Demethylation of 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*] metacyclophane-1-ynes with BBr_3 to afford novel [*n*]benzofuranophanes

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Abstract: Novel [*n*]benzofuranophanes (*n* = 8 & 10) **2a**–**b** have been prepared by successive intramolecular cyclization from 5,19-di-*tert*-butyl-8,22-dimethoxy[*n*]metacyclophane-1-yne (*syn*-**1a**–**b**) by treatment with BBr_3 in CH_2Cl_2 at room temperature for 8 h. [2.*n*]Benzofuranophanes **2a**–**b** were also obtained by treatment of 1,2-di-*endo*-bromo-5,19-di-*tert*-butyl-8,22-dimethoxy[*n*]metacyclophane (*meso*-**3a**–**b**) with BBr_3 in CH_2Cl_2 by using same reaction condition. ^{1}H NMR spectra of **2a**–**b** reveals the formation of intramolecular hydrogen bonding between hydroxyl proton with the oxygen of furan moiety and X-ray analysis shows that the length between H (OH) and O (furan) are 1.981 and 1.823 Å, respectively. The conformation of [8]benzofuranophane **2a** in solution is rigid and restricted rotation around the diaryl linkage rather than [10]benzofuranophane **2b** because of weak intramolecular hydrogen bonding and short length of cross-linking chain.

Keywords: [2.*n*]metacyclophanes, demethylation, [*n*]benzofuranophanes, intramolecular hydrogen bond.

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HIGHLIGHT

♦ Novel hydroxy[*n*]benzofuranophanes have been synthesized by intramolecular cyclization.

♦ Intramolecular hydrogen bonding between hydroxyl proton and the oxygen of furan ring was observed.

♦ Weak intramolecular hydrogen bonding causes the rigid structures of [*n*]benzofuranophanes.

1. Introduction

Cyclophanes have been gathering much attention on physical and chemical properties due to theirs rigid structure with intriguing geometry [1–5]. To study the molecular functions based on the novel structures, several macrocyclic cyclophanes with strained acetylenic bonds have been synthesized by using the McMurry coupling as a key step [6–8]. The strained cyclophynes was synthesized as an intermediate by a trapping method [9–12]. [*n*]MCP-diynes (MCP = metacyclophane) easily reacts with strong bases to achieve allenic and olefinic isomers which change the basic characteristics of cyclic diynes [13]. Fallis with his co-workers have reported the synthetic route of novel acetylenic cyclophanes by Pd- and Cu-mediated coupling reactions [14,15]. On the other hand, we have succeeded to prepare dimethoxy[2.*n*]MCP-1-ynes with bent triple bonds [16] by the bromination-dehydrobromination of the corresponding [2.*n*]MCP-1-enes [17–19]. These latter intermediates 1,2-dibromo-4,22-dimethoxy[2.10]MCPs can afford convenient starting materials for the preparation of 4b,9b-dihydro[10]benzofuro[3,2-*b*] benzofuranophane by double intramolecular cyclization in presence of BBr_3 in CH_2Cl_2 at room temperature [18].

Yamaguchi and co-workers released a series of fully ring-fused ladder π-conjugated skeletons by the double intramolecular cyclization of diaryl acetylenes [20–24]. A highly efficient and atom-economical construction of 2 substituted 5-hydroxybenzofurans featuring the dienone-phenol rearrangement reaction of quinols containing an alkyne moiety [25–27]. Recently, our group has illuslated an efficient synthetic route to achieve arene-based macrocyclic [3.3.1]MCPs containing a benzofuran ring. Treatment of [3.3.1]MCP-2,11-dione with TMSCl (trimethyl silyl chloride) can afford dihydrobenzofuran and benzofuran rings by simple intramolecular nucleophilic cyclization [28]. Due to the innate structural aspects, we anticipated that 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*]MCP-1-ynes would provide a unique platform for the framework of unsymmetrical benzofuranophane and inspired us to attempt the synthesis of cyclophane containing benzofuran analogues. The mainly purpose of this research is present an efficient approach to synthesize unsymmetrical benzofuranophanes, furthermore, the relationship between structure with their properties have been investigated details.

2. Experimental

2.1. General procedures

All reagents used were procured from commercial sources and were used without further purification. All the solvents used were dried and distilled by the usual procedures before use. ^{1}H and ^{13}C NMR spectra were recorded on a Nippon Denshi JEOL FT-300 NMR spectrometer and Varian-400MR-vnmrs400 and referenced to 7.26 and 77.0 ppm, respectively for chloroform-D solvent with $SiMe_4$ as an internal reference: *J*-values are given in Hz. Infrared (IR) spectra were obtained on a Nippon Denshi JIR-AQ2OM spectrophotometer as KBr disks. Mass spectra were obtained on a Nippon Denshi JMS-HX110A Ultrahigh Performance Mass Spectrometer at 75 eV using a direct-inlet system. Elemental analyses were performed by a Yanaco MT-5. All melting points (Yanagimoto MP-S1) are uncorrected. Silica gel columns were prepared by use of Merk silica gel 60 (63-200 μm).

2.2. Materials

The starting materials 5,19-di-*tert*-butyl-8,22-dimethoxy[2.8]MCP-1-yne (*syn*-**1a**) and 5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP-1-yne (*syn*-**1b**) were synthesized by dehydrobromination reaction in presence of $HOBu^t$ as published report [17,30]. *anti*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy[2.8]MCP (*dl*- **5a**) and *syn*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy[2.8]MCP (*meso*-**3a**) were prepared according to the literatures [17,30]. 1,2-di-*endo*-bromo- (*meso*-**3b**) and 1-*endo*,2-*exo*-dibromo-5,21-di-*tert*-butyl-8,24-dimethoxy[2.10] MCP (*dl*-**5b**) were processed according to the reported procedure [17,30,31].

*2.3. Synthesis of 5-tert-butyl-1-(5'-tert-butyl-2'-hydroxyphenyl)[8](7,3')benzofuranophane (**2a**)*

To a solution of 5,19-di-*tert*-butyl-8,22-dimethoxy[2.8]MCP-1-yne (*syn*-**1a**) (60 mg, 0.13 mmoL) in CH_2Cl_2 (6 mL) at 0 °C was gradually added a solution of BBr_3 (0.14 mL, 1.32 mmoL) in CH_2Cl_2 (0.1 mL). After the reaction mixture has been stirred at room temperature for 8 h, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (3 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-

chloroform (3:1) as eluent to give the crude compound **2a** as a colorless solid. Recrystallization from hexane gave 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-hydroxyphenyl)[8](7,3*'*)benzofuranophane **2a** (35 mg, 73 %) as colorless prisms, M.p. 173–174 °C. IR (KBr): ν = 3427 (OH), 2959, 2856, 1476, 1362, 1203 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.17–1.77 (12 H, m, C*H*$_2$), 1.31 (9 H, s, *t*Bu), 1.37 (9 H, s, *t*Bu), 2.80–2.86 (2H, m, C*H*$_2$), 2.89–2.96 (2H, m, C*H*$_2$), 6.91 (1H, s, furan–*H*), 7.11 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.12 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.18 (1H, s, *J* = 2.4 Hz, O*H*, exchanged by D_2O), 7.22 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.44 (1H, d, *J* = 2.4 Hz, Ar–*H*) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ: 28.15 (*C*H$_2$), 29.17 (*C*H$_2$), 29.70 (*C*H$_2$), 29.80 (*C*H$_2$), 29.85 (*C*H$_2$), 29.93 (*C*H$_2$), 30.06 (*C*H$_2$), 30.28 (*C*H$_2$), 31.51 (C(*C*H$_3$)$_3$), 31.91 (C(*C*H$_3$)$_3$), 34.04 (*C*H$_2$), 34.77 (*C*H$_2$), 102.01 (Ar*C*), 115.02 (Ar*C*), 116.00 (Ar*C*), 122.68 (Ar*C*), 123.29 (Ar*C*), 125.70 (Ar*C*), 127.98 (Ar*C*), 128.67 (Ar*C*), 131.77 (Ar*C*), 142.93 (Ar*C*), 146.89 (Ar*C*), 150.78 (Ar*C*), 151.33 (Ar*C*), 155.32 (Ar*C*) ppm. EI-MS: *m*/*z* 432 [M^+]. $C_{30}H_{40}O_2$ (432.65): calcd. C 83.28, H 9.32. Found: C 83.72, H 8.32.

*2.4. Synthesis of 5-tert-butyl-1-(5'-tert-butyl-2'-hydroxyphenyl)[10](7,3')benzofuranophane (**2b**)*

To a solution of 5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP-1-yne (*syn*-**1b**) (60 mg, 0.12 mmoL) in CH_2Cl_2 (6 mL) at 0 °C was gradually added a solution of BBr_3 (0.12 mL, 1.23 mmoL) in CH_2Cl_2 (0.10 mL). After the reaction mixture has been stirred at room temperature for 0.5 h, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (2 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-chloroform (2:1) as eluent to give the crude compound **2b** as a colorless solid. Recrystallization from ethanol gave 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-hydroxyphenyl)[10](7,3*'*)benzofuranophane **2b** (44 mg, 79 %) as colorless prisms, M.p. 127–128 °C. IR (KBr): ν = 3529, 3514 (OH), 2955, 2933, 2857, 1481, 1459, 1365, 1261, 1232 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.21–1.48 (12 H, m, C*H*$_2$), 1.33 (9 H, s, *t*Bu), 1.38 (9 H, s, *t*Bu), 1.68–1.74 (2H, m, C*H*$_2$), 1.78–1.88 (2H, m, C*H*$_2$), 2.74–2.77 (2H, m, C*H*$_2$), 2.84–2.89 (2H, m, C*H*$_2$), 6.91 (1H, s, furan–*H*), 7.14 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.16 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.34 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.44 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.67 (1H, s, O*H*, exchanged by D_2O) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ: 26.61 (*C*H$_2$), 27.57 (*C*H$_2$), 27.95 (*C*H$_2$), 28.52 (*C*H$_2$), 28.77 (*C*H$_2$), 28.96 (*C*H$_2$), 29.16 (*C*H$_2$), 29.32 (*C*H$_2$),

29.90 (CH_2), 31.26 (CH_2), 31.51(C(CH_3)$_3$), 31.89(C(CH_3)$_3$), 34.06 (CH_2), 34.74 (CH_2), 102.54 (Ar*C*), 114.87 (Ar*C*), 115.04 (Ar*C*), 121.75 (Ar*C*), 122.91 (Ar*C*), 125.57 (Ar*C*), 127.95 (Ar*C*), 129.09 (Ar*C*), 130.99 (Ar*C*), 142.78 (Ar*C*), 146.89 (Ar*C*), 150.10 (Ar*C*), 151.15 (Ar*C*), 155.72 (Ar*C*) ppm. EI-MS: *m*/*z* 460 [M^+]. $C_{32}H_{44}O_2$ (460.70): calcd. C 83.43, H 9.63. Found: C 83.36, H 9.63.

*2.5. Synthesis of 5-tert-butyl-1-(5'-tert-butyl-2'-hydroxyphenyl)[8](7,3')benzofuranophane (**2a**)*

To a solution of *syn*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy[2.8]MCP (*meso*-**3a**) (80 mg, 0.13 mmoL) in CH_2Cl_2 (8 mL) at 0 °C was gradually added a solution of BBr_3 (0.12 mL, 1.29 mmoL) in CH_2Cl_2 (0.2 mL). After the reaction mixture has been stirred at room temperature for 8 h, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (3 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-chloroform (3:1) as eluent to give crude compound **2a** as a colorless solid. Recrystallization from hexane gave 5-*tert*-butyl-1-(5'-*tert*-butyl-2'-hydroxyphenyl)[10](7,3')benzofuranophane **2a** (35 mg, 73 %) as colorless prisms.

Similary, compound *dl*-**5a** was treated with BBr_3 in CH_2Cl_2 at room temperature for 8 h to afford **2a** in 73 % yield as colorless prisms.

*2.6. Synthesis of 5-tert-butyl-1-(5'-tert-butyl-2'-hydroxyphenyl)[10](7,3')benzofuranophane (**2b**)*

To a solution of 1,2-di-*endo*-bromo-5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP (*meso*-**3b**) (60 mg, 0.09 mmoL) in CH_2Cl_2 (6 mL) at 0 °C was gradually added a solution of BBr_3 (0.09 mL, 0.92 mmoL) in CH_2Cl_2 (0.1 mL). After the reaction mixture has been stirred at room temperature for 0.5 h, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (2 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-chloroform (4:1) as eluent to give crude compound **2b** as a colorless solid. Recrystallization from ethanol gave 5-*tert*-butyl-1-(5'-*tert*-butyl-2'-hydroxyphenyl)[10](7,3')benzofuranophane **2b** (35 mg, 83 %) as colorless prisms.

Similarly, compound 1-*endo*,2-*exo*-dibromo-5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP (*dl*-**5b**) was treated with BBr_3 in CH_2Cl_2 at room temperature for 0.5 h to afford **2b** in 87 % yield as colorless prisms.

*2.7. Synthesis of 5-tert-butyl-1-(5'-tert-butyl-2'-methoxyphenyl)[10](7,3')benzofuranophane (**6b**)*

A mixture of 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-hydroxyphenyl)[10](7,3*'*)benzofuranophane **2b** (40 mg, 0.09 mmoL) and NaH (29 mg, 1.22 mmoL, 60%) in dry tetrahydrofuran (4 mL) was heated at reflux for 1 h under N_2. Then methyl iodide (0.05 mL, 0.87 mmol) was added and the mixture heated at reflux for an additional 3 h. After cooling the reaction mixture to room temperature, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (2 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane as eluent to give 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-methoxyphenyl)[10](7,3*'*) benzofuranophane **6b** (26 mg, 64 %) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.18–1.39 (12 H, m, C*H*$_2$), 1.33 (9 H, s, *t*Bu), 1.39 (9 H, s, *t*Bu), 1.44–1.60 (2H, m, C*H*$_2$), 1.68-1.85 (2H, m, C*H*$_2$), 2.01–2.17 (1H, m, C*H*$_2$), 2.37–2.49 (1H, m, C*H*$_2$), 2.67–2.83 (1H, m, C*H*$_2$), 2.86–3.07 (1H, m, C*H*$_2$), 3.42 (3H, s, OC*H*$_3$), 6.82 (1H, s, furan–*H*), 7.12 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.20 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.31 (1H, d, *J* = 2.4 Hz, Ar–*H*), 7.44 (1H, d, *J* = 2.4 Hz, Ar–*H*) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ: 26.68 (*C*H$_2$), 27.25 (*C*H$_2$), 27.88 (*C*H$_2$), 28.05 (*C*H$_2$), 28.10 (*C*H$_2$), 28.71 (*C*H$_2$), 28.84 (*C*H$_2$), 29.20 (*C*H$_2$), 30.74 (*C*H$_2$), 31.47 (*C*H$_2$), 31.79 (C(*C*H$_3$)$_3$), 31.95 (C(*C*H$_3$)$_3$), 34.24 (*C*H$_2$), 34.67 (*C*H$_2$), 59.67 (*C*H$_2$), 103.02 (Ar*C*), 114.39 (Ar*C*), 122.19 (Ar*C*), 122.81 (Ar*C*), 125.23(Ar*C*), 126.25 (Ar*C*), 128.15 (Ar*C*), 128.45 (Ar*C*), 135.86 (Ar*C*), 145.62 (Ar*C*), 145.80 (Ar*C*), 152.35 (Ar*C*), 154.97 (Ar*C*), 155.71 (Ar*C*) ppm. EI-MS: *m*/*z* 474 [M^+]. $C_{33}H_{46}O_2$ (474.72): calcd. C 83.49, H 9.77. Found: C 83.37, H 9.61.

*2.8. Synthesis of 3,8-Di-tert-butyl-1,6-dimethyl-cis-4b,9b-dihydrobenzofuro[3,2-b]benzofuran (**8**)*

To a solution of (*E*)-1,2-bis(5-*tert*-butyl-2-methoxy-3-methylphenyl)ethane **7** (60 mg, 0.09 mmoL) in CH_2Cl_2 (6 mL) at 0 °C was gradually added a solution of BBr_3 (0.09 mL, 0.92 mmoL) in CH_2Cl_2 (0.1 mL). After the reaction mixture has been stirred at room temperature for 5 h, it

was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (3 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-$CHCl_3$ (4:1) as eluent to give crude **8** (80 %) as a colorless solid. 3,8-di-*tert*-butyl-1,6-dimethyl-*cis*-4b,9b-dihydrobenzofuro[3,2-b]benzofuran **8** was obtained as colorless prisms (hexane), M.p. 184–185 °C. IR (KBr): ν = 2944, 1616, 1487, 1362, 1181 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.31 (18 H, s, *t*Bu × 2), 2.21 (6 H, s, C*H*$_3$), 6.23 (2 H, s, furan–*H*), 7.12 (1 H, d, *J* = 2.4 Hz, Ar–*H*), 7.40 (1 H, d, *J* = 2.4 Hz, Ar–*H*) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ: 15.67 (*C*H$_3$), 31.73 (C(*C*H$_3$)$_3$), 34.32 (*C*H$_2$), 87.13 (Ar*C*O), 119.96 (Ar*C*), 120.44 (Ar*C*), 123.64 (Ar*C*), 129.54 (Ar*C*), 144.10 (Ar*C*), 156.55 (Ar*C*) ppm. EI-MS: *m*/*z* 350 [M^+]. $C_{24}H_{30}O_2$ (350.51): calcd. C 82.24, H 8.63. Found: C 82.03, H 8.63.

*2.9. Synthesis of 2-(5-tert-butyl-7-methylbenzofuran-2-yl)-4-tert-butyl-6-methylphenol (**9**)*

To a solution of (*E*)-1,2-bis(5-*tert*-butyl-2-methoxy-3-methylphenyl)ethane **7** (60 mg, 0.09 mmoL) in CH_2Cl_2 (6 mL) at 0 °C was gradually added a solution of BBr_3 (0.09 mL, 0.92 mmoL) in CH_2Cl_2 (0.1 mL). After the reaction mixture has been stirred at room temperature for 5 h, it was poured into ice-water (10 mL), extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with water (2 × 10 mL), dried over $MgSO_4$ and then concentrated under reduced pressure. The residue was chromatographed over silica gel (Wako C-300, 100 g) with hexane-$CHCl_3$ (1:4) as eluent to give crude **9** (10 %) as a colorless solid. 2-(5-*tert*-butyl-7-methylbenzofuran-2-yl)-4-*tert*-butyl-6-methylphenol **9** was obtained as colorless prisms (hexane), M.p. 143–145 °C. IR (KBr): ν = 3425 (OH), 2956, 2853, 1452, 1280 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.34 (9 H, s, *t*Bu), 1.38 (9 H, s, *t*Bu), 2.21 (3 H, s, C*H*$_3$), 2.55 (3 H, s, C*H*$_3$), 6.98 (1 H, s, furan –*H*), 7.12 (1 H, d, *J* = 2.4 Hz, Ar–*H*), 7.16 (1 H, d, *J* = 2.4 Hz, Ar–*H*), 7.43 (1 H, d, *J* = 2.4 Hz, Ar–*H*), 7.46 (1 H, d, *J* = 2.4 Hz, Ar–*H*), 7.79 (1 H, s, O*H*, exchanged by D_2O) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ: 14.37 (*C*H$_3$), 14.89 (*C*H$_3$), 15.41 (*C*H$_2$), 28.68 (*C*H$_2$), 30.79 (C(*C*H$_3$)$_3$), 33.50 (C(*C*H$_3$)$_3$), 101.98 (Ar*C*), 113.64 (Ar*C*), 118.93 (Ar*C*), 119.21 (Ar*C*), 120.03 (Ar*C*), 122.36 (Ar*C*), 124.50 (Ar*C*), 126.91 (Ar*C*), 128.51 (Ar*C*), 141.80 (Ar*C*), 142.82 (Ar*C*), 145.75 (Ar*C*), 148.69 (Ar*C*), 155.58 (Ar*C*). EI-MS: *m*/*z* 352 [M^+]. $C_{29}H_{32}O_2$ (352.52): calcd. C 81.77, H 9.15. Found: C 81.73, H 9.16.

3. Results and Discussion

According to our previous reported, the starting compound 5,19-di-*tert*-butyl-8,22-dimethoxy[2.8]MCP-1-yne (*syn*-**1a**) was synthesized by dehydrobromination reaction of *syn*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy[2.8]MCP in presence of $HOBu^t$ at 80 °C for 12 h, 48 % yield [17,30]. Subsequently, demethylation reaction of *syn*-**1a** with BBr_3, a commercially available, excellent demethylating or dealkylating agent for the cleavage of ethers also with subsequent cyclization, in CH_2Cl_2 solution at room temperature for 8 h (Scheme 1) afford the expected [8]benzofuranophane **2a** in 67 % yield. So this example inspired us to further investigate the effect of the increase of carbon chain in MCP skeleton structure for BBr_3-induced cyclization reaction. The length of the cross-linking chain can be increased up to a certain level to form benzofuranophane. Therefore, [2.10]MCP is treated with BBr_3 for synthesis of benzofuranophane.

At higher temperature and prolonged reaction time 17,18-di-*endo*-bromo-13,21-di-*tert*-butyl-16,24-dimethoxy[2.10]MCP was treated with potassium *tert*-butoxide in refluxing $HOBu^t$ at 80 °C for 3 h and synthesized 5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP-1-yne (*syn*-**1b**) in 93 % yield, along with 7 % monodehydrobrominated product as reported procedure [17,30]. Bromination of *syn*-**1b** with BBr_3 carried out in a CH_2Cl_2 solution at room temperature for 0.5 h generates [10]benzofuranophane **2b** in 79 % yield. In this case, the reaction occurred within a very short time (3 h) than that of *syn*-**1a**.

Insert Scheme 1 in here

The structure of **2a** was characterized by ^1H and ^{13}C-NMR, mass spectra and elemental analysis, as well as single crystal X-ray diffraction. The ^1H-NMR spectrum of **2a** (300 MHz, $CDCl_3$) shows five aromatic protons are observed as a singlet at δ 6.91 ppm and doublets at δ 7.11, 7.13, 7.23, 7.45 ppm, respectively, which are clearly associated with the unsymmetrical structure of **2a**. The ^1H-NMR (300 MHz, $CDCl_3$) spectrum also exhibits the signal for one hydroxyl group in the lower magnetic field δ 7.18 ppm, which is exchanged by D_2O. This data is consistent with the existence of intramolecular hydrogen bonding between the hydroxyl group

and the oxygen of the benzofuran ring. A peak for O–H band was observed at 3527 cm^{-1} in the IR spectrum. On the basis of the spectral data and the chemical conversion, compound **2a** is assigned to the structure, 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-hydroxyphenyl)[8](7,3*'*) benzofuranophane.

The ^{1}H-NMR (300 MHz, $CDCl_3$) spectrum exhibits the signal for one hydroxyl group in the lower magnetic field δ 7.67 ppm, which is exchanged by D_2O strongly suggested the highly formation of an intramolecular hydrogen bond. The IR spectrum of **2b** also shows the absorption of the hydroxyl stretching vibration around 3511 cm^{-1}. On the basis of the spectral data and the chemical analysis, compound **2b** is assigned to the structure, 5-*tert*-butyl-1-(5*'*-*tert*-butyl-2*'*-hydroxyphenyl)[10](7,3*'*)benzofuranophane.

Despite the fact that the detailed reaction mechanism of generation of [n]benzofuranophane from 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*]MCP-1-ynes is not clear at this time, it can be considered to have progressed as follows in Scheme 2. The mechanism of BBr_3 reaction of starting material *syn* apparently proceeds via the formation of a complex **A** followed by elimination of an alkyl bromide. **A** can undergo hydrolysis to give a hydroxyl group based product **B** from which the electrophilic attack to the triple bond to initiate the cation intermediate **C** provided final compound [*n*]benzofuranophane by dehydrobromination. In this reaction, BBr_3 as excellent demethylating or dealkylating agent, play a significant role to activate the cyclization reaction. The detailed mechanism of the BBr_3-induced cyclization reaction will discuss in below.

Insert Scheme 2 in here

Bromination of *anti*- and *syn*-5,10-di-*tert*-butyl-8,22-dimethoxy[2.8]MCP-1-ene with 1.1 equiv. of benzyltrimethylammonium tribromide ($BTMABr_3$), which was found to be a convenient solid brominating agent [29], in CH_2Cl_2 solution at room temperature for 1 h and 2 h led to the *trans* and *cis* adduct *anti*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy [2.8]MCP (*dl*-**5a**) and *syn*-15,16-di-*endo*-bromo-11,19-di-*tert*-butyl-14,22-dimethoxy[2.8]MCP (*meso*-**3a**), respectively following previous report [17,30]. Both *meso*-**3a** and *dl*- **5a** react with

BBr_3 in CH_2Cl_2 as former reaction conditions (Scheme 3) to afford compound **2a**. Extension of reaction time to 8 h will give more percentage of the product.

Similarly, 1,2-di-*endo*-bromo- (*meso*-**3b**) and 1-*endo*,2-*exo*-dibromo-5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP (*dl*-**5b**) were prepared by bromination of *(Z)*- and *(E)*-5,2-di-*tert*-butyl-8,24-dimethoxy-[2.10]MCP-1-ene with 1.1 equiv. of $BTMABr_3$ in CH_2Cl_2 at room temperature for 5 min in 54 and 88 % yields, respectively, according to the reported procedure [17,30,31]. Under different conditions for demethylation of *meso*-**3b** to afford *meso*-**4b** with trimethylsilyl iodide in acetonitrile solution [32–34] was not succeeded. Only an awkward mixture of products was obtained. Interestingly, treatment of *meso*-**3b** with BBr_3 in CH_2Cl_2 at room temperature for 0.5 h divergent outcomes were procured.

However, the formation of the corresponding demethylation product, 1,2-di-*endo*-bromo-8,24-dihydroxy[2.10]MCP (*meso*-**4b**) was not observed during the reaction. Similar reaction to afford [10]benzofuranophane **2b** was resulted in the treatment of *dl*-**5b** with BBr_3 in CH_2Cl_2 under the same conditions described above in 87 % yield (Scheme 3).

Insert Scheme 3 in here

The mechanism of formation of [*n*]benzofuranophane from *meso* compounds in presence of BBr_3 is based on speculation as shown in Scheme 4. The present BBr_3 induced conversion from 1,2-di-*endo*-bromo-5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*]MCP to desired [*n*]benzofuranophane possibly raised by demethylation of methoxy groups to provide the corresponding phenol derivatives *meso*-**4a**, **b** followed by the nucleophilic substitution at the C_2 carbon to afford five membered dihydrofuran skeleton (**D**) from which the final product [*n*]benzofuranophane was formed by dehydrobromination reaction.

Insert Scheme 4 in here

Intramolecular hydrogen bonding in compound **2** has been investigated in solution by NMR as a major tool. The evidence of hydrogen bonding can be provided by ^1H and heteronuclear chemical shifts, coupling constants, solvent and deuterium isotope effects on chemical shifts. The use of hydroxyl protons in hydrogen bonding and conformational NMR studies in solution,

displays experimental challenges because of rapid chemical exchange between hydroxyl groups and protic solvents. Proton exchange rates in alcohol –OH groups can be weakened by dissolving in DMSO-d_6 or acetone-d_6 or by using organic co-solvents and thus, have already been promoted in structural analysis of benzofuranophane. For compound **2a**, in DMSO-d_6 a very sharp peak for hydroxyl group observed at δ 8.71 ppm. In acetone-d_6 the hydroxyl peak shifted to lower frequency at δ 7.97 ppm. In $CDCl_3$, the signal, this is further shifted to lowest frequency at δ 7.18 ppm. For compound **2b**, in DMSO-d_6 a very sharp peak for hydroxyl group observed at δ 8.35 ppm. In acetone-d_6 the hydroxyl peak shifted to lower frequency at δ 7.91 ppm. In $CDCl_3$ the peak shifted to lowest frequency at δ 7.67 ppm. The phenolic hydroxyl proton form intramolecular hydrogen bond with the oxygen in benzofuran unit. The ^{1}H NMR of **2a**–**b** (400 MHz) in DMSO-d_6 and acetone-d_6 lead to shift the hydroxyl peak at low field region indicating that the intramolecular hydrogen bonding is disrupted in polar solvent and the formation of intermolecular hydrogen bonding with solvent (SI Fig. S4-1 & S4-2). For compound **2a** OH peak shifted to lower field than that of compound **2b**. This is because of the shorter number of carbon chain length, which causes more steric hindrance into the cyclophane system.

The suitable crystals **2a** and **2b** for single crystal X-ray analysis were cultivated from a hexane-chloroform (V_{hexane}:$V_{Chloroform}$ = 1:1) by slow evaporation process at room temperature. Compound **2a** crystallizes in the orthorhombic crystal system with space group Pbca, whereas compound **2b** in the monoclinic crystal system with space group Cc. The key crystallographic data are summarized in Table 1 and each crystal structure **2a** and **2b** are shown in Figure 1.

Insert Table 1 in here

The X-ray structure of novel [8]benzofuranophane **2a** and [10]benzofuranophane **2b** were displayed in Figure 1. In **2a**, the benzofuran ring is not co-planer with phenyl ring with a torsion angle of 34.2^o, the hydroxyl (OH) at the 2-position of benzene has formed an intramolecular hydrogen bonding with the adjacent oxygen atom (O2), and the distance of O2-H2…O1 is 1.98 Å. Similarly, in compound **2b** with 10 carbon line alkyl, the torsion angle (23.5^o) is less than **2a** between benzofuran ring and phenyl ring, which indicated the length of alkyl would affect the molecular conformation; for example, hydroxyl (OH) in **2a** is strongly affected by steric effects of the neighbor carbon line alkyl, however, the compound **2b** with longer line alkyl would

release the strain. Indeed, as our speculation, some methylene groups are involved in a strong intermolecular interaction and disorder with occupancy ratio 0.5:0.5 for C23, C24 and C25 in X-ray structure, respectively. However, no disordered structure was observed in compound **2b**. Also the bond angle of O2–H2–O1 for **2b** (148.42°) and **2a** (134.98°) clearly demonstrated that the strong intramolecular hydrogen bonding occurs in **2b** rather than **2a**.

Insert Figure 1 in here

In case of compound **2b** the present conformational rigidity might be attributed to the strong intramolecular hydrogen bond among the hydroxyl group and the oxygen atom on the benzofuran ring which strongly reduce the conformational ring flipping. The hydrogen bond O2-H2…O1 was 1.82 Å, which is a reasonable distance for intramolecular hydrogen bonding.

In addition, the intramolecular hydrogen bonds were further confirmed by the temperature-dependent NMR. The conformation of this compound in solution is rigid and the signals of the benzylic methylene protons do not coalesce below 150 °C in DMSO. This finding strongly suggest the restricted rotation around the diaryl linkage of [10]benzofuranophane **2b**. Both ^{1}H NMR and X-ray results strongly suggests that compound **2b** have stronger intramolecular hydrogen bonding in comparison with compound **2a**.

To gain a deep insight into the synergistic effect of the steric effects and intramolecular hydrogen bonding for molecular conformation in benzofuranophane derivatives, the hydroxyl group in **2b** was replaced by a methyl group as follows Scheme 5. After that compound **2b** was treated with methyl iodide in the presence of NaH in anhydrous THF solution at room temperature for 3 h, the corresponding methoxy derivative **6b** was obtained in 64 % yield. The hydroxyl group of compound **2b** is converted into the larger methoxy group. The ^{1}H-NMR peak of OH disappears from the spectrum and conducts internal methoxy proton as a singlet at δ 3.41 ppm and H proton of benzofuran ring as a singlet at δ 6.91 ppm (relative intensity 3:1).

Insert Scheme 5 in here

In fact, 1,2-dibromo-1,2-bis(5-*tert*-butyl-2-methoxy-3-methylphenyl)ethane **7** as reference compound, was treated with BBr_3 in CH_2Cl_2 under the same conditions as those in *meso*-**3b**, but

only the recovery of the starting compound resulted (Scheme 6). When the reaction time was extended to 5 h instead of 0.5 h, resulted the corresponding 2-(2-hydroxyphenyl)benzofuran **9** in 10 % yield along with the further cyclisation product, *cis*-4b,9b-dihydrobenzofuro[3,2-b] benzofuran **8** in 80 % yield [35–37]. Prolonged the reaction time to 24 h resulted in the exclusive formation of the compound **8**. These results strongly support the reaction mechanism for the formation of the benzofuran skeleton as described above.

Insert Scheme 6 in here

The much faster reaction was observed in *meso*-**3b** than that of **7** under the same reaction conditions for treatment of BBr_3 in CH_2Cl_2 at room temperature. The enhanced reactivity towards the nucleophilic attack of phenolic oxygen in the C_2 carbon may be attributable to the cyclophane structure of *meso*-**5b** in which the reaction site can be sterically much closer than that in compound **7**.

Insert Scheme 7 in here

Second cyclization of **9** to **8** might be attributable to the conformational flexibility of **9** around the diaryl linkage of 2-arylbenzofuran. However, in the case of [*n*]benzofuranophane, formation of compound **10** was not observed by prolonging the reaction time (Scheme 7). The rotation around the diaryl linkage to form conformer **E** might be restricted due to its cyclophane structure containing sterically hindered tertiary butyl group.

Conclusions

We have denoted an expedient preparation procedure of novel [8]benzofuranophane **2a** and [10]benzofuranophane **2b** by treatment of 5,19-di-*tert*-butyl-8,22-dimethoxy[2.8]MCP-1-yne (*syn*-**1a**) and 5,21-di-*tert*-butyl-8,24-dimethoxy[2.10]MCP-1-yne (*syn*-**1b**) with BBr_3 in CH_2Cl_2 at room temperature, respectively by intramolecular cyclization reaction. Enthrallingly, *meso*-**3a**, *dl*-**5a**, *meso*-**3a** and *dl*-**5b** under the same reaction conditions with BBr_3 in CH_2Cl_2 rendered

compound **2a** and **2b** in good yield. Further studies on the synthesis, reactions and chemical properties of different [n]benzofuranophanes are now in progress will be reported in due time.

Acknowledgments

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Highlights

♦ Novel hydroxy[*n*]benzofuranophanes have been synthesized by intramolecular cyclization.

♦ Intramolecular hydrogen bonding between hydroxyl proton and the oxygen of furan ring was observed.

♦ Weak intramolecular hydrogen bonding causes the rigid structures of [*n*]benzofuranophanes.

Figure(s)

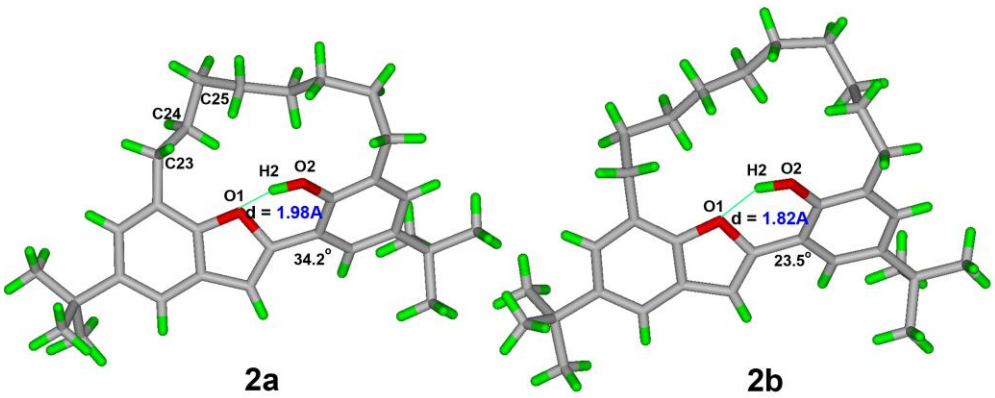
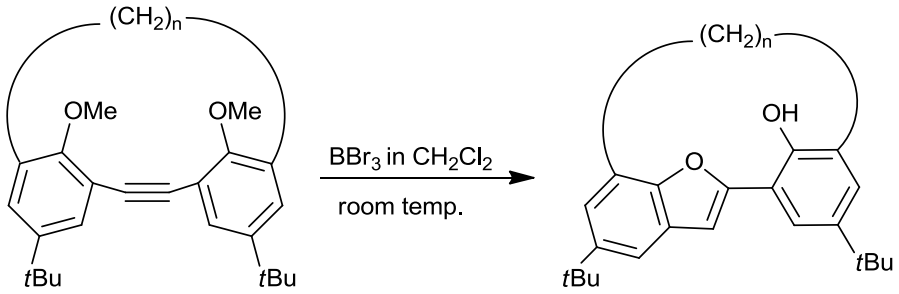


Fig. 1 X-ray structures for **2a** and **2b**.

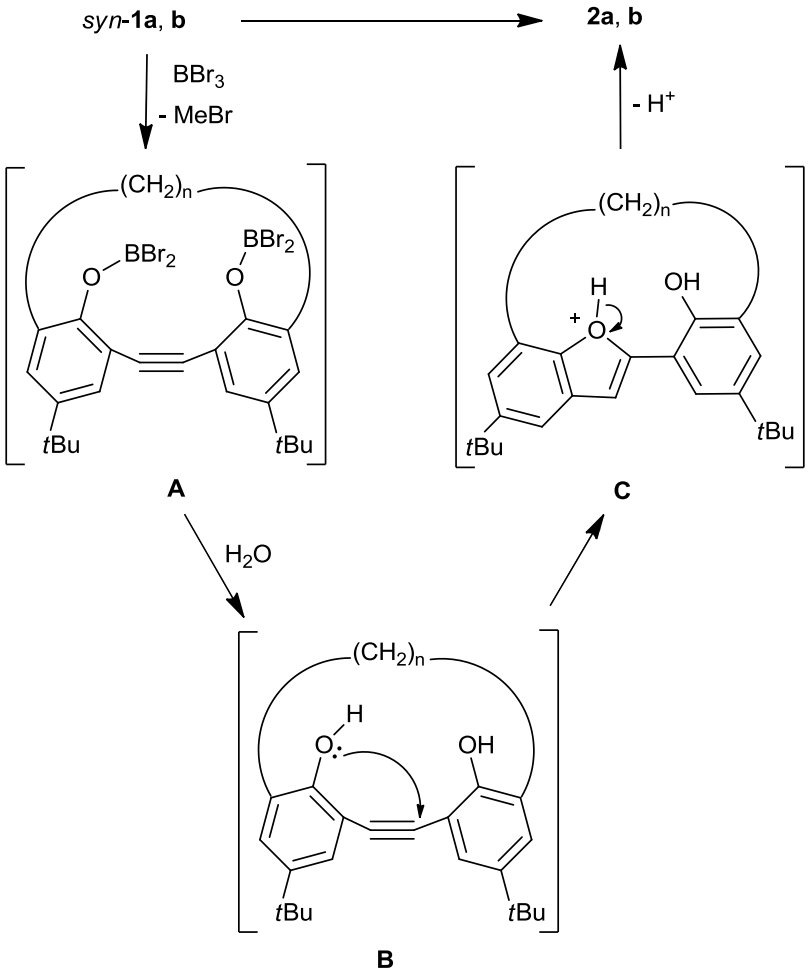
Scheme 1



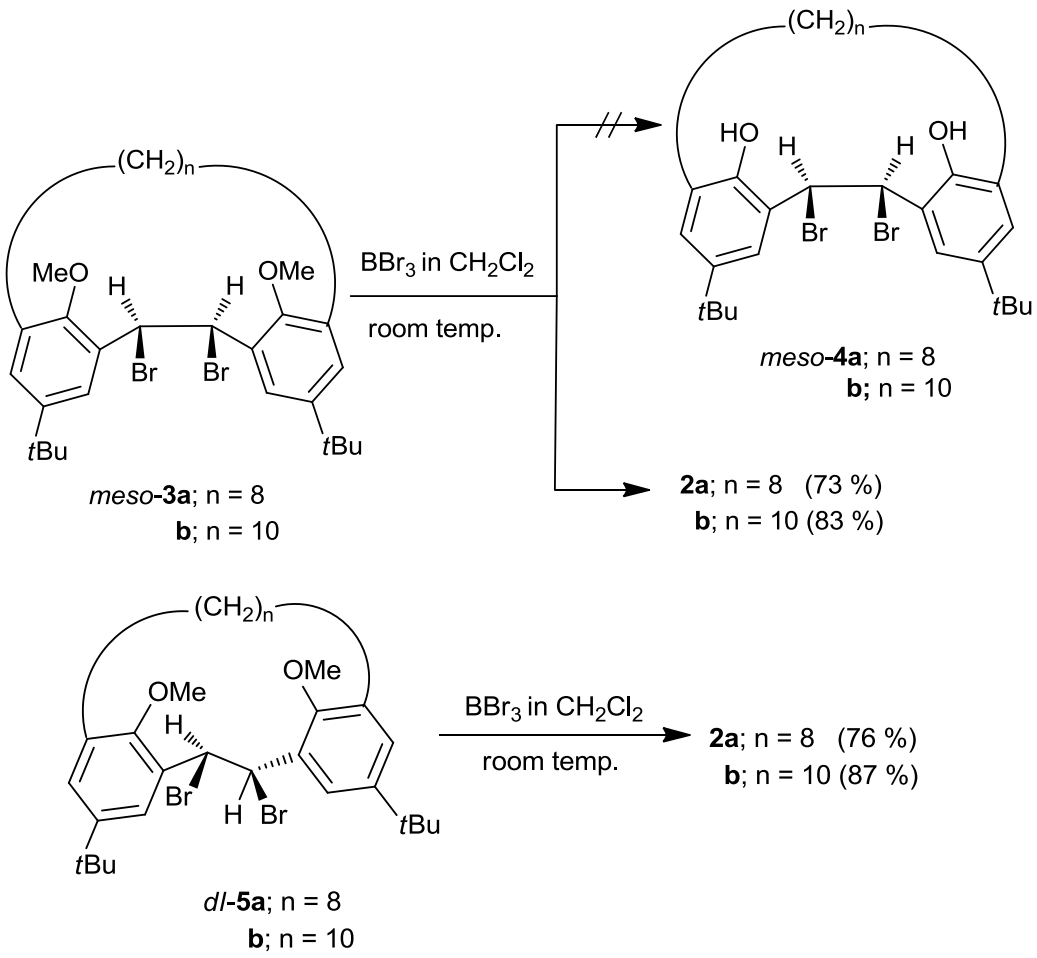
syn-**1a**; n = 8
b; n = 10

2a; n = 8 (67 %)
b; n = 10 (79 %)

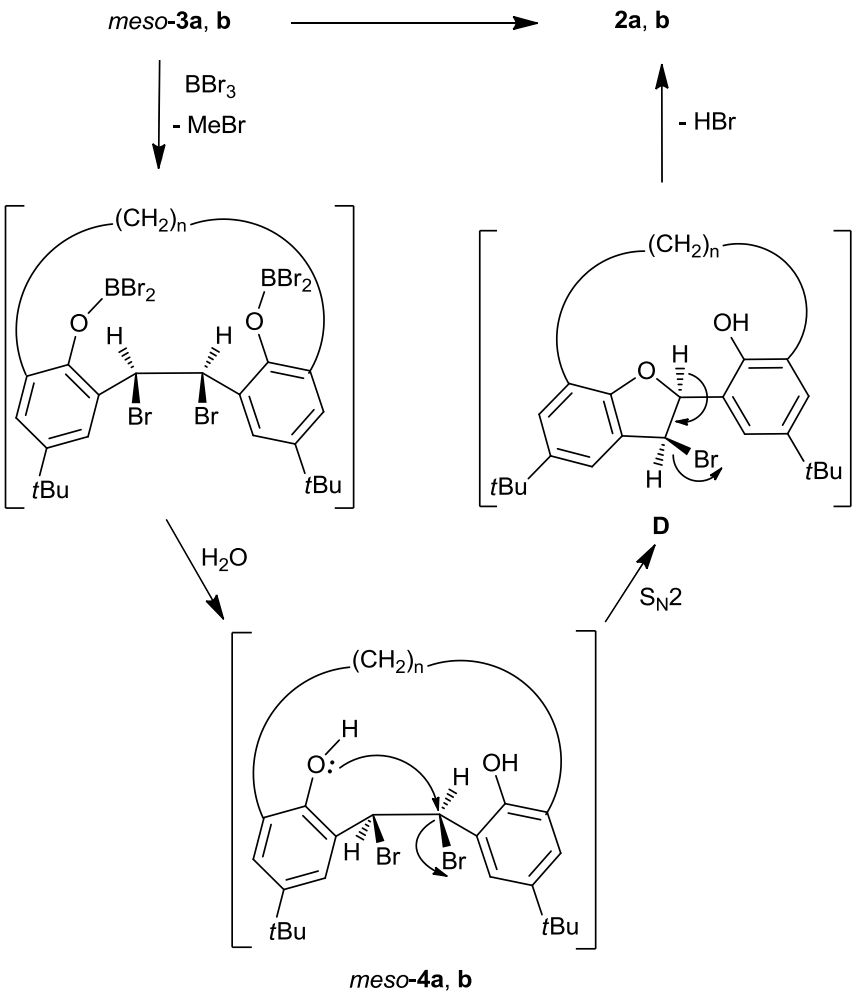
Scheme 2



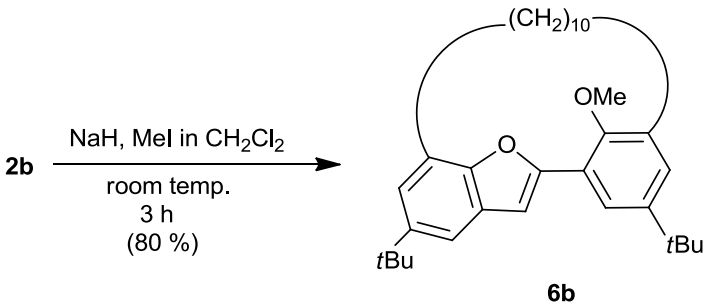
Scheme 3



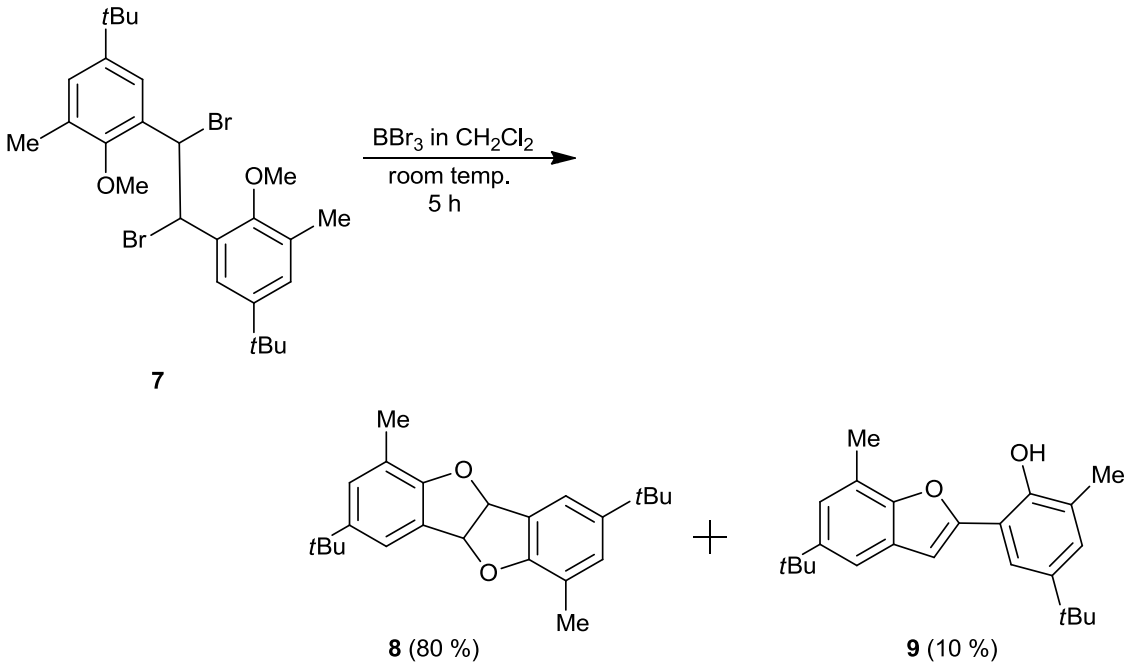
Scheme 4



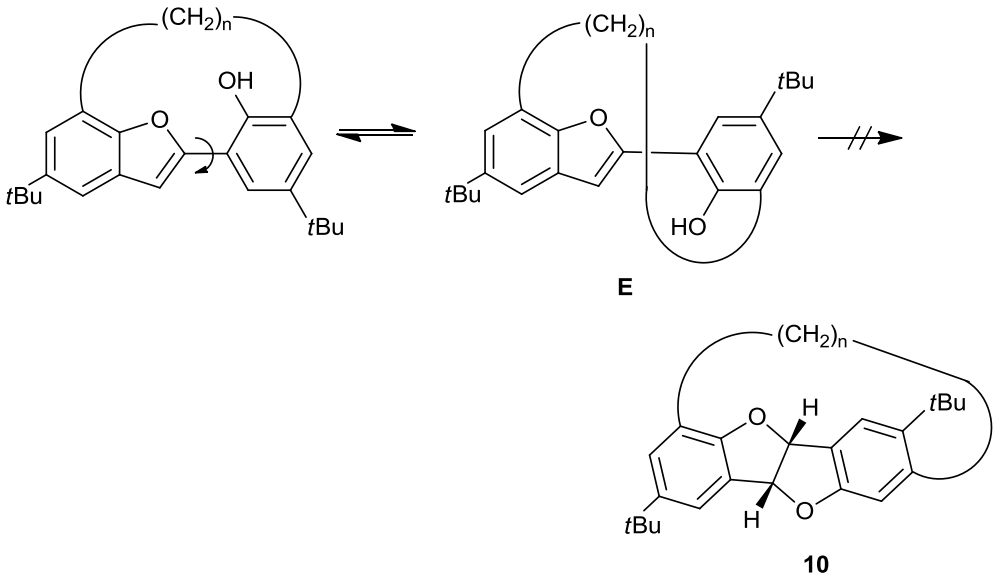
Scheme 5



Scheme 6



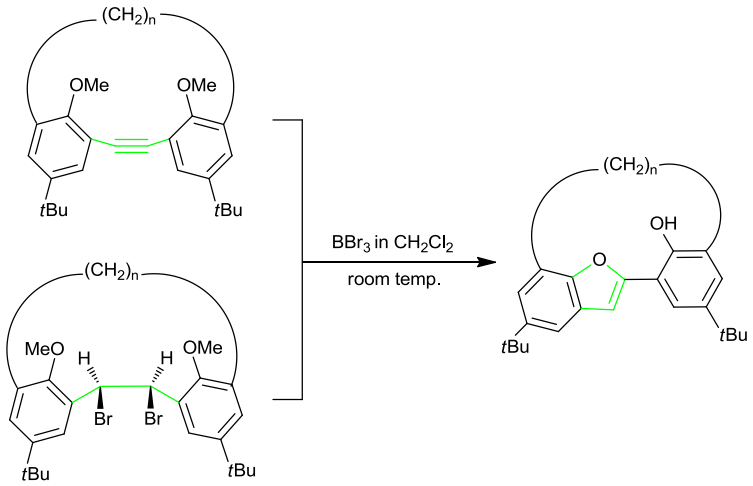
Scheme7



Graphical Abstract

Demethylation of 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*] metacyclophane-1-ynes with BBr_3 to afford novel [*n*]benzofuranophanes

Thamina Akther [a], Md. Monarul Islam[a,b], Taisuke Matsumoto[c], Junji Tanaka[c], Xing Feng [d], Carl Redshaw[e] and Takehiko Yamato[a,*]



Table(s)

Table 1 Summary of crystal data for **2a** and **2b**

Complex	**2a**	**2b**
Empirical	C_{30} H_{40} O_2	C_{32} H_{44} O_2
Formula weight	432.64	460.67
Crystal system	orthorhombi	monoclinic
Space group	*Pbca*	*C c*
a[Å]	28.1308(5)	14.6104(12)
b[Å]	18.0592(3)	21.5562(19)
c[Å]	9.95585(18)	9.0564(4)
α[º]	--	--
β[º]	--	100.897(4)
γ[º]	--	--
Volume[Å^3]	5057.77(16)	2800.8(4)
Z	8	4
Dcalcd[Mg/m^3]	1.136	1.092
temperature [K]	123	100
unique reflns	4616	2512
obsd reflns	3514	2235
parameters	326	314
R(int)	0.0408	0.0270
$R[I> 2\sigma(I)]$[a]	0.0628	0.0822
wR_2[all data][b]	0.1691	0.2292
GOF on F^2	1.039	0.963

[a] Conventional *R* on F_{hkl}: $\Sigma||F_o| - |F_c||/\sigma|F_o|$. [b] Weighted *R* on $|F_{hkl}|^2$: $\Sigma[w(F_o^2 - F_c^2)^2]/\Sigma[w(F_o^2)^2]^{1/2}$

Supporting Information for

Demethylation of 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*] metacyclophane- 1-ynes with BBr_3 to afford novel [*n*]benzofuranophanes

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Table Contents

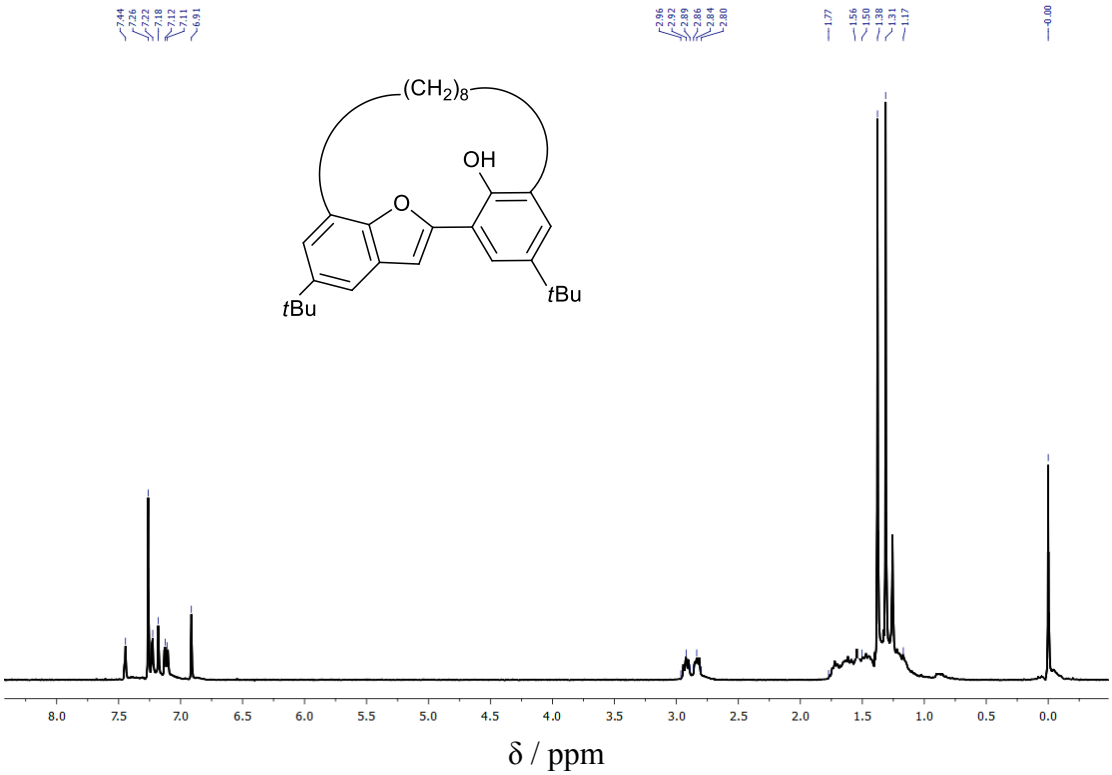


Figure S1-1 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **2a**.

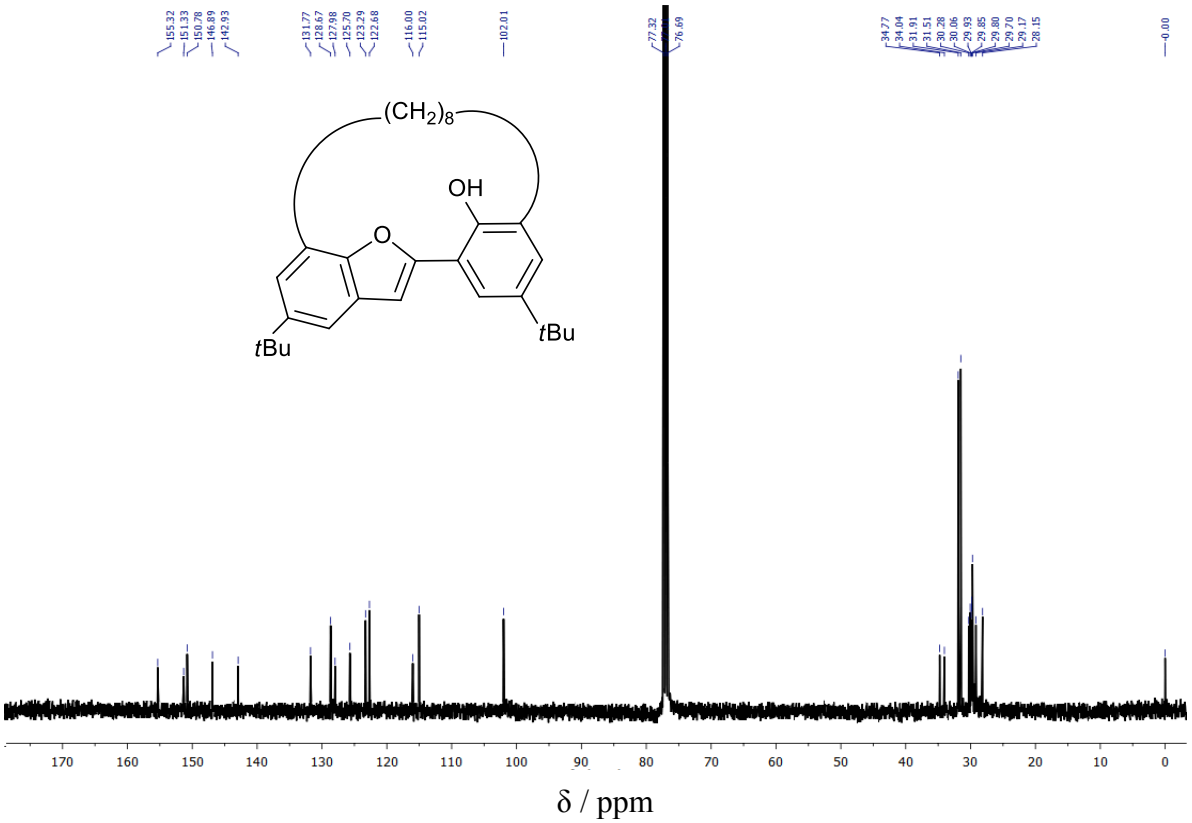


Figure S1-2 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **2a**.

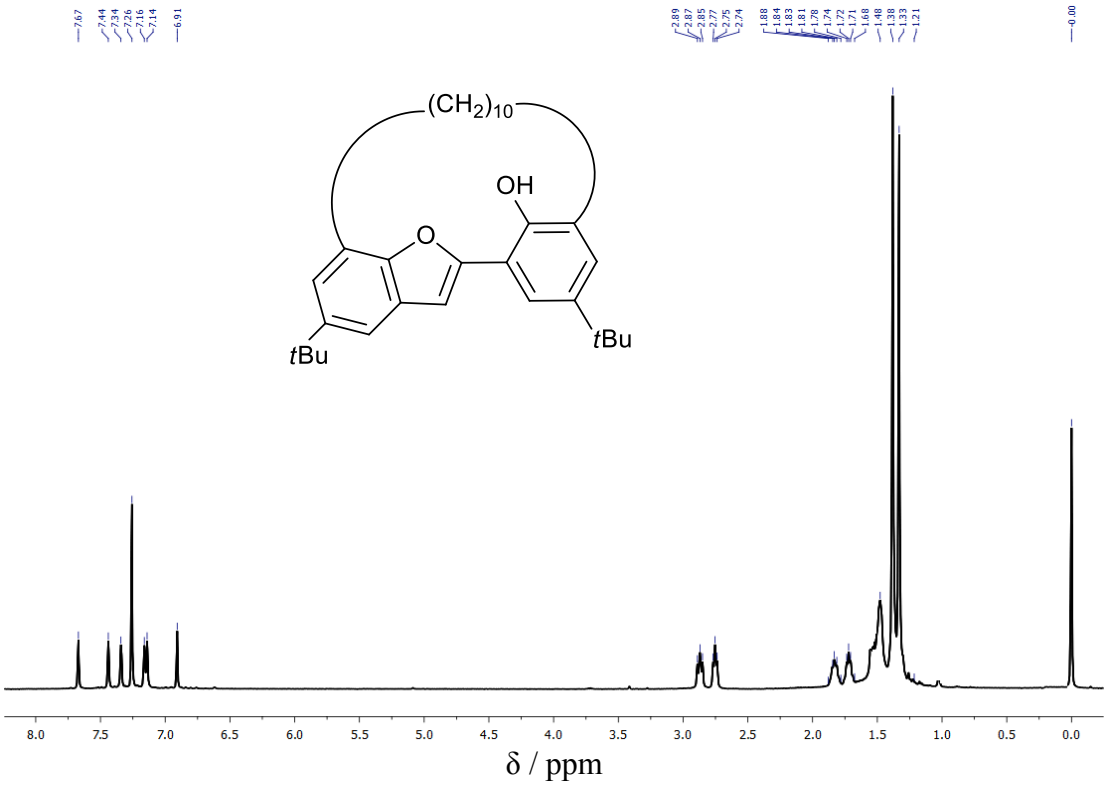


Figure S1-3 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **2b**.

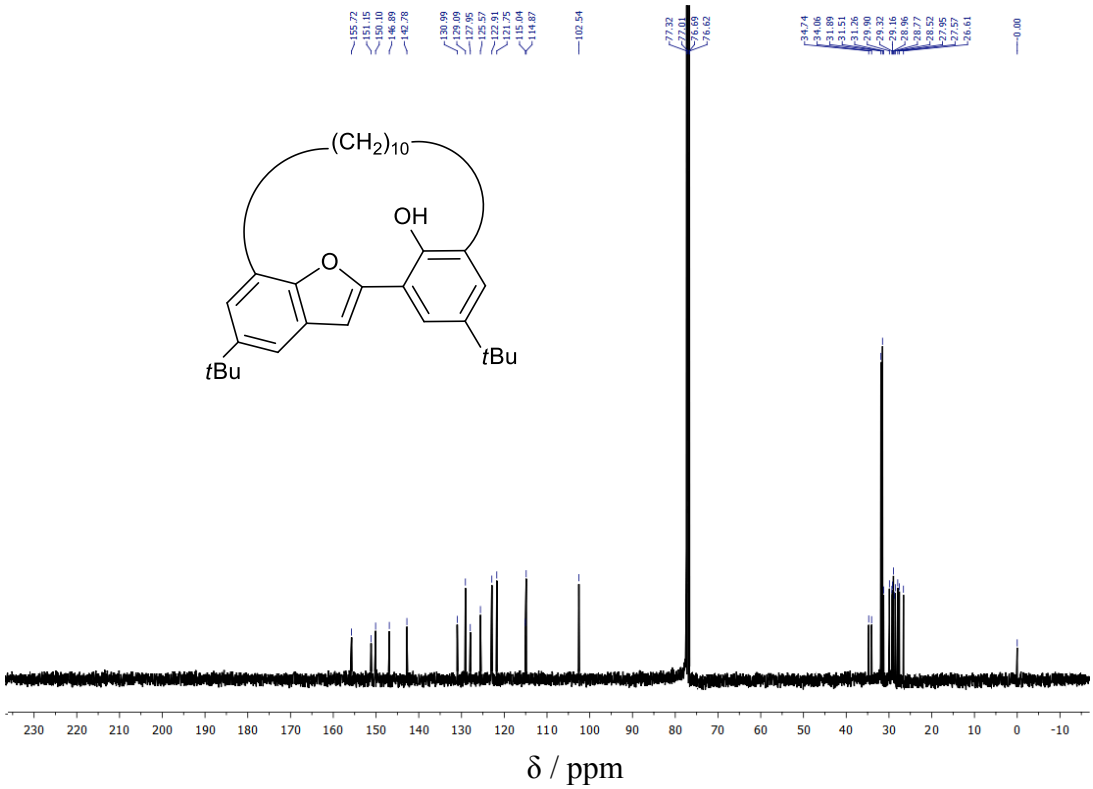


Figure S1-4 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **2b**.

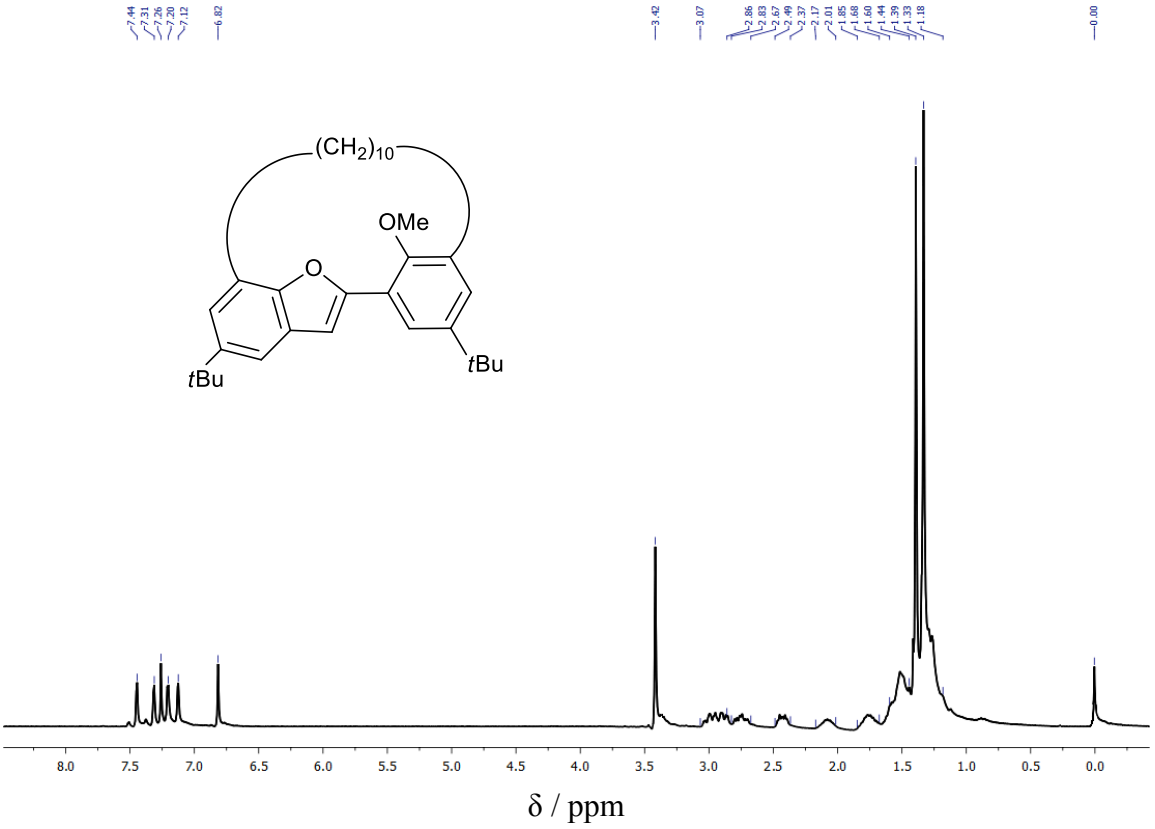


Figure S1-5 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **6b**.

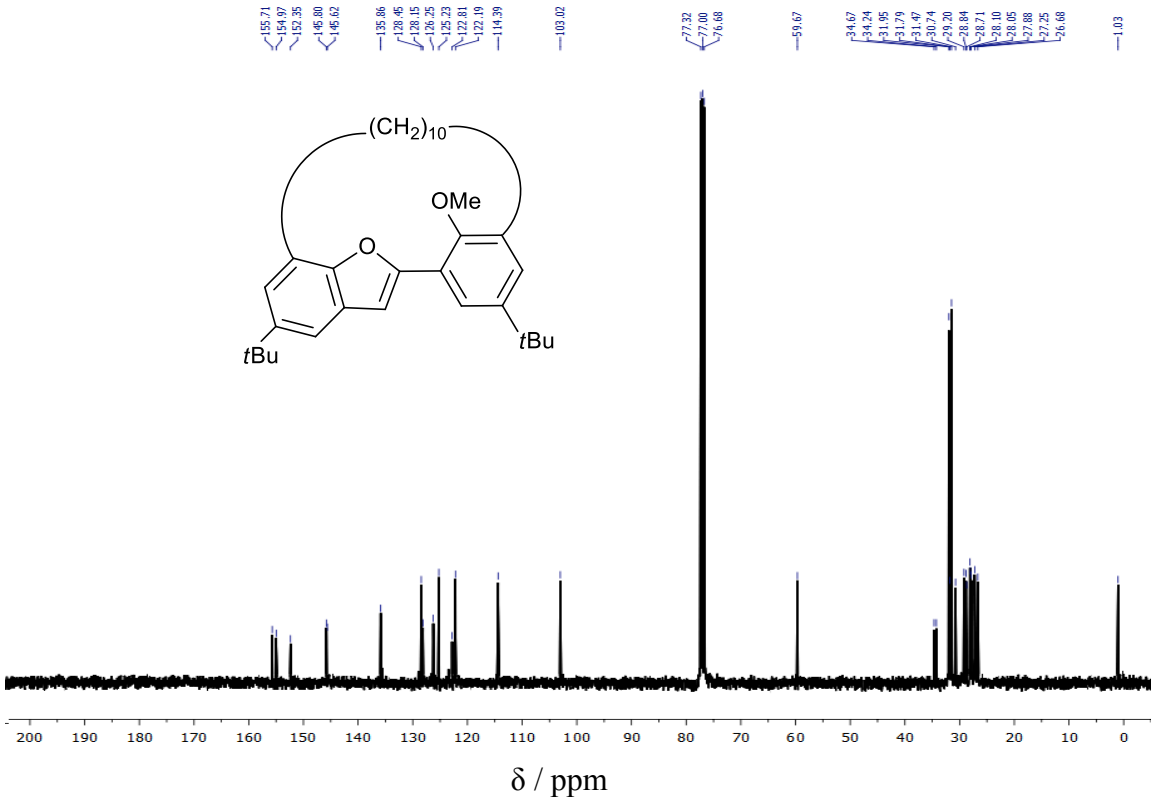


Figure S1-6 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **6b**.

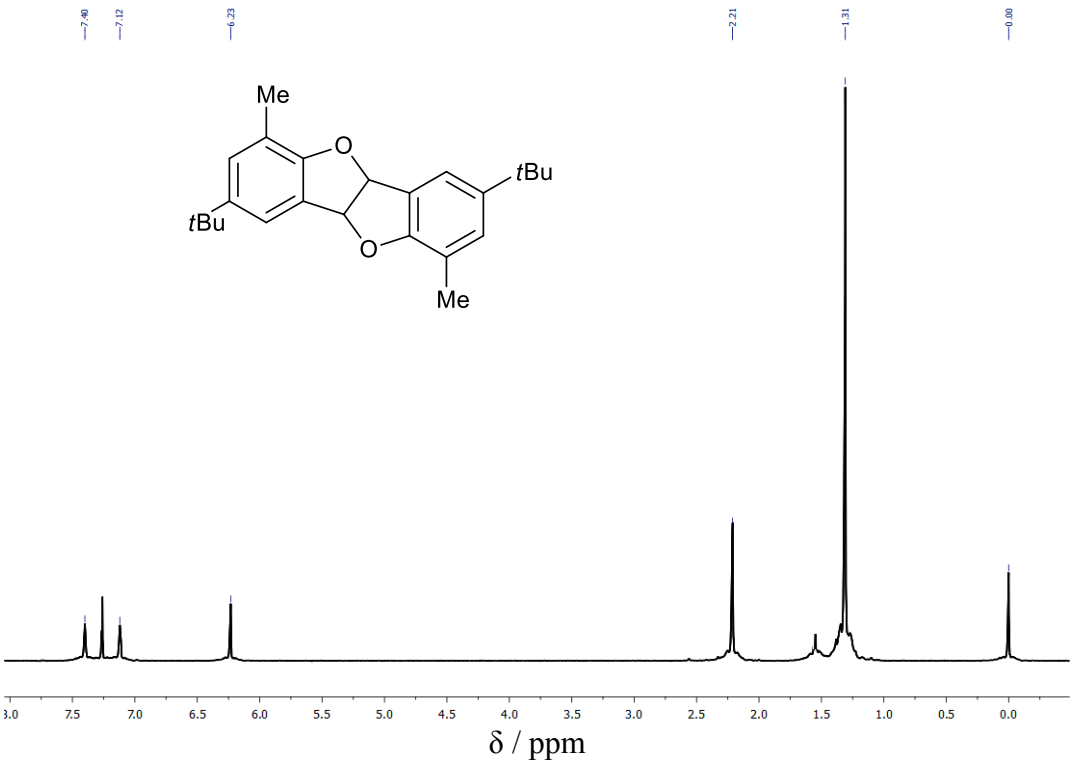


Figure S1-7 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **8**.

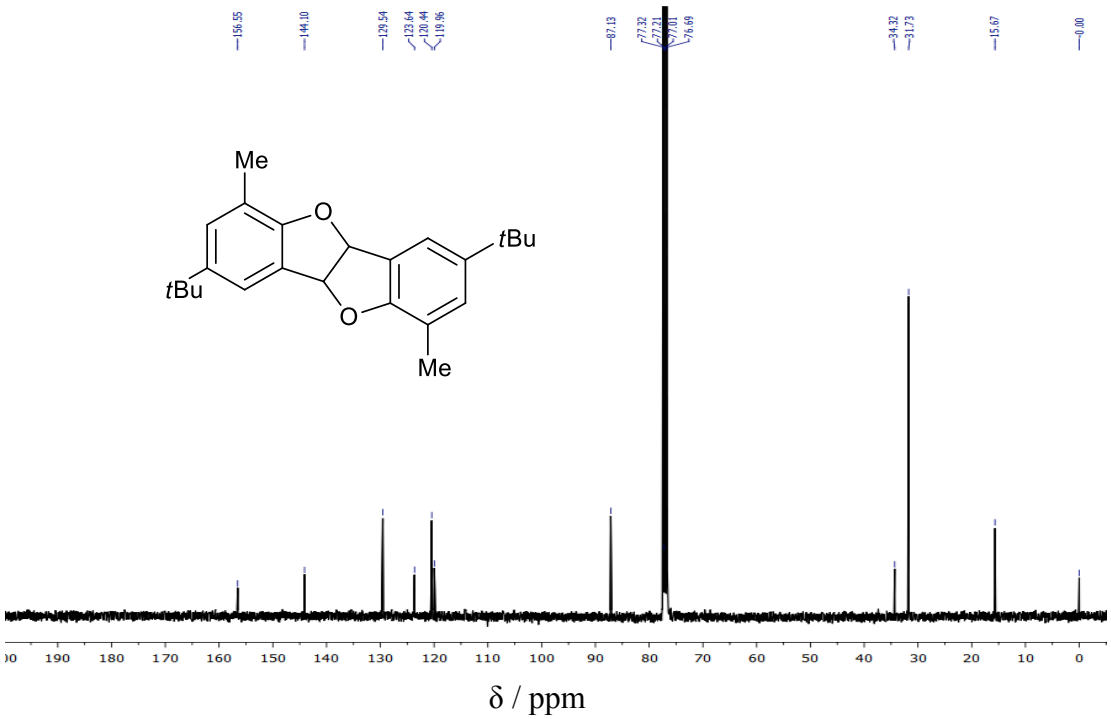


Figure S1-8 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **8**.

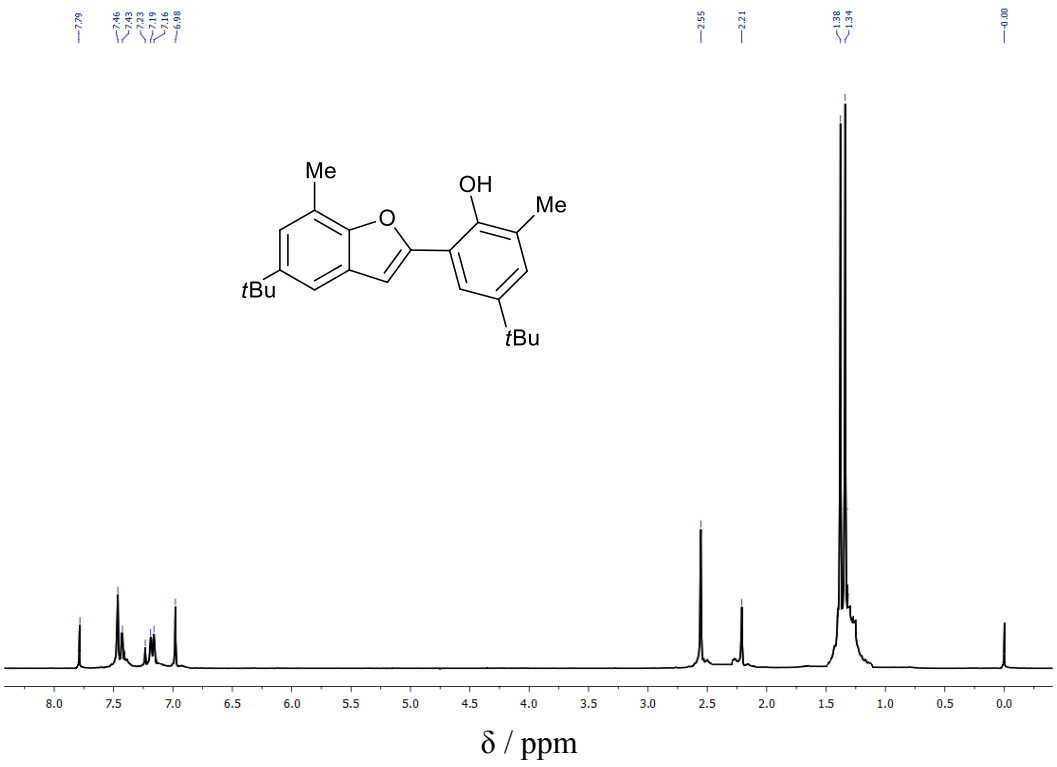


Figure S1-9 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **9**.

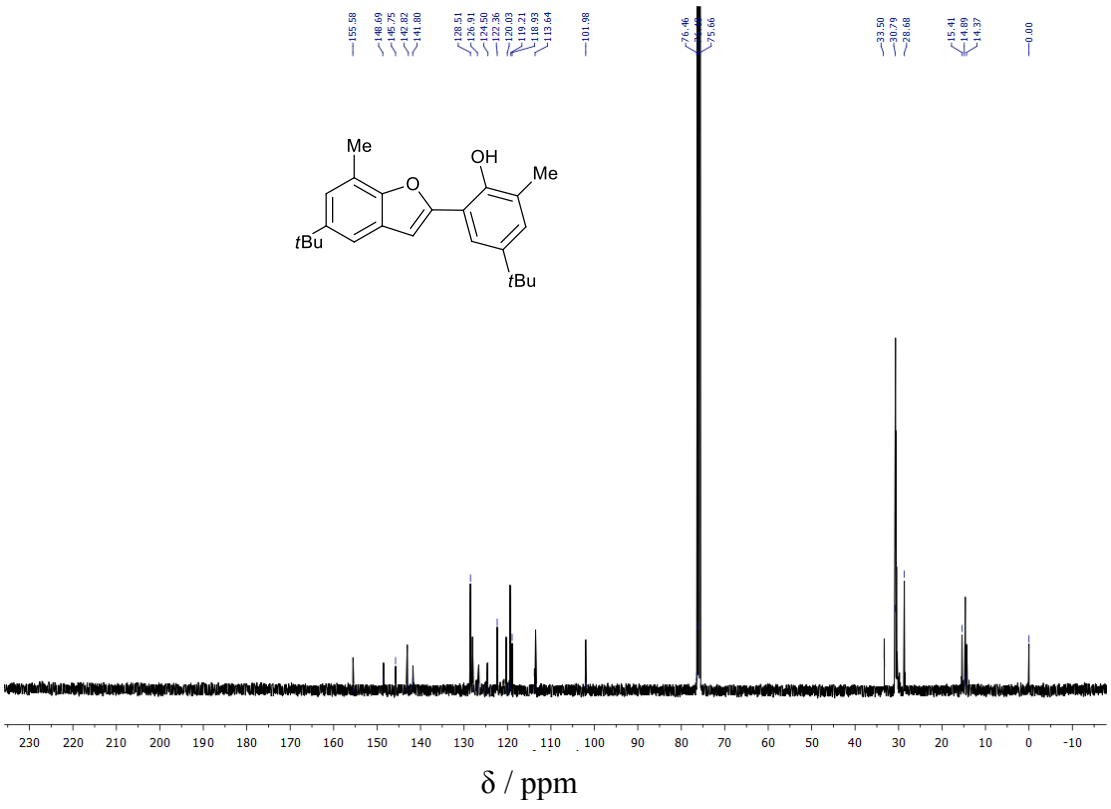


Figure S1-10 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **9**.

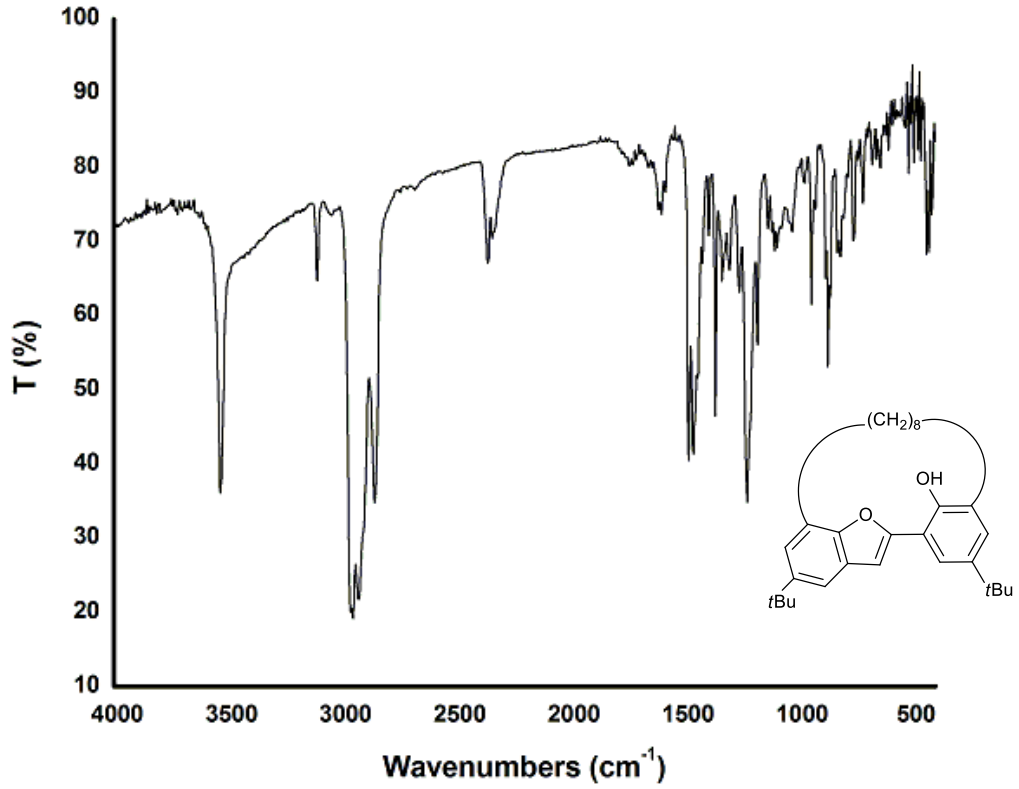


Figure S2-1 FT-IR spectrum for **2a**.

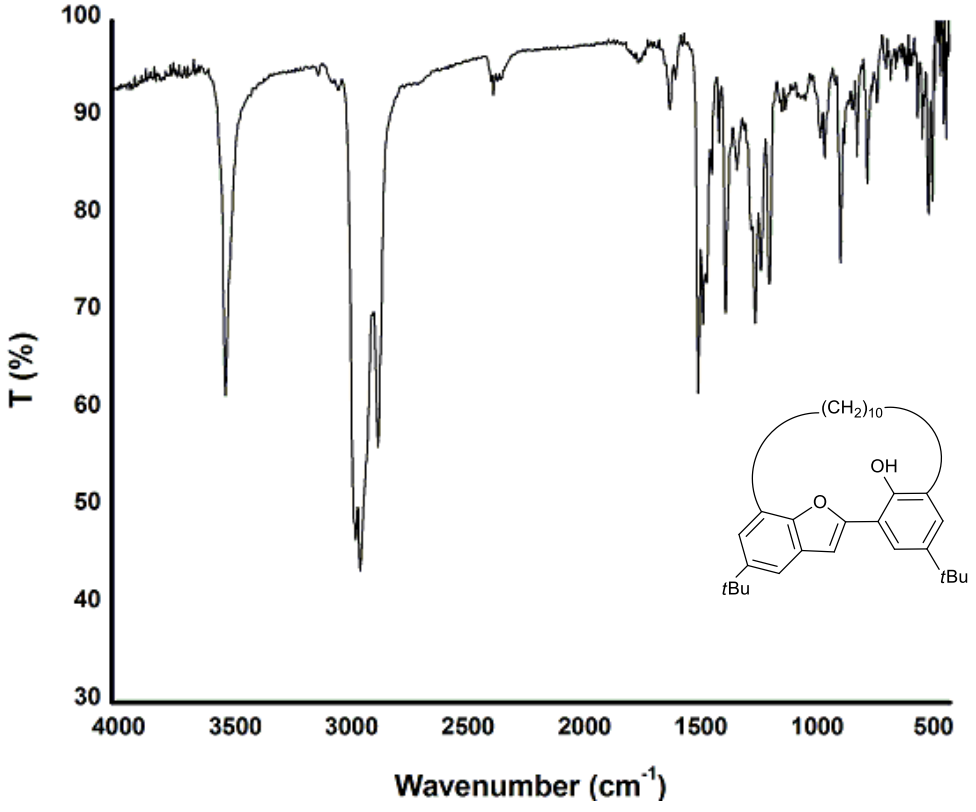


Figure S2-2 FT-IR spectrum for **2b**.

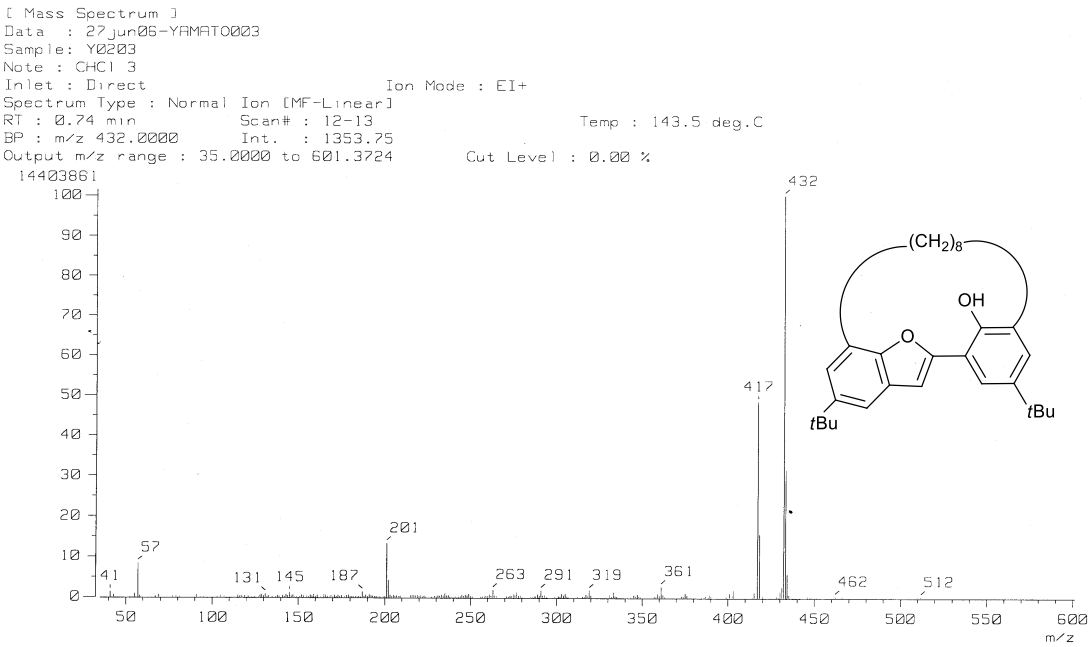


Figure S3-1 Mass spectrum for **2a**.

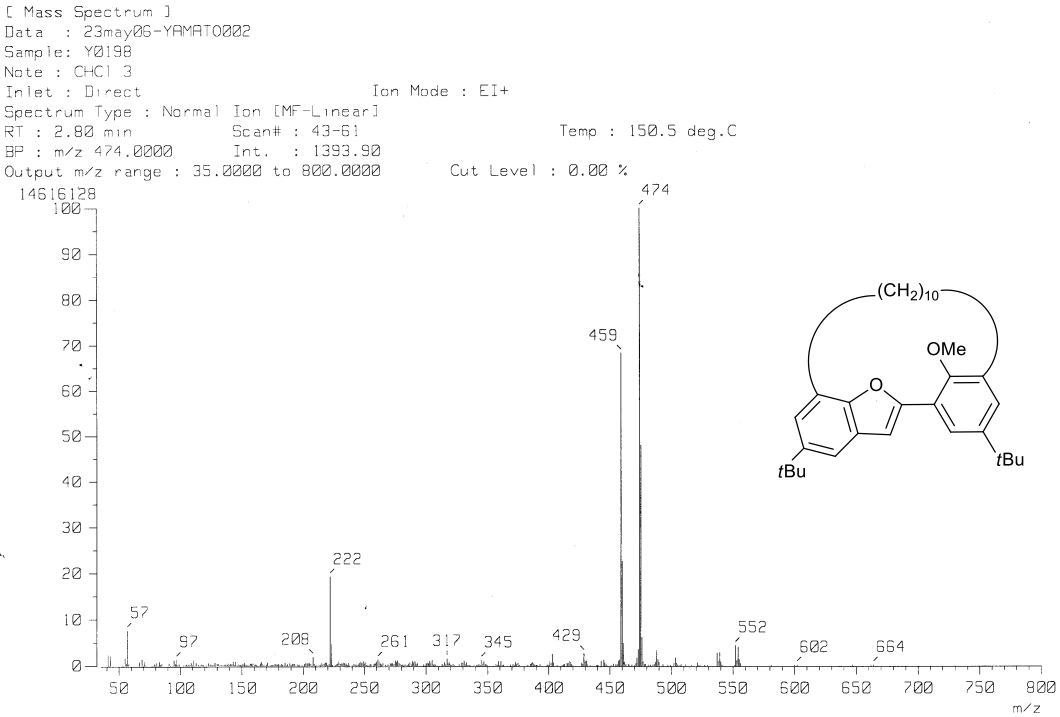


Figure S3-2 Mass spectrum for **6b**.

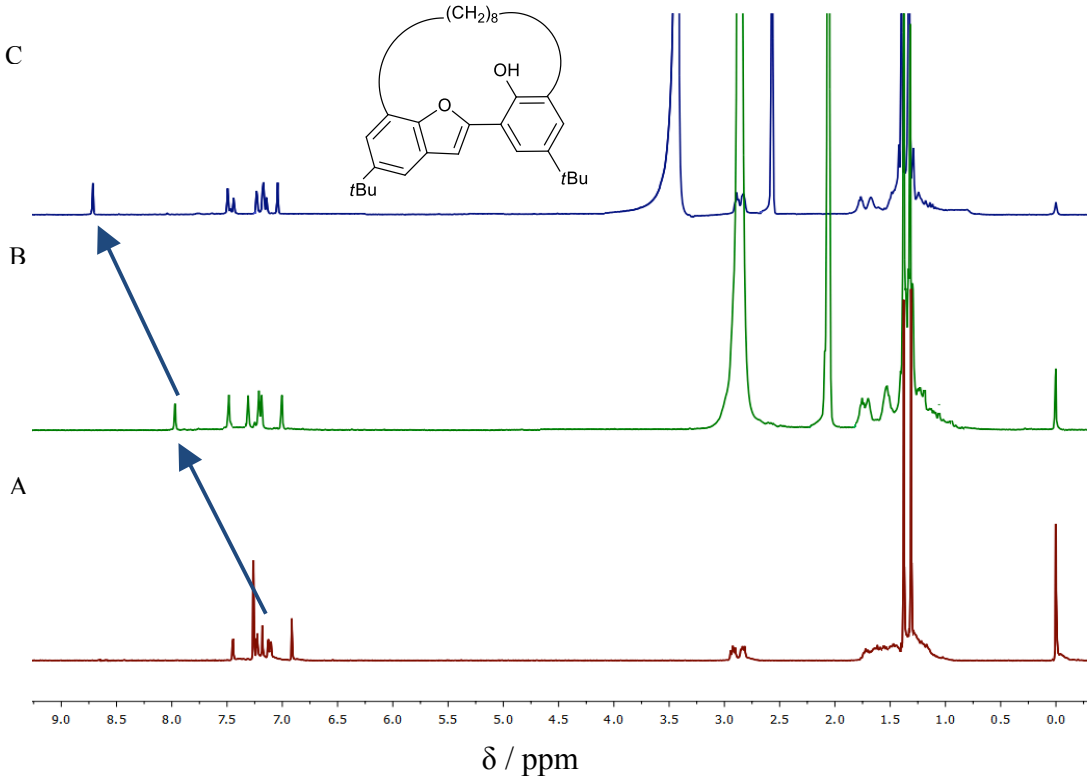


Figure S4-1 ^{1}H–NMR spectra for **2a** (400 MHz, 293 K); (A) $CDCl_3$, (B) $(CD_3)_2CO$, (C) $(CD_3)_2SO$.

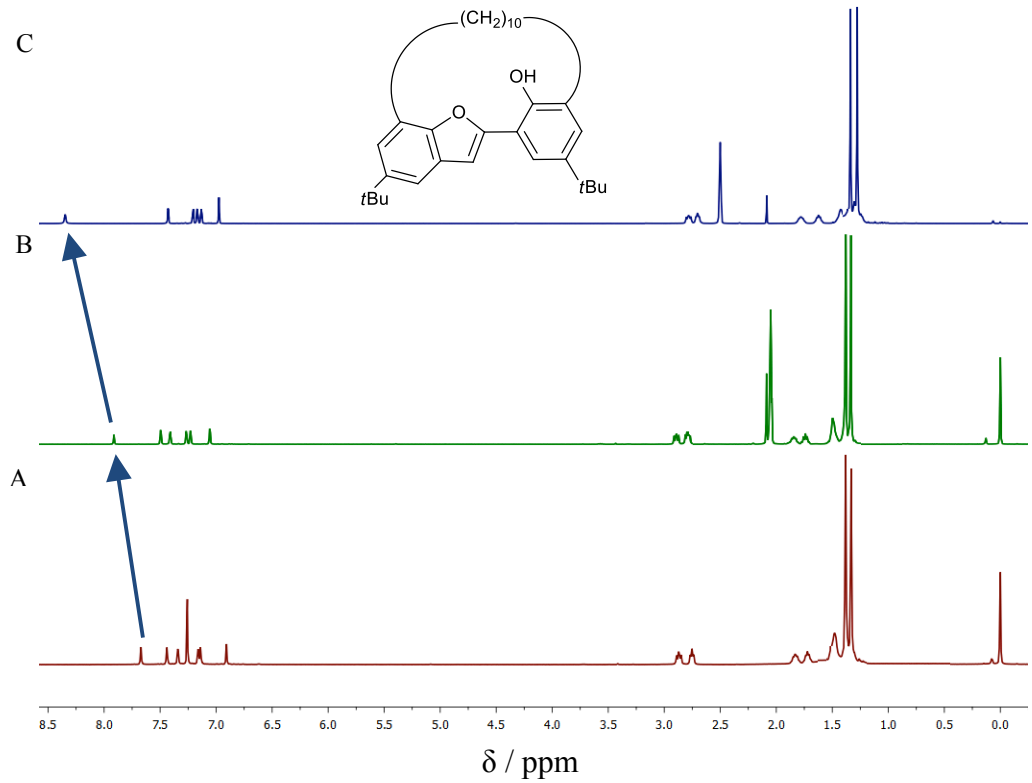
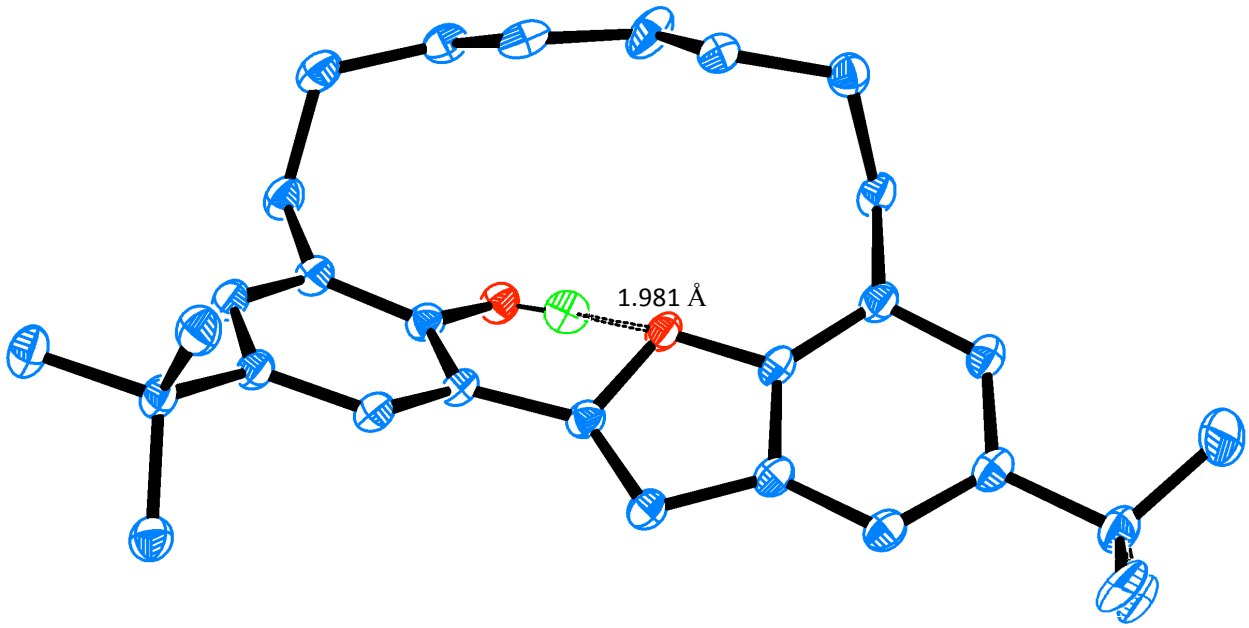
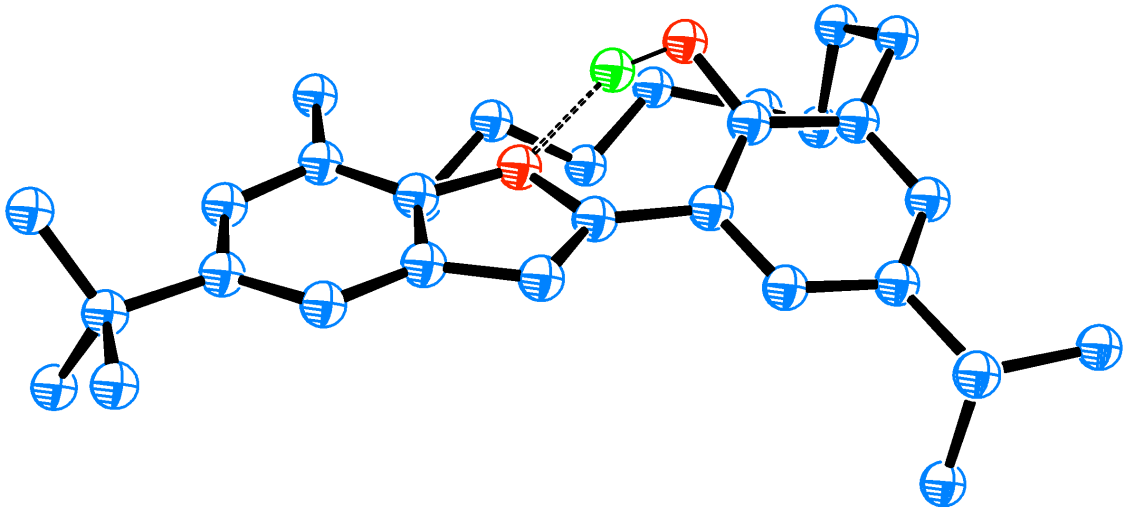


Figure S4-2 ^{1}H–NMR spectra for **2b** (400 MHz, 293 K); (A) $CDCl_3$, (B) $(CD_3)_2CO$, (C) $(CD_3)_2SO$.

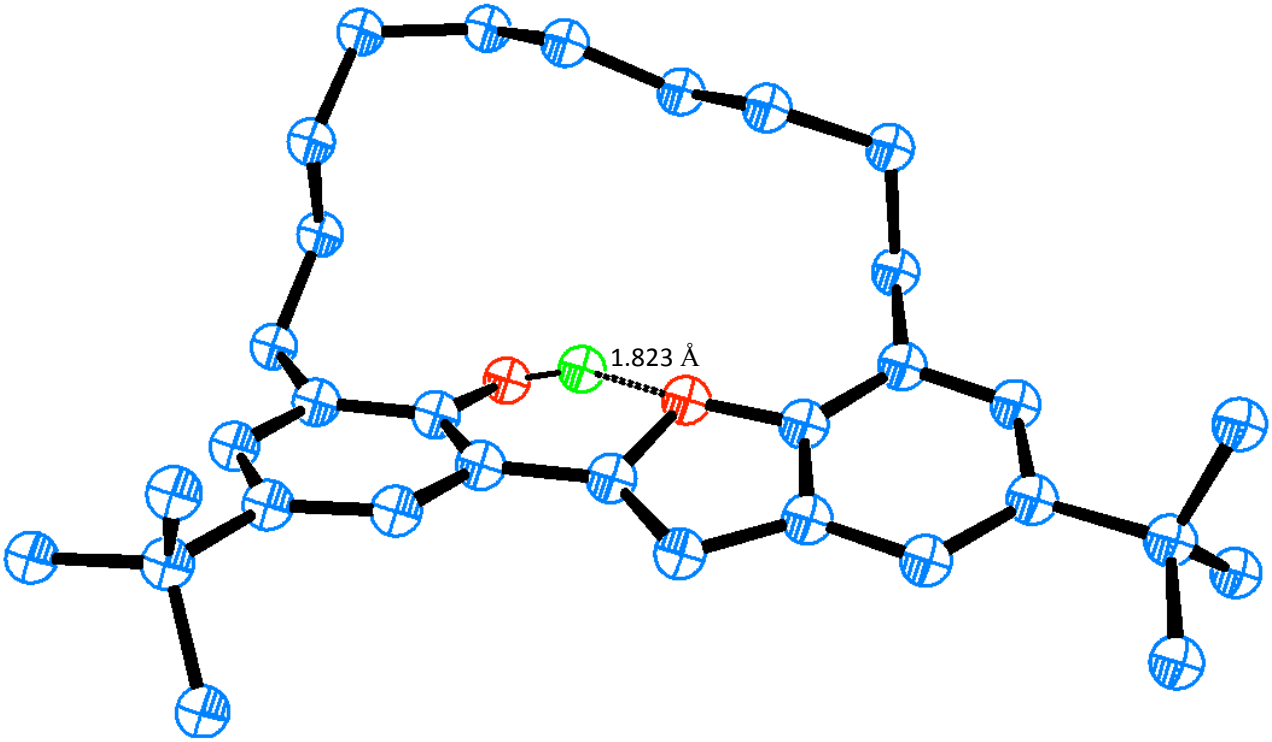


Top view

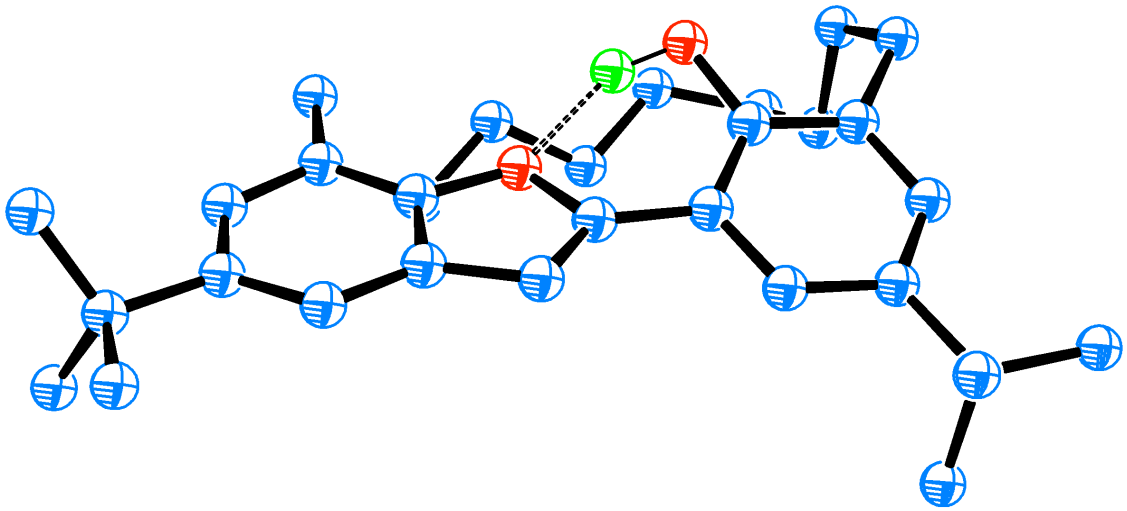


Side view

Figure S5-1 X-ray crystal structure for **2a**.



Top view



Side view

Figure S5-2 X-ray crystal structure for **2b**.

checkCIF/PLATON report

You have not supplied any structure factors. As a result the full set of tests cannot be run.

THIS REPORT IS FOR GUIDANCE ONLY. IF USED AS PART OF A REVIEW PROCEDURE FOR PUBLICATION, IT SHOULD NOT REPLACE THE EXPERTISE OF AN EXPERIENCED CRYSTALLOGRAPHIC REFEREE.

No syntax errors found. CIF dictionary Interpreting this report

Datablock: yt1511a

```
Bond precision:  C-C = 0.0034 A          Wavelength=1.54187

Cell:            a=28.1308(5)     b=18.0592(3)     c=9.95585(18)
                 alpha=90         beta=90          gamma=90
Temperature:     123 K

                Calculated                Reported
Volume          5057.77(15)               5057.77(16)
Space group     P b c a                   P b c a
Hall group      -P 2ac 2ab                -P 2ac 2ab
Moiety formula  C30 H40 O2                C30 H40 O2
Sum formula     C30 H40 O2                C30 H40 O2
Mr              432.62                    432.64
Dx,g cm-3       1.136                     1.136
Z               8                         8
Mu (mm-1)       0.527                     0.528
F000            1888.0                    1888.0
F000'           1892.92
h,k,lmax        33,21,11                  33,21,11
Nref            4616                      4616
Tmin,Tmax       0.904,0.929               0.771,0.929
Tmin'           0.854

Correction method= # Reported T Limits: Tmin=0.771 Tmax=0.929
AbsCorr = MULTI-SCAN

Data completeness= 1.000          Theta(max)= 68.242

R(reflections)= 0.0628( 3514)     wR2(reflections)= 0.1691( 4616)

S = 1.039                 Npar= 326
```

The following ALERTS were generated. Each ALERT has the format
test-name_ALERT_alert-type_alert-level.
Click on the hyperlinks for more details of the test.

Alert level B

```
DIFMX01_ALERT_2_B  The maximum difference density is > 0.1*ZMAX*1.00
           _refine_diff_density_max given =      0.830
           Test value =      0.800
PLAT097_ALERT_2_B Large Reported Max.  (Positive) Residual Density       0.83 eA-3
```

Alert level C

```
DIFMX02_ALERT_1_C  The maximum difference density is > 0.1*ZMAX*0.75
           The relevant atom site should be identified.
PLAT094_ALERT_2_C Ratio of Maximum / Minimum Residual Density ....       2.68 Report
PLAT213_ALERT_2_C Atom C12            has ADP max/min Ratio .....        3.5 prolat
PLAT220_ALERT_2_C Large Non-Solvent  C     Ueq(max)/Ueq(min) Range       4.0 Ratio
PLAT241_ALERT_2_C High      Ueq as Compared to Neighbors for .....       C26 Check
PLAT242_ALERT_2_C Low       Ueq as Compared to Neighbors for .....        C9 Check
```

Alert level G

```
CHEMS02_ALERT_1_G  Please check that you have entered the correct
           _publ_requested_category classification of your compound;
           FI or CI or EI for inorganic; FM or CM or EM for metal-organic;
           FO or CO or EO for organic.
           From the CIF: _publ_requested_category   CHOOSE FI FM FO CI CM CO or
           From the CIF: _chemical_formula_sum:C30 H40 O2
PLAT005_ALERT_5_G No _iucr_refine_instructions_details  in the CIF     Please Do !
PLAT007_ALERT_5_G Number of Unrefined Donor-H Atoms ..............         1 Report
PLAT300_ALERT_4_G Atom Site Occupancy of *C23    is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *C24    is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *C25    is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *C123   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *C124   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *C125   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12D   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12E   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12F   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12G   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12H   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12I   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12J   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H12K   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H23A   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H23B   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H24A   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H24B   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H25A   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H25B   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H26A   is Constrained at      0.500 Check
PLAT300_ALERT_4_G Atom Site Occupancy of *H26B   is Constrained at      0.500 Check
PLAT301_ALERT_3_G Main Residue  Disorder ..... Percentage =          9 Note
PLAT779_ALERT_4_G Suspect or Irrelevant (Bond) Angle in CIF .... #        119 Check
             H24A -C24  -H12I    1.555   1.555   1.555            20.25 Deg.
PLAT779_ALERT_4_G Suspect or Irrelevant (Bond) Angle in CIF .... #        169 Check
             C24  -H12I -H24A    1.555   1.555   1.555            39.59 Deg.
```

```
   0 ALERT level A = Most likely a serious problem - resolve or explain
   2 ALERT level B = A potentially serious problem, consider carefully
   6 ALERT level C = Check. Ensure it is not caused by an omission or oversight
  28 ALERT level G = General information/check it is not something unexpected

   2 ALERT type 1 CIF construction/syntax error, inconsistent or missing data
```

```
  7 ALERT type 2 Indicator that the structure model may be wrong or deficient
  1 ALERT type 3 Indicator that the structure quality may be low
 24 ALERT type 4 Improvement, methodology, query or suggestion
  2 ALERT type 5 Informative message, check
```

It is advisable to attempt to resolve as many as possible of the alerts in all categories. Often the minor alerts point to easily fixed oversights, errors and omissions in your CIF or refinement strategy, so attention to these fine details can be worthwhile. In order to resolve some of the more serious problems it may be necessary to carry out additional measurements or structure refinements. However, the purpose of your study may justify the reported deviations and the more serious of these should normally be commented upon in the discussion or experimental section of a paper or in the "special_details" fields of the CIF. checkCIF was carefully designed to identify outliers and unusual parameters, but every test has its limitations and alerts that are not important in a particular case may appear. Conversely, the absence of alerts does not guarantee there are no aspects of the results needing attention. It is up to the individual to critically assess their own results and, if necessary, seek expert advice.

Publication of your CIF in IUCr journals

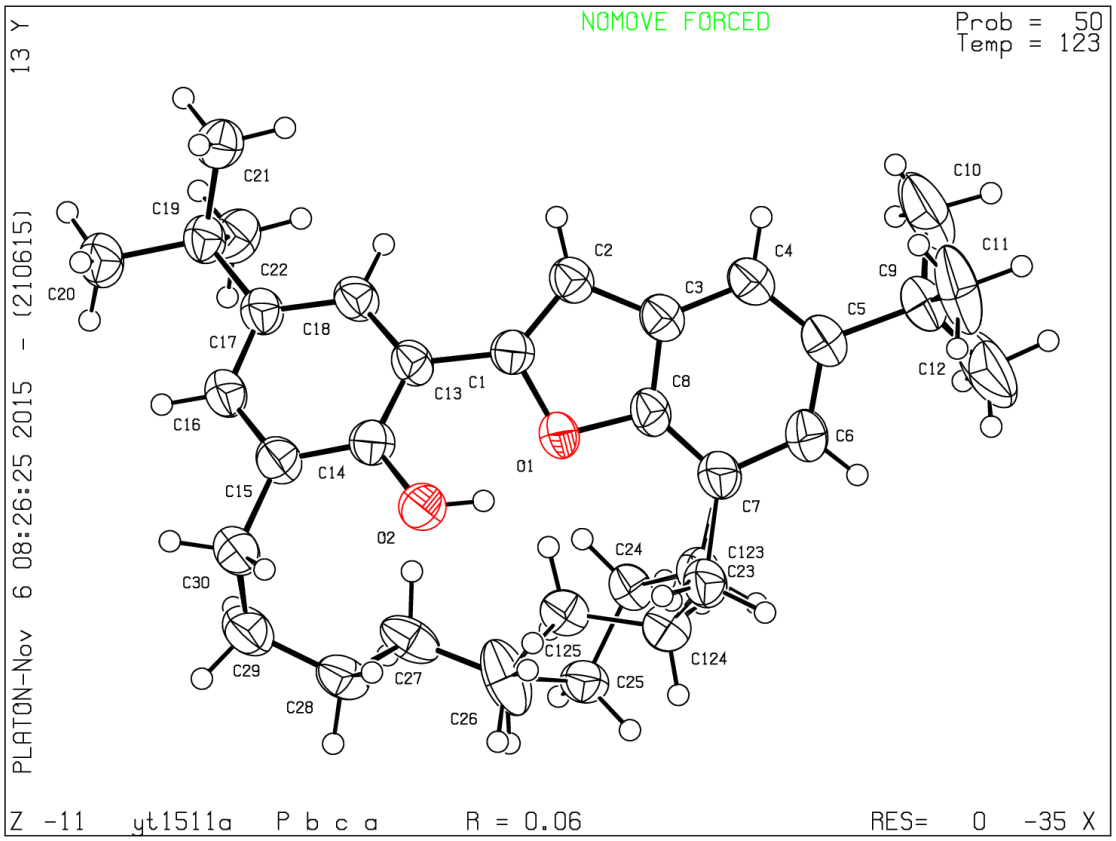
A basic structural check has been run on your CIF. These basic checks will be run on all CIFs submitted for publication in IUCr journals (*Acta Crystallographica, Journal of Applied Crystallography, Journal of Synchrotron Radiation*); however, if you intend to submit to *Acta Crystallographica Section C* or *E*, you should make sure that full publication checks are run on the final version of your CIF prior to submission.

Publication of your CIF in other journals

Please refer to the *Notes for Authors* of the relevant journal for any special instructions relating to CIF submission.

PLATON version of 21/06/2015; check.def file version of 21/06/2015

Datablock yt1511a - ellipsoid plot



checkCIF/PLATON report

Structure factors have been supplied for datablock(s) y0602

THIS REPORT IS FOR GUIDANCE ONLY. IF USED AS PART OF A REVIEW PROCEDURE FOR PUBLICATION, IT SHOULD NOT REPLACE THE EXPERTISE OF AN EXPERIENCED CRYSTALLOGRAPHIC REFEREE.

No syntax errors found. CIF dictionary Interpreting this report

Datablock: y0602

```
Bond precision:  C-C = 0.0089 A          Wavelength=0.71073

Cell:           a=14.6104(12)    b=21.5562(19)       c=9.0564(4)
                alpha=90         beta=100.897(4)     gamma=90
Temperature:    100 K

                Calculated                Reported
Volume          2800.8(4)                 2800.8(4)
Space group     C c                       C c
Hall group      C -2yc                    ?
Moiety formula  C32 H44 O2                ?
Sum formula     C32 H44 O2                C32 H44 O2
Mr              460.67                    460.67
Dx,g cm-3       1.092                     1.092
Z               4                         4
Mu (mm-1)       0.066                     0.066
F000            1008.0                    1008.0
F000'           1008.39
h,k,lmax        17,26,11                  17,26,11
Nref            5313[ 2663]               2512
Tmin,Tmax       0.991,0.995
Tmin'           0.991

Correction method= Not given

Data completeness= 0.94/0.47      Theta(max)= 25.680

R(reflections)= 0.0822( 2235)     wR2(reflections)= 0.2290( 2512)

S = 0.963                 Npar= 314
```

The following ALERTS were generated. Each ALERT has the format
test-name_ALERT_alert-type_alert-level.
Click on the hyperlinks for more details of the test.

Alert level B

PLAT029_ALERT_3_B _diffrn_measured_fraction_theta_full Low .... 0.943 Note

---

Alert level C

DIFMX01_ALERT_2_C The maximum difference density is > 0.1*ZMAX*0.75
_refine_diff_density_max given = 0.734
Test value = 0.600
DIFMX02_ALERT_1_C The maximum difference density is > 0.1*ZMAX*0.75
The relevant atom site should be identified.
STRVA01_ALERT_4_C Flack test results are meaningless.
From the CIF: _refine_ls_abs_structure_Flack 0.000
From the CIF: _refine_ls_abs_structure_Flack_su 3.000
PLAT094_ALERT_2_C Ratio of Maximum / Minimum Residual Density .... 3.50 Report
PLAT097_ALERT_2_C Large Reported Max. (Positive) Residual Density 0.73 eA-3
PLAT230_ALERT_2_C Hirshfeld Test Diff for C30 -- C31 .. 5.4 su
PLAT230_ALERT_2_C Hirshfeld Test Diff for C31 -- C32 .. 5.2 su
PLAT234_ALERT_4_C Large Hirshfeld Difference C19 -- C22 .. 0.16 Ang.
PLAT241_ALERT_2_C High Ueq as Compared to Neighbors for ..... C31 Check
PLAT242_ALERT_2_C Low Ueq as Compared to Neighbors for ..... C19 Check
PLAT242_ALERT_2_C Low Ueq as Compared to Neighbors for ..... C30 Check
PLAT340_ALERT_3_C Low Bond Precision on C-C Bonds ..... 0.0089 Ang.

Alert level G

PLAT002_ALERT_2_G Number of Distance or Angle Restraints on AtSite 7 Note
PLAT003_ALERT_2_G Number of Uiso or Uij Restrained non-H Atoms ... 5 Report
PLAT005_ALERT_5_G No _iucr_refine_instructions_details in the CIF Please Do !
PLAT007_ALERT_5_G Number of Unrefined Donor-H Atoms ..... 1 Report
PLAT032_ALERT_4_G Std. Uncertainty on Flack Parameter Value High . 3.000 Report
PLAT072_ALERT_2_G SHELXL First Parameter in WGHT Unusually Large. 0.18 Report
PLAT850_ALERT_4_G Check Flack Parameter Exact Value 0.00 and su .. 3.00 Check
PLAT860_ALERT_3_G Number of Least-Squares Restraints ..... 39 Note
PLAT899_ALERT_4_G SHELXL97 is Deprecated and Succeeded by SHELXL 2014 Note

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Publication of your CIF in IUCr journals

A basic structural check has been run on your CIF. These basic checks will be run on all CIFs submitted for publication in IUCr journals (*Acta Crystallographica, Journal of Applied Crystallography, Journal of Synchrotron Radiation*); however, if you intend to submit to *Acta Crystallographica Section C* or *E*, you should make sure that full publication checks are run on the final version of your CIF prior to submission.

Publication of your CIF in other journals

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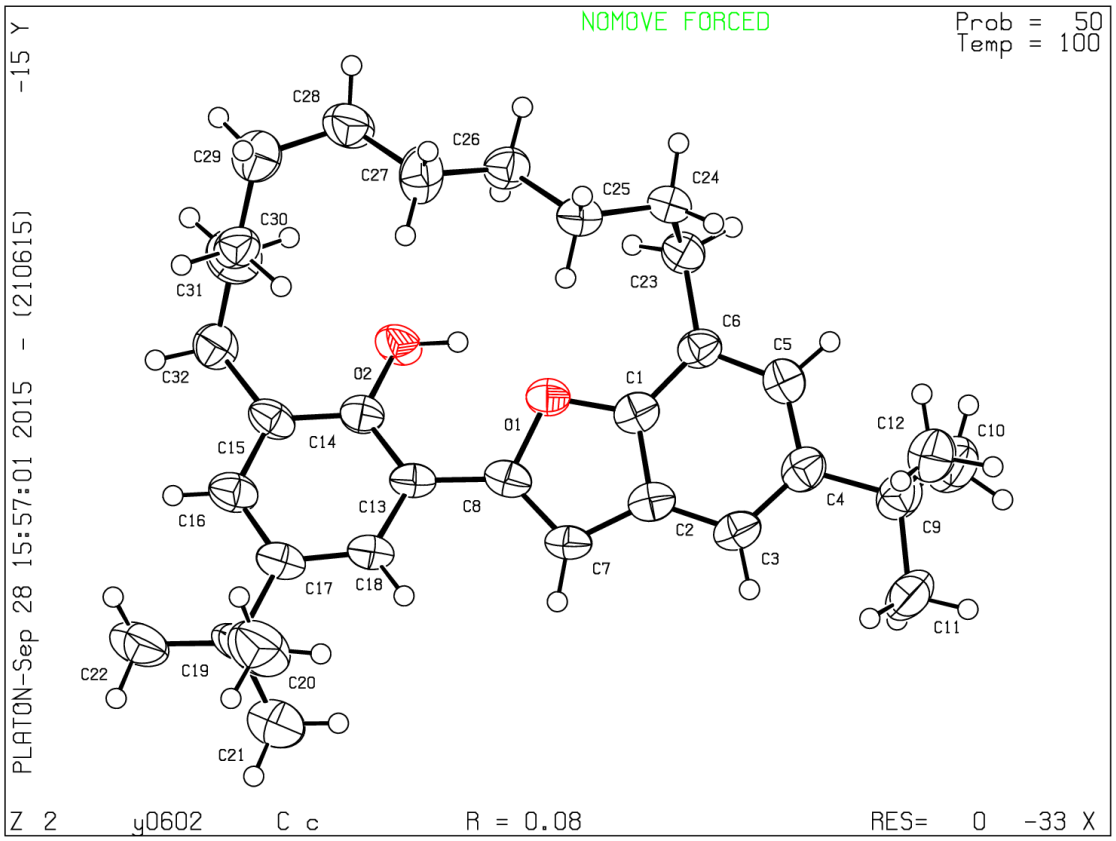
PLATON version of 21/06/2015; check.def file version of 21/06/2015

Datablock y0602 - ellipsoid plot



Supporting Information for

Demethylation of 5,*n*-di-*tert*-butyl-8,*n*-dimethoxy[2.*n*] metacyclophane- 1-ynes with BBr_3 to afford novel [*n*]benzofuranophanes

Thamina Akther [a], Md. Monarul Islam[a,b], Taisuke Matsumoto[c], Junji Tanaka[c], Xing Feng [d], Carl Redshaw[e] and Takehiko Yamato[a,*]

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[c]*Institute of Material Chemistry and Engineering, Kyushu University, 6-1, Kasugakoen, Kasuga 816-8580, Japan*

[d] *Beijing Institute of Graphic Communication, Beijing 102600, PR China*

[e]*Department of Chemistry, The University of Hull, Cottingham Road, Hull, Yorkshire, HU6 7RX, UK*

Corresponding author:
Prof. Dr. Takehiko Yamato
Phone: +81 952 28 8679; fax: +81 952 28 8548.
E-mail address: yamatot@cc.saga-u.ac.jp

Table Contents

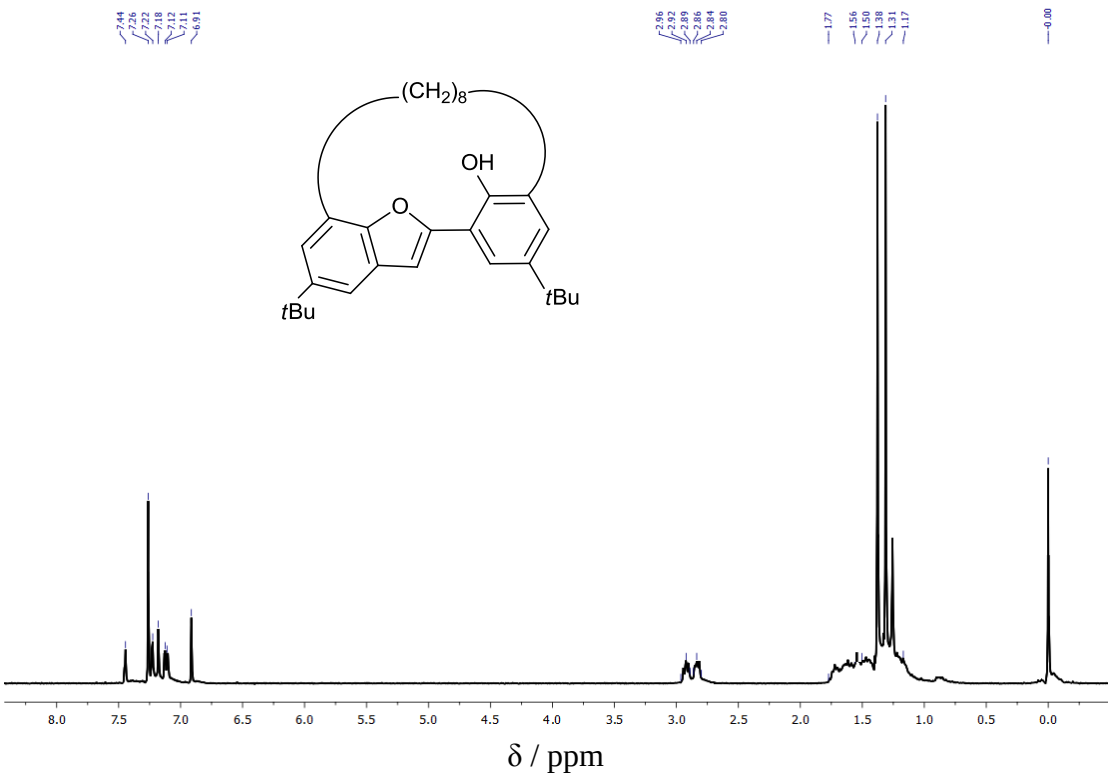


Figure S1-1 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **2a**.

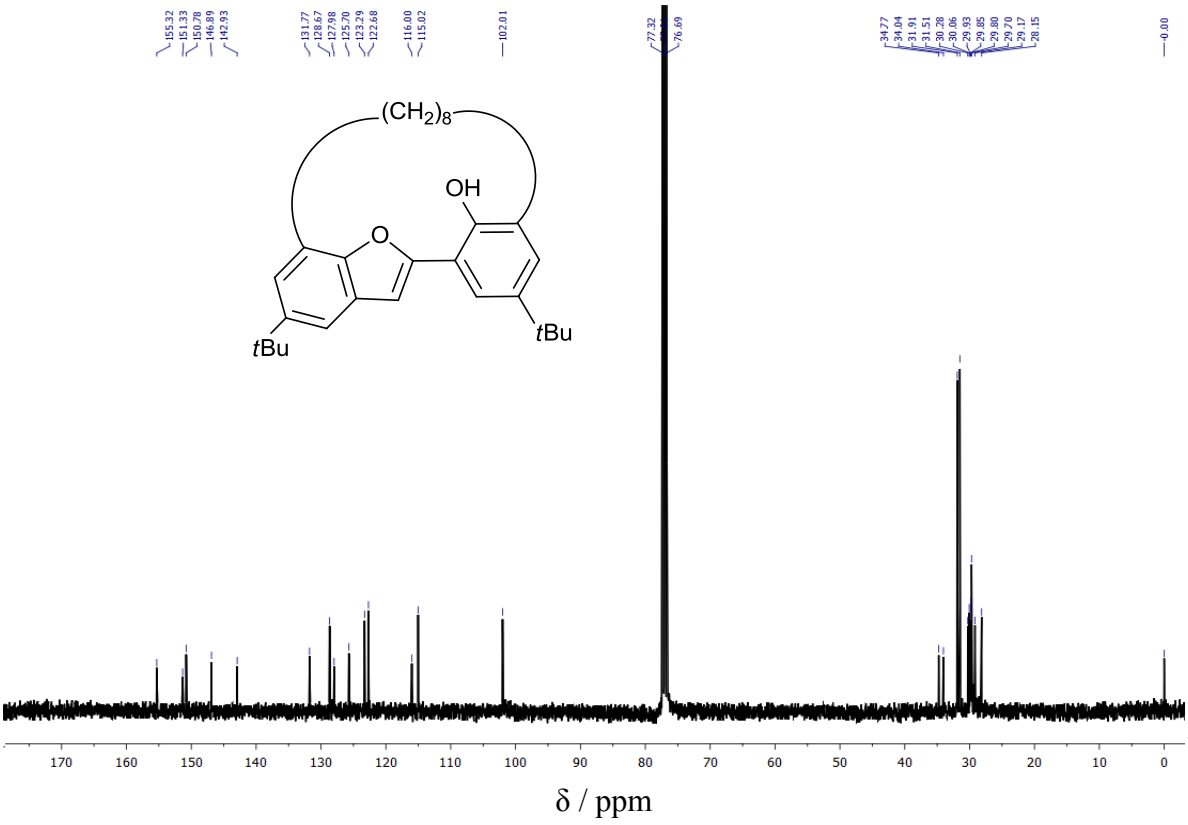


Figure S1-2 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **2a**.

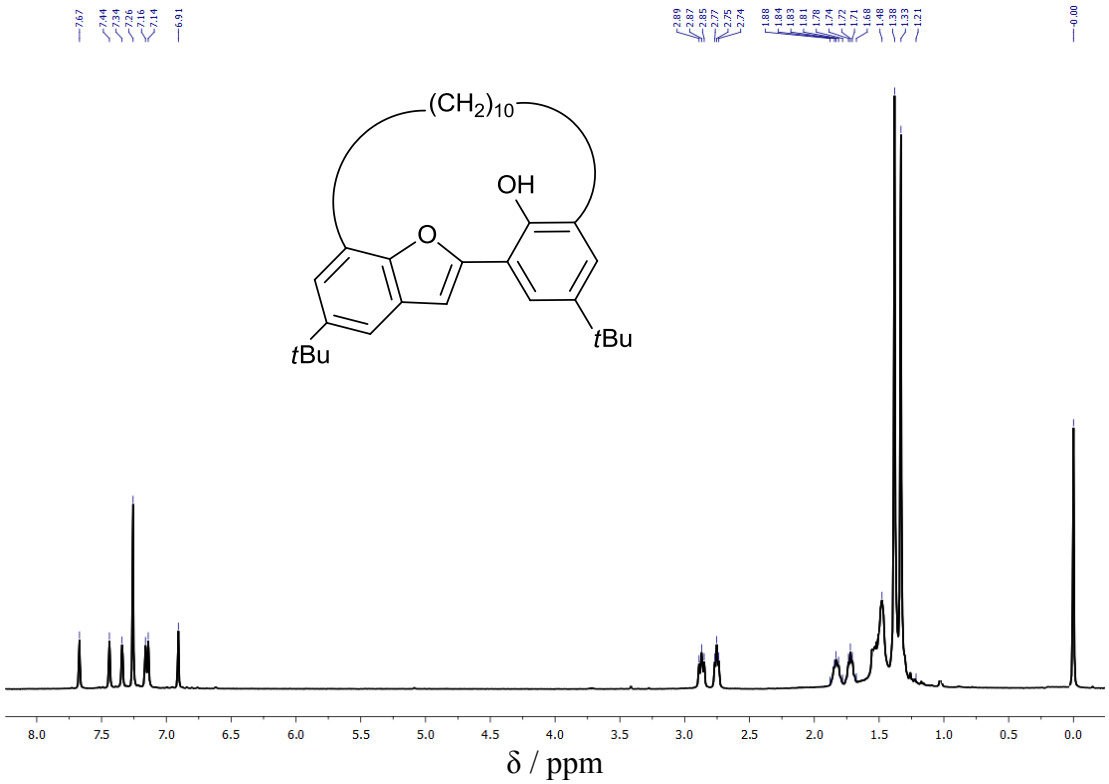


Figure S1-3 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **2b**.

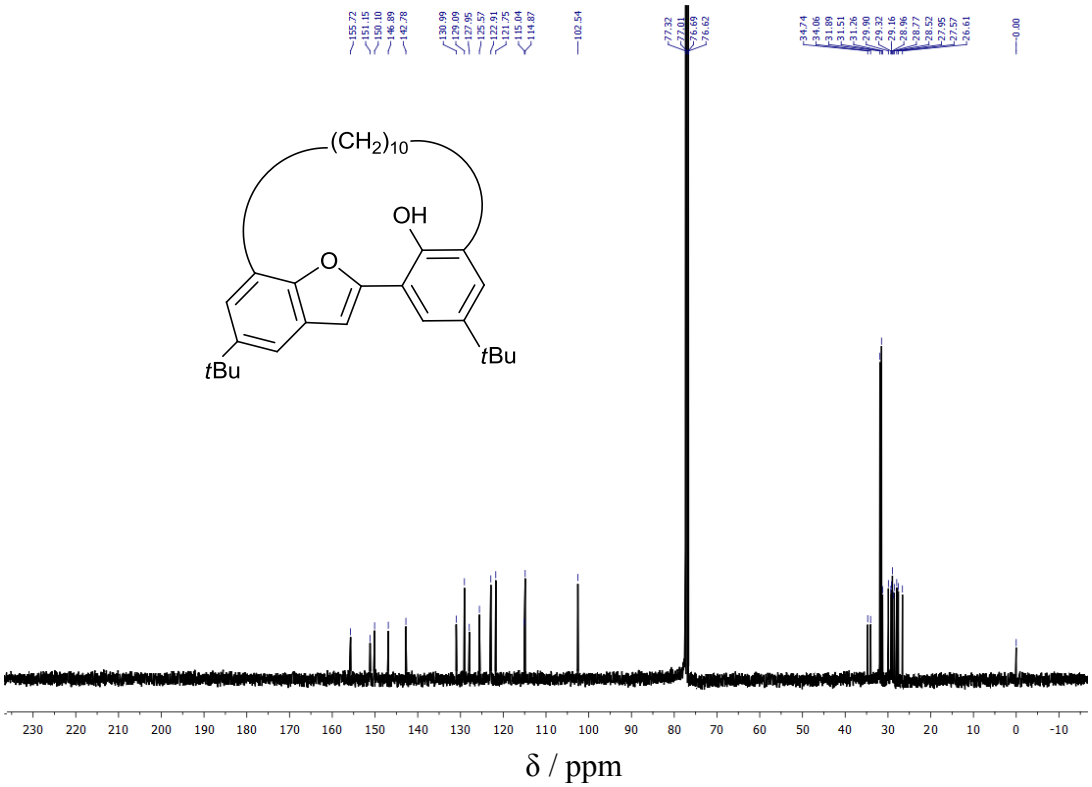


Figure S1-4 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **2b**.

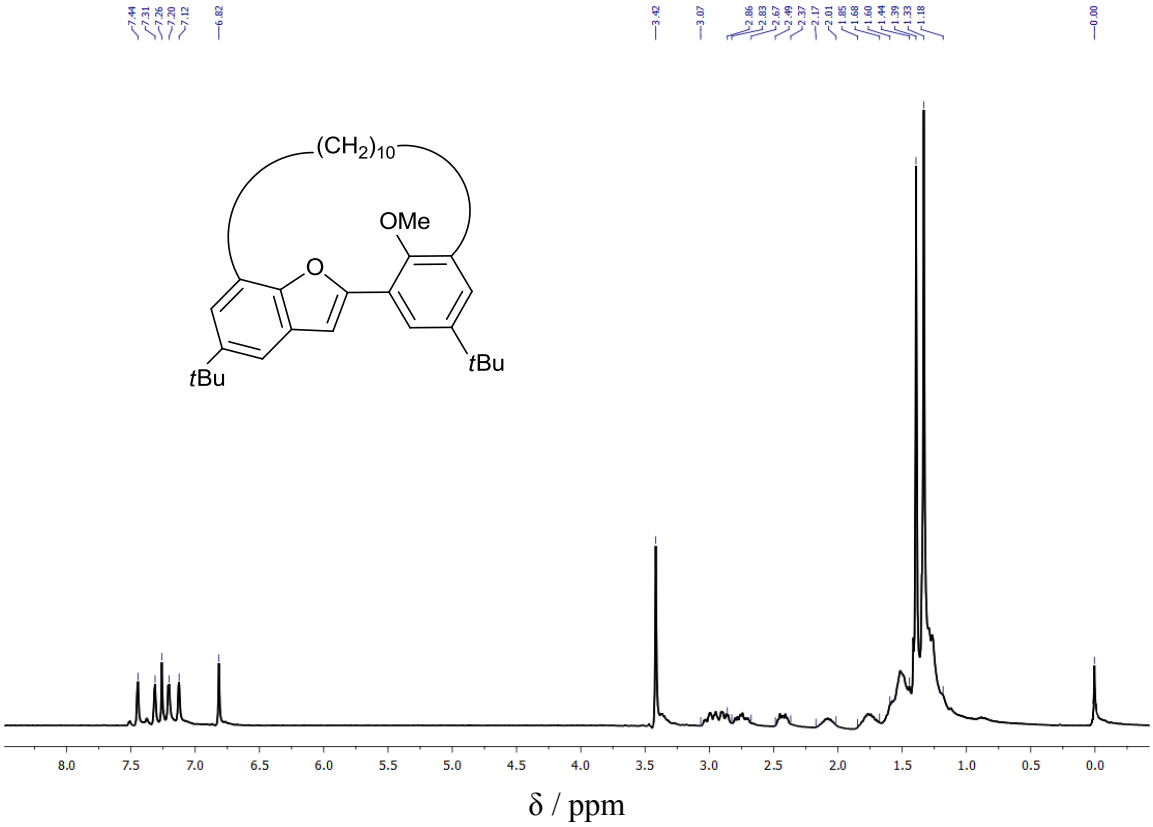


Figure S1-5 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **6b.**

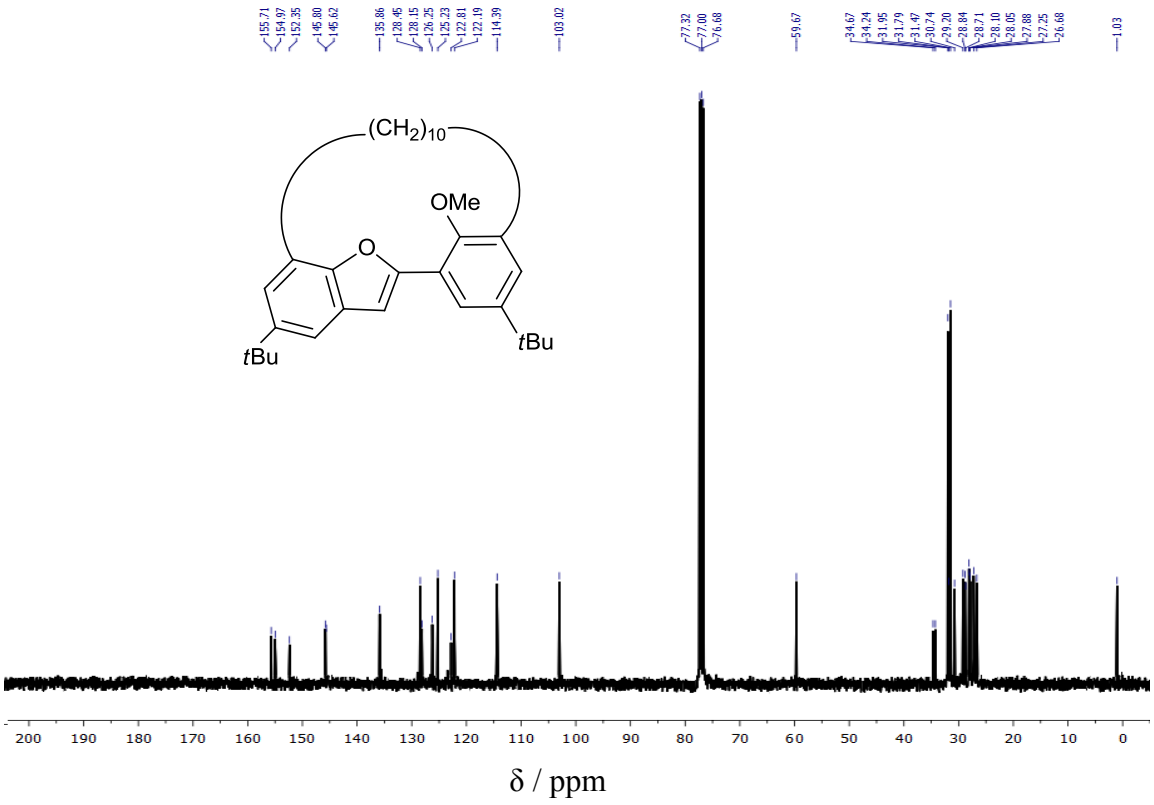


Figure S1-6 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **6b.**

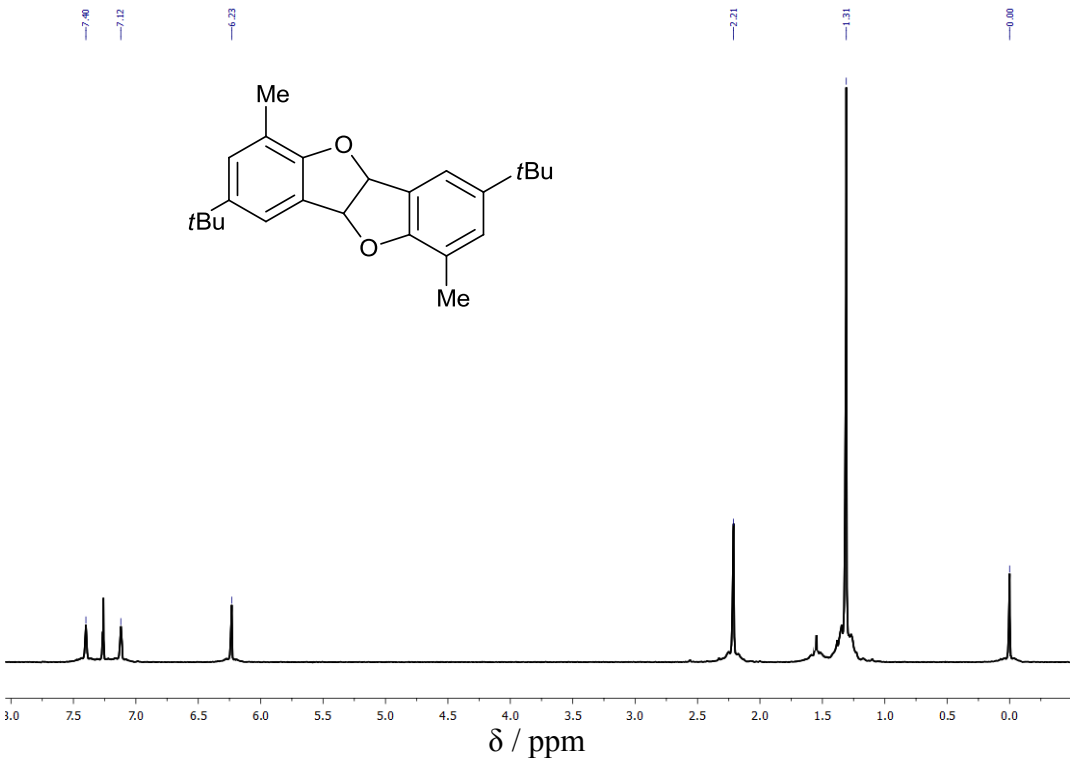


Figure S1-7 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **8**.

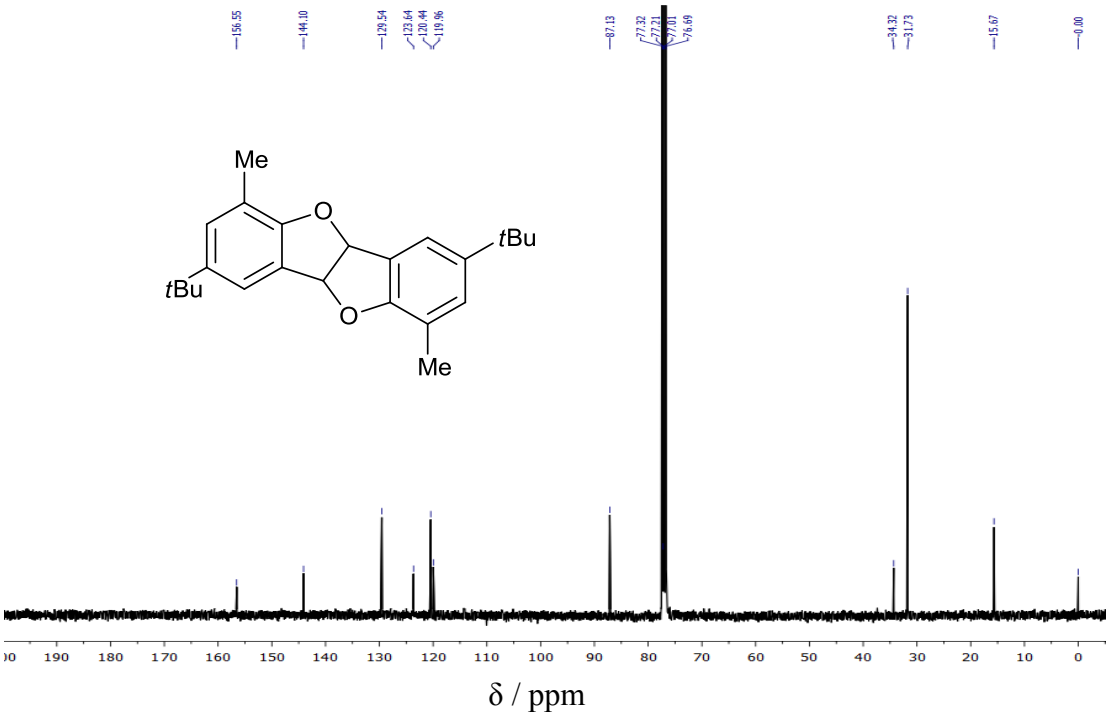


Figure S1-8 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **8**.

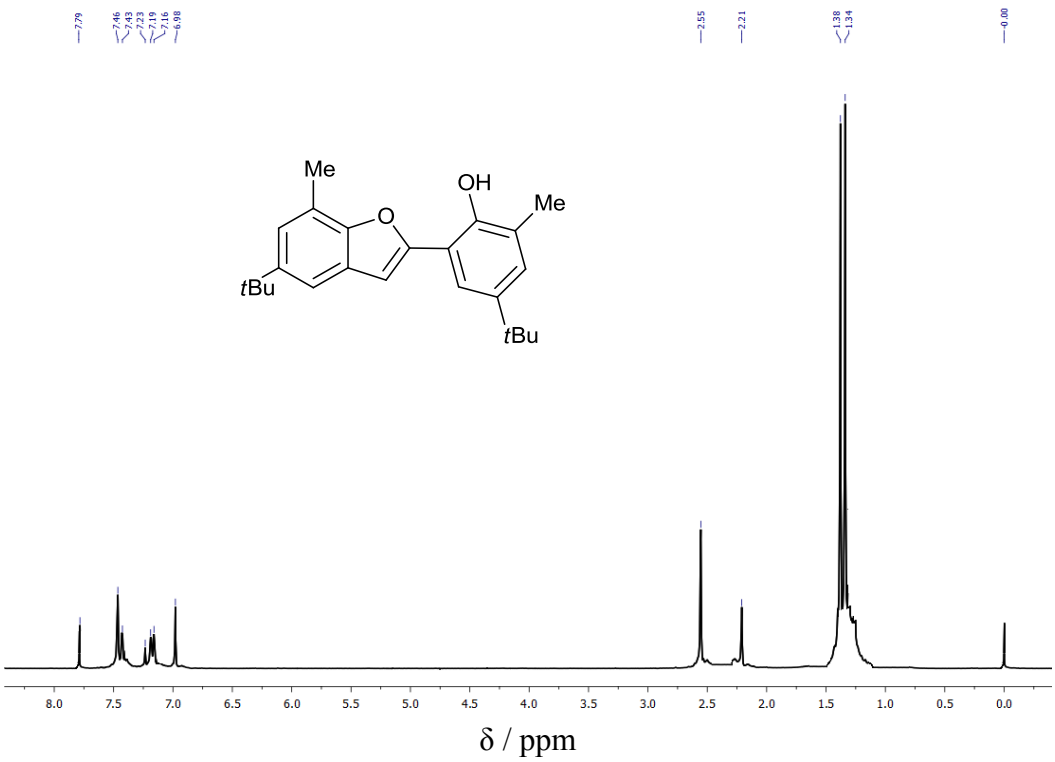


Figure S1-9 ^{1}H–NMR spectrum (300 MHz, 298 K, * $CDCl_3$) for **9**.

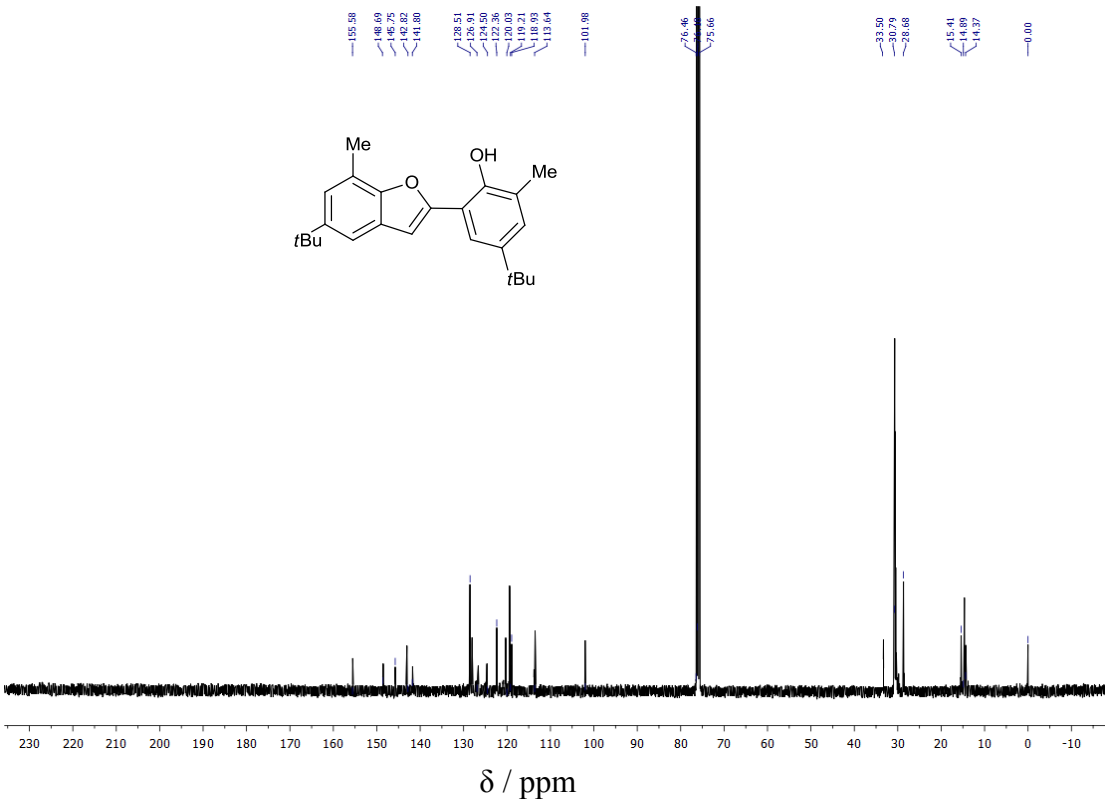


Figure S1-10 ^{13}C–NMR spectrum (100 MHz, 298 K, * $CDCl_3$) for **9**.

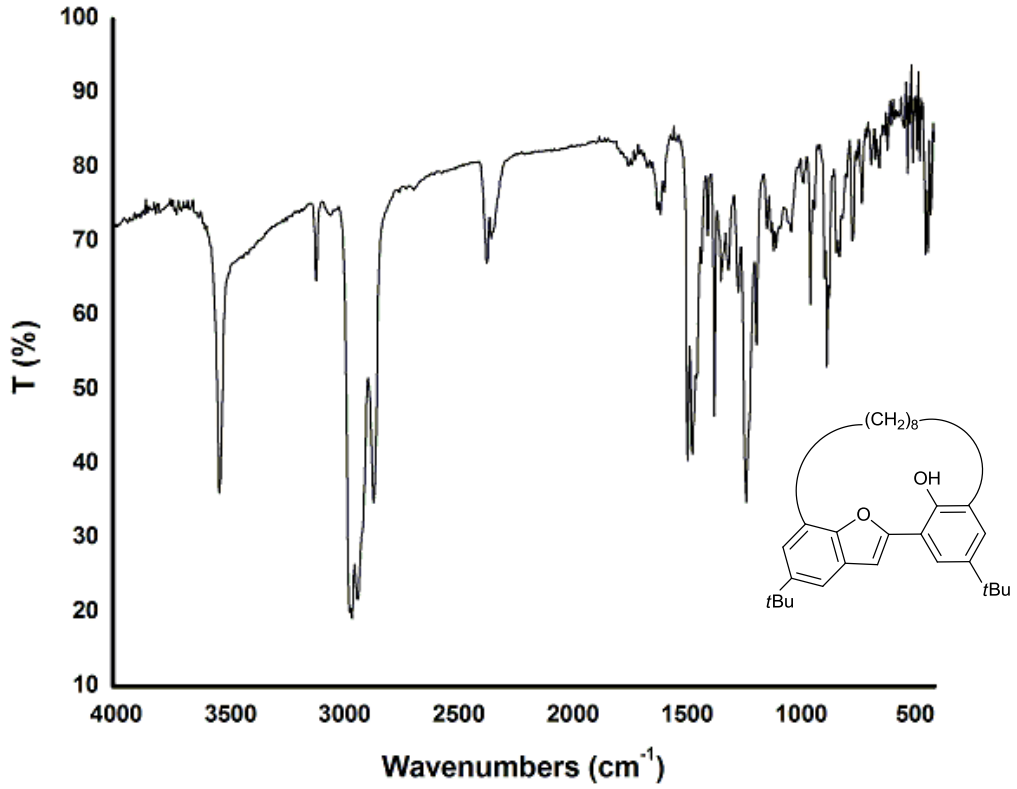


Figure S2-1 FT-IR spectrum for **2a**.

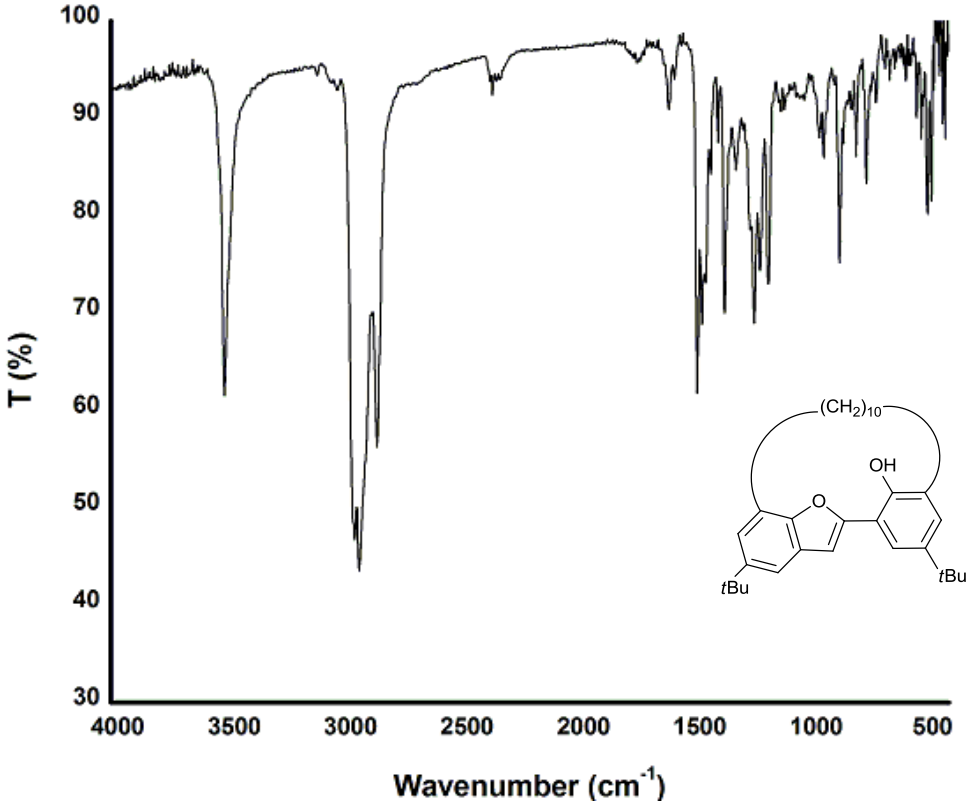


Figure S2-2 FT-IR spectrum for **2b**.

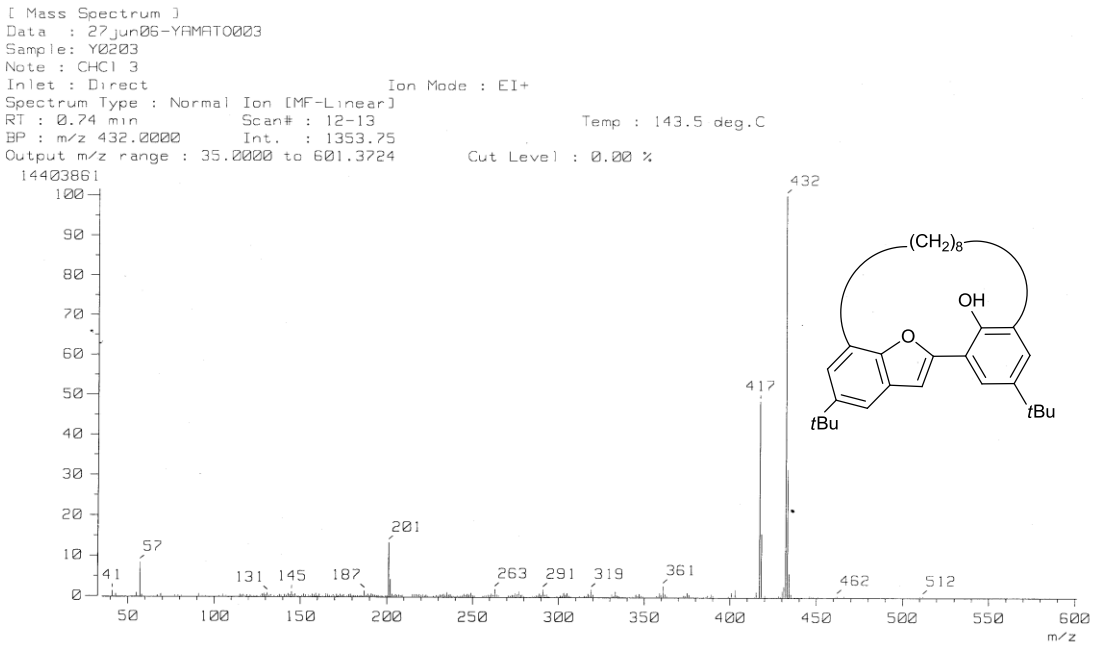


Figure S3-1 Mass spectrum for **2a**.

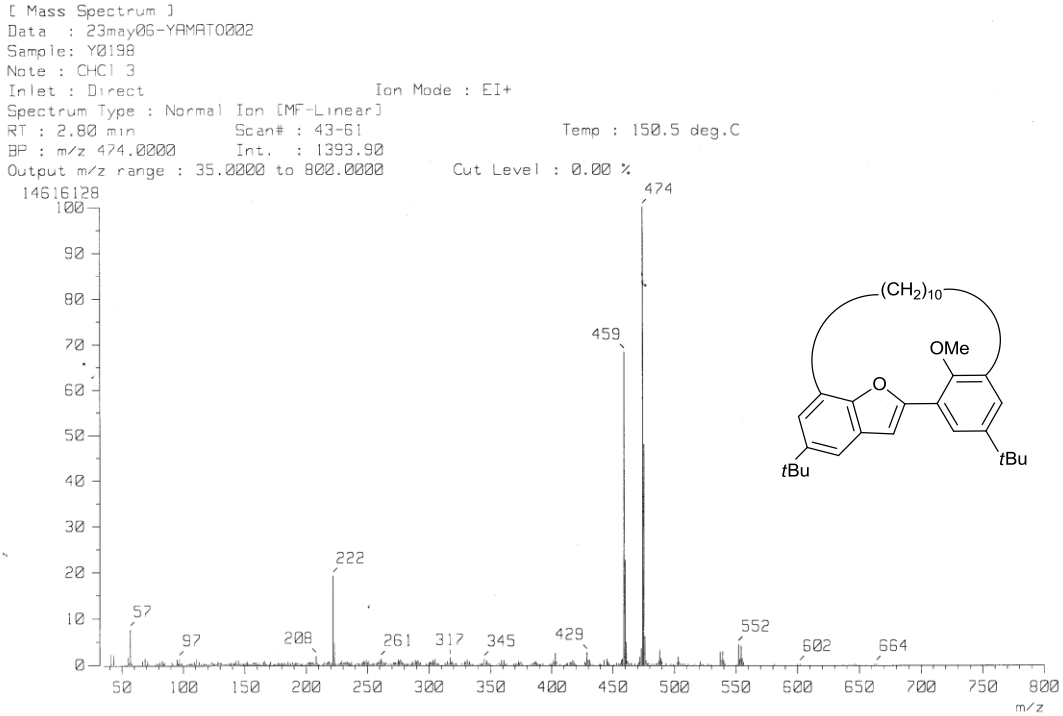


Figure S3-2 Mass spectrum for **6b**.

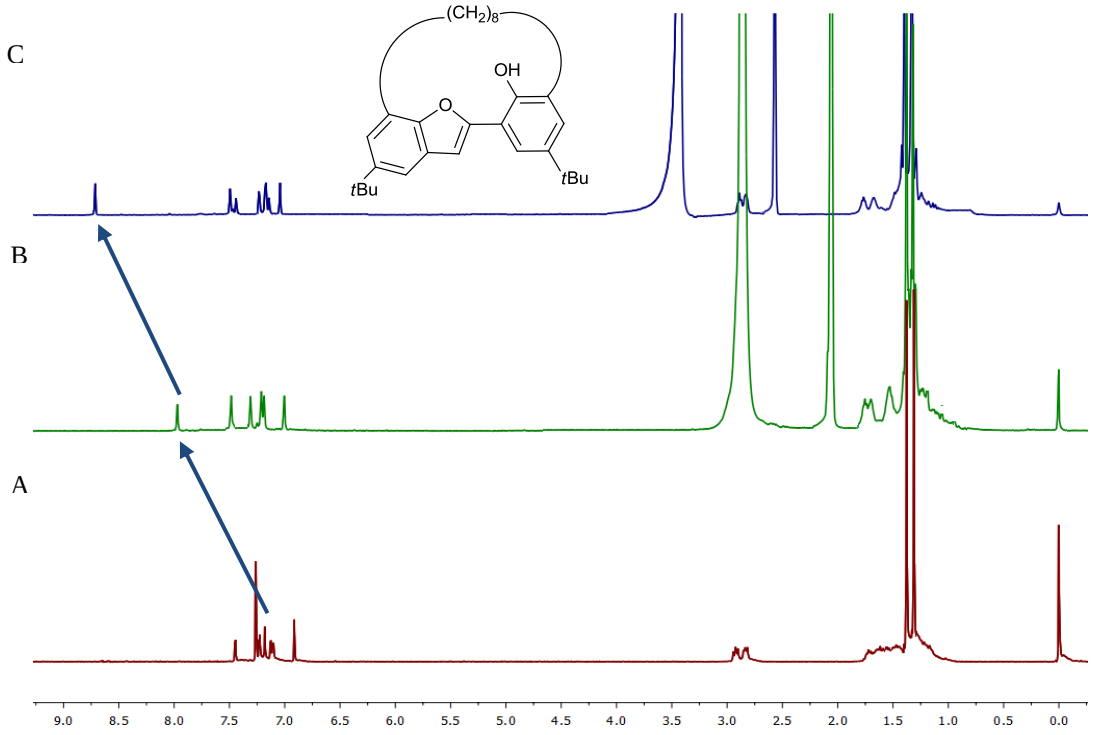


Figure S4-1 ^{1}H–NMR spectra for **2a** (400 MHz, 293 K); (A) $CDCl_3$, (B) $(CD_3)_2CO$, (C) $(CD_3)_2SO$.

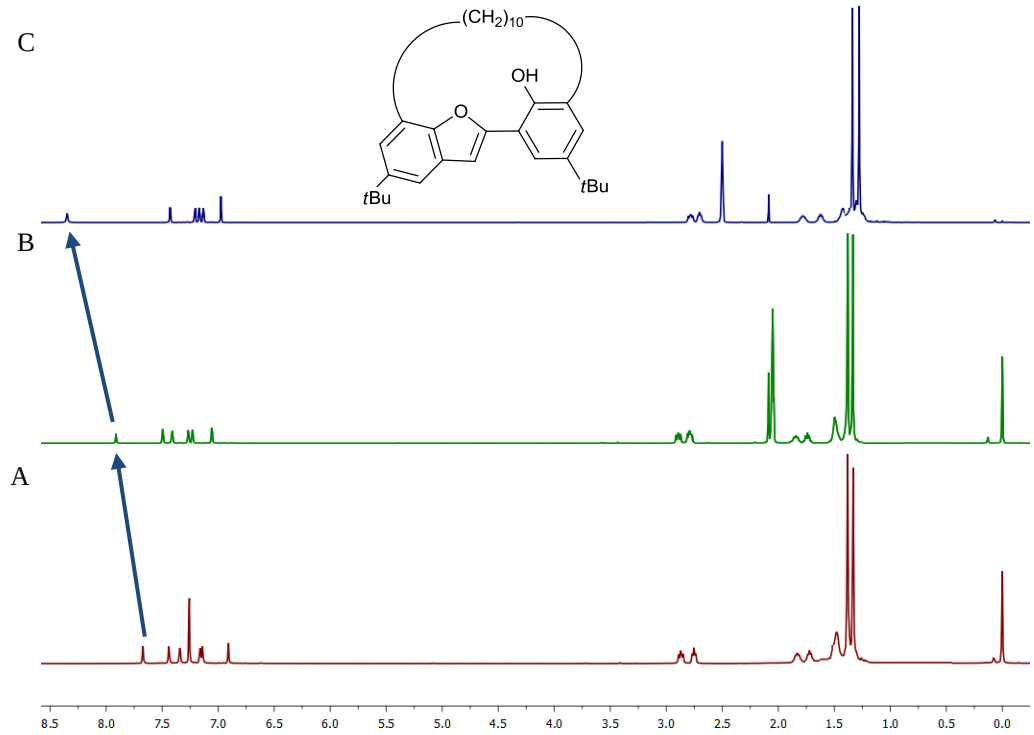
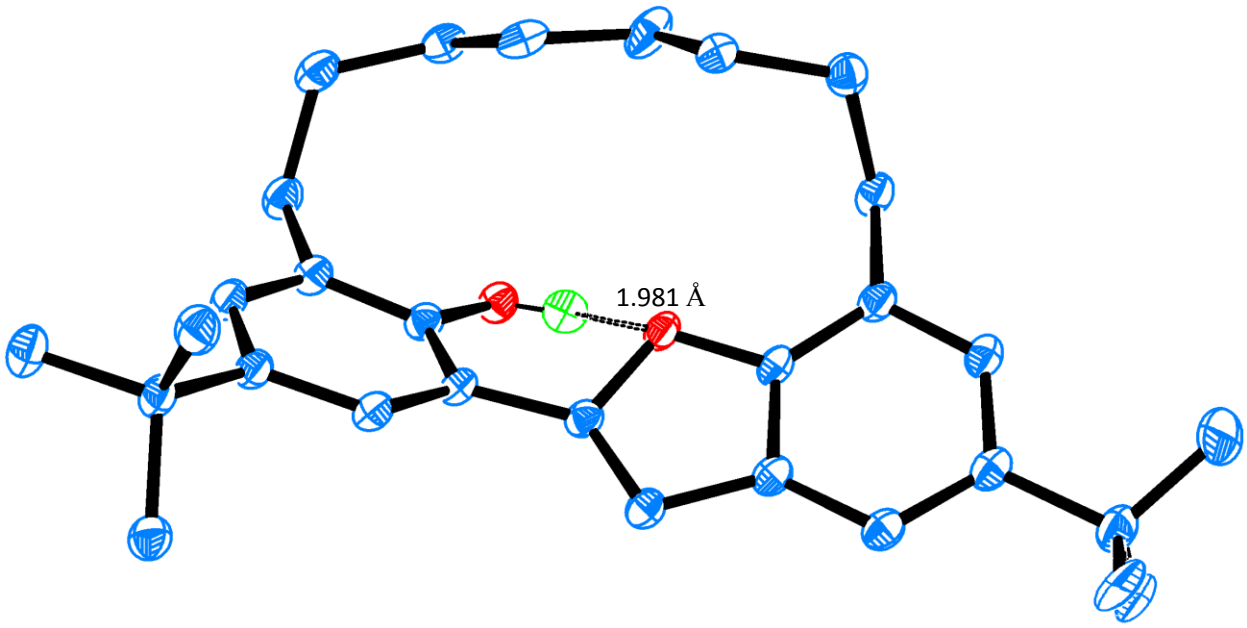
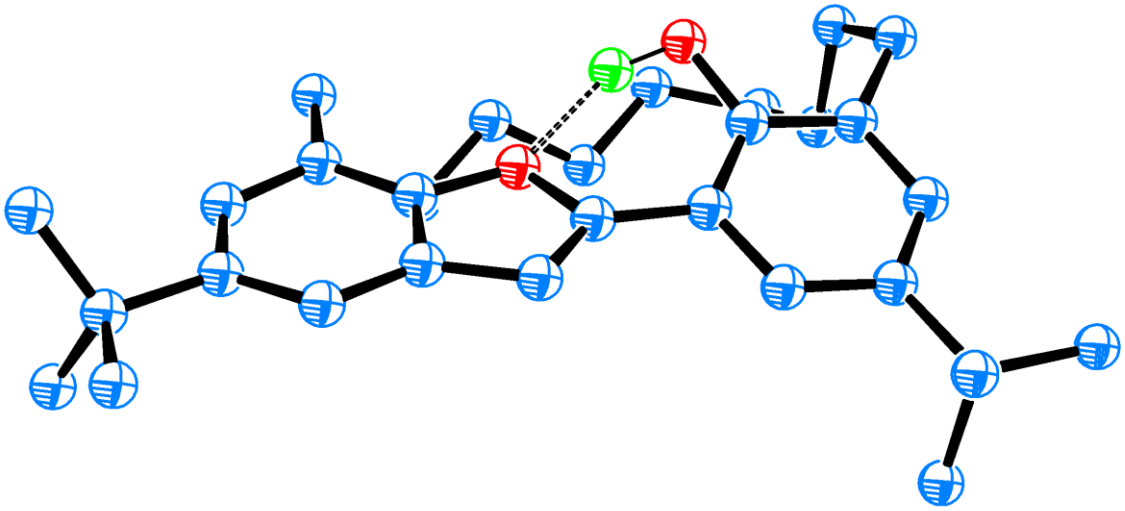


Figure S4-2 ^{1}H–NMR spectra for **2b** (400 MHz, 293 K); (A) $CDCl_3$, (B) $(CD_3)_2CO$, (C) $(CD_3)_2SO$.

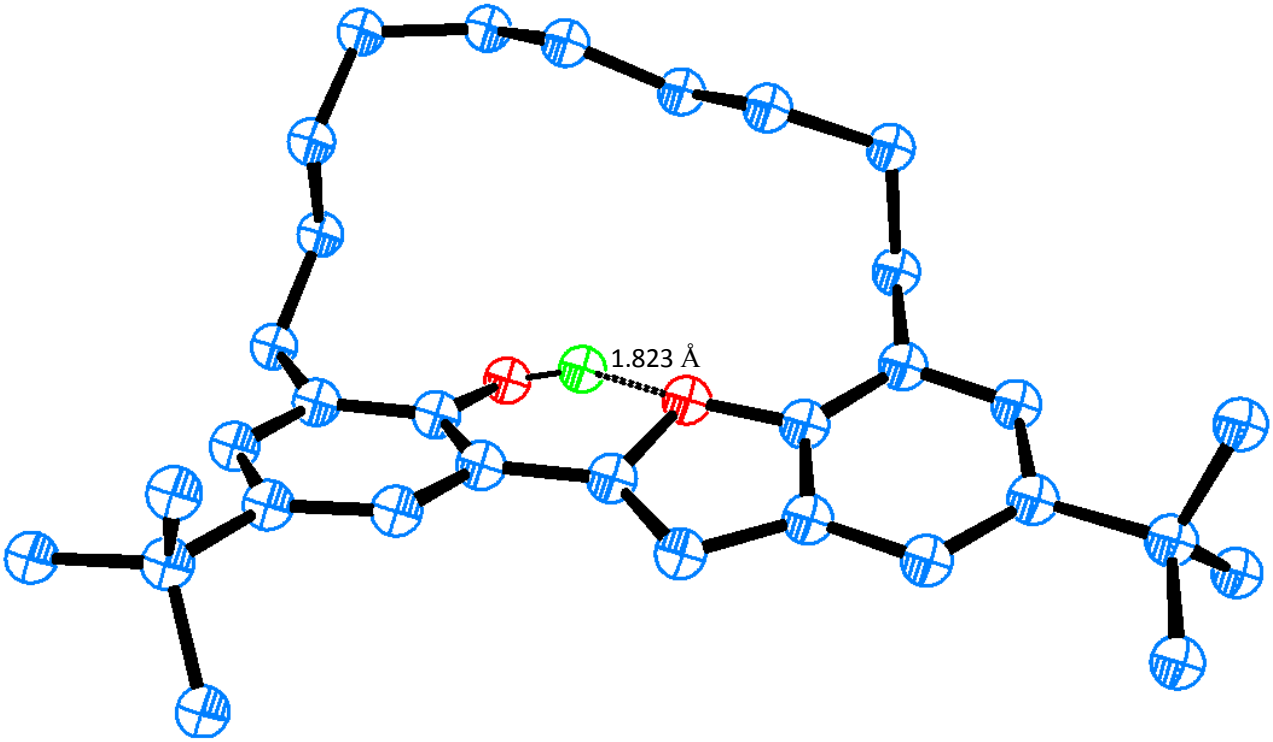


Top view

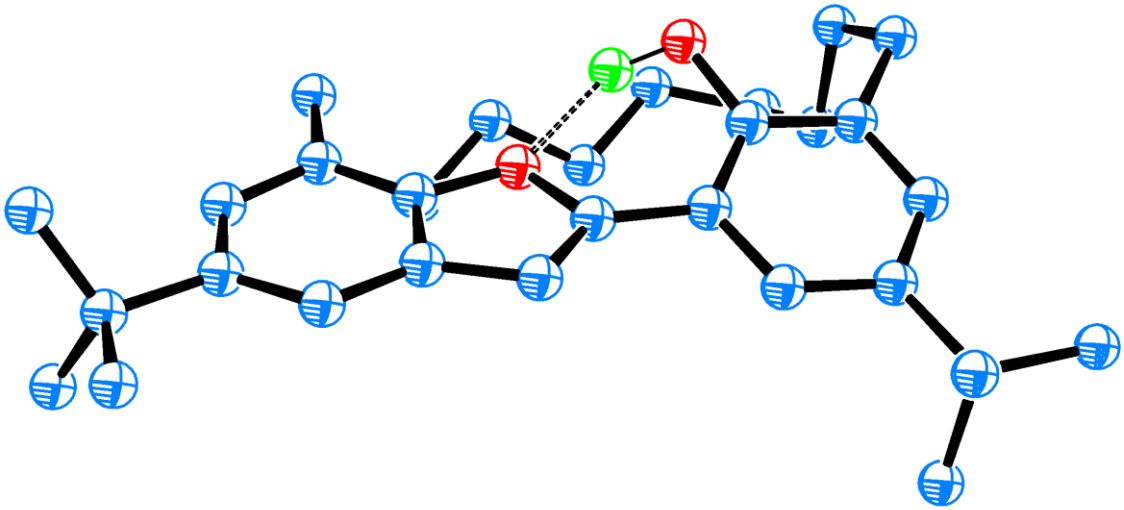


Side view

Figure S5-1 X-ray crystal structure for **2a**.



Top view



Side view

Figure S5-2 X-ray crystal structure for **2b**.