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Supporting Online Material for

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A Reversible, Unidirectional Molecular Rotary Motor Driven by Chemical Energy

Supporting Information

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General

Unless otherwise stated all reagents and anhydrous solvents were purchased from Aldrich. Solvents were purified before use employing standard techniques (1). Column chromatography was performed using silica gel (60 Angstrom, 230-400 Mesh, Merck, Germany) as the stationary phase. TLC was performed on precoated silica gel plates (0.25 mm thick, $60F_{254}$, Merck, Germany), and the product observed under UV light or with phosphomolybdic acid dip. All ^{1}H and ^{13}C NMR spectra were recorded on a Varian VXR-300 (300 MHz) or a Varian Mercury Plus (400 MHz) spectrometer. Chemical shifts were determined relative to the residual solvent peaks ($CDCl_3$, δ =7.26 ppm for ^{1}H NMR, δ = 77.0 ppm for ^{13}C). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constant (Hz) and integration. Melting points were determined on a Buchi B-545 melting point apparatus. Mass spectra were recorded on a AEI-MS-902 mass spectrometer.

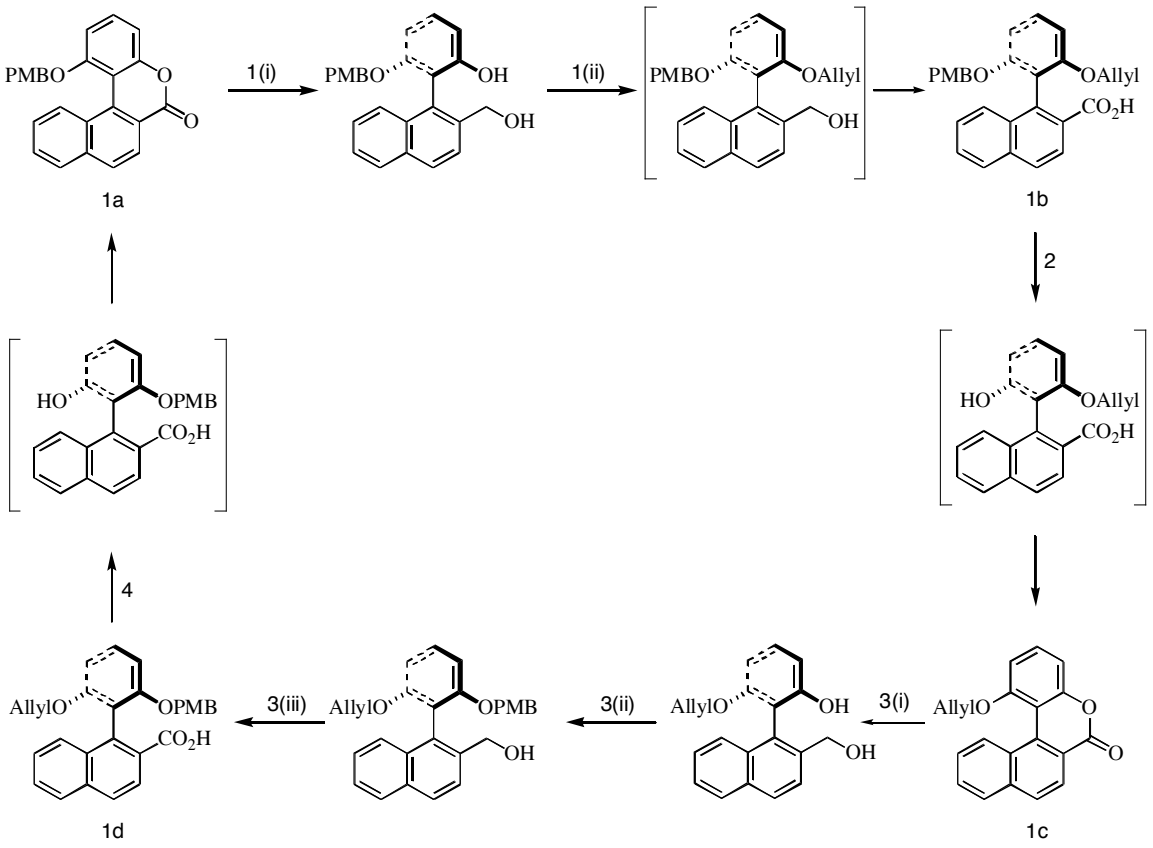
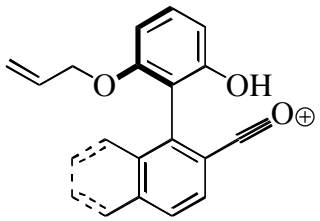


Figure S1. Chemical structures and detailed reaction scheme for unidirectional chemically driven rotory motor **1**. The intermediates shown in brackets were not isolated. Reagents and conditions (unless otherwise stated reactions were carried out at room temperature) were as follows: **step 1**, (i) (*S*)-2-methyl-CBS-oxazaborolidine solution in PhMe, BH_3.THF, THF, 0 °C, 25 min, 92%, ratio of molecules that have undergone rotation in the indicated direction: 96.8:3.2 (ii) allyl bromide, K_2CO_3, DMF, 20 h, then acetone, $CrO_3.H_2SO_4.H_2O$, 2 h, then $NaClO_2$, 2-methyl-2-butene, AcOH, H_2O, THF, 1 h, 76% overall. **step 2**, $Ce(OTf)_3$, 1,3-dimethoxybenzene, $MeNO_2$, 60 °C, 25 min, 76%. **step 3**, (i) (*S*)- 2-methyl-CBS-oxazaborolidine solution in PhMe, BH_3.THF, THF, 0 °C, 7 min, 56%, ratio of molecules that have undergone rotation in the indicated direction: 90.3:9.7 (ii) *p*-methoxybenzyl chloride, K_2CO_3, NaI, acetone, reflux, 30 h, 87%, (iii) MnO_2, CH_2Cl_2, 48 h, then $NaClO_2$, 2-methyl-2-butene, AcOH, H_2O, THF, 1 h, 82% overall. **step 4**, $Pd(PPh_3)_4$, HCO_2H, THF, reflux, 24 h, then *N, N*'-dicyclohexylcarbodiimide, 15 min, 99% overall. The yields refer to preparatively isolated compounds.

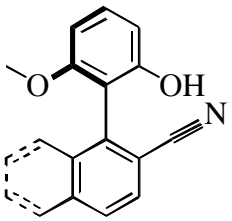
It was suggested during review that an acylium ion (Figure S2, **2**) could not be excluded as a possible intermediate in the lactonization parts of step 2 (treatment with $Ce(OTf)_3$) and step 4 (DCC coupling). Since the acylium is smaller than any of the substituents (on the 2 position preventing biaryl rotation) of isolated compounds which have been demonstrated to be configurationally stable, it was suggested that this could lead to racemization of the molecule.

To verify that this intermediate was still configurationally stable (no uncontrolled rotation of the phenyl relative to the naphthalene), we performed DFT calculations (2, 3, 4, 5, 6) on a sterically similar intermediate (Figure S2, **3**), where the acylium was replaced by a cyano substituent to facilitate the calculations.



2

Proposed acylium



3

Compound modelled

Figure S2: Proposed acylium intermediate 2 and sterically similar model compound 3.

For racemization to occur, one of the oxygens should pass over the CN group (a model for the acyl cation) and the other over the second naphthalene ring. The energy barrier for the oxygen passing over the CN group is probably quite low and the transition state could not be found. However the transition state for slippage over the naphthalene ring (Figure S3) could be calculated. It is almost independent of the substitution on the oxygen. The activation free energy is 151.3 kJ/mol (36.16 kcal/mol) for the shown TS. The other TS with OH and OMe the exchanged has the activation free energy 150.4 kJ/mol (35.94 kcal/mol).

This energy barrier suggests that the half-life for racemization at 60 °C is over 1100 years, confirming that even if an acylium cation is formed during the reaction, the enantiopurity will be preserved.

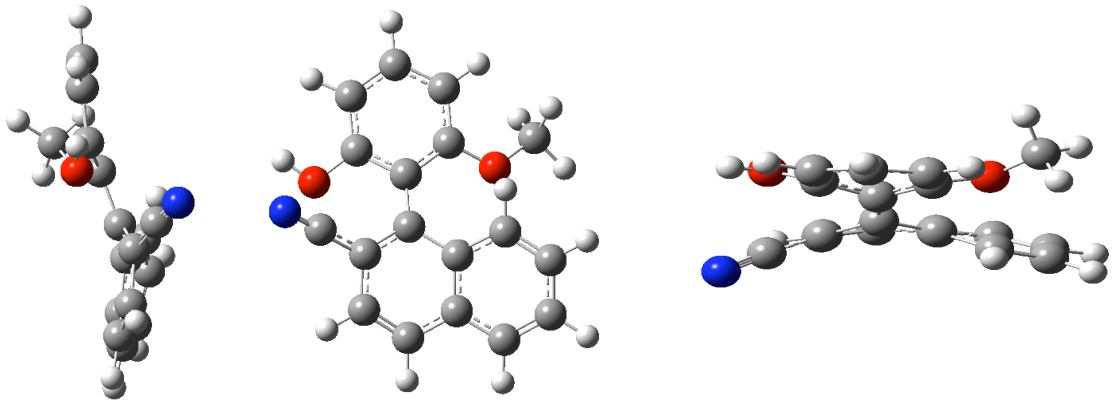
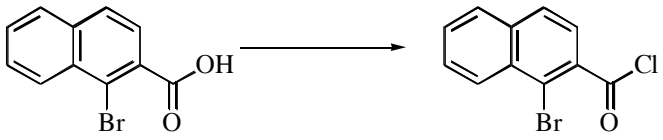


Figure S3: Models of the calculated transition state viewed from: side, front, and top. The carbon atoms are grey, hydrogens are light grey, oxygens in red and nitrogen in blue.

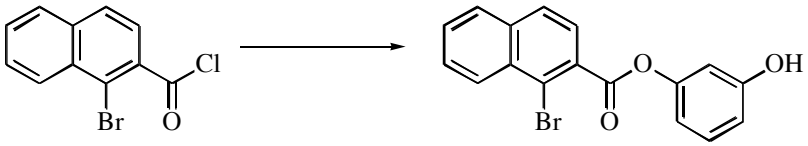
Preparation of compounds:

1-Bromonaphthalene-2-carbonyl chloride (E. Weber, I. Csöregh, B. Stensland, M. Czugler, *J. Am. Chem. Soc*. **1984**, *106*, 3297-3306).



Thionyl chloride (10 mL, 140 mmol) was added over 5 min to a stirred solution of the carboxylic acid (5.0 g, 20 mmol) in dry PhMe (10 mL) under an atmosphere of N_2. The reaction mixture was heated to reflux for 3 h, and cooled to room temperature before the solvents were removed under vacuum. Recrystallization from hexanes afforded pure 1-bromonaphthalene-2-carbonyl chloride as a white solid.

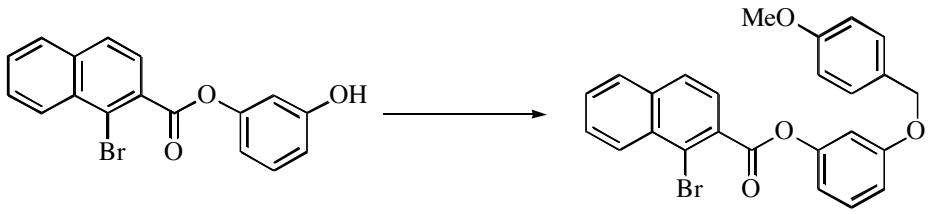
1-Bromonaphthalene-2-carboxylic acid 3-hydroxyphenyl ester.



A solution of 1-bromonaphthalene-2-carbonyl chloride (5.37 g, 19.9 mmol) in dry CH_2Cl_2 (200 mL) was added dropwise over 1 h to a stirred and cooled (0 °C) solution of resorcinol (7.88 g, 79.7 mmol) and Et_3N (35 mL, 250 mmol) in dry CH_2Cl_2 (100 mL) under an atmosphere of N_2. A few crystals of DMAP were added and stirring was continued for 18 h, before water (100 mL) was added. The reaction mixture was neutralized to pH = 7 with 1 M aq. HCl and extracted with CH_2Cl_2 and the organic material dried ($MgSO_4$), filtered and evaporated. Flash chromatography of the residue

over silica gel with CH_2Cl_2, gave 1-bromonaphthalene-2-carboxylic acid 3-hydroxyphenyl ester (3.20 g, 47%) as a yellow solid: mp = 139-140 °C, ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.50-5.90 (br s, 1H), 6.77 (dd, *J* = 2.8, 8.0 Hz, 1 H), 6.84 (t, *J* = 2.8 Hz, 1 H), 6.89 (dd, *J* = 2.8, 8.0 Hz, 1 H), 7.30 (t, *J* = 8.4 Hz, 1 H), 7.62-7.70 (m, 2H), 7.84-7.92 (m, 3H), 8.49 (d, *J* = 8.4 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 109.2 (d), 113.5 (d), 113.6 (d), 125.8 (d), 127.3 (s), 128.0 (d), 128.2 (d), 128.3 (d), 128.5 (d), 128.7 (d), 130.2 (d), 132.3 (s), 135.4 (s), 140.5 (s), 151.5 (s), 156.7 (s), 165.9 (s).

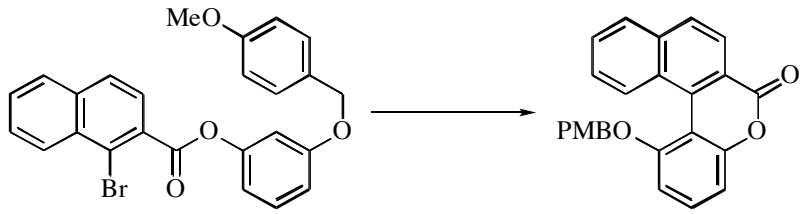
1-Bromonaphthalene-2-carboxylic acid 3-(4-methoxybenzyloxy)-phenyl ester.



p-Methoxybenzyl chloride (2.0 mL, 15 mmol) was added to a stirred solution of 1-bromonaphthalene-2-carboxylic acid 3-hydroxyphenyl ester (3.20 g, 9.32 mmol) and K_2CO_3 (3.60 g, 26.5 mmol) in dry acetone (50 mL) under an atmosphere of N_2. The reaction mixture was heated to reflux for 24 h, cooled, and the volatiles removed under vacuum. The residue was taken up in CH_2Cl_2, washed with 1 M aq. HCl and water, dried ($MgSO_4$), filtered and the solvent evaporated. Flash chromatography of the residue over silica gel using 50% heptane-CH_2Cl_2, gave 1-bromonaphthalene-2-carboxylic acid 3-(4-methoxybenzyloxy)-phenyl ester (2.35 g, 54%) as a white powder: mp = 113-114 °C, ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.83 (s, 3 H), 5.02 (s, 2 H), 6.91-6.98 (m, 5 H), 7.36-

7.39 (m, 3 H), 7.63-7.71 (m, 2 H), 7.85-7.92 (m, 3 H), 8.50 (d, *J* = 7.1 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 55.2 (t), 70.0 (q), 108.4 (d), 112.7 (d), 113.9 (d), 114.0 (d), 115.5 (s), 119.4 (d), 123.3 (s), 125.8 (d), 127.9 (d), 128.2 (d), 128.3 (d), 128.4 (d), 128.6 (d), 129.9 (d), 130.4 (s), 132.2 (s), 135.3 (s), 151.6 (s), 159.5 (s), 159.8 (s), 165.6 (s); exact mass *m*/*z* calcd for $C_{25}H_{19}BrO_4$ 464.04462, found 464.04568.

1-(4-Methoxybenzyloxy)-5-oxabenzo[*c*]phenanthren-6-one (1a).

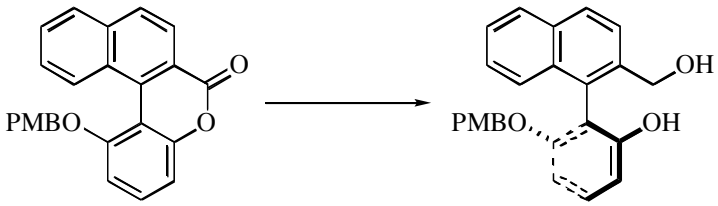


1a

$(Ph_3P)_2PdCl_2$ (960 mg, 1.10 mmol) was added to a stirred solution of 1-bromonaphthalene-2-carboxylic acid 3-(4-methoxybenzyloxy) phenyl ester (2.35 g, 5.07 mmol) and NaOAc (830 mg, 10.2 mmol) in dry dimethylformamide (25 mL) under an atmosphere of N_2. The reaction mixture was heated to 130 °C for 5 h, and cooled to room temperature. Evaporation of the volatiles under reduced pressure and repeated flash chromatography of the residue over silica gel using 99.5% CH_2Cl_2-*t*BuOMe provided **1a** (670 mg, 29%) as a brindled solid: mp = 207-209 °C, ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.74 (s, 3H), 4.94 (s, 2H), 6.68 (d, *J* = 8.8 Hz, 2 H), 6.88 (d, *J* = 8.4 Hz, 2 H), 7.01 (d, *J* = 8.1 Hz, 1 H), 7.13 (d, *J* = 8.4 Hz, 1 H), 7.37 (t, *J* = 8.4 Hz, 1 H), 7.46 (t, *J* = 8.4 Hz, 1 H), 7.57 (t, *J* = 8.1 Hz, 1 H), 7.88 (d, *J* = 8.1 Hz, 1 H), 7.94 (d, *J* = 8.4 Hz, 1 H), 8.17 (d,

J = 8.8 Hz, 1 H), 8.24 (d, *J* = 8.8 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 55.1 (t), 71.2 (q), 109.7 (d), 110.2 (d), 113.5 (d), 113.9 (s), 120.8 (s), 123.5 (d), 124.9 (d), 127.4 (d), 127.7 (s), 128.5 (d), 128.8 (d), 129.3 (d), 130.1 (s), 130.3 (d), 130.4 (d), 133.9 (s), 136.3 (s), 152.5 (s), 155.8 (s), 159.2 (s), 161.7 (s); exact mass *m*/*z* calcd for $C_{25}H_{18}O_4$ 382.12049, found 382.12096.

2-(2-Hydroxymethyl-naphthalen-1-yl)-3-(4-methoxy-benzyloxy)-phenol.

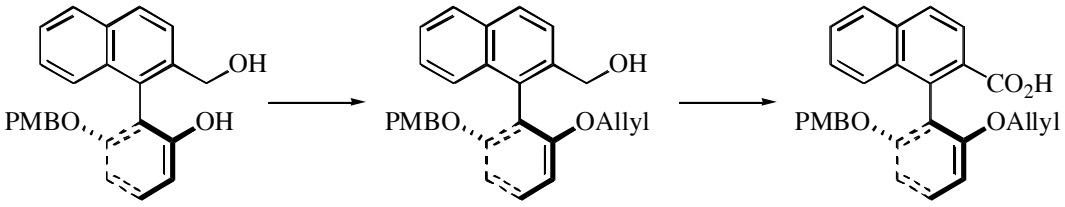


1a

BH_3.THF (1.0 M in THF, 4.20 mL, 4.2 mmol) was injected at a fast dropwise rate to a stirred and cooled (0 °C) solution of (*S*)- 2-methyl-CBS-oxazaborolidine (Aldrich, 1.0 M in PhMe; 5.80 mL, 5.80 mmol) and dry THF (30 mL) under N_2. Stirring was continued for 45 min and then **1a** (698.3 mg, 1.814 mmol) was tipped into the solution. After 25 additional min, water (5 mL) was carefully added (gas evolution), followed by aq. HCl (1 M, 10 mL). Stirring was continued for 20 min. The mixture was partitioned between $CHCl_3$ and brine, and the aqueous layer was extracted with $CHCl_3$ (twice). The combined organic extracts were dried ($MgSO_4$), filtered and the solvent evaporated. Flash chromatography of the residue over silica gel, using EtOAc-pentane mixtures from 10% to 50% EtOAc, gave the desired product (652.4 mg, 92%): ^{1}H NMR ($CDCl_3$, 400

MHz) δ 3.65 (s, 3 H), 4.43 (AB q, J = 11.6 Hz, ΔυAB = 22.1 Hz, 2 H), 4.79 (AB q, J = 12.0 Hz, ΔυAB = 32.7 Hz, 2 H), 4.76 (dt, J = 5.6, 1.3 Hz, 2 H), 6.61 (d, J = 8.4 Hz, 2 H), 6.68 (t, J = 8.0 Hz, 2 H), 6.74 (d, J = 8.4 Hz, 2 H), 7.27 (d, J = 8.4 Hz, 1 H), 7.34-7.49 (m, 3 H), 7.60 (d, J = 8.4 Hz, 1 H), 7.87 (apparent d, J = 8.4 Hz, 2 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 55.0 (q), 64.1 (t), 70.4 (t), 105.9 (d), 109.4 (d), 113.5 (2 x d), 114.2 (s), 125.7 (d), 125.9 (d), 126.5 (d), 127.0 (d), 128.1 (d) 128.4 (2 x d), 128.5 (s), 128.6 (s), 128.9 (d), 129.7 (d), 132.4 (s), 133.3 (s), 137.9 (s), 154.6 (s), 156.9 (s), 158.9 (s); exact mass m/z calcd for $C_{25}H_{22}O_4$ 386.15179, found 386.15229. HPLC: column, chiralpak AD- column (0.46 cm x 15 cm); eluant 85:15 heptane-isopropanol; flow rate 0.6 mL/min; detection at 225 nm, temperature 40 °C. Under these conditions the major enantiomer was detected at R_t 12.87 min, and the minor was detected at R_t 15.54 min. Material prepared as above had an enantiomeric ratio of 97:3.

1-[2-Allyloxy-6-(4-methoxy-benzyloxy)-phenyl]-naphthalene-2-carboxylic acid (1b).



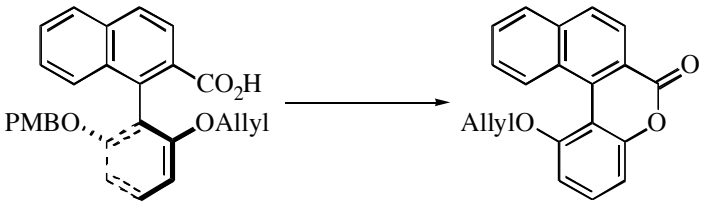
1b

Allyl bromide (0.20 mL, 248 mg, 2.30 mmol) was added to a stirred solution of the above alcohol (292 mg, 0.766 mmol) and K_2CO_3 (211 mg, 1.53 mmol) in dry DMF (10 mL) under an atmosphere of N_2. After 20 h acetone (5 mL), and then Jones' reagent (3.5 M, 1.0 mL, 3.5 mmol) were added and stirring was continued for a further 2 h. The

reaction mixture was partitioned between Et_2O and water, and the aqueous phase was extracted twice with Et_2O. The combined organic extracts were washed with water and brine, dried ($MgSO_4$), filtered and evaporated. The residue was dissolved in THF (15 mL). Water (5 mL), AcOH (5 mL), 2-methyl-2-butene (0.41 mL, 240 mg, 3.8 mmol), and $NaClO_2$ (205 mg, 2.30 mmol) were added (in that order) while stirring. After 1 h the mixture was partitioned between Et_2O and water. The aqueous phase was extracted twice with Et_2O, and the combined organic extracts were washed with water and brine, dried ($MgSO_4$), filtered and evaporated. Flash chromatography of the residue over silica gel, using first pentane then 25% EtOAc-pentane, and finally 50% EtOAc-pentane, gave **1b** (256 mg, 76%) as an oil: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.64 (s, 3 H), 4.33 (d, *J* = 3.2 Hz, 2 H), 4.81 (AB q, *J* = 12.4 Hz, Δυ*AB* = 19.6 Hz, 2 H), 4.85-4.94 (m, 2 H), 5.55-5.66 (m, 2 H), 6.61 (d, *J* = 8.4 Hz, 2 H), 6.66 (q, *J* = 8.0 Hz, 2 H), 6.79 (d, *J* = 8.4 Hz, 2 H), 7.30 (t, *J* = 7.6 Hz, 1 H), 7.36 (t, *J* = 7.6 Hz, 1 H), 7.52 (t, *J* = 7.6 Hz, 2 H), 7.87 (d, *J* = 8.4, 2 H), 8.09 (d, *J* = 8.4 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 50.0 (q), 69.0 (t), 70.0 (t), 105.9 (d), 106.3 (d), 113.4 (2 x d), 116.3 (t), 117.4 (s), 126.18 (d), 126.22 (d), 127.2 (s), 127.4 (d), 127.5 (d), 127.6 (d), 127.8 (d), 128.1 (2 x d), 129.0 (d), 129.2 (s), 132.6 (s), 133.1 (d), 135.3 (s), 136.6 (s), 156.7 (s), 156.8 (s), 158.7 (s), 172.8 (s); exact mass *m*/*z* calcd for $C_{28}H_{24}O_2$ 440.16235, found 440.16473. HPLC: column, chiralpak AD column (0.46 cm x 15 cm); eluant 75:25 heptane-isopropanol; flow rate 0.6 mL/min; detection at 225 nm, temperature 40 °C. Under these conditions the minor enantiomer was detected at R_t 12.71 min, and the major was detected at R_t 16.01 min. Material

prepared as above had an enantiomeric ratio of 4:96.

1-Allyloxy-5-oxa-benzo[*c*]phenanthren-6-one (1c).

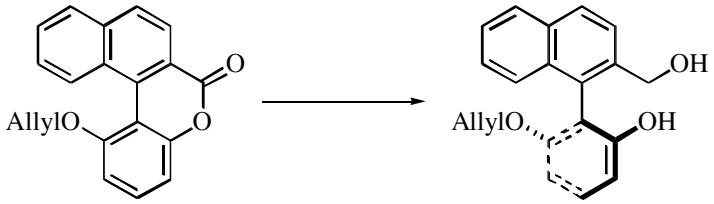


1b **1c**

$Ce(OTf)_3$ (90 mg, 0.15 mmol) was tipped into a stirred solution of **1b** (332 mg, 0.733 mmol) and 1,3-dimethoxybenzene (0.20 ml, 1.5 mmol) in $MeNO_2$ (10 mL) under a N_2 atmosphere. The reaction flask was placed in a preheated oil bath (60 °C) and stirring was continued for 25 min. The reaction mixture was cooled to room temperature and partitioned between water and $CHCl_3$. The aqueous phase was extracted with $CHCl_3$, and the combined organic extracts were dried ($MgSO_4$) and the solvents evaporated. The residue was subjected to flash chromatography over silica gel using 20% EtOAc-pentane and then 50% EtOAc-pentane. Flash chromatography of this material over silica gel using EtOAc-pentane mixtures from 0% to 20% EtOAc, gave **1c** (174 mg, 76%): ^1H NMR ($CDCl_3$, 400 MHz) δ 4.50 (br s, 2 H), 5.0 (m, 2 H), 5.68-5.82 (m, 1 H), 6.86 (d, J = 7.6 Hz, 1 H), 7.05 (d, J = 7.6 Hz, 1 H), 7.41 (AB q, J = 6.0 Hz, $\Delta\upsilon$AB = 14.9 Hz, 2 H), 7.58 (apparent t, J = 6.4 Hz, 1 H), 7.84 (d, J = 8.0 Hz, 1 H), 7.89 (d, J = 8.4 Hz, 1 H), 8.05 (d, J = 8.4 Hz, 1 H), 8.20 (apparent t, J = 8.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 69.5 (t), 108.3 (d), 108.9 (s), 109.8 (d), 117.7 (t), 120.8 (s), 123.5 (d), 124.7 (d),

127.4 (d), 128.2 (s), 128.6 (d), 129.3 (d), 130.28 (d), 130.34 (d), 131.9 (d), 133.8 (s), 136.3 (s), 152.4 (s), 155.3 (s), 161.6 (s); exact mass *m*/*z* calcd for $C_{20}H_{14}O_3$ 302.09428, found 302.09298.

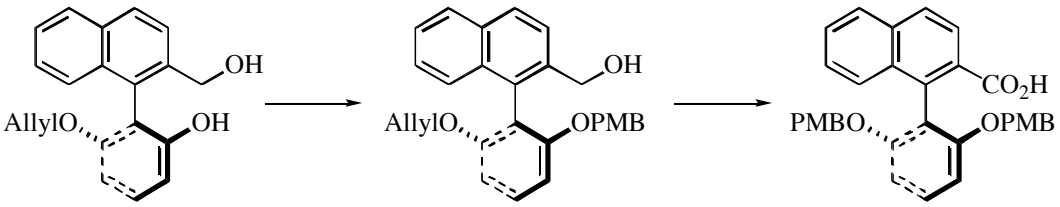
2-Allyloxy-2-(2-hydroxymethyl-naphthalen-1-yl)-phenol.



(*S*)- 2-methyl-CBS-oxazaborolidine (1.0 M in PhMe; 1.55 mL, 1.55 mmol) and then dry THF (5 mL) were added to a flame dried flask under N_2. The mixture was cooled to 0 °C and stirred. BH_3.THF (1.0 M in THF, 2.03 mL, 2.03 mmol) was injected at a fast dropwise rate, and stirring was continued for 25 min. **1c** (146 mg, 0.483 mmol) dissolved in THF (2 mL) was quickly injected into the above solution. After 7 min, water (5 mL) was carefully added (gas evolution), followed by aq. HCl (1 M, 5 mL) and stirring was continued for 1 h. The mixture was extracted three times with $CHCl_3$, and the combined organic extracts were dried ($MgSO_4$), filtered and evaporated. Flash chromatography of the residue over silica gel, using pentane, then 30% to 50% EtOAc-pentane mixtures, gave 2-allyloxy-2-(2-hydroxymethyl-naphthalen-1-yl)-phenol (83 mg, 56%). ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.46 (br s, 1 H), 4.35 (br t, *J* = 17.6 Hz, 2 H), 4.46 (br s, 2 H), 4.94 (m, 2 H), 5.22 (br s, 1 H), 5.59-5.70 (m, 1 H), 6.62 (d, *J* = 8.4 Hz, 1 H), 6.68 (d, 7.6 Hz, 1 H), 7.28 (t, *J* = 8.0 Hz, 1 H), 7.34 (m, 3 H), 7.63 (d, *J* = 17.2 Hz, 1 H),

7.87 (t, J = 9.6 Hz, 2 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 64.2 (br t), 69.1 (t), 105.1 (d), 109.2 (d), 113.6 (s), 117.1 (t), 125.6 (d), 126.1 (d), 126.6 (d), 127.0 (d), 128.1 (d), 128.2 (s), 129.1 (d), 129.8 (d), 133.3 (s), 132.6 (d), 133.4 (s), 138.1 (s), 154.4 (s), 156.8 (s); exact mass m/z calcd for $C_{20}H_{18}O_3$ 306.12558, found 306.12465. HPLC: column, chiralpak OD- column (0.46 cm x 15 cm); eluant 85:15 heptane-isopropanol; flow rate 0.6 mL/min; detection at 225 nm, temperature 40 °C. Under these conditions the major enantiomer was detected at R_t 8.20 min, and the minor was detected at R_t 10.51 min. Material prepared as above had an enantiomeric ratio of 90:10.

1-[2-Allyloxy-6-(4-methoxy-benzyloxy)-phenyl]-naphthalene-2-carboxylic acid (1d).



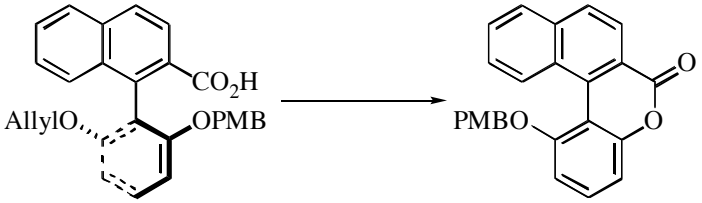
1d

p-Methoxybenzyl chloride (0.04 mL, 0.3 mmol) was added to a stirred solution of 2-allyloxy-2-(2-hydroxymethyl-naphthalen-1-yl)-phenol (13.9 mg, 0.0454 mmol), K_2CO_3 (20.3 mg, 0.147 mmol), and NaI (13.6 mg, 0.0454 mmol) in acetone (10 mL). The mixture was heated to reflux for 30 h and then cooled to room temperature. The mixture was partitioned between $CHCl_3$ and water, and the organic material dried ($MgSO_4$), filtered and the solvent evaporated. Flash chromatography of the residue over silica gel, using first pentane then EtOAc-pentane mixtures up to 100% EtOAc to gave

the expected alcohol (16.9 mg, 87%) as an oil. A separate batch of the alcohol (420 mg, 9.85 mmol) was dissolved in CH_2Cl_2 (10 mL). MnO_2 (427 mg, 4.93 mmol) was added and the reaction mixture was stirred for 24 h. Another portion of MnO_2 (420 mg, 4.9 mmol) was added and stirring was continued for a further 24 h. The reaction was filtered through Celite, rinsed with CH_2Cl_2 (2 x 10 mL) and concentrated. The residue was dissolved in THF (20 mL), and water (5 mL), AcOH (3 mL), 2-methyl-2-butene (1.0 mL, 9.3 mmol), and $NaClO_2$ (356 mg, 1.94 mmol) were added in that order while stirring. Stirring was continued for 1 h, and the mixture partitioned between $CHCl_3$ and water. The aqueous phase was extracted twice with $CHCl_3$, and the combined organic extracts were washed with water, dried ($MgSO_4$), filtered and the solvent evaporated. Flash chromatography of the residue over silica gel, using first pentane then 25% EtOAc-pentane, and finally 50% EtOAc-pentane, gave **1d** (355 mg, 82%; 71% for three steps) as an oil: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.63 (s, 3 H), 4.33 (d, J = 5.6 Hz, 2 H), 4.81 (AB q, J = 12.4 Hz, $\Delta\upsilon$AB = 19.6 Hz, 2 H), 4.85-4.94 (m, 2 H), 5.58-5.68 (m, 2 H), 6.61 (d, J = 8.4 Hz, 2 H), 6.66 (q, J = 8.0 Hz, 2 H), 6.79 (d, J = 8.4 Hz, 2 H), 7.30 (t, J = 7.6 Hz, 1 H), 7.36 (t, J = 7.6 Hz, 1 H), 7.52 (t, J = 7.6 Hz, 2 H), 7.87 (d, J = 8.4, 2 H), 8.09 (d, J = 8.4 Hz, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 50.0 (q), 69.0 (t), 70.0 (t), 105.9 (d), 106.3 (d), 113.4 (2 x d), 116.3 (t), 117.4 (s), 126.18 (d), 126.22 (d), 127.2 (s), 127.4 (d), 127.5 (d), 127.6 (d), 127.8 (d), 128.1 (2 x d), 129.0 (d), 129.2 (s), 132.6 (s), 133.1 (d), 135.3 (s), 136.6 (s), 156.7 (s), 156.8 (s), 158.7 (s), 172.8 (s); exact mass m/z calcd for $C_{28}H_{24}O_2$ 440.16235, found 440.16473. HPLC: Chiralpak AD column (0.46 cm x 15 cm); eluant

75:25 heptane-isopropanol; flow rate 0.6 mL/min; detection at 225 nm, temperature 40 °C. Under these conditions the major enantiomer was detected at R_t 12.93 min, and the minor was detected at R_t 16.35 min. Material prepared as above had an enantiomeric ratio of greater than 92:8.

1-(4-Methoxybenzyloxy)-5-oxabenzo[*c*]phenanther-6-one (1a).

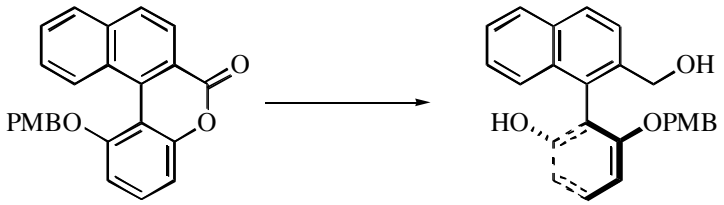


1d **1a**

$Pd(PPh_3)_4$ (15.6 mg, 0.0135 mmol) was tipped into a stirred solution of **1d** (59.5 mg, 0.135 mmol) and HCO_2H (0.05 ml, 1.3 mmol) in THF (5 mL) under a N_2 atmosphere. The reaction flask was placed in a preheated oil bath (80 °C) and stirring was continued for 24 h. The reaction mixture was cooled to room temperature and partitioned between water and $CHCl_3$. The aqueous phase was extracted with $CHCl_3$, and the combined organic extracts were dried ($MgSO_4$), filtered and the solvent evaporated. The residue was dissolved in THF (20 mL), and *N*, *N*'-dicyclohexylcarbodiimide (134 mg, 0.675 mmol) was added while stirring. Stirring was continued for 15 min, and the mixture partitioned between $CHCl_3$ and water. The aqueous phase was extracted with $CHCl_3$, and the combined organic extracts dried ($MgSO_4$), filtered and evaporated. Flash chromatography of the residue over silica gel

using 20% EtOAc-pentane, gave **1a** (51.8 mg, 99%).

2-(2-Hydroxymethyl-naphthalen-1-yl)-3-(4-methoxy-benzyloxy)-phenol.



1a

BH_3.THF (1.0 M in THF, 6.38 mL, 6.38 mmol) was injected at a fast dropwise rate to a stirred and cooled (0 °C) solution of (*R*)- 2-methyl-CBS-oxazaborolidine (1.0 M in PhMe; 4.86 mL, 4.86 mmol) and dry THF (30 mL) under N_2. Stirring was continued for 1 h and then **1a** (584 mg, 1.52 mmol) was tipped into the solution, followed by THF (5 mL) as a rinse. After 50 min, water (5 mL) was carefully added (gas evolution), followed by HCl (1 M, 10 mL), and stirring was continued for 10 min. The mixture was extracted three times with $CHCl_3$, and the combined organic extracts were dried ($MgSO_4$), filtered and evaporated. Flash chromatography of the residue over silica gel, using EtOAc-pentane mixtures from 0% to 50% EtOAc, gave 2-(2-hydroxymethyl-naphthalen-1-yl)-3-(4-methoxy-benzyloxy)-phenol. (566 mg, 96%). HPLC: column, Chiralpak AD- column (0.46 cm x 15 cm); eluant 85:15 heptane-isopropanol; flow rate 0.6 mL/min; detection at 225 nm, temperature 40 °C. Under these conditions the minor enantiomer was detected at R_t 12.95 min, and the major was detected at R_t 15.55 min. Material prepared as above had an enantiomeric ratio of 3:97.

References

1) Perrin., D. D.; Armarego, W. L. F.; Perrin, D. R. *Purification of Laboratory Chemicals, 2nd ed.*; (Pergamon: New York, 1980).

2) Martin Walko is gratefully acknowledged for performing these calculations.

3) Computational Methods: Density functional theory (DFT) calculations were carried out with the GAUSSIAN 03W (rev. C.02) program package[1]. All the calculations were performed on systems in th gass phase using the Becke's three-parameter hybrid functional[2] with the LYP correlation functional[3] (B3LYP). The 6-31G(d) basis set was used. The geometry optimization was followed by the frequency calculation for each stationary point to prove thet they are a minima with no imaginary frequency or transition states with one imaginary frequency.

4) M. J. Frisch, et al. Gaussian 03, Revision C.02, Gaussian, Inc., Wallingford CT, 2004.

5) A. D. Becke, J. Chem. Phys. 98 (1993) 5648.

6) C. Lee, W. Yang, R. G. Parr, Phys. Rev. B 37 (1988) 785.