Enantioselective Cascade Reaction between \( \alpha,\beta \)-Unsaturated Carbonyls and Malonic Half-thioesters: Rapid Access to Chiral \( \delta \)-lactones

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1. General Information

Chemicals and solvents were purchased from commercial suppliers and used as received. $^1$H and $^{13}$C NMR spectra were recorded on a Bruker ACF300 (300 MHz) or AMX500 (500 MHz) spectrometer. Chemical shifts were reported in parts per million (ppm), and the residual solvent peak was used as an internal reference: proton (chloroform $\delta$ 7.26), carbon (chloroform $\delta$ 77.0) or tetramethylsilane (TMS $\delta$ 0.00) was used as a reference. Multiplicity was indicated as follows: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (doublet of doublet), bs (broad singlet). Coupling constants were reported in Hertz (Hz). Low resolution mass spectra were obtained on a Finnigan/MAT LCQ spectrometer in ESI mode, and a Finnigan/MAT 95XL-T mass spectrometer in EI mode. All high resolution mass spectra were obtained on a Finnigan/MAT 95XL-T spectrometer. For thin layer chromatography (TLC), Merck pre-coated TLC plates (Merck 60 F254) were used, and compounds were visualized with a UV light at 254 nm. Flash chromatography separations were performed on Merck 60 (0.040-0.063 mm) mesh silica gel. The enantiomeric excesses of products were determined by chiral phase HPLC analysis. Optical rotations were recorded on Jasco DIP-1000 polarimeter.
2. Experimental Procedure for Decarboxylative Reaction of MAHTs to Enals

![Chemical Structure]

Typical procedure for the decarboxylative reaction:

To a solution of cinnamaldehyde 1a (26.4 mg, 25.2 μL, 0.2 mmol) in DCM (0.5 mL) was added catalyst V (25.6 mg, 0.04 mmol) at 0 °C. After 40 min, malonic acid half thioester 2c (98.1 mg, 0.5 mmol) was added in one portion. Then, TEA (50.5 mg, 69.6 μL, 0.5 mmol) in 0.5 mL DCM was added dropwise via syringe in 10 min at 0 °C. The resulting reaction mixture was kept stirring at 0°C for 24 h.

The crude product was purified by silica gel flash chromatography, eluted by hexane/EtOAc = 10:1 to afford the desired product 3ac as white solid (46.7 mg, 82% yield).

(4S,6S)-4-phenyl-6-(phenylthio)tetrahydro-2H-pyran-2-one (3ac) (Table 2, entry 1). 46.7 mg, 82% yield; White solid; 1H NMR (500 MHz, CDCl₃) δ (ppm): 7.61 – 7.59 (m, 2H), 7.36 (ddd, J = 7.7, 4.0, 1.7 Hz, 5H), 7.30 – 7.26 (m, 1H), 7.17 – 7.16 (m, 2H), 5.74 (dd, J = 11.3, 4.1 Hz, 1H), 3.19 (tt, J = 12.3, 4.4 Hz, 1H), 2.88 (ddd, J = 17.7, 5.1, 2.3 Hz, 1H), 2.58 – 2.51 (m, 2H), 2.04 – 1.97 (m, 1H); 13C NMR (125 MHz, CDCl₃) δ (ppm): 169.4, 141.5, 133.3, 131.8, 129.2, 129.1, 128.6, 127.5, 126.4, 86.3, 37.4, 37.2, 36.3; HRMS (EI) calcd for C₁₇H₁₆O₂S 284.0871, found 284.0876; HPLC (Chiralpak IC, i-propanol/hexane = 20/80, flow rate 1.0 mL/min, λ = 254 nm): tᵣ (major) = 28.2 min, tᵣ (minor) = 23.0 min, ee = 92%; [a]D²⁵ = -96.6 (c = 1.08 in DCM).
(4S,6S)-4-(4-chlorophenyl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3bc) (Table 2, entry 2).

52.9 mg, 83% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.60 – 7.58 (m, 2H), 7.38 – 7.34 (m, 3H), 7.11 – 7.09 (m, 2H), 5.72 (dd, $J = 11.3$, 4.1 Hz, 1H), 3.17 (tt, $J = 12.2$, 4.5 Hz, 1H), 2.86 (ddd, $J = 17.6$, 5.1, 2.2 Hz, 1H), 2.56 – 2.46 (m, 2H), 2.00 – 1.93 (m, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 169.1, 134.0, 133.3, 133.3, 131.6, 129.2, 129.2, 128.7, 127.8, 86.2, 37.1, 36.9, 36.1; HRMS (EI) calcd for C$_{17}$H$_{15}$O$_2$ClS 318.0481, found 318.0486; HPLC (Chiralpak IC, i-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 28.4 min, $t_R$ (minor) = 24.7 min, $ee = 94\%$; $[\alpha]^{25}_D = -52.7$ ($c = 1.05$ in DCM).

(4S,6S)-4-(4-nitrophenyl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3cc) (Table 2, entry 3). 57.3 mg, 87% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 8.21 (d, $J = 8.7$ Hz, 2H), 7.60 – 7.58 (m, 2H), 7.37 – 7.34 (m, 5H), 5.74 (dd, $J = 11.1$, 4.1 Hz, 1H), 3.35 (tt, $J = 12.1$, 4.5 Hz, 1H), 2.90 (ddd, $J = 17.5$, 5.2, 2.2 Hz, 1H), 2.61 – 2.51 (m, 2H), 2.02 (dt, $J = 13.8$, 11.7 Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 168.5, 148.7, 147.3, 133.4, 131.3, 129.2, 128.8, 127.5, 124.3, 86.0, 37.3, 36.6, 35.7; HRMS (EI) calcd for C$_{17}$H$_{15}$O$_2$NS 329.0722, found 329.0723; HPLC (Chiralpak IA, i-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 36.5 min, $t_R$ (minor) = 26.9 min, $ee = 95\%$.
\[ \alpha \]_{D}^{25} = -68.8 \ (c = 0.97 \text{ in DCM}).

(4S,6S)-4-(2-nitrophenyl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3dc) (Table 2, entry 4). 52.0 mg, 79% yield; Colorless oil; \(^1\text{H} \text{NMR} \ (500 \text{ MHz, CDCl}_3) \delta \text{ (ppm):} \ 7.87 \ (d, J = 8.1 \text{ Hz, 1H}), 7.64 \ (t, J = 7.6 \text{ Hz, 1H}), 7.59 \ (dd, J = 6.4, 2.8 \text{ Hz, 2H}), 7.44 \ (t, J = 7.7 \text{ Hz, 1H}), 7.37 - 7.35 \ (m, 4H), 5.74 \ (dd, J = 11.3, 3.8 \text{ Hz, 1H}), 3.79 \ (td, J = 11.6, 5.8 \text{ Hz, 1H}), 2.99 \ (ddd, J = 17.5, 5.3, 1.8 \text{ Hz, 1H}), 2.64 - 2.54 \ (m, 2H), 2.03 \ (dd, J = 25.3, 11.7 \text{ Hz, 1H}); \ ^{13}\text{C} \text{ NMR} \ (125 \text{ MHz, CDCl}_3) \delta \text{ (ppm):} \ 168.7, 149.3, 136.0, 133.7, 133.3, 131.4, 129.2, 128.7, 128.3, 127.4, 124.9, 86.0, 36.5, 35.9, 32.2; \text{HRMS (EI) calecd for C}_{17}\text{H}_{15}\text{O}_{4}\text{NS} \ 329.0722, \text{found} \ 329.0734; \text{HPLC (Chiralpak IA, i-propanol/hexane = 10/90, flow rate 1.0 mL/min, } \lambda = 254 \text{ nm):} \ t_R \ (\text{major}) = 30.4 \text{ min, } t_R \ (\text{minor}) = 34.1 \text{ min, } ee \ = 96%; \ [\alpha]_{D}^{25} = -57.2 \ (c = 1.00 \text{ in DCM}).

(4S,6S)-4-(4-methoxyphenyl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3ec) (Table 2, entry 5). 51.7 mg, 82% yield; White solid; \(^1\text{H} \text{NMR} \ (500 \text{ MHz, CDCl}_3) \delta \text{ (ppm):} \ 7.59 \ (dd, J = 6.4, 3.2 \text{ Hz, 2H}), 7.35 \ (dd, J = 4.9, 1.9 \text{ Hz, 3H}), 7.10 - 7.04 \ (m, 2H), 6.90 - 6.87 \ (m, 2H), 5.72 \ (dd, J = 11.3, 4.1 \text{ Hz, 1H}), 3.80 \ (s, 3H), 3.13 \ (tt, J = 12.6, 3.8 \text{ Hz, 1H}), 2.86 \ (ddd, J = 17.7, 5.1, 2.3 \text{ Hz, 1H}), 2.55 - 2.46 \ (m, 2H), 2.00 - 1.92 \ (m, 1H); \ ^{13}\text{C} \text{ NMR} \ (125 \text{ MHz, CDCl}_3) \delta \text{ (ppm):} \ 169.6, 158.8, 133.6, 133.2, 131.80, 129.2,
128.6, 127.4, 114.4, 86.4, 55.3, 37.5, 36.7, 36.5; HRMS (EI) calcd for C_{18}H_{18}O_{3}S 314.0977, found 314.0987; HPLC (Chiralpak IC, i-propanol/hexane = 20/80, flow rate 1.0 mL/min, λ = 254 nm): \( t_R \) (major) = 42.9 min, \( t_R \) (minor) = 38.0 min, ee = 88%; \([\alpha]_{25}^{25D} = -74.7 (c = 0.91 \text{ in DCM}).

(4S,6S)-6-(phenylthio)-4-p-tolyltetrahydro-2H-pyran-2-one (3fc) (Table 2, entry 6). 48.6 mg, 81% yield; Colorless oil; \(^1\)H NMR (500 MHz, CDCl\(_3\)) δ (ppm): 7.60 (dd, \( J = 6.4, 3.1 \text{ Hz, 2H} \)), 7.38 – 7.33 (m, 3H), 7.16 (d, \( J = 8.0 \text{ Hz, 2H} \)), 7.05 (d, \( J = 8.0 \text{ Hz, 2H} \)), 5.73 (dd, \( J = 11.3, 4.1 \text{ Hz, 1H} \)), 3.15 (tt, \( J = 12.0, 4.4 \text{ Hz, 1H} \)), 2.86 (ddt, \( J = 17.7, 5.1, 2.3 \text{ Hz, 1H} \)), 2.55 – 2.48 (m, 2H), 2.34 (s, 3H), 2.02 – 1.94 (m, 1H); \(^1\)C NMR (125 MHz, CDCl\(_3\)) δ (ppm): 169.6, 138.6, 137.2, 133.2, 131.8, 129.7, 129.1, 128.6, 126.2, 86.5, 37.3, 37.1, 36.4, 21.0; HRMS (EI) calcd for C\(_{18}\)H\(_{16}\)O\(_2\)S 298.1028, found 298.1028; HPLC (Chiralpak IC, i-propanol/hexane = 20/80, flow rate 1.0 mL/min, λ = 254 nm): \( t_R \) (major) = 25.8 min, \( t_R \) (minor) = 22.5 min, ee = 93%; \([\alpha]_{25}^{25D} = -35.2 (c = 1.05 \text{ in DCM}).

(4S,6S)-4-(2-methoxyphenyl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3gc) (Table 2, entry 7). 58.3 mg, 93% yield; Colorless oil; \(^1\)H NMR (500 MHz, CDCl\(_3\)) δ (ppm): 7.63 – 7.59 (m, 2H), 7.36 – 7.33 (m, 3H), 7.26 (td, \( J = 8.0, 1.7 \text{ Hz, 1H} \)), 7.06 (dd, \( J = 7.5, 1.6 \text{ Hz, 1H} \)), 6.94 (td, \( J = 7.5, 0.9 \text{ Hz, 1H} \)), 6.88 (d, \( J = 8.2 \text{ Hz, 1H} \)), 5.74 (dd, \( J = 11.4, 3.9 \text{ Hz, 1H} \)), 3.81 (s, 3H), 3.53 (tt, \( J = 12.0, 4.7, 1H \)), 3.15 (tt, \( J = 12.0, 4.7, 1H \)).
2.87 (ddd, $J = 17.6, 5.4, 2.1$ Hz, 1H), 2.57 (dd, $J = 17.6, 11.7$ Hz, 1H), 2.49 (dt, $J = 13.8, 3.9, 2.1$ Hz, 1H), 2.11 – 2.03 (m, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ (ppm): 170.2, 156.8, 133.1, 132.1, 129.6, 129.1, 128.4, 126.5, 120.8, 110.7, 86.4, 55.2, 35.5, 34.5, 32.0; HRMS (EI) calcd for C$_{18}$H$_{18}$O$_3$S 314.0977, found 314.0977; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 20.6 min, $t_R$ (minor) = 24.6 min, ee = 94%; $[\alpha]_{D}^{25} = -25.3$ (c = 1.37 in DCM).

2-methoxy-4-((4S,6S)-2-oxo-6-(phenylthio)tetrahydro-2H-pyran-4-yl)phenyl acetate (3hc) (Table 2, entry 8). 60.8 mg, 82% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) δ (ppm): 7.61 – 7.58 (m, 2H), 7.37 – 7.34 (m, 3H), 7.02 – 6.99 (m, 1H), 6.73 (dd, $J = 6.7, 1.9$ Hz, 2H), 5.72 (dd, $J = 11.3, 4.1$ Hz, 1H), 3.82 (s, 3H), 3.18 (tt, $J = 12.2, 4.4$ Hz, 1H), 2.88 (ddd, $J = 17.6, 5.1, 2.2$ Hz, 1H), 2.60 – 2.47 (m, 2H), 2.31 (s, 3H), 2.04 – 1.91 (m, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ (ppm): 169.3, 169.0, 151.4, 140.4, 138.9, 133.3, 131.6, 129.2, 128.7, 123.2, 118.3, 110.7, 86.2, 55.9, 37.3, 37.2, 36.3, 20.6; HRMS (EI) calcd for C$_{20}$H$_{20}$O$_5$S 372.1031, found 372.1024; HPLC (Chiralpak IA, $i$-propanol/hexane = 10/90, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 36.7 min, $t_R$ (minor) = 40.9 min, ee = 92%; $[\alpha]_{D}^{25} = -31.6$ (c = 1.34 in DCM).

(4S,6S)-4-(furan-2-yl)-6-(phenylthio)tetrahydro-2H-pyran-2-one (3ic) (Table 2, entry 9). 43.8 mg,
80% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.59 – 7.58 (m, 2H), 7.35 – 7.33 (m, 4H), 6.31 (dd, $J = 3.2$, 1.9 Hz, 1H), 6.06 (d, $J = 3.2$ Hz, 1H), 5.70 (dd, $J = 11.3$, 4.0 Hz, 1H), 3.32 (tt, $J = 11.8$, 4.6 Hz, 1H), 2.94 (ddd, $J = 17.7$, 5.3, 2.1 Hz, 1H), 2.66 (dtdd, $J = 14.1$, 4.0, 2.2 Hz, 1H), 2.57 (dd, $J = 17.7$, 11.9 Hz, 1H), 1.95 (dt, $J = 14.1$, 11.6 Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 168.8, 154.4, 142.1, 133.4, 131.6, 129.2, 128.7, 110.3, 105.0, 86.0, 34.2, 33.9, 31.2; HRMS (EI) calcd for C$_{15}$H$_{14}$O$_3$S 274.0664, found 274.0667; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 23.3 min, $t_R$ (minor) = 19.0 min, ee = 91%; $[\alpha]^{25}_D = -67.7$ ($c = 0.96$ in DCM).

(4S,6S)-4-ethyl-6-(phenylthio)tetrahydro-2$H$-pyran-2-one (3jc) (Table 2, entry 10). 33.4 mg, 71% yield; Colorless oil; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.58 – 7.56 (m, 2H), 7.35 – 7.32 (m, 3H), 5.59 (dd, $J = 11.2$, 4.0 Hz, 1H), 2.68 (ddd, $J = 17.5$, 5.2, 2.0 Hz, 1H), 2.36 (dtdd, $J = 13.9$, 4.0, 2.2 Hz, 1H), 2.05 (dd, $J = 17.5$, 11.6 Hz, 1H), 1.91 – 1.82 (m, 1H), 1.48 (dt, $J = 13.9$, 11.4 Hz, 1H), 1.37 (p, $J = 7.3$, 2H), 0.93 (t, $J = 7.4$ Hz, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 170.1, 133.0, 132.1, 129.1, 128.4, 86.4, 35.9, 34.8, 33.3, 28.7, 10.7; HRMS (EI) calcd for C$_{13}$H$_{16}$O$_2$S 236.0871, found 236.0870; HPLC (Chiralpak IC, $i$-propanol/hexane = 10/90, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 35.2 min, $t_R$ (minor) = 40.4 min, ee = 94%; $[\alpha]^{25}_D = -11.9$ ($c = 0.86$ in DCM).
(4S,6S)-4-pentyl-6-(phenylthio)tetrahydro-2H-pyran-2-one (3ke) (Table 2, entry 11). 38.2 mg, 69% yield; Colorless oil; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.57 – 7.55 (m, 2H), 7.34 – 7.32 (m, 3H), 5.59 (dd, $J = 11.3, 4.0$ Hz, 1H), 2.67 (dd, $J = 17.4, 5.0, 2.0$ Hz, 1H), 2.37 – 2.32 (m, 2H), 2.05 (dd, $J = 17.4, 11.6$ Hz, 1H), 1.95 – 1.91 (m, 1H), 1.48 (dt, $J = 13.8, 11.4$ Hz, 1H), 1.37 – 1.26 (m, 8H), 0.88 (t, $J = 7.0$ Hz, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 170.1, 133.0, 132.1, 129.1, 128.4, 86.4, 36.2, 35.8, 35.2, 31.7, 31.6, 25.9, 22.5, 14.0; HRMS (EI) calcd for C$_{16}$H$_{22}$O$_2$S 278.1341, found 278.1341; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 18.1 min, $t_R$ (minor) = 20.7 min, ee = 94%; $[\alpha]^{25}_D$ = -20.6 (c = 0.89 in DCM).

(4S,6S)-6-(4-fluorophenylthio)-4-phenyltetrahydro-2H-pyran-2-one (3ad) (Table 2, entry 12). 51.6 mg, 85% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.62 – 7.59 (m, 2H), 7.36 (dd, $J = 10.3, 4.7$ Hz, 2H), 7.30 – 7.27 (m, 1H), 7.17 – 7.15 (m, 2H), 7.08 – 7.04 (m, 2H), 5.65 (dd, $J = 11.3, 4.1$ Hz, 1H), 3.19 (tt, $J = 12.0, 4.4$ Hz, 1H), 2.88 (ddd, $J = 17.7, 5.1, 2.3$ Hz, 1H), 2.56 – 2.50 (m, 2H), 1.96 (ddd, $J = 13.9, 12.2, 11.4$ Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 169.4, 164.3, 162.3, 141.4, 136.2, 136.2, 129.1, 127.5, 126.5, 126.4, 116.4, 116.2, 86.4, 37.4, 37.2, 36.2; HRMS (EI) calcd for C$_{17}$H$_{15}$O$_2$FS 302.0777, found 302.0777; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate
1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 22.7 min, $t_R$ (minor) = 16.6 min, $ee = 91\%$; $[\alpha]^{25}_D = -76.2$ ($c = 1.01$ in DCM).

(4S,6S)-6-(4-chlorophenylthio)-4-phenyltetrahydro-2H-pyran-2-one (3ae) (Table 2, entry 13).

50.6 mg, 79% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.54 – 7.52 (m, 2H), 7.38 – 7.31 (m, 4H), 7.29 (d, $J = 7.5$ Hz, 1H), 7.17 (d, $J = 7.5$ Hz, 2H), 5.69 (dd, $J = 11.3$, 4.1 Hz, 1H), 3.19 (tt, $J = 12.3$, 4.4 Hz, 1H), 2.89 (ddd, $J = 17.7$, 5.1, 2.2 Hz, 1H), 2.58 – 2.52 (m, 2H), 1.98 (dt, $J = 13.8$, 11.9 Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 169.3, 141.4, 135.1, 134.7, 130.2, 129.4, 129.1, 127.6, 126.4, 86.1, 37.4, 37.2, 36.3; HRMS (EI) calcd for C$_{17}$H$_{15}$O$_2$ClS 318.0481, found 318.0485; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 23.8 min, $t_R$ (minor) = 18.0 min, $ee = 92\%$; $[\alpha]^{25}_D = -90.1$ ($c = 1.05$ in DCM).

(4S,6S)-6-(4-methoxyphenylthio)-4-phenyltetrahydro-2H-pyran-2-one (3af) (Table 2, entry 14).

53.6 mg, 85% yield; White solid; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.56 – 7.53 (m, 2H), 7.35 (dd, $J = 10.3$, 4.7 Hz, 2H), 7.28 (dt, $J = 3.9$, 1.6 Hz, 1H), 7.15 (d, $J = 7.2$ Hz, 2H), 6.90 – 6.88 (m, 2H), 5.59 (dd, $J = 11.2$, 4.1 Hz, 1H), 3.82 (s, 3H), 3.16 (tt, $J = 12.0$, 4.5 Hz, 1H), 2.85 (ddd, $J = 17.7$, 5.1, 2.3 Hz, 1H), 2.53 – 2.45 (m, 2H), 1.94 (ddd, $J = 13.9$, 12.3, 11.4 Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$
HRMS (EI) calcd for C\textsubscript{18}H\textsubscript{18}O\textsubscript{3}S 314.0977, found 314.0978; HPLC (Chiralpak IC, \(i\)-propanol/hexane = 20/80, flow rate 1.0 mL/min, \(\lambda = 254\) nm): \(t_R\) (major) = 43.3 min, \(t_R\) (minor) = 28.1 min, ee = 92%;

\([\alpha]^{25}_D = -60.3\) (\(c = 1.08\) in DCM).

(4S,6S)-6-(2-methoxyphenylthio)-4-phenyltetrahydro-2\(H\)-pyran-2-one (3ag) (Table 2, entry 15).

52.7 mg, 84% yield; Colorless oil; \(^1\)H NMR (500 MHz, CDCl\textsubscript{3}) \(\delta\) (ppm): 7.61 (dd, \(J = 7.6, 1.6\) Hz, 1H), 7.37 – 7.27 (m, 4H), 7.21 – 7.18 (m, 2H), 6.97 (td, \(J = 7.5, 1.1\) Hz, 1H), 6.91 (d, \(J = 8.2\) Hz, 1H), 5.87 (dd, \(J = 10.9, 4.3\) Hz, 1H), 3.89 (s, 3H), 3.20 (tt, \(J = 12.6, 4.4\) Hz, 1H), 2.88 (ddd, \(J = 17.5, 5.0, 2.3\) Hz, 1H), 2.63 – 2.56 (m, 2H), 2.05 (ddd, \(J = 14.0, 12.2, 11.0\) Hz, 1H); \(^{13}\)C NMR (125 MHz, CDCl\textsubscript{3}) \(\delta\) (ppm): 169.6, 158.4, 141.7, 134.4, 130.0, 129.0, 127.4, 126.4, 121.4, 119.9, 111.1, 84.5, 55. 9, 37.4, 37.3, 36.0; HRMS (EI) calcd for C\textsubscript{18}H\textsubscript{18}O\textsubscript{3}S 314.0977, found 314.0979; HPLC (Chiralpak IA, \(i\)-propanol/hexane = 20/80, flow rate 1.0 mL/min, \(\lambda = 254\) nm): \(t_R\) (major) = 11.1 min, \(t_R\) (minor) = 13.1 min, ee = 94%; \([\alpha]^{25}_D = -67.5\) (\(c = 0.96\) in DCM).

(4S,6S)-6-(3,4-dimethoxyphenylthio)-4-phenyltetrahydro-2\(H\)-pyran-2-one (3ah) (Table 2, entry 16).

54.8 mg, 80% yield; Colorless oil; \(^1\)H NMR (500 MHz, CDCl\textsubscript{3}) \(\delta\) (ppm): 7.35 (dd, \(J = 10.2, 4.7\) Hz, 1H),
2H), 7.30 – 7.25 (m, 2H), 7.19 (dd, $J = 8.3, 2.1$ Hz, 1H), 7.16 – 7.13 (m, 3H), 6.85 (d, $J = 8.3$ Hz, 1H), 5.63 (dd, $J = 11.2, 4.2$ Hz, 1H), 3.89 (s, 6H), 3.20 – 3.13 (m, 1H), 2.85 (ddd, $J = 17.7, 5.1, 2.3$ Hz, 1H), 2.55 – 2.43 (m, 2H), 1.94 (ddd, $J = 13.9, 12.3, 11.3$ Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 169.6, 150.1, 149.1, 141.6, 129.0, 127.9, 127.4, 126.4, 121.7, 117.7, 111.4, 86.6, 56.1, 55.9, 37.3, 37.21, 36.3; HRMS (EI) calcd for C$_{19}$H$_{20}$O$_4$S 344.1082, found 344.1081; HPLC (Chiralpak IA, $i$-propanol/hexane = 5/95, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 46.4 min, $t_R$ (minor) = 52.4 min, $ee = 92\%$; $[\alpha]^{25}_{D} = -61.1$ ($c = 0.99$ in DCM).

(4S,6S)-6-(phenethylthio)-4-styryltetrahydro-2H-pyran-2-one (3lc) (Table 2, entry 17). 46.2 mg, 74% yield; Pale yellow oil; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.55 (dd, $J = 6.5, 2.9$ Hz, 2H), 7.31 – 7.21 (m, 8H), 6.39 (d, $J = 15.9$ Hz, 1H), 5.97 (dd, $J = 15.9, 7.0$ Hz, 1H), 5.63 (dd, $J = 11.2, 4.0$ Hz, 1H), 2.82 – 2.72 (m, 2H), 2.42 (ddd, $J = 13.9, 6.1, 3.8$ Hz, 1H), 2.29 (dd, $J = 17.2, 11.4$ Hz, 1H), 1.72 (dt, $J = 13.8, 11.5$ Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 169.2, 136.3, 133.3, 131.7, 130.8, 129.9, 129.2, 128.7, 128.6, 127.9, 126.2, 86.1, 35.7, 35.1, 35.1; HRMS (EI) calcd for C$_{19}$H$_{18}$O$_2$S 310.1028, found 310.1035; HPLC (Chiralpak IC, $i$-propanol/hexane = 20/80, flow rate 1.0 mL/min, $\lambda = 254$ nm): $t_R$ (major) = 36.6 min, $t_R$ (minor) = 29.6 min, $ee = 80\%$; $[\alpha]^{25}_{D} = -48.2$ ($c = 0.78$ in DCM).
(R)-S-phenyl 5-oxo-3-phenylpentanethioate (4). Colorless oil; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 9.74 (s, 1H), 7.47 – 7.45 (m, 3H), 7.42 – 7.38 (m, 4H), 7.34 – 7.31 (m, 3H), 3.95 – 3.86 (m, 1H), 3.09 (d, $J$ = 7.2 Hz, 2H), 3.00 – 2.89 (m, 2H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 200.4, 195.6, 141.8, 134.4, 129.5, 129.2, 128.8, 127.4, 127.2, 49.5, 49.0, 36.7; HRMS (EI) calcd for C$_{17}$H$_{16}$O$_2$S 284.0871, found 284.0878.

3. Proposed Mechanism

Our proposed mechanism is illustrated in Scheme below. Initially, malonic half-thioester 2a reacts with triethyl amine to form the intermediate B and follow to attack the iminium intermediate A. A subsequent decarboxylation triggers the formation of the Michael addition intermediate C. A hydrolysis of intermediate C would lead to a recycle of cat.VI and generates the intermediate D. The intermediate D undergoes a sequence of tautomerization, cyclization and nucleophilic addition to afford the product 3ac. As proof of this mechanism, we set out to investigate the key intermediate 4. As indicated in eqn. (2), the synthesized compound 4 was found to be an active intermediate and could generate 3ac under weak base or base-free condition (95% and 11% yield, respectively) and gave no loss of ee. Meanwhile, we found that this process did not require Cat. IV. This result suggests that the compound 4 may involve in this transformation as a potential key intermediate. To further understand this mechanism, we then investigated the proton transfer in the process of 3ac formation. we conducted an isotopic experiment using deuterated half-thioester d-2c to react with cinnamaldehyde 1a under standard conditions. $^1$H NMR analysis of d-3ac demonstrated the isotope labelling of two protons located at $\alpha$-position of carbonyl group is ab. 49:51 (eqn. (2)). It suggests that the water (generated from the condensation of cinnamaldehyde 1a and cat. VI), functionalized as a potential proton source, is not involved in Michael addition step.
490.6 mg (2.5 mmol) of malonic acid half thioester (MAHT) 2c was placed into a 50 mL flask and 5.0 mL of acetonitrile was added. When the MAHT 2c has dissolved, 6.0 mL D$_2$O was added and the solution was stirred for 6 hours under nitrogen. The solvent was removed under vacum and the process was repeated two more times to yield 473.2 mg (95% yield) of the product $d$-2c.\textsuperscript{[1]} $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ (ppm): 7.46 – 7.42 (m, 5H), 3.70 (s, 0.2H); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ (ppm): 189.9, 170.5, 134.4, 130.0, 129.4, 126.4, 48.0 (t, $1^C, J = 20.5$ Hz).
To a solution of cinnamaldehyde 1a (66.1 mg, 62.9 uL, 0.5 mmol,) in CH$_3$CN (2.5 mL) was added catalyst VI (64.0 mg, 0.1 mmol) at 0 °C. After 40 min, $d$-2c (249.0 mg, 1.25 mmol) was added in one portion. Then, TEA (126.2 mg, 173.9 uL, 1.25 mmol) was added dropwise at 0 °C. The resulting reaction mixture was kept stirring at 0°C for 24 h. The crude product was purified by silica gel flash chromatography, eluted by hexane/EtOAc = 10:1 to afford the desired product $d$-3ac as white solid (89.1 mg, 62% yield). $^1$H NMR (500 MHz, CDCl$_3$) δ (ppm): 7.60 (dd, $J = 6.4$, 3.2 Hz, 2H), 7.40 – 7.32 (m, 5H), 7.28 (t, $J = 7.4$ Hz, 1H), 7.16 (d, $J = 7.6$ Hz, 2H), 5.74 (dd, $J = 11.2$, 4.0 Hz, 1H), 3.23 – 3.14 (m, 1H), 2.88 (dd, $J = 17.7$, 5.0 Hz, 0.49H), 2.59 – 2.49 (m, 1H), 2.04 – 1.97 (m, 0.49H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ (ppm): 169.5, 141.5, 133.3, 131.8, 129.2, 129.1, 128.6, 127.5, 126.4, 86.3, 86.3, 86.2, 37.4, 37.3, 37.2, 36.3.

4. Application

**Synthesis of (-)-Paroxetine**

To a solution of 4-fluorocinnamaldehyde 1m (300.1 mg, 2.0 mmol,) in DCM (5.0 mL) was added catalyst VI (238.8 mg, 0.4 mmol) at 0 °C. After 40 min, malonic acid half thioester 2c (981.1 mg, 5.0 mmol) was added in one portion. Then, TEA (695.6 uL, 5.0 mmol) in 5.0 mL DCM was added
dropwise via syringe at 0 °C. The resulting reaction mixture was kept stirring at 0°C for 24 h. The crude product was purified by silica gel flash chromatography, eluted by hexane/EtOAc = 10:1 to afford the desired product 3mc as a white solid (436.2 mg, 72% yield, 91% ee).\(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta = 7.59\) (dd, \(J = 6.2, 2.8 \text{ Hz, } 2\text{H}\)), \(7.39 - 7.33\) (m, 3H), \(7.13\) (dd, \(J = 8.5, 5.3 \text{ Hz, } 2\text{H}\)), \(7.04\) (t, \(J = 8.6 \text{ Hz, } 2\text{H}\)), \(5.72\) (dd, \(J = 11.2, 4.1 \text{ Hz, } 1\text{H}\)), \(3.18\) (ddd, \(J = 12.3, 8.4, 4.5 \text{ Hz, } 1\text{H}\)), \(2.87\) (ddd, \(J = 17.6, 5.0, 2.1 \text{ Hz, } 1\text{H}\)), \(2.57 - 2.46\) (m, 2H), \(1.97\) (dd, \(J = 25.7, 11.8 \text{ Hz, } 1\text{H}\)); \(^1^3\)C NMR (125 MHz, CDCl\(_3\)) \(\delta = 169.2, 163.0, 161.0, 137.3, 137.3, 133.4, 131.7, 129.2, 128.7, 128.0, 127.9, 116.1, 115.9, 86.2, 37.4, 36.8, 36.4; HRMS (EI) calcd for C\(_{17}\)H\(_{15}\)FO\(_2\)S 302.0777, found 302.0771; HPLC (Chiralpak IC, \(i\)-propanol/hexane = 20/80, flow rate 1.0 mL/min, \(\lambda = 254 \text{ nm})\): \(t_R\) (minor) = 23.4 min, \(t_R\) (major) = 25.8 min, ee = 91%; [\(\alpha\)]\(^{25}\)_D = -78.2 (c = 1.51 in DCM).

![Chemical structure of 3mc](attachment:image.png)

Compound 3mc (302.36mg, 1.0 mmol) was added to a suspension of Raney Ni (0.3 g) in absolute MeOH (5.0 mL). The mixture was stirred for 10 hours at room temperature, before the Raney Ni was removed by filtration through a celite pad. Then the catalyst was washed with absolute MeOH (3 \times 10 mL) and the filtrate was concentrated under reduced pressure. The crude product was purified by silica gel column chromatography (hexane–EtOAc = 6:1) to afford the compound 4 as a colorless oil (156.1 mg, 70% yield). \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta = 9.64\) (t, \(J = 1.5 \text{ Hz, } 1\text{H}\)), \(7.23 - 7.12\) (m, 2H), \(7.03 - 6.94\) (m, 2H), \(3.78 - 3.68\) (m, 1H), \(3.58\) (s, 3H), \(2.88 - 2.71\) (m, 2H), \(2.71 - 2.56\) (m, 2H); \(^1^3\)C NMR (75 MHz, CDCl\(_3\)) \(\delta = 200.3, 171.8, 163.3, 160.0, 138.1, 138.1, 128.8, 128.7, 115.7, 115.4, 51.6, 49.4, 40.6, 35.3; HRMS (EI) calcd for C\(_{12}\)H\(_{13}\)FO\(_2\) 224.0849, found 224.0841.
Sodium borohydride (11.3 mg, 0.3 mmol) was added into a solution of compound 4 (44.8 mg, 0.20 mmol) in MeOH (2.0 mL) at 0°C. The reaction mixture was stirred at 0°C for 10 min. Then water (1 mL) was added to quench this reaction. The mixture was extracted with CH₂Cl₂ and the combined organic layers were dried with MgSO₄. Filtration and evaporation of the solvent gave a residue which was purified by silica gel column chromatography (hexane–EtOAc = 3:1) to afford the product 5 as a colorless oil (39.4 mg, 87% yield, 94% ee). ¹H NMR (500 MHz, CD₃OD) δ = 7.25 – 7.22 (m, 2H), 7.02 – 6.99 (m, 2H), 3.54 (s, 3H), 3.42 (ddd, J = 11.0, 6.9, 5.3 Hz, 1H), 3.37 – 3.32 (m, 1H), 3.31 – 3.24 (m, 1H), 2.70 (dd, J = 15.2, 6.4 Hz, 1H), 2.59 (dd, J = 15.2, 9.0 Hz, 1H), 1.94 – 1.87 (m, 1H), 1.82 – 1.76 (m, 1H); ¹³C NMR (125 MHz, CD₃OD) δ = 174.3, 164.0, 162.1, 140.8, 140.8, 130.3, 130.3, 116.1, 116.0, 60.5, 51.9, 42.3, 39.9, 39.3; HRMS (EI) calcd for C₁₂H₁₅FO₃ 226.1005, found 226.0999; HPLC (Chiralpak OB-H, i-propanol/hexane = 10/90, flow rate 0.8 mL/min, λ = 254 nm): tᵣ (major) = 11.1 min, tᵣ (minor) = 14.1 min, ee = 94%; [α]²⁵D = -16.0 (c = 1.06 in DCM).

Reference:
5. HPLC and NMR Spectra

Compound 3ac
Compound 3bc
Compound 3cc
Compound 3dc
Compound 3ec
Compound 3fc
Compound 3gc
Compound 3hc
Compound 3ic
Compound 3ke
Compound 3ae
Compound 3af
Compound 3ag
Compound 3ah
Compound 3lc
Compound $d$-$2c$
Compound $d$-3ac
Compound 3mc

[Chemical structure image]

[1D NMR spectrum image]

[2D NMR spectrum image]
Compound 5
Compound 6

\[
\begin{align*}
\text{F} & \quad \text{OMe} \\
\text{OH} & \\
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Racemic 3ac

==== Shimadzu LCsolution Analysis Report ====

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Enantiomeric enriched 3ac

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Enantiomeric enriched 3bc

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Enantiomeric enriched 3cc

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Enantiomeric enriched 3dc

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S45
### Racemic 3fc

#### Shimadzu LCsolution Analysis Report

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### Enantiomeric enriched 3fc

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<th>Height</th>
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<th>Height %</th>
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<tbody>
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Racemic 3ge

Shimadzu LC solution Analysis Report

Acquired by: Admin
Sample Name: RQD227
Sample ID: RQ
Data File Name: rq612.lcd
Method File Name: 20%IPA, 1ml/min, 60min.lcm
Batch File Name:
Report File Name: Default.lcr
Description: IC column; 20%IPA; 1ml/min

Chromatogram
Detector A Ch1 254nm

<table>
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<tr>
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<th>Height %</th>
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</thead>
<tbody>
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Enantiomeric enriched 3ge

Shimadzu LC solution Analysis Report

Acquired by: Admin
Sample Name: RQD234
Sample ID: RQ
Data File Name: rq618.lcd
Method File Name: 20%IPA, 1ml/min, 60min.lcm
Batch File Name:
Report File Name: Default.lcr
Description: IC column; 20%IPA; 1ml/min

Chromatogram
Detector A Ch1 254nm

<table>
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Racemic 3hc

==== Shimadzu LC solution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq644.lcd
Acquired by : Admin
Sample Name : RQD259
Sample ID : RQ
Data File Name : rq644.lcd
Method File Name : 10%IPA, 1ml-min, 40min,lcm
Batch File Name : 
Report File Name : Default.lcr
Description : 1a column ;10%IPA ;1ml/min

Detector A Ch1 254nm

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</table>

Enantiomeric enriched 3hc

==== Shimadzu LC solution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq646.lcd
Acquired by : Admin
Sample Name : RQD260
Sample ID : RQ
Data File Name : rq646.lcd
Method File Name : 10%IPA, 1ml-min, 40min,lcm
Batch File Name : 
Report File Name : Default.lcr
Description : 1a column ;10%IPA ;1ml/min

Detector A Ch1 254nm

<table>
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</thead>
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Racemic 3ic

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq615.lcd
Acquired by: Admin
Sample Name: RQD231
Sample ID: RQ
Data File Name: rq615.lcd
Method File Name: 20%IPA, 1ml-min, 60min.lcm
Batch File Name:
Report File Name: Default.lcr
Description: IC column; 20%IPA; 1ml/min

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<th>Height %</th>
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</thead>
<tbody>
<tr>
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</table>

Enantiomeric enriched 3ic

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq625.lcd
Acquired by: Admin
Sample Name: RQD246
Sample ID: RQ
Data File Name: rq625.lcd
Method File Name: 20%IPA, 1ml-min, 60min.lcm
Batch File Name:
Report File Name: Default.lcr
Description: IC column; 20%IPA; 1ml/min

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
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S50
Racemic 3jc

== Shimadzu LCsolution Analysis Report ==

Acquired by: Admin
Sample Name: RQD237
Sample ID: RQ
Data File Name: rq635.lcd
Method File Name: 10%IPA, 1ml-min, 40min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IC column, 10%IPA, 1ml/min

Detector A Ch1 254nm

<table>
<thead>
<tr>
<th>Peak#</th>
<th>Ret. Time</th>
<th>Area</th>
<th>Height</th>
<th>Area %</th>
<th>Height %</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

Enantiomeric enriched 3jc

== Shimadzu LCsolution Analysis Report ==

Acquired by: Admin
Sample Name: RQD250
Sample ID: RQ
Data File Name: rq637.lcd
Method File Name: 10%IPA, 1ml-min, 40min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IC column, 10%IPA, 1ml/min

Detector A Ch1 254nm

<table>
<thead>
<tr>
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<tbody>
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</table>
Racemic 3kc

==== Shimadzu LC solution Analysis Report ====

Acquired by: Admin
Sample Name: RQD239
Sample ID: RQ
Data File Name: rq624.lcd
Method File Name: 20%IPA, 1ml-min, 60min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IC column, 20%IPA, 1ml/min

Chromatogram

Detector A Ch1 254nm

<table>
<thead>
<tr>
<th>Peak#</th>
<th>Ret. Time</th>
<th>Area</th>
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<th>Height %</th>
</tr>
</thead>
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Enantiomeric enriched 3kc

==== Shimadzu LC solution Analysis Report ====

Acquired by: Admin
Sample Name: RQD248
Sample ID: RQ
Data File Name: rq626.lcd
Method File Name: 20%IPA, 1ml-min, 60min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IC column, 20%IPA, 1ml/min

Chromatogram

Detector A Ch1 254nm

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Racemic 3ad

==== Shimadzu LCsolution Analysis Report ====

```
C:\Users\User\Desktop\LC data\Ren Qiao\rq576.lcd
Acquired by : Admin
Sample Name : RQD197
Sample ID : RQ
Data File Name : rq576.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name :
Report File Name : Default.lcr
Description : IC column ;20%IPA ;1ml/min
```

Chromatogram

```
RQD197 C:\Users\User\Desktop\LC data\Ren Qiao\rq576.lcd
```

Detector A Ch1 254nm

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</thead>
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Enantiomeric enriched 3ad

==== Shimadzu LCsolution Analysis Report ====

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C:\Users\User\Desktop\LC data\Ren Qiao\rq596.lcd
Acquired by : Admin
Sample Name : RQD213
Sample ID : RQ
Data File Name : rq596.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name :
Report File Name : Default.lcr
Description : IC column ;20%IPA ;1ml/min
```

Chromatogram

```
RQD213 C:\Users\User\Desktop\LC data\Ren Qiao\rq596.lcd
```

Detector A Ch1 254nm

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<th>Height %</th>
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Racemic 3ae

Shimadzu LC solution Analysis Report

C:\Users\User\Desktop\LC data\Ren Qiao\rq743.lcd
Acquired by : Admin
Sample Name : RQD215
Sample ID : RQ
Data File Name : rq743.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name : 
Report File Name : Default.lcr
Description : IC column; 20%IPA : 1ml/min

Chromatogram

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<th>Height %</th>
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</table>

Enantiomeric enriched 3ae

Shimadzu LC solution Analysis Report

C:\Users\User\Desktop\LC data\Ren Qiao\rq601.lcd
Acquired by : Admin
Sample Name : RQD217
Sample ID : RQ
Data File Name : rq601.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name : 
Report File Name : Default.lcr
Description : IC column; 20%IPA : 1ml/min

Chromatogram

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</tr>
</thead>
<tbody>
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S54
Racemic 3af

==== Shimadzu LCsolution Analysis Report ====

Detector A Ch1 254nm

<table>
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</tr>
</thead>
<tbody>
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Enantiomeric enriched 3af

==== Shimadzu LCsolution Analysis Report ====

Detector A Ch1 254nm

<table>
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<th>Height</th>
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<th>Height %</th>
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</thead>
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</table>
Racemic 3ag

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq602.lcd
Acquired by : Admin
Sample Name : RQD216
Sample ID : RQ
Data File Name : rq602.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name :
Report File Name : Default.lcr
Description : IA column; 20%IPA; 1ml/min

Chromatogram
RQD216 C:\Users\User\Desktop\LC data\Ren Qiao\rq602.lcd

Detector A Ch1 254nm

<table>
<thead>
<tr>
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<tbody>
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<td>53.125</td>
</tr>
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<td>2</td>
<td>13.032</td>
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<td>783270</td>
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</table>

Enantiomeric enriched 3ag

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq603.lcd
Acquired by : Admin
Sample Name : RQD218
Sample ID : RQ
Data File Name : rq603.lcd
Method File Name : 20%IPA, 1ml-min, 60min.lcm
Batch File Name :
Report File Name : Default.lcr
Description : IA column; 20%IPA; 1ml/min

Chromatogram
RQD218 C:\Users\User\Desktop\LC data\Ren Qiao\rq603.lcd

Detector A Ch1 254nm

<table>
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<tr>
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<tbody>
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S56
Racemic 3ah

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq606.lcd
Acquired by: Admin
Sample Name: RQD220
Sample ID: RQ
Data File Name: rq606.lcd
Method File Name: 5%IPA, 1ml-min, 60min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IA column; 5%IPA; 1ml/min

Chromatogram

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Enantiomeric enriched 3ah

==== Shimadzu LCsolution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq608.lcd
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Sample Name: RQD222
Sample ID: RQ
Data File Name: rq608.lcd
Method File Name: 5%IPA, 1ml-min, 60min.lcm
Batch File Name: 
Report File Name: Default.lcr
Description: IA column; 5%IPA; 1ml/min

Chromatogram

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Racemic 3lc

==== Shimadzu LC solution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq831.lcd
Acquired by: Admin
Sample Name: RQE245
Sample ID: RQ
Data File Name: rq831.lcd
Method File Name: 20%IPA, 1ml-min, 60min,lcmm
Batch File Name:
Report File Name: Default.lcr
Description: IC column with IC guard column ;20%IPA ;1 ml/min

Chromatogram

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Enantiomeric enriched 3lc

==== Shimadzu LC solution Analysis Report ====

C:\Users\User\Desktop\LC data\Ren Qiao\rq832.lcd
Acquired by: Admin
Sample Name: RQE247
Sample ID: RQ
Data File Name: rq832.lcd
Method File Name: 20%IPA, 1ml-min, 60min,lcmm
Batch File Name:
Report File Name: Default.lcr
Description: IC column with IC guard column ;20%IPA ;1 ml/min

Chromatogram

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Racemic 3mc

==== Shimadzu LCsolution Analysis Report ====

Chromatogram

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Enantiomeric enriched 3mc

==== Shimadzu LCsolution Analysis Report ====

Chromatogram

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Racemic 6

==== Shimadzu LCsolution Analysis Report ====

Detector A Ch1 254nm

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Enantiomeric enriched 18

==== Shimadzu LCsolution Analysis Report ====

Detector A Ch1 254nm

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