$^2\Delta$-Stereocontrolled Entry to (*E*)- or (*Z*)-Prenyl Aromatics and Quinones. Synthesis of Menaquinone-4

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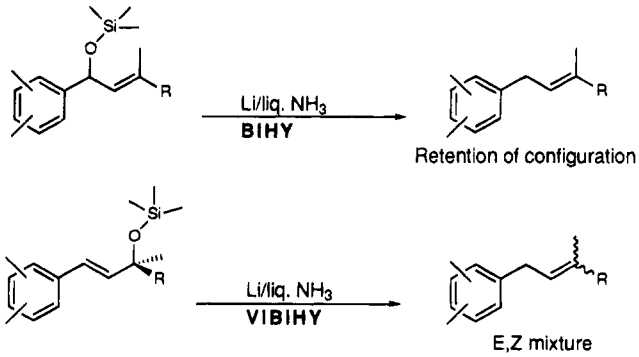
Received March 3, 1994

In the course of our efforts toward a $^2\Delta$-stereocontrolled synthesis of prenylated benzoquinones based on the oxidative degradation approach (ODA),[1] we observed that Birch hydrogenolysis (BIHY) of (*E*)- or (*Z*)-α-alkenylbenzyl alcohols (as silyl ethers) took place with almost complete retention of configuration of the $^2\Delta$ double bond. This is in contrast to the so-called vinylogous Birch hydrogenolysis (VIBIHY) of the corresponding cinnamyl alcohols, which occurs with loss of the stereochemical integrity of the double bond (Scheme 1).[2] This previously unnoticed feature permitted us to successfully achieve practical syntheses of some prenylated aromatics[3] and benzoquinones.[2] We were, however, curious to see whether or not aromatic systems having lower LUMO energies behaved in an analogous manner, since the LUMO has a possible role in determining the stereochemical fate of the BIHY and VIBIHY reactions.

The available methodology for the preparation of prenyl-substituted quinones and aromatics,[4] namely (1) the catalyzed or uncatalyzed prenylation of quinones or masked quinones[5] with allylmagnesium,[5] allylsilanes,[6] allyltin,[7] or allylnickel reagents[8] and (2) the prenylation of lithium,[9] tin,[10] or copper[11,12] organometallics derived

Scheme 1



from quinone synthons, as well as some other methods,[13] allows for attaching simple (C_5, C_{10}, C_{15}, etc.) prenyl groups to the selected synthon. Unfortunately, some of these methods lack generality in that prenyl groups can only be appended ortho to an existing phenolic group,[14] while others lack the necessary regio-[7c] and/or stereocontrol at the sensitve $^2\Delta$ double bond.[8,15]

We have pursued the study of the above hydrogenolysis reactions with a 2-fold objective: (1) to find their scope and limitations and (2) to provide a precise mechanistic explanation of these otherwise puzzling stereochemical results.[16] Regardless of the mechanistic rational, it was clear that a general, efficient protocol for the prenylation of aromatics would be more useful than current methodologies because (1) it would allow for the stereocontrolled synthesis of either one of the $^2\Delta$ stereoisomers, (2) it would employ readily available reagents such as organolithium compounds and stereochemically pure, unsaturated aldehydes, and (3) it would be rapid and efficient. Herewith, we demonstrate the validity of our synthetic approach, based on the above stereocontrolled BIHY-based methodology, to the preparation of prenylated naphthalenes and menaquinones **1**. These important prenylnaphthoquinones[17] have been synthesized with strict stereochemical control by Snyder and Rapoport, after an initial unsuccessful attempt at achieving the hydrogenolytic removal of the −OH function of α-alkenylnaphthyl alcohols.[12]

Condensation of the organolithium species, derived from a halogen-to-metal exchange reaction applied to

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(3) Ballester, P.; Capó, M.; Saá, J. M. *Tetrahedron Lett.* **1990**, *31*, 1339.

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(10) Godschalx, J. P.; Stille, J. K. *Tetrahedron Lett.* **1983**, *24*, 1905. For the recent use of stannylquinones for this purpose, see: Liebeskind, L. S.; Foster, B. S. *J. Am. Chem. Soc.* **1990**, *112*, 8612.

(11) (a) Fujita, Y.; Ishiguro, M.; Onishi, J.; Nishida, T. *Synthesis* **1981**, 469. (b) Swenton, J. S.; Jackson, D. K.; Manning, M. J.; Raynolds, P. W. *J. Am. Chem. Soc.* **1978**, *100*, 6182. (c) Raynolds, P. W.; Manning, M. J.; Sewnton, J. S. *J. Chem. Soc., Chem. Commun.* **1977**, 499. (d) Chenard, B. L.; Manning, M. J.; Raynolds, P. W.; Swenton, J. S. *J. Org. Chem.* **1980**, *45*, 378. (e) Keinan, E.; Eren, D. *J. Org. Chem.* **1987**, *52*, 3872. Sato, K. (f) Miyamoto, O.; Inoue, S.; Yamamoto, T.; Hirasawa, Y. *J. Chem. Soc., Chem. Commun.* **1982**, 153. See also ref 12.

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(15) Partial loss of stereochemistry has been noticed by several authors when attempting the synthesis of (*Z*)-$^2\Delta$-prenylquinones and aromatics. See, for example: Naruta, Y.; Maruyama, K. *Chem. Lett.* **1979**, 885. See also refs 7d,e, and 12. Not unfrequently chemical yields are significantly lower for the *Z* isomers. See, for example: Yoshizawa, T.; Toyofuka, H.; Tachibana, K.; Kuroda, T. *Chem. Lett.* **1982**, 1131.

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bromonaphthalene **2**,[18] with the appropriate, recently prepared unsaturated aldehyde[19] (geranial, neral, and *all-trans*-geranylgeranial) led to the corresponding α-alkenylnaphthyl alcohols **3**. These were then submitted to a slightly modified BIHY protocol[2,3] involving (1) silyl ether formation, (2) lithium-promoted reductive cleavage in THF, to avoid reduction of the naphthalene nucleus, which occurs when working in liquid ammonia,[20] and (3) quenching of the resulting organolithium species with ammonium chloride solution. As previously reported for the benzene series, Birch hydrogenolysis of the naphthyl alcohols **3** preserved the $^2\Delta$ stereochemistry already present in the starting alcohols (2′*E*)-**3a**, (2′*Z*)-**3a**, and (2′*E*,6′*E*,10′*E*)-**3b**, thus resulting in the formation of prenylated naphthalenes **4** in a stereodefined manner (retention of configuration). This was determiend by careful examination of the ^{1}H, ^{13}C, and NOESY spectra (supplementary material). The reaction with commercial citral (68:32 *E*:*Z*) eventually gave rise to a 2:1 *E*,*Z* mixture of prenylated naphthalenes **4a**, thereby lending further credit to the above results.

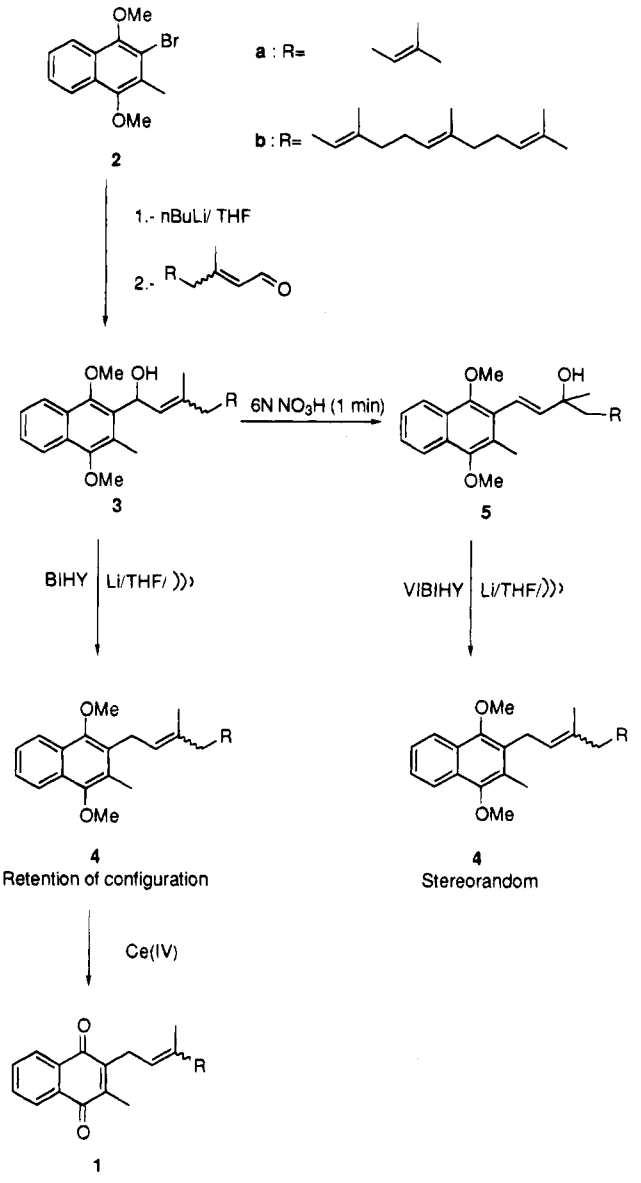
These stereochemical results were further confirmed by examining the NMR properties of the all trans menaquinone-4 **1c** obtained by Ce(IV) oxidation of the all-trans **4b** in the presence of a catalytic amount of Adogen. On the other hand, compounds (2′*E*)- and (2′*Z*)-**4a** have already been converted into the corresponding menaquinone-2.[12]

Acid-catalyzed isomerization of alcohols **3** yielded the isomeric all-trans cinnamyl-type alcohols **5a**,**b** (J = 16.3 Hz). Best results were obtained with a short treatment (1 min) of **3** with nitric acid, thereby avoiding dehydration, as reported by Rapoport.[9] In line with previous observations,[2,3] cinnamyl-type alcohol **5a** afforded **4a** as an *E*:*Z* mixture (56:44) when submitted to the VIBIHY protocol. Alcohol **5b** eventually (after VIBIHY and subsequent oxidation as above) afforded menaquinone-4 **1b** as a $^2\Delta$ *E*:*Z* (60:40) mixture.

In summary, the BIHY-based synthesis of $^2\Delta$-stereodefined prenylquinones and aromatics works well for the naphthalene series and validates this protocol for the stereocontrolled (with retention of configuration at the sensitive $^2\Delta$ double bond) access to either the *E* or *Z* isomers of these type of compounds.[2,3] The corresponding VIBIHY is a nonstereocontrolled process yielding, instead, *E*:*Z* mixtures. The mechanistic implications of these results are presently being studied.[16]

Experimental Section

General Methods. Proton NMR spectra were obtained at 300 MHz in $CDCl_3$ with TMS as internal standard, unless otherwise noted. Electron impact mass spectra were recorded at 70 eV ionizing energy. Column chromatographies were performed on Merck silica gel (Kieselgel 40). TLC was performed on silica plates purchased from Scharlau (Glasschrom Si F_{254} 0.5 mm). Geranial, neral, and geranylgeranial were prepared from the corresponding commercial alcohols (Aldrich) by Swern oxidation and their purity checked by ^{1}H NMR and ^{13}C NMR spectroscopy.[19]



THF and diethyl ether were distilled from sodium benzophenone ketyl prior to use. All reactions with organolithium compounds were carried under a blanket atmosphere of argon.

The standard workup procedure employed throughout involved extraction of the aqueous solution with three to five 25-mL portions of CH_2Cl_2 or Et_2O, followed by drying of the organic phases over Na_2SO_4 and evaporation *in vacuo*. The residue was usually flash chromatographed on silica gel using hexane:ethyl acetate (9:1) for elution.

Unless otherwise noted, the purity of new compounds for which combustion analysis could not be obtained was judged to be ≥95% on the basis of its ^{1}H NMR spectrum (available as supplementary material).

Preparation of α-Alkenylnaphthyl Alcohols 3. A solution of bromonaphthalene **2** (281 mg, 1 mmol) in anhydrous diethyl ether (2 mL), at 0 °C, was treated with 1 equiv of n-BuLi (1.6 M, 625 μL, 1 mmol). After the solution was stirred for 10 min the ice–water bath was removed and the reaction continued to stir for another 1 h. The resulting heterogeneous solution of the lithio derivative was cooled to 0 °C and 0.9 equiv of the appropriate unsaturated aldehyde (137 mg, 163 μL) added, after which stirring was continued for an additional 30 min. The standard extractive workup and purification yielded $^2\Delta$ stereochemically pure naphthyl alcohols **3a**,**b**.

(2′*Z*)-2-Methyl-3-(1′-hydroxy-3′,7′-dimethyl-2′,6′-octadienyl)-1,4-dimethoxynaphthalene ((2′*Z*)-3a). Obtained in 68% yield (based on neral[19]) as a colorless oil (13:87 *E*:*Z* mixture). ^{1}H NMR: 1.60 (s, 3H), 1.67 (bs, 3H), 1.77 (bs, 3H), 2.1–2.4 (m, 4H), 2.51 (s, 3H), 3.11 (d, J = 6.2 Hz, 1H), 3.86 (s, 3H), 3.99 (s,

(18) Adams, R.; Geisman, T. A.; Baker, B. R.; Teeter, H. M. *J. Am. Chem. Soc.* **1941**, *63*, 528.

(19) Obtained from commercial samples of geraniol, nerol, and geranylgeraniol by oxidation according to the Swern procedure: Mancuso, A. J., Huang, S. L.; Swern, D. *J. Org. Chem.* **1978**, *43*, 2480. Geranial and neral were shown to be 95:5 and 10:90 *E*:*Z* mixtures according to the ^{1}H and ^{13}C NMR spectra.[3] Geranylgeranial was shown to be >95% stereochemically (*E*,*E*,*E*) pure.

(20) Rabideau, P. W. *Tetrahedron* **1989**, 45, 1579 and references cited therein.

3H), 5.15 (t, 1H), 5.72 (d, J = 8.4 Hz, 1H), 5.98 (dd, J = 8.4 y 6.2 Hz, 1H), 7.48–7.44 (m, 2H), 8.07–8.01 (m, 2H) ppm. ^{13}C NMR: 150.56, 150.03, 140.22, 132.27, 132.18, 128.22, 127.50, 127.16, 126.03, 125.64, 125.48, 123.97, 122.37, 122.23, 66.54, 63.11, 61.23, 32.32, 26.42, 25.63, 23.44, 17.62, 12.75 ppm. IR (film): 3450 (br), 2940 (br), 1585, 1455, 1380, 1355, 1065, 780 cm^{-1}. MS *m/e*: 354 (M$^+$, 26), 339 (14), 323 (27), 235 (20), 229 (100), 202 (24), 199 (21), 187 (31), 149 (53). HRMS: calcd for $C_{23}H_{30}O_3$ 354.219 49, found 354.218 96.

(2′*E*)-2-Methyl-3-(1′-hydroxy-3′,7′-dimethyl-2′,6′-octadienyl)-1,4-dimethoxynaphthalene ((2′*E*)-3a). Obtained in 65% yield (based on geranial) as a colorless oil (93:7 *E*:*Z* mixture). ^{1}H NMR: 1.55 (s, 3H), 1.62 (bs, 3H), 1.85 (bs, 3H), 2.0–2.2 (m, 4H), 2.48 (s, 3H), 3.40 (d, J = 6.8 Hz, 1H), 3.86 (s, 3H), 4.00 (s, 3H), 5.04 (bt, 1H), 5.65 (d, J = 8.2 Hz, 1H), 5.95 (dd, J = 8.2 Hz, 1H), 7.46–7.50 (m, 2H), 8.01–8.08 (m, 2H) ppm. ^{13}C NMR: 150.51, 149.86, 139.81, 132.31, 131.62, 128.15, 127.08, 126.55, 126.00, 125.61, 125.43, 123.82, 122.27, 122.21, 67.02, 63.06, 61.19, 39.64, 26.25, 25.57, 17.59, 16.60, 12.58 ppm. IR (film): 3450 (br), 2940 (br), 1585, 1450, 1380, 1350, 1280, 1065, 775 cm^{-1}. MS *m/e*: 354 (M$^+$, 23), 339 (2), 239 (16), 229 (100), 202 (17), 199 (17), 187 (22), 115 (19), 69 (48). HRMS: calcd for $C_{23}H_{30}O_3$ 354.219 49, found 354.219 37.

(2′*E*,6′*E*,10′*E*)-2-Methyl-3-(1′-hydroxy-3′,7′,11′,15′-tetramethyl-2′,6′,10′,14′-hexadecatetraenyl)-1,4-trimethoxynaphthalene ((2′*E*,6′*E*,10′*E*)-3b). Obtained in 58% yield (based on geranylgeranial) as a colorless oil (>95% stereochemically pure). ^{1}H NMR: 1.55 (s, 3H), 1.57 (d, J = 0.7 Hz, 3H), 1.59 (s, 3H), 1.67 (d, 0.7 Hz, 3H), 1.86 (d, J = 1.2 Hz, 3H), 2.14–1.92 (m, 12H), 2.49 (s, 3H), 3.40 (d, J = 6.8 Hz, 1H), 3.86, (s, 3H), 4.00 (s, 3H), 5.04–5.10 (m, 3H), 5.67 (d, J = 8.3 Hz, 1H), 5.96 (dd, J = 8.3 y 6.8 Hz, 1H), 7.51–7.46 (m, 2H), 8.07–8.01 (m, 2H) ppm. ^{13}C NMR: 150.44, 149.75, 139.67, 135.19, 134.74, 132.21, 131.02, 128.07, 127.00, 126.44, 125.91, 125.59, 125.33, 124.27, 124.00, 123.60, 122.20, 122.12, 66.80, 62.93, 61.05, 39.60, 39.56, 39.53, 26.61, 26.44, 26.17, 25.55, 17.53, 16.56, 15.88, 15.81, 12.56 ppm. IR (film): 3450 (br), 2940 (br), 1595, 1460, 1380, 1360, 1270, 1175, 1020, 780, 740 cm^{-1}. MS *m/e*: 490 (M$^+$, 13), 472 (5), 253 (12), 239 (18), 237 (23), 231 (32), 229 (100), 215 (32), 202 (20), 69 (30). HRMS: calcd for $C_{33}H_{46}O_3$ 490.3447, found 490.3444.

Acid-Catalyzed Rearrangement. Preparation of Cinnamyl-Type Alcohols 5. The procedure described by Rapoport et al.[9] was employed.

(1′*E*)-2-Methyl-(3′-hydroxy-3′,7′-dimethyl-1′,6′-octadienyl)-1,4-dimethoxynaphthalene ((1′*E*)-5a). Obtained in 64% yield (overall from **2**). ^{1}H NMR: 1.45 (s, 3H), 1.63 (s, 3H), 1.70 (bs, 3H), 1.77–1.72 (m, 2H), 2.21–2.12 (m, 2H), 2.43 (s, 3H), 3.81 (s, 3H), 3.87 (s, 3H), 5.17 (bt, J = 7.1 Hz, 1H), 6.36 (d, J = 16.3 Hz, 1H), 6.72 (d, J = 16.3 Hz, 1H), 7.50–7.43 (m, 2H), 8.03–8.10 (m, 2H) ppm. ^{13}C NMR: 149.89, 149.82, 142.77, 131.97, 127.71, 127.53, 127.46, 125.90, 125.86, 125.44, 124.24, 122.42, 121.97, 120.77, 73.68, 61.22, 60.68, 42.52, 28.44, 25.66, 22.96, 17.68, 13.62 ppm. IR (film): 3460 (br), 2970, 2940, 1580, 1445, 1345, 1260, 1190, 1095, 1060, 1010, 965, 770 cm^{-1}. MS *m/e*: 354 (M$^+$, 31), 336 (22), 305 (33), 296 (38), 271 (100), 239 (50), 235 (86), 229 (66), 215 (55), 201 (45), 199 (44), 197 (57), 165 (46), 152 (45), 115 (43), 69 (97). HRMS: calcd for $C_{23}H_{30}O_3$ 354.219 45, found 354.220 43.

(1′*E*,6′*E*,10′*E*)-2-Methyl-3-(3′-hydroxy-3′,7′,11′,15′-tetramethyl-1′,6′,10′,14′-hexadecatetraenyl)-1,4-dimethoxynaphthalene ((1′*E*,6′*E*,10′*E*)-5b). Obtained from (1′*E*,6′*E*,10′*E*)-**3b** in 62% yield (based on geranylgeranial) as a colorless oil. ^{1}H NMR: 1.45 (s, 3H), 1.59 (s, 6H), 1.63 (s, 3H), 1.68 (s, 3H), 2.3–1.90 (m, 12H), 2.43 (s, 3H), 3.81 (s, 3H), 3.87 (s, 3H), 5.11–5.14 (m, 2H), 5.22 (t, 1H), 6.37 (d, J = 16.4 Hz, 1H), 6.73 (d, J = 16 Hz, 1H), 7.49–7.45 (m, 2H), 8.12–8.05 (m, 2H) ppm. ^{13}C NMR: 149.83, 149.76, 142.77, 135.50, 134.90, 131.08, 127.66, 127.51, 127.41, 125.84, 125.81, 125.38, 124.31, 124.11, 124.02, 122.37, 121.91, 120.71, 73.58, 61.12, 60.60, 42.52, 39.63, 28.39, 26.67, 26.48, 25.60, 22.84, 17.58, 15.98, 15.91, 13.57 ppm. IR (film): 3440 (br), 2950, 2910, 2830, 1580, 1445, 1345, 1090, 1060, 765 cm^{-1}. MS *m/e*: 490 (M$^+$, 8), 472 (3), 432 (7), 296 (16), 271 (74), 239 (29), 229 (41), 215 (100), 200 (29), 184 (22), 69 (43). HRMS: calcd for $C_{33}H_{46}O_3$ 490.3447, found 490.3441.

Modified[2,3] BIHY and VIBIHY Reactions. Silylation of alcohols **3** and **5** was carried out as previously described,[2] the crude silyl ethers, without further purification, being immediately used in the following BIHY or VIBIHY reactions. Small pieces of lithium, washed with hexane, were placed in a three-necked round-bottomed flask containing dry THF (2 mL), cooled to 0 °C. The crude silylated alcohols **3** and **5** (1 mmol), dissolved in dry THF (3 mL), were added via syringe to the above solution. The mixture was sonicated for 15 min at ca. 0–5 °C. The dark green reaction was then quenched by addition of solid NH_4Cl until the color disappeared. Standard workup yielded prenylated naphthalenes **4**.

(2′*E*)-2-Methyl-3-(3′,7′-dimethyl-2′,6′-octadienyl)-1,4-dimethoxynaphthalene ((2′*E*)-4a). Obtained from (2′*E*)-**3a** in 69% yield as a colorless oil (95:5 *E*:*Z* mixture). ^{1}H NMR: 1.58 (bs, 3H), 1.65 (bs, 3H), 1.83 (bs, 3H), 2.10–2.00 (m, 4H), 2.38 (s, 3H), 3.57 (d, J = 6.3 Hz), 3.88 (s, 3H), 3.90 (s, 3H), 5.06 (bt, J = 6.2 Hz, 1H), 5.12 (bt, J = 5.3 Hz, 1H), 7.50–7.45 (m, 2H), 8.03–8.08 (m, 2H) ppm. ^{13}C NMR: 150.05, 149.69, 135.64, 131.37, 130.90, 127.44, 127.22, 126.93, 125.37, 125.24, 124.19, 122.88, 122.25, 122.07, 62.16, 61.29, 39.62, 26.51, 26.30, 25.65, 17.64, 16.31, 12.32 ppm. IR (film): 2960, 2950, 2850, 1590, 1455, 1375, 1350, 1260, 1095, 1060, 1015, 775 cm^{-1}. MS *m/e*: 338 (M$^+$, 100), 323 (3), 307 (4), 269 (7), 239 (42), 223 (33), 215 (28), 201 (25). HRMS: calcd for $C_{23}H_{30}O_2$ 338.224 58, found 338.225 52.

(2′*Z*)-2-Methyl-3-(3′,7′-dimethyl-2′,6′-octadienyl)-1,4-dimethoxynaphthalene ((2′*Z*)-4a). Obtained from (2′*Z*)-**3a** in 72% yield as a colorless oil (10:90 *E*:*Z* mixture). ^{1}H NMR: 1.68 (s, 3H), 1.71 (d, J = 1.4 Hz, 3H), 1.74 (s, 3H), 2.17–2.37 (m, 4H), 2.38 (s, 3H), 3.57 (dd, J = 6.3 y 1.2 Hz, 2H), 3.87 (s, 3H), 3.88 (s, 3H), 5.11 (bt, J = 6.3 Hz, 1H), 5.23 (bt, J = 6.1 Hz, 1H), 7.44–7.48 (m, 2H), 8.08–8.03 (m, 2H) ppm. ^{13}C NMR: 150.06, 149.71, 135.99, 131.74, 130.92, 127.46, 127.22, 126.84, 125.36, 125.23, 124.30, 123.43, 122.26, 122.08, 62.18, 61.30, 32.33, 26.32, 26.06, 25.77, 23.31, 17.67, 12.45 ppm. IR (film): 2955, 2940, 2850, 1595, 1455, 1380, 1360, 1265, 1100, 1065, 1010, 780 cm^{-1}. EM *m/e*: 338 (M$^+$, 100), 323 (9), 307 (18), 239 (45), 223 (41), 215 (32), 201 (31). HRMS: calcd for $C_{23}H_{30}O_2$ 338.224 58, found 338.223 00.

(2′*E*,*Z*)-2-Methyl-3-(3′,7′-dimethyl-2′,6′-octadienyl)-1,4-dimethoxynaphthalene ((2′*E*,*Z*)-4a). Obtained from (1′*E*)-**5a** in 59% yield as a colorless oil (56:44 *E*:*Z* mixture). ^{1}H NMR: 1.58 (s), 1.65 (s), 1.68 (s), 1.71 (s), 1.74 (s), 1.83 (s), 2.10–2.37 (m), 2.38 (s), 3.57 (dd, J = 6.3 y 1.2 Hz, 2H), 3.87 (s), 3.90 (s), 5.06 (bt), 5.12 (bt), 5.23 (bt), 7.44–7.48 (m), 8.03–8.08 (m) ppm. ^{13}C NMR: 150.04, 149.70, 135.99, 135.65, 131.74, 131.38, 130.91, 127.43, 127.21, 126.94, 125.37, 125.03, 124.30, 124.19, 123.42, 122.87, 122.25, 122.07, 62.17, 61.30, 39.62, 32.33, 26.51, 26.30, 26.05, 25.77, 25.66, 23.31, 17.67, 17.64, 16.32, 12.45, 12.32 ppm. IR (film): 3050–2850 (br), 1590, 1455, 1375, 1350, 1260, 1095, 1060, 1015, 775 cm^{-1}. MS *m/e*: 338 (M$^+$, 100), 323 (6), 307 (11), 239 (45), 223 (35), 215 (27), 201 (24). HRMS: calcd for $C_{23}H_{30}O_2$ 338.224 58, found 338.223 86.

(2′*E*,6′*E*,10′*E*)-2-Methyl-3-(3′,7′,11′,15′-tetramethyl-2′,6′,-10′,14′-hexadecatetraenyl)-1,4-dimethoxynaphthalene ((2′*E*,6′*E*,10′*E*)-4b). Obtained from (2′*E*,6′*E*,10′*E*)-**3b** in 53% yield as a colorless oil (>95% stereochemically pure). ^{1}H NMR: 1.56 (d, J = 1.2 Hz, 3H), 1.57 (d, J = 1.1 Hz, 3H), 1.59 (s, 3H), 1.67 (d, J = 0.9 Hz, 3H), 1.83 (d, J = 0.9 Hz, 3H), 2.00–2.07 (m, 12H), 2.38 (s, 3H), 3.56 (d, J = 6.3 Hz), 3.86 (s, 3H), 3.88 (s, 3H), 5.05–5.13 (m, 4H), 7.47–7.44 (m, 2H), 8.04–8.00 (m, 2H) ppm. ^{13}C NMR: 150.05, 149.70, 135.74, 135.08, 134.89, 131.24, 130.90, 127.45, 127.22, 126.92, 125.37, 125.24, 124.38, 124.17, 124.04, 122.78, 122.25, 122.09, 62.18, 61.31, 39.69, 26.73, 26.60, 26.54, 26.31, 25.68, 17.66, 16.40, 16.00, 15.95, 12.38 ppm. IR (film): 3050, 2950, 2800, 1615, 1480, 1380, 1290, 1125, 1090, 800 cm^{-1}. MS *m/e*: 474 (M$^+$, 34), 239 (50), 223 (36), 215 (100), 200 (26), 185 (37), 69 (50). HRMS: calcd for $C_{33}H_{46}O_2$ 474.349 78, found 474.348 33.

Cerium Ammonium Nitrate Oxidation. Preparation of Menaquinones. A 0.5 M cerium ammonium nitrate solution in 1:1 acetonitrile:water (1 mL) was added to a cold, stirred solution (1:1 acetonitrile:hexane) of prenylnaphthalenes **4** containing a catalytic amount of Adogen (in mL of water). After the mixture was stirred for another 30 min., hexane was added and the organic phase separated, washed and evaporated to dryness. Column chromatography yielded menaquinones.

***all-trans*-Menaquinone-4 ((2′*E*,6′*E*,10′*E*)-1b).** Isolated in 86% yield as a yellow solid (>95% stereochemically pure), from the oxidation of (2′*E*,6′*E*,10′*E*)-**4b**. ^{1}H NMR: 8.09–8.06 (m, 2H), 7.70–7.67 (m, 2H) 5.07–5.01 (m, 4H), 3.37 (d, J = 6.9 Hz, 2H), 2.18 (s, 3H), 2.07–1.91 (m, 12H), 1.79 (bs, 3H), 1.67 (s, 3H), 1.66

(s, 3H), 1.59 (s, 3H), 1.56 (s, 3H) ppm. ^{13}C NMR: 185.46, 184.51, 146.15, 143.34, 137.54, 135.19, 134.87, 133.32, 133.26, 132.17, 132.13, 131.23, 126.29, 126.18, 124.38, 124.14, 123.85, 119.06, 39.70, 39.65, 26.74, 26.60, 26.48, 26.00, 25.83, 25.68, 17.67, 16.41, 16.01, 15.95, 12.67 ppm. IR (film): 2955, 2925, 2850, 1660, 1600, 1440, 1380, 1330, 1300, 710, 700 cm^{-1}. MS *m/e*: 444 (M^+, 5), 239 (15), 225 (64), 197 (26), 187 (23), 121 (18), 105 (18), 81 (41), 69 (100). HRMS calcd for $C_{31}H_{40}O_2$ 444.3028, found 444.3000.

(2′*E*,*Z*,6′*E*,10′*E*)-Menaquinone-4 ((2′*E*,*Z*,6′*E*,10′*E*)-1b). Obtained by Ce^{IV} oxidation of the crude prenylnaphthalene **4b** ($^2\Delta$, *E*,*Z* mixture), itself obtained through the VIBIHY protocol applied to **5b** as shown above. Isolated as a yellow solid in 61% overall yield from **5b** as a 60:40 *E*:*Z* mixture. ^1H NMR: 1.55 (s, 3H), 1.58 (s, 3H), 1.60 (s, 3H), 1.65 (s, 3H), 1.67 (s, 3H), 1.69 (s, 3H), 1.78 (s, 3H), 1.79 (s, 3H), 2.3–1.94 (m, 12 H), 2.19 (s, 3H), 2.18 (s, 3H), 3.37 (d, J = 6.8 Hz, 2H), 5.22–4.99 (m, 4H), 7.71–7.65 (m, 2H), 8.08–8.04 (m, 2H) ppm. ^{13}C NMR: 185.43, 184.49, 146.12, 146.09, 143.32, 143.26, 137.83, 137.52, 135.48, 135.17, 134.95, 134.85, 133.30, 133.24, 132.15, 132.11, 131.24, 131.21, 126.28, 126.16, 124.37, 124.17, 124.13, 123.89, 123.84, 119.68, 119.04, 39.73, 39.71, 39.68, 39.63, 32.16, 26.75, 26.72, 26.58, 26.45, 26.35, 25.98, 25.82, 25.67, 23.40, 17.66, 16.40, 16.00, 15.94, 12.68, 12.65 ppm. IR (film): 3600–3200 (br), 3050–2800 (br), 1595, 1460, 1380, 1360, 1270, 1200, 1175, 1020, 780, 740 cm^{-1}. MS *m/e*: 444 (M^+, 2), 239 (27), 225 (100), 197 (31), 187 (35), 121 (17), 105 (16), 95 (13), 93 (14), 81 (23), 69 (56). HRMS: calcd for $C_{33}H_{40}O_2$ 444.3028, found 444.3029.

Acknowledgment. Financial support by the DGICYT (Project PB90-0040) is gratefully acknowledged. One of us (X.G.) wishes to thank the M.E.C. (Spain) for a predoctoral fellowship.

Supplementary Material Available: The ^1H and/or ^{13}C NMR spectra of compounds (2′*Z*)-**3a**, (2′*E*)-**3a**, (2′*E*,6′*E*,10′*E*)-**3b**, (1′*E*)-**5a**, (1′*E*,6′*E*,10′*E*)-**5b**, (2′*E*)-**4a**, (2′*Z*)-**4a**, (2′*E*,*Z*)-**4a**, (2′*E*,6′*E*,10′*E*)-**4b**, (2′*E*,6′*E*,10′*E*)-**1b**, and (2′*E*,*Z*,6′*E*,10′*E*)-**1b**, the NOESY spectra of (2′*E*)-**4a** and (2′*Z*)-**4a**, and the DEPT spectrum of (2′*E*,6′*E*,10′*E*)-**1b** are provided (26 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.