

# Synthesis of a Class of Chiral-Bridged Phosphoramidite Ligands and Their Applications in the First Iridium-Catalyzed Asymmetric Addition of Arylboronic Acids to Isatins

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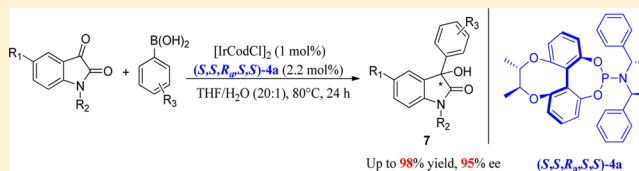
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## Supporting Information

**ABSTRACT:** A series of novel chiral phosphoramidite ligands based on chiral-bridged biphenyl backbones have been prepared conveniently and characterized. The ligands complexed with [IrCodCl]<sub>2</sub> provided the first iridium catalyst system for the asymmetric addition of arylboronic acids to N-protected isatins with high efficiency. When performed in THF/H<sub>2</sub>O at 80 °C with 2 equiv of the arylboronic acids, the transformations acquired good to excellent results (up to 98% yield and 95% ee).



## INTRODUCTION

Transition-metal-catalyzed asymmetric reactions lie at the core of organic synthesis, in which design and synthesis of efficient chiral ligands plays a key role. Since Monophos was synthesized in 1994<sup>1</sup> and employed in an asymmetric addition reaction later,<sup>2</sup> plenty of phosphoramidite ligands were developed for their easy synthesis, convenient modification, and potential applications in many kinds of enantioselective catalytic reactions.<sup>3</sup> Nowadays, chiral phosphoramidite compounds have become one of the most widely used ligands.

Chiral 3-substituted oxindoles are common structural motifs that constitute a useful class of compounds that can be found in various biologically active molecules and natural products.<sup>4</sup> A number of successful methods for 3-hydroxyoxindoles have been developed in recent years,<sup>5</sup> and the formation of quaternary carbon centers via addition of arylboronic acids to isatins seems to be one of the most useful methods for efficient construction of this structural scaffold. In 2006, Hayashi and co-workers first reported the asymmetric addition of arylboronic acids to N-protected isatins catalyzed with a Rh/(R)-MeO-mop complex, achieving high enantioselectivities and excellent yields. In their paper, a chiral phosphoramidite ligand was also tested; however, the obtained enantioselectivity was only 39% ee.<sup>6</sup> Meanwhile, use of a rhodium/chiral H<sub>8</sub>-BINOL-derived phosphoramidite as the catalyst afforded 55% ee in a similar reaction.<sup>7</sup> Recently, several ligands including Me-BIPAM,<sup>8</sup> H<sub>8</sub>-BINOL-derived phosphine-oxazoline ligands,<sup>9</sup> chiral NHC,<sup>10</sup> and chiral sulfoxide phosphine<sup>11</sup> complexed with ruthenium, palladium, copper, or rhodium were also employed

for the catalysis. However, most of the obtained ee values via these cheaper central metal catalytic systems such as Ru or Pd are still lower than those with a Rh complex. A relatively economical and efficient catalytic system is expected. Herein, we disclose the development of a new type of chiral phosphoramidite ligands based on chiral-bridged biphenyl backbones<sup>12</sup> and their applications in the first iridium-catalyzed asymmetric addition of arylboronic acids to N-protected isatins. The addition reactions acquired high yields and good to excellent enantioselectivities.

## RESULTS AND DISCUSSION

As shown in Scheme 1, synthesis of ligands **4a–h** was quite simple and robust. The key desymmetrized annulation diphenol intermediates **3a–c** were readily prepared from prochiral 2,2,6,6-tetrahydroxy-biphenyl with different chiral bis(mesylate) or bis(tosylate)<sup>13</sup> by a Williamson synthesis. Following a S<sub>N</sub>2 substitution reaction mechanism, the central chirality configuration of the ether-linked backbone became reversed from **2**. Meanwhile, perfect chirality transfer from central to axial chirality was performed, and products **3a–c** were given in 76%, 53%, and 68% yields, respectively.<sup>14</sup> Reaction of **3a–c** with phosphorus trichloride yielded the corresponding intermediates with phosphoryl chlorides first. Subsequent addition of the desired amine to the reaction system in the presence of a base finally acquired the phosphoramidite ligands **4a–d** and **4f–n**.

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Scheme 1. Synthesis of Ligands 4a–h

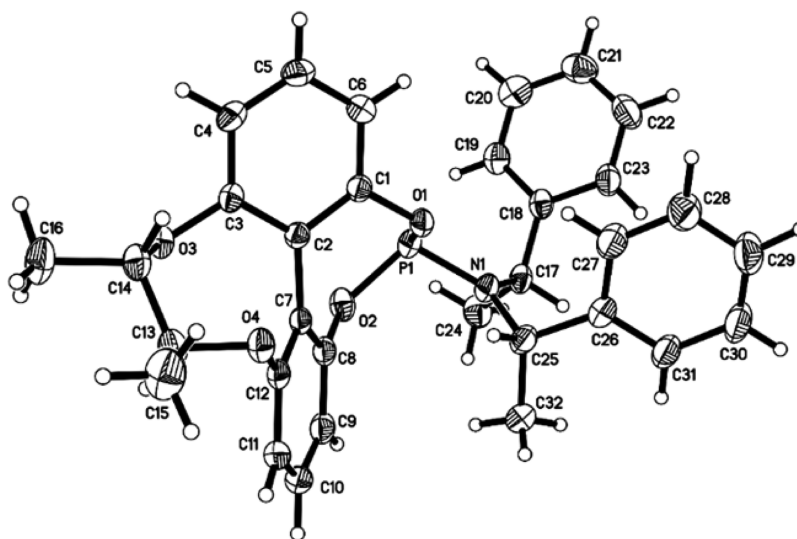
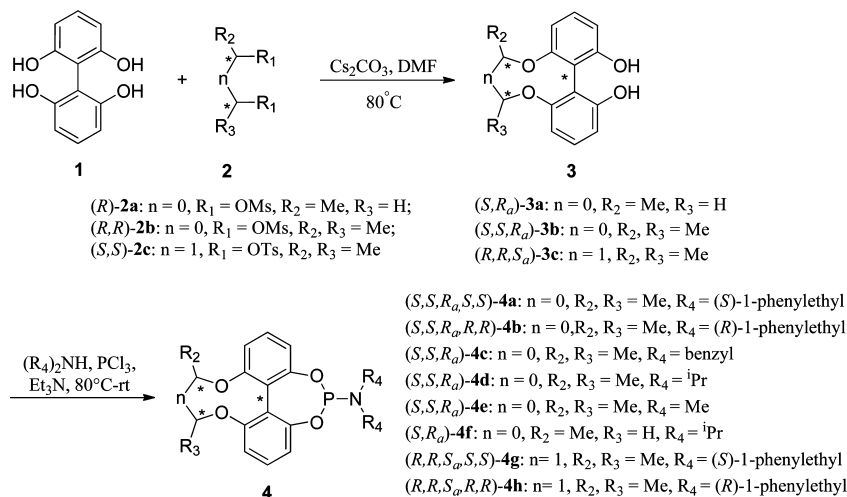
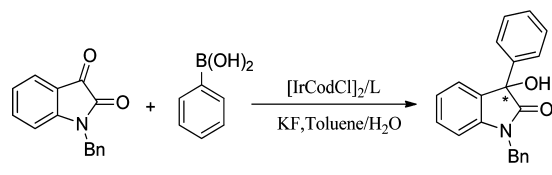


Figure 1. X-ray crystal structure of ligand  $(S,S,R_a,S,S)$ -**4a** (ORTEP drawing at 30% ellipsoid probability).

The dimethylamine-derived phosphoramidite ligand  $(S,S,R_a)$ -**4e** was prepared via another reaction of  $(S,S,R_a)$ -**3b** with hexamethylphosphorus triamide.<sup>1</sup> Through a single-crystal X-ray diffraction analysis of ligand  $(S,S,R_a,S,S)$ -**4a**, all its chiral configurations were confirmed (Figure 1). It is worthy to note that these ligands are stable enough and can be purified by common silica gel column chromatography without special precaution to water or air.

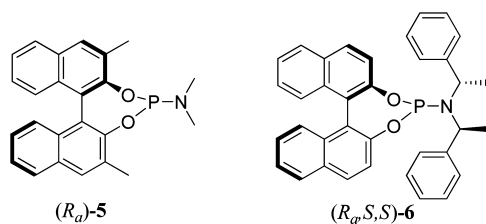
After acquiring the new type of ligands **4a–h**, we turned to investigation on the asymmetric addition reaction of *N*-protected isatin and phenylboronic acid. At first, complexes of ligand  $(S,S,R_a,S,S)$ -**4a** with different metal sources were examined for the reaction in the presence of 2.0 equiv of KF as base at 50 °C (Table 1, entries 1–5).  $[\text{IrCodCl}]_2$  as the metal source afforded the best result with the yield up to 88% and 84% ee (Table 1, entry 5). In contrast, both palladium- and rhodium-catalyzed reactions with this ligand showed comparable activities but much lower enantioselectivities (Table 1, entries 1–4). To gain insight into this catalytic system, we then tested the rest of the ligands (**4b–4h**) complexed with  $[\text{IrCodCl}]_2$  in the reaction. In comparison with phosphoramidite  $(S,S,R_a,S,S)$ -**4a** bearing a highly bulky bis[(*S*)-1-

phenylethyl]amine, ligand  $(S,S,R_a,R,R)$ -**4b** possessing a bis[(*R*)-1-phenylethyl]-amine counterpart provided a slight decrease in the yield and a much poorer enantiomeric excess (Table 1, entries 5 vs 6). This may be due to the considerable effects of matching/mismatching between stereochemical elements of the chiral amine and axial chirality in the ligands.<sup>15</sup> Similar phenomenon also occurred in the reaction for ligands  $(R,R,S_a,S,S)$ -**4g** and  $(R,R,S_a,R,R)$ -**4h** (Table 1, entries 11 vs 12). Analyzing the catalytic results, we found that axial chirality contrary to the central chiralities of the amine was the matched configuration. Ligands  $(S,S,R_a)$ -**4c–4e** only provided moderate yields and very low ee values of the phenyl adduct (Table 1, entries 7–9). The results indicated that both larger steric hindrance and proper central chirality in the amine unit of the phosphoramidite ligand led to higher enantioselection. Ligand  $(S,R_a)$ -**4f** derived from enantiomerically pure (*S*)-1,2-propanediol as the auxiliary shows two signals in <sup>31</sup>P NMR, because of the two possible diastereomers caused by the phosphorus center and the *C*<sub>1</sub> symmetrical propyldioxy backbone.<sup>16</sup> It also gave low enantioselectivity in spite of high yield (Table 1, entry 10). As a reference, we also used Feringa's (*R*)-BINOL-backbone ligands (*R<sub>a</sub>*)-**5** and (*R<sub>a</sub>*)-**6** (Figure 2) in this

Table 1. Metal Sources and Ligand Screening<sup>a</sup>


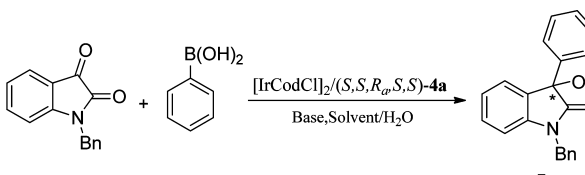
entry	metal	ligand	yield <sup>b</sup> (%)	ee <sup>c</sup> (%)
1	Rh(Cod) <sub>2</sub> BF <sub>4</sub>	(S,S,R <sub>w</sub> ,S,S)-4a	86	8
2	Rh(Cod) <sub>2</sub> Cl <sub>2</sub>	(S,S,R <sub>w</sub> ,S,S)-4a	69	14
3	[RhNBDCl] <sub>2</sub>	(S,S,R <sub>w</sub> ,S,S)-4a	86	2
4	Pd(OAc) <sub>2</sub>	(S,S,R <sub>w</sub> ,S,S)-4a	81	8
5	[IrCodCl] <sub>2</sub>	(S,S,R <sub>w</sub> ,S,S)-4a	88	84
6	[IrCodCl] <sub>2</sub>	(S,S,R <sub>w</sub> ,R,R)-4b	87	15
7	[IrCodCl] <sub>2</sub>	(S,S,R <sub>a</sub> )-4c	53	17
8	[IrCodCl] <sub>2</sub>	(S,S,R <sub>a</sub> )-4d	61	21
9	[IrCodCl] <sub>2</sub>	(S,S,R <sub>a</sub> )-4e	75	10
10	[IrCodCl] <sub>2</sub>	(S,R <sub>a</sub> )-4f	84	13
11	[IrCodCl] <sub>2</sub>	(R,R,S <sub>w</sub> ,S,S)-4g	48	55
12	[IrCodCl] <sub>2</sub>	(R,R,S <sub>w</sub> ,R,R)-4h	43	76
13	[IrCodCl] <sub>2</sub>	(R <sub>a</sub> )-5	32	6
14	[IrCodCl] <sub>2</sub>	(R <sub>w</sub> ,S,S)-6	83	81

<sup>a</sup>Reaction conditions: *N*-benzyl isatin (0.2 mmol), phenylboronic acid (2 equiv), [IrCodCl]<sub>2</sub> (1 mol %), ligand (2.2 mol %), KF (2 equiv), 50 °C, 48 h; solvent: THF/H<sub>2</sub>O (2 mL/0.1 mL). <sup>b</sup>Yield of isolated product. <sup>c</sup>Determined by chiral HPLC.

Figure 2. Ligands (R)-5 and (R<sub>w</sub>,S,S)-6.

model reaction. However, the former yielded a disappointing result (Table 1, entry 13). The latter provided a slight drop in the yield and enantioselectivity in comparison with ligand (S,S,R<sub>w</sub>,S,S)-4a (Table 1, entries 14 vs 5), and ligand (S,S,R<sub>w</sub>,S,S)-4a was shown to be the most effective for the arylation reaction. To improve the reaction, solvents, bases, and temperature were further optimized, and the results are outlined in Table 2. Conditional experiments showed that THF, [IrCodCl]<sub>2</sub>, and KF were the best combination for this reaction. It is noticed that our system does require adding water as a protic source. Without water, the yield of arylation product decreased dramatically from 95% to 37% (Table 2, entries 4 vs 11). While no ligand existed, [IrCodCl]<sub>2</sub> could just catalyze the reaction with low yield and racemic product (Table 2, entry 28). When no base was added, the reaction also acquired moderate enantioselectivity; however, the yield dropped sharply (Table 2, entry 29). The reaction temperature had little effect on enantiomeric excess of the product, but it influenced the yield significantly. When the temperature was raised from 50 to 80 °C, the yield increased from 64% to 98% (Table 2, entries 24–26).

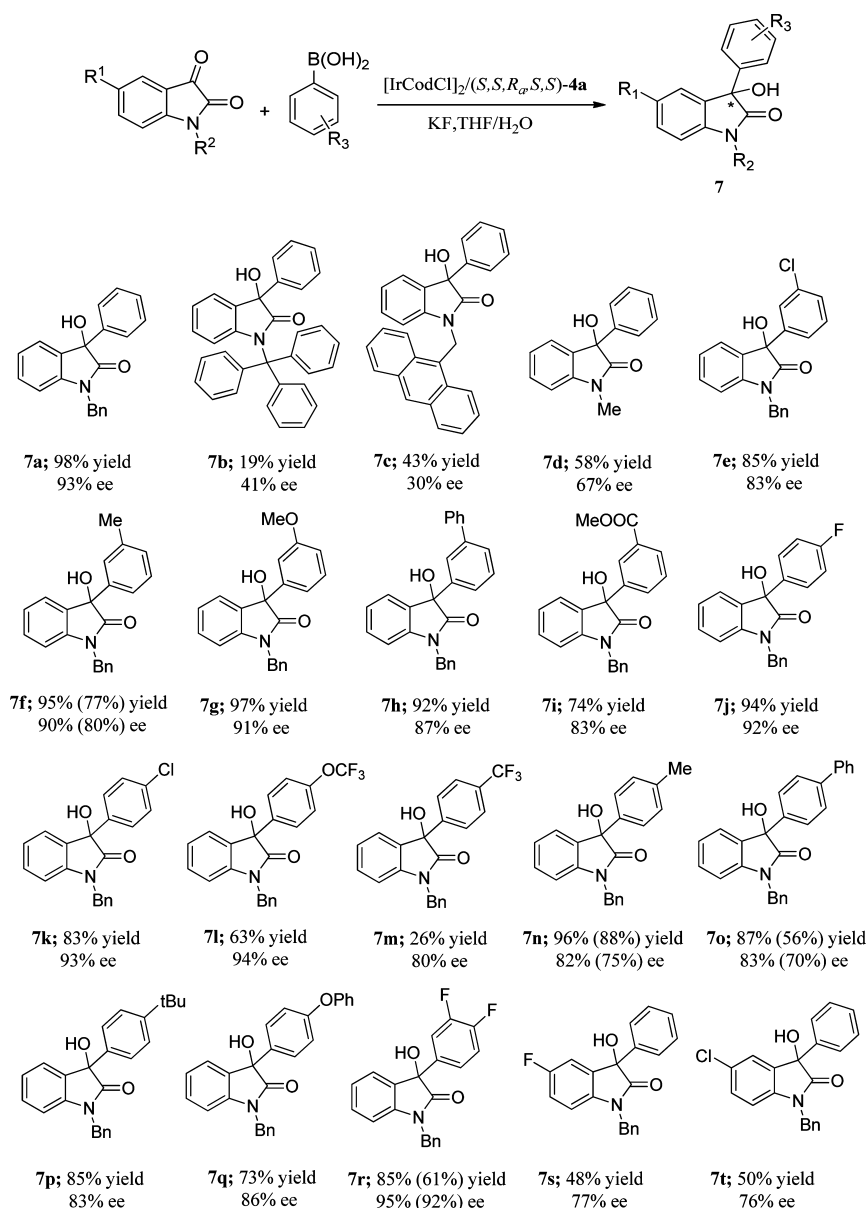
To evaluate the scope of the reaction, we examined different arylboronic acids and *N*-protected isatins under the optimal reaction conditions, and the results are summarized in Scheme 2. At first, various isatin substrates bearing methyl-, benzyl-, 1-

Table 2. Solvents, Bases, and Temperature Screening<sup>a</sup>


entry	metal	base	solvent	yield <sup>b</sup> (%)	ee <sup>c</sup> (%)
1	[IrCodCl] <sub>2</sub>	KF	EtOH/H <sub>2</sub> O	76	90
2	[IrCodCl] <sub>2</sub>	KF	<sup>i</sup> PrOH/H <sub>2</sub> O	66	90
3	[IrCodCl] <sub>2</sub>	KF	<sup>t</sup> BuOH/H <sub>2</sub> O	93	88
4	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	95	91
5	[IrCodCl] <sub>2</sub>	KF	MTBE/H <sub>2</sub> O	97	88
6	[IrCodCl] <sub>2</sub>	KF	DCM/H <sub>2</sub> O	45	42
7	[IrCodCl] <sub>2</sub>	KF	dioxane/H <sub>2</sub> O	58	79
8	[IrCodCl] <sub>2</sub>	KF	DME/H <sub>2</sub> O	92	86
9	[IrCodCl] <sub>2</sub>	KF	DMF/H <sub>2</sub> O	28	71
10	[IrCodCl] <sub>2</sub>	KF	xylylene/H <sub>2</sub> O	96	83
11	[IrCodCl] <sub>2</sub>	KF	THF	37	90
12	[IrCodCl] <sub>2</sub>	HKF	THF/H <sub>2</sub> O	81	90
13	[IrCodCl] <sub>2</sub>	K <sub>2</sub> CO <sub>3</sub>	THF/H <sub>2</sub> O	88	91
14	[IrCodCl] <sub>2</sub>	KOH	THF/H <sub>2</sub> O	83	51
15	[IrCodCl] <sub>2</sub>	K <sub>3</sub> PO <sub>4</sub>	THF/H <sub>2</sub> O	64	72
16	[IrCodCl] <sub>2</sub>	KO <sup>t</sup> Bu	THF/H <sub>2</sub> O	trace	ND <sup>d</sup>
17	[IrCodCl] <sub>2</sub>	CsF	THF/H <sub>2</sub> O	31	90
18	[IrCodCl] <sub>2</sub>	Cs <sub>2</sub> CO <sub>3</sub>	THF/H <sub>2</sub> O	54	79
19	[IrCodCl] <sub>2</sub>	Et <sub>3</sub> N	THF/H <sub>2</sub> O	39	88
20	[IrCodCl] <sub>2</sub>	LiOH H <sub>2</sub> O	THF/H <sub>2</sub> O	73	65
21	[IrCodCl] <sub>2</sub>	DIPEA	THF/H <sub>2</sub> O	<10	ND
22	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	27	93 <sup>e</sup>
23	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	50	88 <sup>f</sup>
24	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	64	90 <sup>g</sup>
25	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	82	90 <sup>h</sup>
26	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	98	93 <sup>i</sup>
27	–	KF	THF/H <sub>2</sub> O	–	– <sup>j</sup>
28	[IrCodCl] <sub>2</sub>	KF	THF/H <sub>2</sub> O	23	0 <sup>k</sup>
29	[IrCodCl] <sub>2</sub>	–	THF/H <sub>2</sub> O	17	67 <sup>l</sup>

<sup>a</sup>Reaction conditions: *N*-benzyl isatin (0.2 mmol), phenylboronic acid (2 equiv), [IrCodCl]<sub>2</sub> (1 mol %), ligand (2.2 mol %), base (2 equiv), 50 °C, 48 h; solvent: solvent/H<sub>2</sub>O (2 mL/0.1 mL). <sup>b</sup>Yield of isolated product. <sup>c</sup>Determined by chiral HPLC. <sup>d</sup>Not determined. <sup>e</sup>50 °C, 48 h, 1 equiv of base. <sup>f</sup>50 °C, 48 h, 3 equiv of base. <sup>g</sup>60 °C, 24 h, 1 equiv of base. <sup>h</sup>70 °C, 24 h, 1 equiv of base. <sup>i</sup>80 °C, 24 h, 1 equiv of base. <sup>j</sup>[IrCodCl]<sub>2</sub> was not used. <sup>k</sup>Ligand was not used. <sup>l</sup>Base was not used.

trityl- or 1-anthracen-9-ylmethyl substituents on their nitrogen atoms were selected for the reactions with phenylboronic acid. Benzyl-protected isatin got the best result; other *N*-protected isatins only acquired small amounts of the corresponding products with lower ee values (7a–7d). Further experiments showed that the 5-substituent of the *N*-benzyl protected isatins on the aromatic rings had a significant influence on this reaction. The addition of phenylboronic acid to *N*-benzyl-5-chloro or *N*-benzyl-5-fluoro isatin all obtained lower enantioselectivities and yields in contrast with the reaction of nonsubstituted *N*-benzyl-isatin (7s and 7t). Moreover, *N*-benzyl-5-methoxy-isatin and free isatin as the substrates achieved hardly any of arylation products. This displayed the necessity of the *N*-benzyl protection in the catalytic system. Then, the impact of boronic acids on the 1,2-addition reaction was explored. Arylboronic acids bearing weak electron-with-

Scheme 2. Catalytic Asymmetric Arylation of Isatins with Arylboronic Acids<sup>a</sup>

<sup>a</sup>Reaction conditions: N-protected isatins (0.2 mmol), arylboronic acids (2 equiv),  $[\text{IrCodCl}]_2$  (1 mol %), (*S,S,R<sub>a</sub>,S,S*)-**4a** (2.2 mol %), KF (1 equiv), 80 °C, 24 h; solvent: THF/H<sub>2</sub>O (2 mL/0.1 mL). Yield is that of isolated product. The ee values were determined by chiral HPLC. Data in the brackets represent the results with (*R<sub>a</sub>,S,S*)-**6** as the ligand. Other reaction conditions were the same as listed above.

drawing substituents at para or meta positions afforded the corresponding 3-aryl-3-hydroxy-2-oxindole derivatives in high yields with excellent enantioselectivities in the range 83–95% ees (**7e**, **7j–7l**, and **7r**), while introduction of a strong electron-withdrawing group to the phenyl ring led to a somewhat decrease of the yields and enantioselectivities (**7i** and **7m**). Interestingly, meta-electron-donating groups on the arylboronic acids resulted in high yields and enantioselectivities (**7f–7h**). However, para-substituted arylboronic acids possessing electron-donating substituents lowered both the yields and enantioselectivities (**7n–7q**). Besides, another phenomenon was also noted. By using ligand (*R<sub>a</sub>,S,S*)-**6** instead of (*S,S,R<sub>a</sub>,S,S*)-**4a**, the reactions afforded lower ee values and yields (**7f**, **7n**, **7o**, and **7r**). This demonstrates as well the effectiveness of our synthetic ligands. We infer that the increase of the rigidity of the ligands was favorable for the stereo-

selectivity and the yield of the reaction. We have also examined other substrates such as benzaldehyde, 2,2,2-trifluoroacetophenone, 2-oxo-4-phenylbutyric acid ethyl ester, *N,N*-dimethylsulfonyl-protected benzaldimine, and chalcone. However, those substrates reacted with aryl boronic acid in trace or did not react under the optimum conditions.

In conclusion, a class of novel chiral-bridged biphenyl phosphoramidite ligands has been synthesized on the basis of inducing stereochemistry right in the beginning of the synthetic pathway. Iridium-catalyzed enantioselective addition of arylboronic acids to isatins was successfully realized unprecedentedly along with use of the ligands. A series of chiral 3-aryl-3-hydroxy-2-oxindoles were afforded in high yields with up to 95% ee. The match of axial and central chiralities in the ligands showed significant influence on the reaction. Further

applications of these newly developed phosphoramidite ligands in other asymmetric catalysis are on going in our laboratory.

## EXPERIMENTAL SECTION

**General Information.** Anhydrous 1,4-dioxane, THF, and methyl *tert*-butyl ether (MTBE) were distilled from sodium and benzophenone before use. Anhydrous toluene, DMF, DME, Et<sub>3</sub>N, DCM, pyridine, and xylene were refluxed and distilled from CaH<sub>2</sub>. Ethanol, <sup>t</sup>BuOH, and <sup>i</sup>PrOH were distilled over magnesium turnings. Reagents were obtained from commercial sources and used directly without further purification unless otherwise specified. NMR spectra were recorded on a 400 or 300 MHz spectrometer. Optical rotations were measured on a polarimeter and calibrated with pure solvent as a blank. High-resolution mass spectrometry (HRMS) were performed on an electrospray ionization quadrupole time-of-flight (ESI-Q-TOF) mass spectrometer. Enantiomeric excesses (ee) were determined by high-performance liquid chromatography (HPLC) using Daicel Chiralpak OD-H, IA-3, or IC-3 columns.

**Preparation of (S)-[6,6'-(2*R*,4*R*-Pentadioxy)]-(2,2')-dihydroxy-(1,1')-biphenyl (*R,R,S<sub>a</sub>*-3c).** To a solution of 2,2',6,6'-tetrahydroxybiphenyl (**1**) (0.8 g, 3.67 mmol) and Cs<sub>2</sub>CO<sub>3</sub> (3.56 g, 10.93 mmol) in 120 mL of DMF was added a solution of compound (*S,S*)-2c (1.00 g, 2.43 mmol) in 100 mL of DMF over a period of 4 h at 80 °C under N<sub>2</sub>. The resulting suspension was stirred for 24 h at this temperature. The solvent was removed under reduced pressure, and the obtained crude product was poured into water and extracted three times with ethyl acetate. The extract was washed successively with 1 N HCl solution, water, and brine. The combined organic layer was separated, dried over MgSO<sub>4</sub>, and concentrated in vacuo. Purification of the residue by flash chromatography afforded a white solid (*R,R,S<sub>a</sub>*)-3c. White solid: 0.47 mg, 68% yield; mp 145–146 °C; [α]<sub>D</sub><sup>25</sup> +140 (*c* = 1.0, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.20–7.14 (m, 2H), 6.72 (d, *J* = 8.1 Hz, 2H), 6.65–6.58 (m, 2H), 4.69–4.57 (m, 2H), 1.36 (d, *J* = 6.5 Hz, 5H), 1.28 (t, *J* = 7.1 Hz, 2H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 158.6, 153.9, 129.4, 111.1, 110.1, 75.1, 40.8, 22.1. HRMS (ESI) [M + H]<sup>+</sup>: calcd for C<sub>17</sub>H<sub>19</sub>O<sub>4</sub><sup>+</sup> 287.1283, found 287.1279.

**General Procedure for the Synthesis of 4.** Under N<sub>2</sub> atmosphere and at 80 °C, a solution of PCl<sub>3</sub> (0.73 mmol), the corresponding amine (0.73 mmol), and triethylamine (3.65 mmol) in toluene (20 mL) was stirred for 6 h; then, a solution of diol **3** (0.73 mmol) in THF (10 mL) was added into this solution. The resulting suspension was stirred further for 12 h at room temperature. The precipitated Et<sub>3</sub>N·HCl salt was filtered off, and the solvent of the filtrate was removed under vacuum. The residue was then purified by flash column chromatography on silica gel (PE/EA = 10/1) to afford product ligand **4**.

**(*R*)-[6,6'-(2*S*,3*S*-Butadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-bis(*S*)-1-phenylethylamine ((*S,S,R<sub>a</sub>,S,S*)-4a).** White solid: 341.1 mg, 89% yield; mp 92–93 °C; [α]<sub>D</sub><sup>25</sup> +42 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.37–7.24 (m, 2H), 7.16–7.04 (m, 11H), 7.00–6.87 (m, 3H), 4.67–4.48 (m, 2H), 4.02–3.86 (m, 2H), 1.73 (d, *J* = 7.0 Hz, 6H), 1.42 (d, *J* = 5.8 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 159.2, 152.5, 152.4, 151.4, 142.9, 129.7, 129.2, 128.0, 127.7, 126.6, 118.5, 118.2, 117.5, 116.9, 85.4, 85.2, 52.2, 52.0, 18.9. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 144.69. HRMS (ESI) [M + H]<sup>+</sup>: calcd for C<sub>32</sub>H<sub>33</sub>NO<sub>4</sub>P<sup>+</sup> 526.2147, found 526.2155.

**(*R*)-[6,6'-(2*S*,3*S*-Butadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-bis(*R*)-1-phenylethylamine ((*S,S,R<sub>a</sub>,R,R*)-4b).** White solid: 325.7 mg, 85% yield; mp 83–84 °C; [α]<sub>D</sub><sup>25</sup> +354 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.39 (t, *J* = 8.1 Hz, 1H), 7.22–7.10 (m, 12H), 7.01 (d, *J* = 8.1 Hz, 1H), 6.92–6.86 (m, 2H), 4.57–4.43 (m, 2H), 4.01–3.92 (m, 2H), 1.70 (d, 6H), 1.43 (dd, *J* = 5.6, 2.8 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 159.4, 159.1, 152.8, 152.7, 151.7, 143.2, 129.7, 129.3, 128.0, 128.0, 127.7, 126.6, 118.5, 118.1, 118.1, 117.7, 116.7, 85.4, 85.3, 54.3, 54.2, 22.9, 22.8, 18.8, 18.8. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 149.67. HRMS (ESI) [M + H]<sup>+</sup>: calcd for C<sub>32</sub>H<sub>33</sub>NO<sub>4</sub>P<sup>+</sup> 526.2147, found 526.2162.

**(*R*)-[6,6'-(2*S*,3*S*-Butadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-dibenzylamine ((*S,S,R<sub>a</sub>*)-4c).** White

solid: 183.8 mg, 73% yield; mp 158–159 °C; [α]<sub>D</sub><sup>27</sup> +176 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.44–7.36 (m, 5H), 7.34–7.28 (m, 6H), 7.22–7.17 (m, 2H), 7.04 (d, *J* = 8.1 Hz, 1H), 6.90 (d, *J* = 7.9 Hz, 1H), 6.75 (d, *J* = 8.1 Hz, 1H), 4.33 (dd, *J* = 15.1, 7.9 Hz, 2H), 3.97–3.89 (m, 2H), 3.58–3.44 (m, 2H), 1.42 (dd, *J* = 13.5, 6.1 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 159.2, 158.8, 152.2, 152.1, 151.2, 137.9, 129.7, 128.8, 128.3, 127.2, 118.6, 117.9, 117.9, 117.4, 117.0, 85.3, 85.2, 48.3, 48.1, 18.9. <sup>31</sup>P NMR (121 MHz, CDCl<sub>3</sub>) δ 144.30. [M + H]<sup>+</sup>: calcd for C<sub>30</sub>H<sub>29</sub>NO<sub>4</sub>P<sup>+</sup> 498.1834, found 498.1851.

**(*R*)-[6,6'-(2*S*,3*S*-Butadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-diisopropylamine ((*S,S,R<sub>a</sub>*)-4d).** White solid: 282.9 mg, 78% yield; mp 130–131 °C; [α]<sub>D</sub><sup>27</sup> +64 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.36–7.25 (m, 2H), 7.05 (d, *J* = 8.1 Hz, 1H), 7.00–6.92 (m, 3H), 4.02–3.88 (m, 2H), 3.52–3.41 (m, 2H), 1.43 (dd, *J* = 6.0, 2.7 Hz, 6H), 1.21 (dd, *J* = 8.7, 6.9 Hz, 12H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 159.1, 158.9, 152.7, 152.6, 152.1, 129.6, 129.1, 118.2, 118.0, 118.0, 117.4, 116.9, 85.3, 85.2, 44.7, 44.6, 24.5, 24.4, 18.9. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 142.20. [M + H]<sup>+</sup>: calcd for C<sub>22</sub>H<sub>29</sub>NO<sub>4</sub>P<sup>+</sup> 402.1834, found 402.1841.

**(*R*)-[6,6'-(2*S*,3*S*-Butadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-dimethylamine ((*S,S,R<sub>a</sub>*)-4e).** White solid: 312 mg, 86% yield; mp 134–135 °C; [α]<sub>D</sub><sup>27</sup> +19 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.35 (t, *J* = 8.1 Hz, 1H), 7.29 (t, *J* = 8.1 Hz, 1H), 7.05 (d, *J* = 8.1 Hz, 1H), 7.00 (d, *J* = 8.1 Hz, 1H), 6.96 (d, *J* = 8.2 Hz, 1H), 6.93 (d, *J* = 8.2 Hz, 1H), 4.02–3.84 (m, 2H), 2.63 (d, *J* = 9.1 Hz, 6H), 1.43 (dd, *J* = 5.9, 2.9 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 160.2, 160.2, 153.7, 129.9, 115.5, 114.5, 114.3, 112.8, 86.1, 34.9, 34.5, 18.8. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 147.97. HRMS (ESI) [M + H]<sup>+</sup>: calcd for C<sub>18</sub>H<sub>21</sub>NO<sub>4</sub>P<sup>+</sup> 346.1203, found 346.1208.

**(*R*)-[6,6'-(2*S*-Propyldioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-diisopropylamine ((*S,R<sub>a</sub>*)-4f).** White solid: 189.2 mg, 67% yield; [α]<sub>D</sub><sup>27</sup> +47 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.38–7.31 (m, 1H), 7.01–7.27 (m, 1H), 7.08–7.04 (m, 1H), 7.02–6.93 (m, 3H), 4.46–4.40 (m, 1H), 4.37–4.26 (m, 1H), 3.79 (dd, *J* = 22.4, 11.8 Hz, 1H), 3.52–3.40 (m, 2H), 1.38 (dd, *J* = 6.5, 3.4 Hz, 3H), 1.21 (td, *J* = 7.6, 2.9 Hz, 12H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 159.4, 159.2, 159.0, 158.8, 152.6, 152.5, 152.2, 129.8, 129.7, 129.3, 129.2, 118.6, 118.5, 118.3, 118.3, 118.2, 118.2, 117.6, 117.3, 117.3, 80.3, 78.3, 44.7, 44.6, 24.5, 24.4, 17.2, 17.2. <sup>31</sup>P NMR (121 MHz, CDCl<sub>3</sub>) δ 151.56, 151.24. [M + H]<sup>+</sup>: calcd for C<sub>21</sub>H<sub>27</sub>NO<sub>4</sub>P<sup>+</sup> 388.1672, found 388.1649.

**(*S*)-[6,6'-(2*R*,4*R*-Pentadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-bis(*S*)-1-phenylethylamine ((*R,R,S<sub>a</sub>,S,S*)-4g).** White solid: 338.3 mg, 86% yield; mp 102–103 °C; [α]<sub>D</sub><sup>27</sup> –83 (*c* = 0.5 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.37–7.28 (m, 1H), 7.22–7.15 (m, 9H), 7.10 (t, 2H), 7.00 (t, *J* = 8.5 Hz, 2H), 6.83 (dd, *J* = 16.0, 8.1 Hz, 2H), 4.79–4.66 (m, 2H), 4.53–4.44 (m, 2H), 2.09–1.89 (m, 2H), 1.70 (d, *J* = 7.0 Hz, 6H), 1.44 (t, *J* = 6.4 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 158.2, 158.1, 153.0, 152.9, 152.1, 143.3, 129.1, 128.6, 128.0, 128.0, 127.7, 126.5, 116.1, 116.1, 115.9, 113.1, 111.6, 74.8, 74.4, 54.2, 54.1, 41.5, 22.9, 22.8, 22.6, 22.3. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 148.28. [M + K]<sup>+</sup>: calcd for C<sub>33</sub>H<sub>34</sub>NO<sub>4</sub>PK<sup>+</sup> 578.1862, found 578.1834.

**(*S*)-[6,6'-(2*R*,4*R*-Pentadioxy)]-(1,1')-biphenyl-(3,5-dioxa-4-phosphacyclohepta[e,g][1,4])-bis(*R*)-1-phenylethylamine ((*R,R,S<sub>a</sub>,R,R*)-4h).** White solid: 330.5 mg, 84% yield; mp 109–110 °C; [α]<sub>D</sub><sup>27</sup> +59 (*c* = 1.0 mg/mL, CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.31–7.25 (m, 2H), 7.13 (bs, 2H), 6.98 (dd, *J* = 13.6, 8.2 Hz, 2H), 6.89 (t, *J* = 7.5 Hz, 2H), 4.77–4.68 (m, 2H), 4.63–4.52 (m, 2H), 2.08–1.89 (m, 2H), 1.44 (dd, *J* = 6.4, 3.6 Hz, 6H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 158.1, 157.9, 152.6, 152.5, 151.9, 143.0, 128.9, 128.5, 128.2, 128.0, 127.7, 127.7, 126.5, 120.8, 118.8, 116.2, 116.2, 115.6, 113.3, 111.8, 74.8, 74.5, 52.2, 52.0, 41.7, 22.6, 22.3. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 143.28. [M + H]<sup>+</sup>: calcd for C<sub>33</sub>H<sub>35</sub>NO<sub>4</sub>P<sup>+</sup> 540.2298, found 540.2299.

**General Procedure for the Synthesis of 3-Aryl-3-hydroxyoxindoles 7a–7t.** Under an argon atmosphere, a solution of [IrCodCl]<sub>2</sub> (1.34 mg, 0.01 mmol) and (*S,S,R<sub>a</sub>,S,S*)-4a (2.2 mg, 0.021 mmol) in THF (1.0 mL) was stirred for 30 min at room temperature. Isatins

(0.20 mmol), arylboronic acids (0.4 mmol), and KF (11.6 mg, 0.1 mmol) were added. The resulting mixture was stirred for 24 h at 80 °C. Then, the solvent was evaporated under reduced pressure, and the residue was purified by flash column chromatography on silica gel with petroleum ether/EtOAc as eluent to afford the desired product.

**1-Benzyl-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7a).** White solid: 61.7 mg, 98% yield; mp 132–133 °C;  $[\alpha]_{\text{D}}^{18} +23$  ( $c = 1.0$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.46–7.42 (m, 2H), 7.40–7.28 (m, 9H), 7.25 (td,  $J = 7.8, 1.3$  Hz, 1H), 7.07 (td,  $J = 7.6, 0.9$  Hz, 1H), 6.82 (d,  $J = 7.8$  Hz, 1H), 5.08 (d,  $J = 15.7$  Hz, 1H), 4.87 (d,  $J = 15.7$  Hz, 1H), 3.41 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  142.6, 140.2, 135.4, 129.7, 128.9, 128.7, 128.3, 127.8, 127.3, 125.4, 125.0, 123.6, 109.8, 44.1. HPLC Daicel Chiralpak OD-H column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 93% ee, 13.9 min (minor), 15.6 min (major).

**1-Trityl-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7b).** White solid: 17.7 mg, 19% yield; mp 165–166 °C;  $[\alpha]_{\text{D}}^{18} -27$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.50–7.36 (m, 11H), 7.31–7.19 (m, 10H), 7.02–6.94 (m, 2H), 6.43–6.37 (m, 1H), 3.27 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  141.8, 129.9, 129.1, 128.7, 128.6, 128.3, 128.3, 127.8, 127.0, 125.4, 125.3, 125.0, 124.4, 123.6, 123.0, 116.2, 108.7, 78.0. HPLC Daicel Chiralpak OD-H column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 30% ee, 10.1 min (major), 11.3 min (minor).

**1-Anthracen-9-ylmethyl-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7c).** White solid: 35.6 mg, 43% yield; mp 169–170 °C;  $[\alpha]_{\text{D}}^{31} +11$  ( $c = 0.4$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.54 (s, 1H), 8.46–8.41 (m, 1H), 8.12–8.06 (m, 1H), 7.59–7.50 (m, 3H), 7.39–7.28 (m, 9H), 7.18–7.12 (m, 1H), 6.90–6.81 (m, 2H), 6.20 (d,  $J = 15.5$  Hz, 1H), 5.82 (d,  $J = 15.5$  Hz, 1H), 3.28 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.6, 147.1, 138.3, 131.4, 130.8, 129.8, 129.6, 128.5, 127.4, 127.0, 125.3, 125.2, 124.5, 123.3, 119.1, 112.1, 37.9. HPLC Daicel Chiralpak IC-3 column (flow rate = 0.7 mL/min, <sup>i</sup>PrOH/hex = 15/85, UV = 227 nm): 30% ee, 21.7 min (major), 28.0 min (minor).

**1-Methyl-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7d).** White solid: 27.7 mg, 58% yield; mp 138–139 °C;  $[\alpha]_{\text{D}}^{31} +52$  ( $c = 1.0$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.44–7.40 (m, 2H), 7.39–7.35 (m, 2H), 7.35–7.28 (m, 3H), 7.15–7.09 (m, 1H), 6.94 (d,  $J = 7.8$  Hz, 1H), 3.36 (s, 1H), 3.29 (s, 3H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.6, 143.5, 140.1, 131.6, 129.9, 128.6, 128.3, 125.4, 125.0, 123.6, 108.7, 26.5. HPLC Daicel Chiralpak OD-H column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 15/85, UV = 227 nm): 91% ee, 25.0 min (minor), 31.8 min (major).

**1-Benzyl-3-hydroxy-3-(3-chlorophenyl)-1,3-dihydro-indol-2-one (7e).** White solid: 59.3 mg, 85% yield; mp 138–139 °C;  $[\alpha]_{\text{D}}^{31} +24$  ( $c = 0.7$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.41 (s, 1H), 7.37–7.17 (m, 10H), 7.04 (t,  $J = 10.8, 4.2$  Hz, 1H), 6.79 (d,  $J = 7.7$  Hz, 1H), 5.01 (d,  $J = 15.5$  Hz, 1H), 4.79 (d,  $J = 15.5$  Hz, 1H), 4.41 (s, 1H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  177.5, 142.6, 135.5, 134.8, 131.7, 131.2, 130.2, 129.8, 129.0, 128.6, 128.1, 127.5, 127.0, 126.5, 125.1, 124.9, 124.1, 122.9, 111.3, 109.1, 44.5. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 83% ee, 17.5 min (major), 19.5 min (minor).

**1-Benzyl-3-hydroxy-3-*m*-tolyl-1,3-dihydro-indol-2-one (7f).** White solid: 62.51 mg, 95% yield; mp 155–156 °C;  $[\alpha]_{\text{D}}^{31} +54$  ( $c = 0.6$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.40–7.27 (m, 5H), 7.27–7.15 (m, 5H), 7.11 (d,  $J = 5.8$  Hz, 1H), 7.03 (t,  $J = 7.5$  Hz, 1H), 6.78 (d,  $J = 7.8$  Hz, 1H), 5.05 (d,  $J = 15.6$  Hz, 1H), 4.81 (d,  $J = 15.6$  Hz, 1H), 3.67 (s, 1H), 2.33 (s, 3H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  177.9, 142.8, 140.4, 138.5, 135.7, 132.1, 129.8, 129.3, 129.1, 128.7, 128.0, 127.6, 126.1, 125.2, 123.8, 122.6, 109.9, 78.3, 44.4, 22.0. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.7 mL/min, <sup>i</sup>PrOH/hex = 15/85, UV = 227 nm): 90% ee, 16.3 min (major), 18.4 min (minor).

**1-Benzyl-3-hydroxy-3-(3-methoxyphenyl)-1,3-dihydro-indol-2-one (7g).** White solid: 66.9 mg, 97% yield; mp 157–158 °C;  $[\alpha]_{\text{D}}^{30} +69$  ( $c = 0.6$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.35–7.27 (m, 4H), 7.27–7.18 (m, 4H), 7.06–6.99 (m, 2H), 6.91 (d,  $J = 7.7, 1.7$  Hz, 1H), 6.84 (dd,  $J = 8.2, 2.5$  Hz, 1H), 6.78 (d,  $J = 7.8$  Hz, 1H), 5.05 (d,  $J = 15.6$  Hz, 1H), 4.81 (d,  $J = 15.6$  Hz, 1H), 3.76 (s, 3H), 3.65 (s, 1H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  176.2, 158.5, 141.3, 140.5, 134.2, 130.4,

128.5, 128.4, 127.6, 126.5, 126.1, 123.7, 122.3, 116.3, 112.7, 109.8, 108.5, 76.8, 54.1, 43.0. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.7 mL/min, <sup>i</sup>PrOH/hex = 10/90, UV = 227 nm): 91% ee, 30.5 min (major), 33.8 min (minor).

**1-Benzyl-3-hydroxy-3-biphenyl-3-yl-1,3-dihydro-indol-2-one (7h).** White solid: 71.9 mg, 92% yield; mp 164–165 °C;  $[\alpha]_{\text{D}}^{30} +57$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.65 (d,  $J = 5.5$  Hz, 1H), 7.58–7.52 (m, 3H), 7.47–7.42 (m, 4H), 7.40–7.31 (m, 7H), 7.30–7.23 (m, 1H), 7.07 (t,  $J = 7.5$  Hz, 1H), 6.84 (d,  $J = 7.9$  Hz, 1H), 5.14 (d,  $J = 15.6$  Hz, 1H), 4.82 (d,  $J = 15.6$  Hz, 1H), 3.86 (d,  $J = 5.0$  Hz, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.7, 142.6, 141.6, 140.9, 140.8, 135.5, 131.8, 129.8, 129.1, 128.9, 128.7, 127.8, 127.4, 127.3, 127.1, 125.0, 124.1, 124.1, 123.7, 109.8, 78.1, 44.1. HRMS (ESI)  $[M + Na]^+$ : calcd for C<sub>27</sub>H<sub>21</sub>NO<sub>2</sub>Na<sup>+</sup> 414.1470, found 414.1482. HPLC Daicel Chiralpak IC-3 column (flow rate = 0.7 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 92% ee, 16.6 min (major), 18.9 min (minor).

**1-Benzyl-3-hydroxy-3-(3-methoxycarbonylphenyl)-1,3-dihydro-indol-2-one (7i).** White solid: 55.2 mg, 74% yield; mp 148–149 °C;  $[\alpha]_{\text{D}}^{30} +55$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.14 (s, 1H), 8.02 (d,  $J = 7.7$  Hz, 1H), 7.63 (d,  $J = 7.7$  Hz, 1H), 7.58–7.52 (m, 1H), 7.45 (t,  $J = 7.8$  Hz, 1H), 7.39–7.25 (m, 6H), 7.11–7.04 (m, 1H), 6.85 (d,  $J = 7.8$  Hz, 1H), 5.09 (d,  $J = 15.6$  Hz, 1H), 4.89 (d,  $J = 15.6$  Hz, 1H), 3.93 (d,  $J = 3.1$  Hz, 3H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.3, 166.7, 155.7, 142.6, 140.7, 135.3, 131.2, 131.2, 130.7, 130.1, 129.8, 129.7, 129.6, 129.0, 128.9, 127.9, 127.3, 126.5, 125.0, 123.8, 121.9, 120.1, 116.3, 110.0, 52.2, 44.2, 29.7. HRMS (ESI)  $[M + Na]^+$ : calcd for C<sub>23</sub>H<sub>19</sub>NO<sub>4</sub>Na<sup>+</sup> 396.1206, found 396.1207. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 83% ee, 23.4 min (major), 25.7 min (minor).

**1-Benzyl-3-hydroxy-3-(4-fluorophenyl)-1,3-dihydro-indol-2-one (7j).** White solid: 62.6 mg, 94% yield; mp 145–146 °C;  $[\alpha]_{\text{D}}^{30} +34$  ( $c = 0.6$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.43–7.37 (m, 2H), 7.36–7.23 (m, 7H), 7.13–6.99 (m, 3H), 6.83 (d,  $J = 7.8$  Hz, 1H), 5.05 (d,  $J = 15.6$  Hz, 1H), 4.84 (d,  $J = 15.6$  Hz, 1H), 3.73 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.5, 162.7 (d,  $J = 247.3$  Hz), 142.6, 136.0, 135.9, 135.3, 131.4, 130.0, 128.9, 127.9, 127.4 (d,  $J = 8.3$  Hz), 127.3, 125.0, 123.7, 115.6 (d,  $J = 21.7$  Hz), 109.9, 44.1. <sup>19</sup>F NMR (377 MHz, CDCl<sub>3</sub>)  $\delta$  -113.78. HRMS (ESI)  $[M + Na]^+$ : calcd for C<sub>21</sub>H<sub>16</sub>FNO<sub>2</sub>Na<sup>+</sup> 356.1057, found 356.1067. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.7 mL/min, <sup>i</sup>PrOH/hex = 15/85, UV = 227 nm): 92% ee, 16.5 min (major), 20.0 min (minor).

**1-Benzyl-3-hydroxy-3-(4-chlorophenyl)-1,3-dihydro-indol-2-one (7k).** White solid: 65.6 mg, 94% yield; mp 147–148 °C;  $[\alpha]_{\text{D}}^{30} +25$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.40–7.24 (m, 10H), 7.23–7.19 (m, 1H), 7.04 (t,  $J = 7.5$  Hz, 1H), 6.81–6.76 (m, 1H), 5.00 (d,  $J = 15.6$  Hz, 1H), 4.78 (d,  $J = 15.6$  Hz, 1H), 4.35 (s, 1H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  177.6, 142.6, 139.0, 135.5, 134.4, 131.7, 130.1, 129.1, 128.9, 128.1, 127.5, 127.2, 125.1, 124.0, 110.1, 110.0, 44.4. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 93% ee, 21.6 min (major), 26.2 min (minor).

**1-Benzyl-3-hydroxy-3-(4-trifluoromethoxyphenyl)-1,3-dihydro-indol-2-one (7l).** White solid: 50.2 mg, 63% yield; mp 109–110 °C;  $[\alpha]_{\text{D}}^{30} +33$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.45 (t,  $J = 5.7$  Hz, 2H), 7.39–7.25 (m, 7H), 7.20 (d,  $J = 8.4$  Hz, 2H), 6.84 (d,  $J = 7.8$  Hz, 1H), 5.05 (d,  $J = 15.6$  Hz, 1H), 4.85 (d,  $J = 15.6$  Hz, 1H), 3.87 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.3, 149.1, 142.5, 138.8, 135.2, 131.3, 130.1, 129.0, 127.9, 127.3, 127.1, 125.0, 123.8, 120.4 (q,  $J = 255.9$  Hz), 121.0, 110.0, 77.6, 44.1. <sup>19</sup>F NMR (377 MHz, CDCl<sub>3</sub>)  $\delta$  -57.79. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min, <sup>i</sup>PrOH/hex = 20/80, UV = 227 nm): 94% ee, 17.2 min (major), 21.4 min (minor).

**1-Benzyl-3-hydroxy-3-(4-trifluoromethylphenyl)-1,3-dihydro-indol-2-one (7m).** White solid: 19.9 mg, 26% yield; mp 145–146 °C;  $[\alpha]_{\text{D}}^{30} +48$  ( $c = 0.5$ , CHCl<sub>3</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.60 (d,  $J = 8.3$  Hz, 2H), 7.52 (d,  $J = 8.3$  Hz, 2H), 7.39–7.31 (m, 5H), 7.31–7.23 (m, 2H), 7.08 (t,  $J = 7.5$  Hz, 1H), 6.85 (d,  $J = 7.9$  Hz, 1H), 5.05 (d,  $J = 15.6$  Hz, 1H), 4.84 (d,  $J = 15.6$  Hz, 1H), 4.30 (s, 1H). <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  177.2, 144.2, 142.5, 135.2, 131.3, 130.2 (q,  $J = 32.2$  Hz), 130.2, 129.0, 128.0, 127.3, 125.9, 125.6 (q,  $J = 3.8$  Hz),

125.0, 124.0 (q,  $J = 270.4$  Hz), 123.9, 110.0, 77.9, 44.2.  $^{19}\text{F}$  NMR (377 MHz,  $\text{CDCl}_3$ )  $\delta$  -62.66. HRMS (ESI)  $[\text{M} + \text{Na}]^+$ : calcd for  $\text{C}_{22}\text{H}_{16}\text{F}_3\text{NO}_2\text{Na}^+$  406.1025, found 406.1024. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 80% ee, 14.9 min (major), 16.9 min (minor).

**1-Benzyl-3-hydroxy-3-*p*-tolyl-1,3-dihydro-indol-2-one (7n).** White solid: 63.1 mg, 96% yield; mp 155–156 °C;  $[\alpha]_{\text{D}}^{20} +28$  ( $c = 0.5$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.36–7.26 (m, 7H), 7.26–7.18 (m, 2H), 7.15 (d,  $J = 8.4$  Hz, 2H), 7.03 (t,  $J = 7.5$  Hz, 1H), 6.77 (d,  $J = 7.8$  Hz, 1H), 4.94 (dd,  $J = 66.3$ , 15.6 Hz, 2H), 3.33 (s, 1H), 2.34 (s, 3H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  178.0, 142.7, 138.2, 137.5, 135.7, 132.2, 129.8, 129.5, 129.1, 127.9, 127.5, 125.6, 125.2, 123.8, 109.9, 78.3, 44.4, 21.6. HPLC Daicel Chiralpak OD-H column (flow rate = 0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 82% ee, 14.8 min (minor), 16.1 min (major).

**1-Benzyl-3-hydroxy-4-biphenyl-4-yl-1,3-dihydro-indol-2-one (7o).** White solid: 68.0 mg, 87% yield; mp 169–170 °C;  $[\alpha]_{\text{D}}^{20} +19$  ( $c = 0.5$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.62–7.56 (m, 4H), 7.53–7.49 (m, 2H), 7.46 (t,  $J = 7.5$  Hz, 2H), 7.39–7.31 (m, 6H), 7.31–7.25 (m, 2H), 7.16–7.03 (m, 1H), 6.84 (d,  $J = 7.9$  Hz, 1H), 5.10 (d,  $J = 15.6$  Hz, 1H), 4.89 (d,  $J = 15.6$  Hz, 1H), 3.41 (s, 1H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  177.6, 142.7, 141.3, 140.6, 139.1, 135.4, 131.5, 129.9, 128.8, 127.9, 127.5, 127.3, 127.1, 125.8, 125.0, 123.7, 109.9, 100.0, 77.9, 44.1. HPLC Daicel Chiralpak IC-3 column (flow rate = 0.7 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 83% ee, 16.6 min (major), 22.8 min (minor).

**1-Benzyl-3-hydroxy-3-(4-*tert*butylphenyl)-1,3-dihydro-indol-2-one (7p).** White solid: 63.0 mg, 85% yield; mp 135–136 °C;  $[\alpha]_{\text{D}}^{20} +30$  ( $c = 0.5$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.35 (d,  $J = 0.9$  Hz, 3H), 7.34–7.28 (m, 6H), 7.26–7.23 (m, 1H), 7.22–7.18 (m, 1H), 7.04 (t,  $J = 7.5$  Hz, 1H), 6.77 (d,  $J = 7.8$  Hz, 1H), 5.04 (d,  $J = 15.6$  Hz, 1H), 4.83 (d,  $J = 15.7$  Hz, 1H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  177.9, 151.5, 142.8, 137.3, 135.6, 131.8, 129.9, 129.1, 127.9, 127.5, 125.8, 125.3, 123.7, 110.0, 109.9, 78.1, 44.4, 34.9, 31.6. HPLC Daicel Chiralpak IC-3 column (flow rate = 0.7 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 83% ee, 52.6 min (major), 55.6 min (minor).

**1-Benzyl-3-hydroxy-3-(3,4-fluorophenyl)-1,3-dihydro-indol-2-one (7q).** White solid: 59.4 mg, 73% yield; mp 138–139 °C;  $[\alpha]_{\text{D}}^{20} +30$  ( $c = 0.5$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.43–7.23 (m, 11H), 7.17–7.06 (m, 2H), 7.05–6.97 (m, 3H), 6.81 (d,  $J = 7.8$  Hz, 1H), 5.06 (d,  $J = 15.7$  Hz, 1H), 4.86 (d,  $J = 15.7$  Hz, 1H), 3.45 (s, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  177.6, 157.6, 156.7, 142.6, 135.4, 134.7, 131.5, 129.9, 129.8, 128.9, 127.8, 127.3, 127.0, 125.0, 123.6, 119.2, 118.7, 109.8, 44.1. HRMS (ESI)  $[\text{M} + \text{H}]^+$ : calcd for  $\text{C}_{27}\text{H}_{22}\text{NO}_3^+$  408.1594, found 408.1598. HPLC Daicel Chiralpak IC-3 column (flow rate = 0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 86% ee, 20.4 min (major), 23.1 min (minor).

**1-Benzyl-3-hydroxy-3-(3,4-fluorophenyl)-1,3-dihydro-indol-2-one (7r).** White solid: 59.6 mg, 85% yield; mp 137–138 °C;  $[\alpha]_{\text{D}}^{20} +39$  ( $c = 0.5$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.41–7.23 (m, 8H), 7.18–6.99 (m, 3H), 6.84 (d,  $J = 7.7$  Hz, 1H), 5.03 (d,  $J = 15.6$  Hz, 1H), 4.82 (d,  $J = 15.6$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  177.2, 151.5 (dd,  $J = 247.3$ , 12.7 Hz), 149.9 (dd,  $J = 247.6$ , 12.6 Hz), 142.4, 137.3 (d,  $J = 4.2$  Hz), 135.2, 131.2, 130.2, 129.0, 128.0, 127.3, 124.9, 123.9, 121.6 (dd,  $J = 6.5$ , 3.7 Hz), 117.4 (d,  $J = 17.5$  Hz), 115.1 (d,  $J = 18.8$  Hz), 110.0, 44.1.  $^{19}\text{F}$  NMR (377 MHz,  $\text{CDCl}_3$ )  $\delta$  -136.44, -136.50, -138.07, -138.13. HRMS (ESI)  $[\text{M} + \text{Na}]^+$ : calcd for  $\text{C}_{21}\text{H}_{15}\text{F}_2\text{NO}_2\text{Na}^+$  374.0963, found 374.0970. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 10/90$ , UV = 227 nm): 95% ee, 26.7 min (major), 32.3 min (minor).

**1-Benzyl-5-fluoro-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7s).** White solid: 31.9 mg, 48% yield; mp 151–152 °C;  $[\alpha]_{\text{D}}^{20} +11$  ( $c = 0.3$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.50–7.30 (m, 9H), 7.29 (s, 1H), 7.05 (dd,  $J = 7.6$ , 2.6 Hz, 1H), 6.94 (td,  $J = 8.8$ , 2.6 Hz, 1H), 6.73 (dd,  $J = 8.6$ , 4.0 Hz, 1H), 5.07 (d,  $J = 15.7$  Hz, 1H), 4.87 (d,  $J = 15.7$  Hz, 1H), 3.50 (s, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  177.6, 159.6 (d,  $J = 241.5$  Hz), 139.7, 138.4, 135.1, 133.2 (d,  $J = 7.6$  Hz), 129.0, 128.8, 128.6, 127.9, 127.3, 125.2, 116.1 (d,  $J = 23.7$  Hz), 113.1 (d,  $J = 24.9$  Hz), 110.51 (d,  $J = 7.9$  Hz), 44.2.  $^{19}\text{F}$  NMR (377 MHz,  $\text{CDCl}_3$ )  $\delta$  -118.89. HPLC Daicel Chiralpak IA-3 column (flow rate =

0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 77% ee, 16.0 min (minor), 17.1 min (major).

**1-Benzyl-5-chloro-3-hydroxy-3-phenyl-1,3-dihydro-indol-2-one (7t).** White solid: 34.9 mg, 50% yield; mp 157–158 °C;  $[\alpha]_{\text{D}}^{20} +98$  ( $c = 0.3$ ,  $\text{CHCl}_3$ ).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.45–7.31 (m, 9H), 7.30–7.28 (m, 2H), 7.22 (dd,  $J = 8.4$ , 2.1 Hz, 1H), 6.73 (d,  $J = 8.4$  Hz, 1H), 5.06 (d,  $J = 15.7$  Hz, 1H), 4.87 (d,  $J = 15.7$  Hz, 1H), 3.48 (s, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  177.3, 141.1, 139.6, 134.9, 133.2, 129.7, 129.0, 129.0, 128.9, 128.7, 128.0, 127.3, 125.5, 125.2, 110.8, 44.2. HPLC Daicel Chiralpak IA-3 column (flow rate = 0.5 mL/min,  $^i\text{PrOH}/\text{hex} = 20/80$ , UV = 227 nm): 76% ee, 18.0 min (major), 21.7 min (minor).

## ■ ASSOCIATED CONTENT

### Supporting Information

Crystallographic data (CIF file) of (*S,S,R<sub>w</sub>,S,S*)-**4a**;  $^1\text{H}$ ,  $^{13}\text{C}$ , and  $^{31}\text{P}$  NMR spectra and HPLC chromatograms for all described compounds. The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b00595.

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### Notes

The authors declare no competing financial interest.

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## ■ REFERENCES

- Hulst, R.; de Vries, N. K.; Feringa, B. L. *Tetrahedron: Asymmetry* **1994**, *5*, 699–708.
- de Vries, A. H. M.; Meetsma, A.; Feringa, B. L. *Angew. Chem., Int. Ed.* **1996**, *35*, 2374–2376.
- (a) Zhang, H.; Fang, F.; Xie, F.; Yu, H.; Yang, G.; Zhang, W. *Tetrahedron Lett.* **2010**, *51*, 3119–3122. (b) Arnold, L. A.; Imbos, R.; Mandoli, A.; de Vries, A. H. M.; Naasz, R.; Feringa, B. L. *Tetrahedron* **2000**, *56*, 2865–2878. (c) Kurihara, K.; Sugishita, N.; Oshita, K.; Piao, D.; Yamamoto, Y.; Miyaura, N. *J. Org. Chem.* **2007**, *69*, 428–435. (d) Keller, E.; Maurer, J.; Naasz, R.; Schader, T.; Meetsma, A.; Feringa, B. L. *Tetrahedron: Asymmetry* **1998**, *9*, 2409–2413. (e) Zhou, H.; Wang, W.-H.; Fu, Y.; Xie, J.-H.; Shi, W.-J.; Wang, L.-X.; Zhou, Q.-L. *J. Org. Chem.* **2003**, *68*, 1582–1584. (f) Palais, L.; Mikhel, I. S.; Bournaud, C.; Micouin, L.; Falciola, C. A.; Vuagnoux-d'Augustin, M.; Rosset, S.; Bernardinelli, G.; Alexakis, A. *Angew. Chem., Int. Ed.* **2007**, *46*, 7462–7465. (g) Teichert, J. F.; Feringa, B. L. *Angew. Chem., Int. Ed.* **2010**, *49*, 2486–2528. (h) Castello, L. M.; Najera, C.; Sansano, J. M.; Larranaga, O.; de Cozar, A.; Cossio, F. P. *Org. Lett.* **2013**, *15*, 2902–2905. (i) von Delius, M.; Le, C. M.; Dong, V. M. *J. Am. Chem. Soc.* **2012**, *134*, 15022–15032. (j) Giacomin, F.; Meetsma, A.; Panella, L.; Lefort, L.; de Vries, A. H. M.; de Vries, J. G. *Angew. Chem., Int. Ed.* **2007**, *46*, 1497–1500. (k) Van den Berg, M.; Minnaard, A. J.; Haak, R. M.; Leeman, M.; Schudde, E. P.; Meetsma, A.; Feringa, B. L.; De Vries, A. H. M.; Maljaars, C. E. P.; Willans, C. E.; Hyett, D.; Boogers, J. A. F.; Henderickx, H. J. W.; De Vries, J. G. *Adv. Synth. Catal.* **2003**, *345*, 308–323.
- (a) Tokunaga, T.; Hume, W. E.; Nagamine, J.; Kawamura, T.; Taiji, M.; Nagata, R. *Bioorg. Med. Chem. Lett.* **2005**, *15*, 1789–1792. (b) Tokunaga, T.; Hume, W. E.; Umezome, T.; Okazaki, K.; Ueki, Y.; Kumagai, K.; Hourai, S.; Nagamine, J.; Seki, H.; Taiji, M.; Noguchi, H.; Nagata, R. *J. Med. Chem.* **2001**, *44*, 4641–4649. (c) Marti, C.; Carreira,

E. M. *Eur. J. Org. Chem.* **2003**, 2209–2219. (d) Raunak, Kumar, V.; Mukherjee, S.; Poonam; Prasad, A. K.; Olsen, C. E.; Schaffer, S. J. C.; Sharma, S. K.; Watterson, A. C.; Errington, W.; Parmar, V. S. *Tetrahedron* **2005**, *61*, 5687–5697. (e) Khuzhaev, V. U.; Zhalolov, I.; Turgunov, K. K.; Tashkhodzhaev, B.; Levkovich, M. G.; Aripova, S. F.; Shashkov, A. S. *Chem. Nat. Compd.* **2004**, *40*, 269–272.

(5) (a) Shirai, T.; Ito, H.; Yamamoto, Y. *Angew. Chem., Int. Ed.* **2014**, *53*, 2658–2661. (b) Lu, S.; Poh, S. B.; Siau, W.-Y.; Zhao, Y. *Angew. Chem., Int. Ed.* **2013**, *52*, 1731–1734. (c) Guo, X.; Liu, W.; Hu, W. *Chem.—Asian J.* **2014**, *9*, 117–120. (d) Barroso, S.; Blay, G.; Cardona, L.; Fernandez, I.; Garcta, B.; Pedro, J. R. *J. Org. Chem.* **2004**, *69*, 6821–6829. (e) Qiao, X.-C.; Zhu, S.-F.; Zhou, Q.-L. *Tetrahedron: Asymmetry* **2009**, *20*, 1254–1261. (f) Hanhan, N. V.; Sahin, A. H.; Chang, T. W.; Fettingner, J. C.; Franz, A. K. *Angew. Chem., Int. Ed.* **2010**, *49*, 744–747. (g) Tomita, D.; Yamatsugu, K.; Kanai, M.; Shibasaki, M. *J. Am. Chem. Soc.* **2009**, *131*, 6946–6948. (h) Zhang, Z.; Zheng, W.; Antilla, J. C. *Angew. Chem., Int. Ed.* **2011**, *50*, 1135–1138. (i) Yin, L.; Kanai, M.; Shibasaki, M. *Angew. Chem., Int. Ed.* **2011**, *50*, 7620–7623. (j) Li, Y.; Zhu, D.-X.; Xu, M.-H. *Chem. Commun.* **2013**, *49*, 11659–11661.

(6) Shintani, R.; Inoue, M.; Hayashi, T. *Angew. Chem., Int. Ed.* **2006**, *45*, 3353–3356.

(7) Toullec, P. Y.; Jagt, R. B. C.; de Vries, J. G.; Feringa, B. L.; Minnaard, A. J. *Org. Lett.* **2006**, *8*, 2715–2718.

(8) Yamamoto, Y.; Yohda, M.; Shirai, T.; Ito, H.; Miyaura, N. *Chem.—Asian J.* **2012**, *7*, 2446–2449.

(9) Li, Q.; Wan, P.; Wang, S.; Zhuang, Y.; Li, L.; Zhou, Y.; He, Y.; Cao, R.; Qiu, L.; Zhou, Z. *Appl. Catal., A* **2013**, *458*, 201–206.

(10) (a) Liu, Z.; Gu, P.; Shi, M.; McDowell, P.; Li, G. *Org. Lett.* **2011**, *13*, 2314–2317. (b) Shintani, R.; Takatsu, K.; Hayashi, T. *Chem. Commun.* **2010**, *46*, 6822–6824.

(11) (a) Gui, J.; Chen, G.; Cao, P.; Liao, J. *Tetrahedron: Asymmetry* **2012**, *23*, 554–563. (b) Lai, H.; Huang, Z.; Wu, Q.; Qin, Y. *J. Org. Chem.* **2009**, *74*, 283–288.

(12) (a) Zhang, Z.; Qian, H.; Longmire, J.; Zhang, X. *J. Org. Chem.* **2000**, *65*, 6223–6226. (b) Qiu, L.; Wu, J.; Chan, S.; Au-Yeung, T. T.-L.; Ji, J.-X.; Guo, R.; Pai, C.-C.; Zhou, Z.; Li, X.; Fan, Q.-H.; Chan, A. S. C. *Proc. Natl. Acad. Sci. U.S.A.* **2004**, *101*, 5815–5820. (c) Qiu, L.; Kwong, F. Y.; Wu, J.; Lam, W. H.; Chan, S.; Yu, W.-Y.; Li, Y.-M.; Guo, R.; Zhou, Z.; Chan, A. S. C. *J. Am. Chem. Soc.* **2006**, *128*, 5955–5965.

(13) (a) Tuyet, T. M. T.; Harada, T.; Hashimoto, K.; Hatsuda, M.; Oku, A. *J. Org. Chem.* **2000**, *65*, 1335–1343. (b) Harada, T.; Tuyet, T. M. T.; Oku, A. *Org. Lett.* **2000**, *2*, 1319–1322.

(14) Wang, S.; Li, J.; Miao, T.; Wu, W.; Li, Q.; Zhuang, Y.; Zhou, Z.; Qiu, L. *Org. Lett.* **2012**, *14*, 1966–1969.

(15) (a) Burk, M. J.; Hems, W.; Herzberg, D.; Malan, C.; Zanotti-Gerosa, A. *Org. Lett.* **2000**, *2*, 4173–4176. (b) Zou, D.-Y.; Duan, Z.-C.; Hu, X.-P.; Zheng, Z. *Tetrahedron: Asymmetry* **2009**, *20*, 235–239.

(16) Hannen, P.; Militzer, H.-C.; Vogl, E. M.; Rampf, F. A. *Chem. Commun.* **2003**, 2210–2211.