New Chiral 1,2-Diamines and Their Use in Zinc-Catalyzed Asymmetric Hydrosilylation of Acetophenone

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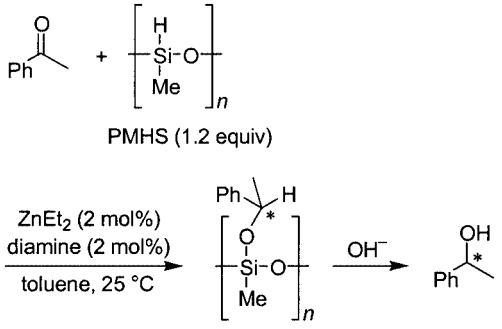
Keywords: Asymmetric catalysis / Diamine ligands / Hydrosilylation / PMHS / Zinc

The preparation of two new series of chiral 1,2-diamines and their use in the [ZnR_2-diamine]-catalyzed asymmetric hydrosilylation of acetophenone with poly(methylhydrosiloxane) (PMHS) in an aprotic medium is reported. The effect of structural modifications of the secondary diamine ligand, in particular a possible cooperative effect of two different types of chiral centers, on the *N*-benzylic side-arms and on the ethylene bridge of the diamine skeleton, has been investigated. A new diamine ligand giving up to 91% *ee* is described.

Introduction

Over the past two decades enantiomerically pure 1,2-diamines and some of their derivatives have attracted considerable attention as chiral ligands in a variety of transition-metal-catalyzed asymmetric processes.[1] Noteworthy is their application in the enantioselective reduction of C=O and C=N bonds, mostly by hydrogenation and transfer hydrogenation, in association with group 8 metals.[2] The use of chiral diamines for the hydrosilylation/reduction of carbonyl compounds is more restricted.[3] Recently, Mimoun et al. reported a chiral hydrosilylation system, based on catalyst combinations of $ZnEt_2$ and optically active secondary 1,2-diamines, that enables the reduction of simple aryl alkyl ketones (Scheme 1).[4] High yields and enantioselectivities were obtained for the reduction of acetophenone using C_2-symmetric diamines as chiral ligands, for example, (*S*,*S*)-*N*,*N*′-dibenzyl-1,2-diphenyl-1,2-ethanediamine (Bn-dpen, **1**) (up to 88% *ee*) or (*S*,*S*)-*N*,*N*′-ethylenebis(1-phenylethylamine) (ebpe, **2**) (up to 75% *ee*) (Scheme 2).[4a] The attractiveness of this system lies also in the use of poly(methylhydrosiloxane) (PMHS), a safe and inexpensive polymer coproduct of the silicon industry, that acts as an efficient alternative to noxious and expensive molecular hydrosilanes.[3,5]



Scheme 1

In this contribution, we report some results related to the zinc-catalyzed asymmetric hydrosilylation of acetophenone with PMHS using differently substituted chiral secondary 1,2-diamines;[4b,4c] some of these diamines are new and were designed with the aim of improving the enantioselectivity of the reaction. In particular, we investigated the catalytic ability of two series of such ligands: the ligands of the first series combine the structural features of Bn-dpen (**1**) and ebpe (**2**) and were prepared in order to assess the possible cooperative effect of chiral centers at the 1,2-positions of the ethylene backbone and at the α-position of the *N*-benzyl arms, that is, **3a**−**d**; the second series consists of *ortho*-phenyl-substituted analogues of Bn-dpen, that is, **4b**,**c** (Scheme 2). The impact of the ligand structure and relative stereochemistry on the catalyst activity and enantioselectivity has been investigated.

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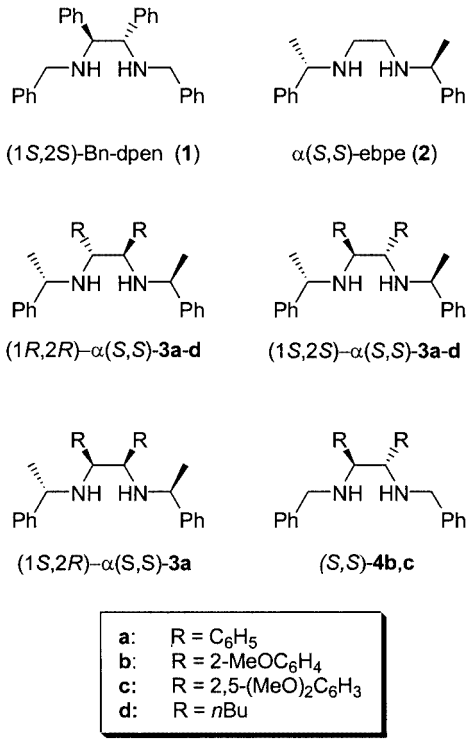
  DOI: 10.1002/ejoc.200400129

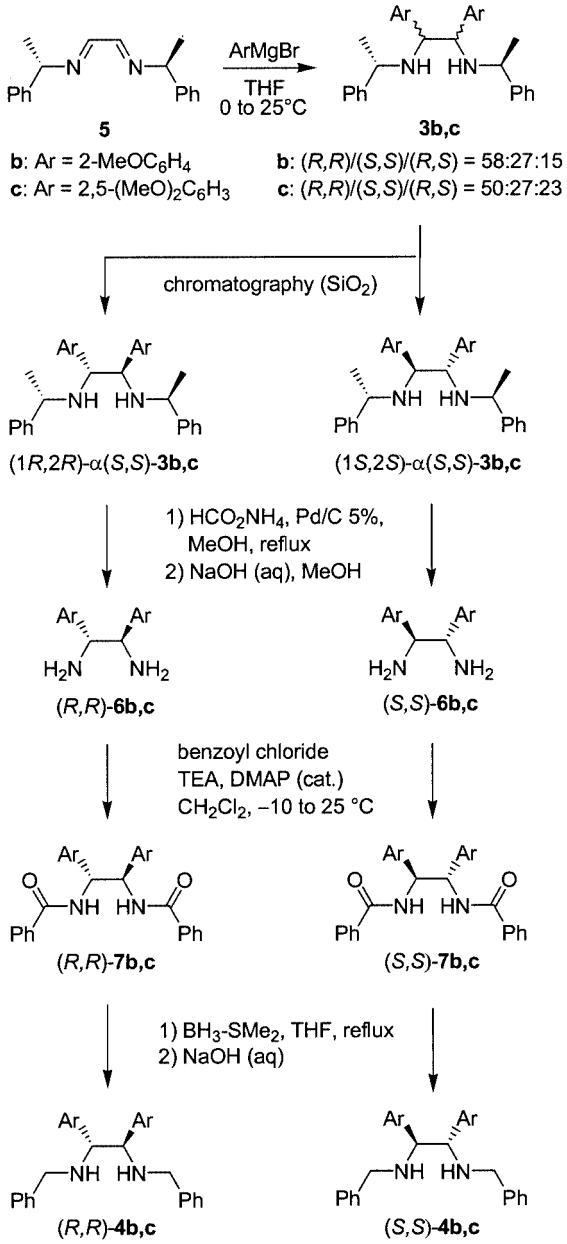


Scheme 2

Results and Discussion

Preparation of the Chiral 1,2-Diamines

The 1,2-disubstituted-1,2-diamines were prepared by double addition of the appropriate organometallic reagent to the corresponding 1,2-bis(imine) **5**, derived from the condensation of glyoxal with 2 equivalents of (*S*)-1-(phenyl)-ethylamine (Scheme 3).[6] The 1,2-diphenyl- and 1,2-dibutyl-substituted compounds **3a** and **3d** are known compounds, and are available by the addition of PhMgCl and *n*BuLi to **5** in THF at −78 °C, respectively.[7,8] In addition, a new series of secondary diamines have been developed as an *ortho*-substituents affect the orientation of the phenyl rings at the 1,2-positions, and consequently the overall conformation of the diamine ligand in the intermediate zinc complex involved in the enantio-determining step. To explore the effect of *ortho*-substituents on catalytic activity and enantioselectivity, 2-methoxyphenyl and 2,5-dimethoxyphenyl substituents were selected and the new diamines **3b**,**c** were prepared according to the route described in Scheme 3, starting from **5** and the relevant Grignard reagents. Although the efficiency and diastereoselectivity of the first step can be in part controlled by the appropriate choice of Grignard reagent and experimental conditions (e.g. syringe-controlled addition of the organometallic reagent, temperature),[6,8] our choice was to achieve moderate stereocontrol as we wished to obtain all three possible stereoisomers [i.e. with the (1*S*,2*S*), (1*R*,2*R*) and (1*S*,2*R*) configurations], and assess their behavior in the zinc-catalyzed hydrosilylation/reduction of a model ketone. Column chromatography of the crude mixtures obtained by the addition of 2-methoxyphenyl- and 2,5-(dimethoxyphenyl)-magnesium chloride to the imine **5** at 0 °C led to the isolation, in a pure state, of only the two prevalent diastereomers of both compounds in moderate to low yields [19−33% for (1*R*,2*R*)-**3b**,**c** and 13−17% for (1*S*,2*S*)-**3b**,**c**]. The minor diastereomers (1*S*,2*R*)-**3b**,**c** could not be completely separated from the (1*R*,2*R*)-**3b**,**c** diastereomers.



Scheme 3

The *N*,*N*′-dibenzyl derivatives (1*S*,2*S*)- and (1*R*,2*R*)-**4b,c** were then prepared by a three-step sequence (Scheme 3). The first step was the reductive cleavage of the *N*,*N*′-substituents (chiral auxiliaries) of **3b,c** using ammonium formate and Pd/C in refluxing methanol,[9] which gave the cor-

responding primary 1,2-diamines (1*S*,2*S*)- and (1*R*,2*R*)-**6b,c** in 75−81% yields. The crude primary diamines, being rather sensitive to air, light and acidic media, were directly used in the next step to avoid the loss of products during purification. In our hands, the direct *N*,*N*′-dibenzylation of **6b,c** under the conditions used by Alexakis et al. for the *N*,*N*′-dibenzylation of 1,2-cyclohexanediamine (benzyl bromide, KI, K_2CO_3, EtOH, room temp.)[10] was not successful, providing yields of less than 10% of the desired compounds **4b,c**. Better results were achieved by conventional *N*-benzoylation to give the amides **7b,c**, followed by reduction with borane-dimethyl sulfide in THF at reflux. By using this route, the enantiomers (1*R*,2*R*)-**4b,c** were obtained in 37% overall yield (2 steps) as some loss of the products occurred during crystallization and chromatographic purification. The same two-step sequence was applied to the other diastereomers (1*S*,2*S*)-**7b,c** to obtain the desired secondary 1,2-diamines (1*S*,2*S*)-**4b,c**.

It should be underlined that attempted resolution of *d*,*l*-**3b**, obtained by reductive dimerization of *N*-*ortho*-(methoxybenzylidene)benzylamine[11] with zinc/methanesulfonic acid and chromatographic separation of the *meso* diastereomer, failed using both 1 and 2 equivalents of tartaric acid. Analogously, we did not find suitable conditions for the separation of the enantiomers of **4b,c** by HPLC analysis on a chiral column. This would have been useful to assess the *ee* of these compounds when obtained from the chiral bis(imine) **5**. However, their enantiomeric purity was indirectly demonstrated using the results of the enantioselective hydrosilylation reactions of acetophenone, as the enantiomers of both diamines **4b**,**c** afforded (almost) the same degree of enantiocontrol (vide infra).

Zinc-Promoted Asymmetric Hydrosilylation of Acetophenone

The secondary chiral diamines prepared in this work, in combination with $ZnEt_2$, were investigated in the hydrosilylation/reduction of acetophenone, chosen as a model substrate, using PMHS as the reducing agent (Scheme 1). Representative results are reported in Table 1 and are compared to those obtained under the same conditions with chiral diamines **1** and **2** (Entries 1 and 2).[4a]

The so-called mixed "ebpe-dpen" diamines **3**, in which both types of chiral centers are present, led to classical "matched" and "mismatched" effects (Entries 3−10). The best results, in terms of enantioselectivity, were obtained with the diastereomers (1*S*,2*S*)-α(*S*,*S*), which is consistent with the fact that both (1*S*,2*S*)-Bn-dpen (**1**) and α(*S*,*S*)-ebpe (**2**) lead to the same major enantiomer of 2-phenylethanol. Quite low enantioselectivity was achieved with the "mismatched" pairs (1*R*,2*R*)-α(*S*,*S*), whereas the pseudo-*meso* derivative (1*S*,2*R*)-α(*S*,*S*)-**3a** gives intermediate performance (Entry 5). Disappointingly, the results for the **3a** series indicate that no cooperation occurs within this system: indeed, the enantioselective performance of the "matched" (1*S*,2*S*)-α(*S*,*S*) ligand (84% *ee*, $\Delta\Delta G^{\#}$ = 1.45 kcal·mol^{-1}) was in between that of *N*-Bn-dpen (88% *ee*, $\Delta\Delta G^{\#}$ = 1.64 kcal·mol^{-1}) and ebpe (75% *ee*, $\Delta\Delta G^{\#}$ = 1.16 kcal·mol^{-1})

Table 1. Reduction of acetophenone with the $ZnEt_2$/diamine/PMHS system

Entry[a]	1,2-Diamine	Time [h][b]	Yield [%]	*ee* [%] (Conf.)
1[c]	(1*S*,2*S*)-**1**	18	98	88 (*S*)
2[c]	α(*S*,*S*)-**2**	18	99	75 (*S*)
3	(1*R*,2*R*)-α(*S*,*S*)-**3a**	72	4	< 5 (nd)
4	(1*S*,2*S*)-α(*S*,*S*)-**3a**	170	56	84 (*R*)
5	(1*S*,2*R*)-α(*S*,*S*)-**3a**	48	11	37 (*R*)
6	(1*R*,2*R*)-α(*S*,*S*)-**3b**	216	30	25 (*R*)
7	(1*S*,2*S*)-α(*S*,*S*)-**3b**	288	66	91 (*R*)
8[d]	(1*S*,2*S*)-α(*S*,*S*)-**3b**	18	33	78 (*R*)
		40	56	78 (*R*)
9	(1*R*,2*R*)-α(*S*,*S*)-**3d**	48	44	33 (*R*)
10	(1*S*,2*S*)-α(*S*,*S*)-**3d**	44	78	67 (*R*)
11	(*S*,*S*)-**4b**	72	> 99	83 (*R*)
12	(*R*,*R*)-**4b**	72	> 99	83 (*S*)
13[d]	(*R*,*R*)-**4b**	18	> 99	83 (*S*)
14	(*R*,*R*)-**4c**	96	94	87 (*S*)
15	(*S*,*S*)-**4c**	72	> 99	84 (*R*)

[a] PMHS/acetophenone/$ZnEt_2$/diamine, 60:50:1:1, [acetophenone] = 0.89 M in toluene. Reactions were carried out at 20 °C unless otherwise stated. [b] Reaction time not optimized. [c] See ref.[4a] [d] Reaction was carried out at 50 °C.

(the enantioselectivity of all the systems reported in this paper is constant over the whole reaction time, as determined by GLC monitoring). While *n*Bu derivatives **3d** afforded poor *ee*'s (Entries 9 and 10), introduction of an *ortho*-methoxyphenyl substituent at the 1,2 positions (**3b**) allowed a promising 91% *ee* to be obtained (Entry 7); this is the highest enantioselectivity so far achieved in this new hydrosilylation/reduction of acetophenone. This good performance may possibly be due to hindered (restricted) rotation of the phenyl moiety. On the other hand, quite low reaction rates were observed with all of these mixed ligands, probably because of their increased bulkiness compared with ligands **1** and **2**. Presumably, the size of the aryl substituents on the ethylene chain affects the conformation/mobility of the *N*-(1-phenylethyl) substituents, whose steric effects are thus more important in the reactive intermediate (Zn complex). In the case of **3b**, reduction at a higher temperature (50 °C) led to increased activity of the catalytic system, allowing a satisfactory conversion to be achieved after a reasonable reaction time, although with a reduction in the enantioselectivity (Entry 8).

The introduction of an α-methyl substituent on the *N*-benzyl arms lowers the activity and enantioselectivity of the catalyst system, as compared with *N*-Bn-dpen (**1**). Therefore, the use of 1,2-diaryl-*N*,*N*′-dibenzyldiamines **4b**,**c**, analogues of **1**, was investigated (Entries 11−15). Significantly higher reaction rates were obtained with **4b**,**c,** confirming the fact that steric bulkiness is the likely cause of the modest catalytic activity of systems based on ligands **3**.[12] Surprisingly, the enantioselectivity of the system based on the 2-methoxyphenyl-substituted diamine **4b** was found to be lower than that of **1**, in contrast with the trend observed for the mixed ebpe-dpen ligands **3b**, in which the *ortho*-methoxy substituent was observed to have a positive effect

on the enantioselectivity (Entry 7). The enantioselectivity of **4b** is, however, not affected by temperature, which allows the reaction to be completed within much shorter time periods than systems based on **3b**, whilst still maintaining a reasonably high level of enantioselectivity (Entry 13).

In conclusion, two new series of chiral diamines have been developed and their behaviour in the asymmetric hydrosilylation of acetophenone has been thoroughly investigated. Relatively high enantioselectivity could be reached, although the introduction of substituents onto the ligand backbone led to quite modest catalyst activity. No simple structure-selectivity relationship has been established so far that would allow a rational design of the optimum ligand.

Experimental Section

General: Optical rotations were measured with a digital polarimeter at 25 °C in a 1-dm cell and $[\alpha]_D$ values are given in 10^{-1} deg·cm^3·g^{-1}. ^{1}H NMR spectra were recorded with a Varian Gemini instrument at 300 or 200 MHz for samples in $CDCl_3$ which was stored over Mg: ^{1}H chemical shifts are reported in ppm downfield from TMS and were determined by reference to the residual ^{1}H (δ = 7.25 ppm) solvent peak; ^{1}H chemical shifts are reported in ppm relative to $CHCl_3$ (δ_H = 7.27 ppm). GLC analyses were performed on Chrompack CP 9001 apparatuses equipped with a flame ionization detector and, respectively, BPX5 (25 m × 0.32 mm, SGE) and chiral Chirasil-DEX CB (25 m × 0.25 mm, Chrompack) columns. MS spectra were recorded at an ionizing voltage of 70 eV with a Hewlett−Packard 5970 or 5890 spectrometer with GLC injection. Microanalyses were carried out at the chemistry department of the Università di Bologna. IR spectra were recorded with a Nicolet 510 FTIR spectrophotometer; absorption maxima are expressed in wave numbers (cm^{-1}). Chromatographic separations were performed on columns of SiO_2 (Merck, 230−400 mesh) at medium pressure. Melting points are uncorrected.
Bn-Dpen (**1**),[13] ebpe (**2**),[4a] 1,2-diimine **5**,[14]and diamines **3a**[7,8] and **3d**[7] were prepared following reported procedures and rigorously purified by distillation or column chromatography and subsequent recrystallization. Benzoyl chloride was distilled before use under N_2. $ZnEt_2$ (1.1 M solution in toluene) was purchased from Aldrich and used as received. Acetophenone (99%, Aldrich) was distilled from over CaH_2 and degassed before use. PMHS (Aldrich) was degassed before use. All other chemicals were used as purchased from Aldrich or Fluka. Toluene was freshly distilled from a Na/K amalgam and degassed before use. Solvents for organic synthesis were purified and dried following standard procedures.

Preparation of the Secondary 1,2-Diamines 3b,c. General Procedure

(1*R*,2*R*)- and (1*S*,2*S*)-1,2-Bis(2-methoxyphenyl)-*N*,*N*′-bis[(*S*)-1-phenylethyl]-1,2-ethanediamine [(1*R*,2*R*)- and (1*S*,2*S*)-α(*S*,*S*)-3b]: A catalytic amount of iodine and 2-bromoanisole (1.60 mL, 12.9 mmol) were added to a suspension of magnesium turnings (1.22 g, 50.2 mmol) in THF (10 mL) under Ar. After the Grignard reaction was started, a solution of 2-bromoanisole (4.00 mL, 32.3 mmol) in THF (10 mL) was added dropwise over 10 min. After stirring for 20 min, the mixture was heated to 60 °C for 1 h. The Grignard reagent obtained was added over 15 min to a solution of 1,2-diimine **5** (3.96 g, 15.0 mmol) in THF (30 mL) at 0 °C. The mixture was stirred at 0 °C for 1 h, then at room temp. for 1 h and quenched with water (20 mL). The organic phase was extracted with Et_2O (3 × 20 mL) and the ethereal layers were dried (Na_2SO_4) and concentrated to give an oil (6.28 g). The mixture could not be analyzed by GC-MS analysis owing to decomposition of the secondary diamines **3b**,**c**. ^{1}H NMR analysis showed the presence of the (1*R*,2*R*) and (1*S*,2*S*) diastereomers in a 68:32 ratio, whereas the (1*R*,2*S*) diastereomer was not discerned; moreover, anisole and 1-phenylethylamine, the latter deriving from hydrolysis of the starting diimine or the intermediate α-aminoimine, were present. The pure diastereomers were obtained by column chromatography (SiO_2, cyclohexane/EtOAc mixtures). The (1*R*,2*R*) isomer of **3b** was further purified by crystallization (MeOH) to give a white crystalline solid.

(1*R*,2*R*)-α(*S*,*S*)-3b: Yield 1.17 g (19%); m.p. 104−106 °C. $[\alpha]_D^{20}$ = −184.4 (*c* = 0.77, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3305, 3061, 3025, 1599, 1586, 1490, 1463, 1368, 1242, 753, 700 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.24 (d, *J* = 6.6 Hz, 6 H, CHC*H*$_3$), 2.35 (br. s, 2 H, NH), 3.36 (s, 6 H, OCH_3), 3.42 (q, *J* = 6.6 Hz, 2 H, C*H*CH$_3$), 3.92 (s, 2 H, NCHCHN), 6.59 (d, *J* = 8.4 Hz, 2 H, Ar), 6.78 (t, *J* = 7.8 Hz, 2 H, Ar), 6.97−7.13 (m, 4 H, Ar), 7.13−7.34 (m, 10 H, Ph) ppm. $C_{32}H_{36}N_2O_2$ (480.65): calcd. C 79.96, H 7.55, N 5.83; found C 79.90, H 7.57, N 5.82.

(1*S*,2*S*)-α(*S*,*S*)-3b: Yellow oil, yield 1.07 g (17%). $[\alpha]_D^{20}$ = −29.4 (*c* = 0.57, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3296, 3060, 3027, 1599, 1490, 1463, 1243, 1029, 753, 700 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.33 (d, *J* = 6.6 Hz, 6 H, CHC*H*$_3$), 2.30 (br. s, 2 H, NH), 3.51 (s, 6 H, OCH_3), 3.64 (q, *J* = 6.6 Hz, 2 H, C*H*CH$_3$), 4.41 (s, 2 H, NCHCHN), 6.54 (d, *J* = 8.4 Hz, 2 H, Ar), 6.73 (t, *J* = 7.2 Hz, 2 H, Ar), 7.0 (t, *J* = 7.2 Hz, 2 H, Ar), 7.08−7.32 (m, 12 H, Ph and Ar) ppm.

(1*R*,2*R*)-1,2-Bis(2,5-dimethoxyphenyl)-*N*,*N*′-bis[(*S*)-1-phenylethyl]-1,2-ethanediamine [(1*R*,2*R*)-α(*S*,*S*)-3c]: Yellow oil, yield 1.76 g (33%). $[\alpha]_D^{20}$ = −120.1 (*c* = 0.97, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3297, 3058, 3022, 3000, 1607, 1587, 1496, 1464, 1272, 1217, 1048, 759, 701 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.23 (d, *J* = 6.6 Hz, 6 H, CHC*H*$_3$), 2.07 (br. s, 2 H, NH), 3.32 (s, 6 H, OCH_3), 3.42 (q, *J* = 6.6 Hz, 2 H, C*H*CH$_3$), 3.70 (s, 6 H, OCH_3), 3.88 (s, 2 H, NCHCHN), 6.54 (d, *J* = 8.8 Hz, 2 H, Ar), 6.64 (dd, *J* = 8.8, 3.0 Hz, 2 H, Ar), 6.87 (m, 2 H, Ar), 7.0 (m, 4 H, Ph), 7.10−7.30 (m, 6 H, Ph) ppm. $C_{34}H_{40}N_2O_4$ (540.71): calcd. C 75.52, H 7.46, N 5.18; found C 75.49, H 7.48, N 5.17.

(1*S*,2*S*)-1,2-Bis(2,5-dimethoxyphenyl)-*N*,*N*′-bis[(*S*)-1-phenylethyl]-1,2-ethanediamine [(1*S*,2*S*)-α(*S*,*S*)-3c]: Yellow oil, yield 0.70 g (13%). $[\alpha]_D^{20}$ = −41.2 (*c* = 0.38, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3283, 3051, 3022, 1601, 1587, 1497, 1464, 1273, 1218, 1048, 700 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.33 (d, *J* = 6.6 Hz, 6 H, CHC*H*$_3$), 2.28 (br. s, 2 H, NH), 3.51 (s, 6 H, OCH_3), 3.60 (q, *J* = 6.6 Hz, 2 H, C*H*CH$_3$), 3.67 (s, 6 H, OCH_3), 4.37 (s, 2 H, NCHCHN), 6.50 (d, *J* = 8.8 Hz, 2 H, Ar), 6.58 (dd, *J* = 8.8, 2.8 Hz, 2 H, Ar), 6.82 (m, 2 H, Ar), 7.15−7.30 (m, 10 H, Ph) ppm.

Preparation of the Primary 1,2-Diamines 6b,c. General Procedure

(1*R*,2*R*)-1,2-Bis(2-methoxyphenyl)-1,2-ethanediamine [(*R*,*R*)-6b]: A mixture of the secondary diamine (1*R*,2*R*)-**3b** (1.41 g, 2.90 mmol), HCO_2NH_4 (3.70 g, 58.7 mmol) and Pd/C 10% (1.00 g) in MeOH (40 mL) was refluxed for 10 h under Ar. After cooling to room temp., the mixture was filtered through a pad of Celite which was washed with EtOH. The ethanolic solution was concentrated to leave a yellowish oil, which was then dissolved in CH_2Cl_2 (20 mL). An aqueous solution of NaOH (pH 11, 10 mL) was added, the mixture was stirred for 5 min and the organic phase was extracted with CH_2Cl_2 (3 × 15 mL). The organic phase was washed with brine (20 mL), dried (Na_2SO_4) and concentrated to give the pri-

mary 1,2-diamine (*R*,*R*)-**6b** as a yellow oil (0.64 g, 81%); the compound was about 95% pure by ^{1}H NMR analysis and was not further purified. $[\alpha]_D^{20}$ = +55.7 (*c* = 0.89, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3364, 3297, 3072, 3029, 3000, 1600, 1487, 1368, 1235, 1109, 1036, 746 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.83 (br. s, 4 H, NH_2), 3.79 (s, 6 H, OCH_3), 4.46 (s, 2 H, NCHCHN), 6.73−6.88 (m, 4 H, Ar), 7.07−7.28 (m, 4 H, Ar) ppm. Partial decomposition occurred during the GC-MS analysis. $C_{16}H_{20}N_2O_2$ (272.35): calcd. C 70.56, H 7.40, N 10.29; found C 70.52, H 7.43, N 10.27.

(1*S*,2*S*)-1,2-Bis(2-methoxyphenyl)-1,2-ethanediamine [(*S*,*S*)-6b]: Yellow oil, yield 0.59 g (75%). $[\alpha]_D^{20}$ = −56.4 (*c* = 1.21, $CHCl_3$).

(1*R*,2*R*)-1,2-Bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(1*R*,2*R*)-6c]: Yellow oil, yield 0.74 g (77%). $[\alpha]_D^{20}$ = +34.7 (*c* = 1.16, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3374, 3321, 3072, 1595, 1589, 1498, 1221, 1179, 1158, 1047, 871, 804, 753 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.65 (br. s, 4 H, NH_2), 3.73 (s, 6 H, OCH_3), 3.77 (s, 6 H, OCH_3), 4.45 (s, 2 H, NCHCHN), 6.71 (m, 4 H, Ar), 6.88 (d, *J* = 2.6 Hz, 2 H, Ar) ppm. $C_{18}H_{24}N_2O_4$ (332.40): calcd. C 65.04, H 7.28, N 8.43; found C 65.00, H 7.29, N 8.42.

(1*S*,2*S*)-1,2-Bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(1*S*,2*S*)-6c]: Yellow oil, **yield** 0.74 g (77%). $[\alpha]_D^{20}$ = −27.8 (*c* = 0.64, $CHCl_3$).

Preparation of the Diamides 7b,c. General Procedure

(1*R*,2*R*)-*N*,*N*′-Dibenzoyl-1,2-bis(2-methoxyphenyl)-1,2-ethanediamine [(*R*,*R*)-7b]: Triethylamine (0.45 mL, 3.30 mmol), benzoyl chloride (0.38 mL, 3.30 mmol) and a catalytic amount of 4-(dimethylamino)pyridine were added to a solution of the primary diamine (*R*,*R*)-**6b** (0.35 g, 1.30 mmol) in anhydrous CH_2Cl_2 (10 mL) cooled to 0 °C under Ar. After 5 min the mixture was allowed to reach room temp. and stirred for 5 h. Further triethylamine (90 μL, 0.70 mmol) and benzoyl chloride (75 μL, 0.7 mmol) were then added and the mixture was stirred overnight. HCl (2 N) was added until pH 4 was reached, followed by H_2O (5 mL). The organic phase was extracted with Et_2O (3 × 5 mL), washed with brine (10 mL), dried (Na_2SO_4) and concentrated to give a yellowish solid that was crystallized from cyclohexane/EtOAc (0.39 g, 63%). M.p. 78−80 °C. $[\alpha]_D^{20}$ = −7.3 (*c* = 0.98, $CHCl_3$). IR (KBr): $\tilde{\nu}_{max.}$ = 3433, 3300 (br), 3062, 3029, 3007, 1638, 1524, 1488, 1291, 1247, 1021, 692 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.96 (s, 6 H, OCH_3), 5.94 (dd, *J* = 2.6, 6.2 Hz, NCHCHN), 6.67 (t, *J* = 7.2 Hz, 2 H, Ar), 6.85 (t, *J* = 8.0 Hz, 4 H, Ar), 7.14 (t, *J* = 8.0 Hz, 2 H, Ar), 7.33−7.52 (m, 6 H, Ph), 7.76 (m, 4 H, Ph), 7.98 (m, 2 H, NH) ppm. $C_{30}H_{28}N_2O_4$ (480.56): calcd. C 74.98, H 5.87, N 5.83; found C 74.96, H 5.88, N 5.82.

(1*S*,2*S*)-*N*,*N*′-Dibenzoyl-1,2-bis(2-methoxyphenyl)-1,2-ethanediamine [(*S*,*S*)-7b]: Pure (*S*,*S*)-**7b** was obtained by crystallization in a yield of 0.36 g (58%). M.p. 79−81 °C. $[\alpha]_D^{20}$ = +8.1 (*c* = 0.25, $CHCl_3$).

(1*R*,2*R*)-*N*,*N*′-Dibenzoyl-1,2-bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(*R*,*R*)-7c]: (*R*,*R*)-**7c** was obtained by chromatography of the crude reaction mixture on a column of SiO_2 (cyclohexane/EtOAc). Yellowish solid, yield 0.41 g (58%); m.p. 82−84 °C. $[\alpha]_D^{20}$ = +5.4 (*c* = 0.95, $CHCl_3$). IR (KBr): $\tilde{\nu}_{max.}$ = 3426, 3345 (br.), 3061, 2997, 1646, 1224, 1045, 804, 714 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.72 (s, 6 H, OCH_3), 3.93 (s, 6 H, OCH_3), 5.83 (dd, *J* = 2.7, 6.0 Hz, NCHCHN), 6.44 (d, *J* = 3.0 Hz, 2 H, Ar), 6.67 (dd, *J* = 3.0, 9.0 Hz, 2 H, Ar), 6.77 (d, *J* = 9.0 Hz, 2 H, Ar), 7.40 (m, 6 H, Ph), 7.76 (m, 4 H, Ph), 8.02 (m, 2 H, NH) ppm. $C_{32}H_{32}N_2O_6$ (540.62): calcd. C 71.09, H 5.97, N 5.18; found C 71.07, H 5.98, N 5.16.

(1*S*,2*S*)-*N*,*N*′-Dibenzoyl-1,2-bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(*S*,*S*)-7c]: (*S*,*S*)-**7c** was isolated by chromatography as a yellowish solid. Yield 0.22 g (31%); m.p. 78−80 °C. $[\alpha]_D^{20}$ = −9.9 (*c* = 0.71, $CHCl_3$).

Preparation of the *N*,*N*′-Dibenzyl-1,2-Diamines 4b,c. General Procedure

(1*R*,2*R*)-*N*,*N*′-Dibenzyl-1,2-bis(2-methoxyphenyl)-1,2-ethanediamine [(*R*,*R*)-4b]: A solution of the (*R*,*R*)-dibenzoyldiamine **7** (0.26 g, 0.50 mmol) in THF (4 mL) was slowly added to a solution of BH_3−SMe_2 (170 μL, 1.70 mmol) in THF (4 mL) cooled to 0 °C under Ar. The mixture was refluxed while stirring for 6 h, then quenched at 0 °C with aq. NaOH. The organic phase was extracted with Et_2O (3 × 7 mL), dried over Na_2SO_4 and concentrated to give a yellowish oil. The pure *N*,*N*′-dibenzyldiamine was obtained as a yellowish oil by chromatography on an Al_2O_3 column eluting with cyclohexane/EtOAc mixtures (0.145 g, 58%). $[\alpha]_D^{20}$ = −38.3 (*c* = 0.85, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3306, 3061, 3026, 2999, 1599, 1586, 1280, 1111, 1029, 751, 698 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.51 (br. s, 2 H, NH), 3.53 (s, 6 H, OCH_3), 3.57 (qAB, *J* = 13.2 Hz, 4 H, NCH_2), 4.24 (s, 2 H, NCHCHN), 6.63 (d, *J* = 8.4 Hz, 2 H, Ar), 6.79 (t, *J* = 7.8 Hz, 2 H, Ar), 7.08 (t, *J* = 7.8 Hz, 2 H, Ar), 7.16−7.34 (m, 12 H, Ar and Ph) ppm. $C_{30}H_{32}N_2O_2$ (452.60): calcd. C 79.61, H 7.13, N 6.19; found C 79.60, H 7.14, N 6.18.

(1*S*,2*S*)-*N*,*N*′-Dibenzyl-1,2-bis(2-methoxyphenyl)-1,2-ethanediamine [(*S*,*S*)-4b]: Yield 0.12 g (49%). $[\alpha]_D^{20}$ = +33.3 (*c* = 0.67, $CHCl_3$).

(1*R*,2*R*)-*N*,*N*′-Dibenzyl-1,2-bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(*R*,*R*)-4c]: Yield 0.16 g (64%). $[\alpha]_D^{20}$ = −9.7 (*c* = 0.98, $CHCl_3$). IR (neat): $\tilde{\nu}_{max.}$ = 3305, 3060, 3026, 2994, 1604, 1588, 1221, 1048, 804, 734 699 cm^{-1}. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.48 (br. s, 2 H, NH), 3.52 (s, 6 H, OCH_3), 3.58 (qAB, *J* = 13.2 Hz, 4 H, NCH_2), 3.70 (s, 3 H, OCH_3), 4.22 (s, 2 H, NCHCHN), 6.58 (d, *J* = 8.7 Hz, 2 H, Ar), 6.64 (dd, *J* = 8.7, 3.0 Hz, 2 H, Ar), 6.88 (m, 2 H, Ar), 7.18−7.40 (m, 10 H, Ph) ppm. $C_{32}H_{36}N_2O_4$ (512.65): calcd. C 74.97, H 7.08, N 5.46; found C 74.94, H 7.09, N 5.45.

(1*S*,2*S*)-*N*,*N*′-Dibenzyl-1,2-bis(2,5-dimethoxyphenyl)-1,2-ethanediamine [(*S*,*S*)-4c]: Yield 0.10 g (40%). $[\alpha]_D^{20}$ = +7.3 (*c* = 0.67, $CHCl_3$).

Zn-Diamine-Catalyzed Asymmetric Hydrosilylation of Acetophenone by PMHS. General Procedure: Catalytic reactions were performed under nitrogen using standard Schlenk techniques. In a typical experiment (Table 1, Entry 15), $ZnEt_2$ (50 μL of a 1.1 M solution in toluene, 0.055 mmol), acetophenone (0.32 mL, 2.75 mmol) and finally PMHS (0.21 mL, 3.30 mmol) were successively added to a solution of (*S*,*S*)-**4c** (28.2 mg, 0.055 mmol) in freshly distilled toluene (2.5 mL). The resulting solution was stirred with a magnetic stir bar at room temperature and the reaction was monitored by GLC as follows: aliquot samples (ca. 0.1 mL) from the reaction mixture were hydrolyzed by aqueous KOH (45% wt.); the organic products (acetophenone and 1-phenylethanol) were extracted in diethyl ether, and this organic phase was analysed by quantitative GLC. The enantiomeric purity of 1-phenylethanol was assessed by GLC on a Chirasil-DEX CB column (110 °C, 0.70 bar). When the same reaction was carried out on a preparative scale, no aliquots were sampled and the final mixture was hydrolysed after 3 days and extracted as described above, to yield spectroscopically pure 1-phenylethanol in more than 95% isolated yield.

Acknowledgments

We thank the CNRS and PPG-SIPSY (PhD grant to V. B.) and the Consorzio Interuniversitario Nazionale Metodologie e Processi

Innovativi di Sintesi (grant to F. F.) for financial support of this research.

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Received February 24, 2004

