Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry

SUPPLEMENTARY INFORMATION 1

Synthesis of a C1–C11 Fragment of Zincophorin Using Planar Chiral, Neutral π-Allyl Iron Complexes

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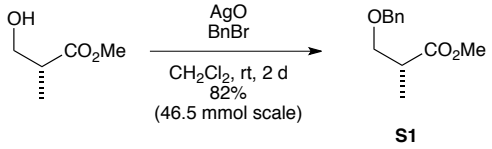
CONTENTS

GENERAL INFORMATION AND MATERIALS

All reactions requiring anhydrous conditions were conducted under a nitrogen atmosphere in flame-dried glassware unless stated otherwise. All reagents and solvents were obtained from commercial suppliers and used as supplied unless stated otherwise. Where appropriate, solvents and reagents were dried by standard methods i.e. distillation from the usual drying agent under an nitrogen atmosphere prior to use: THF and Et_2O from sodium benzophenone ketyl; CH_2Cl_2, MeCN and Pentane, PhMe from CaH_2. Petrol refers to distilled light petroleum (bp 40-60 ºC). All reactions were magnetically stirred under an atmosphere of nitrogen unless stated otherwise and monitored by TLC using 0.25 mm E. Merck pre-coated silica gel plates visualised with UV light followed by phosphomolybdic acid (PMA) unless stated otherwise. All organic extracts were dried over sodium sulphate (Na_2SO_4) and concentrated *in vacuo* using a Büchi rotary evaporator. All yields refer to chromatographically and spectroscopically pure products unless stated otherwise. All NMR spectra were recorded on Bruker DPX-300 and DRX-500 spectrometers in the solvents specified. Chemical shifts (δ) are reported in ppm relative to the residual signals of chloroform (δ_H = 7.27, δ_C = 77.2) unless stated otherwise. Coupling constants (*J*) are reported in Hertz (Hz) with multiplicities described using the following abbreviations: s = singlet, d = doublet, t = triplet, q = quartet, quint = quintet, sext = sextet, sept = septet, m = multiplet. Signal assignments are based on COSY and HMQC correlation experiments. In ^{13}C NMR spectra, multiplicities and signal assignments were elucidated using DEPT 135 and HMBC correlation experiments. ^{1}H and ^{13}C NMR assignments are based on the numbering system used for Zincophorin as reported by Danishefsky.[1] Infrared spectra were recorded neat on NaCl plates or as a solid on a diamond transmission accessory using a Perkin Elmer FT-IR spectrometer; details are reported as ν_{MAX} in cm^{-1}, followed by a description using the following abbreviations: s = strong, m = medium, w = weak, br = broad. Mass spectra analysis was carried out at the Mass Spectra service, Department of Chemistry, University of Leeds using a Microsmass LCT (ES mode), Bruker Daltonic (ES mode) and Waters GCT Premier (EI and FI mode) apparatus and are reported as values in atomic mass units followed by the peak intensity relative to the base peak (100%). Elemental analysis was carried out at the Microanalytical Laboratory, Department of Chemistry, University of Leeds using a Carlo Erba 1108 Elemental Analyser apparatus. Specific optical rotations were recorded at ambient temperature (22 ±3 ºC) in the solvents specified on an AA-1000 polarimeter reported in $10^{-1}degcm^2g^{-1}$. Melting points were measured using a Griffin melting point apparatus and are uncorrected.

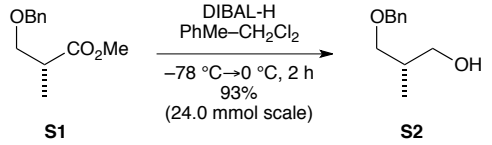
EXPERIMENTAL PROCEDURES

(2*R*)-Methyl 3-(benzyloxy)-2-methylpropanoate (S1)



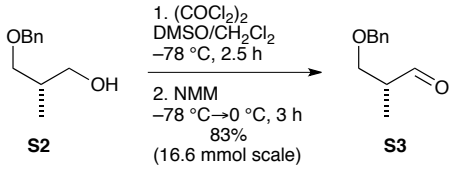
The title compound was prepared using the general procedure of Sauvé.[2] Silver(I)oxide (purified by leaching with H_2O in a Soxhlet apparatus; 16.1 g, 69.8 mmol, 1.5 equiv) then benzyl bromide (5.53 mL, 46.5 mmol, 1.0 equiv) was added to a solution of commercially available (–)-methyl hydroxyisobutyrate (5.15 mL, 46.5 mmol, 1.0 equiv) in CH_2Cl_2 (50 mL) at room temperature. The resulting black suspension was stirred vigorously at room temperature in the absence of light for 2 d. The reaction mixture was filtered through a celite pad, the black residue washed with CH_2Cl_2 (*ca* 200 mL) and the filtrate concentrated *in vacuo* to give a yellow oil that was purified by column chromatography on SiO_2 eluting with petrol/Et_2O (20:1)→(10:1) to give the title compound (7.90 g, 37.9 mmol, 82%) as a colourless oil. Spectroscopic data [^{1}H NMR (300 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported.[3] ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.39–7.27 (5H, m, ArH), 4.53 (2H, s, $PhCH_2O$), 3.71 (3H, s, CO_2Me), 3.67 (1H, dd, J = 9.2, 7.4, C3H_AH_B), 3.50 (1H, dd, J = 9.2, 5.9, C3H_AH_B), 2.80 (1H, qdd, J = 7.2, 7.2, 5.9, C2H), 1.19 (3H, d, J = 7.2, C2 CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 175.0 (C1), 138.1 (C_{Ar}), 128.2 (2C, $C_{Ar}H$), 127.4 (3C, $C_{Ar}H$/C_{Ar}), 72.9 (C3H_2), 71.8 ($PhCH_2O$), 51.5 (CO_2CH_3), 40.0 (C2H), 13.8 (C2 CH_3). IR (neat): ν = 3064 w, 3030 m, 2978 m, 2951 m, 2862 m, 1739 s, 1496 w, 1454 m, 1435 m, 1364 m cm^{-1}. LRMS (ES+ mode) *m/z* = 231 [MNa^+, 100%], 215 (20%). $[\alpha]_D$ = −12.1(c 1.0, $CHCl_3$); Lit.[3] $[\alpha]_D$ = –11.8 (c 3.6, $CHCl_3$).

(2*S*)-3-(Benzyloxy)-2-methylpropan-1-ol (S2)



DIBAL-H (1.5 M in PhMe, 33.6 mL, 50.4 mmol, 2.1 equiv) was added dropwise to a solution of ester **S1** (5.0 g, 24.0 mmol, 1.0 equiv) in CH_2Cl_2 (100 mL) at −78 °C. The resulting colourless solution was stirred at −78 °C for 1 h, allowed to warm to 0 °C and stirred at 0 °C for a further 1 h. The reaction was quenched with KNa tartrate (saturated aqueous, 100 mL), the resulting solution stirred vigorously for 2 h, the layers separated and the aqueous layer extracted with CH_2Cl_2 (3 × 100 mL). The combined organic layers were dried (Na_2SO_4), filtered and concentrated *in vacuo* to give a pale yellow oil that was purified by column chromatography on SiO_2 eluting with petrol/Et_2O (1:2) to give the title compound (4.0 g, 22.3 mmol, 93%) as a colourless oil. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported.[3] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.40–7.28 (5H, m, ArH), 4.53 (2H, s, $PhCH_2O$), 3.68–3.58 (2H, m, C1H_2), 3.57 (1H, dd, J = 9.0, 4.5, C3H_AH_B), 3.44 (1H, dd, J = 8.8, 8.8, C3H_AH_B), 2.52 (1H, broad dd, J = 6.4, 4.7, OH), 2.14–2.04 (1H, m, C2H), 0.90 (3H, d, J = 6.8, C2 CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 138.2 (C_{Ar}), 128.7 (2C, $C_{Ar}H$), 127.9 (C_{Ar}), 127.8 (2C, $C_{Ar}H$), 75.7 (C3H_2), 73.6 ($PhCH_2O$), 68.2 (C1H_2), 35.7 (C2H), 13.6 (C2 CH_3). IR (neat): ν = 3600–3100 br s, 2872 s, 1496 w, 1453 s, 1363 m, 1094 s, 1039 s cm^{-1}. LRMS (ES+ mode) *m/z* = 203 [MNa^+, 100%], 181 [MH^+, 50%]. $[\alpha]_D$ = −17.3 (c 2.0, $CHCl_3$); Lit.[3] $[\alpha]_D$ = –17.6 (c 4.53, $CHCl_3$).

(2*R*)-3-(Benzyloxy)-2-methylpropanal (S3)

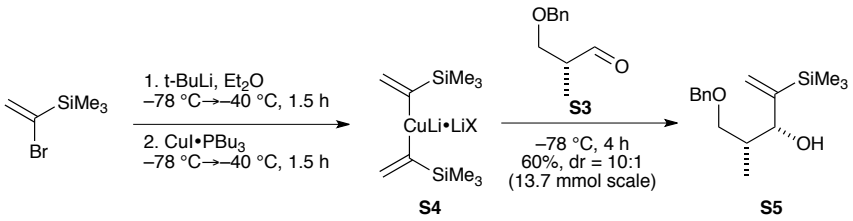


The title compound was prepared using the procedure of Kocieński.[4] Dimethyl sulfoxide (3.0 mL, 41.6 mmol, 2.5 equiv) in CH_2Cl_2 (13 mL) was added dropwise to oxalyl chloride (2.14 mL, 25.0 mmol, 1.5 equiv) in CH_2Cl_2 (13 mL) at −78 °C and the resulting colourless solution stirred at −78 °C for 15 mins. Alcohol **S2** (3.0 g, 16.6 mmol, 1.0 equiv) in CH_2Cl_2 (6.5 mL) was added dropwise to the reaction mixture at −78 °C and the resulting white suspension stirred at −78 °C for 2.5 h. *N*-Methyl morpholine (5.48 mL, 49.8 mmol, 3.0 equiv) was added dropwise to the reaction mixture at −78 °C and the resulting white suspension allowed to warm to 0 °C slowly (3 h). The reaction mixture was poured onto 2M HCl (25 mL) and Et_2O (30 mL), the layers separated and the aqueous layer extracted with Et_2O (3 × 30 mL). The combined organic layers were washed with H_2O (3 × 100 mL) and $NaHCO_3$ (saturated aqueous, 100 mL), dried (Na_2SO_4), filtered, concentrated *in vacuo* and azeotroped using PhH (3 × 20 mL) to give the title compound (2.90 g) as a pale yellow oil (2.45 g, 13.7 mmol, 83%) that was used with no further purification. Spectroscopic data [^{1}H NMR (300 MHz, $CDCl_3$] are in accordance with those reported.[5] ^{1}H NMR (300 MHz, $CDCl_3$): δ = 9.74 (1H, d, *J* = 1.3, C1H), 7.37–7.27 (5H, m, ArH), 4.54 (2H, s, $PhCH_2O$), 3.74–3.62 (2H, m, $C3H_2$), 2.75–2.62 (1H, m, C2H), 1.15 (3H, d, *J* = 7.2, C2 CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 204.1 (C1H), 138.1 (C_{Ar}), 128.6 (2C, $C_{Ar}H$), 127.9 (C_{Ar}), 127.8 (2C, $C_{Ar}H$), 73.5 ($PhCH_2O$), 70.3 ($C3H_2$), 47.0 (C2H), 10.9 (C2 CH_3).

Copper(I) iodide•tri-*n*-butylphosphine complex

The title compound was prepared on a 200 mmol scale (54% yield from tri-*n*-butylphosphine) according to the procedure of Taylor.[6] Copper(I) iodide•tri-*n*-butylphosphine complex can be stored for long periods (several months) in a freezer at *ca* −15 °C under an inert atomsphere in a Schlenk tube with no observable decomposition. mp (acetone/MeOH) 74–75 °C; Lit.[6] mp (acetone/MeOH) 75–75.5 °C.

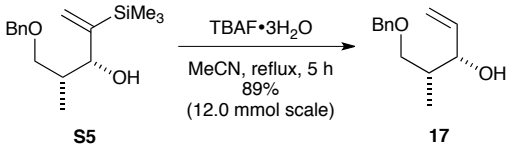
(3*R*,4*R*)-5-(Benzyloxy)-4-methyl-2-(trimethylsilyl)pent-1-en-3-ol (S5)



The title compound was prepared using a modification of the procedure of Burke.[7] *tert*-Butyl lithium (1.60 M in pentane, 42.9 mL, 68.7 mmol, 5.0 equiv) was added dropwise to commercially available (1-bromovinyl)trimethylsilane (5.30 mL, 34.4 mmol, 2.5 equiv) in Et_2O (40 mL) at −78 °C. The resulting pale yellow solution was stirred at −78 °C for 30 min and allowed to warm to −40 °C for 1 h forming a yellow suspension. The reaction mixture was added *via* a cannulla to a colourless solution of copper(I) iodide•tri-*n*-butylphosphine complex (6.75 g, 17.2 mmol, 1.25 equiv) in Et_2O (25 mL) at −78 °C. The resulting yellow/orange suspension was stirred at −78 °C for 30 min, allowed to warm to −40 °C for 1 h then re-cooled to −78 °C. Aldehyde **S4** (2.45 g, 13.7 mmol, 1.0 equiv) in Et_2O (17 mL) was added to the reaction mixture at −78 °C and the resulting yellow suspension stirred at −78 °C for 4 h. The reaction was quenched at −78 °C with NH_4Cl (saturated aqueous, 100 mL), the layers separated and the aqueous layer extracted with Et_2O (3 × 100 mL). The combined organic layers were washed with brine (100 mL), dried (Na_2SO_4), filtered and concentrated *in vacuo* to give a crude 10:1 diastereoisomeric mixture of the title compound **S5** and its *syn*-diastereoisomer as a yellow/orange oil that was purified by column chromatography on SiO_2 eluting with hexane/Et_2O (10:1) to give the more non-polar title compound (2.30 g, 8.26 mmol, 60%) as a colourless oil. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] for compound are in accordance with those reported.[7] The dr of the reaction was assigned using ^{1}H NMR spectroscopy of the crude product by integration of the

signals corresponding to C1H_AH_B [δ_H = 5.75 (1H, d, J = 2.6) for the title compound and 5.86 (t, J = 2.4) for the *syn*-diastereoisomer]. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.39–7.28 (5H, m, ArH), 5.75 (1H, dd, J = 2.6, 0.9, C1H_AH_B), 5.49 (1H, d, J = 2.6, C1H_AH_B), 4.54 (1H, d, J = 12.0, OCH_AH_BPh), 4.50 (1H, d, J = 12.0, OCH_AH_BPh), 4.14 (1H, dd, J = 7.1, 3.8, C3H), 3.64 (1H, dd, J = 9.0, 3.9, C5H_AH_B), 3.55 (1H, d, J = 3.8, OH), 3.49 (1H, dd, J = 9.0, 6.4, C5H_AH_B), 2.03–1.94 (1H, m, C4H), 0.91 (3H, d, J = 7.3, C4 CH_3), 0.15 (9H, s, Si$(CH_3)_3$). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 153.8 (C2), 137.9 (C_{Ar}), 128.5 (2C, C_{Ar}H), 127.8 (C_{Ar}), 127.7 (2C, C_{Ar}H), 125.9 (C1H_2), 82.9 (C3H), 74.9 (C5H_2), 73.6 (PhCH_2O), 37.5 (C4H), 15.0 (C4 *C*H_3), –0.1 (Si(*C*$H_3)_3$). IR (neat): ν = 3600–3100 br s, 3032 m, 2957 s, 2897 m, 2861 m, 1496 w, 1454 m, 1408 m, 1362 m, 1247 s cm^{-1}. LRMS (ES+ mode) *m/z* = 301 [MNa^+, 25%], 261 (75%), 203 (100%). $[\alpha]_D$ = −24.4 (c 2.3, CH_2Cl_2); Lit.[7] $[\alpha]_D$ = –24.53 (c 1.5, CH_2Cl_2).

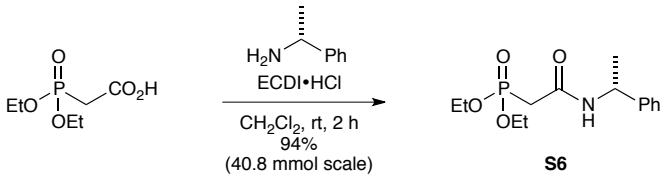
(3*R*,4*R*)-5-(Benzyloxy)-4-methylpent-1-en-3-ol (17)



S5 **17**

The title compound was prepared using a modification of the procedure of Burke.[7] A solution of tetrabutylammonium fluoride trihydrate (6.30 g, 24.0 mmol, 2.0 equiv) in THF (25 mL) was added to a solution of alcohol **S5** (3.35 g, 12.0 mmol, 1.0 equiv) in MeCN (75 mL) and the resulting yellow solution heated under reflux for 5 h. The reaction mixture was allowed to cool to room temperature, H_2O (100 mL) added, the layers separated and the aqueous layer extracted with Et_2O (3 × 100 mL). The combined organic layers were dried (Na_2SO_4), filtered and concentrated *in vacuo* to give a yellow oil that was purified by column chromatography on SiO_2 eluting with petrol/Et_2O (4:1) to give the title compound (2.20 g, 10.6 mmol, 89%) as a colourless oil. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported.[7] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.40–7.28 (5H, m, ArH), 5.86 (1H, ddd, J = 17.1, 10.3, 6.8 C2H), 5.27 (1H, d, J = 17.1, C1H_AH_B), 5.16 (1H, d, J = 10.3, C1H_AH_B), 4.53 (2H, s, PhCH_2O), 4.04 (1H, ddd, J = 6.8, 6.8, 3.8, C3H), 3.63 (1H, dd, J = 9.4, 4.3, C5H_AH_B), 3.48 (1H, dd, J = 9.4, 7.3, C5H_AH_B), 3.26 (1H, d, J = 3.8, OH), 1.97–1.88 (1H, m, C4H), 0.93 (3H, d, J = 7.3, C4 CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.6 (C_{Ar}), 137.9 (C2H), 128.5 (2C, C_{Ar}H), 127.8 (3C, C_{Ar}H/C_{Ar}), 115.9 (C1H_2), 77.6 (C3H), 74.5 (C5H_2), 73.5 (PhCH_2O), 38.6 (C4H), 13.8 (C4 *C*H_3). IR (neat): ν = 3600–3100 br s, 3065 m, 3030 m, 2963 s, 2859 s, 1496 m, 1454 s, 1363 s cm^{-1}. LRMS (ES+ mode) *m/z* = 229 [MNa^+, 100%], 181 (10%), 171 (10%). $[\alpha]_D$ = −31.3 (c 1.3, CH_2Cl_2); Lit.[7] $[\alpha]_D$ = –32.6 (c 2.5, CH_2Cl_2).

(1′*R*)-Diethyl 2-oxo-2-(1′-phenylethylamino)ethylphosphonate (S6)

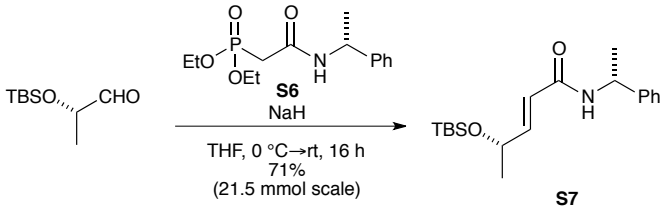


S6

The title compound was prepared using the procedure of Kocieński.[8] 4-Dimethylaminopyridine (10.0 g, 81.6 mmol, 2.0 equiv) then 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (15.6 g, 81.6 mmol, 2.0 equiv) was added to a solution of diethylphosphonoacetic acid (6.6 mL, 40.8 mmol, 1.0 equiv) and (*S*)-α-methylbenzylamine (5.2 mL, 40.8 mmol, 1.0 equiv) in CH_2Cl_2 (1 L) at room temperature and the resulting colourless solution was stirred at room temperature for 2 h. 1M HCl (500 mL) was added to the reaction mixture, the layers separated. The organic layer was washed with 1M HCl (500 mL), then brine (500 mL), dried (Na_2SO_4), filtered and concentrated *in vacuo* to give the title compound (11.5 g, 38.5 mmol, 94%) as a colourless oil that was used with no further purification. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported for *ent*-**S6**.[8] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.36-7.29 (4H, m, ArH), 7.26–7.21 (1H, m, ArH), 7.14 (1H, br s, NH), 5.11 (1H, apparent quint, J = 7.3, C1′H), 4.14 (2H, overlapping dq, J = 15.0, 7.3,

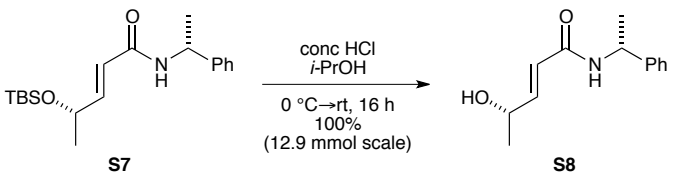
OCH_2CH_3), 4.02 (2H, overlapping dq, J = 15.0, 7.3, OCH_2CH_3), 2.86 (1H, dd, J = 20.9, 15.4, C2H_AH_B), 2.81 (1H, overlapping dd, J = 20.5, 15.4, C2H_AH_B), 1.49 (3H, d, J = 6.8, C1′ CH_3), 1.34 (3H, t, J = 7.3. OCH_2CH_3), 1.22 (3H, t, J = 7.3, OCH_2CH_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 163.0 (C1), 143.1 (C_{Ar}), 128.5 ($C_{Ar}H$), 128.4 ($C_{Ar}H$), 127.1 (C_{Ar}), 126.0 (2C, $C_{Ar}H$), 62.6 (2C, ^2J (^{31}P-^{13}C) = 6.9, OCH_2CH_3), 49.1 (C1'H), 35.0 (d, ^1J (^{31}P-^{13}C) = 131.0, C2H_2), 22.0 (C1′ CH_3), 16.2 (2C, t, ^3J (^{31}P-^{13}C) = 6.9, OCH_2CH_3). IR (neat): ν = 3280 s, 3064 s, 2981 s, 2932 s, 1651 s, 1552 s 1245 s cm^{-1}. LRMS (ES+ mode) m/z = 300 [MH$^+$, 100%], 197 (30%), 196 (75%), 179 (65%), 168 (20%). HRMS (ES+ mode): m/z = 322.1178 [MNa$^+$, 100%]; calculated for $C_{14}H_{22}NaNO_4P$ [MNa$^+$]: m/z = 322.1184. $[\alpha]_D$ = +48.2 (*c* 1.0, $CHCl_3$); *ent*-**S6** Lit.[8] $[\alpha]_D$ = –48.4 (c 1.0, $CHCl_3$).

(2*E*,1′*R*,4*S*)-4-(*tert*-Butyldimethylsilyloxy) pent-2-enoic acid (1′-phenylethyl) amide (S7)



The title compound was prepared using a modification of the procedure of Kocieński.[8] Phosphonate **S6** (7.08 g, 23.6 mmol, 1.1 equiv) in THF (50 mL) was added *via* a cannula to a white suspension of sodium hydride (60% dispersion in mineral oil; washed with anhydrous pentane 2 × 5 mL, 947 mg, 23.6 mmol, 1.1 equiv) in THF (50 mL) at 0 °C and the resulting white suspension was stirred at room temperature for 2 h. (2*R*)-2-(*tert*-Butyldimethylsilyloxy)propanal[9] (4.04 g, mmol, 1.0 equiv) in THF (10 mL + 5 mL rinse) was added to the reaction mixture *via* a cannula and the resulting white suspension was stirred at room temperature for 18 h. The reaction was quenched with Et_2O (75 mL) and pre-mixed NH_4Cl (saturated aqueous, 50 mL) and brine (50 mL), the layers separated and the aqueous layer extracted with Et_2O (3 × 100 mL). The combined organic layers were dried (Na_2SO_4), filtered and concentrated *in vacuo* to give a yellow oil that was purified by column chromatography on SiO_2 eluting with petrol/Et_2O (3:1) followed by crystallisation from petrol to give the title compound (5.10 g, 15.3 mmol, 71%) as white needles. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported for *ent*-**S7**.[8] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.35 (4H, d, J = 4.3, ArH), 7.30-7.25 (1H, m, ArH), 6.86 (1H, dd, J = 15.0, 3.9, C3H), 5.94 (1H, d, J = 15.0, C2H), 5.71 (1H, broad s, NH), 5.23 (1H, quint, J = 7.3, C1′H), 4.50–4.44 (1H, m, C4H), 1.54 (3H, d, J = 6.8, C1′ CH_3), 1.24 (3H, d, J = 6.4, C5H_3), 0.93 (9H, s, $(CH_3)_3CSi$), 0.09 (6H, s, $(CH_3)_2Si$). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 165.1 (C1), 148.3 (C3H), 143.3 (C_{Ar}), 128.8 (2C, $C_{Ar}H$), 127.5 ($C_{Ar}H$), 126.4 (2C, $C_{Ar}H$), 121.0 (C2H), 67.9 (C4H), 48.9 (C1′H), 26.0 ($(CH_3)_3CSi$), 23.8 (C1′ CH_3), 21.8 (C5H_3), 18.4 ($(CH_3)_3CSi$), −4.7 ($(CH_3)_2Si$). IR (solid): ν = 3248 s, 3062 s, 2948 s, 1668 s, 1633 s, 1538 s cm^{-1}. LRMS (ES+ mode) m/z = 334 [MH$^+$, 100%], 230 (20%), 213 (65%) 202 (35%). mp (Petrol) 71–72 °C; *ent*-**S7** Lit.[8] mp (petrol) 70-72 °C. $[\alpha]_D$ = +92.0 (c 1.0, $CHCl_3$); *ent*-**S7** Lit.[8] $[\alpha]_D$ = −91.8 (c 1.0, $CHCl_3$).

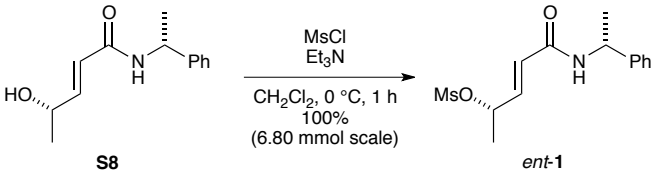
(2*E*,1′*R*,4*S*)-4-Hydroxypent-2-enoic acid (1′-phenylethyl) amide (S8)



The title compound was prepared using the procedure of Kocieński.[8] Concentrated hydrochloric acid (3.0 mL) was added dropwise to a solution of amide **S7** (4.30 g, 12.9 mmol, 1.0 equiv) in *i*-PrOH (60 mL) at 0 ºC and the resulting colourless solution stirred at room temperature for 18 h. Solid $NaHCO_3$ was added portionwise until no further gas evolution was observed. H_2O (50 mL) and CH_2Cl_2 (50 mL) was added, the layers separated and the aqueous layer extracted with CH_2Cl_2 (3

× 50 mL). The combined organic layers were dried (Na_2SO_4), filtered and concentrated *in vacuo* to give a colourless oil that was purified by column chromatography on SiO_2 eluting with petrol/EtOAc (1:5) followed by crystallisation from petrol to give the title compound (2.80 g, 12.9 mmol, 100%) as a white solid. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported for *ent*-**S8**.[8] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.35–7.30 (4H, m, ArH), 7.28–7.24 (1H, m, ArH), 6.82 (1H, dd, *J* = 15.2, 4.5, C3H), 6.10 (1H, br s, NH), 5.96 (1H, dd, *J* = 15.2, 1.7, C2H), 5.18 (1H, quint, J = 7.5, C1′H), 4.40 (1H, m, C4H), 2.53 (br s, OH), 1.51 (3H, d, *J* = 6.8, C1′ CH_3), 1.28 (3H, d, *J* = 6.6, C5H_3). ^{13}C NMR (75MHz, $CDCl_3$): δ = 165.4 (C1), 147.6 (C3H), 143.4 (C_{Ar}), 128.7 (2C, C_{Ar}H), 127.4 (C_{Ar}), 126.4 (2C, C_{Ar}H), 121.8 (C2H), 67.0 (C4H), 49.0 (C1′H), 22.7 (C1′ *C*H_3), 21.9 (C5H_3). IR (solid): ν = 3469 s, 3062 s, 2978 s, 2933 s, 1943 w, 1870 w, 1801 w, 1658 s, 1633 s, 1538 s cm^{-1}. LRMS (ES+ mode) *m/z* = 220 [MH$^+$, 100%]. mp (petrol) 76-78 °C; *ent*-**S8** Lit.[8] mp (petrol) 76–77 °C. $[\alpha]_D$ = +159.0 (c 0.5, $CHCl_3$); *ent*-**S8** Lit.[8] $[\alpha]_D$ = −159.2 (c 0.5, $CHCl_3$).

(2*E*,1′*R*,4*S*)-4-(Methanesulfonyl) pent-2-enoic acid -(1′-phenylethyl) amide (*ent*-1)

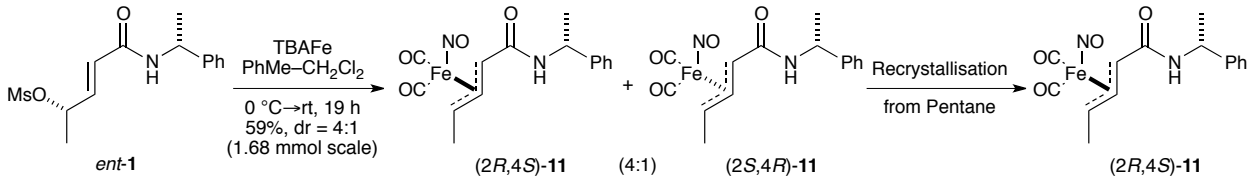


The title compound was prepared using a modification of the procedure of Kocieński.[8] Methanesulfonic acid chloride (0.53 mL, 6.8 mmol, 1.0 equiv) was added dropwise to a solution of alcohol **S8** (1.50 g, 6.80 mmol, 1.0 equiv), triethylamine (0.95 mL, 6.80 mmol, 1.0 equiv) and CH_2Cl_2 (98 mL) at 0 °C and the resulting colourless solution was stirred at 0 °C for 1 h. The reaction was quenched with $NaHCO_3$ (saturated aqueous, 100 mL), the layers separated and the aqueous layer extracted with CH_2Cl_2 (3 × 100 mL). The combined organic layers were washed with 1M HCl (150 mL, chilled using an ice-water bath), dried (Na_2SO_4), filtered and concentrated *in vacuo* to give the title compound (2.00 g, 6.80 mmol, 100%) as a white solid that was used with no further purification. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported for **1**.[8] ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.31–7.24 (4H, m, ArH), 7.23–7.18 (1H, m, ArH), 6.72 (1H, dd, *J* = 15.4, 5.6, C3H), 6.36 (1H, broad s, NH), 6.05 (1H, d, *J* = 15.4, C2H), 5.27 (1H, apparent quint, *J* = 6.4, C4H), 5.12 (1H, apparent quint, *J* = 7.3, C1′H), 2.93 (3H, s, OSO_2CH_3), 1.46 (3H, d, *J* = 7.3, C1′ CH_3), 1.45 (3H, d, *J* = 6.4, C5 CH_3). ^{13}C NMR (75MHz, $CDCl_3$): δ = 163.7 (C1), 143.0 (C_{Ar}), 140.3 (C3H), 128.8 (2C, C_{Ar}H), 127.6 (C_{Ar}), 126.3 (2C, C_{Ar}H), 125.2 (C2H), 77.3 (C4H), 49.3 (C1′H), 39.1 (OSO_2CH_3), 21.8 (C1′ *C*H_3), 21.4 (C5 *C*H_3). IR (solid): ν = 3332 s, br s, 3033 s, 2978 s, 2934 s, 1671 s, 1630 s, 1531 s, 1445 s, 1338 s cm^{-1}. LRMS (ES+ mode) *m/z* = 320 [MNa$^+$, 80%], 298 [MH$^+$, 95%], 265 (40%), 236 (20%), 224 (35%), 202 (100%). HRMS (ES+ mode) *m/z* = 298.1108 [MH$^+$, 30%]; calculated for $C_{14}H_{20}NO_4S$ [MH$^+$]: *m/z* = 298.1113.

Tetrabutylammonium tricarbonylnitrosylferrate (TBAFe)

The title compound was prepared on a 25.0 mmol scale in an 81% yield according to a literature procedure.[10] Spectroscopic data [IR] are in accordance with those reported. TBAFe can be stored for long periods (several months) in a freezer at *ca* −15 °C under an inert atomsphere in a Schlenk tube with no observable decomposition. mp (hexane) = 52–54 °C; Lit.[10] mp = 56–56.5 °C.

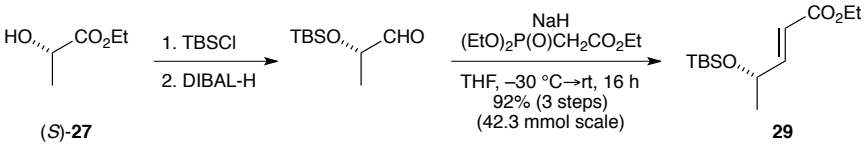
Neutral π-allyl iron complex [(2*R*,4*S*)-11]



ent-**1** (2*R*,4*S*)-**11** (4:1) (2*S*,4*R*)-**11** (2*R*,4*S*)-**11**

The title compound was prepared using a modification of the procedure of Kocieński.[8] Mesylate *ent*-**1** (500 mg, 1.68 mmol, 1.0 equiv) in CH_2Cl_2 (1.1 mL) was added in one portion to tetrabutylammonium tricarbonylnitrosylferrate (693 mg, 1.68 mmol, 1.0 equiv) in PhMe (8 mL) at 0 ºC. The resulting red/orange inhomogeneous solution was stirred at 0 ºC for 1 h, allowed to warm to room temperature and stirred at room temperature for 18 h. The reaction mixture was passed rapidly through a SiO_2 column under N_2 eluting with degassed CH_2Cl_2, the 2 characteristic red bands were collected and concentrated *in vacuo* to give a 4:1 mixture of the title compound (2*R*,4*S*)-**11** and its diastereoisomer (2*S*,4*R*)-**11** (340 mg, 0.99 mmol, 59%, dr = 4:1) as a red oily solid. Recrystallisation of the mixture from anhydrous pentane (*ca* 10 mL) gave (2*R*,4*S*)-**11** (189 mg) as a red solid and as a single diastereoisomer. The mother liquors were concentrated *in vacuo* to give enriched (2*S*,4*R*)-**11** (142 mg) as red oil. Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$) are in accordance with those reported for its enantiomer (2*S*,4*R*)-**2**.[8] The dr of the reaction was assigned by ^{1}H NMR spectroscopy using the signals corresponding to C2H [δ_H = 3.59 (d, *J* = 10.2) for the title compound and 3.57 (d, *J* = 10.2) for its diastereoisomer (2*S*,4*R*)-**11**]. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.42–7.28 (5H, m, ArH), 5.96 (1H, br d, *J* = 7.7, NH), 5.27 (1H, apparent quint, *J* = 6.9, C1′H), 5.04 (1H, dd, *J* = 12.0, 10.2, C3H), 4.22 (1H, overlapping dq, *J* = 12.3, 6.2, C4H), 3.59 (1H, d, *J* = 10.2, C2H), 2.01 (3H, d, *J* = 6.1, C5H$_3$), 1.59 (3H, d, *J* = 6.7, C1′ CH$_3$). ^{13}C NMR (75MHz, $CDCl_3$): δ = 217.9 (CO), 217.4 (CO), 170.1 (C1), 143.3 (C_{Ar}), 128.8 (2C, C_{Ar}H), 127.5 (C_{Ar}), 126.5 (2C, C_{Ar}H), 96.8 (C4H), 77.0 (C3H), 60.5 (C2H), 49.4 (C1′H), 21.8 (C1′ *C*H$_3$), 19.8 (C5H$_3$). IR (solid): ν = 3459 w, 3277 s, 3076 s, 3029 s, 2979 s, 2920 m, 2023 s, 1964 s, 1731 s**,** 1634 s, 1555 s cm^{-1}. LRMS (ES+ mode) *m/z* = 345 [MH$^+$, 5%], 330 (90%), 300 (95%), 289 (50%), 259 (5%), 242 (100%). HRMS (ES+ mode) *m/z* = 345.0531 [MH$^+$, 25%]; calculated for $C_{15}H_{17}FeN_2O_4$ [MH$^+$]: *m/z* = 345.0538. mp (Pentane) = decomposition at 130 ºC; (2*S*,4*R*)-**2** Lit.[8] mp (Pentane) = decomposition at 130 ºC. $[\alpha]_D$ = +134 (*c* 0.2, $CHCl_3$); (2*S*,4*R*)-**2** Lit.[8] $[\alpha]_D$ = −132 (*c* 0.2, $CHCl_3$).

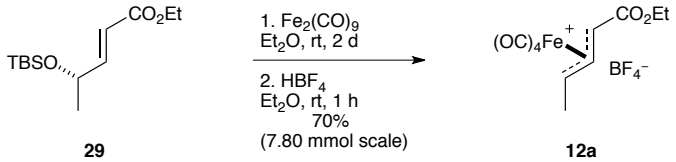
(2*E*,4*S*)-Ethyl-4-(*tert*-Butyldimethylsilyloxy)pent-2-enoate (29)



(*S*)-**27** **29**

The title compound was prepared over 3 steps from commercial ethyl (*S*)-lactate (**27**) according to conventional literature procedures.[9, 11] Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported.[11] $[\alpha]_D$ = +6.9 (c 2.8, $CHCl_3$); Lit.[11] $[\alpha]_D$ = +4.4 (c 1.2, $CHCl_3$).

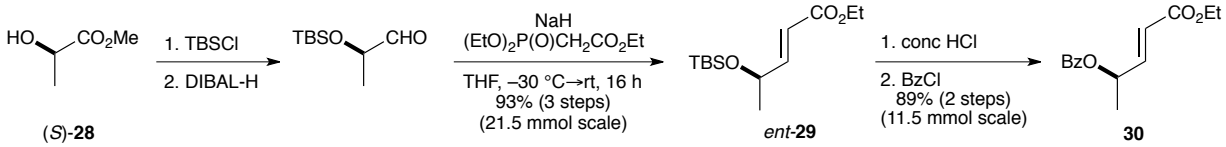
Cationic π-allyl iron complex (12a)



29 **12a**

The title compound was prepared on a 7.80 mmol scale (70% yield from compound **29**) using the general procedure of Kocieński.[12]

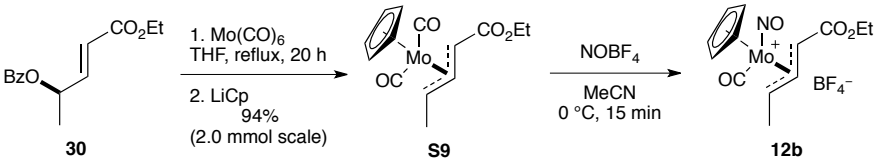
(2*E*,4*R*)-Ethyl-4-benzoyloxypent-2-enoate (30)



(*S*)-**28** *ent*-**29** **30**

The title compound was prepared over 5 steps from commercial methyl (*R*)-lactate (**28**) according to conventional literature procedures.[9, 11, 13] Spectroscopic data [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$), and IR] are in accordance with those reported for its enantiomer.[12] $[\alpha]_D$ = −75.5 (c 1.0, $CHCl_3$); *ent*-**30** Lit.[12] $[\alpha]_D$ = +61.7 (c 1.5, $CHCl_3$).

Cationic π-allyl molybdenum complex (12b)



30 **S9** **12b**

The title compound was prepared on a 2.0 mmol scale using the general procedure of Kocieński.[13] Spectroscopic data for compound **S9** [^{1}H NMR (500 MHz, $CDCl_3$), ^{13}C NMR (75 MHz, $CDCl_3$) are in accordance with those reported for its enantiomer.[12] $[\alpha]_D$ = +96.1 (c 0.1, $CHCl_3$); *ent*-**S9** Lit.[12] $[\alpha]_D$ = −97.8 (c 0.1, $CHCl_3$).

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