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Chiral 6,6′-Bis(oxazolyl)-1,1′-biphenyls as Ligands for Copper(I)-Catalyzed Asymmetric Cyclopropanation

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A series of chiral bis(oxazoline)s with biphenyl backbones were synthesized from enantiomerically pure (*S*)- and (*R*)-hexabenzyloxydiphenic acid (**1**) and their utility in copper(I)-catalyzed asymmetric cyclopropanation was investigated.

Introduction

Asymmetric catalysis is certainly one of the most important disciplines of enantioselective synthesis, a large number of chiral catalysts having been developed in recent years. Chiral transition metal catalysts usually involve a mono- or bidentate chiral ligand for the induction of asymmetry, axially chiral binaphthyl ligands containing C_2-symmetry axes having been introduced by Noyori in this context,[1] while very efficient catalysts based on axially chiral biphenyl ligands have also been developed for several types of reactions.[2] In addition to the chemistry of the known species, there is still demand for novel chiral ligands for exploration of new reactions or further improvement of the already established processes. In this paper we report the synthesis of several optically active bis(oxazoline)s with biphenyl backbones and their use as chiral ligands in the copper(I)-catalyzed asymmetric cyclopropanation of styrene with ethyl diazoacetate.

Results and Discussion

The axially chiral hexaoxydiphenoyl moiety is a constituent of many naturally occurring ellagitannins as well as the complex tannins.[3] Recently, we developed a practical method for the synthesis of ellagitannins[4] through the use of enantiomerically pure (*R*)- and (*S*)-hexabenzyloxydiphenic acids (R_a)-**1** and (S_a)-**1**.[5] As (R_a)-**1** and (S_a)-**1** are configurationally very stable compounds, we decided to extend their use as axially chiral ligands for asymmetric catalysis, and to this end we started from (S_a)-**1** or (R_a)-**1** and for the first time synthesized the following chiral ligands: (S_a,*S*,*S*)-**10**, (S_a,*S*,*S*)-**11**, (S_a)-**12**, (R_a,*R*,*R*)-**10**, (R_a,*S*,*S*)-**10**, (R_a,*R*,*R*)-**15**, (R_a)-**12**, and (R_a)-**16** (Scheme 1). To prepare these ligands, we first synthesized the (S_a)-configured β-hydroxylamides (S_a,*S*,*S*)-**7**, (S_a,*S*,*S*)-**8**, (S_a)-**9**, together with the (R_a)-configured β-hydroxylamides (R_a,*R*,*R*)-**7**, (R_a,*S*,*S*)-**7**, (R_a,*R*,*R*)-**13**, (R_a)-**9**, and (R_a)-**14**. For the synthesis of these β-hydroxylamides from enantiomerically pure (S_a)-**1** or (R_a)-**1**, prior activation of their carboxylic groups was necessary, and this was accomplished by treatment with thionyl chloride. The resulting axially chiral 2,2′,3,3′,4,4′-hexabenzyloxy-6,6′-biphenyldicarboxylic dichlorides (not shown) were then condensed in situ with one of the commercially available amines **2**–**6** to furnish the corresponding β-hydroxylamides (Scheme 1), and subsequent mesylation of the free hydroxy groups spontaneously generated the new ligands (Scheme 1).

To investigate the catalytic potential of these chiral ligands, we decided to perform a series of stereoselective copper(I)-catalyzed cyclopropanations of styrene (**17**) with ethyl diazoacetate (**18**), with freshly prepared chiral copper complex **II** being used for this purpose (Scheme 2). In principle, four stereoisomers [two pairs of *trans*-(1*S*,2*S*)-**19**/*trans*-(1*R*,2*R*)-**19** and *cis*-(1*S*,2*R*)-**19**/*cis*-(1*R*,2*S*)-**19** enantiomers] can be formed in this reaction; we expected that the presence of the enantiomeric ligands **I** in this reaction should favor the production of one of the two possible diastereomeric pairs, either *trans*-(1*R*,2*R*)-**19**/*cis*-(1*R*,2*S*)-**19** or *trans*-(1*S*,2*S*)-**19**/*cis*-(1*S*,2*R*)-**19** (Scheme 2).

We performed a series of cyclopropanation reactions in the presence of the new chiral ligands (4–10 mol-% loading of catalyst) and analyzed the product mixtures by gas chromatography (GC) on a chiral column with FS-Hydrodex-β-3P. For complete consumption of the ethyl diazoacetate (**18**), the styrene (**17**) was generally used in excess (2.5 equiv.). Before the determination of product composition by GC, the metal components were separated by flash chromatography on silica gel; the results of these reactions

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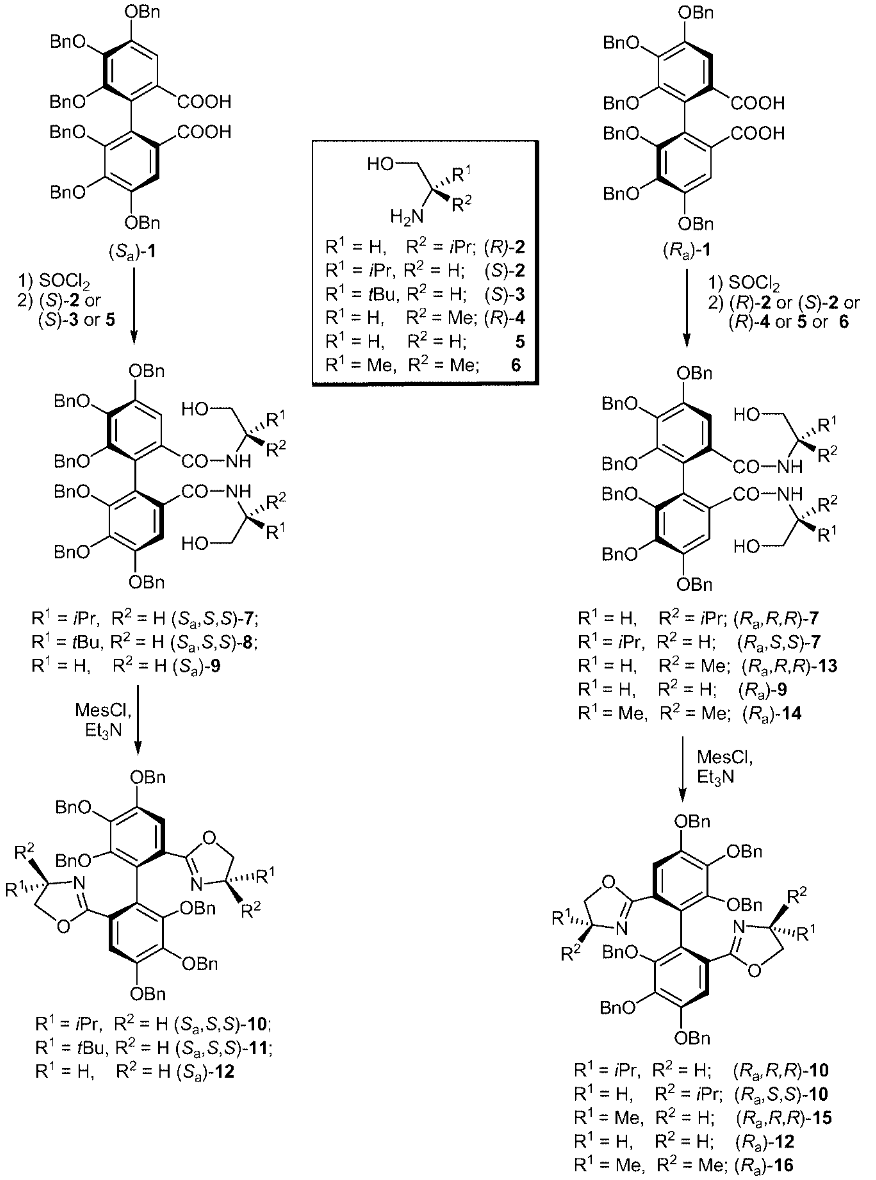
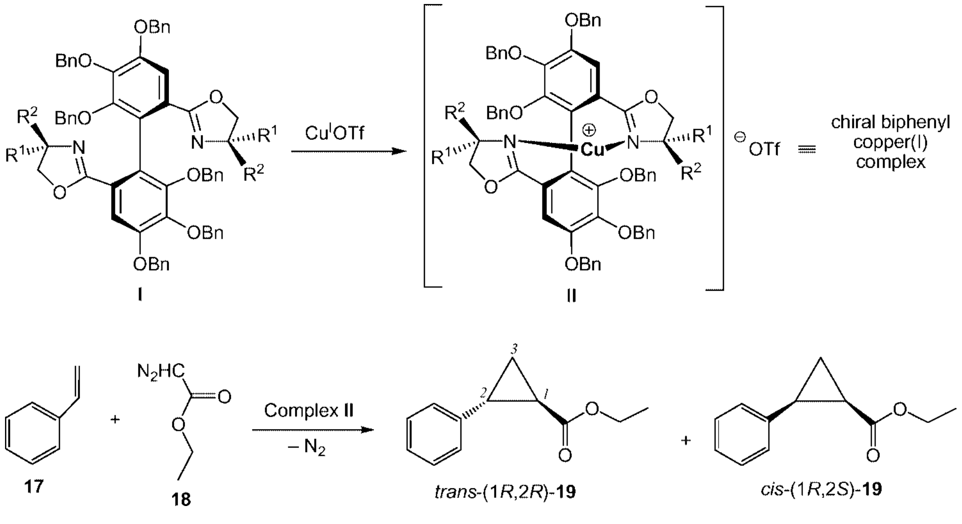


Scheme 1. Synthesis of the chiral ligands.



Scheme 2. Cu^I-catalyzed asymmetric cyclopropanation.

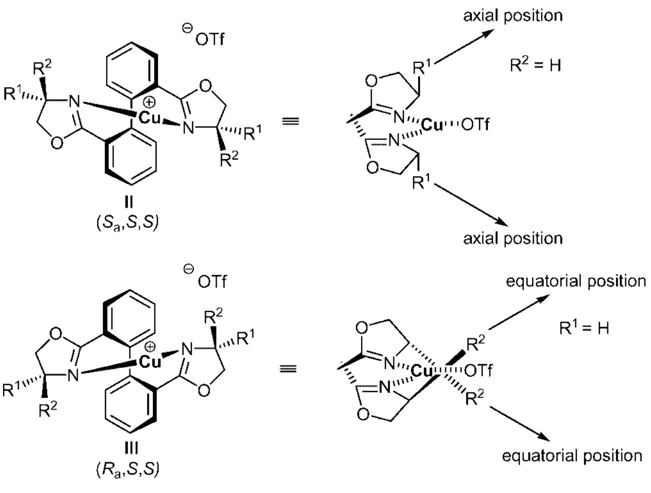
are summarized in Table 1 and show clearly that most of the ligands influenced the stereochemical course of the reaction. We were able to establish that the ligand (S_a,*S*,*S*)-**10** preferentially gave rise to the formation of a mixture of the diastereomeric compounds *trans*-(1*R*,2*R*)-**19**/*cis*-(1*R*,2*S*)-**19**, while its enantiomeric ligand (R_a,*R*,*R*)-**10** afforded the opposite diastereomeric pair *trans*-(1*S*,2*S*)-**19**/*cis*-(1*S*,2*R*)-**19**.

Table 1. Results of the enantioselective cyclopropanation of styrene with ethyl diazoacetate in the presence of various transition metal complexes **II** containing different chiral ligands.[a]

Ligand	Yield[b] (%)	Ratio[c] of *trans*/*cis*	% *ee*[c] (config.)[d] *trans*, *cis*
(S_a,*S*,*S*)-**10**	45	56:44	66 (1*R*,2*R*), 59 (1*R*,2*S*)
(R_a,*R*,*R*)-**10**	45	62:38	47 (1*S*,2*S*), 47 (1*S*,2*R*)
(S_a,*S*,*S*)-**11**	41	59:41	82 (1*R*,2*R*), 81 (1*R*,2*S*)
(R_a,*R*,*R*)-**15**	42	71:29	22 (1*S*,2*S*), 23 (1*S*,2*R*)
(R_a)-**16**	43	74:26	58 (1*S*,2*S*), 35 (1*S*,2*R*)

[a] Styrene (4.7 mmol), ethyl diazoacetate (1.9 mmol), $[\mathrm{Cu^IOTf}\text{-}(\mathrm{C_6H_6})_{0.5}]$ (1 mol-%), ligand (4–10 mol-%) in chloroform (4 mL) at room temperature for 24 h. [b] Isolated yield of a mixture of *trans*- and *cis*-**19**. [c] Determined by GC with FS-Hydrodex-β-3P. [d] By comparison of their specific rotations with those reported for *trans*- and *cis*-**19**.

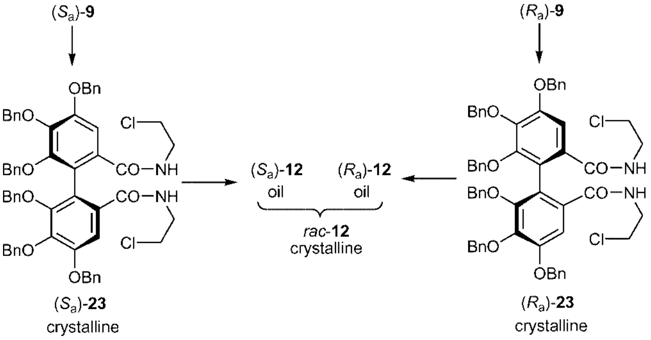
The highest enantioselectivity (82 % *ee*) was provided by the use of the chiral ligand (S_a,*S*,*S*)-**11**, probably arising from the presence of the bulky *tert*-butyl groups in proximity to the nitrogen atoms of the catalyst. This result is similar to the best known levels of asymmetric induction for this reaction [for cyclopropane *trans*-(1*R*,2*R*)-**19**, 87 % *ee*], when a chiral binaphthyl ligand was utilized.[6] At this stage we were also interested in testing the catalytic potential of (R_a,*S*,*S*)-**10**, with two opposite configurations of its chiral elements. Surprisingly, the metal complex **III** (Scheme 3) derived from this ligand was found to be catalytically completely inactive in this reaction. When, however, the reaction mixture was heated above 40 °C, the cyclopropanation reaction took place in a nonstereoselective manner, affording all four possible stereoisomers of **19**, so we assume that the copper(I) cation first coordinates on the ligand to generate the catalytically active transition metal complex **II**, as shown in Schemes 2 and 3. In the case of the chiral ligand (R_a,*S*,*S*)-**10**, however, the substituents R^2 are assumed to occupy equatorial positions and therefore hinder the active surface of the coordinated metal cation and preclude the approach of the corresponding transition metal complex **III** to the ethyl diazoacetate substrate.[2d] Obviously, at 40 °C or above the decomposition of the transition metal complex **III** takes place with release of copper(I) cation, which then catalyzes the process in a nonstereoselective manner.



The benzyloxy groups are omitted for clarity

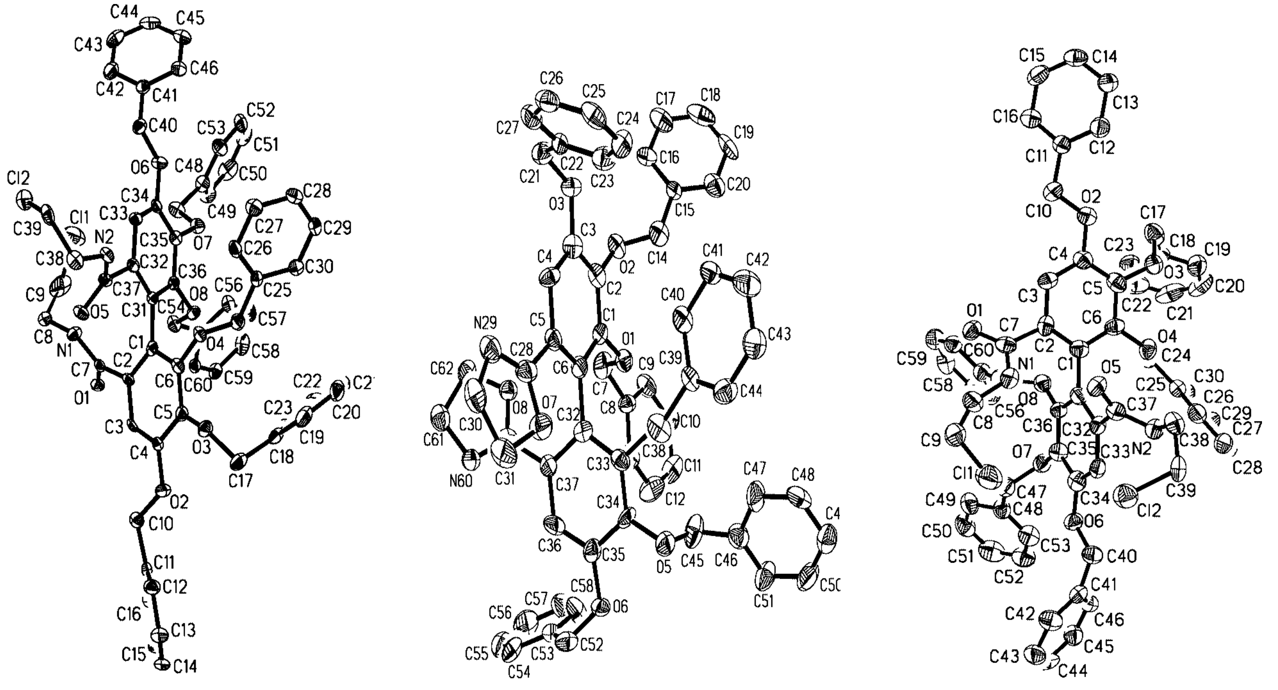
Scheme 3. Perspective illustration of the structures of the transition metal complexes **II** (S_a,*S*,*S*) and **III** (R_a,*S*,*S*).

With these results to hand, we next turned our attention to the axially chiral ligand (S_a)-**12** and its enantiomer (R_a)-**12** ($R^1 = R^2 = H$), which could also be synthesized by our synthetic approach, although because of their unusually high polarities these compounds could not be purified by chromatography on silica gel, so we decided to use them as chiral ligands in the asymmetric cyclopropanation without any further purification. Unfortunately, though, no significant reactivity could be observed when the reaction was performed at room temperature, despite the fact that these ligands do not have any sterically demanding R^1 and R^2 substituents. On the other hand, heating of the reaction mixture above 40 °C again gave all four possible *trans* and *cis* stereoisomers **19**, without any enantioselectivity. To ascertain the integrity of the structures (S_a)-**12** and (R_a)-**12**, we decided to synthesize them again, but by a different synthetic strategy, and so the stereoisomers (S_a)-**9** and (R_a)-**9** were first treated with thionyl chloride to produce β-chloramides (S_a)-**23** and (R_a)-**23**, respectively (Scheme 4). As these β-chloramides (S_a)-**23** and (R_a)-**23** are crystalline solids, we were able for the first time to determine their absolute configurations directly by X-ray analysis. X-ray structures of these compounds, in which the aromatic ring pairs in their biphenyl systems appear orthogonal to each other, allowing the determination of their absolute configurations as (S_a) and (R_a), respectively, are shown in Figure 1.



Scheme 4. Syntheses of (S_a)-**23** and (R_a)-**23** and also of *rac*-**12**.

Compounds (S_a)-**23** and (R_a)-**23** were then cyclized under basic conditions to provide the corresponding enantiomeric ligands (S_a)-**12** and (R_a)-**12**, both also displaying very high polarities (Scheme 4). All efforts to crystallize these compounds failed. However, as racemic mixtures have different physical properties from their pure enantiomers, we prepared a racemic mixture of (*rac*)-**12** by mixing equivalent



(S_a)-**23** *rac*-**12** (R_a)-**23**

Figure 1. X-ray structures of (S_a)- and (R_a)-**23** and also of *rac*-**12**.

amounts of (S_a)-**12** and (R_a)-**12**, and the resulting racemic mixture (*rac*)-**12** was fortunately a crystalline solid and we were able to establish its structure by X-ray analysis (Figure 1).

The ligand pair (S_a)-**12** and (R_a)-**12** with $R^1 = R^2 = H$ constitutes a solitary exception in this series; the high polarity is assumed to be the result of the absence of any bulky groups in the neighborhood of the nitrogen atoms, so the unhindered nitrogen atoms of these molecules can strongly interact with the surface of the silica gel. To test this hypothesis, we next synthesized ligand (R_a,*R*,*R*)-**15** (R^1 = Me, R^2 = H; Scheme 1), which possesses one methyl group in each oxazoline ring positioned in the neighborhood of the nitrogen atoms of the ligands. As predicted, this ligand displayed normal polarity and could be purified by chromatography on silica gel. The use of this ligand in the catalytic process resulted in the formation of the diastereomeric compounds (1*S*,2*S*)-**19**/(1*S*,2*R*)-**19**, which had also been obtained with the ligand (R_a,*R*,*R*)-**10**, though the enantioselectivity was shown to be lower than that observed with ligand (R_a,*R*,*R*)-**10**, probably because of the presence of the bulkier isopropyl groups. To study the behavior of axially chiral ligands lacking carbon-centered chirality, we next synthesized the ligand (R_a)-**16** with two methyl groups in the neighborhood of the nitrogen atoms ($R^1 = R^2$ = Me). Comparison of the results from this reaction with those obtained when (R_a,*R*,*R*)-**15** was used showed similar reactivity and catalytic potential: this is a very important result as it shows that biaryl ligands without carbon-centered chirality can also be catalytically active without any significant lowering of the *ee*s and, secondly, that the presence of the methyl groups, even in the equatorial positions, does not affect the activity of the catalysts **II**.

As representative examples, the absolute configurations of the products obtained from the reaction with ligand (S_a,*S*,*S*)-**11** were assigned as *trans*-(1*R*,2*R*)-**19** {$[\alpha]_D$ = –218.4 (*c* = 1.0, $CHCl_3$) (82 % *ee*)} and *cis*-(1*R*,2*S*)-**19** {$[\alpha]_D$ = –12.8 (*c* = 1.0, $CHCl_3$) (81 % *ee*)}. The specific rotations for these two stereoisomers **19** have been reported to be $[\alpha]_D$ = +18.6 (*c* = 1.01, $CHCl_3$) for *cis*-(1*S*,2*R*)-**19** (99 % *ee*) and $[\alpha]_D$ = +296 (*c* = 0.88, $CHCl_3$) for *trans*-(1*S*,2*S*)-**19** (99 % *ee*).[7] Chiral transition metal complexes **II** derived from the ligands (S_a)-**12**, (R_a)-**12**, and (R_a,*S*,*S*)-**10** are not included in Table 1 because they are not catalytically active in reactions performed at room temperature.

Summary

The synthesis of several chiral bidentate bis(oxazoline)s possessing biphenyl backbones and their application as ligands in asymmetric transition metal catalysis was described. Further detailed investigation concerning the inactivity of the chiral catalyst (R_a,*S*,*S*)-**10** is necessary in order to gain a better understanding of the catalytic process.

Experimental Section

General Remarks: All solvents were dried and purified by standard literature methods prior to use. Melting points were determined with a Büchi SMP-20 apparatus, IR spectra (film or KBr) were measured with a Nicolet 510 P FT-IR spectrometer, mass spectra were recorded with a Finnigan MAT 8200 apparatus, optical rotations were measured with a Perkin–Elmer Polarimeter 241, and elemental analyses were carried out with a Perkin–Elmer Elemental Analyzer 2400. Reactions were monitored by TLC on Merck aluminium sheets (Kieselgel 60 F_{254}) and preparative chromatography was carried out on silica gel 60 (70–230 mesh ASTM). ^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra were acquired with a Bruker AMX 500 spectrometer in $CDCl_3$, with TMS as internal standard, while X-ray structures were determined with a Bruker-AXS SMART APEX CCD diffractometer.

General Procedure I for the Preparation of β-Hydroxylamides: A solution of biaryldicarboxylic acid and Et_3N in dried dichloromethane was treated at 0 °C with thionyl chloride and the solution was stirred at room temperature for 3 h. The solvent and the thionyl chloride were evaporated at room temperature, the CH_2Cl_2 first in a rotary evaporator and then the excess thionyl chloride at high vacuum. The resulting dichloride was then redissolved in dry dichloromethane and treated dropwise at 0 °C with a solution of the chiral amine in dry dichloromethane. After addition of Et_3N in dry dichloromethane, the reaction mixture was stirred at room temperature for 5 h and then diluted with water and extracted three times with dichloromethane. The organic phases were washed once with a saturated solution of NaCl in water and dried with Na_2SO_4. After filtration, the solvent was evaporated and the resulting material was purified by chromatography on silica gel and elution with ethyl acetate/hexane.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(1*R*)-(1-methyl-2-hydroxyethyl)carboxamido]-1,1′-biphenyl [(R_a)-13]: This compound was prepared according to General Procedure I from (R_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and chiral amine (*R*)-**4** to give, after chromatographic purification, (R_a)-**13** as a yellow solid (0.39 g, 70%). M.p. 75 °C. $[\alpha]_D$ = –53.3 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 1.01 (d, *J* = 6.8 Hz, 6 H, CH_3), 2.41 (2 H, O*H*), 3.29–3.34 (m, 2 H, *H*-2), 3.39–3.42 (m, 2 H, *H*-2), 3.9–3.95 (m, 2 H, *H*-1), 4.86 (d, *J* = 11 Hz, 2 H, OCH_2Ph), 5.01 (d, *J* = 11 Hz, 2 H, OCH_2Ph), 5.02 (s, 4 H, OCH_2Ph), 5.24 (s, 4 H, OCH_2Ph), 6.78–7.56 (m, 32 H, Ar-H) ppm. ^{13}C NMR ($CDCl_3$): δ = 16.36 (q, *C*H_3), 48.34 (d, *C*-1), 66.44 (t, *C*-2), 71.47, 75.05, 75.47 (t, O*C*H_2Ph), 108.55 (d, HBDP-*C*-5, *C*-5′), 121.59 (s, HBDP-*C*-1, *C*-1′), 127.48, 127.61, 127.74, 127.85, 128.09, 128.15, 128.24, 128.35, 128.47, 128.66 (d, Ar-*C*), 136.42, 137.17, 137.7, 143.66, 150.98, 152.93 (s, Ar-*C*), 169.88 (s, *C*ONHR) ppm. IR (KBr): $\tilde{\nu}$ = 3386, 3064, 3024, 2933, 2868, 1636, 1530, 1450, 1098 cm^{-1}. MS (FAB/NBA): *m*/*z* (%) = 994.7 (30) $[M + 1]^+$. $C_{62}H_{60}N_2O_{10}$ (993.147): calcd. C 74.98, H 6.09, N 2.82; found C 74.7, H 5.95, N 2.6.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(1*R*)-(2-hydroxy-1-isopropylethyl)carboxamido]-1,1′-biphenyl [(R_a)-7]: This compound was prepared according to General Procedure I from (R_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and chiral amine (*R*)-**2** to give, after chromatographic purification, (R_a)-**7** as a yellow solid (0.41 g, 70%). M.p. 104 °C. $[\alpha]_D$ = –37 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.76–0.86 (dd, *J* = 14.3, 6.7 Hz, 12 H, CH_3), 1.72–1.88 (m, 2 H, *H*-*i*Pr), 2.5 (2 H, O*H*), 3.4–3.5 (m, 4 H, *H*-2), 3.59–3.7 (m, 2 H, *H*-1), 4.84 (d, *J* = 10.8 Hz, 2 H, OCH_2Ph), 5.03 (s, 4 H, OCH_2Ph), 5.05 (d, *J* = 10.8 Hz, 2 H, OCH_2Ph), 5.26 (s, 4 H, OCH_2Ph), 6.87–7.63 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 19.26, 19.67 (q, *C*H_3), 29.31 (d, *C*-*i*Pr), 58.53 (d, *C*-1), 64.0 (t, *C*-2), 71.9, 75.44, 75.81 (t, O*C*H_2Ph), 109.09 (d, HBDP-*C*-5, *C*-5′), 122.09 (s, HBDP-*C*-1, *C*-1′), 127.99, 128.16, 128.52, 128.64, 128.76, 128.86, 129.07 (d, Ar-*C*), 136.88, 137.6, 138.09, 144.17, 151.46, 153.32 (s, Ar-*C*), 170.73 (s, *C*ONHR) ppm. IR (KBr): $\tilde{\nu}$ = 3420, 3332, 3239, 3053, 2960, 1641, 1253 cm^{-1}. MS (FAB/NBA): *m*/*z* (%) = 1049.4 (27) $[M + 1]^+$. $C_{66}H_{68}N_2O_{10}$ (1049.254): calcd. C 75.55, H 6.53, N 2.67; found C 74.91, H 6.12, N 2.69.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(1*S*)-(2-hydroxy-1-isopropylethyl)carboxamido]-1,1′-biphenyl [(S_a)-7]: This compound was prepared according to General Procedure I from (S_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and chiral amine (*S*)-**2** to give, after chromatographic purification, (S_a)-**7** as a yellow solid (0.41 g, 70%). M.p. 104 °C. $[\alpha]_D$ = +37 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.76–0.86 (dd, *J* = 14.3, 6.7 Hz, 12 H, CH_3), 1.72–1.88 (m, 2 H, *H*-*i*Pr), 2.5 (2 H, O*H*), 3.4–3.5 (m, 4 H, *H*-2), 3.59–3.7 (m, 2 H, *H*-1), 4.84 (d, *J* = 10.8 Hz, 2 H, OCH_2Ph), 5.03 (s, 4 H, OCH_2Ph), 5.05 (d, *J* = 10.8 Hz, 2 H, OCH_2Ph), 5.26 (s, 4 H, OCH_2Ph), 6.87–7.63 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 19.26, 19.67 (q, *C*H_3), 29.31 (d, *C*-*i*Pr), 58.53 (d, *C*-1), 64.0 (t, *C*-2), 71.9, 75.44, 75.81 (t, O*C*H_2Ph), 109.09 (d, HBDP-*C*-5, *C*-5′), 122.09 (s, HBDP-*C*-1, *C*-1′), 127.99, 128.16, 128.52, 128.64, 128.76, 128.86, 129.07 (d, Ar-*C*), 136.88, 137.6, 138.09, 144.17, 151.46, 153.32 (s, Ar-*C*), 170.73 (s, *C*ONHR) ppm. IR (KBr): $\tilde{\nu}$ = 3420, 3332, 3239, 3053, 2960, 1641, 1253, 1098 cm^{-1}. MS (FAB/NBA): *m*/*z* (%) = 1049.4 (13) $[M + 1]^+$. $C_{66}H_{68}N_2O_{10}$ (1049.254): calcd. C 75.55, H 6.53, N 2.67; found C 75.33, H 5.67, N 2.76.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(1*S*)-(1-*tert*-butyl-2-hydroxyethyl)carboxamido]-1,1′-biphenyl [(S_a)-8]: This compound was prepared according to General Procedure I from (S_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and chiral amine (*S*)-**3** to give, after chromatographic purification, (S_a)-**8** as a yellow solid (0.5 g, 82%). M.p. 52 °C. $[\alpha]_D$ = +41 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.83 (s, 18 H, CH_3), 3.31–3.35 (dd, 2 H, *J* = 11.3, 8.1 Hz, *H*-2), 3.66–3.69 (dd, 2 H, *J* = 11.3, 3.3 Hz, *H*-2), 3.78–3.83 (m, 2 H, *H*-1), 4.82 (d, *J* = 10.8 Hz, 2 H, OCH_2Ph), 5.03 (m, 6 H, OCH_2Ph), 5.25 (s, 4 H, OCH_2Ph), 6.83–7.53 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 26.81 (q, *C*H_3), 33.41 (s, *C*-*t*Bu), 60.32 (d, *C*-1), 63.14 (t, *C*-2), 71.57, 74.91, 75.38 (t, O*C*H_2Ph), 108.89 (d, HBDP-*C*-5, *C*-5′), 122.15 (s, HBDP-*C*-1, *C*-1′), 127.49, 127.67, 127.72, 127.99, 128.03, 128.16, 128.31, 128.42, 128.64 (d, Ar-*C*), 136.61, 137.37, 137.32, 137.81, 143.88, 151.05, 152.78 (s, Ar-*C*), 170.6 (s, *C*ONHR) ppm. IR (KBr): $\tilde{\nu}$ = 3426, 3064, 3029, 2954, 2873, 1641, 1364, 1098 cm^{-1}. MS (FAB/NBA): *m*/*z* (%) = 1077.3 (10) $[M]^+$. $C_{68}H_{72}N_2O_{10}$ (1077.307): calcd. C 75.81, H 6.74, N 2.6; found C 75.5, H 6.77, N 2.63.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(2-hydroxy-1,1-dimethylethyl)carboxamido]-1,1′-biphenyl [(R_a)-14]: This compound was prepared according to General Procedure I from (R_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and amine **6** to give, after chromatographic purification, (R_a)-**14** as a yellow solid (0.47 g, 82%). M.p. 47 °C. $[\alpha]_D$ = –64 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 1.05 (d, *J* = 18 Hz, 12 H, CH_3), 3.36 (d, *J* = 11.6 Hz, 2 H, *H*-2), 3.52 (d, *J* = 11.6, 2 H, *H*-2), 4.69 (d, *J* = 10.7 Hz, 2 H, OCH_2Ph), 4.97 (d, *J* = 10.7, 2 H, OCH_2Ph), 5.04–5.09 (dd, *J* = 14.6, 10.4 Hz, 4 H, OCH_2Ph), 5.27 (s, 4 H, OCH_2Ph), 6.58 (s, 2 H, HBDP-*H*-5, *H*-5′), 6.92–7.55 (m, 30 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 23.54, 24.28 (q, *C*H_3), 56.48 (s, *C*-1), 69.82 (t, *C*-2), 71.53, 75.16, 75.52 (t, O*C*H_2Ph), 108.77 (d, HBDP-*C*-5, *C*-5′), 121.64 (s, HBDP-*C*-1, *C*-1′), 127.72, 127.75, 127.79, 128.16, 128.19, 128.39, 128.56, 128.70 (d, Ar-*C*), 133.79, 136.36, 137.09, 137.36, 143.85, 150. 63, 152.84 (s, Ar-*C*), 169.92 (s, *C*ONHR) ppm. IR (KBr): $\tilde{\nu}$ = 3410, 3295, 3055, 3032, 2965, 2877, 1641, 1357, 1253, 1098 cm^{-1}. MS (FAB/NBA): *m*/*z* (%) = 1022.6 (8) $[M + 1]^+$. $C_{64}H_{64}N_2O_{10}$ (1021.2): calcd. C 75.27, H 6.32, N 2.74; found C 75.01, H 6.16, N 2.24.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(2-chloroethyl)carboxamido]-1,1′-biphenyl [(R_a)-23]: This compound was prepared according to General Procedure I from (R_a)-**1** (0.5 g, 0.57 mmol), thionyl chloride (300 µL, 4.14 mmol), and amine **5** to give first (R_a)-**9**, which could be converted in situ into (R_a)-**23** by addition of one more portion of thionyl chloride (300 µL, 4.14 mmol) to the reaction mixture. The solvent and the excess thionyl chloride were evaporated and the crude product was recrystallized from chloroform/petroleum ether (20:80) to give colorless crystals (0.46 g, 87%). M.p. 105 °C. $[\alpha]_D$ = –61.5 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 3.33–3.4 (m, 6 H, *H*-1, *H*-2), 3.6–3.65 (m, 2 H, *H*-1, *H*-2), 4.8 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.93 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.99–5.05 (dd, J = 17.5, 10.7 Hz, 4 H, OC*H*$_2$Ph), 5.23 (s, 4 H, OC*H*$_2$Ph), 6.93–7.55 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 41.6, 43.04 (t, *C*-1, *C*-2), 71.39, 74.94, 75.42 (t, O*C*H$_2$Ph), 108.85 (d, HBDP-*C*-5, *C*-5′), 121.88 (s, HBDP-*C*-1, *C*-1′), 127.35, 127.56, 127.69, 128.09, 128.11, 128.22, 128.34, 128.55, 128.67 (d, Ar-*C*), 133.17, 136.48, 137.13, 137.72, 143.75, 150.99, 152.77 (s, Ar-*C*), 169.68 (s, *C*ONHR) ppm. IR (KBr): ṽ = 3291, 3229, 3053, 2910, 2875, 1630, 1343, 1098 cm^{-1}. MS (FAB/NBA): m/z (%) = 1001.5 (16) [M]$^+$. $C_{60}H_{54}Cl_2N_2O_8$ (1001.985): calcd. C 71.92, H 5.43, N 2.8; found C 71.84, H 5.04, N 2.7.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[*N*-(2-chloroethyl)carboxamido]-1,1′-biphenyl [(S_a)-23]: This compound was prepared according to General Procedure I from (S_a)-**1** (0.3 g, 0.34 mmol), thionyl chloride (300 µL, 4.14 mmol), and amine **5** to give (S_a)-**9**, which could be converted in situ to the (S_a)-**23** by addition of one more portion of thionyl chloride (300 µL, 4.14 mmol) to the reaction mixture. The solvent and the excess thionyl chloride were evaporated and the crude product was recrystallized from chloroform/petroleum ether (20:80) to give colorless crystals (0.26 g, 82%). M.p. 105 °C. $[\alpha]_D$ = +61.5 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 3.33–3.4 (m, 6 H, *H*-1, *H*-2), 3.6–3.65 (m, 2 H, *H*-1, *H*-2), 4.8 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.93 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.99–5.05 (dd, J = 17.5, 10.7 Hz, 4 H, OC*H*$_2$Ph), 5.23 (s, 4 H, OC*H*$_2$Ph), 6.93–7.55 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 41.6, 43.04 (t, *C*-1, *C*-2), 71.39, 74.94, 75.42 (t, O*C*H$_2$Ph), 108.85 (d, HBDP-*C*-5, *C*-5′), 121.88 (s, HBDP-*C*-1, *C*-1′), 127.35, 127.56, 127.69, 128.09, 128.11, 128.22, 128.34, 128.55, 128.67 (d, Ar-*C*), 133.17, 136.48, 137.13, 137.72, 143.75, 150.99, 152.77 (s, Ar-*C*), 169.68 (s, *C*ONHR) ppm. IR (KBr): ṽ = 3291, 3229, 3053, 2910, 2875, 1630, 1343, 1098 cm^{-1}. MS (FAB/NBA): m/z (%) = 1001.6 (14) [M]$^+$, $C_{60}H_{54}Cl_2O_8N_2$ (1001.985): calcd. C 71.92, H 5.43, N 2.8; found C 71.96, H 5.2, N 2.54.

General Procedure II for the Preparation of Chiral Ligands: A solution of β-hydroxylamide and Et_3N in dried dichloromethane was treated at 0 °C with mesyl chloride, allowed to warm to room temperature, and stirred for 3 h. The reaction mixture was then diluted with water, the products were extracted three times with dichloromethane, and the organic phase was then dried with Na_2SO_4. After filtration, the solvent was evaporated and the crude product was purified by chromatography on silica gel by elution with ethyl acetate/hexane.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis(4,5-dihydro-1,3-oxazol-2-yl)-1,1′-biphenyl [(R_a)-12]: This compound was prepared according to General Procedure II from (R_a)-**9** (0.15 g, 0.15 mmol), mesyl chloride (200 µL, 2.1 mmol), and Et_3N (3 mL). After chromatographic purification, (R_a)-**12** was obtained as a yellow oil (0.137 g, 95%). $[\alpha]_D$ = –21 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 3.79–3.86 (m, 4 H, *H*-4, *H*-5), 3.99–4.05 (m, 2 H, *H*-4, *H*-5), 4.07–4.13 (m, 2 H, *H*-4, *H*-5), 4.85 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.98 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 5.02 (s, 4 H, OC*H*$_2$Ph), 5.21–5.27 (dd, J = 19.0, 11.4 Hz, 4 H, OC*H*$_2$Ph), 6.93–7.56 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 54.56, 67.96 (t, *C*-4, *C*-5), 71.03, 74.48, 75.38 (t, O*C*H$_2$Ph), 110.04 (d, HBDP-*C*-5, *C*-5′), 126.01 (s, HBDP-*C*-1, *C*-1′), 127.25, 127.33, 127.66, 127.71, 127.89, 127.95, 128.01, 128.22, 128.27, 128.53 (d, Ar-*C*), 136.81, 137.56, 138.11, 144.15, 151.54, 151.97 (s, Ar-*C*), 165.35 (s, *C*NO) ppm. IR (KBr): ṽ = 3058, 3022, 2934, 2867, 1651, 1356, 1098 cm^{-1}. MS (FAB/NBA): m/z (%) = 929.5 (8) [M]$^+$. $C_{60}H_{52}N_2O_8$ (929.063): calcd. C 77.57, H 5.64, N 3.02; found C 77.39, H 5.72, N 2.78.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis(4,5-dihydro-1,3-oxazol-2-yl)-1,1′-biphenyl [(S_a)-12]: This compound was prepared according to General Procedure II from (S_a)-**9** (0.18 g, 0.18 mmol), mesyl chloride (200 µL, 2.1 mmol), and Et_3N (3 mL). After chromatographic purification, (S_a)-**12** was obtained as a yellow oil (0.129 g, 90%). $[\alpha]_D$ = +21 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 3.79–3.86 (m, 4 H, *H*-4, *H*-5), 3.99–4.05 (m, 2 H, *H*-4, *H*-5), 4.07–4.13 (m, 2 H, *H*-4, *H*-5), 4.85 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 4.98 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 5.02 (s, 4 H, OC*H*$_2$Ph), 5.21–5.27 (dd, J = 19.0, 11.4 Hz, 4 H, OC*H*$_2$Ph), 6.93–7.56 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 54.56, 67.96 (t, *C*-4, *C*-5), 71.03, 74.48, 75.38 (t, O*C*H$_2$Ph), 110.04 (d, HBDP-*C*-5, *C*-5′), 126.01 (s, HBDP-*C*-1, *C*-1′), 127.25, 127.33, 127.66, 127.71, 127.89, 127.95, 128.01, 128.22, 128.27, 128.53 (d, Ar-*C*), 136.81, 137.56, 138.11, 144.15, 151.54, 151.97 (s, Ar-*C*), 165.35 (s, *C*NO) ppm. IR (KBr): ṽ = 3058, 3022, 2934, 2867, 1651, 1356, 1098 cm^{-1}. MS (FAB/NBA): m/z (%) = 929.5 (8) [M]$^+$. $C_{60}H_{52}N_2O_8$ (929.063): calcd. C 77.57, H 5.64, N 3.02; found C 77.39, H 5.72, N 2.78.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[(4*R*)-4-methyl-4,5-dihydro-1,3-oxazol-2-yl]-1,1′-biphenyl [(R_a)-15]: This compound was prepared according to General Procedure II from (R_a,*R*,*R*)-**13** (0.295 g, 0.29 mmol), mesyl chloride (200 µL, 2.1 mmol), and Et_3N. After chromatographic purification, (R_a)-**15** was obtained as a yellow oil (0.27 g, 96%). $[\alpha]_D$ = +20.5 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 1.27 (d, J = 6.3 Hz, 6 H, C*H*$_3$), 3.49 (t, J = 7.1 Hz, 2 H, *H*-4, *H*-5), 4.15–4.2 (m, 4 H, *H*-4, *H*-5), 4.89 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 5.02 (s, 4 H, OC*H*$_2$Ph), 5.04 (d, J = 11.3 Hz, 2 H, OC*H*$_2$Ph), 5.22 (d, J = 11.4 Hz, 2 H, OC*H*$_2$Ph), 5.28 (d, J = 11.4 Hz, 2 H, OC*H*$_2$Ph), 6.97–7.55 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 21.15 (q, *C*H$_3$), 61.7 (d, *C*-4), 71.05 (t, O*C*H$_2$Ph), 74.36 (t, *C*-5), 74.4, 75.38 (t, O*C*H$_2$Ph), 110.09 (d, HBDP-*C*-5, *C*-5′), 126.28 (s, HBDP-*C*-1, *C*-1′), 127.19, 127.29, 127.45, 127.48, 127.62, 127.71, 127.90, 127.94, 128.24, 128.52, 128.56, 128.6, 128.64 (d, Ar-*C*), 136.84, 137.56, 138.23, 144.15, 151.57, 151.98 (s, Ar-*C*), 164.23 (s, *C*NO) ppm. IR (KBr): ṽ = 3055, 3012, 2930, 2865, 1657, 1355, 1095 cm^{-1}. $C_{62}H_{56}N_2O_8$ (957.117): calcd. C 77.8, H 5.9, N 2.93; found C 75.78, H 5.87, N 2.46.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[(4*R*)-4-isopropyl-4,5-dihydro-1,3-oxazol-2-yl]-1,1′-biphenyl [(R_a)-10]: This compound was prepared according to General Procedure II from (R_a,*R*,*R*)-**7** (0.1 g, 0.095 mmol), mesyl chloride (200 µL, 2.1 mmol), and Et_3N (3 mL). After chromatographic purification, (R_a)-**10** was obtained as a yellow oil (0.08 g, 83%). $[\alpha]_D$ = –10 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.82–0.95 (dd, J = 19.6, 6.7 Hz, 12 H, C*H*$_3$), 1.62–1.75 (m, 2 H, *H*-*i*Pr), 3.69–3.92 (m, 4 H, *H*-4, *H*-5), 4.03–4.15 (m, 2 H, *H*-4, *H*-5), 4.93 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 5.03 (s, 4 H, OC*H*$_2$Ph), 5.07 (d, J = 11 Hz, 2 H, OC*H*$_2$Ph), 5.22–5.35 (dd, J = 14.5, 11.5 Hz, 4 H, OC*H*$_2$Ph), 6.89–7.58 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 18.66, 19.57 (q, *C*H$_3$), 33.19 (d, *C*-*i*Pr), 70.51 (t, *C*-5), 71.63 (t, O*C*H$_2$Ph), 73.05 (d, *C*-4), 74.77, 75.83 (t, O*C*H$_2$Ph), 110.82 (d, HBDP-*C*-5, *C*-5′), 124.41 (s, HBDP-*C*-1, *C*-1′), 127.67, 128.05, 128.19, 128.36, 128.68, 128.94, 129.04 (d, Ar-*C*), 137.39, 138.02, 138.73, 144.64, 151.9, 152.15 (s, Ar-*C*), 163.71

(s, *C*NO) ppm. IR (KBr): $\tilde{\nu}$ = 3062, 3022, 2955, 2867, 1645, 1357, 1099 cm^{-1}. $C_{66}H_{64}N_2O_8$ (1013.223): calcd. C 78.24, H 6.37, N 2.76; found C 77.46, H 5.42, N 2.89.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[(4*S*)-4-isopropyl-4,5-dihydro-1,3-oxazol-2-yl]-1,1′-biphenyl [(S_a)-10]: This compound was prepared according to General Procedure II from (S_a,*S*,*S*)-**7** (1.1 g, 1.05 mmol), mesyl chloride (500 µL, 5.25 mmol), and Et_3N (5 mL). After chromatographic purification, (S_a)-**10** was obtained as a yellow oil (1.01 g, 95%). $[\alpha]_D$ = +10 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.82–0.95 (dd, *J* = 19.6, 6.7 Hz, 12 H, CH_3), 1.62–1.75 (m, 2 H, *H*-*i*Pr), 3.69–3.92 (m, 4 H, *H*-4, *H*-5), 4.03–4.15 (m, 2 H, *H*-4, *H*-5), 4.93 (d, *J* = 11 Hz, 2 H, OCH_2Ph), 5.03 (s, 4 H, OCH_2Ph), 5.07 (d, *J* = 11 Hz, 2 H, OCH_2Ph), 5.22–5.35 (dd, *J* = 14.5, 11.5 Hz, 4 H, OCH_2Ph), 6.89–7.58 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 18.66, 19.57 (q, CH_3), 33.19 (d, *C*-*i*Pr), 70.51 (t, *C*-5), 71.63 (t, OCH_2Ph), 73.05 (d, *C*-4), 74.77, 75.83 (t, OCH_2Ph), 110.82 (d, HBDP-*C*-5, *C*-5′), 124.41 (s, HBDP-*C*-1, *C*-1′), 127.67, 128.05, 128.19, 128.36, 128.68, 128.94, 129.04 (d, Ar-*C*), 137.39, 138.02, 138.73, 144.64, 151.9, 152.15 (s, Ar-*C*), 163.71 (s, *C*NO) ppm. IR (KBr): $\tilde{\nu}$ = 3062, 3022, 2955, 2867, 1645, 1357, 1099 cm^{-1}. $C_{66}H_{64}N_2O_8$ (1013.223): calcd. C 78.24, H 6.37, N 2.76; found C 77.04, H 5.38, N 2.6.

(S_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis[(4*S*)-4-*tert*-butyl-4,5-dihydro-1,3-oxazol-2-yl]-1,1′-biphenyl [(S_a)-11]: This compound was prepared according to General Procedure II from (S_a,*S*,*S*)-**8** (0.215 g, 0.2 mmol), mesyl chloride (500 µL, 5.25 mmol), and Et_3N (5 mL). After chromatographic purification, (S_a)-**11** was obtained as a yellow oil (0.18 g, 87%). $[\alpha]_D$ = –1.8 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 0.81 (s, 18 H, CH_3), 3.8–3.85 (m, 4 H, *H*-5), 3.99–4.05 (m, 2 H, *H*-4), 4.89–5.33 (m, 12 H, OCH_2Ph), 6.89–7.65 (m, 32 Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 25.92 (q, CH_3), 33.67 (s, *C*-*t*Bu), 68.19 (t, *C*-5), 71.36, 74.35, 75.47 (t, OCH_2Ph), 76.26 (d, *C*-4), 110.59 (d, HBDP-*C*-5, *C*-5′), 124.16 (s, HBDP-*C*-1, *C*-1′), 127.21, 127.53, 127.58, 127.79, 127.88, 127.95, 127.97, 128.03, 128.05, 128.25, 128.34, 128.52, 128.57, 128.64, 128.68 (d, Ar-*C*), 137.08, 137.65, 138.36, 144.33, 151.41, 151.66 (s, Ar-*C*), 162.82 (s, *C*NO) ppm. IR (KBr): $\tilde{\nu}$ = 3064, 3029, 2948, 2898, 2868, 1656, 1364, 1093 cm^{-1}. $C_{68}H_{68}N_2O_8$ (1041.276): calcd. C 78.44, H 6.58, N 2.69; found C 75.79, H 6.55, N 2.77.

(R_a)-2,2′,3,3′,4,4′-Hexabenzyloxy-6,6′-bis(4,4-dimethyl-4,5-dihydro-1,3-oxazol-2-yl)-1,1′-biphenyl [(R_a)-16]: This compound was prepared according to General Procedure II from (R_a)-**14** (0.18 g, 0.18 mmol), mesyl chloride (200 µL, 2.1 mmol), and Et_3N (3 mL). After chromatographic purification, (R_a)-**16** was obtained as a yellow oil (0.168 g, 96%). $[\alpha]_D$ = –2.7 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ = 1.23 (s, 6 H, CH_3), 1.33 (s, 6 H, CH_3), 3.69 (d, *J* = 7.8 Hz, 2 H, *H*-5), 3.82 (d, *J* = 7.8 Hz, 2 H, *H*-5), 4.97 (d, *J* = 10.9 Hz, 2 H, OCH_2Ph), 5.07 (s, 4 H, OCH_2Ph), 5.09 (d, *J* = 11 Hz, 2 H, OCH_2Ph), 5.26 (d, *J* = 11.3 Hz, 2 H, OCH_2Ph), 5.32 (d, *J* = 11.3 Hz, 2 H, OCH_2Ph), 7.04–7.58 (m, 32 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 28.12, 28.17 (q, CH_3), 67.07 (s, *C*-4), 71.18, 74.46, 75.48 (t, OCH_2Ph), 79.38 (t, *C*-5), 110.16 (d, HBDP-*C*-5, *C*-5′), 126.34 (s, HBDP-*C*-1, *C*-1′), 127.35, 127.79, 127.86, 127.96, 127.98, 128.04, 128.29, 128.54, 128.63, 136.89, 137.59, 138.31 (d, Ar-*C*), 144.13, 151.78, 152.05 (s, Ar-*C*), 162.79 (s, *C*NO) ppm. IR (KBr): $\tilde{\nu}$ = 3062, 3032, 2954, 2877, 1645, 1355, 1103 cm^{-1}. $C_{64}H_{60}N_2O_8$ (985.17): calcd. C 78.03, H 6.14, N 2.84; found C 77.26, H 6.33, N 2.86.

General Procedure III for the Preparation of the *cis*- and the *trans*-Cyclopropanes: Cyclopropanes were prepared from styrene (**17**) (4.7 mmol), ethyl diazoacetate (**18**) (1.9 mmol), $[Cu^IOTf(C_6H_6)_{0.5}]$ (1 mol-%), and chiral biaryl ligand (4–10 mol-%) in chloroform (4 mL) at room temperature. The reaction mixture was then stirred at room temperature for 24 h to give a mixture of *trans*- and *cis*-**19** as a yellow oil after purification of the crude products on silica gel. The composition of the diastereomeric mixture of products was determined by GC analysis with an FS-Hydrodex-β-3P chiral column.

Compound *trans*-19: ^{1}H NMR ($CDCl_3$): δ = 1.34 (t, *J* = 7.1 Hz, 3 H, CH_3), 1.3–1.38 (m, 1 H, *H*-3), 1.61–1.7 (m, 1 H, *H*-3), 1.92–2.0 (m, 1 H, *H*-1), 2.53–2.63 (m, 1 H, *H*-2), 4.15–4.28 (dd, *J* = 14.3, 7.1 Hz, 2 H, CH_2), 7.13–7.38 (m, 5 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 14.71 (q, CH_3), 17.51 (t, *C*-3), 24.63, 26.61 (d, *C*-1, *C*-2), 61.14 (t, CH_2), 126.59, 126.9, 128.9 (d, Ar-*C*), 140.56 (s, Ar-*C*), 173.85 (s, *C*OOEt) ppm.

Compound *cis*-19: ^{1}H NMR ($CDCl_3$): δ (ppm) = 1.01 (t, *J* = 7.1 Hz, 3 H, CH_3), 1.31–1.42 (m, 1 H, *H*-3), 1.71–1.81 (m, 1 H, *H*-3), 2.06–2.18 (m, 1 H, *H*-1), 2.56–2.69 (m, 1 H, *H*-2), 3.86–3.97 (dd, *J* = 14.3, 7.1 Hz, 2 H, CH_2), 7.18–7.34 (m, 5 H, Ar-*H*) ppm. ^{13}C NMR ($CDCl_3$): δ = 11.5 (t, CH_3), 14.42 (q, *C*-3), 22.22, 25.86 (d, *C*-1, *C*-2), 60.56 (t, CH_2), 127.04, 128.28, 129.72 (d, Ar-*C*), 136.99 (s, Ar-*C*), 171.37 (s, *C*OOEt) ppm.

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