Enantiopure fluorous 1,2-diaryl-1,2-diaminoethanes: synthesis and applications in asymmetric organometallic catalysis

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Dedicated to Professor Guy Quéguiner on his 70th birthday

Abstract
The synthesis of a new enantiopure fluorous 1,2-diaryl-1,2-diaminoethane bearing two fluorous ponytails is described. The palladium-catalyzed reaction of 1,3-diphenyl-2-propenyl acetate with dimethyl malonate in the presence of this ligand and its analogue bearing four fluorous ponytails gave the alkylated product with *ee* up to 44%. Their application as ligands in hydrogen transfer reactions associated with rhodium, iridium, or ruthenium in a two-phase system gave *ee* up to 39%, the catalyst being recycled without loss of enantioselectivity in the case of the ruthenium complex.

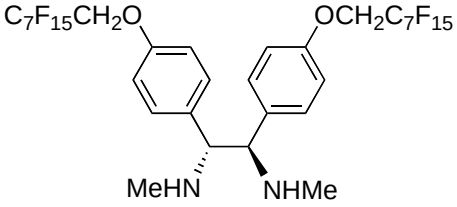
Keywords: Enantiopure fluorous diamines, asymmetric catalysis, allylic alkylation, hydrogen-transfer reaction

Introduction

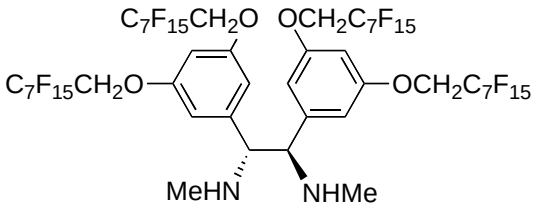
Enantiopure 1,2-diamines, particularly those possessing C_2-symmetry, and their derivatives, have found wide applications as chiral auxiliaries and ligands in asymmetric synthesis.[1,2] Among the large variety of 1,2-diamine structures that have been synthesized and used as ligands in asymmetric catalysis, enantiomerically pure 1,2-diaryl-1,2-ethanediamines and their derivatives seem to be among the most studied, giving high enantioselectivities in a large number of metal-catalyzed enantioselective reactions. Intensive research has been devoted to the synthesis of such easily recoverable enantiopure 1,2-diaryl-1,2-ethanediamines. The hydrosolubilization of such ligands has been performed by attachment on the aromatic rings of hydrophilic substituents, such as phenolic hydroxy groups,[3] polyethylene glycol chains,[3,4] sulfonic acid[5] or phosphonic acid[6] functions. Heterogenization of these enantiopure diamines has also been performed by

attachment to soluble or insoluble organic polymers,[4,7] or immobilization onto inorganic supports.[8] Fluorous techniques have recently been introduced in asymmetric synthesis and are rapidly emerging as convenient alternatives for the recovery of chiral catalysts.[9]

Our group has recently described the synthesis of some enantiopure fluorous 1,2-diamines and diimines, and described their use as ligands in metal-catalyzed asymmetric transfer hydrogenation of ketones using the FBS (Fluorous Biphasic System) concept.[10] We also described the preparation of a fluorous 1,2-diphenyl-1,2-ethanediamine bearing four fluorous ponytails.[11] Herein we report the synthesis of a new fluorous 1,2-diphenyl-1,2-ethanediamine bearing only two fluorous ponytails, and the application of these two fluorous ligands in asymmetric transfer hydrogenation and asymmetric allylic alkylation.



(R,R)-**1a**



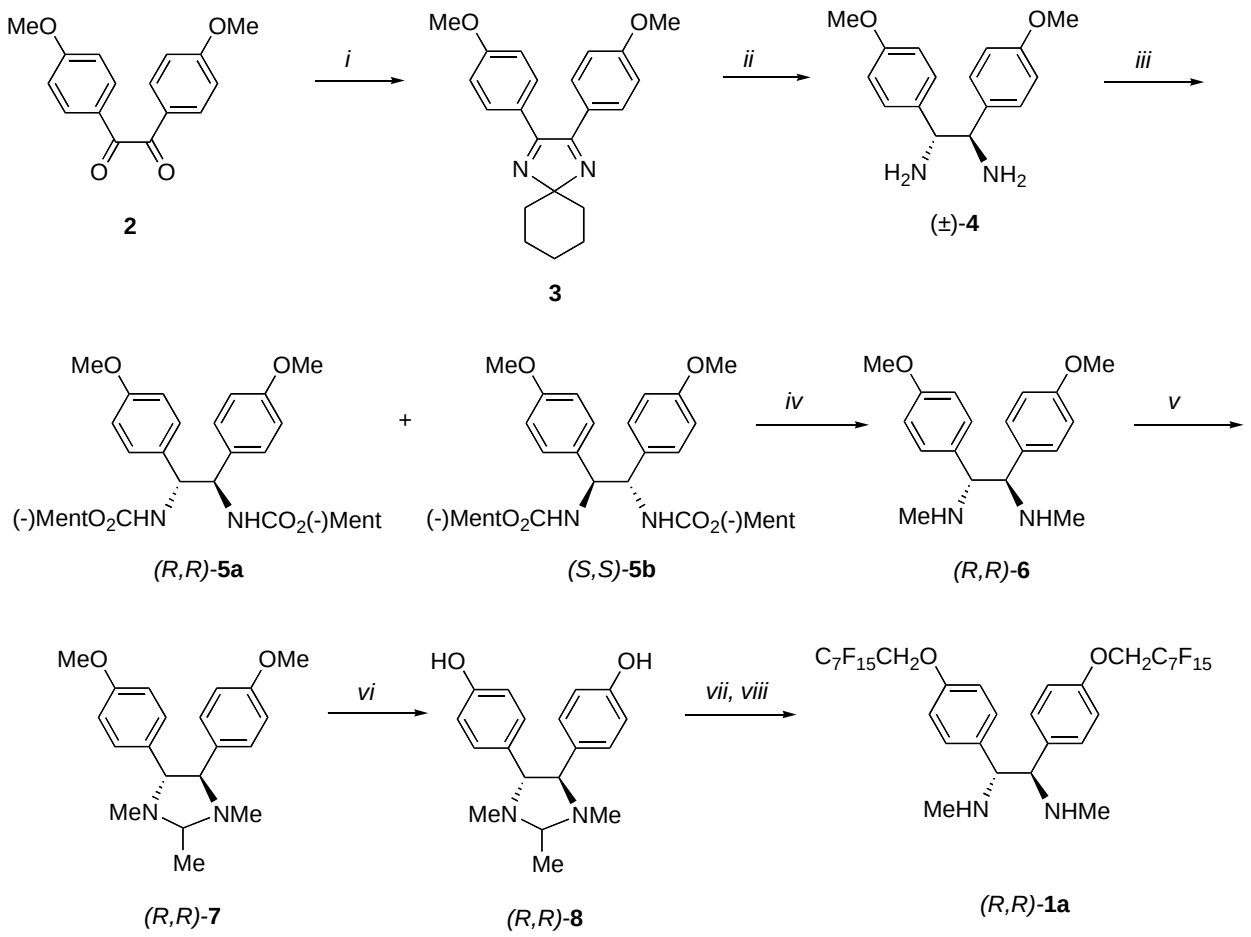
(R,R)-**1b**

Figure 1

Results and Discussion

The synthesis of the fluorous enantiopure diamine **1b** has already been described by our group.[11]

The preparation of the enantiopure fluorous 1,2-diphenyl-1,2-diamine **1a** is shown in Scheme 1. Racemic (1*R**,2*R**)-1,2-bis-(4-methoxyphenyl)ethane-1,2-diamine (**4**) was prepared according to Corey's procedure.[12] Refluxing commercial 4,4'-dimethoxybenzil (**2**) in acetic acid with 1 equivalent of cyclohexanone and ammonium acetate afforded the diimine **3** in 91% yield. Reduction of this diimine **3** with lithium (4 equiv.) in a mixture of NH_3/THF (5:4) at –78 °C, followed by acidic hydrolysis using aqueous HCl, gave stereoselectively the racemic primary diamine **4** in 89% yield. Reaction of this racemic diamine **4** with (–)-menthyl chloroformate in the presence of pyridine, according to Denmark's procedure[13] gave the corresponding bis-(menthyl carbamate) diastereoisomers (1*R*,2*R*)-**5a** and (1*S*,2*S*)-**5b**. Separation of these two diastereoisomers was performed by column chromatography, affording pure **5a** and **5b** in 32 and 19% yields, respectively. The absolute configuration of the diamine moiety of the two diastereoisomers **5a** and **5b** was deduced by comparison of their ^{1}H NMR spectra and their relative polarity on TLC with those described in the literature.[13]



Scheme 1. Reagents and conditions: (*i*) cyclohexanone, NH_4OAc, AcOH; (*ii*) Li, THF/NH_3, -78 °C, then H_3O^+; (*iii*) (–)-MenthOCOCl, C_5H_5N, CH_2Cl_2; (*iv*) separation by column chromatography, then $LiAlH_4$ for (*R,R*)-**5b**, DME; (*v*) MeCHO, molecular sieves; (*vi*) BBr_3, CH_2Cl_2, 0 °C; (*vii*) $C_7F_{15}CH_2OSO_2C_4F_9$, $CsCO_3$, DMF, 80 °C; (*viii*) H_3O^+.

(1*R*,2*R*)-1,2-Bis-(4-methoxyphenyl)-*N*,*N*′-dimethylethane-1,2-diamine (**6**) was obtained in 66% chemical yield by reduction of the diastereoisomer (1*R*,2*R*)-**5a** with $LiAlH_4$ in anhydrous DME. This enantiopure diamine **6** was transformed into (4*R*,5*R*)-4,5-bis-(4-methoxyphenyl)-1,2,3-trimethylimidazolidine (**7**) in 90% yield by condensation with acetaldehyde in the presence of 4 Å molecular sieve as H_2O scavenger. Cleavage of the two methoxy groups of compound **7** by BBr_3 in dichloromethane afforded the corresponding dihydroxy amine **8** in 90% yield. This protected diamine **8** was reacted with 1*H*,1*H*-perfluorooctan-1-yl nonafluorobutanesulfonate in the presence of $CsCO_3$ in DMF allowing the introduction of two fluorous ponytails into this compound. Acidic treatment of the latter fluorous compound gave the fluorous (1*R*,2*R*)-1,2-diaryl-*N*,*N*′-dimethylethanediamine **1a** in a 38% yield overall.

In order to use these two substrates as ligands in asymmetric organometallic catalysis we measured their equilibrium distribution between FC-72, a fluorous solvent, and various non-

fluorous solvents (Table 1). As expected, the fluorous diamine **1a**, bearing two fluorous ponytails and with a fluorous content of 55%, is preferentially dissolved in the non-fluorous solvent, whatever the latter. Conversely, the fluorous diamine **1b**, bearing four fluorous ponytails and a fluorous content of 62.2%, exhibited very good fluorophilicity, with partition coefficients of 10.36 and 2.23, respectively in the presence of acetonitrile or ethanol, allowing its probable use as a ligand in a two-phase system of fluorous solvent–non-fluorous solvent.

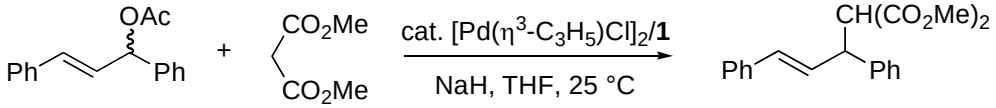
Table 1. Partition coefficients *P* ($P = c_{\text{fluorous phase}}/c_{\text{organic solvent}}$) for fluorous diamines **1a**-**b** between FC-72 and standard organic solvents[a]

Diamine	% F	Toluene/FC-72		CH_3CN/FC-72		C_2H_5OH/FC-72	
		% *v*/*v*	*P*	% *v*/*v*	*P*	% *v*/*v*	*P*
1a	55.0	82.8/17.2	0.21	74.0/26.0	0.35	90.0/10.0	0.11
1b	62.2	16.0/84.0	5.25	8.8/91.2	10.36	31.0/69.0	2.23

[a] In a 50:50 (*v*:*v*) mixture of FC-72/organic solvent at 25 °C. Determined gravimetrically (see Experimental Section).

The fluorous diamines **1a**,**b** were tested as ligands in the allylic alkylation of 1,3-diphenyl-2-propenyl acetate with dimethyl malonate catalyzed by Pd(0) (Tsuji–Trost alkylation). This reaction was first done at room temperature in THF, using the fluorous ligand **1** (6 mol.%) and $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ (2.5 mol.%) in the presence of NaH as the base. The alkylated product was obtained in 28% and 32%, after two days, using ligands **1a** and **1b**, respectively, with 28 and 32% *ee* (Table 2, entries 1 and 2). However, performing this reaction at 50 °C afforded quantitatively the coupling product with 29 and 35% *ee*, respectively (Table 2, entries 2 and 4). All attempts to perform this alkylation reaction in a two-phase system of fluorous solvent/non-fluorous solvent failed.

Table 2. Enantioselective allylic alkylation of 1,3-diphenyl-2-propenyl acetate using fluorous diamines **1**[a]



Entry	Ligand	Temp (°C)	Time (h)	Conv. (%)	*ee* (%) Config.
1	**1a**	25	48	28	32 (*R*)
2	**1a**	50	24	99	29 (*R*)
3	**1b**	25	48	32	44 (*R*)
4	**1b**	50	24	98	35 (*R*)

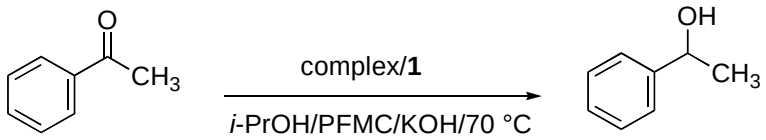
[a] Diamine **1** = 6 mol. %; $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ = 2.5 mol. %; conversion and *ee* determined by GC and HPLC, respectively (see Experimental Section for details).

We next turned our attention to the catalytic hydrogen-transfer reduction. These fluorous diamines **1a-b**, in association with $[Rh(C_6H_{10})Cl]_2$ were successfully tested in the asymmetric reduction of acetophenone with isopropanol as the hydride source in the presence of PFMCH as the fluorous solvent at 70 °C (Table 3, entry 1 and 2). The reduction was almost quantitative after one hour using the two ligands, with *ee* up to 35% in the presence of ligand **1b**. Since only ligand **1b** could allow the recycling of the catalyst, all the following experiments were performed in the presence of **1b**. It is to be noted that the recycling of the catalyst $[Rh(C_6H_{10})Cl]_2$/ligand **1b** gave also a quantitative conversion after one hour, but with a lower enantioselectivity (22% *ee*) (Table 3, entry 2*).

The catalyst obtained by mixing $[Ir(COD)Cl]_2$ and ligand **1b** afforded quantitatively the alcohol after one hour with *ee* up to 28. The recycling of this catalyst was also possible with the same activity; unfortunately the enantioselectivity dropped to 7% (Table 3, entries 3 and 3*).

Finally the complex [Ru(*p*-cymene))$Cl]_2$ associated with diamine **1b** gave quantitatively the reduced product after three hours, with 33% *ee*; this catalyst allowed efficient recycling, 39% *ee* being obtained in this case (Table 3, entries 4 and 4*).

Table 3. Catalytic hydrogen transfer reduction of acetophenone using fluorous chiral diamines **1**[a]



Entry	Ligand	Complex	Time (h)	Conv. (%)	*ee* (%) Config.
1	**1a**	$[Rh(C_6H_{10})Cl]_2$	1	99	26 (*S*)
2	**1b**	$[Rh(C_6H_{10})Cl]_2$	1	98	35 (*S*)
2*[,b]	**1b**	$[Rh(C_6H_{10})Cl]_2$	1	98	22 (*S*)
3	**1b**	$[Ir(COD)Cl]_2$	1	99	28 (*S*)
3*[,b]	**1b**	$[Ir(COD)Cl]_2$	1	98	7 (*S*)
4	**1b**	[Ru(*p*-cymene)$Cl]_2$	3	98	33 (*S*)
4*[,b]	**1b**	[Ru(*p*-cymene)$Cl]_2$	4	97	39 (*S*)

[a] Diamine = 10 mol.%; complex = 5 mol.%; PFMCH/*i*-PrOH = 1:1 *v/v*; conversion and *ee* determined by GC (see Experimental Section for details). [b] With recycling of the catalyst.

Conclusions

We describe here a quite general approach for the synthesis of enantiopure fluorous 1,2-diaryl-1,2-diaminoethanes, bearing some fluorous ponytails. These fluorous ligands have been used as ligands in the palladium-catalyzed alkylation of 1,3-diphenyl-2-propenyl acetate with dimethyl malonate in tetrahydrofuran as the solvent, with *ee* up to 44% being obtained. These fluorous

diamines have also been used in the reduction of acetophenone by hydrogen transfer associated with rhodium, iridium, or ruthenium complexes, with *ee* in the range of 26–35% . The use of a biphasic system *i*-PrOH–fluorous solvent allows recycling of the catalyst, with no decrease in enantioselectivity in the case of the ruthenium catalyst.

Experimental Section

General Procedures. Solvents were purified by standard methods and dried if necessary, except for perfluoromethylcyclohexane (PFMC), which was used as received. FC-72 (mixture of fluorous hexanes) and 4,4'-dimethoxybenzil (**2**) were commercially available, 1*H*,1*H*-perfluorooctan-1-yl nonafluorobutanesulfonate was prepared according to the literature.[14] Column chromatography was performed on silica gel 60 (230–240 mesh, Merck). Melting points (uncorrected) were determined with a Büchi SMP-20 capillary melting point apparatus. Optical rotations were recorded using a Perkin–Elmer 241 polarimeter. The NMR spectra (1H- 300 MHz, ^{13}C- 75.4 MHz, ^{19}F- 282 MHz) were recorded on a Bruker AC 300 MHz instrument with Me_4Si, $CDCl_3$, and $CFCl_3$, respectively, as the internal standards. Reactions involving organometallic catalysis were carried out in Schlenk tubes under an inert atmosphere. Absolute configurations of the enantiomers were determined by comparison of GC- and HPLC retention times with those of authentic samples.

2,3-Bis-(4-methoxyphenyl)-1,4-diazaspiro[4.5]deca-1,3-diene (3). A mixture of 4,4'-dimethoxybenzil **2** (4 g, 14.8 mmol), cyclohexanone (1.5 g, 15.2 mmol), and ammonium acetate (7.87 g, 102.1 mmol) in glacial acetic acid (40 mL) was heated at reflux for 1.5 h, and then poured into water (50 mL). The mixture was extracted with CH_2Cl_2 (3x30 mL). The combined organic phases were washed with a saturated aqueous solution of $NaHCO_3$ (2x30 mL), and dried over Na_2SO_4. Evaporation of the solvent under reduced pressure gave a residue that was purified by column chromatography on silica gel [petroleum–EtOAc, 3:2 eluent] to afford the diimine **3** (4.69 g, 91%) as a yellow solid; mp 96–98 °C (lit.[15] mp 109–110 °C); R_f 0.62 (petroleum–EtOAc, 3:2); ^{1}H NMR ($CDCl_3$) δ 1.71–1.80 (6 H, m, CH_2), 1.95 (4 H, m, CH_2), 3.83 (6 H, s, OCH_3), 6.86 (4 H, d, J = 8.7 Hz, H_{arom}), 7.47 (4 H, d, J = 8.7 Hz, H_{arom}).

(±)-(*1R*,2R)-1,2-Bis-(4-methoxyphenyl)ethane-1,2-diamine (4).** To a solution of **3** (4.69 g, 13.5 mmol) in a NH_3/THF mixture (36 mL, 5:4) at –78 °C was slowly introduced Li (0.41 g, 59.2 mmol). The solution was stirred at –78 °C for 2 h, during which additional amounts of EtOH were slowly added (1. 6 mL, 27 mmol). The mixture was stirred for an additional 30 min at –78 °C, and then treated with NH_4Cl (3.76 g, 70 mmol). The mixture was allowed to warm to 0 °C, water (15 mL) was carefully added, and the mixture was extracted with Et_2O (3x15 mL). The combined organic phases were washed with brine (20 mL), dried (Na_2SO_4), and concentrated under reduced pressure. The residue was treated with Et_2O (20 mL), and then with 2*M* aq. HCl (13 mL) at 0 °C. After stirring at RT for 1 h, the obtained precipitate was filtered, the

solid was washed with Et_2O (3x20 mL), and then poured into H_2O (20 mL). A solution of aqueous 2M NaOH (15 mL) was added, the mixture extracted with CH_2Cl_2 (3x30 mL), and the combined organic phase dried (Na_2SO_4). Evaporation of the solvent under reduced pressure gave the racemic diamine **4** (3.26 g, 89%) as a yellow oil. ^{1}H NMR ($CDCl_3$) δ 1.59 (4 H, br s, NH_2), 3.80 (6 H, s, OCH_3), 4.03 (2 H, s, CHN), 6.82 (4 H, d, *J* = 8.6 Hz, H_{arom}), 7.18 (4 H, d, *J* = 8.6 Hz, H_{arom}) in agreement with the literature.[15]

Resolution of diamine (4) *via* bis-[(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl][(1*R*,2*R*)-1,2-bis-(4-methoxyphenyl)ethane-1,2-diyl]bis-carbamate (5). To a solution of racemic diamine **4** (1.0 g, 3.67 mmol) and pyridine (1.0 mL, 12.85 mmol) in anhydrous CH_2Cl_2 (15 mL) at 0 °C was added (–)-menthyl chloroformate (2.0 mL, 9.55 mmol). After being stirred at RT for 2 h, the solvent was co-evaporated with toluene. The residue was purified by column chromatography on silica [CH_2Cl_2–EtOAc (20:1) as eluent] to afford the less polar (**1*R*,2*R***)-**5a** (740 mg, 32%) and the more polar (**1*S*,2*S***)-**5b** (435 mg, 19%).

Bis-[(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl][(1*R*,2*R*)-1,2-bis-(4-methoxyphenyl)ethane-1,2-diyl]-bis-carbamate [(1*R*,2*R*)-5a]. Colorless solid; mp 236–238 °C; R_f = 0.68 (CH_2Cl_2–EtOAc, 30:1); $[\alpha]_D^{20}$ –65 (*c* 0.5, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 0.71 (6 H, d, *J* = 6.8 Hz, CH_3), 0.84–2.10 (30 H, m, $H_{menthyl}$), 3.73 (6 H, s, OCH_3), 4.54 (2 H, dt, *J* = 10.9, 4.4 Hz, CHO), 4.89 (2 H, m, CHN), 5.54 (2 H, br s, NH), 6.74 (4 H, d, *J* = 8.6 Hz, H_{arom}), 6.99 (4 H, d, *J* = 8.6 Hz, H_{arom}) in agreement with the literature.[13]

Bis-[(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl][(1*S*,2*S*)-1,2-bis-(4-methoxyphenyl)ethane-1,2-diyl]bis-carbamate [(1*S*,2*S*)-5b]. Colorless oil; R_f 0.64 (CH_2Cl_2–EtOAc, 20:1); ^{1}H NMR ($CDCl_3$) δ 0.85–1.92 (36 H, m, $H_{menthyl}$), 3.75 (6 H, s, OCH_3), 4.52 (2 H, m, CHO), 4.84 (2 H, m, CHN), 5.57 (2 H, br s, NH), 6.73 (4 H, d, *J* = 8.1 Hz, H_{arom}), 6.93 (4 H, d, *J* = 8.1 Hz, H_{arom}) in agreement with the literature.[13]

(1*R*,2*R*)-1,2-Bis-(4-methoxyphenyl)-*N*,*N*′-dimethylethane-1,2-diamine [1*R*,2*R*)-(6)]. To a solution of the bis-carbamate (1*R*,2*R*)-**5** (1.43 g, 2.26 mmol) in anhydrous DME (60 mL) maintained at 0 °C was added $LiAlH_4$ (0.86 g, 22.6 mmol) in portions. The reaction mixture was heated at 85 °C for 20 h, and the cooled to 0 °C. Water (4 mL) was added slowly at 0 °C, and then the mixture was heated at reflux for 30 min. The mixture was cooled to RT, and the white precipitate filtered using a pad of Celite and washed with THF (3x20 mL). Evaporation of the solvent under reduced pressure gave a residue that was diluted with Et_2O (20 mL); a 1*M* solution of gaseous HCl (3.7 mL) in Et_2O was then added. The mixture was stirred at RT for 10 min, and the solid obtained was filtered and washed with Et_2O. The solid was suspended in Et_2O and treated with an aqueous 1% NaOH solution until dissolution of the solid. The organic phase was separated, washed with H_2O (2x5 mL), and dried (Na_2SO_4). Evaporation of the solvent under reduced pressure gave the diamine **6** as a colorless solid (450 mg, 66%), which was washed with hexane and dried. Mp 118–120 °C (lit.[13] mp 118–120 °C); $[\alpha]_D^{20}$ +36 (*c* 0.9, $CHCl_3$) (lit.[13] $[\alpha]_D^{20}$ +36.4 (*c* 1, $CHCl_3$)); ^{1}H NMR ($CDCl_3$) δ 1.79 (2 H, br s, NH)), 2.23 (6 H, s, NCH_3), 3.46 (2 H, s, CHN), 3.74 (6 H, s, OCH_3), 6.71 (4 H, d, *J* = 8.6 Hz, H_{arom}), 6.93 (4 H, d, *J* = 8.6 Hz, H_{arom}).

(4*R*,5*R*)-4,5-Bis-(4-methoxyphenyl)-1,2,3-trimethylimidazolidine [(4*R*,5*R*)-7]. The diamine **6** (268 mg, 0.9 mmol) was dissolved in Et_2O (10 mL) containing 4 Å molecular sieves (310 mg) under magnetic stirring. Acetaldehyde (0.093 mL, 1.66 mmol) was then added and the mixture was stirred at RT for 1 h, then diluted with CH_2Cl_2 (10 mL). The molecular sieves were removed by filtration. Evaporation of the solvent and the excess acetaldehyde under reduced pressure gave a residue that was purified by column chromatography on silica [CH_2Cl_2–MeOH (10:1)] to give compound **7** (263 mg, 90%) as a colorless solid. Mp 88–90 °C; R_f = 0.56 (CH_2Cl_2–CH_3OH, 9:1); ^{1}H NMR ($CDCl_3$) δ 1.31 (3 H, d, *J* = 5.8 Hz, CH_3), 2.21 (3 H, s, NCH_3), 2.25 (3 H, s, NCH_3), 3.27 and 3.56 (each 1 H, d, *J* = 8.7 Hz, CHN), 3.77 (6 H, s, OCH_3), 3.84 (1 H, q, *J* = 5.8 Hz, C*H*CH_3), 6.77 (4 H, d, *J* = 8.6 Hz, H_{arom}), 7.04 (2 H, d, *J* = 8.6 Hz, H_{arom}), 7.09 (2 H, d, *J* = 8.6 Hz, H_{arom}).

(4*R*,5*R*)-4,5-Bis-(4-hydroxyphenyl)-1,2,3-trimethylimidazolidine [(4*R*,5*R*)-8]. A 1*M* solution of BBr_3 in CH_2Cl_2 (3.54 mL, 3.54 mmol) was added slowly at 0 °C to a solution of the acetaminal (4*R*,5*R*)-**7** (263 mg, 0.8 mmol) in CH_2Cl_2 (5 mL). After stirring for 16 h at RT, the mixture was hydrolyzed by treatment with aqueous 1*M* NaOH (12.5 mL). The CH_2Cl_2 was evaporated under reduced pressure, the resulting mixture filtered through Celite, and the pH of the solution adjusted to 8.5 with 0.1*M* aq. HCl. Diethyl ether (10 mL) was added, the organic layer was separated, and the aqueous layer extracted with Et_2O (5x10 mL). The combined organic phases were washed with brine (2x10 mL), and dried (Na_2SO_4). Evaporation of the solvent under reduced pressure gave the acetaminal **7** (141 mg, 90%) as a brown solid, that was directly used for the next step without further purification; mp 100–102 °C; R_f = 0.28 (CH_2Cl_2–CH_3OH, 9:1); $[\alpha]_D^{20}$ = +96.1 (*c* 0.5, CH_3OH); ^{1}H NMR (CD_3COCD_3) δ 1.28 (3 H, d, *J* = 5.8 Hz, CH_3), 2.18 (3 H, s, NCH_3), 2.20 (3 H, s, NCH_3), 3.20 (1 H, d, *J* = 8.3 Hz, CHN), 3.49 (1 H, d, *J* = 8.3 Hz, CHN), 3.85 (1 H, q, *J* = 5.8 Hz, C*H*CH_3), 6.71 (4 H, d, *J* = 8.5 Hz, H_{arom}), 6.95 (2 H, d, *J* = 8.5 Hz, H_{arom}), 6.99 (2 H, d, *J* = 8.5 Hz, H_{arom}).

(1*R*,2*R*)-*N*,*N'*-Dimethyl-1,2-bis-{4-[(1*H*,1*H*-perfluorooctyl)oxy]phenyl}ethane-1,2-diamine [(1*R*,2*R*)-1a]. A mixture of compound (1*R*,2*R*)-**7** (142 mg, 0.48 mmol), $CsCO_3$ (53 mg, 1.62 mmol), and $C_7F_{15}CH_2OSO_2C_4F_9$ (842 mg, 1.23 mmol), in anhydrous DMF (6 mL) was stirred at 80 °C for 18 h. After cooling to RT, H_2O (10 mL) was added, and the mixture extracted with Et_2O (3x10 mL). The combined organic phase was washed with brine (10 mL), and dried (Na_2SO_4). Evaporation of the solvent under reduced pressure gave a residue, that was purified by column chromatography on silica [petroleum–EtOAc (1:2)] to give the corresponding protected fluorous compound (227 mg, 45%), that was used directly for the next step. The product obtained was diluted with Et_2O (5 mL), and a 1*M* solution of gaseous HCl in Et_2O (0.9 mL) was added at 0 °C. After stirring for 1 h at RT, the solvent was evaporated under reduced pressure, and the solid filtered off, and washed with Et_2O (3x5 mL). To this solid was added Et_2O (5 mL), followed by aq. 1% NaOH solution until all the solid had dissolved. The organic phase was separated, washed with H_2O (3x5 mL), and dried (Na_2SO_4). Evaporation of the solvent under reduced pressure afforded the fluorous diamine (1*R*,2*R*)-**8** (186 mg, 38%) as a brown oil; $[\alpha]_D^{20}$ = +19 (*c* 0.5, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 2.12 (2 H, br s, NH), 2.24 (6 H, s, NCH_3), 3.45 (2 H,

s, >CH-N), 4.38 (4 H, t, *J* = 13.0 Hz, OCH_2), 6.73 (4 H, d, *J* = 8.7 Hz, H_{arom}), 6.93 (4 H, d, *J* = 8.7 Hz, H_{arom}); ^{13}C NMR ($CDCl_3$) δ 34.7, 65.7 (d, *J* = 26.0 Hz), 70.9, 114.8, 129.5, 135.4, 156.7; ^{19}F NMR ($CDCl_3$) δ –126;6 (4 F, m, CF_2), –123.6 (4 F, m, CF_2), –123.2 (4 F, m, CF_2), –122.5 (8 F, m, CF_2), –120.3 (4 F, m, CF_2), –81.4 (6 F, t, *J* = 9.1 Hz, CF_3). HRMS (ESI) Calcd for $C_{32}H_{22}N_2O_2F_{30}$ ($[M + H]^+$) 1037.1280. Found: 1037.1275.

Determination of partition coefficients *P*. A 10 mL vial equipped with a magnetic stirrer was charged with the fluorous diamine **1** (50 mg), PFMC (2 mL) and the organic solvent (2 mL). The mixture was thermostatted at 25 °C and stirred vigorously for 4 h. A 1 mL sample was taken out of each phase, evaporated to dryness, and weighed on an analytical balance. The partition coefficient *P* was determined as the ratio between the weight of the fluorous phase residue and the weight of the organic phase residue.

Alkylation of (±)-1,3-diphenyl-2-propenyl acetate. The catalyst was prepared in a Schlenk tube by stirring $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ (45.6 mg, 12.5 μmol) and the fluorinated diamine (30 μmol) in degassed THF (1.5 mL) at R.T. for 1 h. 1,3-Diphenyl-2-propenyl acetate (126 mg, 0.5 mmol) dissolved in THF (1.5 mL) was added and the solution stirred for a further 20 min, after which it was transferred under nitrogen into another Schlenk tube containing a solution of NaH (36 mg, 1.5 mmol) and dimethyl malonate (198 mg, 1.5 mmol) in THF (2 mL). The solution was stirred at the desired temperature for the time indicated in Table 2. The conversion was determined by GC using a Quadrex OV1 column (30 m x 0.25 mm) and the enantioselectivity by HPLC on a chiral stationary phase (column: Chiralpak AD; eluent hexane/*i*-PrOH 60:40).

Hydrogen-transfer reduction of acetophenone. The catalyst was prepared in a Schlenk tube by stirring $[Rh(C_6H_{10})Cl]_2$ (8.8 mg, 20 μmol), $[Ir(COD)Cl]_2$ (10.3 mg, 20 μmol), or [Ru(*p*-cymene)Cl_2]$_2$ (12.2 mg, 20 μmol) and the fluorinated diamine **1** (40 μmol) in degassed PFMC (5 mL) at 70 °C for 3 h. To this solution, cooled to RT, was added a solution of acetophenone (48 mg, 0.4 mmol) and KOH (5.6 mg, 0.1 mmol) in *i*-PrOH (5 mL). The mixture was stirred at 70 °C. The conversion and enantiomeric excess were determined by GC analysis using a capillary Quadrex OV1 column (30 m x 0.25 mm) and a capillary Cyclodex-β column (30 m x 0.25 mm), respectively.

References

1. Bennani, Y. L.; Hanessian, S. *Chem. Rev.* **1997**, *97*, 3161. (b) Lucet, D.; Le Gall, T.; Mioskowski, C. *Angew. Chem., Int. Ed.* **1998**, *37*, 2580. (c) Fache, F.; Schulz, E.; Tommasino, M.; Lemaire, M. *Chem. Rev.* **2000**, *100*, 2159.
2. Selected recent examples: (a) Alexakis, A.; Tomassini, A.; Andrey, O.; Bernardinelli, G. *Eur. J. Org. Chem.* **2005**, 1332. (b) Xue, D.; Chen, Y.–C.; Cui, X.; Wang, Q.–W.; Zhu, J.; Deng, J.–G. *J. Org. Chem.* **2005**, *70*, 3584. (c) Zhang, H.–L.; Liu, H.; Cui, X.; Mi, A.–Q.; Jiang, Y.–Z.; Gong, L.–Z. *Synlett* **2005**, 615. (d) Terakado, D.; Koutaka, H.; Oriyama, T.

Tetrahedron: Asymmetry **2005**, *16*, 1157. (e) Cobb, A. J. A.; Marson, C. M. *Tetrahedron* **2005**, *61*, 1269.
3. Ferrand, A.; Bruno, M.; Tommasino, M. L.; Lemaire, M. *Tetrahedron: Asymmetry* **2002**, *13*, 1379.
4. Li, X.; Chen, W.; Hems, W.; King, F.; Xiao, J. *Tetrahedron Lett*. **2004**, *45*, 951.
5. Ma, Y.; Liu, H.; Chen, L.; Cui, X.; Zhu, J.; Deng, J. *Org. Lett.* **2003**, *5*, 2103. (b) Bubert, C.; Blacker, J.; Brown, S. M.; Crosby, J.; Fitzjohn, S.; Muxworthy, J. P.; Thorpe, T.; Williams, J. M. J. *Tetrahedron Lett*. **2001**, *42*, 4037.
6. Maillet, C.; Praveen, T.; Janvier, P.; Minguet, S.; Evain, M.; Saluzzo, C.; Tommasino, M. L.; Bujoli, B. *J. Org. Chem*. **2002**, *67*, 8191.
7. Li, X.; Chen, W.; Hems, W.; King, F.; Xiao, J. *Org. Lett.* **2003**, *5*, 4559. (b) Itsuno, S.; Tsuji, A.; Takahashi, M. *Tetrahedron Lett.* **2003**, *44*, 3825.
8. Liu, P. N.; Gu, P. M.; Wang, F.; Tu, Y. Q. *Org. Lett.* **2004**, *6*, 169. (b) Brethon, A.; Moreau J. J. E.; Wong Chi Man, M. *Tetrahedron: Asymmetry* **2004**, *15*, 495.
9. Reviews: G. Pozzi, G.; Shepperson, I. *Coord. Chem. Rev*. **2003**, *242*, 115. (b) Sinou, D. in *Handbook of Fluorous Chemistry*; Gladysz, J. A.; Curran, D.; Horváth, I. T. Eds.; Wiley-VCH: Weinheim, 2004; p 306. (c) Takeuchi, S.; Nakamura, Y. *ibid*. p 316. (d) Fache, F. *New J. Chem*. **2004**, 1277.
10. Maillard, D.; Nguefack, C.; Pozzi, G.; Quici, S.; Valadé, B.; Sinou, D. *Tetrahedron: Asymmetry* **2000**, *11*, 2881. (b) Maillard, D.; Pozzi, G.; Quici, S.; Sinou, D. *Tetrahedron* **2002**, *58*, 3971. (c) Bayardon, J.; Sinou, D. *Tetrahedron Lett.* **2003**, *44*, 1449. (d) Bayardon, J.; Sinou, D. *J. Org. Chem.* **2004**, *69*, 3121. (e) Bayardon, J.; Sinou, D.; Holczknecht, O.; Mercs, L.; Pozzi, G. *Tetrahedron: Asymmetry* **2005**, *16*, 2319.
11. Bayardon, J.; Sinou, D. *Synthesis* **2005**, 425.
12. Corey, E. J.; Lee, D.–H.; Sarshar, S. *Tetrahedron: Asymmetry* **1995**, *6*, 3.
13. Denmark, S. E.; Su, X.; Nishigaichi, Y.; Coe, D. M.; Wong, K.–T.; Winter, S. B. D.; Choi, J. Y. *J. Org. Chem*. **1999**, *64*, 1958.
14. Maillard, D.; Pozzi, G.; Sinou, D. *Eur. J. Org. Chem.* **2002**, 269.
15. Itsuno, S.; Takahashi, M.; Tsuji, A. *Macromol. Symp*. **2004**, *217*, 191.