Bio-inspired enantioselective full transamination with readily available cyclodextrin

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SUPPORTING INFORMATION

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1. General procedures

Chemicals: Solvents, inorganic salts, and organic reagents were purchased from commercial resources, and used without further purification unless otherwise mentioned. Column chromatography was performed on silica gel (200-300 mesh).

^{1}H NMR spectra were recorded on a 400 or 600 MHz NMR spectrometer. Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal (DMSO, δ=2.51). Spectra were reported as follows: chemical shift (δ ppm), multiplicity (s=single, d=doublet, t=triplet, q=quartet, m=multiplet), coupling constants (Hz), integration and assignment.

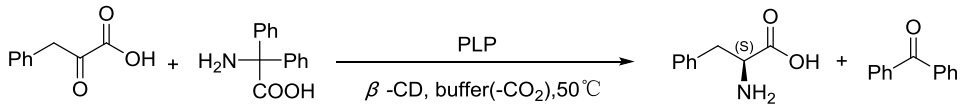
Enantiomeric excesses (ee) were determined by HPLC analysis using the corresponding commercial chiral column as stated in experimental procedures at 30℃ with UV detector at 210 nm. CHIRAL PAK AD-H normal-phase analytical columns (4.6 mm Φ×250mm), CHIRAL PAK OD-H normal-phase analytical columns (4.6 mm Φ×250mm) and CHIRAL PAK IC normal-phase analytical columns (4.6 mm Φ×250mm) were used as solid phase.

α-Keto acids : phenylpyruvic acid, 4-hydroxy phenylpyruvic acid, benzoyl formic acid, pyruvic acid and 4-methyl-2-oxovaleric acid were purchased commercially. α-Keto acids including 2-methoxypyruricacid, 3-methoxypyruric acid, 4-methoxypyruric acid, 4-methylpyruric acid, 3,4-dimethoxypyruric acid, 4-fluoropyruric acid, 4-chlorophenyl pyruric acid, 4-bromopyruric acid, and 2-oxo-3-thien-2-ylpropanoic acid were synthesized following a modified literature method[1], from the corresponding aldehydes condensed with hydantoin with ethanolamine as catalystand then hydrolyzed under alkaline conditions. 4-Nitrephenylpyruric acid was prepared by following literature procedure[2], from4-nitrobenzaldehyde and *N*-acetyl glycine in the presence of acetic anhydride and sodium acetate, followed by ring opening under reflux, and acetamide hydrolyzed off to give the final product.

2,2-Disubstituted glycines as sacrificial amine sources including methylphenylglycine and diphenylglycine were purchased commercially, and when equimolecular suspension of diphenylglycine and bases were added to the methanol solution, removed the solvent after stirring at room temperature, alkali metal salts of diphenylglycine including lithium, sodium and potassium were prepared.

2. Optimization for PLP-catalyzed asymmetric transamination of phenylpyruvic acidin pure aqueous phase

Table S1. Additives and reaction time screening for PLP-catalyzed asymmetric transamination of phenylpyruvic acid[a]



3a **7a** **4a** **8**

Entry	Additives	Time(h)	Yield(%)[b]	ee(%)[c]
1	None	24	7	12
2	EDTA	24	4	23
3	EDTA	12	2	21
4	EDTA	36	9	20
5	EDTA	48	9	20
6	EDTA	72	9	20
7	EDTA	96	9	20
8	EDTA	144	10	16

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 m mol), diphenylglycine (**7a**) (0.05 m mol), EDTA (0.01mmol), β-CD (0.06mmol) and PLP (0.01 m mol) in 300mM Tris buffer (4.0 mL), pH 8.0, at 50℃for certain time;

[b] The yield was determined by chiral HPLC through standard addition method[3, 4]:
The reaction liquid was divided into two parts, with the same subsequent operations except one was added 10% of the target product marked Ⅰ, another marked Ⅱ served as blank control ; results of HPLC showed that :$A_{Ⅰ}$(the peak areas of the target product in I), $A_{Ⅱ}$(the peak areas of the target product in Ⅱ),$E_{Ⅰ}$(the ee's of the target product in I), $E_{Ⅱ}$(the ee's of the target product in Ⅱ);
yield= $A_{Ⅱ}/(A_{Ⅰ}-A_{Ⅱ})\times10\%$ or yield=$E_{Ⅰ}/(E_{Ⅱ}-E_{Ⅰ})\times10\%$;
[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives[5], the absolute configuration of **4a** was assigned as *S* by comparison with the standard product.

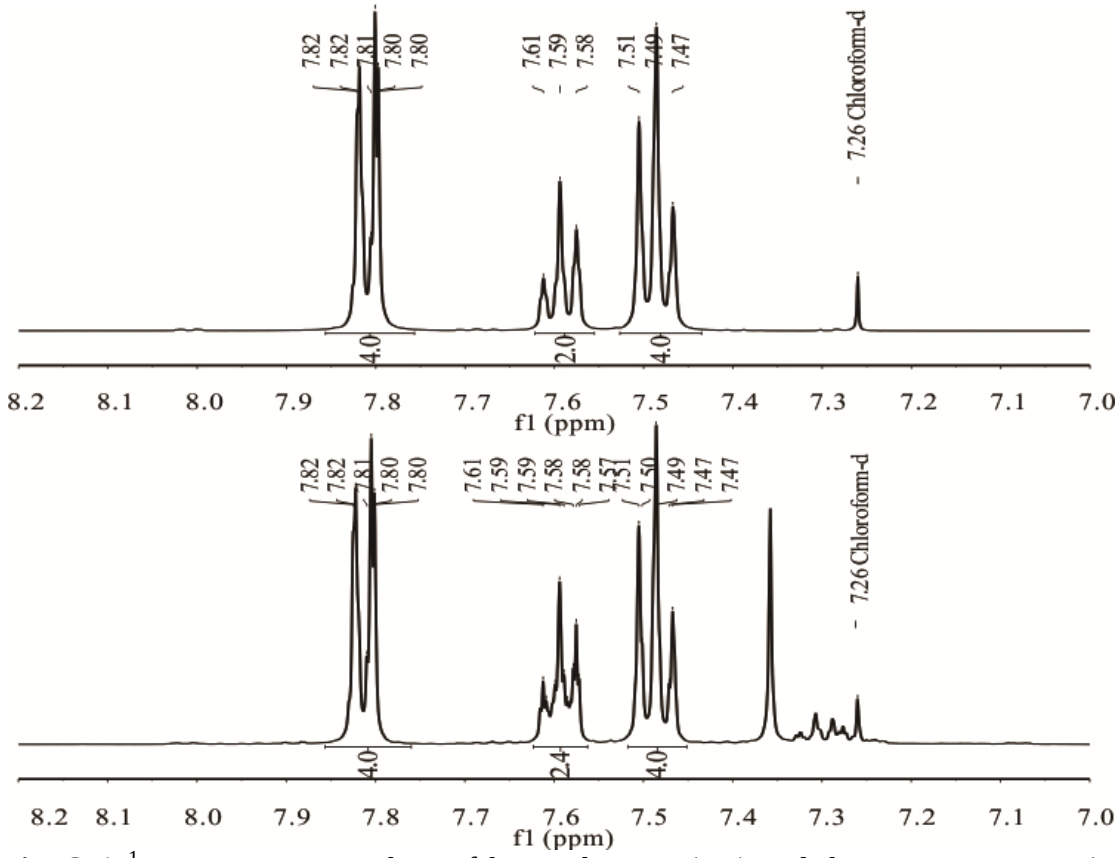
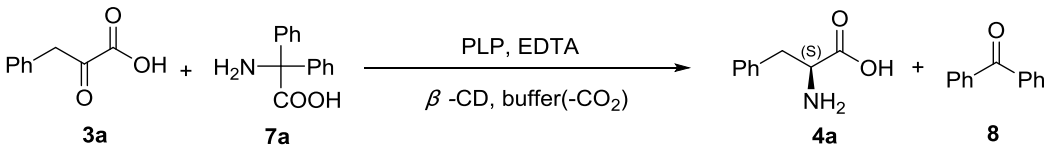


Fig. S1† ^{1}H NMR contrast chart of benzophenone (top) and the reaction mixture's CH_2Cl_2 extract fraction (bottom)[a]

Reaction was carried out with phenylpyruvic acid (**3a**) (0.5mmol), diphenylglycine (**7a**) (0.5mmol), β-CD (0.6mmol) and PLP (0.1 m mol) in 300mM Tris buffer (40.0 mL), pH 8.0, at 50℃for 24h. The reaction mixture was extracted with CH_2Cl_2, removed the solvent by vacuum distillation obtaining the off-white solid, compared its ^{1}H NMR spectrum (bottom) with benzophenone (top) in $CDCl_3$ which proved benzophenone was produced as a byproduct.

Table S2. Temperature screening for PLP-catalyzed asymmetric transamination of phenylpyruvic acid[a]



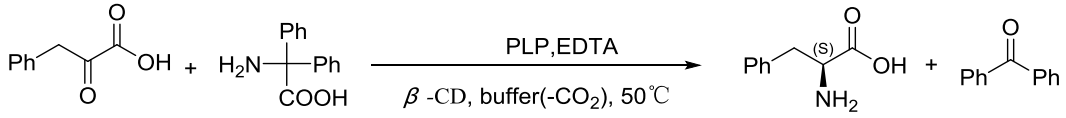
3a **7a** **4a** **8**

Entry	Temperature(℃)	Yield(%)[b]	ee(%)[c]
1	30	Trace	—
2	40	2	25

3	50	9	20
4	60	10	19
5	70	12	13
6	80	15	12
7	90	19	7

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 m mol), diphenylglycine (**7a**) (0.05 m mol), *β*-CD (0.06mmol),EDTA (0.01mmol) and PLP (0.01 m mol) in Tris buffer (4.0 m L), pH 8.0, for 36 h if not mentioned..[b] The yield was determined by chiral HPLC through standard addition method (Table S1†).[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4a** was assigned as *S* by comparison with the standard product.

Table S3. Screening of buffers for PLP-catalyzed asymmetric transamination of phenylpyruvic acid[a]

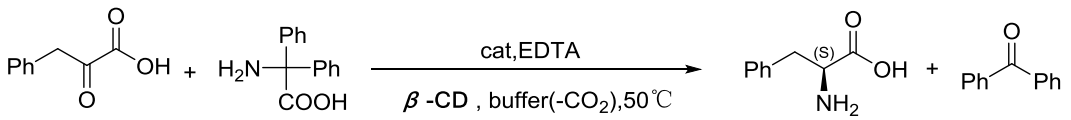


3a **7a** **4a** **8**

Entry	Buffer	Concentration (mM)	pH	Yield(%)[b]	ee(%)[c]
1	Tris buffer	300	8.0	9	20
2	Phosphate buffer (PB)	300	8.0	5	9
4	Borate buffer	300	8.0	trace	nd
5	Carbonic acidbuffer	300	8.0	4	16
6	EDTA buffer	300	8.0	6	12
7	MOPS buffer	300	8.0	4	15
8	HEPES buffer	300	8.0	6	14
9	NaCl aqueous solution	300	8.0	trace	nd
10	Tris buffer	150	8.0	6	17
11	Tris buffer	600	8.0	9	21
12	Tris buffer	300	6.0	trace	nd
13	Tris buffer	300	6.5	trace	nd
14	Tris buffer	300	7.0	1	8
15	Tris buffer	300	7.5	3	17
16	Tris buffer	300	8.5	4	23
17	Tris buffer	300	9.0	3	24
18	Tris buffer	300	10.0	2	34

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 mmol), diphenylglycine (**7a**) (0.05 mmol), *β*-CD (0.06mmol),EDTA (0.01mmol) and PLP (0.01 mmol) in various buffer (4.0 mL), at 50℃for 36 h if not mentioned..[b] The yield was determined by chiral HPLC through standard addition method(Table S1†).[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4a** was assigned as *S* by comparison with the standard product.

Table S4. Screening of catalysts for asymmetric transamination of phenylpyruvic acid[a]

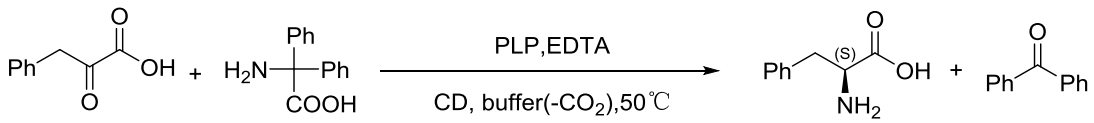


3a **7a** **4a** **8**

Entry	Catalyst	Dosage (m mol)	Yield(%)[b]	ee(%)[c]
1	PLP	0.01	9	20
2	PL[d]	0.01	10	0
3	PM	0.01	10	0
4	PLP	0.005	5	25
5	PLP	0.015	9	17
6	PLP	0.025	11	15
7	PLP	0.05	10	11

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 mmol), diphenylglycine (**7a**) (0.05 mmol), *β*-CD (0.06mmol), EDTA (0.01mmol) and in Tris buffer (4.0 mL), pH 8.0, at 50℃for 36 h if not mentioned..[b] The yield was determined by chiral HPLC through standard addition method(Table S1†).[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4a** was assigned as *S* by comparison with the standard product. [d] PL was an abbreviation for pyridoxal.

Table S5. Screening of CDs for PLP-catalyzed asymmetric transamination of phenylpyruvic acid[a]

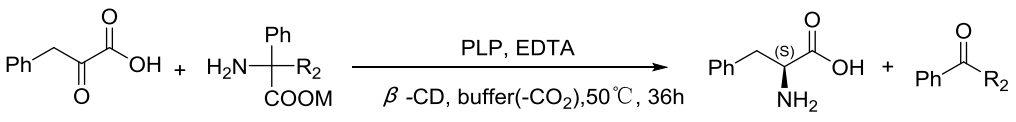


3a **7a** **4a** **8**

Entry	CD	Dosage (m mol)	Yield(%)[b]	ee(%)[c]
1	*β*-CD	0.06	9	20
2	*α*-CD	0.06	2	5
3	*γ*-CD	0.06	2	0
4	*HP-β*-CD	0.06	3	0
5	*β*-CD	0	4	0
6	*β*-CD	0.015	6	7
7	*β*-CD	0.03	7	17
8	*β*-CD	0.12	7	25
9	*β*-CD	0.24	5	27

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 mmol), diphenylglycine (**7a**) (0.05 mmol),EDTA (0.01mmol) and PLP (0.01 mmol) in Tris buffer (4.0 mL), pH 8.0, at 50℃for 36 h if not mentioned..[b] The yield was determined by chiral HPLC through standard addition method(Table S1†).[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4a** was assigned as *S* by comparison with the standard product.

Table S6. Screening of sacrificial amine sources for PLP-catalyzed asymmetric transamination of phenylpyruvic acid[a]



3a **7** **4a** **8**

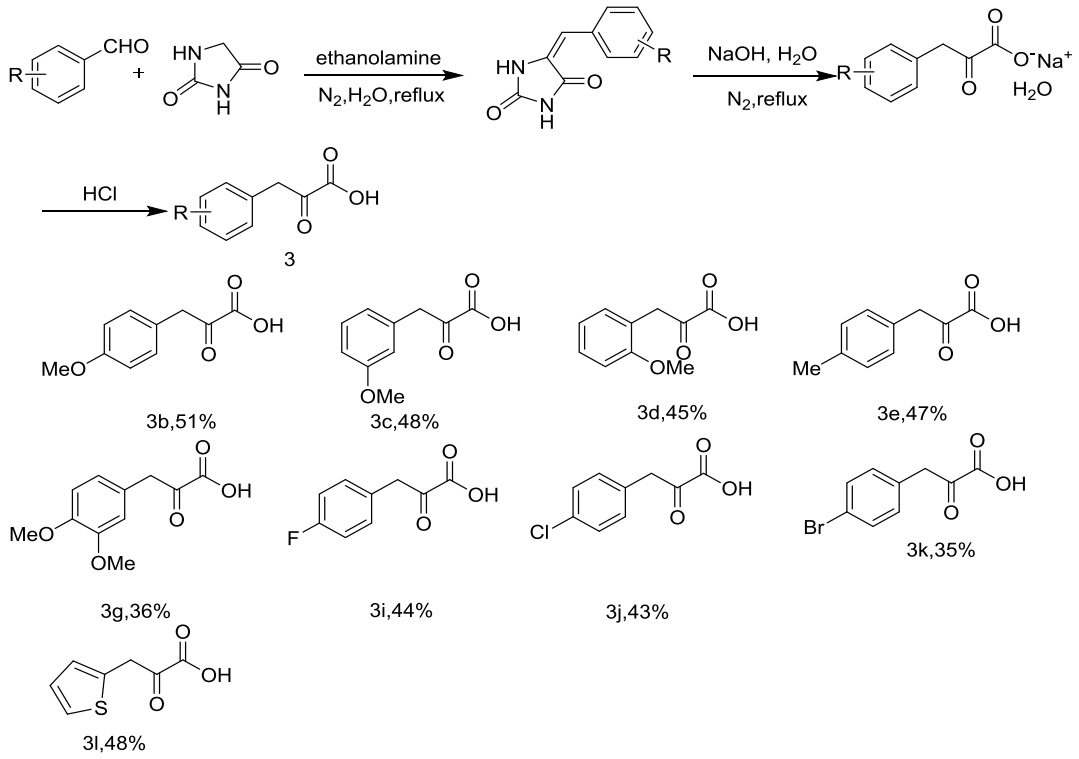
Entry	Amine source	Dosage (m mol)	Yield(%)[b]	ee(%)[c]
1	**7a**(R2:Ph, M:H)	0.05	9	20
2	**7b**(R2:Me, M:H)	0.05	11	19
3	**7c**(R2:Ph, M:Li^+)	0.05	23	20

4	**7d**(R2:Ph, M:Na^+)	0.05	27	20
5	**7e**(R2:Ph, M:K^+)	0.05	24	20
6	**7d**	0.1	27	20
7	**7d**	0.2	28	20
8	**7d**	0.3	27	20
9	**7d**	0.4	25	20

[a]All reactions were carried out with phenylpyruvic acid (**3a**) (0.05 mmol),*β*-CD (0.06mmol),EDTA (0.01mmol) and in Tris buffer (4.0 mL), pH 8.0, at 50℃for 36 h if not mentioned..[b] The yield was determined by chiral HPLC through standard addition method(Table S1†).[c] The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4a** was assigned as *S* by comparison with the standard product.

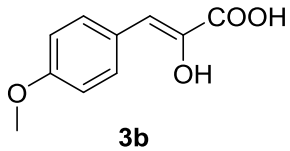
3. Synthesis of *α*-keto acids

A



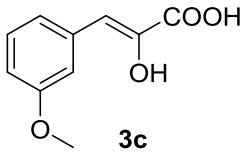
A. A reaction tube was charged with 3 m mol of corresponding aldehydes,3 m mol of hydantoin, and 0.03 m mol of ethanolamine in 7 g of permuted water , under agitation and in an inert atmosphere, heated for 2 to 4 hours with reflux until a large amount of solid was produced turn the clear solution into suspension. Thereafter, 30ml of 6g sodium hydroxyde or 8.5g potassium hydroxide was introduced, continued to reflux for more than another 30 minutes until the muddy liquid turned back to clear. The obtained solution was then cooled to the ambient temperature, brought to acidity with the addition of concentrated hydrochloric acid and extracted with ethyl acetate, the organic phase was washed with iced water, dried with anhydrous Na_2SO_4, evaporated at reduced pressure to get the crude product which was purified by flash

column or recrystallization.



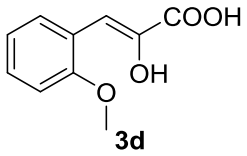
3b

^{1}H NMR (400 MHz, DMSO) δ 13.01 (s, 1H), 8.96 (s, 1H), 7.71 (d, *J* = 8.8 Hz, 2H), 6.92 (d, *J* = 8.9 Hz, 2H), 6.38 (s, 1H), 3.76 (s, 3H).



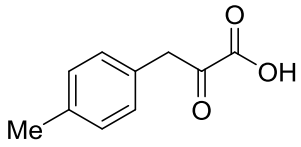
3c

^{1}H NMR (400 MHz, DMSO) δ 13.18 (s, 1H), 9.26 (s, 1H), 7.37 (s, 1H), 7.32 (d, *J* = 7.8 Hz, 1H), 7.25 (t, *J* = 7.9 Hz, 1H), 6.84 – 6.79 (m, 1H), 6.38 (s, 1H), 3.74 (s, 3H).



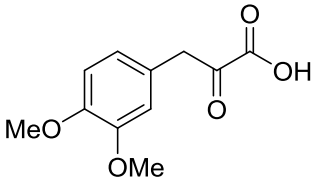
3d

^{1}H NMR (400 MHz, DMSO) δ 13.14 (s, 1H), 9.13 (s, 1H), 8.17 (dd, *J* = 7.8, 1.6 Hz, 1H), 7.25 – 7.19 (m, 1H), 7.03 – 6.93 (m, 2H), 6.80 (s, 1H), 3.81 (s, 3H).



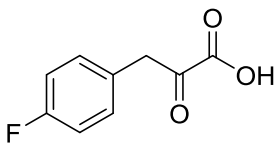
3e

^{1}H NMR (400 MHz, DMSO) δ 13.11 (s, 1H), 9.09 (s, 1H), 7.64 (d, *J* = 8.1 Hz, 2H), 7.15 (d, *J* = 8.1 Hz, 2H), 6.37 (s, 1H), 2.29 (s, 3H).



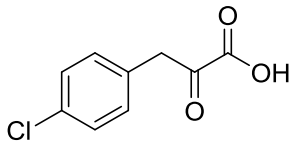
3g

^{1}H NMR (400 MHz, DMSO) δ 13.00 (s, 1H), 8.98 (s, 1H), 7.43 (d, *J* = 1.7 Hz, 1H), 7.31 (dd, *J* = 8.4, 1.8 Hz, 1H), 6.94 (d, *J* = 8.5 Hz, 1H), 6.38 (s, 1H), 3.76 (s, 3H), 3.74 (s, 3H).



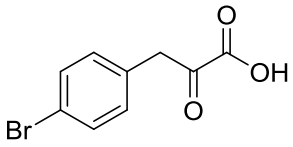
3i

^{1}H NMR (400 MHz, DMSO) δ 13.25 (s, 1H), 9.29 (s, 1H), 7.81 (dd, *J* = 8.5, 5.9 Hz, 2H), 7.17 (t, *J* = 8.9 Hz, 2H), 6.41 (s, 1H).



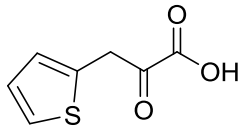
3j

^{1}H NMR (400 MHz, DMSO) δ 13.30 (s, 1H), 9.49 (s, 1H), 7.77 (d, *J* = 8.5 Hz, 2H), 7.40 (d, *J* = 8.5 Hz, 2H), 6.39 (s, 1H).



3k

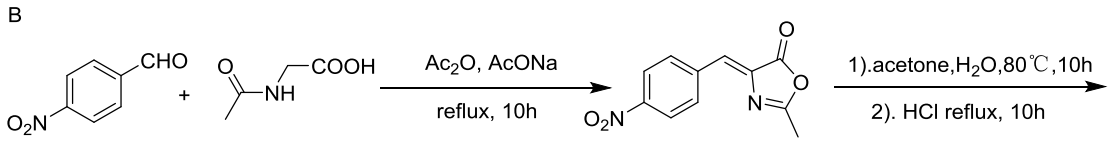
^{1}H NMR (400 MHz, DMSO) δ 13.29 (s, 1H), 9.49 (s, 1H), 7.71 (d, *J* = 8.5 Hz, 2H), 7.53 (d, *J* = 8.4 Hz, 2H), 6.37 (s, 1H).

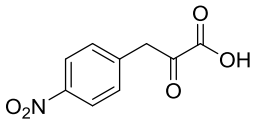


3l

^{1}H NMR (400 MHz, DMSO) δ 13.08 (s, 1H), 9.51 (s, 1H), 7.54 (d, *J* = 5.1 Hz, 1H), 7.26 (d, *J* = 3.4 Hz, 1H), 7.05 (dd, *J* = 5.0, 3.8 Hz, 1H), 6.78 (s, 1H).

B

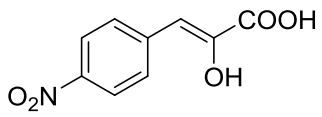




3h, 36%

B. A reaction tube was charged with 3 mmol of 4-nitrobenzaldehyde, 15 mmol of anhydrous sodium acetate, and 3.6 mmol of *N*- acetylglycine, the mixture was heated at reflux in 3ml acetic anhydride for 10 hours, this was then cooled to the ambient temperature. After standing overnight in refrigerator, the precipitate was collected on a filter, washed with cold water and ethanol, then dried in vacuo to afford 0.6 g (91%) of brown solid. Following that, 4.5 ml acetone and 3ml H_2O were added to the product obtained from the previous step, heated at reflux for 10 hours, then cooled to the ambient temperature, after removal of the solvent under reduced pressure, 15 ml of 1M HCl solution was added, kept refluxing at 120℃ for 10 hours. Whereafter, the solution cooled down and crystallized out brown crystals obtaining by filtering,

and purified by recrystallization yielding 0.1g 4-nitrephenylpyruric acidas the final product (36%).

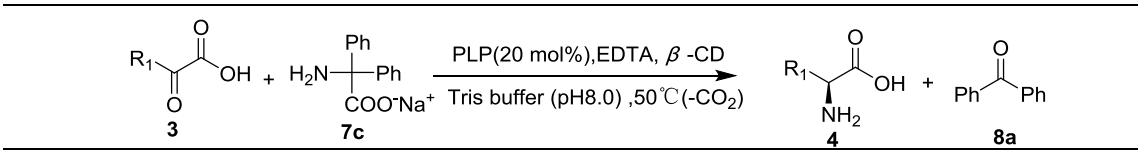


3h

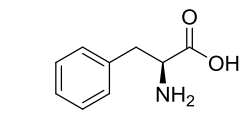
^{1}H NMR (400 MHz, DMSO) δ 13.58 (s, 1H), 10.17 (s, 1H), 8.20 (d, *J* = 8.7 Hz, 2H), 7.99 (d, *J* = 8.7 Hz, 2H), 6.50 (s, 1H).

4. Representative procedure for asymmetric transamination of *α*-keto acids

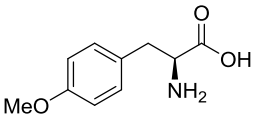
Table 2 Substrate screening for the asymmetric transamination of *α*-keto acids



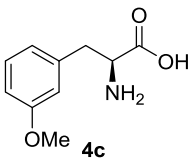
3 **7c** **4** **8a**



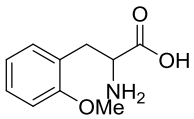
4a
27%,20%ee



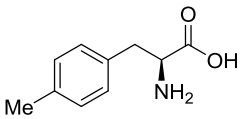
4b
30%,38%ee



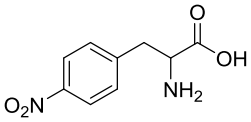
4c
42%,28%ee



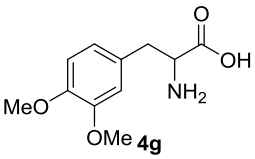
4d
16%,0%ee



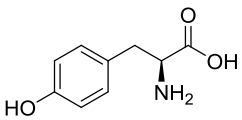
4e
25%,44%ee



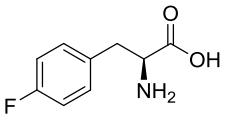
4f
trace, nd



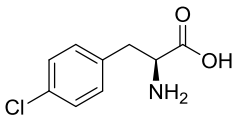
4g
8%,0%ee



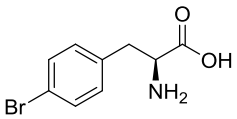
4h
9%,16%ee



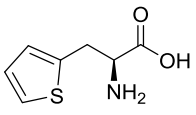
4i
37%,35%ee



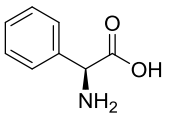
4j
24%,31%ee



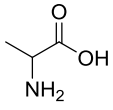
4k
27%,46%ee



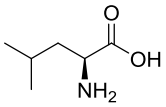
4l
5%,14%ee



4m
4%,5%ee



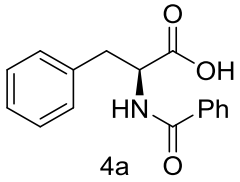
4n
2%,0%ee



4o
3%,6%ee

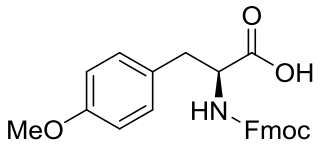
The general transamination reaction condition: *α*-keto acid **3** (0.05 mmol), amine source **7d** (0.05 mmol), PLP(0.01 mmol), EDTA (0.01 mmol) and *β*-CD (0.06 mmol) were added into 4mL 300mM Tris buffer, pH=8. The mixture was stirred at 50℃ for

36h or 72h. Followed by *N*-derivatization of the amino acid as the literature procedure shown[5], and the ee's were determined by chiral HPLC analysis.



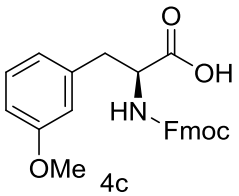
4a

^{1}H NMR (600 MHz, DMSO) δ 12.76 (s, 1H), 8.69 (d, *J* = 8.1 Hz, 1H), 7.83 – 7.76 (m, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.44 (t, *J* = 7.6 Hz, 2H), 7.32 (d, *J* = 7.6 Hz, 2H), 7.26 (t, *J* = 7.6 Hz, 2H), 7.18 (t, *J* = 7.3 Hz, 1H), 4.63 (ddd, *J* = 10.8, 8.3, 4.4 Hz, 1H), 3.20 (dd, *J* = 13.8, 4.3 Hz, 1H), 3.08 (dd, *J* = 13.7, 10.8 Hz, 1H).



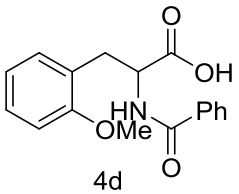
4b

^{1}H NMR (400 MHz, DMSO) δ 12.72 (s, 1H), 7.89 (d, *J* = 7.5 Hz, 2H), 7.70 (d, *J* = 8.5 Hz, 1H), 7.65 (t, *J* = 6.9 Hz, 2H), 7.41 (t, *J* = 7.4 Hz, 2H), 7.31 (dt, *J* = 9.9, 7.5 Hz, 2H), 7.19 (d, *J* = 8.5 Hz, 2H), 6.83 (d, *J* = 8.6 Hz, 2H), 4.26 – 4.14 (m, 3H), 4.14 – 4.05 (m, 1H), 3.70 (s, 3H), 3.01 (dd, *J* = 13.8, 4.3 Hz, 1H), 2.80 (dd, *J* = 13.7, 10.6 Hz, 1H).



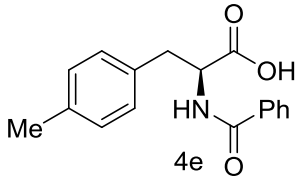
4c

^{1}H NMR (400 MHz, DMSO) δ 12.78 (s, 1H), 7.88 (d, *J* = 7.5 Hz, 2H), 7.74 (d, *J* = 8.4 Hz, 1H), 7.64 (t, *J* = 6.7 Hz, 2H), 7.40 (dd, *J* = 10.0, 4.5 Hz, 2H), 7.29 (dd, *J* = 7.0, 4.8 Hz, 2H), 7.18 (t, *J* = 7.9 Hz, 1H), 6.93 – 6.81 (m, 2H), 6.81 – 6.71 (m, 1H), 4.28 – 4.07 (m, 4H), 3.71 (s, 3H), 3.06 (dd, *J* = 13.7, 4.1 Hz, 1H), 2.85 (dd, *J* = 13.5, 10.8 Hz, 1H).



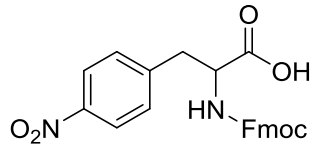
4d

^{1}H NMR (400 MHz, DMSO) δ 12.63 (s, 1H), 8.58 (d, *J* = 8.1 Hz, 1H), 7.77 (d, *J* = 7.2 Hz, 2H), 7.51 (t, *J* = 4.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 2H), 7.23 (d, *J* = 7.4 Hz, 1H), 7.17 (dd, *J* = 11.5, 4.0 Hz, 1H), 6.95 (d, *J* = 8.2 Hz, 1H), 6.82 (t, *J* = 7.4 Hz, 1H), 4.65 (ddd, *J* = 10.5, 8.2, 4.5 Hz, 1H), 3.81 (s, 3H), 3.29 – 3.22 (m, 1H), 2.95 (dd, *J* = 13.5, 10.6 Hz, 1H).



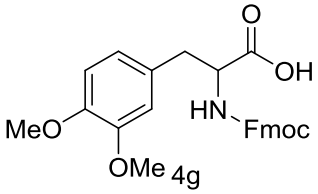
4e

^{1}H NMR (400 MHz, DMSO) δ 8.19 (s, 1H), 7.75 (d, *J* = 7.3 Hz, 2H), 7.50 (t, *J* = 7.2 Hz, 1H), 7.43 (t, *J* = 7.4 Hz, 2H), 7.13 (d, *J* = 7.7 Hz, 2H), 7.00 (d, *J* = 7.7 Hz, 2H), 4.45 (s, 1H), 3.18 (dd, *J* = 13.3, 4.1 Hz, 1H), 3.02 (dd, *J* = 13.4, 8.7 Hz, 1H), 2.20 (s, 3H).



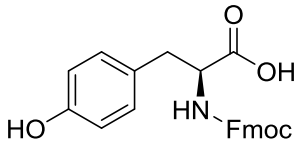
4f

^{1}H NMR (400 MHz, DMSO) δ 9.19 (s, 1H), 7.88 (d, *J* = 7.4 Hz, 2H), 7.75 – 7.57 (m, 2H), 7.41 (td, *J* = 7.1, 3.2 Hz, 2H), 7.31 (dd, *J* = 16.2, 7.9 Hz, 2H), 7.01 (d, *J* = 8.1 Hz, 2H), 6.63 (d, *J* = 8.1 Hz, 2H), 4.25 (dd, *J* = 13.2, 8.0 Hz, 1H), 4.22 – 4.08 (m, 2H), 4.00 (dd, *J* = 18.4, 6.2 Hz, 1H), 2.98 (dd, *J* = 13.8, 3.3 Hz, 1H), 2.75 (dd, *J* = 13.6, 9.5 Hz, 1H).



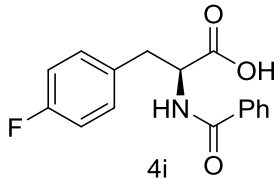
4g

^{1}H NMR (400 MHz, DMSO) δ 12.70 (s, 1H), 7.88 (d, *J* = 7.5 Hz, 2H), 7.67 (dd, *J* = 21.3, 7.8 Hz, 3H), 7.41 (t, *J* = 7.2 Hz, 2H), 7.36 – 7.17 (m, 2H), 6.92 (s, 1H), 6.80 (dd, *J* = 21.1, 8.1 Hz, 2H), 4.34 – 4.00 (m, 4H), 3.70 (d, *J* = 8.9 Hz, 6H), 3.01 (dd, *J* = 13.6, 4.1 Hz, 1H), 2.79 (dd, *J* = 13.7, 10.8 Hz, 1H).



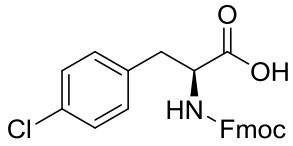
4h

^{1}H NMR (600 MHz, DMSO) δ 8.13 (d, *J* = 8.3 Hz, 2H), 7.86 (d, *J* = 7.4 Hz, 2H), 7.76 (d, *J* = 8.5 Hz, 1H), 7.67 – 7.57 (m, 2H), 7.54 (d, *J* = 8.3 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.28 (dd, *J* = 16.2, 7.8 Hz, 2H), 4.30 – 4.24 (m, 1H), 4.21 (dd, *J* = 12.2, 9.2 Hz, 2H), 4.15 (t, *J* = 6.7 Hz, 1H), 3.25 – 3.22 (m, 1H), 3.05 – 2.96 (m, 1H).



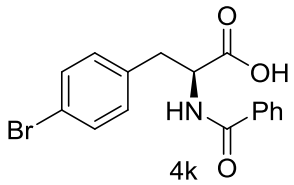
4i

^{1}H NMR (400 MHz, DMSO) δ 12.79 (s, 1H), 8.72 (d, *J* = 8.2 Hz, 1H), 7.79 (d, *J* = 7.2 Hz, 2H), 7.52 (t, *J* = 7.3 Hz, 1H), 7.45 (t, *J* = 7.4 Hz, 2H), 7.35 (dd, *J* = 8.4, 5.7 Hz, 2H), 7.09 (t, *J* = 8.8 Hz, 2H), 4.60 (ddd, *J* = 10.9, 8.3, 4.4 Hz, 1H), 3.18 (dd, *J* = 13.8, 4.3 Hz, 1H), 3.05 (dd, *J* = 13.6, 11.0 Hz, 1H).

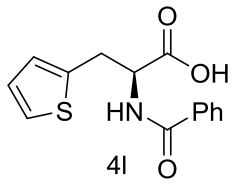


4j

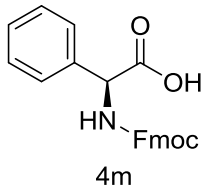
^{1}H NMR (400 MHz, DMSO) δ 12.87 (s, 1H), 7.88 (d, *J* = 7.5 Hz, 2H), 7.75 (d, *J* = 8.5 Hz, 1H), 7.69 – 7.56 (m, 2H), 7.41 (t, *J* = 7.3 Hz, 2H), 7.35 – 7.25 (m, 6H), 4.17 (dt, *J* = 12.5, 4.9 Hz, 4H), 3.08 (dd, *J* = 13.7, 4.1 Hz, 1H), 2.86 (dd, *J* = 13.4, 11.1 Hz, 1H).



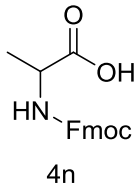
^{1}H NMR (400 MHz, DMSO) δ 8.74 (d, *J* = 8.1 Hz, 1H), 7.79 (d, *J* = 7.6 Hz, 2H), 7.52 (t, *J* = 7.3 Hz, 1H), 7.45 (dd, *J* = 7.7, 6.1 Hz, 4H), 7.28 (d, *J* = 8.2 Hz, 2H), 4.66 – 4.55 (m, 1H), 3.17 (dd, *J* = 13.8, 4.3 Hz, 1H), 3.08 – 2.96 (dd, *J* = 13.8, 8.9 Hz, 1H).



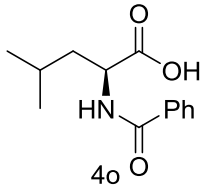
^{1}H NMR (400 MHz, DMSO) δ 12.85 (s, 1H), 8.76 (d, *J* = 16.2 Hz, 1H), 7.85 (d, *J* = 7.3 Hz, 2H), 7.51 (dt, *J* = 27.5, 7.2 Hz, 3H), 7.32 (d, *J* = 4.8 Hz, 1H), 6.93 (dd, *J* = 11.8, 7.0 Hz, 2H), 4.69 – 4.47 (m, 1H), 3.48 – 3.29 (m, 2H).



^{1}H NMR (400 MHz, DMSO) δ 12.87 (s, 1H), 7.88 (d, *J* = 7.5 Hz, 2H), 7.75 (d, *J* = 8.5 Hz, 1H), 7.69 – 7.57 (m, 2H), 7.41 (t, *J* = 7.3 Hz, 2H), 7.33 – 7.26 (m, 5H), 4.17 (dt, *J* = 12.5, 4.9 Hz, 4H), 3.08 (dd, *J* = 13.7, 4.1 Hz, 1H), 2.86 (dd, *J* = 13.4, 11.1 Hz, 1H).

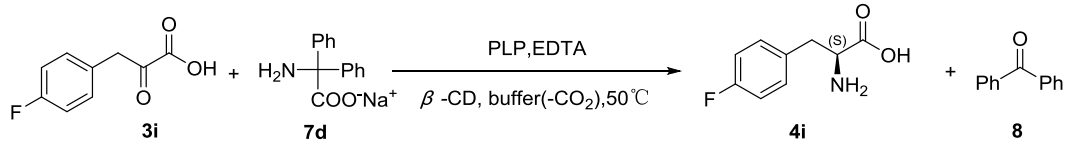


^{1}H NMR (400 MHz, DMSO) δ 12.52 (s, 1H), 8.65 (d, *J* = 7.1 Hz, 1H), 7.88 (d, *J* = 7.2 Hz, 2H), 7.54 (t, *J* = 7.3 Hz, 1H), 7.47 (t, *J* = 7.4 Hz, 2H), 4.42 (p, *J* = 7.4 Hz, 1H), 1.39 (d, *J* = 7.3 Hz, 3H).



^{1}H NMR (400 MHz, DMSO) δ 12.53 (s, 1H), 8.57 (d, *J* = 7.9 Hz, 1H), 7.89 (d, *J* = 7.3 Hz, 2H), 7.54 (t, *J* = 7.2 Hz, 1H), 7.47 (t, *J* = 7.3 Hz, 2H), 4.59 – 4.33 (m, 1H), 1.91 – 1.63 (m, 2H), 1.59 (ddd, *J* = 12.7, 8.8, 4.2 Hz, 1H), 0.90 (dd, *J* = 17.1, 6.3 Hz, 6H).

5. Table S7. Control experiments for PLP-catalyzed asymmetric transamination of 4-fluorophenylpyruvic acid[a]



3i 7d 4i 8

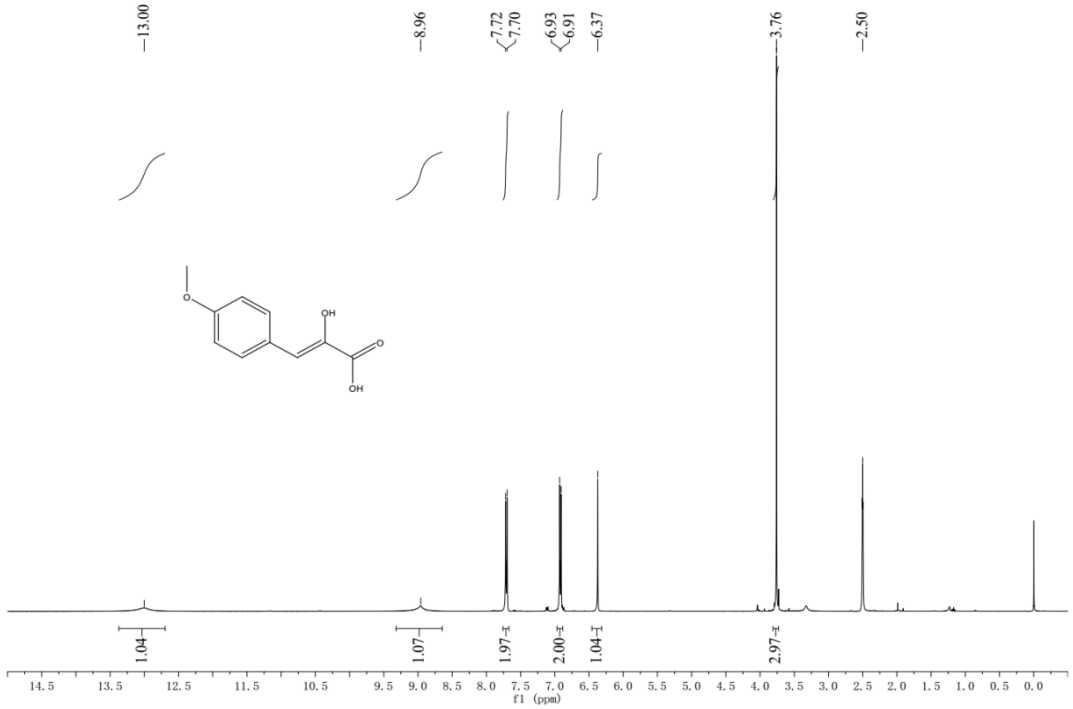
entry	condition	Yield(%)[b]	ee(%)[c]
1	one-pot method[a]	37	35
2	**3i**+*β*-CD[d]	39	44
3	**7d**+*β*-CD[e]	36	35
4	**3i**+*β*-CD(2.4eq)[f]	38	50

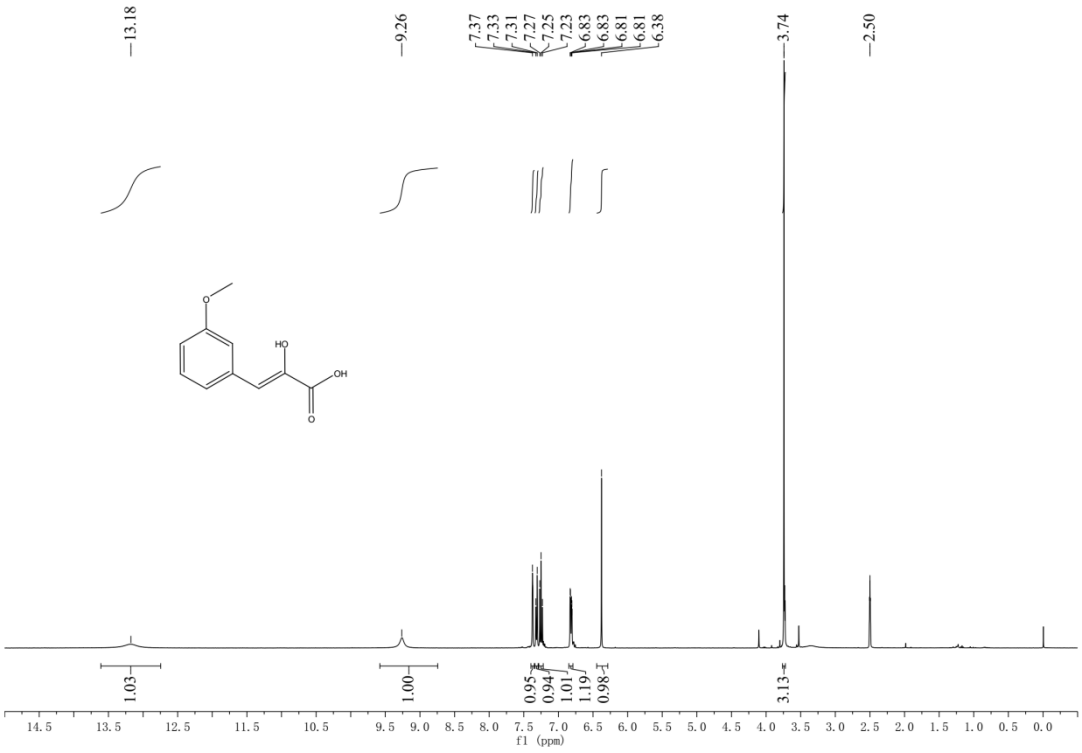
[a]All reactions were carried out with 4-fluorophenylpyruric acid (**3i**) (0.05 m mol), *β*-CD (0.06 m mol), EDTA (0.01 m mol) and in Tris buffer (4.0 m L), pH 8.0, at 50℃for 48 h if not mentioned. [b]The yield was determined by chiral HPLC through standard addition method(Table S1†).[c]The ee's were determined by chiral HPLC (Chiralpak AD-H column) after the amines were converted into their *N*-Bz derivatives, the absolute configuration of **4i** was assigned as *S* by comparison with the standard product. [d]**3i**, *β*-CD, EDTA and Tris buffer solution were stirred overnight at 50 ℃ to get the resulting mixtures, then added **7d** and PLP keeping on stirring for another 48h. [e]**7d**, *β*-CD, EDTA and Tris buffer solution were stirred overnight at 50 ℃ to get the resulting mixtures, then added **3i** and PLP keeping on stirring for another 48h. [f]The same as [d] except dosage of *β*-CD was 2.4 eq.(0.12mmol).

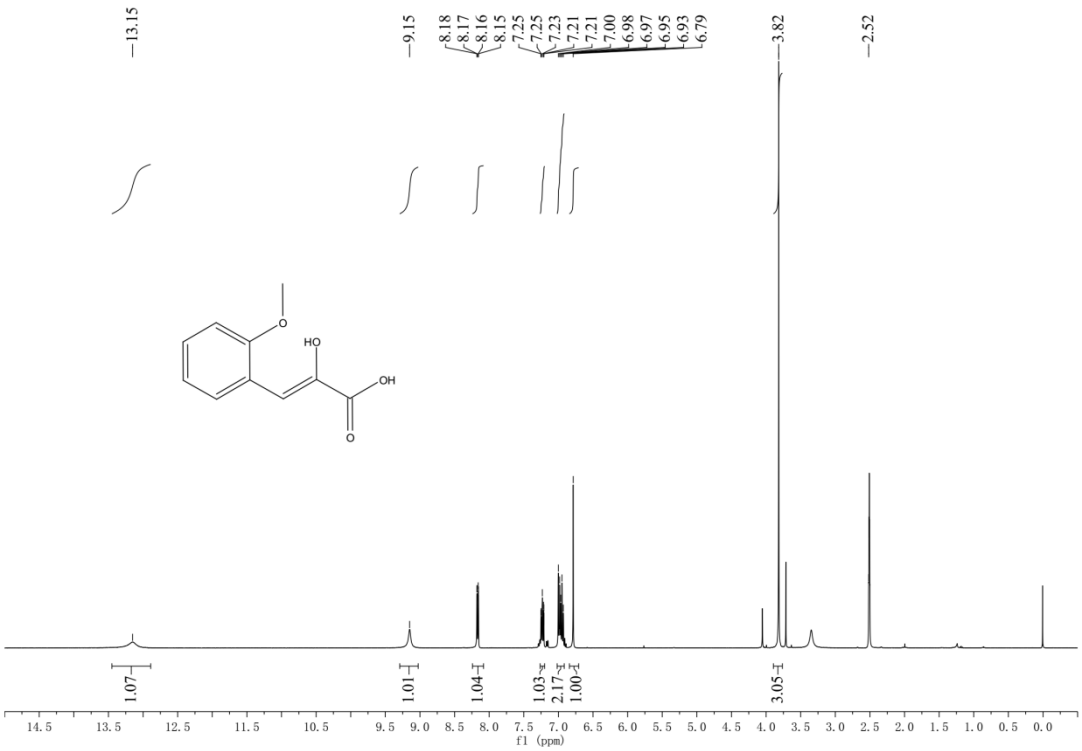
6. Characterization data

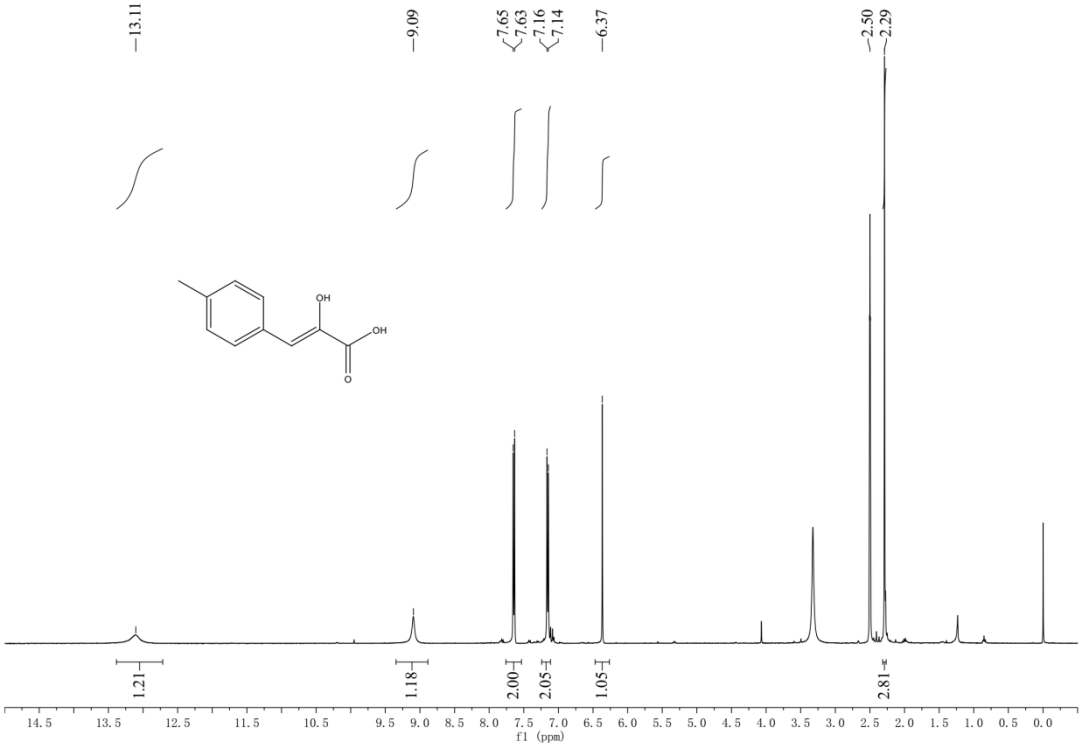
^{1}H NMR of the *α*-keto acids and derivatives of amino acids

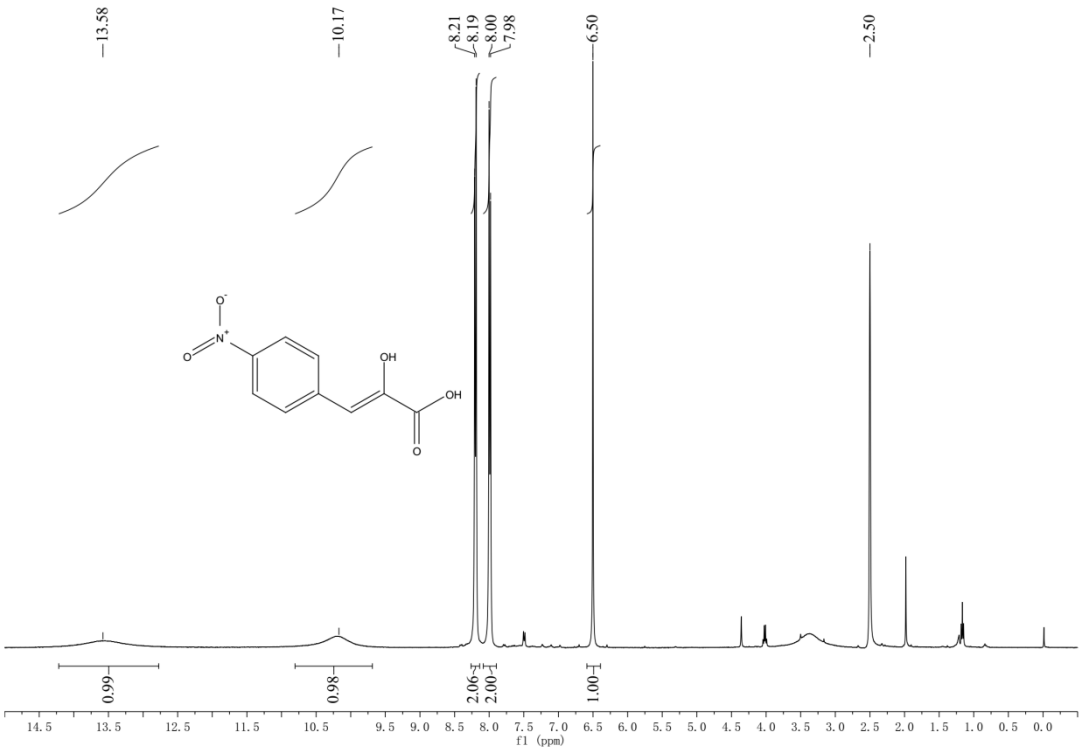
^{1}H NMR of the *α*-keto acids

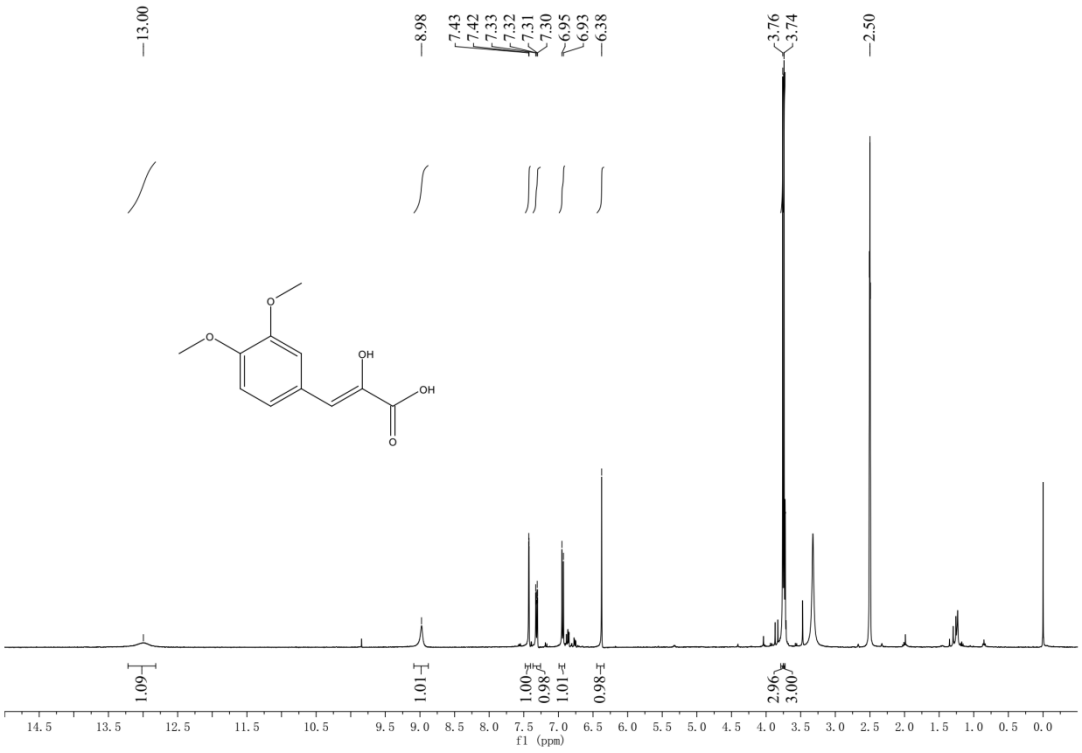


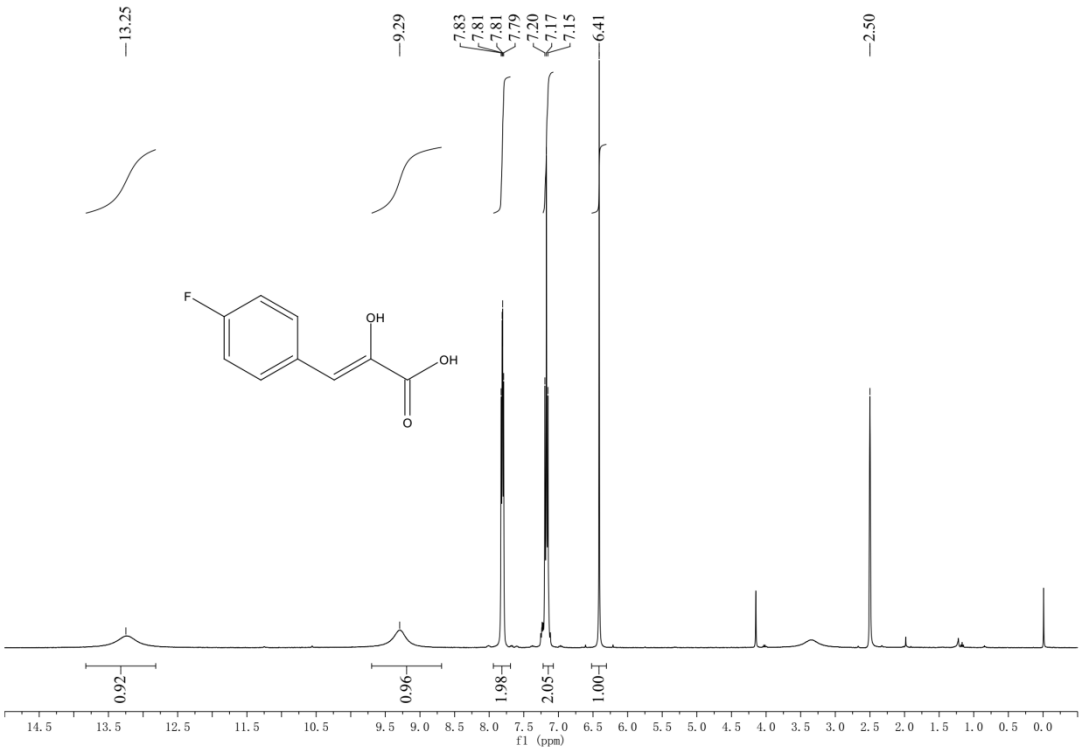

13.18
9.26
7.37
7.33
7.31
7.27
7.25
7.23
6.83
6.83
6.81
6.81
6.38
3.74
2.50
HO
OH
O
O
1.03
1.00
0.95
0.94
1.01
1.19
0.98
3.13
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

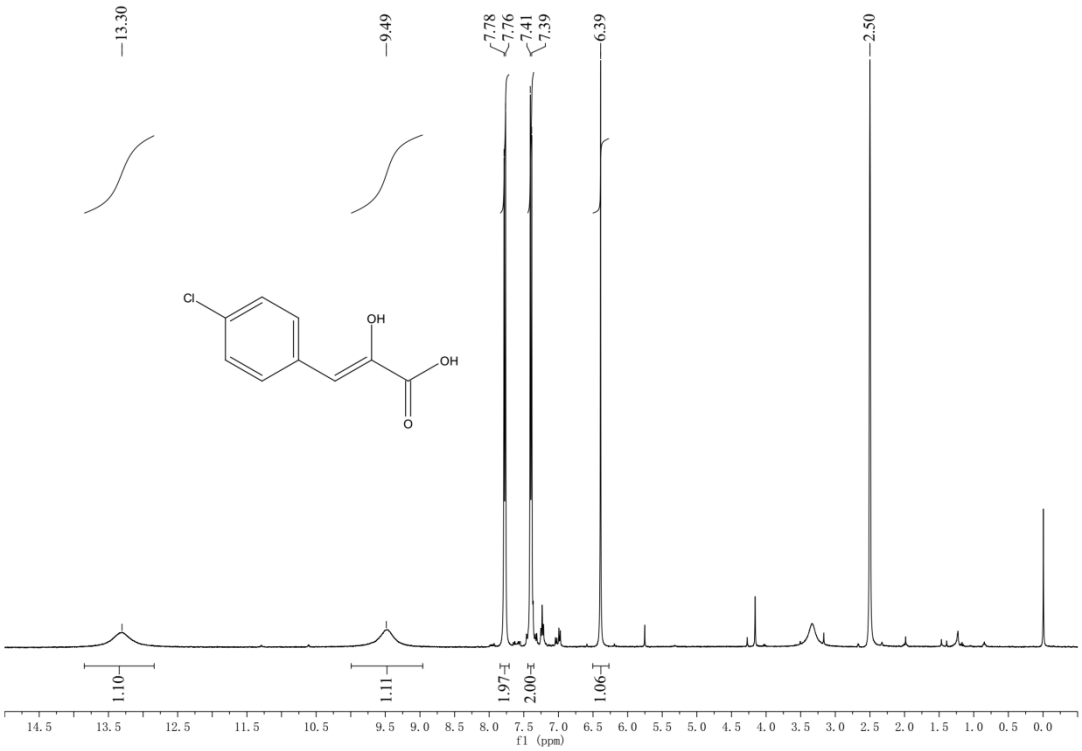

13.15
9.15
8.18
8.17
8.16
8.15
7.25
7.25
7.23
7.21
7.21
7.00
6.98
6.97
6.95
6.93
6.79
3.82
2.52
HO
OH
O
O
1.07
1.01
1.04
1.03
2.17
1.00
3.05
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

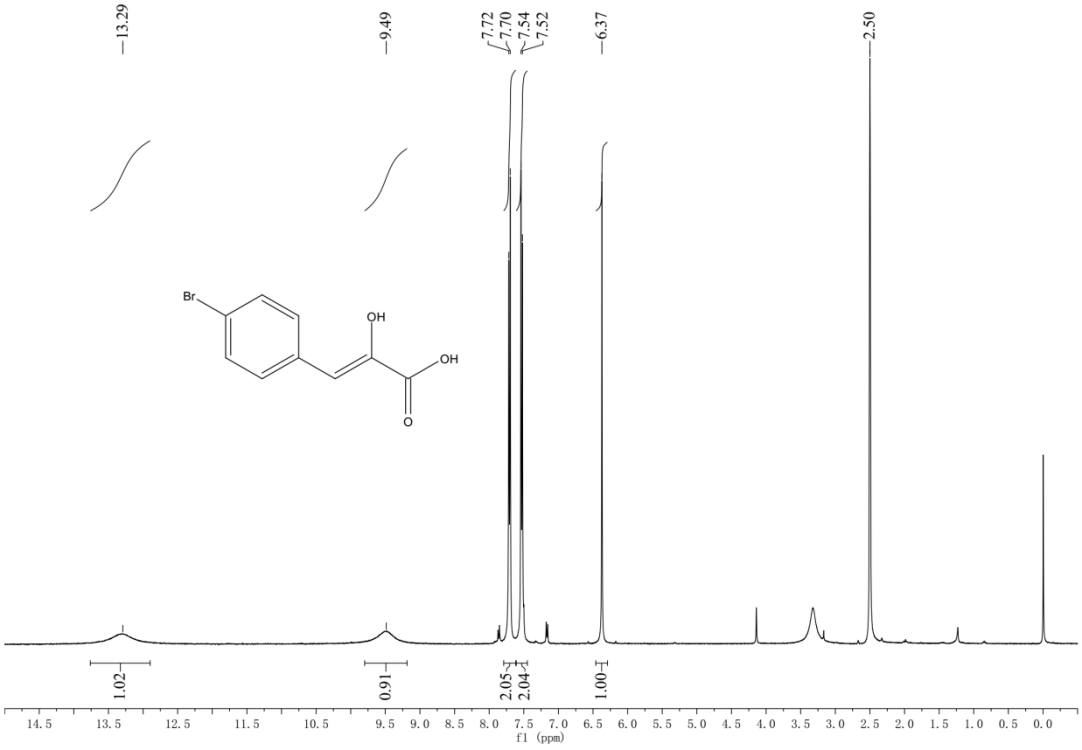

13.11
9.09
7.65
7.63
7.16
7.14
6.37
2.50
2.29
OH
OH
O
1.21
1.18
2.00
2.05
1.05
2.81
f1 (ppm)

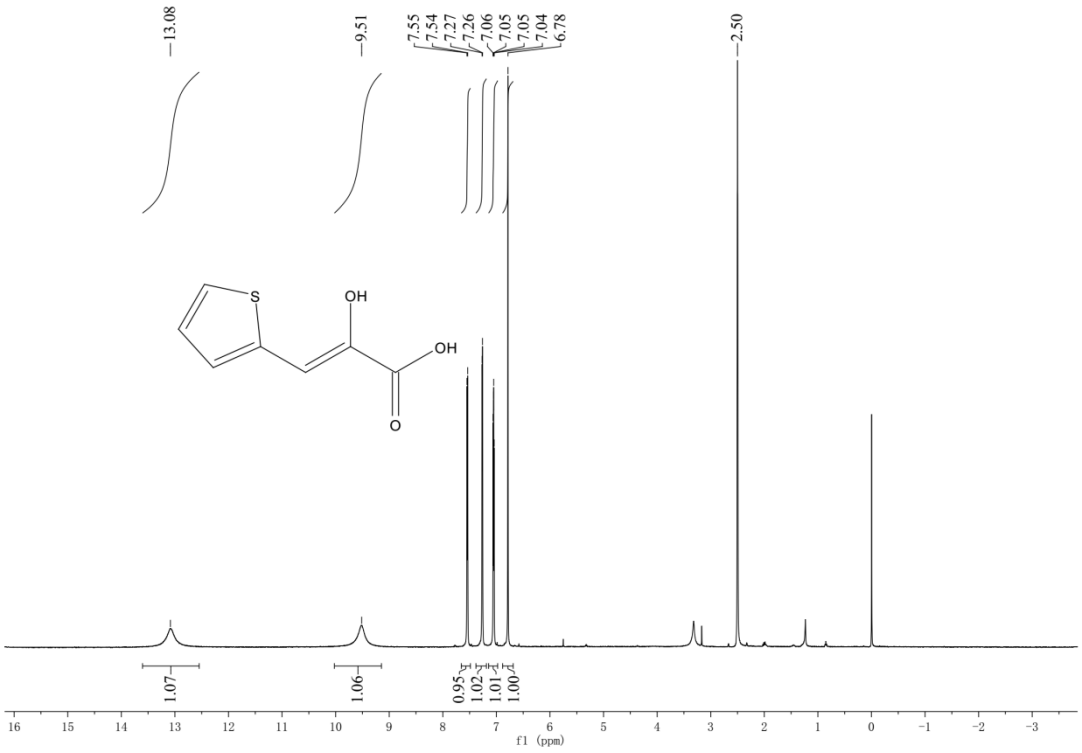

13.58
10.17
8.21
8.19
8.00
7.98
6.50
2.50
O
N
O
OH
OH
O
0.99
0.98
2.06
2.00
1.00
f1 (ppm)


13.00
8.98
7.43
7.42
7.33
7.32
7.31
7.30
6.95
6.93
6.38
3.76
3.74
2.50
O
O
OH
OH
O
1.09
1.01
1.00
0.98
1.01
0.98
2.96
3.00
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

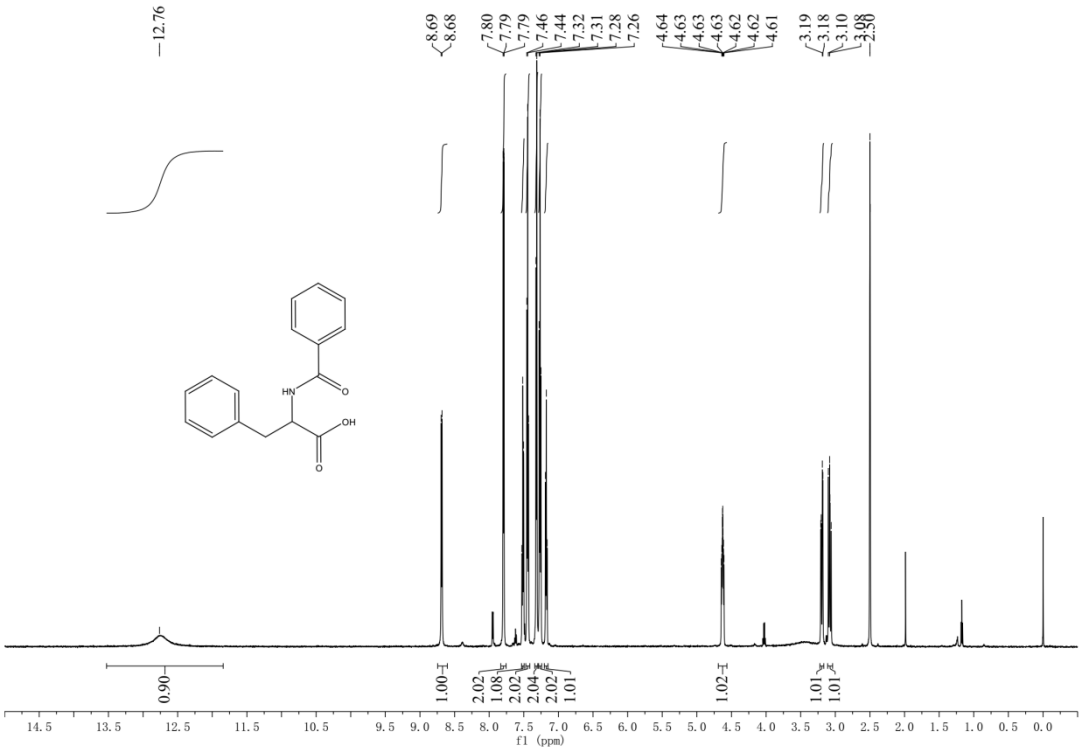

13.25
9.29
7.83
7.81
7.81
7.79
7.20
7.17
7.15
6.41
2.50
F
OH
OH
O
0.92
0.96
1.98
2.05
1.00
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

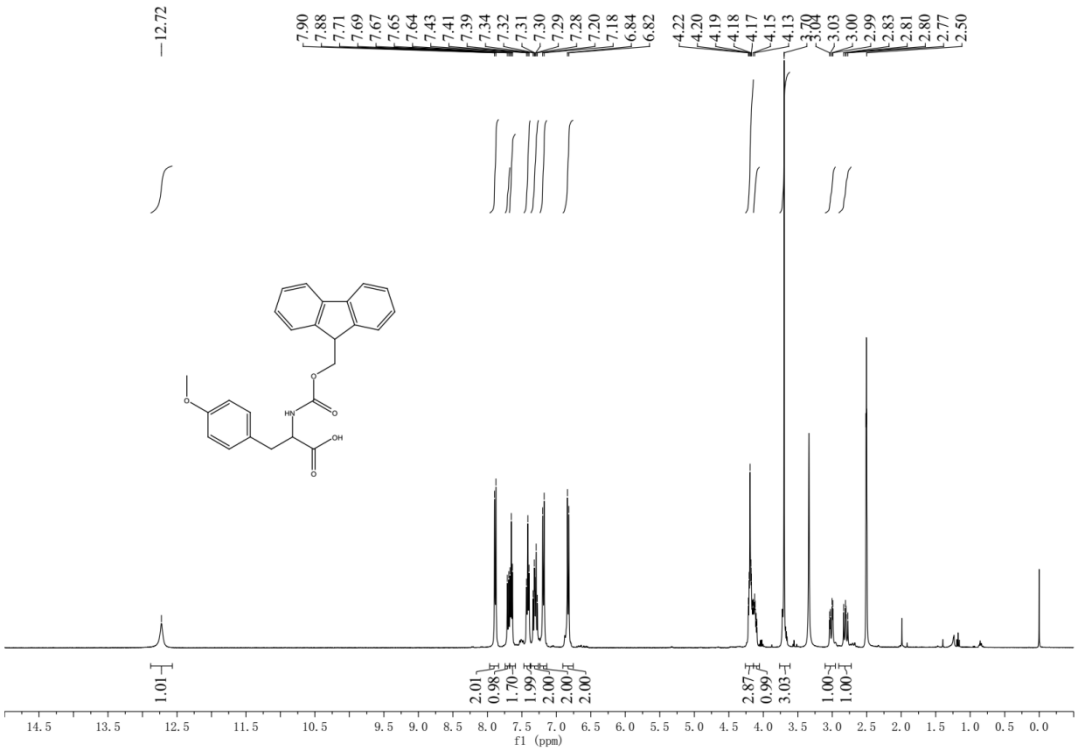

13.30
9.49
7.78
7.76
7.41
7.39
6.39
2.50
Cl
OH
OH
O
1.10
1.11
1.97
2.00
1.06
f1 (ppm)

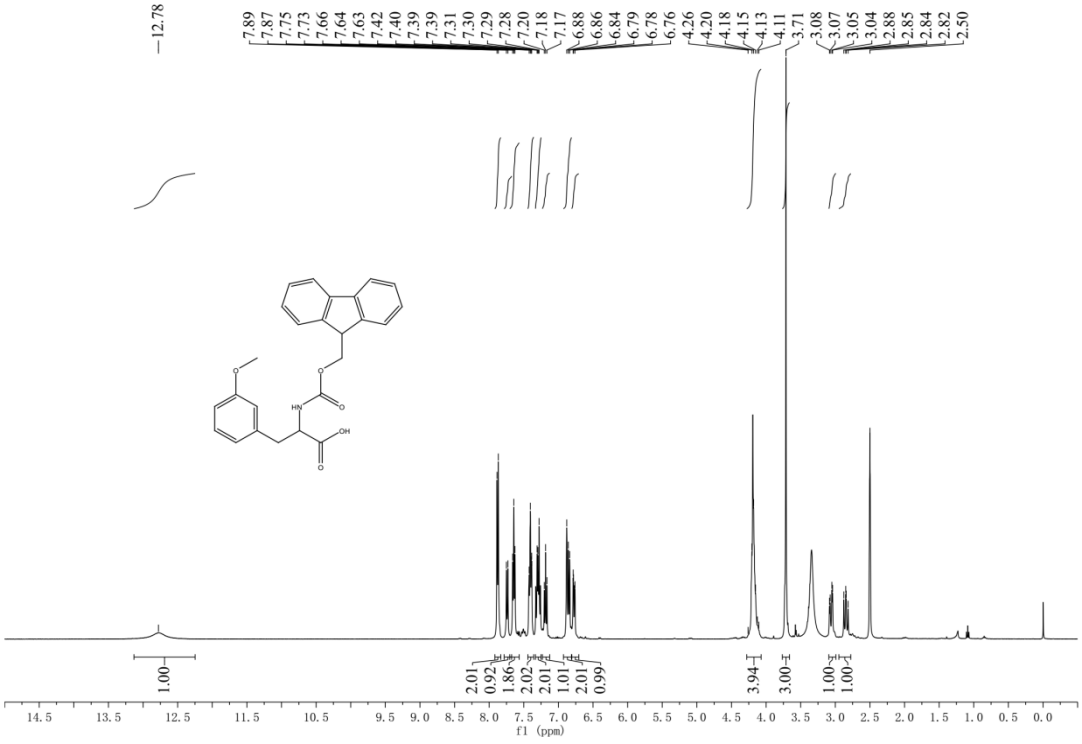

13.29
9.49
7.72
7.70
7.54
7.52
6.37
2.50
Br
OH
OH
O
1.02
0.91
2.05
2.04
1.00
f1 (ppm)

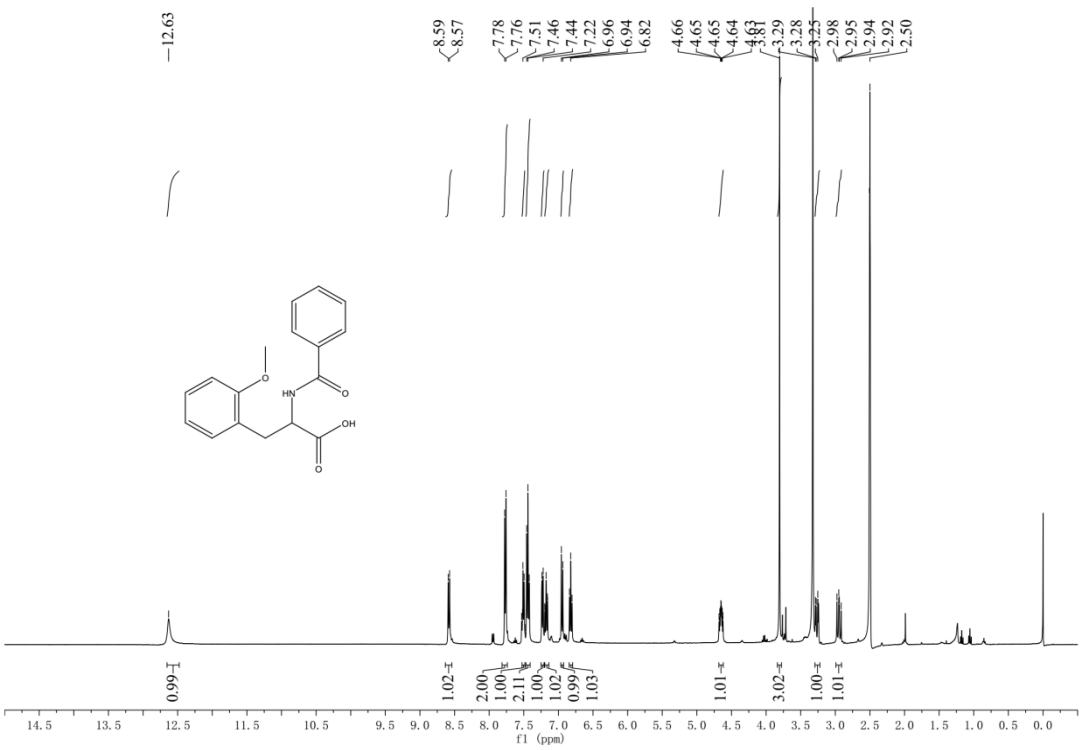


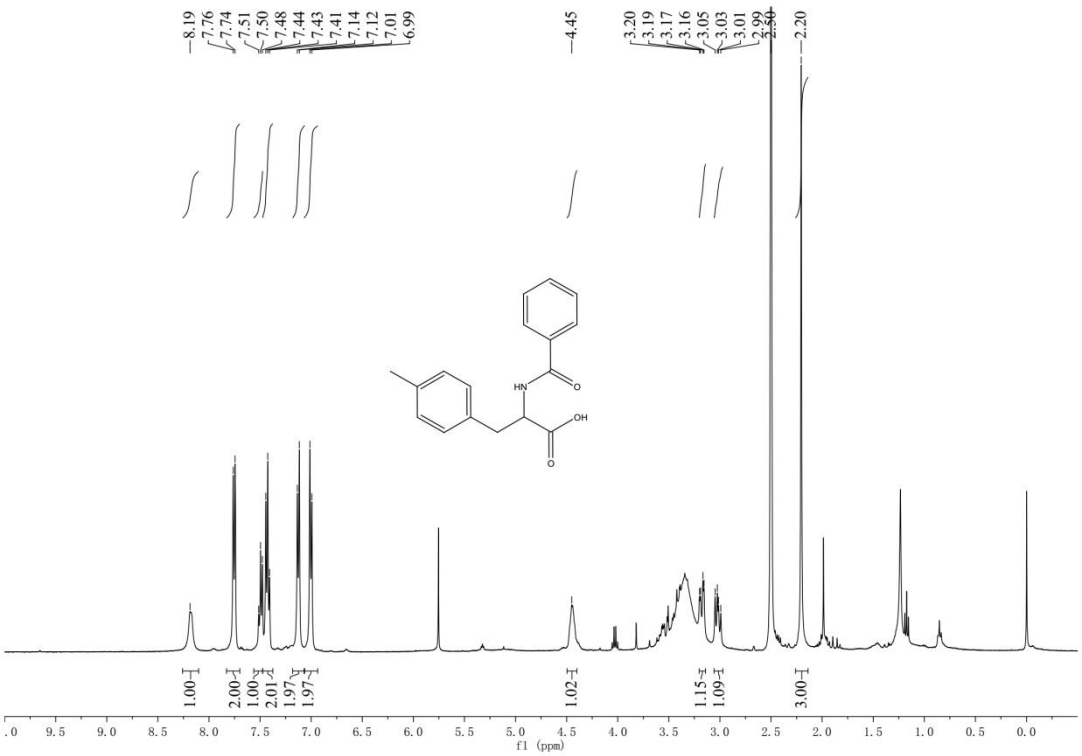
^{1}H NMR of the *α*-amino acid derivatives

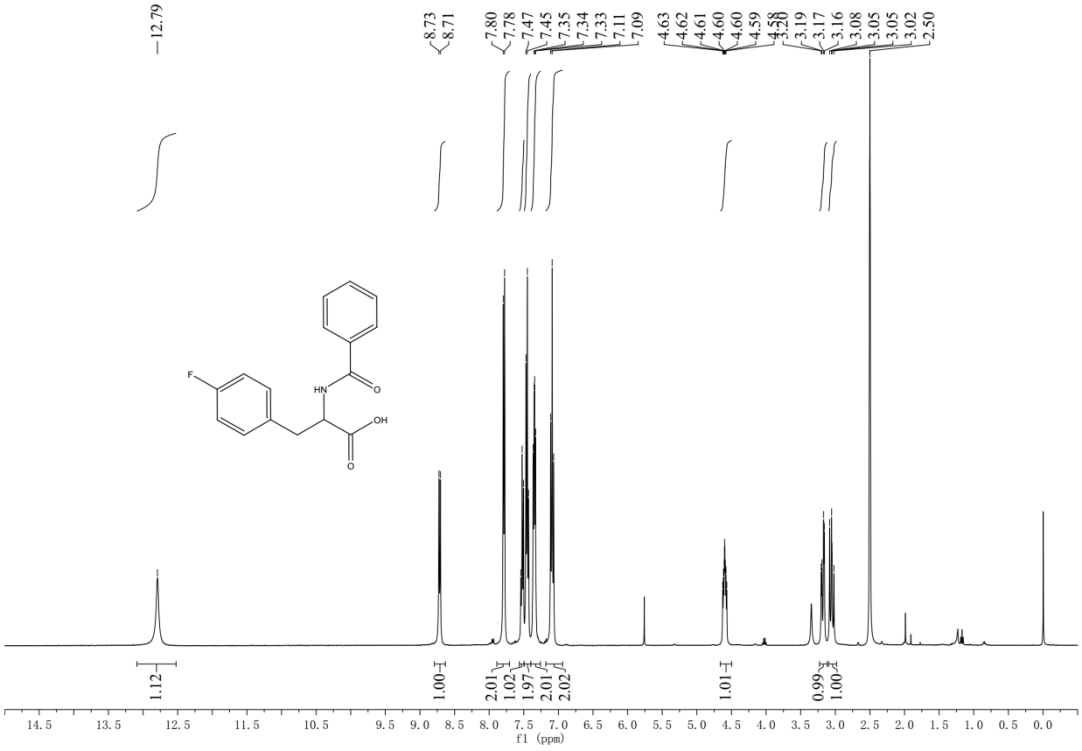



12.72
7.90
7.88
7.71
7.69
7.67
7.65
7.64
7.43
7.41
7.39
7.34
7.32
7.31
7.30
7.29
7.28
7.20
7.18
6.84
6.82
4.22
4.20
4.19
4.18
4.17
4.15
4.13
3.70
3.04
3.03
3.00
2.99
2.83
2.81
2.80
2.77
2.50
1.01
2.01
0.98
1.70
1.99
2.00
2.00
2.00
2.87
0.99
3.03
1.00
1.00
f1 (ppm)


12.78
7.89
7.87
7.75
7.73
7.66
7.64
7.63
7.42
7.40
7.39
7.39
7.31
7.30
7.29
7.28
7.20
7.18
7.17
6.88
6.86
6.84
6.79
6.78
6.76
4.26
4.20
4.18
4.15
4.13
4.11
3.71
3.08
3.07
3.05
3.04
2.88
2.85
2.84
2.82
2.50
1.00
2.01
0.92
1.86
2.02
2.01
1.01
2.01
0.99
3.94
3.00
1.00
1.00
f1 (ppm)


12.63
8.59
8.57
7.78
7.76
7.51
7.46
7.44
7.22
6.96
6.94
6.82
4.66
4.65
4.65
4.64
4.63
3.81
3.29
3.28
3.25
2.98
2.95
2.94
2.92
2.50
HN
O
OH
O
O
0.99
1.02
2.00
1.00
2.11
1.00
1.02
0.99
1.03
1.01
3.02
1.00
1.01
f1 (ppm)


8.19
7.76
7.74
7.51
7.50
7.48
7.44
7.43
7.41
7.14
7.12
7.01
6.99
4.45
3.20
3.19
3.17
3.16
3.05
3.03
3.01
2.99
2.50
2.20
HN
O
OH
O
1.00
2.00
1.00
2.01
1.97
1.97
1.02
1.15
1.09
3.00
f1 (ppm)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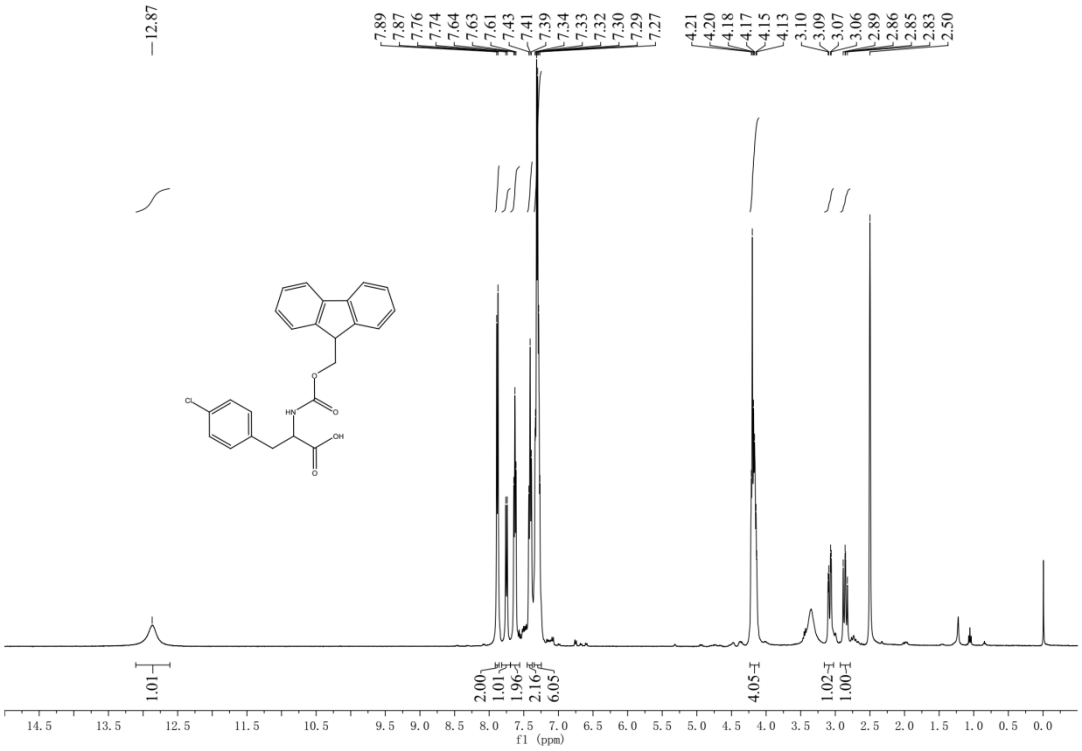
8.73
8.71
7.80
7.78
7.47
7.45
7.35
7.34
7.33
7.11
7.09
4.63
4.62
4.61
4.60
4.60
4.59
3.20
3.19
3.17
3.16
3.08
3.05
3.02
2.50
F
HN
O
OH
O
1.12
1.00
2.01
1.02
1.97
2.01
2.02
1.01
0.99
1.00
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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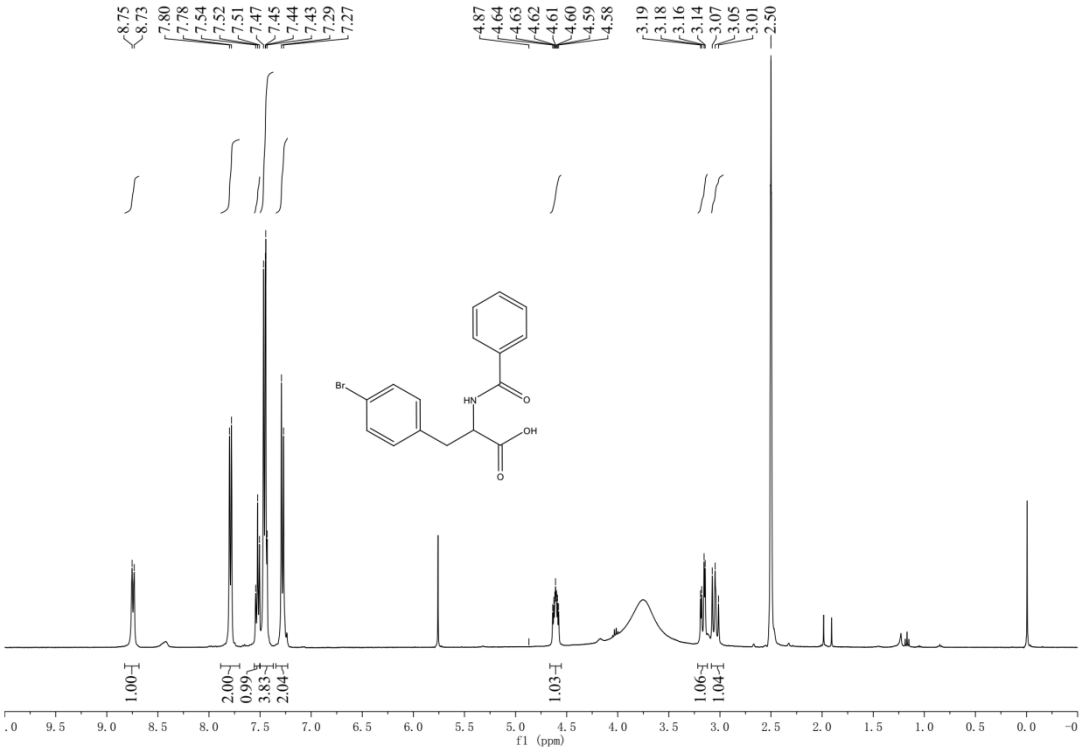
7.87
7.76
7.74
7.64
7.63
7.61
7.43
7.41
7.39
7.34
7.33
7.32
7.30
7.29
7.27
4.21
4.20
4.18
4.17
4.15
4.13
3.10
3.09
3.07
3.06
2.89
2.86
2.85
2.83
2.50
Cl
HN
O
O
OH
O
1.01
2.00
1.01
1.96
2.16
6.05
4.05
1.02
1.00
14.5 13.5 12.5 11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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7.80
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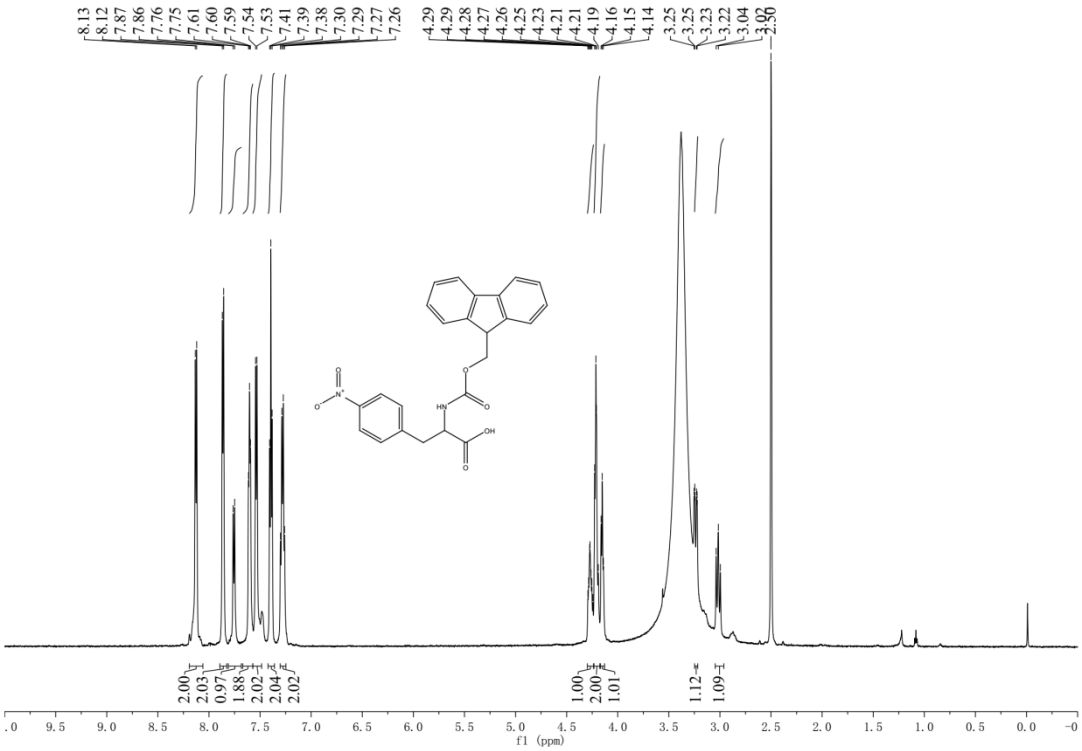
7.52
7.51
7.47
7.45
7.44
7.43
7.29
7.27
4.87
4.64
4.63
4.62
4.61
4.60
4.59
4.58
3.19
3.18
3.16
3.14
3.07
3.05
3.01
2.50
Br
HN
O
OH
O
1.00
2.00
0.99
3.83
2.04
1.03
1.06
1.04
f1 (ppm)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8.12
7.87
7.86
7.76
7.75
7.61
7.60
7.59
7.54
7.53
7.41
7.39
7.38
7.30
7.29
7.27
7.26
4.29
4.29
4.28
4.27
4.26
4.25
4.23
4.21
4.21
4.19
4.16
4.15
4.14
3.25
3.25
3.23
3.22
3.04
3.02
2.50
O
N+
O-
HN
O
O
OH
O
2.00
2.03
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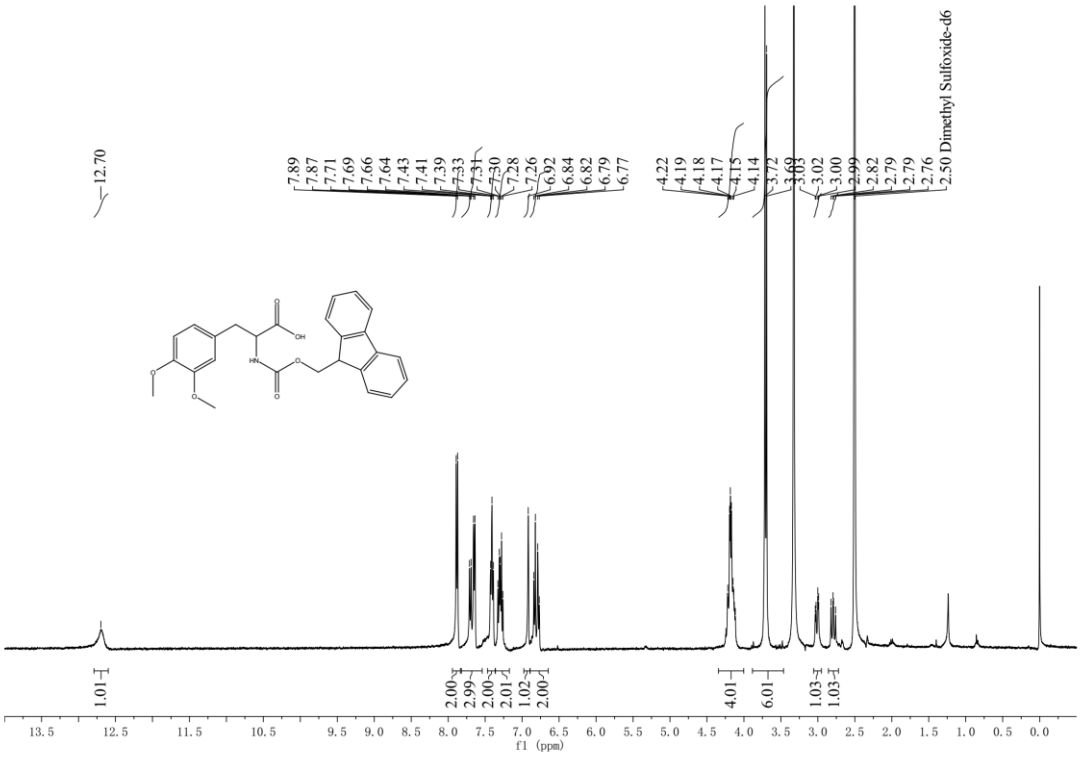
2.02
2.04
2.02
1.00
2.00
1.01
1.12
1.09
f1 (ppm)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7.69
7.66
7.64
7.43
7.41
7.39
7.33
7.31
7.30
7.28
7.26
6.92
6.84
6.82
6.79
6.77
4.22
4.19
4.18
4.17
4.15
4.14
3.72
3.69
3.03
3.02
3.00
2.99
2.82
2.79
2.79
2.76
2.50 Dimethyl Sulfoxide-d6
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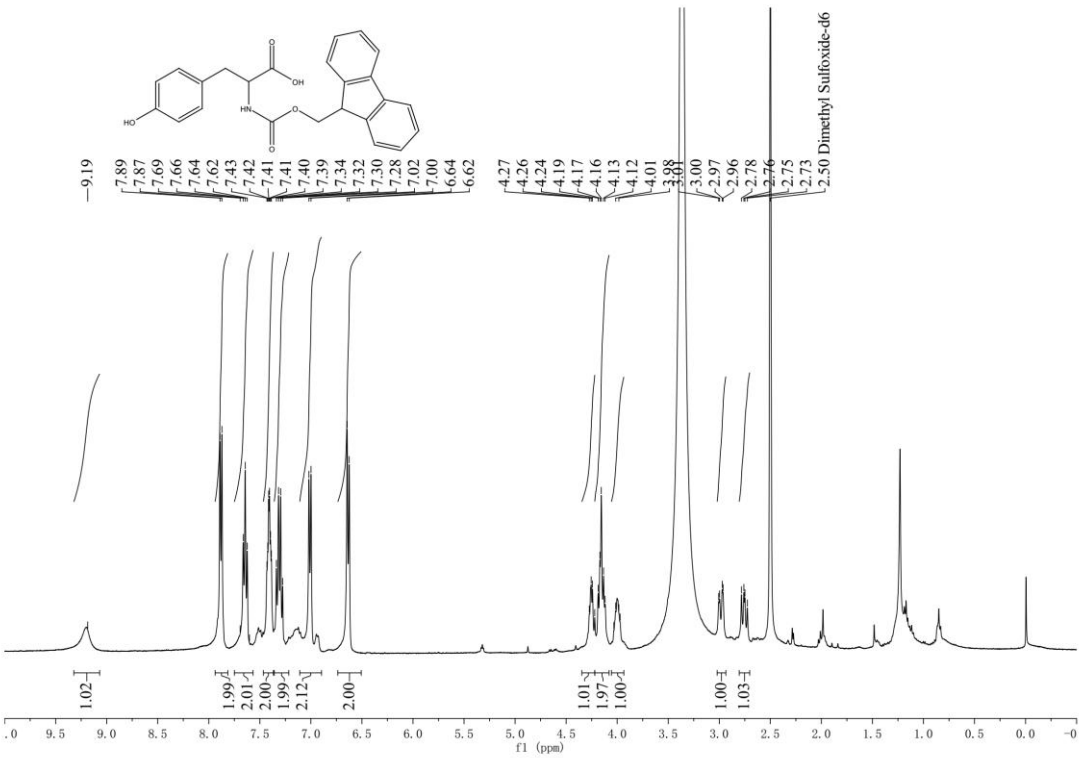
2.99
2.00
2.01
1.02
2.00
4.01
6.01
1.03
1.03
f1 (ppm)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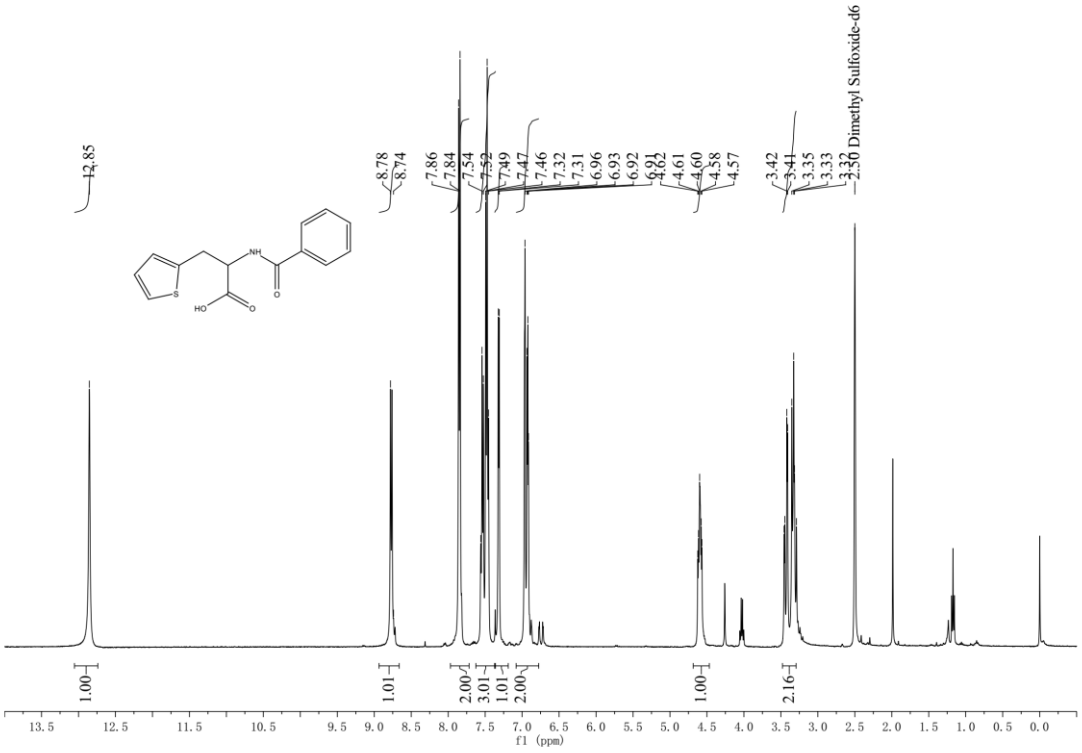
7.64
7.62
7.43
7.42
7.41
7.41
7.40
7.39
7.34
7.32
7.30
7.28
7.02
7.00
6.64
6.62
4.27
4.26
4.24
4.19
4.17
4.16
4.13
4.12
4.01
3.98
3.00
2.97
2.96
2.78
2.76
2.75
2.73
2.50 Dimethyl Sulfoxide-d6
1.02
1.99
2.01
2.00
1.99
2.12
2.00
1.01
1.97
1.00
1.00
1.03
f1 (ppm)


12.85
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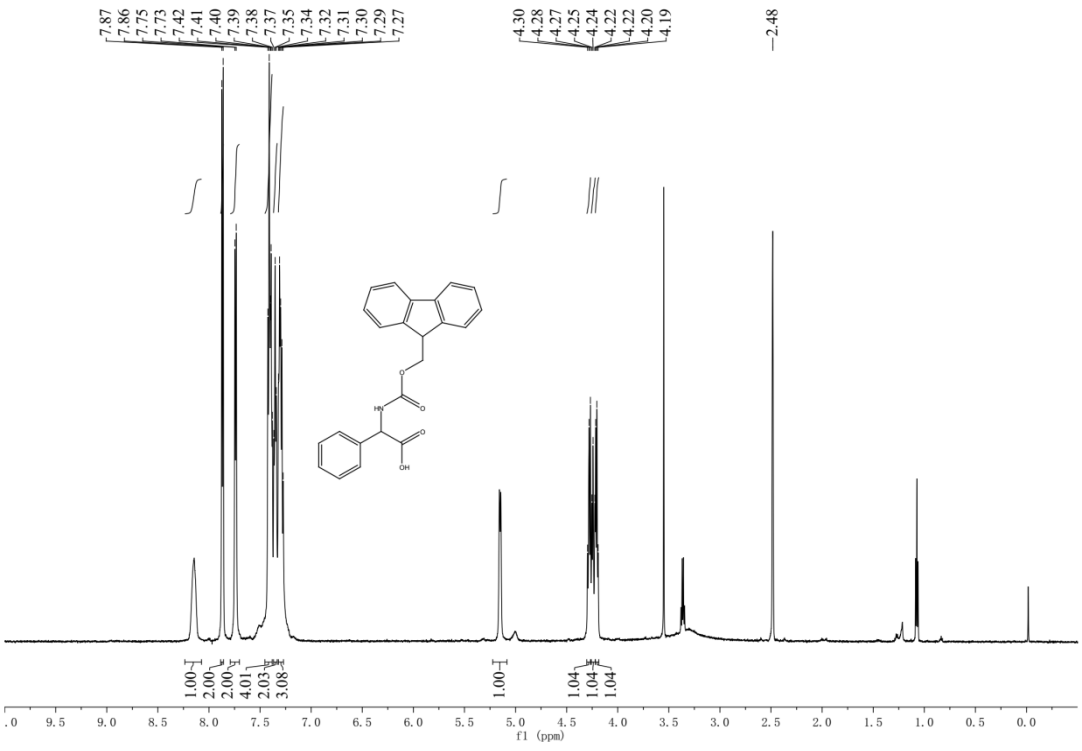
7.86
7.84
7.54
7.52
7.49
7.47
7.46
7.32
7.31
6.96
6.93
6.92
6.91
4.62
4.61
4.60
4.58
4.57
3.42
3.41
3.35
3.33
3.32
2.50 Dimethyl Sulfoxide-d6
NH
S
HO
O
O
1.00
1.01
2.00
3.01
1.01
2.00
1.00
2.16
f1 (ppm)


7.87
7.86
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7.73
7.42
7.41
7.40
7.39
7.38
7.37
7.35
7.34
7.32
7.31
7.30
7.29
7.27
4.30
4.28
4.27
4.25
4.24
4.22
4.22
4.20
4.19
2.48
HN
O
O
OH
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2.00
4.01
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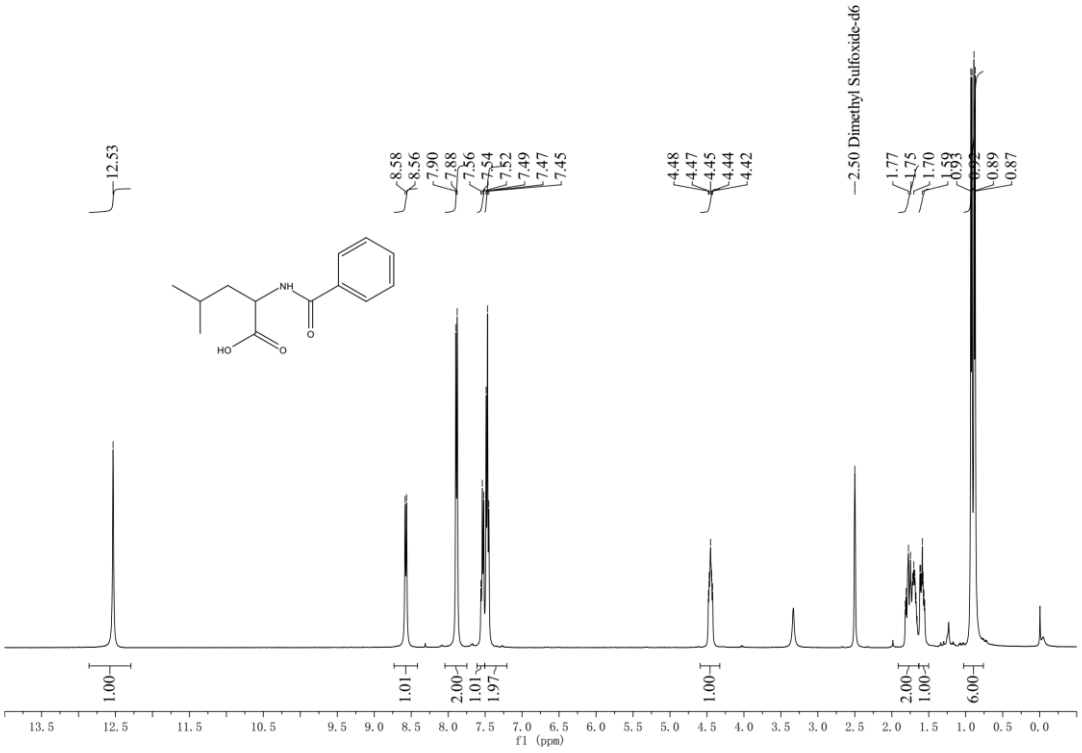
3.08
1.00
1.04
1.04
1.04
f1 (ppm)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8.58
8.56
7.90
7.88
7.56
7.54
7.52
7.49
7.47
7.45
4.48
4.47
4.45
4.44
4.42
2.50 Dimethyl Sulfoxide-d6
1.77
1.75
1.70
1.59
0.93
0.89
0.87
NH
HO
O
O
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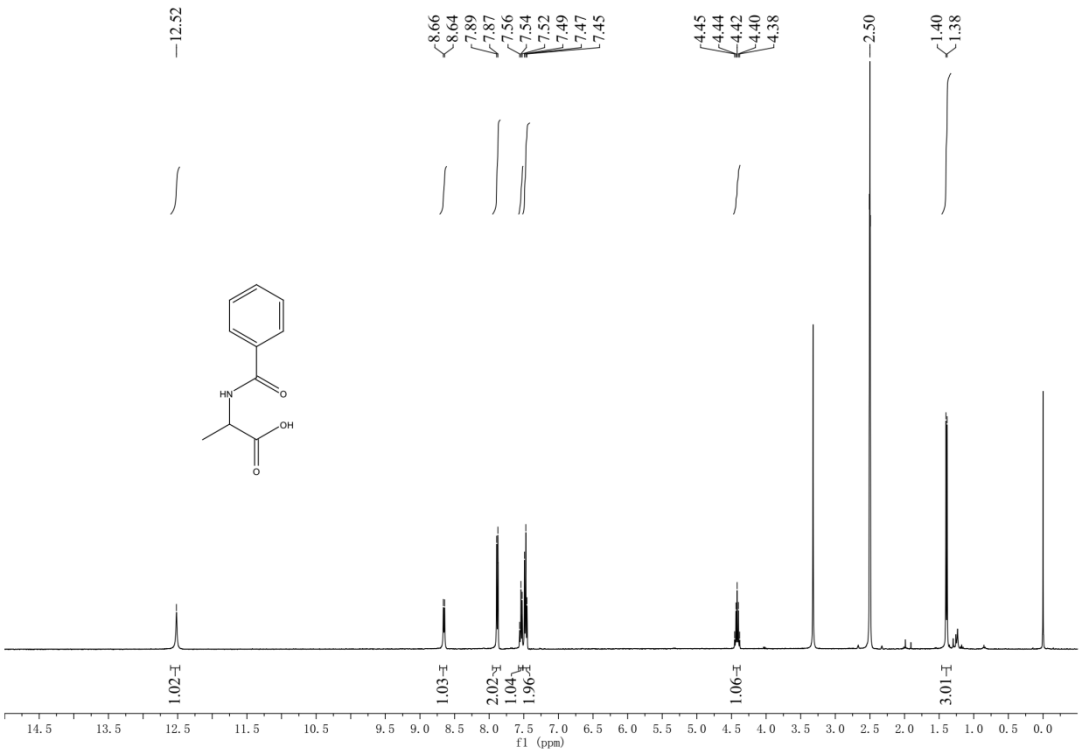
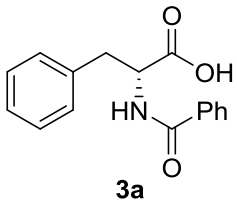
1.01
2.00
1.01
1.97
1.00
2.00
1.00
6.00
f1 (ppm)


12.52
8.66
8.64
7.89
7.87
7.56
7.54
7.52
7.49
7.47
7.45
4.45
4.44
4.42
4.40
4.38
2.50
1.40
1.38
HN
O
OH
O
1.02
1.03
2.02
1.04
1.96
1.06
3.01
f1 (ppm)

HPLC for the determination of enantiomeric excessess

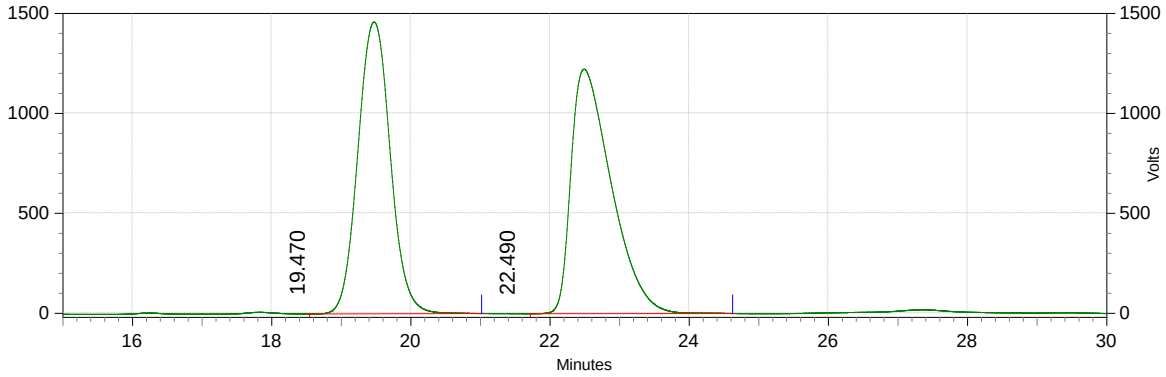
Table 3, compound 4a



3a

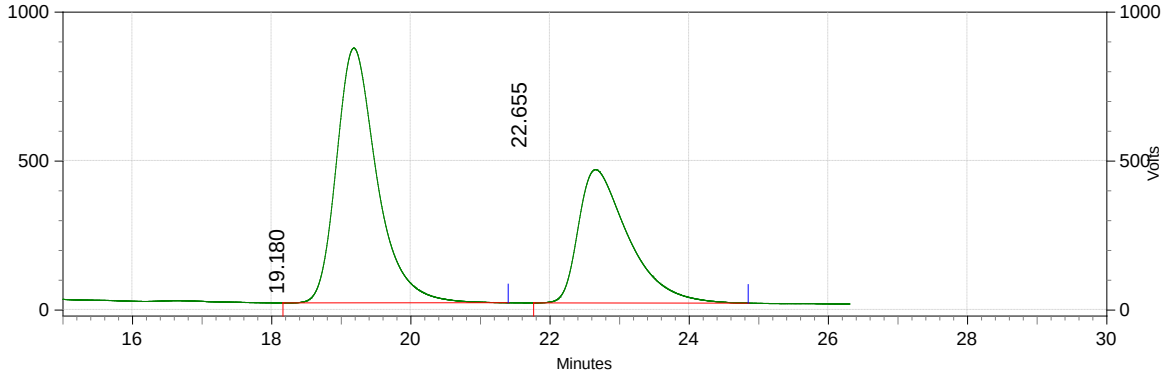
HPLC Conditions:Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(14/1) containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



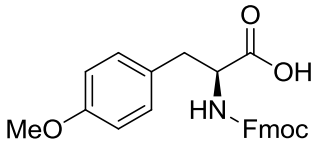
Peak#	RT(min)	Area	Aera%
1	19.470	47234600	49.025
2	22.490	49113239	50.975

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	19.180	34667956	60.861
2	22.655	22294653	39.139

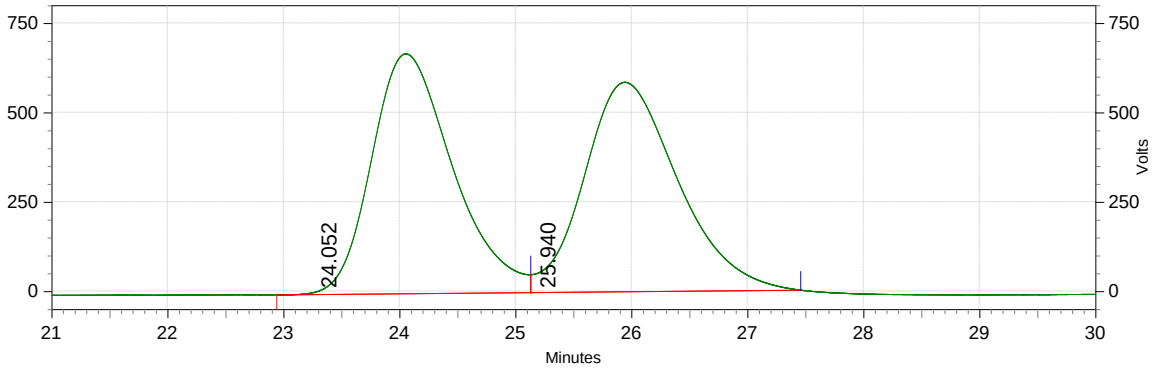
Table 2, compound 4b



4b

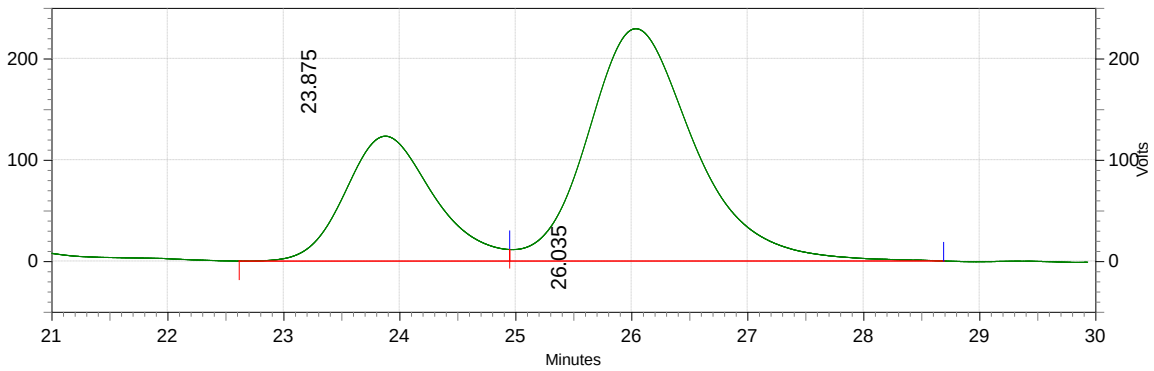
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(10:1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



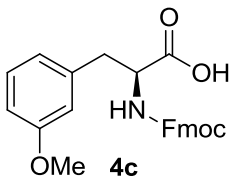
Peak#	RT(min)	Area	Aera%
1	24.052	32654064	49.814
2	25.940	32898368	50.186

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	23.875	6560276	30.889
2	26.035	14677691	69.111

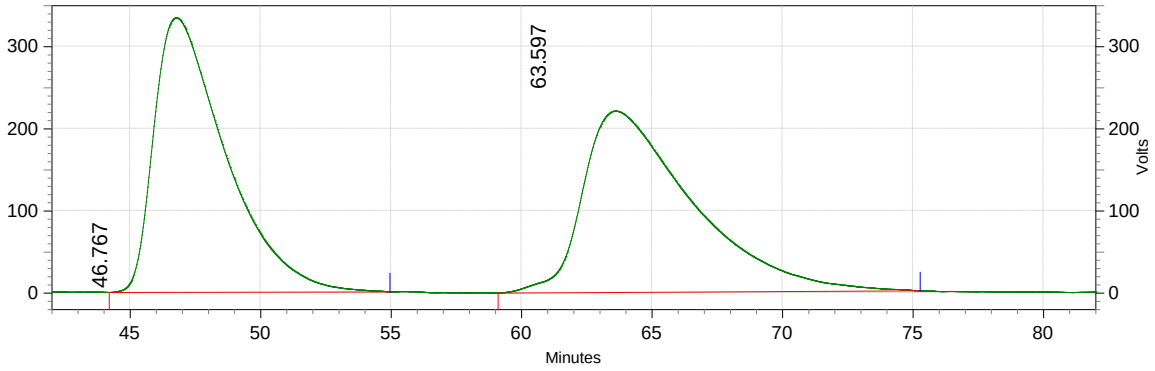
Table 2, compound 4c



4c

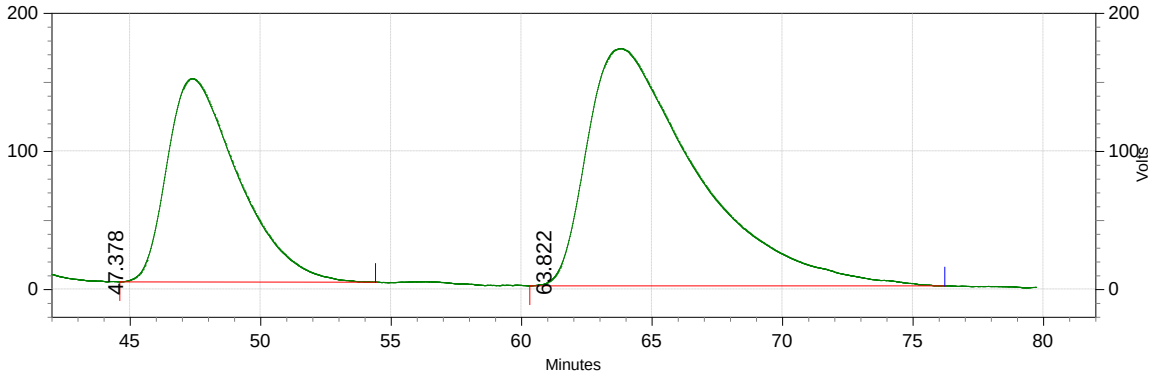
HPLC Conditions: Column: Chiralcel OD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA (14/1) containing 0.3% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



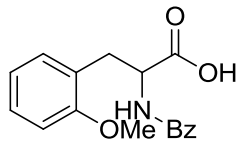
Peak#	RT(min)	Area	Aera%
1	46.767	63690881	49.722
2	63.597	64403855	50.278

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	47.378	27909618	35.787
2	63.822	50078348	64.213

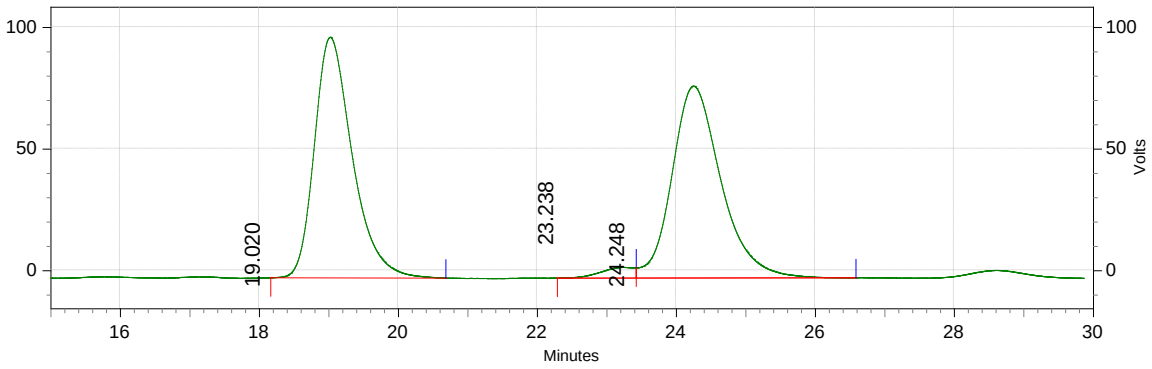
Table 2, compound 4d



4d

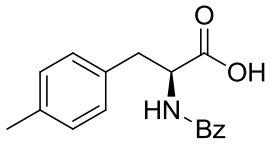
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA (8/1) containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



Peak#	RT(min)	Area	Aera%
1	19.020	3750251	48.362
2	24.248	3859756	49.775

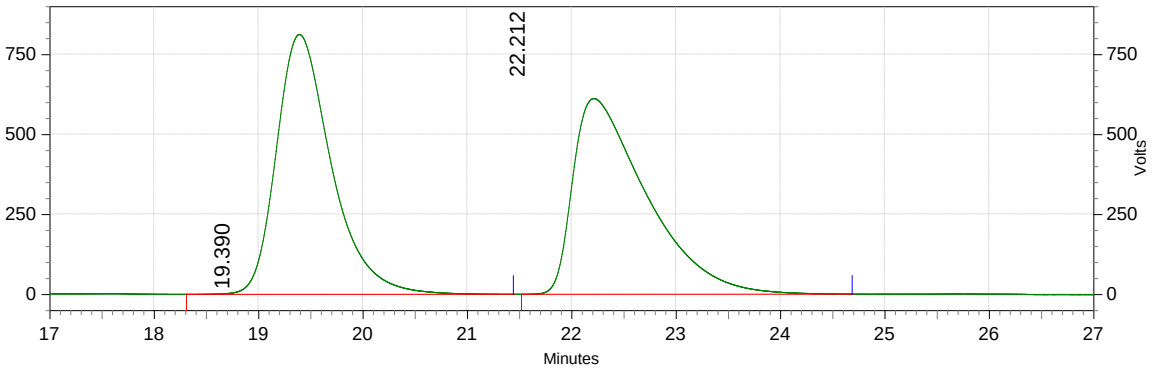
Table 2, compound 4e



4e

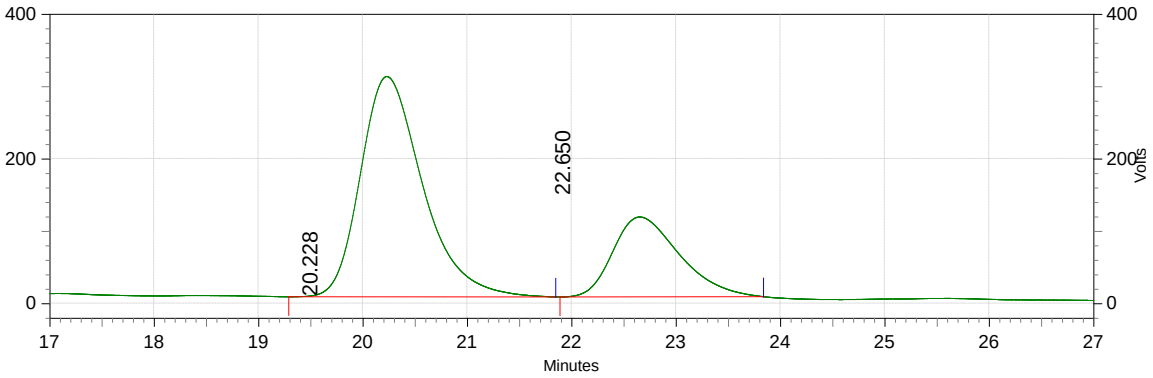
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(10:1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



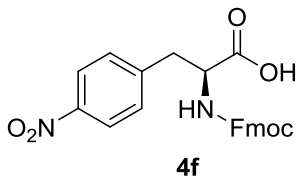
Peak#	RT(min)	Area	Aera%
1	19.390	29771168	49.811
2	22.212	29996595	50.189

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	20.228	12598767	72.052
2	22.650	4886826	27.948

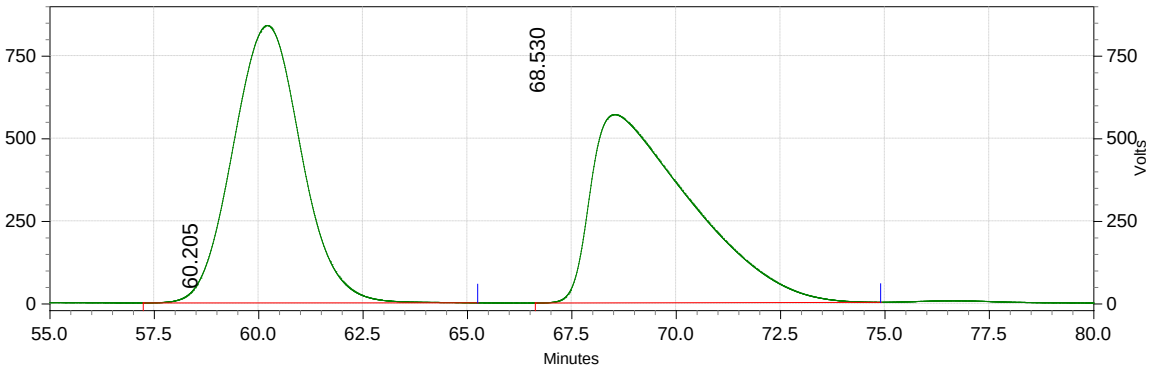
Table 2, compound 4f



4f

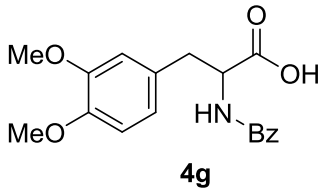
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(14/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



Peak#	RT(min)	Area	Aera%
1	60.205	95597538	50.084
2	68.530	95276723	49.916

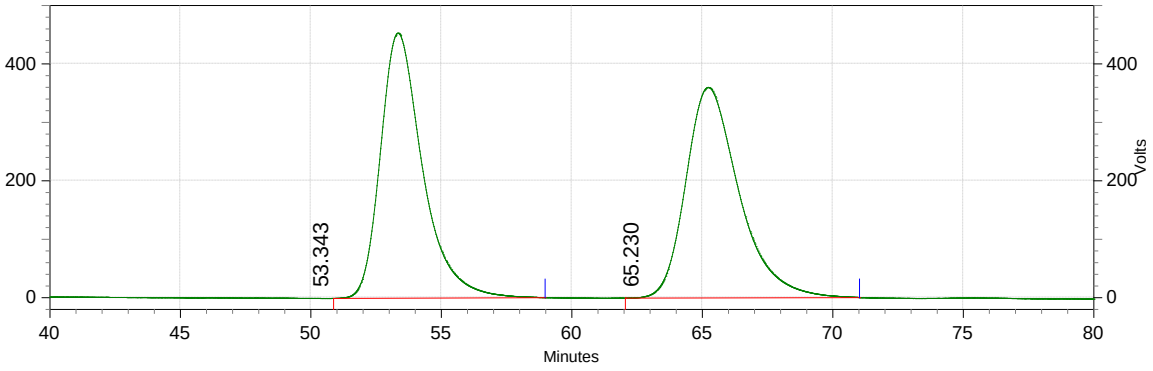
Table 2, compound 4g



4g

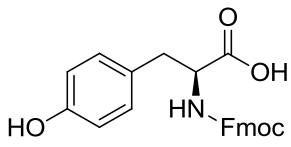
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(14/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



Peak#	RT(min)	Area	Aera%
1	53.343	50882363	49.896
2	65.230	51094863	50.104

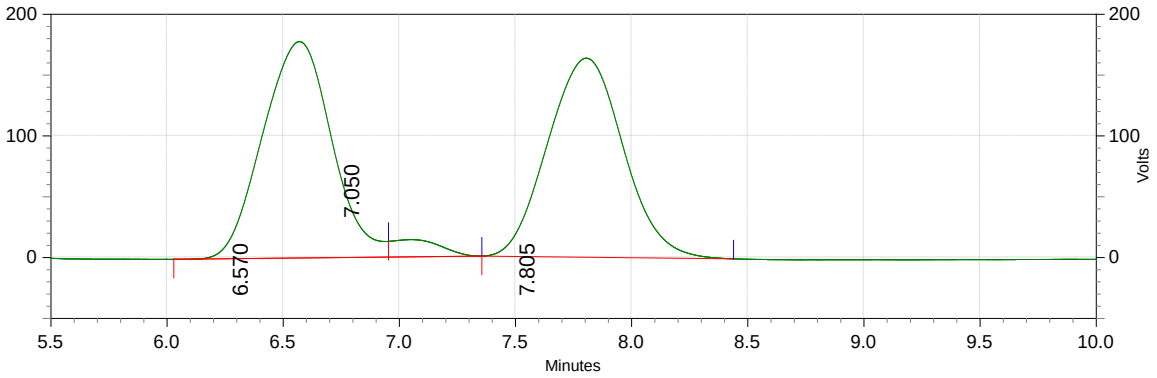
Table 2, compound 4h



4l

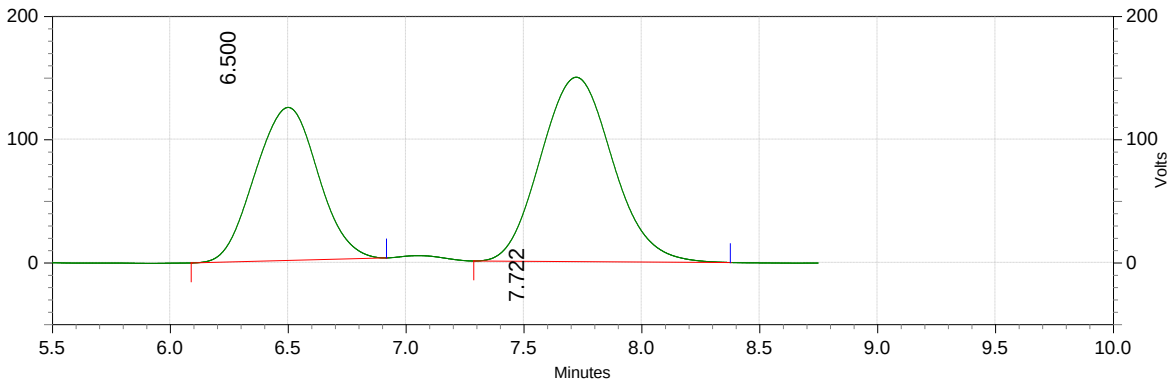
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(7/3)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



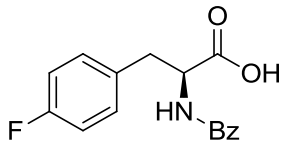
Peak#	RT(min)	Area	Aera%
1	6.570	3672084	48.432
2	7.805	3704707	48.862

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	6.500	2304690	42.022
2	7.722	3179808	57.978

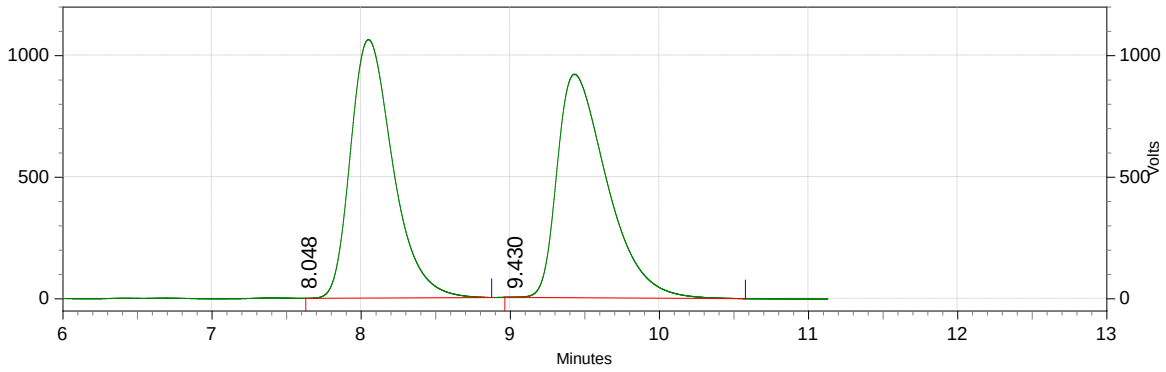
Table 2, compound 4i



4i

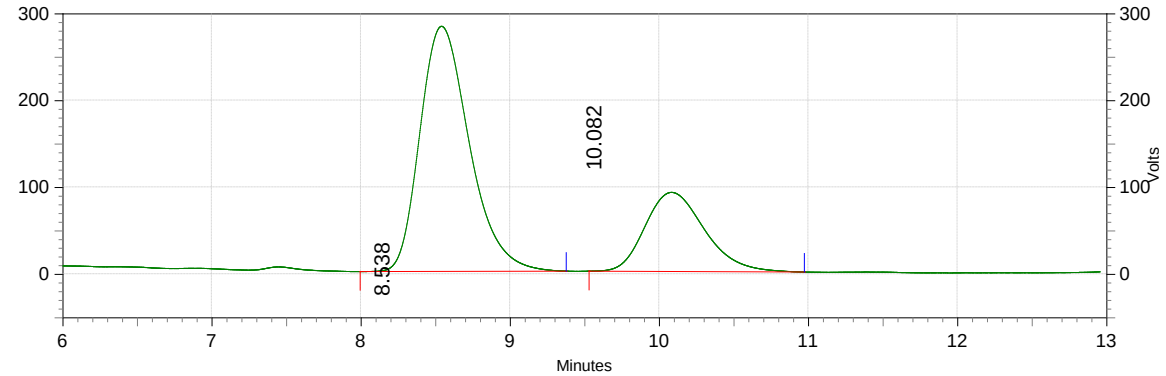
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(5.4/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



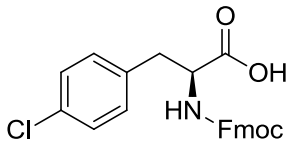
Peak#	RT(min)	Area	Aera%
1	8.048	21053054	49.609
2	9.430	21385147	50.391

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	8.538	6493229	71.988
2	10.082	2526666	28.012

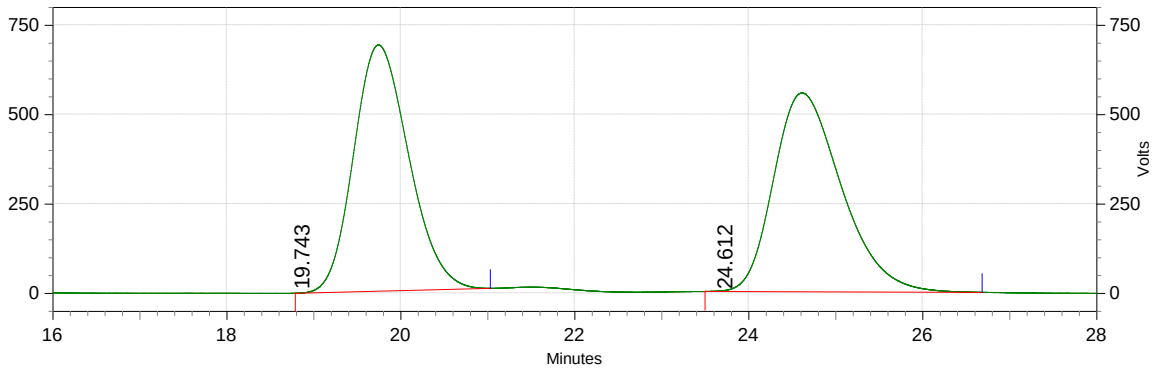
Table 2, compound 4j



4j

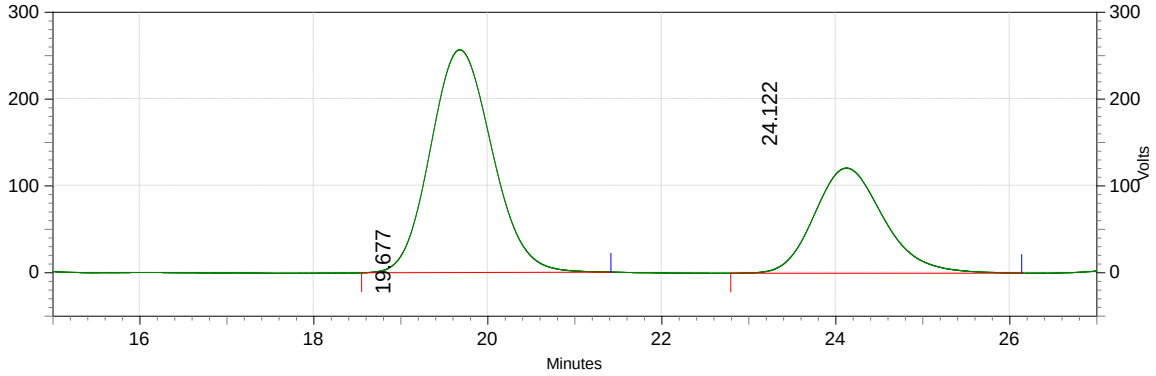
HPLC Conditions: Column: Chiralcel IC, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(14/1)containing 0.1% TFA;Flow rate: 0.8 mL/min; Detection: UV 210 nm

Racemic



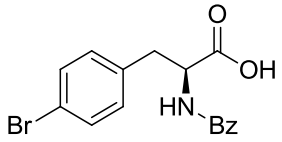
Peak#	RT(min)	Area	Aera%
1	19.743	30332380	50.175
2	24.612	30120286	49.825

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	19.677	12624137	65.249
2	24.122	6723489	34.751

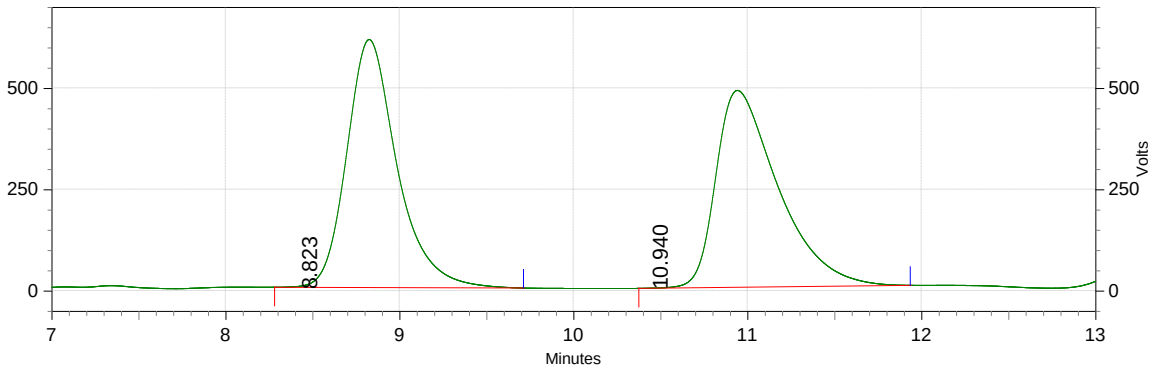
Table 2, compound 4k



4k

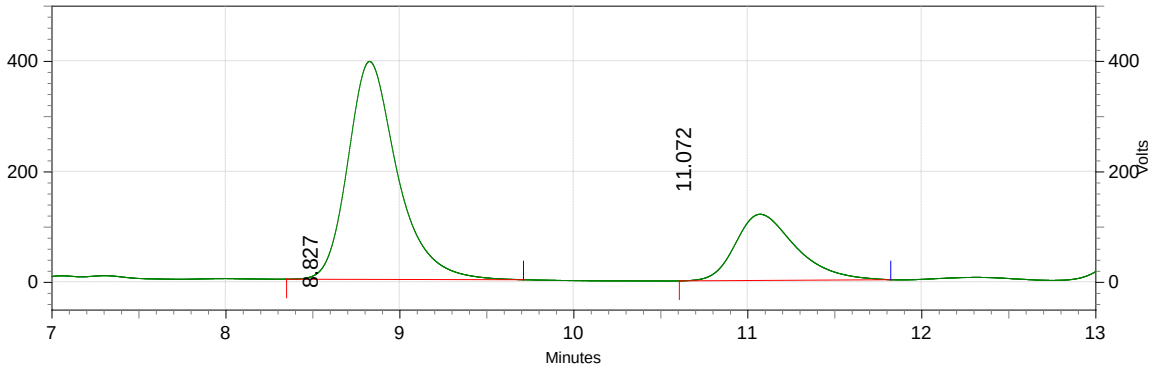
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(5.4/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



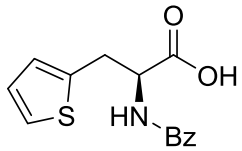
Peak#	RT(min)	Area	Aera%
1	8.823	17498240	50.098
2	10.940	17429685	49.902

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	8.827	7777919	73.019
2	11.072	2874055	26.981

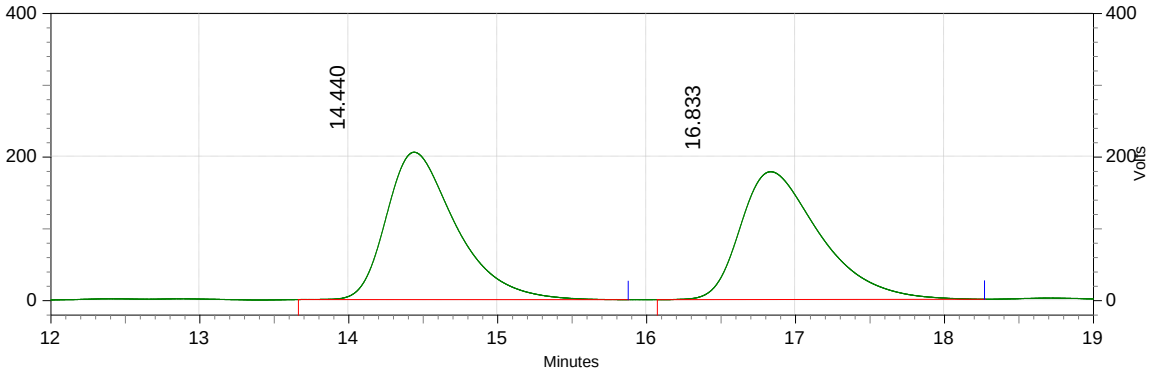
Table 2, compound 4l



4l

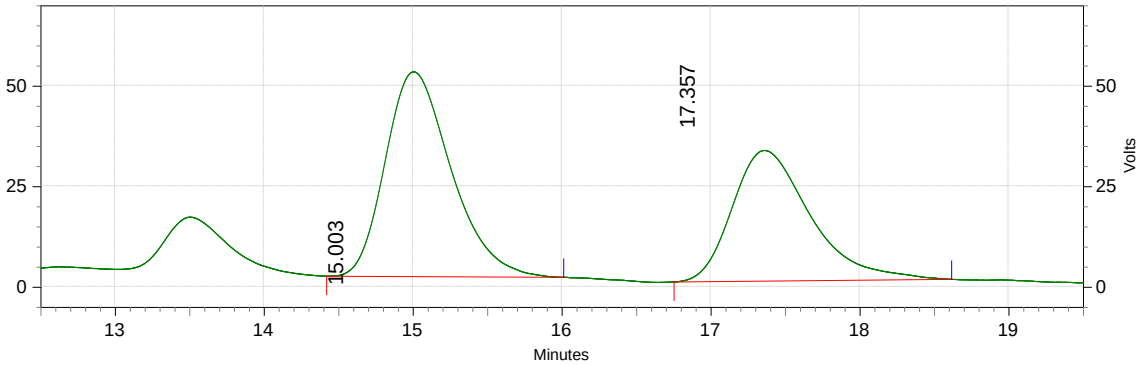
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(10/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



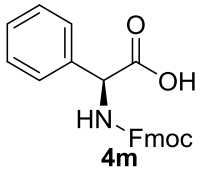
Peak#	RT(min)	Area	Aera%
1	14.440	6668761	50.228
2	16.833	6608261	49.772

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	15.003	1564163	56.912
2	17.357	1184238	43.088

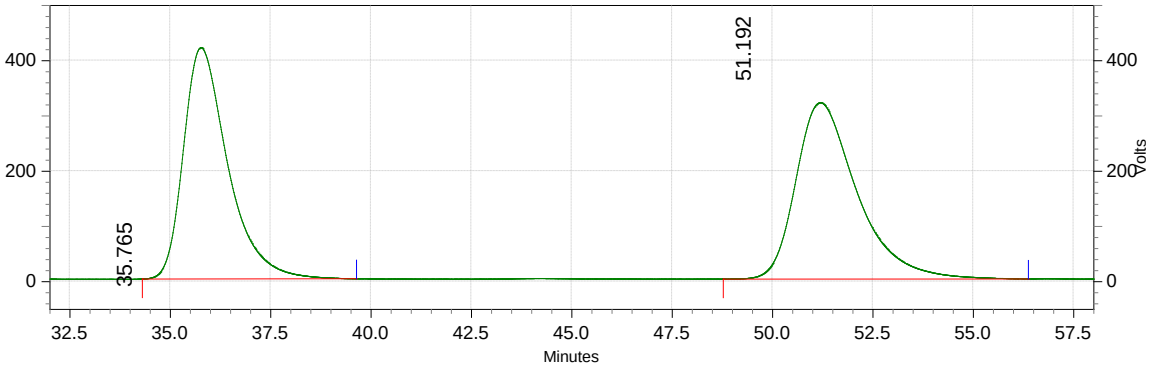
Table 2, compound 4m



4m

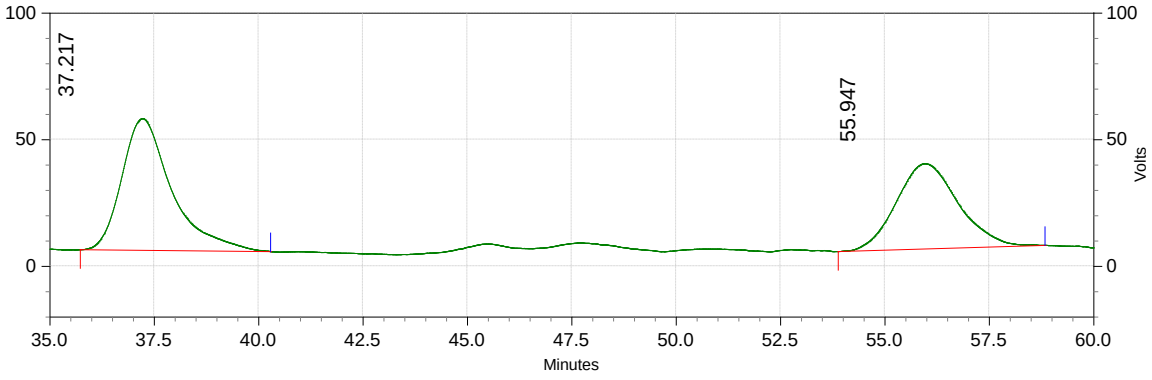
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(14/1) containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



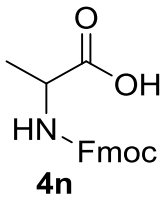
Peak#	RT(min)	Area	Aera%
1	35.765	32183825	49.742
2	51.192	32517685	50.258

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	4318863	3827439	52.460
2	3468480	3468480	47.540

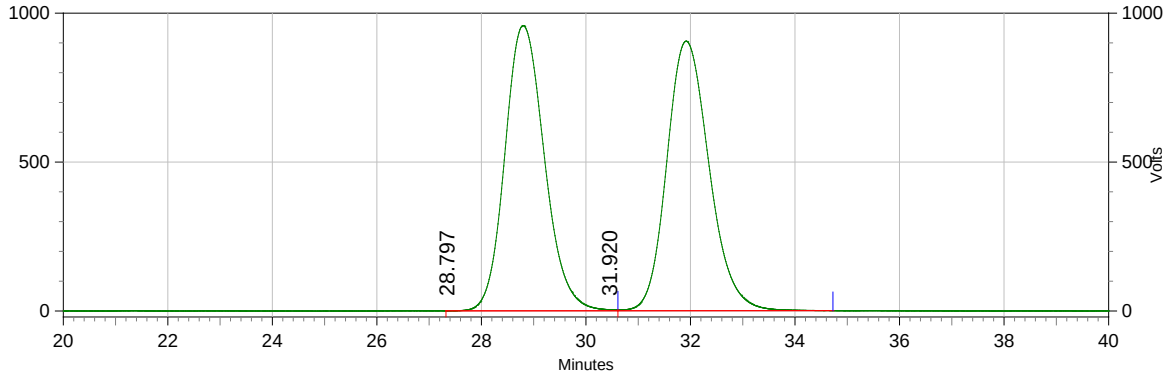
Table 2, compound 4n



4n

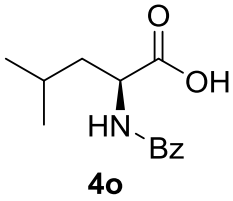
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(25/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



Peak#	RT(min)	Area	Aera%
1	28.797	50278778	49.668
2	31.920	50950890	50.332

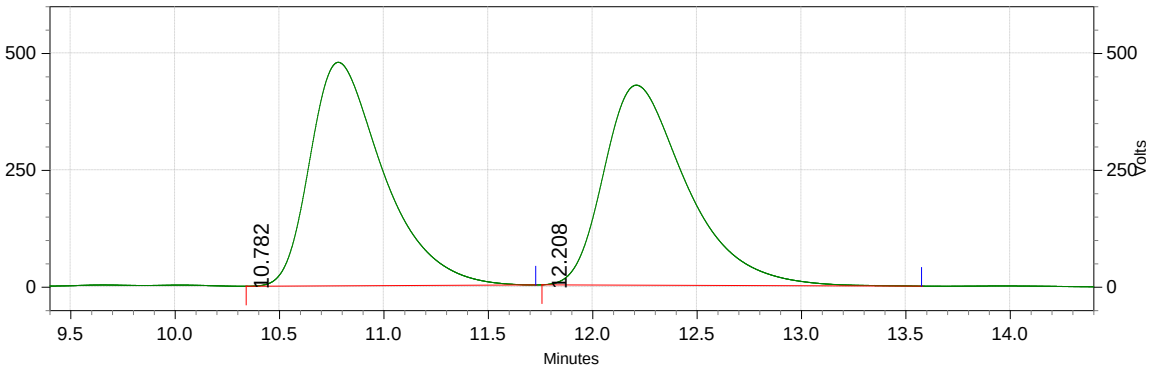
Table 2, compound 4o



4o

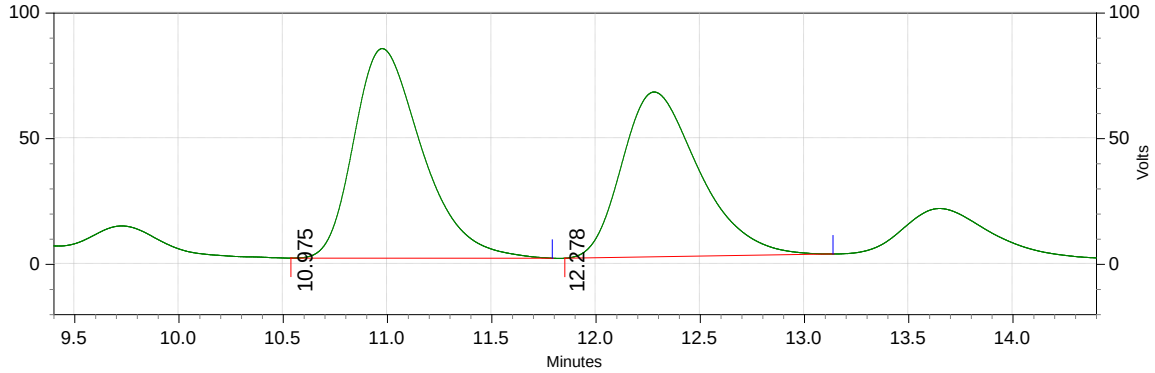
HPLC Conditions: Column: Chiralcel AD-H, Daicel Chemical Industries, Ltd., Eluent: Hexanes / IPA(10/1)containing 0.1% TFA; Flow rate: 1.0 mL/min; Detection: UV 210 nm

Racemic



Peak#	RT(min)	Area	Aera%
1	10.782	11696299	49.761
2	12.208	11808811	50.239

The Reaction Result



Peak#	RT(min)	Area	Aera%
1	10.975	1903220	53.015
2	12.278	1686733	46.985

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4 A. V. Sakkiadi, C. A. Georgiou and S. A. Haroutounian, *Molecules,* 2007, **12**, 2259-2269.

5 M. E. Gunay and C. J. Richards, *Organometallics,* 2009, **28**, 5833-5836.