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Efficient Synthesis of a New L-Shaped Dimer of Naphthalene, and Its Analogs

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Efficient syntheses of 14*H*-dinaphtho[1,8-*bc*:1′,8′-*fg*]oxocin-14-one (2), 14*H*-dinaphtho[1,8-*bc*:1′,2′-*f*]oxepin-14-one (3), and 2,2′(2*H*,2′*H*)-spirobi[naphtho[1,8-*bc*]furan] (9) are described. The putative structure of 2 has been reported previously, but the synthetic route was not reproducible. 7*H*-Dibenzo[*c*,*h*]xanthen-7-one (4), a known compound, was obtained by a different method. Possible reaction mechanism are proposed.

Key words: L-shaped dimer; chiral derivatizing reagents; anisotropy effect; Friedel-Crafts cyclization reaction

In recent years, many reagents have been developed for chiral recognition of organic compounds by NMR,[1)] and our group has reported several axially chiral reagents for this purpose.[2–4)] In an attempt to develop more useful reagents, we designed a new reagent that has an L-shaped dimer of naphthalene[5)] as a skeleton and has strong anisotropy effects due to naphthalene moieties (Fig. 1). 14*H*-Dinaphtho[1,8-*bc*:1′,8′-*fg*]oxocin-14-one (**2**) is a skeleton of this designed reagent that was synthesized by Kubo and Sato,[6)] but the reported method was not reproducible. In addition, to our knowledge, an efficient method for the synthesis of L-shaped compounds such as **2** has not yet been developed. This may be due to the fact that these L-shaped dimers have no known applications; nevertheless, they have unique and attractive structures. Here we report the efficient synthesis of L-shaped dimer **2** and its analogs, which were found in the reaction process for **2**.

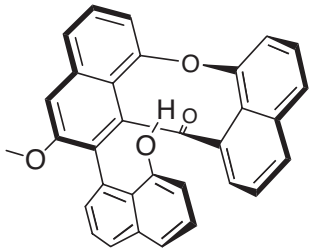
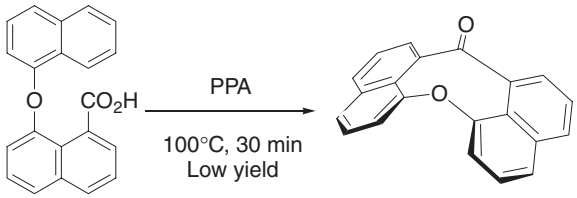


Fig. 1. A Target Molecule as a New Chiral Reagent.



Scheme 1.

Results and Discussion

According to the literature,[6)] the L-shaped compound **2** is synthesized by Friedel-Crafts ring closure of carboxylic acid **1** in polyphosphoric acid (PPA) (Scheme 1). We repeated the reaction under the original conditions, but did not obtain **2**, instead obtaining a 7-membered adduct (**3**) in 86% yield and a 6-membered adduct (**4**) in 14% yield. When we used TFAA along with a catalytic amount of trifluoromethansulfonic acid, the reaction gave **3** exclusively (Scheme 2). These results indicate that the formation of **3** proceeds under kinetic control while the formation of **4** proceeds under thermodynamic control. 7*H*-Dibenzo[*c*,*h*]xanthen-7-one (**4**) is a known compound synthesized by the reaction naphthol and hydroxynaphthoate.[7)] We did not obtain dimer **4** by treatment of **3** in PPA at 100 °C for 8 h. This result indicates that dimer **4** is formed from an

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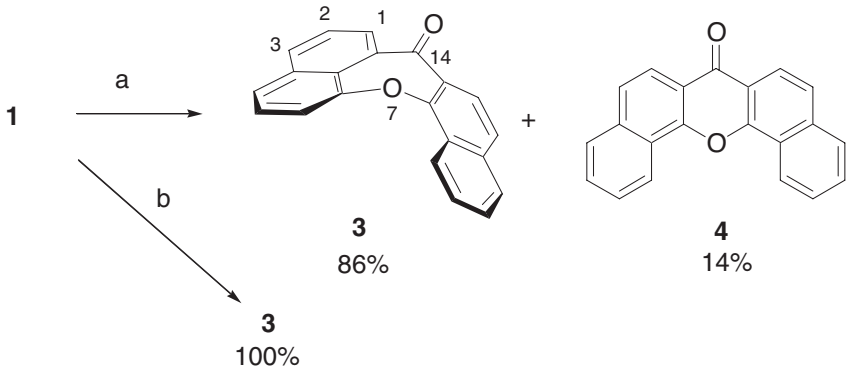
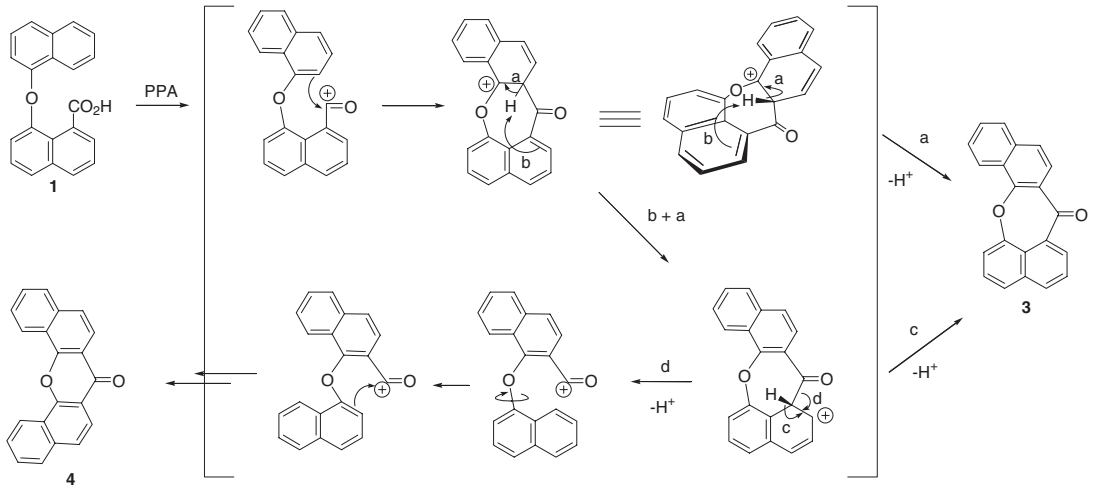


Scheme 2.
Reagents and conditions: (a) PPA, 100 °C, 30 min; (b) $(CF_3CO)_2O$, CF_3SO_3H, CH_2Cl_2, 0 °C, 1 min



Scheme 3. Possible Mechanism for the Formation of **3** and **4**.

intermediate in Friedel-Crafts cyclization reaction of **1**. A possible mechanism is shown in Scheme 3.

Dimer **3** was a new compound, and hence we determined its structure by extensive 2D NMR analysis (Table 1). The ^{1}H NMR spectrum showed two clear doulets, which were attributable to H-12 and H-13. We found the physicochemical data of **3** to be very similar to those of **2** in the original study by Kudo and Sato[6] (Table 2). Their similarities were as follows: (i) The UV spectral data of **3** were completely coincident with those of **2** (reported). (ii) Methine carbon signals of **3** in ^{13}C NMR were approximately coincident with those of **2** (reported). (iii) The values of their melting points are similar. We estimated that compound **3** might in fact has been **2** in the study.[6]

Since we were unable to obtain **2** by the route shown in Scheme 1, we developed a new, efficient synthetic route, as shown in Scheme 4. Lithium intermediate **6**[8] was easily prepared from 1,8-dibromonaphthalene **5**;[9] treatment of **6** with lactone **7**[10] gave ketone **8** in quantitative yield. An intramolecular Ullmann ether coupling reaction[11] of **8** in 1-methyl-2-pyrrolidone (NMP) gave dimer **2** exclusively. In addition, we selectively obtained a new spiro compound **9** by the same method, but using pyridine instead of NMP. The structure of **2** was established on the basis of extensive 2D NMR analysis (Table 3); single-crystal X-ray analysis of **2*** (Fig. 2) confirmed the interpretation of the NMR data. We determined the structure of **9** by extensive 2D NMR analysis (Table 4). The ^{13}C NMR spectrum included 11 signals containing acetal carbon (δ122.4). This indicates that **9** was asymmetrical spiroketal.

In addition, we briefly investigated substituent effects in Friedel-Crafts ring closure (Scheme 5). Carboxylic acid **10** was prepared by Ullmann ether coupling of 7-methoxy-1-naphthol with isopropyl 8-iodo-1-naphthoate,[4] followed by hydrolysis. Carboxylic acid **11** was prepared by Ullmann ether coupling of 1-naphthol with isopropyl 8-iodo-1-naphthoate, followed by bromination[12] and hydrolysis. Friedel-Crafts ring

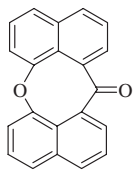
* Thecrystal information file on **2** was deposited in the Cambridge Crystallographic Data Center as supplementary publication no. CCDC-685567. Copies of the data can be obtained free of charge by application to CCDC, 12 Union Road, Cambridge CB2 1EZ, U.K. (Fax: +44-1223-336-033; E-mail: deposit@ccdc.cam.ac.uk).

Table 1. NMR Data for **3** in C_5D_5N

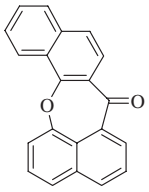
Position	δC	δH[a](J = Hz)	COSY	NOESY	HMBC[b]
1	130.4	8.54 d (7.5, 1.0)	2	2	3
2	126.1	7.57 dd (8.2, 7.5)	1, 3	1, 3	—
3	134.8	8.10 dd (8.2, 1.0)	2	2, 4	1, 4
3a	136.0	—	—	—	2, 5
4	126.2	7.78 dd (8.1, 1.0)	5, 6	3, 5	3, 6
5	127.0	7.53 dd (8.1, 7.5)	4, 6	4, 6	—
6	119.2	7.86 dd (7.5, 1.0)	4, 5	4, 5	4
6a	153.5	—	—	—	5
7a	153.1	—	—	—	8, 13
7b	126.8	—	—	—	9, 11, 12
8	123.5	8.88 dd (8.1, 0.8)	9	6, 9, 10	10
9	127.5	7.70 ddd (8.1, 7.2, 0.8)	8, 10	8, 10	11
10	128.8	7.62 ddd (7.5, 7.2, 0.8)	9, 11	9, 11	8
11	128.2	7.91 dd (7.5, 0.8)	10	10, 12	9, 12
11a	137.1	—	—	—	8, 10, 13
12	125.2	7.74 d (8.5)	13	13	11
13	125.3	7.88 d (8.5)	12	12	—
13a	130.0	—	—	—	12
14	193.2	—	—	—	1, 13
14a	133.2	—	—	—	2
14b	125.5	—	—	—	1, 4, 6

[a]From HMQC.
[b]Numbers show proton positions.

Table 2. Comparison of Physiochemical Data for **2** (previously reported), **3**, and **2** (present report)



2 (previously reported)



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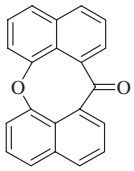
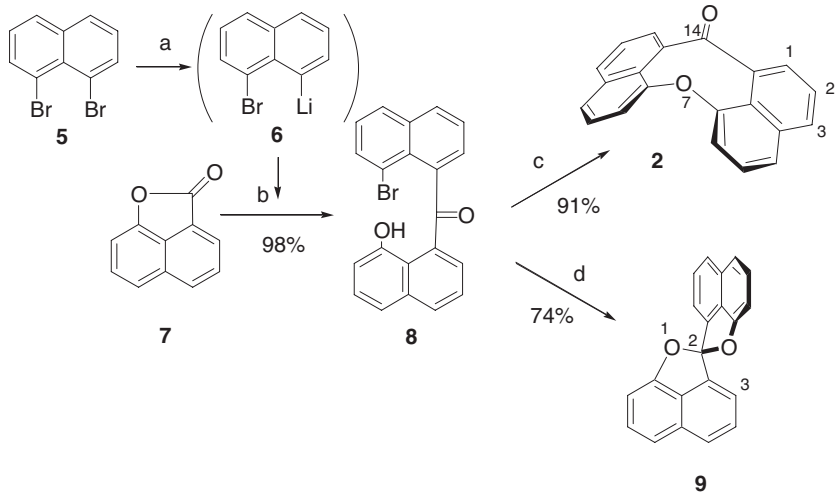


2 (present report)

State and m.p.	**Pale yellow** needles 210–212 °C (benzene)	**Pale yellow** plates 226.2–226.8 °C (benzene)	**Colorless** needles 297.5–298.0 °C (benzene)
UV (EtOH)	**215 (4.89)**	**215 (4.91)**	214 (4.69)
	257 (4.42)	**258 (4.44)**	234 (4.07)
	293 (3.87)	**293 (3.86)**	306 (3.59)
	303 sh (3.82)	**303 sh (3.82)**	333 (3.48)
	333 (3.81)	**338 (3.80)**	
	356 sh (3.76)	**356 sh (3.76)**	
^{13}C NMR ($CDCl_3$)	**118.7**	**118.7 (CH)**	118.8
	123.4	**123.3 (CH)**	125.4
	124.4	**124.8 (CH)**	125.5
	124.9	**124.9 (CH)**	125.6
	126.0	125.5 (C)	126.5
	127.0	125.6 (C)	126.9
	128.0	**125.9 (CH)**	129.6
	128.6	126.4 (CH)	134.8
	129.6	126.6 (C)	138.5
	130.4	**127.0 (CH)**	155.1
	131.9	**127.9 (CH)**	204.6
	133.2	**128.4 (CH)**	
	134.0	**129.5 (CH)**	
	134.5	**130.2 (CH)**	
	135.8	**133.1 (CH)**	
	136.9	**134.4 (CH)**	
	173.2	**135.7 (C)**	
		136.8 (C)	
		153.0 (CH)	
		153.5 (CH)	
		193.6 (C=O)	



Scheme 4.
Reagents and conditions: (a) *n*-BuLi, hexane, −78 °C, 30 min; (b) Et_2O, 0 °C → r.t., 2 h; (c) K_2CO_3, Cu_2O, Py., refl. 1 h; (d) K_2CO_3, Cu_2O, NMP, refl. 1 h

Table 3. NMR Data for **2** in C_5D_5N

Position	δC	δH[a] (J = Hz)	COSY	NOESY	HMBC[b]
1	126.1	7.80 dd (7.4, 1.0)	2	*	3
2	127.1	7.51 dd (8.5, 7.4)	1, 3	*	—
3	130.0	7.85 dd (8.5, 1.0)	2	*	1, 4
3a	135.2	—	—	—	2, 5
4	126.2	7.71 dd (8.1, 1.0)	5	5	3, 4
5	127.6	7.48 dd (8.1, 7.5)	4, 6	4, 6	—
6	120.0	7.89 dd (7.5, 1.0)	5	5	4
6a	155.5	—	—	—	4, 5
14	204.0	—	—	—	1
14a	139.1	—	—	—	2
14b	125.7	—	—	—	1, 3, 4, 6

[a]From HMQC.
[b]Numbers show proton positions.
*Overlapped.

Table 4. NMR Data for **9** in $CDCl_3$

Position	δC	δH[a] (J = Hz)	COSY	NOESY	HMBC[b]
2	122.4	—	—	—	3, 4
2a	136.5	—	—	—	4, 5
2b	126.8	—	—	—	3, 5, 6, 8
3	119.8	7.26 d (7.4)	4	4	3, 4, 5
4	129.1	7.60 dd (8.2, 7.4)	3, 5	3, 5	3, 5
5	126.4	7.91 d (8.2)	4	4, 6	3, 5, 6
5a	131.1	—	—	—	4, 5, 7
6	117.4	7.50 d (8.5)	*	5, *	5, 6, 8
7	129.8	7.54 dd (8.5, 7.4)	*, 8	*, 8	6
8	102.7	6.91 d (7.4)	7	7	6, 8
8a	157.0	—	—	—	5, 7, 8

[a]From HMQC.
[b]Numbers show proton positions.
*Overlapped.

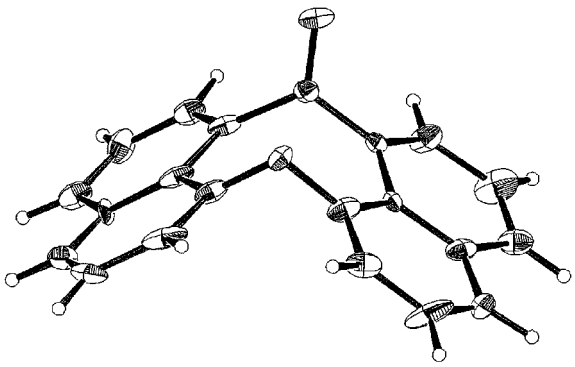


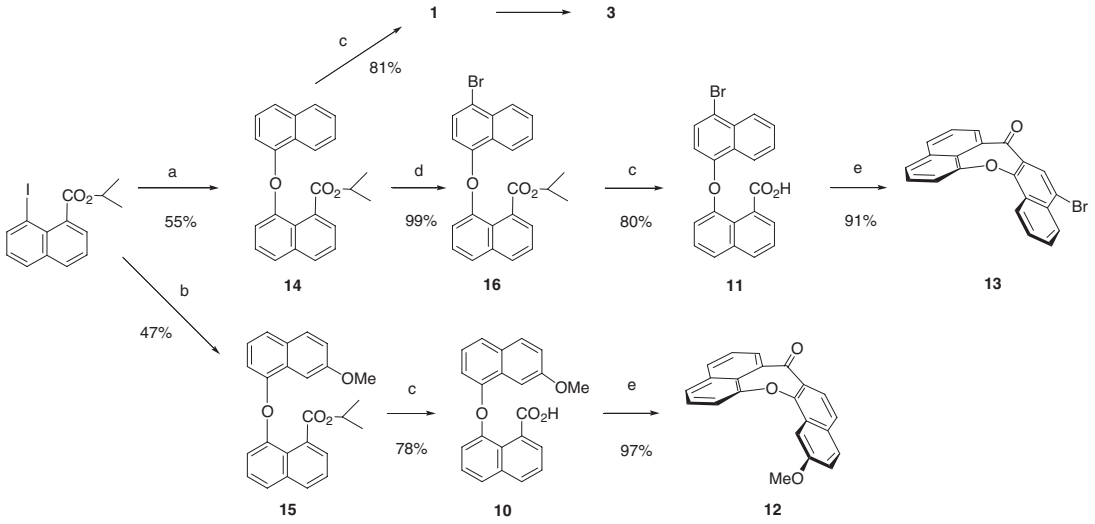
Fig. 2. Molecular Structure of 14*H*-Dinaphtho[1,8-*bc*:1′,8′-*fg*]oxocin-14-one (**2**).

closure of **10** afforded **12** selectively, although **10** contains an electron-donating group at the 7′ position. Similarly, ring closure of **11** gave **13** selectively, even though **11** has an electron-withdrawing group at the 4′ position. These results indicate that if there is a hydrogen at the 2′ position of any dinaphthyl ether such as **1**, Friedel-Crafts closure will occur at the 2′ position, not at the 8′ position, regardless of the directing effect. 8-Membered compounds such as **2** are known not to invert at over 200 °C, but 7-membered compounds such as **3** have been reported to invert easily at room temperature.[13] Hence, the resulting 7-membered compounds (**3**, **11**, and **12**) might have been unsuitable as skeletons for our chiral reagents due to their potential flappable structure.

In conclusion, we succeeded in developing efficient syntheses for L-shaped naphthalene dimer **2**, 7-membered compounds **3**, **12**, and **13**, and spiro compound **9**. Further derivatization of **2** and **9** to form chiral recognition reagents and/or chiral ligands for asymmetric synthesis is under investigation.

Experimental

General procedures. Et_2O was dried by distillation over Na/benzophenone under a nitrogen atmosphere. Unless otherwise stated, solvent and reagents were used



Scheme 5.
Reagents and conditions: (a) 1-naphthol, K_2CO_3, Cu_2O, Py. refl. 4 h; (b) 7-methoxy-1-napthol, K_2CO_3, Cu_2O, Py. refl. 5 h; (c) KOH, DMI, 100–130 °C, 0.5–4 h; (d) NBS, CH_2Cl_2, r.t., 6 h; (e) $(CF_3CO)_2O$, CF_3SO_3H, CH_2Cl_2, 0 °C, 1 min

without purification. NMR spectra were recorded at 500 MHz/125 MHz ($^1H/^{13}C$) in $CDCl_3$, unless stated otherwise.

*14*H-*Dinaphtho[1,8*-bc*:1′,8′*-fg*]oxocin-14-one (**2**).* To a solution of **8** (0.20 g, 0.52 mmol) and potassium carbonate (0.11 g, 0.79 mmol) in degassed NMP was added Cu_2O (7 mg, 0.05 mmol). The reaction mixture was heated at reflux for 1 h, cooled to room temperature, and concentrated *in vacuo*. The residue was dissolved in a mixture of 2 M aq. HCl and EtOAc, and the water layer was extracted with additional EtOAc. The combined EtOAc layers were washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 0.14 g (91%) of **2** as a colorless solid.

2: Colorless needles; m.p.: 292.5–293.5 °C (acetone), 297.5–298.0 °C (benzene); IR ν_{max} (KBr) cm^{-1}: 1662, 1458, 1331, 1224, 1128, 880, 845, 823, 779; UV λ_{max} (EtOH) nm (log ε): 214 (4.69), 234 (4.07), 306 (3.59), 333 (3.48); NMR δ_H (500 MHz, $CDCl_3$): 7.49–7.56 (2H, m), 7.60 (1H, dd, $J = 7.1$, 1.0 Hz), 7.68–7.71 (2H, m), 7.85 (1H, dd, $J = 8.2$, 1.0 Hz); NMR δ_C (125 MHz, $CDCl_3$): 204.6, 155.1, 138.5, 134.8, 129.6, 126.9, 126.5, 125.6, 125.5, 125.4, 118.8; NMR δ_H (500 MHz, C_5D_5N): see Table 2; NMR δ_C (125 MHz, C_5D_5N): see Table 2.; EIMS *m/z* (rel. int. %): 297 ($M^+ + 1$, 22), 296 (M^+, 100), 269 (14), 268 (60), 242 (37), 240 (20), 239 (64), 237 (20), 214 (14), 213 (11), 134 (20), 120 (25), 119 (17), 107 (11), 44 (15), 40 (16); HREIMS *m/z* (M^+): Calcd. for $C_{21}H_{12}O_2$: 296.0838, Found: 296.0872.

*14*H-*Dinaphtho[1,8*-bc*:1′,2′*-f*]oxepin-14-one (**3**) and 7*H-*dibenzo[*c,h*]xanthen-7-one (**4**).* Procedure 1: A mixture of **1** (78 mg, 0.25 mmol) and polyphosphoric acid (10 ml) was heated and stirred at 100 °C for 30 min. After cooling, the mixture was neutralized with sat. aq. K_2CO_3 (30 ml) and extracted with $CHCl_3$. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 74 mg (86%) of **3** and 13 mg of **4** (14%). Procedure 2: To a suspension of **1** (100 mg, 0.32 mmol) in CH_2Cl_2 (5 ml) was added trifluoroacetic anhydride (67 µl, 0.48 mmol) at 0 °C, and trifluoromethanesulfonic acid (3 µl, 0.03 mmol) was added to the resulting yellow solution. After 1 min, the reaction mixture was poured into 2 M aq. HCl and extracted with $CHCl_3$. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 95 mg (100%) of **3** as a yellow solid.

3: Pale yellow plates; m.p.: 218.0–219.0 °C (EtOH), 226.2–226.8 °C (benzene); IR ν_{max} (KBr) cm^{-1}: 2363, 1651, 1503, 1457, 1428, 1348, 1282, 1240, 1122, 1029, 879, 836, 820, 803, 767; UV λ_{max} (EtOH) nm (log ε): 215 (4.89), 258 (4.44), 293 (3.86), 303 sh (3.82), 338 (3.80). 356 sh (3.76); NMR δ_H (270 MHz, $CDCl_3$): 7.48–7.74 (8H, m), 7.86 (1H, d, $J = 8.1$ Hz), 8.07 (1H, d, $J = 7.3$ Hz), 8.43 (1H. d, $J = 8.1$ Hz), 8.74 (1H, d, $J = 8.1$ Hz); NMR δ_C (63 MHz, $CDCl_3$): 193.6, 153.5, 153.0, 136.8, 135.7, 134.4, 133.1, 130.2, 129.5, 128.4, 127.9, 127.0, 126.6, 126.4, 125.9, 125.6, 125.5, 124.9, 124.8, 123.3, 118.7; NMR δ_H (500 MHz, C_5D_5N) and NMR δ_C (125 MHz, C_5D_5N): see Table 1; EIMS *m/z* (rel. int. %): 297 ($M^+ + 1$, 30), 296 (M^+, 100), 269 (20), 268 (95), 239 (42), 237 (15), 134 (23), 120 (16); HREIMS *m/z* (M^+): Calcd. for $C_{21}H_{12}O_2$: 296.0838, Found: 296.0795.

4: Colorless needles; m.p.: 258.8–259.2 (EtOH), lit. 251–253 °C;[7] IR ν_{max} (KBr) cm^{-1}: 2363, 2341, 1700, 1653, 1559, 1541, 1460, 669; UV λ_{max} (EtOH) nm

(log ε): 212 (4.30), 246 (3.59), 261 (3.68), 288 (3.78), 300 sh (3.47), 360 (3.11); NMR δ_H (270 MHz, $CDCl_3$): 7.72–7.80 (6H, m), 7.93–7.96 (2H, m), 8.32 (2H, d, $J = 8.6$ Hz), 8.79–8.83 (2H, m); EIMS m/z (rel. int. %): 297 ($M^+ + 1$, 25), 296 (M^+, 100), 268 (27), 239 (23), 237 (10), 134 (14), 120 (12), 40 (13); HREIMS m/z (M^+): Calcd. for $C_{21}H_{12}O_2$: 296.0838, Found: 296.0850.

*Isomerization reaction of **3** in PPA.* A mixture of **3** (70 mg, 0.24 mmol) and polyphosphoric acid (2 ml) was heated and stirred at 100 °C for 8 h. No spot except the starting material was detected by TLC analysis.

*8-Bromo-1-naphthyl 8-hydroxy-1-naphthyl ketone (**8**).* To a stirred solution of **5** (2.00 g, 7.00 mmol) in ether (50 ml) cooled at −78 °C was added dropwise over 5 min 2.6 M *n*-BuLi in hexane (2.70 ml, 7.10 mmol). The solution was stirred at −78 °C for 30 min, and added to a solution of **7** (1.07 g, 6.30 mmol) in Et_2O (20 ml) cooled to 0 °C. The resulting dark red suspension was stirred at 0 °C for 30 min and then at room temperature for 2 h. The reaction mixture was poured into 2 M aq. HCl (50 ml) and extracted with EtOAc (50 ml). The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using hexane–EtOAc (5:1) as eluent afforded 2.32 g (98%) of **8** as an orange solid.

8: Orange prisms; m.p.: 164.0–166.0 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 3466, 1633, 1608, 1513, 1451, 1274, 1258, 821, 779, 767, 757; NMR δ_H (270 MHz, $CDCl_3$): 7.18–7.64 (9H, m), 7.80 (1H, d, $J = 7.8$ Hz), 7.95 (1H, d, $J = 7.9$ Hz), 8.04 (1H, d, $J = 6.9$ Hz), 11.10 (1H, s); NMR δ_C (67.5 MHz, $CDCl_3$): 116.6, 119.7, 121.2, 122.3, 123.3, 125.2, 127.3, 128.4, 128.7, 129.2, 129.7, 131.5, 133.4, 135.7, 135.8, 136.5, 137.3, 138.5, 139.4, 154.8, 204.7; EIMS m/z (rel. int. %): 378 ($M^+ + 2$, 30), 376 (M^+, 30), 298 (25), 297 (100), 171 (11), 170 (12), 149 (18), 127 (11), 126 (11), 115 (11); HREIMS m/z (M^+): Calcd. for $C_{21}H_{13}BrO_2$: 376.0099, Found: 376.0077.

*2,2′(2H,2′H)-Spirobi[naphtho[1,8-bc]furan] (**9**).* To a solution of **8** (0.20 g, 0.52 mmol) and potassium carbonate (0.11 g, 0.79 mmol) in degassed pyridine was added Cu_2O (7 mg, 0.05 mmol). The reaction mixture was heated at reflux for 2 h, cooled to room temperature, and concentrated *in vacuo*. The residue was dissolved in a mixture of 2 M aq. HCl and EtOAc, and the water layer was extracted with additional EtOAc. The combined EtOAc layers were washed with brine, dried with $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 0.12 g (74%) of **9** as a colorless solid.

9: Amorphous; m.p.: 183.2–184.0 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 1618, 1603, 1491, 1467, 1368, 1293, 1167, 925, 854, 810, 769; UV λ_{max} (EtOH) nm (log ε): 220 sh (5.14), 237 (5.17), 307 (4.48), 320 sh (4.42); NMR δ_H (500 MHz, $CDCl_3$) and NMR δ_C (125 MHz, $CDCl_3$): see Table 3; NMR δ_H (500 MHz, C_5D_5N): 6.99–7.03 (1H, m), 7.29 (1H, d, $J = 8.4$ Hz), 7.53–7.56 (2H, m), 7.59 (1H, dd, $J = 7.7$, 6.4 Hz), 7.92 (1H, d, $J = 8.4$ Hz); NMR δ_C (125 MHz, C_5D_5N): 157.5, 136.5, 131.1, 129.8, 129.1, 126.8, 126.4, 119.8, 117.4, 102.7; EIMS m/z (rel. int. %): 297 ($M^+ + 1$, 21), 296 (M^+, 100), 295 (47), 267 (11), 239 (16), 120 (14); HREIMS m/z (M^+): Calcd. for $C_{21}H_{12}O_2$: 296.0838, Found: 296.0814.

*General procedure for carboxylic acids (**1**, **10**, and **11**).* A solution of ether (**14**–**16**, 1.00 mmol) and KOH (10 mmol) in DMI (5 ml) was heated at 100–130 °C for 0.5–4 h. After cooling, the mixture was quenched with 2 M aq. HCl (50 ml) and extracted with toluene (50 ml). The organic layer was washed with brine and dried over $MgSO_4$. The solvent was removed under reduced pressure, and the solid residue was washed with hexane/CH_2Cl_2 to give acids **1**, **10**, and **11** as colorless solids in 81, 78, and 80% yield respectively.

1: Colorless amorphous; m.p.: 171.2–172.2 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 3507 (br), 2363, 1704, 1596, 1573, 1506, 1464, 1394, 1368, 1248, 1211, 1107, 1047, 832, 791, 669; NMR δ_H (270 MHz, $CDCl_3$): 6.90 (1H, d, $J = 7.6$ Hz), 7.05 (1H, d, $J = 7.6$ Hz), 7.18 (1H, d, $J = 6.9$ Hz), 7.36 (1H, t, $J = 8.1$ Hz), 7.38 (1H, t, $J = 8.1$ Hz), 7.45–7.67 (5H, m), 7.93 (2H, t, $J = 7.3$ Hz), 8.26 (1H, d, $J = 8.3$ Hz); NMR δ_C (67.5 MHz, $CDCl_3$) 113.5, 113.8, 122.2, 122.4, 123.2, 123.7, 125.4, 125.5, 125.9, 126.2, 126.6, 126.9, 127.7, 128.4, 130.0, 134.9, 135.2, 152.5, 153.0, 175.5; EIMS m/z (rel. int. %): 315 ($M^+ + 1$, 23), 314 (M^+, 100), 270 (10), 269 (44), 268 (25), 239 (15), 171 (12), 144 (22), 115 (37); HREIMS m/z (M^+): Calcd. for $C_{21}H_{14}O_3$: 314.0943, Found: 314.0895.

8-(7-Methoxy-1-naphthalenyloxy)-1-naphthalenecarboxylic acid (**10**): Colorless prisms; m.p.: 222.1–223.1 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 3855, 3651, 3406 (br), 2362, 2341, 1700, 1652, 1559, 1542, 1509, 1287, 1106, 777, 669; NMR δ_H (270 MHz, $CDCl_3$): 3.81 (3H, s), 6.98 (2H, t, $J = 8.1$ Hz), 7.14–7.25 (3H, m), 7.38 (1H, t like, $J = 7.9$ Hz), 7.46–7.63 (4H, m), 7.78 (1H, d, $J = 9.1$ Hz), 7.93 (1H, d, $J = 8.2$ Hz); NMR δ_C (67.5 MHz, $CDCl_3$): 55.3, 113.7, 113.9, 114.1, 119.8, 122.4, 123.2, 123.3, 123.4, 125.4, 125.5, 126.6, 127.9, 128.4, 129.3, 129.9, 130.4, 135.2, 151.6, 152.6, 158.0, 175.9; EIMS m/z (rel. int. %): 327 ($[M - OH]^+$, 24), 326 ($[M - H_2O]^+$, 99), 310 (11), 309 (35), 308 (29), 307 (12), 282 (34), 281 (79), 279 (11), 265 (14), 253 (13), 252 (27), 250 (15), 199 (55), 171 (16), 156 (15), 155 (100), 128 (28), 127 (76), 126 (29), 125 (12), 115 (24); HREIMS m/z ($[M - H_2O]^+$): Calcd. for $C_{22}H_{14}O_3$: 326.0943, Found: 326.0913.

8-(4-Bromo-1-naphthalenyloxy)-1-naphthalenecarboxylic acid (**11**): Colorless plates; m.p.: 257.0–259.5 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 3433 (br), 2363, 2341, 1699, 1600, 1594, 1507, 1468, 1456, 1421, 1372, 1296,

1241, 1203, 1156, 1101, 1052, 916, 837, 819, 766, 669; NMR δ_H (270 MHz, C_5D_5N): 6.95 (1H, d, $J = 8.3$ Hz), 7.06–7.19 (2H, m), 7.20 (1H, d, $J = 6.9$ Hz), 7.26 (1H, t, $J = 6.9$ Hz), 7.36–7.56 (1H, m), 7.64 (1H, d, $J = 8.3$ Hz), 7.69 (1H, d, $J = 7.9$ Hz), 7.83 (1H, d, $J = 6.3$ Hz), 7.93 (1H, d, $J = 8.3$ Hz), 8.09 (1H, d, $J = 8.6$ Hz), 8.47 (1H, s), 8.54 (1H, d, $J = 8.3$ Hz); NMR δ_C (67.5 MHz, $CDCl_3$): 113.7, 116.9, 122.2, 122.3, 123.2, 123.8, 125.4, 125.5, 125.9, 126.2, 126.6, 126.9, 127.7, 129.0, 130.0, 135.0, 135.2, 152.4, 153.0, 174.5; EIMS *m/z* (rel. int. %): 395 ($M^+ + 3$, 23), 394 ($M^+ + 2$, 99), 393 ($M^+ + 1$, 23), 392 (M^+, 100), 269 (15), 268 (54), 239 (14), 224 (23), 222 (23), 171 (23), 126 (13), 115 (34); HREIMS *m/z* (M^+): Calcd. for $C_{21}H_{13}{}^{79}BrO_3$: 392.0048, Found: 392.0061.

*14*H-*9-Methoxy-dinaphtho[1,8-*bc*:1′,2′-*f*]oxepin-14-one* (***12***). To a suspension of **10** (0.50 g, 1.45 mmol) in CH_2Cl_2 (5 ml) was added trifluoroacetic anhydride (0.32 ml, 2.25 mmol) at 0 °C, and to the resulting yellow solution was added trifluoromethanesulfonic acid (13 µl, 0.15 mmol). After 1 min, the reaction mixture was poured into 2 M aq. HCl and extracted with $CHCl_3$. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 0.45 g (97%) of **12** as yellow solid.

12: Yellow needles; m.p.: 147.2–149.0 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 2363, 2341, 1655, 1609, 1559, 1508, 1459, 1219, 1124, 1033, 843, 772, 745, 669; NMR δ_H (270 MHz, $CDCl_3$): 4.09 (3H, s), 7.27 (1H, d, $J = 8.6$ Hz), 7.48–7.77 (7H, m), 8.03 (1H, d, $J = 7.3$ Hz), 8.05 (1H, d, $J = 8.1$ Hz), 8.41 (1H, d, $J = 7.3$ Hz); NMR δ_H (500 MHz, C_5D_5N): 3.96 (3H, s), 7.40 (1H, dd, $J = 8.9$, 2.6 Hz), 7.55 (1H, dd, $J = 8.2$, 7.3 Hz), 7.58 (1H, dd, $J = 8.1$, 7.4 Hz), 7.70 (1H, d, $J = 8.4$ Hz), 7.77 (1H, d, $J = 8.4$ Hz), 7.80 (1H, dd, $J = 8.2$, 1.5 Hz), 7.85 (1H, d, $J = 8.9$ Hz), 7.94 (1H, dd, $J = 7.3$, 1.5 Hz), 8.11 (1H, dd, $J = 8.1$, 1.5 Hz), 8.21 (1H, d, $J = 2.6$ Hz), 8.54 (1H, dd, $J = 7.4$, 1.5 Hz); NMR δ_C (67.8 MHz, $CDCl_3$): 193.9, 158.6, 153.5, 151.9, 135.7, 134.3, 133.3, 132.3, 130.2, 130.1, 129.5, 127.7, 126.3, 125.9, 125.6, 125.5, 124.6, 122.5, 121.0, 118.6, 101.5, 55.5; EIMS *m/z* (rel. int. %): 327 ($M^+ + 1$, 24), 326 (M^+, 100), 298 (19), 255 (23); HREIMS *m/z* (M^+): Calcd. for $C_{22}H_{14}O_3$: 326.0943, Found: 326.0954.

*14*H-*12-Bromo-dinaphtho[1,8-*bc*:1′,2′-*f*]oxepin-14-one* (***13***). To a suspension of **11** (150 mg, 0.38 mmol) in CH_2Cl_2 (10 ml) was added trifluoroacetic anhydride (67 µl, 0.57 mmol) at 0 °C, and to the resulting yellow solution was added trifluoromethanesulfonic acid (4 µl, 0.04 mmol). After 1 min, the reaction mixture was poured into 2 M aq. HCl and extracted with $CHCl_3$. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using $CHCl_3$ as eluent afforded 130 mg (91%) of **13** as a yellow solid.

13: Yellow needles; m.p.: 230.0–232.0 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 2363, 1700, 1653, 1600, 1542, 1508, 1458, 1348, 1239, 758, 669; NMR δ_H (500 MHz, C_5D_5N): 7.56 (1H, t, $J = 7.9$ Hz), 7.61 (1H, t, $J = 7.7$ Hz), 7.72 (1H, td, $J = 6.9$, 1.7 Hz), 7.75 (1H, td, $J = 6.9$, 1.7 Hz), 7.83 (1H, dd, $J = 7.9$, 1.2 Hz), 7.86 (1H, dd, $J = 7.9$, 1.2 Hz), 8.15 (1H, dd, $J = 7.7$, 1.5 Hz), 8.16 (1H, s), 8.23 (1H, dd, $J = 6.9$, 1.7 Hz), 8.56 (1H, dd, $J = 7.7$, 1.5 Hz), 8.86 (1H, dd, $J = 6.9$, 1.7 Hz); NMR δ_C (500 MHz, C_5D_5N): 118.9, 119.5, 123.1, 123.9, 124.4, 125.5, 126.5, 126.6, 127.3, 127.7, 128.5, 128.9, 130.3, 130.4, 131.0, 132.9, 135.1, 135.9, 136.3, 153.5, 191.8: EIMS *m/z* (rel. int. %): 377 ($M^+ + 3$, 23), 376 ($M^+ + 2$, 100), 375 ($M^+ + 1$, 24), 374 (M^+, 98), 348 (36), 346 (37), 267 (10), 239 (43), 238 (13), 237 (29), 174 (15), 173 (14), 120 (22), 119 (17); HREIMS *m/z* (M^+): Calcd. for $C_{21}H_{11}{}^{79}BrO_2$: 373.9942, Found: 373.9901.

Isopropyl 8-(1-naphthalenyloxy)-1-naphthalenecarboxylate (***14***). To a mixture of isopropyl 8-iodonaphthalenecarboxylate[4] (0.50 g, 1.47 mmol), 1-naphthol (0.32 g, 2.21 mmol), and potassium carbonate (0.34 g, 2.50 mmol) in degassed pyridine (10 ml) was added Cu_2O (21 mg, 0.15 mmol). The reaction mixture was heated at reflux for 4 h, cooled to room temperature, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using hexane–EtOAc (20:1) as eluent afforded 0.28 g (55%) of **14** as a colorless solid.

14: Colorless plates; m.p.: 123.0–124.5 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 2983, 2363, 2341, 1717, 1653, 1623, 1596, 1573, 1541, 1506, 1461, 1389, 1346, 1286, 1242, 1204, 1175, 1148, 1111, 1098, 1079, 1044, 844, 832, 806, 770, 670, 41; NMR δ_H (270 MHz, $CDCl_3$): 1.05 (6H, d, $J = 6.3$ Hz), 4.95 (1H, sept, $J = 6.3$ Hz), 6.76 (1H, d, $J = 7.6$ Hz), 7.12 (1H, d, $J = 7.6$ Hz), 7.31 (1H, t, $J = 7.9$ Hz), 7.39–7.60 (6H, m), 7.68 (1H, d, $J = 7.9$ Hz), 7.88 (1H, d, $J = 7.9$ Hz), 7.94 (1H, d, $J = 7.6$ Hz), 8.18 (1H, d, $J = 8.2$ Hz); NMR δ_C (67.5 MHz, $CDCl_3$): 21.5, 69.0, 112.5, 115.1, 121.9, 122.4, 122.8, 124.1, 125.2, 125.5, 125.8, 126.1, 126.4, 126.6, 127.0, 127.7, 129.3, 130.4, 134.9, 135.2, 152.1, 153.8, 170.3; EIMS *m/z* (rel. int. %): 357 ($M^+ + 1$, 26), 356 (M^+, 100), 314 (10), 297 (21), 270 (12), 269 (53), 268 (29), 239 (17), 171 (49), 144 (21), 127 (11), 115 (17); HREIMS *m/z* (M^+): Calcd. for $C_{24}H_{20}O_3$: 356.1413, Found: 356.1369.

Isopropyl 8-(7-methoxy-1-naphthalenyloxy)-1-naphthalenecarboxylate (***15***). To a mixture of isopropyl 8-iodonaphthalenecarboxylate (6.50 g, 19.1 mmol), 7-methoxy-1-naphthol[14] (4.99 g, 28.6 mmol), and potassium carbonate (3.95 g, 28.6 mmol) in degassed pyridine (100 ml) was added Cu_2O (273 mg, 1.91 mmol). The reaction mixture was heated at reflux for 5 h, cooled to room temperature, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using toluene as eluent afforded 3.45 g (47%) of **15** as a colorless solid.

15: Colorless prisms; m.p.: 125.5–127.2 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 3855, 3676, 3651, 2362, 2341, 1716, 1653, 1634, 1603, 1559, 1541, 1507, 1376, 1344, 1286, 1214, 1202, 1024, 987, 833, 768, 669, 419; NMR δ_H (270 MHz, $CDCl_3$): 1.04 (6H, br), 3.82 (3H, s), 4.98 (1H, sept, $J = 6.3$ Hz), 6.83 (1H, d, $J = 7.7$ Hz), 7.12–7.62 (9H, m), 7.77 (1H, d, $J = 9.1$ Hz), 7.93 (1H, dd, $J = 7.9$, 1.3 Hz); NMR δ_C (67.5 MHz, $CDCl_3$) 21.6, 55.4, 69.1, 100.3, 112.3, 115.6, 119.8, 122.0, 122.7, 123.3, 123.9, 125.1, 125.6, 126.5, 128.3, 129.3, 129.4, 130.5, 130.6, 135.3, 151.2, 153.6, 158.0, 170.6; EIMS m/z (rel. int. %): 387 ($M^+ + 1$, 27), 386 (M^+, 100), 299 (11), 174 (11), 171 (19), 158 (10); HREIMS m/z (M^+): Calcd. for $C_{25}H_{22}O_4$: 386.1519, Found: 386.1474.

*Isopropyl 8-(4-bromo-1-naphthalenyloxy)-1-naphthalenecarboxylate (**16**).* To a stirred solution of **14** (200 mg, 0.56 mmol) in CH_2Cl_2 (10 ml) was added dropwise over 15 min *N*-bromosuccinimide (100 mg, 0.56 mmol) in CH_2Cl_2 (50 ml). After 6 h, the reaction mixture was poured into saturated Na_2SO_3 solution and extracted with $CHCl_3$. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. Purification of the residue by column chromatography on SiO_2 using hexane–EtOAc (20:1) as eluent afforded 237 mg (99%) of **16** as a colorless solid.

16: Colorless plates; m.p.: 96.7–97.2 °C (EtOH); IR ν_{max} (KBr) cm^{-1}: 2986, 2363, 2341, 1706, 1624, 1600, 1593, 1579, 1461, 1420, 1375, 1349, 1282, 1243, 1198, 1152, 1107, 1052, 1021, 987, 918, 850, 831, 811, 766, 670, 417; NMR δ_H (270 MHz, $CDCl_3$): 1.06 (6H, d, $J = 6.2$ Hz), 4.91 (1H. sept, $J = 6.2$ Hz), 6.79 (1H, d, $J = 7.6$ Hz), 6.98 (1H, d, $J = 8.2$ Hz), 7.33 (1H, t, $J = 7.9$ Hz), 7.51–7.72 (5H, m), 7.94 (1H, d, $J = 7.6$ Hz), 8.22–8.27 (2H, m); NMR δ_C (67.5 MHz, $CDCl_3$): 21.6, 69.1, 113.0, 115.4, 117.5, 122.0, 122.9, 123.4, 125.5, 125.7, 126.4, 127.0, 127.2, 128.1, 128.2, 129.5, 129.6, 130.3, 133.1, 135.3, 152.2, 153.4, 170.3; EIMS m/z (rel. int. %): 437 ($M^+ + 3$, 25), 436 ($M^+ + 2$, 97), 435 ($M^+ + 1$, 25), 434 (M^+, 96), 392 (11), 377 (10), 296 (11), 269 (19), 268 (70), 239 (27), 237 (10), 224 (19), 172 (12), 171 (100), 170 (14), 126 (14), 115 (24); HREIMS m/z (M^+): Calcd. for $C_{24}H_{19}{}^{79}BrO_3$: 434.0518, Found: 434.0487.

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