Enantioselective Sulfonylation Reactions Mediated by a Tetrapeptide Catalyst

Kristin Williams Fiori, Angela L. A. Puchlopek and Scott J. Miller*

Department of Chemistry, Yale University
P.O. Box 208107, New Haven, CT 06520-8107
E-mail: scott.miller@yale.edu
Table of Contents

Materials and Methods ................................................................. (1)
Experimental Data ........................................................................... (2)
Experimental Procedures and Compound Characterization ................. (2)
Preparation of 1,3-diol Substrates ......................................................... (2)
Synthesis of myo-Inositol-derived substrates ........................................ (2)
Synthesis of acyclic 1,3-diols (19 and 20, Table 2, entries 7 and 8) ........... (11)
Solid Phase Synthesis of Peptide Catalyst 10 ....................................... (16)
Catalytic Enantioselective Sulfonylation Reactions ............................... (17)
General procedure for initial screenings ............................................. (17)
General procedure for sulfonylation using condition A (Table 2) .......... (18)
General procedure for sulfonylation using condition B (Table 2) .......... (18)
Kinetic Resolution of Racemic (Mono)sulfonate 2a ............................... (23)
Determination of Absolute Stereochemistry ...................................... (24)

Materials and Methods
Proton NMR spectra were recorded on a 400 or 500 MHz spectrometer. Proton chemical shifts were reported in ppm (δ) relative to internal tetramethylsilane (TMS, δ, 0.00 ppm), or with the solvent reference relative to TMS employed as the internal standard (CDCl₃, δ 7.26 ppm; CD₂OD, δ 3.30 ppm; CD₂Cl₂, δ 5.32 ppm). Spectral data are reported as follows: chemical shift (multiplicity [singlet (s), doublet (d), triplet (t), quartet (q), and multiplet (m)], coupling constants [Hz], integration). Carbon NMR spectra were recorded on a 400 (100) or 500 (125) MHz spectrometer with complete proton decoupling. Carbon chemical shifts are reported in ppm (δ) relative to the residual solvent signal (CDCl₃, δ 77.0 ppm; CD₂OD, δ 49.0 ppm; CD₂Cl₂, δ 53.8 ppm). When two peaks appear very close together, carbon chemical shifts are reported to two decimal places. NMR data were collected at ambient temperature unless otherwise indicated. Infrared spectra were obtained on a Nicolet 6700 FT-IR spectrometer, νmax (cm⁻¹) are partially reported. Analytical thin-layer chromatography (TLC) was performed using Silica Gel 60 Å F254 pre-coated plates (0.25 mm thickness). TLC Rf values are reported and visualization was accomplished by irradiation with a UV lamp and/or staining with cerium ammonium molybdate.
(CAM) or KMnO₄ solutions. Flash column chromatography was performed using Silica Gel 60 Å (32-63 micron). Optical rotations were recorded on a Rudolf Research Analytical Autopol IV Automatic polarimeter at the sodium D line (100 mm path length). High resolution mass spectra were acquired from the Mass Spectrometry Facility of the University of Illinois (Urbana-Champaign, IL) or at the Keck Center of Yale University. The method of ionization is given in parentheses. Chiral analytical normal phase HPLC was performed at a column temperature of 20 °C on a Hewlett-Packard 1100 Series chromatograph equipped with a diode array detector (210 nm, 230 nm or 254 nm).

All reactions were carried out under a nitrogen atmosphere employing oven- and flame-dried glassware. Solvents were purified using a Seca Solvent Purification System by GlassContour. All arenesulfonyl chlorides were recrystallized from Et₂O and petroleum ether and checked for purity by melting point analysis prior to use. All other chemicals were purchased commercially and used as received unless indicated otherwise.

**Experimental Data**

**Experimental Procedures and Compounds Characterization**

**Preparation of 1,3-diol Substrates.**

**Synthesis of myo-Inositol-derived substrates.**

2,4,6-Tribenzyl myo-inositol (1) was prepared in three steps from commercially available myo-inositol according to the method of Billington and coworkers.¹ 2,4,6-Tri-O-para-methoxybenzylmyo-inositol (12) (Table 2, entry 2) was prepared in an analogous manner using a modified procedure.²

---

¹ Billington, D. C., Baker, R., Kulagowski, J. J., Mawer, I. M., Vacca, J. P., Jane deSolms, S. & Huff, J. R. The total synthesis of myo-inositol phosphates via myo-inositol orthoformate. *J. Chem. Soc., Perkin Trans. 1*, 1423–1429 (1989).
² (a) Lampe, D., Liu, C. & Potter, B. V. L. Synthesis of selective non-Ca²⁺ mobilizing inhibitors of D-myo-inositol 1,4,5-Trisphosphate 5-phosphatase. *J. Med. Chem.*, 37, 907–912 (1994). (b) Xu, Y., Seulimbren, B. R. & Miller, S. J. Streamlined synthesis of phosphatidylinositol (PI), PI3P, PI3,5P₂, and deoxygenated analogues as potential biological probes. *J. Org. Chem.*, 71, 4919–4928 (2006).
2,4,6-Tri-O-benzyl-5-O-tert-butyldimethylsilyl-myoinositol (13, Table 2, entry 3):

To an oven-dried 50 mL round bottom flask equipped with a stir bar was added 1.0 g (2.22 mmol) 2,4,6-tri-O-benzyl-myoinositol (I) and 11 mL DMF. Imidazole (0.226 g, 3.33 mmol) and TBSCl (0.502 g, 3.33 mmol) were then added to the solution. After stirring at 23 °C for 3 hours, 20 mL of deionized water was added, and the reaction mixture was transferred to a 125 mL separatory funnel containing 80 mL of Et₂O. After agitation and separation of the aqueous layer, the organic phase was washed with additional deionized water (3 x 20 mL), then 20 mL sat. aq. NaCl. The organic layer was dried (Na₂SO₄), filtered, and concentrated under reduced pressure to provide a mixture of (mono)silylated and (bis)silylated regioisomers. The desired 5-silylated product was obtained by silica gel flash chromatography (gradient elution: 9:1→4:1 hexanes/EtOAc) of the crude reaction mixture to isolate the lowest Rᵢ product spot as a colorless oil (190 mg, 15% yield).

TLC Rᵢ = 0.47 (2:1 hexanes/EtOAc); ¹H NMR (CDCl₃, 400 MHz) δ 7.40-7.26 (m, 15H), 4.87 (d, J = 11.5 Hz, 2H), 4.72 (s, 2H), 4.71 (d, J = 11.5 Hz, 2H), 3.95 (t, J = 2.7 Hz, 1H), 3.62 (t, J = 9.1 Hz, 2H), 3.55-3.50 (m, 3H), 2.14 (d, J = 5.5 Hz, 2H), 0.95 (s, 9H), 0.07 (s, 6H) ppm; ¹³C NMR (CDCl₃, 125 MHz) δ 138.60, 138.59, 128.5, 128.4, 127.99, 127.97, 127.8, 127.7, 82.4, 78.8, 75.5, 75.2, 75.1, 72.5, 26.1, 18.0, –4.0 ppm; IR (thin film) ν 3554, 2925, 2857, 1454, 1401, 1359, 1256, 1158, 1122, 1088, 1069, 1028, 837, 818 cm⁻¹; HRMS calcd for [C₃₀H₄₃O₆Si H]⁺ requires m/z 565.2980; found 565.2981 (ESI+).

2,4,6-Tri-O-benzyl-5-deoxy-myoinositol (14, Table 2, entry 4):

This substrate was prepared in 4 steps from the known orthoester.¹
In a 100 mL round bottom flask, orthoester 26 (3.72 g, 8.10 mmol) was dissolved in 50 mL of CH₂Cl₂ and cooled to 0 ºC. To the cooled solution was added di-isobutyl aluminium hydride (1M solution in hexanes, 19.53 mL, 19.53 mmol) and the grey reaction mixture was stirred for 2.5 h. The reaction mixture was then transferred via cannula to a cooled solution (0 ºC) of potassium sodium tartrate (11.28 g) in 40 mL of water and 40 mL of sat. aq. NH₄Cl. The reaction mixture was allowed to stir overnight and then extracted with EtOAc three times, dried over Na₂SO₄, filtered, and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (gradient elution: 85:15 → 4:1 hexanes/EtOAc) yielded a clear, colorless oil (3.73 g, 100%). The spectral data for this compound matched that which had been previously reported.³

In a 50 mL round bottom flask, acetal 27 (250 mg, 0.54 mmol) was dissolved in THF (17 mL) and the solution was cooled to 0 ºC. NaH (25.92 mg, 1.08 mmol) was then added to the cooled solution and the mixture was allowed to stir for 30 minutes at 0 ºC. Then CS₂ (114.4 µL, 1.89 mmol) was added to the reaction mixture and it was allowed to stir at 0 ºC for 30 minutes. Finally, MeI (100.9 µL, 1.62 mmol) was added to the reaction mixture at 0 ºC and the mixture was allowed to stir overnight while gradually warming to room temperature. The yellow reaction mixture was then quenched with sat. aq. NH₄Cl and diluted with CH₂Cl₂ and water. The layers were extracted and the aqueous layer was washed with CH₂Cl₂ twice. The combined organic layers were washed with sat. aq. NaCl solution, dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The crude yellow oil was purified by silica gel flash chromatography (10:1 hexanes/EtOAc) to provide a pale yellow oil (246 mg, 82%). **TLC** **Rf** = 0.40 (5:1 hexanes/EtOAc); **¹H NMR** (CDCl₃, 500 MHz) δ 7.25-7.34 (m, 15H), 6.06 (s, 2H), 5.54 (d, J = 4.3 Hz, 1H), 4.77 (d, J = 12.0 Hz, 2H), 4.63-4.64 (m, 3H), 4.59 (d, J = 12.0 Hz, 2H), 4.37 (s, 2H), 4.34 (s, 1H), 3.99 (s, 2H), 2.49 (s, 3H) ppm; **¹³C NMR** (CDCl₃, 125 MHz) δ 214.3, 137.9, 137.8, 128.64, 128.56, 128.05, 128.00, 127.9, 127.8, 85.5, 79.1, 77.5, 77.3, 77.0, 76.8, 72.4, 71.0, 70.8, 70.2, 18.5 ppm; **IR** (thin film) ν 3089, 3060, 3028, 2917, 2852, 1957, 1875, 1720, 1601, 1581.

³ Gilbert, I. H., Holmes, A. B., Pestchanker, M. J. & Young, R. C. Lewis acid-catalysed rearrangements of myo-inositol orthoformate derivatives. *Carbohydr. Res.*, 234, 117–130 (1992).
In a flame dried 250 mL round bottom flask, to a solution of the xanthate ester 28 (1.90 g, 3.44 mmol) in toluene (104 mL) was added Bu$_3$SnH (2.73 mL, 10.31 mmol) and AIBN (169.50 mg, 1.03 mmol). The yellow solution was brought to reflux and monitored by thin layer chromatography for disappearance of starting material. After approximately 1h the black reaction mixture was cooled to room temperature and concentrated under reduced pressure. The resulting black residue was partitioned between hexanes and acetonitrile to remove excess Bu$_3$Sn. Purification of the crude reaction mixture by silica gel flash chromatography (5:1 hexanes/EtOAc) provides the 5-deoxy acetal (1.12 g, 73%) as a pale yellow oil.  

TLC $R_f$ = 0.34 (25:1 toluene/acetone); $^1$H NMR (CDCl$_3$, 500 MHz) $\delta$ 7.27-7.35 (m, 15H), 5.61 (d, $J$ = 4.5 Hz, 1H), 4.67 (d, $J$ = 4.6 Hz, 2H), 4.64 (d, $J$ = 11.9 Hz, 2H), 4.60 (s, 2H), 4.46 (d, $J$ = 11.9 Hz, 2H), 4.43 (brs, 1H), 4.39 (br d, $J$ = 3.4 Hz, 2H), 3.90 (dd, $J$ = 2.9, 1.1 Hz, 2H), 2.24 (dt, $J$ = 15.8, 4.2 Hz, 1H), 2.04 (brd, $J$ = 15.8 Hz, 1H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) $\delta$ 138.5, 138.0, 128.4, 128.3, 127.8, 127.7, 127.4, 85.1, 77.5, 71.4, 71.2, 70.4, 70.4, 23.4 ppm; IR (thin film) v 3444, 3085, 3056, 3023, 2913, 2868, 1957, 1875, 1806, 1601, 1581, 1495, 1446, 1356, 1266, 1205, 1172, 1140, 1103, 1066, 1005, 731 cm$^{-1}$; HRMS calcd for [C$_{28}$H$_{30}$O$_5$H]$^+$ requires m/z 447.2171; found 447.2186 (ESI+).

In a flame dried 100 mL round bottom flask, to a solution of the acetal (1.12 g, 2.53 mmol) in methanol (41.0 mL) was added concentrated HCl (6.15 mL). The cloudy white reaction mixture was brought to reflux and monitored by thin layer chromatography for disappearance of starting material. After approximately 4.5 h the solution was allowed to cool to room temperature and then diluted with ethyl acetate. The solution was neutralized to pH 7-8 with sat. aq. NaHCO$_3$, extracted twice with EtOAc, dried over Na$_2$SO$_4$, filtered, and concentrated under reduced pressure leaving a clear oil. Purification of the crude oil by silica gel flash chromatography (2:1 hexanes/EtOAc) provides 5-deoxy inositol 14 (911.2 mg, 83%) as a clear, colorless oil. TLC $R_f$ = 0.27 (2:1 hexanes/EtOAc); $^1$H NMR (CDCl$_3$, 500 MHz) $\delta$ 7.30-7.38 (m, 15H), 4.84 (s, 2H),
4.67 (d, $J = 11.5$ Hz, 2H), 4.58 (d, $J = 11.0$ Hz, 2H), 4.09 (t, $J = 2.5$ Hz, 1H), 3.70 (ddd, $J = 11.3$, 9.5, 4.5 Hz, 2H), 3.62 (ddd, $J = 9.3$, 5.3, 3.0 Hz, 2H), 2.52 (d, $J = 4.5$ Hz, 2H), 2.48 (dt, $J = 12.5$, 4.5 Hz, 1H), 1.29 (q, $J = 11.8$ Hz, 1H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) $\delta$ 138.8, 138.3, 128.5, 128.4, 127.80, 127.78, 127.69, 79.3, 77.2, 76.7, 75.3, 74.9, 71.9, 31.3 ppm; IR (thin film) v 3440 3060, 3023, 2921, 2872, 1716, 1605, 1495, 1450, 1389, 1348, 1270, 1205, 1115, 1091, 1066, 1033, 731 cm$^{-1}$; HRMS cale for [C$_{27}$H$_{30}$O$_5$ Na]$^+$ requires m/z 457.1985; found 457.1980 (ESI+).

2,4,6-Tri-O-benzyl-5-keto-myoinositol (15, Table 2, entry 5):

Prepared in 3 steps from 2,4,6-tri-O-benzyl-myoinositol (1).

In a 50 mL round bottom flask, 2,4,6-tri-O-benzyl-myoinositol (1) (2.0 g, 4.4 mmol) was dissolved in DMF (22 mL). Imidazole (1.51 g, 22.2 mmol) and tert-butyldiphenylsilyl chloride (5.77 mL, 22.2 mmol) were subsequently added and the reaction solution was allowed to stir for 48 hours. The solution was then diluted with Et$_2$O, washed with water four times, washed with sat. aq. NaCl, dried over Na$_2$SO$_4$, and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (toluene) yielded the desired product as a thick, colorless oil (1.59 g, 71%). TLC $R_f$ = 0.51 (5:1 hexanes/EtOAc); $^1$H NMR (CDCl$_3$, 500 MHz) $\delta$ 7.65 (dd, $J = 8.0$, 1.2 Hz, 4H), 7.55 (dd, $J = 7.9$, 1.2 Hz, 4H), 7.51 (d, $J = 7.2$ Hz, 2H), 7.44 (t, $J = 7.6$ Hz, 2H), 7.35-7.41 (m, 4H), 7.29 (t, $J = 7.5$ Hz, 4H), 7.21-7.25 (m, 10H), 7.04 (dd, $J = 7.2$, 2.2 Hz, 4H), 4.80 (s, 2H), 4.72 (d, $J = 11.3$ Hz, 2H), 4.59 (d, $J = 11.3$ Hz, 2H), 3.90 (t, $J = 9.3$ Hz, 2H), 3.53 (dd, $J = 9.5$, 2.2 Hz, 2H), 3.34 (t, $J = 2.1$ Hz, 1H), 3.29 (td, $J = 9.0$, 2.3 Hz, 1H), 2.20 (d, $J = 2.4$ Hz, 1H), 0.98 (s, 18H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) $\delta$ 139.7, 139.0, 136.1, 135.9, 133.6, 133.3, 129.8, 129.4, 128.2, 128.1, 127.7, 127.5, 127.4, 127.1, 126.9, 81.9, 81.7, 76.1, 74.7, 74.4, 74.2, 27.2, 19.3 ppm; IR (thin film) v 3571, 3473, 3088, 3069, 3049, 3031, 2999, 2959, 2930, 2891, 2858, 2296, 1957, 1883, 1822, 1773, 1659, 1606, 1587, 1567, 1495, 1470, 1453, 1425, 1388, 1357, 1263, 1209, 1151, 1108, 1026, 938, 842, 821, 802 cm$^{-1}$; HRMS cale for [C$_{59}$H$_{60}$O$_6$Si$_2$ Na]$^+$ requires m/z 949.4296; found 949.4341 (ESI+).
In a oven-dried 50 mL round bottom flask, 2,4,6-tri-O-benzyl-1,3-di-O-tert-butyldiphenylsilyl-
myo-inositol 30 (1.68 g, 1.81 mmol) was dissolved in CH₂Cl₂ (12 mL). Triethylamine (5.05 mL, 36.2 mmol) was subsequently added and the reaction solution was cooled to 0 °C. A solution of SO₃•pyridine (2.88 g, 18.1 mmol) in anhydrous DMSO (6 mL) was added over the course of 5 min at 0 °C. The pale orange solution was allowed to warm gradually to room temperature and was stirred for 48 h. The reaction was then diluted with 1:1 hexanes/EtOAc (200 mL), washed with 1 N HCl (3 x 40 mL), sat. aq. NaHCO₃ (40 mL), then sat. aq. NaCl. The organic layer was dried over Na₂SO₄, and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (toluene) yielded the desired product as white solid (1.41 g, 84%). TLC R_f = 0.41 (9:1 hexanes/EtOAc); mp = 163.5–165.5 °C; ¹H NMR (CDCl₃, 400 MHz) δ 7.57-7.54 (m, 4H), 7.48-7.31 (m, 13H), 7.26-7.20 (m, 10H), 7.19-7.14 (m, 4H), 7.13-7.09 (m, 4H), 4.85 (s, 2H), 4.66 (d, J = 10.2 Hz, 2H), 4.52 (d, J = 9.9 Hz, 2H), 4.17 (d, J = 10.2 Hz, 2H), 3.55 (dd, J = 9.9, 2.1 Hz, 2H), 3.49 (t, J = 2.1 Hz, 1H), 0.96 (s, 18H) ppm; ¹³C NMR (CDCl₃, 125 MHz) δ 204.2, 139.2, 137.7, 136.1, 135.9, 133.4, 132.7, 129.8, 129.5, 128.4, 128.3, 127.8, 127.5, 127.33, 127.30, 82.7, 81.5, 75.7, 73.4, 72.8, 27.1, 19.3 ppm; IR (thin film) ν 3069, 3054, 3038, 2960, 2931, 2857, 2847, 1736, 1472, 1455, 1427, 1391, 1265, 1148, 1113, 1105, 1081, 1049, 1028, 1008, 945, 822, 808 cm⁻¹; HRMS calcd for [C₅₈H₆₀O₆Si₂Na]⁺ requires m/z 947.4134; found 947.4138 (ESI+).

To a 50 mL polypropylene reaction vessel equipped with a stir bar were added 0.800 g (0.865 mmol) of bis(tert-butyldiphenylsilylated) ketone 31 and 10 mL of dry THF. The reaction was cooled to 0 °C and 5.4 mL of HF•pyridine was added via a plastic graduated pipette. The mixture was allowed to warm slowly to room temperature. The reaction was monitored by TLC and two additional portions (2.0 mL each) of HF•pyridine were added to the reaction at 24 h and 48 h. After approximately 60 h, the reaction was cooled to 0 °C and was quenched by adding sat. aq. NaHCO₃ dropwise until a pH of 8 was achieved. The mixture was transferred to a separatory funnel and extracted using EtOAc (2 x 200 mL). The combined organic layers were dried over Na₂SO₄, and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (gradient elution: 4:1→1:1 hexanes/EtOAc) yielded desired product (15) as a
white solid (0.300 g, 77%). **TLC Rf** = 0.36 (1:1 hexanes/EtOAc); **mp** = 133–135 ºC; **1H NMR** (CDCl₃, 500 MHz) δ 7.45-7.42 (m, 4H), 7.40-7.30 (m, 11H), 4.96 (d, J = 11.0 Hz, 2H), 4.93 (s, 2H), 4.50 (d, J = 11.0 Hz, 2H), 4.42 (d, J = 9.9 Hz, 2H), 4.25 (t, J = 2.7 Hz, 1H), 3.79 (ddd, J = 9.9, 4.3, 2.7 Hz, 2H), 2.54 (d, J = 4.3 Hz, 2H) ppm; **13C NMR** (CDCl₃, 125 MHz) δ 202.9, 138.2, 137.3, 128.6, 128.5, 128.3, 128.1, 127.9, 82.7, 77.9, 75.7, 73.4, 72.4 ppm; **IR** (thin film) ν 3578, 3416, 2905, 1736, 1454, 1359, 1214, 1128, 1081, 1038, 1028, 1003, 917 cm⁻¹; **HRMS** calcd for \([C_{27}H_{28}O_6Na]^+\) requires m/z 471.1778; found 471.1775 (ESI+).

**2,4,6-Tri-O-benzyl-1,3-di-O-tert-butyldiphenylsilyl-5-methylene-cyclohexane-1,2,3/4,6 pentol** (16, Table 2, entry 6):

Methyltriphénylphosphonium bromide (0.568 g, 1.59 mmol), previously dried in vacuo at 70 ºC, was suspended in dry THF (5 mL) in a flame dried 20 mL round bottom flask under N₂ at −78 ºC. A 2.2 M solution of nBuLi in hexanes (0.69 mL, 1.51 mmol) was added and the reaction mixture was warmed to 0 ºC and the resulting yellow suspension was stirred for 20 min. A solution of ketone 31 (0.700 g, 0.757 mmol) in dry THF (3 mL) was added via cannula under N₂ pressure. The reaction was stirred at 0 ºC. After 7 h, TLC showed the reaction to be complete, and the solvent was removed by evaporation in vacuo. The residue was taken up in Et₂O and washed with water (20 mL), then sat. aq. NaCl (20 mL). The combined organic layers were dried over Na₂SO₄, and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (gradient elution: 2:1→1:1 hexanes/toluene) yielded the desired product as viscous colorless oil (0.390 g, 56%). **TLC Rf** = 0.46 (9:1 hexanes/EtOAc); **1H NMR** (CDCl₃, 500 MHz) δ 7.68 (d, J = 7.1 Hz, 4H), 7.58 (d, J = 7.2 Hz, 4H), 7.49 (d, J = 7.3 Hz, 2H), 7.43-7.32 (m, 7H), 7.28-7.21 (m, 14H), 7.06-7.02 (m, 4H), 5.16 (s, 2H), 4.78 (s, 2H) 4.51 (d, J = 11.1 Hz, 2H), 4.36 (d, J = 11.1 Hz, 2H), 4.30 (d, J = 9.3 Hz, 2H), 3.47 (d, J = 9.3 Hz, 2H), 3.39 (br s, 1H), 1.00 (s, 18H) ppm; **13C NMR** (CDCl₃, 125 MHz) δ 141.9, 139.8, 138.4, 136.1, 136.0, 134.1, 133.6, 129.6, 129.2, 128.1, 127.9, 127.6, 127.4, 127.24, 127.23, 127.17, 127.0, 81.8, 79.3, 76.4, 75.4, 72.2, 27.2, 19.3 ppm; **IR** (thin film) ν 3066, 3053, 3032, 2955, 2930, 2894, 2857, 1497, 1472, 1454, 1391, 1359, 1266, 1190, 1113, 1105, 1028, 1008, 963, 943, 840, 823 cm⁻¹; **HRMS** calcd for \([C_{60}H_{56}Si_2K]^+\) requires m/z 961.4080; found 961.4074 (ESI+).
To a 50 mL polypropylene reaction vessel equipped with a stir bar were added 0.480 g (0.52 mmol) of bis(tert-butyldiphenylsilylated) alkene 32 and 6 mL dry THF. The reaction was cooled to 0 ºC and 3.0 mL of HF•pyridine was added via a plastic graduated pipette. The mixture was allowed to warm slowly to room temperature and the reaction was monitored by TLC. After approximately 48 h, the reaction was cooled to 0 ºC and was quenched by adding sat. aq. NaHCO₃ dropwise until a pH of 8 was achieved. The mixture was transferred to a separatory funnel and extracted using EtOAc (2 x 70 mL). The combined organic layers were dried over Na₂SO₄ and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (gradient elution: 2:1→1:1 hexanes/EtOAc) yielded desired product (16) as a white solid (0.196 g, 84%). TLC Rᵢ = 0.52 (1:1 hexanes/EtOAc); mp = 88.5–90 ºC; ¹H NMR (CDCl₃, 500 MHz) δ 7.42-7.30 (m, 15H), 5.41 (s, 2H), 4.85 (s, 2H), 4.79 (d, J = 11.5 Hz, 2H), 4.56 (d, J = 11.5 Hz, 2H), 4.14-4.10 (m, 3H), 3.65 (br s, 2H), 2.76 (br s, 2H) ppm; ¹³C NMR (CDCl₃, 125 MHz) δ 140.4, 138.6, 138.0, 128.5, 128.4, 127.83, 127.78, 127.76, 127.69, 80.3, 77.6, 74.7, 74.6, 72.5 ppm; IR (thin film) ν 3530, 3459, 3030, 2908, 2883, 2872, 1497, 1454, 1390, 1361, 1210, 1122, 1087, 1072, 1042, 1028, 915 cm⁻¹; HRMS calcd for [C₂₈H₃₀O₅Na]⁺ requires m/z 469.1985; found 469.1967 (ESI+).

2-O-methyl-4,6-di-O-benzyl-myo-inositol (17, Table 2, entry 7):
Prepared in 2 steps from the known dibenzyl orthoester.²

To a 50 mL flame-dried round bottom flask equipped with a stir bar were added dibenzyl orthoester 33 (0.400 g, 1.08 mmol) and DMF (11 mL). The solution was cooled to 0 ºC and NaH (95%, 41 mg, 1.62 mmol) was added. After the mixture was stirred at 0 ºC for 20 min, MeI was added and the reaction was allowed to warm to 23 ºC. After 1 h, the reaction was cooled to 0 ºC and 20 mL of deionized water was added to quench the remaining NaH. The mixture was
transferred to a separatory funnel and extracted using Et\(_2\)O (100 mL). The combined organic layers were washed with water (3 x 20 mL) and sat. aq. NaCl (20 mL), dried over Na\(_2\)SO\(_4\), and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (2:1 hexanes/EtOAc) yielded the desired product as viscous colorless oil (0.356 g, 86%). **TLC** \(R_f = 0.43\) (2:1 hexanes/EtOAc); **\(^1\)H NMR** (CDCl\(_3\), 400 MHz) \(\delta 7.32\)–7.28 (m, 10H), 5.50 (d, \(J = 1.2\) Hz, 1H), 4.71 (d, \(J = 11.6\) Hz, 2H), 4.58 (d, \(J = 11.6\) Hz, 2H), 4.48–4.44 (m, 1H), 4.38 (t, \(J = 3.8\) Hz, 2H), 4.35–4.33 (m, 2H), 3.82–3.80 (m, 1H), 3.45 (s, 3H) ppm; **\(^{13}\)C NMR** (CDCl\(_3\), 125 MHz) \(\delta 137.6, 128.5, 128.0, 127.7, 103.2, 74.0, 71.9, 69.8, 69.4, 68.0, 56.7\) ppm; **IR** (thin film) \(\nu 2965, 2884, 1497, 1454, 1396, 1368, 1307, 1276, 1198, 1166, 1138, 1116, 1095, 1001, 948, 897, 823\) cm\(^{-1}\); **HRMS** calcd for [C\(_{22}\)H\(_{24}\)O\(_6\)H]\(^+\) requires \(m/z\) 385.1648; found 385.1646 (ESI+).

In a 100 mL round bottom flask, to a solution of orthoester 34 (0.353 g, 0.92 mmol) in methanol (12.0 mL) was added deionized water (0.27 mL) followed by concentrated HCl (0.54 mL). The cloudy white reaction mixture was brought to reflux and monitored by thin layer chromatography for disappearance of starting material. After approximately 2 h the solution was allowed to cool to room temperature and the solution was neutralized to pH 8 with sat. aq. NH\(_4\)OH. The reaction mixture was concentrated under reduced pressure and the resulting oil was dissolved in EtOAc. The insoluble white solid was removed by filtering through celite, and the resulting solution was concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (1:1 hexanes/EtOAc) provides 17 as a clear, colorless oil (334.5 mg, 97%). **TLC** \(R_f = 0.36\) (1:2 hexanes/EtOAc); **\(^1\)H NMR** (CDCl\(_3\), 500 MHz) \(\delta 7.41\)–7.35 (m, 8H), 7.34–7.30 (m, 2H), 4.89 (d, \(J = 11.3\) Hz, 2H), 4.85 (d, \(J = 11.3\) Hz, 2H), 3.67 (t, \(J = 2.7\) Hz, 1H), 3.65 (s, 3H), 3.61 (t, \(J = 9.3\) Hz, 2H), 3.53-3.47 (m, 3H), 2.66 (d, \(J = 2.2\) Hz, 1H), 2.58 (d, \(J = 5.8\) Hz, 2H) ppm; **\(^{13}\)C NMR** (CDCl\(_3\), 125 MHz) \(\delta 138.5, 128.5, 127.9, 127.8, 81.9, 81.2, 75.0, 74.8, 72.4, 61.8\) ppm; **IR** (thin film) \(\nu 3467, 3089, 3064, 3031, 2931, 2247, 1701, 1603, 1585, 1497, 1454, 1399, 1363, 1314, 1270, 1209, 1189, 1119, 1005, 911, 864, 829\) cm\(^{-1}\); **HRMS** calcd for [C\(_{14}\)H\(_{19}\)O\(_5\)Na]\(^+\) requires \(m/z\) 397.1622; found 397.1618 (ESI+).
Synthesis of acyclic 1,3-diols (19 and 20, Table 2, entries 7 and 8):
The *syn,syn-* and *anti,anti-*acyclic 1,3-diols (20 and 19) were synthesized in 6 steps from xylitol and adonitol, respectively, using procedures adapted from Linclau and coworkers\(^4\) and Miller and coworkers.\(^5\)

![Chemical diagram](image)

In a flame dried 250 mL round bottom flask, 2,2-dimethoxypropane (8.87 mL, 72.4 mmol) was dissolved in 100 mL of THF and xylitol (5.0 g, 32.9 mmol) was added. The mixture was allowed to stir at reflux for 15 minutes and then L-(-)-camphorsulfonic acid (764.3 mg, 3.3 mmol) was added at refluxing temperature and pentaol 35 dissolved. After refluxing for another 5 minutes, the reaction was quenched at refluxing temperature with 2M NaOH (20 mL). The suspension was extracted with Et\(_2\)O and H\(_2\)O. The aqueous layer was further extracted three times with Et\(_2\)O. The organic layer was dried over Na\(_2\)SO\(_4\), filtered, and concentrated to provide a colorless oil. After dissolving the oil in CH\(_2\)Cl\(_2\) (100 mL), Et\(_3\)N (4.99 mL, 35.9 mmol) was added and the solution was brought to reflux. Succinic anhydride (823.1 mg, 8.2 mmol) was added to the reaction at refluxing temperature and the reaction was allowed to stir at reflux for an additional hour. The reaction was then quenched with sat. aq. NaHCO\(_3\) (10 mL) at refluxing temperature.

\(^4\) Linclau, B., Boydell, A. J., Clarke, P. J., Horan, R. & Jacquet, C. Efficient desymmetrization of \textit{“pseudo”}\(^-\text{C}_2\) symmetric substrates: illustration in the synthesis of a disubstituted butenolide from arabitol. \textit{J. Org. Chem.}, \textbf{68}, 1821–1826 (2003).

\(^5\) Lewis, C. A., Sculimbrenes, B. R., Xu, Y. & Miller, S. J. Desymmetrization of glycerol derivatives with peptide-based acylation catalysts. \textit{Org. Lett.}, \textbf{7}, 3021–3023 (2005).
and the layers were separated once cool. The organic layer was dried over Na₂SO₄, filtered, and concentrated under reduced pressure to yield a pale yellow oil. Purification of the crude oil by silica gel flash chromatography (gradient elution: 1:1→3:2 Et₂O/hexanes) provided the (bis)acetal as a clear, colorless oil (3.19 g, 42%). **TLC** *R*ₐ = 0.32 (3:2 Et₂O/hexanes); **¹H NMR** (CDCl₃, 500 MHz) δ 4.16 (q, *J* = 6.0 Hz, 2H), 4.06 (t, *J* = 7.4 Hz, 2H), 3.88 (t, *J* = 7.4 Hz, 2H), 3.58 (q, *J* = 5.4 Hz, 1H), 2.44 (dd, *J* = 6.1, 1.6 Hz, 1H), 1.44 (s, 6H), 1.37 (s, 6H) ppm; **¹³C NMR** (CDCl₃, 125 MHz) δ 109.5, 76.0, 71.6, 66.0, 26.4, 25.2 ppm; **IR** (thin film) ν 3481, 2983, 2934, 2893, 1368, 1250, 1209, 1152, 882, 854 cm⁻¹; **HRMS** calcd for [C₁₁H₂₅O₅]⁺ requires *m/z* 233.1384; found 233.1380 (ESI+).

In a flame dried 100 mL round bottom flask, 2,2-dimethoxypropane (4.43 mL, 36.2 mmol) was dissolved in 25 mL of THF and adonitol (2.5 g, 16.4 mmol) was added. The mixture was allowed to stir at reflux for 15 minutes and then L-(-)-camphorsulfonic acid (381.7 mg, 1.6 mmol) was added at refluxing temperature and pentaol 36 dissolved. After refluxing for another 5 minutes, the reaction was quenched at refluxing temperature with 2M NaOH (10 mL). The suspension was extracted with Et₂O and H₂O. The aqueous layer was further extracted three times with Et₂O. The organic layer was dried over Na₂SO₄, filtered, and concentrated to provide a colorless oil. After dissolving the oil in CH₂Cl₂ (50 mL), Et₃N (2.49 mL, 17.9 mmol) was added and the solution was brought to reflux. Succinic anhydride (411.0 mg, 4.1 mmol) was added to the reaction at refluxing temperature and the reaction was allowed to stir at reflux for an additional hour. The reaction was then quenched with sat. aq. NaHCO₃ (5 mL) at refluxing temperature and the layers were separated once cool. The organic layer was dried over Na₂SO₄, filtered, and concentrated to yield a pale yellow oil. Purification of the crude oil by silica gel flash chromatography (1:1 to 3:2 Et₂O/hexanes) provided the (bis)acetal as a clear, colorless oil (3.26 g, 86%). **TLC** *R*ₐ = 0.41 (3:2 Et₂O/hexanes); **¹H NMR** (CDCl₃, 500 MHz) δ 4.09-4.13 (m, 2H), 4.07 (dd, *J* = 6.4, 1.5 Hz, 2H), 3.99 (dd, *J* = 6.0, 2.0 Hz, 2H), 3.84 (td, *J* = 5.3, 2.0 Hz, 1H), 2.22 (d, *J* = 2.1 Hz, 1H), 1.43 (s, 6H), 1.36 (s, 6H) ppm; **¹³C NMR** (CDCl₃, 125 MHz) δ 109.2, 75.8, 71.2, 65.5, 26.5, 25.1 ppm; **IR** (thin film) ν 3463, 2943, 2932, 2866, 1454, 1363, 1246, 1211, 1153, 1065, 915, 843, 793 cm⁻¹; **HRMS** calcd for [C₁₁H₂₅O₅ Na]⁺ requires *m/z* 255.1203; found 255.1203 (ESI+).
In a flame dried 250 mL round bottom flask (bis)acetal 37 (2.75 g, 11.8 mmol) was dissolved in THF (90 mL) and cooled to 0 °C, then NaH (95%, 315.4 mg, 13.1 mmol) was added slowly and the mixture was allowed to stir at 0 °C for 45 minutes. Then benzyl bromide (1.56 mL, 13.1 mmol) was added to the reaction and the mixture was allowed to warm up to room temperature. After stirring at room temperature overnight, the reaction was heated to 55 °C and monitored by TLC for disappearance of starting material. The mixture was then quenched with sat. aq. NaHCO₃ and extracted with Et₂O and water. The aqueous layer was then extracted three more times with Et₂O and the combined organic layers were dried over Na₂SO₄, filtered, and concentrated under reduced pressure to leave a clear oil. Purification of the crude oil by silica gel flash chromatography (1:1 Et₂O/hexanes) provides the (bis)acetal as a clear, colorless oil (3.80 g, 100%). TLC Rᵢ = 0.53 (3:2 Et₂O/hexanes); ¹H NMR (CDCl₃, 500 MHz) δ 7.33-7.38 (m, 4H), 7.27-7.30 (m, 1H), 4.79 (s, 2H), 4.24 (q, J = 6.5 Hz, 2H), 4.02 (dd, J = 6.6, 1.8 Hz, 2H), 3.82 (t, J = 7.9 Hz, 2H), 3.50 (t, J = 5.6 Hz, 1H), 1.43 (s, 6H), 1.35 (s, 6H) ppm; ¹³C NMR (CDCl₃, 125 MHz) δ 138.4, 128.3, 128.0, 127.6, 109.1, 78.5, 78.0, 73.8, 66.1, 26.4, 25.3 ppm; IR (thin film) ν 2983, 2929, 2889, 2450, 1364, 1250, 1209, 1152, 1074, 1054, 890, 850, 731, 694, 662 cm⁻¹; HRMS calcd for [C₁₈H₂₆O₅H]⁺ requires m/z 323.1853; found 323.1852 (ESI+).

In a flame dried 250 mL round bottom flask (bis)acetal 38 (3.26 g, 14.1 mmol) was dissolved in THF (106 mL) and cooled to 0 °C, then NaH (374.3 mg, 15.6 mmol) was added slowly and the mixture was allowed to stir at 0 °C for 45 minutes. Then benzyl bromide (1.85 mL, 15.6 mmol) was added to the reaction and the mixture was allowed to warm up to room temperature. After stirring at room temperature overnight, the reaction was heated to 55 °C and monitored by TLC for disappearance of starting material. The mixture was then quenched with sat. aq. NaHCO₃ and extracted with Et₂O and water. The aqueous layer was then extracted three more times with Et₂O and the combined organic layers were dried over Na₂SO₄, filtered, and concentrated under reduced pressure to leave a clear oil. Purification of the crude oil by silica gel flash chromatography (1:1 Et₂O/hexanes) provides the (bis)acetal as a clear, colorless oil (4.50 g,
The (mono)benzyl-(bis)acetal 39 (3.49 g, 10.8 mmol) was dissolved in 181 mL of an 80% (v/v) acetic acid in water solution. The mixture was allowed to stir at room temperature while monitoring for the disappearance of starting material by TLC. After all starting material was consumed (approximately 24 h), the solution was concentrated under reduced pressure and purified by silica gel flash chromatography (9:1 CH₂Cl₂/MeOH) to yield a white solid (2.37 g, 91%). TLC Rₜ = 0.79 (3:2 Et₂O/hexanes); ¹H NMR (CDCl₃, 500 MHz) δ 7.32-7.38 (m, 4H), 7.27-7.31 (m, 1H), 4.79 (s, 2H), 4.16 (dt, J = 6.6, 5.0 Hz, 2H), 4.04 (dd, J = 6.6, 1.6 Hz, 2H), 3.92 (dd, J = 6.6, 1.4 Hz, 2H), 3.76 (t, J = 5.0 Hz, 1H), 1.44 (s, 6H), 1.35 (s, 6H) ppm; ¹³C NMR (CDCl₃, 125 MHz) δ 138.3, 128.4, 128.0, 127.8, 109.2, 78.5, 76.1, 74.8, 65.8, 26.5, 25.1 ppm; IR (thin film) ν 2987, 2934, 2876, 1450, 1379, 1369, 1259, 1244, 1215, 1207, 1158, 1134, 1075, 1027, 857, 848, 748, 734, 698, 664 cm⁻¹; HRMS calcd for [C₁₈H₂₆O₅H]⁺ requires m/z 323.1853; found 323.1855 (ESI+).

The (mono)benzyl-(bis)acetal 40 (4.91 g, 15.2 mmol) was dissolved in 245 mL of an 80% (v/v) acetic acid in water solution. The mixture was allowed to stir at room temperature while monitoring for the disappearance of starting material by TLC. After all starting material was consumed (approximately 20 h), the solution was concentrated and purified by silica gel flash chromatography (9:1 CH₂Cl₂/MeOH) to yield a clear, colorless thick oil (2.74 g, 75%). TLC Rₜ = 0.30 (9:1 CH₂Cl₂/MeOH); ¹H NMR (CD₂OD, 500 MHz) δ 7.40 (d, J = 7.6 Hz, 2H), 7.32 (t, J = 7.5 Hz, 2H), 7.26 (t, J = 7.3 Hz, 1H), 4.70 (s, 2H), 3.86 (q, J = 5.1 Hz, 2H), 3.63-3.67 (m, 4H), 3.61 (t, J = 4.2 Hz, 1H) ppm; ¹³C NMR (CD₂OD, 125 MHz) δ 139.9, 129.3, 129.2, 128.7, 80.5, 75.5, 73.0, 64.2 ppm; IR (thin film) ν 3305, 2921, 2868, 1450, 1393, 1319, 1246, 1213, 1131, 1103, 1074, 1038, 1025, 980, 882, 862, 751, 731, 690 cm⁻¹; HRMS calcd for [C₁₂H₁₈O₅H]⁺ requires m/z 243.1227; found 243.1223 (ESI+).
In a 100 mL round bottom flask, diisopropyl azodicarboxylate (1.85 mL, 9.6 mmol) and triphenylphosphine (2.73 g, 10.4 mmol) were added to a mixture of tetraol 41 (1.0 g, 4.2 mmol) in toluene (34 mL). The mixture was brought to reflux and monitored for disappearance of starting material by TLC (approximately 8 h). After the starting material was consumed, the excess diisopropyl azodicarboxylate was quenched with methanol and the mixture was concentrated under reduced pressure. Purification of the crude reaction mixture by silica gel flash chromatography (9:1 toluene/acetone) yielded a mixture containing the desired bis-epoxide. Further purification by silica gel flash chromatography (gradient elution: 10:1→6:1 hexanes/EtOAc) provided the bis-epoxide as a clear, colorless oil (524.6 mg, 62%). The spectral data for this compound matched that which had been previously reported.\(^6\)

In a 250 mL round bottom flask, diisopropyl azodicarboxylate (5.06 mL, 26.2 mmol) and triphenylphosphine (7.48 g, 28.5 mmol) were added to a mixture of the tetraol 42 (2.74 g, 11.4 mmol) in toluene (92 mL). The mixture was brought to reflux and monitored for disappearance of starting material by TLC (approximately 8 h). After the starting material was consumed, the excess diisopropyl azodicarboxylate was quenched with methanol and the mixture was concentrated under reduced pressure. Purification of the crude reaction mixture by silica gel flash chromatography (9:1 toluene/acetone) yielded a mixture containing the desired bis-epoxide. Further purification by silica gel flash chromatography (gradient elution: 10:1→6:1 hexanes/EtOAc) provided the bis-epoxide as a clear, colorless oil (748.6 mg, 33%). The spectral data for this compound matched that which had been previously reported.\(^6\)

\(^6\) Kapitán, P. & Gracza, T. Stereocontrolled oxycarbonylation of 4-benzyloxyhepta-1,6-diene-3,5-diols promoted by chiral palladium(II) complexes. Tetrahedron: Asymmetry, 19, 38–44 (2008).
In a 100 mL round bottom flask, bis-epoxide 43 (250 mg, 1.2 mmol) was dissolved in Et₂O (56 mL) and cooled to 0 °C. Upon cooling of the solution to 0 °C, LiAlH₄ (139.4 mg, 3.7 mmol) was slowly added and the mixture was allowed to stir while gradually warming to room temperature. The reaction mixture was monitored by TLC for disappearance of starting material (approximately 8 h) and then quenched with 2.2 mL of water, followed by 2.2 mL of a 10% NaOH in water solution, and finally another 6.6 mL of water. The reaction mixture was then separated and the organic layer was dried over Na₂SO₄, filtered, and concentrated under reduced pressure. Purification of the resulting oil by silica gel flash chromatography (1:1 hexanes/EtOAc) yielded diol 20 as a clear, colorless oil (187.5 mg, 73%). The spectral data for this compound matched that which had been previously reported.⁵

In a 100 mL round bottom flask, bis-epoxide 44 (250 mg, 1.2 mmol) was dissolved in Et₂O (56 mL) and cooled to 0 °C. Upon cooling of the solution to 0 °C, LiAlH₄ (139.4 mg, 3.7 mmol) was slowly added and the mixture was allowed to stir while gradually warming to room temperature. The reaction mixture was monitored by TLC for disappearance of starting material (approximately 8 h) and then quenched with 2.2 mL of water, followed by 2.2 mL of a 10% NaOH in water solution, and finally another 6.6 mL of water. The reaction mixture was then separated and the organic layer was dried over Na₂SO₄, filtered, and concentrated under reduced pressure. Purification of the resulting oil by silica gel flash chromatography (1:1 hexanes/EtOAc) yielded diol 19 as a clear, colorless oil (213 mg, 83%). The spectral data for this compound matched that which had been previously reported.⁵

**Solid Phase Synthesis of Peptide Catalyst 10.**

Peptide catalysts used for the reactions in Table 1 were synthesized on solid support using commercially available Wang polystyrene resin preloaded with the appropriate amino acid. Couplings were performed using 5.0 equiv of amino acid derivative, 5.0 equiv of HBTU, and 10.0 equiv of Hunig’s base in DMF, for 3 h. Deprotections were performed using 20% piperidine in DMF for 20 min (to minimize diketopiperazine formation; dipeptides were deprotected using 50% piperidine in DMF for 5 min). Peptides were cleaved from solid support using 5.0 equiv of
DBU in a mixture of MeOH:DMF (9:1) for 3 h. The peptides were passed through a plug of silica using 10:1 CH$_2$Cl$_2$/MeOH to remove the DBU, concentrated under reduced pressure, and then placed on high vacuum overnight. The resulting yellow residues were purified by reverse phase chromatography on a Biotage SP4 using C18 silica gel. The peptides were purified by a gradient of 40% MeOH/water to 75% MeOH/water over 30 column volumes.

Pale yellow solid: mp = 95–100 °C; $^1$H NMR (major conformer) (CD$_3$OD, 500 MHz) δ 7.57 (s, 1H), 6.80 (s, 1H), 4.54 (dd, $J = 9.7, 4.7$ Hz, 1H), 4.50-4.41 (m, 3H), 3.73 (dd, $J = 10.5, 5.0$ Hz, 1H), 3.69 (s, 3H), 3.66 (s, 3H), 3.57 (dd, $J = 10.5, 2.9$ Hz, 1H), 2.98 (dd, $J = 15.4, 4.6$ Hz, 1H), 2.90 (dd, $J = 15.4, 9.8$ Hz, 1H), 2.25 (dt, $J = 13.5, 7.1$ Hz, 1H), 2.10-2.02 (m, 4H), 1.96 (dt, $J = 13.2, 5.9$ Hz, 1H), 1.34 (s, 9H), 1.19 (s, 9H), 0.91 (d, $J = 10.0$ Hz, 3H), 0.90 (d, $J = 10.0$ Hz, 3H) ppm; $^{13}$C-NMR (CD$_3$OD, 125 MHz) δ 176.2, 174.7, 174.3, 171.7, 157.4, 139.2, 129.1, 128.6, 80.6, 75.5, 71.2, 68.2, 60.9, 55.9, 52.6, 52.4, 41.7, 39.0, 38.3, 37.0, 31.8, 28.9, 28.7, 28.6, 27.2, 25.8, 25.6, 25.3, 23.2, 22.6 ppm; IR (thin film) ν 3316, 2973, 2872, 1743, 1643, 1507, 1443, 1391, 1366, 1324, 1252, 1171, 1109, 1054, 1025 cm$^{-1}$; HRMS calcd for [C$_{34}$H$_{56}$N$_6$O$_8$ H]$^+$ requires m/z 677.4232; found 677.4217 (ESI+); $[\alpha]_{D}^{25.0} = -23.4$ (c 1.0, CHCl$_3$).

**Catalytic Enantioselective Sulfonylation Reactions.**

General procedure for initial screenings: To an oven-dried 1 dram vial equipped with a magnetic stir bar was added 2,4,6-tri-O-benzyl-myko-inositol (1) (45.1 mg, 0.10 mmol) and CH$_2$Cl$_2$ (0.4 mL). Solid NaHCO$_3$ (9.2 mg, 0.11 mmol) was then added followed by peptide catalyst 10 (3.4 mg, 0.005 mmol). The reaction was cooled to 0 °C and 4-nitrobenzenesulfonyl chloride (22.2 mg, 0.10 mmol) was added. The reaction was allowed to stir at 0 °C for 24 h at
which point it was diluted with CH₂Cl₂ (3 mL), filtered through celite, and concentrated under reduced pressure. The resulting yellow oil was purified by silica gel flash chromatography.

**General procedure for sulfonylation using condition A (Table 2):**
To an oven-dried 1 dram vial equipped with a magnetic stir bar was added diol substrate (0.10 mmol) and CH₂Cl₂ (0.4 mL). The peptide catalyst 10 (3.4 mg, 0.005 mmol) was then added and the reaction was cooled to 0 °C. 4-Nitrobenzenesulfonyl chloride (28.8 mg, 0.13 mmol) was added followed by 0.2 mL sat. aq. NaHCO₃ solution. The reaction was monitored by TLC for the disappearance of the sulfonyl chloride and allowed to stir at 0 °C for 5-48 h. The biphasic reaction mixture was diluted with CH₂Cl₂ (2 mL) and sat. aq. NaHCO₃, and the layers were separated. The aqueous layer was extracted with CH₂Cl₂ (2 x 2 mL). The combined organic layers were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The resulting yellow oil was purified by silica gel flash chromatography.

**General procedure for sulfonylation using condition B (Table 2):**
To an oven-dried 1 dram vial equipped with a magnetic stir bar was added diol substrate (0.10 mmol) and CH₂Cl₂ (0.4 mL). The peptide catalyst 10 (3.4 mg, 0.005 mmol) was then added and the reaction was cooled to 0 °C. 4-Nitrobenzenesulfonyl chloride (28.8 mg, 0.13 mmol) was added followed by 2,6-lutidine (17.5 µL, 0.15 mmol). The reaction was monitored by TLC for the disappearance of the sulfonyl chloride and allowed to stir at 0 °C for 5-48 h. The reaction mixture was diluted with CH₂Cl₂ (2 mL), and 1M HCl (0.5 mL) was added. The layers were separated, and the aqueous layer was extracted with CH₂Cl₂ (2 x 2 mL). The combined organic layers were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The resulting yellow oil was purified by silica gel flash chromatography.

Purified by silica gel flash chromatography (gradient elution: 4:1→2:1 hexanes/EtOAc); pale yellow solid (49.8 mg, 78%): **TLC Rₚ = 0.52 (2:1 hexanes/EtOAc); mp = 117–120 °C; **¹H NMR (CDCl₃, 500 MHz) δ 8.00-7.97 (m, 2H), 7.95-7.92 (m, 2H), 7.47-7.30 (m, 10H), 7.28-7.25 (m, 3H), 7.07-7.03 (m, 2H), 4.91 (d, J = 11.5 Hz, 1H), 4.83 (d, J = 11.4 Hz, 1H), 4.82 (d, J = 11.5 Hz, 1H), 4.81 (d, J = 11.4 Hz, 1H), 4.72 (d, J = 11.2 Hz, 1H), 4.46 (dd, J = 10.0, 2.6 Hz, 1H), 4.39 (d, J = 11.2 Hz, 1H), 4.27 (t, J = 2.6 Hz, 1H), 3.87 (t, J = 9.5 Hz, 1H), 3.65 (t, J = 9.5 Hz, 1H), 3.59
(ddd, J = 9.6, 6.2, 2.6 Hz, 1H), 3.51 (td, J = 9.1, 2.6 Hz, 1H), 2.38 (d, J = 2.6 Hz, 1H), 2.16 (d, J = 6.2 Hz, 1H) ppm; 13C NMR (CDCl3, 125 MHz) δ 150.4, 141.7, 138.2, 137.9, 137.6, 129.0, 128.7, 128.6, 128.3, 128.1, 127.9, 127.0, 124.1, 82.5, 81.0, 78.9, 78.6, 75.8, 75.1, 75.04, 75.01, 71.7 ppm; IR (thin film) ν 3549, 3105, 3065, 2918, 1608, 1533, 1497, 1454, 1404, 1350, 1314, 1186, 1114, 1071, 1027, 966, 858, 835 cm⁻¹; HRMS calcd for [C33H33NO10S Na]⁺ requires m/z 658.1717; found 658.1715 (ESI+); [α]D25.0 = −14.0 (c 1.0, CHCl3, 97:3 er); HPLC Chiracel AD; 35% ethanol/hexanes; flow rate = 0.5 mL/min.; tR = 36.4 min. (major ent.), tR = 31.6 min. (minor ent.).
(2H), 4.85 (d, $J = 11.6$ Hz, 1H), 4.79 (d, $J = 10.9$ Hz, 1H), 4.75 (d, $J = 10.9$ Hz, 1H), 4.73 (d, $J = 12.0$ Hz, 1H), 4.67 (d, $J = 11.6$ Hz, 1H), 4.54 (dd, $J = 9.7$, 2.8 Hz, 1H), 4.46 (d, $J = 12.0$ Hz, 1H), 4.25 (t, $J = 2.7$ Hz, 1H), 3.82 (t, $J = 9.1$ Hz, 1H), 3.65 (t, $J = 9.1$ Hz, 1H), 3.57-3.53 (m, 2H), 1.97 (d, $J = 5.6$ Hz, 1H), 0.84 (s, 9H), 0.05 (s, 3H), –0.09 (s, 3H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) δ 150.3, 141.7, 138.3, 138.1, 137.8, 128.7, 128.6, 128.4, 128.0, 127.9, 127.2, 125.9, 124.1, 82.9, 81.3, 79.4, 78.4, 75.6, 75.5, 74.7, 74.6, 71.6, 25.9, 17.8, –4.07, –4.13 ppm; IR (thin film) ν 3556, 3033, 2927, 2855, 1608, 1534, 1497, 1455, 1404, 1350, 1313, 1258, 1208, 1187, 1158, 1113, 1094, 1071, 971, 937, 829 cm$^{-1}$; HRMS calcd for [C$_{39}$H$_{47}$NO$_{10}$SSi Na]$^+$ requires m/z 775.2582; found 775.2575 (ESI+); $[\alpha]_D^{25.0} = -14.1$ (c 1.0, CHCl$_3$, 95.5:4.5 er); HPLC Chiracel AD; 10% ethanol/hexanes; flow rate = 1.0 mL/min.; $t_r = 8.7$ min. (major ent.), $t_r = 7.0$ min. (minor ent.).

Purified by silica gel flash chromatography (gradient elution: 4:1→2:1 hexanes/EtOAc); pale yellow oil (37.8 mg, 61%): TLC $R_f$ = 0.83 (1:1 hexanes/EtOAc); $^1$H NMR (CDCl$_3$, 500 MHz) δ 7.93 (s, 4H), 7.24-7.38 (m, 13H), 7.03 (dd, $J = 7.7$, 1.4 Hz, 2H), 4.86 (AB quartet, $J$= 11.3, 8.6 Hz, 2H) 4.65 (d, $J = 11.5$ Hz, 1H), 4.55 (d, $J = 11.5$ Hz, 1H), 4.45 (dd, $J = 9.6$, 2.8 Hz, 1H), 4.44 (d, $J = 10.8$ Hz, 1H), 4.33 (t, $J = 2.7$ Hz, 1H), 4.14 (d, $J = 10.8$ Hz, 1H), 3.88 (ddd, $J = 11.4$, 9.4, 4.6 Hz, 1H), 3.62 (ddd, $J = 9.4$, 4.8, 2.6 Hz, 1H), 2.50 (dt, $J = 12.8$, 4.9 Hz, 1H), 2.40 (d, $J = 4.8$ Hz, 1H), 1.22 (q, $J = 11.9$ Hz, 1H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) δ 150.3, 142.0, 138.2, 138.0, 137.3, 129.1, 128.6, 128.5, 128.3, 128.1, 127.96, 127.93, 127.90, 127.8, 123.9, 84.7, 79.1 75.9, 75.5, 74.4, 73.5, 72.1, 71.8, 31.5 ppm; IR (thin film) 3555, 3105, 3060, 3028, 2921, 2864, 1605, 1528, 1495, 1450, 1401, 1348, 1307, 1181, 1111, 1091, 1070, 1052, 968, 910, 837, 735, 694, 617 cm$^{-1}$; HRMS calcd for [C$_{33}$H$_{33}$O$_9$NS Na]$^+$ requires m/z 642.1768; found 642.1766 (ESI+); $[\alpha]_D^{25.0} = -11.5$ (c 1.0, CHCl$_3$, 96:4 er); HPLC Chiracel AD; 25% 2-propanol/hexanes; flow rate = 1.0 mL/min.; $t_r = 20.4$ min. (major ent.), $t_r = 15.9$ min. (minor ent.).
Purified by silica gel flash chromatography (gradient elution: 4:1→3:1 hexanes/EtOAc); white solid (49.7 mg, 78%): **TLC** \( R_f = 0.52 \) (2:1 hexanes/EtOAc); **mp** = 147–148 °C (decomp.); **\(^1\)H NMR** (CDCl\(_3\), 500 MHz) \( \delta \) 7.89 (s, 4H), 7.47-7.52 (m, 13H), 7.13-7.11 (m, 2H), 4.99 (s, 2H), 4.94 (d, \( J = 11.1 \) Hz, 1H), 4.73 (d, \( J = 10.1 \) Hz, 1H), 4.54 (t, \( J = 2.5 \) Hz, 1H), 4.51 (dd, \( J = 10.7, 1.1 \) Hz, 1H), 4.49-4.45 (m, 3H), 4.09 (d, \( J = 10.2 \) Hz, 1H), 3.77 (dt, \( J = 10.2, 2.9 \) Hz, 1H), 2.52 (d, \( J = 3.3 \) Hz, 1H) ppm; **\(^{13}\)C NMR** (CDCl\(_3\), 125 MHz) \( \delta \) 201.1, 150.3, 141.2, 137.6, 137.0, 136.5, 129.2, 128.5, 128.2, 128.19, 128.12, 128.0, 123.9, 82.1, 80.9, 80.1, 77.9, 76.4, 73.6, 73.5, 71.4 ppm; **IR** (thin film) ν 3550, 3107, 3062, 2920, 2897, 2872, 1743, 1608, 1533, 1497, 1455, 1405, 1350, 1315, 1187, 1147, 1120, 1081, 1028, 1014, 979, 943, 912, 857, 830 cm\(^{-1}\); **HRMS** calcd for \([\text{C}_{33}\text{H}_{31}\text{NO}_{10}\text{S}\text{Na}]^+\) requires \( m/z \) 656.1561; found 656.1558 (ESI+); \( [\alpha]_D^{25.0} = -2.3 \) (c 1.0, CHCl\(_3\), 96:4 er); **HPLC** Chiracel OD; 35% ethanol/hexanes; flow rate = 1.0 mL/min.; \( t_r = 9.5 \) min. (major ent.), \( t_c = 12.1 \) min. (minor ent.).

Purified by silica gel flash chromatography (gradient elution: 6:1→2:1 hexanes/EtOAc); pale yellow oil (50.0 mg, 79%): **TLC** \( R_f = 0.53 \) (2:1 hexanes/EtOAc); **\(^1\)H NMR** (CDCl\(_3\), 500 MHz) \( \delta \) 7.92 (s, 4H), 7.38-7.26 (m, 13H), 7.10-7.06 (m, 2H), 5.45 (d, \( J = 1.1 \) Hz, 1H), 5.40 (d, \( J = 1.1 \) Hz, 1H), 4.90 (d, \( J = 11.2 \) Hz, 1H), 4.87 (d, \( J = 11.2 \) Hz, 1H), 4.77 (d, \( J = 11.5 \) Hz, 1H), 4.59 (d, \( J = 11.1 \) Hz, 1H), 4.53 (d, \( J = 11.5 \) Hz, 1H), 4.37 (dd, \( J = 9.5, 2.8 \) Hz, 1H), 4.35 (t, \( J = 2.8 \) Hz, 1H), 4.30 (d, \( J = 9.5 \) Hz, 1H), 4.24 (d, \( J = 11.1 \) Hz, 1H), 4.13 (d, \( J = 9.2 \) Hz, 1H), 3.55-3.51 (m, 1H), 2.46 (t, \( J = 1.7 \) Hz, 1H) ppm; **\(^{13}\)C NMR** (CDCl\(_3\), 125 MHz) \( \delta \) 150.2, 141.8, 139.4, 138.0, 137.7, 137.2, 129.0, 128.6, 128.2, 128.00, 127.98, 127.92, 127.85, 127.83, 127.1, 123.9, 110.2, 84.0, 79.0, 78.2, 76.7, 76.0, 74.2, 73.0, 72.7 ppm; **IR** (thin film) ν 3572, 2884, 2871, 1532, 1497, 1454, 1404, 1350, 1314, 1187, 1119, 1097, 1086, 1027, 976, 949, 856, 836 cm\(^{-1}\); **HRMS** calcd for \([\text{C}_{34}\text{H}_{33}\text{NO}_{9}\text{S}\text{Na}]^+\) requires \( m/z \) 654.1768; found 654.1770 (ESI+); \( [\alpha]_D^{25.0} = -11.1 \) (c 1.0, CHCl\(_3\), 96.5:3.5 er); **HPLC** Chiracel OD; 30% ethanol/hexanes; flow rate = 1.0 mL/min.; \( t_r = 11.4 \) min. (major ent.), \( t_c = 20.2 \) min. (minor ent.).
Purified by silica gel flash chromatography (gradient elution: 4:1→2:1 hexanes/EtOAc); colorless oil (32.5 mg, 58%): \textbf{TLC $R_f$} = 0.36 (2:1 hexanes/EtOAc); \textbf{$^1$H NMR} (CDCl$_3$, 500 MHz) δ 8.01-7.99 (m, 2H), 7.96-7.94 (m, 2H), 7.38-7.29 (m, 5H), 7.26-7.22 (m, 3H), 7.05-7.02 (m, 2H), 4.85 (d, $J = 11.4$ Hz, 1H), 4.83 (d, $J = 11.4$ Hz, 1H), 4.72 (d, $J = 11.2$ Hz, 1H), 4.42 (dd, $J = 10.0$, 2.6 Hz, 1H), 4.37 (d, $J = 11.2$ Hz, 1H), 4.01 (t, $J = 2.6$ Hz, 1H), 3.79 (t, $J = 9.6$ Hz, 1H), 3.70 (s, 3H), 3.62-3.55 (m, 2H), ppm; \textbf{$^{13}$C NMR} (CDCl$_3$, 125 MHz) δ 150.4, 141.7, 138.3, 137.7, 129.0, 128.6, 128.0, 127.93, 127.91, 127.0, 124.1, 82.7, 81.2, 80.9, 78.5, 75.2, 75.04, 74.96, 71.7, 62.3 ppm; \textbf{IR} (thin film) ν 3557, 3476, 2931, 1608, 1533, 1498, 1454, 1404, 1351, 1314, 1292, 1267, 1187, 1110, 1071, 1015, 965, 898, 836 cm$^{-1}$; \textbf{HRMS} calcd for [C$_{27}$H$_{29}$NO$_{10}$S Na]$^+$ requires m/z 397.1622; found 397.1618 (ESI+); [$\alpha$]$_D^{25.0}$ = −17.5 (c 1.0, CHCl$_3$, 88:12 er); \textbf{HPLC} Chiracel AD; 45% ethanol/hexanes; flow rate = 1.0 mL/min.; $t_r$ = 19.8 min. (major ent.), $t_r$ = 8.1 min. (minor ent.).

Purified by silica gel flash chromatography (gradient elution: 3:1→1:1 hexanes/EtOAc); colorless oil (19.8 mg, 66%): \textbf{TLC $R_f$} = 0.33 (1:1 hexanes/EtOAc); \textbf{$^1$H NMR} (CDCl$_3$, 500 MHz) δ 8.42-8.38 (m, 2H), 8.13-8.09 (m, 2H), 4.58 (tt, $J = 10.7$, 4.5 Hz, 1H), 3.65-3.57 (m, 1H), 2.22-2.20 (m, 1H), 1.95-1.78 (m, 3H), 1.60 (br s, 1H), 1.53 (dt, $J = 11.7$, 10.7 Hz, 1H), 1.49-1.40 (m, 1H), 1.29-1.19 (m, 2H) ppm; \textbf{$^{13}$C NMR} (CDCl$_3$, 125 MHz) δ 150.6, 143.2, 128.9, 137.7, 124.5, 80.9, 68.1, 41.3, 33.8, 31.6, 19.6 ppm; \textbf{IR} (thin film) ν 3396, 2945, 2861, 1608, 1532, 1454, 1404, 1352, 1312, 1184, 1096, 1064, 928, 905, 855, 825 cm$^{-1}$; \textbf{HRMS} calcd for [C$_{12}$H$_{15}$NO$_6$S Na]$^+$ requires m/z 324.0693; found 324.0511 (ESI+); \textbf{HPLC} Chiracel OJ-H; 20% 2-propanol/hexanes; flow rate = 1.0 mL/min.; $t_r$ = 28.0 min., $t_r$ = 33.1 min.

Purified by silica gel flash chromatography (gradient elution: 5:1→1:1 hexanes/EtOAc); pale yellow solid (29.3 mg, 74%): \textbf{TLC $R_f$} = 0.66 (1:1 hexanes/EtOAc); mp = 56–58°C; \textbf{$^1$H NMR} (CDCl$_3$, 500 MHz) δ 8.34 (dt, $J = 8.9$, 2.3 Hz, 2H), 8.07 (dt, $J = 8.8$, 2.1 Hz, 2H), 7.29-7.36 (m,
5H), 5.12 (qd, J = 6.6, 2.3 Hz, 1H), 4.74 (d, J = 11.4 Hz, 1H), 4.59 (d, J = 11.4 Hz, 1H), 3.72-3.78 (m, 1H), 3.48 (dd, J = 6.7, 2.3 Hz, 1H), 1.56 (d, J = 5.3 Hz, 1H), 1.37 (d, J = 6.6 Hz, 3H), 1.22 (d, J = 6.3 Hz, 3H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) $\delta$ 150.6, 143.0, 137.6, 129.0, 128.5, 128.0, 127.9, 124.4, 84.2, 82.0, 74.1, 67.6, 20.1, 15.7 ppm; IR (thin film) $\nu$ 3551, 3448, 3105, 150.6, 143.0, 137.6, 129.0, 128.5, 128.0 cm$^{-1}$; HRMS calcd for [C$_{18}$H$_{21}$NO$_7$S H]$^+$ requires m/z 396.1111; found 396.1111 (ESI+); $[\alpha]_D^{25.0} = 0$ (c 2.0, CHCl$_3$, 89:11 er); HPLC Chiracel AD; 10% 2-propanol/hexanes; flow rate = 1.0 mL/min.; $t_r$ = 14.3 min. (major ent.), $t_r$ = 17.2 min. (minor ent.).

Purified by silica gel flash chromatography (gradient elution: 5:1→1:1 hexanes/EtOAc); pale yellow oil (20.2 mg, 51%): TLC $R_f$ = 0.57 (1:1 hexanes/EtOAc); $^1$H NMR (CDCl$_3$, 500 MHz) $\delta$ 8.15 (dt, J = 9.0, 2.1 Hz, 2H), 8.00 (dt, J = 8.9, 2.2 Hz, 2H), 7.29 (dd, J = 4.5, 2.0 Hz, 3H), 7.14-7.16 (m, 2H), 4.94 (p, J = 6.6 Hz, 1H), 4.60 (d, J = 11.3 Hz, 1H), 4.53 (d, J = 11.3 Hz, 1H), 3.79-3.86 (m, 1H), 3.25 (dd, J = 7.1, 2.9 Hz, 1H), 1.80 (d, J = 8.9 Hz, 1H), 1.44 (d, J = 6.5 Hz, 3H), 1.21 (d, J = 6.4 Hz, 3H) ppm; $^{13}$C NMR (CDCl$_3$, 125 MHz) $\delta$ 150.4, 142.7, 137.2, 128.9, 128.4, 128.1, 127.3, 124.2, 83.9, 82.2, 75.2, 66.7, 20.4, 17.8 ppm; IR (thin film) $\nu$ 3555, 3428, 3105, 150.4, 142.7, 137.2, 128.9, 128.4, 128.1, 127.3, 124.2, 83.9, 82.2, 75.2, 66.7, 20.4, 17.8 cm$^{-1}$; [\alpha]_D^{25.0} = -1.4 (c 1.0, CHCl$_3$, 70:30 er); HRMS calcd for [C$_{18}$H$_{21}$NO$_7$S H]$^+$ requires m/z 396.1111; found 396.1111 (ESI+); HPLC Chiracel AD; 10% 2-propanol/hexanes; flow rate = 1.0 mL/min.; $t_r$ = 23.5 min. (major ent.), $t_r$ = 21.2 min. (minor ent.).

**Kinetic Resolution of Racemic (Mono)sulfonate 2a.**

To an oven-dried 1 dram vial equipped with a magnetic stir bar was added (mono)nosylate 2a (32.0 mg, 0.05 mmol) and CH$_2$Cl$_2$ (0.2 mL). The peptide catalyst 10 (1.7 mg, 0.0025 mmol) was then added and the reaction was cooled to 0 °C. 4-Nitrobenzenesulfonyl chloride (6.1 mg, 0.276
mmol) was added followed by 0.1 mL sat. aq. NaHCO₃ solution. The reaction was monitored by TLC for the disappearance of the sulfonyl chloride and allowed to stir at 0 °C for 4 h. The biphasic reaction mixture was diluted with CH₂Cl₂ (2 mL) and sat. aq. NaHCO₃, and the layers were separated. The aqueous layer was extracted with CH₂Cl₂ (2 x 2 mL). The combined organic layers were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The resulting yellow oil was purified by silica gel flash chromatography (gradient elution: 4:1 → 2:1 hexanes/EtOAc) to obtain the starting material as pale yellow solid (16.6 mg, 52%) and the bis(nosylate) as a pale yellow solid (18.2 mg, 44%)

\[ \text{O} \text{Bn} \text{NsO} \text{BnO} \text{H} \text{O} \text{BnO} \text{ONs} \]

\[ \text{OBn(PhO)₂PO} \text{BnOHO} \text{BnO ONs} \]

**TLC** \( R_f = 0.54 \) (4:1 hexanes/EtOAc); **mp** = 189–192 °C; \(^1\)H NMR (CD₂Cl₂, 500 MHz) \( \delta \) 8.07-8.04 (m, 4H), 7.99-7.96 (m, 4H), 7.41-7.34 (m, 5H), 7.26-7.23 (m, 6H), 7.06-7.04 (m, 4H), 4.86 (s, 2H), 4.67 (d, \( J = 11.3 \) Hz, 2H), 4.52 (dd, \( J = 10.0, 2.6 \) Hz, 2H), 4.46 (t, \( J = 2.6 \) Hz, 1H), 4.40 (d, \( J = 11.3 \) Hz, 2H), 3.85 (t, \( J = 9.6 \) Hz, 2H), 3.52 (td, \( J = 9.5, 3.2 \) Hz, 1H), 2.42 (d, \( J = 3.2 \) Hz, 1H) ppm; \(^{13}\)C NMR (CD₂Cl₂, 125 MHz) \( \delta \) 151.0, 141.8, 138.0, 137.9, 129.4, 128.8, 128.6, 128.4, 128.2, 128.1, 127.5, 124.7, 81.4, 81.0, 78.9, 78.2, 76.8, 75.4, 75.3 ppm; **IR** (thin film) \( \nu \) 3559, 3107, 2917, 2878, 1608, 1533, 1498, 1455, 1405, 1351, 1314, 1292, 1188, 1118, 1095, 1028, 1014, 977, 940, 858, 841, 821 cm⁻¹; **HRMS** calcd for [C₃₉H₃₆N₂O₁₄S₂Na]⁺ requires \( m/z \) 843.1500; found 843.1509 (ESI+).

**Determination of Absolute Stereochemistry**

Monophosphate 24 (40.0 mg, 0.059 mmol) was dissolved in 236.0 µL of CH₂Cl₂ and \( N,N \)-dimethyl-4-aminopyridine (7.2 mg, 0.059 mmol), solid NaHCO₃ (10.9 mg, 0.13 mmol), and 4-nitrobenzenesulfonyl chloride (25.9 mg, 0.117 mmol) were added respectively. The reaction mixture was allowed to stir for 48 h and then the mixture was run through a short plug of celite and concentrated under reduced pressure. Purification of the crude oil by silica gel flash chromatography (gradient elution: 4:1 → 2:1 hexanes/EtOAc) provided 25 as a light yellow oil (20.0 mg, 39%). **TLC** \( R_f = 0.56 \) (2:1 hexanes/EtOAc); \(^1\)H NMR (CDCl₃, 500 MHz) \( \delta \) 7.94 (dd, \( J = 8.9, 1.3 \) Hz, 2H), 7.89 (dd, \( J = 8.8, 1.4 \) Hz, 2H), 7.14-7.39 (m, 23H), 7.02-7.03 (m, 2H), 4.79 (d,
\[ J = 11.4 \text{ Hz, 1H}) , 4.73 (dd, J = 11.2, 2.2 \text{ Hz, 2H}) , 4.61 (dd, J = 6.4, 4.2 \text{ Hz, 3H}) , 4.48 (s, 1H), 4.41 (dd, J = 8.3, 1.8 \text{ Hz, 1H}) , 4.33 (d, J = 11.2 \text{ Hz, 1H}) , 3.92 (t, J = 9.6 \text{ Hz, 1H}) , 3.86 (t, J = 9.5 \text{ Hz, 1H}) , 3.52 (t, J = 9.3 \text{ Hz, 1H}) , 2.30 (d, J = 2.0 \text{ Hz, 1H}) \text{ ppm;} \]

\[ ^{13}C \text{ NMR (CDCl}_3, 125 MHz) \delta 150.6, 138.0, 137.9, 137.7, 129.95, 129.85, 129.1, 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.5, 127.2, 125.69, 125.66, 125.5, 124.1, 120.1, 120.02, 119.98, 119.9, 81.5, 79.34, 79.30, 78.71, 78.65, 78.5, 78.1, 76.0, 75.3, 75.1, 74.8 \text{ ppm;} \]

\[ ^{31}P \text{ NMR (CDCl}_3, 202 MHz) \delta -12.44 \text{ ppm;} \]

\[ ^{\text{IR}} \text{(thin film) } \nu 3567, 3424, 3105, 3064, 3028, 2921, 2868, 2844, 1949, 1867, 1806, 1720, 1588, 1531, 1488, 1454, 1347, 1311, 1288, 1217, 1188, 1163, 1115, 1091, 1070, 1024, 960, 829, 737, 686, 615 \text{ cm}^{-1}; \]

\[ [\alpha]_{D}^{25^0} = -20.6 (c 1.0, \text{ CHCl}_3, 99:1 \text{ er}); \]

\[ ^{\text{HRMS}} \text{ caled for } [C_{45}H_{42}O_{13}NPS Na]^+ \text{ requires } m/z \text{ 868.2187;} \text{ found } 868.2162 \text{ (ESI+);} \]

\[ ^{\text{HPLC}} \text{ Chiracel OD; 15% ethanol/hexanes; flow rate = 0.75 mL/min.; } t_r = 20.6 \text{ min. (major ent.), } t_r = 16.2 \text{ min. (minor ent.).} \]
NMR Data
$^{31}$P NMR: