Anal. Calcd for $C_{29}H_{48}O_2$: C, 81.25, H, 11.28. Found: C, 81.40; H, 11.20.

Acknowledgment. This work was supported by the Italian Research Council (Progetto Finalizzato Chimica Fine e Secondaria). We thank Professor G. Galli for mass spectra.

Registry No. **1a**, 72962-43-7; **3a**, 91861-37-9; **3b**, 91879-21-9; 4, 57-87-4; **5a**, 474-67-9; **5b**, 91926-36-2; **6a**, 2465-11-4; **6b**, 61425-09-0; 7, 88852-68-0; 8, 91861-38-0; 9, 91861-39-1; **10a**, 91861-40-4; **10b**, 91861-41-5; **11a**, 91861-42-6; **11c**, 91861-43-7; (3-methyl-2-methylenebutyl)triphenylphosphonium bromide, 33355-56-5; (20*S*)-6β-methoxy-3α,5-cyclopregnane-20-carboxaldehyde, 25819-77-6.

Ozonolysis of 1,2,4-Tri-*tert*-butylnaphthalene

Yoshikatsu Ito,* Akira Matsuura, and Teruo Matsuura

Department of Synthetic Chemistry, Faculty of Engineering, Kyoto University, Kyoto 606, Japan

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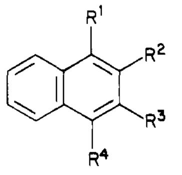
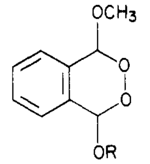
Naphthalenes **1a–g** are readily attacked by 2 mol of ozone exclusively at 1,2 and 3,4 bonds.[1,2] Final products were shown to depend on the nature of solvents employed and workup conditions. For example, cyclic peroxides A were obtained from **1a–f** in CH_3OH, a participating solvent, while phthalic acid derivatives were isolated in nonparticipating solvents.[2]



1a, $R^1 = R^3 = R^4 = H$
1b, $R^1 = R^4 = H$; $R^2 = R^3 = CH_3$
1c, $R^1 = R^3 = R^4 = H$; $R^2 = CH_3$
1d, $R^1 = R^3 = R^4 = H$; $R^2 = OH$
1e, $R^1 = R^3 = R^4 = H$; $R^2 = OCH_3$
1f, $R^1 = R^3 = R^4 = H$; $R^2 = OEt$
1g, $R^1 = CH_3$; $R^2 = R^3 = R^4 = H$
1h, $R^1 = R^2 = R^4 = CH_3$; $R^3 = H$
1i, $R^1 = R^2 = R^4 = t\text{-Bu}$; $R^3 = H$



A

Ozonolysis of naphthalenes having bulky substituents is interesing in view of the effects of the bulky substituents on the reactivity to ozone and on the stability of peroxide intermediates. It is known that the bulky *tert*-butyl group can stabilize certain initial ozone addcuts; the primary ozonide of *trans*-di-*tert*-butylethylene[3] and the transannlar ozonide of 9-*tert*-butyl-10-methylanthracene[4] are typical examples. It is also known that many hindered olefins often produce so-called "partial cleavage" products instead of usual ozonolysis products.[5] We have report that 1,2,4-tri-*tert*-butylnaphthalene (**1i**) reacts, in contrast with the ozonolysis of the unhindered naphthalenes **1a–8**, with only 1 mol of ozone.

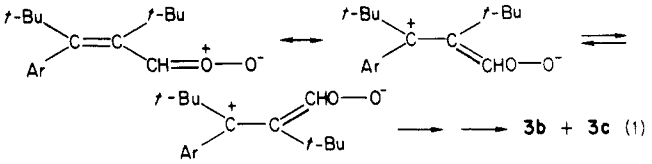
Results and Discussion

Table I summarizes the products obtained from ozonolyses of 1,2,4-tri-*tert*-butylnaphthalene (**1i**) and 1,2,4-trimethylnaphthalene (**1h**). As expected, they were highly dependent on the reaction media. Scheme I describes possible reaction sequences.

o-Dipivaloylbenzene (**5a**) was a sole identified product in $CH_3OH–CHCl_3$ (1:1 v/v) and on SiO_2 (Table I, entries 3 and 7). The other expected product *t*-BuCOCHO was not looked for. SiO_2 is functioning like a participating solvent, probably due to adsorbed water or surface-OH groups.

In nonparticipating solvents (Freon-11 and *n*-hexane) **1i** gave **5a** and two stereoisomeric ketone diperoxides **2a** and **2b** as major products (Table I, entries 1 and 2). The diperoxides **2a** and **2b** were converted by catalytic reduction on Pd–C into a single aldehyde **3a** in 80% and 67% yield, respectively. This reduction reaction indicates that **2a** and **2b** differ as cis–trans isomers about the peroxide ring, not as cis–trans isomers about the C–C double bond. The diperoxides were probably formed via dimerization of an intermediate carbonyl oxide **7** (Scheme I). In general, carbonyl oxides generated in nonparticipating solvents dimerize or polymerize as major modes of reactions.[3a,6]

In acetone, ozonation of **1i** afforded cis and trans isomers of a cinnamic acid derivative **3b** and **3c** in addition to **5a** (Table I, entry 4). A cis–trans isomerization of the C–C double bond of **7** may occur as shown in eq 1, leading ultimately to **3b** and **3c** probably via a dioxirane intermediate. However, it is not clear why the cis–trans isomerism about the C–C double bond was observed only in acetone.



Pyridine has been shown to function as a reducing agent of peroxidic intermediates in ozonolysis.[7] In fact, the cinnamaldehyde **3a** was produced as a major product upon ozonolysis of **1i** in the presence of pyridine (Table I, entries 5 and 6).

The ozonolysis of **1i** differs from that of the previously studied unhindered naphthalenes **1a–g** in that most of the products (except in $CH_3OH–CHCl_3$ and on SiO_2) result from addition of only 1 mol of ozone; i.e., **2a**, **2b**, and **3a–c** were formed.[8] These products were found to be entirely inert toward ozone under the reaction conditions mentioned in Table I. Thus, as illustrated in Scheme I, the reaction of **1i** with ozone may be explained by addition of an ozone molecule to the 3,4 bond to form a primary ozonide **6**, which subsequently decomposes into **2** and **3** via the carbonyl oxide **7** or undergoes further ozonolysis to give **5a**. The failure to isolate **2** and **3** upon ozonolysis in the presence of CH_3OH may be ascribed to rapid methanolysis[9] of **6** (or addition of methanol to **7**) leading

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[1] (a) Bailey, P. S. "Ozonation in Organic Chemistry"; Academic Press: New York, 1982; Vol. 2. (b) Murphy, J. S.; Orr, J. R. "Ozone Chemistry and Technology"; Frankling Institute Press: Philadelphia, 1975. (c) Bailey, P. S. *Chem. Rev.* **1985**, *58*, 925. (d) Bailey, P. S.; Ferrel, T. M. *J. Org. Chem.* **1981**, *46*, 5028.

[2] (a) Bailey, P. S.; Garcia-Sharp, F. J. *J. Org. Chem.* **1957**, *22*, 1008. (b) Bailey, P. S.; Bath, S. S.; Dobinson, F.; Garcia-Sharp, F. J.; Johnson, C. D. *J. Org. Chem.* **1964**, *29*, 697.

[3] (a) Criegee, R.; Schroder, G. *Chem. Ber.* **1960**, *93*, 689. (b) Bailey, P. S.; Thompson, J. A.; Shoulders, B. A. *J. Am. Chem. Soc.* **1966**, *88*, 4098.

[4] Ito, Y.; Matsuura, A.; Otani, R.; Matsuura, T.; Fukuyama, K. *J. Am. Chem. Soc.* **1983**, *105*, 5699.

[5] (a) Bailey, P. S.; Lane, A. G. *J. Am. Chem. Soc.* **1967**, *89*, 4473. (b) Bailey, P. S. "Ozonation in Organic Chemistry"; Academic Press: New York, 1978; Vol. 1, p 197.

[6] (a) Reference 5b, p 83. (b) Schroder, G. *Chem. Ber.* **1962**, *95*, 733. (c) Criegee, R.; Bath, S. S.; von Bornhanpt, B. *Chem. Ber.* **1960**, *93*, 2891.

[7] Reference 5b, p 133.

[8] It was reported that 2-naphthol reacted with 1 mol of ozone to afford *O*-carboxycinnamic acid: Johnson, C. D.; Bailey, P. S. *J. Org. Chem.* **1964**, *29*, 703. However, this is thought to be a rare example.

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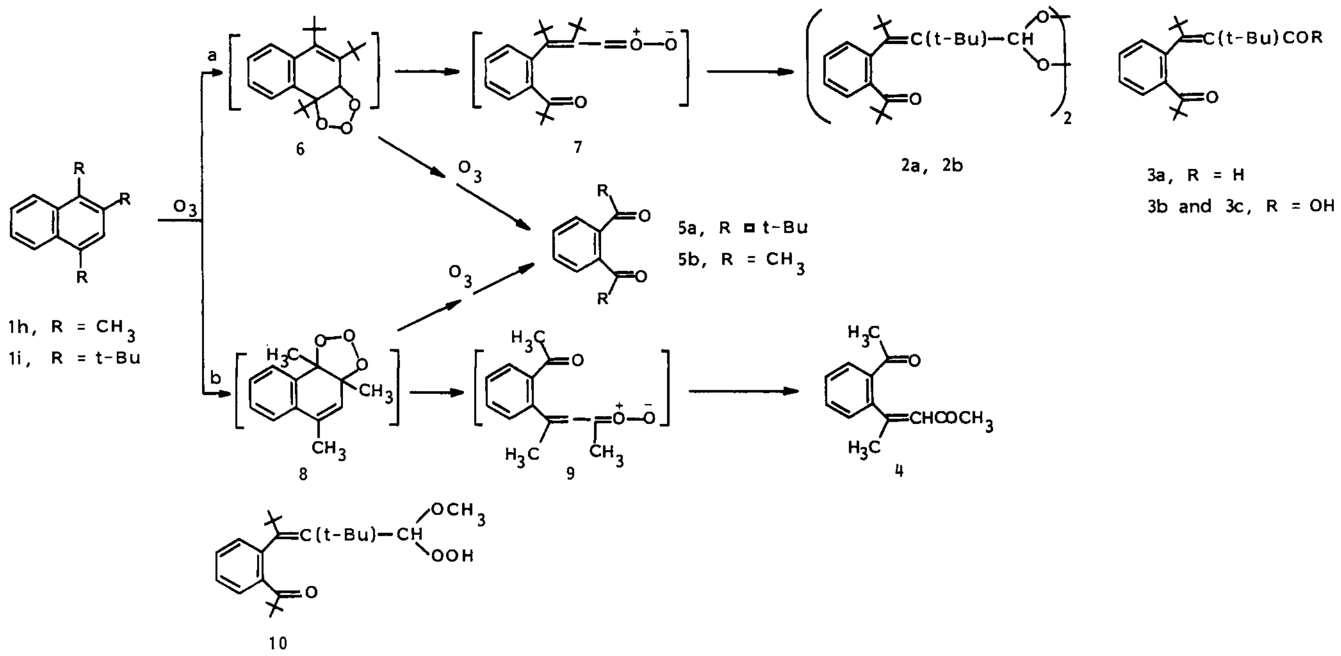
Table I. Ozonolysis of 1,2,4-Trialkylnaphthalenes 1i and 1h in Various Solvents

entry	compd	medium	O_3 passed,[a] min	temp, °C	products (isolated yield, %)[b]
1	**1i**	$CFCl_3$	42	-78	**2a** (34), **2b** (7), **5a** (16)
2	**1i**	*n*-hexane	50	-78	**2a** (9), **2b** (12), **3a** (3), **5a** (15)
3	**1i**	CH_3OH-$CHCl_3$ (1:1 v/v)	17	-78	**5a** (56)
4	**1i**	acetone	48	-78	**3b** (22), **3c** (26), **5a** (22)
5	**1i**	$CFCl_3$-pyridine (1:1 v/v)	60	-78	**3a** (41), **3c** (12), **5a** (3)
6	**1i**	CCl_2F_2-pyridine (1:1 v/v)	67	-130	**3a** (61), **5a** (15)
7	**1i**	SiO_2	90	-78	**5a** (46)
8	**1h**	acetone	63	-78	**5b** (52)
9	**1h**	$CFCl_3$-pyridine (1:1 v/v)	107	-78	**4** (26), **5b** (15)

[a] Ozone-oxygen stream (1.5 g of O_3/h) was bubbled through a solution. [b] Many minor products were formed and in most cases they were not isolated.

Scheme I



to the methoxy hydroperoxide **10**, which will undergo further ozonolysis into **5a**. Since the C–C double bond in the side chain of **10** is more electron rich than those of **3a–c** and seems less sterically hindered than those of **2a** and **2b**, **10** is expected to be more prone to ozone attack. The existence of the primary ozonide **6** was unable to be demonstrated by low-temperature NMR spectroscopy (-70 °C in CD_2Cl_2).

Ozonolyses of the less-hindered naphthalene **1h** afforded *o*-diacetylbenzene (**5b**) in actone and **5b** and ketone **4** in pyridine–Freon-11 (1:1 v/v) (Table I, entries 8 and 9). Evidently **1h** has a greater tendency to absorb 2 mol of ozone than **1i** (compare entries 8 and 9 with entries 4 and 5). Furthermore, production of **4** implies that the addition of the first ozone molecule may have occurred at the 1,2 bond rather than 3,4 bond (Scheme I, path b). As aforementioned, the primary ozone addition to **1i** occurred at the 3,4 bond, probably due to a large steric hindrance around the positions 1 and 2.

Experimental Section

All melting points and a boiling point are uncorrected. The NMR, IR, and mass spectra were measured by Varian T-60 (or FT-80A), JASCO IRA-1, and JEOL-JMS-DX 300 spectrometers, respectively.

1,2,4-Trimethylnaphthalene (**1h**) was prepared according to the original literature.[10]

Synthesis of 1,2,4-Tri-*tert*-butylnaphthalene (1i). 1,2,4-Tri-*tert*-butylnaphthalene (**1i**) was prepared according to Yoshida's procedure.[11] Thus 2.13 g (8.59 mmol) of 1,2,4-tri-*tert*-butylcyclopentadienone[12] and 5 g (14.6 mmol) of diphenyliodonium carboxylate monohydrate are added to 30 mL of ethylbenzene. After mixture was refluxed for 1 h, the solvent was removed by distillation. The residue was separated by column chromatography on silica gel (hexane) to give 1.64 g (65%) of **1i**: mg 69–71 °C (from *n*-hexane); ^1H NMR ($CDCl_3$) δ 1.48 (s, 9 H), 1.57 (s, 9 H), 1.62 (s, 9 H), 7.07–7.30 (m, 2 H), 7.40 (s, 1 H), 8.03–8.36 (m, 2 H); IR (Nujol) 1600, 1265, 1220, 890, 800, 770, 695 cm^{-1}; high-resolution mass spectrum, calcd for $C_{22}H_{32}$ 296.2504, found 296.2511.

General Procedures for Ozonolysis. Through a solution containing 1 g of 1,2,4-trialkylnaphthalene **1i** or **1h** in various solvents (10 mL) was bubbled an ozone–oxygen stream (1.5 g of O_3/h) at -78 °C until starting material was consumed. After excess ozone was swept with nitrogen at the same temperature, the solvent was evaporated at room temperature under reduced pressure. The residue was separated by column chromatography on silica gel, eluting with benzene, or by preparative TLC on silica gel (benzene).

Ozonolysis of 1i in Freon-11 or *n*-Hexane. Ozonation of **1i** (1.0 g, 3.4 mmol) in Freon-11 gave cyclic ketone diperoxides **2a** (372 mg, 34%) and **2b** (80 mg, 7%) and *o*-dipivaloylbenzene (**5a**)[13] (132 mg, 16%), whereas in *n*-hexane 1.0 g (3.4 mmol) of

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(9) Reference 5b, p 16.

(10) Cocker, W.; Cross, B. E.; McCormick, J. *J. Chem. Soc.* **1952**, 72.

(11) Yoshida, Z.; Kawamoto, F.; Miyoshi, H.; Ikikoshi, H. *Chem. Abstr.* **1980**, *92*, P163763*q*.

(12) Nishinaga, A.; Shimizu, T.; Matsuura, T. *J. Org. Chem.* **1979**, *44*, 2983.

(13) Gibbons, W. A.; Gil, V. M. S. *Mol. Phys.* **1965**, *9*, 163.

1i afforded **2a** (100 mg, 9%), **2b** (127 mg, 12%), and **5a** (123 mg, 15%).

2a: mp 178–180 °C (from $CHCl_3$); R_f 0.75 (benzene); ^1H NMR ($CDCl_3$) δ 0.93 (s, 18 H), 1.20 (s, 18 H), 1.37 (s, 18 H), 6.83–7.43 (m, 6 H), 7.67 (s, 2 H), 7.78–8.00 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 205.6, 158.8, 144.5, 134.9, 132.4, 130.9, 129.9, 128.9, 125.6, 111.1, 44.1, 38.2, 36.9, 32.8, 29.0; mass spectrum, *m/e* (relative intensity) 344 (1), 287 (100), 271 (100), 259 (78), 243 (16), 57 (100); IR (Nujol), 1675 cm^{-1}; M_r 684 ± 30 (determined by the depression of the freezing point of camphor). Anal. Calcd for $C_{44}H_{64}O_6$: C, 76.70; H, 9.36 (M_r 688). Found: C, 76.48; H, 9.44.

2b: mp 179–182 °C (from $CHCl_3$); R_f 0.56 (benzene); ^1H NMR ($CDCl_3$) δ 0.95 (s, 18 H), 1.23 (s, 18 H)8 1.40 (s, 18 H), 6.87–7.47 (m, 6 H), 7.65 (s, 2 H), 7.77–8.00 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 205.4, 158.8, 144.4, 134.9, 132.4, 130.8, 129.9, 128.9, 125.6, 111.1, 44.2, 38.2, 36.9, 32.9, 29.0; mass spectrum, *m/e* (relative intensity) 344 (1), 287 (95), 271 (80), 259 (78), 243 (16), 57 (100); IR (Nujol) 1678 cm^{-1}; M_r 659 ± 57 (determined by the depression of the freezing point of camphor). Anal. Calcd for $C_{44}H_{64}O_6$: C, 76.70; H, 9.36 (M_r = 688). Found; C. 77.04; H, 9.54.

Ozonolysis of 1i in Acetone. After an ozone–oxygen stream was introduced to a solution of **1i** (1.0 g, 3.4 mmol) in acetone (10 mL) for 48 min, the mixture was worked up as described above to give cinnamic acid derivatives **3b** (257 mg, 22%) and **3c** (304 mg, 26%) in addition to 5a (184 mg, 22%).

3b: mp 208–212.5 °C (from $CHCl_3$); R_f 0.37 (benzene:AcOEt = 5 : 1); ^1H NMR δ 0.93 (s, 9 H), 1.17 (s, 9 H), 1.43 (s, 9 H), 7.0–7.5 (m, 3 H), 7.67–8.00 (m, 1 H), 8.50 (br s, 1 H, COOH); IR (Nujol) 3400–2200, 1695, 1682 cm^{-1}; mass spectrum, *m/e* (relative intensity) 344 (9), 287 (100), 57 (76). Anal. Calcd for $C_{22}H_{32}O_3$: C, 76.70; H, 9.36. Found: C, 76.46; H, 9.59.

3c: mp 197–205 °C (from $CHCl_3$); R_f 0.31 (benzene:AcOEt = 5 : 1); ^1H NMR ($CDCl_3$) δ 0.90 (s, 9 H), 1.15 (s, 9 H), 1.45 (s, 9 H), 7.17–7.77 (m, 4 H), 9.57 (br s, 1 H, COOH); IR (neat) 3400–2200, 1695, 1684 cm^{-1}; mass spectrum, *m/e* (relative intensity) 344 (1), 287 (6), 57 (100). Anal. Calcd for $C_{22}H_{32}O_3$: C, 76.70; H, 9.36. Found: C, 76.47; H, 9.52.

Ozonolysis of 1i in Pyridine–Freon-11 or Pyridine–Freon-12. A solution of **1i** (1.0 g, 3.4 mol) in pyridine-Freon-11 (v/v, 1:1) (10 mL) gave a cinnamaldehyde derivative **3a** (470 mg, 41%) along with **3c** (139 mg, 12%) and **5a** (25 mg, 3%).

3a: mp 160.5–163.0 °C (from *n*-hexane); ^1H NMR ($CDCl_3$) δ 0.83 (s, 9 H), 1.00 (s, 9 H), 1.40 (s, 9 H), 6.90–7.48 (m, 3 H), 7.70–8.00 (m, 1 H), 10.45 (s, 1 H, CHO); IR (neat) 2763, 1673 cm^{-1}; mass spectrum, *m/e* (relative intensity) 328 (6), 327 (9), 271 (100), 57 (100). The aldehyde **3a** was gradullay changed into acid **3c** on exposure to air.

Ozonation of **1i** (260 mg, 0.9 mmol) is pyridine–Freon-12 (1:1), v/v) (10 mL) at −130 °C (liquid N_2–*n*-pentane as refrigerant) afforded **3a** (102 mg, 61%), **5a** (19 mg, 15%), and recovered **1i** (110 mg, 42%).

Ozonolysis of 1i in $CHCl_3$–CH_3OH (1:1 v/v). A solution of **1i** (205 mg, 60.7 mmol) in $CHCl_3$–CH_3OH (5 mL) gave **5a** (96 mg, 56%).

Ozonolysis of 1h in Acetone or Pyridine–Freon-11 (1:1 v/v). A solution of **1h** (1.0 g, 5.9 mmol) in acetone (10 mL) afforded *o*-diacetylbenzene (**5b**)[14] (495 mg, 52%). A solution of **1h** (1.0 g, 5.9 mmol) in pyridine–Freon-11 (20 mL) gave 4 (288 mg, 26%) and **5b** (146 mg, 12%).

4: oil, bp 150 °C (1 mmHg); ^1H NMR ($CDCl_3$) δ 1.86 (s, 3 H), 2.17 (br s, 3 H), 2.53 (s, 3 H), 6.10 (br s, 1 H), 6.80–7.80 (m, 4 H); IR (neat) 1685 cm^{-1}; high-resolution mass spectrum; calcd for $C_{1},_3H_{14}O_2$ 202.0993, found 202.1006.

Dry Ozonation. An ozone–oxygen stream was introduced to 5 g of silica gel, on which **1i** 498 mg (1.7 mmol) was adsorbed, at −78 °C for 1.5 h. The products were eluted with chloroform and the solvent was evaporated. The residue was separated by preparative TLC (benzene) to give **5a** (187 mg 46%).

Reduction of 2a and 2b with Pd–C. To a solution of **2a** (100 mg, 0.15 mmol) in AcOEt (5 mL) was added 5% Pd–C (20 mg, 9.4 × 10^{-3} mmol), and the reaction mixture was stirred at room temperature for 30 h under H_2. After the solution was filtered, solvent was evaporated under reduced pressure and the residue was separated by preparative TLC (benzene) to give **3a** (31 mg, 67%). Reduction of the other isomer **2b** (100 mg, 0.15 mmol) with 5% Pd–C (20 mg) was done as above to afford **3a** (76 mg, 80%).

Registry No. **1h**, 2717-42-2; **1i**, 73319-62-7; *cis*-**2a**, 92011-63-7; *trans*-**2b**, 92077-26-4; **3a**, 92011-66-0; (*E*)-**3b**, 92011-64-8; (*Z*)-**3c**, 92011-65-9; **4**, 92011-67-1; **5a**, 25402-91-9; **5b**, 704-00-7; $Ph_2I^+CO_2^-$, 92011-62-6; $CH_3C(O)CH_3$, 67-64-1; CH_3OH, 67-56-1; $CHCl_3$, 67-66-3; $CH_3(CH_2)_4CH_3$, 110-54-3; 1,2,4-tri-*tert*-butylcyclopenta-2,4-dienone, 36319-95-6; Freon-11, 75-69-4; Freon-12, 75-71-8; pyridine, 110-86-1.

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[14] Cooper, M. A.; Manatt, S. L. *J. Am. Chem. Soc.* **1970**, *92*, 1605.

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tert-Butylation of 3,6-Di-*tert*-butyl-2-naphthol. Formation of 3,6,8-Tri-*tert*-butyl-2-naphthol

Dwight W. Chasar

BFGoodrich R&D Center, Brecksville, Ohio 44141

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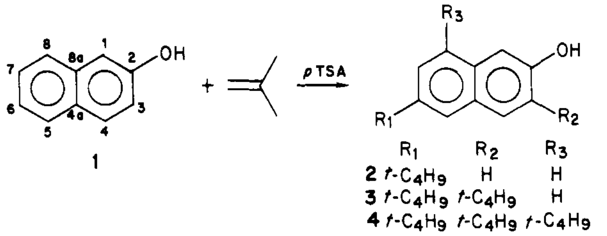
Interest in the Friedel–Crafts *tert*-butylation of 2-naphthol (1) has persisted over the last 3 decades.[1-3] The mono-*tert*-butyl product 2 was shown[1] to have resulted from attack at the 6 position of 1. However, the di-*tert*-butyl product, initially identified as the 1,6 isomer,[1] was later shown to be the product (3) resulting from 3,6-attack.[2] Layer[3] reported that in the di-*tert*-butylation of 2-naphthol with isobutylene using *p*-toluenesulfonic acid as catalyst in toluene at 110 °C, both the 3- and the 6-mono-*tert*-butyl products formed first and at about the same rate, followed by a second *tert*-butylation at the remaining 6 or 3 position.



We now report the synthesis of 3,6,8-tri-*tert*-butyl-2-naphthol (4). Under conditions essentially identical with those of Layer,[3] with the exception of the temperature being 90–95 °C (vs. 110 °C), a new product forms which corresponds to a tri-*tert*-butyl-2-naphthol. During the course of the reaction (as followed by gas chromatography), this new material can be debutylated to 3 by raising the reaction temperature to 110 °C, even with the continued addition of isobutylene. Butylation can reoccur again by lowering the temperature to 90–95 °C and with continued isobutylene addition.

The position of the third *tert*-butyl group was initially unclear. Both the 1 and 8 positions are available from a reactivity point of view, although the 1 position is sterically less accessible. The hydroxyl absorption of 4 in the IR was shifted to a higher frequency (3565 cm^{-1} vs. 3518 for 3), suggesting higher crowdedness (and therefore 1-substitution).

Both Brady et al.[2] and Layer[3] have shown that the proton at the 1 position of 3 and 3-*tert*-butyl-2-naphthol exhibits a ^1H NMR singlet absorption at 6.85 and 6.71

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(1) Buu-Hoi, N. P.; LeBihan, H.; Binon, F.; Rayet, P. *J. Org. Chem* **1950**, *15*, 1060.

(2) Brady, P. A.; Carnduff, J.; Leppard, D. G. *Tetrahedron Lett.* **1972**, 4183.

(3) Layer, R. W. *Tetrahedron Lett.* **1974**, 3459.

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