Electronic Supplementary Material (ESI) for Chemical Communications

Calcium amido-bisoxazoline comlexes in asymmetric hydroamination/cyclization catalysis

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Experimental

General methods and instrumentation:

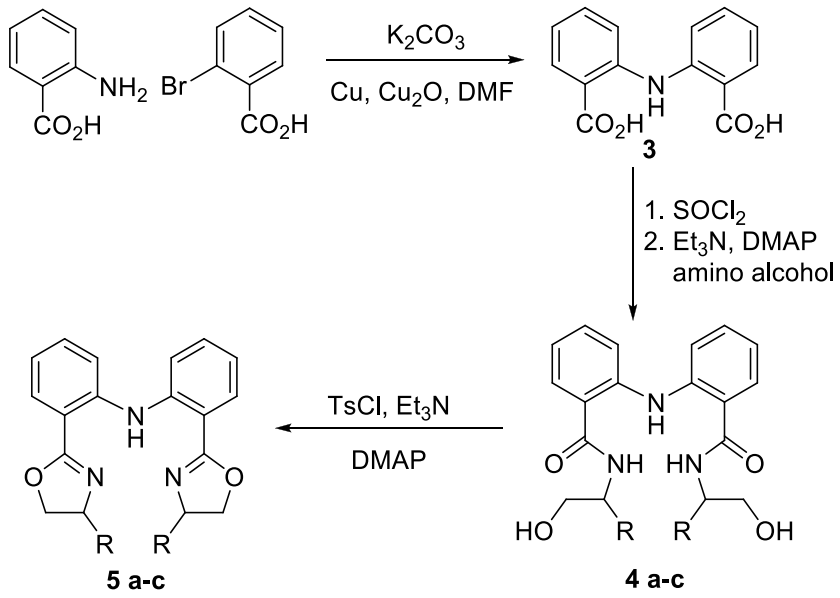
All manipulations of air and moisture sensitive species were performed under an atmosphere of argon or dinitrogen using standard Schlenk and glove box techniques. Solvents were dried by passing through an alumina drying column incorporated into a MBraun SPS800 solvent purification system except in the case of tetrahydrofuran (THF), which was dried over potassium and distilled under argon. All solvents were degassed and stored under argon in Teflon valve ampoules. Deuterated choloroform was passed through a column of basic alumina before being stored over 4Å molecular sieves prior to use. Benzene-d_6 and thf-d_8 were dried over potassium under an argon atmosphere before being vacuum transferred, freeze pump thaw degassed and stored in a glove box. All other reagents were purchased from commercial suppliers and used as received unless otherwise stated.

Air sensitive samples for NMR spectroscopy were prepared in a glovebox under a dinitrogen atmosphere using 5 mm Nolan NMR tubes equipped with J. Young Teflon valves. All other samples were prepared in Wilmad5 mm NMR tubes. NMR spectra were recorded on Bruker Avance DPX 250, 400, 500 or Jeol Eclipse 300 spectrometers. NMR spectra are quoted in ppm and were referenced internally relative to the residual protio-solvent (^{1}H) or solvent (^{13}C) resonances; all coupling constants are quoted in Hertz. In all cases, NMR assignments were confirmed by the use of two-dimensional ^{1}H-^{1}H or ^{1}H-^{13}C correlation experiments (HSQC and HMBC). Mass spectra were recorded by the EPSRC National Mass Spectrometry Service. Infrared spectra were prepared as liquid films on NaCl plates, or KBr pellets and were recorded on a Jasco 660-Plus FT/IR spectrometer. Infrared data are quoted in wavenumbers (cm^{-1}).

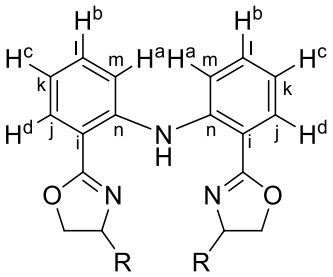
Preparation of R-BOPA (3a-c)

A modified literature procedure was used in the preparation of R-BOPA.[1] The bis(carboxylic acid) bridge **3** was synthesised following the procedure of Xu followed by step 2 with addition of DMAP in synthesis of **4 a-c** in order to limit competing side reactions. For the synthesis of **5 a-c** a known procedure for ring closing oxazolines was employed.[2] To a dry DCM solution of the bis-hydroxyamide (**4 a-c**) was added dry NEt_3 (8.0 eq.), DMAP (10 mg) and cooled to 0

°C. To this a dry DCM solution of TsCl (2.0 eq.) was added dropwise and left to stir at room temperature for 3 days. The DCM solution was washed with aqueous NH_4Cl solution and brine, dried over Na_2SO_4 and the solvent removed under reduced pressure to yield the crude product. Ligands **(5 a–c)** were purified by flash column chromatography using silica gel eluting with DCM.



BOPA ligand synthesis



Lettering for NMR

General procedure for the preparation of [Ca(R-BOPA)[N(SiMe$_3$)$_2$](THF)] (1 a-c) and [Ca(R-BOPA)$_2$] (2 a-c): In a nitrogen filled glove box R-BOPA (1eq. wrt to Ca) and Ca[N(TMS)$_2$)]$_2$.thf$_x$ (100 mg, 0.20 mmol, x = 1.79) were added to a Schlenk followed by dry toluene (20mL). This was allowed to stir at room temperature overnight. The solvent was removed *in vacuo* and the solid residue extracted with hexane (40 mL), filtered and solvent removed to afford a yellow solid. By ^{1}H NMR at this stage the major product was the heterolepic complex **1b** and **1c**. Upon crystallation the majority product was found to be the more stable homoleptic complexes **2b** and **2c**. In the case of R = ^{i}Pr the solution was heated

overnight and to prevent a mixtures of **1a** and **2a** being observed by ^{1}H NMR, only **2a** was observed.

[Ca(^{i}Pr-BOPA)$_2$] (2a): ^{1}H NMR (500.1 MHz, C_6D_6, 293 K) δ 8.03 (m, NArH, 1H), 7.72 (dd, ^{3}J = 7.80 Hz, NArH, 1H), 6.96 (m, NArH, 1H), 7.85 (m, NArH, 3H), 6.41 (m, NArH, 2H), 3.87 – 3.44 (m, OCH_2CH, $OCHH$, 6H), 1.70 (m, $(CH_3)_2CH$, 2H), 0.17 – 0.43 (m, CH_3CHCH_3, 12H), 0.23 (s, $N(TMS)_2$, 18H); ^{13}C NMR (100.6 MHz, C_6D_6, 293 K) δ 167.9 (C=N), 156.9 (NArC), 132.8 (NArC), 131.8 (NArC), 128.2 (NArC), 117.2 (NArC), 115.5 (NArC), 70.9 (OCH_2C), 65.9 (OCH_2), 30.5 ($(CH_3)_2CH$), 19.7, 19.4, 19.2, 14.6, 14.3, 13.4 (CH_3CHCH_3), 6.1 ($N(TMS)_2$); IR (υ cm^{-1}) (KBr): 2962 m, 2907 w, 2871 w, 1622 s, 1575 m, 1552 w, 1533 w, 1516 w, 1480 w, 1458 s, 1424 m, 1363 w, 1316 w, 1284 w, 1259 s, 1212 s, 1157 m, 1055 m, 1041 m, 966 m, 800 m, 742 m; Mass spectrum (EI): $[M]^+$ = 820.4; HR-MS (EI) data: $[M]^+$, found (calc. for $C_{48}H_{56}N_6O_4Ca$) 820.4035 (820.3989).

Ca(Ph-BOPA)[N(TMS)$_2$](THF) (1b): ^{1}H NMR (500.1 MHz, C_6D_6, 293 K) δ 7.95 (d, ^{3}J = 7.99 Hz, NArH^{d}, 2H), 7.04 – 6.95 (m, 12H), 6.54 (m, NArH^{a}, 2H), 6.49 (m, NArH^{c}, 2H), 5.34 (dd, ^{4}J = 4.65 Hz, ^{3}J = 9.47 Hz, OCH_2CH, 1H), 4.39 (dd, ^{4}J = 4.65 Hz, ^{3}J = 8.98 Hz, OCH_2CH, 1H), 4.06 (app.t, ^{3}J = 4.22 Hz, $OCHH$ 1H), 3.86 (m, $OCHH$, 1H), 3.65 (app.t, ^{3}J = 4.56 Hz, $OCHH$, 1H), 3.50 (m, $OCHH$, 1H), 3.22 (br s, THF, 2H), 2.92 (br s, THF, 2H), 0.95 (br s, THF, 4H), 0.10 (br s, $N(TMS)_2$, 18H); ^{13}C NMR (100.6 MHz, C_6D_6, 293 K) δ 169.1 (C=N), 168.4 (C=N), 159.6 (NArC^{m}), 159.1 (NArC^{m}), 142.5 (*i*-C$^{*}HC_6H_5$), 142.4 (*i*-C$^{*}HC_6H_5$), 131.9 (NArC^{k}), 131.7 (NArC^{k}), 130.7 (NArC^{i}), 127.7 (oxaz – C_6H_5), 127.1 (oxaz – C_6H_5), 125.8 (oxaz – C_6H_5), 125.7 (oxaz – C_6H_5), 124.3 (NArC^{l}), 124.1 (NArC^{l}), 114.2 (NArC^{j}), 113.3 (NArC^{n}), 74.1 (OCH_2), 73.9 (OCH_2), 69.3 (OCH_2C), 69.2 (THF), 68.3 (THF), 68.3 (OCH_2C), 25.0 (THF), 4.6 ($N(SiMe_3)_2$); IR (υ cm^{-1}) (KBr): 2958 m, 2902 br m, 1633 m, 1608 s, 1575 m, 1522 w, 1533 w, 1460 m, 1421 m, 1360 w, 1321 w, 1261 s, 1214 sw, 1156 w, 1094 s, 1020 s, 946 m, 874 w, 799 s; **[Ca(Ph-BOPA)$_2$] (2b)**: Mass spectrum (CI): $[M+H]^+$ = 957.3; HR-MS (ES) data:$[M+H]^+$, found (calc. for $C_{60}H_{48}N_6O_4Ca$+H) 957.3431 (957.3441).

Ca(Bn-BOPA)[N(TMS)$_2$](THF) (1c): ^{1}H NMR (500.1 MHz, C_6D_6, 293 K) δ 7.90 (dd, ^{4}J = 1.73 Hz, ^{3}J = 8.16 Hz, NArH^{d}, 2H), 7.08-7.03 (m, CHC_6H_5, 10H), 6.94-6.91 (m, NArH^{b}, NArH^{a}, 4H), 6.46 (ddd, ^{3}J = 7.06 Hz, NArH^{c}, 2H), 4.63 (m, OCH_2CH, 2H), 3.72 (m, OCH_2CH, 4H), 3.36 (dd, ^{4}J = 4.1 Hz, ^{3}J = 13.9 Hz, $CHHC_6H_5$, 2H), 2.24 (dd, ^{4}J = 3.8 Hz , ^{3}J = 13.9 Hz, $CHHC_6H_5$, 2H), 0.25 (s, $N(TMS)_2$, 18H); ^{13}C NMR (100.6 MHz, C_6D_6, 293 K) δ 169.2 (C=N),

156.3 ($NArC^{m}$), 136.6 (i-$CH_2C_6H_5$), 134.0 ($NArC^{k}$ or $NArC^{l}$), 132.5 ($NArC^{i}$), 129.5 ($CH_2\underline{C}_6H_5$), 129.1 ($CH_2\underline{C}_6H_5$), 127.3 ($CH_2\underline{C}_6H_5$), 126.9 ($NArC^{k}$ or $NArC^{l}$), 118.4 ($NArC^{j}$), 115.8 ($NArC^{n}$), 70.4 ($O\underline{C}H_2$), 67.1 ($OCH_2\underline{C}H$), 41.2 ($\underline{C}H_2C_6H_5$), 5.4 ($N(Si\underline{Me}_3)_2$); IR (υ cm^{-1}) (KBr): 3083 w, 3025 w, 2958 m, 2896 m, 1639 s, 1606 s, 1580 m, 1524 m, 1494 w, 1458 s, 1357 w, 1315 w, 1261 s, 1215 w, 1159 w, 1159 m, 1097 m, 1052 s, 1030 s, 974 w, 928 w, 801 s, 745 m, 700 m; **[Ca(Bn-BOPA)$_2$] (2c)**: Mass spectrum (EI): $[M]^+$ = 1012.4; HR-MS (EI) data:$[M]^+$, found (calc. for $C_{64}H_{56}N_6O_4Ca$) 1012.3997 (1012.3989).

General procedure for hydroamination catalysis: Both the 1-amino 2,2-dimethylpent-4-ene and 1-amino 2,2-diphenylpent-4-ene were prepared according to literature methods.[3,4] In a dinitrogen filled glovebox R-BOPA (0.0192 mmol, 10 mol%)* was predissolved in C_6D_6 (0.5 mL) and successively added to $Ca[N(TMS)_2]_2(thf)_x$ (0.0192 mmol, 10 mol%)*. The resulting mixture was added the corresponding amino olefin (0.192 mmol, 45.6 mg). The solution was transferred to a J. Young Teflon valve equipped NMR tube and sealed. All catalyst reactions were monitored *via* ^{1}H NMR periodically to monitor conversion (Conversion was checked against notable resonances in the spectra corresponding to the cyclic amide product).[5] Upon conversion ceasing, a solution of (*S*)-(+)-*O*-acetylmandelic acid (0.212 mmol, 41 mg) predissolved in a minimal amount of $CDCl_3$ was added to the reaction mixture producing the diasteromeric salts. The resulting enantioexcess (e.e.) was then determined by ^{1}H NMR spectroscopy.[6]

* amounts changed wrt to the amino olefin for higher catalyst loadings.

References

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