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Synthesis of 9,9′-biphenanthryl-10,10′-bis(oxazoline)s and their preliminary evaluations in the Friedel–Crafts alkylations of indoles with nitroalkenes

Shuang-zheng Lin, Tian-pa You *

Department of Chemistry, University of Science and Technology of China, Hefei 230026, China

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ABSTRACT

Chiral 9,9′-biphenanthryl-10,10′-bis(oxazoline)s **6a–d** were firstly prepared. These new chiral compounds were evaluated as ligands for the Friedel–Crafts alkylations of indoles with nitroalkenes, excellent yields and modest to good enantioselectivities were achieved.

1. Introduction

Biaryl compounds, especially the chiral 1,1′-binaphthyl compounds, are among the most widely used ligands in asymmetric synthesis. Some binaphthyl ligands are illustrated in Figure 1.

A search of the literature revealed that the parent binaphthyl ligands (Fig. 1, **1**–**3**, R=H) do not lead to satisfactory enantioselectivities in some catalytic asymmetric reactions. In these cases, high selectivities are often obtained when large substituted groups (Fig. 1, **1**–**3**, R≠H) are introduced into the 3,3′-positions of the parent ligands.[1] The coordination atoms of these ligands are embedded within chiral pockets created by the hindrances of the large R substituents. However, 9,9′-biphenanthryl ligands (Fig. 2, **4**), in which the chiral pockets are created by the hindrances of the aryl units, are seldom used for the asymmetric reactions except for the parent biphenanthrol (Fig. 2, **4**, R^1=R^2=H, X=OH).[2]

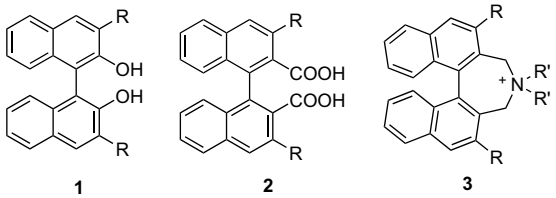

Figure 1. Some binaphthyl ligands.

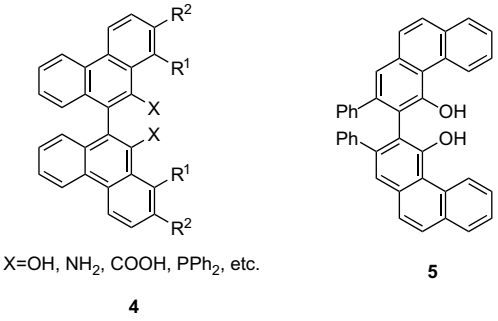

Figure 2. Biphenanthryl ligands.

The studies of the 9,9′-biphenanthrol as a chiral ligand have not revealed significant advantages over the 1,1′-binaphthols (**1**).[2] In contrast, the vaulted biaryl ligand **5** is superior to binaphthols **1** in many reactions.[3] We conceived that 9,9′-biphenanthryl ligands (substituted or unsubstituted) would be good chiral ligands in some reactions. Herein we would like to report the synthesis of 9,9′-biphenanthryl-10,10′-bis(oxazoline)s (Fig. 3, **6**) and their preliminary evaluations as ligands for the Friedel–Crafts alkylations of indoles with nitroalkenes.

* Corresponding author. Tel.: +86 551 3606944.
E-mail address: lins@mail.ustc.edu.cn (T.-pa You).

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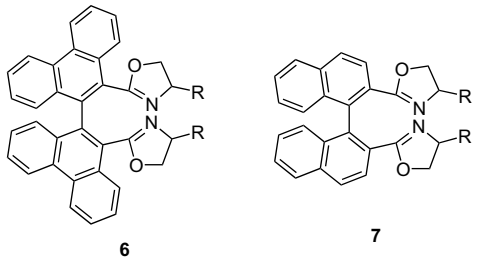
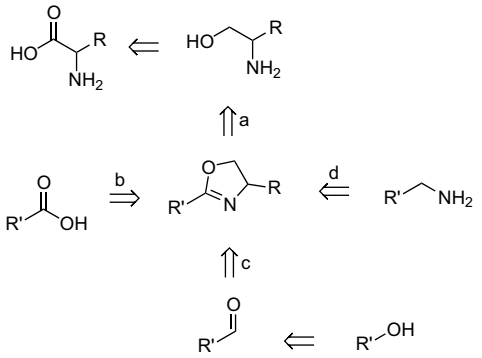


Figure 3. Biphenanthryl bis(oxazoline)s and binaphthryl bis(oxazoline)s.

2. Results and discussion

2.1. Preparations of biphenanthryl bis(oxazoline)s

Due to (a) the high enantioselectivities in the asymmetric catalysis mediated by the 1,1′-binaphthryl-2,2′-bis(oxazoline)s (Fig. 3, **7**),[4] (b) the facile preparations of oxazolines from natural amino-acids (Scheme 1, a),[5] and (c) the easy conversions to other functional groups from oxazolines (Scheme 1, b–d),[5b] we try to prepare the 9,9′-biphenanthryl-10,10′-bis(oxazoline)s (**6**) and explore their applications as ligands in catalytic asymmetric reactions.



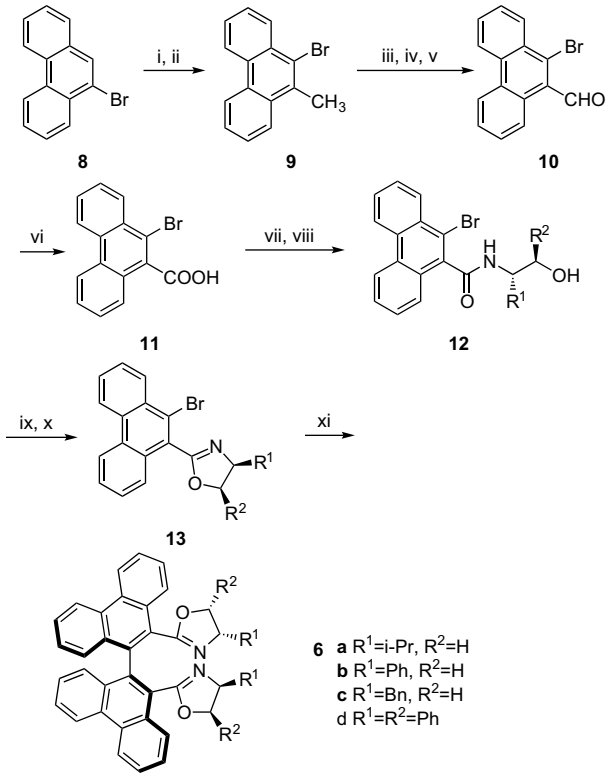
Scheme 1.

The synthetic sequence of biphenanthryl bis(oxazoline)s is outlined in Scheme 2.

The commercial available 9-bromophenanthrene (**8**) was treated with *n*-BuLi, and then methylated with dimethyl sulfate to form 9-methylphenanthrene first, which was brominated to give 9-bromo-10-methylphenanthrene (**9**). This compound was converted to 10-bromophenanthrene-9-carbaldehyde (**10**) after bromination, hydrolysis, and oxidation. The aldehyde intermediate **10** was smoothly oxidized with sodium chlorite to afford 10-bromophenanthrene-9-carboxylic acid (**11**).[6] The yields of oxidations using transition metal oxides were uniformly low for this step.[7] With the acid **11** in hand, the oxazolines **13** could be easily prepared by the classical methods.[5] The Ullmann reactions of **13** led to the bis(oxazoline)s **6**.[8] We were unable to separate the diastereomers by column chromatography. Fortunately, the major diastereomers, which were supposed to be *S*-axial configurational, could be obtained by recrystallization.[9]

2.2. Friedel–Crafts alkylation reactions of indoles and nitroalkenes

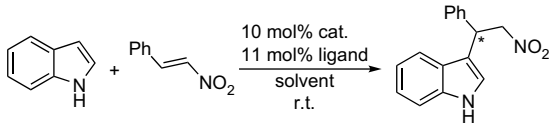
With the four biphenanthryl bis(oxazoline)s (**6a–d**) in hand, we tried to evaluate them as ligands for catalytic asymmetric reactions. C_2-symmetric bis(oxazoline)s have received a great deal of attention as ligands in coordination chemistry and asymmetric catalysis.[5] Recently, bis(oxazoline)s were reported to be used in the Friedel–Crafts alkylations of indoles with nitroalkenes, and satisfactory enantioselectivities were reported.[10] As the indole skeleton is one of the privileged structures in medicinal chemistry and 2-indolyl-1-nitro derivatives are useful intermediates for the synthesis of tryptamines and 1,2,3,4-tetrahydro-β-carbolines,[11] the reactions of indoles and nitroalkenes mediated by the biphenanthryl bis(oxazoline)s were investigated.



Scheme 2. Preparations of biphenanthryl bis(oxazoline)s. Reagents and conditions: (i) *n*-BuLi (1.1 equiv), Et_2O, rt, 1 h; then Me_2SO_4 (2 equiv), Et_2O, reflux, 5 h, 99%; (ii) NBS (1.1 equiv), CH_3CN, rt in dark, 24 h, 92%; (iii) NBS (1.01 equiv), BPO (0.02 equiv), CCl_4, reflux, 7 h; (iv) $CaCO_3$ (5 equiv), dioxane/H_2O (1:1), reflux, 10 h, 92% (2 steps); (v) PCC (1.3 equiv), CH_2Cl_2, 2 h, 84%; (vi) 2-methyl-2-butene (7.3 equiv), $NaClO_2$ (8.7 equiv), $NaH_2PO_4\cdot 2H_2O$ (6.9 equiv), *t*-BuOH/H_2O (2:1), rt, 24 h; (vii) $SOCl_2$, reflux, 5 h; (viii) Et_3N (3.1 equiv), aminoalcohol (1.0 equiv), THF, overnight; (ix) $SOCl_2$ (10.2 equiv), CH_2Cl_2, rt, 24 h; (x) NaOH (2.0 equiv), THF/MeOH (3:1), reflux, 5 h; (xi) activated Cu powder (10.0 equiv), pyridine, reflux, 24 h.

When $Cu(OTf)_2$, $Mg(OTf)_2$, or $Ba(OTf)_2$ was employed as a Lewis acid (Table 1, entries 1, 3, and 4), and the bis(oxazoline) **6a** was used as a ligand, the reaction took place very slowly in chloroform. On the contrast, the reaction mediated by $Zn(OTf)_2$ was carried out smoothly (Table 1, entry 2), giving the product 3-(2-nitro-1-phenylethyl)-1*H*-indole (**16aa**) in an excellent yield (>99%) and modest enantioselectivity (59% ee). When the reaction was catalyzed by $La(OTf)_3$ or $Sm(OTf)_3$ (Table 1, entries 5 and 6), the enantiomeric excess of the product was zero, though the yield was excellent (>99%). The other three biphenanthryl bis(oxazoline)s (**6b–d**) were also examined, but the ees of the products were all inferior to **6a** (Table 1, entries 7–9). This may indicate different properties of these bulky biphenanthryl ligands compared to other type of bis(oxazoline)s, since the bis(oxazoline)s ligands bearing phenyl groups on the oxazoline rings usually gave better results than the

Table 1
Alkylation reactions of indole with *trans*-β-nitrostyrene[a]



14a 15a 16aa

Entry	Lewis acid	Solvent	Ligand	Time (h)	Yield[b] (%)	ee[c] (%)
1[d]	$Cu(OTf)_2$	$CHCl_3$	**6a**	24	<5	—
2	$Zn(OTf)_2$	$CHCl_3$	**6a**	24	>99	59
3[d]	$Mg(OTf)_2$	$CHCl_3$	**6a**	24	<5	—
4[d]	$Ba(OTf)_2$	$CHCl_3$	**6a**	24	<5	—
5	$La(OTf)_3$	$CHCl_3$	**6a**	18	>99	0
6	$Sm(OTf)_3$	$CHCl_3$	**6a**	18	>99	0
7	$Zn(OTf)_2$	$CHCl_3$	**6b**	24	>99	17
8	$Zn(OTf)_2$	$CHCl_3$	**6c**	24	>99	41
9	$Zn(OTf)_2$	$CHCl_3$	**6d**	24	>99	38
10	$Zn(OTf)_2$	CH_2Cl_2	**6a**	24	>99	59
11	$Zn(OTf)_2$	CCl_4	**6a**	24	>99	47
12	$Zn(OTf)_2$	$ClCH_2CH_2Cl$	**6a**	48	>99	52
13	$Zn(OTf)_2$	$PhCH_3$	**6a**	72	>99	58
14	$Zn(OTf)_2$	Et_2O	**6a**	20	>99	63
15[e]	$Zn(OTf)_2$	THF	**6a**	72	—	—
16	$Zn(OTf)_2$	CH_3CN	**6a**	48	>99	10

[a] The reactions were performed at rt using 0.1 equiv of Lewis acid, 0.11 equiv of ligand, 1 equiv of indole (**14a**), and 2 equiv of *trans*-β-nitrostyrene (**15a**) under N_2 atmosphere.
[b] Isolated yield.
[c] Determined by chiral HPLC. The absolute configuration is *S*, see Ref. 10b.
[d] Estimated by TLC.
[e] No reaction.

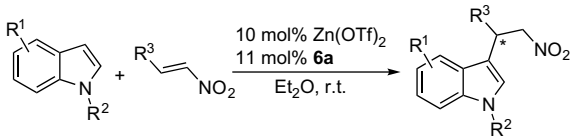
isopropyl substituted ones in the reactions of indoles and nitroalkenes.[10] Thus, the complex of $Zn(OTf)_2$ and bis(oxazoline) **6a** was found to be the best catalyst here. Different solvents were then screened under this condition (Table 1, entries 10–16). The reaction in diethyl ether gave the best result, the conversion was completed within 20 h and excellent yield (>99%) was obtained, but the ee was still modest (63%).

To optimize the reaction conditions further, we screened other parameters such as additives, temperature, and catalyst loading. When water or molecular sieve was employed as an additive, the enantioselectivity was decreased to 55% ee or 32% ee, respectively. The enantiomeric excess was improved only slightly (65%) if the catalyst loading was increased to 15%, while the ee was decreased to 57% when 5% catalyst loading was used for the reaction. Low reaction temperature did not bring much benefit. The enantioselectivity was improved slightly to 67% ee, while a long reaction time of 72 h was needed for a complete conversion.

The scope of the alkylations of indoles with nitroalkenes was explored at room temperature under the optimal conditions, and the results are summarized in Table 2.

Firstly, the *para*-substituted nitrostyrenes were screened, excellent yields and modest enantioselectivities were achieved in all cases (Table 2, entries 1–9). Comparable results were obtained when other aryl nitroalkenes were examined (Table 2, entries 10–12). The best result was achieved when this reaction was extended to unbranched aliphatic nitroalkene **15m**, the enantioselectivity was 79% ee, which was further enhanced to 85% ee when the reaction was conducted at 0 °C (Table 2, entry 13). However, the enantioselectivity was significantly decreased with enhanced steric hindrance when branched aliphatic nitroalkenes were employed in this reaction. 3-Methyl-1-nitrobut-1-ene (**15n**) gave 67% ee (Table 2, entry 14), cyclohexyl-substituted nitroalkene **15p** gave 39% ee (Table 2, entry 16), and the reaction of 3,3-dimethyl-1-nitrobut-1-ene (**15o**) with indole was completely restrained (Table 2, entry 15). The substituent effect on the indole ring was also studied. 1-Me-, 5-Br-, and 5-MeO-indole gave modest enantioselectivities (Table 2, entries 17, 19, and 20), while 2-methylindole gave lower ee value because of the existence of steric hindrance (Table 2, entry 18).

Table 2
Scope of the alkylations of indoles with nitroalkenes[a]



14 15 16

Entry	Indole	R^1	R^2	R^3	Product	Yield[b] (%)	ee[c] (%)
1	**14a**	H	H	Ph (**15a**)	**16aa**	>99	63 (67)
2	**14a**	H	H	4-F-Ph (**15b**)	**16ab**	>99	57
3	**14a**	H	H	4-Cl-Ph (**15c**)	**16ac**	>99	62
4	**14a**	H	H	4-Br-Ph (**15d**)	**16ad**	>99	60
5	**14a**	H	H	4-O_2N-Ph (**15e**)	**16ae**	>99	57
6	**14a**	H	H	4-Me-Ph (**15f**)	**16af**	>99	60
7	**14a**	H	H	4-MeO-Ph (**15g**)	**16ag**	>99	46
8	**14a**	H	H	3,4,5-$(MeO)_3$-Ph (**15h**)	**16ah**	>99	48
9	**14a**	H	H	4-HO-Ph (**15i**)	**16ai**	>99	55
10	**14a**	H	H	2-Br-Ph (**15j**)	**16aj**	>99	50
11	**14a**	H	H	1-Naphthyl (**15k**)	**16ak**	>99	53
12	**14a**	H	H	2-Furyl (**15l**)	**16al**	>99	41
13	**14a**	H	H	*n*-Pr (**15m**)	**16am**	>99	79 (85)
14	**14a**	H	H	*i*-Pr (**15n**)	**16an**	>99	67
15[d]	**14a**	H	H	*t*-Bu (**15o**)	**16ao**	—	—
16	**14a**	H	H	*c*-hex (**15p**)	**16ap**	>99	39
17	**14b**	H	Me	Ph (**15a**)	**16ba**	>99	55
18	**14c**	2-Me	H	Ph (**15a**)	**16ca**	>99	40
19	**14d**	5-Br	H	Ph (**15a**)	**16da**	>99	60
20	**14e**	5-MeO	H	Ph (**15a**)	**16ea**	>99	56

[a] The reactions were performed at rt using 0.1 equiv of $Zn(OTf)_2$, 0.11 equiv of **6a**, 1 equiv of indole, and 2 equiv of nitroalkene under N_2 atmosphere.
[b] Isolated yield.
[c] Determined by chiral HPLC. The values in the parentheses are the enantioselectivities of the products obtained at 0 °C.
[d] No reaction.

3. Conclusion

In conclusion, biphenanthryl bis(oxazoline)s **6a–d** were firstly prepared. These new chiral compounds were employed as ligands for the Friedel–Crafts alkylations of indoles with nitroalkenes, excellent yields and modest to good enantioselectivities were achieved. The enantioselectivity was highly affected by the steric hindrance between the substrates. Unlike the results induced by other types of bis(oxazoline)s ligands,[10] unbranched aliphatic nitroalkene **15m** gave much better enantioselectivity than the rigid nitrostyrenes in our experiments. Further evaluations of these biphenanthryl bis(oxazoline)s and the preparations and evaluations of other chiral ligands containing biphenanthryl unit are still in progress in our laboratory.

4. Experimental section

4.1. General

All reactions were conducted in oven-dried glassware. NMR spectra were measured on a Bruker 300 MHz (or 400 MHz) spectrometer. Chemical shifts were reported in parts per million relative to internal tetramethylsilane. High resolution mass spectroscopy (HRMS) was performed on a Micromass GCT mass spectrometer. Column chromatography was carried out on silica gel (200–400 mesh) using petroleum ether (bp 60–90 °C) and EtOAc as eluents. The enantiomeric excess of the products was determined by chiral

HPLC. All solvents were purified before use. PCC,[12] (*S*)-valinol,[13] (*S*)-phenylglycinol,[13] (*S*)-phenylalaninol,[13] nitroalkenes,[14] metal triflates,[15] and 2-methyl-2-butene[16] were prepared according to the literature procedures. Other reagents were purchased from vendors and used without further purification. N_2 was used without further purification.

4.2. General procedures for the preparation of biphenanthryl bis(oxazoline)s

4.2.1. 9-Methylphenanthrene[17]

Under N_2 atmosphere, 9-bromophenanthrene (**8**) (2.57 g, 10.0 mmol) was dissolved in 50 mL of dry Et_2O. Cooled by ice-bath, *n*-BuLi (2.5 M in hexane, 4.4 mL, 11.0 mmol) was slowly added to the reactants in 10 min. Stirring was continued at room temperature for 1 h before recooled to 0 °C. Then Me_2SO_4 (1.8 mL, 2.5 g, 19.8 mmol) was added carefully in 30 min. After addition, the reaction was refluxed for 5 h. After cooling, 100 mL of $NH_3 \cdot H_2O$ was added, the mixture was stirred for 1 h, and then poured in separatory funnel. The ether phase was separated and the water phase was extracted twice by Et_2O. The organic phases were combined and dried with $MgSO_4$. After evaporation of the solvent and recrystallized from hexane, 9-methylphenanthrene was obtained as white solid (1.9 g, 9.88 mmol, 99% yield).

*4.2.2. 9-Bromo-10-methylphenanthrene (**9**)*[17]

9-Methylphenanthrene (1.9 g, 9.88 mmol) and NBS (1.93 g, 10.8 mmol) were dissolved in 30 mL of CH_3CN, the mixture was stirred in dark at ambient temperature for 24 h. Then the reaction was ceased by addition of 100 mL of 1 M NaOH. The organics were extracted with CH_2Cl_2 and dried with $MgSO_4$. Purification by column chromatography gave 9-bromo-10-methylphenanthrene as a white solid (2.47 g, 9.1 mmol, 92% yield).

*4.2.3. 10-Bromophenanthrene-9-carbaldehyde (**10**)*[7a]

9-Bromo-10-methylphenanthrene (2.47 g, 9.1 mmol), NBS (1.64 g, 9.2 mmol), and BPO (44 mg, 0.18 mmol) were refluxed in CCl_4 (25 mL) for 7 h. Then the solvent was evaporated under reduced pressure. The residue was refluxed with $CaCO_3$ (5.5 g, 55.0 mmol) in 30 mL dioxane and 30 mL H_2O for 10 h. After cooling, excess diluted hydrochloric acid was added to dissolve residual $CaCO_3$. Extracted with CH_2Cl_2, dried with $MgSO_4$, purified by column chromatography, the alcohol product was gained as a white solid (2.41 g, 8.4 mmol, 92% yield). This alcohol was oxidized with PCC in CH_2Cl_2 to give aldehyde **10** (2.0 g, 7.0 mmol, 84% yield) as a white solid. Total yield 70%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.91 (s, 1H), 8.72 (d, J=8.1 Hz, 1H), 8.71–8.63 (m, 3H), 7.86–7.66 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.7, 133.1, 132.5, 130.3, 130.0, 129.9, 129.6, 128.9, 128.8, 128.5, 128.2, 127.9, 125.6, 123.0, 122.9.

*4.2.4. (S)-10-Bromo-N-(1-hydroxy-3-methylbutan-2-yl)-phenanthrene-9-carboxamide (**12a**)*

To a mixture of 10-bromophenanthrene-9-carbaldehyde (**10**) (1.0 g, 3.5 mmol) and *tert*-butyl alcohol (60 mL) was added 2-methyl-2-butene (2.7 mL, 25.5 mmol). A 30 mL of aqueous solution of $NaClO_2$ (80%, 3.44 g, 30.4 mmol) and $NaH_2PO_4 \cdot 2H_2O$ (3.76 g, 24.1 mmol) was added dropwise over a period of 15 min. This resulted in a clear solution, which was allowed to stir for 24 h at room temperature. The *t*-BuOH was removed by rotary evaporation and the mixture was treated with 20 mL of H_2O and washed with two portions of 20 mL hexane. The aqueous layer was then acidified to pH 1 and extracted with EtOAc (3×30 mL). The organic extracts were combined, dried over $MgSO_4$, and concentrated by rotary evaporation to afford the crude 10-bromophenanthrene-9-carboxylic acid (**11**). This crude product was refluxed in $SOCl_2$ (10 mL) for 5 h, $SOCl_2$ was then removed by rotary evaporation. The residue was dissolved in 20 mL of dry THF, added dropwise to a 20 mL THF solution of Et_3N (1.5 mL, 10.8 mmol) and (*S*)-valinol (0.36 g, 3.5 mmol) at 0 °C. The mixture was allowed to stir overnight at room temperature. After removal of THF, the residue was dispersed in 1 M HCl and EtOAc. The organic phase was separated and the aqueous phase was extracted twice with EtOAc. The organic layers were combined, concentrated, and chromatographed on silica gel to give (*S*)-10-bromo-*N*-(1-hydroxy-3-methylbutan-2-yl)phenanthrene-9-carboxamide (**12a**) (1.25 g, 3.24 mmol, 92.5% yield).

*4.2.5. (S)-2-(10-Bromophenanthren-9-yl)-4-isopropyl-4,5-dihydrooxazole (**13a**)*

(*S*)-10-Bromo-*N*-(1-hydroxy-3-methylbutan-2-yl)phenanthrene-9-carboxamide (**12a**) (1.25 g, 3.24 mmol) and $SOCl_2$ (2.4 mL, 33.1 mmol) were stirred in dry CH_2Cl_2 (30 mL) for 24 h at room temperature. After carefully addition of 20 mL of water, the organic layer was separated and the aqueous layer was extracted twice with CH_2Cl_2. The organic extracts were combined, washed successively with saturated aqueous $NaHCO_3$ and water, dried over $MgSO_4$. Removal of the solvent gave (*S*)-10-bromo-*N*-(1-chloro-3-methylbutan-2-yl)phenanthrene-9-carboxamide as a crude product. This residue was dissolved in dry THF (45 mL) and then a 15 mL MeOH solution of NaOH (0.26 g, 6.5 mmol) was added. The mixture was refluxed for 5 h. The solvent was removed by rotary evaporation, and the residue was dispersed in CH_2Cl_2 and brine. The organic layer was separated and the aqueous layer was extracted twice with CH_2Cl_2. The organic extracts were combined, dried, concentrated, and purified by chromatography to give (*S*)-2-(10-bromophenanthren-9-yl)-4-isopropyl-4,5-dihydrooxazole (**13a**) (1.15 g, 3.13 mmol, 96.5% yield). ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.67 (d, J=7.5 Hz, 2H), 8.48 (dd, J=7.5, 2.1 Hz, 1H), 7.90 (d, J=7.8 Hz, 1H), 7.75–7.59 (m, 4H), 4.70–4.61 (m, 1H), 4.40–4.30 (m, 2H), 2.13–2.02 (m, 1H), 1.20 (d, J=6.6 Hz, 3H), 1.12 (d, J=6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.7, 131.6, 130.4, 129.8, 129.7, 129.0, 128.8, 128.5, 127.9, 127.8, 127.5, 126.1, 123.8, 123.0, 122.8, 73.8, 71.1, 33.2, 19.5, 19.3.

*4.2.6. (S)-2-(10-Bromophenanthren-9-yl)-4-phenyl-4,5-dihydrooxazole (**13b**)*

Yield from 10-bromophenanthrene-9-carbaldehyde (**10**) was 82.1%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.73–8.70 (m, 2H), 8.52 (dd, J=7.5, 1.5 Hz, 1H), 7.99 (d, J=7.5 Hz, 1H), 7.80–7.70 (m, 3H), 7.64 (t, J=7.2 Hz, 1H), 7.57 (d, J=7.2 Hz, 2H), 7.45 (t, J=7.5 Hz, 2H), 7.36 (t, J=7.2 Hz, 1H), 5.71 (t, J=9.9 Hz, 1H), 5.04 (dd, J=10.2, 8.4 Hz, 1H), 4.49 (t, J=9.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.1, 141.9, 131.6, 130.3, 129.7, 128.9, 128.6, 128.4, 127.9, 127.8, 127.5, 127.1, 126.0, 123.9, 123.0, 122.8, 75.1, 70.9.

*4.2.7. (S)-4-Benzyl-2-(10-bromophenanthren-9-yl)-4,5-dihydrooxazole (**13c**)*

Yield from 10-bromophenanthrene-9-carbaldehyde (**10**) was 84.0%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.68–8.64 (m, 2H), 8.47 (dd, J=7.5, 1.5 Hz, 1H), 7.72–7.65 (m, 4H), 7.56 (t, J=7.5 Hz, 1H), 7.34–7.24 (m, 5H), 4.91–4.81 (m, 1H), 4.59 (t, J=9.0 Hz, 1H), 4.36 (t, J=8.1 Hz, 1H), 3.37 (dd, J=13.8, 5.7 Hz, 1H), 3.05 (dd, J=13.8, 8.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.4, 138.0, 131.7, 130.3, 129.8, 129.7, 129.0, 128.9, 128.6, 128.0, 127.8, 127.6, 126.8, 126.2, 123.9, 123.0, 122.9, 72.4, 68.8, 41.7, 31.0.

*4.2.8. (4S,5R)-2-(10-Bromophenanthren-9-yl)-4,5-diphenyl-4,5-dihydrooxazole (**13d**)*

Yield from 10-bromophenanthrene-9-carbaldehyde (**10**) was 80.7%; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.61 (d, J=3.5 Hz, 2H), 8.48 (d, J=8.0 Hz, 1H), 8.12 (dd, J=5.8, 2.8 Hz, 1H), 7.66–7.65 (m, 4H),

7.53–7.52 (m, 4H), 7.44–7.41 (m, 4H), 7.37–7.32 (m, 2H), 5.64 (d, J=9.5 Hz, 1H), 5.56 (d, J=9.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.3, 141.5, 139.6, 131.6, 130.3, 129.7, 129.0, 128.9, 128.63, 128.59, 128.3, 127.92, 127.87, 127.8, 127.5, 127.0, 126.3, 125.9, 124.1, 123.0, 122.8, 89.8, 79.4.

4.2.9. (*S*)-10,10′-Bis[(*S*)-4-isopropyl-4,5-dihydrooxazol-2-yl]-9,9′-biphenanthrene (**6a**)

A mixture of (*S*)-2-(10-bromophenanthren-9-yl)-4-isopropyl-4,5-dihydrooxazole (**13a**) (1.0 g, 2.72 mmol) and 1.73 g (27.2 mmol) of freshly activated copper powder[18] in 5.0 mL of freshly distilled pyridine was refluxed for 24 h. After cooled, the mixture was diluted with CH_2Cl_2 and washed with aqueous ammonia repeatedly until the copper had been completely removed. The organic portion was washed with water and dried over $MgSO_4$. The solvent was removed in vacuo and the residue was chromatographed to give a mixture of bis(oxazoline)s diastereomers. This mixture was recrystallized twice from Et_2O to give the major diastereomer, (*S*)-10,10′-bis[(*S*)-4-isopropyl-4,5-dihydrooxazol-2-yl]-9,9′-biphenanthrene (**6a**), as a white solid (0.33 g, 0.57 mmol). Yield 42.0%; $[\alpha]_D^{26}$ −207.2 (*c* 1.02, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (t, J=8.7 Hz, 4H), 8.19 (d, J=8.3 Hz, 2H), 7.73–7.71 (m, 2H), 7.67–7.64 (m, 4H), 7.58 (d, J=8.4 Hz, 2H), 7.39–7.37 (m, 2H), 3.72 (dd, J=9.3, 1.4 Hz, 2H), 3.52–3.45 (m, 2H), 3.40 (t, J=8.1 Hz, 2H), 1.01–0.95 (m, 2H), 0.50 (t, J=6.9 Hz, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.1, 135.5, 130.9, 130.8, 130.3, 129.7, 128.8, 127.6, 127.2, 127.1, 127.0, 126.7, 122.6, 122.3, 73.2, 70.0, 32.8, 19.1, 18.5; HRMS calcd for $C_{40}H_{36}N_2O_2$ (M^+) 576.2777, found 576.2781.

4.2.10. (*S*)-10,10′-Bis[(*S*)-4-phenyl-4,5-dihydrooxazol-2-yl]-9,9′-biphenanthrene (**6b**)

White solid; 39.0% yield; $[\alpha]_D^{26}$ −116.8 (*c* 1.02, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.85 (d, J=8.2 Hz, 2H), 8.76 (d, J=8.2 Hz, 2H), 8.26 (d, J=7.8 Hz, 2H), 7.80 (t, J=6.9 Hz, 2H), 7.72 (t, J=7.0 Hz, 2H), 7.64 (d, J=7.2 Hz, 2H), 7.60 (dd, J=8.3, 0.7 Hz, 2H), 7.37 (t, J=7.0 Hz, 2H), 7.01 (t, J=7.4 Hz, 2H), 6.84 (t, J=7.7 Hz, 4H), 6.62 (d, J=7.5 Hz, 4H), 5.01 (t, J=9.8 Hz, 2H), 4.23 (dd, J=10.2, 8.3 Hz, 2H), 3.38 (t, d, J=8.5 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.6, 141.8, 135.7, 130.9, 130.8, 130.5, 129.6, 128.8, 128.1, 127.8, 127.40, 127.37, 127.1, 126.92, 126.87, 126.5, 122.9, 122.5, 74.0, 70.5; HRMS calcd for $C_{46}H_{32}N_2O_2$ (M^+) 644.2464, found 644.2468.

4.2.11. (*S*)-10,10′-Bis[(*S*)-4-benzyl-4,5-dihydrooxazol-2-yl]-9,9′-biphenanthrene (**6c**)

White solid; 40.3% yield; $[\alpha]_D^{26}$ −63.4 (*c* 1.02, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80 (t, J=8.4 Hz, 4H), 8.13 (d, J=7.6 Hz, 2H), 7.72–7.65 (m, 8H), 7.44 (t, J=7.5 Hz, 2H), 7.12–7.10 (m, 6H), 6.76 (dd, J=7.5, 1.8 Hz, 4H), 4.11–4.05 (m, 2H), 3.71 (t, J=8.8 Hz, 2H), 3.41 (dd, J=8.4, 6.8 Hz, 2H), 2.41 (dd, J=13.6, 5.1 Hz, 2H), 1.56 (dd, J=13.9, 9.5 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.6, 138.3, 136.1, 131.0, 130.2, 129.5, 129.0, 128.8, 128.4, 127.8, 127.3, 127.0, 126.9, 126.7, 126.2, 122.7, 122.6, 71.1, 68.2, 40.8; HRMS calcd for $C_{48}H_{36}N_2O_2$ (M^+) 672.2777, found 672.2776.

4.2.12. (*S*)-10,10′-Bis[(4*S*,5*R*)-4,5-diphenyl-4,5-dihydrooxazol-2-yl]-9,9′-biphenanthrene (**6d**)

White solid; 39.8% yield; $[\alpha]_D^{26}$ 57.4 (*c* 1.02, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.90 (d, J=8.1 Hz, 2H), 8.79 (d, J=8.2 Hz, 2H), 8.44 (d, J=7.7 Hz, 2H), 7.87 (t, J=7.6 Hz, 2H), 7.80 (t, J=7.7 Hz, 2H), 7.70 (d, J=7.8 Hz, 2H), 7.64 (t, J=7.6 Hz, 2H), 7.37 (t, J=7.6 Hz, 2H), 7.13 (t, J=7.5 Hz, 2H), 7.05–6.98 (m, 6H), 6.87 (t, J=7.7 Hz, 4H), 6.80 (d, J=7.5 Hz, 4H), 6.64 (d, J=7.3 Hz, 4H), 4.81 (d, J=10.0 Hz, 2H), 4.59 (d, J=10.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.0, 141.3, 139.3, 135.5, 131.0, 130.7, 129.8, 129.0, 128.4, 128.3, 128.0, 127.6, 127.5, 127.1, 127.0, 126.7, 126.0, 123.1, 122.5, 88.9, 78.8; HRMS calcd for $C_{58}H_{40}N_2O_2$ (M^+) 796.3090, found 796.3096.

4.3. General procedures for the catalytic asymmetric Friedel–Crafts alkylation reactions

4.3.1. (*S*)-3-(2-Nitro-1-phenylethyl)-1H-indole (**16aa**)[10]

To a dried Schlenk tube were added $Zn(OTf)_2$ (4 mg, 0.011 mmol) and biphenanthryl bis(oxazoline)s **6a** (7 mg, 0.012 mmol) under N_2 atmosphere, followed by addition of Et_2O (0.5 mL). The solution was stirred at room temperature for 2 h under N_2 atmosphere and *trans*-β-nitrostyrene (**15a**) (33 mg, 0.22 mmol) was added. The mixture was stirred for 15 min before the indole (**14a**) (13 mg, 0.11 mmol) was added. After the reaction was complete (monitored by TLC), the mixture was chromatographed on silica gel column to afford the product (*S*)-3-(2-nitro-1-phenylethyl)-1*H*-indole (**16aa**) (30 mg, quant.) as an oil: 63% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=15.04 min (major), t_2=19.24 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95 (s, 1H), 7.38 (d, J=8.4 Hz, 1H), 7.15–7.03 (m, 7H), 6.92 (t, J=7.5 Hz, 1H), 6.72 (d, J=1.8 Hz, 1H), 5.01 (t, J=7.8 Hz, 1H), 4.84 (dd, J=12.6, 7.5 Hz, 1H), 4.73 (dd, J=12.6, 8.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.3, 136.5, 128.9, 127.8, 127.5, 126.1, 122.6, 121.8, 119.9, 118.9, 114.1, 111.5, 79.5, 41.6.

4.3.2. 3-[1-(4-Fluorophenyl)-2-nitroethyl]-1H-indole (**16ab**)[10]

Yield >99%; 57% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=16.40 min (major), t_2=21.13 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.11 (s, 1H), 7.36 (d, J=7.8 Hz, 1H), 7.26–7.12 (m, 4H), 7.03 (t, J=7.5 Hz, 1H), 6.91 (t, J=8.7 Hz, 2H), 6.86 (d, J=2.1 Hz, 1H), 5.10 (t, J=8.1 Hz, 1H), 4.95 (dd, J=12.6, 7.5 Hz, 1H), 4.80 (dd, J=9.9, 8.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.1 (d, J=244 Hz), 136.6, 135.2, 129.5, 129.4, 126.0, 122.8, 121.6, 120.0, 118.9, 115.9, 115.7, 114.1, 111.6, 79.6, 40.9.

4.3.3. 3-[1-(4-Chlorophenyl)-2-nitroethyl]-1H-indole (**16ac**)[10]

Yield >99%; 62% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=18.71 min (major), t_2=24.04 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.04 (s, 1H), 7.34 (d, J=7.8 Hz, 1H), 7.22–7.11 (m, 6H), 7.02 (t, J=7.5 Hz, 1H), 6.79 (d, J=2.4 Hz, 1H), 5.05 (t, J=7.8 Hz, 1H), 4.89 (dd, J=12.6, 7.5 Hz, 1H), 4.75 (dd, J=12.6, 8.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 137.9, 136.5, 133.2, 129.1, 129.0, 125.9, 122.7, 121.7, 120.0, 118.7, 113.6, 111.6, 79.2, 40.9.

4.3.4. 3-[1-(4-Bromophenyl)-2-nitroethyl]-1H-indole (**16ad**)[10]

Yield >99%; 60% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=19.90 min (major), t_2=26.03 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.08 (s, 1H), 7.31–7.26 (m, 3H), 7.20 (d, J=8.1 Hz, 1H), 7.11–7.04 (m, 3H), 6.96 (t, J=7.5 Hz, 1H), 6.82 (d, J=2.1 Hz, 1H), 5.01 (t, J=7.8 Hz, 1H), 4.89 (dd, J=12.3, 7.5 Hz, 1H), 4.74 (dd, J=12.6, 8.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.5, 136.7, 132.1, 129.6, 126.0, 122.9, 121.7, 121.6, 120.1, 118.8, 113.8, 111.6, 79.3, 41.1.

4.3.5. 3-[2-Nitro-1-(4-nitrophenyl)ethyl]-1H-indole (**16ae**)[10]

Yield >99%; 57% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=37.48 min (major), t_2=48.29 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.15 (s, 1H), 8.03 (d, J=7.8 Hz, 2H), 7.38 (d, J=8.1 Hz, 2H), 7.26 (d, J=8.1 Hz, 2H), 7.11 (t, J=7.8 Hz, 1H), 6.98 (t, J=7.5 Hz, 1H), 6.92 (s, 1H), 5.17 (t, J=7.8 Hz, 1H), 4.98 (dd, J=12.6, 7.2 Hz, 1H), 4.87 (dd, J=12.6, 9.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 146.9, 136.7, 128.9, 125.8, 124.3, 123.2, 121.8, 120.5, 118.6, 113.1, 111.8, 78.9, 41.4.

4.3.6. 3-[1-(4-Methylphenyl)-2-nitroethyl]-1H-indole (**16af**)[10]

Yield >99%; 60% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=13.28 min (major), t_2=15.80 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87 (s, 1H), 7.39 (d,

J=7.8 Hz, 1H), 7.20–7.09 (m, 4H), 7.05–6.99 (m, 3H), 6.78 (d, *J*=2.4 Hz, 1H), 5.07 (t, *J*=8.1 Hz, 1H), 4.91 (dd, *J*=12.3, 7.5 Hz, 1H), 4.79 (dd, *J*=12.6, 8.7 Hz, 1H), 2.23 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 137.2, 136.6, 134.3, 129.6, 127.7, 126.2, 122.6, 121.7, 119.9, 118.9, 114.4, 111.5, 79.7, 41.3, 21.0.

4.3.7. 3-[1-(4-Methoxyphenyl)-2-nitroethyl]-1H-indole (**16ag**)[10]

Yield >99%; 46% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=16.74 min (major), t_2=19.95 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.43 (d, *J*=7.8 Hz, 1H), 7.33 (d, *J*=8.1 Hz, 1H), 7.25–7.16 (m, 3H), 7.06 (t, *J*=7.5 Hz, 1H), 6.99 (d, *J*=2.1 Hz, 1H), 6.84 (dd, *J*=6.9, 2.1 Hz, 2H), 5.13 (t, *J*=7.8 Hz, 1H), 5.03 (dd, *J*=12.3, 7.5 Hz, 1H), 4.88 (dd, *J*=12.3, 8.4 Hz, 1H), 3.76 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 159.1, 136.7, 131.5, 129.0, 126.3, 122.8, 121.6, 120.1, 119.2, 115.0, 114.5, 111.5, 79.9, 55.4, 41.1.

4.3.8. 3-[2-Nitro-1-(3,4,5-trimethoxyphenyl)ethyl]-1H-indole (**16ah**)

Yield >99%; 48% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=15.80 min (major), t_2=23.37 min]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.55 (s, 1H), 7.47 (d, *J*=7.8 Hz, 1H), 7.28 (d, *J*=8.1 Hz, 1H), 7.15 (t, *J*=7.2 Hz, 1H), 7.06 (t, *J*=7.2 Hz, 1H), 6.95 (d, *J*=2.1 Hz, 1H), 6.55 (s, 2H), 5.11 (t, *J*=8.1 Hz, 1H), 5.00 (dd, *J*=12.6, 7.5 Hz, 1H), 4.89 (dd, *J*=12.6, 8.9 Hz, 1H), 3.80 (s, 3H), 3.74 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 153.5, 137.4, 136.7, 135.2, 126.1, 122.5, 121.9, 119.8, 118.7, 113.9, 111.6, 105.2, 79.6, 60.8, 56.2, 41.9.

4.3.9. 3-[1-(4-Hydroxyphenyl)-2-nitroethyl]-1H-indole (**16ai**)

Yield >99%; 55% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=13.64 min, t_2=14.48 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.90 (s, 1H), 7.28 (d, *J*=8.1 Hz, 1H), 7.08–6.86 (m, 4H), 7.70 (d, *J*=7.5 Hz, 1H), 6.61–6.57 (m, 2H), 6.50 (dd, *J*=8.1, 2.1 Hz, 1H), 6.12 (s, 1H), 4.89 (t, *J*=8.1 Hz, 1H), 4.72 (dd, *J*=12.6, 7.8 Hz, 1H), 4.61 (dd, *J*=12.6, 8.4 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 156.1, 141.3, 136.5, 130.1, 126.1, 122.6, 121.8, 120.1, 119.9, 118.8, 114.9, 114.7, 113.9, 111.6, 79.5, 41.4.

4.3.10. 3-[1-(2-Bromophenyl)-2-nitroethyl]-1H-indole (**16aj**)

Yield >99%; 50% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=12.94 min, t_2=18.93 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05 (s, 1H), 7.49 (d, *J*=7.5 Hz, 1H), 7.32 (d, *J*=7.8 Hz, 1H), 7.17 (d, *J*=8.1 Hz, 1H), 7.10–6.89 (m, 6H), 5.61 (t, *J*=8.1 Hz, 1H), 4.87–4.75 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.3, 136.6, 133.5, 129.2, 128.0, 126.3, 124.6, 122.8, 122.1, 120.1, 119.0, 113.3, 111.5, 77.9, 40.7.

4.3.11. 3-[1-(1-Naphthyl)-2-nitroethyl]-1H-indole (**16ak**)[10]

Yield >99%; 53% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=17.72 min, t_2=21.23 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.23 (d, *J*=7.2 Hz, 1H), 7.95 (s, 1H), 7.83 (dd, *J*=6.9, 2.7 Hz, 1H), 7.72 (t, *J*=4.8 Hz, 1H), 7.49–6.97 (m, 8H), 6.81 (d, *J*=2.4 Hz, 1H), 6.02 (t, *J*=7.8 Hz, 1H), 5.02–4.94 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.7, 134.9, 134.3, 131.3, 129.2, 128.4, 126.9, 126.2, 126.0, 125.4, 124.7, 122.8, 120.0, 119.3, 118.8, 114.3, 111.6, 78.7, 37.1.

4.3.12. 3-[1-Furan-2-yl-2-nitroethyl]-1H-indole (**16al**)[10]

Yield >99%; 41% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=11.36 min, t_2=15.02 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.20 (s, 1H), 7.52 (d, *J*=7.8 Hz, 1H), 7.32 (d, *J*=1.5 Hz, 1H), 7.27 (d, *J*=8.1 Hz, 1H), 7.17 (t, *J*=7.2 Hz, 1H), 7.09 (t, *J*=7.5 Hz, 1H), 6.98 (d, *J*=2.4 Hz, 1H), 6.26–6.27 (m, 1H), 6.11 (d, *J*=3.3 Hz, 1H), 5.20 (t, *J*=7.8 Hz, 1H), 5.00 (dd, *J*=12.6, 8.1 Hz, 1H), 4.85 (dd, *J*=12.6, 5.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 152.4, 142.3, 136.4, 125.8, 122.9, 122.6, 120.0, 118.7, 111.7, 111.5, 110.5, 107.4, 78.0, 35.8.

4.3.13. 3-(1-Nitromethylbutyl)-1H-indole (**16am**)[10]

Yield >99%; 79% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=90:10, 1.0 mL/min, 254 nm; t_1=25.45 min, t_2=27.39 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.59 (d, *J*=7.8 Hz, 1H), 7.26 (d, *J*=7.5 Hz, 1H), 7.19–7.08 (m, 2H), 6.87 (d, *J*=2.4 Hz, 1H), 4.65–4.53 (m, 2H), 3.81–3.71 (m, 1H), 1.87–1.63 (m, 2H), 1.33–1.20 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.6, 126.3, 122.3, 122.1, 119.7, 118.7, 114.1, 111.7, 80.6, 36.1, 34.7, 20.4, 13.8.

4.3.14. 3-(1-Isopropyl-2-nitroethyl)-1H-indole (**16an**)[11]

Yield >99%; 67% ee [Daicel Chiralcel AD-H column, *n*-hexane/*i*-PrOH=90:10, 1.0 mL/min, 254 nm; t_1=8.77 min, t_2=9.81 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.02 (s, 1H), 7.58 (d, *J*=7.8 Hz, 1H), 7.27 (d, *J*=7.8 Hz, 1H), 7.19–7.08 (m, 2H), 6.87 (d, *J*=2.4 Hz, 1H), 4.78–4.64 (m, 2H), 3.67–3.60 (m, 1H), 2.17–2.06 (m, 1H), 0.96 (d, *J*=6.6 Hz, 3H), 0.87 (d, *J*=6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.4, 127.0, 122.3, 119.7, 119.1, 113.2, 111.5, 78.8, 42.7, 30.9, 20.7, 20.1.

4.3.15. 3-(1-Cyclohexyl-2-nitroethyl)-1H-indole (**16ap**)[10]

Yield >99%; 39% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=90:10, 1.0 mL/min, 254 nm; t_1=29.02 min, t_2=31.12 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.59 (d, *J*=7.8 Hz, 1H), 7.31 (d, *J*=7.8 Hz, 1H), 7.23–7.09 (m, 2H), 6.93 (s, 1H), 4.80 (dd, *J*=12.0, 6.3 Hz, 1H), 4.70 (t, *J*=9.3 Hz, 1H), 3.70–3.62 (m, 1H), 1.84–1.62 (m, 5H), 1.26–0.84 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.5, 127.0, 122.4, 119.8, 119.2, 113.5, 111.5, 78.7, 42.0, 40.7, 31.3, 30.6, 29.8, 26.3.

4.3.16. 1-Methyl-3-(2-nitro-1-phenylethyl)-1H-indole (**16ba**)[10]

Yield >99%; 55% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=90:10, 1.0 mL/min, 254 nm; t_1=41.70 min, t_2=45.74 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42 (d, *J*=7.8 Hz, 1H), 7.31–7.14 (m, 7H), 7.03 (t, *J*=6.9 Hz, 1H), 6.79 (s, 1H), 5.13 (t, *J*=8.1 Hz, 1H), 4.97 (dd, *J*=12.3, 7.5 Hz, 1H), 4.85 (dd, *J*=12.6, 8.7 Hz, 1H), 3.62 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.6, 137.4, 128.9, 127.8, 127.5, 126.6, 126.4, 122.3, 119.5, 119.0, 112.9, 109.6, 79.6, 41.6, 32.8.

4.3.17. 2-Methyl-3-(2-nitro-1-phenylethyl)-1H-indole (**16ca**)[10]

Yield >99%; 40% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=12.45 min, t_2=48.66 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.73 (s, 1H), 7.34 (d, *J*=7.8 Hz, 1H), 7.27–7.12 (m, 6H), 7.08–6.96 (m, 2H), 5.18–4.99 (m, 3H), 2.22 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.7, 135.5, 133.0, 128.8, 127.4, 127.1, 126.9, 121.3, 119.8, 118.6, 110.8, 108.8, 78.7, 40.6, 11.9.

4.3.18. 5-Bromo-3-(2-nitro-1-phenylethyl)-1H-indole (**16da**)[10]

Yield >99%; 60% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=9.90 min, t_2=11.12 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.52 (s, 1H), 7.30–7.19 (m, 6H), 7.12 (d, *J*=9.6 Hz, 1H), 6.93 (d, *J*=2.4 Hz, 1H), 5.06 (t, *J*=8.1 Hz, 1H), 4.94 (dd, *J*=12.6, 8.1 Hz, 1H), 4.84 (dd, *J*=12.1, 8.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.9, 135.2, 129.1, 128.0, 127.8, 127.7, 125.7, 123.0, 121.5, 114.0, 113.3, 113.0, 79.5, 41.4.

4.3.19. 5-Methoxy-3-(2-nitro-1-phenylethyl)-1H-indole (**16ea**)[10]

Yield >99%; 56% ee [Daicel Chiralcel OD column, *n*-hexane/*i*-PrOH=70:30, 1.0 mL/min, 254 nm; t_1=10.05 min, t_2=10.89 min (major)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.27–7.18 (m, 5H), 7.12 (dd, *J*=6.9, 3.0 Hz, 1H), 6.86–6.79 (m, 3H), 5.08 (t, *J*=8.1 Hz, 1H), 4.96 (dd, *J*=12.6, 7.5 Hz, 1H), 4.85 (dd, *J*=12.6, 8.4 Hz, 1H), 3.72 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.3, 139.4, 131.8, 129.0, 127.8, 127.6, 126.7, 122.5, 114.0, 112.7, 112.2, 101.1, 79.6, 55.9, 41.6.

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