Chiral High-Pressure Liquid Chromatographic Stationary Phases. 4. Separation of the Enantiomers of Bi-β-naphthols and Analogues[1]

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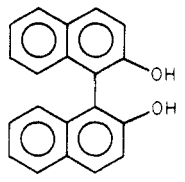
The enantiomers of a number of bi-β-naphthols and analogues thereof are readily separable upon an ionically bonded chiral high-pressure liquid chromatographic stationary phase. The elution orders of the enantiomers are related to absolute configuration by a chiral recognition rationale that also provides insight into the efficiency of the chiral recognition process. The method is advocated as a means for assigning absolute configurations to bi-β-naphthols and analogues.

General methods for the direct chromatographic separation of enantiomers are evolving rapidly as an understanding of chiral recognition requirements is gained. Such separations, both analytical and preparative, will find myriad applications and will influence experimental design in rather varied areas of chemistry, medicine, and pharmacology. Having previously described the design, preparation and initial evaluation of some chiral stationary phases (CSP) for the separation of the enantiomers of a number of compounds of varied functionality,[2-4] we focused our attention upon the direct chromatographic resolution of bi-β-naphthol (1) and its analogues.

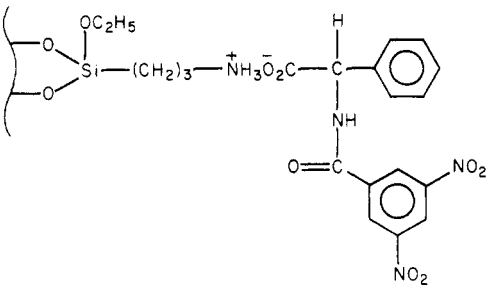


1

A general method for resolving bi-β-naphthols efficiently and conveniently would facilitate a variety of stereochemical studies. Once resolved, bi-β-naphthol (1) can be converted into chiral crown ethers useful as stereoselective complexing agents.[5] Moreover, 1 has also been shown to afford a highly selective attenuated LAH reagent for asymmetric reduction of ketones.[6] To date, 1 has been resolved only by classical means involving separation of diastereomeric derivatives.[7,8,23] We now elaborate upon our report[9] that 1 and a great many of its analogues can be directly resolved by chromatography upon a recently described CSP, the elution order of the enantiomers being that expected on the basis of a chiral recognition rationale of considerable scope.

Results and Discussion

Figure 1 and Table I document the facility with which the enantiomers of 1 and its analogues are resolved upon CSP 2, recently described[4] as suitable for the resolution of alkyl aryl carbinols. As noted for the alkyl aryl carbinols, the degree of chiral recognition shown by CSP 2 toward bi-β-naphthols is somewhat dependent upon the silica used to prepare CSP 2.[10] Figure 1 and a portion of the data in Table I were obtained by using a 4.6 mm × 25 cm commercial column modified in situ to render it chiral.[11] This column accommodates samples in the nanogram to milligram range, larger quantities being accommodated upon a 2 × 40 in. preparative column.[12]



2

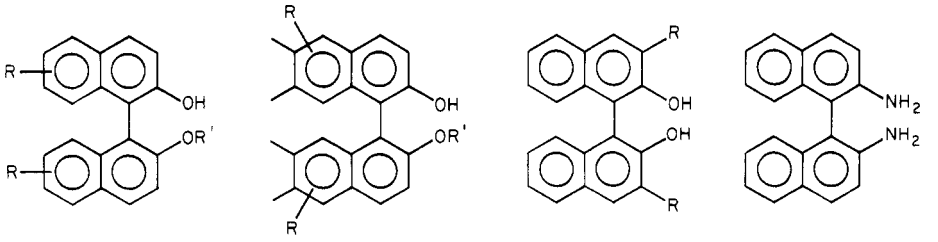
Four resolved configurationally known bi-β-naphthols 1, 1a, 8b, and 9 were available to us. These and several derivatives thereof were used to establish the elution orders of the enantiomers from CSP 2. A quantity of 6,6′,7,7′-tetramethylbi-β-naphthol (7) was resolved preparatively and the CD spectrum of the initially eluted enantiomer was found to be virtually identical with that of (*S*)-(−)-1. Hence, the absolute configuration of each enantiomer of 7 (and its derivatives) is considered to be established. In each instance where elution order is known (entries in Table I are marked with an asterisk), that elution order conforms to the accompanying chiral recognition rationale. The elution orders for the configurationally unknown bi-β-naphthols (and analogues) in Table I are presumed to similarly conform.

If a CSP is to show a greater affinity for one solute enantiomer than the other, then the preferentially bound enantiomer must undergo a minimum of three simultaneous interactions with the CSP, with at least one of the interactions being dependent upon the stereochemistry of that solute enantiomer. In the present instance, the three interactions, shown in 13 for the preferentially bound solute enantiomer of 1, are believed to consist of a π−π interaction between the dinitrobenzoyl group of 2 and one naphthyl π-system, a hydrogen bond between the amide hydrogen of 2 and the oxygen of the non-π-complexed

(1) Presented in part at the 15th Annual Midwest Regional Meeting of the American Chemical Society, St. Louis, MO, Nov 9, 1979, No. 648.
(2) W. H. Pirkle and D. W. House, *J. Org. Chem.*, **44**, 1957 (1979).
(3) W. H. Pirkle, D. W. House, and J. M. Finn, *J. Chromatogr.*, **192**, 143 (1980).
(4) W. H. Pirkle and J. M. Finn, *J. Org. Chem.*, **46**, 2935 (1981).
(5) (a) Y. Chao, G. R. Weisman, G. D. Y. Sogah, and D. J. Cram, *J. Am. Chem. Soc.*, **101**, 4948 (1979); (b) M. Newcomb, J. L. Toner, R. C. Helgeson, and D. J. Cram, *ibid.*, **101**, 4941 (1979); (c) J. M. Timko, R. C. Helgeson, and D. J. Cram, *ibid.*, **100**, 2828 (1978); (d) D. J. Cram et al., *ibid.*, **100**, 4555 (1978); (e) D. J. Cram et al., *ibid.*, **100**, 8190 (1978).
(6) R. Noyori, I. Tomino, and Y. Tanimoto, *J. Am. Chem. Soc.*, **101**, 3129 (1979).
(7) J. Jacques, C. Fouquay, and R. Viterbo, *Tetrahedron* Lett., 4617 (1971).
(8) D. J. Cram et al., *J. Org. Chem.*, **42**, 4173 (1977).
(9) W. H. Pirkle, J. M. Finn, J. L. Schreiner, and B. C. Hamper, *J. Am. Chem. Soc.*, **103**, 3964 (1981).
(10) This subject is discussed in ref 3.
(11) This type of column is now available from Regis Chemical Co., Morton Grove, IL.
(12) A preliminary account of this work was presented at the 179th National Meeting of the American Chemical Society Houston, TX, March 24, 1980.

0022-3263/81/1946-4988$01.25/0

Table I. Resolution of Bi-β-naphthols and Analogues upon CSP 2



1, 3-6 7 8 9

	R	R'	α Regis[a]	% [c]	α Ventron[b]	% [c]	k_1' Regis[a]	k_1' Ventron[b]	rotation[d]
1*	H	H	1.33	5	1.45	10	17.4	28.8	−
1a*		Me	1.53	5	1.75	10	3.8	16.8	−
1b*		Et	1.18	5	1.27	10	2.2	4.1	
1c*		*i*-Pr	1.14	5	1.21	10	1.4	1.1	
1d*		Bu	1.17	5	1.29	10	1.4	3.2	
1e*		allyl	1.21	5	1.28	10	2.3	1.8	
1f[16]		acetal			1.22	10		4.6	
3*	6,6'-dibromo	H	1.25	5	1.41	10	22.4	41.4	+
3a		Me	1.37	5	1.57	10	4.1	9.6	
4	7,7'-dimethoxy	H	1.42	5	1.51	5	24.2	41.0	+
5	7,7'-dibutoxy	H	1.62	5	1.54	5	13.4	12.0	+
6	7,7'-diallyloxy	H	1.48	5	1.43	5	20.7	18.5	
7*	H	H	2.0	5	2.39	20	12.1	5.1	+
7a*		Me	3.03	5	3.67	20	3.3	2.0	+
7b*		$CH_2C(=O)OEt$	1.87	10	1.25	5	4.4	13.3	+
7c	5,5'-dibromo	H	2.31	5			17.5		
8a	CH_3		1.18	5			8.5		
8b*[17]	Ph		1.05	1			13.5		
9*[18]			1.16	5			6.4		

[a] A prepacked commercial column supplied by the Regis Company was modified in situ as described.[3] [b] Ball-milled Ventron silica converted to CSP 2 as previously described.[3] [c] Percent isopropyl alcohol in hexane. [d] Sign of rotation of first eluted enantiomer.

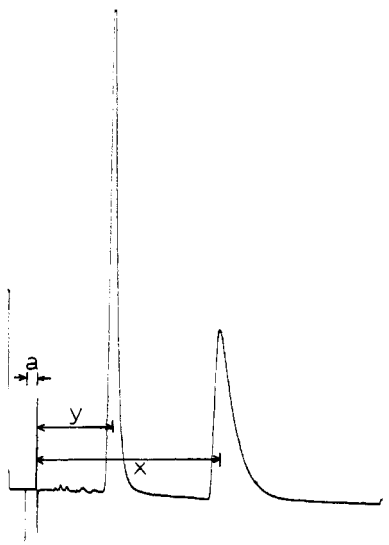
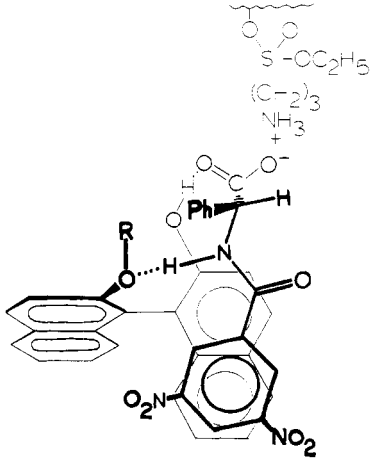


Figure 1. Chromatogram of racemic 7 upon CSP 2, using 10% isopropyl alcohol in hexane at 27 °C.

naphthyl ring, and a hydrogen bond between the carboxylate group of 2 and the hydroxyl group of the π-complexed naphthyl ring. Models show this "templating" to pose no problems in terms of steric hindrance or bond-angle deformation when the amino acid portion of 2 is in the conformation shown. The essential feature here is population of the *Z* rotamer (about the rotationally hindered nitrogen–carbonyl bond) and preferential population of the N–CH rotamer which places the methine hydrogen near the carbonyl oxygen of the DNB group, essentially in the plane of this carbonyl group. This conformation, demonstratable in solution, is that previously invoked in the chiral recognition model involving alkyl aryl carbinols.[4] If the *N*-(3,5-dinitrobenzoyl)phenylglycine is treated as being "rigidly" fixed in the aforementioned conformation during solvation of the bi-β-naphthol enantiomers, one easily sees that the presence or absence of the third interaction depends upon the absolute configuration of the bi-β-naphthol enantiomer. On this basis, one expects the *R* enantiomer of 1 (or its analogues) to show greater affinity for (*R*)-CSP-2 and to be eluted second. This is the experimentally observed result. Note that rotation about the N–CH bond so as to allow the third interaction for both enantiomers of 1 would not equalize the stability of the two diastereomeric solvates. The *RR* diastereomer depicted in 13 would still be more stable, the other diaste-



13

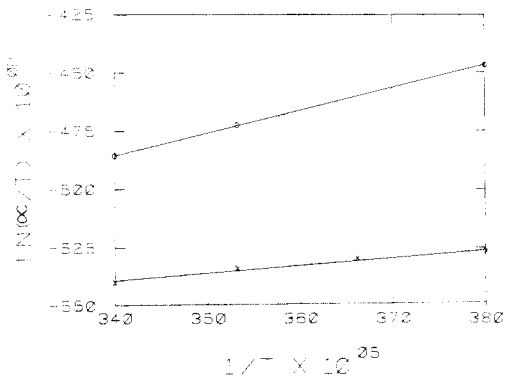


Figure 2. The linear inverse relationship between ln α and temperature. The $\Delta\Delta H$ and $\Delta\Delta S$ values for bi-β-naphthol (**1**) are $(-6.6 \times 10^2) \pm (7.7 \times 10^{-1})$ cal/mol and $(-6.0 \times 10^1) \pm 0.3$ eu (x). For the tetramethyl analogue **7**, the corresponding values are $(-1.9 \times 10^3) \pm (1.0 \times 10^1)$ cal/mol and $(-6.3 \times 10^1) \pm 0.4$ eu (●).

reomer (interchange the methine hydrogen and the phenyl group in **13**)[13] now having the phenyl eclipsed with the carbonyl oxygen of the DNB group, a higher energy conformation. This latter view gives some insight into the possible efficacy of CSP's similar to **2** but derived from α-amino acids other than phenylglycine.[14]

The above model easily rationalizes the effect upon α, the separability factor,[15] with changes in the π basicity of the naphthol system. Greater π basicity affords larger α's. Methylation of one hydroxyl presumably serves to increase the basicity of the oxygen used as a hydrogen bond receptor, thus again improving α. Groups larger than methyl lessen α, presumably for reasons of steric congestion about a region important to chiral recognition. Methylation of both hydroxyls precludes the third interaction previously mentioned, thus destroying the bulk of the chiral recognition. The residual chiral recognition shown by the dimethyl ether, $\alpha = 1.06$, $k'_1 = 0.8$, stems from a less effectual third interaction that we presume to be steric repulsion between the phenyl of CSP **2** and the *O*-methyl (or the edge of the naphthyl ring itself) borne upon the π-complexed naphthyl ring of **1**. Such repulsions have been noted in other systems and will be described in a later paper. Resolution of the diethyl or di-*n*-butyl ethers is not easily observed upon CSP **2**, presumably as a consequence of increased hindrance in the vital region. Although other chiral recognition models can be devised, the preceding model is presently believed to best represent the actual mechanism of chiral recognition.

The diastereomeric pair having the greatest degree of simultaneous bonding is not only expected to afford the more stable solvate but is also expected to lose the most degrees of freedom upon solvation. Hence, one expects and finds (Figure 2) that temperature reduction substantially enhances the magnitude of α, a value approaching 9 having been observed for **7a** at −25 °C. Although mass transfer problems degrade column efficiency at lower temperatures, the increase in the magnitude of α more than offsets the loss in column performance.

Conclusion

The ability to resolve a wide assortment of bi-β-naphthols upon CSP's such as **2** (or its improved successors) will not only facilitate the assignment of absolute configuration to these compounds but will provide ready access to small samples of enantiomerically pure material for chiroptic studies. Indeed, the chiral column not only provides an initial means for resolving such compounds, it also provides a micromethod for following rates of racemization. Large preparative columns of CSP **2** can resolve multigram quantities for synthetic work, as will be described in a subsequent paper. Finally, the reciprocal nature of chiral recognition leads one to surmise the CSP's derived from optimized bi-β-naphthols will prove useful for the resolution of α-amino acids (derivatized as their *N*-3,5-dinitrobenzamides) and related compounds.

Experimental Section

General Procedure. Solvents were reagent grade. Microanalyses were performed by J. Nemeth and Associates, University of Illinois. Melting points were determined with a Büchi apparatus or a hot-stage apparatus and are uncorrected. NMR spectra were obtained on Varian EM-390 or HR-220 spectrometers. Tetramethylsilane is the internal standard. Chiral chromatography was performed by using an Altex 100A pump, a Valco 7000 psi injector with a 10-μL loop, and an Altex Model 152 dual-wavelength (254 and 280 nm) detector.

1,1′-Bi-2-naphthol (1) was prepared by $FeCl_3$ oxidative coupling of 2-naphthol.[19]

6,6′-Dibromo-1,1′-bi-2-naphthol (3). This compound was found in the Marvel Storeroom at the University of Illinois: mp 198–199 °C (lit.[20] mp 199–199.5 °C); NMR ($(CD_3)_2CO$) δ 6.84 (d, 2 H, J = 7.5 Hz), 6.91 (d of d, 2 H, J = 2, 7.5 Hz), 6.92 (d, 2 H, J = 7.5 Hz), 7.02 (d, 2 H, J = 7.5 Hz), 7.06 (d, 2 H, J = 2 Hz).

6,7-Dimethyl-2-naphthol (10) was prepared by using the procedure of Modest:[20] mp 159–160 °C (lit.[21] mp 158–160 °C).

General Synthesis of Symmetrical Bi-β-naphthols. The appropriate substituted β-naphthol was dissolved in CH_3CN and $FeCl_3 \cdot 6H_2O$ was added. The solution was heated to reflux for 3 h. Chromatographic workup afforded the bi-β-naphthols in 30–50% yields.

6,6′,7,7′-Tetramethyl-1,1′-bi-2-naphthol (7): mp 234–235 °C; NMR ($CDCl_3$) δ 2.19 (s, 6 H), 2.38 (s, 6 H), 4.93 (br s, exchanges with D_2O, 2 H), 6.91 (s, 2 H), 7.27 (d, 2 H, J = 9 Hz), 7.62 (s, 2 H), 7.83 (d, 2 H, J = 9 Hz).

Anal. Calcd for $C_{24}H_{22}O_2$: C, 84.18; H, 6.48. Found: C, 84.07; H, 6.55.

7,7′-Dimethoxy-1,1′-bi-2-naphthol (4): mp 151–152 °C; NMR ($(CD_3)_2CO$) δ 3.27 (s, 6 H), 6.18, (d, 2 H, J = 3 Hz), 6.58 (d of d, 2 H, J = 3, 8 Hz), 6.80 (d, 2 H, J = 9 Hz), 7.27 (br s, exchanges with D_2O, 2 H), 7.40 (d, 2 H, J = 9 Hz), 7.43 (d, 2 H, J = 8 Hz); mass spectrum (70 eV), m/e (relative intensity) 347 (30, $(M + 1)^+$), 346 (100, M^+), 314 (12, $M^+ - CH_3OH$), 287 (15), 157 (14), 145 (16), 121 (13), 113 (22), 107 (27).

7,7′-Dibutoxy-1,1′-bi-2-naphthol (5): mp 81–82.5 °C; NMR ($CDCl_3$) δ 0.72–0.95 (br t, 6 H), 1.12–1.75 (m, 8 H), 3.62–3.77 (br t, 4 H), 5.00 (br s, exchanges with D_2O, 2 H), 6.47 (d, 2 H, J = 2 Hz), 7.00 (d of d, 2 H, J = 8, 2 Hz), 7.18 (d, 2 H, J = 9 Hz), 7.77 (d, 2 H, J = 9 Hz), 7.85 (d, 2 H, J = 8 Hz).

(13) This actually produces the mirror image of the relevant diastereomer. However, this interchange is more readily visualized and has the same energetic consequences as inverting the configuration of the bi-β-naphthol.

(14) CSP's analogous to **2** but prepared from either valine or leucine separate the enantiomers of **1** with α values of 1.30 and 1.36 with k'_1 of 9.3 and 5.0, respectively. Elution orders are unchanged.

(15) The separability factor, α, is the relative retention of the enantiomers by the chiral column and is illustrated in Figure 1 where $\alpha = x/y$. The capacity factor, k'_1, a measure of the retention of the first enantiomer by the chiral column, is also illustrated in Figure 1, where $k'_1 = y/a$.

(16) The monoacetyl bi-β-naphthol **1f** was prepared from **1** and acetic anhydride. The ^1H NMR spectrum of the residue was consistent with the expected spectrum and similar to the spectra of the monoalkylated bi-β-naphthols.

(17) This compound was supplied by D. J. Cram, University of California at Los Angeles.

(18) This compound was supplied by Shozo Yamaguchi of Tohoku University.

(19) R. Pummerer, E. Prell, and A. Rieche, *Chem. Ber.*, **59**, 2159 (1926).

(20) A. Riecker, N. Zeller, K. Schurr, and E. Müller, *Ann. Chem.*, **697**, 1 (1966).

(21) A. Rosowsky, K. K. N. Che, N. Papathanasopoulus, and E. J. Modest, *J. Heterocycl. Chem.*, **9**, 263 (1972).

Anal. Calcd for $C_{28}H_{30}O_4$: C, 78.11; H, 7.02. Found: C, 77.61; H, 7.38.

7,7′-Bis(1-propen-3-yloxy)-1,1′-bi-2-naphthol (6): mp 82–83.5 °C; NMR ($CDCl_3$) δ 4.55 (d of d, 4 H), 4.73 (br s, exchanges with D_2O, 2 H), 5.13–5.5 (m, 4 H), 5.83–6.2 (m, 2 H), 6.57–7.00 (m, 6 H), 7.58 (m, 4 H).

Anal. Calcd for $C_{26}H_{22}O_4$: C, 78.37; H, 5.57. Found: C, 78.44; H, 5.75.

Monoalkylation of Symmetric Dihydroxy Compounds. This is a representative procedure. A solution of the diol (17 mmol) in 20 mL of acetone was stirred with 3 g of anhydrous K_2CO_3 for 1 h under nitrogen prior to the addition of the corresponding alkylation agent (19 mmol), (CH_3I, ethyl iodide, isopropyl iodide, *n*-butyl iodide, allyl bromide, or ethyl bromoacetate). After being stirred overnight, the reaction mixture was filtered, the solid being washed repeatedly with acetone. The filtrate was evaporated to dryness and the residue was taken up in 50 mL of CH_2Cl_2 and filtered to remove any remaining potassium salts. The compound was isolated by chromatography and furthur purification by recrystallization from toluene, hexane, or petroleum ether (bp 90–110 °C).

2′-Methoxy-1,1′-binaphthyl-2-ol (1a): mp 151–152 °C (lit.[7] mp 152–153 °C); NMR (CCl_4) δ 3.63 (s, 3 H), 6.90–7.27 (m, 9 H), 7.57–7.83 (m, 4 H).

2′-Ethoxy-1,1′-binaphthyl-2-ol (1b): mp 139–140 °C; NMR ($CDCl_3$) δ 1.08 (t, 3 H), 4.00 (q, 2 H), 4.92 (br s, exchanges with D_2O, 1 H), 6.98–7.42 (m, 8 H), 7.73–7.98 (m, 4 H).

Anal. Calcd for $C_{22}H_{18}O_2$: C, 84.05; H, 5.77. Found: C, 84.20; H, 5.73.

2′-(2-Propoxy)-1,1′-binaphthyl-2-ol (1c): mp 153–155 °C; NMR ($CDCl_3$) δ 0.96 (d, 3 H), 1.10 (d, 3 H), 4.35 (septet, 1 H), 4.55 (br s, exchanges with D_2O, 1 H), 6.90–7.40 (m, 8 H), 7.67–7.95 (m, 4 H).

Anal. Calcd for $C_{23}H_{20}O_2$: C, 84.12; H, 6.14. Found: C, 84.10; H, 5.96.

2′-(1-Butoxy)-1,1′-binaphthyl-2-ol (1d): mp 92.5–94 °C; NMR ($CDCl_3$) δ 0.67 (t, 3 H, J = 7.5 Hz), 0.83–1.57 (m, 4 H), 3.95 (t, 2 H, J = 7 Hz), 4.95 (br s, exchanges with D_2O, 1 H), 6.97–7.47 (m, 8 H), 7.80–8.03 (m, 4 H).

Anal. Calcd for $C_{24}H_{22}O_2$: C, 84.18; H, 6.48. Found: C, 84.00; H, 6.39.

2′-(1-Propen-3-yloxy)-1,1′-binaphthyl-2-ol (1e): mp 109.5–111 °C; NMR ($CDCl_3$) δ 4.43 (br d, 2 H), 4.80–5.03 (m, 3 H), 5.45–5.87 (m, 1 H), 6.90–7.35 (m, 8 H), 7.67–7.93 (m, 4 H).

Anal. Calcd for $C_{23}H_{18}O_2$: C, 84.64; H, 5.56. Found: C, 84.42; H, 5.60.

6,6′-Dibromo-2′-methoxy-1,1′-binaphthyl-2-ol (3a): mp 148–149 °C; NMR ($CDCl_3$) δ 3.72 (s, 3 H), 6.85 (br d, 2 H), 7.22 (m, 3 H), 7.38 (br d, 2 H), 7.82 (br d, 2 H), 7.97 (br s, 2 H).

Anal. Calcd for $C_{21}H_{14}O_2Br_2$: C, 55.05; H, 3.08; Br, 34.88. Found: C, 55.07; H, 3.00; Br, 34.75.

2′-Methoxy-6,6-,7,7′-tetramethyl-1,1′-binaphthyl-2-ol (7a): mp 173–174.5 °C; NMR ($CDCl_3$) δ 2.15 (s, 3 H), 2.17 (s, 3 H), 2.36 (s, 3 H), 2.38 (s, 3 H), 4.75 (br s, exchanges with D_2O, 1 H), 6.81 (s, 1 H), 6.94 (s, 1 H), 7.25 (d, 1 H, J = 9 Hz), 7.38 (d, 1 H, J = 9 Hz), 7.61 (s, 1 H), 7.65 (s, 1 H), 7.78 (d,,1 H, J = 9 Hz), 7.92 (d, 1 H, J = 9 Hz); mass spectrum (70 eV), m/e (relative intensity) 358 (4, $(M + 2)^+$), 357 (28, $(M + 1)^+$), 356 (100, M^+), 326 (13, $M^+ - CH_2O$).

Ethyl [6,6′,7,7′-tetramethyl-1,1′-binaphthyl-2-ol-2′-oxy]-acetate (7b): mp 165.5–167 °C; NMR ($CDCl_3$) δ 1.22 (t, 3 H, J = 7 Hz), 2.09 (s, 6 H), 2.40 (s, 6 H), 4.10 (t, 2 H, J = 7 Hz), 4.45 (d, 1 H, J_{AB} = 17 Hz), 4.75 (d, 1 H, J_{AB} = 17 Hz), 5.67 (br s, exchanges with D_2O, 1 H), 6.77 (s, 1 H), 6685 (s, 1 H), 7.12 (d, 1 H), 7.22 (d, 1 H), 7.55 (br s, 2 H), 7.72 (d, 1 H), 7.82 (d, 1 H); mass spectrum (70 eV), m/e (relative intensity) 429 (13, $(M + 1)^+$), 428 (44, M^+), 326 (15), 162 (16), 86 (21), 57 (100), 56 (50).

7-Methoxy-2-naphthol (11): mp 117–118 °C (lit.[22] mp 116–117 °C); NMR ($CDCl_3$) δ 3.77 (s, 3 H), 4.73 (br s, exchanges with D_2O, 1 H), 6.50–6.68 (m, 4 H), 7.28 (d, 2 H, J = 9 Hz).

7-(1-Butoxy)-2-naphthol (12): mp 78.5–80 °C; NMR ($(C-D_3)_2CO$) δ 0.93 (t, 3 H, J = 6 Hz), 1.22–1.80 (m, 4 H), 3.82 (t, 2 H, J = 7 Hz), 6.50–6.80 (m, 4 H), 7.28 (d, 2 H, J = 8 Hz), 8.07 (br s, exchanges with D_2O, 1 H).

Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.61; H, 7.37.

7-(1-Propen-3-yloxy)-2-naphthol (13): mp 83–84 °C; NMR ($(CD_3)_2CO$) δ 4.25 (d of d, 2 H), 4.83–5.18 (m, 2 H), 5.55–5.92 (m, 1 H), 6.55–6.93 (m, 4 H), 7.28 (d, 2 H, J = 8 Hz), 8.19 (br s, exchanges with D_2O, 1 H).

Anal. Calcd for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04. Found: C, 77.76; H, 5.89.

5,5′-Dibromo-6,6′,7,7′-tetramethyl-1,1′-bi-2-naphthol (7c). To a solution of **7** (1.56 g, 4.6 mmol) in 50 mL of CH_2Cl_2 was added excess Br_2. The mixture was stirred for 12 h under a nitrogen atmosphere. The solvent was removed in vacuo. The residue was recrystallized from toluene, affording 1.83 g (80%) of **7c** as a white solid: mp 246–248 °C; NMR ($CDCl_3$) δ 2.25 (s, 6 H), 2.55 (s, 6 H), 4.95 (br s, exchanges with D_2O, 2 H), 6.84 (s, 2 H), 7.37 (d, 2 H, J = 9 Hz), 8.43 (d, 2 H, J = 9 Hz).

Anal. Calcd for $C_{24}H_{20}Br_2O_2$: C, 57.63; H, 4.03; Br, 31.95. Found: C, 57.95; H, 4.00; Br, 31.99.

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Registry No. 1, 41024-90-2; **1a**, 35193-70-5; **1b**, 79044-23-8; **1c**, 79044-24-9; **1d**, 79044-25-0; **1e**, 79044-26-1; **1f**, 79044-27-2; **3**, 79082-80-7; **3a**, 79044-28-3; **4**, 79044-29-4; **5**, 79044-30-7; **6**, 79044-31-8; **7**, 78772-75-5; **7a**, 78772-76-6; **7b**, 79044-32-9; **7c**, 79044-33-0; **8a**, 55442-34-7; **8b**, 75640-70-9; **9**, 79082-81-8; **10**, 37436-32-1; 11, 5060-82-2; **12**, 79044-34-1; **13**, 79044-35-2.

(22) L. F. Fieser and R. H. Brown, *J. Am. Chem. Soc.*, 71, 3615 (1949).

(23) The chromatographic resolution of bi-β-naphthol upon an HPLC column packed with a chiral polymer has been recently reported [Y. Okamoto, I. Okamota, and H. Yuki, *Chem. Lett.*, 835 (1981)].