Lewis Base-Catalyzed, Enantioselective, Intramolecular Sulfenoamination of Olefins

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SUPPORTING INFORMATION

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**General Experimental**

All reactions were performed in oven (110 °C) and/or flame-dried glassware under an atmosphere of dry argon unless otherwise noted. Reaction solvents tetrahydrofuran (Fisher, HPLC grade), ether (Fisher, BHT stabilized ACS grade), and dichloromethane (Fisher, unstabilized HPLC grade) were dried by percolation through two columns packed with neutral alumina under a positive pressure of argon. Reaction solvents hexanes (Fisher, OPTIMA grade) and toluene (Fisher, ACS grade) were dried by percolation through a column packed with neutral alumina and a column packed with Q5 reactant (supported copper catalyst for scavenging oxygen) under a positive pressure of argon. Solvents for filtration, transfers, and chromatography were certified ACS grade. “Brine” refers to a saturated solution of sodium chloride in water. All reaction temperatures correspond to internal temperatures measured with Teflon coated thermocouples. A ThermoNesLab CC-100 Cryocool with an attached Cryotrol was used for reactions at subambient temperatures.

$^1$H and $^{13}$C NMR spectra were recorded on Varian Unity (400 MHz, $^1$H; 101 MHz, $^{13}$C) or Inova (500 MHz, $^1$H; 126 MHz, $^{13}$C) spectrometers. $^{31}$P NMR and $^{19}$F spectra were recorded on Inova (202 MHz) and Inova (470 MHz) spectrometers respectively. Acquisition times were 4.096 s for $^1$H NMR, 1.024 s for $^{13}$C NMR, 0.655 s for $^{31}$P NMR, and 0.328 s for $^{19}$F NMR. Spectra are referenced to residual chloroform ($\delta = 7.26$ ppm, $^1$H; 77.0 ppm, $^{13}$C). Chemical shifts are reported in parts per million, multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), p (pentet), h (hextet), sept (septet), m (multiplet), and br (broad). Coupling constants, $J$, are reported in Hertz, and integration is provided and assignments are indicated. Assignments were confirmed through 2-D COSY, HMQC/HSQC, and HMBC experiments. Elemental analysis was performed by the University of Illinois Microanalysis Laboratory or Robertson Microlit Laboratories. Mass spectrometry (MS) was performed by the University of Illinois Mass Spectrometry Laboratory. Electron Impact (EI) spectra were performed at 70 eV using methane as the carrier gas on a Finnegan-MAT C5 spectrometer. Electrospray Ionization (ESI) spectra were performed on a Micromass Q-Tof Ultima spectrometer. Data are reported in the form of m/z (intensity relative to the base peak = 100). Infrared spectra (IR) were recorded on a Perkin-Elmer FT-IR system with NaCl salt plates or as neat. The peaks are reported in cm$^{-1}$ with indicated relative intensities: s (strong, 0–33% T); m (medium, 34–66% T), w (weak, 67–100% %), and br (broad). Melting points (mp) were determined on a Thomas-Hoover capillary melting
point apparatus in sealed tubes and are corrected.

Analytical thin-layer chromatography was performed on Merck silica gel 60 F$_{254}$ or Merck silica gel 60 RP-18 F$_{254s}$ plates. Visualization was accomplished with UV light and/or Ceric Ammonium Molybdate (CAM) solution. R$_f$ values reported were measured using a 10 × 2 cm TLC plate in a developing chamber containing the solvent system described. Flash chromatography was performed using Merck silica gel 60 230–400 mesh (60–63 µ, 60 Å pore size).

Analytical supercritical fluid chromatography (SFC) was performed on an Agilent 1100 HPLC equipped with an Aurora Systems A-5 supercritical CO$_2$ adapter for supercritical fluid chromatography and a UV detector (220 nm) using Daicel Chiralcel OD, OJ, OB or Chiralpak AD, and AS columns as well as a Regis Whelk-O1 column, or a Berger Instruments SFC with a 220 nm UV-detector and identical columns.

Commercial reagents were purified by distillation or recrystallization prior to use unless noted. Solvents for chromatography, filtration and recrystallization were dichloromethane (Aldrich, ACS grade), ethyl acetate (Fisher, ACS grade), diethyl ether (Fisher, ACS grade), tert-butyl methyl ether (Aldrich, ACS grade) and hexane (Fisher, Optima). Selenium powder (Aldrich) was used as received. Methanesulfonic acid (Aldrich) was distilled from P$_2$O$_5$. Isopropylamine (Aldrich), triethylamine (Alfa-Aesar) and pyridine (Fisher) were distilled from CaH$_2$. 
Experimental Procedures

Preparation of Amines with Protecting Groups

Preparation of the Precursor Amine

Compound (E)-ethyl 5-phenyl-4-pentenoate (39) was prepared according to a literature procedure.¹

Preparation of (E)-5-Phenylpent-4-enamide (40)²

An oven-dried 250 mL Schlenk flask was equipped with a stir bar, septum and a positive argon inlet. Solid ammonium chloride (16.1 g, 302 mmol, 2.80 equiv) was loaded into the flask which was purged with argon. Anhydrous toluene was added via syringe to afford a suspension of ammonium chloride/toluene. The suspension was cooled in an ice-bath for five minutes. To the suspension was added a solution of trimethylaluminum (151 mL, 302 mmol, 2.0 M in toluene, 2.80 equiv) dropwise via addition funnel over 1 h with observation of gas evolution. The mixture was allowed to stir at 0 °C for 1 h at it became homogeneous. Then the mixture was allowed to warm to room temperature and was stirred for an additional 30 min. The aluminum reagent mixture was then transferred via cannula over 1 h to a solution of the ester 39 (22.0 g, 108 mmol) in toluene (150 mL) in an oven-dried, argon purged 1000-mL, 3-necked round-bottomed-flask. After addition, the mixture was heated at 55 °C under argon for 14 h. After completion, the reaction was quenched with slow addition of 1 M HCl (150 mL) at 0 °C. The mixture was diluted with water (250 mL) and ethyl acetate (250 mL) and phases were separated. The aqueous layer was extracted with ethyl acetate (300 mL x3) and the combined organic extracts were washed with brine (300 mL), dried over Na₂SO₄, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford a white solid. Recrystallization of the solid with hot ethyl acetate (77 °C, 40 mL) afforded 11.1 g (76%) of 40 as white crystals. The spectroscopic data matched those reported in the literature.²
Data for 40:

**mp:** 132-133 °C (sealed tube)

**$^1$H NMR:** (500 MHz, CDCl$_3$)

δ 7.40 – 7.18 (m, 5 H), 6.46 (d, $J = 16.0$ Hz, 1 H), 6.23 (dt, $J = 16.0$, and 7.0 Hz, 1 H), 5.61 (brs, 1 H), 5.50 (brs, 1 H), 2.60 – 2.53 (m, 2 H), 2.42 – 2.37 (m, 2 H).

**$^{13}$C NMR:** (126 MHz, CDCl$_3$)

δ 174.5, 137.2, 131.2, 128.5, 127.3, 126.1, 125.9, 35.4, 28.7.

**MS:** (ESI)

117 (51), 159 (25), 176 (M+H, 100), 177 (14), 198 (10)

**HRMS:** calcd for C$_{11}$H$_{14}$NO: 176.1075, found: 176.1079

**Preparation of (E)-5-Phenylpent-4-enylamine (41)**

An oven-dried, 500-mL Schlenk flask was equipped with a stir bar, was charged with a solution of amide 40 (10.0 g, 57.1 mmol) in anhydrous tetrahydrofuran (190 mL) at 0 °C. To the solution was added lithium aluminum hydride (3.25 g, 85.6 mmol, 1.50 equiv) in portions with caution. Then the mixture allowed to warm to room temperature and was 12 h. The standard Fieser and Fieser work up was used, adding 3.24 mL of water, 3.24 mL of 15% NaOH solution, and 9.75 mL of water in sequence under 0 °C. Then the mixture was allowed to warm to room temperature and stir for 15 min. To the mixture was added 5 g of MgSO$_4$ and the resulting solids were filtered through a pad of Celite (5 g, 35 mm). The resulting solution was concentrated under concentrated in vacuo (30 °C, 10 mmHg) and purified by passing through a short pad of silica (SiO$_2$, 5 g, 20 mm Ø, dichloromethane/methanol = 9:1, then dichloromethane/methanol = 9:1 with 1% triethylamine) to afford 7.3 g (79%) of the primary amine 41. The spectroscopic data matched those reported in the literature.
Data for 41:

\(^1\)H NMR: (500 MHz, CDCl\(_3\))
\[\delta 7.36 - 7.16 (m, 5 \text{ H}), 6.40 (d, J = 15.5 \text{ Hz}, 1 \text{ H}), 6.22 (d, J = 16.0 \text{ Hz}, 1 \text{ H}), 2.77 (t, J = 7.0 \text{ Hz}, 2 \text{ H}), 2.27 (q, J = 7.5 \text{ Hz}, 2 \text{ H}), 1.87 (brs, 2 \text{ H}), 1.64 (p, J = 7.5 \text{ Hz}, 2 \text{ H}).\]

\(^13\)C NMR: (126 MHz, CDCl\(_3\))
\[\delta 137.7, 130.2, 130.2, 128.4, 126.9, 125.9, 41.6, 33.1, 30.3.\]

Protection of Precursor Amine (Table 1)

Preparation of \((E)\)-N-(4-Toluenesulfonyl)-5-phenylpent-4-enylamine (5\(^5,6\)) (Table 1 Entry 1)

\[
\begin{align*}
\text{41} & \quad 1) \text{Et}_3\text{N (2 equiv)} \quad \text{CH}_2\text{Cl}_2, 0 \degree \text{C} \\
& \quad 2) \text{TsCl (1.05 equiv),} \\
& \quad \text{CH}_2\text{Cl}_2, 0 \degree \text{C} \quad \text{then 4 h at rt}
\end{align*}
\]

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (500 mg, 3.10 mmol) in dichloromethane (4 mL) and a solution of triethylamine (864 µL, 6.20 mmol, 2.00 equiv) in dichloromethane (3 mL). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of tosyl chloride (621 mg, 3.26 mmol, 1.05 equiv) in dichloromethane (3 mL) portion wise. The resulting reaction mixture was allowed to warm to room temperature and was stirred for 4 h. The resulting mixture was allowed to warm to room temperature and was stirred for 4 h. The resulting mixture was diluted with 20 mL of dichloromethane and washed with 20 mL of 1 M HCl, 1 M NaOH, water and brine, respectively. The resulting organic layer was dried over Na\(_2\)SO\(_4\), filtered, and concentrated \textit{in vacuo} (30 °C, 10 mmHg) to afford the crude yellow liquid. Purification via silica gel flash column chromatography (SiO\(_2\), 15 g, 20 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 792 mg (81%) of 5, as a white solid. The spectroscopic data matched those reported in the literature.\(^7\)

Data for 5:

\textit{mp}: 59-60 °C (sealed tube)

\(^1\)H NMR: (500 MHz, CDCl\(_3\))
\[\delta 7.76 (d, J = 8.5 \text{ Hz}, 2 \text{ H}), 7.35 - 7.16 (m, 7 \text{ H}), 6.34 (dt, J = 16.0, \text{ and } 1.5 \text{ Hz}, 1 \text{ H}).\]
H), 6.09 (dt, J = 16.0, and 7.0 Hz, 1 H), 4.46 (t, J = 6.5 Hz, 1 H), 3.01 (q, J = 7.0, and 6.5 Hz, 2 H), 2.42 (s, 3 H), 2.25 – 2.19 (m, 2 H), 1.66 (p, J = 7.0 Hz, 2 H)

$^{13}$C NMR: (126 MHz, CDCl$_3$)
\[ \delta \] 143.3, 137.4, 136.9, 130.9, 129.7, 128.9, 128.4, 127.1, 127.0, 125.9, 42.5, 29.8, 29.1, 21.4.

MS: (ESI)
316 (M+H, 100), 317 (22), 333 (10), 338 (18)

HRMS: calcld for C$_{18}$H$_{22}$NO$_2$S: 316.1371, found: 316.1365

TLC: $R_f$ 0.32 (hexanes/EtOAc, 7:3) [UV/KMnO$_4$]

Preparation of (E)-N-(4-Nitrobenzenesulfonyl)-5-phenylpent-4-enylamine (6) (Table 1 Entry 3)

To an oven dried, 25-mL round-bottomed-flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in dichloromethane (3 mL) and triethylamine (432 µL, 3.10 mmol, 2.00 equiv). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of p-nitrobenzenesulfonyl chloride (361 mg, 1.63 mmol, 1.05 equiv) in dichloromethane (2 mL). The resulting reaction mixture was allowed to warm to room temperature and was stirred for 10 h. The resulting mixture was diluted with 10 mL of dichloromethane and washed with 10 mL of 1 M HCl, 1 M NaOH, water and brine, respectively. The resulting organic layer was dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude yellow liquid. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 445 mg (83%) of 6, as a white solid. The spectroscopic data matched those reported in the literature.$^8$

Data for 6:

mp: 97-98 °C (sealed tube)
**Preparation of (E)-N-(2,4,6-Triisopropylbenzenesulfonyl)-5-phenylpent-4-enylamine (7) (Table 1 Entry 5)**

![Chemical Structure Image]

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in dichloromethane (2 mL) and a solution of triethylamine (432 µL, 3.10 mmol, 2.00 equiv) in dichloromethane (1.5 mL). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of trisyl chloride (470 mg, 1.55 mmol, 1.00 equiv) in dichloromethane (1.5 mL) portion wise. The resulting reaction mixture was allowed to warm to room temperature and was stirred for 12 h. The resulting mixture was diluted with 10 mL of dichloromethane and washed with 15 mL of 1 M HCl, 1 M NaOH, water and brine, respectively. The resulting organic layer was dried over Na₂SO₄, filtered, and concentrated *in vacuo* (30 °C, 10 mmHg) to afford the crude yellow liquid. Purification via silica gel flash column chromatography (SiO₂, 15 g, 20 mm Ø, hexanes/EtOAc, 4:1) afforded 504 mg (76%) of 7, as a white solid.
Data for 7:

**mp:** 85-86 °C (sealed tube)

**^1^H NMR:** (500 MHz, CDCl$_3$)

δ 7.31 – 7.18 (m, 7 H), 6.35 (d, $J = 16.0$ Hz, 1 H), 6.12 (dt, $J = 16.0$, 7.0 Hz, 1H), 4.47 (t, $J = 6.0$ Hz, 1 H), 4.24 – 4.34 (m, 2 H), 3.05 (app. q, $J = 7.5$, 7.0 Hz, 2H), 2.96 – 2.88 (m, 1 H), 2.24 (app. q, $J = 7.5$, 7.0 Hz, 2 H), 1.70 (p, $J = 7.0$ Hz, 2 H), 1.28 (t, $J = 6.0$ Hz, 18 H).

**^13^C NMR:** (126 Hz, CDCl$_3$)

δ 152.6, 150.2, 137.3, 132.3, 130.9, 128.9, 128.4, 127.0, 125.9, 123.8, 42.3, 34.1, 30.0, 29.6, 29.4, 24.8, 23.5.

**MS:** (ESI)

428 (M+H, 100), 429 (35), 430 (17), 445 (13), 450 (11)

**HRMS:** calcd for C$_{26}$H$_{38}$NO$_2$S: 428.2623, found: 428.2615

**TLC:** $R_f$ 0.54 (hexanes/EtOAc, 7:3) [UV/KMnO$_4$]

### Preparation of (E)-N-Benzoyl-5-phenylpent-4-enylamine (8) (Table 1 Entry 7)$^9$

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in dichloromethane (2 mL) and a solution of triethylamine (432 µL, 3.10 mmol, 2.00 equiv) in dichloromethane (1.5 mL). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of benzylic chloride (180 µL, 1.55 mmol, 1.00 equiv) in dichloromethane (1.5 mL) portion wise. The resulting reaction mixture was allowed to warm to room temperature and was stirred for 16 h. The resulting mixture was diluted with 15 mL of dichloromethane and washed with 20 mL of water, 1 M HCl, and sat. NaHCO$_3$ aq. solution, respectively. The resulting organic layer was dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude orange oil. Purification via silica gel flash column chromatography (SiO$_2$, 15 g,
20 mm Ø, hexanes/EtOAc, 4:1) afforded 304 mg (74%) of 8, as a white solid. The melting point data matched the literature value.²

Data for 8:

mp: 62-63 °C (sealed tube)

¹H NMR: (500 MHz, CDCl₃)

δ 7.74 (d, J = 8.0 Hz, 2 H), 7.50 – 7.19 (m, 8 H), 6.44 (d, J = 16.0 Hz, 1 H), 6.32 (brs, 1 H), 6.25 (dt, J = 16.0, and 7.0 Hz, 1 H), 3.53 (td, J = 7.0, and 7.0 Hz, 2 H), 2.33 (td, J = 7.0, and 7.0 Hz, 2 H), 1.82 (p, J = 7.0 Hz, 2 H).

¹³C NMR: (126 MHz, CDCl₃)

δ 167.4, 137.4, 134.7, 131.3, 130.7, 129.7, 128.5, 128.5, 127.0, 126.8, 126.0, 39.8, 30.7, 29.3.

MS: (ESI)

105 (40), 122 (25), 145 (20), 266 (M+H, 100), 267 (23), 282 (15), 288 (22)

HRMS: calcd for C₁₈H₂₀N₂O: 266.1545, found: 266.1540

TLC: Rₚ 0.20 (hexanes/EtOAc, 7:3) [UV/KMnO₄]

**Preparation of Benzyl ((E)-5-phenylpent-4-enyl)carbamate (9) (Table 1 Entry 8)**

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in THF (2 mL) and a solution of triethylamine (648 µL, 4.65 mmol, 3.00 equiv) in THF (1.5 mL). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of benzyl chloroformate (529 mg, 3.10 mmol, 2.00 equiv) in THF (1.5 mL) portion wise. The resulting reaction mixture was allowed to warm to room temperature and was stirred for 4 h. The resulting mixture was diluted with 10 mL of dichloromethane and was added 10 mL of 1 M HCl. The resulting biphasic mixture was extracted with dichloromethane (10 mL x 5) and was washed with 30 mL of sat. NaHCO₃ aq. solution, brine, respectively. The resulting organic layer was dried
over Na$_2$SO$_4$, filtered, and concentrated *in vacuo* (30 °C, 10 mmHg) to afford a crude yellow liquid. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1) afforded 348 mg (76%) of 9, as a white solid.

Data for 9:

mp: 50-51 °C (sealed tube)

$^1$H NMR: (500 MHz, CDCl$_3$)

δ 7.40 – 7.16 (m, 10 H), 6.40 (d, J = 16.0 Hz, 1 H), 6.19 (dt, J = 16.0, and 7.0 Hz, 1 H), 5.10 (s, 2 H), 4.78 (brs, 1 H), 3.26 (q, J = 7.0, and 7.0 Hz, 2 H), 2.26 (q, J = 7.0, and 7.0 Hz, 2 H), 1.70 (p, J = 7.0 Hz, 2 H).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 156.4, 137.5, 136.6, 130.6, 129.5, 128.5, 128.5, 128.1, 127.0, 126.0, 66.6, 40.6, 30.2, 29.6.

MS: (ESI)

91 (19), 218 (17), 235 (26), 252 (100), 253 (26), 296 (M+H, 65), 297 (14), 313 (26), 318 (34)

HRMS: calcd for C$_{19}$H$_{22}$NO$_2$: 296.1651, found: 296.1651

TLC: $R_f$ 0.38 (hexanes/EtOAc, 7:3) [UV/KMnO$_4$]

Preparation of tert-Butyl ((E)-5-phenylpent-4-enyl)carbamate (10) (Table 1 Entry 9)$^{11}$

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in dichloromethane (3 mL) and a solution of di-tert-butyl carbonate (372 mg, 1.71 mmol, 1.10 equiv) in dichloromethane (2 mL) portion wise and the resulting reaction mixture was stirred for 16 h at room temperature. The resulting mixture was diluted with 10 mL of dichloromethane and 10 mL of water. The biphasic mixture was extracted with dichloromethane (10 mL x 3), and the combined organic layer was washed with sat. NaHCO$_3$ aq. solution. The resulting organic layer was dried over Na$_2$SO$_4$, filtered, and concentrated *in vacuo* (30 °C, 10 mmHg) to afford the crude
yellow solid. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1) afforded 380 mg (94%) of 10, as a white solid. The spectroscopic data matched those reported in the literature.$^{12}$

**Data for 10:**

$^1$H NMR: (500 MHz, CDCl$_3$)

$\delta$ 7.40 – 7.18 (m, 5 H), 6.41 (d, $J = 16.0$ Hz, 1 H), 6.21 (dt, $J = 16.0$, and 7.0 Hz, 1 H), 4.58 (brs, 1 H), 3.23 – 3.15 (m, 2 H), 2.26 (app. q, 7.0 Hz, 2 H), 1.68 (p, $J = 7.0$ Hz, 2 H), 1.46 (s, 9 H).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

$\delta$ 155.9, 137.5, 130.5, 129.7, 128.4, 126.9, 125.9, 79.1, 40.2, 30.3, 29.7, 28.4.

**Preparation of P,P-Diphenyl-N-((E)-5-phenylpent-4-enyl)phosphinic amide (11) (Table 1 Entry 10)$^{13}$**

To an oven dried, 25-mL Schlenk flask equipped with a magnetic stir bar, purged with positive pressure of argon, were added a solution of parent amine 41 (250 mg, 1.55 mmol) in dichloromethane (2 mL) and a solution of $N$-methylmorpholine (341 µL, 3.10 mmol, 2.00 equiv) in dichloromethane (1.5 mL). After equilibration at 0 °C (internal temperature), to the mixture was added a solution of diphenylphosphinic chloride (296 µL, 1.55 mmol, 1.00 equiv) in dichloromethane (1.5 mL) portion wise. The resulting reaction mixture was allowed to warm to room temperature and was stirred for 5 h. The resulting mixture was diluted with 15 mL of dichloromethane and was added 5 mL of 1 M HCl. The resulting biphasic mixture was extracted with dichloromethane (15 mL x 3). The combined organic extracts were dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude yellow oil. The product was purified via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, hexanes/EtOAc, 30:1) affording 375 mg (67%) of 11, as a white solid.
Data for 11:

**^1^H** NMR: (400 MHz, CDCl₃)
\[\delta 7.90 - 7.81 \text{ (m, 4 H)}, 7.50 - 7.12 \text{ (m, 11 H)}, 6.34 \text{ (d, } J = 16.0 \text{ Hz, 1 H)}, 6.12 \text{ (dt, } J = 16.0, \text{ and } 6.8 \text{ Hz, 1 H)}, 3.05 - 2.93 \text{ (m, 2 H)}, 2.87 \text{ (brs, 1 H)}, 2.23 \text{ (dt, } J = 6.8, \text{ and } 6.8 \text{ Hz, 2 H)}, 1.73 \text{ (p, } J = 6.8 \text{ Hz, 2 H}).\]

**^13^C** NMR: (101 MHz, CDCl₃)
\[\delta 132.2, 132.1, 131.8, 131.7, 130.7, 129.7, 128.6, 128.5, 127.0, 126.0, 40.5, 31.8, 30.2.\]

**^31^P** NMR: (202 MHz, CDCl₃)
\[\delta 24.36.\]

**MS:** (ESI)
362 (M+H, 100), 363 (27), 364 (23), 378 (44), 379 (11)

**HRMS:** calcd for C₂₃H₂₅NOP: 362.1674, found: 362.1672

**General Procedure I: Survey of Amine Protecting Groups**

An oven-dried, 4-mL vial equipped with a magnetic stir bar was charged with the protected amine substrate (5-11, 0.063 mmol), N-(phenylthio)phthalimide 2 (PhthSPh, 16.2 mg, 0.063 mmol, 1.0 equiv), tetrahydrothiophene (THT, none or 0.10 equiv), and CH₂Cl₂ (500 µL, 0.13 M) and capped with a septum cap. After stirring the mixture until a homogeneous solution was obtained, methanesulfonylic acid (MsOH, none or 1.0 equiv) was added at room temperature. The reaction was monitored by TLC at 5 min, 1 h, 3 h, 12 h, 24 h, and 48 h time points until no amine substrate was detected. Upon completion, the reaction mixture was quenched by addition of 1 mL of sat. NaHCO₃ aq solution and the biphasic mixture was extracted with CH₂Cl₂ (1 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude product. The product was purified via silica gel flash column chromatography. In case of incomplete reaction after 48 h, the reaction mixture was quenched following above method, and the crude product was analyzed by ^1^H NMR spectroscopy to assess conversion.
Survey of Amine Protecting Groups (Table 1)

Table 1 Entry 1

Following General Procedure I, an oven-dried vial was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CH$_2$Cl$_2$ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis showed immediate full conversion to 12 at 5 min. The reaction was quenched at 5 min and the crude product was purified via silica gel flash column chromatography (SiO$_2$, 5 g, 10 mm Ø, hexanes/EtOAc, 19:1) affording 25 mg (93%) of rac-12 as white solid.

Data for rac-12:

$^1$H NMR: (500 MHz, CDCl$_3$)

$\delta$ 7.82 (dd, $J$ = 6.5, and 2.0 Hz, 2 H, HC(18)), 7.51 – 7.46 (m, 2 H, HC(13)), 7.37 – 7.18 (m, 10 H, HC(aryl)), 5.41 (s, 1 H, HC(2)), 3.92 (d, $J$ = 2.5 Hz, 1 H, HC(3)), 3.76 (dd, $J$ = 13.5, and 2.5 Hz, 1 H, HC(6)), 3.23 (td, $J$ = 13.0, and 3.0 Hz, 1 H, HC(6)), 2.43 (s, 3 H, HC(21)), 1.92 – 1.73 (m, 3 H, HC(4,5)), 1.44 – 1.37 (m, 1 H, HC(5)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

$\delta$ 143.0 (C(20)), 138.8 (C(7)), 137.7 (C(17)), 135.1 (C(12)), 132.3 (C(13)), 129.2 (C(19)), 129.2 (C(14)), 128.7 (C(9)), 127.7 (C(18)), 127.5 (C(15)), 127.1 (C(10)), 126.8 (C(8)), 60.0 (C(2)), 49.7 (C(3)), 41.8 (C(6)), 24.1 (C(4)), 21.5 (C(21)), 19.9 (C(5)).

MS: (ESI) 314 (100), 315 (23), 424 (M+H, 49), 425 (14), 441 (11), 446 (18), 462 (12)

HRMS: caled for C$_{24}$H$_{26}$NO$_2$S$_2$: 424.1405, found: 424.1406

TLC: $R_f$ 0.48 (hexanes/EtOAc, 7:3) [UV/KMnO$_4$]
Table 1 Entry 2 (Background reaction with no catalyst)

Following General Procedure I, an oven-dried vial was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. The reaction was incomplete at 48 h. The reaction was quenched and worked up. The conversion to 12 (4%) was determined by analysis of ¹H NMR spectroscopy of the crude product. Conversion to product was measured by the appearance of the diagnostic ¹H NMR resonance for the product 12 at 5.41 ppm with respect to the substrate peaks at 6.34 ppm and 6.09 ppm.

Table 1 Entry 3

Following General Procedure I, an oven-dried vial was charged with 6 (22 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis showed immediate full conversion to 42 at 5 min. The reaction was quenched at 5 min and the crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 19:1) affording 25 mg (95%) of rac-42 as white solid.
Data for *rac-42*:

$^1$H NMR: (500 MHz, CDCl$_3$) 
$\delta$ 8.29 (dt, $J = 9.0$, and 2.0 Hz, 2 H), 8.05 (dt, $J = 9.0$, and 2.0 Hz, 2 H), 7.44 – 7.19 (m, 10 H), 5.39 (s, 1H), 3.95 (d, $J = 9.0$, and 2.0 Hz, 1 H), 3.88 (dd, $J = 13.5$, and 2.5 Hz, 1 H), 3.30 (td, $J = 12.0$, and 3.0 Hz, 1 H), 1.90 – 1.75 (m, 3 H), 1.54 – 1.45 (m, 1 H).

$^{13}$C NMR: (126 MHz, CDCl$_3$) 
$\delta$ 149.8, 146.3, 138.0, 134.5, 131.8, 129.4, 128.9, 128.7, 127.6, 127.6, 126.7, 123.9, 60.6, 49.1, 42.3, 23.8, 19.9.

**MS:** (ESI) 
345 (100), 346 (21), 455 (M+H, 54), 456 (15), 471 (33), 472 (83), 473 (26), 474 (14), 477 (11), 482 (12), 493 (12)

**HRMS:** calcd for C$_{23}$H$_{23}$N$_2$O$_4$S$_2$: 455.1099, found: 455.1102

**TLC:** $R_f$ 0.45 (hexanes/EtOAc, 7:3) [UV/KMnO$_4$]

Table 1 Entry 4 (Background reaction with no catalyst)

Following General Procedure I, an oven-dried vial was charged with 6 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), and CH$_2$Cl$_2$ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. The reaction was incomplete at 48 h. The reaction was quenched and worked up. The conversion to 42 (11%) was determined by analysis of $^1$H NMR spectroscopy of the crude product. Conversion to product was measured by the appearance of the diagnostic $^1$H NMR resonance for the product 42 at 5.39 ppm with respect to the substrate peaks at 6.34 ppm and 6.08 ppm.
Following General Procedure I, an oven-dried vial was charged with 7 (27 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis showed immediate full conversion to 43 at 5 min. The reaction was quenched at 5 min and the crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 19:1) affording 29 mg (84%) of rac-43 as white solid.

Data for rac-43:

**¹H NMR:** (500 MHz, CDCl₃)
δ 7.35 – 7.09 (m, 12 H), 5.03 (s, 1 H), 4.00 – 3.85 (m, 3 H), 3.68 (d, J = 3.5 Hz, 1 H), 3.60 (td, J = 12.0, and 3.0 Hz, 1 H), 2.92 (sept, J = 7.0 Hz, 1 H), 2.10 – 1.82 (m, 3 H), 1.70 – 1.58 (m, 1 H), 1.28 (d, J = 6.0 Hz, 6 H), 1.23 (d, J = 6.0 Hz, 6 H), 1.19 (d, J = 6.0 Hz, 6 H).

**¹³C NMR:** (126 MHz, CDCl₃)
δ 152.6, 151.4, 140.1, 132.7, 129.0, 128.2, 127.6, 127.4, 127.2, 126.4, 123.8, 123.0, 60.6, 51.3, 42.2, 34.2, 29.8, 25.5, 25.2, 24.9, 23.6, 23.5, 21.2.

**MS:** (ESI)
384 (22), 426 (11), 536 (M+H, 100), 537 (40), 538 (18), 558 (12)

**HRMS:** called for C₃₂H₄₂NO₂S₂: 536.2657, found: 536.2656

**TLC:** Rₜ 0.63 (hexanes/EtOAc, 7:3) [UV/KMnO₄]
Table 1 Entry 6 (Background reaction with no catalyst)

Following General Procedure I, an oven-dried vial was charged with 7 (27 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. The reaction was incomplete at 48 h. The reaction was quenched and worked up. The conversion to 43 (2%) was determined by analysis of ¹H NMR spectroscopy of the crude product. Conversion to product was measured by the appearance of the diagnostic ¹H NMR resonance for the product 43 at 5.03 ppm with respect to the substrate peaks at 6.35 ppm and 6.12 ppm.

Table 1 Entry 7

Following General Procedure I, an oven-dried vial was charged with 8 (17 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis showed full conversion to 44 at 48 h. The reaction was quenched and the crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) affording 20 mg (86%) of rac-44 as white solid.
Data for *rac*-44:

**^1^H NMR:** (500 MHz, CDCl₃, –40 °C)

Major rotamer: \( \delta 7.70 – 7.09 \) (m, 15 H), 5.11 (s, 1 H), 4.80 (d, \( J = 16.5 \) Hz, 1 H), 4.10 (s, 1 H), 2.92 (td, \( J = 16.5 \) and 3.5 Hz, 1 H), 2.15 – 1.96 (m, 1 H), 1.92 – 1.78 (m, 2 H), 1.50 (d, \( J = 16.5 \) Hz, 1 H).

Minor rotamer: \( \delta 7.70 – 7.09 \) (m, 15 H), 6.05 (s, 1 H), 4.24 (s, 1 H), 3.65 (d, \( J = 17.5 \) Hz, 1 H), 3.00 (t, \( J = 15.0 \) Hz, 1 H), 2.15 – 1.96 (m, 1 H), 1.92 – 1.78 (m, 2 H), 1.36 (d, \( J = 8.5 \) Hz, 1 H).

**^1^3^C NMR:** (126 MHz, CDCl₃, –40 °C)

\( \delta 172.8, 172.1, 137.6, 137.4, 136.1, 135.4, 134.6, 134.0, 133.6, 130.9, 129.6, 129.5, 129.1, 129.0, 128.8, 128.5, 128.2, 127.9, 127.3, 127.0, 126.7, 126.4, 126.1, 61.1, 54.5, 49.0, 48.3, 43.6, 38.3, 24.8, 24.7, 21.0, 20.0. \)

**MS:** (ESI)

264 (100), 265 (21), 374 (M+H, 80), 375 (22), 396 (18)

**HRMS:** calcd for C₂₄H₂₄NOS: 374.1579, found: 374.1582

**TLC:** \( R_f 0.36 \) (hexanes/EtOAc, 7:3) [UV/KMnO₄]

### Table 1 Entry 8

Following General Procedure I, an oven-dried vial was charged with 9 (19 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL). To the mixture MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis showed full conversion to 45 at 48 h. The reaction was quenched and the crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) affording 21 mg (81%) of *rac*-45 as white solid.
Data for rac-45:

\[ ^1H \text{NMR:} \] (500 MHz, CDCl\textsubscript{3})
\[ \delta 7.52 – 7.14 \text{ (m, 15 H)}, 5.59 \text{ (s, 1 H)}, 5.24 \text{ (d, } J = 12.0 \text{ Hz, 1 H)}, 5.18 \text{ (d, } J = 12.0 \text{ Hz, 1 H)}, 4.27 \text{ (d, } J = 12.0 \text{ Hz, 1 H)}, 4.08 \text{ (d, 1 H)}, 4.92 \text{ (td, } J = 13.0 \text{, and 3.0 Hz, 1 H)}, 2.10 – 1.98 \text{ (m, 1 H)}, 1.96 – 1.83 \text{ (m, 2 H)}, 1.44 \text{ (d, } J = 13.0 \text{ Hz, 1 H}). \]

\[ ^13C \text{NMR:} \] (126 MHz, CDCl\textsubscript{3})
\[ \delta 156.6, 138.8, 136.8, 135.1, 132.5, 129.1, 128.8, 128.4, 127.8, 127.7, 127.4, 127.0, 126.3, 67.4, 57.4, 48.3, 40.2, 24.5, 20.3. \]

\[ \text{MS:} \] (ESI)
\[ 160 (11), 204 (61), 250 (29), 294 (67), 295 (14), 404 (M+H, 100), 405 (30), 421 (45), 426 (36), 442 (20) \]

\[ \text{HRMS:} \] calcd for C\textsubscript{25}H\textsubscript{26}NO\textsubscript{2}S: 404.1684, found: 404.1689

\[ \text{TLC:} \] \( R_f 0.53 \) (hexanes/EtOAc, 7:3) [UV/KMnO\textsubscript{4}]

### Table 1 Entry 9

Following General Procedure I, an oven-dried vial was charged with 10 (17 mg, 0.063 mmol), PhthSPh \( 2 \) (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 \( \mu \)L, 6.3 \( \mu \)mol, 0.10 equiv), and CH\textsubscript{2}Cl\textsubscript{2} (500 \( \mu \)L). To the mixture MsOH (4.1 \( \mu \)L, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis indicated partial consumption of the substrate. However, after quenching the reaction at 48 h, analysis of the crude mixture by \( ^1H \) NMR spectroscopy gave a complex mixture.

### Table 1 Entry 10

Following General Procedure I, an oven-dried vial was charged with 11 (23 mg, 0.063 mmol), PhthSPh \( 2 \) (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 \( \mu \)L, 6.3 \( \mu \)mol, 0.10 equiv), and CH\textsubscript{2}Cl\textsubscript{2} (500 \( \mu \)L). To the mixture MsOH (4.1 \( \mu \)L, 0.063 mmol, 1.0 equiv) was added and the reaction was monitored by TLC. TLC analysis indicated partial consumption of the substrate. However, after quenching the reaction at 48 h, analysis of the crude mixture by \( ^1H \) NMR spectroscopy gave a complex mixture.
General Procedure II: Survey of Chiral Lewis Base Catalysts

An oven-dried, 4-mL vial equipped with a magnetic stir bar was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (3a-3f, 6.3 µmol, 0.10 equiv), and solvent (CH₂Cl₂ or CDCl₃, 500 µL, 0.13 M) and capped with a septum cap. After stirring the mixture well making a homogeneous solution, the vial was cooled to –20 °C in a Cryocool unit. After reaching equilibrium, MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. After indicated time, the reaction mixture was quenched by rapid addition of 1 mL of sat. NaHCO₃ aq solution upon stirring and the biphasic mixture was extracted with CH₂Cl₂ (1 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude product. The product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) prior to SFC analysis.

Survey of Chiral Lewis Base Catalysts (Table 2)

Table 2 Entry 1

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (R)-3a (3.3 mg, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 24 mg (90%) of pure 12.

SFC: (2S,3R)-12, tₑ 14.8 min (11.5%); (2R,3S)-12, tₑ 16.5 min (88.5%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)
Table 2 Entry 2

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3b (3.3 mg, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 24 mg (88%) of pure 12.

\[ \text{SFC: (2S,3R)-12, } t_R \text{ 14.8 min (89.4%); (2R,3S)-12, } t_R \text{ 16.5 min (10.6%) (Chiralcel OJ, Gradient 3% MeOH in CO}_2\text{ to 8% MeOH in CO}_2\text{ over 30 min, 2.5 mL/min, 220 nm, 40 °C)} \]

Table 2 Entry 3

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3c (3.4 mg, 6.3 µmol, 0.10 equiv), and CH₂Cl₂ (500 µL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 21 mg (79%) of pure 12.

\[ \text{SFC: (2S,3R)-12, } t_R \text{ 14.8 min (88.1%); (2R,3S)-12, } t_R \text{ 16.5 min (11.9%) (Chiralcel OJ, Gradient 3% MeOH in CO}_2\text{ to 8% MeOH in CO}_2\text{ over 30 min, 2.5 mL/min, 220 nm, 40 °C)}} \]
Table 2 Entry 4

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3d (3.4 mg, 6.3 μmol, 0.10 equiv), and CH₂Cl₂ (500 μL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 μL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 18 mg (67%) of pure 12.

SFC: (2S,3R)-12, tₚ 14.8 min (91.4%); (2R,3S)-12, tₚ 16.5 min (8.6%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Table 2 Entry 5

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3e (3.7 mg, 6.3 μmol, 0.10 equiv), and CH₂Cl₂ (500 μL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 μL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 22 mg (82%) of pure 12.

SFC: (2S,3R)-12, tₚ 14.8 min (92.8%); (2R,3S)-12, tₚ 16.5 min (7.2%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)
Table 2 Entry 6

Following General Procedure II, an oven-dried NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CH2Cl2 (500 µL, 0.13 M) and capped. The vial was cooled to –20 °C and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. After 72 h, the reaction was quenched, and purified by flash chromatography afforded 20 mg (75%) of pure 12.

SFC: (2S,3R)-12, tR 14.8 min (94.6%); (2R,3S)-12, tR 16.5 min (5.4%) (Chiralcel OJ, Gradient 3% MeOH in CO2 to 8% MeOH in CO2 over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Preparation of (S)-4-(Diisopropylamino)-3,5-dimethyl-4,5-dihydro-3H-dinaphtho[2,1-d:1’,2’-f][1,3,2]diazaphosphepine-4-selenide ((S)-3f)

To a flame-dried, 100-mL Schlenk flask equipped with a magnetic stir bar was added (S)-dimethyl BINAM (S)-4614 (1.56 g, 5.00 mmol) under argon and capped with a septum. To the flask was added anhydrous THF (33.3 mL, 0.15 M) via syringe under argon. After stirring for 30 min at -74 °C (internal temperature) in a dry-ice/i-PrOH bath, to the homogeneous solution was added a solution of n-BuLi in hexanes (2.29 M, 4.37 mL, 10.0 mmol, 2.0 equiv) dropwise over 10 min whereupon the solution turned to yellow-orange. The dry-ice/i-PrOH bath was removed after the addition and the solution was stirred for 30 min at room temperature as the color turned yellowish black. Then the flask was immersed back into the dry-ice/i-PrOH bath and was
allowed to equilibrate for another 30 min. To the mixture was added a freshly prepared solution of 47 in THF (910 µL in 8.3 mL of THF, 5.00 mmol, 1.0 equiv) dropwise over 10 min, whereupon the color of the solution turned to burgundy-red immediately. After warming to room temperature by removing the dry-ice/i-PrOH bath the solution turned to bright red then bright orange after stirring for 30 min. To the bright orange solution was added powdered selenium (1.18 g, 15.0 mmol, 3.0 equiv) at room temperature under gentle argon flow whereupon the color turned brown-black immediately. The mixture was stirred for an hour at an ambient temperature and the resulting heterogeneous mixture was filtered through a pad of Celite (10 g, 35 mm), which was rinsed with EtOAc (50 mL). The bright orange filtrate was concentrated in vacuo (40 ºC, 10 mmHg) to afford an orange solid. Purification by Combiflash® column chromatography (SiO2, 24 g Luknova column, hexanes/EtOAc, 100:0 to 20:1) afforded an off-white solid (2.24 g). Recrystallization of this solid with n-pentane (1.0 L, 36 ºC) afforded 2.06 g (79%) of (S)-3f as an off-white, crystalline solid.

Data for (S)-3f:

mp: 148-150 ºC (sealed tube)

$^1$H NMR: (500 MHz, DMSO-d$_6$, 80 ºC, heating for sharpening diisopropyl region)

δ 8.05 (t, J = 10.0 Hz, 2 H, HC(4) and HC(4’)), 7.99 (d, J = 8.0 Hz, 1 H, HC(6)), 7.95 (d, J = 8.0 Hz, 1 H, HC(6’)), 7.81 (d, J = 9.0 Hz, 1 H, HC(3)), 7.66 (d, J = 9.0 Hz, 1 H, HC(6’)), 7.43 (t, J = 7.5 Hz, 1 H, HC(7)), 7.39 (t, J = 7.5 Hz, 1 H, HC(7’)), 7.23 (t, J = 7.5 Hz, 1 H, HC(8)), 7.14 (t, J = 7.5 Hz, 1 H, HC(8’)), 7.06 (d, J = 8.5 Hz, 1 H, HC(9)), 6.83 (d, J = 8.5 Hz, 1 H, HC(9’)), 3.64 – 3.50 (m, 2 H, HC(12) and HC(12’)), 3.24 (d, J = 12.5 Hz, 3 H, H$_3$C(11)), 3.03 (d, J = 14.0 Hz, 3 H, H$_3$C(11’)), 1.39 (d, J = 6.5 Hz, 6 H, H$_3$C(13) and H$_3$C(13’)), 1.28 (d, J = 6.0 Hz, 6 H, H$_3$C(14) and H$_3$C(14’))

$^{13}$C NMR: (126 MHz, DMSO-d$_6$, 80 ºC, heating for sharpening diisopropyl region)

δ 142.7 (d, J = 5.9 Hz, C(2)), 141.8 (C(2’)), 131.6 (C(10)), 131.3 (C(10’)), 130.6 (d, J = 2.0 Hz, C(5’)), 130.0 (C(5)), 128.2 (C(4’)), 128.1 (C(4)), 127.61 (C(6’)), 127.57 (C(C6)), 126.9 (C(9)), 126.8 (d, J = 3.8 Hz, C(1’)), 126.21 (C(1)), 126.16 (C(9’)), 125.8 (C(8)), 125.4 (C(8’)), 124.6 (C(7)), 124.4 (C(7’)), 122.7 (C(3’)), 122.6 (C(3)), 47.4 (C(12) and C(12’)), 36.8 (d, J = 11.8 Hz, C(11)), 36.0 (d, J = 5.9 Hz, C(11’)), 23.9 (C(13,13’)), 21.9 (C(14,14’))
\[^{31}\text{P NMR:}\] (202 MHz, DMSO-\text{d}_6, 80 °C)

81.07 (t, J = 414.7 Hz, Se satellite)

\[\text{IR:}\]

(KBr)

3059 (w), 2961 (m), 1618 (w), 1590 (w), 1503 (m), 1465 (m), 1365 (m), 1330 (m),
1271 (m), 1257 (m), 1174 (s), 1143 (m), 1084 (m), 980 (s), 928 (s), 848 (w), 810 (s),
751 (s)

\[\text{MS:}\]

(EI)

55 (26), 57 (34), 67 (10), 68 (11), 69 (82), 70 (13), 71 (20), 81 (43), 83 (17), 84 (42),
85 (14), 86 (28), 86 (10), 95 (16), 97 (13), 100 (22), 109 (10), 136 (11), 137 (15),
281 (14), 341 (100), 342 (25), 521 (M+)

\[\text{HRMS:}\]

calcd for C\(_{28}\)H\(_{32}\)N\(_3\)PSe: 521.1499, found: 521.1502

\[\text{TLC:}\]

\(R_f\) 0.41 (hexanes/EtOAc, 9:1) \([\text{CAM}]\)

\[\text{Opt Rot:}\]

\([\alpha]\)_D\(^{24}\) 438.9 \((c = 1.01, \text{CHCl}_3)\) [non-linear ORD]

\[\text{SFC:}\]

(R)-3f, \(t_R\) 7.9 min (0.2%); (S)-3f, \(t_R\) 9.3 min (99.8%) (Chiralcel OJ, Gradient 3% MeOH in CO\(_2\) to 8% MeOH in CO\(_2\), 2.5 mL/min, 220 nm.)

\[\text{Analysis:}\]

C\(_{28}\)H\(_{32}\)N\(_3\)PSe (520.51)

Calcd: C, 64.61%; H, 6.20%; N, 8.07%

Found: C, 64.36%; H, 6.22%; N, 7.77%

### Preparation of N,N-Diisopropylphosphoramidodichloridite (47)\(^{15}\)

A flame-dried, 100-mL two-necked, round-bottomed-flask equipped with a magnetic stir bar, a septum, and a argon inlet was added a solution of PCl\(_3\) (2 mL, 22.9 mmol, 1 equiv) in hexanes (53 mL) via syringe under argon. The solution was cooled to 0 °C (internal temperature) and was added diisopropylamine (6 mL, 42.9 mmol, 1.87 equiv) dropwise, whereupon the solution turned immediately into a white suspension. After stirring for 1 h at room temperature, a Schlenk filter was connected and the white suspension was filtered to a flame-dried, 250-mL round-bottomed-flask under high vacuum (0.1 mmHg). Rinsing the original flask with hexanes
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(30 mL x 3) gave a turbid suspension, and excess hexane was evaporated in vacuo (23 °C, 10 mmHg). Distillation of the resulting residue was through short-path distillation (115-116 °C at 30 mmHg) afforded 3.27 g (71%) of compound 47 as clear liquid which solidified in freezer. The spectroscopic data matched those reported in the literature.\(^\text{15}\)

Data for 47:

| Property | Value                        |
|----------|------------------------------|
| mp       | 26-27 °C (upon standing)     |
| bp       | 115-116 °C, 30 mmHg          |
| \(^1\)H NMR | (500 MHz, CDCl\(_3\))       |
|          | 3.93 (brm, 2 H, HC(1)), 1.29 (d, 12 H, \(J = 7.0\) Hz, HC(2)). |
| \(^13\)C NMR | (126 MHz, CDCl\(_3\))   |
|          | 48.1 (d, C(1)), 23.4 (br, C(2)). |
| \(^31\)P NMR | (202 MHz, CDCl\(_3\))       |
|          | 170.2 (br).                  |

Isomerization Study (Scheme 3)

An oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), THT (0.6 µL, 6.3 µmol, 0.10 equiv), and CDCl\(_3\) (500 µL, 0.13 M) and capped with a rubber septum cap. After shaking the mixture well making a homogeneous solution, MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe at room temperature. Conversion to product was measured by the appearance of the diagnostic \(^1\)H NMR resonance for the “initial” product (proposed to be 12) at 5.41 ppm and the “converted” product (proposed to be 13) at 4.07 ppm with respect to the substrate peaks at 6.34 ppm and 6.09 ppm. Generally, no other products were observed in the \(^1\)H NMR spectra. Formation of phthalimide byproduct was visually confirmed by the precipitation out of the solution. Full conversion was
observed after 5 min by $^1$H NMR spectroscopy giving 12 as only product. After 12 h, a 1:2.8 mixture of two products (“initial”: “converted”) was observed.

Data for 12+13:

$^1$H NMR: (500 MHz, CDCl$_3$)
\[ \delta 7.82 \text{ (d, } J = 8.0 \text{ Hz, 12),} \ 7.68 \text{ (d, } J = 8.0 \text{ Hz, 13) } \ 7.60 - 7.44 \text{ (m, 12+13),} \ 7.41 - 7.10 \text{ (m, 12+13),} \ 5.41 \text{ (s, 12),} \ 5.05 \text{ (d, } J = 3.5 \text{ Hz, 13),} \ 4.10 - 4.05 \text{ (m, 13),} \ 3.92 \text{ (s, 12),} \ 3.76 \text{ (d, } J = 14.5 \text{ Hz, 12),} \ 3.49 - 3.39 \text{ (m, 13),} \ 3.23 \text{ (td, } J = 12.0, 3.0 \text{ Hz, 12),} \ 2.43 \text{ (s, 12),} \ 2.38 \text{ (s, 13),} \ 2.15 - 2.03 \text{ (m, 13),} \ 1.95 - 1.73 \text{ (m, 12+13),} \ 1.70 - 1.55 \text{ (m, 13),} \ 1.44 - 1.30 \text{ (m, 12+13).} \]

Isomerization on Under Acidic Media (Scheme 3)

An oven-dried, 5-mm NMR tube was charged with 12 (140 mg, 0.33 mmol), and CDCl$_3$ (1.0 mL, 0.33 M) and capped with a rubber septum cap. After shaking the mixture well making a homogeneous solution, MsOH (21.4 µL, 0.33 mmol, 1.0 equiv) was added via syringe at room temperature. Conversion between two compounds was measured by the appearance of the diagnostic $^1$H NMR resonance for the “initial” product (proposed to be 12) at 5.41 ppm and the “converted” product (proposed to be 13) at 4.07 ppm. No other products were observed in the $^1$H NMR spectra. $^1$H NMR spectra were recorded at 5 min, 10 min, 15 min, 20 min, and 12 h. Converted product 13 was already observed at 5 min, until it reached the equilibrium after 20 min. At the equilibrium, 1:2.8 mixture of two products (“initial”: “converted”) was observed.
Reverse Direction Isomerization on Under Acidic Media

![Diagram of isomerization reaction]

From the above isomerization experiment, a pyrrolidine-enriched (12:13, 1:5.2) fraction was isolated by chromatotron (SiO\textsubscript{2}, 4 mm plate, hexanes/EtOAc, 9:1 to 6:1). An oven-dried, 5-mm NMR tube was charged with the mixture of 12+13 (53.5 mg, 0.13 mmol), and CDCl\textsubscript{3} (0.6 mL, 0.21 M) and capped with a rubber septum cap. After shaking the mixture well making a homogeneous solution, MsOH (8.2 \(\mu\)L, 0.13 mmol, 1.0 equiv) was added via syringe at room temperature. Conversion between two compounds was measured by the diagnostic \(^1\)H NMR resonance for the “initial” product (proposed to be 12) at 5.41 ppm and the “converted” product (proposed to be 13) at 4.07 ppm. No other products were observed in the \(^1\)H NMR spectra. \(^1\)H NMR spectra were recorded at 0 min (immediately after MsOH addition), 5 min, 10 min, 2 h, and 12 h. Conversion of pyrrolidine 13 to piperidine 12 was already observed at 0 min, until it reached the equilibrium after 12 h. At the equilibrium, 1:2.8 mixture of two products (“initial”:“converted”) was observed.

General Procedure III:\textsuperscript{16,17} Determination of the Product Structure by Desulfurization

An oven-dried, round-bottomed-flask equipped with a magnetic stir bar was charged with a solution of the sulfonyl compound (1 equiv) in methanol (0.005 M). To the solution was then added NiCl\textsubscript{2}·6H\textsubscript{2}O (20 equiv), which turned into a green solution upon stirring. The suspension was cooled to 0 °C (internal temperature) and NaBH\textsubscript{4} (60 equiv) was added slowly portion wise, in order to minimize the gas evolution. The black suspension was then allowed to warm to room temperature and thoroughly stirred for indicated time. After this time, water (3 mL) was added slowly at 0 °C and the black resulting mixture was passed through a short pad of Celite (5 g, 35 mm) to remove the nickel salts. The resulting solution was concentrated \textit{in vacuo} (40 °C, 10 mmHg). To the resulting crude oil was added water (30 mL) and extracted with Et\textsubscript{2}O (30 mL x
3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated *in vacuo* (23 °C, 10 mmHg). The crude product was purified via silica gel flash column chromatography afforded the desulfurized products.

### Desulfurization of 12 to 2-Phenyl-N-(4-toluenesulfonyl)piperidine (48)

Following General Procedure III, an oven-dried, 50-mL round-bottomed-flask was charged with a solution of the “*initial*” product **12** (36 mg, 0.086 mmol) in methanol (17 mL, 0.005 M). To the solution was then added NiCl₂·6H₂O (407 mg, 1.71 mmol, 20 equiv). The suspension was cooled to 0 °C and NaBH₄ (194 mg, 5.14 mmol, 60 equiv) was added portion wise. After 12 h of stirring at room temperature, the reaction was quenched and worked up. The crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) affording 20 mg (74%) of **48** as white solid. The spectroscopic data matched those reported in the literature.¹⁸

**Data for 48:**

mp: 138-139 °C (sealed tube)

**¹H NMR:** (500 MHz, CDCl₃)

δ 7.76 (d, J = 8.5 Hz, 2 H), 7.40 – 7.23 (m, 7 H), 5.27 (d, J = 4.5 Hz, 1 H), 3.84 (d, J = 14.0 Hz, 1 H), 3.01 (td, J = 13.5, and 3.0 Hz, 1 H), 2.44 (s, 3 H), 2.21 (d, J = 13.0 Hz, 1 H), 1.71 – 1.62 (m, 1 H), 1.54 – 1.47 (m, 1 H), 1.44 – 1.35 (m, 2 H), 1.34 – 1.24 (m, 1 H).

**¹³C NMR:** (126 MHz, CDCl₃)

δ 142.9, 138.9, 138.7, 129.6, 128.6, 127.00, 126.96, 126.8, 55.2, 41.8, 27.3, 24.3, 21.5, 18.9.

**MS:** (EI) 315 (M⁺), 238 (100), 207 (19), 161 (18), 160 (81), 159 (52), 91 (65).
Desulfurization of 12 and 13 mixture to 48 and 2-Benzyl-N-(4-toluenesulfonyl)pyrrolidine (49) (Scheme 16 Entry b)

Following General Procedure III, an oven-dried, 500-mL round-bottomed-flask was charged with a solution of the mixture of “initial” product 12 and “converted” product 13 (230 mg, 0.543 mmol) in methanol (109 mL, 0.005 M). To the solution was then added NiCl₂·6H₂O (2.58 g, 10.9 mmol, 20 equiv). The suspension was cooled to 0 °C and NaBH₄ (1.23 g, 32.6 mmol, 60 equiv) was added portion wise. After 12 h of stirring at room temperature, the reaction was quenched and worked up. The crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 19:1) affording 30 mg (18%) of 48 as a white solid and 91 mg (53%) of 49 as white solid (overall 71% yield). The spectroscopic data matched those reported in the literature.¹⁸,¹⁹

Data for 49:

¹H NMR: (500 MHz, CDCl₃)
δ 7.77 (d, J = 8.0 Hz, 2 H), 7.36 – 7.20 (m, 7 H), 3.88 – 3.80 (m, 1 H), 3.44 – 3.38 (m, 1 H), 3.26 (dd, J = 13.0, and 3.5 Hz, 1 H), 3.18 – 3.11 (m, 1 H), 2.77 (dd, J = 13.0, and 10.0 Hz, 1 H), 2.43 (s, 3H), 1.71 – 1.60 (m, 2 H), 1.51 – 1.39 (m, 2 H).

¹³C NMR: (126 MHz, CDCl₃)
δ 143.3, 138.5, 134.7, 129.6, 129.6, 128.4, 127.5, 126.4, 61.6, 49.2, 42.7, 29.9, 23.8, 21.5.

General Procedure IV: Survey of Reaction Temperature

An oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped with a rubber septum cap. After shaking the mixture well making a homogeneous solution, the NMR tube was set to an indicated temperature (external temperature) in a Cryocool unit or a cold room. After reaching equilibrium, MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. Conversion to product was measured by the
appearance of the diagnostic $^1$H NMR resonance for the piperidine $\mathbf{12}$ at 5.41 ppm and the pyrrolidine $\mathbf{13}$ at 4.07 ppm with respect to the substrate peaks at 6.34 ppm and 6.09 ppm. Generally, no other products were observed in the $^1$H NMR spectra. Formation of phthalimide byproduct was visually confirmed by the precipitation out of the solution. Monitoring by $^1$H NMR spectroscopy was done at 30 min, 3 h, 6 h, 12 h, 24 h, 48 h, and 72 h, by freezing the NMR tube in a Dewar flask with dry-ice/acetone bath (-78 °C) while transferring to a pre-cooled (-20 °C) NMR instrument. Reactions were run until complete consumption of $\mathbf{5}$ was observed by $^1$H NMR spectroscopy or at 72 h. The reaction mixture was quenched by rapidly pouring into 1 mL of sat. NaHCO$_3$ aq solution and the biphasic mixture was extracted with CH$_2$Cl$_2$ (1 mL x 3). The combined organic extracts were dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo (30 °C, 10 mmHg) to afford the crude product. The product was purified via silica gel flash column chromatography (SiO$_2$, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) prior to SFC analysis.

**Temperature Survey**

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with $\mathbf{5}$ (20 mg, 0.063 mmol), PhthSPh $\mathbf{2}$ (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-$\mathbf{3f}$ (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl$_3$ (500 µL, 0.13 M) and capped. The NMR tube was cooled to -20 °C in a Cryocool unit and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. The reaction was incomplete at 72 h, whereupon the reaction mixture was quenched. Purification of the crude product via silica gel flash column chromatography (SiO$_2$, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 20 mg (73%) of $\mathbf{12}$.

**SFC:** (2S,3R-$\mathbf{12}$, $t_R$ 14.8 min (94.6%); (2R,3S-$\mathbf{12}$, $t_R$ 16.5 min (5.4%) (Chiralcel OJ, Gradient 3% MeOH in CO$_2$ to 8% MeOH in CO$_2$ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with $\mathbf{5}$ (20 mg, 0.063 mmol), PhthSPh $\mathbf{2}$ (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-$\mathbf{3f}$ (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl$_3$ (500 µL, 0.13 M) and capped. The NMR tube
was cooled to -10 °C in a Cryocool unit and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. The reaction was incomplete at 72 h, whereupon the reaction mixture was quenched. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 23 mg (85%) of 12.

SFC: (2S,3R)-12, tᵣ 14.8 min (93.9%); (2R,3S)-12, tᵣ 16.5 min (6.1%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. The reaction was complete at 48 h, whereupon the reaction mixture was quenched. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 25 mg (95%) of 12.

SFC: (2S,3R)-12, tᵣ 14.8 min (93.6%); (2R,3S)-12, tᵣ 16.5 min (6.4%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped. The NMR tube was cooled to 5 °C in a cold room and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. The reaction was complete at 48 h, whereupon the reaction mixture was quenched. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 26 mg (95%) of 12.

SFC: (2S,3R)-12, tᵣ 14.8 min (93.0%); (2R,3S)-12, tᵣ 16.5 min (7.0%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)
Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl$_3$ (500 µL, 0.13 M) and capped. The NMR tube was allowed run at 20 °C (room temperature) in a water bath and MsOH (4.1 µL, 0.063 mmol, 1.0 equiv) was added via syringe. The reaction was complete at 6 h, whereupon the reaction mixture was quenched. Purification of the crude product via silica gel flash column chromatography (SiO$_2$, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 26 mg (96%) of 12.

**SFC:** (2S,3R)-12, $t_R$ 14.8 min (91.5%); (2R,3S)-7a, $t_R$ 16.5 min (8.5%) (Chiraleel OJ, Gradient 3% MeOH in CO$_2$ to 8% MeOH in CO$_2$ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

**General Procedure V: Survey of Acid Loadings**

An oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl$_3$ (500 µL, 0.13 M) and capped with a rubber septum cap. After shaking the mixture well making a homogeneous solution, the NMR tube was set to 0 °C in a Cryocool unit. After reaching equilibrium, indicated amount of MsOH was added via syringe. Conversion to product was measured by the appearance of the diagnostic $^1$H NMR resonance for the piperidine 12 at 5.41 ppm and the pyrrolidine 13 at 4.07 ppm with respect to the substrate peaks at 6.34 ppm and 6.09 ppm. Generally, no other products were observed in the $^1$H NMR spectra. Formation of phthalimide byproduct was visually confirmed by the precipitation out of the solution. Monitoring by $^1$H NMR spectroscopy was done at 6 h, 12 h, 24 h, and 72 h, by freezing the NMR tube in a Dewar flask with dry-ice/acetone bath (–78 °C) while transferring to a pre-cooled (–20 °C) NMR instrument. After 48 h, the reaction mixture was quenched by rapidly pouring into 1 mL of sat. NaHCO$_3$ aq solution and the biphasic mixture was extracted with CH$_2$Cl$_2$ (1 mL x 3). The combined organic extracts were dried over Na$_2$SO$_4$, filtered, and concentrated *in vacuo* (30 °C, 10 mmHg) to afford the crude product. The ratio of 12 to 13 was determined by analysis with $^1$H NMR spectroscopy of the reaction mixture and the crude product. The product was purified via silica gel flash column chromatography (SiO$_2$, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) prior to SFC analysis.
Acid Loading Study

Table 3 Entry 1

Following General Procedure V, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 μmol, 0.10 equiv), and CDCl₃ (500 μL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (4.1 μL, 0.063 mmol, 1.0 equiv) was added via syringe. The ratio of 12 to 13 of the reaction mixture were 97.5:2.5 (76.1% conversion, 6 h), 94.4:5.6 (93.4% conversion, 12 h), 86.4:13.6 (full conversion at 24 h), and of the crude product was 85.7:14.3. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) gave 22 mg (82%) of 12.

SFC: (2S,3R)-12, tᵣ 14.8 min (91.6%); (2R,3S)-13, tᵣ 16.5 min (8.4%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Table 3 Entry 2

Following General Procedure V, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 μmol, 0.10 equiv), and CDCl₃ (500 μL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (3.1 μL, 0.048 mmol, 0.75 equiv) was added via syringe. The ratio of 12 to 13 of the reaction mixture were 99.2:0.8 (76.9% conversion, 6 h), 99.3:0.7 (93.5% conversion, 12 h), 99.0:1.0 (full conversion at 24 h), and of the crude product was 98.9:1.1. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 23 mg (84%) of 12.

SFC: (2S,3R)-12, tᵣ 14.8 min (92.9%); (2R,3S)-12, tᵣ 16.5 min (7.1%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)
### Table 3 Entry 3

Following General Procedure V, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (2.1 µL, 0.032 mmol, 0.50 equiv) was added via syringe. The ratio of 12 to 13 of the reaction mixture were 99.3:0.7 (73.8% conversion, 6 h), 99.3:0.7 (92.9% conversion, 12 h), 99.2:0.8 (full conversion at 24 h), and of the crude product was 99.2:0.8. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 26 mg (96%) of 12.

**SFC:** \((2S,3R)-12, t_R\ 14.8\ min\ (93.5%); \(2R,3S)-12, t_R\ 16.5\ min\ (6.5\%)\) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

### Table 3 Entry 4

Following General Procedure V, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (1.0 µL, 0.016 mmol, 0.25 equiv) was added via syringe. The ratio of 12 to 13 of the reaction mixture were 99.4:0.6 (62.0% conversion, 6 h), 99.4:0.6 (85.0% conversion, 12 h), 99.4:0.6 (97.9% conversion at 24 h), and of the crude product was 99.4:0.6. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) gave 23 mg (87%) of 12.

**SFC:** \((2S,3R)-12, t_R\ 14.8\ min\ (93.6\%); \(2R,3S)-12, t_R\ 16.5\ min\ (6.4\%)\) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

### Table 3 Entry 5

Following General Procedure V, an oven-dried, 5-mm NMR tube was charged with 5 (20
mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 µmol, 0.10 equiv), and CDCl₃ (500 µL, 0.13 M) and capped. The NMR tube was cooled to 0 °C in a Cryocool unit and MsOH (0.4 µL, 0.0063 mmol, 0.10 equiv) was added via syringe. Since the reaction was incomplete at 24 h, the reaction mixture was quenched at 72 h. The ratio of 12 to 13 of the reaction mixture were (no data points at 6 h, and 12 h due to overlapping) 99.5:0.5 (68.7% conversion, 24 h), 99.3:0.7 (87.2% conversion, 72 h), and of the crude product was 99.3:0.7. Purification of the crude product via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) gave 21 mg (79%) of 12.

**SFC:** (2S,3R)-12, tᵣ 14.8 min (93.9%); (2R,3S)-12, tᵣ 16.5 min (6.1%) (Chiralcel OJ, Gradient 3% MeOH in CO₂ to 8% MeOH in CO₂ over 30 min, 2.5 mL/min, 220 nm, 40 °C)

**Determination of the Absolute Configuration**

**Preparation of (R)-2-Phenyl-N-(4-toluenesulfonyl)piperidine ((R)-48)**

Following General Procedure III, an oven-dried, 50-mL round-bottomed-flask was charged with a solution of the “initial” product 12 (60 mg, 0.14 mmol) in methanol (28 mL, 0.005 M). To the solution was then added NiCl₂·6H₂O (673 mg, 2.83 mmol, 20 equiv). The suspension was cooled to 0 °C and NaBH₄ (322 mg, 8.50 mmol, 60 equiv) was added portion wise. After 12 h of stirring at room temperature, the reaction was quenched and worked up. The crude product was purified via silica gel flash column chromatography (SiO₂, 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) affording 31 mg (69%) of (R)-48 as white solid. The spectroscopic data matched those reported in the literature.²⁰

**Data for (R)-48:**

¹H NMR: (500 MHz, CDCl₃)

δ 7.76 (d, J = 8.5 Hz, 2 H), 7.40 – 7.23 (m, 7 H), 5.27 (d, J = 4.5 Hz, 1 H), 3.84 (d,
$J = 14.0$ Hz, 1 H), 3.01 (td, $J = 13.5$, and 3.0 Hz, 1 H), 2.44 (s, 3 H), 2.21 (d, $J = 13.0$ Hz, 1 H), 1.71 – 1.62 (m, 1 H), 1.54 – 1.47 (m, 1 H), 1.44 – 1.35 (m, 2 H), 1.34 – 1.24 (m, 2 H).

$^{13}$C NMR:  (126 MHz, CDCl$_3$)  
$\delta 142.9, 138.9, 138.7, 129.6, 128.5, 127.00, 126.96, 126.7, 55.2, 41.8, 27.2, 24.3, 21.5, 18.9.$

MS: (EI)  
315 (M$^+$), 238 (100), 207 (19), 161 (18), 160 (81), 159 (52), 91 (65).

Opt Rot.: $[\alpha]_D^{24} +54.8$ (c = 0.65, CHCl$_3$, 89:11 er.)

**Substrate Scope Survey (Table 4)**

**Substrate Preparation**

Compounds (E)-5, 22, (Z)-5, 27 and 31 were prepared according to literature procedures.

Compounds 14, 16, 18, and 20 were prepared by following an established procedure for sequential mesylation and tosylamine substitution of the corresponding precursor alcohols 50, 51, 52, and 53 respectively (See General Procedure VI). The corresponding alcohols were prepared according to literature procedures.

![Chemical Reaction Diagram]

Compounds 33, 35, and 37 were prepared by sequential mesylation, nitrile substitution, reduction, and tosylation of the corresponding precursor alcohols 54, 55, and 56 respectively (See General Procedure VII). The corresponding alcohols were prepared according to literature procedures.
General Procedure VI: Substrate Preparation I

An oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol (2.0 mmol, 1 equiv) in CH₂Cl₂ (20 mL), and Et₃N (0.98 mL, 7.0 mmol, 3.5 equiv) dropwise via syringe. The solution was cooled to 0 °C (internal temperature), and to the flask was added methanesulfonyl chloride (232 µL, 3.0 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched by slowly addition of water (20 mL) over 5 min. The resulting biphasic mixture was extracted with CH₂Cl₂ (20 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (40 °C, 10 mmHg) to afford the crude mesylate. The crude mesylate was directly dissolved in DMF (20 mL) and transferred to an oven-dried, 50-mL round-bottomed-flask. To the flask were added K₂CO₃ (1.93 g, 14.0 mmol, 7 equiv) and p-toluenesulfonamide (2.40 g, 14.0 mmol, 7 equiv) and equipped with a reflux condenser. The suspension was heated to 80 °C (internal temperature) and stirred for 12 h. Upon reaction completion monitored by TLC, the suspension was cooled to 0 °C (internal temperature) and quenched by adding 2 M HCl (20 mL) dropwise. The resulting mixture was extracted with Et₂O (20 mL x 5). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (80 °C, 10 mmHg) to afford the crude product. The crude product was purified via silica gel flash column chromatography (SiO₂, 15 g, 20 mm Ø, toluene/EtOAc, 9:1 to 4:1).

General Procedure VII: Substrate Preparation II

An oven-dried, 250-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol (10.0 mmol, 1 equiv) in CH₂Cl₂ (100 mL),
and Et₃N (4.88 mL, 35.0 mmol, 3.5 equiv) dropwise via syringe. The solution was cooled to 0 °C (internal temperature), to the flask was added methanesulfonyl chloride (1.16 mL, 15.0 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched by slowly adding water (100 mL) over 10 min. The resulting biphasic mixture was extracted with CH₂Cl₂ (100 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (40 °C, 10 mmHg) to afford the crude product. Purification via silica gel flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/EtOAc, 9:1) afforded mesylate as a colorless oil. Then to an oven-dried, 250-mL round-bottomed flask were added a solution of the resulted mesylate (1 equiv) in DMF (100 mL) and NaCN (3 equiv) as a solid in one portion. The flask was equipped with a reflux condenser and heated to 90 °C (internal temperature) and stirred for 24 h. Upon reaction completion monitored by TLC, the suspension was cooled to 0 °C (internal temperature) and quenched by adding water pre-cooled to 0 °C (50 mL) dropwise. The resulting mixture was extracted with Et₂O (100 mL x 5). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (80 °C, 10 mmHg) to afford the crude nitrile. Purification via silica gel flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/EtOAc, 19:1) afforded nitrile.

An oven-dried, 100-mL Schlenk flask equipped with a magnetic stir bar was charged with LiAlH₄ (285 mg, 7.5 mmol, 1.5 equiv) and capped with a septum under argon. The flask was immersed in an ice-bath and was added Et₂O (10 mL). To the resulting suspension was added a solution of nitrile (5.0 mmol, 1 equiv) in Et₂O (7 mL) via syringe over 10 min at 0 °C (internal temperature). After addition was complete, the suspension was warmed to room temperature and stirred for 2 h. Upon reaction completion monitored by TLC, the suspension was cooled to 0 °C (internal temperature) and quenched by slow addition of 1 M NaOH (5 mL) dropwise. The resulting slurry was filtered through a pad of Celite (5 g, 35 mm) and concentrated in vacuo (23 °C, 10 mmHg). The resulting amine was then acidified by addition of 2 M HCl in Et₂O (2.5 mL, 5 mmol, 1 equiv) to afford the corresponding amine·HCl salt, which was thoroughly dried in vacuo (23 °C, 0.1 mmHg). Then an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar were charged with amine·HCl salt (5.0 mmol, 1 equiv), CH₂Cl₂ (10 mL), and Et₃N (2.09 mL, 15.0 mmol, 3 equiv) and capped with a septum under argon. The solution was cooled to 0 °C (internal temperature) and was added a solution of p-toluenesulfonyl chloride (1.00 g, 5.25 mmol, 1.05 equiv) in CH₂Cl₂ (7 mL) via syringe. The solution was
warmed to room temperature and was stirred for 4 h. Upon reaction completion monitored by TLC, the mixture was cooled to 0 °C (internal temperature) and quenched by adding 1 M HCl (15 mL) dropwise. The resulting biphasic mixture was extracted with CH₂Cl₂ (20 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (23 °C, 10 mmHg) to afford the crude product. Purification via silica gel flash column chromatography (SiO₂, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded the homologated tosylamine.

**Preparation of (E)-N-(4-Toluenesulfonyl)-5-(4-methoxyphenyl)pent-4-enylamine (14)**

Following General Procedure VI, an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar, a septum, and an argon inlet were charged with a solution of alcohol 50 (443 mg, 2.3 mmol, 1 equiv) in CH₂Cl₂ (23 mL), and Et₃N (1.12 mL, 8.07 mmol, 3.5 equiv). After cooled to 0 °C, to the flask was added methanesulfonyl chloride (268 µL, 3.46 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched. After the work-up, the crude mesylate (604 mg, 2.23 mmol) was dissolved in DMF (22 mL) and transferred to an oven-dried, 50-mL round-bottomed-flask. To the flask were added K₂CO₃ (2.16 g, 15.6 mmol, 7 equiv) and p-toluenesulfonylamide (2.68 g, 15.6 mmol, 7 equiv) and equipped with a reflux condenser. The suspension was heated to 80 °C (internal temperature) and stirred for 12 h. Upon reaction completion, the suspension was cooled to 0 °C and quenched. Purification via silica gel flash column chromatography (SiO₂, 15 g, 20 mm Ø, toluene/EtOAc, 9:1 to 4:1) afforded 664 mg (86% over two steps from 50) of 14 as a white solid.

**Data for 14:**

mp: 99-100 °C

$^1$H NMR: (500 MHz, CDCl₃)

$\delta$ 7.76 (d, $J$ = 8.0 Hz, 2 H, HC(13)), 7.31 (d, $J$ = 8.5 Hz, 2 H, HC(14)), 7.24 (d, $J$ = 8.5 Hz, 2 H, (HC(7)), 6.85 (d, $J$ = 8.5 Hz, 2 H, HC(8)), 6.29 (d, $J$ = 16.0 Hz, 1 H, HC(5)), 5.95 (dt, $J$ = 15.5, and 7.0 Hz, 1 H, HC(4)), 4.47 (br, 1 H, HN), 3.82 (s, 3 H,
HC(11), 3.01 (q, J = 7.0 Hz, 2 H, HC(1)), 2.44 (s, 3 H, HC(16)), 2.20 (q, J = 7.0 Hz, 2 H, HC(3)), 1.66 (p, J = 7.0 Hz, 2 H, HC(2)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

$\delta$ 158.8 (C(9)), 143.4 (C(12)), 136.9 (C(15)), 130.3 (C(5)), 130.1 (C(6)), 129.7 (C(14)), 127.1 (C(7/13)), 126.6 (C(4)), 113.9 (C(8)), 55.3 (C(11)), 42.6 (C(1)), 29.8 (C(3)), 29.2 (C(2)), 21.5 (C(16)).

IR: (Neat)

3247 (w), 1605 (w), 1511 (m), 1436 (w), 1323 (m), 1305 (m), 1288 (w), 1247 (s), 1166 (s), 1155 (s), 1095 (m), 1070 (m), 1059 (m), 1024 (m), 969 (s), 910 (m), 872 (w), 834 (m), 815 (s), 797 (m), 762 (w).

MS: (ESI)

175 (35), 346 (M+H, 100), 347 (25), 362 (12), 363 (25), 368 (17)

HRMS: (ESI) calcd for C$_{19}$H$_{24}$NO$_3$S (M+H$^+$): 346.1477, found: 346.1461

TLC: $R_f$ 0.39 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Analysis: C$_{19}$H$_{23}$NO$_3$S (345.46)

Calcd: C, 66.06; H, 6.71% N, 4.05%

Found: C, 65.74; H, 6.68% N, 4.03%

Preparation of (E)-N-(4-Toluenesulfonyl)-5-(4-trifluoromethylphenyl)pent-4-enylamine (16)

Following General Procedure VI, an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol 51$^{23}$ (460 mg, 2.0 mmol, 1 equiv) in CH$_2$Cl$_2$ (20 mL), and Et$_3$N (0.98 mL, 7.0 mmol, 3.5 equiv). After cooled to 0 °C, to the flask was added methanesulfonyl chloride (232 µL, 3.0 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched. After the work-up, the crude mesylate was dissolved in DMF (20 mL) and transferred to an oven-dried, 50-mL round-bottomed-flask. To the flask were added K$_2$CO$_3$ (1.93 g, 14.0 mmol, 7 equiv) and p-toluenesulfonamide (2.40 g, 14.0 mmol, 7 equiv) and equipped with a reflux condenser. The
suspension was heated to 80 °C (internal temperature) and stirred for 12 h. Upon reaction completion, the suspension was cooled to 0 °C and quenched. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, toluene/EtOAc, 9:1 to 4:1) afforded 659 mg (86% over two steps from 51) of 16 as a white solid.

Data for 16:

mp: 116-117 °C

$^1$H NMR: (500 MHz, CDCl$_3$)

δ 7.76 (d, $J = 8.0$ Hz, 2 H, HC(12)), 7.54 (d, $J = 8.5$ Hz, 2 H, HC(8)), 7.39 (d, $J = 8.0$ Hz, 2 H, HC(7)), 7.30 (d, $J = 8.5$ Hz, 2 H, HC(13)), 6.38 (d, $J = 16.0$ Hz, 1 H, HC(5)), 6.21 (dt, $J = 16.0$, and 7.0 Hz, 1 H, HC(4)), 4.48 (t, $J = 6.0$ Hz, 1 H, HN), 3.01 (q, $J = 7.0$ Hz, 2 H, HC(1)), 2.42 (s, 3 H, HC(15)), 2.26 (q, $J = 7.0$ Hz, 2 H, HC(3)), 1.69 (p, $J = 7.0$ Hz, 2 H, HC(2)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 143.4 (C(11)), 140.8 (C(6)), 136.9 (C(14)), 131.8 (C(4)), 129.8 (C(5)), 129.7 (C(13)), 128.9 (q, $J = 32$ Hz, C(9)), 127.1 (C(12)), 126.1 (C(7)), 125.4 (q, $J = 3.8$ Hz, C(8)), 124.2 (q, $J = 272$ Hz, C(10)), 42.5 (C(1)), 29.8 (C(3)), 29.0 (C(2)), 21.5 (C(15)).

$^{19}$F NMR: (470 MHz, CDCl$_3$)

δ -62.90

IR: (Neat)

3237 (w), 1613 (w), 1416 (w), 1319 (s), 1305 (m), 1288 (m), 1156 (s), 1114 (s), 1100 (s), 1068 (s), 1035 (m), 1016 (m), 971 (m), 910 (m), 871 (m), 851 (m), 833 (m), 815 (s), 801 (m).

MS: (ESI)

364 (28), 384 (M+H, 100), 385 (26), 401 (50), 406 (19)

HRMS: (ESI) calcd for C$_{19}$H$_{21}$F$_3$NO$_2$S (M+H$^+$): 384.1245, found: 384.1236

TLC: $R_f$ 0.43 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Analysis: C$_{19}$H$_{20}$F$_3$NO$_2$S (383.43)

Calcd:  C, 59.52;  H, 5.26%  N, 3.65%

Found:  C, 59.80;  H, 5.32%  N, 3.54%
Preparation of (E)-N-(4-Toluenesulfonyl)-7-phenylhept-4-enylamine (18)

Following General Procedure VI, an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol 52\textsuperscript{24} (381 mg, 2.0 mmol, 1 equiv) in CH\textsubscript{2}Cl\textsubscript{2} (20 mL), and Et\textsubscript{3}N (0.98 mL, 7.0 mmol, 3.5 equiv). After cooled to 0 °C, to the flask was added methanesulfonyl chloride (232 µL, 3.0 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched. After work-up, the crude mesylate was dissolved in DMF (20 mL) and transferred to an oven-dried, 50-mL round-bottomed-flask. To the flask were added K\textsubscript{2}CO\textsubscript{3} (1.93 g, 14.0 mmol, 7 equiv) and p-toluenesulfonamide (2.40 g, 14.0 mmol, 7 equiv) and equipped with a reflux condenser. The suspension was heated to 80 °C (internal temperature) and stirred for 12 h. Upon reaction completion, the suspension was cooled to 0 °C and quenched. Purification via silica gel flash column chromatography (SiO\textsubscript{2}, 15 g, 20 mm Ø, toluene/EtOAc, 9:1 to 4:1) afforded 577 mg (84% over two steps from 52) of 18 as a colorless oil.

Data for 18:

bp: 165 °C at 3 x 10\textsuperscript{-5} mm Hg

\textsuperscript{1}H NMR: (500 MHz, CDCl\textsubscript{3})

\[\delta 7.75 (d, J = 8.0 \text{ Hz}, 2 \text{ H}, \text{HC(13)}), 7.32 (d, J = 8.0 \text{ Hz}, 2 \text{ H}, \text{HC(14)}), 7.27 (t, J = 7.5 \text{ Hz}, 3 \text{ H}, \text{HC(10)}), 7.19 (d, J = 7.0 \text{ Hz}, 1 \text{ H}, \text{HC(11)}), 7.16 (d, J = 7.0 \text{ Hz}, 2 \text{ H}, \text{HC(9)}), 5.41 (dt, J = 15.0, and 7.0 \text{ Hz}, 1 \text{ H}, \text{HC(5)}), 5.31 (dt, J = 15.0, and 7.0 \text{ Hz}, 1 \text{ H}, \text{HC(4)}), 4.34 (brs, 1 \text{ H}, \text{HN}), 2.91 (t, J = 7.0 \text{ Hz}, 2 \text{ H}, \text{HC(1)}), 2.64 (t, J = 7.5 \text{ Hz}, 2 \text{ H}, \text{HC(7)}), 2.43 (s, 3 \text{ H}, \text{HC(16)}), 2.28 (q, J = 7.5 \text{ Hz}, 2 \text{ H}, \text{HC(6)}), 1.97 (q, J = 7.0 \text{ Hz}, 2 \text{ H}, \text{HC(3)}), 1.51 (p, J = 7.0 \text{ Hz}, 2 \text{ H}, \text{HC(2)}).\]

\textsuperscript{13}C NMR: (126 MHz, CDCl\textsubscript{3})

\[\delta 143.3 (C(12)), 141.9 (C(8)), 137.0 (C(15)), 130.8 (C(5)), 129.7 (C(14)), 129.2 (C(4)), 128.4 (C(9)), 128.2 (C(10)), 127.1 (C(13)), 125.7 (C(11)), 42.6 (C(1)), 35.9 (C(7)), 34.3 (C(6)), 29.4 (C(3)), 29.2 (C(2)), 21.5 (C(16)).\]

IR: 3289 (m), 2926 (m), 1496 (m), 1455 (s), 1430 (m), 1416 (m), 1337 (s), 1158 (m),
1093 (m), 970 (m), 815 (m).

**MS:**
(ESI)
173 (45), 344 (M+H, 100), 345 (24), 361 (16), 366 (25), 382 (12)

**HRMS:**
(ESI) calcd for C$_{20}$H$_{25}$NO$_2$S (M+H$^+$): 344.1684, found: 344.1676

**TLC:**
$R_f$ 0.50 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

**Analysis:**
C$_{20}$H$_{25}$NO$_2$S (343.48)
Calcd: C, 69.93; H, 7.34% N, 4.08%
Found: C, 69.90; H, 7.42% N, 4.25%

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### Preparation of (E)-$N$-(4-Toluenesulfonyl)-6-methylhept-4-enylamine (20)

Following General Procedure VI, an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar, a septum, and an argon inlet were charged with a solution of alcohol 53$^{25}$ (256 mg, 2.0 mmol, 1 equiv) in CH$_2$Cl$_2$ (20 mL), and Et$_3$N (0.98 mL, 7.0 mmol, 3.5 equiv). After cooled to 0 °C, to the flask was added methanesulfonyl chloride (232 µL, 3.0 mmol, 1.5 equiv) via syringe. After stirring for 1 h at 0 °C, the reaction solution was quenched. After the work-up, the crude mesylate was dissolved in DMF (20 mL) and transferred to an oven-dried, 50-mL round-bottomed-flask. To the flask were added K$_2$CO$_3$ (1.93 g, 14.0 mmol, 7 equiv) and $p$-toluenesulfonylchloride (2.40 g, 14.0 mmol, 7 equiv) and equipped with a reflux condenser. The suspension was heated to 80 °C (internal temperature) and stirred for 12 h. Upon reaction completion, the suspension was cooled to 0 °C and quenched. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, toluene/EtOAc, 9:1 to 4:1) afforded 456 mg (81% over two steps from 53) of 20 as a colorless oil.

**Data for 20:**
bp: decomposed at 150 °C, 2.5 x 10$^{-5}$ mm Hg

$^1$H NMR: (500 MHz, CDCl$_3$)
$\delta$ 7.76 (d, $J = 8.0$ Hz, 2 H, HC(9)), 7.31 (d, $J = 8.0$ Hz, 2 H, HC(10)), 5.32 (dd, $J =$...
15.5, and 6.5 Hz, 1 H, HC(5)), 5.23 (dt, J = 15.5, and 6.5 Hz, 1 H, HC(4)), 4.74 (t, J = 6.0 Hz, 1 H, HN), 2.92 (q, J = 6.5 Hz, 2 H, HC(1)), 2.43 (s, 3 H, HC(12)), 2.18 (hept, J = 7.0 Hz, 1 H, HC(6)), 1.95 (q, J = 7.0 Hz, 2 H, HC(3)), 1.52 (p, J = 7.0 Hz, 2 H, HC(2)), 0.92 (d, J = 7.0 Hz, 6 H, HC(7)).

\[^{13}\text{C} \text{NMR:}\] (126 MHz, CDCl\textsubscript{3})

\begin{align*}
\delta & \quad 143.2 \text{ (C(8))}, \quad 138.9 \text{ (C(5))}, \quad 137.0 \text{ (C(11))}, \quad 129.6 \text{ (C(10))}, \quad 127.1 \text{ (C(9))}, \quad 125.3 \text{ (C(4))}, \quad 42.6 \text{ (C(1))}, \quad 30.9 \text{ (C(6))}, \quad 29.4 \text{ (C(3))}, \quad 29.2 \text{ (C(2))}, \quad 22.5 \text{ (C(7))}, \quad 21.5 \text{ (C(12))}.
\end{align*}

IR:

3289 (m), 3024 (w), 2958 (m), 2869 (m), 1456 (m), 1324 (s), 1216 (w), 1159 (s), 1094 (s), 971 (m), 814 (m), 757 (s).

MS:

(ESI) 184 (21), 224 (38), 238 (16), 280 (71), 282 (M+H, 100), 283 (22), 296 (14), 299 (13), 304 (10), 331 (51), 336 (20)

HRMS:

(ESI) calcd for C\textsubscript{15}H\textsubscript{24}NO\textsubscript{2}S (M+H\textsuperscript{+}): 282.1528, found: 282.1520

TLC:

\( R_f \) 0.53 (hexanes/EtOAc, 3:2) [UV/KMnO\textsubscript{4}]

Analysis:

\( \text{C}_{15}\text{H}_{23}\text{NO}_{2}\text{S} \) (281.41)

Calcd: C, 64.02; H, 8.24%; N, 4.98%

Found: C, 63.91; H, 8.09%; N, 4.94%

Preparation of (\( \text{E} \))-N-(4-Toluenesulfonyl)-1,1-dimethyl-5-phenylpent-4-enylamine (24)

Following a reported procedure for addition of organocerium reagents to nitriles,\textsuperscript{27} an flame-dried, three-necked, 50-mL Schlenk flask equipped with a magnetic stir bar, two glass stopper, and a argon inlet was charged with finely ground CeCl\textsubscript{3}-7H\textsubscript{2}O (4.02 g, 10.8 mmol, 3 equiv). CeCl\textsubscript{3}-7H\textsubscript{2}O was dried by following a reported process.\textsuperscript{28} After purging with argon, the flask was cooled to 0 °C (external temperature) and was added anhydrous THF (21 mL). The
white suspension was warmed to room temperature and stirred for 2 h. The suspension was cooled to -72 °C (internal temperature) in a dry-ice/i-PrOH bath and was added a solution of MeLi (1.61 M in Et₂O, 6.68 mL, 10.8 mmol, 3 equiv), whereupon the suspension turned yellow. After stirring for 30 min at -72 °C, the flask was transferred to a cold bath (-65 °C), controlled with a Cryocool unit. To the flask was added a solution of nitrile 606 (565 mg, 3.6 mmol, 1 equiv, pre-cooled to -65 °C) in THF (6 mL) via cannula at -65 °C (internal temperature). After 4 h, the reaction was complete, and the reaction solution was quenched by adding concentrated NH₄OH solution (6.5 mL) dropwise at -65 °C. The resulting mixture was warmed to room temperature and was filtered through a pad of Celite (5 g, 35 mm), rinsed thoroughly with CH₂Cl₂ (50 mL). The filtrate was dried over Na₂SO₄, filtered, and concentrated in vacuo (50 °C, 10 mmHg) to afford crude oil. The crude oil was dissolved in toluene (20 mL) and was added a solution of H₃PO₄ (3%, 20 mL) and was stirred for 15 min. The organic layer was separated from the aqueous layer, and was added concentrated NH₄OH solution (20 mL). The biphasic mixture was extracted with CH₂Cl₂ (20 mL x 5), dried over Na₂SO₄, filtered, and concentrated in vacuo (70 °C, 10 mmHg) to afford crude amine. Then an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar were charged with the amine (680 mg, 3.59 mmol, 1 equiv), CH₂Cl₂ (12 mL), and Et₃N (1.75 mL, 12.6 mmol, 3.5 equiv) and capped with a septum under argon. The solution was cooled to 0 °C (internal temperature) and was added a solution of p-toluenesulfonyl chloride (754 mg, 3.95 mmol, 1.1 equiv) in CH₂Cl₂ (2 mL) via syringe. The solution was warmed to room temperature and was stirred for 24 h. Upon reaction completion monitored by TLC, the solution was cooled to 0 °C (internal temperature) and quenched by adding 1 M HCl (10 mL) dropwise. The resulting biphasic mixture was extracted with CH₂Cl₂ (10 mL x 3). The combined organic extracts were dried over Na₂SO₄, filtered, and concentrated in vacuo (23 °C, 10 mmHg) to afford the crude product. Purification via silica gel flash column chromatography (SiO₂, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 1.04 g (84%) the tosylamine 24 as white solid.

**Data for 24:**

mp: 111-112 °C

[^1]H NMR: (500 MHz, CDCl₃)

δ 7.80 (d, J = 8.5 Hz, 2 H, HC(12)), 7.32 – 7.27 (m, 6 H, HC(7,8,13)), 7.24 – 7.18 (m, 1 H, HC(9)), 6.32 (d, J = 16.0 Hz, 1 H, HC(5)), 6.08 (dt, J = 16.0, and 7.0 Hz, 1 H, HC(4)), 4.64 (brs, 1 H, HN), 2.42 (s, 3 H, HC(15)), 2.23 – 2.17 (m, 2 H, HC(3)),
1.70 – 1.65 (m, 2 H, HC(2)), 1.23 (s, 6 H, HC(10)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 142.9 (C(11)), 140.5 (C(14)), 137.6 (C(6)), 137.2 (C(5)), 129.8 (C(4)), 129.5 (C(13)), 128.5 (C(8)), 127.0 (C(12)), 126.9 (C(9)), 125.9 (C(7)), 57.0 (C(1)), 42.2 (C(2)), 27.8 (C(10)), 27.6 (C(3)), 21.5 (C(15)).

IR: (Neat)

3296 (w), 2920 (w), 1426 (w), 1321 (m), 1220 (w), 1149 (s), 1089 (m), 1019 (w), 991 (m), 966 (m), 867 (w), 847 (w), 819 (m), 742 (m).

MS: (ESI)

117 (14), 173 (82), 174 (16), 344 (M+H, 100), 345 (25), 361 (100), 362 (27), 366 (18)

HRMS: (ESI) calcd for C$_{20}$H$_{25}$NO$_2$S (M+H$^+$): 344.1684, found: 344.1683

TLC: $R_f$ 0.51 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Analysis: C$_{20}$H$_{25}$NO$_2$S (343.48)

Calcd: C, 69.93; H, 7.34%; N, 4.08%

Found: C, 69.98; H, 7.40%; N, 4.28%

Preparation of (E)-N-(4-Toluenesulfonyl)-5-phenylpent-4-enamide (29)$^{29}$

An oven-dried, 25-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of carboxylic acid $^{61}$ (352 mg, 2.0 mmol, 1 equiv) in THF (7 mL), and Et$_3$N (558 µL, 4.0 mmol, 2 equiv). After stirring 5 min at room temperature, to the flask was added $p$-toluenesulfonyl isocyanate (321 µL, 2.1 mmol, 1.05 equiv) dropwise via syringe with observation of gas evolution. After stirring for 16 h at room temperature, the reaction was complete monitored by TLC. The reaction mixture was cooled to 0 °C (internal temperature) and was added 2 M HCl (7 mL) to quench the reaction. Resulting biphasic mixture was extracted with Et$_2$O (7 mL x 3). The combined organic extracts were dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo (50 °C, 10 mmHg) to afford the crude product. Purification
via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, toluene/EtOAc, 3:1) afforded 593 mg (90%) of 29 as white solid.

Data for 29:

**mp:** 113-114 °C

$^1$H NMR: (500 MHz, CDCl$_3$)

$\delta$ 8.42 (brs, 1 H, HN), 7.93 (d, $J$ = 8.0 Hz, 2 H, HC(12)), 7.33 – 7.20 (m, 7 H, HC(7,8,9,13)), 6.33 (d, $J$ = 16.0 Hz, 1 H, HC(5)), 6.07 (dt, $J$ = 16.0, and 6.5 Hz, 1 H, HC(4)), 2.51 – 2.42 (m, 4 H, HC(2,3)), 2.42 (s, 3 H, HC(15)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

$\delta$ 170.3 (C(1)), 145.1 (C(11)), 137.0 (C(6)), 135.4 (C(14)), 131.5 (C(5)), 129.6 (C(13)), 128.4 (C(8)), 128.2 (C(12)), 127.3 (C(4)), 127.2 (C(9)), 126.1 (C(7)), 35.9 (C(2)), 27.6 (C(3)), 21.6 (C(15)).

IR: (Neat)

3290 (w), 1719 (s), 1594 (w), 1433 (m), 1415 (m), 1373 (w), 1335 (m), 1187 (w), 1169 (s), 1118 (m), 1082 (s), 1042 (w), 1019 (w), 959 (m), 859 (s), 848 (m), 774 (w).

MS: (ESI)

158 (22), 330 (M+H, 100), 331 (24), 347 (20), 352 (21)

HRMS: (ESI) calcd for C$_{18}$H$_{20}$NO$_3$S (M+H$^+$): 330.1164, found: 330.1166

TLC: $R_f$0.27 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Analysis: C$_{18}$H$_{19}$NO$_3$S (329.41)

Calcd:  C, 65.63; H, 5.81% N, 4.25%

Found:  C, 65.33; H, 5.84% N, 4.30%

Preparation of (E)-N-(4-Toluenesulfonyl)-6-phenylpent-5-enylamine (33)

1) MsCl (1.5 equiv)  
Et$_3$N (3.5 equiv)  
CH$_2$Cl$_2$, 0 °C, 1 h  

2) NaCN (15 equiv)  
DMF, 80 °C, 4 h

1) LIAH$_4$ (1.5 equiv)  
Et$_2$O, 0 °C to rt, 2 h

2) TsCl (1.05 equiv)  
Et$_3$N (3 equiv)  
DCM, rt, 8 h

Following General Procedure VII, an oven-dried, 250-mL Schlenk flask equipped with a
magnetic stir bar, a septum, and an argon inlet were charged with a solution of alcohol 54 (2.43 g, 15.0 mmol, 1 equiv) in CH₂Cl₂ (150 mL), and Et₃N (7.32 mL, 52.5 mmol, 3.5 equiv). The solution was cooled to 0 °C, to the flask was added methanesulfonyl chloride (1.74 mL, 22.5 mmol, 1.5 equiv). After stirring for 1 h at 0 °C, the reaction was quenched. Purification via silica gel flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/EtOAc, 9:1) afforded 3.16 g (88%) of mesylate as a colorless oil. Then to an oven-dried, 250-mL round-bottomed flask were added a solution of the resulted mesylate (3.16 g, 13.1 mmol, 1 equiv) in DMF (44 mL) and NaCN (9.67 g, 197 mmol, 15 equiv) as a solid in one portion. The flask was equipped with a reflux condenser and heated to 80 °C and stirred for 4 h. Upon reaction completion the reaction was quenched. Purification via silica gel flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/EtOAc, 19:1) afforded 1.92 g (86%) of nitrile 57 as a colorless oil. The ¹H NMR spectroscopic data matched those reported in the literature.³¹

Data for 57:
¹H NMR: (500 MHz, CDCl₃)
δ 7.42 – 7.25 (m, 5 H), 6.49 (d, J = 16.0 Hz, 1 H), 6.15 (dt, J = 16.0, and 7.0 Hz, 1 H), 2.45 – 2.37 (m, 4 H), 1.86 (qt, J = 7.0 Hz, 2 H).

An oven-dried, 100-mL Schlenk flask equipped with a magnetic stir bar was charged with LiAlH₄ (569 mg, 15.0 mmol, 1.5 equiv) and capped with a septum under argon. The flask was immersed in an ice-bath and was added Et₂O (26 mL). To the resulting suspension was added a solution of nitrile 57 (1.71 g, 10.0 mmol, 1 equiv) in Et₂O (7 mL). The suspension was warmed to room temperature and stirred for 2 h. The reaction was quenched upon completion, and acidified to afford the corresponding amine·HCl salt. Then an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar was charged with amine·HCl salt (1.47 g, approx. 8.39 mmol, 1 equiv), CH₂Cl₂ (21 mL), and Et₃N (3.51 mL, 25.2 mmol, 3 equiv). To the solution was added a solution of p-toluenesulfonyl chloride (1.68 g, 8.81 mmol, 1.05 equiv) in CH₂Cl₂ (7 mL) at 0 °C. The solution was warmed to room temperature and was stirred for 8 h. The reaction was quenched upon completion. Purification via silica gel flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 2.63 g (80% over two steps from 57) of the homologated tosylamine 33 as white solid. The ¹H NMR spectroscopic data matched those reported in the literature.⁵
Data for 33:

**mp:** 61-62 °C

**$^1$H NMR:** (500 MHz, CDCl$_3$)

\[\delta 7.76 \text{ (d, } J = 8.5 \text{ Hz, } 2 \text{ H, HC(12))}, \text{ 7.34} – \text{ 7.28 (m, } 6 \text{ H, HC(8,9,13))}, \text{ 7.23} – \text{ 7.19 (m, } 1 \text{ H, HC(10))}, \text{ 6.34 (d, } J = 16.0 \text{ Hz, } 1 \text{ H, HC(6))}, \text{ 6.13 (dt, } J = 16.0 \text{ and } 7.0 \text{ Hz, } 1 \text{ H, } \text{HC(5))}, \text{ 4.61 (brt, } J = 5.5 \text{ Hz, } 1 \text{ H, } \text{HN})], \text{ 2.97 (q, } J = 6.5 \text{ Hz, } 2 \text{ H, HC(1))}, \text{ 2.42 (s, } 3 \text{ H, HC(15))}, \text{ 2.17 (q, } J = 7.0 \text{ Hz, } 2 \text{ H, HC(4))}, \text{ 1.56} – \text{ 1.42 (m, } 4 \text{ H, HC(2,3))}.

**$^{13}$C NMR:** (126 MHz, CDCl$_3$)

\[\delta 143.3 \text{ (C(11))}, \text{ 137.5 (C(7))}, \text{ 136.9 (C(14))}, \text{ 130.3 (C(5))}, \text{ 129.9 (C(4))}, \text{ 129.6 (C(13))}, \text{ 128.4 (C(9))}, \text{ 127.0 (C(12))}, \text{ 126.9 (C(10))}, \text{ 125.9 (C(8))}, \text{ 43.0 (C(1))}, \text{ 32.3 (C(4))}, \text{ 29.0 (C(2))}, \text{ 26.1 (C(3))}, \text{ 21.5 (C(15))}.

**IR:** (Neat)

3255 (w), 2944 (w), 1495 (w), 1421 (w), 1321 (s), 1290 (w), 1159 (s), 1094 (m), 1067 (w), 968 (m), 911 (w), 872 (w), 820 (m), 741 (m).

**MS:** (ESI)

330 (M+H, 100), 331 (23), 347 (12), 352 (17)

**HRMS:** (ESI) calcd for C$_{19}$H$_{24}$N$_2$O$_2$S (M+H$^+$): 330.1528, found: 330.1525

**TLC:** $R_f$ 0.48 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

**Analysis:** C$_{19}$H$_{25}$NO$_2$S (329.46)

Calcd: C, 69.27; H, 7.04% N, 4.25%

Found: C, 69.38; H, 7.16% N, 4.48%

Preparation of (E)-N-(4-Toluenesulfonyl)-6-phenylpent-5-enylamine (35)

Following General Procedure VII, an oven-dried, 250-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol 55$_{25}^5$ (1.28 g, 10.0 mmol, 1 equiv) in CH$_2$Cl$_2$ (100 mL), and Et$_3$N (4.88 mL, 35.0 mmol, 3.5 equiv). The
solution was cooled to 0 °C, to the flask was added methanesulfonyl chloride (1.16 mL, 15.0 mmol, 1.5 equiv). After stirring for 1 h at 0 °C, the reaction was quenched. Purification via silica gel flash column chromatography (SiO$_2$, 30 g, 30 mm Ø, hexanes/EtOAc, 9:1) afforded 1.90 g (92%) of mesylate as a colorless oil. Then to an oven-dried, 250-mL round-bottomed-flask were added a solution of the resulted mesylate (1.90 g, 9.20 mmol, 1 equiv) in DMF (100 mL) and NaCN (1.35 g, 27.6 mmol, 3 equiv) as a solid in one portion. The flask was equipped with a reflux condenser and heated to 90 °C and stirred for 24 h. Upon reaction completion the reaction was quenched. Purification via silica gel flash column chromatography (SiO$_2$, 30 g, 30 mm Ø, hexanes/EtOAc, 19:1) afforded 1.09 g (86%) of nitrile 58 as a colorless oil. The $^1$H NMR spectroscopic data matched those reported in the literature.  

**Data for 58:**

$^1$H NMR: (500 MHz, CDCl$_3$)

δ 5.49 (ddt, $J = 15.5$, 6.5, and 1.5 Hz, 1 H, HC(6)), 5.28 (dtd, $J = 15.5$, 6.5, and 1.5 Hz, 1 H, HC(5)), 2.33 (t, $J = 7.0$ Hz, 2 H, HC(1)), 2.30 – 2.22 (m, 1 H, HC(7)), 2.15 (q, $J = 7.0$ Hz, 2 H, HC(4)), 1.73 (p, $J = 7.0$ Hz, 2 H, HC(3)), 0.98 (d, $J = 6.5$ Hz, 6 H, HC(8)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 140.2 (C(6)), 124.1 (C(5)), 119.3 (C(1)), 31.2 (C(4)), 31.0 (C(7)), 25.1 (C(3)), 22.5 (C(8)), 16.2 (C(2)).

An oven-dried, 100-mL Schlenk flask equipped with a magnetic stir bar was charged with LiAlH$_4$ (285 mg, 7.5 mmol, 1.5 equiv) and capped with a septum under argon. The flask was immersed in an ice-bath and was added Et$_2$O (10 mL). To the resulting suspension was added a solution of nitrile 58$^{25}$ (686 mg, 5.0 mmol, 1 equiv) in Et$_2$O (7 mL). The suspension was warmed to room temperature and stirred for 2 h. The reaction was quenched upon completion, and acidified to afford the corresponding amine·HCl salt. Then an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar was charged with amine·HCl salt (5.0 mmol, 1 equiv), CH$_2$Cl$_2$ (10 mL), and Et$_3$N (2.09 mL, 15.0 mmol, 3 equiv). To the solution was added a solution of p-toluenesulfonyl chloride (1.00 g, 5.25 mmol, 1.05 equiv) in CH$_2$Cl$_2$ (7 mL) at 0 °C. The solution was warmed to room temperature and was stirred for 4 h. The reaction was quenched
upon completion. Purification via silica gel flash column chromatography (SiO$_2$, 30 g, 30 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 1.02 g (69% over two steps from 58) of the homologated tosylamine 35 as a colorless oil.

**Data for 35:**

**$^1$H NMR:** (500 MHz, CDCl$_3$)

δ 7.76 (d, $J = 8.5$ Hz, 2 H, HC(10)), 7.29 (d, $J = 8.0$ Hz, 2 H, HC(11)), 5.31 (dd, $J = 15.5$, and 6.5 Hz, 1 H, HC(6)), 5.23 (dt, $J = 15.5$, and 6.5 Hz, 1 H, HC(5)), 5.02 (t, $J = 6.0$ Hz, 1 H, HN), 2.90 (q, $J = 7.0$ Hz, 2 H, HC(1)), 2.41 (s, 3 H, HC(13)), 2.18 (hept, $J = 6.5$ Hz, 1 H, HC(7)), 1.89 (q, $J = 7.0$ Hz, 2 H, HC(4)), 1.44 (dt, $J = 15.0$, and 7.0 Hz, 2 H, HC(2)), 1.30 (p, $J = 7.44$ Hz, 2 H, HC(3)), 0.92 (d, $J = 7.0$ Hz, 6 H, HC(8)).

**$^{13}$C NMR:** (126 MHz, CDCl$_3$)

δ 143.1 (C(9)), 138.1 (C(6)), 136.9 (C(12)), 129.5 (C(11)), 127.0 (C(10)), 126.2 (C(5)), 43.0 (C(1)), 31.8 (C(4)), 30.8 (C(7)), 28.8 (C(2)), 26.4 (C(3)), 22.5 (C(8)), 21.4 (C(13)).

**IR:** 3283 (m), 2933 (m), 2868 (w), 1598 (w), 1456 (m), 1325 (s), 1158 (s), 1093 (m), 971 (w), 937 (w), 815 (m).

**MS:** (ESI)

252 (31), 294 (100), 296 (M+H, 49), 310 (32), 350 (17)

**HRMS:** (ESI) calcd for C$_{16}$H$_{26}$NO$_2$S (M+H$^+$): 296.1677, found: 296.1684

**TLC:** $R_f$ 0.56 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

**Analysis:** C$_{16}$H$_{25}$NO$_2$S (295.44)

Calcd:  C, 65.05; H, 8.53%  N, 4.74%

Found:  C, 64.98; H, 8.34%  N, 4.65%
Preparation of \((E)-N-(4-Toluenesulfonyl)-8\text{-phenylpent-5-enylamine}\) (37)

Following General Procedure VII, an oven-dried, 250-mL Schlenk flask equipped with a magnetic stir bar, a septum, and a argon inlet were charged with a solution of alcohol \(56\) \(^{24}\) (1.90 g, 10.0 mmol, 1 equiv) in \(\text{CH}_2\text{Cl}_2\) (100 mL), and \(\text{Et}_3\text{N}\) (4.88 mL, 35.0 mmol, 3.5 equiv). The solution was cooled to 0 °C, to the flask was added methanesulfonyl chloride (1.16 mL, 15.0 mmol, 1.5 equiv). After stirring for 1 h at 0 °C, the reaction was quenched. Purification via silica gel flash column chromatography (SiO\(_2\), 30 g, 30 mm Ø, hexanes/EtOAc, 9:1) afforded 2.47 g (92%) of mesylate as a colorless oil. Then to an oven-dried, 250-mL round-bottomed-flask were added a solution of the resulted mesylate (2.47 g, 9.23 mmol, 1 equiv) in DMF (100 mL) and \(\text{NaCN}\) (1.35 g, 27.6 mmol, 3 equiv) as a solid in one portion. The flask was equipped with a reflux condenser and heated to 90 °C and stirred for 24 h. Upon reaction completion the reaction was quenched. Purification via silica gel flash column chromatography (SiO\(_2\), 30 g, 30 mm Ø, hexanes/EtOAc, 19:1) afforded 1.65 g (90%) of nitrile \(59\) as a colorless oil.

Data for \(59\):

**\(^1\text{H NMR:}\)** (500 MHz, CDCl\(_3\))

\[\begin{align*}
\delta & 7.29 \text{ (t, } J = 7.5 \text{ Hz, 2 H, HC(11)), 7.21 - 7.15 \text{ (m, 3 H, HC(12,10)), 5.52 \text{ (dt, } J = 15.0, \text{ and 7.0 Hz, 1 H, HC(6)), 5.30 \text{ (dt, } J = 15.0, \text{ and 7.0 Hz, 1 H, HC(5)), 2.69 \text{ (t, } J = 7.5 \text{ Hz, 2 H, HC(8)), 2.34 \text{ (q, } J = 7.5 \text{ Hz, 2 H, HC(7)), 2.20 \text{ (t, } J = 7.5 \text{ Hz, 2 H, HC(2)), 2.13 \text{ (q, } J = 7.0 \text{ Hz, 2 H, HC(4)), 1.67 \text{ (p, } J = 7.0 \text{ Hz, 2 H, HC(3))}.}
\end{align*}\]

**\(^{13}\text{C NMR:}\)** (126 MHz, CDCl\(_3\))

\[\begin{align*}
\delta & 141.7 \text{ (C(9)), 132.0 (C(6)), 128.5 (C(10)), 128.2 (HC(11)), 128.2 (HC(5)), 125.8 (C(12)), 119.7 (C(1)), 35.7 (C(8)), 34.2 (C(7)), 31.1 (C(4)), 24.9 (C(3)), 16.1 (C(2)).}
\end{align*}\]

**IR:**

\[3026 \text{ (m), 2933 (s), 2851 (m), 2245 (m), 1496 (s), 1454 (s), 1079 (w), 1030 (w), 970 (s), 747 (s).}\]
An oven-dried, 100-mL Schlenk flask equipped with a magnetic stir bar was charged with LiAlH$_4$ (285 mg, 7.5 mmol, 1.5 equiv) and capped with a septum under argon. The flask was immersed in an ice-bath and was added Et$_2$O (10 mL). To the resulting suspension was added a solution of nitrile 59 (996 mg, 5.0 mmol, 1 equiv) in Et$_2$O (7 mL). The suspension was warmed to room temperature and stirred for 2 h. The reaction was quenched upon completion, and acidified to afford the corresponding amine·HCl salt. Then an oven-dried, 50-mL Schlenk flask equipped with a magnetic stir bar was charged with amine·HCl salt (5.0 mmol, 1 equiv), CH$_2$Cl$_2$ (10 mL), and Et$_3$N (2.09 mL, 15.0 mmol, 3 equiv). To the solution was added a solution of $p$-toluenesulfonyl chloride (1.00 g, 5.25 mmol, 1.05 equiv) in CH$_2$Cl$_2$ (7 mL) at 0 °C. The solution was warmed to room temperature and was stirred for 4 h. The reaction was quenched upon completion. Purification via silica gel flash column chromatography (SiO$_2$, 15 g, 20 mm Ø, hexanes/EtOAc, 9:1 to 4:1) afforded 1.22 g (66% over two steps from 59) of the homologated tosylamine 37 as a white solid.

**Data for 37:**

- **mp:** 68-69 °C
- **$^1$H NMR:** (500 MHz, CDCl$_3$)
  
  $\delta$ 7.75 (d, $J = 8.5$ Hz, 2 H, HC(14)), 7.31 (d, $J = 8.0$ Hz, 2 H, HC(15)), 7.27 (t, $J = 7.5$ Hz, 2 H, HC(11)), 7.20 – 7.14 (m, 3 H, HC(12,10)), 5.43 – 5.35 (m, 1 H, HC(6)), 5.35 – 5.27 (m, 1 H, HC(5)), 4.47 (brrs, 1 H, HN), 2.90 (q, $J = 6.5$ Hz, 2 H, HC(1)), 2.65 (t, $J = 8.0$ Hz, 2 H, HC(8)), 2.43 (s, 3 H, HC(17)), 2.28 (q, $J = 7.0$ Hz, 2 H, HC(7)), 1.91 (q, $J = 7.0$ Hz, 2 H, HC(4)), 1.43 – 1.35 (m, 2 H, HC(2)), 1.33 – 1.24 (m, 2 H, HC(3)).
$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 143.3 (C(13)), 142.0 (C(9)), 136.9 (C(16)), 130.1 (C(6)), 130.0 (C(5)), 129.6 (C(15)), 128.4 (C(10)), 128.2 (11)), 127.1 (C(14)), 125.7 (C(12)), 43.0 (C(1)), 35.9 (C(8)), 34.3 (C(7)), 31.8 (C(4)), 28.8 (C(2)), 26.2 (C(3)), 21.5 (C(17)).

IR: 3244 (m), 2924 (w), 2857 (w), 1596 (w), 1449 (2), 1424 (w), 1322 (s), 1307 (m), 1163 (s), 1153 (s), 1093 (m), 1074 (m), 1027 (w), 973 (m), 906 (w), 813 (m), 750 (m).

MS: (ESI)

358 (M+H, 100), 359 (28), 375 (22), 380 (22), 396 (10)

HRMS: (ESI) calcd for C$_{21}$H$_{27}$NO$_2$S (M+H$^+$): 358.1841, found: 358.1829

TLC: $R_f$ 0.53 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Analysis: C$_{21}$H$_{27}$NO$_2$S (357.51)

Calcd:  C, 70.55;  H, 7.61%  N, 3.92%

Found:  C, 70.55;  H, 7.57%  N, 3.98%

General Procedure VIII: Cyclization

An oven-dried, 25-mL Schlenk flask equipped with a stir bar was charged with substrate (1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH$_2$Cl$_2$ (10.0 mL, 0.10 M) and capped with a rubber septum. The flask was placed into an isopropyl alcohol bath, and the bath was cooled to 0 °C via a Cryocool unit. The temperature of the mixture was monitored via a thermocouple digital temperature probe. After the temperature stabilized, MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) was added and the mixture was allowed to stir for the indicated time. The reaction was quenched while cold by addition of pre-cooled sat. NaHCO$_3$ aq. solution upon vigorous stirring. The resulting mixture was extracted with CH$_2$Cl$_2$ (10 mL x 3). The combined organic extracts were dried over Na$_2$SO$_4$, filtered through glass wool and then concentrated in vacuo (23 °C, 10 mm Hg) to afford the crude product. The product was purified via silica gel flash column chromatography prior to SFC analysis.

Sulfenoamination Reactions with (S)-3f (Table 4)

Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-2-phenyl-3-(phenylthio)piperidine (12)
Following General Procedure VIII, a 25-mL Schlenk flask was charged with 5 (315 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 0.2 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.1 equiv), and CH$_2$Cl$_2$ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 24 h. The reaction was worked up following the general procedure. The product 12 was purified by flash chromatography (SiO$_2$, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 393 mg (93%) of a 12 as a white solid.

Data for 12:

mp: 51-53 °C (sealed tube)

$^1$H NMR: (500 MHz, CDCl$_3$)

δ 7.80 (d, $J = 8.0$ Hz, 2 H, HC(18)), 7.47 (d, $J = 8.5$ Hz, 2 H, HC(13)), 7.31 (t, $J = 8.0$ Hz, 2 H, HC(14)), 7.29 - 7.16 (m, 8 H, HC(aryl)), 5.41 (s, 1 H, HC(2)), 3.91 (d, $J = 2.0$ Hz, 1H, HC(3)), 3.75 (dd, $J = 13.0$, and 3.0 Hz, 1 H, HC(6)), 3.21 (td, $J = 12.0$, and 3.0 Hz, 1 H, HC(6)), 2.39 (s, 3 H, HC(21)), 1.91 - 1.70 (m, 3 H, HC(4,5)), 1.38 (dt, $J = 13.5$, and 3.0 Hz, 1 H, HC(5)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 142.9 (C(20)), 138.8 (C(7)), 137.7 (C(17)), 135.0 (C(12)), 132.2 (C(13)), 129.2 (C(19)), 129.1 (C(14)), 128.6 (C(9)), 127.6 (C(18)), 127.4 (C(15)), 127.0 (C(10)), 126.8 (C(8)), 60.0 (C(2)), 49.7 (C(3)), 41.7 (C(6)), 24.1 (C(4)), 21.5 (C(21)), 19.9 (C(5)).

IR: 3025 (w), 2947 (w), 2869 (w), 1598 (w), 1495 (w), 1479 (w), 1438 (m), 1377 (w), 1337 (s), 1304 (m), 1287 (m), 1214 (m), 1182 (w), 1157 (s), 1107 (m), 1090 (s), 1068 (w), 1049 (m), 1003 (w), 942 (s), 915 (w), 882 (w), 859 (w), 827 (w), 814 (w), 760 (s)
MS: (ESI)
314 (98), 315 (27), 316 (10), 424 (M+H, 100), 425 (27), 426 (13), 441 (19), 446 (21), 462 (12)
HRMS: calcd for C_{24}H_{26}NO_2S_2: 424.1405, found: 424.1408
TLC: R_f 0.54 (hexanes/EtOAc, 3:2) [UV/KMnO_4]
Opt Rot: [\alpha]_D^{24} 73.0 (c = 1.00, CHCl_3)
SFC: (2S,3R)-12, t_R 13.6 min (93.6%); (2R,3S)-12, t_R 15.2 min (6.4%) (Chiralcel OJ, Gradient 3% MeOH in CO_2 to 8% MeOH in CO_2 over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Analysis: C_{24}H_{25}NO_2S_2 (423.59)
Calcd: C, 68.05%; H, 5.95% N, 3.31%
Found: C, 67.93%; H, 6.11% N, 3.02%

Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-2-(4-methoxyphenyl)-3-(phenylthio)piperidine (15) (Table 4 Entry 2)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 14 (345 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH_2Cl_2 (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 24 h. The reaction was worked up following the general procedure. The product 15 was purified by flash chromatography (SiO_2, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 414 mg (91%) of 15 as a white solid.

Data for 15:
mp: 53-54 °C (sealed tube)
^1H NMR: (500 MHz, CDCl_3)
\delta 7.84 (d, J = 8.5 Hz, 2 H, HC(20)), 7.48 (d, J = 7.5 Hz, 2 H, HC(15)), 7.36 (t, J = 7.5 Hz, 2 H, HC(16)), 7.32 – 7.26 (m, 3 H, HC(17,21)), 7.18 (d, J = 9.0 Hz, 2 H,
HC(8)), 6.84 (d, J = 9.0 Hz, 2 H, HC(9)), 5.38 (s, 1 H, HC(2)), 3.90 (brd, J = 2.5 Hz, 1 H, HC(3)), 3.80 (s, 3 H, HC(12)), 3.75 (d, J = 13.5 Hz, 1 H, HC(6)), 3.27 – 3.19 (m, 1 H, HC(6)), 2.45 (s, 3 H, HC(23)), 1.93 – 1.78 (m, 3 H, HC(4,5)), 1.47 – 1.40 (m, 1 H, HC(5)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 158.6 (C(10)), 142.9 (C(19)), 137.8 (C(22)), 135.2 (C(14)), 132.2 (C(15)), 130.8 (C(7)), 129.2 (C(21)), 129.2 (C(16)), 128.1 (C(8)), 127.1 (C(20)), 127.4 (C(17)), 114.0 (C(9)), 59.7 (C(2)), 55.3 (C(12)), 49.6 (C(3)), 41.7 (C(6)), 24.1 (C(4)), 21.5 (C(23)), 20.1 (C(5)).

IR: 3026 (w), 2948 (w), 2869 (w), 1610 (w), 1582 (w), 1512 (m), 1459 (w), 1438 (w), 1374 (w), 1336 (m), 1304 (m), 1285 (w), 1252 (m), 1212 (w), 1181 (m), 1157 (s), 1107 (w), 1089 (m), 1069 (w), 1048 (w), 1034 (w), 1003 (w), 944 (m), 929 (m), 886 (w), 863 (w), 839 (w), 814 (w), 751 (m)

MS: (ESI)

344 (M+H, 100), 345 (24), 346 (14), 454 (15), 476 (22)

HRMS: calcd for C$_{25}$H$_{27}$NO$_3$S$_2$: 454.1511, found: 454.1513

TLC: $R_f$ 0.53 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Opt Rot: $[\alpha]_D^{24}$ 41.3 (c = 1.00, CHCl$_3$)

SFC: (2S,3R)-15, $t_R$ 18.0 min (91.8%); (2R,3S)-15, $t_R$ 22.0 min (8.2%) (Chiralpak AD, 10% MeOH in CO$_2$, 2.0 mL/min, 220 nm, 40 °C)

Analysis:

C$_{25}$H$_{27}$NO$_3$S$_2$ (453.62)

Calcd: C, 66.19; H, 6.00% N, 3.09%

Found: C, 66.26; H, 5.82% N, 2.99%
Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-2-(4-trifluoromethylphenyl)-3-(phenylthio)piperidine (17) (Table 4 Entry 3)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 16 (383 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH₂Cl₂ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 17 was purified by flash chromatography (SiO₂, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 191 mg (39%) of 17 as a white solid.

Data for 17:

mp: 107-108 °C (sealed tube)

¹H NMR: (500 MHz, CDCl₃)
δ 7.82 (d, J = 8.5 Hz, 2 H, HC(19)), 7.54 (d, J = 8.5 Hz, 2 H, HC(9)), 7.49 (d, J = 7.0 Hz, 2 H, HC(14)), 7.39 – 7.30 (m, 5 H, HC(8,15,16)), 7.28 (d, J = 8.0 Hz, 2 H, HC(20)), 5.40 (s, 1 H, HC(2)), 3.88 (q, J = 3.5 Hz, 1 H, HC(3)), 3.79 (m, 1 H, HC(6)), 3.25 (ddd, J = 13.5, 12.5, and 3.5 Hz, 1 H, HC(6)), 2.44 (s, 3 H, HC(22)), 1.95 – 1.81 (m, 2 H, HC(4,5)), 1.79 – 1.70 (m, 1 H, HC(4)), 1.51 – 1.43 (m, 1 H, HC(5)).

¹³C NMR: (126 MHz, CDCl₃)
δ 143.3 (C(21)), 143.2 (C(7)), 137.4 (C(18)), 134.6 (C(13)), 132.6 (C(14)), 129.4 (q, J = 32 Hz, C(10)), 129.3 (C(20)), 129.3 (C(15)), 127.8 (C(16)), 127.6 (C(19)), 127.3 (C(8)), 125.6 (q, J = 3.8 Hz, C(9)), 123.9 (q, J = 272 Hz, C(11)), 60.0 (C(2)), 50.0 (C(3)), 42.0 (C(6)), 24.3 (C(4)), 21.5 (C(21)), 19.9 (C(5)).

¹⁹F NMR: (470 MHz, CDCl₃)
δ -63.05.

IR: 3025 (w), 2948 (m), 2872 (w), 1918 (w), 1619 (m), 1598 (w), 1984 (w), 1493 (w),
1479 (w), 1438 (m), 1411 (m), 1336 (s), 1286 (m), 1212 (m), 1132 (s), 1090 (m),
1069 (s), 1050 (m), 1015 (m), 938 (s), 889 (w), 863 (w), 845 (m), 814 (m), 747 (s)

**MS:**
(ESI)
382 (50), 383 (12), 492 (M+H, 100), 493 (31), 494 (15), 514 (15)

**HRMS:**
calcld for C_{25}H_{25}NO_{2}S_{2}F_{3}: 492.1279, found: 492.1276

**TLC:**
R_f 0.60 (hexanes/EtOAc, 3:2) \[UV/KMnO_4\]

**Opt Rot:**
[α]_D^{24} 46.5 (c = 1.00, CHCl_3)

**SFC:**
(2R,3S)-17, t_R 16.9 min (8.1%); (2S,3R)-17, t_R 17.9 min (91.9%) (Chiralcel OD,
Gradient 3% MeOH in CO_2 to 5% MeOH in CO_2 over 30 min, 2.0 mL/min, 220 nm,
40 °C)

**Analysis:**
C_{25}H_{24}F_{3}NO_{2}S_{2} (491.59)
Calcd:  C, 61.08;  H, 4.92%  N, 2.85%
Found:  C, 61.13;  H, 4.70%  N, 2.58%

**Preparation of (2S,6R)-N-(4-Toluenesulfonyl)-2-(3-phenyl-1-(phenylthio)propyl)pyrrolidine (19a) and (2S,3R)-N-(4-Toluenesulfonyl)-2-phenethyl-3-(phenylthio)piperidine (19b) (Table 4 Entry 4)**

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 18 (343 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH_2Cl_2 (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 24 h. The reaction was worked up following
the general procedure. The product 19 was purified by flash chromatography (SiO_2, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1) to afford 411 mg (91%) of a 3.3:1 mixture of 19a:19b as a white solid.
Data for 19a+19b:

$^1$H NMR: (500 MHz, CDCl$_3$)

$\delta$ 7.84 (d, $J = 7.5$ Hz, 2 H, HC(20')), 7.65 (d, $J = 7.5$ Hz, 2 H, HC(20)), 7.50 (d, $J = $ 8.0 Hz, 2 H, HC(9)), 7.38 (d, $J = 8.0$ Hz, 2 H, HC(aryl')), 7.35 – 7.17 (m, 10 H+8 H(')), HC(aryl, aryl')). 7.10 (d, $J = 8.0$ Hz, 2 H, HC(aryl')), 4.29 (t, $J = 7.0$ Hz, 1 H, HC(2')), 3.93 (dt, $J = 9.0$, and 5.0 Hz, 1 H, HC(2)), 3.70 (dt, $J = 9.0$, and 4.5 Hz, 1 H, HC(6)), 3.63 (d, $J = 11.0$ Hz, 1 H, HC(6')), 3.42 – 3.31 (m, 2 H+1 H('), HC(5,3')), 3.10 – 2.97 (m, 1 H+1 H('), HC(13,6')), 2.75 (ddd, $J = 13.5$, 10.0, and 6.0 Hz, 1 H, HC(13)), 2.63 (t, $J = 8.0$ Hz, 2 H, HC(8')), 2.45 (s, 3 H, HC(23')), 2.43 (s, 3 H, HC(23)), 2.07 (ddt, $J = 14.0$, 10.0, and 5.5 Hz, 1 H, HC(12)), 2.00 – 1.79 (m, 3 H+5 H('), HC(3,4,12,4',5',7')), 1.68 (dt, $J = 13.5$, and 7.0 Hz, 1 H, (3)), 1.44 (d, $J = 13.5$ Hz, 1 H, HC(5')), 1.38 – 1.27 (m, 1 H, HC(4)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

$\delta$ 143.3 (C(19)), 142.9 (C(19')), 141.6 (C(14)), 141.1 (C(9')), 135.8 (C(8)), 135.1 (C(22)), 132.2 (C(aryl')), 131.5 (C(9)), 129.6 (C(21)), 129.4(C(21')), 129.1 (C(aryl')), 128.9 (C(10)), 128.5 (C(aryl)), 128.4 (C(aryl')), 128.4 (C(aryl)), 128.3 (C(aryl')), 127.7 (C(20')), 127.5 (C(20)), 127.2 (C(aryl')), 126.6 (C(11)), 126.0 (C(aryl')), 125.9 (C(aryl)), 63.8 (C(2)), 57.0 (C(2')), 55.3 (C(6)), 49.7 (C(5)), 47.6 (C(3')), 40.3 (C(6')), 35.9 (C(12)), 33.7 (C(13)), 32.9 (C(8')), 32.6 (C(4')), 28.0 (C(3)), 24.8 (C(4)), 23.9 (C(7')), 21.5 (C(23,23')), 20.1 (C(5')).

IR: 3025 (m), 2946 (w), 1598 (w), 1495 (w), 1479 (w), 1452 (w), 1438 (w), 1343 (m), 1302 (w), 1216 (m), 1157 (s), 1091 (m), 1019 (w), 989 (w), 927 (w), 815 (w), 755 (s)

MS: (ESI)

342 (24), 452 (M+H, 100), 453 (18), 474 (19)

HRMS: calc'd for C$_{26}$H$_{30}$NO$_2$S$_2$: 452.1718, found: 452.1716

TLC: $R_f$ 0.58 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Opt Rot: $[\alpha]_{D}^{24}$ -46.9 (c = 1.00, CHCl$_3$)

SFC: (2S,6R)-19a, $t_R$ 23.5 min (95.9% (73.6%)); (2S,3R)-19b, $t_R$ 24.9 min (95.8% (22.3%)); (2R,6S)-19a, $t_R$ 27.8 min (4.1% (3.1%)); (2R,6S)-19b, $t_R$ 29.7 min (4.2% (1.0%)) (Welk, 5% MeOH in CO$_2$, 2.0 mL/min, 220 nm, 40°C);
Analysis:  \( \text{C}_2\text{H}_9\text{NO}_2\text{S}_2 \) (451.64)

Calcd:  C, 69.14;  H, 6.47 %  N, 3.10 %

Found:  C, 68.65;  H, 6.44 %  N, 3.43 %

Preparation of (2S,6R)-N-(4-Toluenesulfonyl)-2-(2-methyl-1-(phenylthio)propyl)pyrroli dine (21) (Table 4 Entry 5)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 20 (281 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and \( \text{CH}_2\text{Cl}_2 \) (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 \( \mu \)L, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 21 was purified by flash chromatography (SiO\(_2\), 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 346 mg (89%) of 21 as a white solid.

Data for 21:

**mp:** 140-141 °C (sealed tube)

**\(^1\text{H NMR: \( (500 \text{ MHz, CDCl}_3) \)}}**

\( \delta \) 7.66 (d, \( J = 8.0 \text{ Hz}, 2 \text{ H, HC(16)} \)), 7.53 (dd, \( J = 8.5, \text{ and } 1.0 \text{ Hz, 2 H, HC(9)} \)), 7.32 – 7.25 (m, 4 H, HC(10,17)), 7.19 (t, \( J = 7.5 \text{ Hz, 1 H, HC(11)} \)), 4.01 (ddd, \( J = 8.5, 5.5, \text{ and } 4.0 \text{ Hz, 1 H, HC(2)} \)) , 3.60 (dd, \( J = 6.5, \text{ and } 4.0 \text{ Hz, 1 H, HC(6)} \)), 3.36 (ddd, \( J = 8.0, 5.5, \text{ and } 2.5 \text{ Hz, 2 H, HC(5)} \)), 2.42 (s, 3 H, HC(19)), 2.01 (sept, 1 H, HC(12)), 1.89 (dtd, \( J = 13.0, 7.5, \text{ and } 5.5 \text{ Hz, 1 H, HC(3)} \)), 1.79 (dtt, \( J = 12.0, 5.5, \text{ and } 5.5 \text{ Hz, 1 H, HC(4)} \)), 1.67 (dtd, \( J = 13.0, 8.0, \text{ and } 5.5 \text{ Hz, 1 H, HC(3)} \)), 1.24 (dtt, \( J = 12.0, 8.0, \text{ and } 8.0 \text{ Hz, 1 H, HC(4)} \)), 1.12 (d, \( J = 6.5 \text{ Hz, 3 H, HC(13)} \)), 1.10 (d, \( J = 6.5 \text{ Hz, 3 H, HC(13)} \)).

**\(^{13}\text{C NMR: \( (126 \text{ MHz, CDCl}_3) \)}}**

\( \delta \) 143.3 (C(15)), 137.4 (C(8)), 134.9 (C(18)), 130.8 (C(9)), 129.7 (C(17)), 128.8 (C(10)), 127.5 (C(16)), 126.2 (C(11)), 63.3 (C(6)), 62.2 (C(2)), 49.6 (C(5)), 32.1 (C(12)), 28.6 (C(3)), 24.9 (C(4)), 21.5 (C(19)), 21.0 (C(13)), 20.4 (C(13)).
IR: (neat)
2960 (w), 1583 (w), 1482 (w), 1332 (s), 1309 (w), 1201 (w), 1155 (s), 1111 (w), 1088 (m), 1027 (m), 993 (m), 867 (w), 826 (s), 743 (s)

MS: (ESI)
184 (13), 219 (16), 224 (16), 280 (100), 281 (17), 390 (M+H, 71), 391 (21), 392 (10), 412 (95), 413 (24), 414 (12), 428 (60), 429 (17), 430 (10)

HRMS: calcd for C_{21}H_{28}NO_{2}S_{2}: 390.1561, found: 390.1574

TLC: R_f 0.60 (hexanes/EtOAc, 3:2) [UV/KMnO_4]

Opt Rot: [α]_D ^{24} -20.8 (c = 1.00, CHCl_3)

SFC: (2S,6R)-21, t_R 7.9 min (96.8%); (2R,6S)-21, t_R 10.3 min (3.2%) (Chiralpak AD, 10% MeOH in CO_2, 2.0 mL/min, 220 nm, 40 °C)

Analysis: C_{21}H_{27}NO_{2}S_{2} (389.57)
Calcd: C, 64.74%; H, 6.99 %; N, 3.60%
Found: C, 64.57%; H, 6.95%; N, 3.86%

Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-5,5-dimethyl-2-phenyl-3-(phenylthio)piperidine (23) (Table 4 Entry 6)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 22 (343 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH_2Cl_2 (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 24 h. The reaction was worked up following the general procedure. The product 23 was purified by flash chromatography (SiO_2, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 410 mg (91%) of 23 as a white solid.

Data for 23:
mp: 100-101 °C (sealed tube)
$^1$H NMR: (500 MHz, CDCl$_3$)
\[ \begin{align*}
\delta &\ 7.50 \ (d, J = 8.0 \text{ Hz}, 2 \text{ H}, \text{HC}(19)), \ 7.37 \ (dd, J = 8.0, \text{ and} \ 1.5 \text{ Hz}, 2 \text{ H}, \text{HC}(13)), \\
&\ 7.32 - 7.25 \ (m, 3 \text{ H}, \text{HC}(14,15)), \ 7.22 - 7.12 \ (m, 7 \text{ H}, \text{HC}(8,9,10,20)), \ 4.94 \ (d, J = \\
&\ 6.0 \text{ Hz}, 1 \text{ H}, \text{HC}(2)), \ 3.67 \ (ddd, J = 7.5, 6.0, \text{ and} \ 4.5 \text{ Hz}, 1 \text{ H}, \text{HC}(3)), \ 3.30 \ (d, J = \\
&\ 13.5 \text{ Hz}, 1 \text{ H}, \text{HC}(6)), \ 3.20 \ (d, J = 13.5 \text{ Hz}, 1 \text{ H}, \text{HC}(6)), \ 2.39 \ (s, 3 \text{ H}, \text{HC}(22)), \\
&\ 1.85 \ (dd, J = 14.0, \text{ and} \ 4.5 \text{ Hz}, 1 \text{ H}, \text{HC}(4)), \ 1.67 \ (dd, J = 14.0, 7.5 \text{ Hz}, 1 \text{ H}, \text{HC}(4)), \\
&\ 1.03 \ (s, 3 \text{ H}, \text{HC}(16)), 0.96 \ (s, 3 \text{ H}, \text{HC}(16)).
\end{align*} \]

$^{13}$C NMR: (126 MHz, CDCl$_3$)
\[ \begin{align*}
\delta &\ 142.6 \ (C(21)), \ 138.5 \ (C(7)), \ 137.4 \ (C(18)), \ 134.8 \ (C(12)), \ 132.6 \ (C(13)), \ 129.0 \\
&\ (C(20)), \ 128.9 \ (C(14)), \ 128.1 \ (C(9)), \ 127.7 \ (C(8)), \ 127.5 \ (C(15)), \ 127.4 \ (C(10)), \\
&\ 127.3 \ (C(19)), \ 62.6 \ (C(2)), \ 53.3 \ (C(6)), \ 49.7 \ (C(3)), \ 40.9 \ (C(4)), \ 31.5 \ (C(5)), \ 27.7 \\
&\ (C(16)), \ 27.6 \ (C(16)), \ 21.4 \ (C(22)).
\end{align*} \]

IR: (neat)
\[ \begin{align*}
2957 \ (w), \ 2868 \ (w), \ 1581 \ (w), \ 1494 \ (w), \ 1476 \ (w), \ 1454 \ (m), \ 1441 \ (w), \ 1393 \ (w), \\
1337 \ (m), \ 1313 \ (s), \ 1287 \ (m), \ 1183 \ (w), \ 1148 \ (s), \ 1092 \ (m), \ 1037 \ (m), \ 1026 \ (m), \\
1000 \ (m), \ 956 \ (w), \ 905 \ (m), \ 844 \ (m), \ 809 \ (m), \ 776 \ (s), \ 741 \ (s)
\end{align*} \]

MS: (ESI)
\[ \begin{align*}
342 \ (100), \ 343 \ (24), \ 452 \ (M+H, 38), \ 453 \ (12), \ 469 \ (12), \ 474 \ (33), \ 490 \ (15)
\end{align*} \]

HRMS: calcd for C$_{26}$H$_{29}$NO$_2$S$_2$: 452.1718, found: 452.1717

TLC: \( R_f 0.58 \) (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Opt Rot: \( \alpha \ D^2 43.4 \) (c = 1.00, CHCl$_3$)

SFC: (2R,3S)-23, \( t_R 37.0 \) min (3.7%); (2S,3R)-23, \( t_R 38.6 \) min (96.3%) (Chiralecel OD, 
Gradient 1% MeOH in CO$_2$ to 5% MeOH in CO$_2$ over 60 min, 2.0 mL/min, 220 nm, 
40 °C)

Analysis: C$_{26}$H$_{20}$NO$_2$S$_2$ (451.64)
\[ \begin{align*}
\text{Calcd:} &\ C, 69.14; \ H, 6.47\% \ N, 3.10\% \\
\text{Found:} &\ C, 68.79; \ H, 6.08\% \ N, 2.80\%
\end{align*} \]
Preparation of (5R,6S)-N-(4-Toluenesulfonyl)-2,2-dimethyl-6-phenyl-5-(phenylthio)piperidine (25) (Table 4 Entry 7)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 24 (343 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH₂Cl₂ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 24 h. The reaction was worked up following the general procedure. The product 25 was purified by flash chromatography (SiO₂, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 421 mg (93%) of 25 as a white solid.

Data for 25:

mp: 137-138 °C (sealed tube)

¹H NMR: (500 MHz, CDCl₃)
δ 7.87 (d, J = 8.5 Hz, 2 H, HC(19)), 7.53 (d, J = 7.5 Hz, 2 H, HC(14)), 7.32 (t, J = 7.5 Hz, 2 H, HC(15)), 7.23 (t, J = 7.5 Hz, 1 H, HC(16)), 7.13 – 7.03 (m, 5 H, HC(11,12,20)), 6.97 (d, J = 7.0 Hz, 2 H, HC(10)), 4.82 (d, J = 3.0 Hz, 1 H, HC(6)), 4.38 (ddd, J = 9.5, 3.0, and 1.5 Hz, 1 H, HC(5)), 2.36 (td, J = 12.5, and 7.5 Hz, 1 H, HC(3)), 2.29 (s, 3 H, HC(22)), 2.00 (dd, J = 13.5, and 8.0 Hz, 1 H, HC(4)), 1.86 – 1.77 (m, 1 H, HC(4)), 1.77 (s, 3 H, HC(7)), 1.714 (dd, J = 12.5, and 6.5 Hz, 1 H, HC(3)), 1.49 (s, 3 H, HC(7)).

¹³C NMR: (126 MHz, CDCl₃)
δ 142.7 (C(18)), 139.8 (C(13)), 139.3 (C(21)), 135.6 (C(9)), 129.2 (C(20)), 128.9 (C(10)), 128.5 (C(15)), 128.4 (C(11)), 128.3 (C(14)), 127.3 (C(19)), 127.2 (C(16)), 125.5 (C(12)), 67.9 (C(2)), 66.6 (C(5)), 56.7 (C(6)), 41.5 (C(3)), 28.8 (C(7)), 27.1 (C(7)), 23.9 (C(4)), 21.3 (C(22)).

IR: 2993 (w), 2963 (m), 1595 (w), 1579 (w), 1491 (m), 1475 (m), 1446 (m), 1393 (w), 1351 (w), 1328 (s), 1309 (m), 1286 (w), 1253 (w), 1234 (m), 1205 (m), 1182 (w),
1153 (s), 1117 (m), 1084 (s), 980 (s), 941 (w), 905 (w) 862 (w), 846 (w), 814 (m), 761 (s)

**MS:** (ESI)
181 (41), 281 (57), 282 (14), 342 (95), 343 (24), 452 (M+H, 100), 453 (30), 474 (44), 475 (14), 490 (18)

**HRMS:** calcd for C_{26}H_{30}NO_2S_2: 452.1718, found: 452.1715

**TLC:** $R_f$ 0.64 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

**Opt Rot:** $[\alpha]_D^{24}$ -38.1 (c = 1.00, CHCl$_3$)

**SFC:** (5R,6S)-25, $t_R$ 18.4 min (91.8%); (5S,6R)-25, $t_R$ 20.3 min (8.2%) (Chiracel OD, Gradient 3% MeOH in CO$_2$ to 5% MeOH in CO$_2$ over 30 min, 2.0 mL/min, 220 nm, 40 °C)

**Analysis:** C$_{26}$H$_{29}$NO$_2$S$_2$ (451.64)
Calcd: C, 69.14; H, 6.47% N, 3.10%
Found: C, 69.06; H, 6.38% N, 2.89%

**Preparation of (2R,3R)-N-(4-Toluenesulfonyl)-2-phenyl-3-(phenylthio)piperidine (26)**
(Table 4 Entry 8)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with (Z)-5 (315 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH$_2$Cl$_2$ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 26 was purified by flash chromatography (SiO$_2$, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 288 mg (68%) of 26 as a white solid.

**Data for 26:**
mp: 54-55 °C (sealed tube)
Denmark and Chi

$^1$H NMR: (500 MHz, CDCl$_3$)
$\delta$ 7.42 – 7.37 (m, 4 H, HC(8,18)), 7.34 – 7.22 (m, 8 H, HC(aryl)), 7.09 (d, $J = 8.5$ Hz, 2 H, HC(19)), 5.36 (d, $J = 5.5$ Hz, 1 H, HC(2)), 3.85 (dd, $J = 13.5$, and 4.0 Hz, 1 H, HC(6)), 3.50 (dt, $J = 13.0$, and 5.0 Hz, 1 H, HC(3)), 3.06 (td, $J = 13.5$, and 3.0 Hz, 1 H, HC(6)), 2.37 (s, 3 H, HC(21)), 2.10 (qd, $J = 13.0$, and 4.0 Hz, 1 H, HC(4)), 2.00 (dd, $J = 13.5$, and 3.5 Hz, 1 H, HC(4)), 1.83 (brd, $J = 13.5$ Hz, 1 H, HC(5)), 1.70 (qt, $J = 13.5$, and 5.0 Hz, 1 H, HC(5)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)
$\delta$ 142.8 (C(17)), 137.0 (C(20)), 136.6 (C(7)), 134.4 (C(12)), 131.9 (C(13/14)), 129.7 (C(8)), 129.3 (C(19)), 129.0 (C(14/13)), 128.0 (C(9)), 127.8 (C(15)), 127.3 (C(10)), 127.0 (C(18)), 59.2 (C(2)), 48.7 (C(3)), 40.8 (C(6)), 26.3 (C(4)), 25.5 (C(5)), 21.4 (C(21)).

IR: 3058 (w), 3027 (m), 2949 (w), 2869 (w), 2869 (w), 1598 (w), 1583 (w), 1495 (w), 1479 (w), 1454 (w), 1438 (m), 1334 (s), 1304 (w), 1286 (w), 1216 (s), 1175 (m), 1159 (s), 1133 (m), 1095 (s), 1037 (w), 1022 (w), 1000 (m), 946 (s), 887 (w), 872 (w), 814 (m), 748 (s)

MS: (ESI)
314 (100), 315 (22), 424 (M+H, 53), 425 (14), 446 (16)

HRMS: calcd for C$_{24}$H$_{26}$NO$_2$S$_2$: 424.1405, found: 424.1398

TLC: $R_f$ 0.53 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Opt Rot: $[\alpha]_{D}^{24}$ -14.9 (c = 1.00, CHCl$_3$)

SFC: (2$R$,3$R$)-26, $t_R$ 10.9 min (62.8%); (2$S$,3$S$)-26, $t_R$ 12.4 min (37.2%) (Chiralcel OD, 10% MeOH in CO$_2$, 2.0 mL/min, 220 nm, 40 ºC)

Analysis:
C$_{24}$H$_{25}$NO$_2$S$_2$ (423.59)
Calcd: C, 68.05; H, 5.95% N, 3.31%
Found: C, 67.80; H, 5.89% N, 3.27%
Preparation of (2S)-N-(4-Toluenesulfonyl)-2-((phenylthio)methyl)pyrrolidine (28) (Table 4 Entry 9)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 28 (239 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH₂Cl₂ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 36 h. The reaction was worked up following the general procedure. The product 28 was purified by flash chromatography (SiO₂, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 323 mg (93%) of 28 as a white solid.

Data for 28:

- **mp:** 85-86 °C (sealed tube)
- **¹H NMR:** (500 MHz, CDCl₃) δ 7.58 (d, J = 8.0 Hz, 2 H, HC(14)), 7.49 (d, J = 7.5 Hz, 2 H, HC(9)), 7.37 (t, J = 7.5 Hz, 2 H, HC(10)), 7.28 – 7.21 (m, 3 H, HC(11,15)), 3.71 (ddd, J = 13.5, and 3.0 Hz, 1 H, HC(6)), 3.65 (ddt, J = 11.0, 7.0, and 3.0 Hz, 1 H, HC(2)), 3.51 (ddd, J = 10.5, 6.5, and 4.5 Hz, 1 H, HC(5)), 3.12 (ddd, J = 10.0, 8.0, and 6.5 Hz, 1 H, HC(5)), 2.79 (dd, J = 13.5, and 11.0 Hz, 1 H, HC(6)), 2.42 (s, 3 H, HC(17)), 1.94 – 1.86 (m, 1 H, HC(3)), 1.86 – 1.77 (m, 1 H, HC(4)), 1.70 – 1.60 (m, 1 H, HC(3)), 1.58 – 1.50 (m, 1 H, HC(4)).
- **¹³C NMR:** (126 MHz, CDCl₃) δ 143.4 (C(13)), 135.3 (C(8)), 133.7 (C(16)), 129.6 (C(15)), 129.0 (C(10)), 128.9 (C(9)), 127.4 (C(14)), 126.0 (C(11)), 58.8 (C(2)), 49.7 (C(5)), 38.3 (C(6)), 30.2 (C(3)), 23.7 (C(4)), 21.5 (C(17)).
- **IR:** 2975 (w), 2869 (w), 1597 (w), 1481 (m), 1439 (m), 1345 (s), 1197 (m), 1159 (s), 1092 (m), 1062 (w), 1027 (m), 986 (w), 910 (s), 815 (m), 734 (s)
- **MS:** (ESI) 238 (31), 348 (M+H, 100), 349 (24), 350 (14), 370 (20), 386 (11)
- **HRMS:** calcd for C₁₈H₂₂NO₂S₂: 348.1092, found: 348.1086
TLC: \(R_f\) 0.51 (hexanes/EtOAc, 3:2) [UV/KMnO\(_4\)]

Opt Rot: \([\alpha]_D^{24}\) -228.7 (c = 1.00, CHCl\(_3\))

SFC: (2S)-28, \(t_R\) 13.8 min (92.5%); (2R)-28, \(t_R\) 15.0 min (7.5%) (Chiralcel OD, 5% MeOH in CO\(_2\), 2.0 mL/min, 220 nm, 40 °C)

Analysis: \(C_{24}H_{32}NOS_2\) (347.49)

Calcd: C, 62.21; H, 6.09%  N, 4.03%

Found: C, 62.06; H, 5.69%  N, 3.96%

Preparation of (5R,6S)-N-(4-Toluenesulfonyl)-6-phenyl-5-(phenylthio)piperidin-2-one (30)
(Table 4 Entry 10)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 29 (329 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH\(_2\)Cl\(_2\) (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 30 was purified by flash chromatography (SiO\(_2\), 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 372 mg (85%) of 30 as a white solid.

Data for 30:

\(mp\): 73-74 °C (sealed tube)

\(^1H\) NMR: (500 MHz, CDCl\(_3\))

\(\delta\) 7.77 (d, \(J = 8.5\) Hz, 2 H, HC(18)), 7.55 (d, \(J = 7.0\) Hz, 2 H, HC(13)), 7.44 – 7.28 (m, 6 H, HC(14,15,9,10)), 7.25 (d, \(J = 8.0\) Hz, 2 H, HC(19)), 7.12 (d, \(J = 7.5\) Hz, 2 H, HC(8)), 5.75 (s, 1 H, HC(6)), 3.76 (q, \(J = 3.0\) Hz, 1 H, HC(5)), 2.75 (ddd, \(J = 19.5, 12.0,\) and 8.0 Hz, 1 H, HC(3)), 2.52 (dd, \(J = 19.5,\) and 6.5 Hz, 1 H, HC(3)), 2.43 (s, 3 H, HC(21)), 2.07 – 1.98 (m, 1 H, HC(4)), 1.79 – 1.70 (m, 1 H, HC(4)).
\[^{13}\text{C}\] NMR:  
(126 MHz, CDCl\textsubscript{3})
\[
\delta 169.4 (C(2)), 144.7 (C(17)), 139.8 (C(7)), 135.7 (C(20)), 133.0 (C(13)), 132.7 (C(12)), 129.5 (C(14,18)), 128.9 (C(9,19)), 128.4 (C(15)), 128.1 (C(10)), 126.0 (C(8)), 63.8 (C(6)), 49.7 (C(5)), 29.6 (C(3)), 21.7 (C(21)), 20.2 (C(4)).
\]

IR:  
3028 (w), 2941 (w), 1731 (m), 1694 (s), 1597 (w), 1495 (w), 1480 (w), 1454 (m), 1359 (s), 1295 (m), 1263 (m), 1218 (m), 1169 (s), 1130 (m), 1088 (m), 1024 (w), 963 (m), 822 (m), 751 (s)

MS:  
(ESI)  
328 (100), 329 (25), 438 (M+H, 91), 439 (27), 440 (14), 460 (32), 476 (14)

HRMS:  
calcd for C_{24}H_{23}NO_{3}S_{2}: 438.1198, found: 438.1189

TLC:  
R\textsubscript{f} 0.44 (hexanes/EtOAc, 3:2) [UV/KMnO\textsubscript{4}]

Opt Rot:  
[\alpha]_{D}^{24} 30.0 (c = 1.00, CHCl\textsubscript{3})

SFC:  
(5R,6S)-30, t\textsubscript{R} 13.8 min (83.7%); (5S,6R)-30, t\textsubscript{R} 15.7 min (16.3%) (Chiralcel OJ, Gradient 3% MeOH in CO\textsubscript{2} to 8% MeOH in CO\textsubscript{2} over 30 min, 2.5 mL/min, 220 nm, 40 °C)

Analysis:  
C\textsubscript{24}H\textsubscript{23}NO\textsubscript{3}S\textsubscript{2} (437.57)  
Calcd: C, 65.88; H, 5.30; N, 3.20%  
Found: C, 66.03; H, 5.00%; N, 3.12%

Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-2-phenyl-3-(phenylthio)pyrrolidine (32)  
(Table 4 Entry 11)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 31 (301 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH\textsubscript{2}Cl\textsubscript{2} (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 36 h. The reaction was worked up following the general procedure. The product 32 was purified by flash chromatography (SiO\textsubscript{2}, 25 g, 30 mm
Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 352 mg (86%) of 32 as a white solid.

Data for 32:

mp: 72-73 °C (sealed tube)

\( ^1\text{H NMR:} \) (500 MHz, CDCl\(_3\))
\[ \delta 7.74 \text{ (d, } J = 8.0 \text{ Hz, 2 H, HC(17)), 7.36 \text{ (d, } J = 8.5 \text{ Hz, 2 H, HC(18)), 7.34 – 7.16 (m, 10 H, HC(aryl)), 4.67 \text{ (s, 1 H, HC(2)), 3.82 \text{ (ddd, } J = 9.0, 8.0, 2.5 \text{ Hz, 1 H, HC(5)), 3.68 – 3.59 (m, 2 H, HC(5(left),3(right))), 2.50 \text{ (s, 3 H, HC(20)), 2.38 – 2.28 (m, 1 H, HC(4)), 1.86 – 1.78 (m, 1 H, HC(4)).} \]

\( ^{13}\text{C NMR:} \) (126 MHz, CDCl\(_3\))
\[ \delta 143.4 \text{ (C(16)), 141.6 \text{ (C(6)), 134.6 \text{ (C(19)), 133.6 \text{ (C(11)), 132.2 \text{ (C(13)), 129.5 \text{ (C(18)), 129.0 \text{ (C(12)), 128.4 \text{ (C(8)), 127.8 \text{ (C(17)), 127.6 \text{ (C(14)), 127.4 \text{ (C(9)), 126.0 \text{ (C(7)), 68.7 \text{ (C(2)), 55.5 \text{ (C(3)), 47.8 \text{ (C(5)), 29.2 \text{ (C(4)), 21.6 \text{ (C(20)).} \)} \]

IR: 3026 (w), 2947 (w), 2882 (w), 1598 (w), 1494 (w), 1479 (w), 1439 (w), 1347 (s), 1305 (w), 1216 (m), 1182 (m), 1160 (s), 1096 (s), 1055 (w), 1022 (w), 1009 (m), 814 (m), 752 (s)

MS: (EI)
91 (12), 118 (100), 135 (18), 151 (25), 155 (12), 253 (10), 254 (44), 299 (88), 300 (18), 409 (M+, 81), 410 (18)

HRMS: calcd for C\(_{23}\)H\(_{23}\)NO\(_2\)S\(_2\): 409.1170, found: 409.1162

TLC: \( R_f 0.54 \) (hexanes/EtOAc, 3:2) [UV/KMnO\(_4\)]

Opt Rot: \([\alpha]_D^{24} 103.4 \) (c = 1.00, CHCl\(_3\))

SFC: (2R,3S)-32, \( t_R 12.9 \text{ min (8.7%); (2S,3R)-32, } t_R 15.3 \text{ min (91.3%) (Chiralpak AD, 10% MeOH in CO}_2, 2.0 \text{ mL/min, 220 nm, 40 °C)}

Analysis: C\(_{23}\)H\(_{23}\)NO\(_2\)S\(_2\) (409.56)
Calcd: C, 67.45%; H, 5.66% N, 3.42%
Found: C, 67.73%; H, 5.49% N, 3.65%
Preparation of (2S,3R)-N-(4-Toluenesulfonyl)-2-phenyl-3-(phenylthio)azepane (34) (Table 4 Entry 12)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 33 (329 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH$_2$Cl$_2$ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 36 h. The reaction was worked up following the general procedure. The product 34 was purified by flash chromatography (SiO$_2$, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 368 mg (84%) of 34 as a white solid.

Data for 34:

mp: 129-130 °C (sealed tube)

$^1$H NMR: (500 MHz, CDCl$_3$)
\[ \delta 7.33 – 7.18 (m, 12 H, HC(aryl)), 7.50 (d, J = 8.0 Hz, 2 H, HC(20)), 5.04 (d, J = 10.5 Hz, 1 H, HC(2)), 3.69 (d, J = 15.5 Hz, 1 H, HC(7)), 3.48 (t, J = 9.5 Hz, 1 H, HC(3)), 2.45 (ddd, J = 15.0, 11.5, and 1.5 Hz, 1 H, HC(7)), 2.33 (s, 3 H, HC(22)), 2.27 (dd, J = 15.0, and 6.0 Hz, 1 H, HC(4)), 2.03 – 1.89 (m, 2 H, HC(4,5)), 1.88 – 1.77 (m, 1 H, HC(6)), 1.74 – 1.66 (m, 1 H, HC(6)), 1.48 – 1.35 (m, 1 H, HC(5)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)
\[ \delta 142.5 (C(21)), 140.2 (C(8)), 137.6 (C(18)), 134.4 (C(13)), 132.2 (C(14)), 129.0 (C(20)), 128.9 (C(10)), 128.3 (C(15)), 127.7 (C(11)), 127.6 (C(9)), 127.2 (C(16)), 127.2 (C(19)), 64.3 (C(2)), 54.2 (C(3)), 45.7 (C(7)), 34.4 (C(4)), 29.4 (C(6)), 28.6 (C(5)), 21.4 (C(22)).

IR: (neat)
2922 (w), 2854 (w), 1598 (w), 1494 (w), 1476 (w), 1460 (w), 1437 (w), 1378 (w), 1332 (s), 1306 (w), 1252 (w), 1184 (w), 1157 (s), 1138 (m), 1101 (m), 1088 (m), 1067 (w), 1027 (m), 982 (w), 933 (s), 850 (m), 811 (m), 781 (s)

MS: (ESI)
328 (100), 329 (25), 438 (M+H, 38), 439 (10), 455 (20), 460 (37), 461 (11), 476 (18)
Denmark and Chi

HRMS: calcd for C_{25}H_{28}NO_{2}S_{2}: 438.1561, found: 438.1563

TLC: R_{f} 0.58 (hexanes/EtOAc, 3:2) [UV/KMnO_{4}]

Opt Rot: [α]_{D}^{24} 45.5 (c = 1.00, CHCl_{3})

SFC: (2S,3R)-34, t_{R} 6.0 min (92.7%); (2R,3S)-34, t_{R} 10.4 min (7.3%) (Chiralcel OB, 15% MeOH in CO_{2}, 2.0 mL/min, 220 nm, 40 °C)

Analysis: C_{25}H_{27}NO_{2}S_{2} (437.62)
Calcd: C, 68.61%; H, 6.22% N, 3.20%
Found: C, 68.60%; H, 5.97% N, 3.28%

Preparation of (2S,7R)-N-(4-Toluenesulfonyl)-2-(2-methyl-1-(phenylthio)propyl)piperidine (36) (Table 4 Entry 13)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 35 (295 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10 equiv), and CH_{2}Cl_{2} (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 36 was purified by flash chromatography (SiO_{2}, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 351 mg (87%) of 36 as a white solid.

Data for 36:

mp: 36-37 °C (sealed tube)

^{1}H NMR: (500 MHz, CDCl_{3})

δ 7.75 (d, J = 8.0 Hz, 2 H, HC(17)), 7.44 (d, J = 7.5 Hz, 2 H, HC(10)), 7.29 (d, J = 8.0 Hz, 2 H, HC(18)), 7.25 (t, J = 8.0 Hz, 2 H, HC(11)), 7.18 (t, J = 7.5 Hz, 1 H, HC(12)), 4.19 (dd, J = 11.0, and 5.0 Hz, 1 H, HC(2)), 3.75 (dd, J = 15.0, and 3.5 Hz, 1 H, HC(6)), 3.33 (dd, J = 11.0, and 2.0 Hz, 1 H, HC(7)), 2.86 (ddd, J = 15.0, 13.5, and 3.0 Hz, 1 H, HC(6)), 2.42 (s, 3 H, HC(20)), 2.35 (heptd, J = 6.5, and 2.5 Hz, 1 H, HC(13)), 2.17 (d, J = 14.0 Hz, 1 H, HC(3)), 1.31 – 1.21 (m, 1 H, HC(3)), 1.25 (d, J = 7.0 Hz, 3 H, HC(14)), 1.16 (d, J = 13.5 Hz, 1 H, HC(5)), 1.07 – 1.01 (m, 1 H,
Denmark and Chi

HC(4)), 1.03 (d, J = 6.5 Hz, 3 H, HC(14)), 1.01 – 0.92 (m, 1 H, HC(5)), 0.79 (qt, J = 13.0, and 4.0 Hz, 1 H, HC(4)).

$^{13}$C NMR: (126 MHz, CDCl$_3$)

δ 143.0 (C(19)), 138.7 (C(16)), 137.4 (C(9)), 131.4 (C(10)), 129.6 (C(18)), 128.9 (C(11)), 127.1 (C(17)), 126.6 (C(12)), 57.7 (C(7)), 56.3 (C(2)), 41.0 (C(6)), 27.3 (C(13)), 24.6 (C(3)), 22.6 (C(5)), 22.4 (C(14)), 21.4 (C(20)), 18.2 (C(4)), 16.2 (C(14)).

IR: 3024 (w), 2957 (m), 2870 (w), 1598 (w), 1478 (w), 1464 (w), 1446 (w), 1353 (m), 1336 (s), 1304 (w), 1290 (w), 1216 (w), 1191 (m), 1157 (s), 1116 (w), 1091 (s), 1067 (w), 1042 (w), 1025 (w), 1001 (s), 880 (w), 840 (w), 815 (m), 755 (s)

MS: (ESI)

123 (22), 233 (43), 238 (19), 294 (80), 295 (18), 348 (34), 404 (M+H, 100), 405 (28), 406 (14), 426 (32), 442 (14)

HRMS: calcd for C$_{22}$H$_{29}$NO$_2$S$_2$: 404.1718, found: 404.1719

TLC: $R_f$ 0.63 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

Opt Rot: $\lbrack\alpha\rbrack_D^{24}$ 21.6 (c = 1.00, CHCl$_3$)

SFC: (2S,7R)-36, $t_R$ 7.4 min (95.4%); (2R,7S)-36, $t_R$ 9.1 min (4.6%) (Chiralpak AD, 10% MeOH in CO$_2$, 2.0 mL/min, 220 nm, 40 °C)

Analysis: C$_{22}$H$_{29}$NO$_2$S$_2$ (402.60)

Calcd: C, 65.47; H, 7.24% N, 3.47%

Found: C, 65.20; H, 7.04% N, 3.62%

Preparation of (2S,7R)-N-(4-Toluenesulfonyl)-2-(3-phenyl-1-(phenylthio)propyl)piperidine (38) (Table 4 Entry 14)

Following General Procedure VIII, a 25-mL Schlenk flask was charged with 37 (358 mg, 1.0 mmol, 1.0 equiv), PhthSPh 2 (255 mg, 1.0 mmol, 1.0 equiv), (S)-3f (52.1 mg, 0.1 mmol, 0.10
equiv), and CH$_2$Cl$_2$ (10.0 mL, 0.1 M). After cooled to 0 °C, the mixture was added MsOH (32.5 µL, 0.5 mmol, 0.5 equiv) and was allowed to stir for 48 h. The reaction was worked up following the general procedure. The product 38 was purified by flash chromatography (SiO$_2$, 25 g, 30 mm Ø, hexanes/EtOAc, 19:1 to 9:1) to afford 423 mg (91%) of 38 as a sticky white solid.

**Data for 38:**

**$^1$H NMR:** (500 MHz, CDCl$_3$)

δ 7.68 (d, $J = 8.0$ Hz, 2 H, HC(21)), 7.44 (d, $J = 7.0$ Hz, 2 H, HC(10)), 7.35 – 7.28 (m, 5 H, HC(11,12,17)), 7.26 – 7.18 (m, 5 H, HC(16,18,22)), 4.03 (dd, $J = 10.5$, and 4.0 Hz, 1 H, HC(2)), 3.80 (d, $J = 14.5$ Hz, 1 H, HC(6)), 3.25 (td, $J = 10.5$, and 3.0 Hz, 1 H, HC(7)), 3.14 (ddd, $J = 13.5$, 9.0, and 4.0 Hz, 1 H, HC(14)), 2.88 (dt, $J = 14.0$, and 8.5 Hz, 1 H, HC(14)), 2.67 (td, $J = 15.0$, and 2.5 Hz, 1 H, HC(6)), 2.42 (s, 3 H, HC(24)), 2.28 (d, $J = 13.0$ Hz, 1 H, HC(3)), 2.17 (dtd, $J = 14.5$, 8.5, and 3.0 Hz, 1 H, HC(13)), 1.73 (dtt, $J = 14.0$, 9.5, and 4.5 Hz, 1 H, HC(13)), 1.33 – 1.22 (m, 3 H, HC(3,4,5)), 1.18 – 1.02 (m, 2 H, HC(4,5)).

**$^{13}$C NMR:** (126 MHz, CDCl$_3$)

δ 142.8 (C(20)), 141.6 (C(15)), 138.6 (C(23)), 134.2 (C(9)), 132.8 (C(10)), 129.5 (C(22)), 128.9 (C(11)), 128.6 (C(16)), 128.2 (C(17)), 127.4 (C(12)), 126.9 (C(21)), 125.7 (C(18)).

**IR:**

3025 (w), 2941 (m), 2856 (w), 1599 (w), 1494 (w), 1453 (m), 1336 (s), 1302 (m), 1216 (m), 1182 (w), 1154 (s), 1120 (m), 1091 (m), 1012 (w), 983 (w), 928 (s), 815 (m), 752 (s)

**MS:** (ESI)

185 (12), 356 (41), 357 (23), 358 (11), 466 (M+H, 100), 467 (55), 468 (26), 483 (45), 484 (17), 488 (12)

**HRMS:** calcd for C$_{27}$H$_{32}$NO$_2$S$_2$: 466.1874, found: 466.1871

**TLC:** $R_f$ 0.60 (hexanes/EtOAc, 3:2) [UV/KMnO$_4$]

**Opt Rot:** $[\alpha]_D^{24}$ -17.6 (c = 1.00, CHCl$_3$)

**SFC:** (2S,7R)-38, $t_R$ 11.6 min (97.4%); (2R,7S)-38, $t_R$ 17.1 min (2.6%) (Chiralcel OJ, Gradient 3% MeOH in CO$_2$ to 8% MeOH in CO$_2$ over 30 min, 2.5 mL/min, 220 nm, 40 °C)
Analysis: \[ \text{C}_{27}\text{H}_{31}\text{NO}_{2}\text{S}_{2} (465.67) \]
Calcd: C, 69.64%; H, 6.71%; N, 3.01%
Found: C, 69.68%; H, 6.78%; N, 2.88%

**NMR Study of the Structure of the Catalytically Active Complex i**

To an oven-dried, 5-mm NMR tube was charged with (S)-3f (10 mg, 0.02 mmol), PhthSPh 2 (52 mg, 0.2 mmol, 1 equiv), and CDCl\(_3\) (500 \(\mu\)L). The resulting solution was monitored with \(^{31}\)P NMR spectroscopy.

**Data for \[(S)\text{-}3f+\text{PhthSPh}(2)\]:**

\[^{31}\text{P NMR:} (202 \text{ MHz, CDCl}_3)\]
\(\delta 81.19\) (br).

To an oven-dried, 5-mm NMR tube was charged with (S)-3f (10 mg, 0.02 mmol), PhthSPh 2 (52 mg, 0.2 mmol, 1 equiv), CDCl\(_3\) (500 \(\mu\)L) and MsOH (13 \(\mu\)L, 0.2 mmol, 1 equiv). The resulting solution of catalytically active complex \(i\) was monitored immediately with \(^{31}\)P NMR spectroscopy.

**Data for \[(S)\text{-}3f+\text{PhthSPh}(2)+\text{MsOH}\] (\(i\)):**

\[^{31}\text{P NMR:} (202 \text{ MHz, CDCl}_3)\]
\(\delta 59.77\) (sharp).

**Impact of the Purity of MsOH on Reaction**

The following experiments were performed to investigate the impact of the purity of MsOH:

**Experiment 1: Using bottle 1 of MsOH (non-distilled “old & wet” MsOH)**

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 \(\mu\)mol, 0.10 equiv), and CDCl\(_3\) (500 \(\mu\)L, 0.13 M). To the NMR tube was added MsOH (4.1 \(\mu\)L, 0.063 mmol, 1.0 equiv) at 0 °C. Conversion to product was measured by the appearance of the diagnostic \(^1\)H NMR resonance for the piperidine 12 at 5.41 ppm and the pyrrolidine 13 at 4.07 ppm with respect to the substrate peaks at 6.34 ppm and 6.09 ppm. Interestingly, pyrrolidine 13 was not observed throughout the reaction. Conversion monitored by
\(^1\)H NMR spectroscopy was 20\% (6 h), 44\% (12 h), 63\% (24 h), and 80\% (48 h), whereupon only 12 was observed. Purification via silica gel flash column chromatography (SiO\(_2\), 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 21 mg (77\%) of 12.

**SFC**: (2S,3R)-12, \(t_R\) 14.8 min (92.0\%); (2R,3S)-12, \(t_R\) 16.5 min (8.0\%) (Chiralcel OJ, Gradient 3\% MeOH in CO\(_2\) to 8\% MeOH in CO\(_2\) over 30 min, 2.5 mL/min, 220 nm, 40 °C)

**Experiment 2: Using bottle 2 of MsOH (distilled MsOH\(^{34}\))**

Following General Procedure IV, an oven-dried, 5-mm NMR tube was charged with 5 (20 mg, 0.063 mmol), PhthSPh 2 (16.2 mg, 0.063 mmol, 1.0 equiv), chiral Lewis base catalyst (S)-3f (3.3 mg, 6.3 \(\mu\)mol, 0.10 equiv), and CDCl\(_3\) (500 \(\mu\)L, 0.13 M). To the NMR tube was added distilled MsOH\(^{34}\) (4.1 \(\mu\)L, 0.063 mmol, 1.0 equiv) at 0 °C. Conversion to product was measured by the appearance of the diagnostic \(^1\)H NMR resonance for the piperidine 12 and the pyrrolidine 13 with respect to the substrate peaks. The ratio of 12 to 13 of the reaction mixture were 97:3 (76\% conversion, 6 h), 94:6 (93\% conversion, 12 h), 86:14 (full conversion at 24 h), and of the crude product was 86:14. Purification via silica gel flash column chromatography (SiO\(_2\), 5 g, 10 mm Ø, hexanes/EtOAc, 9:1) afforded 22 mg (82\%) of 12.

**SFC**: (2S,3R)-12, \(t_R\) 14.8 min (91.6\%); (2R,3S)-12, \(t_R\) 16.5 min (8.4\%) (Chiralcel OJ, Gradient 3\% MeOH in CO\(_2\) to 8\% MeOH in CO\(_2\) over 30 min, 2.5 mL/min, 220 nm, 40 °C)
X-Ray Crystal Structure of 34

![ORTEP image of X-ray crystal structure of 34](image)

Figure S1: ORTEP images of X-ray crystal structure of 34.

Recrystallization of 34 in THF/pentane resulted a white crystal. The crystallographic coordinates of 34 have been deposited with the Cambridge Crystallographic Data Centre (CCDC); deposition no. 981943. These data can be obtained free of charge via from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; via www.ccdc.cam.ac.uk/conts/retrieving.html or deposit@ccdc.cam.ac.uk).

Table A. Crystal data and structure refinement for cd24gsa.

| Identification code | cd24gsa |
|---------------------|---------|
| Empirical formula   | C25 H27 N O2 S2 |
| Formula weight      | 437.59 |
| Temperature         | 100(2) K |
| Wavelength          | 0.71073 Å |
| Crystal system      | Orthorhombic |
| Space group         | P 21 21 21 |
| Unit cell dimensions| a = 6.0841(5) Å \(\alpha = 90^\circ\). |
|                     | b = 15.6924(12) Å \(\beta = 90^\circ\). |
|                     | c = 22.5997(18) Å \(\gamma = 90^\circ\). |
| Volume              | 2157.7(3) Å³ |
Z
4
Density (calculated) 1.347 Mg/m³
Absorption coefficient 0.269 mm⁻¹
F(000) 928
Crystal size 0.565 x 0.183 x 0.124 mm³
Theta range for data collection 2.596 to 29.186°.
Index ranges -8<=h<=8, -21<=k<=21, -28<=l<=30
Reflections collected 40407
Independent reflections 5825 [R(int) = 0.0374]
Completeness to theta = 25.242° 99.9 %
Absorption correction Integration
Max. and min. transmission 0.97430 and 0.91819
Refinement method Full-matrix least-squares on F²
Data / restraints / parameters 5825 / 0 / 272
Goodness-of-fit on F² 1.059
Final R indices [I>2sigma(I)] R1 = 0.0253, wR2 = 0.0625
R indices (all data) R1 = 0.0272, wR2 = 0.0634
Absolute structure parameter -0.034(15)
Extinction coefficient n/a
Largest diff. peak and hole 0.289 and -0.255 e.Å⁻³

Table B. Atomic coordinates ( x 10⁴) and equivalent isotropic displacement parameters (Å² x 10³) for cd24gsa. U(eq) is defined as one third of the trace of the orthogonalized Uij tensor.

|       | x     | y     | z     | U(eq) |
|-------|-------|-------|-------|-------|
| S(1)  | 428(1)| 9470(1)| 167(1)| 10(1) |
| S(2)  | 3564(1)| 7888(1)| 2124(1)| 16(1) |
| O(1)  | -624(2)| 9070(1)| 2331(1)| 14(1) |
| O(2)  | 2754(2)| 9628(1)| 152(1) | 14(1) |
| N(1)  | -11(2)| 8878(1)| 747(1) | 10(1) |
| C(1)  | 1659(3)| 8834(1)| 1227(1)| 11(1) |
| C(2)  | 1270(3)| 8028(1)| 1602(1)| 12(1) |
| C(3)  | 1080(3)| 7211(1)| 1225(1)| 16(1) |
| C(4)  | -1296(3)| 6990(1)| 1058(1)| 18(1) |
| S(5)  | -2419(3) | 7608(1) | 635(1)  | 16(1) |
|-------|----------|---------|---------|-------|
| S(6)  | -2259(3) | 8542(1) | 820(1)  | 12(1) |
| S(7)  | -971(3)  | 10444(1)| 285(1)  | 11(1) |
| S(8)  | -3025(3) | 10553(1)| 31(1)   | 13(1) |
| S(9)  | -4263(3) | 11272(1)| 169(1)  | 14(1) |
| S(10) | -3470(3) | 11882(1)| 565(1)  | 14(1) |
| S(11) | -1359(3) | 11775(1)| 797(1)  | 15(1) |
| S(12) | -103(3)  | 11064(1)| 662(1)  | 14(1) |
| S(13) | -4864(3) | 12633(1)| 744(1)  | 19(1) |
| S(14) | 1813(3)  | 9650(1) | 1591(1) | 11(1) |
| S(15) | 3741(3)  | 10128(1)| 1576(1) | 14(1) |
| S(16) | 3928(3)  | 10880(1)| 1905(1) | 18(1) |
| S(17) | 2177(3)  | 11155(1)| 2246(1) | 20(1) |
| S(18) | 239(3)   | 10688(1)| 2261(1) | 18(1) |
| S(19) | 56(3)    | 9936(1) | 1935(1) | 14(1) |
| S(20) | 2828(3)  | 8545(1) | 2737(1) | 14(1) |
| S(21) | 4336(3)  | 9147(1) | 2942(1) | 17(1) |
| S(22) | 3832(3)  | 9644(1) | 3434(1) | 20(1) |
| S(23) | 1816(3)  | 9553(1) | 3714(1) | 20(1) |
| S(24) | 312(3)   | 8957(1) | 3510(1) | 18(1) |
| S(25) | 822(3)   | 8446(1) | 3024(1) | 16(1) |

Table C. Bond lengths [Å] and angles [°] for cd24gsa.

| Bond | Length  |
|------|---------|
| S(1)-O(2) | 1.4370(12) |
| S(1)-O(1) | 1.4379(12) |
| S(1)-N(1) | 1.6294(13) |
| S(1)-C(7) | 1.7702(16) |
| S(2)-C(20) | 1.7827(17) |
| S(2)-C(2) | 1.8407(17) |
| N(1)-C(6) | 1.475(2) |
| N(1)-C(1) | 1.486(2) |
| C(1)-C(14) | 1.524(2) |
| C(1)-C(2) | 1.542(2) |
C(1)-H(1A)  1.0000
C(2)-C(3)  1.545(2)
C(2)-H(2A)  1.0000
C(3)-C(4)  1.534(3)
C(3)-H(3A)  0.9900
C(3)-H(3B)  0.9900
C(4)-C(5)  1.524(2)
C(4)-H(4A)  0.9900
C(4)-H(4B)  0.9900
C(5)-C(6)  1.528(2)
C(5)-H(5A)  0.9900
C(5)-H(5B)  0.9900
C(6)-H(6A)  0.9900
C(6)-H(6B)  0.9900
C(7)-C(8)  1.386(2)
C(7)-C(12)  1.397(2)
C(8)-C(9)  1.393(2)
C(8)-H(8A)  0.9500
C(9)-C(10)  1.395(2)
C(9)-H(9A)  0.9500
C(10)-C(11)  1.397(2)
C(10)-C(13)  1.508(2)
C(11)-C(12)  1.386(2)
C(11)-H(11A)  0.9500
C(12)-H(12A)  0.9500
C(13)-H(13A)  0.9800
C(13)-H(13B)  0.9800
C(13)-H(13C)  0.9800
C(14)-C(15)  1.393(2)
C(14)-C(19)  1.396(2)
C(15)-C(16)  1.398(2)
C(15)-H(15A)  0.9500
C(16)-C(17)  1.384(3)
C(16)-H(16A)  0.9500
C(17)-C(18)  1.388(3)
| Bond                  | Length  |
|----------------------|---------|
| C(17)-H(17A)         | 0.9500  |
| C(18)-C(19)          | 1.396(2) |
| C(18)-H(18A)         | 0.9500  |
| C(19)-H(19A)         | 0.9500  |
| C(20)-C(25)          | 1.392(2) |
| C(20)-C(21)          | 1.396(2) |
| C(21)-C(22)          | 1.392(2) |
| C(21)-H(21A)         | 0.9500  |
| C(22)-C(23)          | 1.388(3) |
| C(22)-H(22A)         | 0.9500  |
| C(23)-C(24)          | 1.388(3) |
| C(23)-H(23A)         | 0.9500  |
| C(24)-C(25)          | 1.394(2) |
| C(24)-H(24A)         | 0.9500  |
| C(25)-H(25A)         | 0.9500  |
| O(2)-S(1)-O(1)       | 119.74(8) |
| O(2)-S(1)-N(1)       | 106.13(7) |
| O(1)-S(1)-N(1)       | 107.96(7) |
| O(2)-S(1)-C(7)       | 109.13(7) |
| O(1)-S(1)-C(7)       | 106.30(7) |
| N(1)-S(1)-C(7)       | 106.97(7) |
| C(20)-S(2)-C(2)      | 103.75(8) |
| C(6)-N(1)-C(1)       | 122.46(12) |
| C(6)-N(1)-S(1)       | 116.39(11) |
| C(1)-N(1)-S(1)       | 120.07(10) |
| N(1)-C(1)-C(14)      | 113.43(12) |
| N(1)-C(1)-C(2)       | 109.53(13) |
| C(14)-C(1)-C(2)      | 113.58(13) |
| N(1)-C(1)-H(1A)      | 106.6    |
| C(14)-C(1)-H(1A)     | 106.6    |
| C(2)-C(1)-H(1A)      | 106.6    |
| C(1)-C(2)-C(3)       | 112.84(13) |
| C(1)-C(2)-S(2)       | 109.55(11) |
| C(3)-C(2)-S(2)       | 108.18(11) |
| Bond                  | Angle (°) |
|----------------------|-----------|
| C(1)-C(2)-H(2A)      | 108.7     |
| C(3)-C(2)-H(2A)      | 108.7     |
| S(2)-C(2)-H(2A)      | 108.7     |
| C(4)-C(3)-C(2)       | 113.19(14)|
| C(4)-C(3)-H(3A)      | 108.9     |
| C(2)-C(3)-H(3A)      | 108.9     |
| C(4)-C(3)-H(3B)      | 108.9     |
| C(2)-C(3)-H(3B)      | 108.9     |
| H(3A)-C(3)-H(3B)     | 107.8     |
| C(5)-C(4)-C(3)       | 115.67(14)|
| C(5)-C(4)-H(4A)      | 108.4     |
| C(3)-C(4)-H(4A)      | 108.4     |
| C(5)-C(4)-H(4B)      | 108.4     |
| C(3)-C(4)-H(4B)      | 108.4     |
| H(4A)-C(4)-H(4B)     | 107.4     |
| C(4)-C(5)-C(6)       | 114.22(14)|
| C(4)-C(5)-H(5A)      | 108.7     |
| C(6)-C(5)-H(5A)      | 108.7     |
| C(4)-C(5)-H(5B)      | 108.7     |
| C(6)-C(5)-H(5B)      | 108.7     |
| H(5A)-C(5)-H(5B)     | 107.6     |
| N(1)-C(6)-C(5)       | 111.81(14)|
| N(1)-C(6)-H(6A)      | 109.3     |
| C(5)-C(6)-H(6A)      | 109.3     |
| N(1)-C(6)-H(6B)      | 109.3     |
| C(5)-C(6)-H(6B)      | 109.3     |
| H(6A)-C(6)-H(6B)     | 107.9     |
| C(8)-C(7)-C(12)      | 120.51(15)|
| C(8)-C(7)-S(1)       | 118.50(12)|
| C(12)-C(7)-S(1)      | 120.82(12)|
| C(7)-C(8)-C(9)       | 119.61(15)|
| C(7)-C(8)-H(8A)      | 120.2     |
| C(9)-C(8)-H(8A)      | 120.2     |
| C(8)-C(9)-C(10)      | 120.85(15)|
| C(8)-C(9)-H(9A)      | 119.6     |
C(10)-C(9)-H(9A) 119.6
C(9)-C(10)-C(11) 118.47(15)
C(9)-C(10)-C(13) 120.92(16)
C(11)-C(10)-C(13) 120.61(15)
C(12)-C(11)-C(10) 121.33(15)
C(12)-C(11)-H(11A) 119.3
C(10)-C(11)-H(11A) 119.3
C(11)-C(12)-C(7) 119.12(16)
C(11)-C(12)-H(12A) 120.4
C(7)-C(12)-H(12A) 120.4
C(10)-C(13)-H(13A) 109.5
C(10)-C(13)-H(13B) 109.5
H(13A)-C(13)-H(13B) 109.5
C(10)-C(13)-H(13C) 109.5
H(13A)-C(13)-H(13C) 109.5
H(13B)-C(13)-H(13C) 109.5
C(15)-C(14)-C(19) 119.00(15)
C(15)-C(14)-C(1) 119.42(14)
C(19)-C(14)-C(1) 121.58(15)
C(14)-C(15)-C(16) 120.70(16)
C(14)-C(15)-H(15A) 119.6
C(16)-C(15)-H(15A) 119.6
C(17)-C(16)-C(15) 119.72(17)
C(17)-C(16)-H(16A) 120.1
C(15)-C(16)-H(16A) 120.1
C(16)-C(17)-C(18) 120.22(16)
C(16)-C(17)-H(17A) 119.9
C(18)-C(17)-H(17A) 119.9
C(17)-C(18)-C(19) 120.05(17)
C(17)-C(18)-H(18A) 120.0
C(19)-C(18)-H(18A) 120.0
C(14)-C(19)-C(18) 120.31(16)
C(14)-C(19)-H(19A) 119.8
C(18)-C(19)-H(19A) 119.8
C(25)-C(20)-C(21) 119.80(15)
C(25)-C(20)-S(2)    121.23(13)  
C(21)-C(20)-S(2)    118.93(13)  
C(22)-C(21)-C(20)   119.95(17)  
C(22)-C(21)-H(21A)  120.0  
C(20)-C(21)-H(21A)  120.0  
C(23)-C(22)-C(21)   120.16(17) 
C(23)-C(22)-H(22A)  119.9  
C(21)-C(22)-H(22A)  119.9  
C(24)-C(23)-C(22)   119.95(16)  
C(24)-C(23)-H(23A)  120.0  
C(22)-C(23)-H(23A)  120.0  
C(23)-C(24)-C(25)   120.22(17)  
C(23)-C(24)-H(24A)  119.9  
C(25)-C(24)-H(24A)  119.9  
C(20)-C(25)-C(24)   119.90(16) 
C(20)-C(25)-H(25A)  120.1  
C(24)-C(25)-H(25A)  120.1  

Symmetry transformations used to generate equivalent atoms:

Table D. Anisotropic displacement parameters (Å² x 10³) for cd24gsa. The anisotropic displacement factor exponent takes the form: -2π²[ h² a*²U₁₁ + ... + 2 h k a* b* U₁₂ ]

|       | U₁₁  | U₂₂  | U₃₃  | U₁₂  | U₁₃  | U₂₃  |
|-------|------|------|------|------|------|------|
| S(1)  | 11(1)| 9(1) | 9(1) | 0(1) | 1(1) | 0(1) |
| S(2)  | 18(1)| 17(1)| 12(1)| -1(1)| -2(1)| 7(1) |
| O(1)  | 17(1)| 13(1)| 10(1)| -2(1)| -1(1)| 1(1) |
| O(2)  | 11(1)| 15(1)| 15(1)| 2(1) | 3(1) | -1(1)|
| N(1)  | 10(1)| 10(1)| 10(1)| 2(1) | 0(1) | -2(1)|
| C(1)  | 10(1)| 12(1)| 10(1)| 0(1) | -1(1)| 1(1) |
| C(2)  | 14(1)| 11(1)| 10(1)| 0(1) | -1(1)| 2(1) |
| C(3)  | 24(1)| 10(1)| 14(1)| -2(1)| -2(1)| 2(1) |
| C(4)  | 26(1)| 12(1)| 17(1)| 0(1) | -2(1)| -5(1)|
| C(5)  | 17(1)| 14(1)| 17(1)| 0(1) | -2(1)| -6(1)|
Table E. Hydrogen coordinates ($\times 10^4$) and isotropic displacement parameters ($\AA^2 \times 10^{-3}$) for cd24gsa.

|       | x    | y    | z    | U(eq) |
|-------|------|------|------|-------|
| H(1A) | 3116 | 8760 | 1029 | 13    |
| H(2A) | -120 | 8102 | 1833 | 14    |
| H(3A) | 1949 | 7285 | 858  | 19    |
| H(3B) | 1723 | 6728 | 1447 | 19    |
| H(4A) | -1310| 6416 | 876  | 22    |
| H(4B) | -2177| 6960 | 1426 | 22    |
| H(5A) | -3991| 7451 | 603  | 19    |
| H(5B)   | -1754 | 7543 | 237 | 19 |
|---------|-------|------|-----|----|
| H(6A)   | -3286 | 8885 | 577 | 15 |
| H(6B)   | -2708 | 8599 | 1239| 15 |
| H(8A)   | -3586 | 10139| -236| 15 |
| H(9A)   | -5664 | 11349| -8  | 17 |
| H(11A)  | -773  | 12199| 1053| 18 |
| H(12A)  | 1329  | 11000| 823 | 17 |
| H(13A)  | -6391 | 12533| 625 | 29 |
| H(13B)  | -4313 | 13149| 550 | 29 |
| H(13C)  | -4795 | 12705| 1175| 29 |
| H(15A)  | 4941  | 9942 | 1340| 17 |
| H(16A)  | 5252  | 11201| 1894| 21 |
| H(17A)  | 2301  | 11665| 2470| 24 |
| H(18A)  | -962  | 10880| 2494| 22 |
| H(19A)  | -1271 | 9617 | 1947| 17 |
| H(21A)  | 5706  | 9217 | 2746| 20 |
| H(22A)  | 4870  | 10045| 3578| 24 |
| H(23A)  | 1466  | 9899 | 4046| 24 |
| H(24A)  | -1070 | 8898 | 3701| 22 |
| H(25A)  | -198  | 8030 | 2890| 19 |

Table F. Torsion angles [°] for cd24gsa.

| Bond                        | Torsion Angle [°] |
|-----------------------------|-------------------|
| O(2)-S(1)-N(1)-C(6)        | -172.93(11)       |
| O(1)-S(1)-N(1)-C(6)        | -43.39(13)        |
| C(7)-S(1)-N(1)-C(6)        | 70.65(12)         |
| O(2)-S(1)-N(1)-C(1)        | 18.65(13)         |
| O(1)-S(1)-N(1)-C(1)        | 148.19(11)        |
| C(7)-S(1)-N(1)-C(1)        | -97.77(12)        |
| C(6)-N(1)-C(1)-C(14)       | -96.20(16)        |
| S(1)-N(1)-C(1)-C(14)       | 71.50(16)         |
| C(6)-N(1)-C(1)-C(2)        | 31.85(19)         |
| S(1)-N(1)-C(1)-C(2)        | -160.45(11)       |
| N(1)-C(1)-C(2)-C(3)        | 51.09(18)         |
C(14)-C(1)-C(2)-C(3) 
N(1)-C(1)-C(2)-S(2) 
C(14)-C(1)-C(2)-S(2) 
C(20)-S(2)-C(2)-C(1) 
C(20)-S(2)-C(2)-C(3) 
C(1)-C(2)-C(3)-C(4) 
S(2)-C(2)-C(3)-C(4) 
C(2)-C(3)-C(4)-C(5) 
C(3)-C(4)-C(5)-C(6) 
C(1)-N(1)-C(6)-C(5) 
S(1)-N(1)-C(6)-C(5) 
C(4)-C(5)-C(6)-N(1) 
O(2)-S(1)-C(7)-C(8) 
O(1)-S(1)-C(7)-C(8) 
N(1)-S(1)-C(7)-C(8) 
O(2)-S(1)-C(7)-C(12) 
O(1)-S(1)-C(7)-C(12) 
N(1)-S(1)-C(7)-C(12) 
C(12)-C(7)-C(8)-C(9) 
S(1)-C(7)-C(8)-C(9) 
C(7)-C(8)-C(9)-C(10) 
C(8)-C(9)-C(10)-C(11) 
C(8)-C(9)-C(10)-C(13) 
C(9)-C(10)-C(11)-C(12) 
C(13)-C(10)-C(11)-C(12) 
C(10)-C(11)-C(12)-C(7) 
C(8)-C(7)-C(12)-C(11) 
S(1)-C(7)-C(12)-C(11) 
N(1)-C(1)-C(14)-C(15) 
C(2)-C(1)-C(14)-C(15) 
N(1)-C(1)-C(14)-C(19) 
C(2)-C(1)-C(14)-C(19) 
C(19)-C(14)-C(15)-C(16) 
C(1)-C(14)-C(15)-C(16) 
C(14)-C(15)-C(16)-C(17)
Symmetry transformations used to generate equivalent atoms:
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147 - 119 ppm region expanded
Denmark and Chi

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1 : 2.8 mixture (equilibrium)
| f1 (ppm) | 2.00 | 2.00 | 2.27 | 1.05 | 1.00 | 5.35 | 2.38 | 2.40 | 2.41 | 2.54 | 2.55 | 2.57 | 2.58 | 5.49 | 5.60 | 6.21 | 6.24 | 6.44 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.38 | | | | | | | | | | | | | | | | | | | |
| 2.40 | | | | | | | | | | | | | | | | | | | |
| 2.41 | | | | | | | | | | | | | | | | | | | |
| 2.54 | | | | | | | | | | | | | | | | | | | |
| 2.55 | | | | | | | | | | | | | | | | | | | |
| 2.57 | | | | | | | | | | | | | | | | | | | |
| 2.58 | | | | | | | | | | | | | | | | | | | |
| 5.49 | | | | | | | | | | | | | | | | | | | |
| 5.60 | | | | | | | | | | | | | | | | | | | |
| 6.21 | | | | | | | | | | | | | | | | | | | |
| 6.24 | | | | | | | | | | | | | | | | | | | |
| 6.44 | | | | | | | | | | | | | | | | | | | |

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Diagram of chemical structure.
Denmark and Chi
Denmark and Chi

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Denmark and Chi
Denmark and Chi
| 20.0  | 10.0 | 0.95 | 3.00 | 2.00 | 0.96 | 0.95 | 2.00 | 2.00 |
|-------|------|------|------|------|------|------|------|------|
| 0.91  | 0.93 | 1.27 | 1.28 | 1.30 | 1.31 | 1.33 | 1.41 | 1.42 |
| 1.44  | 1.45 | 1.47 | 1.86 | 1.88 | 1.89 | 2.15 | 2.16 | 2.17 |
| 2.19  | 2.20 | 2.21 | 2.41 | 2.88 | 2.90 | 2.91 | 2.92 | 5.01 |
| 5.02  | 5.03 | 5.04 | 5.20 | 5.21 | 5.23 | 5.23 | 5.24 | 5.26 |
| 5.29  | 5.30 | 5.32 | 5.33 | 5.34 | 5.35 | 5.36 | 5.37 | 5.38 |
| 5.40  | 5.41 | 5.42 | 5.43 | 5.44 | 5.45 | 5.46 | 5.47 | 5.48 |
| 5.50  | 5.51 | 5.52 | 5.53 | 5.54 | 5.55 | 5.56 | 5.57 | 5.58 |
| 5.60  | 5.61 | 5.62 | 5.63 | 5.64 | 5.65 | 5.66 | 5.67 | 5.68 |
| 5.70  | 5.71 | 5.72 | 5.73 | 5.74 | 5.75 | 5.76 | 5.77 | 5.78 |
| 5.80  | 5.81 | 5.82 | 5.83 | 5.84 | 5.85 | 5.86 | 5.87 | 5.88 |
| 5.90  | 5.91 | 5.92 | 5.93 | 5.94 | 5.95 | 5.96 | 5.97 | 5.98 |
| 6.00  | 6.01 | 6.02 | 6.03 | 6.04 | 6.05 | 6.06 | 6.07 | 6.08 |

The diagram shows a molecular structure labeled 35. The structural formula includes bonds and atoms labeled with numbers 1 through 13. The spectrum below the diagram contains peaks at various ppm values, indicating the chemical shifts of different protons in the compound. The peaks are labeled with their respective chemical shifts in ppm.
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