Asymmetric α-oxyamination of aldehydes by synergistic catalysis of imidazolethiones and metal salts

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Electronic Supplementary Information

Content

General Experimental Details

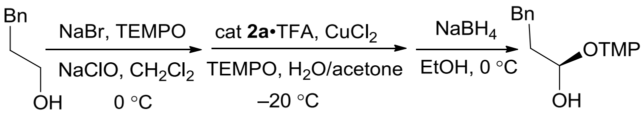
General Information:

All commercial solvents and reagents were used as obtained without further purification. Flash column chromatography was performed using silica-gel (200-400 mesh). Optical rotations were measured on Perkin Elmer Model 341 digital polarimeter. Mass spectra were measured with Termo Finnigan LCQ-Advantage. ^{1}H NMR and ^{13}C NMR spectra were recorded at VARIAN-400 operating at 400 MHz and 100 MHz respectively, and chemical shifts were referenced to internal tetramethylsilane (TMS, δ = 0.0 ppm) for ^{1}H, the central line of $CDCl_3$ (δ = 77.0 ppm) for ^{13}C. Enantiomeric excesses of products were determined by HPLC using a Daicel Chiralcel AD-H, OD-H or AY-H column and eluting with hexane/*i*-PrOH.

Typical procedures for the synthesis of imidazolethione 2a:

Imidazolidinones were prepared according to the literature[1]. Lawsson's reagent was used as the thio reagent of carbonyl. Lawsson's reagent (2.43 g, 6 mmol) were added to the solution of imidazolidinone **1a** (2.18 g, 10 mmol) in 30 mL toluene. The reaction mixture was stirred at 70 ℃ under nitrogen atmosphere for the given time (monitored by TLC). Then the solvent was evaporated under vacuum, and the residue was purified by flash column chromatography over silica gel (petroleum ether/CH_2Cl_2/EtOAc 4:1:1) to get the corresponding imidazolethione **2a** in 95% yield. The obtained imidazolidinones catalyst (2.34 g, 10 mmol) was added to a dried round bottom flask with 10 mL of ether and cooled to 0 ℃. While stirring vigorously, TFA (1.20 g, 10.5 mmol) was added dropwise, and the cooling bath was removed. The mixture was stirred for 0.5 h, while slowly warming to room temperature, after which it was filtered, and the solid was washed with 30 mL EtOAc (10 ml × 3) to yield the catalyst salt as a white solid.

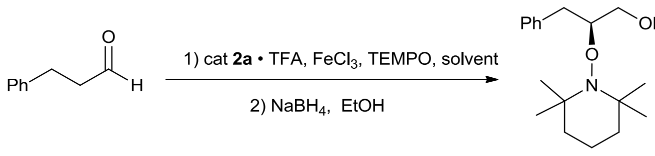
General procedure for the the synthesis of (*S*)-3-cyclohexyl-2-((2,2,6,6-tetrameth-yl piperidin-1-yl)oxy)propan-1-ol (5a)



3a **5a**

A mixture of NaBr (0.021 g, 0.2 mmol), TEMPO (0.016 g, 0.1 mmol), and 3-phenylpropanol (0.136 g, 1 mmol) in CH_2Cl_2 (1 mL) was stirred at 70 ℃. 10% NaClO aqueous solution (1.120 g, 1.5 mmol, pH = 8.5-9.5, which was adjusted by $NaHCO_3$) was added dropwise. The mixture was stirred for 15 minutes at 0 ℃. When the oxidation reaction was finished, the α-oxyamination reaction was carried out without isolating intermediates. H_2O (2 mL), acetone (1 mL) , catalyst salt **2a** (0.070 g, 0.2 mmol), $CuCl_2$ (0.014 g, 0.1mmol) and TEMPO (0.234 g, 1.5 equiv.) were added and the mixture were stirred at -20 ℃ for 48 h until the reaction was judged to be complete by TLC. To the mixture in EtOH (5 mL), cooled to 0 ℃, was added $NaBH_4$ (0.076 g, 2 equiv.). The resulting suspension was stirred for 0.5 h and the solution was filtered over silica gel. The filtrate was extracted with CH_2Cl_2 (10mL × 3). The combined organic layer was dried over Na_2SO_4, The solvent was removed with a rotary evaporator. The residue was purified silica-gel chromatography (petroleum ether/EtOAc 15:1) to afford the desired product **5a**.

Table 1 Solvent screening for *α*-oxyamination of aldehyde:

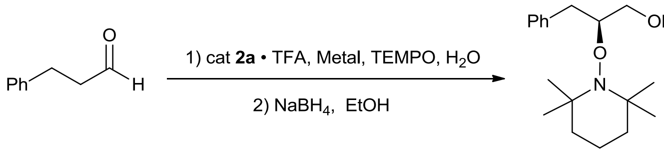


3a 5a

Entry	Solvent	Yield[b] (%)	ee[c] (%)
1	DMF	65	73
2	actone	24	n.d.[d]
3	*i*-PrOH	13	n.d.
4	CH_2Cl_2	trace	n.d.
5	THF	trace	n.d.
6	CH_3CN	trace	n.d.
7	MeOH	20	n.d.
8	H_2O	85	75
9	H_2O/DMF (v/v = 4:1)	73	67
10	H_2O/ *i*-PrOH (v/v = 4:1)	63	57
11	H_2O/ THF (v/v = 4:1)	77	70
12	H_2O/ CH_2Cl_2 (v/v = 4:1)	85	74
13	H_2O/ CH_2Cl_2 (v/v = 1:1)	53	65
13	H_2O/ CH_2Cl_2 (v/v = 1:4)	8	n.d.

[a] Reaction condition: **3a** (1 mmol), TEMPO (2 mmol), catalyst (20 mol%), TFA (20 mol%), $FeCl_3$ (1 equiv.), Solvent (2 mL), r.t., 3 h; $NaBH_4$ (2 equiv.), 0 ℃; [b] Isolated yield after column chromatography. [c] Enantiomeric excess determined by HPLC analysis. [d] not determined.

Table 2 Synergistic metal salt screening for *α*-oxyamination of aldehyde:



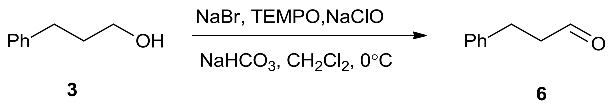
3a 5a

Entry	Metal	T (℃)	t (h)	Yield[b] (%)	ee[c] (%)
1	$FeCl_3$	25	3	85	75
2	$Fe_2(SO_4)_3$	25	3	78	73
3	Fe $(NO_3)_3$	25	3	79	68
4	$FeCl_2$	25	3	83	72
5	$FeSO_4$	25	3	77	72
6	$CuCl_2$	25	3	85	80
7	$CuSO_4$	25	3	77	73
8	$Cu(OTf)_2$	25	3	75	72

9	$Cu(OAC)_2$	25	3	73	63
10	CuCl	25	3	83	85
11	CuBr	25	3	80	83
12[d]	CuCl	-10	24	74	78
13[e]	CuCl	-20	48	65	72
14[e]	$CuCl_2$	-20	48	83	89
15[f]	$CuCl_2$	-20	48	80	90

[a] Reaction condition: **3a** (1 mmol), TEMPO (2 mmol), **2a** (20 mol%), TFA (20 mol%), metal (1 equiv.), H_2O (2 mL), $NaBH_4$ (2 equiv.). [b] Isolated yield after column chromatography. [c] Enantiomeric excess determined by HPLC analysis. [d] H_2O/acetone (v/v = 4:1). [e] H_2O/acetone (v/v = 2:1). [f] $CuCl_2$ (10 mol%), TEMPO (1.5 equiv.).

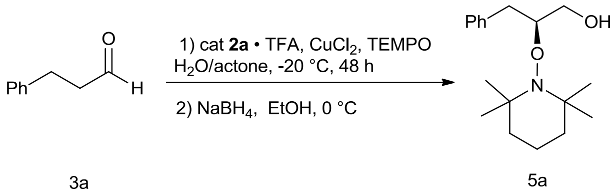
Table 3 Optimization of reaction conditions for oxidation of alcohols:



Entry	NaBr (mol%)	TEMPO (mol%)	NaClO[a] (equiv.)	Yield[b] (%)
1	10	10	1.2	86
2	20	10	1.2	95
3	25	10	1.2	94
4	20	20	1.2	93
5	20	30	1.2	93
6	20	10	1.5	90
7	20	10	1.7	85
8	20	10	2.0	74

[a] 10% NaClO aqueous solution. [b] Isolated yield after column chromatography.

Table 4 Investigation of the amount of TEMPO

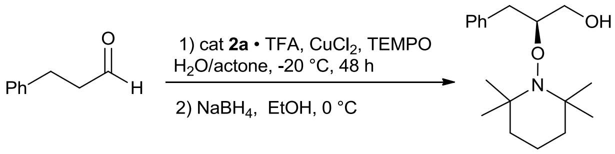


Entry	TEMPO (equiv.)	Yield[b] (%)	ee[c] (%)
1	2.5	84	88
2	2	83	89
3	1.8	82	88
4	1.5	81	90
5	1.3	72	90
6	1.0	65	89

[a] Reaction condition: **3a** (1 mmol), $CuCl_2$ (1 equiv.), catalyst **2a** (20 mol%), TFA (20 mol%), H_2O (2 mL), actone (1 mL), -20 ℃,

48 h, $NaBH_4$ (2 equiv.), 0 ℃, 0.5 h; [b] Isolated yield after column chromatography. [c] Enantiomeric excess determined by HPLC analysis.

Table 5 Investigation of the amount of $CuCl_2$



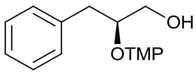
3a 5a

Entry	$CuCl_2$ (equiv.)	Yield[b] (%)	ee[c] (%)
1	1	83	89
2	0.8	83	89
3	0.6	82	88
4	0.4	82	89
5	0.2	81	90
6	0.1	80	90
7	0.05	71	90

[a] Reaction condition: **3a** (1 mmol), TEMPO (1.5 mmol), catalyst **2a** (20 mol%), TFA (20 mol%), H_2O (2 mL), actone (1 mL), -20 ℃, 48 h, $NaBH_4$ (2 equiv.), 0 ℃, 0.5 h; [b] Isolated yield after column chromatography. [c] Enantiomeric excess determined by HPLC analysis.

Experimental characterization data for compounds (5a-5j)

(*S*)-3-phenyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)propan-1-ol (5a)



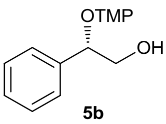
5a

247.4 mg, 85% yield (colorless oil); $[\alpha]_D^{25}$ = -65.4 (c = 0.52, CH_2Cl_2); The enantiomeric purity was determined by HPLC (210 nm, 25 ℃) t_R = 8.0 min (major); t_R = 9.8 min (minor) [Chiralcel OD-H (0.46 cm × 25cm) (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 98/2, 0.8 mL/min] as 90% *ee*. MS (ESI): 292.1 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.29-7.15 (m, 5H), 5.74 (br, 1H), 4.50-4.41 (m, 1H), 4.00-3.92 (m, 1H), 3.64 (d, *J* = 11.8 Hz, 1H), 2.65 (ddd, *J* = 19.0, 13.6, 6.2 Hz, 2H), 1.63-1.33 (m, 6H), 1.29 (s, 3H), 1.21 (s, 3H), 1.11 (s, 3H), 0.97 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 138.0, 129.1, 127.8, 125.8, 80.9, 67.7, 40.2, 39.8, 37.6, 34.5, 32.4, 20.5, 20.2, 17.1.

(*S*)-2-phenyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)ethanol (5b)



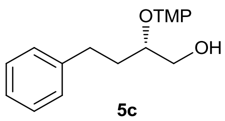
5b

260.4 mg, 94% yield (colorless oil); $[\alpha]_D^{25}$ = -4.53 (c = 0.40, CH_2Cl_2); The enantiomeric purity was determined by HPLC (210 nm, 25 ℃) t_R = 7.3 min (major); t_R = 8.0 min (minor) [Chiralcel AY-H (0.46 cm × 25cm) (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 98/2, 1.0 mL/min] as 4% *ee*. MS (ESI): 278.2 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.39-7.22 (m, 5H), 5.86 (br, 1H), 5.31-5.25 (m, 1H), 4.20 (dd, *J* = 12.2, 9.6 Hz, 1H), 3.70 (d, *J* = 11.8 Hz, 1H), 1.75-1.44 (m, 9H), 1.33 (s, 3H), 1.21 (s, 3H), 1.14 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 138.9, 128.19, 127.7, 126.7, 83.87, 69.4, 61.6, 60.5, 40.45, 34.6, 32.86, 20.9, 20.59, 17.3.

(*S*)-4-phenyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)butan-1-ol (5c)



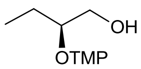
5c

244 mg, 80% yield (colorless oil); $[\alpha]_D^{25}$ = -53.5 (c = 1.42, CH_2Cl_2); The enantiomeric purity was determined by HPLC (210 nm, 25 ℃) t_R = 12.6 min (minor); t_R =14.7 min (major) [Chiralcel OD-H (0.46 cm × 25cm) (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 98/2, 0.8mL/min] as 89% *ee*. MS (ESI): 306.4 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.28-7.14 (m, 5H), 6.00 (br, 1H), 4.30-4.24 (m, 1H), 4.00 (dd, *J* = 12.0, 10.0 Hz, 1H), 3.58 (d, *J* = 11.6 Hz, 1H), 2.85-2.78 (m, 1H), 2.73-2.60 (m, 1H), 1.70-1.46 (m, 8H), 1.34 (s, 3H), 1.25 (s, 3H), 1.20 (s, 3H), 1.13 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 141.8, 128.2, 125.7, 79.5, 68.5, 61.6, 60.0, 40.5, 40.0, 34.6, 33.0, 32.6, 32.2, 20.6, 17.3.

(*S*)-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)butan-1-ol (5d)



5d

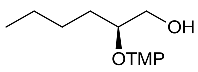
104 mg, 80% yield (colorless oil); $[\alpha]_D^{25}$ = -63.3 (c = 0.98, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃) t_R = 11.5 min (minor); t_R =12.1 min (major) [Chiralcel AD-H (0.46 cm × 25cm) (from Daicel

Chemical Ind., Ltd.) hexane/*i*-PrOH, 98/2, 0.4 mL/min] as 98% *ee*. MS (ESI): 130.0 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.14 (br, 1H), 4.37-4.32 (m, 1H), 3.93 (dd, J = 11.8, 9.8 Hz, 1H), 3.53 (d, J = 11.6 Hz, 1H), 1.74-1.44 (m, 8H), 1.34 (s, 3H), 1.33 (s, 3H), 1.17 (s, 3H), 1.10 (s, 3H), 1.06-0.82 (m, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 81.11, 67.75, 61.15, 59.48, 40.06, 39.63, 34.39, 32.11, 23.91, 20.17, 20.08, 16.96, 10.15.

(*S*)-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)hexan-1-ol (5e)



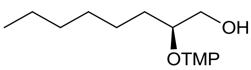
5e

223.6mg, 87% yield (colorless oil); $[\alpha]_D^{25}$ = -42.7 (c 0.50, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃) t_R = 22.5 min (minor); t_R =25.6 min (major) [Chiralcel OD-H (0.46 cm × 25cm) (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 99.9/0.1, 0.2 mL/min→0.6 mL/min] as 89% *ee*. MS (ESI): 258.2 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.04 (br, 1H), 4.39-4.10 (m, 1H), 3.95 (dd, J = 12.0, 9.8 Hz, 1H), 3.57 (d, J = 11.8 Hz, 1H), 1.70-1.34 (m, 12H), 1.33 (s, 3H), 1.32 (s, 3H), 1.17 (s, 3H), 1.11 (s, 3H), 0.90 (t, J = 7.0 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 79.90, 68.50, 61.40, 59.70, 40.3, 39.8, 34.7, 32.3, 30.8, 28.1, 22.9, 20.4, 20.3, 17.2, 14.0.

(*S*)-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)octan-1-ol (5f)



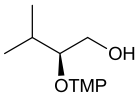
5f

233.2 mg, 88% yield (colorless oil); $[\alpha]_D^{25}$ = -67.4 (c = 0.65, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃) t_R = 11.9 min (minor); t_R =10.4 min (major) [Chiralcel OD-H (0.46 cm × 25cm) (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 99.9/0.1, 0.6 mL/min] as 97% *ee*. MS (ESI): 286.2 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.03 (br, 1H), 4.37-4.15 (m, 1H), 3.95 (dd, J = 12.0, 9.8 Hz, 1H), 3.56 (dd, J = 12.0, 1.8 Hz, 1H), 1.73-1.23 (m, 22H), 1.17 (s, 3H), 1.10 (s, 3H), 0.89 (t, J = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 79.90, 68.6, 61.5, 59.8, 40.3, 39.9, 34.7, 32.4, 31.8, 31.1, 29.5, 25.9, 22.7, 20.5, 20.4, 17.2, 14.2.

(S)-3-methyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)butan-1-ol (5g)



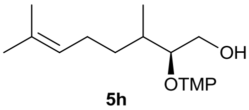
5g

183.0 mg, 75% yield (colorless oil); $[\alpha]_D^{25}$ = -57.8 (c = 1.26, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃). t_R = 8.2 min (minor); t_R =9.7 min (major) [Chiralcel AD-H (0.46 cm × 25cm). (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 98/2, 0.5 mL/min] as 98% *ee*. MS (ESI): 244.0 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.15 (br, 1H), 4.26-3.97 (m, 2H), 3.78-3.46 (m, 1H), 1.75-1.41 (m, 7H), 1.34 (s, 3H), 1.32 (s, 3H), 1.18 (s, 3H), 1.13 (s, 3H), 0.97 (s, 3H), 0.95 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 83.9, 66.6, 61.6, 59.9, 40.3, 39.9, 34.6, 32.1, 30.5, 20.4, 20.3, 19.5, 18.0, 17.1.

(2*S*)-3,7-dimethyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)oct-6-en-1-ol (5h)



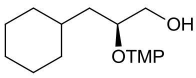
5h

204.2 mg, 77% yield (colorless oil); $[\alpha]_D^{25}$ = -64.0 (c = 1.00, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃). t_R = 22.3 min (major); t_R = 24.3min (minor) [Chiralcel OD-H (0.46 cm × 25 cm). (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 99.9/0.1, 0.2 mL/min→0.6 mL/min] as 99% *ee*. MS (ESI): 312.0$[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.01 (br, 1H), 5.08 (t, *J* = 6.8 Hz, 1H), 4.41-3.96 (m, 2H), 3.60 (dd, *J* = 25.6, 10.6 Hz, 1H), 2.09-1.87 (m, 2H), 1.69 (s, 3H), 1.61 (s, 3H), 1.56 -1.20 (m, 15H), 1.18 (s, 3H), 1.13 (s, 3H), 0.94 (d, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.2, 124.2, 83.4, 82.3, 67.1, 66.1, 61.6, 60.0, 40.4, 40.0, 35.5, 35.1, 34.7, 34.1, 32.5, 32.3, 25.9, 25.7, 20.4, 17.7, 17.1, 16.1, 14.6.

(*S*)-3-cyclohexyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)propan-1-ol (5i)



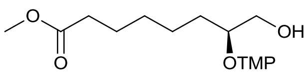
5i

249.5 mg, 84% yield (colorless oil); $[\alpha]_D^{25}$ = -40.28 (c = 1.40, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃). t_R = 14.8 min (major); t_R = 15.5min (minor) [Chiralcel AD-H (0.46 cm × 25 cm). (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 99.5/0.5, 0.5 mL/min] as 95% *ee*. MS (ESI): 298.1 $[M+H]^+$.

^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.16 (br, 1H), 4.37-4.32 (m, 1H), 3.93 (dd, *J* = 11.8, 9.8 Hz, 1H), 3.53 (d, *J* = 11.6 Hz, 1H), 1.83-1.36 (m, 12H), 1.34 (s, 3H), 1.33-1.29 (m, 4H), 1.29-1.18 (m, 3H), 1.17 (s, 3H), 1.10 (s, 3H), 1.06-0.81 (m, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 77.50, 68.9, 61.3, 59.6, 40.3, 39.8, 38.7, 34.6, 34.2, 34.1, 33.2, 32.3, 26.5, 26.3, 26.2, 20.4, 20.3, 17.1.

(*S*)-methyl 8-hydroxy-7-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)octanoate (5j)



5j

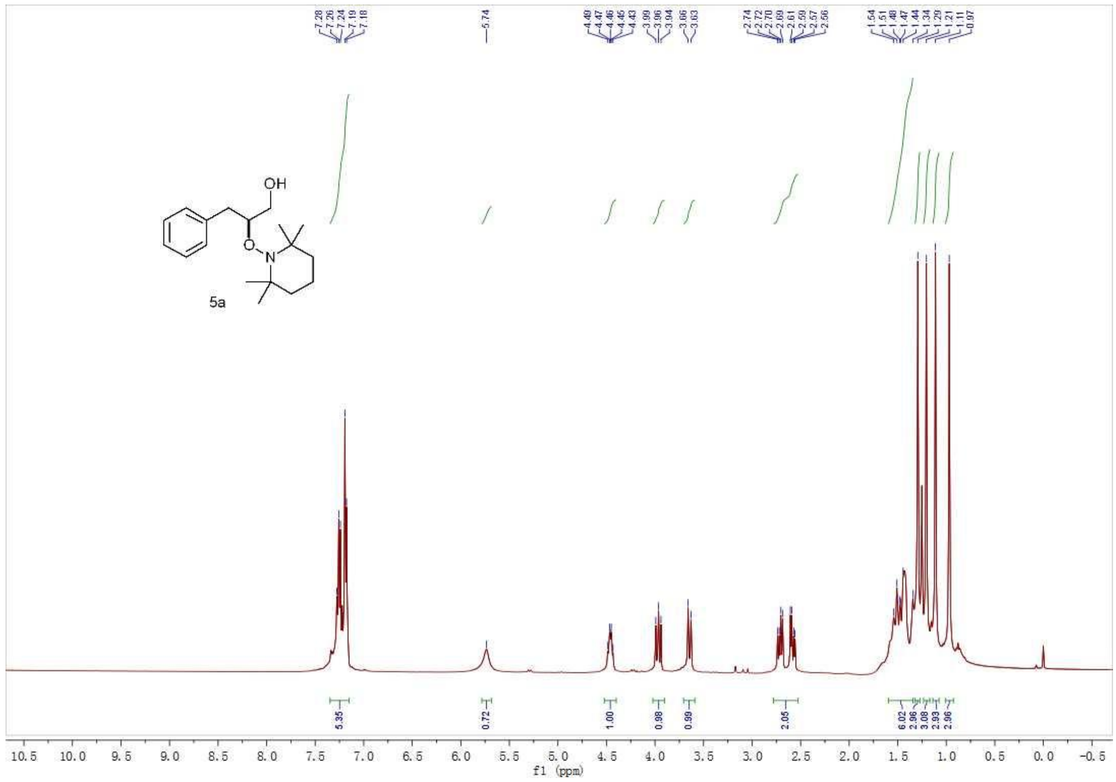
9.3 mg, 87% yield (colorless oil); $[\alpha]_D^{25}$ = -64.6 (c = 0.62, CH_2Cl_2); The enantiomeric purity was determined by HPLC (226 nm, 25 ℃). t_R = 17.8 min (minor); t_R = 20.1min (major) [Chiralcel OD-H (0.46 cm × 25cm). (from Daicel Chemical Ind., Ltd.) hexane/*i*-PrOH, 99/1, 0.4 mL/min] as 97% *ee*. MS (ESI): 330.1 $[M+H]^+$.

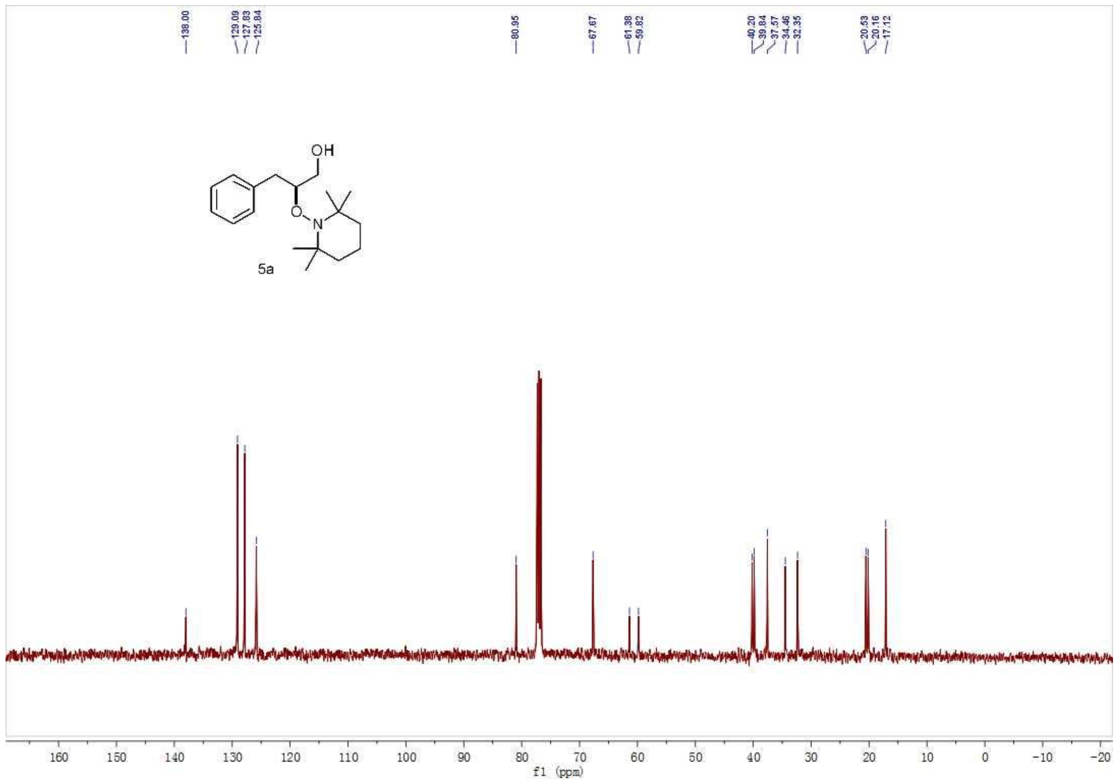
^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.01 (br, 1H), 4.34-4.18 (m, 1H), 4.31-4.24 (m, 1H), 3.66 (s, 3H), 3.62-3.50 (m, 1H), 2.31 (t, *J* = 7.6 Hz, 1H), 1.73-1.22 (m, 20H), 1.17 (s, 3H), 1.11 (s, 3H).

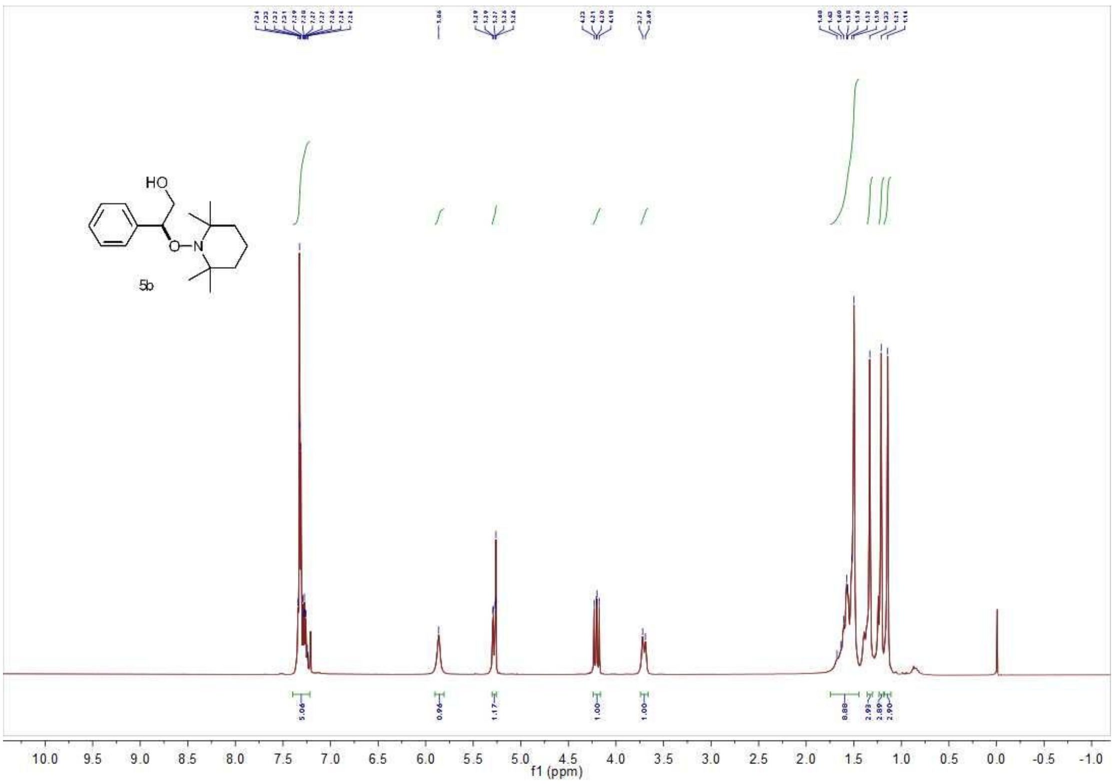
^{13}C NMR (100 MHz, $CDCl_3$) δ = 173.4, 80.0, 68.1, 61.3, 59.7, 51.1, 40.1, 39.6, 34.4, 33.8, 32.1, 30.7, 29.1, 25.3, 24.6, 20.3, 20.2, 17.0.

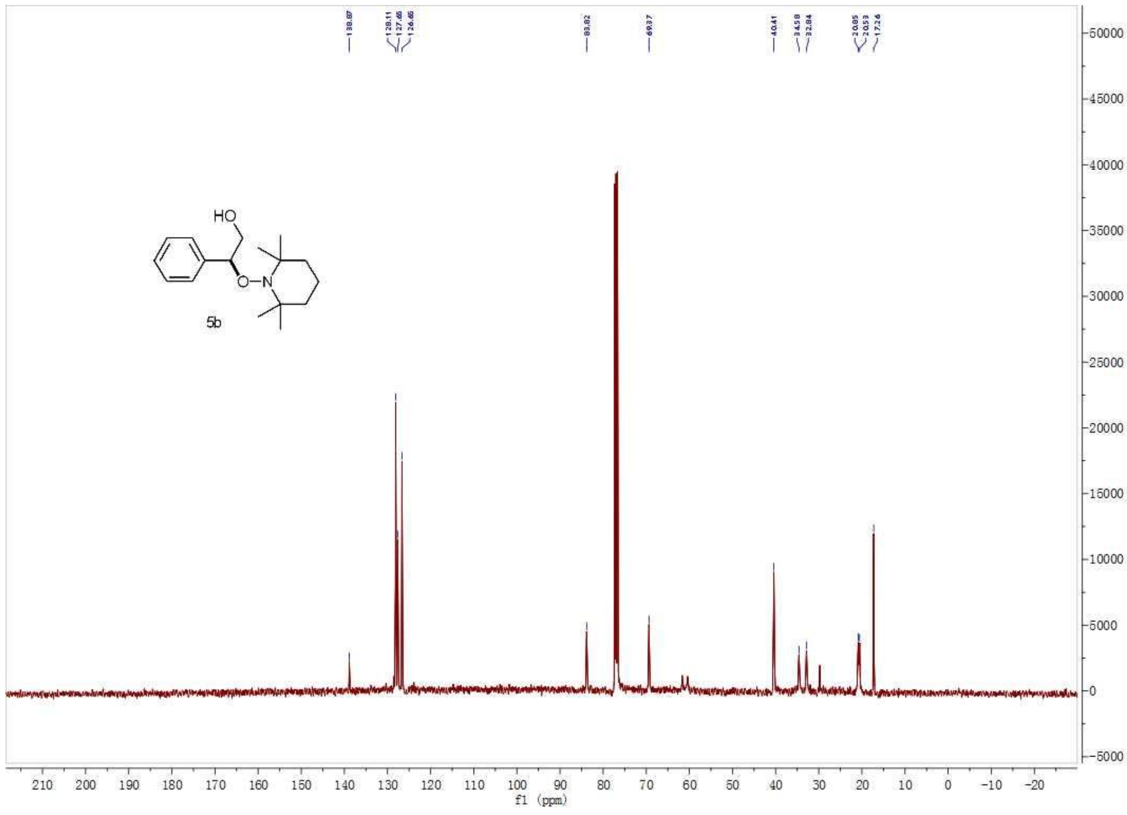
NMR spectra and HPLC analyses for products (5a-5j)

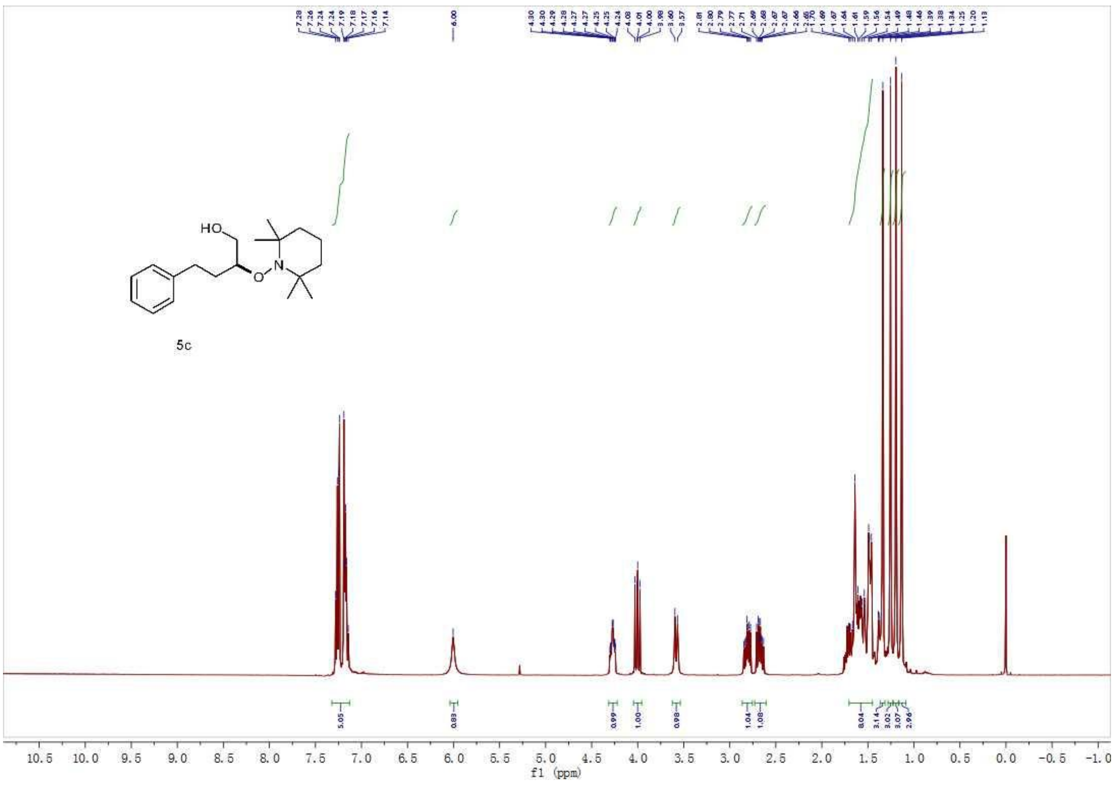
NMR spectra

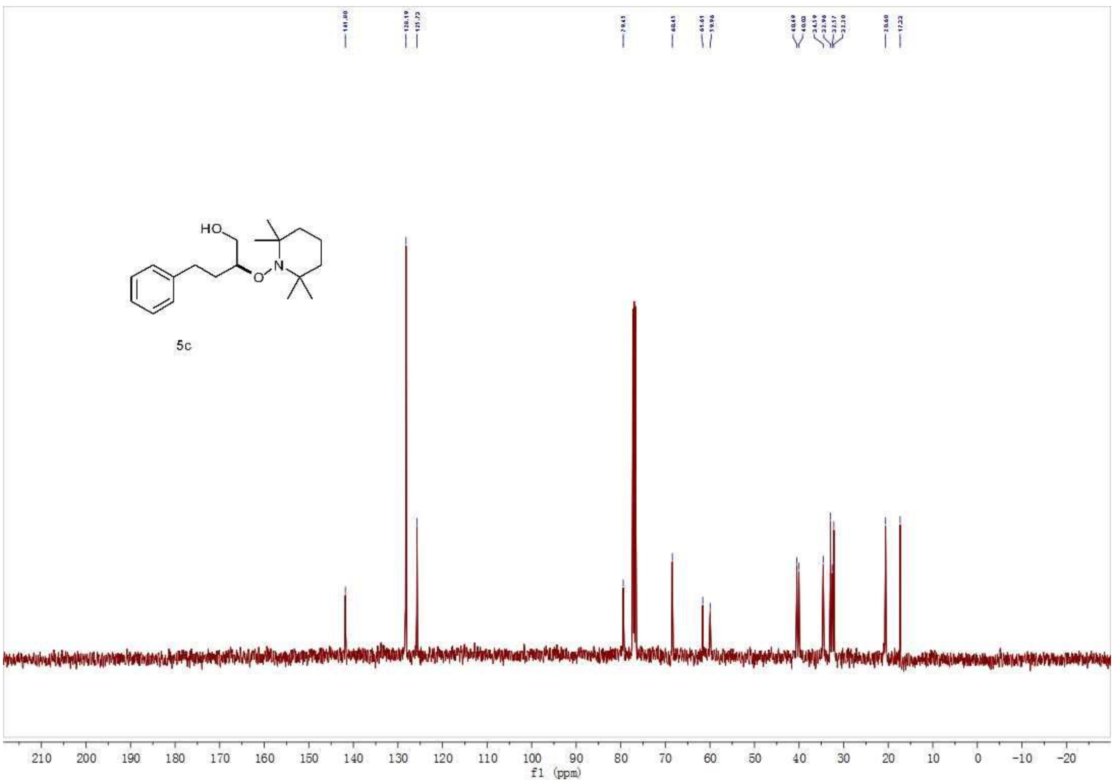


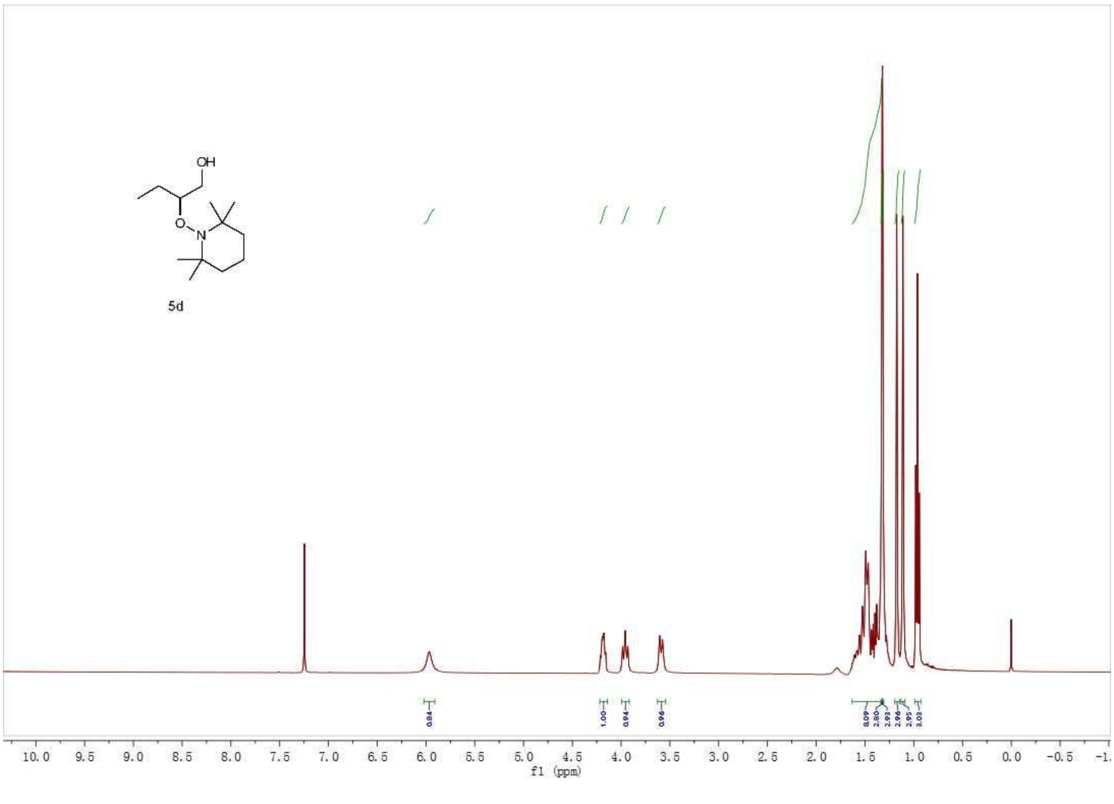



5b
f1 (ppm)

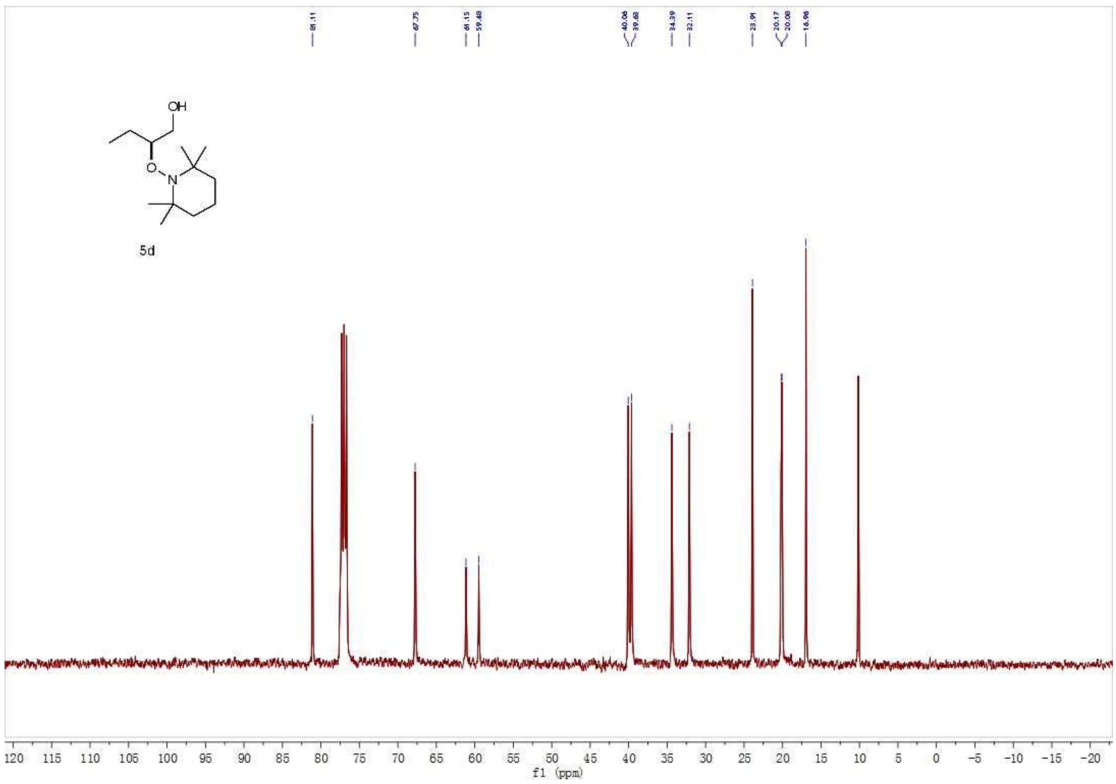

5b
f1 (ppm)



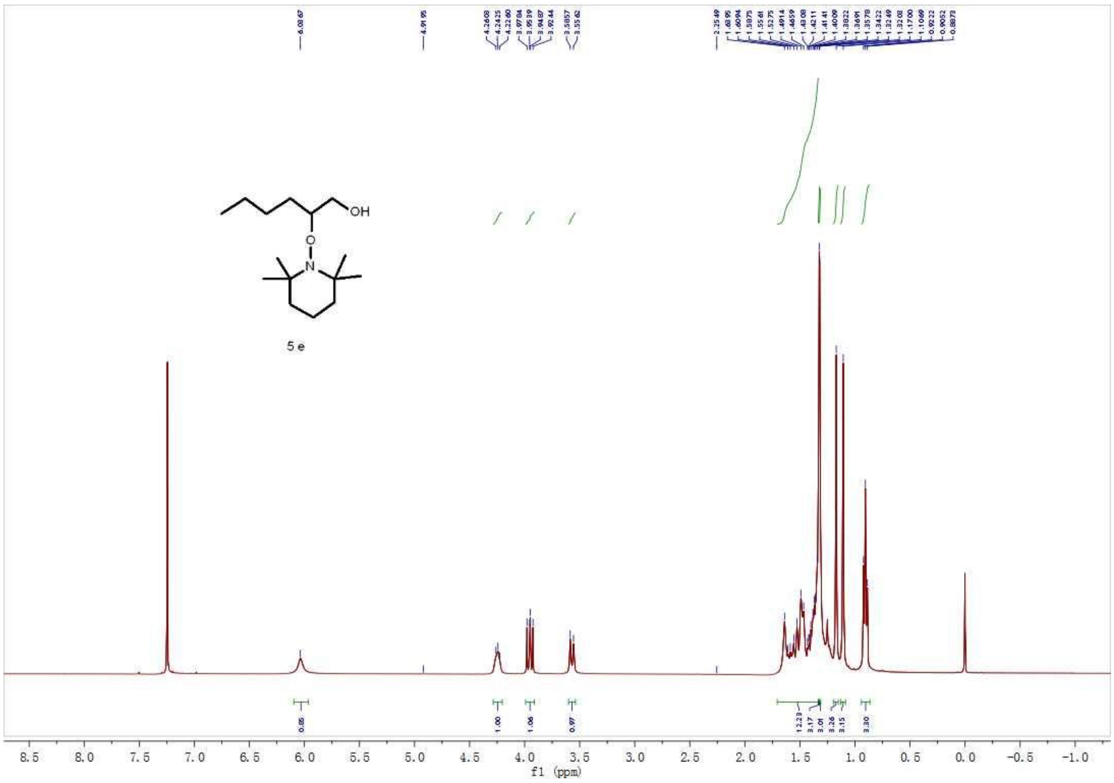


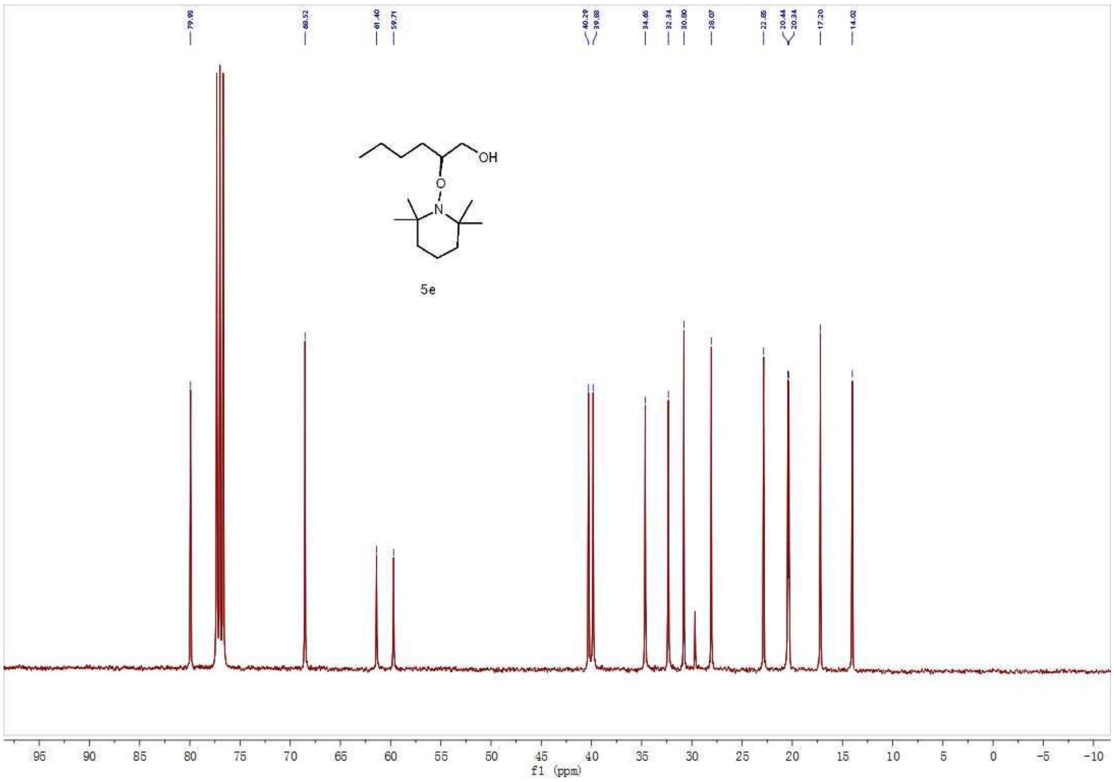


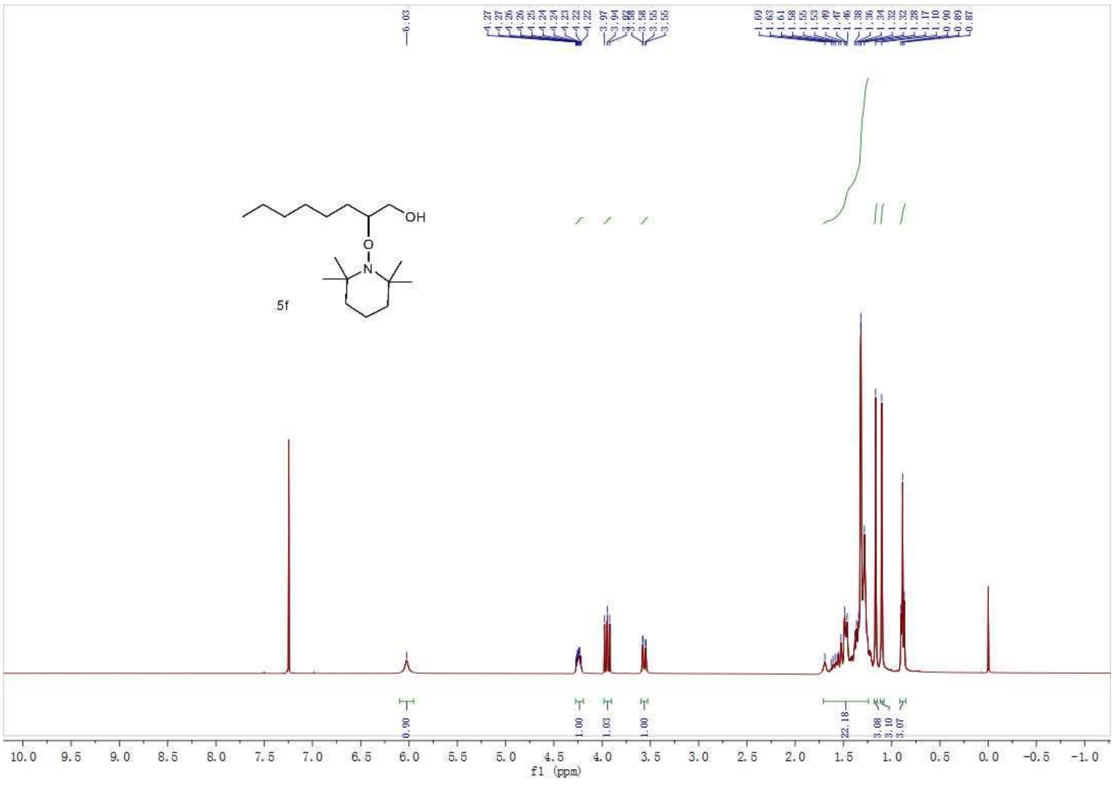
OH
O
N
5d
f1 (ppm)

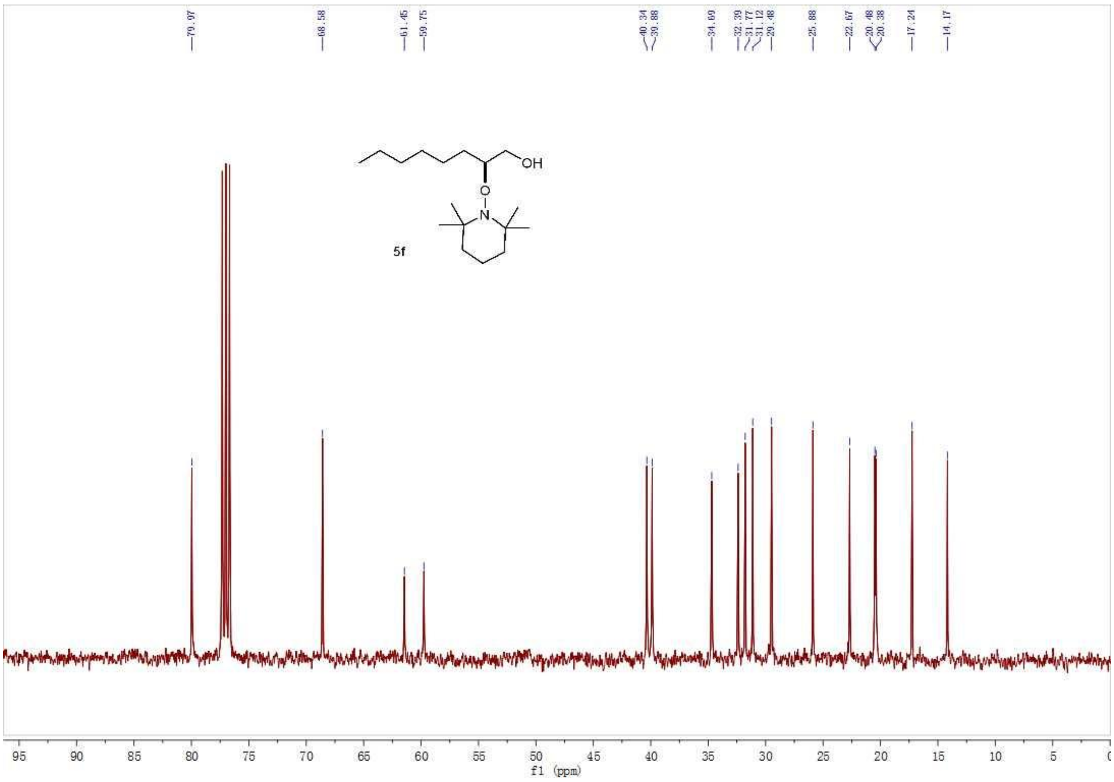


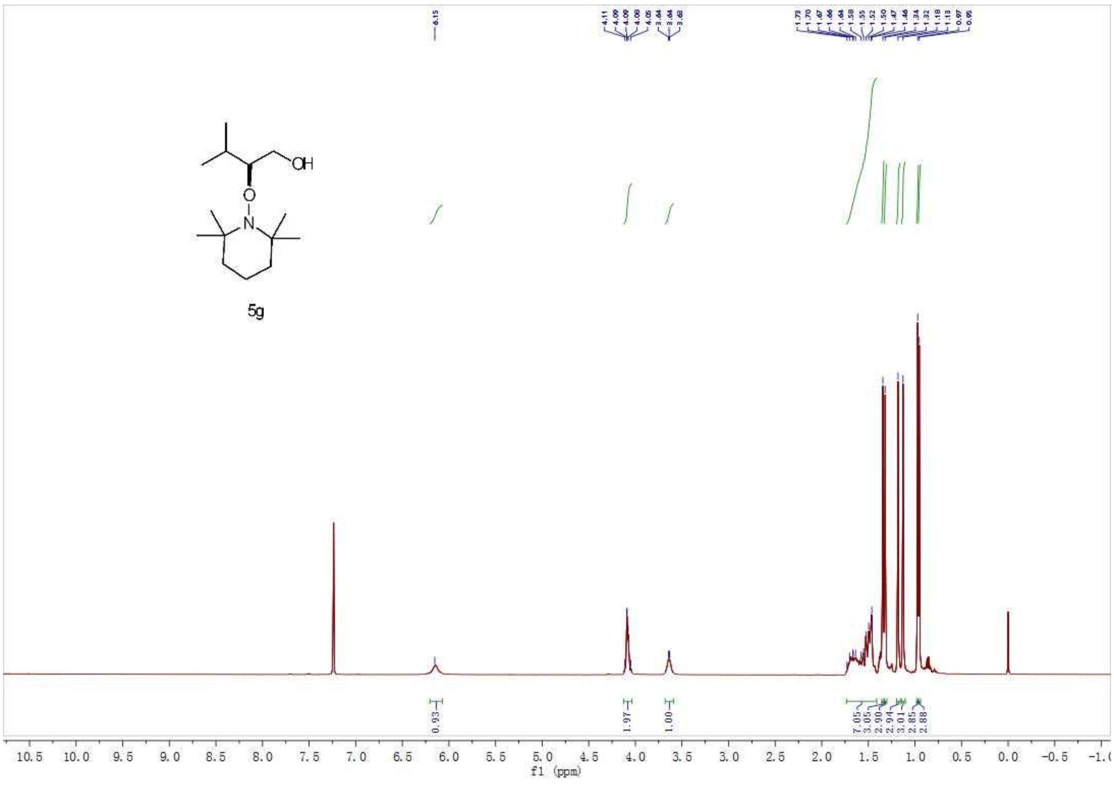
OH
O
N
5d
f1 (ppm)

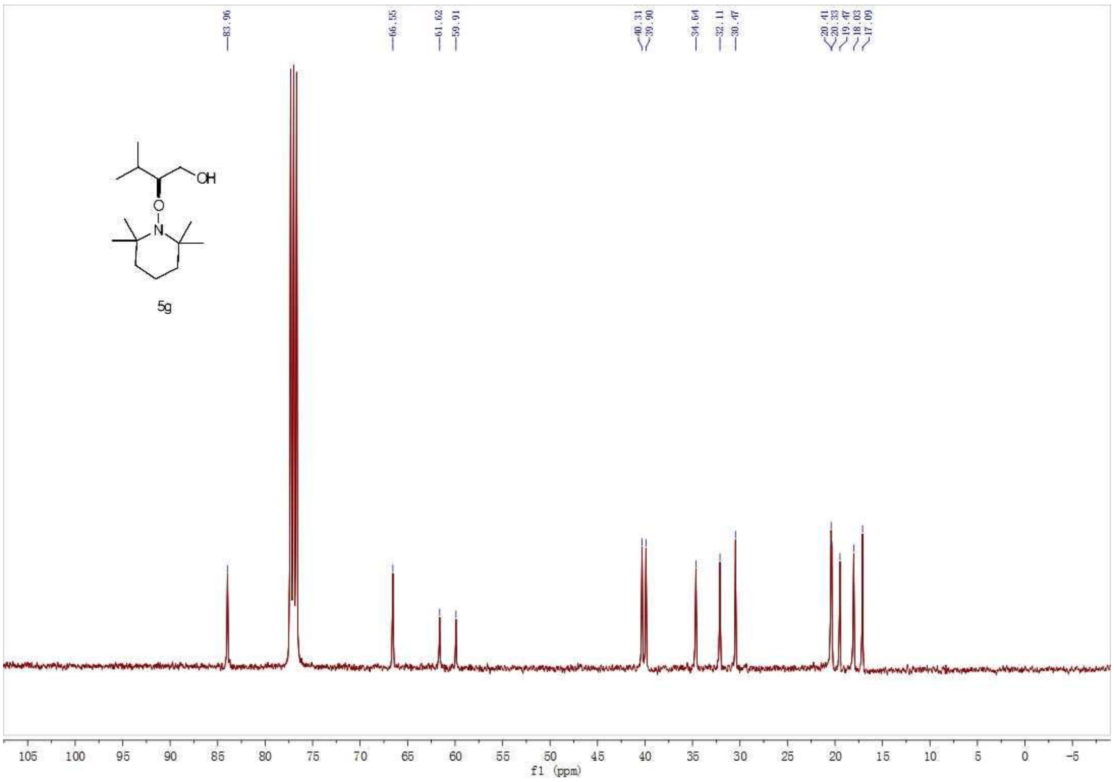


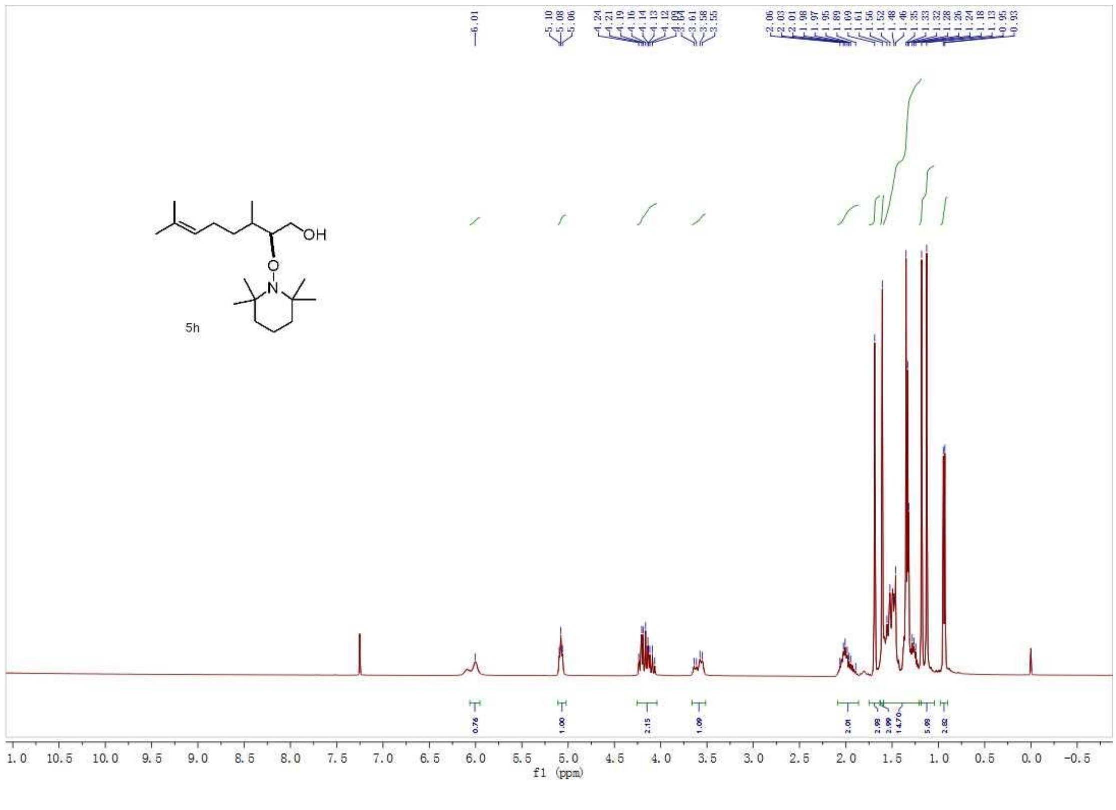


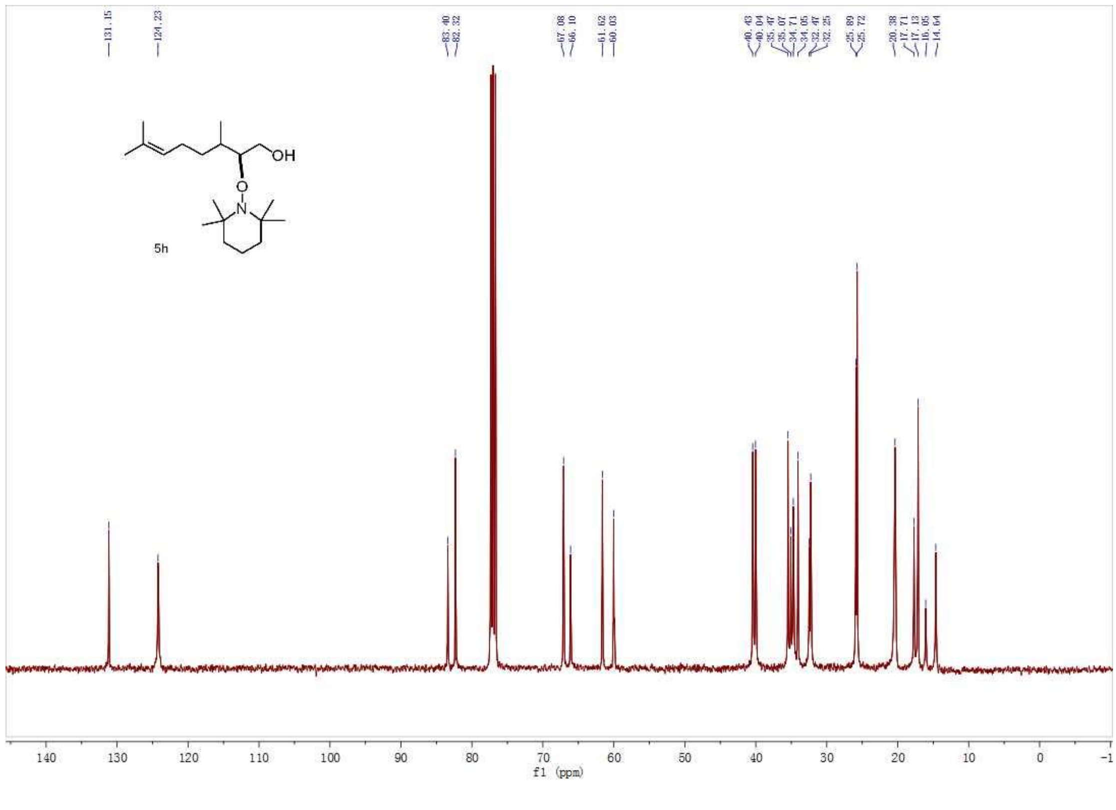

OH
O
N
5f
6.03
3.97
3.94
3.58
3.55
1.69
0.87
0.90
1.00
1.03
1.00
22.18
3.08
3.10
3.07
f1 (ppm)

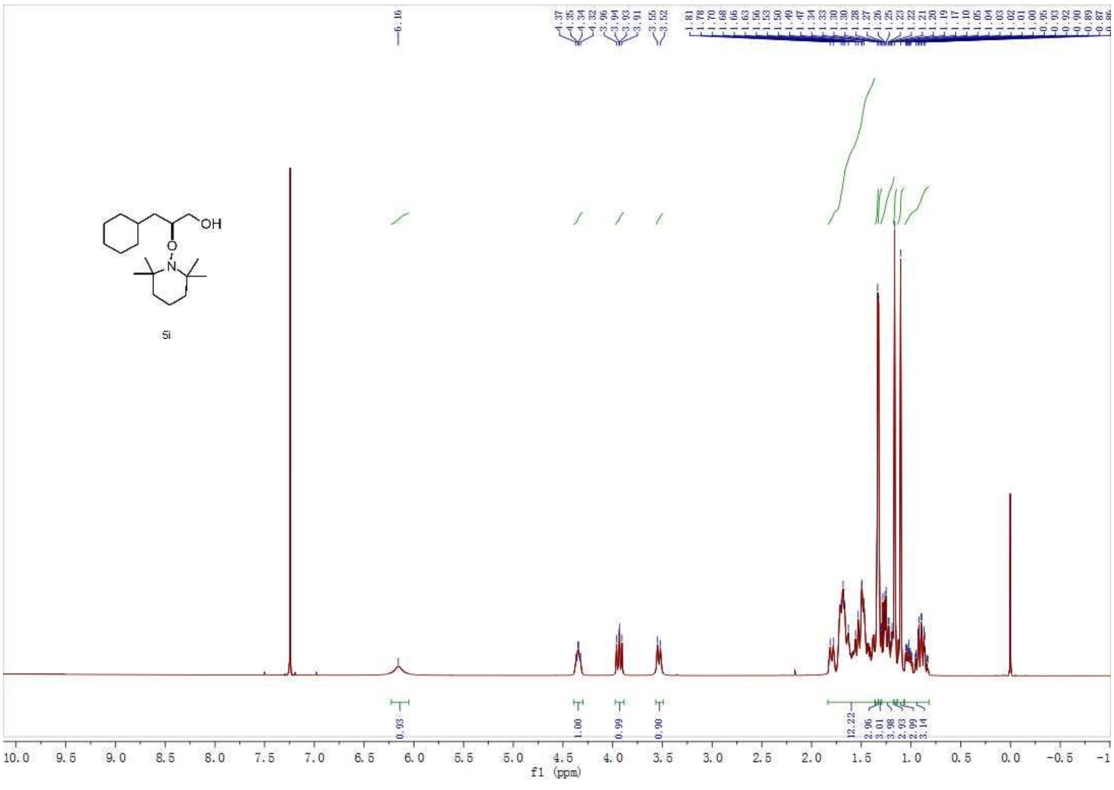

79.97
68.58
61.45
59.75
40.34
39.88
34.69
32.39
31.77
31.12
29.48
25.88
22.67
20.48
20.38
17.24
14.17
OH
O
N
5f
f1 (ppm)

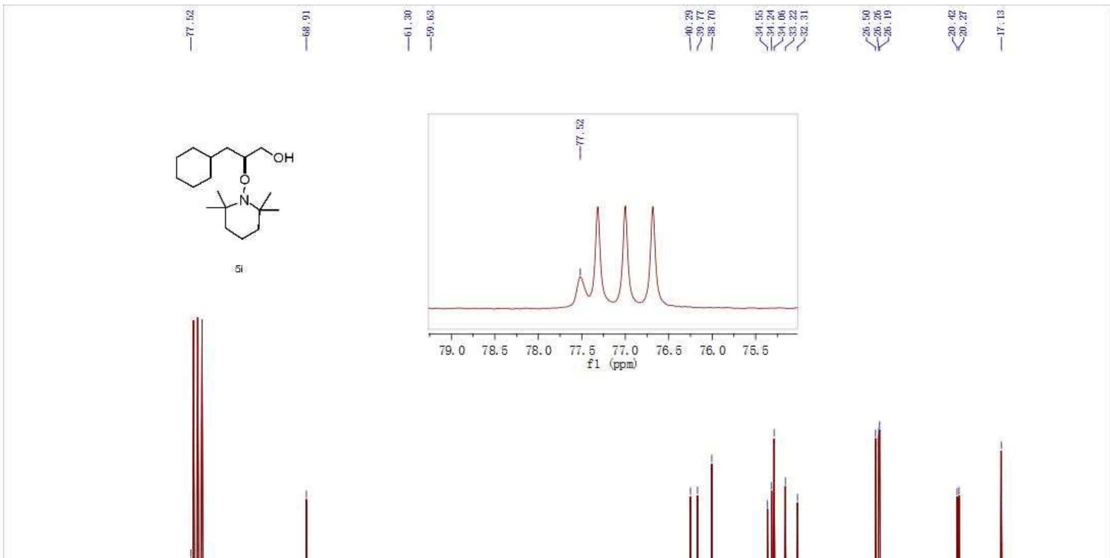


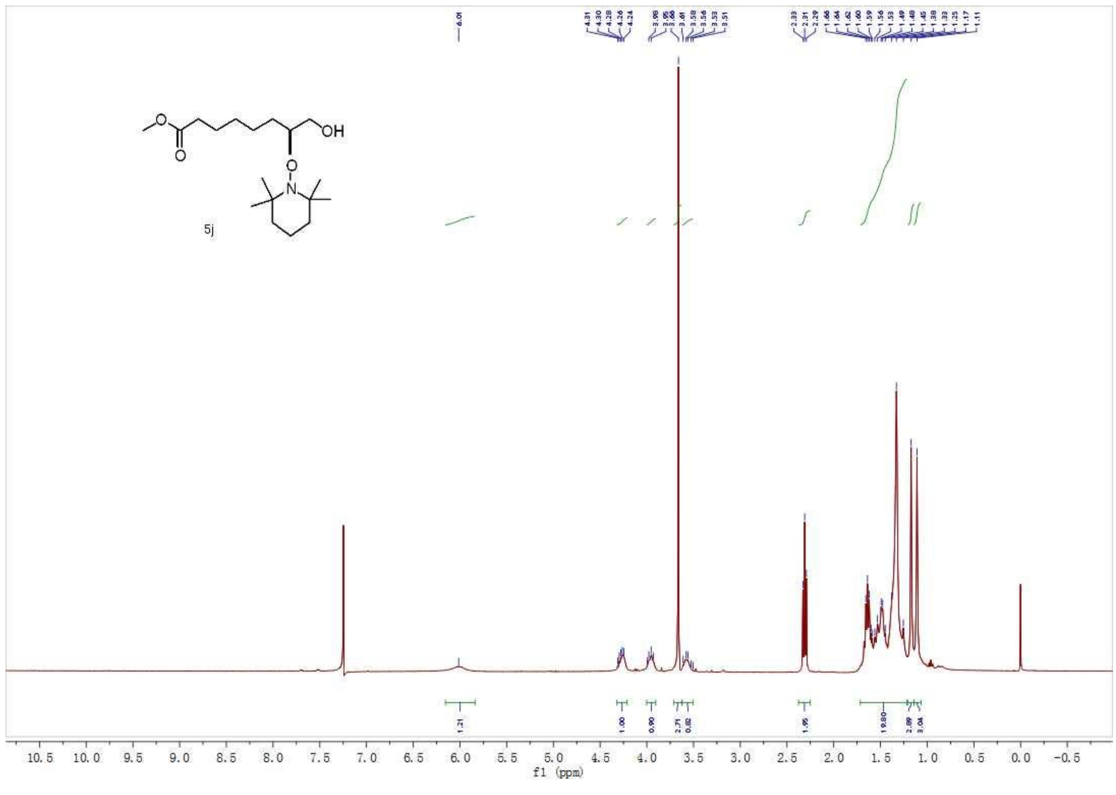


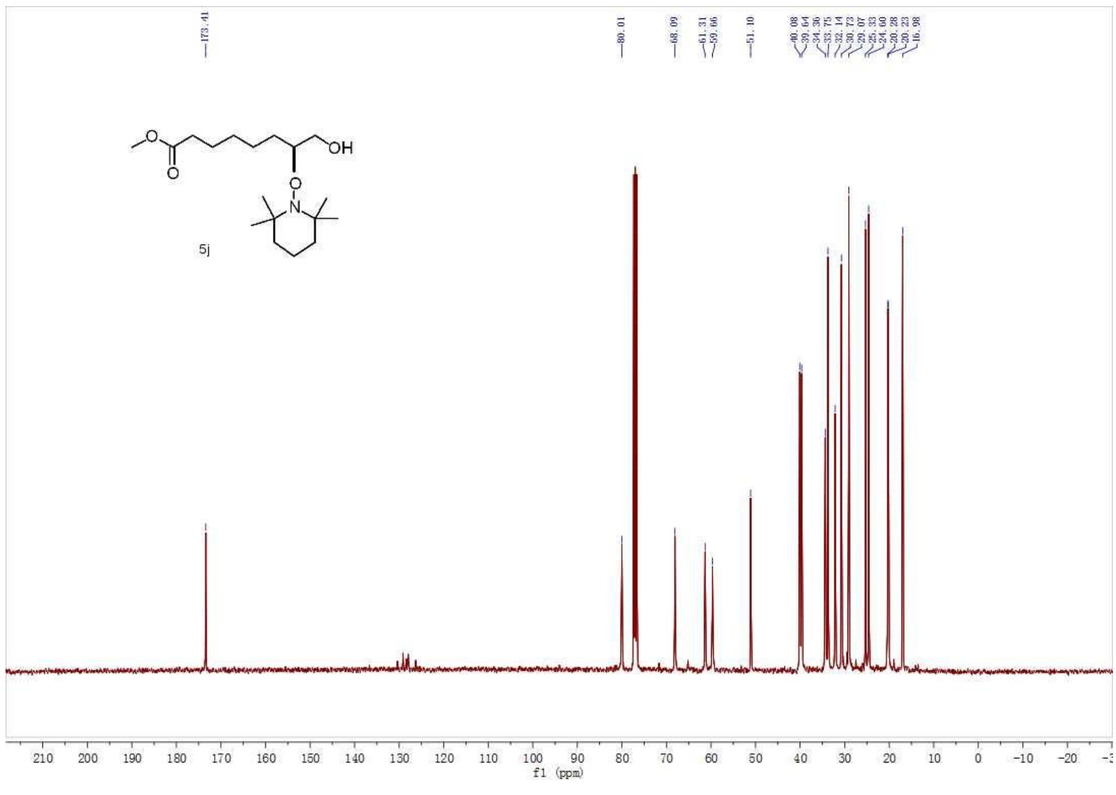

5h
f1 (ppm)


5h
f1 (ppm)

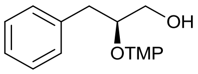






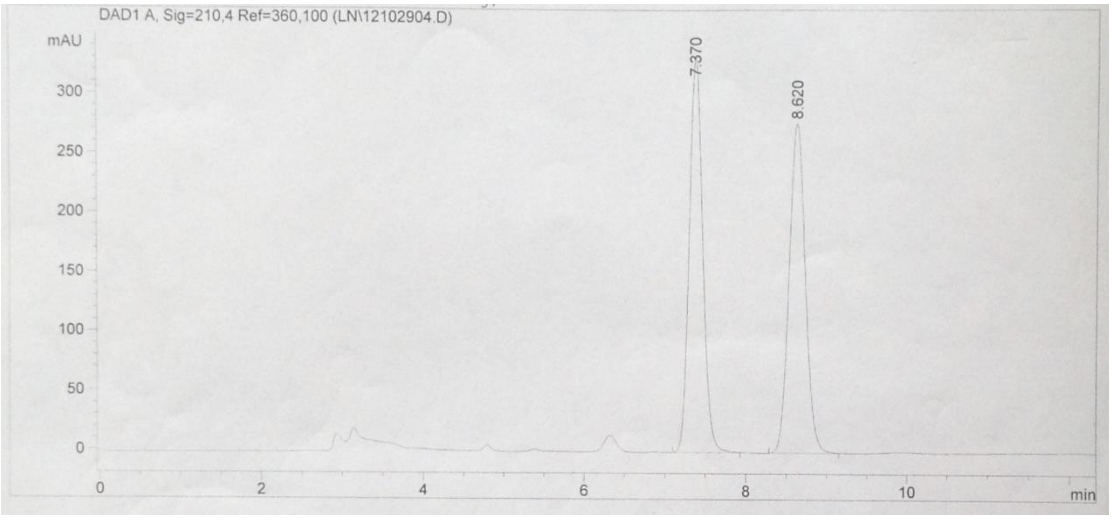


HPLC analyses

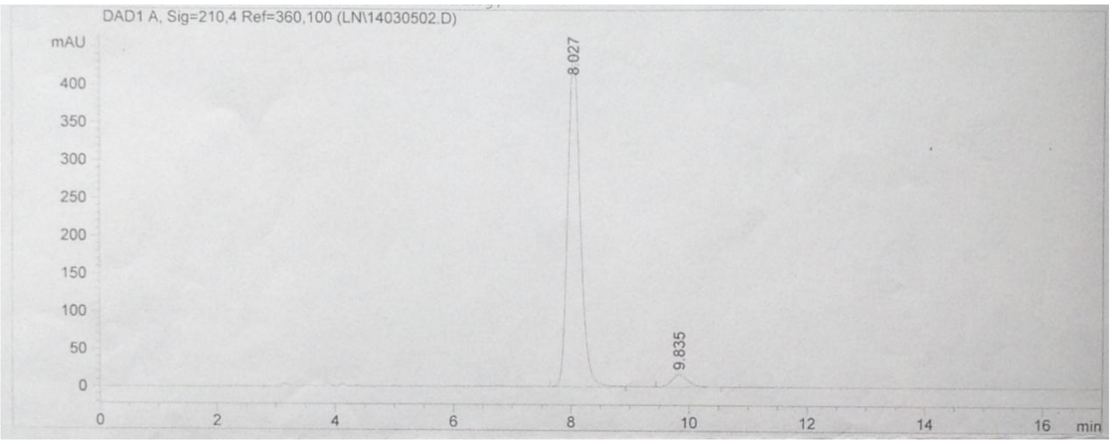


5a

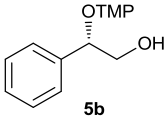
Daicel Chiralcel OD-H, 210 nm, hexane/*i*-PrOH = 98/2, flow rate 0.8 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.370	PB	0.1793	3868.98828	333.58374	50.0429
2	8.620	BB	0.2159	3862.35767	278.24994	49.9571

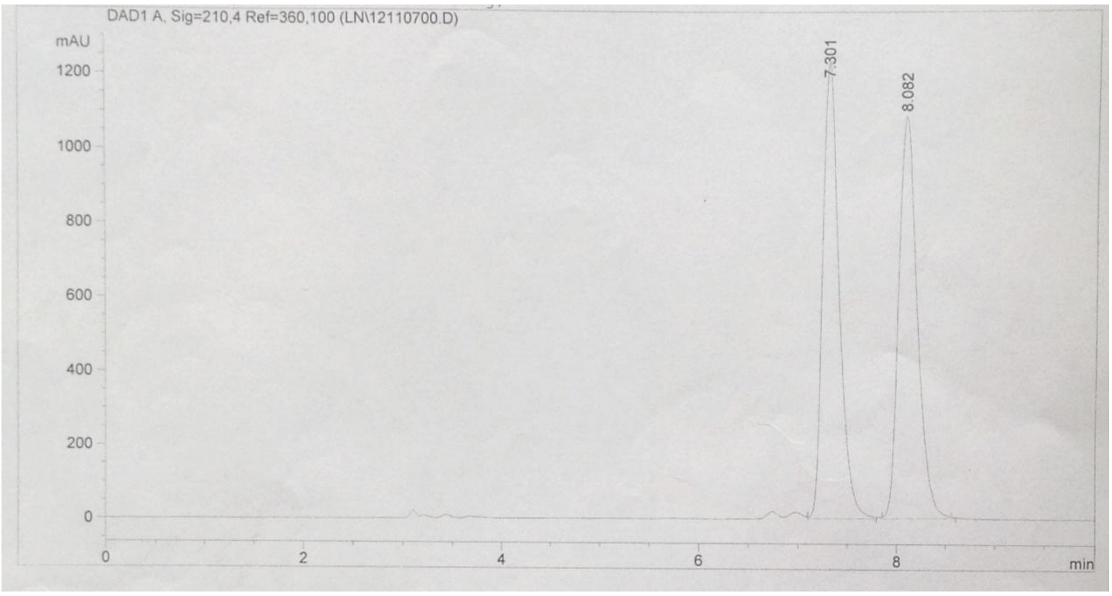


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.027	VB	0.2294	6576.64453	442.41678	95.2374
2	9.835	BB	0.2999	328.88177	16.83292	4.7626

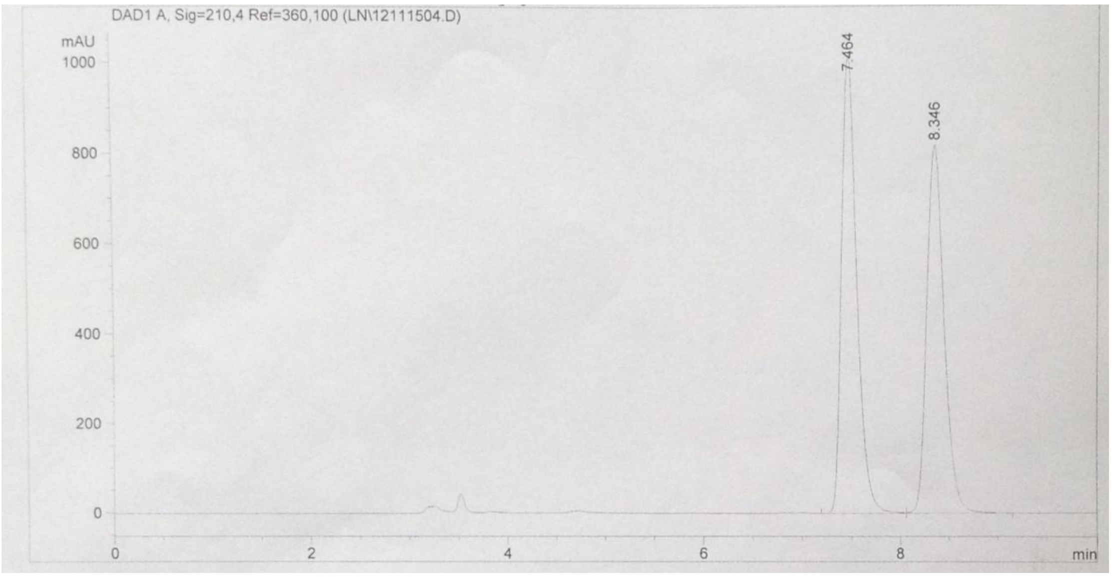


5b

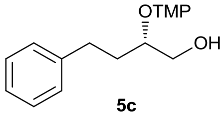
Daicel Chiralcel AY-H, 210 nm, hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.301	VB	0.1764	1.42233e4	1234.36511	49.8212
2	8.082	BB	0.2017	1.43254e4	1087.66699	50.1788

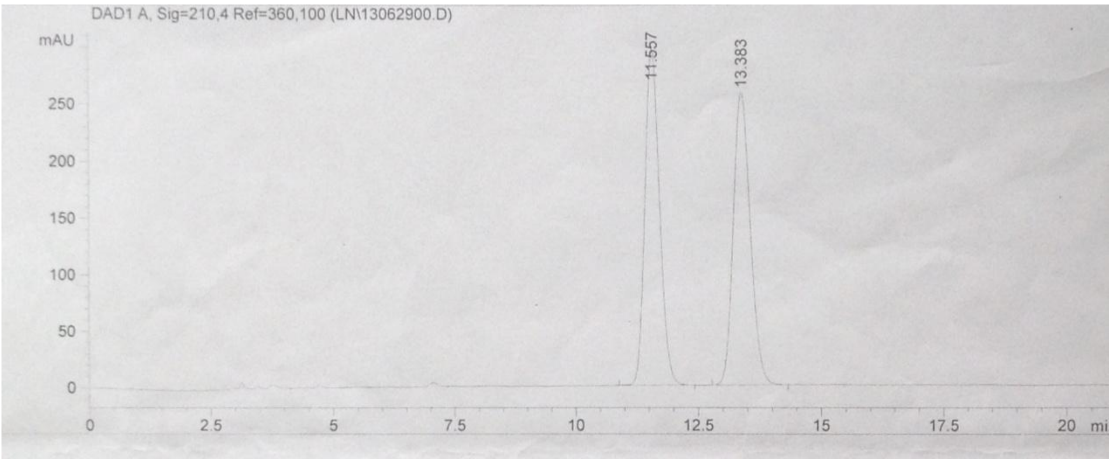


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.464	VV	0.1638	1.09599e4	1016.17242	51.9786
2	8.346	VB	0.1906	1.01255e4	817.16376	48.0214

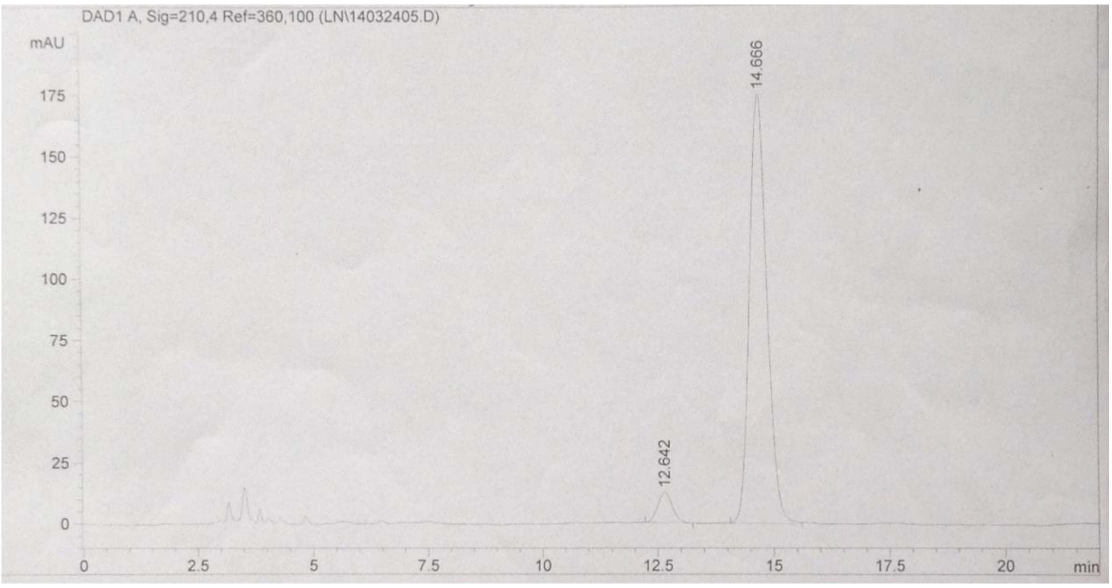


5c

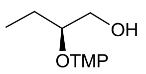
Daicel Chiralcel OD-H, 210 nm, hexane/*i*-PrOH = 98/2, flow rate 0.8 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.557	BB	0.3267	6219.65479	296.51147	50.0293
2	13.383	PP	0.3755	6212.36182	257.43884	49.9707

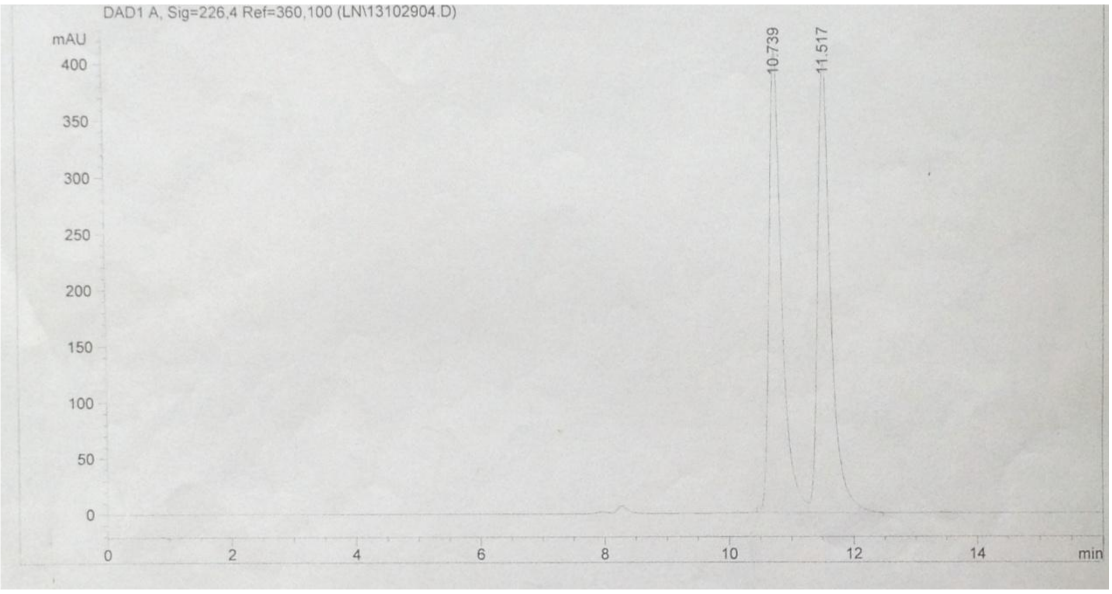


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.642	BB	0.3384	271.97598	12.47489	5.6210
2	14.666	BB	0.4043	4566.61035	175.09503	94.3790

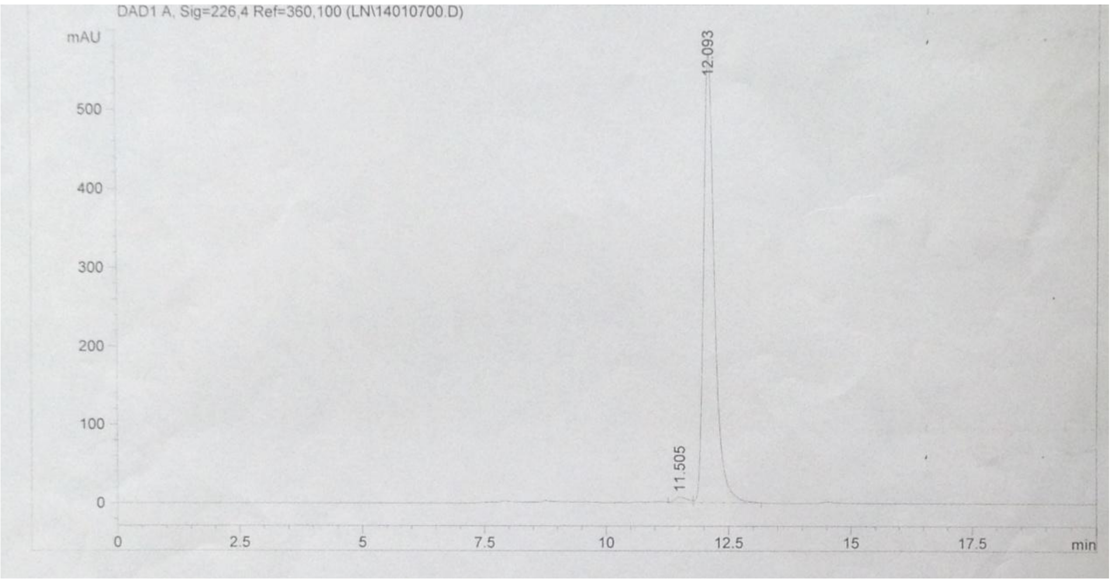


5d

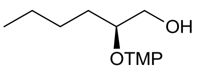
Daicel Chiralcel AD-H, 226 nm, hexane/*i*-PrOH = 98/2, flow rate 0.4 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.739	BV	0.2087	5704.78955	409.18967	49.3424
2	11.517	VB	0.2189	5856.85742	399.76944	50.6576

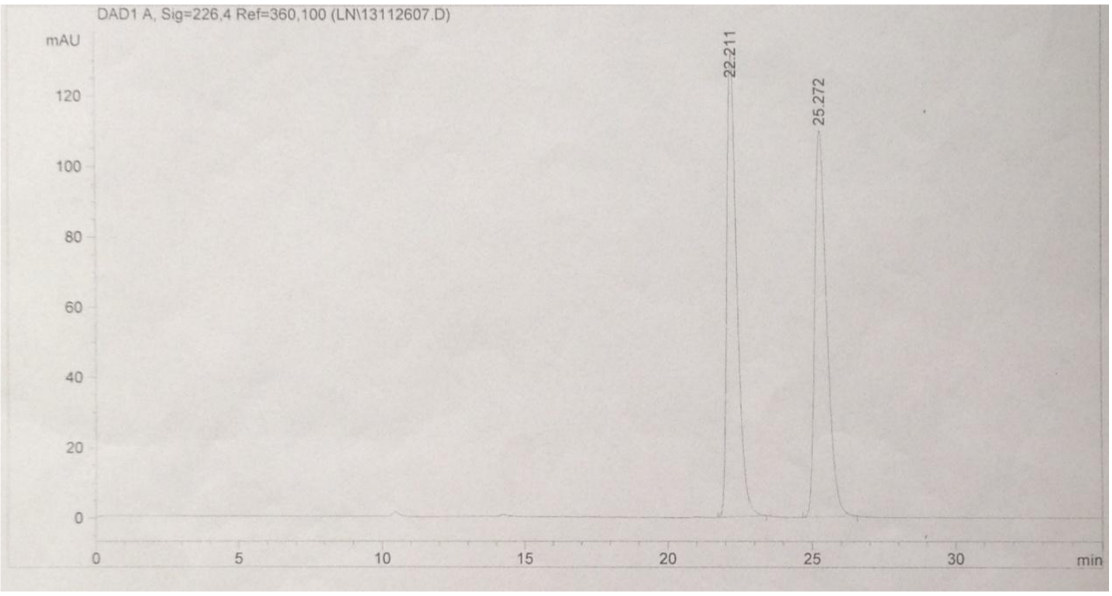


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.505	VV	0.2507	134.57555	7.82149	1.5031
2	12.093	VB	0.2317	8818.59473	572.51624	98.4969

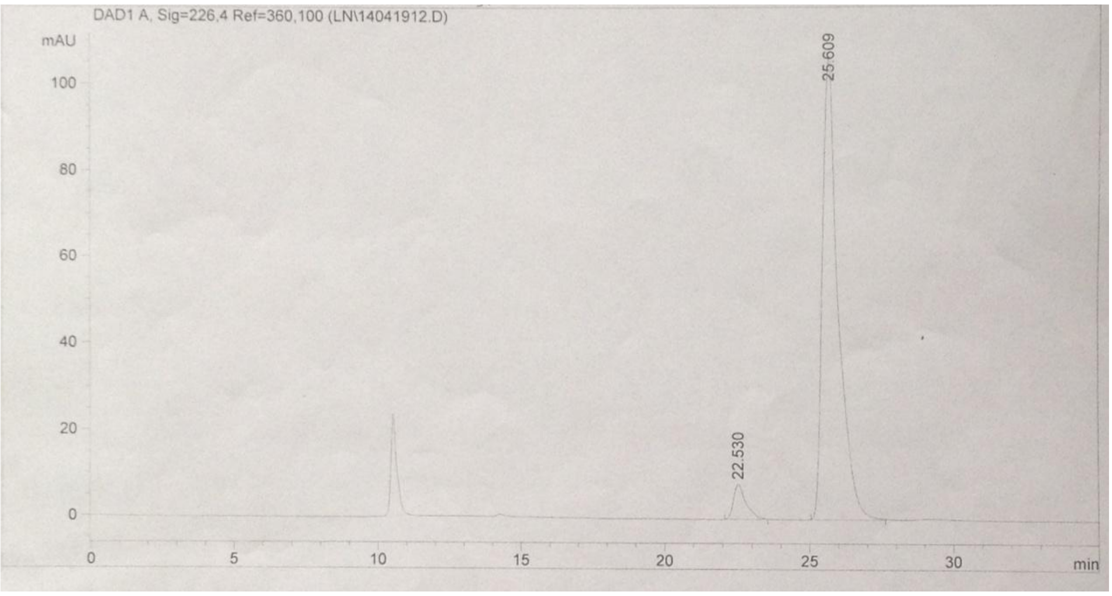


5e

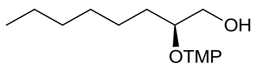
Daicel Chiralcel OD-H, 226 nm, hexane/*i*-PrOH = 99.9/0.1, flow rate 0.2 mL/min→0. 6 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.211	BB	0.3668	3162.19434	131.38857	49.8694
2	25.272	BB	0.4452	3178.76050	109.33730	50.1306

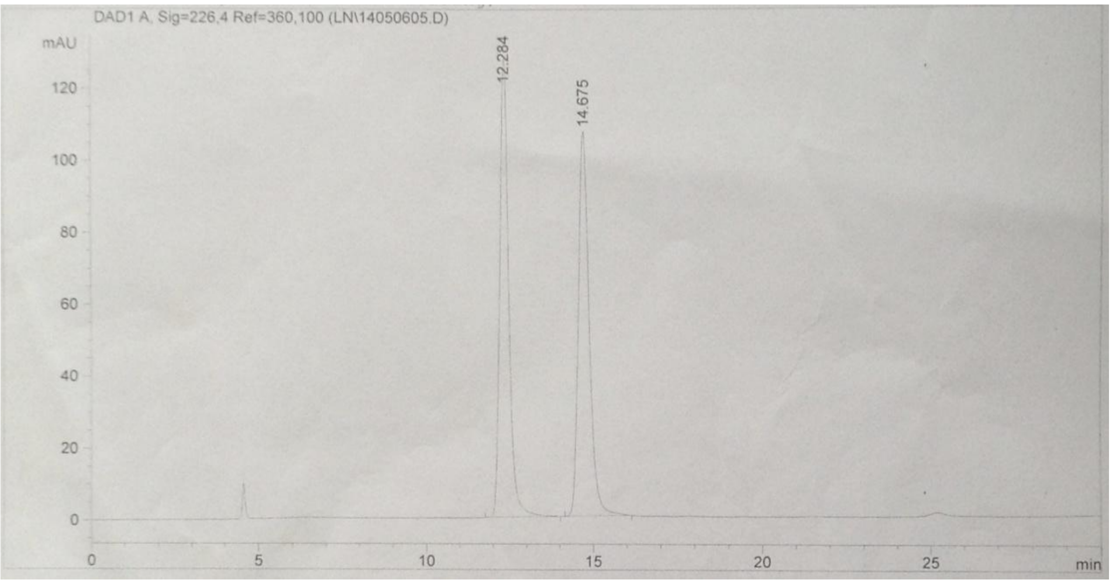


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.530	BB	0.4307	243.76216	8.20265	5.6853
2	25.609	BB	0.5493	4043.83057	106.91897	94.3147

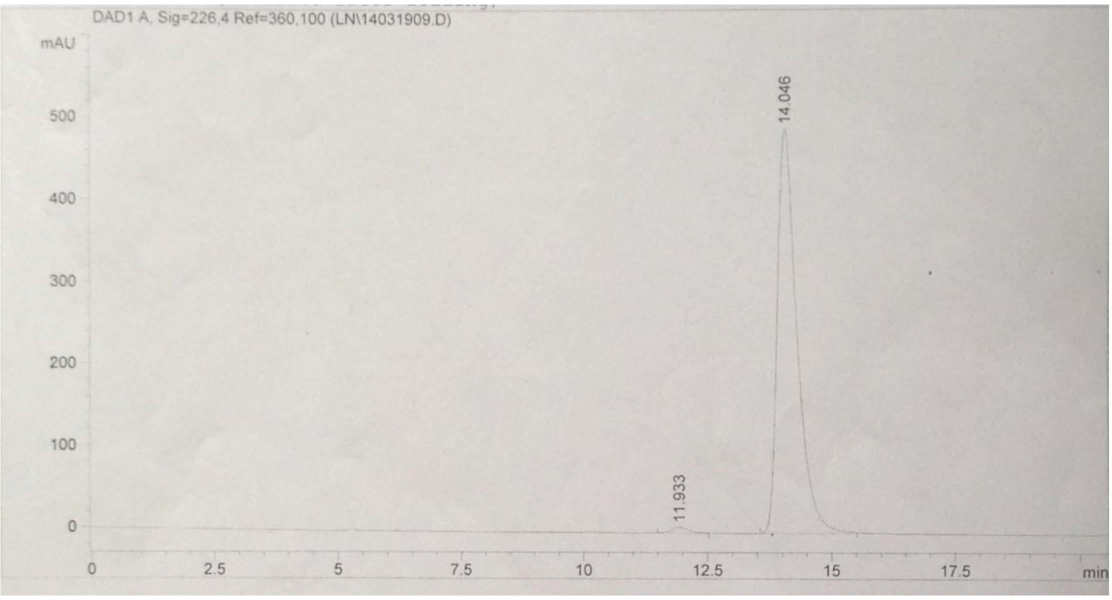


5f

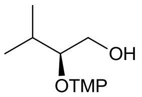
Daicel Chiralcel OD-H, 226 nm, hexane/*i*-PrOH = 99.9/0.1, flow rate 0.6 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.284	MM R	0.2915	2387.53784	127.14625	49.8928
2	14.675	MM R	0.3258	2397.80005	106.91164	50.1072

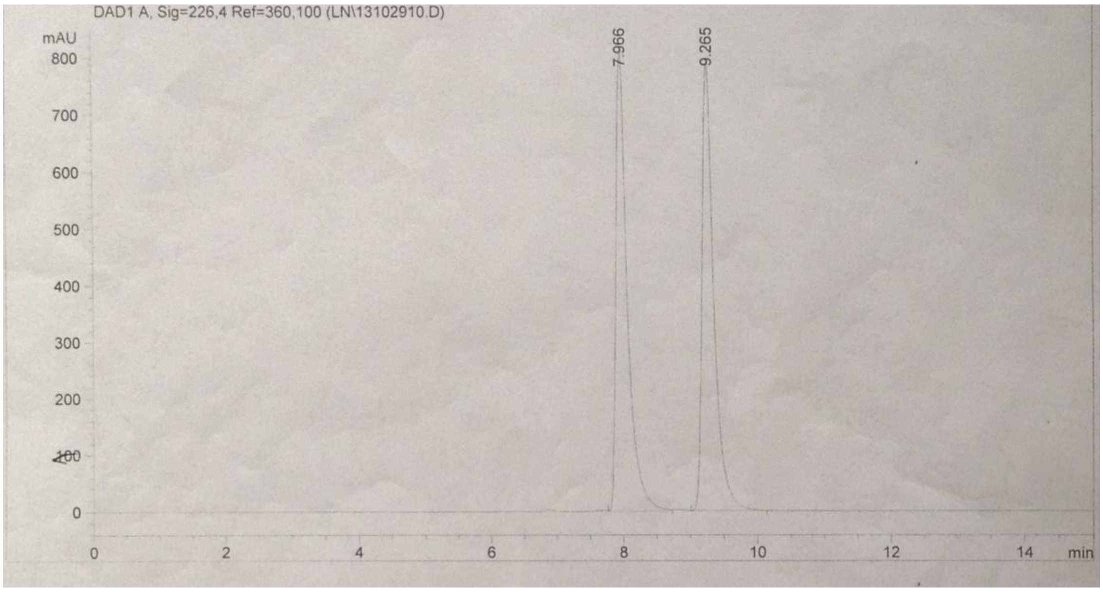


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.505	VV	0.2507	134.57555	7.82149	1.5031
2	12.093	VB	0.2317	8818.59473	572.51624	98.4969

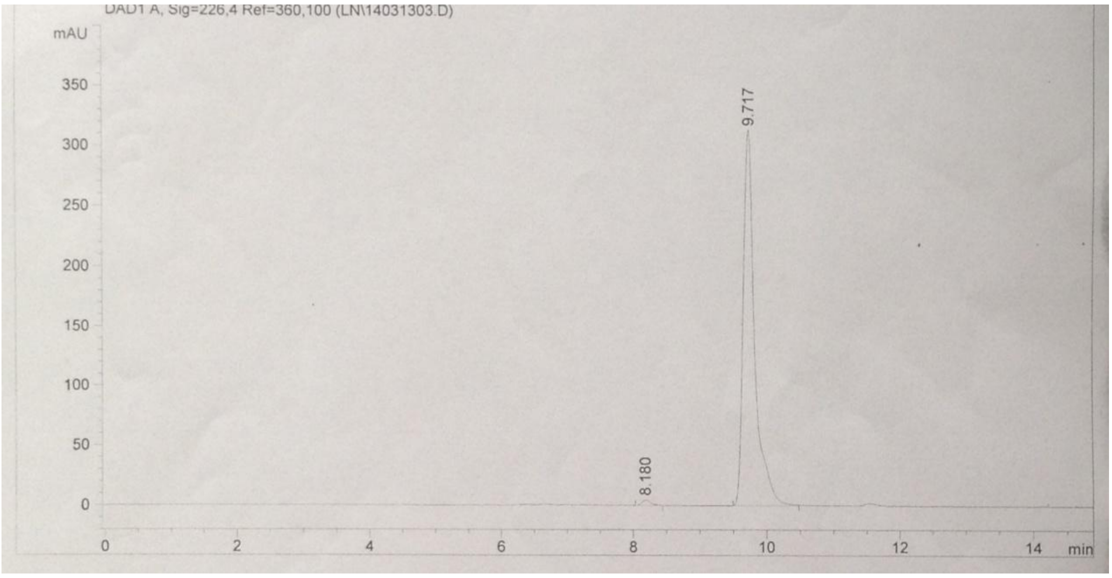


5g

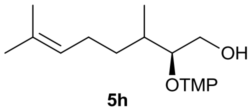
Daicel Chiralcel AD-H, 226 nm, hexane/*i*-PrOH = 98/2, flow rate 0.5 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.966	VV	0.1769	9651.91113	810.71979	50.1445
2	9.265	VB	0.1796	9596.26562	790.39343	49.8555

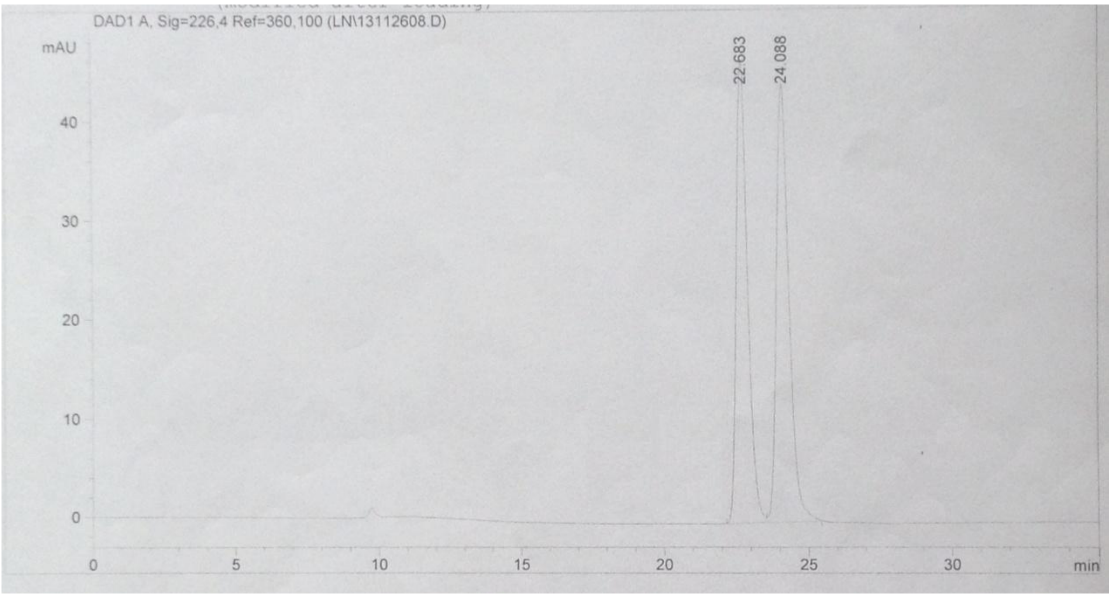


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.180	PB	0.1389	41.01279	4.47503	1.0855
2	9.717	BB	0.1791	3737.19531	313.45963	98.9145

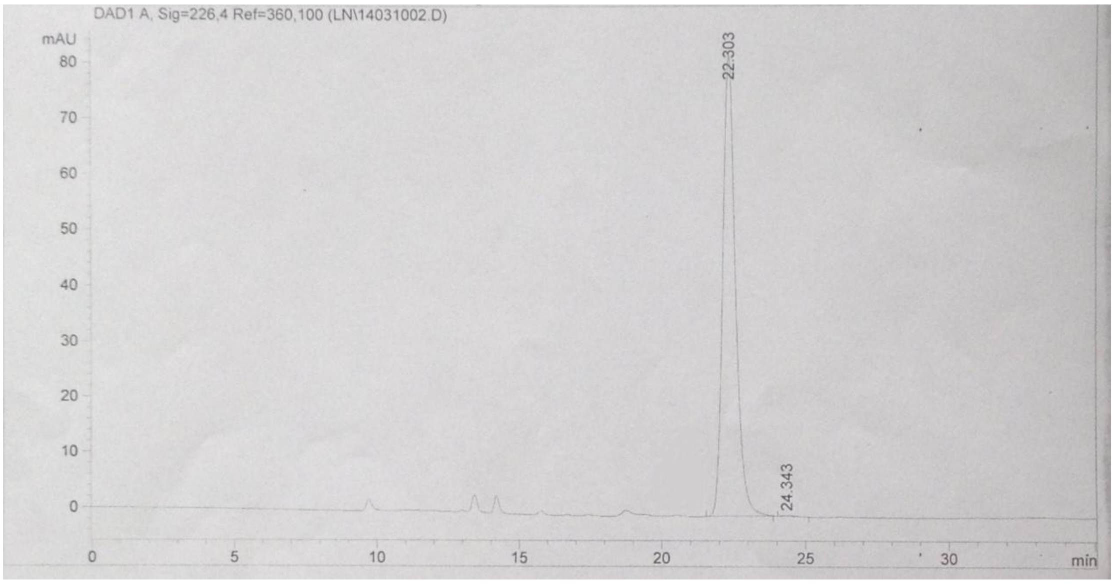


5h

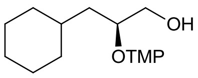
Daicel Chiralcel OD-H, 226 nm, hexane/*i*-PrOH = 99.9/0.1, flow rate 0.2 mL/min→0. 6 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.683	BV	0.4137	1265.21301	46.75899	48.5975
2	24.088	VB	0.4630	1338.23853	44.23165	51.4025

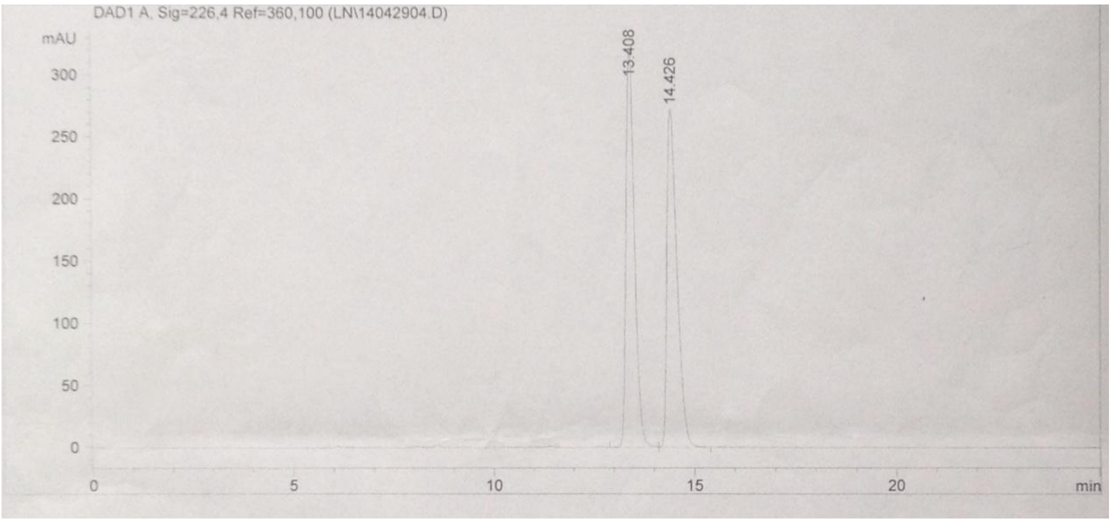


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.303	MM R	0.5455	2544.82446	82.93391	99.7347
2	24.343	MM R	0.5513	6.76870	2.04628e-1	0.2653

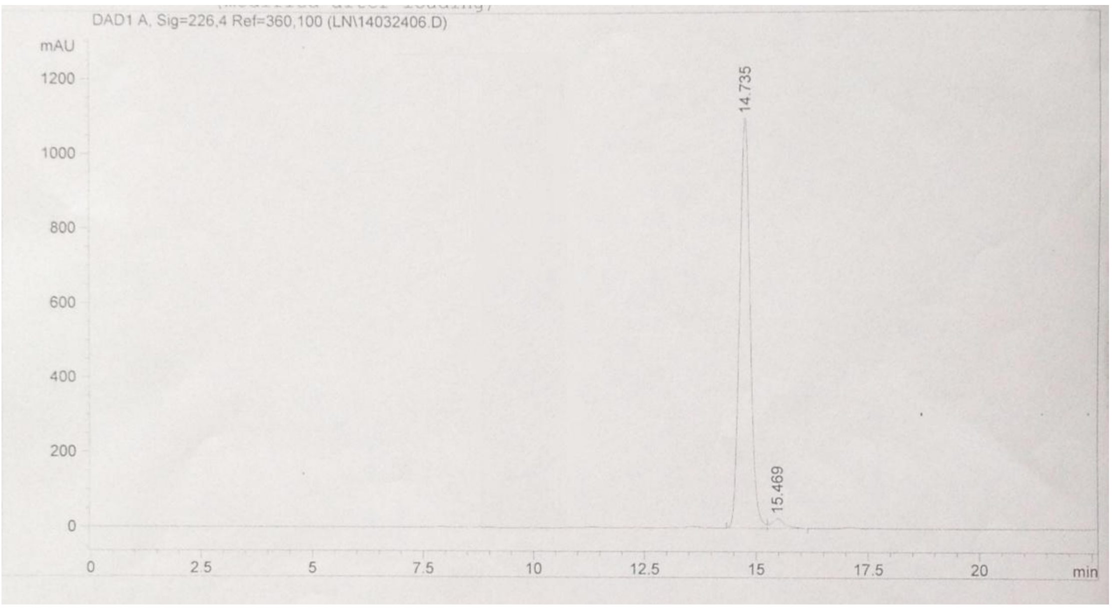


5i

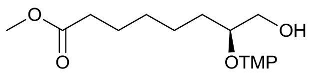
Daicel Chiralcel AD-H, 226 nm, hexane/*i*-PrOH = 99.5/0.5, flow rate 0.5 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.408	VV	0.2278	4720.56250	320.61386	50.0243
2	14.426	VB	0.2660	4715.97998	272.33252	49.9757

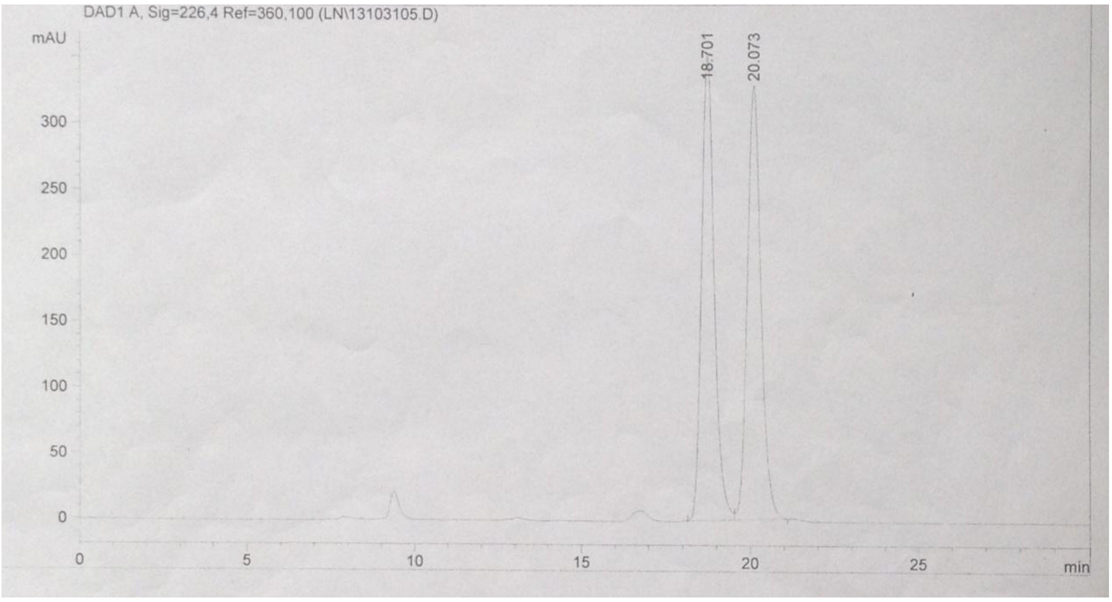


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.735	BV	0.2564	1.81310e4	1099.65503	97.2323
2	15.469	VB	0.2935	516.08563	25.78436	2.7677

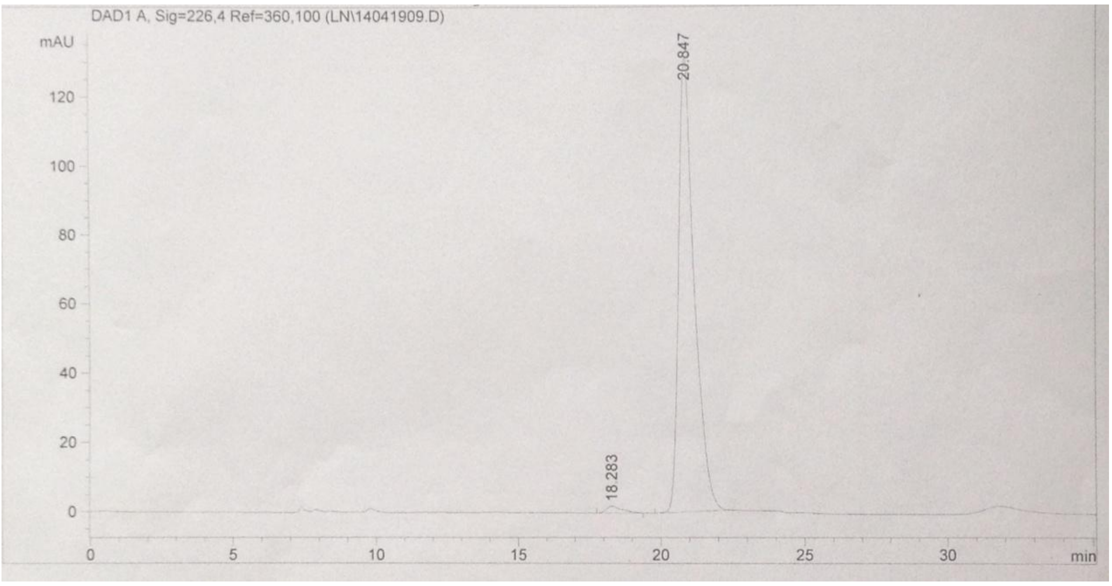


5j

Daicel Chiralcel OD-H, 226 nm, hexane/*i*-PrOH = 99/1, flow rate 0.4 mL/min.



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.701	BV	0.3990	9197.90137	351.86859	50.0687
2	20.073	VB	0.4302	9172.66016	328.10822	49.9313



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.283	PB	0.5235	78.22282	2.05792	1.5473
2	20.847	MM R	0.5457	4977.09961	131.73738	98.4527

Reference:

1. K. A. Ahrendt, C. J. Borths, and D. W. C. MacMillan, *J. Am. Chem. Soc.*, 2000, **122**, 4243-4244.