Supporting Information

Preparation of chiral aryl alcohols: A controllable enzymatic strategy via Light-driven NAD(P)H regeneration

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Table of Content

1. Experimental Section

1.1 Preparation of Rhodamine B-labeled KRED

The enzyme tagging (5 mg mL^{-1} in 10 mM, pH =9.5 carbonate buffer) was done by Rhodamine B (5 mg mL^{-1} in DMSO) and the solution was kept for shaking for 2 h at room temperature in dark. Unbounded Rhodamine B was removed via dialysis and modified Rhodamine B labeled enzyme was then immobilized on Rh-UiO-67. All subsequent procedures were the same as those for the KRED@Rh-UiO-67 preparation.

1.2 Quantum yield measurement

Quantum Efficiency Measurement. The apparent quantum yield at 460 nm for 1-Phenylethanol production was calculated according to eq 1:

$$\text{quantum yield}\ (\%) = \frac{2\times\text{mol of 1-phenylethanol}}{\text{mol of absorbed photons}} \quad (1)$$

The apparent quantum efficiency determination was carried out under the illumination of a 10 W 460 nm (λ = 460 ± 5 nm) blue LED lamp under nitrogen atmosphere. The reaction solution was composed of NAD^+(1 mM), phosphate buffer (100 mM, pH = 7), TEOA (100 mM), photocatalyst (1 mM), and Rh-UIO-67 (3 mg). The photons absorbed by the solutions were calculated according to the light intensity on the front surface of the quartz reactor (500 mW cm^{-2}) and the wavelength of the LED lamp (460 nm).

1.3 Recycling experiments

The initial sample was prepared using 3 mg of *Ch*KRED 20@Rh-UiO-67 and *Ch*KRED 14@Rh-UiO-67, respectively. The reaction medium was composed of phosphate buffer (20 mM, pH=7.0), NAD^+ (1 mM), TEOA (200 mM), $Ru(bpy)_3Cl_2$ (1 mM), and 10 mM conc. of substrates acetophenone (10 mM, dissolved in 50 µL MeCN), with a total volume of 2 ml. Before irradiation, the reaction solution was purged with nitrogen in the dark for 10 min to exclude the effect of air in the reaction. The mixture was placed in a quartz cuvette reactor under argon atmosphere irradiated with a 460 nm (λ = 460 ± 5 nm) blue LED lamp for a duration of 7 hours. Upon completion of the photolysis, the reaction suspension was transferred to a 1.5 mL Eppendorf tube and centrifuged. 100µL of the reaction solution was removed and diluted with MeCN for analysis. The remaining solution was removed out and the remaining yellow powder was washed 3 times with MeCN and water, respectively. The recovered material was then reused following the same protocol 3 additional times utilizing freshly prepared solutions.

1.4 Characterizations.

^1H NMR spectra was obtained by a Bruker AM400 NMR spectrometer (400 MHz). Unless otherwise stated, chemical shifts (ppm) were recorded with respect to TMS in $CDCl_3$. Multiplicities were defined as: s (singlet), bs (broad singlet), d(doublet),

t(triplet), dd (doublet, doublet), or m (multiplet). The number of protons (n) for a given resonance is indicated by nH. Coupling constants are reported as a Jvalues in hertz.

Both enantiomers of the product alcohols (*R*)-2a-o, (*S*)-2a-o, and the substrate ketone 1a-o were well separated by chiral HPLC analysis. The absolute configurations of product alcohols were identified by comparison of elution order of enantiomers on chiral HPLC with the data reported in the literature [1,2] and the enantiomeric excess (ee) was calculated from the peak areas of the enantiomers.

Inductively coupled plasma optical emission spectroscopy (ICP-OES) analysis showed that the content of Rh in Rh-UiO-67 could be tuned from 3.9 to 7.3 wt % (Table S1). Inductively coupled plasma atomic optical emission spectroscopy (ICP-OES, Thermo Fisher Scientific, IRIS Advantage, USA) was performed to measure the ratio of Zr to Rh in Rh-UiO-67 sample. Aqua regia solution (1.5 mL) was added to 2-3 mg Rh-UiO-67 sample in a 5 mL microwave vial for digestion followed by 0.5 mL H_2O_2. After sealing, the vial was heating in a microwave reactor at 150 °C for 15 min. The solution was then diluted by Millipore water, and the ratio of Rh to Zr content was quantified by calibration curve of standard solutions. The Cp*Rh(bpydc)Cl_2 was determined by high resolution liquid chromatograph (LCMS-IT-TOF, Shimadzu, Japan).

Diffuse reflectance UV-vis spectra of the Rh-UiO-67 were recorded with a Shimadzu UV-3600 with a Harrick Praying Mantis diffuse reflectance accessory.

2. Figure Section

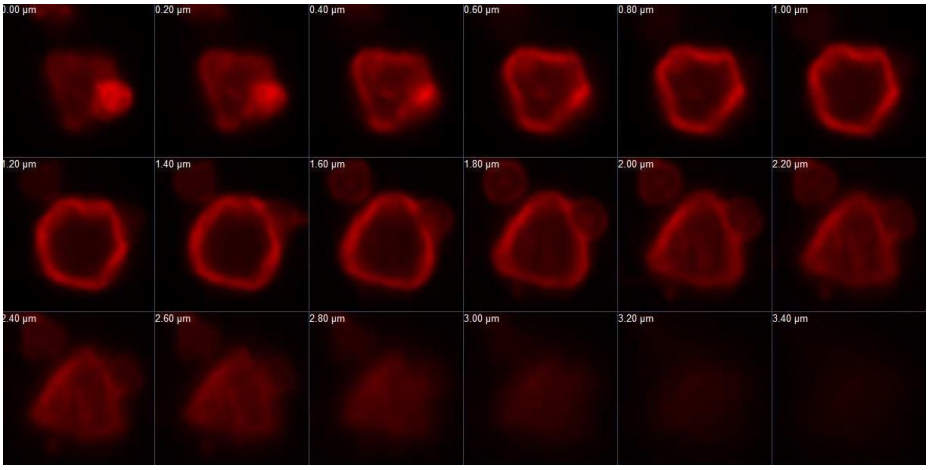


Fig. S1 Images of Rhodamine B-labeled immobilized enzyme along z-axis captured by CLSM using layer-by-layer mode. The materials were excited at 543 nm and Rhodamine B fluorescence was detected between 548 nm and 703 nm.

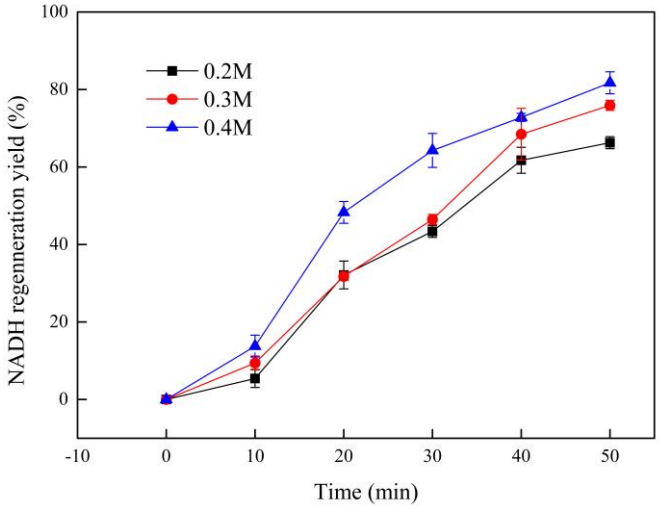


Fig. S2. Photocatalytic NADH regeneration with different TEOA concentrations.

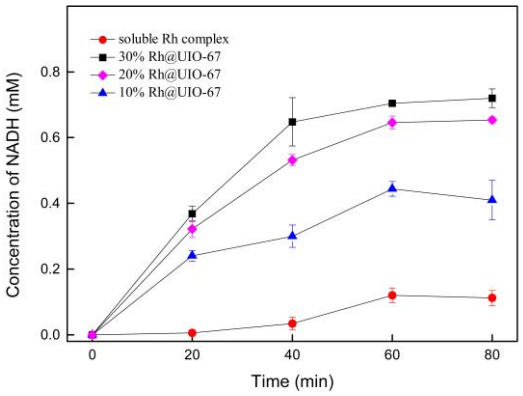


Fig. S3. Effect of rhodium catalyst loading on the rate of mmols of NADH produced.

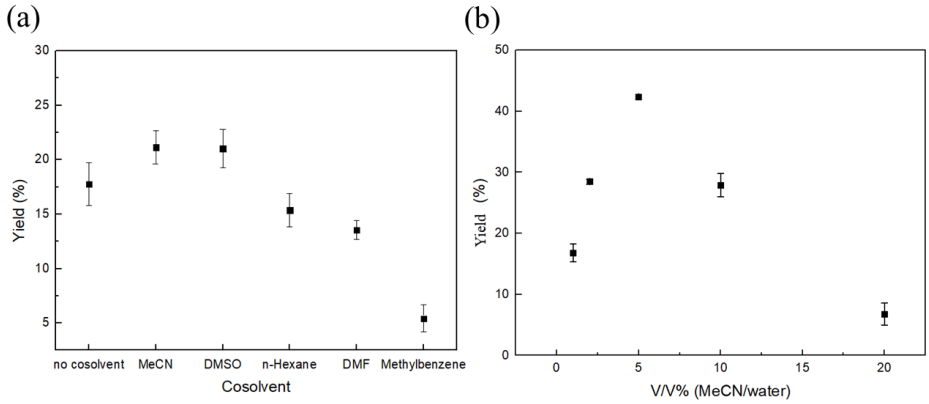


Fig. S4. The influence of (a) cosolvent and (b) the ratio of MeCN/water on the yield of 1-Phenylethanol.

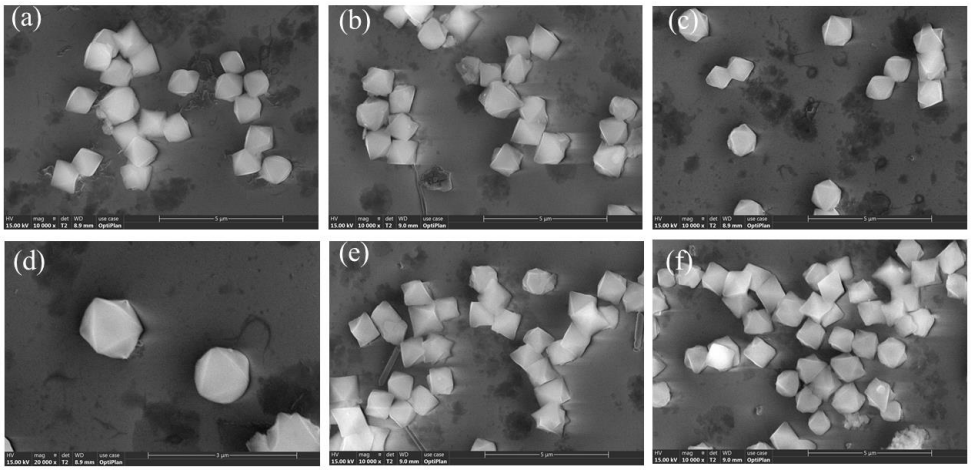


Fig. S5. Scanning electron microscopy images of (a) *Ch*KRED 20, (b) Mutant R125 *Ch*KRED 20, (c)*Ch*KRED 14, (d)*Ch*KRED 03, (e) LKADH, and (f) LBADH.

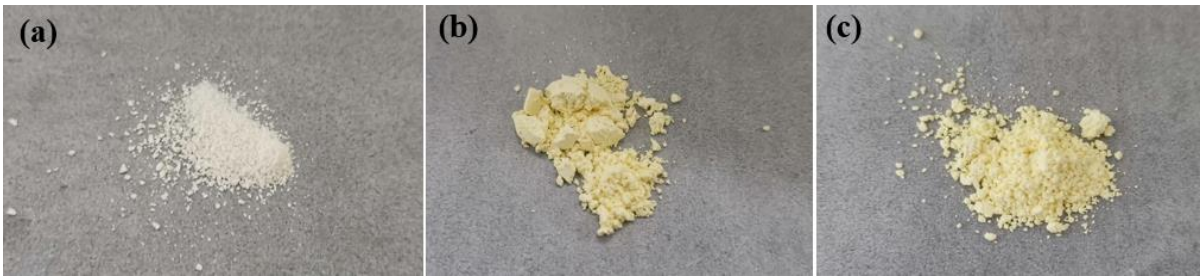


Fig. S6. The reusability of KRED@Rh-UiO-67

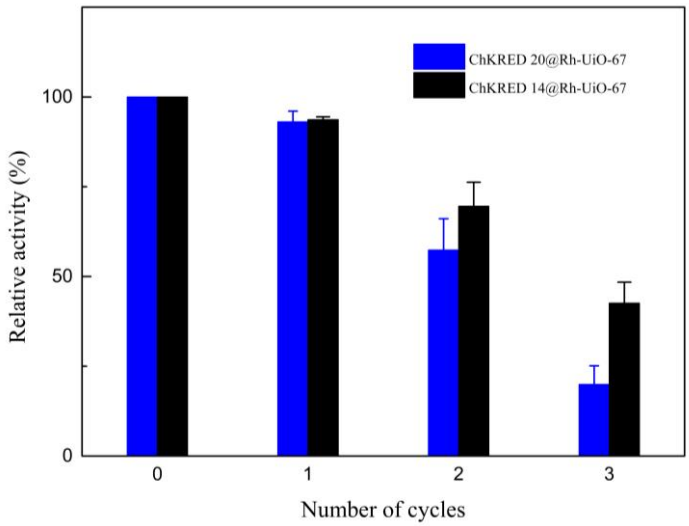


Fig. S7. Photograph of (a) UiO-67, (b) Rh-UiO-67, and (C) KRED@Rh-UiO-67.

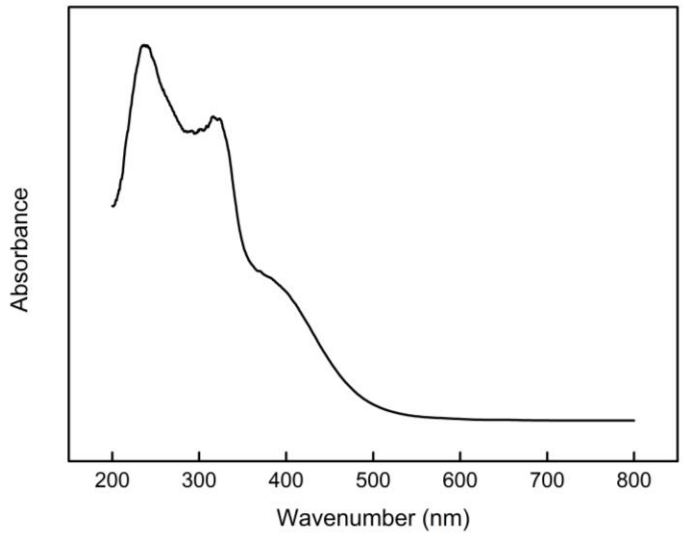


Fig. S8. The UV-vis diffuse reflectance spectra of the Rh-UiO-67.

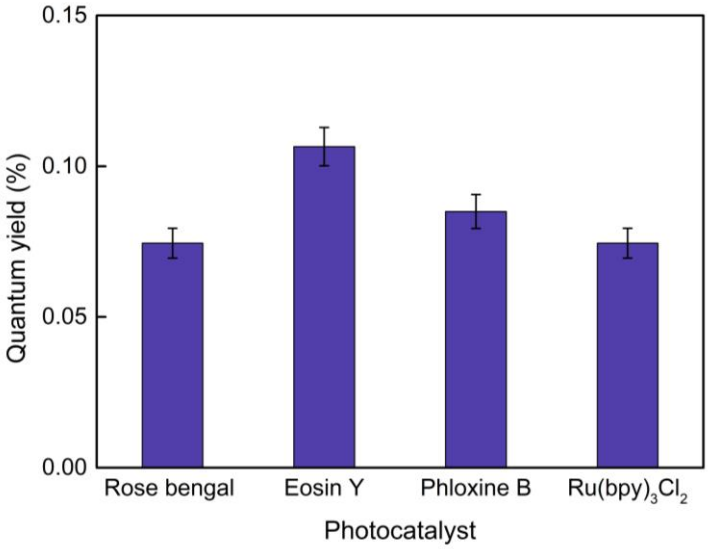
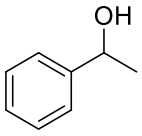


Fig. S9. The apparent quantum yield of the photocatalysts.

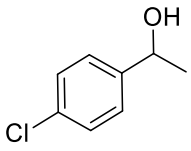
Table S1 ICP OES analysis of the Zr and Rh loading in UiO-67.

sample	Zr (wt%)	Rh (wt%)
10%-Rh-UiO-67	38.8	3.9
20%-Rh-UiO-67	27.6	5.6
30%-Rh-UiO-67	24.2	7.3

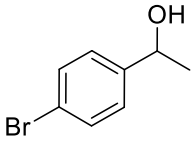
3. ^{1}H NMR of various compounds and HPLC conditions

Alcohol 2a: 

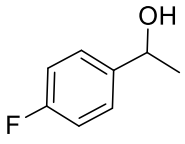
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.77 – 6.85 (m, 5H), 4.87 (q, *J* = 6.2 Hz, 1H), 2.01 (s, 1H), 1.48 (dd, *J* = 6.5, 0.8 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (98:2), 1.0 mL/min; UV 220nm; R-form: 14.6min; S-form: 18.0min.

Alcohol 2b: 

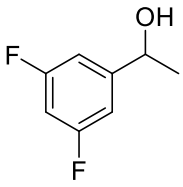
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.35 – 7.23 (m, 4H), 4.85 (q, *J* = 6.4 Hz, 1H), 1.98 (s, 1H), 1.44 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 1.0 mL/min; UV 220nm; R-form: 17.3min; S-form: 19.3min.

Alcohol 2c: 

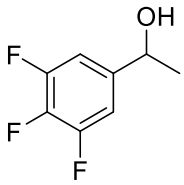
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.44 (dd, *J* = 5.9, 4.3 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 4.88 – 4.78 (m, 1H), 2.03 (s, 1H), 1.44 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 1.0 mL/min; UV 220nm; R-form: 19.4min; S-form: 21.6min.

Alcohol 2d: 

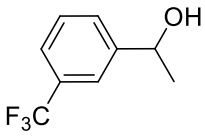
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.34 – 7.22 (m, 2H), 7.07 – 6.96 (m, 2H), 4.84 (q, *J* = 6.4 Hz, 1H), 2.11 (s, 1H), 1.44 (d, *J* = 6.5, 0.7 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5mL/min; UV 210nm; R-form: 36.7min; S-form: 38.7min.

Alcohol 2e: 

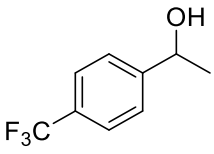
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.24 (s, 1H), 6.87 (dt, J = 6.5, 3.5 Hz, 2H), 6.71 – 6.62 (m, 1H), 4.85 (q, J = 6.4 Hz, 1H), 1.44 (d, J = 7.4 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 33.8min; S-form: 35.7min.

Alcohol 2f: 

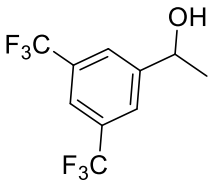
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.01 – 6.92 (m, 2H), 4.82 (q, *J* = 6.4 Hz, 1H), 2.02 (s, 1H), 1.43 (d, *J* = 6.4 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 63.9min; S-form: 71.8min.

Alcohol 2g: 

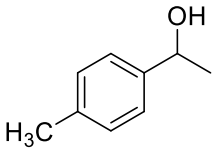
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.66 – 7.40 (m, 4H), 4.98 – 4.90 (m, 1H), 2.00 (s, 1H), 1.49 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 31.8min; S-form: 34.4min.

Alcohol 2h: 

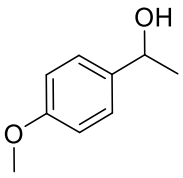
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.58 (d, *J* = 8.2 Hz, 2H), 7.46 (d, *J* = 8.1 Hz, 2H), 4.98 – 4.90 (m, 1H), 2.02 (s, 1H), 1.48 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 38.1min; S-form: 39.9min.

Alcohol 2i: 

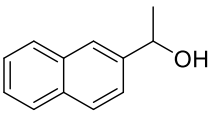
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.80 (d, *J* = 22.7 Hz, 3H), 5.07 – 5.01 (m, 1H), 1.58 (s, 1H), 1.52 (d, *J* = 0.7 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 22.1min; S-form: 27.1min.

Alcohol 2j: 

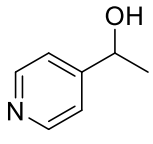
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.25 (d, *J* = 8.1 Hz, 2H), 7.15 (d, *J* = 7.8 Hz, 2H), 4.85 (q, *J* = 6.4 Hz, 1H), 2.33 (s, 3H), 1.85 (s, 1H), 1.47 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 0.5 mL/min; UV 220nm; R-form: 34.1min; S-form: 35.7min.

Alcohol 2k: 

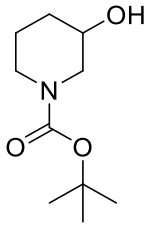
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.27 (dd, *J* = 8.9, 2.1 Hz, 2H), 6.88 – 6.85 (m, 2H), 4.83 (q, *J* = 6.4 Hz, 1H), 3.78 (s, 3H), 1.45 (d, *J* = 6.4 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (99:1), 1.0 mL/min; UV 220nm; R-form: 24.8min; S-form: 29.9min.

Alcohol 2l: 

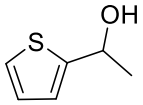
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.92 – 7.74 (m, 4H), 7.59 – 7.40 (m, 3H), 5.06 (dd, *J* = 6.4, 2.9 Hz, 1H), 1.94 (s, 1H), 1.57 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OJ, 30 °C, n-hexane/2-propanol (99:5), 1.0 mL/min; UV 210nm; R-form: 25.5min; S-form: 33.6min.

Alcohol 2m: 

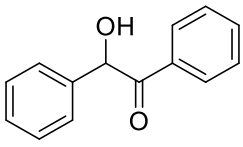
^{1}H NMR (400 MHz, cdcl$_3$) δ 8.52 (dd, *J* = 4.6, 1.5 Hz, 1H), 7.28 (d, *J* = 6.0 Hz, 1H), 7.24 (s, 1H), 4.89 (q, *J* = 6.5 Hz, 1H), 2.46 (s, 1H), 1.48 (d, *J* = 6.5 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (95:5), 0.5 mL/min; UV 254nm; R-form: 37.2min; S-form: 42.8min.

Alcohol 2n: 

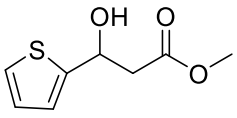
^{1}H NMR (400 MHz, cdcl$_3$) δ 3.78 – 3.66 (m, 2H), 3.49 (s, 1H), 3.06 (dd, *J* = 23.5, 13.1 Hz, 2H), 2.06 – 1.48 (m, 5H), 1.43 (s, 9H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (98:2), 1.0 mL/min; UV 210nm; R-form: 10.4 min; S-form: 11.6 min.

Alcohol 2o: 

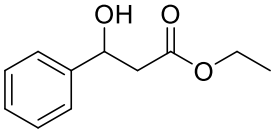
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.25 – 7.20 (m, 1H), 6.98 – 6.92 (m, 2H), 5.14 – 5.07 (m, 1H), 2.19 (s, 1H), 1.58 (d, *J* = 6.4 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OJ, 30 °C, n-hexane/2-propanol (97:3), 1.0 mL/min; UV 233nm; R-form: 15.5min; S-form: 19.5min.

Alcohol 2p: 

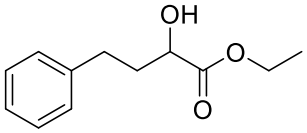
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.90 (d, *J* = 8.2 Hz, 2H), 7.55 – 7.20 (m, 8H), 4.54 (d, *J* = 6.1 Hz, 1H), 1.58 (s, 1H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (95:5), 1.0 mL/min; UV 210nm; R-form: 12.3 min; S-form: 18.2 min.

Alcohol 2q: 

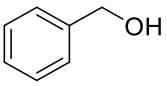
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.26 – 7.21 (m, 1H), 6.98 – 6.92 (m, 2H), 5.39 – 5.33 (m, 1H), 3.71 (s, 3H), 2.92 – 2.79 (m, 2H). Determination of the ee by HPLC analysis: Chiral AD-H, 30 °C, n-hexane/2-propanol (99:1), 0.6 mL/min; UV 233nm; R-form: 77.1 min; S-form: 82.3 min.

Alcohol 2r: 

^{1}H NMR (400 MHz, cdcl$_3$) δ 7.43 – 7.14 (m, 5H), 5.11 (dd, *J* = 8.7, 3.8 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 3.30 (s, 1H), 2.82 – 2.63 (m, 2H), 1.24 (t, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (95:5), 1.0 mL/min; UV 210nm; R-form: 13.1min; S-form: 20.3 min.

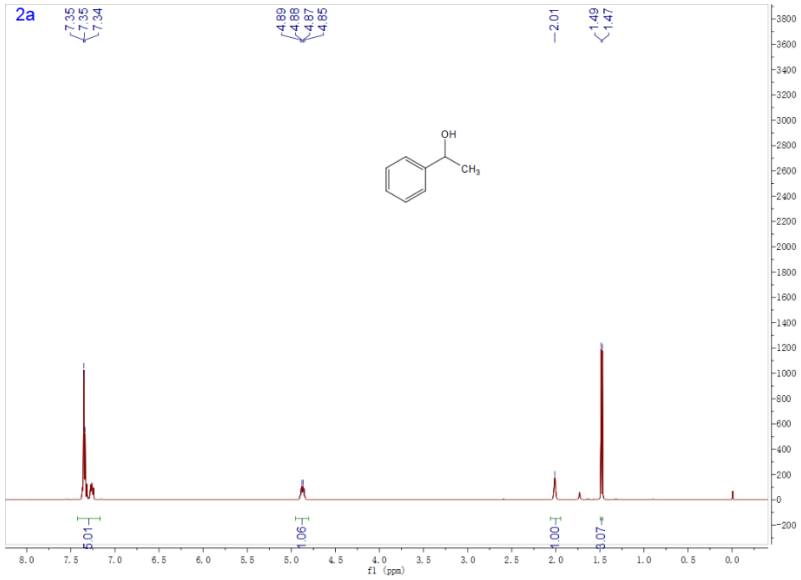
Alcohol 2s: 

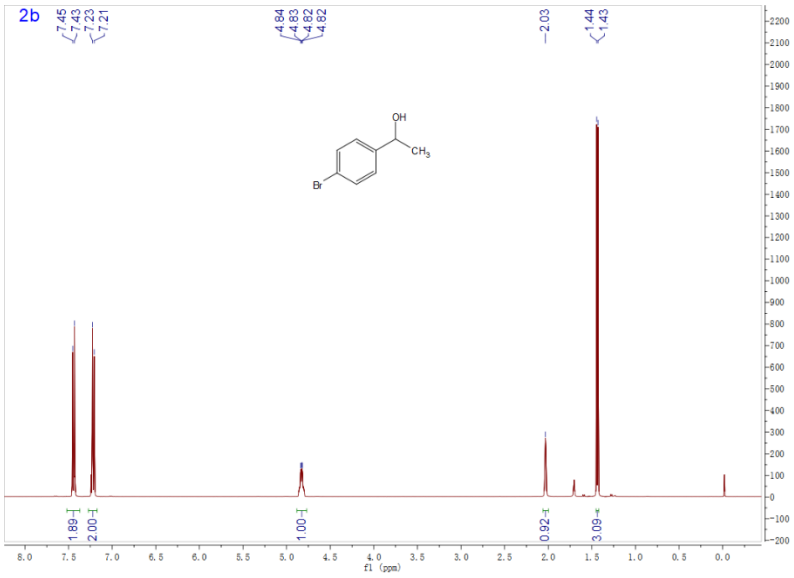
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.31 – 7.15 (m, 5H), 4.23 – 4.13 (m, 3H), 2.82 – 2.67 (m, 3H), 2.11 (m, 1H), 1.99 – 1.87 (m, 1H), 1.27 (t, *J* = 7.1 Hz, 3H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (95:5), 1.0 mL/min; UV 210nm; R-form: 7.5min; S-form: 11.2 min.

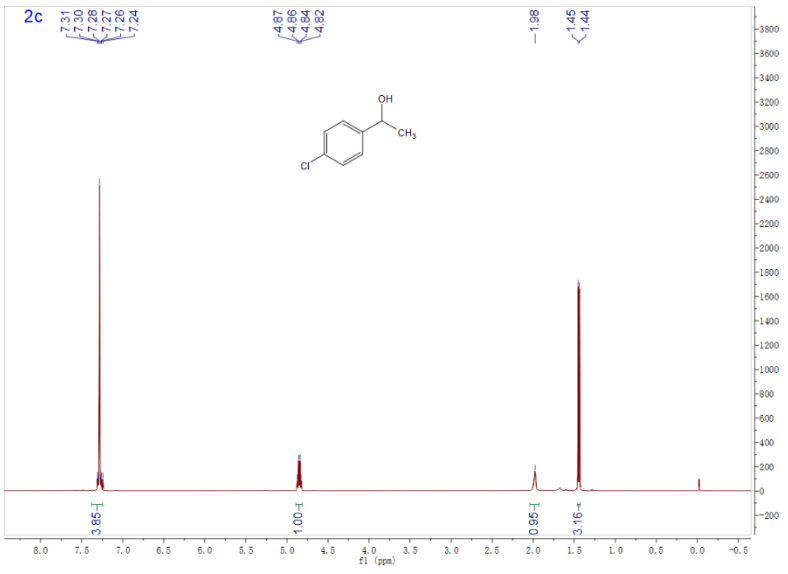
Alcohol 2t: 

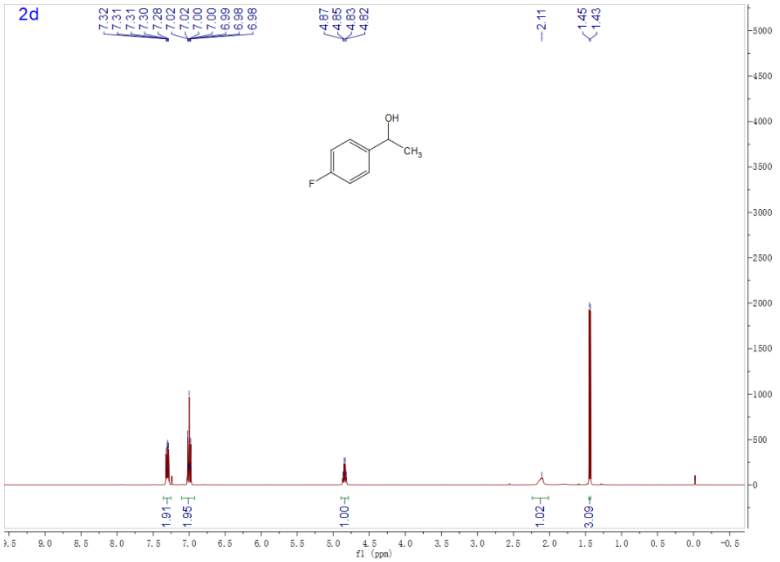
^{1}H NMR (400 MHz, cdcl$_3$) δ 7.37–7.24 (m, 5H), 4.63 (d, *J* = 5.9 Hz, 2H), 2.19 (t, *J* = 5.9 Hz, 1H). Determination of the ee by HPLC analysis: Chiral OD-3, 30 °C, n-hexane/2-propanol (95:5), 1.0 mL/min; UV 220nm; 8.7 min.

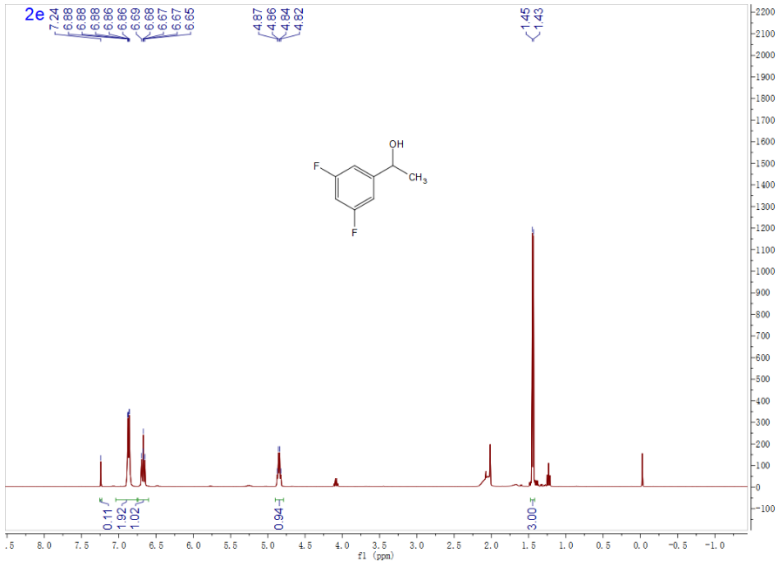
^{1}H NMR spectra of the obtained products

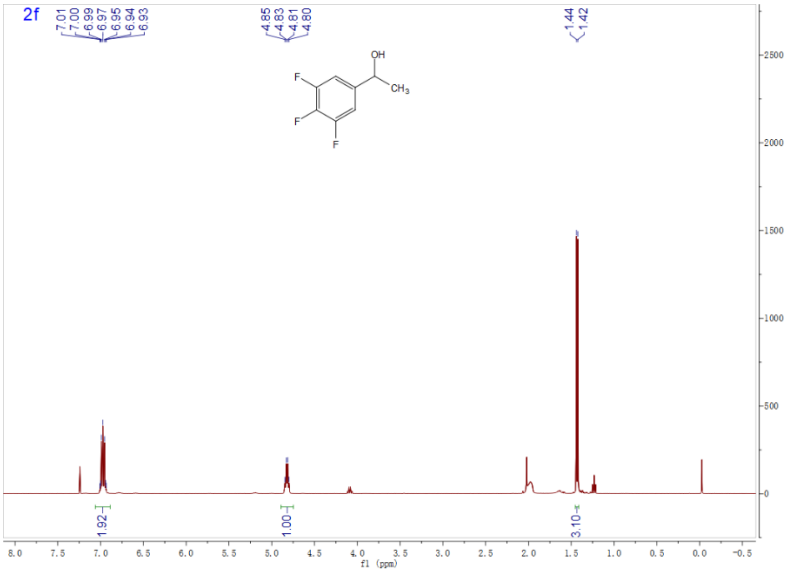


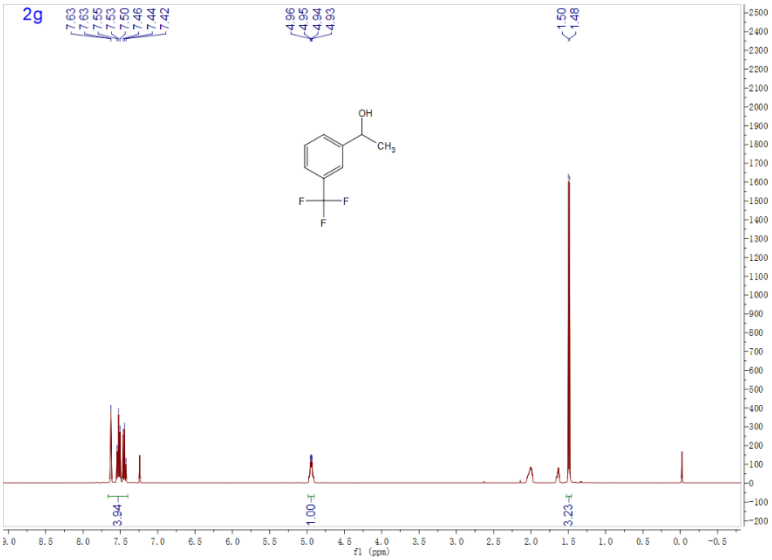


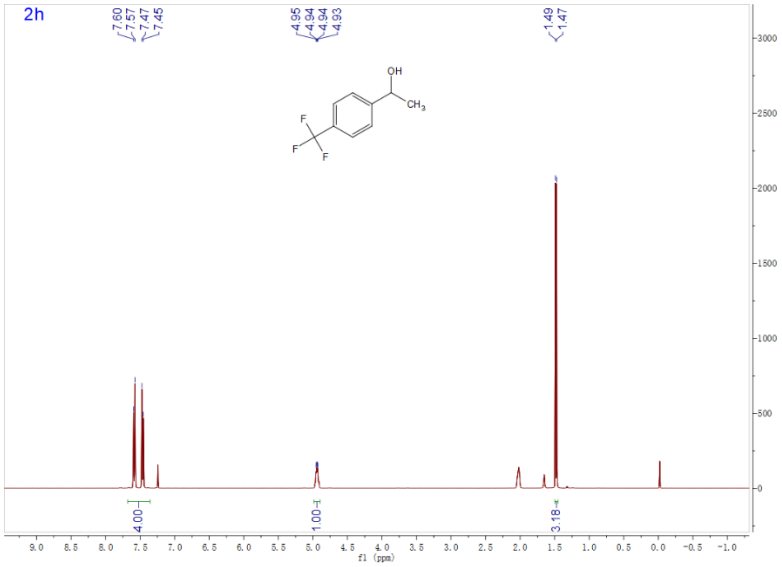


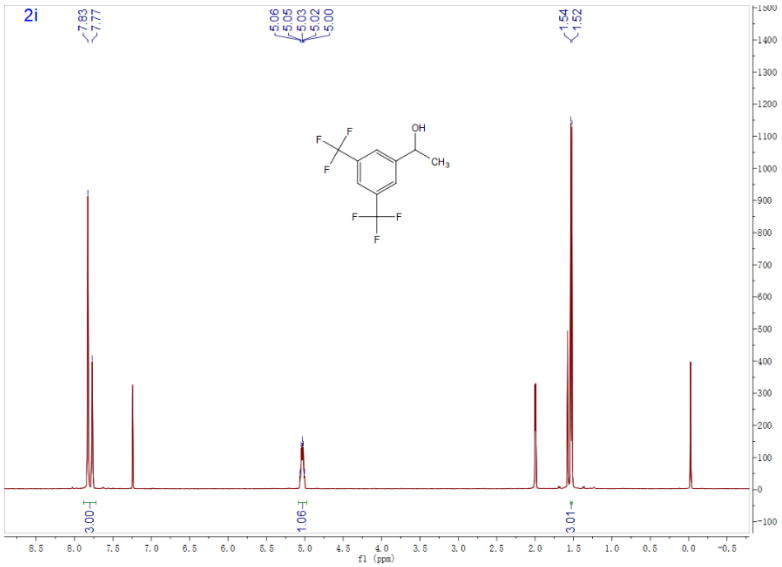

2d
7.32
7.31
7.31
7.30
7.28
7.02
7.02
7.00
7.00
6.99
6.98
6.98
4.87
4.85
4.83
4.82
2.11
1.45
1.43
OH
CH3
F
1.91
1.95
1.00
1.02
3.09
f1 (ppm)

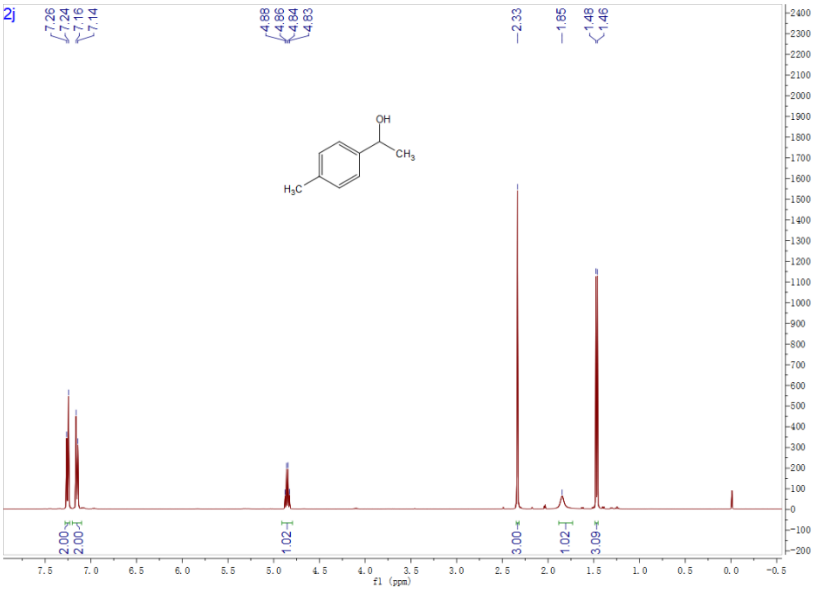

2e
7.24
6.88
6.88
6.88
6.86
6.86
6.69
6.68
6.67
6.67
6.65
4.87
4.86
4.84
4.82
1.45
1.43
OH
CH3
F
F
0.11
1.92
1.02
0.94
3.00
f1 (ppm)

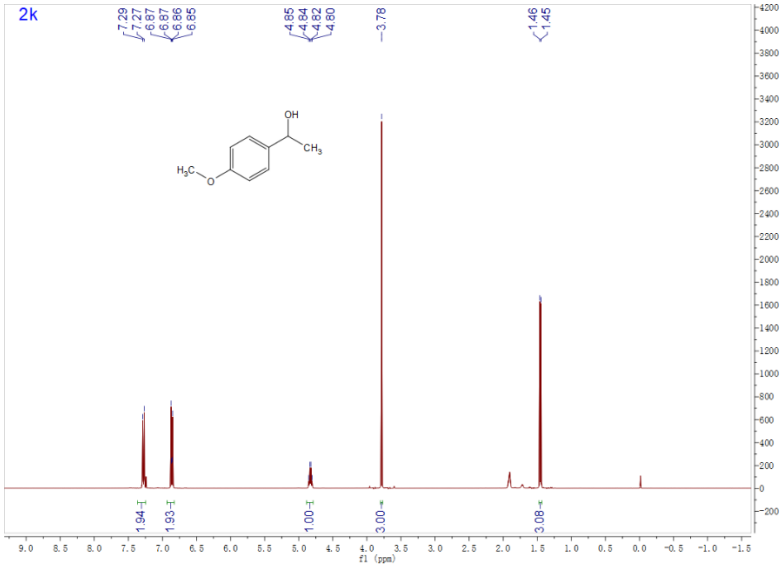

2f
7.01
7.00
6.99
6.97
6.95
6.94
6.93
4.85
4.83
4.81
4.80
1.44
1.42
OH
CH3
F
F
F
1.92
1.00
3.10
f1 (ppm)

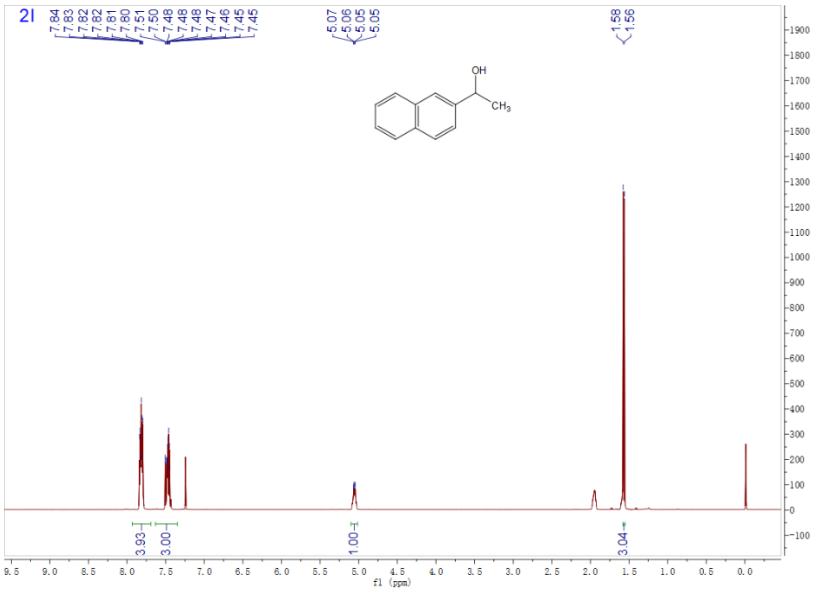

2g
7.63
7.63
7.55
7.53
7.50
7.46
7.44
7.42
4.96
4.95
4.94
4.93
1.50
1.48
OH
CH3
F
F
F
3.94
1.00
3.23
f1 (ppm)

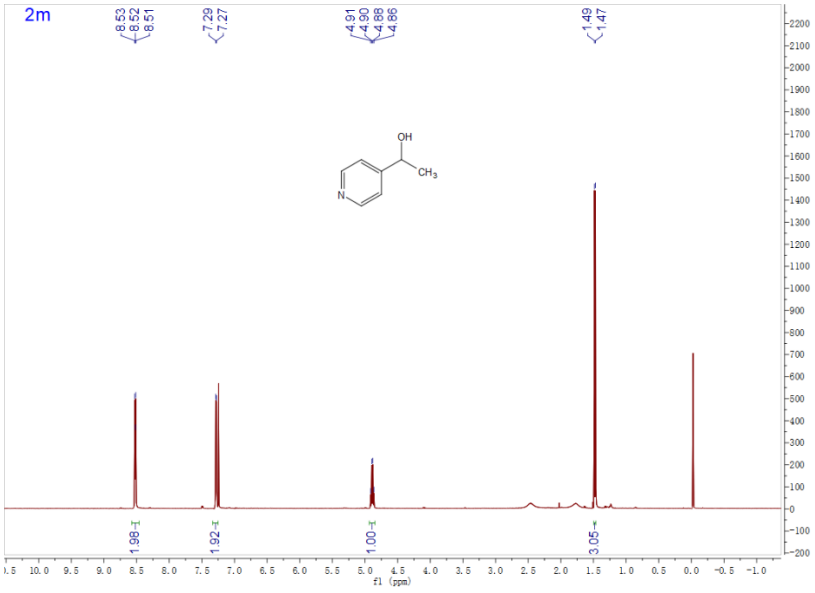

2h
7.60
7.57
7.47
7.45
4.95
4.94
4.94
4.93
1.49
1.47
OH
CH3
F
F
F
4.00
1.00
3.18
f1 (ppm)

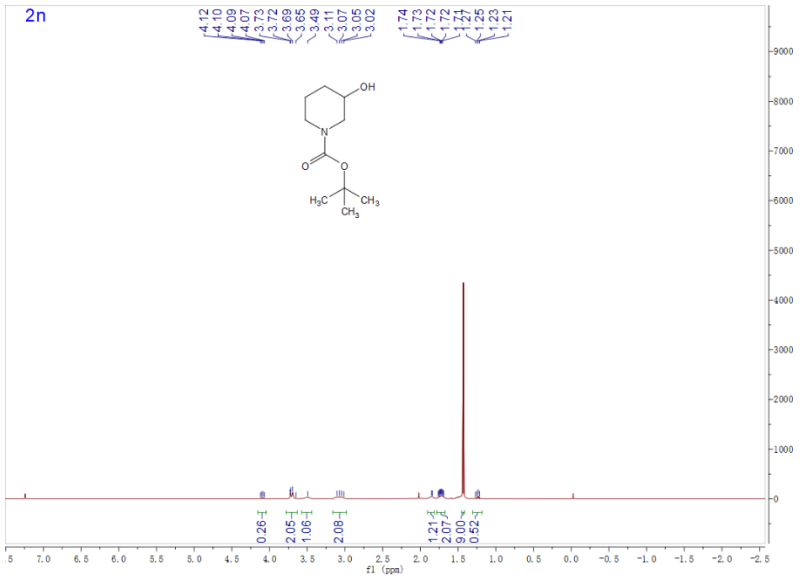

2i
7.83
7.77
5.06
5.05
5.03
5.02
5.00
1.54
1.52
OH
CH3
F
F
F
F
F
F
3.00
1.06
3.01
f1 (ppm)

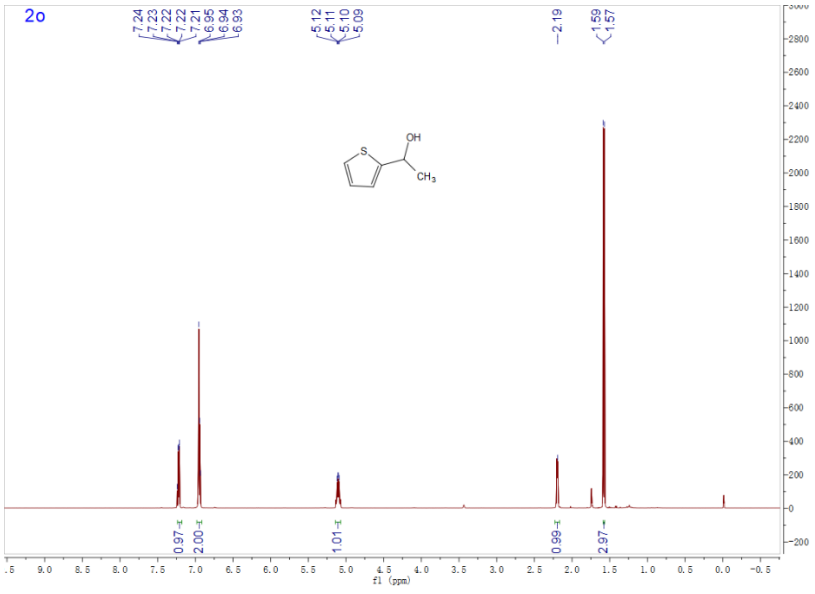

2j
7.26
7.24
7.16
7.14
4.88
4.86
4.84
4.83
2.33
1.85
1.48
1.46
OH
CH3
H3C
2.00
2.00
1.02
3.00
1.02
3.09
f1 (ppm)


2k
7.29
7.27
6.87
6.87
6.86
6.85
4.85
4.84
4.82
4.80
3.78
1.46
1.45
OH
CH3
H3C
O
1.94
1.93
1.00
3.00
3.08
f1 (ppm)


2l
7.84
7.83
7.82
7.82
7.81
7.80
7.51
7.50
7.48
7.48
7.48
7.47
7.46
7.45
7.45
5.07
5.06
5.05
5.05
1.58
1.56
OH
CH3
3.93
3.00
1.00
3.04
f1 (ppm)


2m
8.53
8.52
8.51
7.29
7.27
4.91
4.90
4.88
4.86
1.49
1.47
OH
CH3
N
1.98
1.92
1.00
3.05
f1 (ppm)


2n
4.12
4.10
4.09
4.07
3.73
3.72
3.69
3.65
3.49
3.11
3.07
3.05
3.02
1.74
1.73
1.72
1.72
1.71
1.71
1.25
1.23
1.21
OH
N
O
O
H3C
CH3
CH3
0.26
2.05
1.06
2.08
1.21
2.07
9.00
0.52
f1 (ppm)


2o
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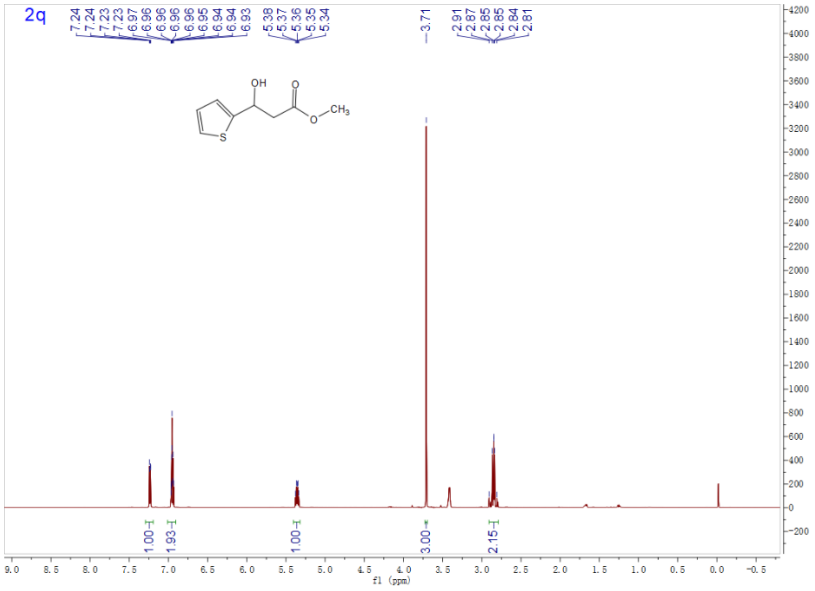
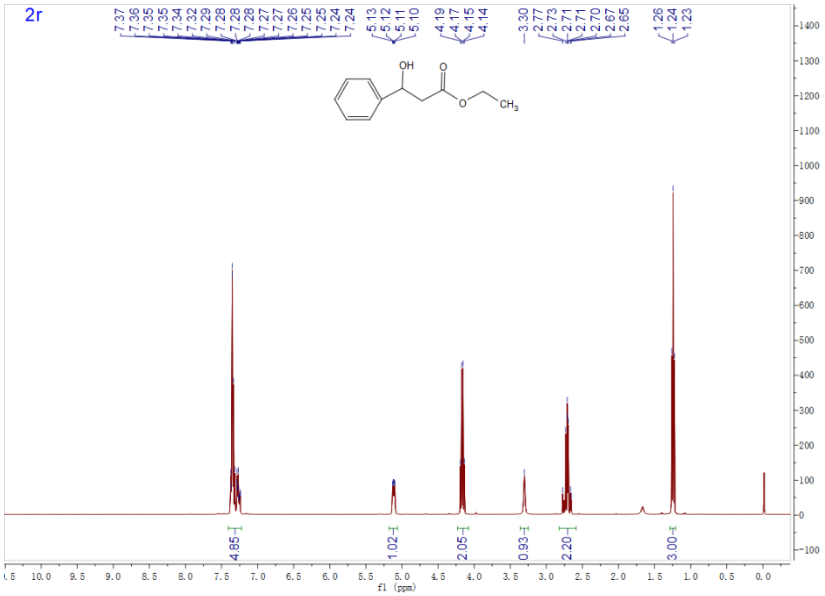
7.23
7.22
7.22
7.21
6.95
6.94
6.93
5.12
5.11
5.10
5.09
2.19
1.59
1.57
OH
S
CH3
0.97
2.00
1.01
0.99
2.97
f1 (ppm)


2q
7.24
7.24
7.23
7.23
6.97
6.96
6.96
6.96
6.96
6.95
6.94
6.94
6.93
5.38
5.37
5.36
5.35
5.34
3.71
2.91
2.87
2.85
2.85
2.84
2.81
OH
O
O
CH3
S
1.00
1.93
1.00
3.00
2.15
f1 (ppm)


2r
7.37
7.36
7.35
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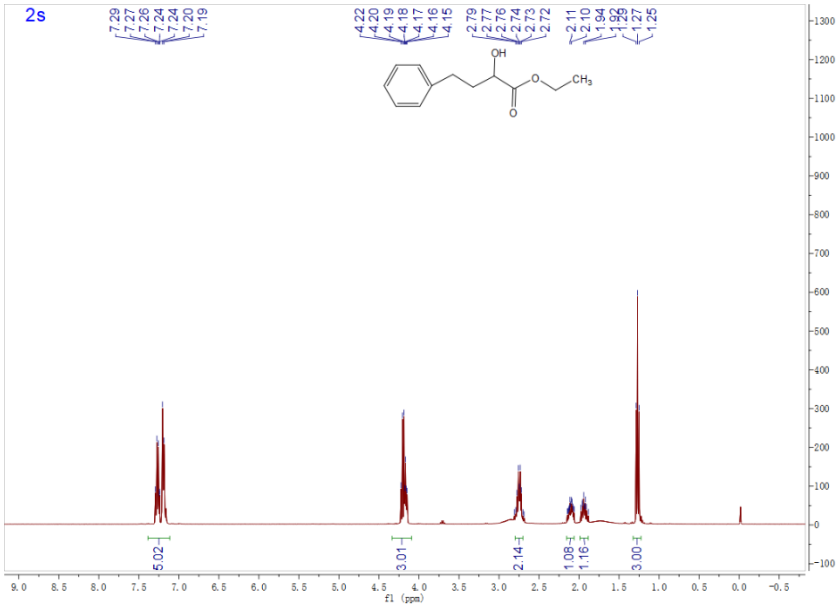
7.34
7.32
7.29
7.28
7.28
7.28
7.27
7.27
7.26
7.25
7.25
7.24
7.24
5.13
5.12
5.11
5.10
4.19
4.17
4.15
4.14
3.30
2.77
2.73
2.71
2.71
2.70
2.67
2.65
1.26
1.24
1.23
OH
O
O
CH3
4.85
1.02
2.05
0.93
2.20
3.00
f1 (ppm)


2s
7.29
7.27
7.26
7.24
7.24
7.20
7.19
4.22
4.20
4.19
4.18
4.17
4.16
4.15
2.79
2.77
2.76
2.74
2.73
2.72
2.11
2.10
1.94
1.92
1.29
1.27
1.25
OH
O
O
CH3
5.02
3.01
2.14
1.08
1.16
3.00
f1 (ppm)

References

1 T.X. Tang, Y. Liu and Z.L. Wu, J. Mol. Catal. B: Enzym. 2014, **105**, 82–88.

2 G.P. Xu, H.B. Wang and Z.L. Wu, Process Biochem., 2016, **51**, 881–885.