The Asymmetric Ullmann Coupling Reaction of Chiral Diol Diesters of 1-Bromo-2-naphthoic Acid and 2-Halo-3-nitrobenzoic Acids: Highly Diastereoselective Synthesis of Atropisomeric 6,6'-Dinitrodiphenic Acids[1]

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The copper-promoted Ullmann reaction of chiral diol diesters of 1-bromo-2-naphthoic acid induced axial dissymmetry into the newly formed 1,1'-binaphthyl bond: chiral diol, apparent net optical yield for the joining of two naphthyl units, and axial chirality induced are as follows: (*S*)-1,1'-binaphthyl-2,2'-diol, 71%, *S*; (1*S*,2*S*)-1,2-diphenyl-1,2-ethanediol, 32%, *S*; (1*R*,2*R*)-1,2-bis(ethoxycarbonyl)-1,2-ethanediol, 33%, *S*; (4*S*,5*S*)-bis(hydroxymethyl)-2,2-dimethyl-1,3-dioxolane, 3.7%, *R*. The reaction of (*R*)-1,1'-binaphthyl-2,2'-diol esters of 2-halo-3-nitrobenzoic acids gave up to 85% net optical yield for the coupling; the intramolecular cyclization proceeded with virtually complete diastereoselectivity to give cyclic diester of *R*,*R*-configuration in a 42% isolated yield. This remarkable stereocontrol is ascribed to the steric requirement of the 12-membered cyclic diester structure containing rigid 1,1'-binaphthyl and 1,1'-biphenyl moiety.

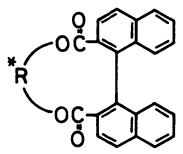
Although axially dissymmetric biaryl skeletons have been successfully utilized in the asymmetric recognition,[2] direct route to the requisite chiral biaryls are limited.[3] Thus, the construction of atropisomeric biaryls by asymmetric induction represents a potential value. Recently two groups disclosed elegant synthesis of chiral binaphthyls through nucleophilic aromatic displacement using oxazolines as the activating substituents for the naphthalene nucleus.[4,5]

In the previous paper,[1] we have reported asymmetric synthesis of atropisomeric 1,1'-binaphthyl derivatives (**3** and **4**) *via* the Ullmann reaction of chiral 1,1'-binaphthyl-2,2'-diol esters (**1a**) of 1-bromo-2-naphthoic acid followed by cleavage of the ester linkage (Scheme 1).

Herein we wish to report the effects of the diol structure on the induction of axial dissymmetry in the asymmetric Ullmann reaction, and an extention to a highly diastereoselective synthesis of chiral 6,6'-dinitrodiphenic acids.

Results and Discussion

Induction of Axial Dissymmetry into 1,1'-Binaphthyl Bond. Chiral diols (**2a—2d**) were converted into respective diesters **1a—1d** by the reaction with 1-bromo-2-naphthoyl chloride in benzene-pyridine. These bifunctional substrates were treated with activated copper powder in gently-refluxing DMF to give thoroughly debrominated products. As evidenced by TLC and HPLC, these mixtures were comprised of many components containing intramolecularly coupled cyclic diester **7**, the reduction product **8**, and various oligomers formed *via* intermolecular reactions. The ester linkage of the reaction products was reductively cleaved to hydroxymethyl function by the treatment with lithium aluminum hydride (LAH). The apparent net optical yields for the induction of axial dissymmetry in joining two naphthyl units by the asymmetric Ullmann reaction were estimated from the optical rotations of the 2,2'-bis(hydroxymethyl)-1,1'-binaphthyls **4** thus obtained (Table 1).



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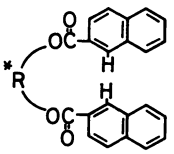

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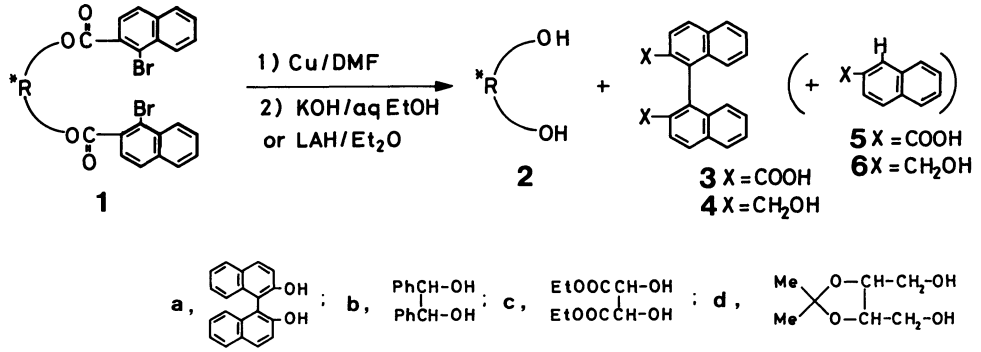
It is noted that axially dissymmetric 1,1'-binaphthyl-2,2'-diol (*S*)-**2a** gave relatively high optical yields of up to 71% under dilution conditions. In the previous paper,[1] we reported that the intramolecular coupling of (*S*)-**1a** proceeds with complete diastereoselectivity to



Scheme 1.

Table 1. Asymmetric ullmann coupling of chiral diol diesters of 1-bromo-2-naphthoic acid[a)]

1	Reaction conditions				4	
	1 (mmol)	Cu (g)	DMF (ml)	Addn time/h	Optical purity/%[b)]	Config
(*S*)-**1a**	0.401	1.0	10	—[c)]	45	*S*
	1.25	2.0	80	5	57	*S*
	0.864	2.0	60	8	71	*S*
(*S*)-**1b**	2.92	2.0	60	1	23	*S*
	2.78	2.0	100	5	32	*S*
(*R*)-**1c**	2.86	2.0	80	5	33	*S*
(*S*)-**1d**	1.99	3.0	50	5	3.7	*R*

a) A solution of **1** in DMF was added to a gently-refluxing suspension of copper powder in DMF. After the addition, the reaction was continued for another 2 h. b) Calculated on the basis of the value for optically pure (*S*)-**4**; $[\alpha]_{546}^{23}$ −86.0° (*c* 1.43, acetone). See Ref. 1. c) Result from Ref. 1 where a mixture of diester and copper powder in DMF was heated at 120—130 °C for 10 h.

give cyclic diester (*S,S*)-**7a** with no detectable amount of (*S,R*)-isomer. This remarkable stereocontrol is ascribed to the steric requirement in assembling 12-membered cyclic diester which contains two sets of 1,1′-binaphthyl residues. However, competing intermolecular coupling of **1** to oligomeric products seems hardly to induce axial dissymmetry in the joining of two naphthyl moieties,[1,6] thus reducing the overall optical yield for the synthesis of chiral binaphthyls *via* the route depicted in Scheme 1. Thus, the substantial improvement of the optical yields under dilution reaction conditions should be attributed to the enhancement of the unimolecular process.

C-Chiral 1,4-diol (*S*)-**2d** was almost ineffective to cause asymmetric induction, while 1,2-diols such as (1*S*,2*S*)-1,2-diphenyl-1,2-ethanediol ((*S*)-**2b**) and (1*R*, 2*R*)-1,2-bis(ethoxycarbonyl)-1,2-ethanediol ((*R*)-**2c**) induced *S* chirality into the binaphthyl linkage with moderate optical yields. As was stated above, intermolecular coupling of chiral 1-bromo-2-naphthoates seems not so effective in asymmetric induction, the monocyclization step to **7** is critical for determining the overall optical yield in Scheme 1. In this respect, 1,2-ethanediol **2b** and **2c** seem not so strictly control the stereochemistry of monocyclization as binaphthol **2a**. Actually, (*S*)-**1b** gave the cycle **7b** as a mixture of (*S,S*)- and (*S,R*)-isomer in a ratio of 5.2:1 (*i.e.* 68% diastereomeric excess) based on HPLC of the crude reaction mixture (5-h addition reaction in Table 1).

Examination of CPK molecular models does not show so much difference in steric distortions between the diastereomeric cycles (*S,S*)- and (*S,R*)-**7b**, showing sharp contrast to the possible cycles (*S,S*)- and (*S,R*)-**7a** from (*S*)-**1a**.[1)] In the case of (*S,R*)-**7b**, however, the lone pair electrons on one of the ester oxygen seem to strongly interact with one naphthalene ring plane. Another explanation for the preferential formation of (*S,S*)-**7b** over (*S,R*)-counterpart may involve the inspection of plausible conformers of (*S*)-**1b** which may lead

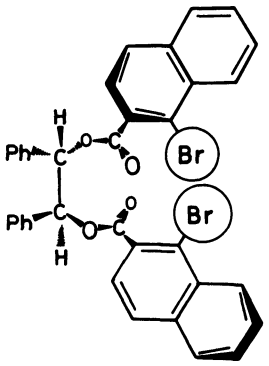


Fig. 1. Conformer (*S*)-**1b**-*S* to (*S,S*)-**7b**.

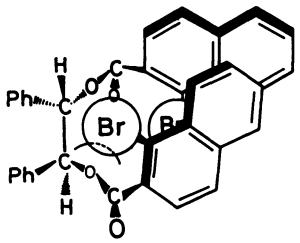
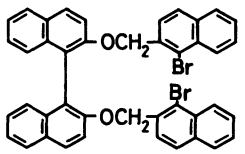


Fig. 2. Conformer (*S*)-**1b**-*R* to (*S,R*)-**7b**.

to the coupling stages and thus may reflect transition states. As schematically shown in Figs. 1 and 2, the conformer (*S*)-**1b**-*S* which may lead to *S,S*-coupling will be significantly favored over (*S*)-**1b**-*R* conformer to *S,R*-coupling because of the severe steric distortion in the latter caused by inwardly directed bromine and one ester oxygen atom. This reasoning is based on the assumption that the central mechanistic feature of the Ullmann coupling reaction involves intermediary of organocopper species and free radicals do not play critical role, thus imposing relatively high steric requirements in the coupling process.[7,8)]

Although we have been unable to resolve reaction products from (*R*)-**1c**, similar rationalization as above may be applied to explain the preferential formation of (*S*)-binaphthyl (*S*)-**4**: Phenyl and ethoxycarbonyl substituents do not exert meaningful differences on the plausible conformers depicted in Fig. 1 and 2. This may explain the similarity of the magnitudes of asymmetric induction and the sense of chirality with (*S*)-**2b** and (*R*)-**2c**.

Highly Asymmetric Synthesis of Chiral 6,6′-Dinitrodiphenic Acids. Knowing that 1,1′-binaphthyl-2,2′-diol is the best chiral auxiliary among the diols examined, we tried the reaction of diether **9**, but did not observe any sign of debromination after an elongated treatment with activated copper powder at reflux in DMF.[9)]



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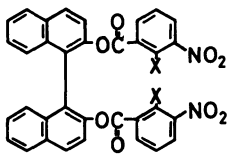
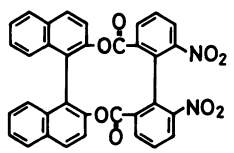


10 X = I
11 X = Cl
12 X = H



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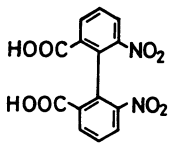

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It is well known that electron-withdrawing substituents activate aromatic nucleus toward the Ullmann reaction.[8] Hoping to enhance the key unimolecular coupling, we tried the reaction of 2-halo-3-nitrobenzoic acid esters (**10** and **11**). A reaction of (*R*)-2,2′-bis(2-iodo-3-nitrobenzoyloxy)-1,1′-binaphthyl ((*R*)-**10**) was carried out as above. HPLC of the reaction mixture showed the presence of, in the order of elution, the cyclic diester (*R,R*)-**13** as the major component as expected (*ca.* 70% of the HPLC peak area by UV absorption at 254 nm), the reduction product (*R*)-**12** (*ca.* 10%), and others. It has been our general experience that monomeric cyclic diesters **7** are more mobile than the open chain counterparts **8** on chromatography. After a hydrolytic treatment and standard extractive workup followed by TLC, a sample of (*R*)-6,6′-dinitrodiphenic acid ((*R*)-**14**) was recovered in *ca.* 50% chemical yield, with $[\alpha]_D^{22}$+116° in 95% EtOH, indicating a 85% optical yield based on the rotation of enantiomerically pure (*R*)-**14** (*vide infra*). It should be noted that the chiral source (*R*)-**2a** was recovered without appreciable loss of optical activity. Similarly, (*S*)-diacid ((*S*)-**14**) was obtainable by the reaction of (*S*)-**10**.

The dichloro ester (*R*)-**11**, prepared from commercially available 2-chloro-3-nitrobenzoic acid, gave analogous results but with slightly reduced overall optical yield (80%). The Ullmann product was subjected to a silica-gel chromatography to give a pure sample of (*R,R*)-**13** as an yellow-orange powder in a 42% isolated yield, $[\alpha]_D^{22}$+226° in $CHCl_3$. The enantiomeric purity of the sample was confirmed by the optical rotations of the recovered (*R*)-**2a** and (*R*)-**14** obtained after hydrolytic cleavage of the ester linkage. The specific rotation of the recovered diacid (*R*)-**14** was $[\alpha]_D^{22}$ +136.6° (95% EtOH), while that claimed for enantiomerically pure (*R*)-**14** is $[\alpha]_D$ +133.7° (95% EtOH).[10]

Here again, high steric requirement in assembling 12-membered cyclic diester **13** which contains rigid binaphthyl and biphenyl skeleton explains the exclusive formation of (*R,R*)-**13** without (*R,S*)-isomer. Moreover, two sets of nitro substituents in (*R,S*)-**13** can not lie on the attaching benzene planes, further disfavoring the formation of it (Figs. 3 and 4).

Although the scope and limitations of the asymmetric Ullmann coupling reaction remains to be exam-

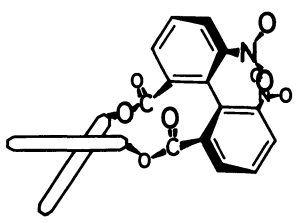

Fig. 3. (*R,R*)-**13**.

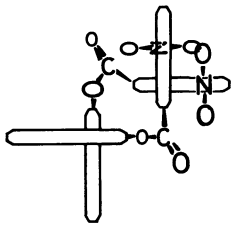

Fig. 4. (*R,S*)-**13**.

ined,[11] the method presented here, that is the intramolecular coupling of two aryl moieties attached to a chiral 1,1′-binaphthyl residue, is likely to provide an entry into the asymmetric synthesis of chiral biaryls.

Experimental

Melting points are uncorrected. Measurements and materials were similar to those described in the previous paper unless otherwise noted.[1]

The following compounds were prepared as described in the literature; 2-iodo-3-nitrobenzoic acid,[12,13] mp 205—209 °C (lit,[13] 210—212 °C), IR (KBr) 1710, 1540, and 1370 cm^{-1}; (4*S*,5*S*)-4,5-bis(hydroxymethyl)-2,2-dimethyl-1,3-dioxolane ((*S*)-**2d**),[14] bp 112 °C/1.5 mmHg.†

Racemic 1,2-diphenyl-1,2-ethanediol was resolved into *R*- and *S*-isomer by direct crystallization from ether solution.[15] Crystals which showed levorotation in $CHCl_3$ were collected[16]; mp 148—149 °C (lit,[16b] 148—149 °C), $[\alpha]_D^{22}$ −95.0° (*c* 1.00, EtOH) (lit,[16b] $[\alpha]_D^{22}$−94.5° (*c* 0.998, EtOH)). Commercial 2-chloro-3-nitrobenzoic acid and (1*R*,2*R*)-1,2-bis(ethoxycarbonyl)-1,2-ethanediol were used as received. 2-Halo-3-nitrobenzoic acids were converted to acid chlorides by the treatment with thionyl chloride.

Synthesis of Diol Diesters. To a stirred, water-chilled solution of a chiral diol **2** (5—6 mmol) in PhH(100 ml)–pyridine(10 ml) was slowly added slightly excess amount of an acid chloride (12—14 mmol). The mixture was stirred overnight at ambient temperature and finally heated under reflux for 3 h. The reaction mixture was diluted with PhH (50 ml), and then 50 ml of 2 M†† HCl was added. The aqueous layer was extracted with PhH (30 ml×3). The combined organic extracts were washed successively with 2 M HCl, 1 M Na_2CO_3, and water, and then dried over Na_2SO_4 in the presence of activated charcoal. After volatiles were removed under a reduced pressure, the crude diester was purified by column chromatography and/or recrystallization. Yields were generally good to excellent (65—95%).

*(S)-2,2′-Bis(1-bromo-2-naphthoyloxy)-1,1′-binaphthyl ((S)-**1a**)*: This compound was the same as was used in the previous work.[1]

*(1S,2S)-1,2-Bis(1-bromo-2-naphthoyloxy)-1,2-diphenylethane ((S)-**1b**)*: The crude material was chromatographed on a silica-gel column with toluene as the eluent to yield white solids: mp 177—179 °C; $[\alpha]_D^{22}$ +12.3° (*c* 1.63, $CHCl_3$); IR (KBr) 3500—3300, 3050—2950, 1730, 1260, 1220, 1110, 960, 808, 750, and 690 cm^{-1}; ^1H NMR ($CDCl_3$) δ=6.47, (2H, s, -CH<×2), 7.20 (10H, s, $-C_6H_5$×2), 7.30—7.80 (10H, m), and 8.15—8.45 (2H, m). Found: C, 63.60; H, 3.43; Br, 23.27%. Calcd for $C_{36}H_{24}Br_2O_4$: C, 63.55; H, 3.56; Br, 23.49%.

*Diethyl (2R,3R)-2,3-Bis(1-bromo-2-naphthoyloxy)-1,4-butanedioate ((R)-**1c**)*: The crude material was chromatographed on a silica-gel column with $CHCl_3$ (1% EtOH) as the eluent, and then recrystallized from MeOH: mp 127—129 °C; $[\alpha]_D^{22}$

† 1 mmHg≈133.322 Pa.

†† 1 M=1 mol dm^{-3}.

−79.1° (*c* 0.923, $CHCl_3$); IR (KBr) 3500—3300, 3000—2850, 1765—1740, 1250, 1220—1195, 1110, 805, and 755 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.1—1.33 (6H, t, *J*=7 Hz, $-CH_3\times2$), 4.06—4.41 (4H, q, *J*=7 Hz, $-CH_2-\times2$), 6.03 (2H, s, $-CH<\times2$), 7.33—7.80 (10H, m), and 8.15—8.40 (2H, m). Found: C, 53.51; H, 3.45; Br, 24.04%. Calcd for $C_{30}H_{24}Br_2O_8$: C, 53.59; H, 3.60; Br, 23.77%.

*(4S,5S)-4,5-Bis(1-bromo-2-naphthoyloxymethyl)-2,2-dimethyl-1,3-dioxolane ((S)-**1d**)*: The crude material was recrystallized from acetone: mp 136—138 °C; $[\alpha]_D^{22}$ −15.3° (*c* 0.979, acetone); IR (KBr) 3500—3300, 3000—2850, 1730, 1460, 1370, 1260, 1220, 1120, 990, and 750 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.40, (6H, s, $-CH_3\times2$), 4.2—4.6 (6H, m), 7.3—7.8 (10H, m), and 8.2—8.4(2H, m). Found: C, 55.54; H, 3.63; Br, 25.20%. Calcd for $C_{29}H_{24}Br_2O_6$: C, 55.44; H, 3.85; Br, 25.43%.

*(R)-2,2′-Bis(2-iodo-3-nitrobenzoyloxy)-1,1′-binaphthyl ((R)-**10**)*: The crude material was chromatographed on a silica-gel column with toluene as the eluent: mp 99—106 °C; $[\alpha]_D^{22}$ +22.3° (*c* 1.03, $CHCl_3$); IR (KBr) 3500—3300, 1750, 1530, 1350, 1250, 1190, 1110, 1090, 805, 760—720, and 690 cm^{-1}; ^1H NMR ($CDCl_3$) δ=6.55—8.00 (m). Found: C, 49.15; H, 2.04; N, 3.19; I, 29.98%. Calcd for $C_{34}H_{18}I_2N_2O_8$: C, 48.83; H, 2.17; N, 3.35; I, 30.35%.

*(S)-**10***: $[\alpha]_D^{22}$ −23.1° (*c* 0.997, $CHCl_3$). Found: C, 49.18; H, 2.08; N, 3.35; I, 29.82%.

*(R)-2,2′-Bis(2-chloro-3-nitrobenzoyloxy)-1,1′-binaphthyl ((R)-**11**)*: The crude material was chromatographed on a silica-gel column with toluene as the eluent: mp 77—80 °C; $[\alpha]_D^{22}$ +43.2° (*c* 1.46, $CHCl_3$); IR (KBr) 1755, 1535, 1350, 1280—1240, 1190, 1120—1080, 805, 735, and 680 cm^{-1}; ^1H NMR ($CDCl_3$) δ=6.90—8.00 (m). Found: C, 62.58; H, 2.73; N, 4.13; Cl, 10.43%. Calcd for $C_{34}H_{18}Cl_2N_2O_8$: C,62.50; H, 2.78; N, 4.29; Cl, 10.85%.

*(±)-2,2′-Bis(3-nitrobenzoyloxy)-1,1′-binaphthyl (**12**)*: The crude material was chromatographed on a silica-gel column with toluene as the eluent: mp 174—177 °C; IR (KBr) 3500—3300, 1750—1740, 1530, 1345, 1240, 1200, 1100, 805, 750, and 705 cm^{-1}; MS (70 eV), *m/z* (%) 584 (M^+, 18.4), 268 (4.32), 150 (44.9), and 104 (12.3). Found: C, 70.06; H, 3.31; N, 4.44% Calcd for $C_{34}H_{20}N_2O_8$: C, 69.86; H, 3.45; N, 4.79%.

*(±)-2,2′-Bis(1-bromo-2-naphthylmethoxy)-1,1′-binaphthyl (**9**)*: (±)-1,1′-Binaphthyl-2,2′-diol (5.74 g, 20.0 mmol) was added to a sodium methoxide (prepared from 1.1 g (48 mmol) of sodium) in 50 ml of DMF. To the mixture was slowly added 1-bromo-2-bromomethylnaphthalene (12.0 g, 40 mmol), and the mixture was diluted with 50 ml of toluene. The reaction was stirred overnight at room temperature, and worked up as usual. The crude material was recrystallized from $CHCl_3$–EtOH (2/1), 8.8 g (61%): mp 177—178 °C; IR (KBr) 1620, 1590, 1500, 1340, 1290, 1235, 1120, 1100, 840, 830, and 765 cm^{-1}; ^1H NMR (CCl_4) δ=5.6(4H, s, $-CH_2-\times2$), and 7.2—8.0 (24H, m). Found: C, 69.89; H, 3.77; Br, 22.31%. Calcd for $C_{42}H_{28}O_2Br_2$: C, 69.63; H, 3.90; Br, 22.06%.

Ullmann Reaction of Bifunctional Substrates. The reaction of (*S*)-**1a** is representative. See Table 1 for the reaction conditions.

*Ullmann Reaction of (S)-**1a***: In a 200-ml, two-necked, round-bottomed flask, copper powder (2.0 g) was pretreated for activation just prior to use.[1] Under a nitrogen atmosphere, to the flask were attached a reflux condenser topped with nitrogen inlet and a pressure-equilibrating Hershberg-type dropping funnel.[17] The funnel was charged with 0.650 g (0.864 mmol) of (*S*)-**1a**, which was then dissolved in 30 ml of DMF. The copper powder was stirred vigorously in 30 ml of DMF and heated to a gentle reflux. To the suspension was added the ester over 8 h period. After the addition had been completed, the reaction mixture was stirred under reflux for another 2 h. After the reaction, the mixture was allowed to cool to room temperature, diluted with 50 ml of PhH, and then filtered. Solids were washed well with portions of PhH. Combined organic layer was washed successively with 2 M HCl and then water (×3), and dried over Na_2SO_4 in the presence of activated charcoal. Evaporation of the solvent *in vacuo* left a pale yellow residue (0.482 g); $[\alpha]_D^{22}$ −201° (*c* 1.03, PhH). A portion of the residue (0.30 g) was boiled with 0.2 g of LAH in ether (40 ml) for 4 h. The reaction was quenched with cautious addition of ethyl acetate and then water, and worked up as usual. Preparative TLC on silica gel with $CHCl_3$–ethyl acetate (4/1) afforded (*S*)-**4** (80 mg), $[\alpha]_{546}^{22}$ −61.1° (*c* 0.973, acetone), and (*S*)-**2a** (127 mg), $[\alpha]_D^{22}$ −35.0° (*c* 1.06, THF).

When the addition time of (*S*)-**1a** was reduced to 5 h, the Ullmann product showed $[\alpha]_D^{22}$ −170° (*c* 1.30, PhH), and the optical rotation of recovered **4** was reduced to $[\alpha]_{546}^{22}$ −49.2° (*c* 0.955, acetone).

*Ullmann Reaction of (S)-**1b***: The addition time of (*S*)-**1b**, optical rotation of the Ullmann product, and that of recovered **4** were as follows; 1 h, $[\alpha]_D^{22}$ +10.1° (*c* 1.19, $CHCl_3$), $[\alpha]_{546}^{22}$ −19.7° (*c* 1.02, acetone); 5 h, $[\alpha]_D^{22}$ −42.3° (*c* 1.40, $CHCl_3$), $[\alpha]_{546}^{22}$ −27.5° (*c* 1.16, acetone).

Among the products of these Ullmann reactions, the component eluted third on HPLC (ODS column, CH_3CN–H_2O (20/1)) was assigned as the reduction product **8b** by comparing the retention volume with that of authentic sample. The most mobile component was assigned as (*S,R*)-**7b**, and the second as (*S,S*)-**7b** on the basis of the peak areas of these two components on HPLC (UV absorption at 254 nm) and optical purity of the **4** obtained after LAH reduction of mixtures of these two components. The HPLC peak areas were calibrated to mole fractions of (*S,S*)- and (*S,R*)-**7b** using the formula

$$\text{O.P.} \times (1/100) \approx (fP_{S,S}-P_{S,R})/(fP_{S,S}+P_{S,R}) = (M_{S,S}-M_{S,R})/(M_{S,S}+M_{S,R})$$

where O.P.=% optical purity of the recovered **4**, $M_{S,S}$=moles of (*S,S*)-**7b**, $M_{S,R}$=moles of (*S,R*)-**7b**, $P_{S,S}$=peak area of (*S,S*)-**7b** on HPLC, $P_{S,R}$=peak area of (*S,R*)-**7b**, and f= a correspondence factor (2.86, r=0.995) experimentally determined from different mixtures of (*S,S*)- and (*S,R*)-**7b** and the optical rotations of recovered **4**.

In an example, a fraction from the column chromatography which contained (*S,R*)- and (*S,S*)-**7b** (0.170 g, HPLC peak area ratio $P_{S,R}/P_{S,S}$=0.202) was treated with LAH to give (*S*)-**4**, 89 mg (86%), $[\alpha]_{546}^{22}$ −73.7° (*c* 1.02, acetone) and (*S*)-**2b**, 68 mg (97%), $[\alpha]_D^{22}$ −91.3° (*c* 1.03, EtOH).

*Ullmann Reaction of (R)-**1c***: The Ullmann product showed $[\alpha]_D^{22}$ −1.9° (*c* 1.08, $CHCl_3$), and the optical rotation of recovered **4** was $[\alpha]_{546}^{23}$ −28.1° (*c* 1.27, acetone).

*Ullmann Reaction of (S)-**1d***: The Ullmann product showed $[\alpha]_D^{23}$ +13.7° (*c* 1.69, acetone), and the optical rotation of recovered **4** was $[\alpha]_{546}^{22}$ +3.2° (*c* 1.89, acetone).

*Attempted Ullmann Reaction of (±)-2,2′-Bis(1-bromo-2-naphthylmethoxy)-1,1′-binaphthyl (**9**)*: A mixture of **9** (2.50 g, 3.45 mmol) and activated copper powder (prepared from 2.0 g of Cu) in 30 ml of DMF was refluxed for 10 h with vigorous stirring under nitrogen. HPLC showed the presence of only starting material; the organic residue weighed 2.20 g (88%), and the IR absorption spectra (KBr) were superimposable to those of **9**.

When an intimate mixture of **9** (2.40 g, 3.31 mmol) and copper powder (1.5 g) was heated to 250 °C for 4 h in a sand bath, an intractable tarry matter resulted.

*Ullmann Reaction of (R)-2,2′-Bis(2-iodo-3-nitrobenzoyloxy)-1,1′-binapthyl ((R)-**10**)*: A solution of (*R*)-**10** (1.26 g, 1.51 mmol) in 40 ml of DMF was added to a gently-refluxing suspension of copper powder (1.5 g) in 60 ml of DMF over 5 h period, and then the reaction was continued for another 2 h. The organic residue weighed 0.824 g, $[\alpha]_D^{22}$ +166° (*c* 1.37, $CHCl_3$).

Part of the residue (0.787 g) was refluxed with KOH (1.5 g) in EtOH(80 ml)-H_2O (10 ml) for 3 h. After solvents were removed *in vacuo*, the mixture was diluted with H_2O (20 ml) and 2 M HCl (10 ml), and then extracted with ethyl acetate (30 ml×3). Combined organic layer was extracted with 1 M Na_2CO_3 (30 ml×3) and then H_2O (30 ml×3), and dried over Na_2SO_4. Removal of the solvent left (*R*)-**2a**, 0.323 g (84%), $[\alpha]_D^{22}$ +36.3° (*c* 1.85, THF). The combined aq extracts were made acidic with conc. HCl, and then extracted with ethyl acetate (30 ml×3). The organic extracts were treated as usual. Evaporation of the solvent left a mixture of *m*-nitrobenzoic acid and 6,6'-dinitrodiphenic acid **14**, 0.381 g, *ca.* 85% yield. A preparative TLC with PhH–ethyl acetate–acetic acid (5/2/trace) gave (*R*)-**14**, 0.211 g (55.4%); $[\alpha]_D^{22}$+116° (*c* 1.18, 95% EtOH); IR (KBr) 3500—2500, 1730, 1690, 1530, 1340, 1260, 1105, 890, 770, 740, and 690 cm^{-1}; ^1H NMR (acetone-d_6) δ= 7.48—7.77 (2H, m), 8.15—8.30 (4H, m), and 10.85 (2H, s, -COOH×2).

Ullmann Reaction of (S)-10: Similar reaction of (*S*)-**10** (0.972 g, 1.16 mmol) with copper powder (1.5 g) in 100 ml of DMF gave the Ullmann product, 0.573 g, $[\alpha]_D^{22}$ −164° (*c* 0.923, $CHCl_3$). The diacid (*S*)-**14** was recovered in a 50% yield and showed $[\alpha]_D^{22}$ −114° (*c* 1.08, 95% EtOH).

Ullmann Reaction of (R)-2,2'-Bis(2-chloro-3-nitrobenzoyloxy)-1,1'-binaphthyl ((R)-11): The chloro ester (*R*)-**11** (1.24 g, 1.90 mmol) was allowed to react with copper powder (2.5 g) using 100 ml of DMF. The organic residue weighed 1.05 g (*ca.* 95%), $[\alpha]_D^{22}$ +159° (*c* 1.24, $CHCl_3$). From the residue, a 0.483 g of sample was chromatographed on a silica-gel column with toluene as the eluent to give (*R,R*)-**13**, 0.213 g (42% yield based on the (*R*)-**11** used); $[\alpha]_D^{22}$ +226° (*c* 0.989, $CHCl_3$); mp 211—215 °C; MS (70 eV), *m/z* (%) 582 (M^+, 34.6), 283 (6.02), 282 (3.69), 269 (6.21), 268 (25.9), 255 (4.85), 239 (4.56), 226 (3.20), 198 (3.10), 138 (4.17), and 134 (3.69); IR (KBr) 3500—3300, 3000—2850, 1755, 1530, 1345, 1260, 1210, 1190, 1090, 850, 805, 745, and 700 cm^{-1}. Found: C, 69.92; H, 3.29; N, 4.88%. Calcd for $C_{34}H_{18}N_2O_8$: C, 70.10; H, 3.11; N, 4.81%.

The cyclic diester (0.189 g, 0.324 mmol) was treated with KOH in aq EtOH as above, affording (*R*)-**14**, 70 mg (65%), $[\alpha]_D^{22}$ +136.6° (*c* 0.915, 95% EtOH), mp 222—225 °C (lit,[9] 231—231.5 °C), and (*R*)-**2a**, 68 mg (73%), $[\alpha]_D^{22}$ +34.6° (*c* 1.10, THF).

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