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## Synthesis of Optically Active Oligonaphthalenes via Second-Order Asymmetric Transformation

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The helical structure is one of the most ordered structures and packs molecular information into a restricted space. In the field of supramolecular chemistry, these helical structures have attracted considerable attention, and various artificial helical molecules have been synthesized.<sup>1</sup> We have focused our attention on optically active rod-shaped oligo(2,3-dioxyfunctionalized)naphthalenes connected at their 1,4-positions.<sup>2</sup> Important characteristics of these oligonaphthalenes include: (1) their frameworks are rigid in the rod direction, (2) they have chirality and some degree of flexibility around the axes, and (3) functional groups can be introduced into scaffolding 2,3-dioxy groups. If all axis chiralities could be controlled, then either *R* or *S*, functionalized, optically active helical oligonaphthalenes, which may be applicable in material science, could be constructed.

There are two reported methods for controlling the axis chirality when coupling 2-naphthol derivatives, which should be the first step toward constructing the optically active oligonaphthalenes. One is the enantioselective oxidative couplings.<sup>3</sup> In this reaction, the axis chirality was directly induced in the coupling step. Furthermore, an attempt of polymerization of chiral binaphtharene derivatives as a monomeric unit was also reported.<sup>4</sup> On the other hand, an alternative synthesis for optically active binaphthols via secondorder asymmetric transformation was reported.5 In this transformation, epimerization of the axis under amine-copper conditions together with diastereoselective crystallization occurs.<sup>6</sup> Although this method is effective for synthesizing optically active compounds, fortuitous conditions are essential. For example, for the self-coupling of 2-naphthol, high selectivity was reported for α-methylphenylethylamine (96% ee), whereas  $\beta$ -methylphenylethylamine (8% ee) or α-methylbenzylamine (8% ee) yielded poor selectivities.<sup>5a</sup> Herein, we report the synthesis of optically active naphthalene derivatives (from tetramer to hexadecamer) via second-order asymmetric transformations.

First, the reaction conditions were investigated using optically active dimer **1** as the starting material (Scheme 1 and Table 1, entries 1–5). Diastereoselectivity was barely observed for the dimer (*S*)-**1**<sup>7</sup> and (*R*)- or (*RS*)- $\alpha$ -methylbenzylamine (Table 1, entries 1 and 2). On the other hand, (*S*)-**1** was treated with (*S*)- $\alpha$ -methylbenzylamine to afford a large amount of brown precipitate. After an acidic workup, (*S*,*S*,*S*)- and (*S*,*R*,*S*)-**2** were obtained in 76% and 11% isolated yield, respectively (75% de).<sup>8</sup> Moreover, after the brown precipitate was removed by filtration, the precipitate and the filtrate were separately purified (entries 4 and 5). An extremely high diastereoselectivity was observed from the precipitate (93% de, 58% yield), but a poor selectivity was obtained from the filtrate

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## Scheme 1<sup>a</sup>



<sup>*a*</sup> Red bonds denote (*S*)-configuration, and the blue square denotes a newly formed bond.

Τ-	-	-	
1 3	<b>n</b>		
10	~		

entry	substrate	aminea	isolation <sup>b</sup>	yield (%) <sup>c</sup>	de (%) <sup>d</sup>
1 2 3 4 5 6 7	1 1 1 1 3 5	(RS)-(R)-(S)-(S)-(S)-(S)-(S)-(S)-	– PF P F PF PF	73 69 87 58 15 86 78	12 26 75 93 17 99 79

<sup>*a*</sup> Amine =  $\alpha$ -methylbenzylamine. <sup>*b*</sup> - = no precipitation; PF = without separating precipitate and filtrate; P = from precipitate; F = from filtrate. <sup>*c*</sup> Isolated yield. <sup>*d*</sup> Based on the isolated yields of corresponding diastereomers.

(17% de, 15% yield). It should be emphasized that the same diastereomer (S,S,S)-2 was preferentially obtained over (S,R,S)-2 from both the precipitate and the filtrate. These data strongly suggested that the mechanism of the axis chirality control should be epimerization of the axis along with diastereoselective crystallization.

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**Figure 1.** Red bonds denote (S)-configuration, and blue squares denote newly formed bonds.

our knowledge, this is the first synthesis of oligonaphthalenes in which 15 continuous axial bonds were controlled.<sup>9</sup>

The absolute configuration of the newly formed axis bond was determined by the following method. During these studies, three empirical rules have been established. (1) The  $R_f$  value on silica gel TLC of the all-S isomer is larger than that of the one-Rcontaining isomer. (2) The absolute value of specific rotation of the all-S isomer is larger than that of the one-R containing isomer. (3) The amplitude on a CD spectrum of the all-S isomer is larger than that of the one-R containing isomer. To confirm the above rules, 4, which was evaluated for (S,S,S,S,S) chirality, was converted to the all-methoxy derivative 12, and the physical data, including <sup>1</sup>H NMR and the  $[\alpha]_D$  value, were consistent with the physical data for (S,S,S,S,S,S,S)-12, which was synthesized by an alternative route.<sup>2a</sup> Furthermore, because the absolute configuration of the unknown bond was sandwiched between two free hydroxy groups, two 4-(2-pyreneyl)-butyric acid was condensed to the scaffolding hydroxy groups as the exciton part (Figure 1, compounds 7-9). Figure 2 shows the UV spectra and CD spectra of these compounds. Comparing the UV spectra of the compounds (7-9 and 14), methylated samples (10, 11, and 13), and methyl 4-(2-pyreneyl)butyrate (15), the absorbance around 350 nm was clearly assigned to the  $\pi - \pi^*$  transition of the pyrene moiety. Thus, a positive or negative sense around 350 nm on the CD spectrum should reflect the absolute configuration of the target axis bond. As shown in Figure 2b, the absolute configuration of (*S*,*S*,*S*)-7 and (*S*,*S*,*S*,*S*,*S*,*S*,*S*)-8 was confirmed by comparing them to the control samples, which indicated a positive sense around 350 nm. Therefore, the absolute configuration of the major hexadecamer 9 was assigned as 

In conclusion, the synthesis of numerous optically active oligonaphthalene derivatives was achieved by second-order asym-



*Figure 2.* (a) UV-visible spectra of all (*S*)-hexadecamer (dark green), all (*S*)-octamer (red), (*S*,*S*,*S*)-tetramer (blue), and (*S*)-dimer (purple). Solid lines and dotted lines show pyrene derivatives (**7**–**9**, **14**, and **15**) and methoxy derivatives (**10**, **11**, and **13**), respectively. Conditions: chloroform,  $1.0 \times 10^{-5}$  M, light path length = 10 mm, 20 °C. (b) CD spectra of all-(*S*)-**9** (dark green), all-(*S*)-**8** (red), (*S*,*S*,*S*)-**7** (blue), (*S*,*R*,*S*)-**7** (green), (*S*)-**14** (purple), and (*R*)-**14** (dotted purple). Conditions: chloroform,  $1.0 \times 10^{-4}$  M, light path length = 1 mm, 25 °C.

metric transformation. We believe that this method is practical and should contribute to the field of material science. Constructing the effective energy transfer system based on the optically active oligonaphthalenes is currently underway.

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**Supporting Information Available:** Procedures, characterization data of all compounds, and full CD spectra of key oligomers (PDF). This material is available free of charge via the Internet at http:// pubs.acs.org.

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- (8) No enantioselectivity was observed for self-coupling of 3-benzyloxynaphthalen-2-ol under CuCl<sub>2</sub> and (S)-α-methylbenzylamine.
- (9) The reaction conditions were not optimized. The de was influenced by reaction concentration.

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