A Highly Enantioselective Indium-Mediated Allylation Reaction of Aldehydes

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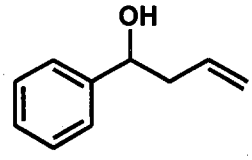
Supplementary Material

General Experimental

Optical rotations were determined using a JASCO DIP-1000 Digital Polarimeter. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker ACF 300 (^{1}H, 300 MHz and ^{13}C, 75.4 MHz) nuclear magnetic resonance spectrometer in $CDCl_3$.

General Procedure of Enantioselective Allylation of α-(2-Propenenyl)benzenemethanol



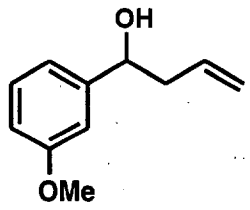
A typical procedure was as follows. To a 50 mL round bottom flask containing an egg-shaped stirring bar was added (-)-chinchonidine **2** (0.5 mmol) and Indium powder (0.5 mmol, 57 mg). The solids were azeotropically dried with 3 mL of dry THF twice and then treated with 3 mL of dry THF and allyl bromide (1.5 mmol, 126 mL). The mixture was stirred vigorously till it turned into a clear solution, then to which was added dropwise 1 mL of dry Hexane. The resulting clear solution was cooled to -78 °C, followed by introduction of benzaldehyde (0.25 mmol, 25 mL) dropwise. The reaction mixture was stirred at -78 °C for 2 hours, then allowed to warm up to room temperature and finally quenched with 10 mL of dilute HCl solution. The aqueous layer was extracted with hexane (10 mL x 3). The combined organic extracts were washed with brine, dried over anhydrous sodium sulphate, concentrated under vacuum and purified by flash silica gel column chromatography to afford 73% of the homoallylic alcohol as a colourless oil (27 mg, 0.183 mmol). $[a]^{25}_{D}$ +49.5 (*c* 1.05, benzene)[9]. The aqueous phase was neutralized with 1M sodium bicarbonate solution and extracted with ethyl acetate (10 mL x 5). The combined organic extracts were dried with sodium sulphate and concentrated under vacuum to give 97% of **2** as a white solid (143 mg, 0.243 mmol).

^{1}H NMR: δ 2.20 (br, 1H), 2.44-2.50 (m, 2H), 4.72 (t, J = 6.3, 1H), 5.12-5.20 (m, 2H), 5.74-5.88(m, 1H), 7.26-7.62 (m, 5H).

^{13}C NMR: δ 43.69, 73.26, 118.19, 125.76, 127.43, 128.32, 134.40, 143.84.

The enantioselectivity of the product was determined to be 75% by HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2. Major: t_R = 11.80 min for the (*R*) isomer; minor: t_R = 13.97 min for the (*S*) isomer).

3-Methoxy-α-(2-propenyl)benzenemethanol

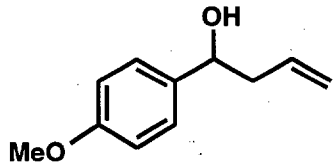


^{1}H NMR: δ 2.06 (br, 1H), 2.47-2.53 (m, 2H), 3.82 (d, *J* = 1.1 Hz, 3H), 4.72 (t, *J* = 6.0 Hz, 1H), 5.13-5.19 (m, 2H), 5.75-5.88 (m, 1H), 6.80-6.83 (m, 1H), 6.93 (d, *J* = 5.5 Hz, 2H), 7.23-7.29 (m, 1H).

^{13}C NMR: δ 43.66, 55.11, 73.11, 111.22, 112.90, 118.01, 118.29, 129.32, 134.31, 145.51, 159.64.

HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 51.68 min for the (*R*) isomer; t_2 = 63.02 min for the (*S*) isomer).

4-Methoxy-α-(2-propenyl)benzenemethanol

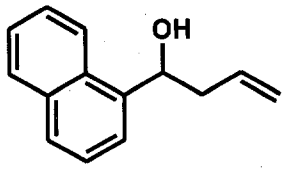


^{1}H NMR: δ 2.07 (br, 1H), 2.47-2.52 (m, 2H), 3.80 (s, 3H), 4.68 (t, *J* = 6.5 Hz), 5.10-5.18 (m, 2H), 5.72-5.86 (m, 1H), 6.87 (d, *J* = 8.7 Hz, 2H), 7.27 (d, *J* = 8.7 Hz, 2H).

^{13}C NMR: δ 43.62, 55.17, 72.91, 113.69, 118.04, 126.98, 134.53, 135.99, 158.94.

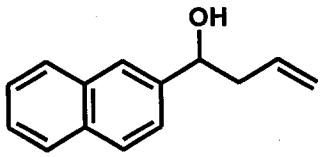
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 34.47 min for the (*R*) isomer; t_2 = 41.92 min for the (*S*) isomer).

α-(2-propenyl)-1-naphthalenemethanol



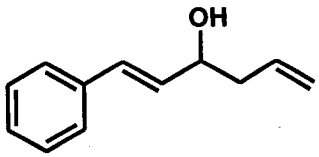
^{1}H NMR: δ 2.22 (br, 1H), 2.56-2.66 (m, 1H), 2.73-2.82 (m, 1H), 5.17-5.29 (m, 2H), 5.52-5.55 (m, 1H), 5.87-6.01 (m, 1H), 7.46-8.10 (m, 7H).
^{13}C NMR: δ 42.78, 69.91, 118.25, 122.80, 122.92, 125.38, 125.45, 125.97, 127.91, 128.89, 130.19, 133.72, 134.74, 139.36.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 17.28 min for the (*S*) isomer; t_2 = 23.33 min for the (*R*) isomer).

α-(2-propenyl)-2-naphthalenemethanol



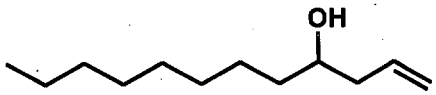
^{1}H NMR: δ 2.14 (br, 1H), 2.53-2.68 (m, 2H), 4.91 (t, *J* = 6.4 Hz, 1H), 5.13-5.22 (m, 2H), 5.77-5.91 (m, 1H), 7.45-7.50 (m, 3H), 7.81-7.85 (m, 4H).
^{13}C NMR: δ 43.62, 73.34, 118.38, 123.94, 124.44, 125.74, 126.04, 127.60, 127.89, 128.13, 132.90, 133.20, 134.30, 141.20.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 26.80 min for the (*S*) isomer; t_2 = 30.63 min for the (*R*) isomer).

(*E*)−1−Phenyl-1,5-hexadien-3-ol



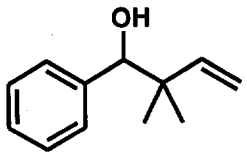
^{1}H NMR: δ 1.80 (br, 1H), 2.33-2.48 (m, 2H), 4.35-4.37 (m, 1H), 5.15-5.21 (m, 2H), 5.79-5.93 (m, 1H), 6.25 (dd, *J* = 15.9, 6.3 Hz, 1H), 6.60 (d, *J* = 15.9 Hz, 1H), 7.21-7.40 (m, 5H).
^{13}C NMR: δ 41.91, 71.62, 118.38, 126.40, 127.57, 128.48, 130.28, 131.48, 133.95, 136.58.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 17.03 min for the (*R*) isomer; t_2 = 28.37 min for the (*S*) isomer).

1-Dodecen-4-ol



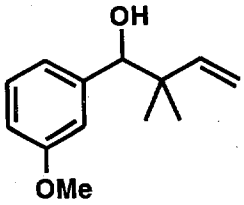
^{1}H NMR: δ 0.88 (t, *J* = 7.3 Hz, 3H), 1.28-1,61 (m, 14H), 2.09-2.18 (m, 1H), 2.26-2.34 (m, 1H), 3.60-3.66 (m, 1H), 5.10-5.15 (m, 2H), 5.76-5.90 (m, 1H).
^{13}C NMR: δ 13.96, 22.53, 25.54, 29.14, 29.45, 29.54, 31.76, 36.73, 41.82, 70.62, 117.87, 134.81.

α-(1,1-Dimethyl-2-Propenenyl)benzenemethanol



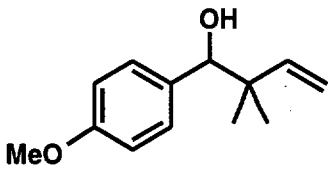
^{1}H NMR: δ 0.97 (s, 3H), 1.02 (s, 3H), 2.06 (d, *J* = 2.9 Hz, 1H), 4.42 (d, *J* = 2.9 Hz, 1H), 5.04-5.16 (m, 2H), 5.92 (dd, *J* = 10.8, 17.6 Hz, 1H), 7.24-7.32 (m, 5H).
^{13}C NMR: δ 21.03, 24.36, 42.16, 80.59, 113.70, 127.31, 127.39, 127.71, 140.80, 145.02.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 9.03 min for the (*S*) isomer; t_2 = 10.83 min for the (*R*) isomer).

3-Methoxy-α-(1,1-dimethyl-2-propenyl)benzenemethanol



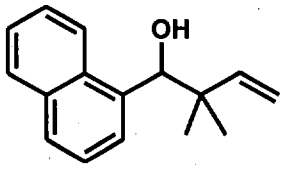
^{1}H NMR: δ 0.97 (s, 3H), 1.02 (s, 3H), 2.00 (d, *J* = 2.9 Hz, 2H), 3.80 (s, 3H), 4.40 (d, *J* = 2.9 Hz), 5.04-5.15 (m, 2H), 5.87-5.96 (m, 1H), 6.80-6.88 (m, 3H), 7.18-7.25 (m, 1H).
^{13}C NMR: δ 21.21, 24.39, 42.10, 55.09, 80.55, 112.66, 113.49, 113.60, 120.29, 128.29, 142.49, 145.03, 158.89.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 16.90 min for the (*S*) isomer; t_2 = 31.96 min for the (*R*) isomer).

4-Methoxy-α-(1,1-dimethyl-2-propenyl)benzenemethanol



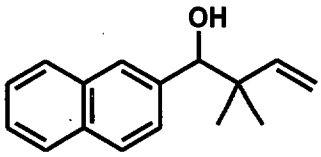
^{1}H NMR: δ 0.95 (s, 3H), 1.00 (s, 3H), 2.03, (br, 1H), 3.80 (d, *J* = 1.1 Hz, 3H), 4.37 (s, 1H), 5.02-5.14 (m, 2H), 5.86-5.96 (m, 1H), 6.84 (d, *J* = 8.7 Hz, 2H), 7.21 (d, *J* = 8.7 Hz, 2H).
^{13}C NMR: δ 21.02, 24.36, 42.21, 55.10, 80.24, 112.81, 113.49, 128.71, 132.97, 145.15, 158.84.
HPLC analysis of the derivative of its 3,5-dinitrobenzoate ester employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 29.29 min for the (*S*) isomer; t_2 = 54.95 min for the (*R*) isomer).

α-(1,1-Dimethyl-2-propenyl)-1-naphthalenemethanol



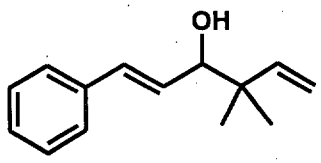
^{1}H NMR: δ 1.06 (s, 3H), 1.09 (s, 3H), 2.17 (d, *J* = 2.8 Hz, 1H), 5.09-5.15 (m, 2H), 5.44 (d, *J* = 2.5 Hz, 1H), 6.03 (dd, *J* = 11.2, 17.1 Hz, 1H), 7.44-8.16 (m, 7H).
^{13}C NMR: 21.71, 24.93, 43.21, 74.77, 113.47, 123.92, 124.82, 125.05, 125.44, 125.73, 127.90, 128.72, 131.84, 133.37, 137.37, 145.26.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 10.18 min for the (*S*) isomer; t_2 = 13.63 min for the (*R*) isomer).

α-(1,1-dimethyl-2-propenyl)-2-naphthalenemethanol



^{1}H NMR: 1.03 (s, 3H), 1.08 (s, 3H), 2.22 (d, *J* = 2.8 Hz, 1H), 4.60 (d, *J* = 2.2 Hz, 1H), 5.07-5.19 (m, 2H), 5.98 (dd, *J* = 10.8, 17.5 Hz, 1H), 7.44-7.52 (m, 3H), 7.75-7.95 (m, 4H).
^{13}C NMR: δ 21.23, 24.43, 42.44, 80.70, 113.79, 125.64, 125.82, 126.00, 126.54, 126.81, 127.49, 127.93, 132.72, 132.86, 138.41, 145.02.
HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 23.83 min for the (*S*) isomer; t_2 = 27.59 min for the (*R*) isomer).

(*E*)–4,4-Dimethyl-1-phenyl-1,5-hexadien-3-ol

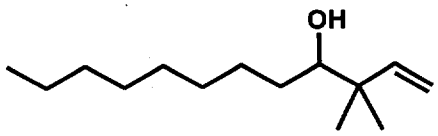


^{1}H NMR: δ 1.08 (s, 3H), 1.10 (s, 3H), 1.81 (br, 1H), 3.99 (d, *J* = 6.9 Hz, 1H), 5.09-5.17 (m, 2H), 5.94 (dd, *J* = 10.9, 17.4 Hz, 1H), 6.26 (dd, *J* = 6.9, 15.6 Hz, 1H), 6.60 (d, *J* = 15.6 Hz, 1H), 7.22-7.41 (m, 5H).

^{13}C NMR: δ 21.84, 23.72, 41.83, 79.23, 113.70, 126.40, 127.50, 128.45, 128.64, 132.03, 136.80, 144.81.

HPLC analysis employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 98:2; 1.0 mL/Min): t_1 = 14.79 min for the (*R*) isomer; t_2 = 22.28 min for the (*S*) isomer).

3,3-Dimethyl-1-dodecen-4-ol



^{1}H NMR: δ 0.87 (t, *J* = 6.4 Hz, 3H), 0.94-1.60 (m, 21H), 3.22 (t, *J* = 9.3 Hz, 1H), 5.00-5.09 (m, 2H), 5.81 (dd, *J* = 11.0, 17.4 Hz, 1H)..

^{13}C NMR: δ 13.94, 21.96, 22.53, 22.97, 26.95, 29.18, 29.49, 29.58, 31.33, 31.76, 41.54, 78.21, 113.03, 145.45.

HPLC analysis of the derivative of its 3,5-dinitrobenzoate ester employing a Daicel Chiracel OD column (*n*-Hexane: *i*-propanol 99:1; 0.3 mL/Min): t_1 = 30.64 min for the (*R*) isomer; t_2 = 33.27 min for the (*S*) isomer).

Optical Rotation Values

Table 1 Allylation of Selected Aldehydes Using Allyl Bromide and Indium

		1	**2**
entry	R	$[\alpha]_D^{25}$	$[\alpha]_D^{25}$
1	Ph	-40.5(c 0.91, C_6H_6)	+49.5(c 1.01 C_6H_6)
2	(*E*)-PHCH=CH	-2.1(c 0.75, C_6H_6)	+3.3(c 0.87, C_6H_6)
3	3-$MeOC_6H_4$	-20.7(c 1.48, C_6H_6)	+41.0(c 2.22, C_6H_6)
4	4-$MeOC_6H_4$	-17.0(c 1.90, C_6H_6)	+29.0(c 1.00, C_6H_6)
5	1-Naphthyl	-69.3(c 2.67, C_6H_6)	+72.6(c 2.36, C_6H_6)
6	2-Naphthyl	-19.5(c 1.61, C_6H_6)	+22.4(c 1.85, C_6H_6)
7	Octyl	+3.2(c 3.05, CCl_4)	-6.0(c 2.48, CCl_4)

Table 2 Isoprenylation of Aldehydes Using Allyl Bromide and Indium

		1	**2**
entry	R	$[\alpha]_D^{25}$	$[\alpha]_D^{25}$
1	Ph	-44.9(c 1.73, C_6H_6)	+48.9(c 1.28, C_6H_6)
2	(*E*)-PHCH=CH	+9.4(c 1.38, C_6H_6)	-7.4(c 2.38, C_6H_6)
3	3-$MeOC_6H_4$	-4.5(c 2.11, C_6H_6)	+1.22(c 0.94, C_6H_6)
4	4-$MeOC_6H_4$	-4.7(c 4.10, C_6H_6)	+30.1(c 1.02, C_6H_6)
5	1-Naphthyl	-28.0(c 1.77, C_6H_6)	+34.9(c 2.22, C_6H_6)
6	2-Naphthyl	-8.5(c 3.00, C_6H_6)	+18.2(c 0.64, C_6H_6)
7	Octyl	+5.7(c 2.44, C_6H_6)	-6.7(c 2.69, C_6H_6)