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Preparation of Sterically Congested Compounds: 6,7-Di-*t*-butyl-1,4-naphthoquinone, 2,3,6,7-Tetra-*t*-butylanthraquinone, and 2,3,6,7-Tetra-*t*-butylanthracene

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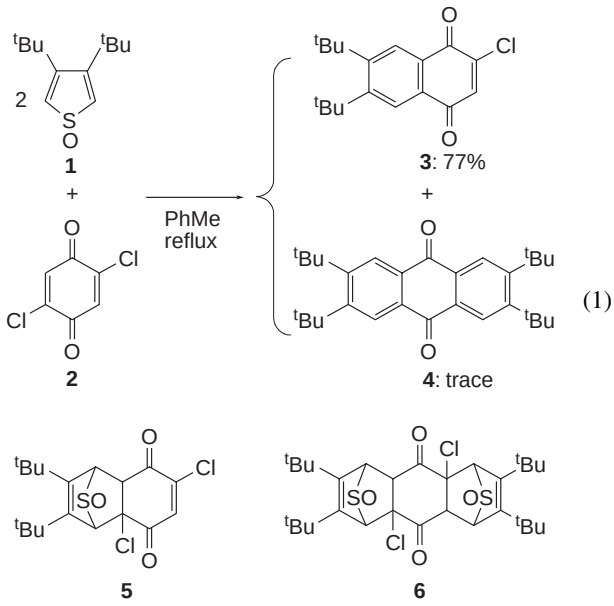
Sterically congested compounds, such as 6,7-di-*t*-butyl-1,4-naphthoquinone, 2,3,6,7-tetra-*t*-butylanthraquinone, and 2,3,6,7-tetra-*t*-butylanthracene, were synthesized via a Diels–Alder reaction involving 3,4-di-*t*-butylthiophene 1-oxide as the key step.

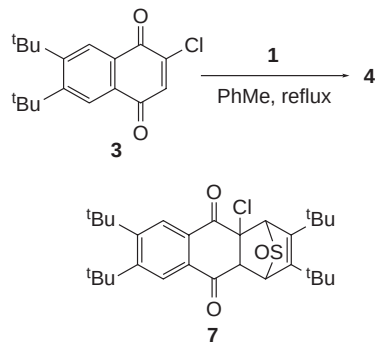
We have been investigating the reactions of 3,4-di-*t*-butylthiophene 1-oxide (**1**), which are easily obtained by oxidizing the corresponding thiophene.[1] 1-Oxide **1** is thermally stable but behaves as a highly reactive, cyclic diene, undergoing a range of addition reactions.[2] Among them, the Diels–Alder reaction is the synthetically most useful and has provided convenient methods for the preparation of a plethora of congested compounds, such as (*Z*)-1,2-di-*t*-butylethene and *o*-di-*t*-butylbenzene derivatives,[2d,2e,2h,2i] which are otherwise difficult to prepare. As an expansion of these studies, we now report the preparation of sterically congested compounds, such as 6,7-di-*t*-butyl-1,4-naphthoquinone (**8**), 2,3,6,7-tetra-*t*-butylanthraquinone (**4**), and 2,3,6,7-tetra-*t*-butylanthracene (**14**) by using a Diels–Alder reaction involving **1** as the key step.[3,4]

Initially, we examined the reaction of **1** with 2,5-dichloro-1,4-benzoquinone (**2**) with the expectation that **2** would react with two molecules of **1** to give bis-adduct **6**, from which the desired compound 2,3,6,7-tetra-*t*-butylanthraquinone (**4**) would be derived by successive elimination of HCl and SO. Thus, **2** was heated with two molar amounts of **1** in boiling toluene. The reaction gave naphthoquinone **3** in 77% yield after purification by using silica-gel column chromatography, in addition to a trace amount of the desired anthraquinone **4**. Although the presence of the 1:1 adduct **5**, which is a precursor of **3**, was detected in the reaction mixture by using ^{1}H NMR spectroscopy, it was not isolated, because it turned into **3** during purification. Bis-adduct **6** was not detected by using ^{1}H NMR spectroscopy.



(1)

The reaction of **3** with an equimolar amount of **1** in boiling toluene gave **4** in a 35% yield. Adduct **7**, which is a precursor of **4**, was observed in the reaction mixture by ^{1}H NMR spectroscopy, and it turned into **4** during purification. Incidentally, the use of **1** in excess (2.5 molar amounts) gave **4** in 80% yield.



(2)

Next, the Diels–Alder reaction of **1** with excess 1,4-benzoquinone was examined to develop a more effective synthesis of **4**. It was found that the above Diels–Alder reaction proceeded quickly even at room temperature and, when the reaction mixture was purified by either using silica-gel column chromatography or treating with silica gel, the initial 1:1 adduct **9** converted to 6,7-di-*t*-butyl-1,4-naphthoquinone (**8**). This conversion was better when alumina was used instead of silica gel. Thus, **1** was allowed to react with excess 1,4-benzoquinone at room temperature, and then, the mixture was stirred with alumina for 12 h to give **8** in 98% yield. These results suggest that a silica gel (alumina)-catalyzed enolization of **9** occurs to afford diol **10**, from which SO is eliminated due to a driving force of aromatization to give **11**. Finally, **11** is oxidized with excess 1,4-benzoquinone, which is present in the mixture, to afford **8**.

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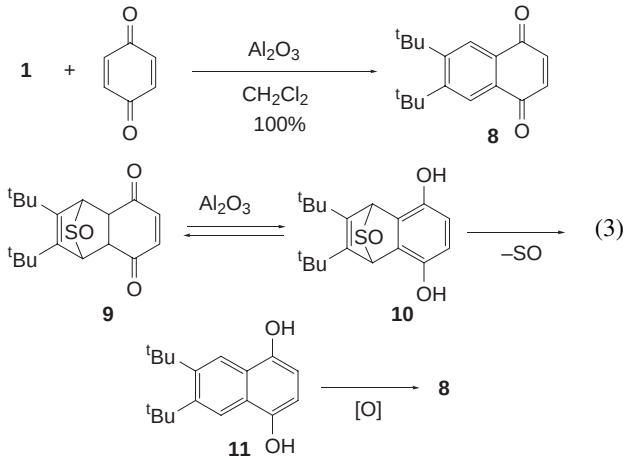
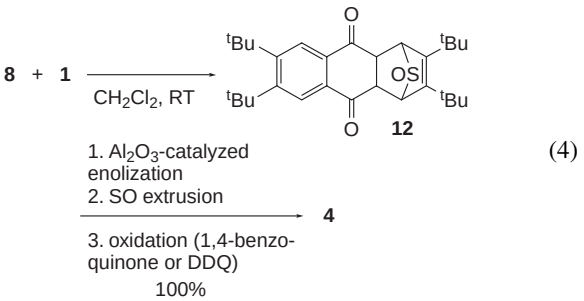


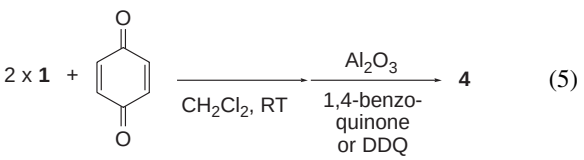
(3)

On the basis of the above results, we thought that quinone **4** would also form in a one-pot reaction of **8** and **1** through an initial adduct **12**. Indeed, the reaction of **8** with **1** in the presence of alumina and 1,4-benzoquinone gave **4** quantitatively. The use of 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) as the oxidizing agent also yielded **4** quantitatively.



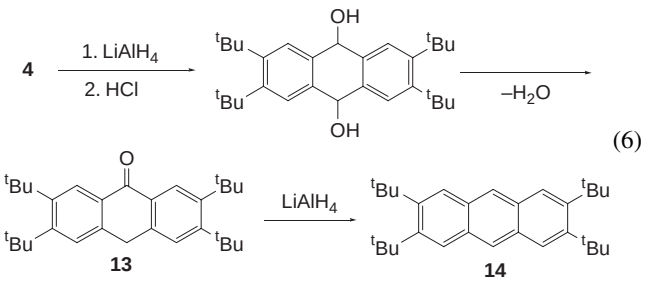
(4)

Finally, on the basis of the results described above, we devised a one-pot synthesis of **4** from **1** and 1,4-benzoquinone. In other words, 1,4-benzoquinone was allowed to react with two molar amounts of **1** at room temperature for 12 h, and then, the mixture was treated with 1,4-benzoquinone and alumina to give **4** in 19% yield. The use of DDQ, in place of 1,4-benzoquinone, as the oxidizing agent also gave **4** in 29% yield.



(5)

Reduction of **4** with $LiAlH_4$ gave 2,3,6,7-tetra-*t*-butylanthrone (**13**) quantitatively. Further reduction of **13** with $LiAlH_4$ afforded 2,3,6,7-tetra-*t*-butylanthracene (**14**) quantitatively.



(6)

In conclusion, we prepared sterically congested quinone and anthracene derivatives. These compounds are highly soluble in ordinary organic solvents, because of the presence of *t*-butyl groups. This will make further manipulations of the compounds easier and lead to the synthesis of other congested molecules.

Experimental

Reaction of 1 with 2; Formation of Naphthoquinone 3. A mixture of **1** (213 mg, 1.00 mmol) and **2** (88 mg, 0.50 mmol) in 30 mL of toluene was heated at reflux for 6 h. The reaction mixture was purified by using silica-gel column chromatography to give a trace amount of **4** and 116 mg (77%) of **3**. Although the 1:1 adduct **5** was detected by using ^{1}H NMR spectroscopy, it could not be isolated, because it turned into **3** during purification. **3**: mp 100–101 °C (from EtOH); ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 1.60 (9H, s), 7.15 (1H, s), 8.28 (1H, s), 8.36 (1H, s); ^{13}C NMR ($CDCl_3$) δ 34.2, 34.3, 38.6, 38.7, 127.6, 128.2, 128.4, 129.2, 135.9, 146.3, 156.8, 157.3, 177.8, 182.7; IR (KBr) 1663, 1683 cm^{-1} (C=O). Anal. Calcd for $C_{18}H_{21}ClO_2$: C, 70.92; H, 6.94%. Found: C, 71.07; H, 6.97%. **5**: ^{1}H NMR ($CDCl_3$) δ 1.36 (9H, s), 1.37 (9H, s), 3.42 (1H, d, J = 1.0 Hz), 4.84 (1H, dd, J = 3.0, 1.0 Hz), 5.08 (1H, d, J = 3.0 Hz), 7.06 (1H, s).

The reaction carried out in the presence of Et_3N or pyridine to promote the conversion of **5** to **3** gave an intractable mixture.

Reaction of 1 with 3; Preparation of Anthraquinone 4. A mixture of **1** (135 mg, 0.64 mmol) and **3** (79 mg, 0.26 mmol) in 30 mL of toluene was heated at reflux for 16 h. The reaction mixture was purified by silica-gel chromatography to give 89 mg (80%) of **4**: mp 244–245 °C (from EtOH); ^{1}H NMR ($CDCl_3$) δ 1.63 (36H, s), 8.49 (4H, s); ^{13}C NMR ($CDCl_3$) δ 34.4, 38.7, 128.6, 130.4, 156.4, 183.5; IR (KBr) 1677 cm^{-1} (C=O). Anal. Calcd for $C_{30}H_{40}O_2$: C, 83.28; H, 9.32%. Found: C, 83.13; H, 9.41%. Intermediate **7**, which could not be isolated in pure form, gave the following ^{1}H NMR data ($CDCl_3$); δ 1.39 (9H, s), 1.40 (9H, s), 1.59 (9H, s), 1.60 (9H, s), 3.48 (1H, d, J = 0.8 Hz), 4.96 (1H, dd, J = 3.0, 0.8 Hz), 5.28 (1H, d, J = 3.0 Hz), 8.23 (1H, s), 8.30 (s, 1H). Heating a 1:1 molar ratio mixture of **1** and **3** in refluxing toluene gave **4** in 35% yield.

Reaction of 1 with 1,4-Benzoquinone; Preparation of Naphthoquinone 8. A mixture of **1** (212 mg, 1.00 mmol) and 1,4-benzoquinone (540 mg, 5.00 mmol) in 30 mL of CH_2Cl_2 was stirred with of alumina (Al_2O_3, 15 g) for 12 h. The reaction mixture was purified by using silica-gel column chromatography to give 270 mg (98%) of **8**: mp 134–135 °C (from EtOH); ^{1}H NMR ($CDCl_3$) δ 1.60 (18H, s), 6.90 (2H, s), 8.28 (2H, s); ^{13}C NMR ($CDCl_3$) δ 34.3, 38.7, 128.1, 128.4, 138.8, 156.6, 185.2; IR (KBr) 1669 cm^{-1} (C=O). Anal. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20%. Found: C, 79.69; H, 8.24%. Intermediate **9** gave the following ^{1}H NMR data ($CDCl_3$); δ 1.16 (18H, s), 3.85 (2H, dd, J = 2.0, 2.0 Hz), 4.46 (2H, dd, J = 2.0, 2.0 Hz), 6.77 (2H, s).

Reaction of 1 with 8; Preparation of Anthraquinone 4. A mixture of **1** (85 mg, 0.40 mmol), **8** (108 mg, 0.40 mmol), and 1,4-benzoquinone (86 mg, 0.80 mmol) in 30 mL of CH_2Cl_2 was stirred with alumina (3 g) for 12 h. The reaction mixture was purified by using silica-gel column chromatography to give 170 mg (100%) of **4**. The use of 2,3-dichloro-4,5-dicyano-1,4-benzoquinone (DDQ), instead of 1,4-benzoquinone, also gave **4** quantitatively. Intermediate **12** gave the following ^{1}H NMR data ($CDCl_3$); δ 1.40 (18H, s), 1.61 (18H, s), 3.79 (2H, s), 6.93 (2H, s), 8.40 (2H, s).

One-Pot Synthesis of Anthraquinone 4. After a mixture of **1** (212 mg, 1.00 mmol) and 1,4-benzoquinone (54 mg, 0.50 mmol) in

30 mL of CH_2Cl_2 was stirred for 12 h at room temperature, alumina (10 g) and 1,4-benzoquinone (216 mg, 2.00 mmol), as the oxidizing agent, were added. The resulting mixture was stirred for 12 h, and then, the alumina was filtered off. The filtrate was purified by using silica-gel column chromatography to give 42 mg (19%) of **4**. The use of DDQ, in place of 1,4-benzoquinone, as the oxidizing agent gave **4** in 29% yield.

Reduction of 4 to Anthrone 13. To a stirred solution of **4** (98 mg, 0.23 mmol) in 10 mL of THF was added $LiAlH_4$ (20 mg, 0.53 mmol) at 0 °C. After the mixture had been stirred for 30 min, the reaction was quenched by addition of 2 M hydrochloric acid. The resulting mixture was extracted with Et_2O, and the extracts were washed with water, dried over $MgSO_4$, and concentrated to dryness. The residue was purified by using silica-gel column chromatography to give 92 mg (97%) of **13**: mp 228–229 °C (from EtOH); ^{1}H NMR ($CDCl_3$) δ 1.60 (18H, s), 1.62 (18H, s), 4.20 (2H, s), 7.65 (2H, s), 8.60 (2H, s); ^{13}C NMR ($CDCl_3$) δ 31.1, 34.6, 34.8, 38.0, 38.1, 128.5, 129.4, 129.6, 137.4, 148.1, 154.5, 184.2; IR (KBr) 1666 cm^{-1} (C=O). Anal. Calcd for $C_{30}H_{42}O$: C, 86.06; H, 10.11%. Found: C, 86.06; H, 10.08%.

Reduction of 13 to Anthracene 14. Anthrone **13** (15 mg, 0.035 mmol) was treated with $LiAlH_4$ (9 mg, 0.079 mmol) in 5 mL of THF to give 13 mg (93%) of **14**: mp 229–230 °C (from pentane); ^{1}H NMR ($CDCl_3$) δ 1.65 (36H, s), 8.15–8.16 (6H); ^{13}C NMR ($CDCl_3$) δ 34.8, 37.9, 123.6, 127.7, 130.4, 146.6; Anal. Calcd for $C_{30}H_{42}$: C, 89.49; H, 10.51%. Found: C, 89.51; H, 10.57%.

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