

Supporting Information *for*

**Integration of Multiple Active Sites on Large-Pore Mesoporous Silica for
Enantioselective Tandem Reactions**

Xuelin Xia, Jingjing Meng, Hanxin Wu, Tanyu Cheng, Guohua Liu*

*Key Laboratory of Resource Chemistry of Ministry of Education, Shanghai Key Laboratory of
Rare Earth Functional Materials, Shanghai Normal University, Shanghai 200234, P. R. China.*

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Experimental

1). General. All experiments, which are sensitive to moisture or air, were carried out under an Ar atmosphere using the standard Schlenk techniques. HAuCl_4 , 1,3-Bis(2,6-di-*i*-propylphenyl)imidazolium chloride $[\text{IPr}(\text{H})]\text{Cl}$, AgBF_4 , tetraethoxysilane (TEOS), 1,3,5-trimethylbenzene, 4-(2-(trimethoxysilyl)ethyl)benzene-1-sulfonyl chloride, *N*-(*p*-toluenesulfonyl)-1,2-diphenylethylenediamine [(*S,S*)-TsDPEN], pluronic F127 surfactant (triblock copolymers F127: $(\text{CH}_2\text{CH}_2\text{O})_{106}(\text{CH}_2(\text{CH}_3)\text{CH}_2\text{O})_{70}(\text{CH}_2\text{CH}_2\text{O})_{106}$), $[\text{mesityleneRuCl}_2]_2$ were purchased from Sigma-Aldrich Company Ltd and used as received. Compound of (*S,S*)-4-(trimethoxysilyl)ethylphenylsulfonyl-1,2-diphenylethylenediamine, MesityleneRuTsDPEN complex (TsDPEN = *N*-(*p*-toluenesulfonyl)-1,2-diphenylethylenediamine), and IPrAuBF_4 complexes were synthesized according to published procedures. The enantiomeric excesses (*ee*) were determined by a HPLC analysis with a UV-Vis detector using a DaicelChiralcel[®] column (Φ 0.46 × 25 cm).

2). Characterization. Ru, Au loading amounts in the catalyst was analyzed using an inductively coupled plasma optical emission spectrometer (ICP, Varian VISTA-MPX). Fourier transform infrared (FTIR) spectra were collected on a Nicolet Magna 550 spectrometer using KBr method. X-ray powder diffraction (XRD) was carried out on a Rigaku D/Max-RB diffractometer with $\text{CuK}\alpha$ radiation. Transmission electron microscopy (TEM) images were performed on a JEOL JEM2010 electron microscope at an acceleration voltage of 220 kV. Nitrogen adsorption isotherms were measured at 77 K with a Quantachrome Nova 4000 analyzer. The samples were measured after being outgassed at 423 K overnight. Pore size distributions were calculated by using the BJH model. The specific surface areas (SBET) of samples were determined from the linear parts of BET plots ($p/p_0 = 0.05$ -1.00). Solid state NMR experiments were explored on a Bruker AVANCE spectrometer at a magnetic field strength of 9.4 T with ^1H frequency of 400.1 MHz, ^{13}C frequency of 100.5 MHz and ^{29}Si frequency of 79.4 MHz, and ^{19}F frequency of 169.3 MHz with 4 mm rotor at two spinning frequency of 5.5 kHz and 8.0 kHz, TPPM decoupling is applied in the during acquisition period. ^1H cross polarization in all solid state NMR experiments was employed using a contact time of 2 ms and the pulse lengths of 4 μs .

3). Preparation of ArDPEN@FUD-12 (1). In a typical synthesis, to a solution of 1.0 g of structure-directing agent F127 [F127: $(\text{CH}_2\text{CH}_2\text{O})_{106}(\text{CH}_2(\text{CH}_3)\text{CH}_2\text{O})_{70}(\text{CH}_2\text{CH}_2\text{O})_{106}$] in a mixture of 100.0 mL hydrochloric acid (1.0 M) was added 2.50 g KCl and 1.20 g mesitylene and the

mixture was allowed to stir at 15°C for 1 h. Then, 1.87 g (9.0 mmol) of tetraethoxysilane (TEOS) was added as the silica precursor at 15°C. After pre-hydrolysis period of 40.0 minutes at 15°C, 0.50 g (1.0 mmol) of (*S,S*)-4-(trimethoxysilyl)ethylphenylsulfonyl-1,2-diphenylethylenediamine in 0.5 mL of CH₂Cl₂ was added and the mixture was stirred at 15°C for 24 h. After that, the mixture was aged at 100 °C for 24 h. The resulting solids were filtered and rinsed with excess deionized water before being dried overnight on a filter. The collected solids were dispersed in 1000 mL of solution (120 mg (1.50 mmol) of ammonium nitrate in 900 mL (95%) of ethanol), and the mixture was stirred at 80 °C for 24 h. After cooling the above mixture down to room temperature, the solids were filtered and rinsed with ethanol again, and dried at 60 °C *in vacuum* overnight to afford ArDPEN@FDU-12 (**1**) (1.56 g) in the form of a white powder. IR (KBr) cm⁻¹: 3444.1 (s), 2981.4 (w), 2926.7 (w), 1635.7 (m), 1458.7 (w), 1386.2 (m), 1087.2 (s), 953.9 (m), 807.4 (m), 697.8 (w), 569.7 (m), 460.2 (m). ¹³C CP/MAS NMR (161.9 MHz): 153.9–119.8 (C of Ph, Ar), 76.4, 71.4 (CH of –NCH-Ph), 58.6 (CH₂ of –OCH₂CH₂O– groups in F127), 28.9 (CH₂ of –CH₂Ar), 19.2–7.6 (CH₃ of –OCH(CH₃)CH₂O– in F127, and CH₂ of –CH₂Si) ppm. ²⁹Si MAS NMR (79.4 MHz): T³ (δ = –68.0 ppm), Q² (δ = –92.5 ppm), Q³ (δ = –102.6 ppm), Q⁴ (δ = –111.5 ppm).

4). Preparation of Catalyst 3. In a typical synthesis, 116.0 mg (0.20 mmol) of [MesityleneRuCl₂]₂ was added to a suspension of ArDPEN@FDU-12 (**1**) (1.0 g) in 40.0 mL of dry CH₂Cl₂ at room temperature, and the resulting mixture was stirred at 25 °C for 12 h. The mixture was filtered through filter paper and then rinsed with excess CH₂Cl₂. After Soxhlet extraction for 4 h in CH₂Cl₂, the solids was collected and dried at ambient temperature. After that, the collected solids were suspended in 40.0 mL of dry CH₂Cl₂ at room temperature again, 136.0 mg (0.20 mmol) of IPrAuBF₄ (**2**) was added to this solution, and the resulting mixture was stirred at 25 °C for 8 h. The solid was filtered and rinsed with excess dry CH₂Cl₂ again. After Soxhlet extraction for 4 h in CH₂Cl₂, the solids was collected and dried at 60 °C *in vacuum* for 4 h to afford catalyst **3** (1.09 g) in the form of a light-red powder. ICP analysis showed that the Au and Ru loadings were 21.67 mg (0.11 mmol of Au) and 13.13 mg (0.13 mmol of Ru) per gram of catalyst, respectively. IR (KBr) cm⁻¹: 3431.5 (s), 2968.9 (w), 2926.7 (w), 1629.8 (m), 1458.8 (w), 1386.2 (m), 1081.3 (s), 953.9 (m), 807.4 (m), 697.8 (w), 661.6 (w), 569.7 (m), 460.2 (m). ¹³C CP/MAS NMR (161.9 MHz): 161.2 (C of carbene), 155.4–117.8 (C of Ph, Ar and –CH=CH– groups), 105.4, 102.5 (C of Arene groups), 76.4, 71.4 (CH of –NCH-Ph), 60.4 (CH₂ of –OCH₂CH₂O– groups in F127), 28.9 (CH of –CH(CH₃)₂, and CH₂ of –CH₂Ar), 24.7 (CH₃ of –CH(CH₃)₂), 20.6 (CH₃ of mesitylene), 21.2–10.2 (CH₃ of –OCH(CH₃)CH₂O– in F127), 8.5 (CH₂ of –CH₂Si) ppm; ¹⁹F MAS NMR (169.3

MHz): -121.8 ("bulk" BF_4^- species), -139.8 (F in BF_4^- hydrogen bonded to the surface silanol group), -147.1 (F in BF_4^- nothydrogen bonded), -161.8 ("bulk" BF_4^- species) ppm. ^{29}Si MAS NMR (79.4 MHz): T^3 ($\delta = -68.6$ ppm), Q^2 ($\delta = -92.7$ ppm), Q^3 ($\delta = -102.9$ ppm), Q^4 ($\delta = -111.6$ ppm).

5). General procedure for the hydration-ATH one-pot tandem reactions of aromatic haloalkynes. A typical procedure was as follows. To a suspension of catalyst **3** (18.30 mg, 2.0 μmol of Au and 2.38 μmol of Ru, based on ICP analysis) in 2.0 mL of dichloroethane were added sequentially haloalkyne (0.10 mmol), HCOOH-NEt_3 (5:2) (0.25 mL, 3.0 mmol) and water (0.30 mmol). The mixture was then stirred at 25 °C for 14-20 h. During this period, the reaction was monitored constantly by TLC. After completion of the reaction, the catalyst was separated by centrifugation (10,000 rpm) for the recycling experiment. The aqueous solution was extracted with ethyl ether (3×3.0 mL). The combined ethyl ether extracts were washed with brine twice and then dehydrated with Na_2SO_4 . After evaporation of ethyl ether, the residue was purified by silica gel flash column chromatography to afford the desired products.

6). Procedure for sequential synthesis of (R)-nifenalol. To a suspension of catalyst **3** (823.50 mg) in 20.0 mL of dichloroethane were added sequentially 1-(bromoethynyl)-4-nitrobenzene (1.0 g, 4.50 mmol), HCOOH-NEt_3 (5:2) (11.25 mL, 135.0 mmol) and water (13.50 mmol). The mixture was then stirred at 25 °C for 16 h. After that, isopropylamine (1.33 g, 22.50 mmol) was added to the mixture and the reaction mixture was stirred at 60 °C for another 20 h. After completion of the reaction, 5 mL water was added to the mixture, which was extracted by ethyl acetate (3×5.0 mL). The combined organic layer was washed with brine twice and dehydrated with anhydrous Na_2SO_4 . After the evaporation of ethyl acetate, the residue was purified by silica gel column chromatography.

Figure S1. FT-IR spectra of **1** and catalyst **3**.

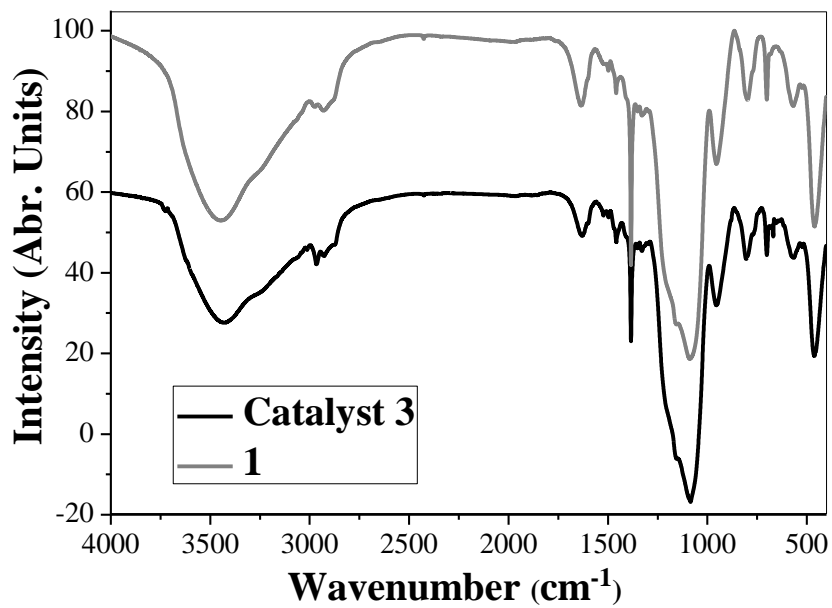


Figure S2. Solid-state ²⁹Si CP MAS NMR spectra of **1** and catalyst **3**.

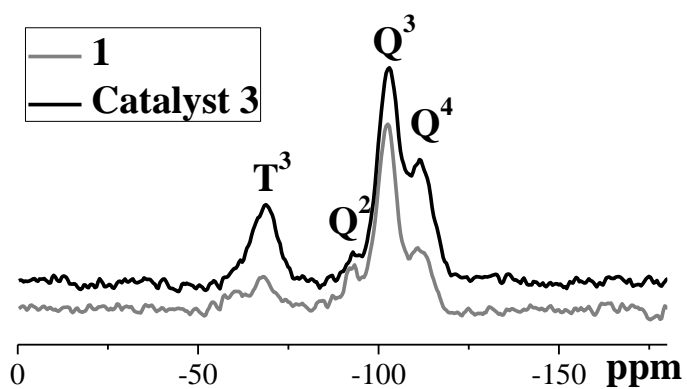


Figure S3. Liquid-state ^{19}F NMR spectrum of IPrAuBF_4 complex

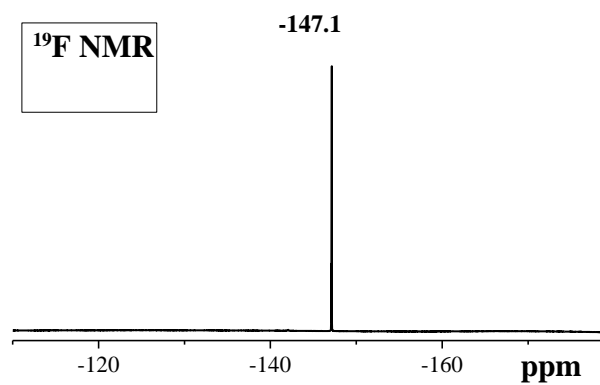


Figure S4. Small-angle powder XRD patterns **1** and catalyst **3**.

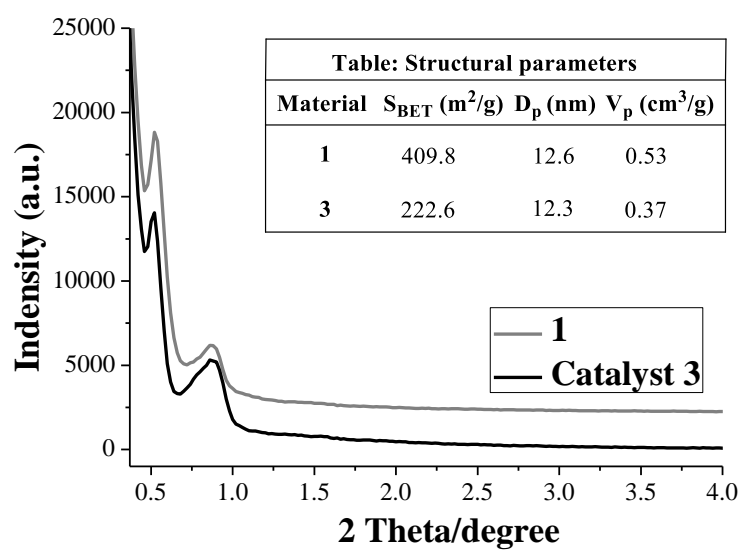


Figure S5. Nitrogen adsorption-desorption isotherms of **1** and catalyst **3**.

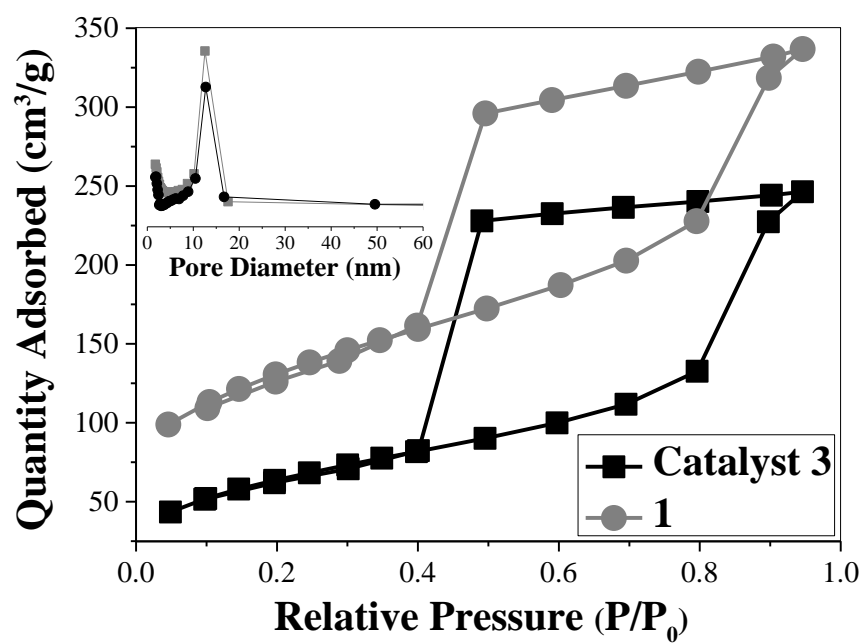


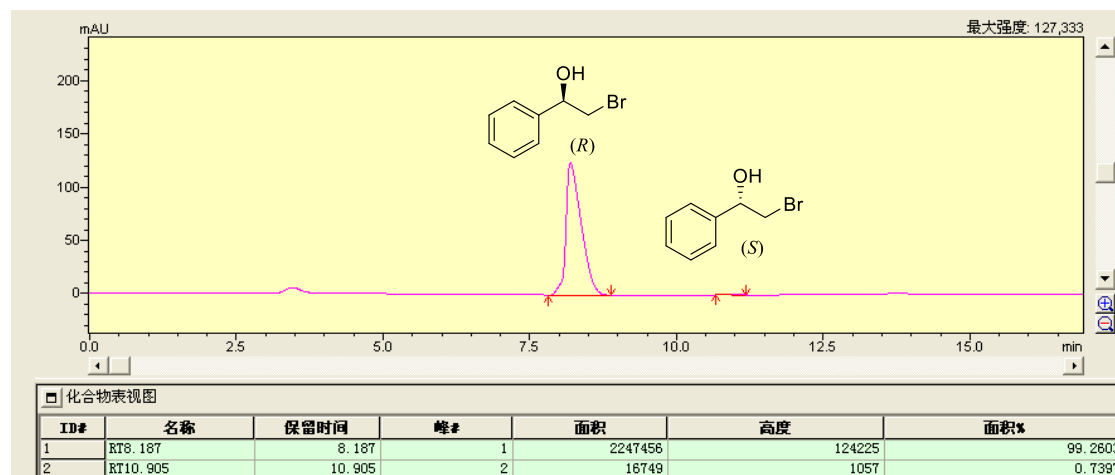
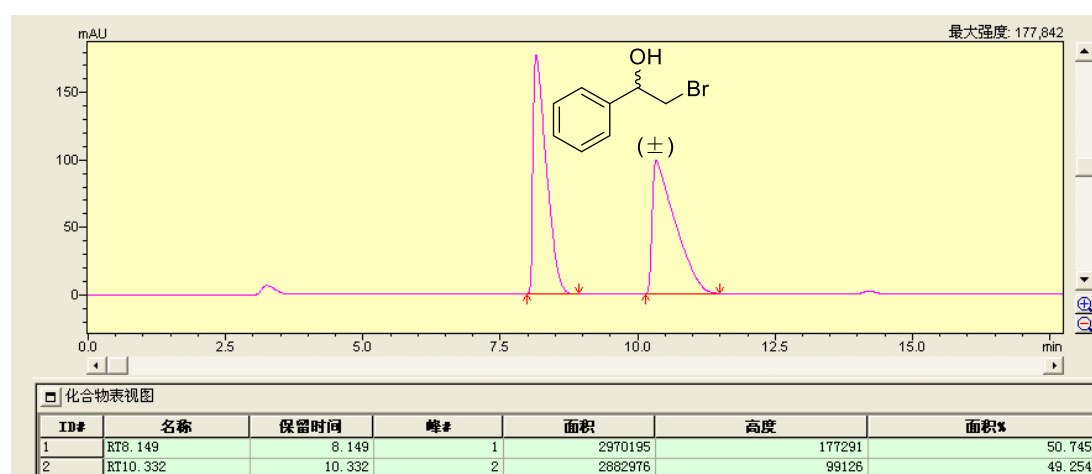
Figure S6. Hydration–ATH one–pot tandem reactions of haloalkynes.

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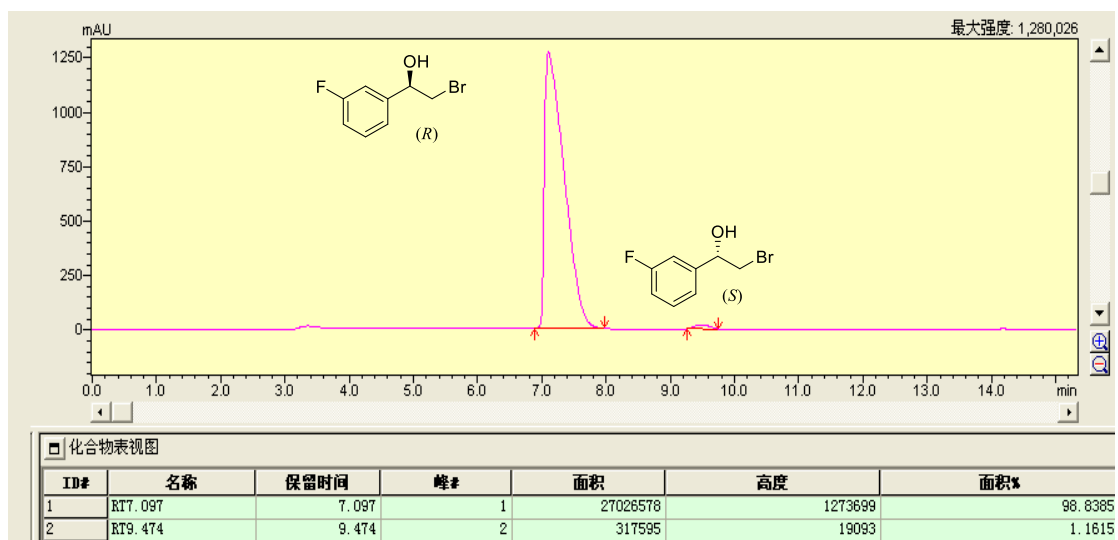
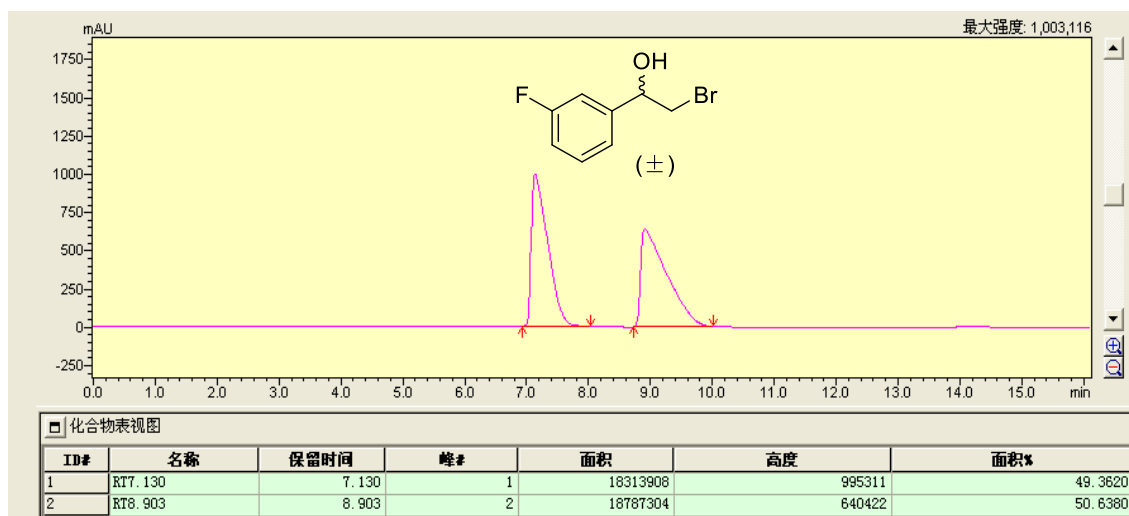
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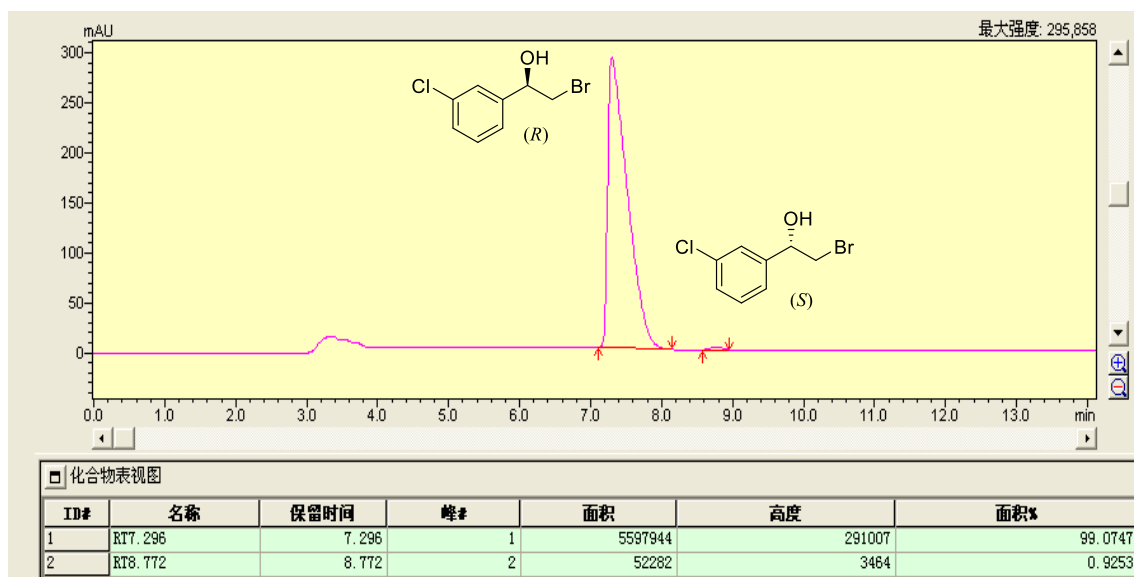
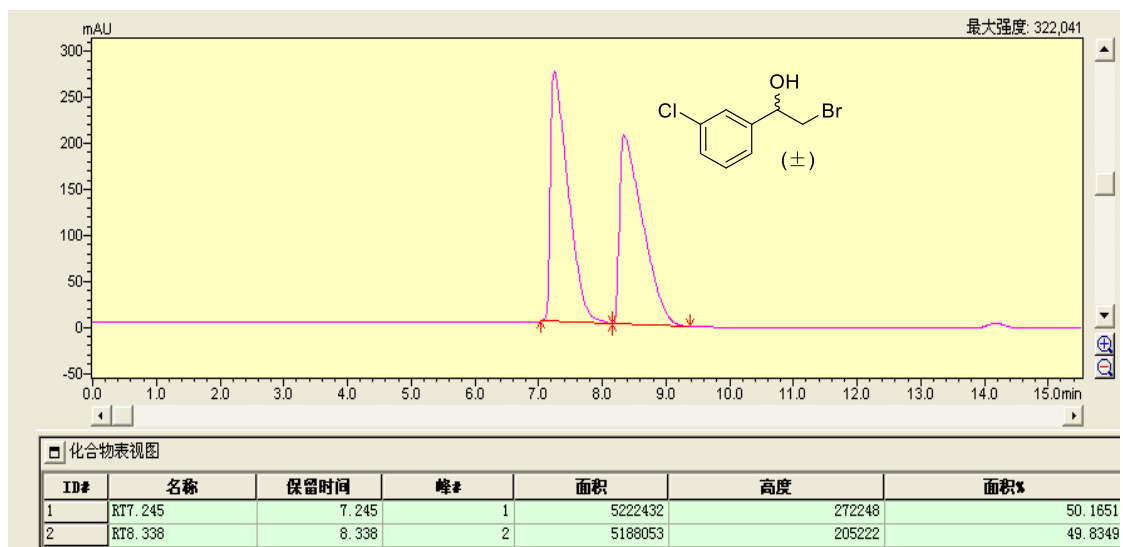
(*R*)-2-bromo-1-phenylethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C).



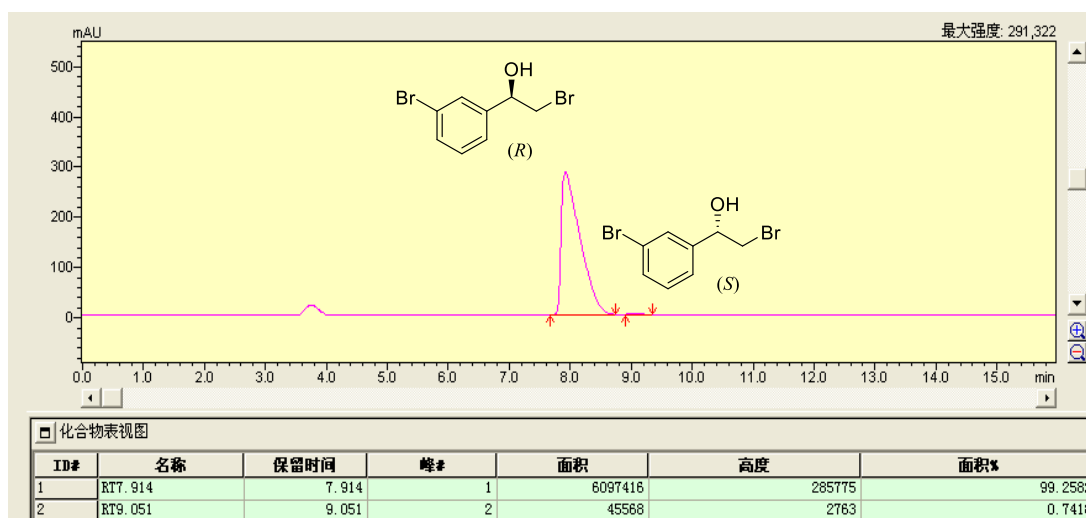
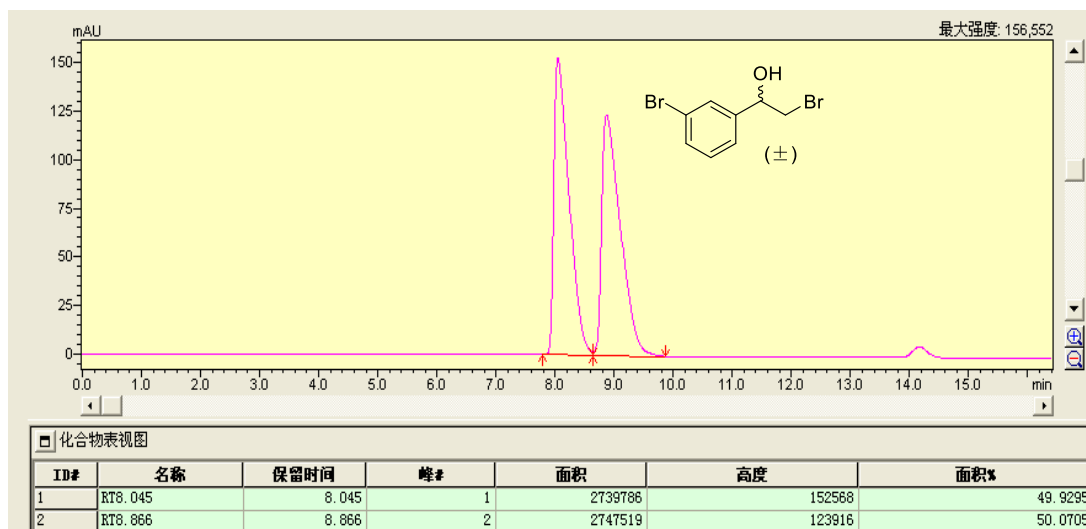
(R)-2-bromo-1-(3-fluorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



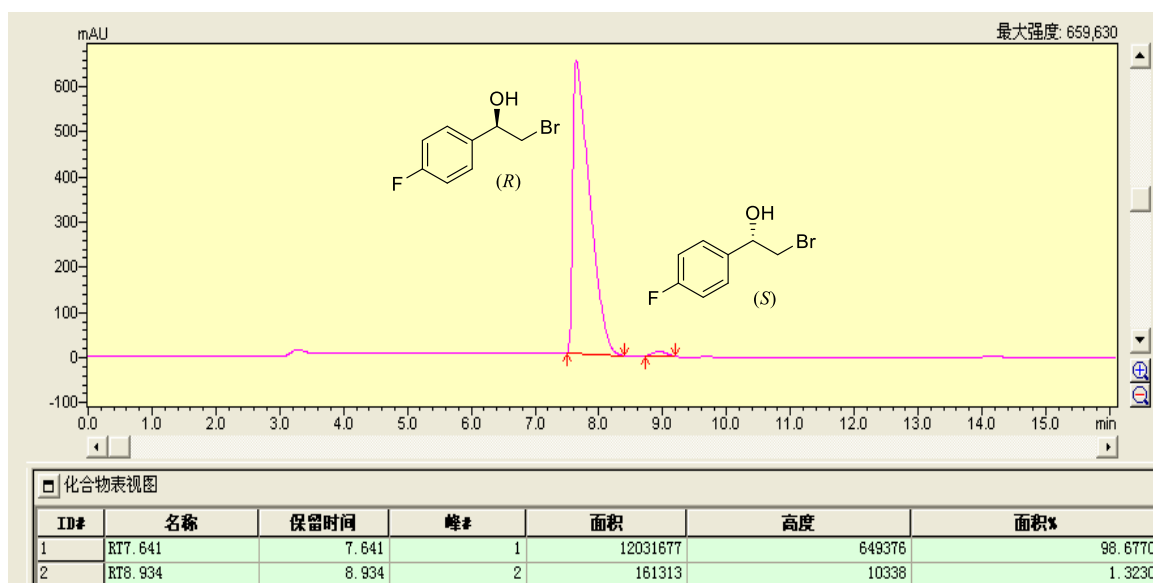
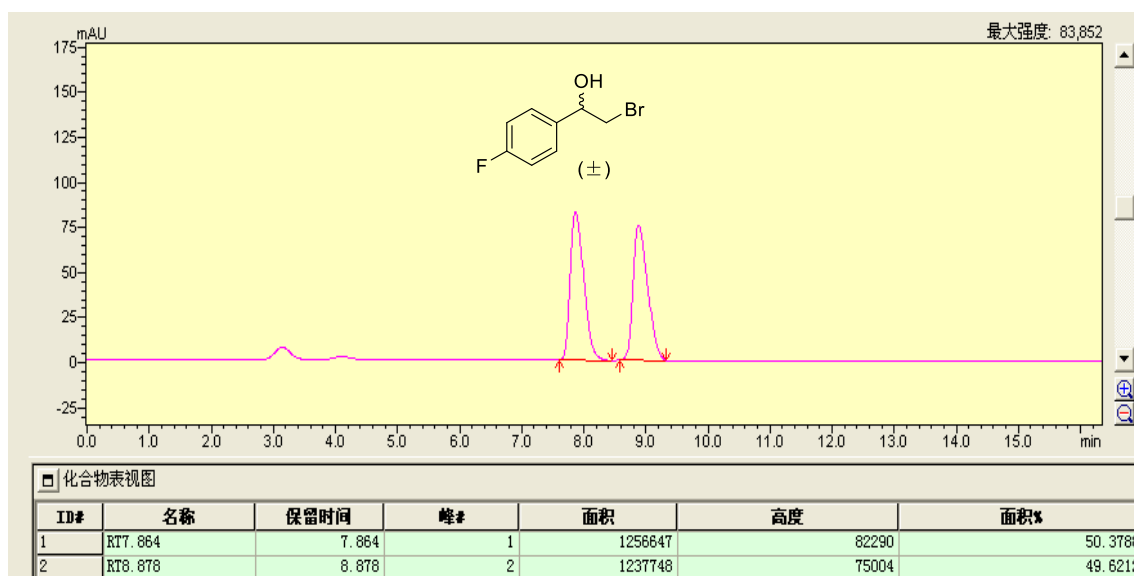
(R)-2-bromo-1-(3-chlorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



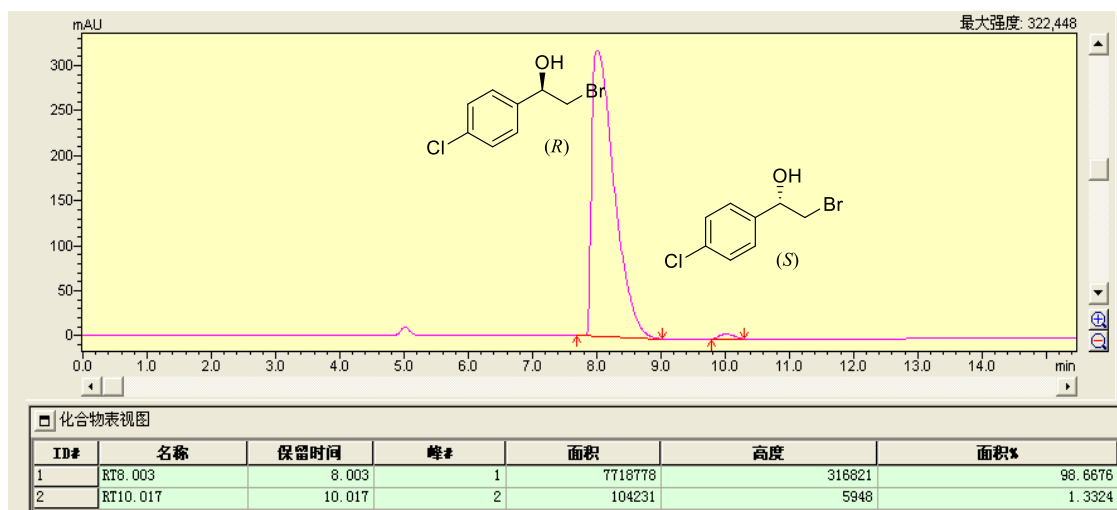
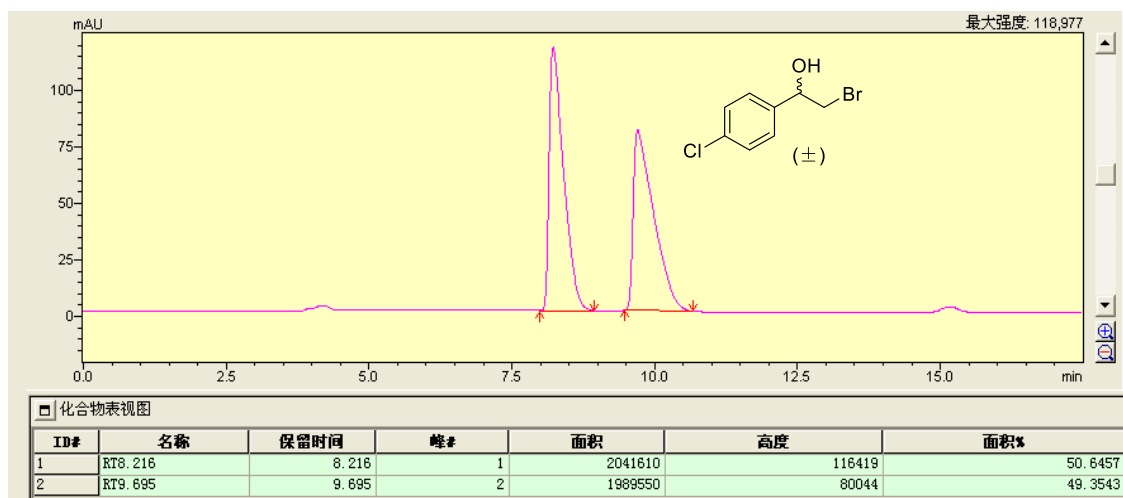
(R)-2-bromo-1-(3-bromophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



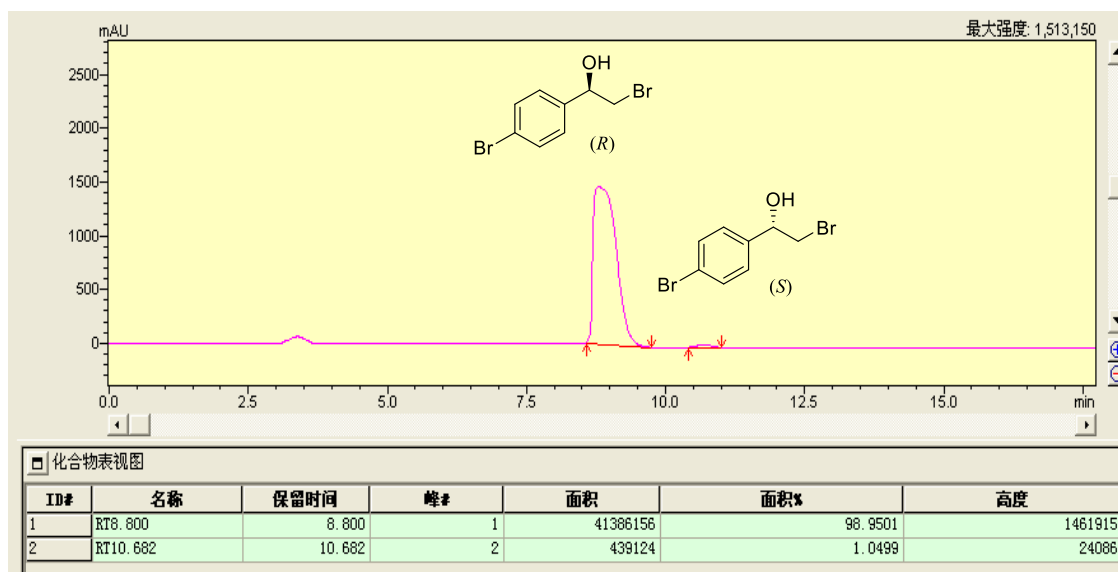
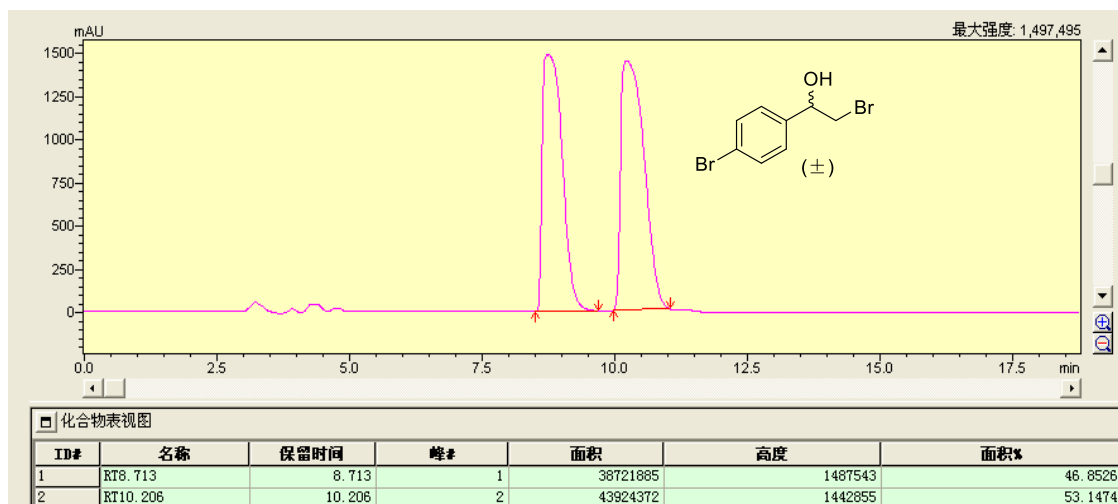
(R)-2-bromo-1-(4-fluorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



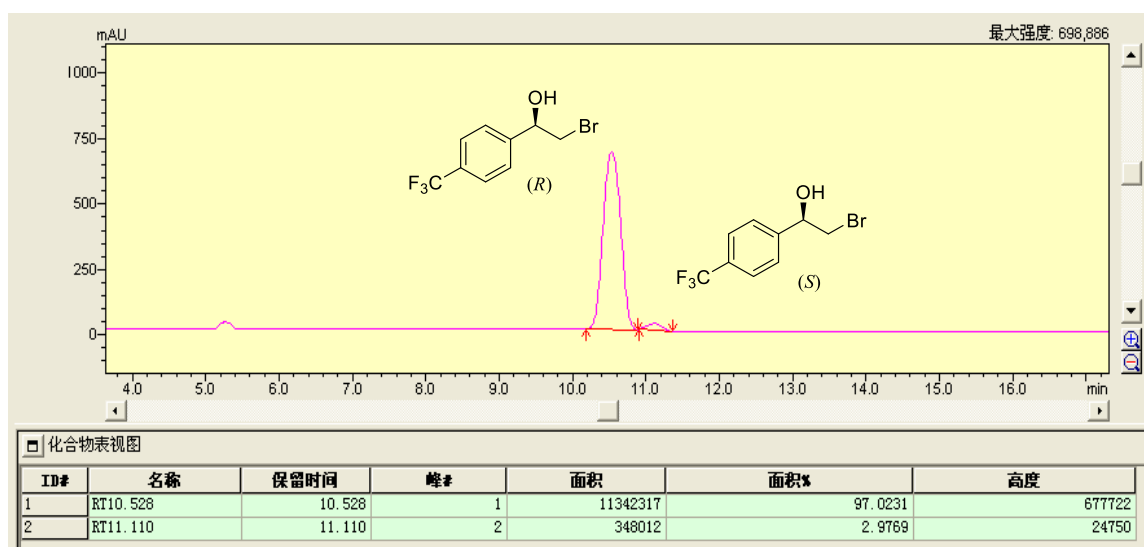
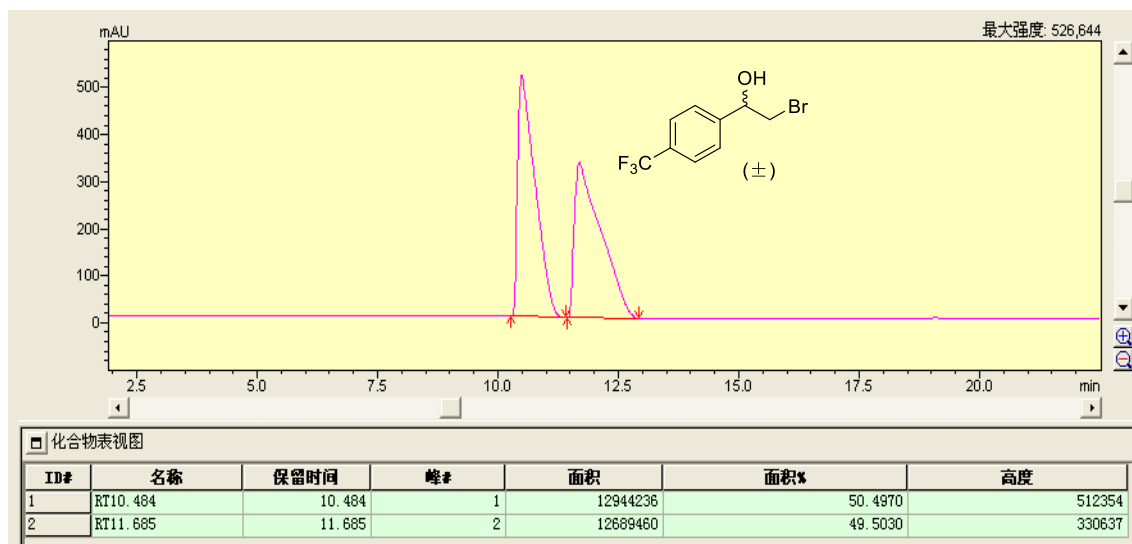
(R)-2-bromo-1-(4-chlorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



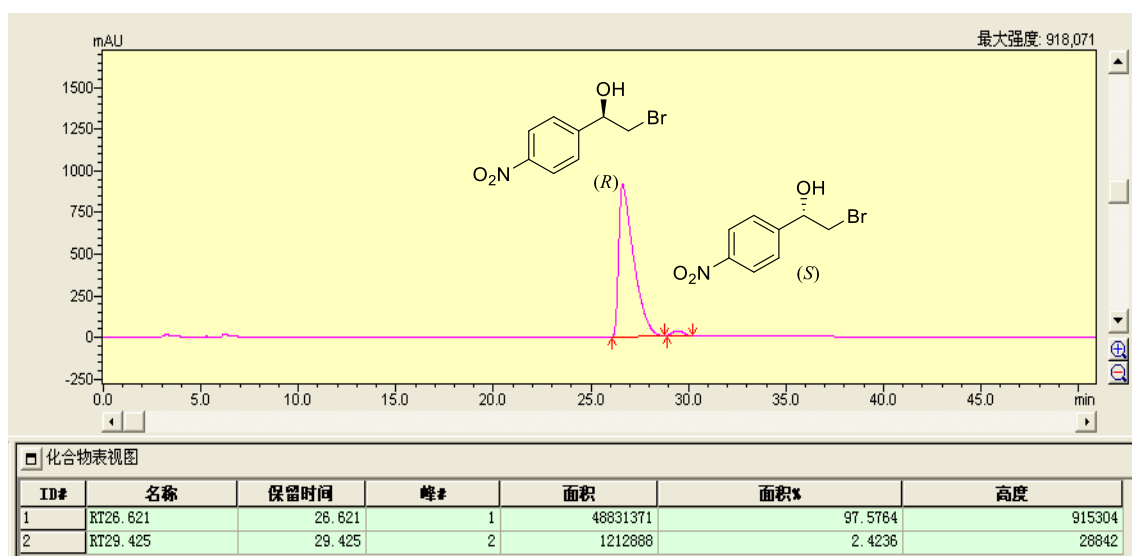
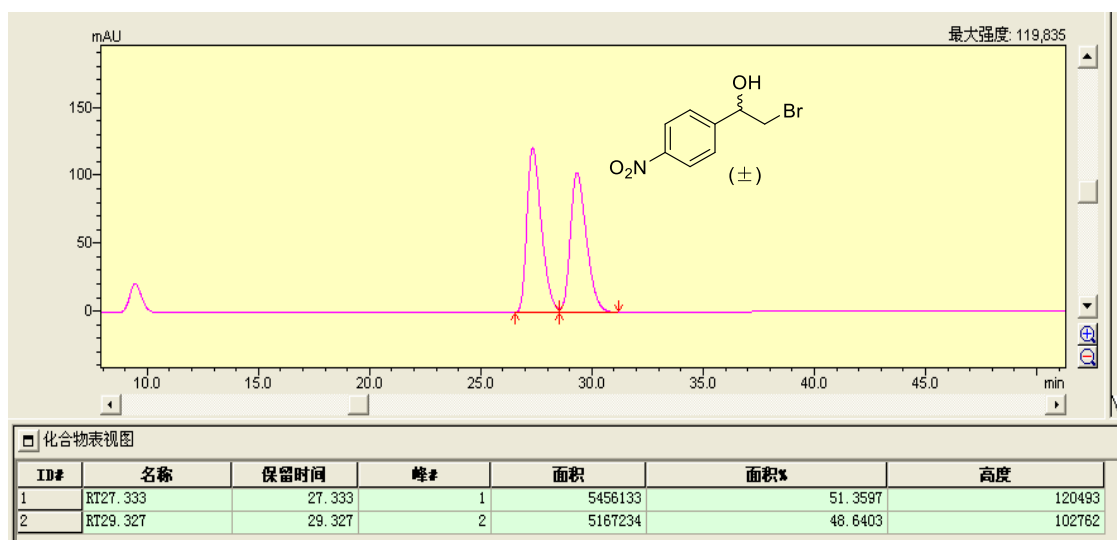
(R)-2-bromo-1-(4-bromophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



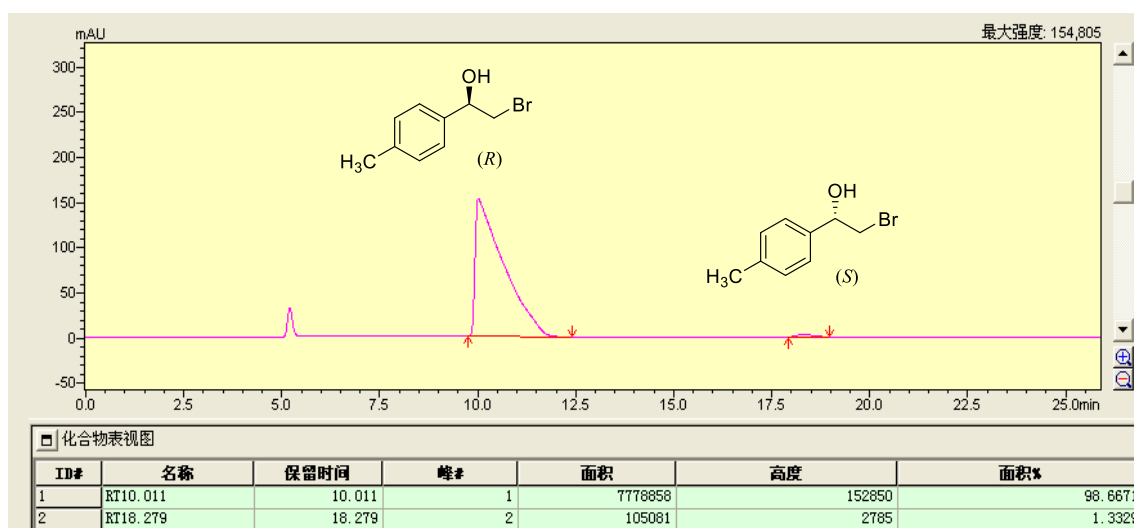
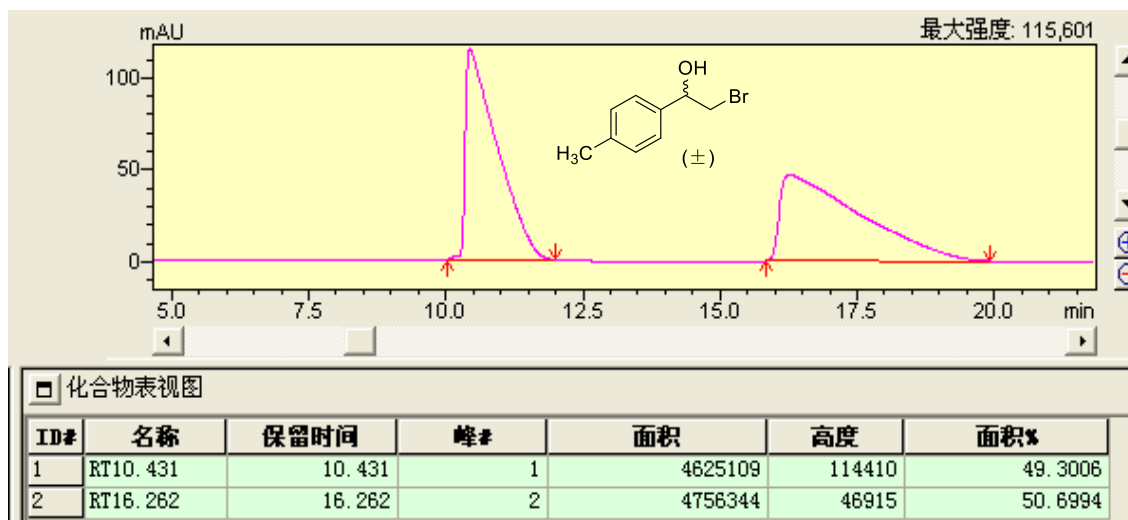
(R)-2-bromo-1-(4-(trifluoromethyl)phenyl)ethanol: (HPLC: Chiracel OJ-H, detected at 254 nm, eluent: n-hexane/2-propanol = 95/5, flow rate = 1.0 mL/min, 25 °C)



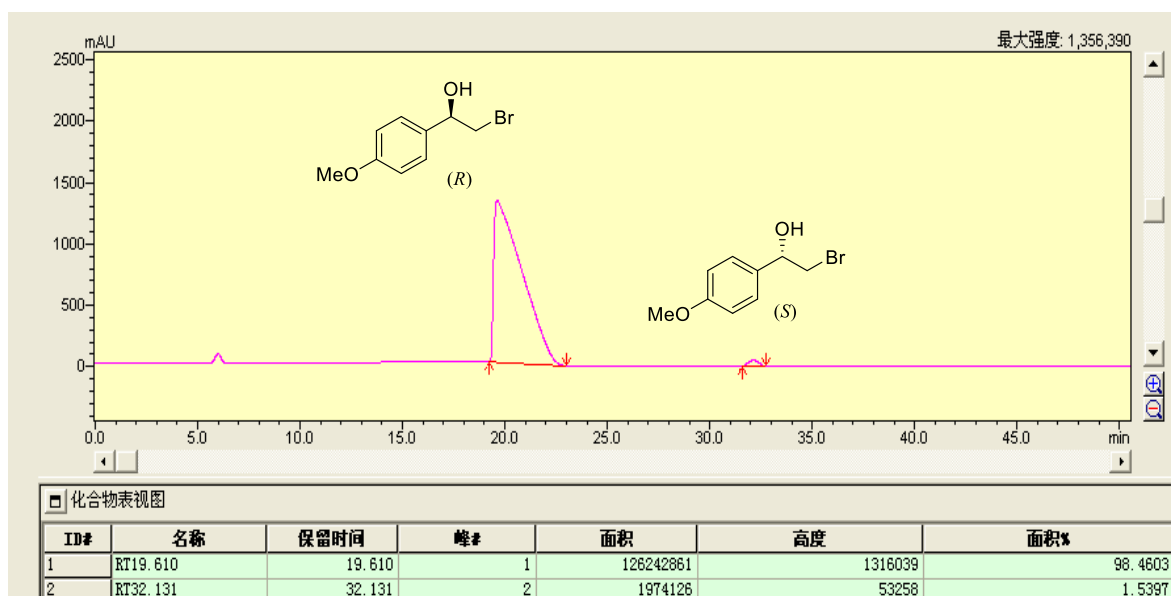
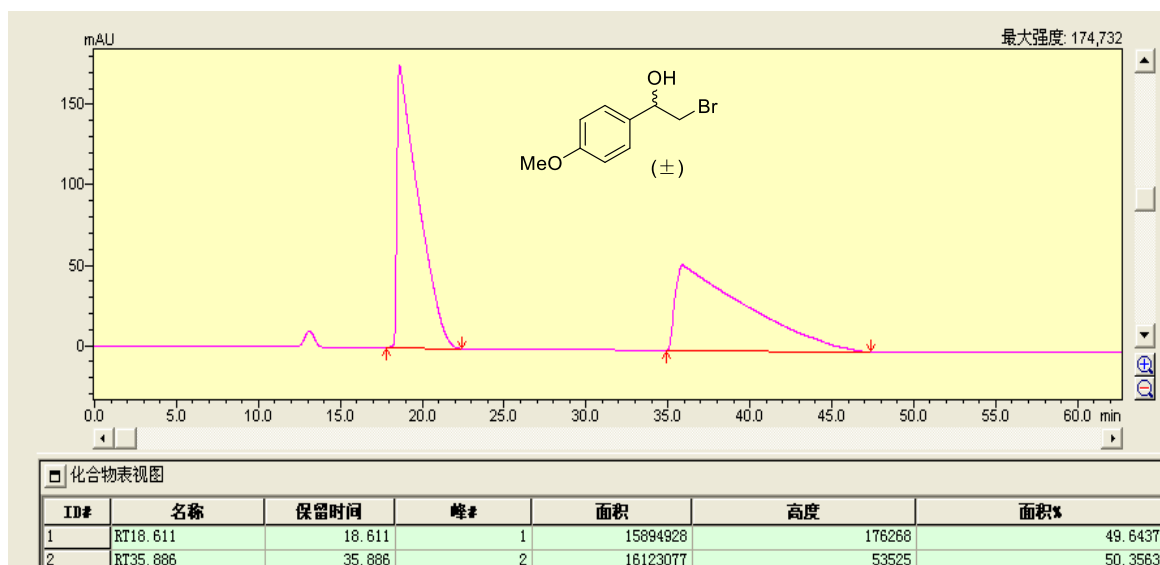
(R)-2-bromo-1-(4-nitrophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 215 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



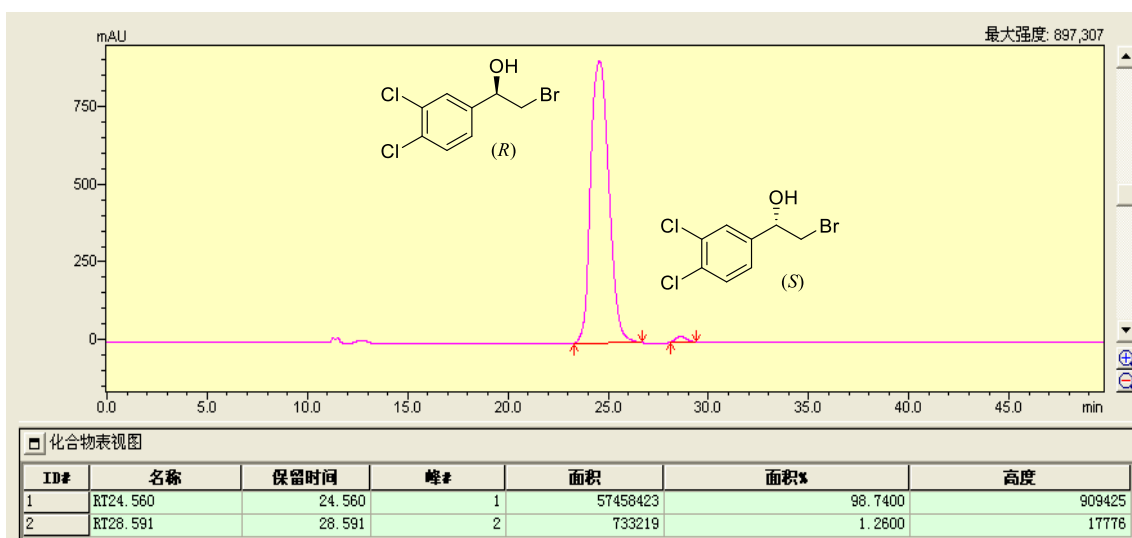
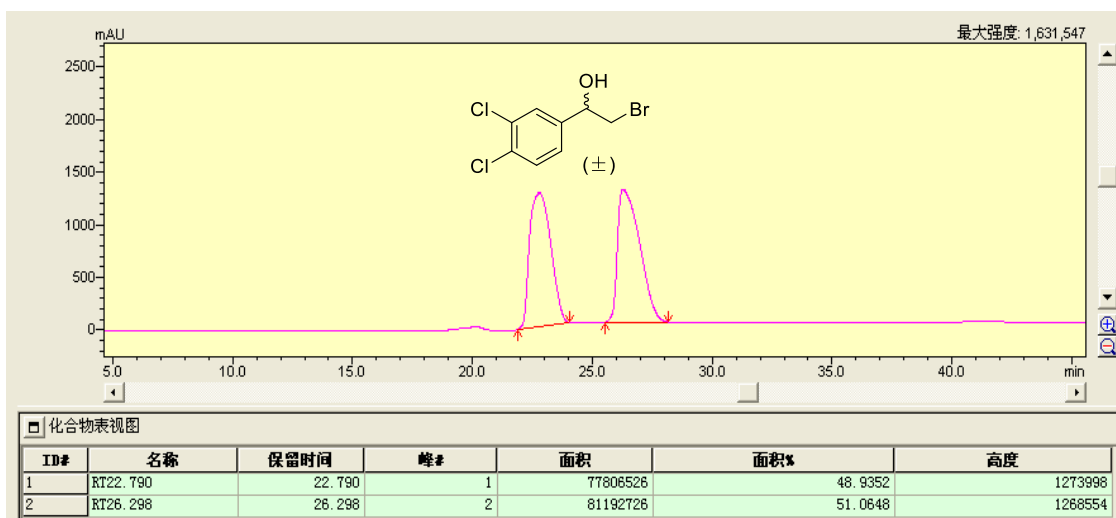
(R)-2-bromo-1-(p-tolyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



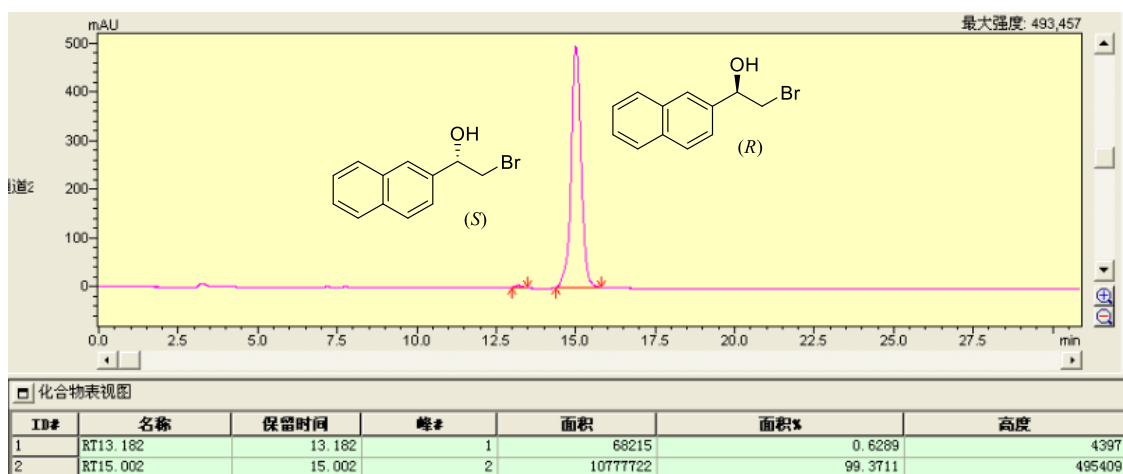
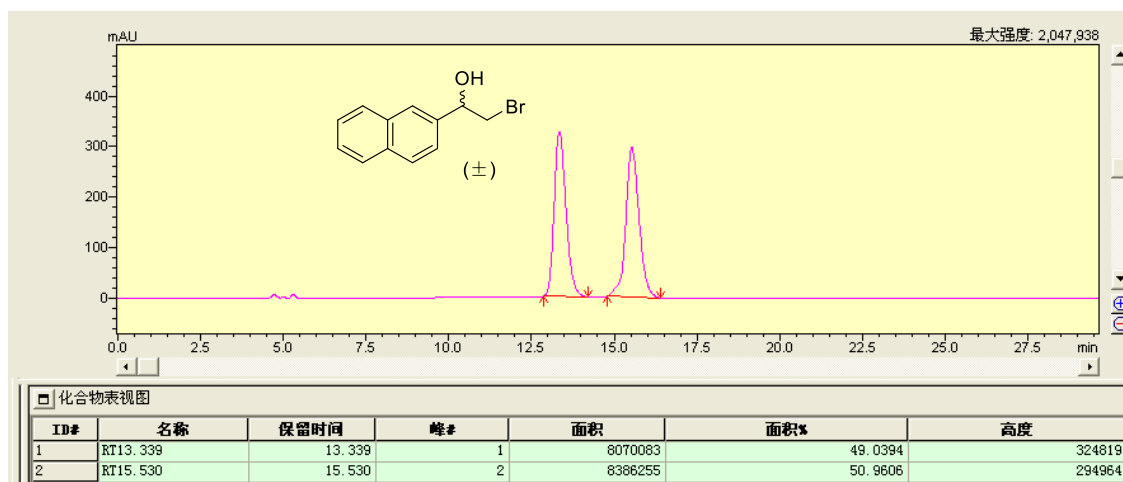
(R)-2-bromo-1-(4-methoxyphenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



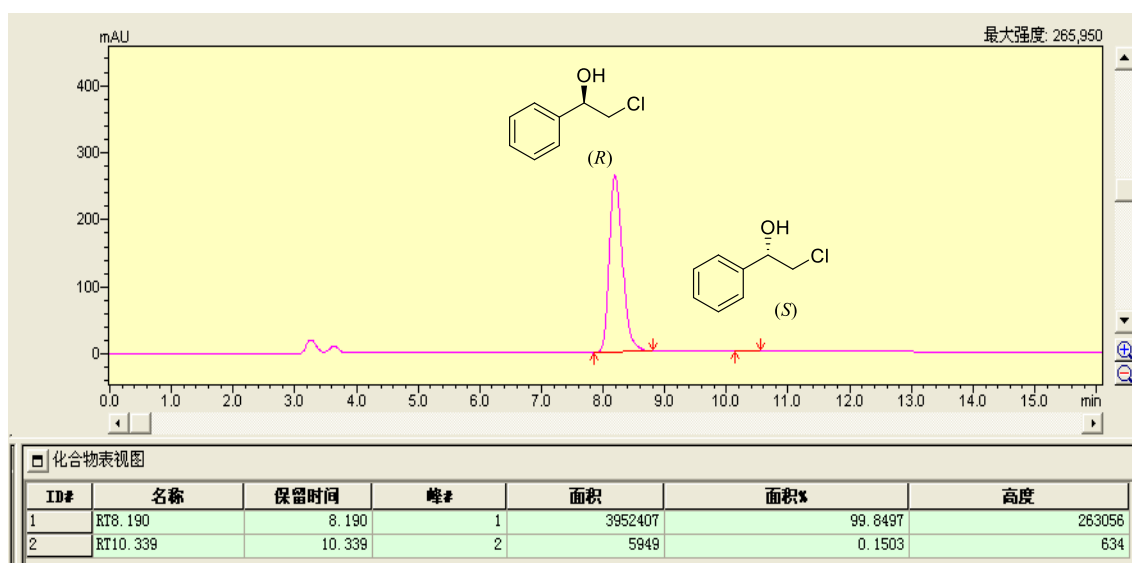
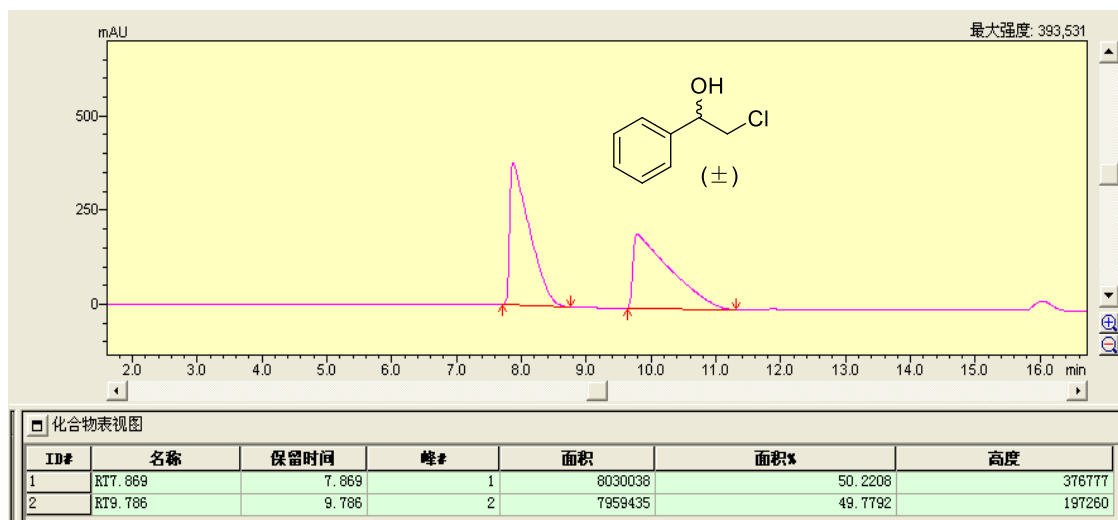
(R)-2-bromo-1-(3,4-dichlorophenyl)ethanol: (HPLC: Chiracel OJ-H, detected at 215 nm, eluent: n-hexane/2-propanol = 97/3, flow rate = 1.0 mL/min, 25 °C)



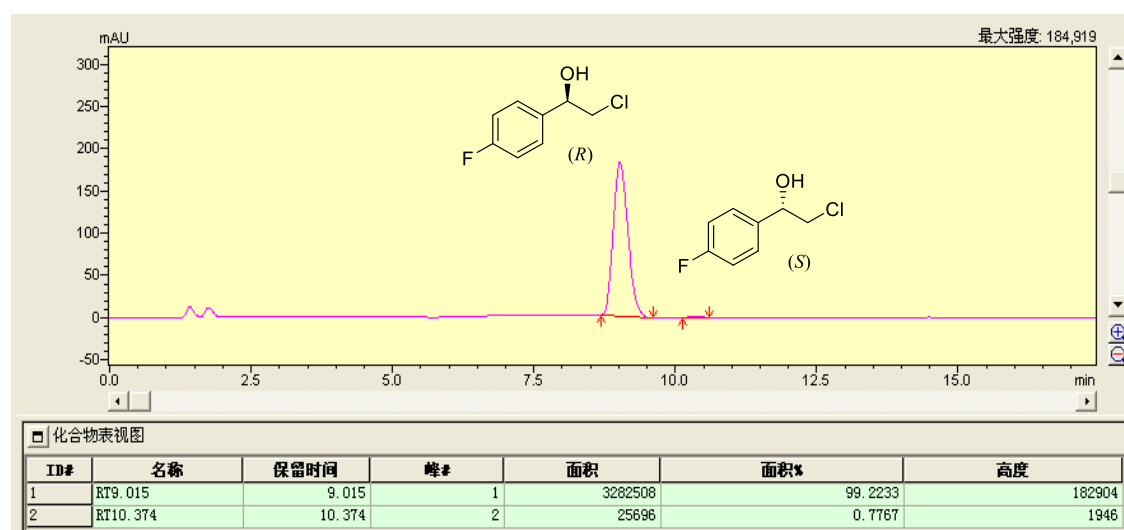
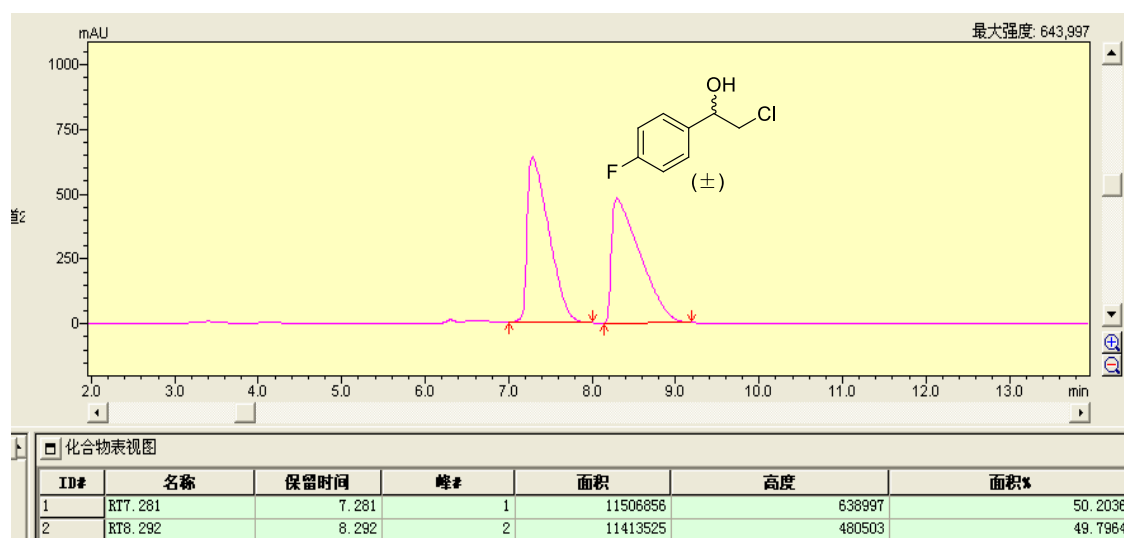
(R)-2-bromo-1-(naphthalen-2-yl)ethanol: (HPLC: Chiracel AS-H, detected at 254 nm, eluent: n-hexane/2-propanol = 95/5, flow rate = 1.0 mL/min, 25 °C)



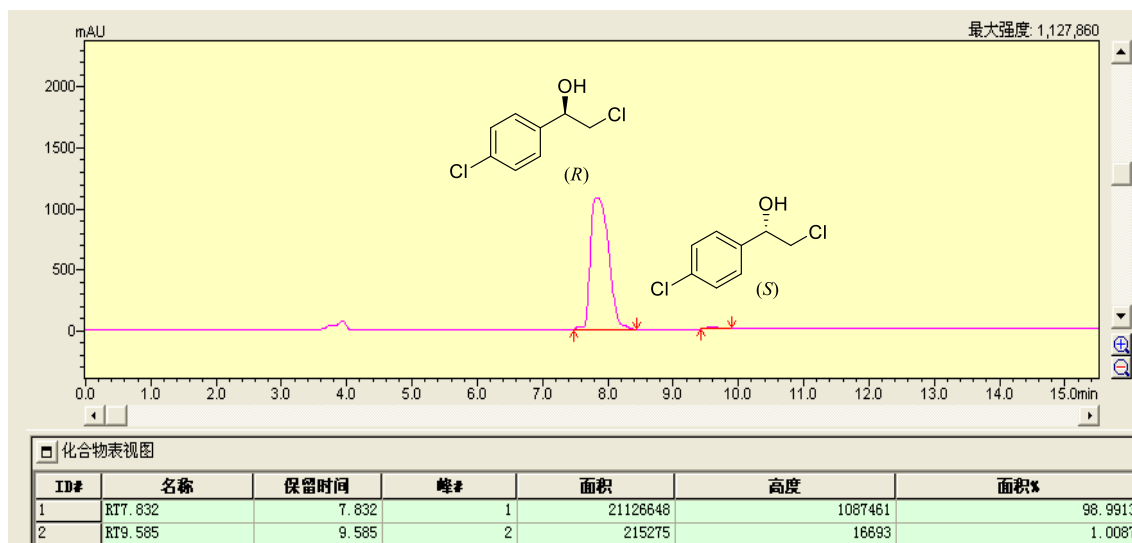
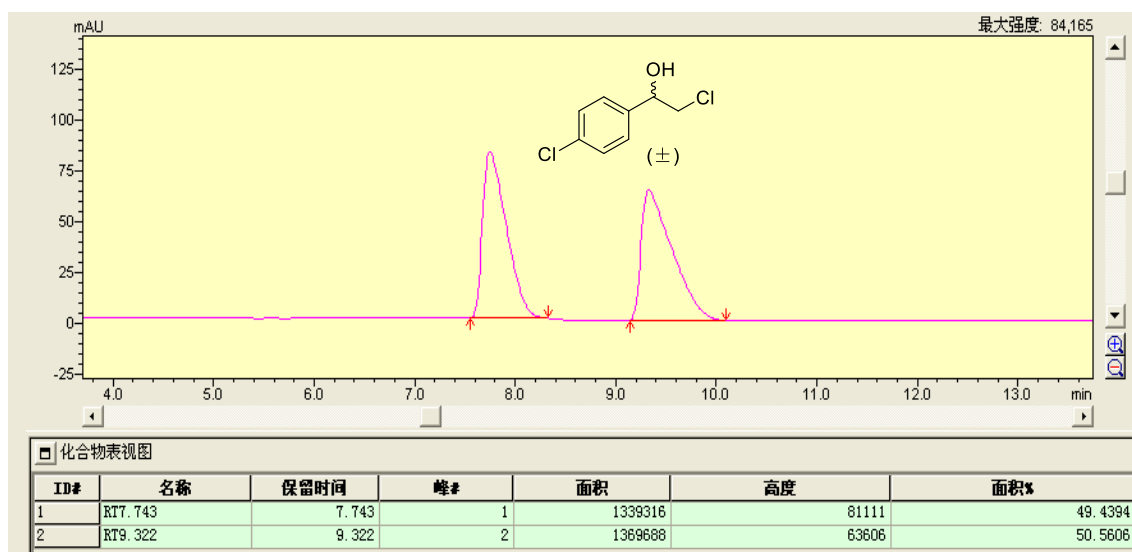
(R)-2-chloro-1-phenylethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



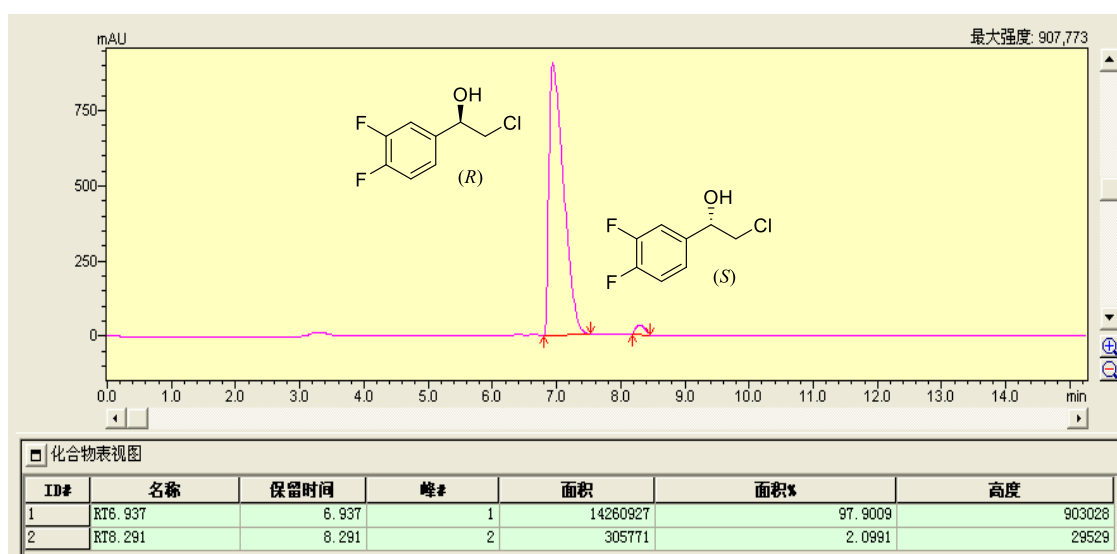
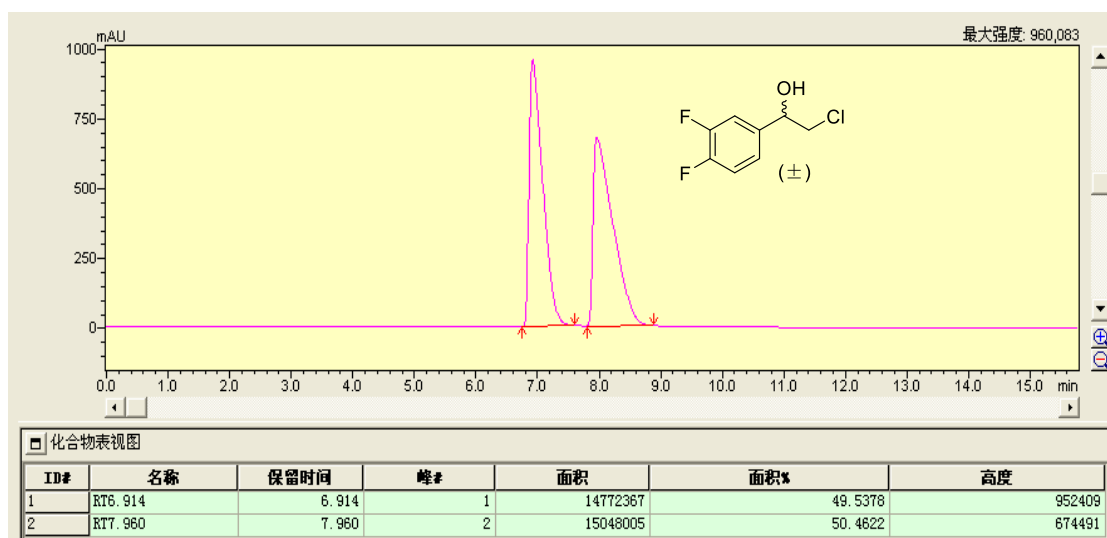
(R)-2-chloro-1-(4-fluorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



(R)-2-chloro-1-(4-chlorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)

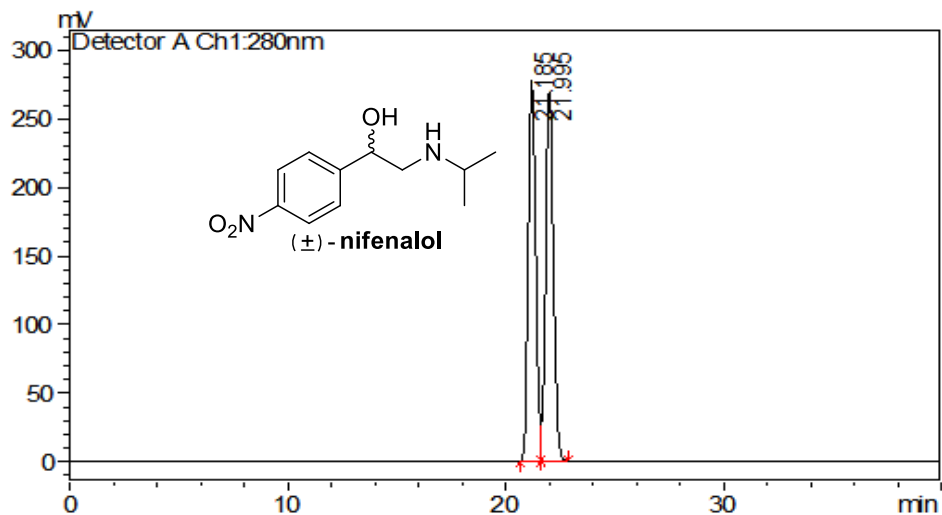


(R)-2-bromo-1-(3,4-difluorophenyl)ethanol: (HPLC: Chiracel OB-H, detected at 254 nm, eluent: n-hexane/2-propanol = 90/10, flow rate = 1.0 mL/min, 25 °C)



(R)-Nifenalol: (HPLC: Chiracel IC, detected at 280nm, eluent: n-hexane/2-propanol/
Ethanolamine = 95/5/0.1, flow rate = 0.5mL/min, 35 °C)

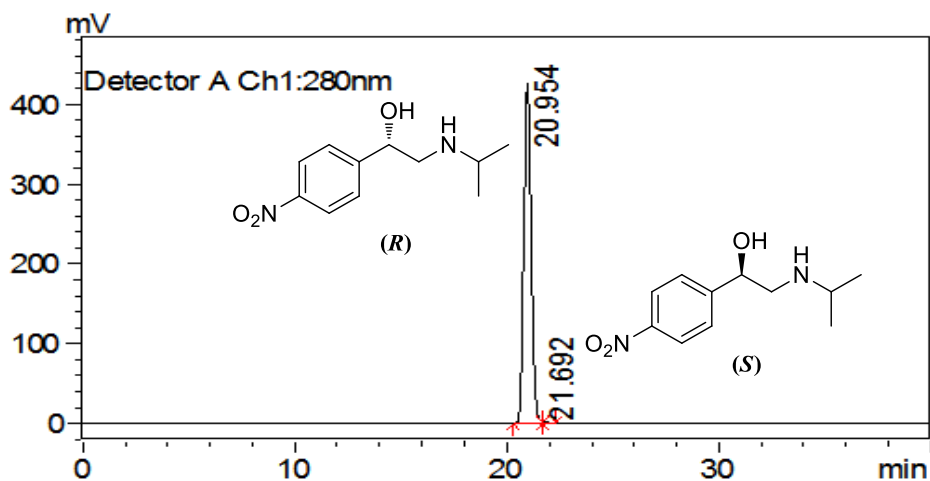
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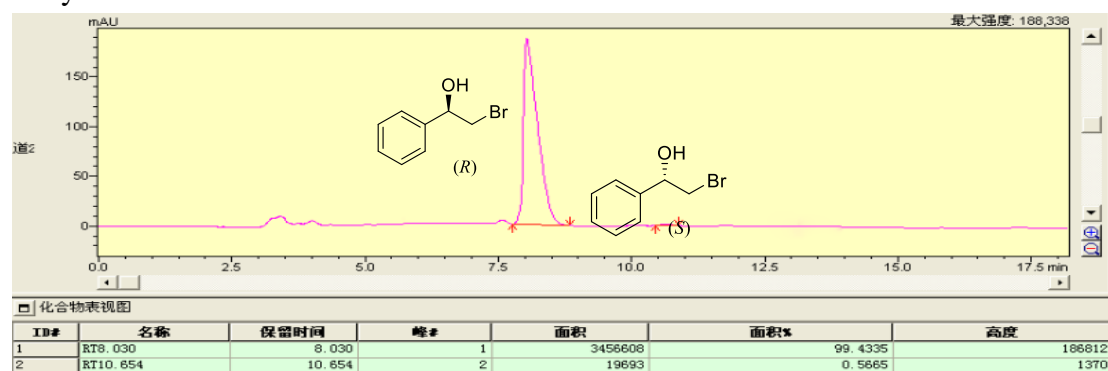
Table S1. Reusability of catalyst **3** using (bromoethynyl)benzene as a substrate.^[a]

Run time	1	2	3	4	5	6	7
% Conversion.	93	92	92	90	87	86	85
% <i>ee</i>	99	99	98	98	98	97	98

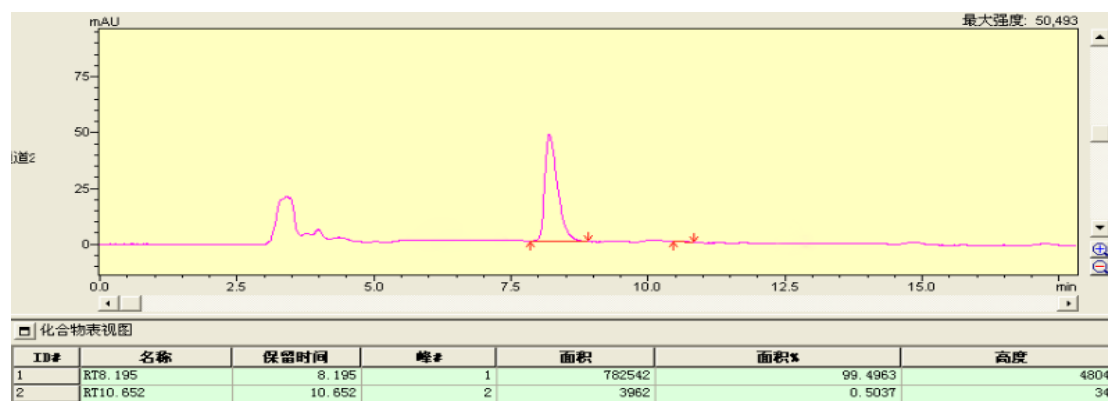
[a] Reaction conditions: catalyst **3** (183.0 mg, 20.0 μ mol of Au and 23.80 μ mol of Ru, based on ICP analysis), haloalkyne (1.0 mmol), HCOOH-NEt₃ (5:2) (2.50 mL, 30.0 mmol) and water 3.0 mmol) in 20.0 mL dichloroethane, reaction temperature (25°C), reaction time (14 h).

Figure S7. Reusability of catalyst **3** using (bromoethynyl)benzene as a substrate.

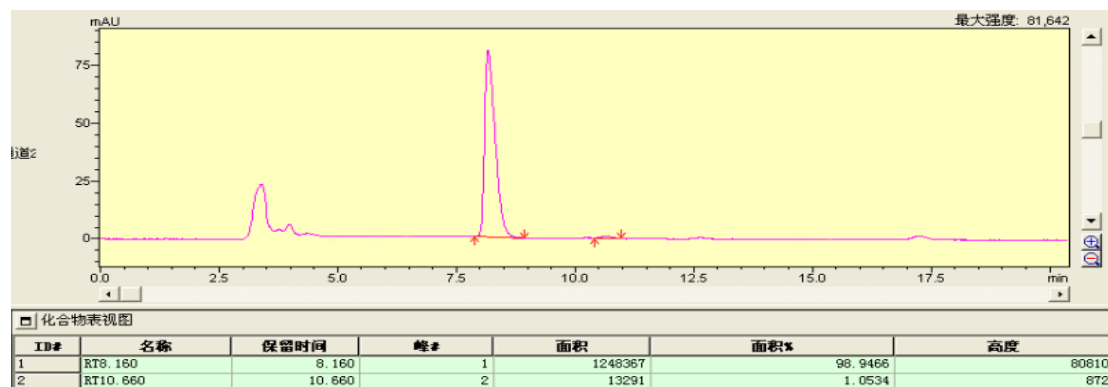
Recycle 2



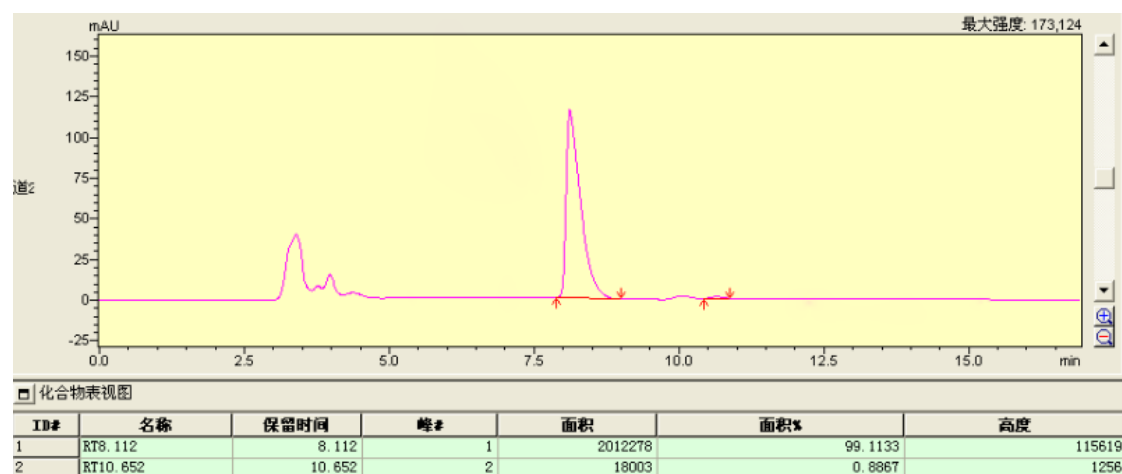
Recycle 3



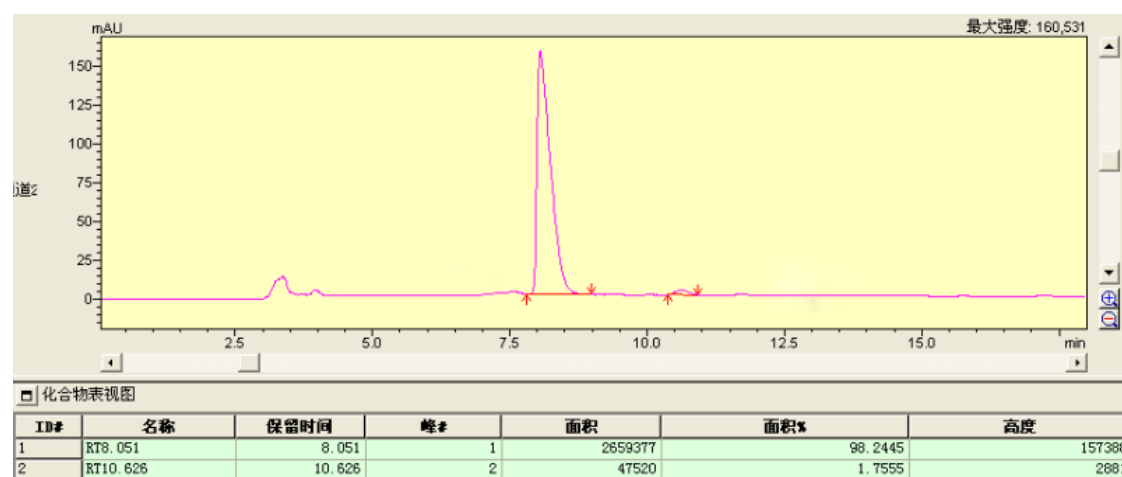
Recycle 4



Recycle 5



Recycle 6



Recycle 7

