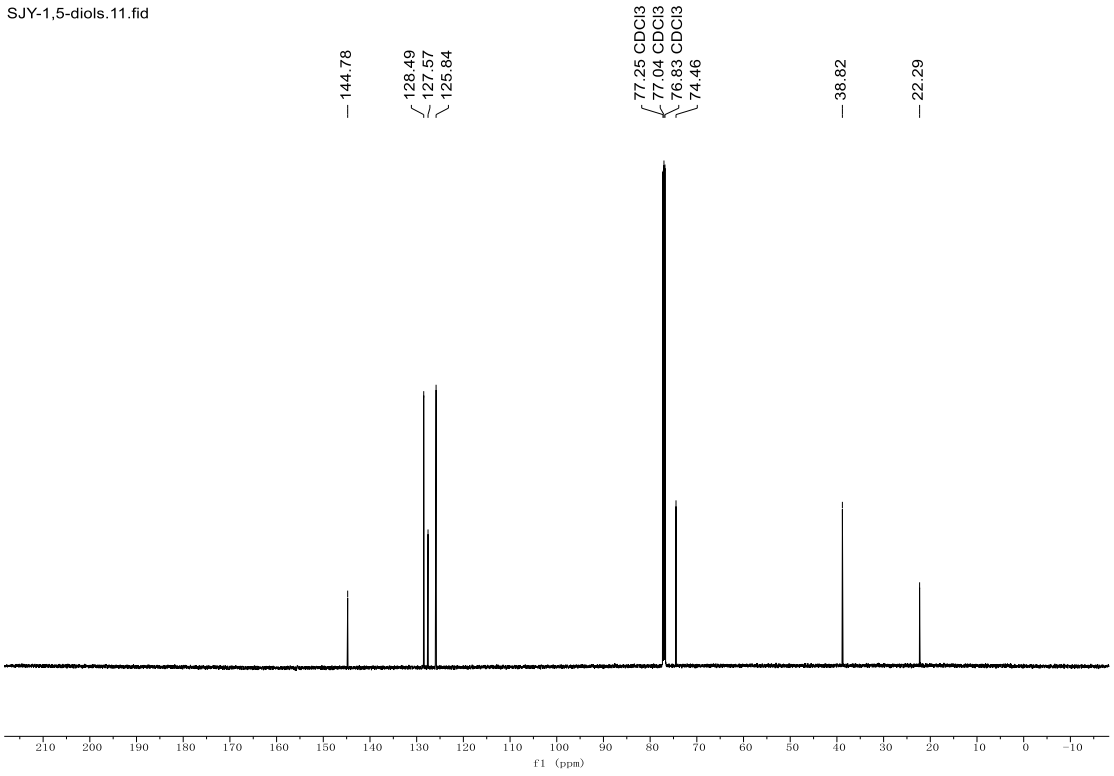


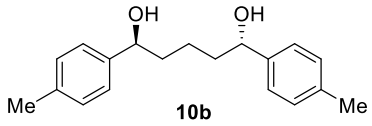
10a

SJY-1,5-diols.10.fid



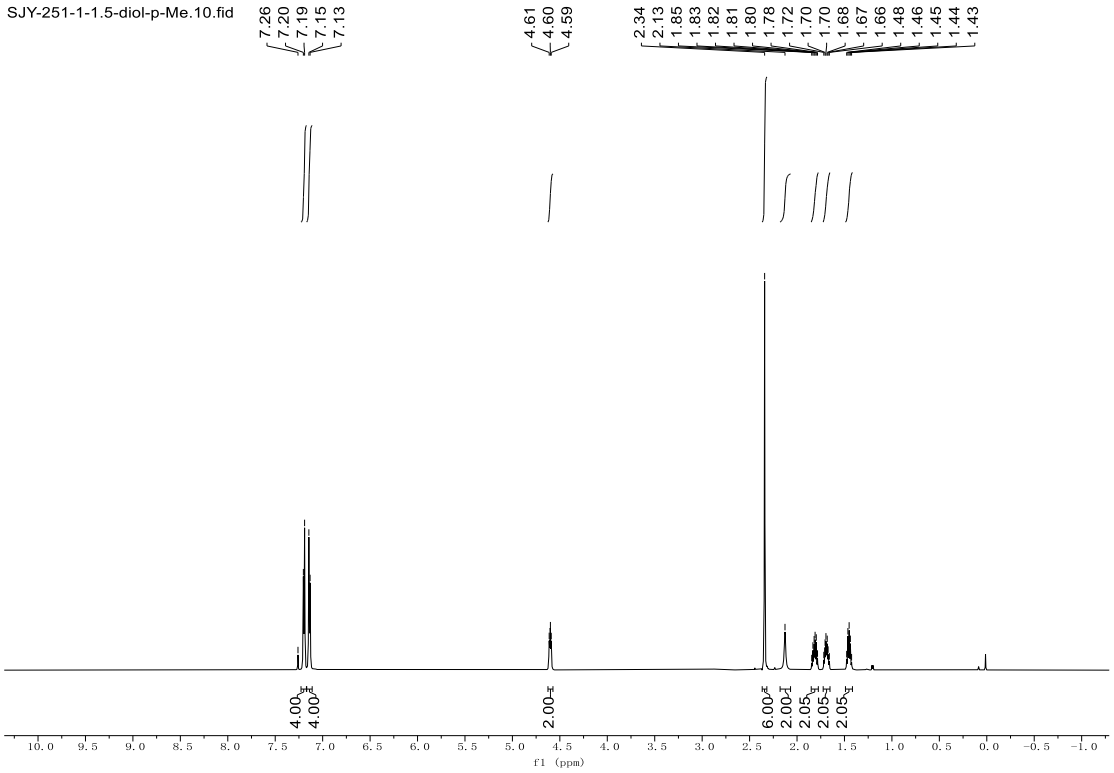
SJY-1,5-diols.11.fid





10b

SJY-251-1-1.5-diol-p-Me.10.fid



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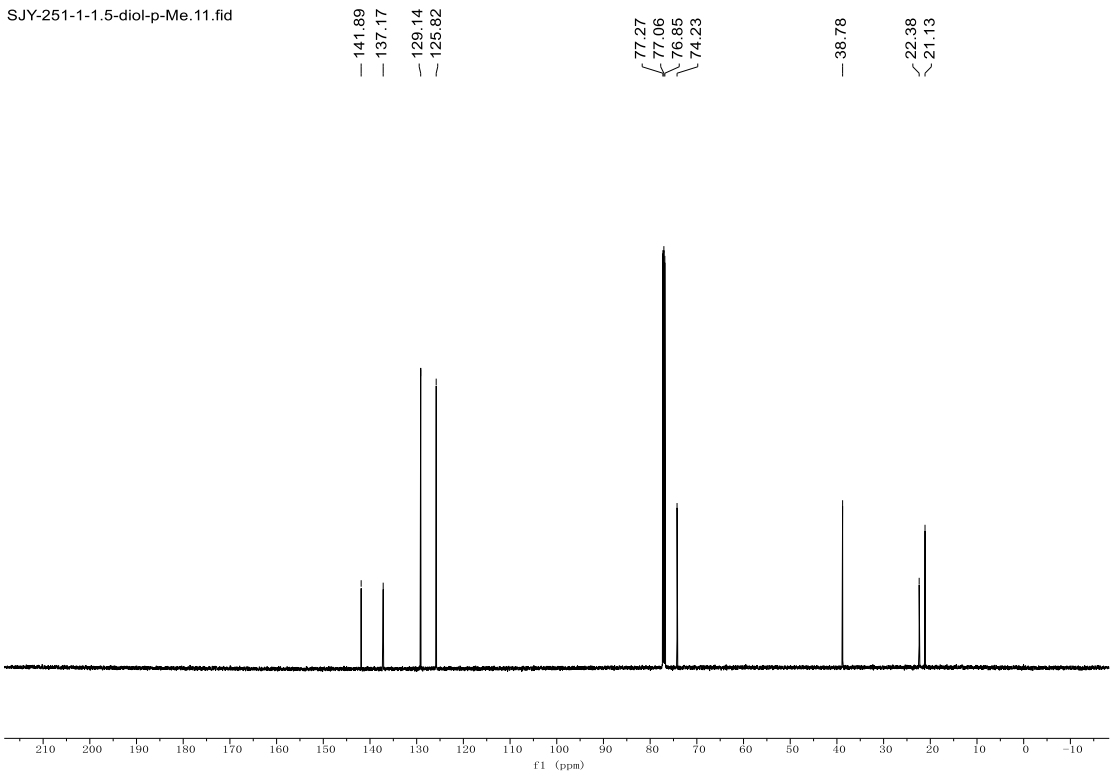
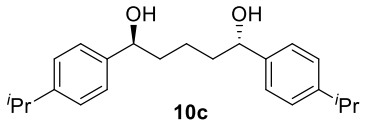
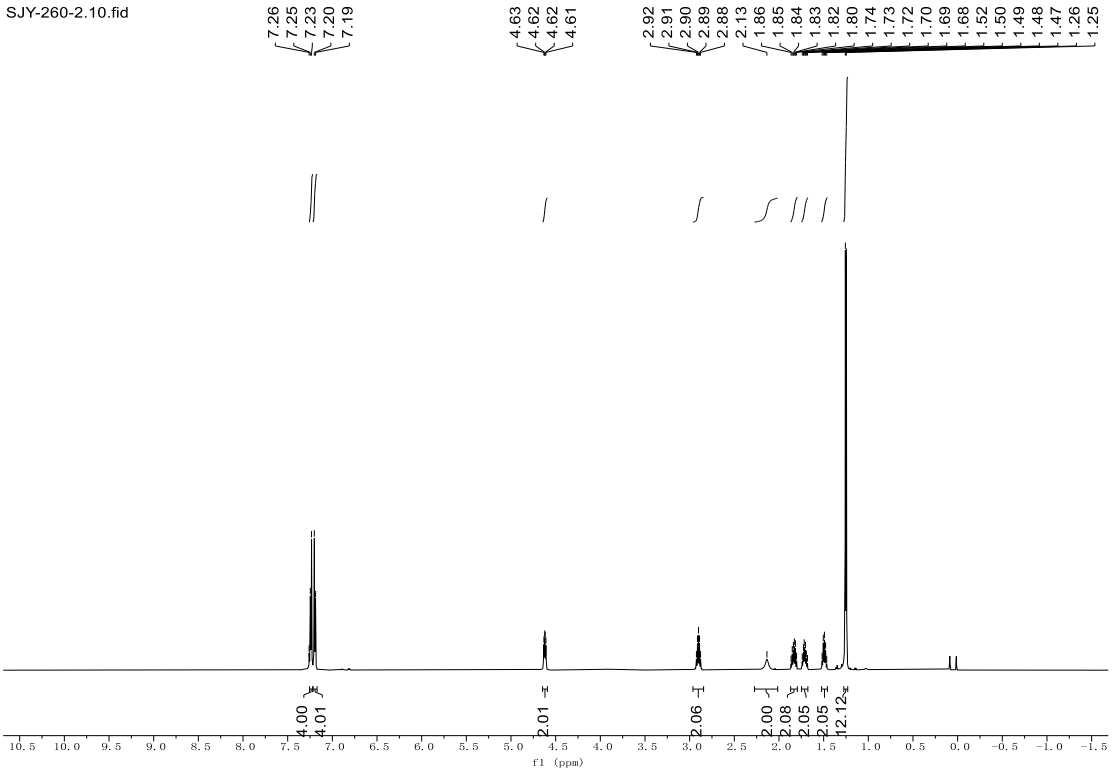




10c

SJY-260-2.10.fid



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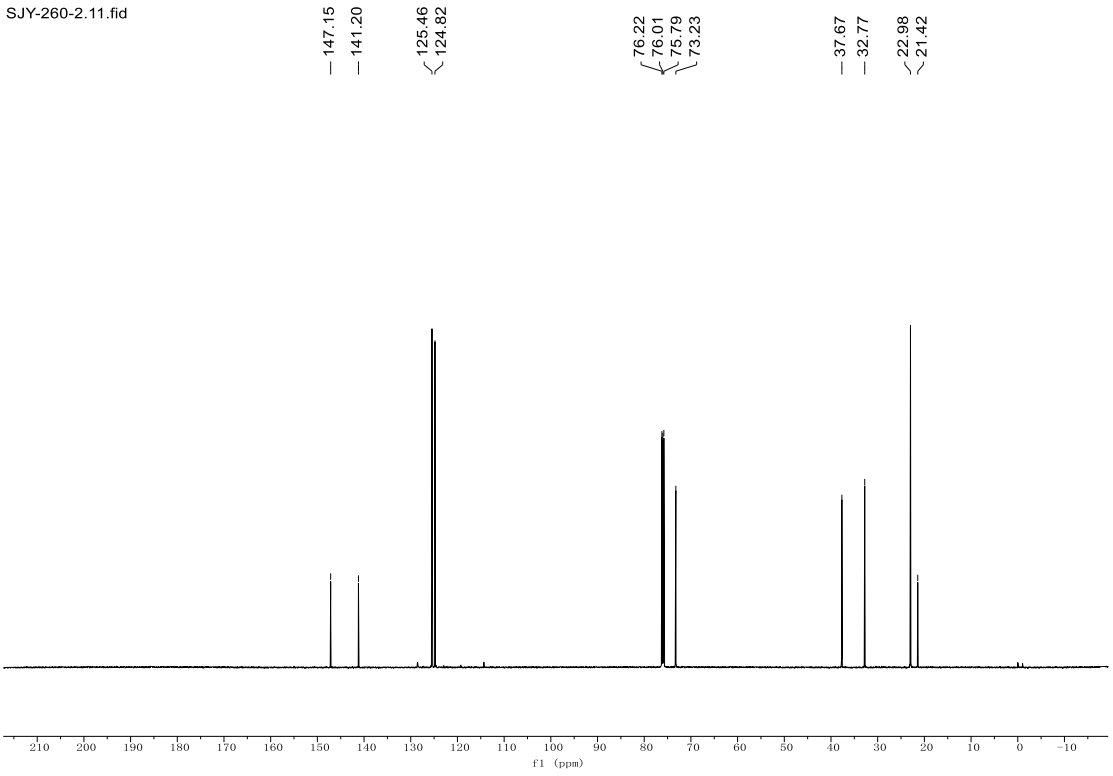
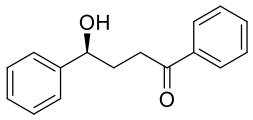
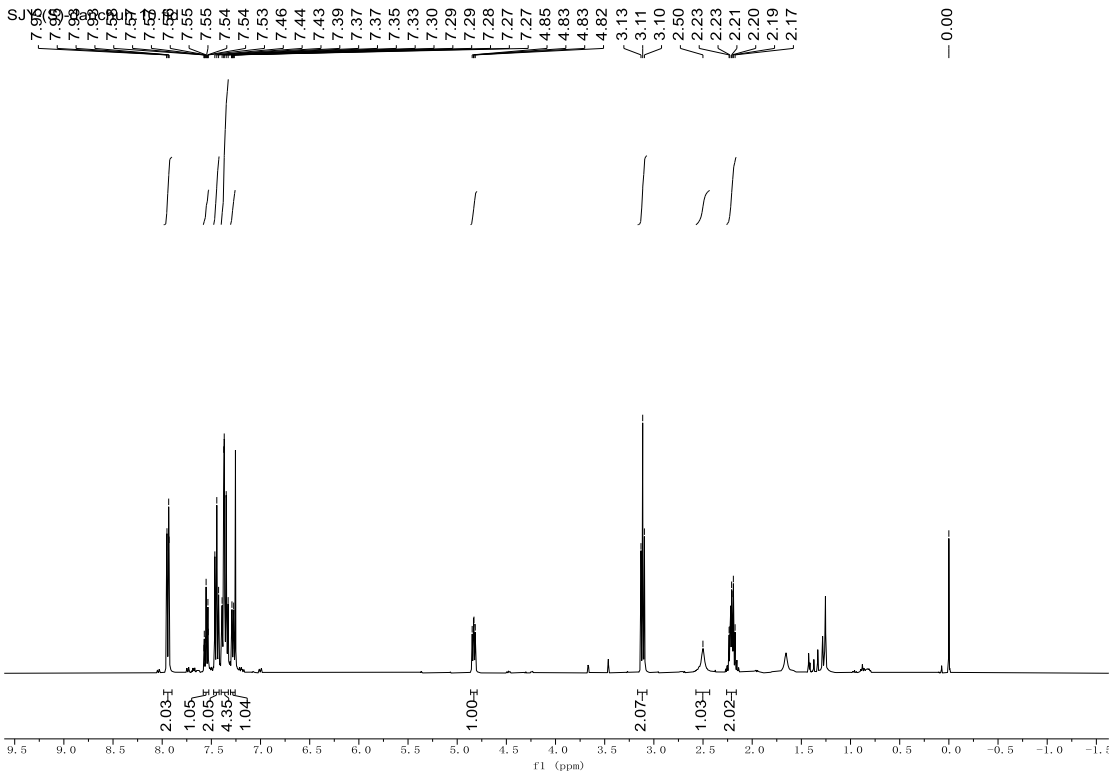
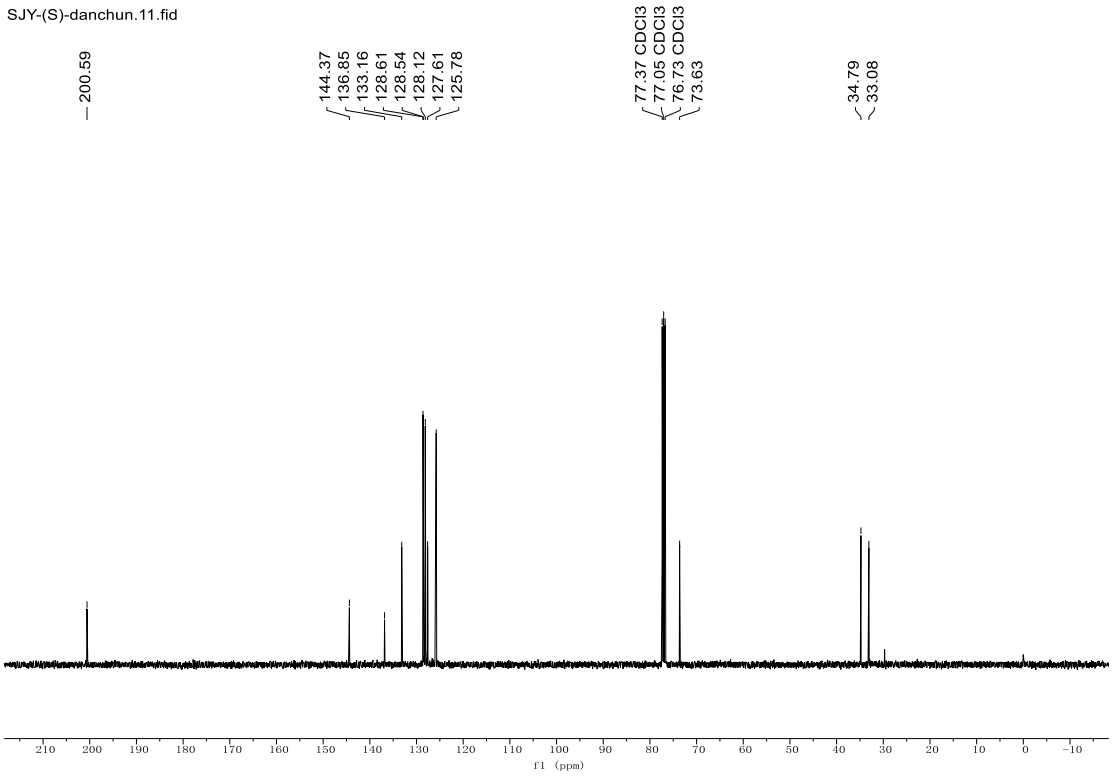
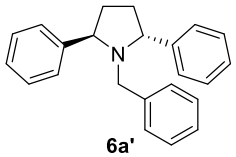



OH
O

5a'

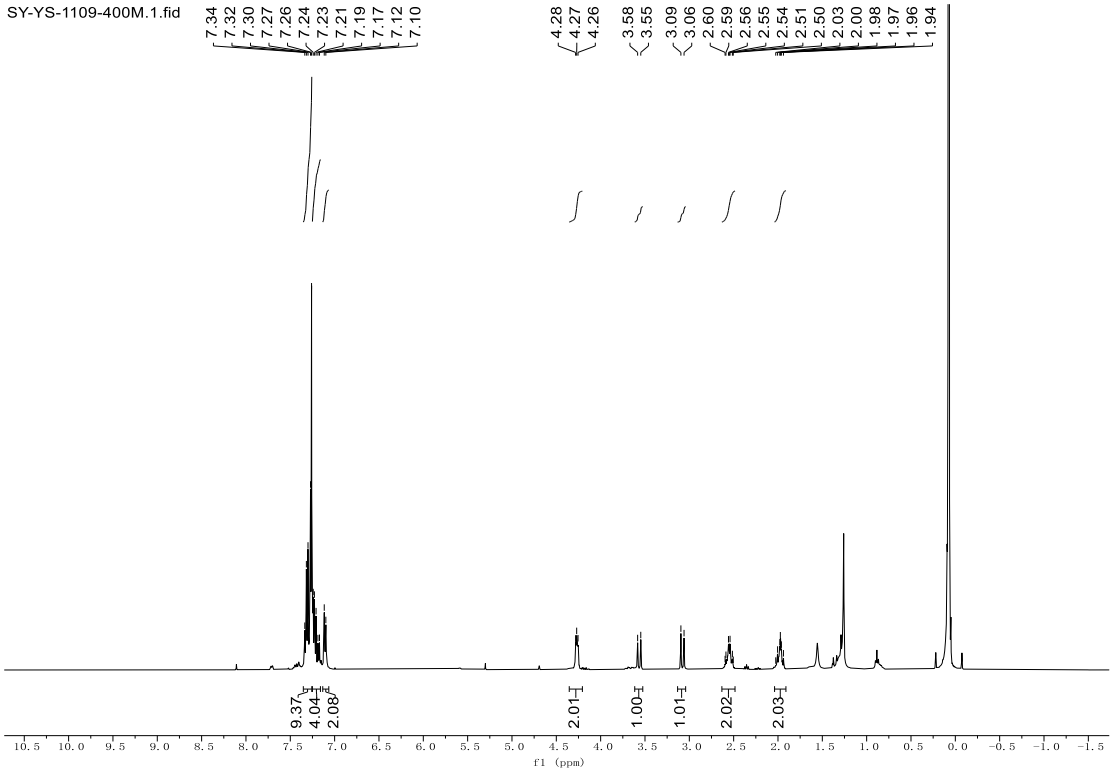

7.55
7.54
7.54
7.53
7.46
7.44
7.43
7.39
7.37
7.37
7.35
7.33
7.30
7.29
7.29
7.28
7.27
7.27
4.85
4.83
4.83
4.82
3.13
3.11
3.10
2.50
2.23
2.23
2.21
2.20
2.19
2.17
0.00
2.03
1.05
2.05
4.35
1.04
1.00
2.07
1.03
2.02
f1 (ppm)


SJY-(S)-danchun.11.fid
200.59
144.37
136.85
133.16
128.61
128.54
128.12
127.61
125.78
77.37 CDCl3
77.05 CDCl3
76.73 CDCl3
73.63
34.79
33.08
f1 (ppm)



6a'

SY-YS-1109-400M.1.fid



SY-YS-1109-400M.2.fid