Catalytic Asymmetric Hydroxymethylation of Silicon Enolates Using an Aqueous Solution of Formaldehyde with a Chiral Scandium Complex

Shunpei Ishikawa, Tomoaki Hamada, Kei Manabe, and Shū Kobayashi*

Graduate School of Pharmaceutical Sciences, The University of Tokyo, Hongo,

Bunkyo-ku, Tokyo 113-0033, Japan.

Supporting Information

Table of Contents	Pages
Experimental	S-1
Typical Experimental Procedures for the Hydroxymethylation	S-1
Characterization Data of the Hydroxymethylated Adducts	S-2
Crystallization of [ScBr ₂ • 1 •H ₂ O]•Br•H ₂ O complexes	S-8
References	S-9
Ortep drawing of [ScBr ₂ • 1 •H ₂ O]•Br•H ₂ O	S-10

Experimental

General: Melting points were uncorrected. CDCl₃ was used as a solvent for ¹H and ¹³C NMR spectra unless otherwise noted. Tetramethylsilane (TMS) served as an internal standard (δ = 0) for ¹H NMR and CDCl₃ as an internal standard (δ = 77.0) for ¹³C NMR. Preparative thin-layer chromatography was carried out using Wakogel B-5F. An aqueous solution of formaldehyde was purchased from Wako Pure Chemical Industries, Ltd.

A Typical Experimental Procedure for the Hydroxymethylation of Propiophenone-derived Silicon Enolate: To a solution of Sc(OTf)₃ (9.8 mg, 0.020 mmol, dried *in vacuo* at 200 °C for 1 h before use) in DME (0.50 mL) was added **1** (7.9 mg, 0.024 mmol), and the mixture was stirred at room temperature. After 5 min, the reaction was cooled to −20 °C, then an aqueous solution of formaldehyde (86 mg, 35% w/w, 1.0 mmol) and **2** (41 mg, 0.20 mmol) were added. The whole was stirred until **2** disappeared completely. The reaction was quenched with saturated aqueous NaHCO₃.

The resultant mixture was extracted with dichloromethane (3 times), and the combined organic layers were dried over anhydrous Na₂SO₄. The solvents were evaporated, and the residue was purified by preparative TLC (silica gel, hexane/ethyl acetate (2/1)) to give the hydroxymethylated adduct. The enantiomeric excess of the product was determined by chiral HPLC analysis.

Characterization Data of the Hydroxymethylated Adducts

(*S*)-3-Hydroxy-2-methyl-1-phenylpropan-1-one¹

¹H NMR (CDCl₃) δ 1.24 (d, 3H, *J* = 7.1 Hz), 2.35 (brs), 3.68 (ddq, 1H, *J* = 4.3, 7.0, 7.1 Hz), 3.80 (dd, 1H, *J* = 4.3, 11.1 Hz), 3.94 (dd, 1H, *J* = 7.0, 11.1 Hz), 7.48 (dd, 2H, *J* = 7.3, 8.5 Hz), 7.58 (t, 1H, *J* = 7.3 Hz), 7.97 (d, 2H, *J* = 8.5 Hz) ppm; ¹³C NMR (CDCl₃) δ 14.5, 42.9, 64.5, 128.4, 128.7, 133.3, 136.1, 204.4 ppm; HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 19/1, flow rate = 1.0 mL/min) *t*_R = 17.5 min (major, *S*), *t*_R = 20.3 min (minor, *R*).

2-(Hydroxymethyl)-1-phenylbutan-1-one

¹H NMR (CDCl₃) δ 0.95 (t, 3H, *J* = 7.4 Hz), 1.61-1.83 (m, 2H), 2.40 (brs), 3.52-3.58 (m, 1H), 3.84 (dd, 1H, *J* = 3.9, 11.0 Hz), 3.98 (dd, 1H, *J* = 6.8, 11.0 Hz), 7.45-7.50 (m, 2H), 7.56-7.60 (m, 1H), 7.95-7.97 (m, 2H) ppm; ¹³C NMR (CDCl₃) δ 11.8, 22.3, 49.5, 62.6, 128.3, 128.7, 133.2, 136.8, 204.6 ppm; IR (neat) 3435, 2966, 1678, 1043, 704 cm⁻¹; HRMS (ESI-TOF) calcd for C₁₁H₁₄O₂Na ([M+Na]⁺): 201.0891, found: 201.0889; [α]_D¹⁸ -9.9 (*c* 1.28, CHCl₃) (for assumed *S*, 88% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 19/1, flow rate = 1.0 mL/min) *t*_R = 18.8 min (major, assumed *S*), *t*_R = 22.4 min (minor, assumed *R*).

(*E*)-4-(Hydroxymethyl)-1-phenylpent-1-en-3-one

¹H NMR (CDCl₃) δ 1.22 (d, 3H, *J* = 7.1 Hz), 2.35 (brs), 3.10 (ddq, 1H, *J* = 4.3, 7.1, 7.1 Hz), 3.75 (dd, 1H, *J* = 4.3, 11.0 Hz), 3.86 (dd, 1H, *J* = 7.1, 11.0 Hz), 6.80 (s, 1H), 6.84 (s, 1H), 7.38-7.41 (m, 2H), 7.55-7.58 (m, 1H), 7.62-7.66 (m, 2H) ppm; ¹³C NMR (CDCl₃) δ 13.7, 46.3, 64.4, 124.7, 128.4, 128.9, 130.6, 134.3, 143.4, 203.6 ppm; IR (neat) 3437, 2932, 1606, 1450, 1030, 980, 764 cm⁻¹; HRMS (ESI-TOF) calcd for C₁₂H₁₄O₂Na ([M+Na]⁺): 213.0891,

found: 213.0898; $[\alpha]^{26}_D +2.8$ (c 1.58, CHCl_3) (for assumed *S*, 92% ee); HPLC (Daicel Chiralcel OD, hexane/*i*-PrOH = 19/1, flow rate = 1.0 mL/min) t_R = 25.1 min (minor, assumed *R*), t_R = 45.1 min (major, assumed *S*).

2-(*tert*-Butyldimethylsilyloxy)-3-hydroxy-1-phenylpropan-1-one

^1H NMR (CDCl_3) δ 0.07 (s, 6H), 0.89 (s, 9H), 2.32 (brs), 3.81 (dd, 1H, J = 6.1, 11.4 Hz), 3.92 (dd, 1H, J = 4.4, 11.4 Hz), 5.05 (dd, 1H, J = 4.4, 6.1 Hz), 7.43-7.47 (m, 2H), 7.54-7.58 (m, 1H), 7.95-7.98 (m, 2H) ppm; ^{13}C NMR (CDCl_3) δ -5.1, -4.7, 18.3, 25.7, 65.2, 77.4, 128.5, 128.7, 133.3, 135.2, 199.4 ppm; IR (neat) 3461, 2931, 2858, 1695, 1188, 885, 781 cm^{-1} ; HRMS (ESI-TOF) calcd for $\text{C}_{15}\text{H}_{24}\text{O}_3\text{SiNa}$: 303.1392 ($[\text{M}+\text{Na}]^+$), found: 303.1393; $[\alpha]^{23}_D -46.0$ (c 0.53, CHCl_3) (for assumed *S*, 78% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 100/1, flow rate = 0.5 mL/min) t_R = 45.2 min (major, assumed *S*), t_R = 48.8 min (minor, assumed *R*).

2,3-Dihydro-2-(hydroxymethyl)-2-methylinden-1-one

^1H NMR (CDCl_3) δ 1.26 (s, 3H), 2.17 (brs), 2.91 (d, 1H, J = 7.2 Hz), 3.24 (d, 1H, J = 7.2 Hz), 3.64 (d, 1H, J = 10.7 Hz), 3.83 (d, 1H, J = 10.7 Hz), 7.35-7.41 (m, 1H), 7.45-7.48 (m, 1H), 7.59-7.64 (m, 1H), 7.64-7.77 (m, 1H) ppm; ^{13}C NMR (CDCl_3) δ 20.7, 38.0, 50.8, 67.8, 124.2, 126.7, 127.5, 135.2, 135.8, 153.2, 211.1 ppm; IR (KBr) 3473, 2962, 2921, 2866, 1703, 1471, 1055, 742 cm^{-1} ; Mp 83-89 $^\circ\text{C}$; Anal. calcd for $\text{C}_{11}\text{H}_{12}\text{O}_2$: C, 74.98; H, 6.86. found: C, 74.80; H, 7.05; $[\alpha]^{21}_D +51.2$ (c 0.51, EtOH) (for assumed *R*, 90% ee); HPLC (Daicel Chiralcel OB-H, hexane/*i*-PrOH = 100/1, flow rate = 1.0 mL/min) t_R = 39.6 min (major, assumed *R*), t_R = 50.0 min (minor, assumed *S*).

3,4-Dihydro-2-(hydroxymethyl)-2-methylnaphthalen-1(2*H*)-one

^1H NMR (CDCl_3) δ 1.23 (s, 3H), 1.78 (ddd, 1H, J = 3.7, 4.9, 13.4 Hz), 2.24 (ddd, 1H, J = 5.1, 12.0, 13.4 Hz), 2.77 (brs), 2.94 (ddd, 1H, J = 3.7, 5.1, 17.3 Hz), 3.15 (ddd, 1H, J = 4.9, 12.0, 17.3 Hz), 3.65 (d, 1H, J = 11.2 Hz), 3.74 (d, 1H, J = 11.2 Hz), 7.24-7.26 (m, 1H), 7.29-7.33 (m, 1H), 7.47-7.50 (m, 1H), 8.00-8.03 (m, 1H) ppm; ^{13}C NMR (CDCl_3) δ 18.2, 25.0, 31.3, 46.3, 69.0, 126.7, 127.7, 128.7, 131.4, 133.6, 143.4, 204.0 ppm; IR (neat) 3456, 2931,

1678, 1047, 742 cm^{-1} ; HRMS (ESI-TOF) calcd for $\text{C}_{12}\text{H}_{14}\text{O}_2\text{Na}$ ($[\text{M}+\text{Na}]^+$): 213.0891, found: 213.0881; $[\alpha]_D^{21}$ -4.1 (c 2.04, EtOH) (for assumed *R*, 94% ee); HPLC (Daicel Chiralcel OD, hexane/*i*-PrOH = 100/1, flow rate = 1.0 mL/min) t_R = 28.6 min (major, assumed *R*), t_R = 34.3 min (minor, assumed *S*).

2-(Hydroxymethyl)-2-methylcyclopentanone

The starting silicon enolate contained 6% of the another regioisomer.

The yield of the product was based on the isomer shown in Table 2.

^1H NMR (CDCl_3) δ 1.05 (s, 3H), 1.71-1.77 (m, 1H), 1.85-2.11 (m, 3H), 2.18-2.41 (m, 3H), 3.49 (d, 1H, J = 11.0 Hz), 3.63 (d, 1H, J = 11.0 Hz) ppm; ^{13}C NMR (CDCl_3) δ 18.8, 19.2, 33.1, 38.3, 50.2, 67.1, 224.3 ppm; IR (neat) 3431, 2961, 1734, 1053 cm^{-1} ; HRMS calcd for $\text{C}_7\text{H}_{12}\text{O}_2$: 128.0837, found: 128.0845; $[\alpha]_D^{29}$ $+54.9$ (c 1.01, CHCl_3) (for assumed *R*, 85% ee)

(1-Methyl-2-oxocyclopentyl)methyl benzoate

To a solution of 2-(hydroxymethyl)-2-methylcyclopentanone (18 mg, 0.14 mmol) in CH_2Cl_2 (1.4 mL) were added benzoyl chloride (33 μL , 0.28 mmol) and pyridine (57 μL , 0.71 mmol) at room temperature.

After stirring for 2 h, the reaction was quenched with water. The resultant mixture was extracted with CH_2Cl_2 (twice), and the combined organic layers were washed with brine and dried over anhydrous Na_2SO_4 . The solvents were evaporated, and the residue was purified by preparative TLC (silica gel, hexane/ethyl acetate (6/1)) to give the desired product (92% yield).

^1H NMR (CDCl_3) δ 1.14 (s, 3H), 1.84-2.08 (m, 3H), 2.15-2.22 (m, 1H), 2.26-2.45 (m, 2H), 4.30 (s, 2H), 7.41-7.45 (m, 2H), 7.54-7.58 (m, 1H), 7.97-7.99 (m, 2H) ppm; ^{13}C NMR (CDCl_3) δ 18.8, 19.7, 33.5, 38.0, 48.5, 68.2, 128.4, 129.5, 129.9, 133.1, 166.2, 220.4 ppm; IR (neat) 2969, 1728, 1452, 1272, 1115, 712 cm^{-1} ; HRMS calcd for $\text{C}_{14}\text{H}_{16}\text{O}_3$: 232.1099, found: 232.1111; $[\alpha]_D^{29}$ $+41.7$ (c 1.39, CHCl_3) (for assumed *R*, 85% ee); HPLC (Daicel Chiralpak AS-H, hexane/*i*-PrOH = 100/1, flow rate = 0.5 mL/min) t_R = 27.7 min (major, assumed *R*), t_R = 31.6 min (minor, assumed *S*).

(*R*)-2-(Hydroxymethyl)-2-methylcyclohexanone²

The starting silicon enolate contained 12% of the another regioisomer.

The yield of the product was based on the isomer shown in Table 2.

¹H NMR (CDCl₃) δ 1.19 (s, 3H), 1.54-1.96 (m, 5H), 2.00-2.07 (m, 1H), 2.24-2.30 (m, 1H), 2.52 (ddd, 1H, *J* = 6.1, 12.9, 14.4 Hz), 3.48 (d, 1H, *J* = 11.5 Hz), 3.52 (d, 1H, *J* = 11.5 Hz) ppm; ¹³C NMR (CDCl₃) δ 20.2, 20.7, 27.3, 35.5, 38.9, 50.1, 69.0, 218.1 ppm; [α]²¹_D –85.4 (*c* 0.80, CHCl₃) (for *R*, 91% ee).

[(*R*)-1-Methyl-2-oxocyclohexyl]methyl benzoate

To a solution of (*R*)-2-(hydroxymethyl)-2-methylcyclohexanone (14 mg, 0.099 mmol) in CH₂Cl₂ (0.99 mL) were added benzoyl chloride (23 μL, 0.20 mmol) and pyridine (40 μL, 0.49 mmol) at room temperature.

After stirring for 2 h, the reaction was quenched with water. The resultant mixture was extracted with CH₂Cl₂ (twice), and the combined organic layers were washed with brine and dried over anhydrous Na₂SO₄. The solvents were evaporated, and the residue was purified by preparative TLC (silica gel, hexane/ethyl acetate (6/1)) to give the desired product (75% yield).

¹H NMR (CDCl₃) δ 1.26 (s, 3H), 1.73-1.98 (m, 6H), 2.42-2.54 (m, 2H), 4.38 (d, 1H, *J* = 11.0 Hz), 4.46 (d, 1H, *J* = 11.0 Hz), 7.41-7.45 (m, 2H), 7.53-7.58 (m, 1H), 7.99-8.01 (m, 2H) ppm; ¹³C NMR (CDCl₃) δ 20.8, 21.0, 27.2, 36.4, 38.8, 48.9, 69.1, 128.3, 129.5, 130.0, 133.0, 166.3, 212.9 ppm; IR (neat) 2937, 1718, 1274, 1115, 714 cm⁻¹; Anal. calcd for C₁₅H₁₈O₃: C, 73.15; H, 7.37. found: C, 73.24; H, 7.54; [α]¹⁸_D –5.8 (*c* 0.75, CHCl₃) (for *R*, 91% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 100/1, flow rate = 0.5 mL/min) *t*_R = 39.7 min (major, *R*), *t*_R = 42.3 min (minor, *S*).

2-(Hydroxymethyl)-2-methylcycloheptanone

The starting silicon enolate contained 3% of the another regioisomer.

The yield of the product was based on the isomer shown in Table 2.

¹H NMR (CDCl₃) δ 1.16 (s, 3H), 1.40-1.78 (m, 8H), 2.42-2.47 (m, 2H), 2.62-2.68 (m, 1H), 3.39 (d, 1H, *J* = 11.2 Hz), 3.74 (d, 1H, *J* = 11.2 Hz) ppm; ¹³C NMR (CDCl₃) δ 21.2, 24.7, 26.3, 30.6, 35.0, 41.1, 52.0, 69.5, 219.9 ppm; IR (neat) 3432, 2928, 2856, 1697, 1457, 1047 cm⁻¹; HRMS (ESI-TOF) calcd for C₉H₁₆O₂Na ([M+Na]⁺):

179.1048, found: 179.1045; $[\alpha]^{27}_D -9.8$ (*c* 0.51, CHCl_3) (for assumed *R*, 90% ee)

(2-Oxocycloheptyl)methyl benzoate

To a solution of 2-(hydroxymethyl)-2-methylcycloheptanone (17.9 mg, 0.115 mmol) in CH_2Cl_2 (1.15 mL) were added benzoyl chloride (27 μL , 0.23 mmol) and pyridine (47 μL , 0.58 mmol) at room temperature. After stirring for 2 h, the reaction was quenched with water. The resultant mixture was extracted with CH_2Cl_2 (twice), and the combined organic layers were washed with brine and dried over anhydrous Na_2SO_4 . The solvents were evaporated, and the residue was purified by preparative TLC (silica gel, CHCl_3 only) to give the desired product (72% yield).

^1H NMR (CDCl_3) δ 1.22 (s, 3H), 1.51-1.72 (m, 7H), 1.92-2.00 (m, 1H), 2.57-2.68 (m, 2H), 4.30 (d, 1H, $J = 11.2$ Hz), 4.38 (d, 1H, $J = 11.2$ Hz), 7.41-7.45 (m, 2H), 7.54-7.57 (m, 1H), 7.99-8.01 (m, 2H) ppm; ^{13}C NMR (CDCl_3) δ 21.3, 24.3, 26.4, 30.6, 34.1, 41.1, 51.1, 69.7, 128.4, 129.5, 130.0, 133.0, 166.3, 215.3 ppm; IR (neat) 2932, 1725, 1450, 1275, 1109, 711 cm^{-1} ; HRMS calcd for $\text{C}_{16}\text{H}_{20}\text{O}_3$: 260.1412, found: 260.1425; $[\alpha]^{26}_D +23.7$ (*c* 1.02, CHCl_3) (for assumed *R*, 90% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 100/1, flow rate = 0.5 mL/min) $t_R = 45.1$ min (major, assumed *R*), $t_R = 47.6$ min (minor, assumed *S*).

(*R*)-2-(Hydroxymethyl)cyclohexanone³

^1H NMR (CDCl_3) δ 1.42-2.56 (m, 9H), 2.63 (brs), 3.60 (dd, 1H, $J = 3.7$, 11.5 Hz), 3.73 (dd, 1H, $J = 7.5$, 11.5 Hz) ppm; ^{13}C NMR (CDCl_3) δ 24.7, 27.5, 30.0, 42.2, 52.2, 62.8, 214.8 ppm; $[\alpha]^{26}_D -8.5$ (*c* 0.41, CHCl_3) (for *R*, 78% ee).

[(*R*)-2-Oxocyclohexyl]methyl benzoate

To a solution of (*R*)-2-(hydroxymethyl)cyclohexanone (7.5 mg, 0.094 mmol) in CH_2Cl_2 (0.94 mL) were added benzoyl chloride (22 μL , 0.187 mmol) and pyridine (38 μL , 0.47 mmol) at room temperature. After stirring for 2 h, the reaction was quenched with water. The resultant mixture was extracted with CH_2Cl_2 (twice), and the combined organic layers were washed with brine and dried over anhydrous Na_2SO_4 . The solvents were evaporated, and the residue was

purified by short column chromatography (silica gel, hexane/ethyl acetate (4/1)) to give the desired product (34% yield).

^1H NMR (CDCl_3) δ 1.50-1.60 (m, 1H), 1.65-1.78 (m, 2H), 1.86-2.00 (m, 1H), 2.07-2.16 (m, 1H), 2.26-2.40 (m, 2H), 2.44-2.49 (m, 1H), 2.79-2.87 (m, 1H), 4.32 (dd, 1H, $J = 6.7$, 11.6 Hz), 4.66 (dd, 1H, $J = 5.8$, 11.6 Hz), 7.41-7.45 (m, 2H), 7.53-7.57 (m, 1H), 8.01-8.03 (m, 2H) ppm; ^{13}C NMR (CDCl_3) δ 24.7, 27.6, 31.1, 42.1, 49.6, 63.8, 128.3, 129.6, 130.2, 132.9, 166.5, 210.3 ppm; IR (neat) 1718, 1088 cm^{-1} ; HRMS (ESI-TOF) calcd for $\text{C}_{14}\text{H}_{16}\text{O}_3\text{Na}$ ($[\text{M}+\text{Na}]^+$): 255.0997, found: 255.1002; $[\alpha]_{\text{D}}^{25} +7.0$ (c 0.09, CHCl_3) (for *R*, 78% ee); HPLC (Daicel Chiralcel OD-H, hexane/*i*-PrOH = 40/1, flow rate = 1.0 mL/min) $t_{\text{R}} = 11.2$ min (minor, *S*), $t_{\text{R}} = 13.1$ min (major, *R*).

2-(Hydroxymethyl)-2-phenylcyclohexanone

The starting silicon enolate contained 8% of the another regioisomer.

The yield of the product was based on the isomer shown in Table 2.

^1H NMR (CDCl_3) δ 1.66-1.80 (m, 3H), 1.94-2.01 (m, 1H), 2.13-2.23 (m, 1H), 2.27-2.44 (m, 3H), 2.56-2.62 (m, 1H), 3.36 (d, 1H, $J = 11.6$ Hz), 3.87 (d, 1H, $J = 11.6$ Hz), 7.18-7.21 (m, 2H), 7.27-7.31 (m, 1H), 7.36-7.40 (m, 2H) ppm; ^{13}C NMR (CDCl_3) δ 21.1, 28.3, 31.9, 40.4, 60.0, 70.1, 126.9, 127.4, 129.1, 138.2, 215.7 ppm; IR (neat) 3464, 2943, 2866, 1701, 1450, 1034, 702 cm^{-1} ; HRMS (ESI-TOF) calcd for $\text{C}_{13}\text{H}_{16}\text{O}_2\text{Na}$ ($[\text{M}+\text{Na}]^+$): 227.1048, found: 227.1042; $[\alpha]_{\text{D}}^{24} +124.2$ (c 1.47, EtOH) (for assumed *S*, 60% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 100/1, flow rate = 1.0 mL/min) $t_{\text{R}} = 35.9$ min (minor, assumed *R*), $t_{\text{R}} = 39.0$ min (major, assumed *S*).

2-Benzyl-2-(hydroxymethyl)cyclohexanone

^1H NMR (CDCl_3) δ 1.40-1.48 (m, 1H), 1.60-1.78 (m, 3H), 1.91-2.11 (m, 2H), 2.35-2.41 (m, 1H), 2.55-2.80 (m, 2H), 2.88 (d, 1H, $J = 13.4$ Hz), 3.08 (d, 1H, $J = 13.4$ Hz), 3.34 (d, 1H, $J = 11.6$ Hz), 3.46 (d, 1H, $J = 11.6$ Hz), 7.21-7.31 (m, 5H) ppm; ^{13}C NMR (CDCl_3) δ 20.6, 27.0, 31.5, 37.0, 39.3, 53.8, 65.6, 126.6, 128.2, 130.5, 135.9, 217.9 ppm; IR (neat) 3452, 2941, 1699, 1454, 1061, 706 cm^{-1} ; HRMS (ESI-TOF) calcd for $\text{C}_{14}\text{H}_{18}\text{O}_2\text{Na}$ ($[\text{M}+\text{Na}]^+$): 241.1204, found: 241.1204; $[\alpha]_{\text{D}}^{30} -85.2$ (c 0.99, CHCl_3) (for assumed *S*, 80% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 40/1, flow rate = 1.0 mL/min) $t_{\text{R}} = 22.9$ min (major, assumed *S*), $t_{\text{R}} = 32.5$ min (minor, assumed *R*).

(S)-3-Hydroxy-2-methyl-thiopropionic acid *S*-*tert*-butyl ester¹

¹H NMR (CDCl₃) δ 1.19 (d, 3H, *J* = 7.2 Hz), 1.47 (s, 9H), 2.06 (brs), 2.77 (ddq, 1H, *J* = 4.6, 7.1, 7.2 Hz), 3.67 (dd, 1H, *J* = 4.6, 11.2 Hz), 3.75 (dd, 1H, *J* = 7.1, 11.2 Hz) ppm; ¹³C NMR (CDCl₃) δ 14.3, 29.8, 48.1, 50.7, 64.8, 204.2 ppm; IR (neat) 3403, 2967, 1682, 1456, 1364, 964 cm⁻¹; MS *m/z* 176 (M⁺); Anal. calcd for C₈H₁₆O₂S: C, 54.51; H, 9.15. found: C, 54.45; H, 8.92; [α]_D²⁶ +43.3 (*c* 0.43, EtOH) (for *S*, 94% ee); HPLC (Daicel Chiralpak AD-H, hexane/*i*-PrOH = 100/1, flow rate = 1.0 mL/min) *t*_R = 30.6 min (minor, *R*), *t*_R = 40.3 min (major, *S*).

Crystallization of [ScBr₂•1**•H₂O]•Br•H₂O complexes**

Crystallization of [ScBr₂•**1**•H₂O]•Br•H₂O was carried out as follows: To a solution of ScBr₃ (12 mg, 43 μmol) in DME (1.5 mL) was added **1** (14 mg, 43 μmol) at room temperature. The solution was warmed to 75 °C (oil bath temperature). Then, a white precipitate was gradually formed, and dissolved by addition of water (70 μL). The resulting solution was allowed to stand at 5 °C under DME vapor to give the crystals.

- (1) Manabe, K.; Ishikawa, S.; Hamada, T.; Kobayashi, S. *Tetrahedron* **2003**, 59, 10439.
- (2) Miyaoka, H.; Kajiwarra, Y.; Hara, M.; Suma, A.; Yamada, Y. *Tetrahedron: Asymmetry* **1999**, 10, 3189.
- (3) Baliri, P. L.; Catelani, G.; Giori, R.; Mastrorilli, E. *Enantiomer* **1998**, 3, 357.

Br and H₂O are disordered.