Supporting Information
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Synthesis of N,N’-alkylated cyclohexanediamines and their application as asymmetric ligands and organocatalysts for the synthesis of alcohols.

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General information

Unless otherwise stated, all reagents were purchased from commercial suppliers and were used without further purification. CH₂Cl₂ was distilled over CaH₂. NMR spectra were recorded using Bruker Avance 200, 300, 400 and 600 MHz spectrometers. Chemical shifts were measured in the δ scale relative to the signal of residual protons of the deuterated solvent. The following abbreviations were used to designate chemical shift multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad; coupling constants are given in Hertz (Hz). Optical rotation was measured on a Perkin-Elmer 341 polarimeter in a temperature-maintained cell (l= 2 cm) at 25 °C. The solvent and the sample concentration in grams per 100 mL were indicated for all compounds. Silica gel Kieselgel 60 (Merck) was used for column chromatography.

Determination of the absolute configuration of (S)-methyl 2-hydroxy-4-oxo-2-phenylpentanoate

A single crystal of methyl (S)-2-hydroxy-4-oxo-2-phenylpentanoate suitable for X-ray diffraction was obtained during crystallization from acetone. Crystals of methyl (S)-2-hydroxy-4-oxo-2-phenylpentanoate (C₁₂H₁₄O₄, M = 222.23) are monoclinic, space group P2₁, at 120K: a = 5.59500(10) Å, b = 7.81110(10) Å, c = 12.6229(2) Å, β = 96.3230 (10), V = 548.304(15) Å³, Z = 2 (Z’ = 1), dcalc = 1.346 gcm⁻³, μ(CuKα) = 0.840 mm⁻¹, F(000) = 236. Intensities of 8399 reflections were measured with a BrukerAPEX Duo CCD diffractometer [λ(CuKα) = 1.54178 Å, φ- and ω-scans, 2θ<131.5°] and 1871 independent reflections [Rint = 0.0215] were used in further refinement. The structure was solved by direct method and refined by the full-matrix least-squares technique against F² in anisotropic approximation. The refinement converged to R1 = 0.0221 (calculated against for 1867 reflections with I>2σ(I)), wR2 = 0.0525 and GOF = 0.991. The absolute configuration was established by Bijvoet pairs analysis, Flack parameter¹ was 0.06(14) for S configuration. All calculations were performed using SHELX software package.²

CCDC 1474739 contains the supplementary crystallographic data for methyl (S)-2-hydroxy-4-oxo-2-phenylpentanoate. These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html (or from the CCDC, 12 Union Road, Cambridge, CB21EZ, UK; or deposit@ccdc.cam.ac.uk).

(R,R)-1,2-cyclohexanediadionium mono-(-)-tartrate

A 2-L beaker equipped with a mechanical overhead stirrer was charged with 250 mL of water. L- (+)-Tartaric acid (52.5 g, 0.35 mol) was added with stirring in one portion. The solution was stirred as 114 g (120 mL, 1 mol) of cis- and racemic trans-cyclohexanediamines was carefully added in one portion. A slurry was initially formed but complete dissolution was observed once the addition was complete. Glacial acetic acid (50 ml) was then added in one portion. The product began to precipitate during the addition, and continued to precipitate while the reaction mixture was allowed to cool from 90°C to 5°C, with stirring, over 3 h. The temperature was maintained at 5°C for an additional hour and the product was isolated by filtration. The filter cake was washed with 50 mL of cold (5°C) water followed by 4x50 mL portions of ambient temperature methanol. The product was dissolved in 500 ml of hot water (100 °C). The solvent was filtered and put into a freezer for recrystallization to give 14.17 g of crystals. Then the foam was dissolved in 500 ml of hot water (100 °C). The solvent was filtered and put into a freezer for recrystallization to give 9.77 g of crystals. Total mass of the product was 23.94 g (0.09 mol, 26%). Enantiomeric excess was determined by chiral GC of a trifluoroacetyl derivative. ee>99.9%

**Synthesis of Schiff bases 2 (general procedure)**

A mixture of (1R,2R)-trans-cyclohexane-1,2-diammonium (S)-tartrate (1.0 eq), K₂CO₃ (1.0 eq) and H₂O (0.66 ml per mmol of potassium carbonate) was stirred until complete dissolution, then MeOH (5.2 mL/mmol of tartrate) was added. The mixture was heated at 65°C and a solution of the aldehyde (2 eq) in MeOH (2.2 ml/mmol of tartrate) was added over 30 min. The mixture was refluxed for additional 4 h and was cooled to room temperature. The mixture was concentrated in vacuo and the residue was dissolved in EtOAc (4 mL/mmol of tartrate), washed with water (2x1 ml/mmol of tartrate), dried (Na₂SO₄) and concentrated in vacuo to give a crude product. The crude product contained the aldehyde and was used in the next step without purification.

**Reduction of Schiff bases (general procedure)**

Sodium borohydride (2.1 eq) was added portionwise over 40 min to a solution of a Schiff base (1.0 eq) in MeOH (4 mL/mmol of a Schiff base) at room temperature and the reaction mixture was stirred for 1 h under reflux. After cooling to room temperature, water (5 mL/mmol of a Schiff base) was added and the mixture was extracted with CH₂Cl₂ (3*4 mL/mmol of Schiff base) and evaporated. If any aldehyde remained in the starting reaction mixture, the residue was dissolved in aqueous solution of hydrochloric acid (35%, 1 mL/mmol of a Schiff base) and washed with CH₂Cl₂ (3*4ml/mmol of Schiff base). Then excess of K₂CO₃ (4.5 eq) was added to a water phase. The aqueous phase was extracted with CH₂Cl₂ (3*3mL/mmol of a Schiff base), dried, and evaporated to give the product in the form of oil. If the product was not sufficiently pure, additional purification by column chromatography was conducted and the product was obtained in the form of oil.

**One-step synthesis of diamines 3**
A glass vial in a 10 mL stainless steel autoclave was charged with Rh₂(OAc)₄ (0.7 mg, 1.60 µmol, 1 mol%), (R,R)-1,2-cyclohexanediethylammonium chloride (30.0 mg, 0.160 mmol, 100 mol%), isopropanol (0.1 mL), water (0.1 mL) and aldehyde (0.320 mmol, 200 mol%). The autoclave was sealed, flushed three times with 5 atm of CO, and then charged with 50 atm of CO. The reactor was placed into a preheated oil bath (140 °C). After 4 h, the reactor was cooled to room temperature and depressurized. The residue was filtrated from precipitate and analyzed by ¹H NMR.

Schiff base 2a

![Schiff base 2a](image)

Yield 82%. [α]₀²⁵_D = -45.5 (c 1.0, CHCl₃). ¹H NMR (300 MHz, CDCl₃) δ 8.64 (s, 2H), 7.91 (d, J 6.4 Hz, 2H), 7.12-7.34 (m, 6H), 3.51 (m, 2H), 1.88 (m, 6H), 1.52 (m, 2H).

(1R,2R)-N₁,N₂-bis(2-chlorobenzyl)cyclohexane-1,2-diamine 3a

![Schiff base 3a](image)

Yield 93%. [α]₀²⁵_D = -30 (c 1.0, CHCl₃). ¹H NMR (300 MHz, CDCl₃) δ 7.47 (dd, J 7.2 Hz, 2.0 Hz, 2H), 7.40 (dd, J 7.2 Hz, 2.0 Hz, 2H), 7.22-7.28 (m, 4H), 4.03 (d, J 13.8 Hz, 2H), 3.81 (d, J 13.8 Hz, 2H), 2.31-2.34 (m, 2H), 2.24 (br d, J = 13.1 Hz, 2H), 2.11 (br s, 2H), 1.71-1.86 (m, 2H), 1.27-1.34 (t, 2H), 1.09-1.14 (m, 2H). ¹³CNMR (101 MHz, CDCl₃) δ 134.9, 133.9, 130.9, 129.5, 129.2, 127.2, 59.5, 47.0, 29.8, 24.6.

One-step method: Yield 61%.

Schiff base 2b

![Schiff base 2b](image)

Yield 99%. ¹H NMR (200 MHz, CDCl₃) δ 8.11 (s, 2H), 7.51 (d, J 10.0 Hz, 4H), 6.81 (d, J 10.0 Hz, 4H), 3.78 (s, 6H) 3.48-3.37 (m, 2H), 1.88-1.48 (m, 8H).

(1R,2R)-N₁,N₂-bis(4-methoxybenzyl)cyclohexane-1,2-diamine 3b

![Schiff base 3b](image)
Yield 80%. \([\alpha]_{25}^D = -54.7 \text{ (c 1.0, CHCl}_3\) \(^1\text{H NMR (600 MHz, CDCl}_3\) \(\delta 7.25 \text{ (d, } J 9.0 \text{ Hz, 4H), 6.87 (d, } J 9.0 \text{ Hz, 4H), 3.93(d, } J 13.2 \text{ Hz, 2H), 3.82 (s, 6H), 3.68 (d, } J 13.2 \text{ Hz, 2H), 2.49-2.42 (m, 2H), 2.23-2.16 \text{ (m, 2H), 1.83-1.74 \text{ (m, 2H), 1.34-1.18 \text{ (m, 4H).}} \) \(^{13}\text{C NMR (101 MHz, CDCl}_3\) \(\delta 158.4, 133.3, 129.3, 113.9, 61.1, 55.7, 50.7, 32.0, 25.7. MS (ESI): m/z = 355 (M+H)\)^+. 

One-step method: Yield 81%.

**Schiff base 2c**

![Schiff base 2c](image)

Yield 96%. \(^1\text{H NMR (200 MHz, CDCl}_3\) \(\delta 8.16 \text{ (s, 2H), 7.25-7.10 \text{ (m, 6H), 6.90-6.85 \text{ (m, 2H), 3.77 \text{ (s, 6H) 3.41-3.38 \text{ (m, 2H), 1.89-1.30 \text{ (m, 8H).}} \) \(^{(1R,2R)}-N1,N2-bis(3-methoxybenzyl)cyclohexane-1,2-diamine 3c

![Schiff base 2d](image)

Yield 85%. \([\alpha]_{25}^D = -52.0 \text{ (c 1.0, CHCl}_3\) \(^1\text{H NMR (600 MHz, CDCl}_3\) \(\delta 7.21 \text{ (t, } J 8.1 \text{ Hz, 2H), 6.93-6.85 \text{ (m, 4H), 6.80-6.74 \text{ (m, 2H), 3.90 (d, } J 13.2 \text{ Hz, 2H), 3.75 (s, 6H) 3.65 (d, } J 13.2 \text{ Hz, 2H), 2.30-2.27 \text{ (m, 2H), 1.77-1.68 \text{ (m, 2H), 1.27-1.21 \text{ (m, 2H), 1.10-1.00 \text{ (m, 4H).}} \) \(^{13}\text{C NMR (101 MHz, CDCl}_3\) \(\delta 159.7, 142.8, 129.4, 120.5, 113.4, 112.6, 61.3, 55.4, 51.3, 32.0, 25.6. MS (ESI): m/z = 355 (M+H)\)^+. 

One-step method: Yield 85%.

**Schiff base 2d**

![Schiff base 2d](image)

Yield 80%. \(^1\text{H NMR (200 MHz, CDCl}_3\) \(\delta 8.97 \text{ (s, 2H), 8.62 (d, } J 8.0 \text{ Hz, 2H), 7.82-7.75 \text{ (m, 6H), 7.43-7.37 \text{ (m, 4H), 7.29-7.22 \text{ (m, 2H), 3.71-3.66 \text{ (m, 2H), 2.06-1.89 \text{ (m, 6H), 1.80-1.40 \text{ (m, 2H).}} \) \(^{(1R,2R)}-N1,N2-bis(naphthalen-1-ylmethyl)cyclohexane-1,2-diamine 3d

![Schiff base 2d](image)
Yield 93%. $[\alpha]_{25}^D = -14.3$ (c 1.0, CHCl$_3$) $^1$H NMR (200 MHz, CDCl$_3$) $\delta$ 8.01 (d, $J$ 8.4 Hz, 2H), 7.82 (d, $J$ 8.0 Hz, 2H) 7.75-7.71 (m, 2H), 7.44-7.19 (m, 8H), 4.32 (d, $J$ 12.8 Hz, 2H), 4.03 (d, $J$ 12.8 Hz, 2H), 2.58-2.20 (m, 4H), 2.20-1.95 (m, 2H), 1.95-1.60 (m, 2H), 1.45-1.00 (m, 2H). $^{13}$C NMR (50.3 MHz, CDCl$_3$) $\delta$ 136.3, 133.9, 131.9, 128.7, 127.8, 126.1, 125.7, 125.5, 124.1, 61.8, 49.2, 32.1, 25.7. MS (ESI): m/z = 395 (M+H)$^+$.  

One-step method: Yield 64%.

**Schiff base 2e**

![Schiff base 2e](image)

Yield 86%. $^1$H NMR (200 MHz, CDCl$_3$) $\delta$ 8.12 (s, 2H), 7.50 (d, $J$ 8.0 Hz, 4H), 7.27 (d, $J$ 8.0 Hz, 4H), 3.40-3.38 (m, 2H), 1.88-1.48 (m, 8H).

**(1R,2R)-N1,N2-bis(4-chlorobenzyl)cyclohexane-1,2-diamine 3e**

![3e](image)

Yield 48%. $[\alpha]_{25}^D = -64.7$ (c 1.2, CHCl$_3$) $^1$H NMR (600 MHz, CDCl$_3$) $\delta$ 7.29 (d, $J$ 8.4 Hz, 4H), 7.25 (d, $J$ 8.4 Hz, 4H), 3.88 (d, $J$ 13.4 Hz, 2H), 3.64 (d, $J$ 13.4 Hz, 2H), 2.28-2.24 (m, 2H), 2.17-2.12 (m, 2H), 1.76-1.71 (m, 2H), 1.27-1.18 (m, 2H), 1.11-0.97 (m, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 139.6, 132.5, 129.5, 128.6, 61.2, 50.5, 32.0, 25.5. MS (ESI): m/z = 363, 365, 367 (M+H)$^+$.  

One-step method: Yield 62%.

**Schiff base 2f**

![Schiff base 2f](image)

Yield 58%. $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 8.53 (d, $J$ 6.0 Hz, 2H), 8.30 (s, 2H), 7.87 (d, $J$ 6.0 Hz, 2H), 7.62 (m, 2H), 7.21-7.17 (m, 2H), 3.54-3.52 (m, 2H), 1.85-1.83 (m, 6H), 1.50 (m, 2H).

**(1R,2R)-N1,N2-bis(pyridin-2-ylmethyl)cyclohexane-1,2-diamine 3f**

![3f](image)
Yield 52%. \([\alpha]_{25}^D = -27.0\) (c 1.0, CHCl\(_3\)) \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.45 (d, \(J\ 4.4\) Hz, 2H), 7.55 (dt, \(J\ 7.8, 2.0\) Hz, 2H), 7.33 (d, \(J\ 7.8\) Hz, 2H), 7.06 (dd, \(J\ 6.8, 5.2\) Hz, 2H), 3.96 (d, \(J\ 14.2\) Hz, 2H) 3.77 (d, \(J\ 14.2\) Hz, 2H), 2.74-2.54 (br s, 2H), 2.30-2.22 (m, 2H), 2.14-2.04 (m, 2H), 1.73-1.58 (m, 2H), 1.22-1.12 (m, 2H), 1.06-0.94 (m, 2H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 160.4, 148.4, 135.9, 121.1, 121.6, 60.4, 52.2, 31.03, 24.2. GC-MS (EI) (m/z): 296 (2%), 204 (38%), 187 (23%), 145 (8%), 109 (30%), 93 (100%), 65 (26%).

One-step method: Yield 50%.

**Schiff base 2g**

Yield 98%. \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 8.73 (s, 2H), 8.55 (d, \(J\ 4.6\) Hz, 2H), 8.21 (s, 2H), 7.94 (d, \(J\ 7.8\) Hz, 2H), 7.28-7.21 (m, 2H), 3.48-3.37 (m, 2H), 1.92-1.72 (m, 6H), 1.56-1.44 (m, 2H).

(1\(R\),2\(R\))-N1,N2-bis(pyridin-3-ylmethyl)cyclohexane-1,2-diamine 3g

Yield 87%. \([\alpha]_{25}^D = -23.5\) (c 1.0, CHCl\(_3\)) \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.53 (d, \(J\ 1.5\) Hz, 2H), 8.23 (dd, \(J\ 4.8, 1.0\) Hz, 2H), 7.34 (d, \(J\ 7.8\) Hz, 2H), 6.91 (dd, \(J\ 7.8, 4.8\) Hz, 2H), 3.58 (d, \(J\ 13.5\) Hz, 2H), 3.35 (d, \(J\ 13.5\) Hz, 2H), 2.15-1.59 (m, 6H), 1.47-1.37 (m, 2H), 0.99-0.86 (m, 2H), 0.82-0.67 (m, 2H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 160.4, 148.8, 135.9, 122.1, 121.6, 60.4, 51.6, 31.2, 24.8.

One-step method: Yield 48%.

**Schiff base 2h**

Yield 53%. \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 8.15 (s, 2H), 7.52 (d, \(J\ 8.5\) Hz, 4H), 6.62 (d, \(J\ 8.5\) Hz, 4H), 3.44-3.32 (m, 2H), 2.95 (s, 12H), 1.97-1.79 (m, 6H), 1.62-1.46 (m, 2H).

(1\(R\),2\(R\))-N1,N2-bis(4-N,N-dimethylaminebenzyl)cyclohexane-1,2-diamine 3h
Yield 30%. \([\alpha]_25^D = -20.6\) (c 1.0, CHCl\textsubscript{3}). \(\textsuperscript{1}H\) NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.19 (d, \(J\) 8.5 Hz, 4H), 6.65 (d, \(J\) 8.5 Hz, 4H), 3.95 (d, \(J\) 12.9 Hz, 2H), 3.72 (d, \(J\) 12.9 Hz, 2H), 2.92 (s, 12H), 2.72-2.64 (m, 2H), 2.25-2.16 (m, 2H), 1.82-1.73 (m, 2H), 1.48-1.41 (m, 2H), 1.31-1.19 (m, 2H). \(\textsuperscript{13}C\) NMR (100 MHz, CDCl\textsubscript{3}) \(\delta\) 150.4, 129.8, 122.5, 112.5, 58.2, 48.3, 40.4, 28.8, 24.3. GC-MS (EI) (m/z): 256 (2%), 255 (18%), 254 (100%), 253 (84%), 237 (19%), 211 (8%), 210 (40%), 208 (15%), 165 (15%), 134 (30%), 118(30%), 91 (8%), 43 (5%), 42 (15%).

One-step method: Yield 43%.

**Schiff base 2i**

Yield 85%. \(\textsuperscript{1}H\) NMR (300 MHz, CDCl\textsubscript{3}) \(\delta\) 8.32 (s, 2H), 7.34-7.26 (m, 2H), 7.21 (dd, \(J\) 7.6, 1.5 Hz, 2H), 6.95 (d, \(J\) 8.2 Hz, 2H), 6.89-6.82 (m, 2H), 3.4-3.32 (m, 2H), 2.06-1.88 (m, 4H), 1.87-1.68 (m, 2H), 1.62-1.46 (m, 2H).

(1\textsubscript{R},2\textsubscript{R})-N\textsubscript{1},N\textsubscript{2}-bis(2-hydroxybenzyl)cyclohexane-1,2-diamine 3i

Yield 53%. \([\alpha]_25^D = -58.9\) (c 1.0, CHCl\textsubscript{3}) \(\textsuperscript{1}H\) NMR (300 MHz, CDCl\textsubscript{3}) \(\delta\) 7.17 (dd appears as t, \(J\) 7.7 Hz, 2H), 6.98 (d, \(J\) 6.9 Hz, 2H), 6.87-6.75 (m, 4H), 4.05 (d, \(J\) 13.8 Hz, 2H), 3.92 (d, \(J\) 13.8 Hz, 2H), 2.58-2.38 (m, 2H), 2.25-2.04 (m, 2H), 1.89-1.58 (m, 2H), 1.44-1.02 (m, 4H). \(\textsuperscript{13}C\) NMR (101 MHz, CDCl\textsubscript{3}) 158.01, 129.0, 128.5, 123.0, 119.4, 116.6, 59.8, 49.7, 30.5, 24.3.

One-step method: Yield 24%.

**Schiff base 2j**

Yield 45%. \(\textsuperscript{1}H\) NMR (200 MHz, CDCl\textsubscript{3}) \(\delta\) 8.20 (s, 2H), 7.60-7.55 (m, 4H), 7.32-7.25 (m, 6H), 3.44-3.39 (m, 2H), 1.85-1.50 (m, 8H).
(1R,2R)-N1,N2-dibenzylcyclohexane-1,2-diamine 3j

![Structure of (1R,2R)-N1,N2-dibenzylcyclohexane-1,2-diamine](image)

Yield 84%. $[\alpha]_D^{25} = -52.9$ (c 1.0, CHCl$_3$). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.37-7.16 (m, 10H), 3.93 (d, $J$ 13.2 Hz, 2H), 3.68 (d, $J$ 13.2 Hz, 2H), 2.35-2.26 (m, 2H), 2.21-2.13 (m, 2H), 1.80-1.67 (m, 2H), 1.29-1.18 (m, 2H), 1.16-1.00 (m, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$) 140.7, 128.4, 128.2, 126.9, 60.7, 50.7, 31.4, 25.0. GC-MS (EI) (m/z): 294 (7%), 203 (14%), 189 (20%), 186 (13%), 146 (6%), 132 (3%), 107 (14%), 106 (22%), 91 (100%), 89 (4%), 65(18%).

One-step method: Yield 77%.

Schiff base 2k

![Structure of Schiff base 2k](image)

Yield 69%. $^1$H NMR (200 MHz, CDCl$_3$) $\delta$ 8.06 (s, 2H), 6.81 (s, 4H), 3.81 (s, 18H), 3.41-3.29 (m, 2H), 1.85-1.50 (m, 8H).

(1R,2R)-N1,N2-bis(3,4,5-trimethoxybenzyl)cyclohexane-1,2-diamine 3k

![Structure of (1R,2R)-N1,N2-bis(3,4,5-trimethoxybenzyl)cyclohexane-1,2-diamine](image)

Yield 79%. $[\alpha]_D^{25} = -31.6$ (c 1.0, CHCl$_3$). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 6.55 (s, 4H), 3.88 (d, $J$ 13.2 Hz, 2H), 3.82 (s, 6H), 3.78 (s, 12H), 3.59 (d, $J$ 13.2 Hz, 2H), 2.35-2.25 (m, 2H), 2.24-2.14 (m, 2H), 1.85-1.69 (m, 2H), 1.35-1.19 (m, 2H), 1.16-1.02 (m, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$) 153.3, 137.0, 136.6, 106.1, 61.2, 60.9, 56.1, 51.4, 31.6, 25.1.

One-step method: Yield 87%.

Ethyl 2-(2,5-dimethylphenyl)-2-oxoacetate 4d

![Structure of Ethyl 2-(2,5-dimethylphenyl)-2-oxoacetate](image)

AlCl$_3$ (4.74 g, 36 mmol, 1.9 eq) was suspended in CH$_2$Cl$_2$ (20 mL) at 0 °C in a three-necked round-bottomed flask equipped with a cooling system. Ethyl chlorooxoacetate (4.0 mL, 36 mmol, 1.9 eq.)
was added dropwise over about 10–15 min. After 10 min the stirred suspension turned into a pale yellow solution. \textit{p}-Xylene (2.00 mL, 18.8 mmol, 1 eq) was added dropwise over about 10 min while keeping the reaction mixture at 0 °C. The solution was stirred at r.t. for 2 h and then a threefold volume of H\textsubscript{2}O was carefully added. Extraction was performed with EtOAc (5 × 30 mL). The organic layers were collected and washed with sat. NaCl solution (2 × 30 mL), dried over Na\textsubscript{2}SO\textsubscript{4} and concentrated in vacuo to give the product as a yellow liquid (1.72 g, 44%).\textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \(\delta 7.47\) (s, 1H), 7.29 (d, \(J 7.9\) Hz, 1H), 7.18 (d, \(J 7.9\) Hz, 1H), 4.43 (q, \(J 7.2\) Hz, 2H), 2.55 (s, 3H), 2.36 (s, 3H), 1.41 (t, \(J 7.1\) Hz, 3H).

\textbf{Ethyl 2-(2,5-dimethoxyphenyl)-2-oxoacetate}

\[
\begin{array}{c}
\text{O}_2\text{Me} \\
\text{O}_2\text{Me} \\
\text{Et}
\end{array}
\]

AlCl\textsubscript{3} (0.667 g, 5.0 mmol, 1 eq) was suspended in CH\textsubscript{2}Cl\textsubscript{2} (5 mL) at 0 °C in a three-necked round-bottomed flask equipped with a cooling system. Ethyl chlorooxocacetate (0.56 mL, 5.0 mmol, 1 eq) was added dropwise over about 10–15 min. After 10 min the stirred suspension turned into a pale yellow solution. 1,4-Dimethoxybenzene (0.69 g, 5.0 mmol, 1 eq) was added dropwise over about 10 min while keeping the reaction mixture at 0 °C. The solution was stirred at r.t. for 2 h and then a threefold volume of H\textsubscript{2}O was carefully added. Extraction was performed with EtOAc (5 × 10 mL). The organic layers were collected and washed with sat. NaCl solution (2 × 30 mL), dried over Na\textsubscript{2}SO\textsubscript{4} and concentrated in vacuo to give the product as a yellow liquid after column chromatography (0.65 g, 55%).

\textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \(\delta 7.36\) (d, \(J 3.1\) Hz, 1H), 7.15 (dd, \(J 9.0, 3.1\) Hz, 1H), 6.94 (d, \(J 9.1\) Hz, 1H), 4.38 (q, \(J 7.1\) Hz, 2H), 3.81 (s, 3H), 3.80 (s, 3H), 1.38 (t, \(J 7.1\) Hz, 3H).

The reaction flask was cooled with an ice bath. Ethyl chlorooxocacetate (2.43 mL, 21.8 mmol, 1.5 eq) was mixed with 1,4-dimethoxybenzene (2.00 g, 14.5 mmol, 1 eq) in anhydrous CH\textsubscript{2}Cl\textsubscript{2} (30 mL). After 10 minutes, AlCl\textsubscript{3} (3.64 g, 27.3 mmol, 1.9 eq) was added portionwise over 15 min. The color of the reaction mixture changed from yellow to dark purple. After 23 hours, ice (100 g) and HCl (40 mL, 12M) were added. The solution was extracted with CH\textsubscript{2}Cl\textsubscript{2} (3x18 mL), the organic layers were washed with aqueous KOH (20 mL, 0.1 N) and brine (3x30 mL), dried (MgSO\textsubscript{4}) and evaporated to give two products after column chromatography: the expected product (207 mg, 6%) and the product of hydrolysis (245 mg, 7.5%).

\textbf{Ethyl 2-(2-hydroxy-5-methoxyphenyl)-2-oxoacetate}

\[
\begin{array}{c}
\text{OH} \\
\text{O}_2\text{Me} \\
\text{Et}
\end{array}
\]

\textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \(\delta 10.89\) (s, 1H), 7.21-7.14 (m, 2H), 6.94 (d, \(J 9.0\) Hz, 1H), 4.45 (q, \(J 7.1\) Hz, 2H), 3.75 (s, 3H), 1.42 (t, \(J 7.1\) Hz, 3H).

The reaction time and the amount of water have a dramatic effect on the product yields.

\textbf{1-fluoro-4-(trichloromethyl)benzene 4f}

\[
\begin{array}{c}
\text{F} \\
\text{CCl}_3
\end{array}
\]

AlCl\textsubscript{3} (7.57 g, 56.7 mmol, 1.8 eq) was suspended in CH\textsubscript{2}Cl\textsubscript{2} (40 mL) at 0 °C in a three-necked round-bottomed flask equipped with a cooling system. Ethyl chlorooxocacetate (5.3 mL, 47.4 mmol, 1.5 eq) was added dropwise over 10–15 min. After 10 min the stirred suspension turned into a pale yellow solution. 1-fluoro-4-(trifluoromethyl)benzene (3 ml, 31.5 mmol, 1 eq) was added dropwise at 0 °C over about 10 min. The solution was stirred at r.t. for 2 h and then a threefold volume of H\textsubscript{2}O was carefully added. Extraction was performed with EtOAc (5 × 20 mL). The organic layers
were collected and washed with sat. NaCl solution (2 × 60 mL), dried over Na₂SO₄ and concentrated in vacuo to give the product as a yellow liquid after column chromatography (0.65 g, 55%). ¹H NMR (400 MHz, CDCl₃) δ 7.93 (dd, J 8.7, 4.9 Hz, 2H), 7.11 (t, J 8.5 Hz, 2H). ¹⁹F NMR (376 MHz, CDCl₃) δ -110.25 (s, 1F). GC-MS (EI): m/z: 212 (3%), 181 (8%), 179 (62%), 177 (100%), 142 (6%), 117 (2%), 108 (24%), 81 (6%), 71 (6%), 57 (6%).

(S)-methyl 2-hydroxy-4-oxo-2-phenylpentanoate

![Chemical structure](image)

Methyl 2-oxo-2-phenylacetate (24.6 mg, 0.15 mmol, 1 eq) in acetone (0.2 mL) was added to catalyst 3g (4.11 mg, 0.015 mmol, 0.1 eq) followed by acetic acid (0.09 mg, 0.0015 mmol, 0.01 eq) in acetone (0.3 mL). After 7 days the mixture was purified by column chromatography to give the product as white crystals (31.5 g, 95%, e.r. 84:16). After one recrystallization from acetone the enantiomeric excess of the product increased to 96.5:3.5 e.r.. The e.r. was determined by HPLC (Chiralpak IB-3 column, hexane/isopropanol: 90/10, flow rate 1 mL/min; tR (minor) 11.6 min, tR (major) = 14.9 min; UV = 254 nm. [α]_{25}^{D} = -112 (c 1.1, CHCl₃). ¹H NMR (300 MHz, CDCl₃) δ 7.56 (dd, J 8.1, 1.2 Hz, 2H), 7.41–7.27 (m, 3H), 4.50–4.40 (br s, 1H), 3.75 (s, 3H), 3.56 (d, J 17.7 Hz, 1H), 3.01 (d, J 17.7 Hz, 1H), 2.21 (s, 3H).

(RS)-ethyl 2-(2,5-dimethylphenyl)-2-hydroxy-4-oxopentanoate

![Chemical structure](image)

Ethyl 2-(2,5-dimethylphenyl)-2-oxoacetate (100 mg, 0.48 mmol 1 eq) in acetone (0.3 mL) was added to pyrrolidine (3.4 mg, 0.048 mmol, 0.1 eq) followed by the solution of acetic acid (1.44 mg, 0.024 mmol, 0.05 eq) in acetone (0.2 mL). After 2 days the mixture was purified by column chromatography to give the product as white crystals (42 mg, 33%). ¹H NMR (400 MHz, CDCl₃) δ 7.29 (s, 1H), 7.07–7.01 (m, 2H), 5.20–5.00 (br s, 1H), 4.33–4.19 (m, 2H), 3.49 (d, J 16.8 Hz, 1H), 2.98 (d, J 16.8 Hz, 1H), 2.39 (s, 3H), 2.33 (s, 3H), 2.29 (s, 3H), 1.27 (t, J 7.1 Hz, 3H).

methyl 2-hydroxy-3-nitro-2-phenylpropanoate

![Chemical structure](image)

20 µl of methyl benzoylformate was added to the mixture of 5 mg (17 µmol, 12 mol%) of diamine ligand 3f and 5.1 mg of Cu(OTf)₂ (10 mol%) in 1 ml of nitromethane. After 5 min 2 µl of triethylamine was added. The reaction was stirred at room temperature for 24 hours. Yield 93%. ¹H NMR (200 MHz, CDCl₃) δ 7.65–7.55 (m, 2H), 7.45–7.3 (m, 3H), 5.26 (d, J 14.2 Hz, 1H), 4.69 (d, J 14.2 Hz, 1H), 4.20–4.40 (br s, 1H), 3.90 (s, 3H). Enantiomeric ratio (56:44) was determined using
HPLC. Column PIRKLE covalent S,S-Whelk-01 25 cm x 4.6 mm. Flow rate 1.5 ml/min. UV detection at 220 nm. tR (major) 13.9 min, tR (minor) 14.9 min.

1-phenylethan-1-ol

\[
\text{HO}\quad \text{Ph}
\]

31 μl of acetophenone was added to the mixture of 4.4 mg (12.5 μmol, 5 mol%) of diamine ligand 3b and 1.6 mg of Ru₃(CO)₁₂ (2.5 μmol, 1 mol%) in 5 ml of 2-propanol. The reaction was refluxed for 12 hours. Yield 97%. \(^1\)H NMR (200 MHz, CDCl₃) δ 7.35–7.20 (m, 5H), 4.85 (q, \(J\ 6.8\ Hz, 1H\)), 2.30-2.10 (br s, 1H), 1.46 (d, \(J\ 6.8\ Hz, 3H\)). Enantiomeric ratio (75:25) was determined using GC. Column Rt®-bDEXsa 30m x 0.25 mm ID, injector 200 °C, detector 220 °C, FID, split 1:20, 1 ml/min nitrogen gas, from 80 °C for 5 min, 10 °C/min to 180 °C; 5 min at 180 °C. tR (minor) 16.9 min, tR (major) 17.8 min.

1-(m-tolyl)ethan-1-ol

\[
\text{HO}\quad \text{Ph}
\]

Yield 88%. \(^1\)H NMR (200 MHz, CDCl₃) δ 7.30–7.05 (m, 5H), 4.84 (q, \(J\ 6.4\ Hz, 1H\)), 2.38 (s, 3H) 2.28-2.15 (br s, 1H), 1.49 (d, \(J\ 6.4\ Hz, 3H\)). Enantiomeric ratio (78:22) was determined using GC. Column Rt®-bDEXsa 30m x 0.25 mm ID, injector 200 °C, detector 220 °C, FID, split 1:20, 1 ml/min nitrogen gas, from 80 °C for 5 min, 10 °C/min to 180 °C; 5 min at 180 °C. tR (minor) 15.5 min, tR (major) 15.6 min.

1-(3-chlorophenyl)ethan-1-ol

\[
\text{HO}\quad \text{Cl}
\]

Yield 88%. \(^1\)H NMR (200 MHz, CDCl₃) δ 7.37–7.18 (m, 5H), 4.84 (q, \(J\ 6.4\ Hz, 1H\)), 2.38-2.23 (br s, 1H), 1.45 (d, \(J\ 6.4\ Hz, 3H\)). Enantiomeric ratio (78:22) was determined using GC. Column Rt®-bDEXsa 30m x 0.25 mm ID, injector 200 °C, detector 220 °C, FID, split 1:20, 1 ml/min nitrogen gas, isocratic 150 °C. tR (minor) 18.9 min, tR (major) 19.0 min.

1-(4-chlorophenyl)ethan-1-ol

\[
\text{HO}\quad \text{Cl}
\]
Yield 88%. $^1$H NMR (200 MHz, CDCl$_3$) $\delta$ 7.33–7.23 (m, 5H), 4.85 (q, $J$ 6.3 Hz, 1H), 2.17-2.05 (br s, 1H), 1.45 (d, $J$ 6.3 Hz, 3H). Enantiomeric ratio (78:22) was determined using GC. Column Rt®-bDEXsa 30m x 0.25 mm ID, injector 200 °C, detector 220 °C, FID, split 1:20, 1 ml/min nitrogen gas, isocratic 150 °C. tR (minor) 22.0 min, tR (major) 22.6 min.
Schiff base 2i (¹H NMR, CDCl₃, 400 MHz). Crude mixture
(1R,2R)-N1,N2-bis(4-chlorobenzyl)cyclohexane-1,2-diamine 3e (1H NMR, CDCl3, 600 MHz)
(1R,2R)-N1,N2-bis(4-chlorobenzyl)cyclohexane-1,2-diamine 3e ($^{13}$C NMR, CDCl$_3$, 151 MHz)
(1R,2R)-N1,N2-bis(4-methoxybenzyl)cyclohexane-1,2-diamine 3b. Reaction mixture by one-step protocol.