Selective Preparation. 31. Oxidative Coupling of 2-Halo-4,6-di-*tert*-butylphenols with Potassium Hexacyanoferrate(III) in Benzene[1,2]

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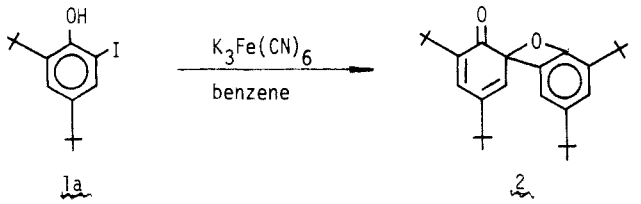
When 2-bromo-4,6-di-*tert*-butylphenol (**1b**) was treated with $K_3Fe(CN)_6$ in benzene, 1,4-dihydro-4-bromo-2,4,6,8-tetra-*tert*-butyl-1-oxodibenzofuran (**3**) was obtained in 81% yield together with a small amount of 2,4,6,8-tetra-*tert*-butyldibenzofuran (**4**). Heating of **3** in primary alcohols such as methanol and ethanol afforded the corresponding 1,4-dihydro-4-alkoxy-2,4,6,8-tetra-*tert*-butyl-1-oxodibenzofuran (**9**) in good yields. However, treatment of **3** with boiling isopropyl alcohol gave in 85% yield 1-hydroxy-2,4,6,8-tetra-*tert*-butyldibenzofuran (**5**), which afforded 1-hydroxydibenzofuran (**6**) by its $AlCl_3$-catalyzed trans *tert*-butylation in toluene. Compound **6** was obtained also by the $AlCl_3$-catalyzed trans alkylation of **3**. Similar trans alkylation of **4** afforded dibenzofuran (**19**). 1-Hydroxy-4-methoxy- (**11**) and 1,4-dihydro-1,4-dioxo-2,6,8-tri-*tert*-butyldibenzofuran (**12**) were also prepared from compound **3**. Similar oxidation of 2-chloro-4,6-di-*tert*-butylphenol (**1c**) afforded 6,6′-bis[2,4-di-*tert*-butyl-6-chlorocyclohexa-2,4-dien-1-one] (**22**) and 2,4-di-*tert*-butyl-4-chloro-6-(2,4-di-*tert*-butyl-6-chlorophenoxy)-cyclohexa-2,5-dien-1-one (**23**) in 23% and 53% yields, respectively. However, oxidation of 2-fluoro-4,6-di-*tert*-butylphenol (**1d**) gave only one product, 2,4-di-*tert*-butyl-4-fluoro-6-(2,4-di-*tert*-butyl-6-fluorophenoxy)-cyclohexa-2,5-dien-1-one (**36**), in 63% yield. The mechanisms of oxidation of 2-halo-4,6-di-*tert*-butylphenols with $K_3Fe(CN)_6$ in benzene were also discussed in this paper.

Müller et al.[3] reported that oxidation of 2-iodo-4,6-di-*tert*-butylphenol (**1a**) with potassium hexacyanoferrate(III) affords the spiro compound **2**.



1a 2

While the oxidation of such elements as given above is interesting from the viewpoint of organic synthesis, hardly any systematic investigations have been reported so far dealing with the similar oxidation of such halo derivatives as 2-bromo- (**1b**), 2-chloro- (**1c**), and 2-fluoro-4,6-di-*tert*-butylphenol (**1d**).

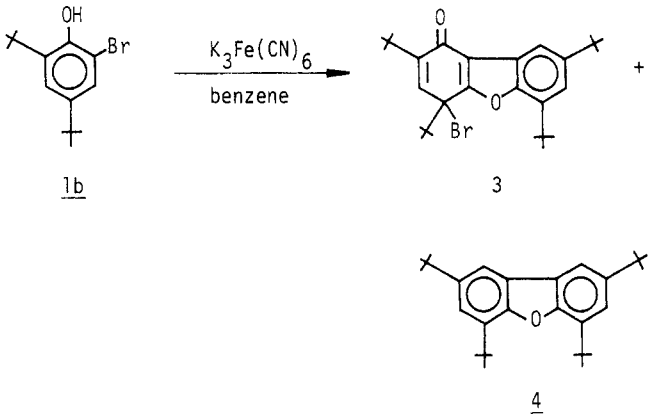
Accordingly, we have undertaken the oxidation of 2-halo-4,6-di-*tert*-butylphenols (**1b–d**) in order to obtain more detailed information on the products resulting through their studies as well as the reaction mechanism.

Results and Discussion

Oxidation of 2-Bromo-4,6-di-*tert*-butylphenol (1b). When **1b** was treated with $K_3Fe(CN)_6$ by following the method reported previously, there was produced, contrary to our expectation, 1,4-dihydro-4-bromo-2,4,6,8-tetra-*tert*-butyl-1-oxo-dibenzofuran (**3**) in 81% yield and also a small amount of 2,4,6,8-tetra-*tert*-butyldibenzofuran (**4**).[3,4] In this reaction, however, there was identified scarcely any spiro compound **2**, as reported by Müller et al.[3]

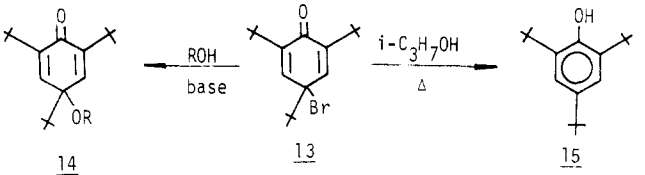
The structure of **3** was determined by its spectral data and elemental analysis and also by the chemical conditions shown in Scheme I.

According to a recent report,[5] the reaction of 4-bromo-2,4,6-tri-*tert*-butyl-2,5-cyclohexadienone (**13**) with methanol or ethanol in the presence of such a base as pyridine or DBU yielded the corresponding 4-alkoxy derivatives **14**.



1b 3 4

On the other hand, it was also reported that heating **13** with isopropyl alcohol in the absence of a base resulted in hydrodebromination of **13**, yielding 95% 2,4,6-tri-*tert*-butylphenol (**15**).



14 13 15

R = CH_3, CH_3CH_2

When compound **3** as well as **13** was heated in isopropyl alcohol, hydrodebromination occurred, yielding 85% 1-hydroxy-2,4,6,8-tetra-*tert*-butyldibenzofuran (**5**). Conversion of compound **3** or **5** into 1-hydroxydibenzofuran (**6**), which is a known compound,[5] resulted in ca. 75% yield with the aid of $AlCl_3$-catalyzed transalkylation[7] with tol-

† Research Institute of Industrial Science.
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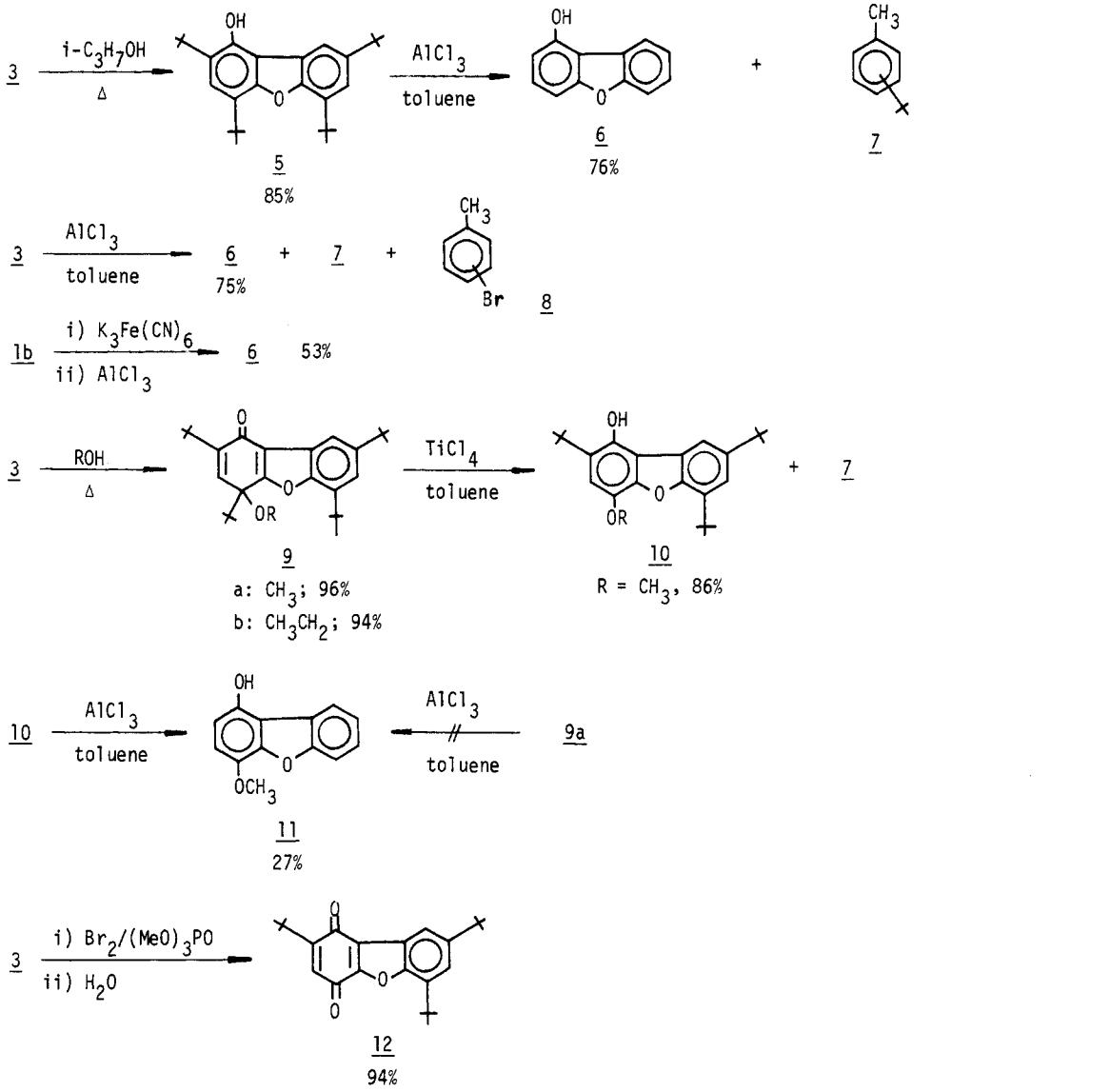
(1) Part 30: M. Tashiro and T. Yamato, submitted for publication in *J. Org. Chem.*
(2) A part of the present work was published as a preliminary communication: Tashiro, M.; Yoshiya, H.; Fukata, G. *Synthesis* **1980**, 495.
(3) Müller, E.; Mayer, R.; Narr, B.; Rieker, A.; Scheffler, K. *Justus Liebigs Ann. Chem.* **1961**, *645*, 25.
(4) After publication of the preliminary communication, formation of this compound was detected.
(5) Tashiro, M.; Yoshiya, H.; Fukata, G. *Synthesis* **1980**, 495.
(6) Stjernstrom, N. E. *Acta Chem. Scand.* **1962**, *16*, 553.
(7) Tashiro, M. *Synthesis* **1979**, 921.

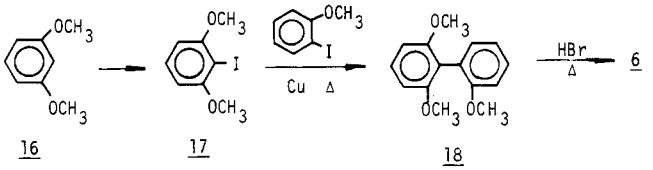
0022-3263/81/1946-3784$01.25/0

Scheme I



uene; in the case of **3**, bromotoluenes **8** were brought forth as side products. Compound **6** was also directly obtained in 53% yield by oxidizing **1b** with $K_3Fe(CN)_6$ in benzene, drying the reaction solution, and then treating it with aluminum chloride.

Stjernstrom[6] reported a preparative route for **6** from **16**. It might be, however, more convenient to follow our preparative route for **6** from **1b** than that method.

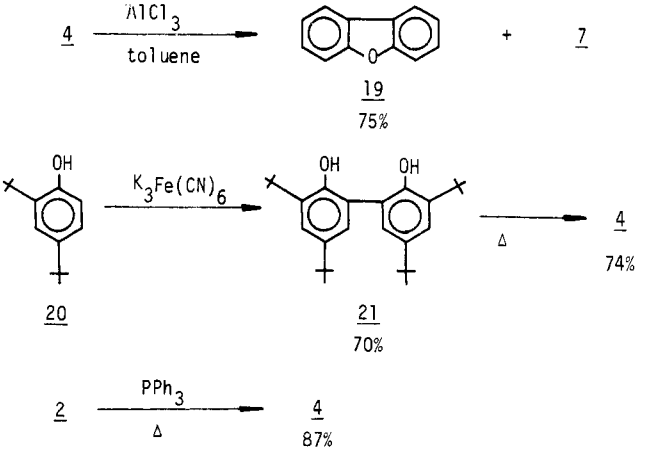


Heating of **3** in methanol or ethanol, even without base, afforded the corresponding 4-alkoxy derivatives **9** in good yields. From these results it might be safe to say that compound **3** reacts better with primary alcohols than compound **13**.

Although $AlCl_3$-catalyzed transalkylation of **9a** gave only a mixture of complex reaction products, selective trans *tert*-butylation occurred in the presence of weak catalyst such as $TiCl_4$,[7] yielding 86% 1-hydroxy-4-methoxy-2,6,8-tri-*tert*-butyldibenzofuran (**10**). The $AlCl_3$-catalyzed transalkylation of **10** gave 1-hydroxy-4-methoxydibenzofuran (**11**), although the yield was low.

The results of treatment of **3** with Br_2 in $(CH_3O)_3PO$ showed 94% quinone derivative **12**.

The $AlCl_3$-catalyzed trans *tert*-butylation of **4** gave, as expected, genuine dibenzofuran (**19**) in good yield.

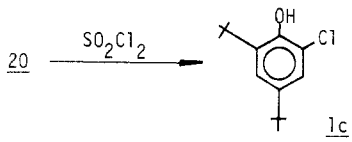


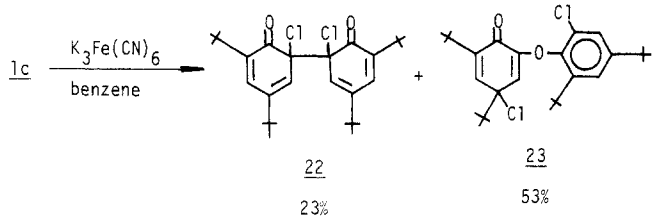
Compound **4** has been readily prepared from **20**, which is commercially available, by Müller et al.[3] Thus, the

(8) Tashiro, M.; Yamato, T.; Fukata, G. *J. Org. Chem.* **1978**, *43*, 1413.

reaction course from **20** to **19** via **4** is a very convenient preparative method of **19**.

Oxidation of 2-Chloro-4,6-di-*tert*-butylphenol (1c). The starting compound **1c** was prepared by chlorination of **20** with sulfuryl chloride. Similar oxidation of **1c** afforded the bis(cyclohexadienone) derivative **22** and the

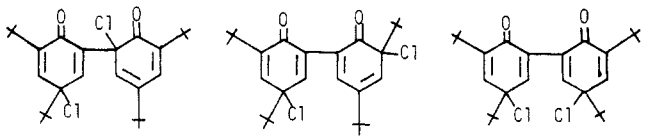




phenoxy derivative **23** in 23% and 53% yields, respectively. When **22** was treated with Raney Ni (W-2) in ethanol, compound **21** was obtained in 95% yield.

$$\mathbf{22} \xrightarrow[\text{ethanol}]{\text{Raney Ni}} \mathbf{21}$$

The ^{1}H NMR spectrum of **22** shows the protons of *tert*-butyl groups as two different singlets at 1.13 and 1.23 ppm, while the olefinic protons give two doublets at 6.14 (J = 2 Hz) and 6.93 (J = 2 Hz) ppm. On the basis of the NMR spectral data, asymmetric structures **24a** and **24b** can be omitted from the possible structures.

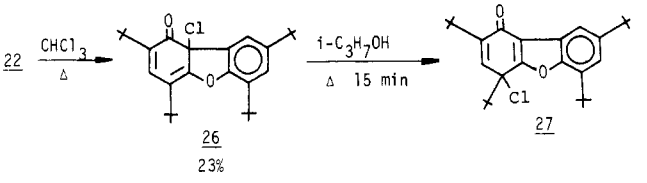


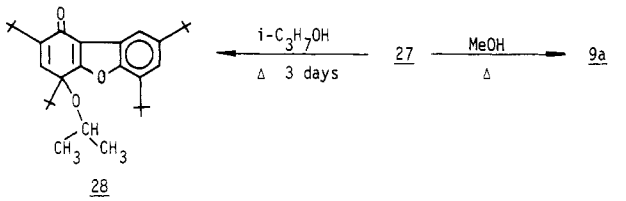
It is well-known[9,10] that the λ_{max} of cyclohexa-2,5-dien-1-ones appear at 230–235 nm (log ϵ 3.90–4.30), but those of cyclohexa-2,4-dien-1-ones appear at 290–340 nm (log ϵ 3.5–3.8), though the λ_{max} of **22** appears at 351 nm (log ϵ 3.60). Consequently, cyclohexa-2,5-dien-1-one derivatives **24a**, **24b**, and **25** can be omitted. When compound **21** was treated with SO_2Cl_2 in $(MeO)_3PO$, a mixture of **25** and **24** (molar ratio of 1:1) was obtained. Heating of the mixture in $CHCl_3$ for 3 h afforded almost pure **25**, whose structure

$$\mathbf{21} \xrightarrow[(MeO)_3PO]{SO_2Cl_2} \mathbf{25} + \mathbf{24}$$

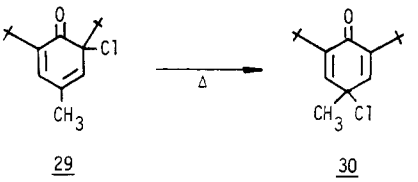
can be determined by its spectral data. It is impossible to isolate compound **24**, but it can be detected by the measurement of the ^{1}H NMR spectrum of the above mixture, which was obtained in the chlorination of **21**. Also it is unknown which of the structure, **24a** or **24b**, is correct. Thus, it is possible to propose that the oxidative product **22** is 6,6′-bis[2,4-di-*tert*-butyl-6-chlorocyclohexa-2,4-dien-1-one].

When **22** was heated in chloroform for 15 min, 1,9b-dihydro-9b-chloro-2,4,6,8-tetra-*tert*-butyl-1-oxo-dibenzofuran (**26**) was obtained in 22% yield along with a large amount of resinous materials. The compound **26** afforded isomerized compound 1,4-dihydro-4-chloro-2,4,6,8-tetra-*tert*-butyl-1-oxo-dibenzofuran (**27**) by heating it in isopropyl alcohol for 15 min.





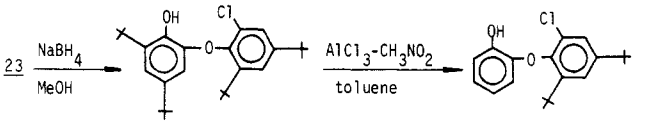
There was observed similar isomerization[11] when 4-methyl-2-chloro-2,6-di-*tert*-butylcyclohexa-2,4-dien-1-one (**29**) was heated, and 4-chloro-4-methyl-cyclohexa-2,5-dien-1-one (**30**) was produced.

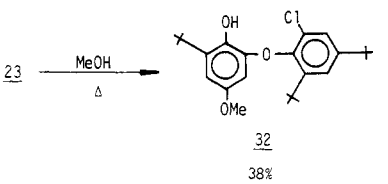


The spectral data such as NMR and UV of **27** and **3** closely resembled each other.

By heating **3** in isopropyl alcohol there was obtained hydrodebrominated compound **5** as stated above, but when **27** was heated in boiling isopropyl alcohol for as long as 3 days, it resulted only in a 21% yield of the corresponding alkoxy derivative **28** along with a large amount of resinous materials, whereas heating of **27** in methanol produced **9a** in 92% yield.

Reduction of **23** with $NaBH_4$ in methanol resulted in 88% yield of 2,4-di-*tert*-butyl-6-(2,4-di-*tert*-butyl-6-chlorophenoxy)phenol (**31**). Heating of **23** in methanol



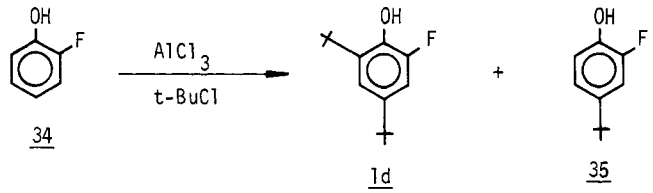


afforded 2-*tert*-butyl-4-methoxy-6-(2,4-di-*tert*-butyl-6-chlorophenoxy)phenol (**32**). When the $AlCl_3$–CH_3NO_2-catalyzed transalkylation[7] of **31** was carried out in toluene, the selective trans *tert*-butylation gave an 84% yield of 2-(2,4-di-*tert*-butyl-6-chlorophenoxy)phenol (**33**).

On the basis of the above results and the spectral data of **23**, its structure was determined as 2,4-di-*tert*-butyl-4-chloro-6-(2,4-di-*tert*-butyl-6-chlorophenoxy)cyclohexa-2,5-dien-1-one.

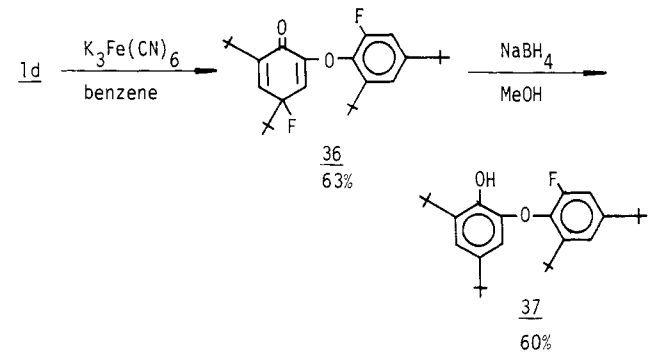
(9) Waring, A. J. *Adv. Alicyclic Chem.* **1966**, *1*, 129.
(10) Rieker, A.; Undel, W. R.; Kessler, H. *Z. Naturforsch., B: Anorg. Chem., Org. Chem.* **1969**, *24B*, 547.
(11) Denivelle, L.; Hedayatullah, M. *Hebd. Seances Acad. Sci.* **1961**, *253*, 2711.

Oxidation of 2-Fluoro-4,6-di-*tert*-butylphenol (1d). The starting compound **1d** was prepared by $AlCl_3$-catalyzed *tert*-butylation of 2-fluorophenol (**34**) with *tert*-butyl chloride.



34 1d 35

Through the oxidation of **1d** we could produce nothing but a 63% yield of **36**. The reduction of **36** with $NaBH_4$ in methanol afforded 2,4-di-*tert*-butyl-6-(2,4-di-*tert*-butyl-6-fluorophenoxy)phenol (**37**) in 60% yield.



36 63% 37 60%

It should be noted that different types of phenols gave different types of products in the oxidation of 2-halophenols **1**.

Reaction Mechanisms. On the basis of the above experimental results, it may be proposed that the reaction mechanisms for the oxidation coupling of **1** with $K_3Fe(CN)_6$ in benzene can be explained by Scheme II.

When X is a small halogen atom such as fluoro, the C–O coupling reaction (course a) is expected to become predominant enough to give compound **36** via intermediate B. On the contrary, bromo and iodo groups might hinder the formation of C–O coupling because their steric hindrance should be larger than that of fluoro group. Thus, in these reactions, C–C coupling selectively occurred to give compounds **2** and **3** through the intermediates shown in Scheme II, respectively. In the case of **1a**, since the C–I bond energy (51 kcal/mol) is lower than that of C–Br (68 kcal/mol), compound **2** will be easily formed. On the other hand, compound **3** might be formed via intermediate G and an unstable compound of type **26**. Since the chloro group is intermediate in size, two different type of compounds, **23** and **22**, will be formed through both courses a and b.

Compound **4** might be formed via intermediates E and F.

Experimental Section

All melting points are uncorrected. IR spectra were measured by a Nippon Bunko IR-A spectrometer as KBr pellets. ^1H NMR spectra were determined with a Nihon Denshi JEOL FT-100 spectrometer with Me_4Si as an internal standard. Mass spectra were determined by using a Nihon Denshi JMS-01SA-2 mass spectrometer at 70 eV with a direct inlet. UV spectra were measured by a Hitachi 124 spectrophotometer.

Oxidation of 1b. See the preliminary communication.[2] After crude **3** was recrystallized from ether, the ether filtrate was evaporated to give a small amount of **4**: colorless plates (MeOH); mp 208.5–210 °C (lit.[3] mp 209–210 °C).

Oxidation of 1c. To a solution of 3.2 g (13.4 mmol) of **1c** in 220 mL of benzene was added a solution of 22 g of $K_3Fe(CN)_6$ and 22 g of KOH in 330 mL of distilled water at room temperature. The mixture was stirred at room temperature under oxygen-free nitrogen for 20 min. The aqueous layer was then removed, and the organic layer was washed with distilled water. The organic solution was dried with Na_2SO_4 and evaporated in vacuo to give a mixture of **22** and **23**. Separation of compounds **22** and **23** was carried out by fractional crystallization by using CCl_4 as solvent.

22: Yellow prisms (ether); yield 0.73 g (23%); mp 126–128 °C dec; IR (KBr) 1685, 1675 cm^{-1}; NMR (CCl_4) δ 1.13 (18 H, s), 1.23 (18 H, s), 6.14 (2 H, d, J = 2 Hz), 6.93 (2 H, d, J = 2 Hz); UV (cyclohexane) λ_{max} 351 nm (log ϵ 3.66). Anal. Calcd for $C_{28}H_{40}O_2Cl_2$: C, 70.13; H, 8.41. Found: C, 70.07; H, 8.43.

23: Pale yellow prisms (hexane); yield 1.69 g (53%); mp 145–146 °C dec; IR (KBr) 1670, 1650 cm^{-1}; NMR (CCl_4) δ 1.09 (9 H, s), 1.33 (9 H, s), 1.37 (18 H, s), 5.41 (1 H, d, J = 3 Hz), 6.75 (1 H d), 7.20–7.30 (2 H, m); UV (cyclohexane) λ_{max} 248 nm (log ϵ 4.11), 299 (2.98). Anal. Calcd for $C_{28}H_{40}O_2Cl_2$: C, 70.13; H, 8.41. Found: C, 70.21; H, 8.47.

Oxidation of 1d. Compound **1d** (3 g) was treated and worked up as described above to give **36**: as pale yellow prisms (hexane); mp 137–138 °C dec; IR (KBr) 1670, 1650 cm^{-1}; NMR (CCl_4) δ 0.96 (9 H, s), 1.27 (9 H, s), 1.30 (9 H, s), 1.33 (9 H, s), 5.40–5.54 (1 H, m), 6.55–7.08 (3 H, m); UV (cyclohexane) λ_{max} 240 nm (log ϵ 4.04), 295 (2.93). Anal. Calcd for $C_{28}H_{40}O_2F_2$: C, 75.30; H, 9.03. Found: C, 75.25; H, 9.01.

Heating of 3 in Isopropyl Alcohol. See the preliminary communication.[2]

Heating of 3 in Methanol. A suspension of **3** (2.44 g, 5 mmol) in methanol (15 mL) was refluxed for 5 min and then evaporated in vacuo. The residue which was recrystallized from methanol to give **9a**: colorless needles; yield 2.10 g (96%); mp 141–142 °C; IR (KBr) 1660 cm^{-1}; NMR ($CDCl_3$) δ 1.08 (9 H, s), 1.37 (9 H, s), 1.41 (9 H, s), 1.53 (9 H, s), 3.07 (3 H, s), 6.63 (1 H, s), 7.40 (1 H, d, J = 2 Hz), 8.15 (1 H, d, J = 2 Hz); UV (cyclohexane) λ_{max} 245 nm (log ϵ 4.38), 300 (3.54). Anal. Calcd for $C_{29}H_{42}O_3$: C, 79.40; H, 9.65. Found: C, 79.48; H, 9.74.

Heating of 3 in Ethanol. A suspension of **3** (2.44 g, 5 mmol) in ethanol (15 mL) was refluxed for 5 min and then evaporated in vacuo. The residue was recrystallized from ethanol to give **9b**: colorless prisms; yield 2.12 g (94%); mp 142.5–143.5 °C; IR (KBr) 1660 cm^{-1}; NMR ($CDCl_3$) δ 1.07 (9 H, s), 1.36 (9 H, s), 1.41 (9 H, s), 1.52 (9 H, s), 1.12 (3 H, t, J = 7 Hz), 2.96–3.36 (2 H, m), 6.65 (1 H, s), 7.37 (1 H, d, J = 2 Hz), 8.12 (1 H, d, J = 2 Hz); UV (cyclohexane) λ_{max} 244 nm (log ϵ 4.37), 296 (3.49). Anal. Calcd for $C_{30}H_{44}O_3$: C, 79.60; H, 9.80. Found: C, 79.60; H, 9.80.

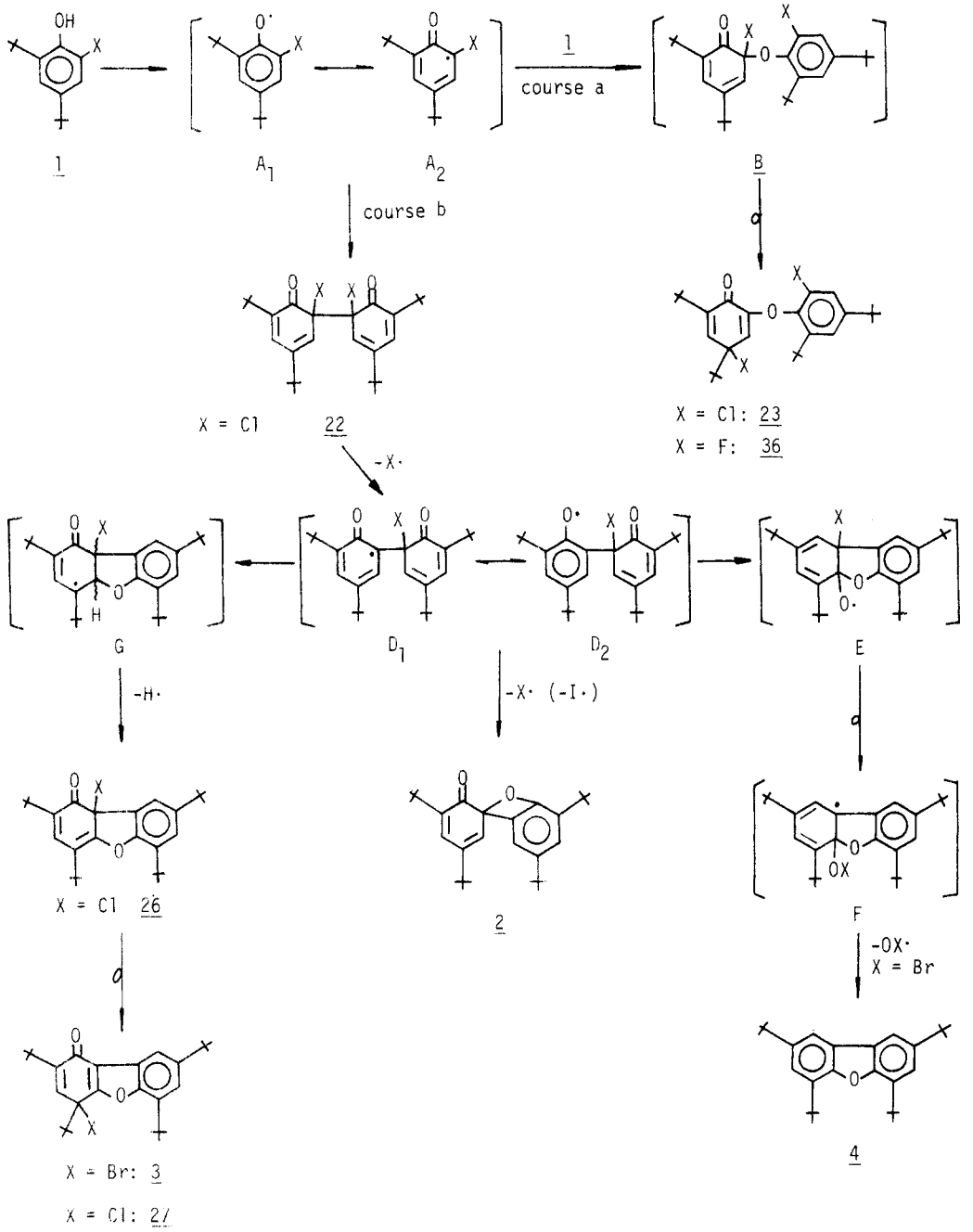
Preparation of 6 from 5, 3, and 1 (One Pot Reaction). See the preliminary communication.[2]

Preparation of 10. To a solution of **9a** (1.31 g, 3 mmol) in dry toluene (60 mL) was added a solution of $TiCl_4$ (2.3 mL, ca. 12 mmol) in dry toluene (5 mL). After the reaction mixture was stirred at room temperature for 15 min, it was poured into a large amount of ice–water and was extracted with ether. The ether solution was dried over Na_2SO_4 and evaporated in vacuo to leave a residue, which was recrystallized from petroleum ether to give **10**: colorless plates; yield 1.01 g (88%); mp 145.5–146 °C; IR (KBr) 3610 cm^{-1}; NMR ($CDCl_3$) δ 1.42 (9 H, s), 1.50 (9 H, s), 1.56 (9 H, s), 4.06 (3 H, s), 5.06 (1 H, br, s), 6.92 (1 H, s), 7.36 (1 H, d, J = 2 Hz), 7.86 (1 H, d, J = 2 Hz); mass spectrum, m/e 382 (M^+). Anal. Calcd for $C_{25}H_{34}O_3$: C, 78.49; H, 8.96. Found: C, 78.21; H, 8.96.

$AlCl_3$-Catalyzed Transalkylation of 10. To a solution of **10** (0.8 g, 2.1 mmol) in dry toluene (40 mL, 0.38 mol) was added finely powdered $AlCl_3$ (0.9 g, 6.7 mmol) at room temperature. After the reaction mixture was stirred for 3 h, it was poured into a large amount of ice–water and extracted with benzene. The benzene solution was extracted with 10% aqueous NaOH solution. The alkaline extract was acidified with 10% aqueous HCl solution and extracted with benzene. The benzene extract was dried over Na_2SO_4 and evaporated in vacuo to leave the residue which was column chromatographed on silica gel with a mixture of benzene and chloroform (1:1) as eluant to render **11**: colorless prisms; yield 120 mg (27%); mp 154–155 °C (lit.[12] mp 155 °C); IR (KBr) 3260 cm^{-1}; NMR ($CDCl_3$) δ 4.02 (3 H, s), 5.08 (1 H, br, s), 6.61 (1 H, d, J = 8 Hz), 6.83 (1 H, d, J = 8 Hz), 7.31–7.77 (3 H, m), 8.05–8.15

(12) Gilman, H.; Van Ess, P. R. *J. Am. Chem. Soc.* **1939**, *61*, 1365.

Scheme II



(1 H, m); mass spectrum, m/e 214 (M^+). *tert*-Butyltoluenes (**7**) were detected by GC analysis.

Preparation of 12. To a suspension of **3** (487 mg, 1 mmol) in 50 mL of $(MeO)_3PO$ was added at 0 °C 800 mg of Br_2. After the reaction mixture was stirred with the temperature kept constant for 1 h, it was poured into a large amount of ice-water. The precipitate was collected, washed with cold water, dried in a desiccator, and recrystallized from a mixture of water and methanol (1:1) to give **12**: yellow needles; yield 345 mg (94%); mp 176–177 °C; IR (KBr) 1670, 1655 cm^{-1}; NMR ($CDCl_3$) δ 1.38 (9 H, s), 1.42 (9 H, s), 1.54 (9 H, s), 6.64 (1 H, s), 7.54 (1 H, d, J = 2 Hz), 8.11 (1 H, d, J = 2 Hz); mass spectrum, m/e 366 (M^+). Anal. Calcd for $C_{24}H_{30}O_3$: C, 78.65; H, 8.25. Found: C, 78.64; H, 8.33.

Preparation of 19. To a solution of **4** (1.57 g, 4 mmol) in dry toluene (85 mL) was added at room temperature finely powdered $AlCl_3$ (1.07 g, 8 mmol). After the reaction mixture was stirred for 3 h, it was poured into a large amount of ice–water and then extracted with benzene. The benzene solution was dried over Na_2SO_4 and evaporated in vacuo to leave the residue which was chromatographed on silica gel by using a mixture of hexane and benzene (2:1) as eluant to give **19**: colorless plates (hexane); yield 510 mg (76%); mp 83–84 °C (lit. mp 83 °C). The formation of **7** was determined by GC analysis.

Preparation of 1c. To a solution of **20** (40.8 g, 0.2 mol) in 100 mL of CCl_4 was added slowly a solution of sulfuryl chloride (27.2 g, 0.2 mol) in 30 mL of CCl_4. The reaction mixture was poured into a large amount of ice–water and extracted with CCl_4. The carbon tetrachloride solution was dried over Na_2SO_4 and evaporated in vacuo to leave the residue which was distilled under reduced pressure to afford **1c**: colorless oil; yield 39.6 g (83%); bp 112.5–113 °C (2 mm); IR (NaCl) 3575 cm^{-1}; NMR ($CDCl_3$) δ 1.38 (9 H, s), 1.41 (9 H, s), 5.72 (1 H, s), 7.22–7.27 (2 H, m); mass spectrum, m/e 240, 242 (M^+). Anal. Calcd for $C_{14}H_{21}OCl$: C, 69.84; H, 8.79. Found: C, 69.77; H, 8.84.

Reduction of 22 with Raney Ni. To a solution of Raney Ni (W-2, ca. 1 g) in 40 mL of ethanol was added a suspension of **22** (480 mg, 1 mmol) in 30 mL of ethanol. After the reaction mixture was stirred at 50 °C for 30 min, the catalyst was filtered off. The filtrate was evaported in vacuo to leave the residue which was recrystallized from methanol to give **21**: colorless prisms; yield 390 mg (95%); mp 194–195 °C (lit.[3] mp 194.5–195.5 °C).

Conversion from 22 to 26. After a solution of **22** (675 mg, 1.4 mmol) in 15 mL of chloroform was refluxed for 3 h, it was

evaporated in vacuo to leave the residue which was recrystallized from ether to give **26**: yellow prisms; yield 141 mg (23%); mp 190–191 °C dec; IR (KBr) 1665 cm^{-1}; NMR (CCl_4) δ 1.14 (9 H, s), 1.39 (9 H, s), 1.45 (9 H, s), 1.52 (9 H, s), 6.18 (1 H, s) 7.18 (1 H, d, J = 2 Hz), 7.86 (1 H, d, J = 2 Hz); UV (cyclohexane) λ_{max} 254 nm (log ϵ 4.31), 335 (3.67). Anal. Calcd for $C_{28}H_{39}O_2Cl$: C, 75.90; H, 8.87. Found; C, 75.80; H, 8.88.

Conversion from 26 to 27. After a suspension of **26** (250 mg, 0.56 mmol) in 25 mL of isopropyl alcohol was refluxed for 15 min, it was evaporated in vacuo to leave the residue which, in a small amount of methanol, gave a precipitate, which was recrystallized from ether to afford **27**: pale yellow prisms; yield 222 mg (89%); mp 191–192 °C dec; IR (KBr) 1655 cm^{-1}; NMR (CCl_4) δ 1.22 (9 H, s), 1.35 (9 H, s), 1.41 (9 H, s), 1.51 (9 H, s), 6.65 (1 H, s), 7.23 (1 H, d, J = 2 Hz), 7.99 (1 H, d, J = 2 Hz); UV (cyclohexane) λ_{max} 245 nm (log ϵ 4.39), 305 (3.36). Anal. Calcd for $C_{28}H_{39}O_2Cl$: C, 75.90; H, 8.87. Found: C, 75.92; H, 8.92.

Prolonged Heating of 27 in Isopropyl Alcohol. After a suspension of **27** (250 mg, 0.56mmol) in 25 mL of isopropyl alcohol was refluxed for 3 days, it was evaporated in vacuo to leave the residue which was recrystallized from ether to give **28**: colorless prisms; yield 55 mg (21%); mp 168–169 °C; IR (KBr) 1655 cm^{-1}; NMr ($CDCl_3$) δ 0.98 (9 H, s), 1.29 (9 H, s), 1.34 (9 H, s), 1.44 (9 H, s), 0.88 (3 H, d, J = 6 Hz), 1.03 (3 H, d, J = 6 Hz), 3.12–3.38 (1 H, m), 6.58 (1 H, s), 7.26 (1 H, d, J = 2 Hz), 8.01 (1 H, d, J = 2 Hz). Anal. Calcd for $C_{31}H_{46}O_3$: C, 79.78; H, 9.94. Found: C, 79.51; H, 10.08.

Heating of 27 in Methanol. A suspension of **27** (250 mg, 0.56 mmol) in 25 mL of methanol was refluxed for 15 min and then evaporated in vacuo to leave the residue which was recrystallized from methanol to give **9a** as colorless needles, yield 227 mg (92%).

Reduction of 23 with $NaBH_4$. To a suspension of **23** (2 g, 4.2 mmol) in 200 mL of methanol was added 1 g of $NaBH_4$. The reaction mixture was stirred at room temperature for 15 min and evaporated in vacuo to leave a residue to which water was added, and the mixture was then extracted with benzene. The benzene solution was dried over sodium sulfate and evaporated in vacuo to leave the residue, which was recrystallized from methanol to give **31**: colorless prisms; yield 1.64 g (88%); mp 150–151 °C; IR (KBr) 3540 cm^{-1}; NMR ($CDCl_3$) δ 1.15 (9 H, s), 1.35 (9 H, s), 1.37 (9 H, s), 1.47 (9 H, s), 5.90 (1 H, s), 6.24 (1 H, d, J = 2 Hz), 6.98 (1 H, d, J = 2 Hz), 7.33 (1 H, d J = 2 Hz), 7.43 (1 H, d, J = 2 Hz). Anal. Calcd for $C_{28}H_{41}O_2Cl$: C, 75.56; H, 9.28. Found: C, 75.53; H, 9.36.

Heating of 23 in Methanol. A suspension of **23** (600 mg, 1.25 mmol) in 40 mL of methanol was refluxed for 30 min and then evaporated in vacuo to leave the residue which was chromatographed on silica gel using a mixture of hexane and benzene (2:1) as eluent to afford **32**: colorless prisms (methanol); yield 202 mg (38%); mp 150–151 °C; IR (KBr) 3540 cm^{-1}; NMR ($CDCl_3$) δ 1.33 (9 H, s), 1.36 (9 H, s), 1.45 (9 H, s), 3.62 (3 H, s), 5.64 (1 H, s), 5.83 (1 H, d, J = 3 Hz), 6.51 (1 H, d, J = 3 Hz), 7.26 (1 H, d, J = 3 Hz), 7.35 (1 H, d, J = 3 Hz); mass spectrum, m/e 418, 420 (M^+). Anal. Calcd for $C_{25}H_{35}O_3Cl$: C, 71.66; H, 8.42. Found: C, 71.62; H, 8.52.

$AlCl_3$-Catalyzed Trans *tert*-Butylation of 31. To a solution of **31** (1.5 g, 3.4 mmol) in 80 mL of dry toluene was added a solution of $AlCl_3$ (1.2 g, 9 mmol) in 3 mL of nitromethane. After the reaction mixture was stirred for 3 h at room temperature, it was treated and worked up as described above to give 940 mg (84%) of **33**: colorless prisms (hexane); IR (KBr) 3520 cm^{-1}; NMR ($CDCl_3$) δ 1.32 (9 H, s), 1.34 (9 H, s), 5.70 (1 H, s), 6.29 (1 H, dd, J = 8, 2 Hz), 6.58–7.05 (3 H, m), 7.25 (1 H, d, J = 2.5 Hz), 7.33 (1 H, d,J = 2.5 Hz); mass spectrum, m/e 332, 334 (M^+). Anal. Calcd for $C_{20}H_{25}O_2Cl$: C, 72.17; H, 7.57. Found: C, 72.23; H, 7.65.

Preparation of 1d. To a suspension of $AlCl_3$ (4.6 g, 34.5 mmol) in 2-fluorophenol (25 g, 0.22 mol) was added *tert*-butyl chloride (49.2 g, 0.53 mol). After the reaction mixture was stirred at room temperature for 1 day, it was poured into a large amount of ice–water and then extracted with benzene. The benzene solution was washed with 10% aqueous NaOH and water, dried over sodium sulfate, and evaporated in vacuo to leave a residue, which was distilled under reduced pressure to afford **1d**. The aqueous NaOH solution was acidified with 10% HCl solution and extracted with benzene. The benzene solution was dried over sodium sulfate and evaporated in vacuo to give **35**.

1d: Colorless oil; yield 12 g (24%); bp 93–93.5 °C (2 mm); IR (NaCl) 3580 cm^{-1}; NMR ($CDCl_3$) δ 1.28 (9 H, s), 1.41 (9 H, s), 5.14 (1 H, d, J = 7 Hz), 6.82–7.12 (2 H, m); mass spectrum, m/e 224 (M^+). Anal. Calcd for $C_{14}H_{21}OF$: C, 74.96; H, 9.44. Found: C, 74.77; H, 9.43.

35: Colorless needles (hexane); yield 21.7 g (58%); mp 59–60 °C; IR (KBr) 3350 cm^{-1}; NMR ($CDCl_3$) δ 1.24 (9 H, s), 5.52 (1 H, s), 6.76–7.08 (3 H, m); mass spectrum, m/e 168 (M^+). Anal. Calcd for $C_{10}H_{13}OF$: C, 71.40; H, 7.79. Found: C, 71.56; H, 7.90.

Reduction of 36 with $NaBH_4$. To a suspension of **36** (230 mg, 0.52 mmol) in 30 mL of methanol was added 1.5 g of $NaBH_4$. After the reaction mixture was heated at 60 °C for 2 h, it was treated and worked up as described above to give 131 mg (60%) of **37**: colorless prisms (MeOH); mp 134–135 °C; IR (KBr) 3540 cm^{-1}; NMR ($CDCl_3$) δ 1.16 (9 H, s), 1.32 (9 H, s), 1.38 (9 H, s), 1.46 (9 H, s), 5.84 (1 H, s), 6.36–6.40 (1 H, m), 6.86–7.18 (3 H, m); mass spectrum, m/e 428 (M^+). Anal. Calcd for $C_{28}H_{41}O_2F$: C, 78.46; H, 9.64. Found: C, 78.22; H, 9.55.

Chlorination of 21 with SO_2Cl_2. To a solution of **21** (2 g, 4.9 mmol) in 50 mL of trimethyl phosphate was slowly added 1.35 g (10 mmol) of sulfuryl chloride at 0 °C. After the reaction mixture was stirred at 0 °C for 20 min, it was poured into a large amount of ice–water to give a yellow precipitate which was a mixutre of **24** and **25**: yellow prisms (ether); yield 1.74 g (74%); IR (KBr) 1670–1640 cm^{-1}; NMR (CCl_4) δ 1.10, 1.16, 1.20 and 1.22 (each 9 H, s), 1.25 (18 H, s), 6.10 (1 H, d, J = 2.5 Hz), 6.64–6.74 (6 H, m), 6.99 (1 H, d, J = 2.5 Hz); UV (cyclohexane) λ_{max} 239 nm (log ϵ 3.98), 323 (3.57). Anal. Calcd for $C_{28}H_{40}O_2Cl_2$: C, 70.13; H, 8.41. Found: C, 70.14; H, 8.42.

After a solution of 1.5 g of the above mixture in 40 mL of chloroform was refluxed for 3 h, it was evaporated in vacuo to leave a residue, which was recrystallized from ether to give pure **25**: pale yellow prisms; yield 0.81 g; mp 175–179 °C dec; IR (KBr) 1640–1650 cm^{-1}; NMR (CCl_4) δ 1.20 (18 H, s), 1.25 (18 H, s), 6.71 (2 H, d, J = 3 Hz), 6.83 (2 H, d, J = 3 Hz); UV (cyclohexane) λ_{max} 248 nm (log ϵ 4.24). Anal. Calcd for $C_{28}H_{40}O_2Cl_2$: C, 70.12; H, 8.41. Found: C, 70.30; H, 8.52.

Registry No. 1b, 20834-61-1; **1c**, 4166-86-3; **1d**, 78231-86-4; **3**, 75116-25-5; **4**, 18813-80-4; **5**, 75116-27-7; **6**, 33483-06-6; **9a**, 78249-44-2; **9b**, 78231-87-5; **10**, 78231-88-6; **11**, 78231-89-7; **12**, 78231-90-0; **19**, 132-64-9; **20**, 96-76-4; **21**, 6390-69-8; **22**, 78231-91-1; **23**, 78231-92-2; **24**, 78249-02-2; **25**, 78231-93-3; **26**, 78231-94-4; **27**, 78231-95-5; **28**, 78231-96-6; **31**, 78231-97-7; **32**, 78249-45-3; **33**, 78231-98-8; **35**, 38946-63-3; **36**, 78249-46-4; **37**, 78231-99-9; benzene, 71-43-2; tripotassium hexakis(cyano-*c*)ferrate(3$^-$), 13746-66-2; methanol, 67-56-1; ethanol, 64-17-5; isopropyl alcohol, 67-63-0; *tert*-butyl chloride, 507-20-0; 2-fluorophenol, 367-12-4.