yellow oil, which was used without further purification; GC indicated no contaminants of comparable volatility: IR 1680, 1630 cm^{-1}, and no OH absorption in the 3-μm region; ^1H NMR δ 0.8–2.8 (18 H, complex), 3.2–4.1 (4 H, m), 4.8 (1 H, m), 5.88 (1 H, s).

10-Carbomethoxy-$\Delta^{1,9}$-octal-2-one (3b).[23] This compound was produced by transesterification of **3c** on a 1-g scale. Chromatography and distillation with an oil bath at 99–110 °C (0.1 mm) gave 68% of **3b** as a colorless oil; although GC and ^1H NMR indicated that the 96 h of reflux had increased the Me/Et ratio from the original 2:3 only to 2:1, this mixture was used for the attempted Cr(II) reduction: IR 1730, 1680, 1630 cm^{-1}; ^1H NMR δ 1.1–2.6 (12 H, complex), 3.75 (3 H, s), 5.92 (1 H, s).

Cr(II) Reduction of 10-(Hydroxymethyl)-$\Delta^{1,9}$-octal-2-one (2a). A mixture of 6.8 mL of deoxygenated DMF and 13.6 mL of deoxygenated water was flushed with N_2 for 30 min before addition by syringe, with stirring, of 12 mL (6.0 mmol) of 0.50 M $CrSO_4$ solution,[24] followed by 1.113 g (18.5 mmol) of ethylenediamine. Following addition of 300 mg (1.66 mmol) of **2a**, the mixture was stirred under N_2 for 30 h at 25 °C. It was worked up by dilution with 10 g each of water and ice, acidification to pH 2–3 with 10% HCl, saturation with NaCl, and extraction with Et_2O (5 × 7.5 mL). The combined, washed, dried, and concentrated extracts were freed of DMF at 0.4 mm by warming to 70–75 °C for 5 h. After passage through a short column of Al_2O_3 and reconcentration, the product consisted of 125 mg (41%) of pale yellow oil having IR and ^1H NMR spectra consistent with absence of **2a**. GC analysis under the conditions described for **2a**, **7**, and **9** showed only **7** to be present.

Cr(II) Reduction of 10-Carboxy-$\Delta^{1,9}$-octal-2-one (3a). A mixture of 8.7 mL of deoxygenated DMF and 17.8 mL of deoxygenated water was flushed with N_2 for 30 min. As described for **2a**, 15 mL (7.5 mmol) of 0.50 M $CrSO_4$, 1.35 g (22.4 mmol) of ethylenediamine, and 200 mg (1.0 mmol) of **3a** were added sequentially. After being stirred 64 h at 25 °C under N_2, the mixture was worked up as described to yield 81 mg (40%) of crude white solid, mp 108–110 °C. GC analysis under the conditions described for **8** and **10** showed the presence of **8** with no detectable **10**, and IR and ^1H NMR spectra were consistent with absence of **3a**. Recrystallization gave 49 mg (24%) of white needles (mp 111–112.5 °C) whose IR and ^1H NMR spectra were identical with those of authentic **8**.

Attempted Cr(II) Reduction of 1b, 2b,c, and 3b. For each of these materials reduction was attempted, on the scale described for **2a** and **3a**, under two sets of conditions: first, by utilizing 3.4–5.0 mmol of $CrSO_4$ and 10.8–14.9 mmol of ethylenediamine per millimole of enone for 35–36 h and then by increasing the amount of reagent and the time to 6.65–8.1 mmol of $CrSO_4$ and 21–25 mmol of ethylenediamine per millimole of enone for 60 h.

In each case unchanged starting material was recovered in 58–62% yield, and, except for the case of **2c**, no evidence for the presence of reduced materials could be found by GC, IR, or ^1H NMR, which displayed retention times and spectra essentially identical with those for starting materials. Although **2a** recovered from attempted reductions of **2c** had a melting point comparable to that of authentic **2a**, GC after 35 h showed an immeasurable peak corresponding to trans ketol **9**, which after 60 h amounted to ca. 6% of total area. Cis ketol **7** could not be detected.

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Registry No. **1b**, 826-56-2; **2a**, 18992-92-2; **2b**, 84987-89-3; **2c**, 84987-90-6; **3a**, 84987-91-7; **3b**, 29494-21-1; **3c** (R = Et), 7478-39-9; **7**, 24795-55-9; **8**, 84987-92-8; **10**, 23595-68-8; $CrSO_4$, 13825-86-0; MEM chloride, 3970-21-6; 10-carboxy-$\Delta^{1,9}$-octal-2-ol, 84987-93-9; ethylenediamine, 107-15-3; dihydropyran, 110-87-2.

(23) (a) Piers, E.; Zbozny, M. *Can. J. Chem.* **1979**, *57*, 2249. (b) Boeckman, R. K., Jr.; Demko, D. M. *J. Org. Chem.* **1982**, *47*, 1789.

(24) Zurqiyah, A.; Castro, C. E. "Organic Syntheses"; Wiley: New York, 1973; Collect. Vol. V, p 993.

Aklavin-Type Anthracyclinones: Brief, Regiospecific Syntheses of Tetracyclic Intermediates

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A brief route for regiospecific synthesis of multigram quantities of diversely functionalized tetracyclic precursors to aklavin-type anthracyclinones is described.

The report that the aklavin-type anthracycline antibiotics 11-deoxydaunorubicin (**1a**), 11-deoxyadriamycin (**1b**),[2] and aklavamycin A_1 (**3**)[3] (Chart I) are less toxic[2,4] than the clinically important rhodomycins daunorubicin (**1c**) and adriamycin (**1d**)[5] has generated interest in their preparation. Elegant total syntheses of the aglycons **2a**[6] and **4**[7] of **1a** and **3**, respectively, as well as the aglycon **2e**[8]

(1) Recipient of a Career Development Award, 1978–1983, from the National Cancer Institute (Grant No. CA 00486).

(2) Arcamone, F.; Cassinelli, G.; DiMatteo, F.; Forenza, S.; Ripamonti, M. C.; Giovanni, R.; Vigeva, A.; Clardy, J.; McCabe, T. *J. Am. Chem. Soc.* **1980**, *102*, 1462.

(3) Oki, T.; Matsuzawa, Y.; Yoshimoto, A.; Numata, K.; Kitamura, I.; Hori, S.; Takamatsu, A.; Umezawa, H.; Ishizuka, M.; Maganawa, H.; Suda, H.; Hamada, M.; Takeuchi, T. *J. Antibiot.* **1975**, *28*, 830.

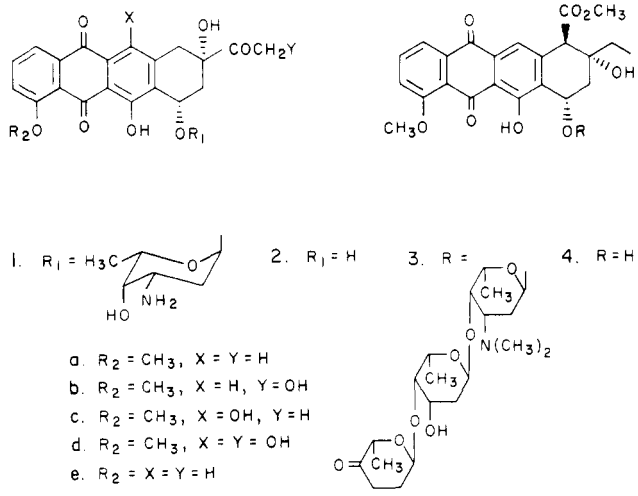
(4) Arcamone, F. "Doxorubicin"; Academic Press: New York, 1981.

(5) (a) Yamaki, H.; Suzuki, H.; Nishimura, T.; Tanaka, N. *J. Antibiot.* **1978**, *31*, 1149. (b) Misumi, M.; Yamaki, H.; Akiyama, T.; Tanaka, N. *Ibid.* **1979**, *32*, 48.

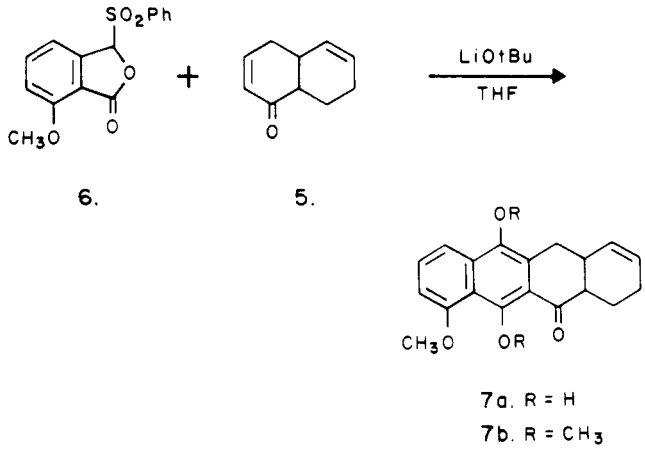
(6) (a) Kende, A. S.; Rizzi, J. P.; Boettger, S. D. Second Chemical Congress of the North American Continent, Las Vegas, 1980; American Chemical Society: Washington, DC, 1980. (b) Yadav, J.; Corey, P.; Hsu, C.-T.; Perlman, K.; Sih, C. J. *Tetrahedron Lett.* **1981**, *22*, 811. (c) Kimball, S. D.; Walt, D. R.; Johnson, F. *J. Am. Chem. Soc.* **1981**, *103*, 1561. (d) Gesson, J.-P.; Mondon, M. *J. Chem. Soc., Chem. Commun.* **1982**, 421. (e) Rao, A. V. R.; Deshpande, V. H.; Reddy, N. L. *Tetrahedron Lett.* **1982**, *23*, 775.

0022-3263/83/1948-1328$01.50/0

Chart I



Scheme I

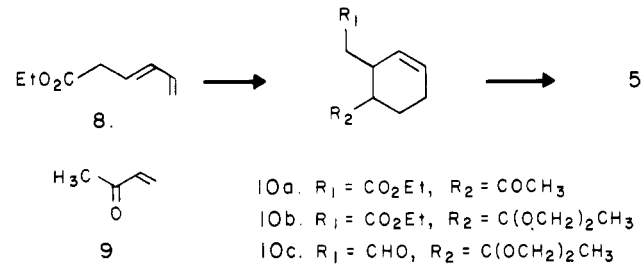


of 11-deoxycarminomycin (**1e**) have been reported. Extensive literature also exists on the preparation of the 9-oxo compound **16**[9] from which total syntheses of the respective aglycons **2a**[6a,d] and **2c**[8] of 11-deoxydaunorubicin (**1a**) and 11-deoxycarminomycin (**1e**) have been achieved.

From our earlier use of the phthalide sulfone annelation reaction[10] in linear routes to naturally occurring polycyclic aromatic systems,[11] it became apparent that this reaction might be employed to achieve convergent regiospecific assembly of tetracyclic precursors to anthracycline antibiotics as shown in Scheme I. However, the absence of convenient methods for preparing 1(4*H*)-naphthalenones such as **5** necessitated prior development of brief procedures for their preparation.

We report here a short, high-yield route to the naphthalenone **5**, its condensation with the phthalide sulfone **6** to give the tetracyclic product **7**, and the subsequent

Scheme II



conversion of **7** to recognized and potential precursors to aklavin-type anthracyclines. The developed route allows ready preparation of multigram quantities of products.

The reaction sequence shown in Scheme II was employed to prepare the 1(4*H*)-naphthalenone **5**. Hundredgram quantities of the cyclohexene **10a**, isolated in 89–94% yield as a mixture of cis and trans isomers, were readily prepared through Diels–Alder reaction of the hexadienoate **8**[12] with excess methyl vinyl ketone (**9**) under stannic chloride catalysis at 0 °C.[13] Since the sp^3-hybridized carbons bearing the substituents in **10** (which become the bridging carbons in the naphthalenone **5**) are transformed to sp^2 centers at a later stage in the scheme, the presence of geometric isomers at this point and in subsequent intermediates was inconsequential and permitted full utilization of the products. Ketalization of **10a** ($HOCH_2CH_2OH$, pyridinium *p*-toluenesulfonate, PhH, 95%) gave **10b** which was reduced (Dibal, $PhCH_3$, –78 °C; 90%) to the aldehyde **10c**. Acid hydrolysis of **10c** followed by intramolecular cyclization and dehydration of the keto aldehyde intermediate gave the unsaturated naphthalenone **5** as a mixture of cis and trans isomers[14] in 76% overall yield.

The anion of sulfone **6**, generated with lithium *tert*-butoxide in THF, was now condensed with the naphthalenone **5** (1.1 equiv) to give the tetracyclic intermediate **7a** in 84% yield. Although we were unable to directly demonstrate that **7a** was a mixture of cis and trans isomers, methylation (K_2CO_3, Me_2SO_4, acetone) of an initially isolated sample of **7a** gave the methyl ether derivative **7b**, the ^1H NMR spectrum of which showed the presence of two sets of methoxyl resonances in a ratio of approximately 85:15. Recrystallization of **7b** gave sharp-melting material, and its ^1H NMR spectrum corresponded to that of the major isomer.

The transformation of **7a** and **7b** to other intermediates was achieved. Selective aromatization of the B ring with prior protection of the C ring was studied first as shown in Scheme III. Reaction of **7b** with phenyltrimethylammonium perbromide[15] in THF gave the 6a-bromo compound **11** (84% yield) which upon dehydrohalogenation (DBU, PhH, room temperature) produced the dihydronaphthacene **12a** in 83% yield.

A reaction sequence for converting the 9,10-olefinic entity to a 9-ketone was described earlier by us;[11d,16] however, in this case, it was necessary to first protect the 6-phenolic group as the benzyl ether derivative **12b** ($PhCH_2Br$, K_2C-

(7) (a) Kende, A. S.; Rizzi, J. P. *J. Am. Chem. Soc.* **1981**, *103*, 4247. (b) Pearlman, B. A.; McNamara, J. M.; Hasan, I.; Hatakeyama, S.; Sekizaki, H.; Kishi, Y. *Ibid.* **1981**, *103*, 4248. (c) Confalone, P. N.; Pizzolato, G. *Ibid.* **1981**, *103*, 4251. (d) Li, T.-T.; Wu, Y. L. *Ibid.* **1981**, *103*, 7007.

(8) Kende, A. S.; Boettger, S. D. *J. Org. Chem.* **1981**, *46*, 2799.

(9) (a) Gesson, J. P.; Jacquesy, J. C.; Mondon, M. *Tetrahedron Lett.* **1980**, *21*, 3351. (b) Bauman, J. G.; Barber, R. B.; Gless, R. D.; Rapoport, H. *Ibid.* **1980**, *21*, 4777. (c) Alexander, J.; Flynn, D. L.; Mitscher, L. A.; Veysoglu, T. *Ibid.* **1981**, *22*, 3711.

(10) Hauser, F. M.; Rhee, R. P. *J. Org. Chem.* **1978**, *43*, 178.

(11) (a) Hauser, F. M.; Rhee, R. P. *J. Org. Chem.* **1980**, *45*, 3061. (b) Hauser, F. M.; Combs, D. W. *Ibid.* **1980**, *45*, 4071. (c) Hauser, F. M.; Prasanna, S. *Ibid.* **1979**, *44*, 2596. (d) Hauser, F. M.; Prasanna, S. *J. Am. Chem. Soc.* **1981**, *103*, 6378. (e) Hauser, F. M.; Prasanna, S. *J. Org. Chem.* **1982**, *47*, 383. (f) Russel, R. A.; Warrener, R. N. *J. Chem. Soc., Chem. Commun.* **1981**, 108. (g) Meyers, A. I.; Avila, W. B. *J. Org. Chem.* 1981, *46*, 3881.

(12) (a) Stevens, R. V.; Cherpeck, R. E.; Harrison, B. L.; Lai, J.; Lapalme, R. *J. Am. Chem. Soc.* **1976**, *98*, 6317. (b) Recently, an alternate and excellent preparation of the dienoate **8** was reported by: Hoye, T. H.; Magee, A. S.; Trumper, W. S. *Synth. Commun.* **1982**, *12*, 183.

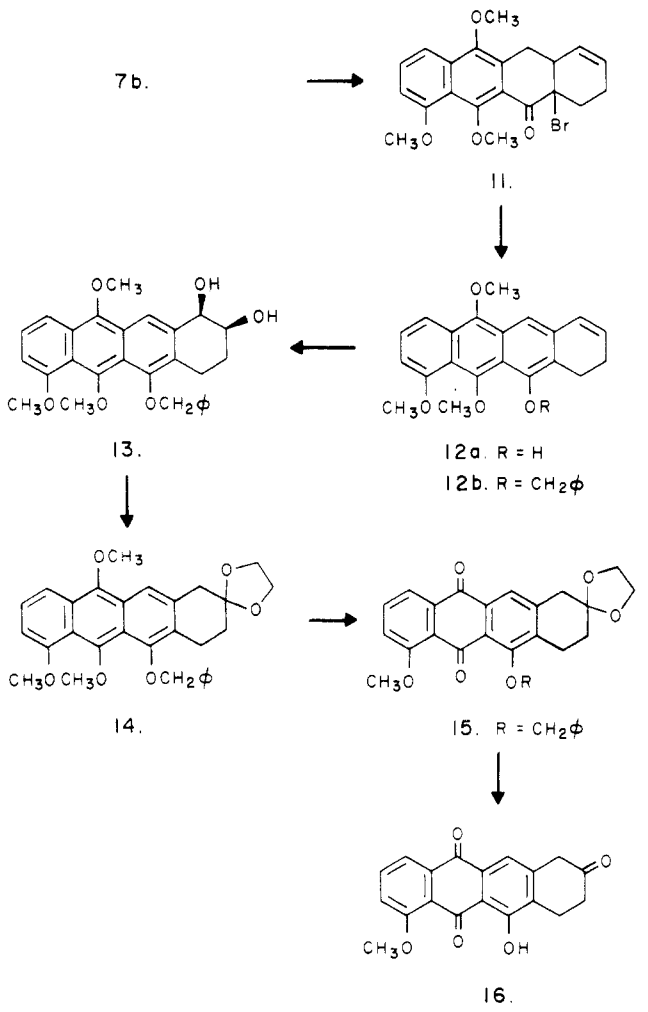
(13) The conditions for the Diels–Alder reaction parallel those given in ref 12a for a similar reaction.

(14) For a recently reported synthesis of *cis*-**8** see: Oppolzer, W.; Snowden, R. L.; Simmons, D. P. *Helv. Chim. Acta* **1981**, *64*, 2022.

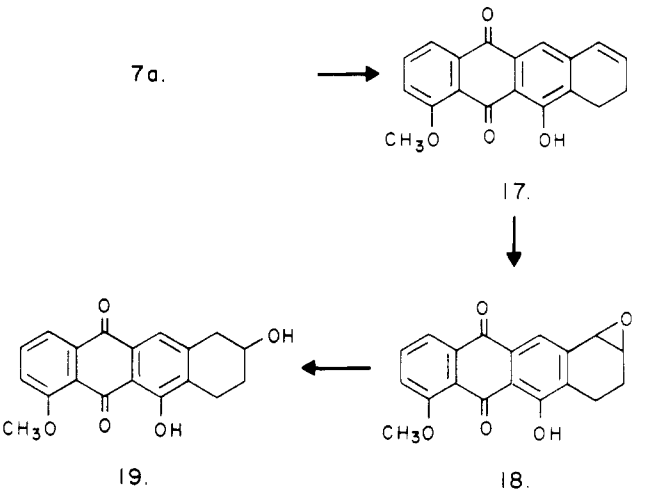
(15) (a) Vorländer, D.; Siebert, E. *Chem. Ber.* **1919**, *52*, 283. (b) Johnson, W. S.; Bass, J. D.; Williamson, K. L. *Tetrahedron* **1963**, *19*, 861.

(16) Hauser, F. M.; Prasanna, S. *Synthesis* **1980**, 621.

Scheme III



Scheme IV



O_3, acetone; 91%). Hydroxylation of the 9,10-olefinic entity to furnish the *cis*-diol **13** in 87% yield was accomplished with trimethylamine *N*-oxide and a catalytic amount of osmium tetraoxide.[17]

The preparation of trioxonaphthacene **16**, an established intermediate to 11-deoxyanthracyclinones, was now performed. Protection of the 9-ketone as its ketal derivative was a prerequisite to the oxidative cleavage of the methoxyl protective groups in the C ring. Direct preparation of the ketal derivative **14** from the *cis*-diol **13** was achieved in a single step in 81% yield by performing the dehydration of **13** with toluenesulfonic acid in benzene in the presence of added ethylene glycol. Oxidation of **14** to the quinone **15** was accomplished in 94% yield by using ceric ammonium nitrate in the presence of pyridinedicarboxylic acid *N*-oxide.[18] Hydrogenolysis of **15** (Pd/C, EtOH) followed by hydrolysis (HCl/DME) gave **16** identical with a sample generously provided by Dr. Andrew Kende.

A more abbreviated route to quinone intermediates was realized by application of our recent finding that treatment of keto hydroquinone systems similar to **7a** with *N*-bromosuccinimide in water–acetone results in selective oxidation of the hydroquinone fragment to a quinone moiety with concomitant aromatization of the ring initially containing the ketone group.[11e] As shown in Scheme IV, addition of *N*-bromosuccinimide (3 equiv) in water to a cold (−5 to −10 °C) solution of **7a** in acetone–water gave dihydronaphthacenone **17** in 76% yield. Epoxidation of **17** (MCPBA, CH_2Cl_2; 94%) gave **18** which upon reduction (Pd–C–$BaSO_4$, H_2, ethanol–triethanolamine) furnished the 9-alcohol product **19** (85%). Oxidation of **19** with pyridinium chlorochromate readily produced the 9-oxo compound in 91% yield.

These results establish the condensation of phthalide sulfones with 1(4*H*)-naphthalenones as an efficient means for convergent regiospecific assembly of tetracyclic precursors to 11-deoxyanthracyclinones. In addition to the further transformation of intermediates obtained in this study to the aglycons **2** and **4**, the possibility of preparing other anthracyclinones from appropriately functionalized naphthalenones is being investigated.

Experimental Section

Melting points were taken on a Kofler hot-stage microscope and are uncorrected. Infrared spectra were measured with a Perkin-Elmer 621 spectrophotometer and are expressed in reciprocal centimeters. Ultraviolet spectra were run on a Cary 15 (Varian) ultraviolet–visible spectrophotometer and are expressed in nanometers. Proton nuclear magnetic resonance (^1H NMR) spectra were obtained on a JEOL FX-90Q spectrometer. Chemical shifts are reported as δ values in parts per million relative to tetramethylsilane (δ 0.0) as an internal standard. Mass spectra were obtained with a CEC Du Pont Model 21-110B or Du Pont Model 21-491B spectrometer at an ionizing voltage of 70 eV. Carbon and hydrogen analyses were performed by Galbraith Laboratories, Knoxville, TN.

Analytical thin-layer chromatography (TLC) was conducted on 5 × 10 cm precoated plates (silica gel 60 F-254, layer thickness 0.25 mm) manufactured by E. Merck and Co. Silica gel columns for chromatography utilized E. Merck silica gel 60, 70–230 mesh ASTM.

Tetrahydrofuran (THF) and dimethoxyethane (DME) were dried by distillation from lithium aluminum hydride. Solvents were reagent grade and were not usually purified prior to use.

Ethyl 5-Acetyl-2-cyclohexeneacetate (10a). Powdered stannic chloride pentahydrate (45.6 g, 0.13 mol) dissolved in a magnetically stirred solution of diene **8** (80 g, 0.57 mol) in benzene (400 mL) under nitrogen was cooled to 0 °C, and a solution of methyl vinyl ketone (121 g, 1.73 mol) in benzene (150 mL) was added. The reaction was allowed to come to room temperature overnight and after 48 h was poured into a separatory funnel. The benzene layer was separated and successively washed with water (2 × 200 mL), bicarbonate (5%, 2 × 200 mL), and brine (100 mL), dried ($MgSO_4$), and filtered. The benzene was removed at reduced pressure and the residue distilled to give 3.21 g (4%) of unreacted diene ester **8** and 109.2 g (91%) of pure cyclohexeneacetate **10a**: bp 75–77 °C (0.1 mm); ^1H NMR δ 5.73 (m, 2 H), 4.12 (q, J = 7.30 Hz, 2 H), 2.90–2.60 (m, 5 H), 2.20 (s, 3 H), 1.80–1.52 (m, 2 H), 1.24 (t, J = 7.30 Hz, 3 H). GC/MS analysis showed the product to be a 94–96% mixture of the cis isomer, the remainder being

(17) Ray, R.; Matteson, D. S. *Tetrahedron Lett.* **1980**, *21*, 449.
(18) Syper, L.; Kloc, K.; Mlochowski, J.; Szulc, Z. *Synthesis* **1979**, 521.

the trans compound. Support for this stereochemical assignment was based on the observation that treatment of a small amount of the distilled product with ethanolic sodium hydroxide and then GLC analysis inverted the ratios of isomers; mass spectrum, m/z 210 ($M^{+\cdot}$). Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.54; H, 8.63. Found: C, 68.61; H, 8.65.

Ethyl 5-[1,1-(Ethylenedioxy)ethyl]-3-cyclohexeneacetate (10b). A solution of **10a** (42 g, 0.2 mol), ethylene glycol (23.0 g, 0.37 mol), and pyridinyl *p*-toluenesulfonate (4.5 g) in benzene (800 mL) was heated at reflux for 16 h. Water formed during the ketalization was continuously removed by utilizing a Dean–Stark trap. The reaction mixture was transferred to a separatory funnel, successively washed with bicarbonate solution (10%, 2 × 200 mL) and water (2 × 200 mL), dried ($MgSO_4$), and filtered. The benzene was evaporated at reduced pressure and the residue distilled to give 48.3 g (95%) of pure ketal **10b**: bp 97 °C (0.05 mm); ^1H NMR δ 5.92–5.40 (m, 2 H), 4.13 (q, J = 7.0 Hz, 2 H), 3.91 (s, 4 H), 1.30 (s, 3 H), 1.26 (t, J = 7.0 Hz, 3 H). Anal. Calcd for $C_{14}H_{22}O_4$: C, 66.11; H, 8.72. Found: C, 66.10; H, 8.62.

5-[1,1-(Ethylenedioxy)ethyl]-3-cyclohexeneacetaldehyde (10c). To a stirred solution of ketal **10b** (45.4 g, 0.179 mol) in dry toluene at −78 °C under nitrogen was added dropwise diisobutylaluminum hydride (135 mL of a 20% hexane solution; 0.19 mol). The reaction mixture was stirred at −78 °C for 1 h and then quenched with water (10 mL). The reaction was warmed to room temperature, and sodium tartrate solution (25%, 300 mL) was added with vigorous stirring to dissolve the aluminum oxide. The toluene layer was separated and the aqueous layer was extracted with ethyl acetate (2 × 200 mL). The combined organic layers were dried ($MgSO_4$), filtered, and evaporated at reduced pressure to give 33.8 g (90%) of aldehyde **10c** as an oil homogeneous by TLC: ^1H NMR δ 9.74 (t, J = 2.14 Hz, 1 H), 5.88–5.36 (m, 2 H), 3.90 (s, 4 H), 2.75–2.20 (m, 4 H), 2.00–1.65 (m, 3 H), 1.29 (s, 3 H).

4a,7,8,8a-Tetrahydro-1(4*H*)-naphthalenone (5). A solution of ketal aldehyde **10c** (31.5 g, 0.15 mol) in tetrahydrofuran–water (1:1, 400 mL) and hydrochloric acid (2 N, 125 mL) was stirred at 50 °C for 1 h, diluted with ice–water (300 mL), and extracted with ether (3 × 150 mL). The combined ether extracts were dried ($MgSO_4$), filtered, and evaporated at reduced pressure to furnish 24.2 g (97%) of the keto aldehyde intermediate as an oil which was used in the next step without further purification: ^1H NMR δ 9.72 (t, J = 2.12 Hz, 1 H), 5.86–5.30 (m, 2 H), 2.65–2.25 (m, 6 H), 2.20 (s, 3 H), 2.26–2.08 (m, 2 H); mass spectrum, m/z 166 ($M^{+\cdot}$).

To a solution of the above keto aldehyde (23.6 g, 0.14 mol) in methanol (415 mL) was added potassium hydroxide (12.0 g, 0.21 mol) dissolved in a minimum amount of water. The mixture was stirred at room temperature for 24 h, cooled (0 °C), and acidified with dilute hydrochloric acid (1 N). Saturated brine (300 mL) and ether (300 mL) were added to the reaction, and the organic layer was separated. The aqueous layer was extracted with ether (3 × 300 mL), and the combined ether extracts were washed once with half-saturated brine (200 mL), dried ($MgSO_4$), filtered, and evaporated at reduced pressure. The residue was distilled to give **5** (16 g; 76%); bp 73–74 °C (1.0 mm). GC/MS analysis showed that this product was a mixture of cis and trans isomers. The ratio was somewhat variable from one preparation to another but was usually around 9:1 trans/cis by GC/MS. Both isomers had virtually identical mass spectra with m/z 148 ($M^{+\cdot}$). Anal. Calcd for $C_{10}H_{12}O$: C, 81.04; H, 8.16. Found: C, 81.09; H, 8.19.

Chromatographic separation of a small amount of the distilled product on silica gel furnished the individual isomers. *trans*-**5** was a low-melting solid: ^1H NMR δ 6.98 (qd, J = 10.0, 2.5 Hz, 1 H), 6.03 (dt, J = 10.0, 3.0 Hz, 1 H), 5.83–5.45 (m, 2 H), 2.65–1.80 (m, 6 H), 1.65–1.30 (m, 2 H). *cis*-**5** was an oil: ^1H NMR δ 6.86 (dt, J = 10.0, 3.5 Hz, 1 H), 5.98 (dt, J = 10.0, 1.6 Hz, 1 H), 5.70–5.58 (m, 2 H), 2.75–2.0 (m, 6 H), 1.95–1.55 (m, 2 H).

5,12-Dihydroxy-4-methoxy-7,8,10a,11-tetrahydro-6-(6a*H*)-naphthacenone (7a). To a cold (−78 °C) magnetically stirred solution of lithium *tert*-butoxide, prepared from *tert*-butyl alcohol (6.00 mL, 63.6 mmol) and *n*-butyllithium (27.65 mL of 2.2 M solution, 60.8 mmol) in dry THF (300 mL) under nitrogen at 0 °C, was added sulfone **6** (8.4 g, 27.6 mmol) as a slurry in THF (30 mL). Upon completion of the addition, the orange-yellow mixture of partially precipitated anion was stirred for 5 min at which point decalone **5** (4.5 g, 30.4 mmol) in THF (30 mL) was injected by syringe into the reaction mixture. The orange color instantly faded to a lighter yellow, and after 5 min the cooling bath was removed. As the reaction mixture warmed the color became progressively redder, and the solids dissolved. When the reaction mixture reached room temperature, it was heated at reflux for 30 min, during which an orange-red precipitate formed. The reaction mixture was cooled to 0 °C and acidified with hydrochloric acid (3 N). The THF was removed at reduced pressure, and the aqueous mixture was extracted with ethyl acetate (400 mL). The ethyl acetate extract was successively washed with aqueous bicarbonate (200 mL) and bisulfite (2%, 200 mL), dried, and filtered. The solvent was removed at reduced pressure, and the syrupy residue was triturated with ether to give orange-red crystals of **7a** (6.15 g, 72% yield) which were filtered, washed thoroughly with ether, and dried. Evaporation of the ether filtrate and washings and chromatography of the residue on silica gel (160 g) with methylene chloride–ethyl acetate (95:5) as the eluent gave an additional 1.05 g of **7a** which raised the overall yield to 84%. A sample was recrystallized from methylene chloride–hexanes: mp 239–242 °C; ^1H NMR δ 7.90 (dd, J = 8.0, 1.5 Hz, 1 H), 7.60 (br t, J = 8.0 Hz, 1 H), 6.86 (dd, J = 8.0, 1.5 Hz, 1 H), 5.90–5.45 (m, 2 H), 4.02 (s, 3 H), 3.50–3.20 (m, 2 H), 2.90–2.25 (m, 5 H); mass spectrum, m/z 310 ($M^{+\cdot}$). Anal. Calcd for $C_{19}H_{18}O_4$: C, 73.53; H, 5.85. Found: C, 73.61; H, 5.80.

4,5,12-Trimethoxy-7,8,10a,11-tetrahydro-6(6a*H*)-naphthacenone (7b). A stirred mixture of naphthacenone **7a** (7.14 g, 23 mmol), dimethyl sulfate (10.5 g, 83.3 mmol), and anhydrous potassium carbonate (15.25 g, 110 mmol) in acetone (450 mL) under nitrogen was heated at reflux overnight at which time TLC indicated that the reaction was complete. The reaction was cooled and filtered to remove inorganic material, and the filtrate was evaporated at reduced pressure. The residue was taken up in ethyl acetate (300 mL), triethylamine (25 mL) was added, and the mixture was allowed to stand for 2 h. The solution was transferred to a separatory funnel, successively washed with water (2 × 100 mL), hydrochloric acid (10%, 2 × 100 mL), and water (2 × 100 mL), dried ($MgSO_4$), and filtered, and the solvent was evaporated at reduced pressure. Three recrystallizations of the residue from methylene chloride–hexanes gave 7.48 g (96%) of light green crystals: mp 208–211 °C: ^1H NMR δ 7.67 (dd, J = 8.0, 1.5 Hz, 1 H), 7.49 (t, J = 8.0 Hz, 1 H), 6.85 (dd, J = 8.0, 1.5 Hz, 1 H), 5.90–5.60 (m, 2 H), 3.99 (s, 3 H), 3.94 (s, 3 H), 3.87 (s, 3 H), 3.62–3.40 (m, 2 H), 2.84–2.14 (m, 5 H); mass spectrum, m/z 338 ($M^{+\cdot}$). Anal. Calcd for $C_{21}H_{22}O_4$: C, 74.53; H, 6.55. Found: C, 74.55; H, 6.61.

6a-Bromo-4,5,12-trimethoxy-7,8,10a,11-tetrahydro-6-(6a*H*)-naphthacenone (11). To a cold (0 °C) stirred solution of **7b** (10.14 g, 30 mmol) in dry THF (200 mL) was added phenyltrimethylammonium perbromide (12.41 g, 33 mmol). The mixture was allowed to warm to room temperature over 2 h, poured into sodium thiosulfate solution (1%, 500 mL), and extracted with ethyl acetate (3 × 150 mL). The combined organic extracts were washed with brine, dried ($MgSO_4$), and filtered, and the solvent was removed at reduced pressure. The residue was crystallized from methanol to give 10.50 g (84%) of **11** as plates: mp 139–143 °C; ^1H NMR δ 7.66 (dd, J = 7.5, 1.5 Hz, 1 H), 7.50 (t, J = 7.5 Hz, 1 H), 6.90 (dd, J = 7.5, 1.5 Hz, 1 H), 6.02–5.85 (m, 2 H), 4.00 (s, 3 H), 3.92 (s, 3 H), 3.89 (s, 3 H), 2.95–2.30 (m, 5 H); mass spectrum, m/z 416, 418 ($M^{+\cdot}$).

6-Hydroxy-5,6,12-trimethoxy-7,8-dihydronaphthacene (12a). To the bromo compound **11** (5.40 g, 13 mmol) dissolved in benzene (200 mL) was added 1,8-diazabicyclo[5.4.0]undec-7-ene (2.9 mL, 19.1 mmol), and the dark mixture was stirred under N_2 at room temperature overnight. The reaction mixture was poured into water (100 mL), and the organic layer was separated and successively washed with HCl (5%, 2 × 100 mL) and water (2 × 100 mL). The benzene solution was dried ($MgSO_4$), filtered, and evaporated at reduced pressure. Chromatography of the residue over silica gel with CH_2Cl_2–EtOAc (98:2) followed by recrystallization from ether–hexanes gave 3.57 g (83%) of **12a** as needles: mp 110–112 °C; ^1H NMR δ 10.43 (s, 1 H), 7.83 (dd, J = 8.5, 1.5 Hz, 1 H), 7.43 (s, 1 H), 7.34 (t, J = 8.5 Hz, 1 H), 6.77 (dd, J = 8.5, 1.5 Hz, 1 H), 6.67 (dt, J = 9.5, 1.0 Hz, 1 H), 6.19 (dt, J = 9.5, 4.0 Hz, 1 H), 4.06 (s, 3 H), 4.03 (s, 3 H), 3.99 (s, 3 H), 3.03 (t, J = 5.5 Hz, 2 H), 2.95 (dt, J = 5.5, 4.0 Hz, 2 H); mass spectrum,

m/z 336 ($M^{+}\cdot$). Anal. Calcd for $C_{21}H_{20}O_4$: C, 74.98; H, 5.99. Found: C, 75.08; H, 6.06.

6-(Benzyloxy)-4,5,12-trimethoxy-7,8-dihydronaphthacene (12b). A vigorously stirred solution of **12a** (4.0 g, 12 mmol), anhydrous potassium carbonate (5.0 g), and benzyl bromide (3.1 g, 18 mmol) in acetone (300 mL) was heated at reflux for 36 h, cooled, and filtered. The filtrate was evaporated at reduced pressure, and the residue was chromatographed on silica gel with methylene chloride–ethyl acetate (99:1) to give 4.61 g (91%) of **12b** as a viscous oil: ^{1}H NMR δ 7.92–7.24 (m, 9 H), 6.69 (dt, J = 8.1, 1.5 Hz, 1 H), 6.17 (dt, J = 8.1, 3.5 Hz, 1 H), 5.04 (br s, 2 H), 4.05 (s, 6 H), 3.91 (s, 3 H), 3.02 (t, J = 6.2 Hz, 2 H), 2.32 (dt with fine splitting, J = 6.2, 3.5, 1.5 Hz, 2 H); mass spectrum, m/z 426 ($M^{+}\cdot$).

6-(Benzyloxy)-*cis*-9,10-dihydroxy-4,5,12-trimethoxy-7,8,9,10-tetrahydronaphthacene (13). A solution of the benzyl ether **12b** (4.50 g, 10.5 mmol), osmium tetraoxide (0.01 g), and trimethylamine N-oxide (2.25 g, 30 mmol) in acetone–water (3:1, 160 mL) was stirred for 8 h at room temperature. Ethyl acetate (200 mL) and water (100 mL) were added to the reaction and the layers separated. The aqueous layer was extracted with ethyl acetate (2 × 100 mL), and the combined organic extracts were washed with sodium metabisulfite solution (1%, 2 × 50 mL), dried ($MgSO_4$), and filtered. The ethyl acetate was removed at reduced pressure, and the residue was recrystallized from methylene chloride–hexane to give 4.23 g (87%) of pure **13**: mp 132–134 °C; ^{1}H NMR δ 8.24 (s, 1 H), 7.84 (dd, J = 8.7, 1.0 Hz, 1 H), 7.57–7.33 (m, 6 H), 6.76 (dd, J = 7.0, 1.0 Hz, 1 H), 5.05 (br s, 2 H), 4.89 (d, J = 3.5 Hz, 1 H), 4.05 (s, 3 H), 4.04 (s, 3 H), 3.86 (s, 3 H), 3.45–2.80 (m, 2 H), 2.26–1.85 (m, 2 H). Anal. Calcd for $C_{25}H_{28}O_6$: C, 73.02; H, 6.13. Found: C, 73.11; H, 6.20.

6-(Benzyloxy)-9-(ethylenedioxy)-4,5,12-trimethoxy-7,8,9,10-tetrahydronaphthacene (14b). A solution of diol **13** (4.10 g, 8.9 mmol), ethylene glycol (15 mL), and p-toluenesulfonic acid (0.01 g) in benzene (150 mL) was heated at reflux for 1 h. Water formed during the reaction was collected in a Dean–Stark trap. The dark red solution was cooled, washed with aqueous $NaHCO_3$ (5%, 2 × 100 mL), and water (100 mL), dried ($MgSO_4$), and filtered. The residue obtained following evaporation of the solvent at reduced pressure was recrystallized from methylene chloride–ether–hexanes to give 3.50 g (81%) of **14** as plates: mp 94–96 °C; ^{1}H NMR δ 7.82 (dd, J = 8.5, 1.0 Hz, 1 H), 7.84 (s, 1 H), 7.57–7.33 (m, 6 H), 6.74 (dd, J = 6.8, 1.0 Hz, 1 H), 5.06 (br s, 2 H), 4.06 (s, 4 H), 4.05 (s, 6 H), 3.88 (s, 3 H), 3.40–3.16 (m, 4 H), 2.00 (t, J = 6.6 Hz, 2 H).

6-(Benzyloxy)-9-(ethylenedioxy)-4-methoxy-7,8,9,10-tetrahydro-5,12-naphthacenedione (15). To a stirred, cold (0 °C) solution of ketal **14b** (3.0 g, 6.17 mmol) in acetonitrile (50 mL) and THF (50 mL) was added pyridinedicarboxylic acid N-oxide (2.37 g, 13.0 mmol) followed by a solution of ceric ammonium nitrate (7.10 g, 13.0 mmol) in water (10 mL). After 10 min, the mixture was partitioned between ethyl acetate (100 mL) and water (70 mL). The organic layer was separated, washed with water (2 × 50 mL), dried ($MgSO_4$), and filtered. The solvent was removed at reduced pressure, and the residue was recrystallized from methylene chloride–hexanes to give 2.65 g (94%) of **15** as yellow needles: product initially melts at 145–148 °C and then resolidifies and melts again at 190–192 °C; ^{1}H NMR δ 7.86 (dd, J = 7.6, 1.6 Hz, 1 H), 7.76–7.34 (m, 8 H), 5.11 (s, 2 H), 4.03 (s, 4 H), 4.00 (s, 3 H), 3.16–2.95 (m, 4 H), 1.90 (t, J = 6.8 Hz, 2 H).

7,8-Dihydro-6-hydroxy-4-methoxy-5,9(10*H*),12-naphthacenetrione (16). A solution of **15** (2.50 g, 5.48 mmol) in ethanol–ethyl acetate (1:1, 100 mL) and 10% palladium on charcoal (0.07 g) was shaken under hydrogen at 34 psi for 2 h in a Parr apparatus. The reaction mixture was filtered through a Celite pad and the filtrate evaporated at reduced pressure to give the crude phenolic ketal (1.90 g). The hydrogenolysis product was taken up in dimethoxyethane–water (2:1, 100 mL), and hydrochloric acid (10%, 15 mL) was added. The reaction was stirred at 40 °C for 2 h, diluted with water (250 mL), extracted with ethyl acetate (3 × 50 mL), dried ($MgSO_4$), and filtered. The solvent was removed at reduced pressure, and the residue was recrystallized from methylene chloride–ether–hexanes to give 1.59 g (90%) of **16** as yellow plates: mp 256–258 °C (lit.[9a] mp 258–259 °C); ^{1}H NMR δ 13.43 (s, 1 H), 8.00 (dd, J = 7.5, 1.7 Hz, 1 H), 7.74 (t, J = 7.5 Hz, 1 H), 7.52 (s, 1 H), 7.36 (dd, J = 7.6, 1.7 Hz, 1 H), 4.08 (s, 3 H), 3.68 (s, 2 H), 3.24 (t, J = 6.1 Hz, 2 H), 2.61 (t, J = 6.1 Hz, 2 H); mass spectrum, m/z 322. Comparison of this product with an authentic sample showed them to have identical spectral (^{1}H NMR, IR, and UV) characteristics. Their TLC behavior was likewise identical, and a mixture melting point determination was undepressed.

7,8-Dihydro-6-hydroxy-4-methoxy-5,12-naphthacenedione (17). To a cold (−10 °C), stirred solution of **7a** (2.85 g, 9.19 mmol) in acetone–water (2:1, 400 mL) was added N-bromosuccinimide (4.91 g, 27.6 mmol) in small portions over the course of 20 min. The resultant deep red solution was allowed to warm to 15 °C over 1.5 h at which point triethylamine (10 mL) was added. The mixture was transferred to a separatory funnel, diluted with ethyl acetate (500 mL), and washed with sodium thiosulfate solution (5%, 500 mL). The aqueous layer was extracted with ethyl acetate (2 × 100 mL), and the combined organic layers were washed with water (150 mL), dried ($MgSO_4$), and filtered. The solvent was evaporated at reduced pressure, and the residue chromatographed on silica gel with methylene chloride–ethyl acetate (9:1). Recrystallization of the eluted product from methylene chloride–hexanes yielded 2.14 g (76%) of pure **17**: mp 217–220 °C; ^{1}H NMR δ 13.23 (s, 1 H), 7.93 (dd, J = 7.46, 1.0 Hz, 1 H), 7.69 (t, J = 8.35 Hz, 3 H), 7.42 (s, 1 H), 7.40 (d, J = 5.30 Hz, 1 H), 6.51 (dt, J = 11.0, 1.0 Hz, 1 H), 6.26 (dt, J = 11.0, 4 Hz, 1 H), 4.05 (s, 3 H), 2.92 (br t, J = 8.0 Hz, 2 H), 2.60–2.20 (m, 2 H); mass spectrum, m/z 306 ($M^{+}\cdot$). Anal. Calcd for $C_{19}H_{14}O_4$: C, 74.50; H, 4.61. Found: C, 74.57; H, 4.70.

9,10-Epoxy-6-hydroxy-4-methoxy-7,8,9,10-tetrahydro-5,12-naphthacenedione (18). To a cold (0 °C) stirred solution of **17** (2.0 g, 6.53 mmol) in methylene chloride (250 mL) was added m-chloroperbenzoic acid (1.24 g, 7.19 mmol) in small portions over 15 min. The reaction mixture was allowed to come to room temperature over 4 h, at which time TLC indicated that the starting material was completely consumed. The reaction mixture was successively washed with aqueous sodium bisulfite (2%, 100 mL), aqueous sodium bicarbonate (saturated, 2 × 100 mL), and water (100 mL), dried ($MgSO_4$), and filtered. The solvent was removed in vacuo, and the residue was recrystallized from methylene chloride–ether–hexanes to give 1.98 g (94%) of pure epoxide **18**: mp 217–219 °C; ^{1}H NMR δ 13.24 (s, 1 H), 7.93 (dd, J = 8.0, 1.5 Hz, 1 H), 7.80 (s, 1 H), 7.71 (t, J = 8.0 Hz, 1 H), 7.34 (dd, J = 7.0, 1.4 Hz, 1 H), 4.05 (s, 3 H), 3.94 (d, J = 11.1 Hz, 1 H), 3.20 (dt, J = 11.1, 5.0 Hz, 1 H), 2.45 (t, 5.0 Hz, 2 H), 2.30–1.95 (m, 2 H); mass spectrum, m/z 322 ($M^{+}\cdot$).

6,9-Dihydroxy-4-methoxy-7,8,9,10-tetrahydro-5,12-naphthacenedione (19). A mixture of the epoxide **18** (1.85 g, 5.75 mmol), dissolved in ethanol (75 mL) and triethanolamine (150 mL), and Pd/C (10%, 30 mg) was shaken on a Parr apparatus with a hydrogen pressure of 35 psi for 3 h. The catalyst was removed by filtration through a Celite pad, and the filtrate was partitioned between EtOAc and H_2O (150 mL each). The aqueous layer was separated and again extracted with ethyl acetate (100 mL). The combined organic layers were washed with brine (2 × 100 mL), dried ($MgSO_4$), and filtered. The solvent was removed at reduced pressure, and the residue was recrystallized from methylene chloride–hexanes to give 1.58 g (85%) of pure alcohol **19**: mp 239–241 °C; ^{1}H NMR δ 13.36 (s, 1 H), 7.85 (dd, J = 9.5, 1.0 Hz, 1 H), 7.72 (t, J = 9.0 Hz, 1 H), 7.49 (s, 1 H), 7.44 (d, J = 9.2 Hz, 1 H), 4.16 (m, 1 H), 4.07 (s, 3 H), 3.60–2.88 (m, 4 H), 2.35–1.80 (m, 2 H); mass spectrum, m/z 324 ($M^{+}\cdot$).

7,8-Dihydro-6-hydroxy-4-methoxy-5,9(10*H*),12-naphthacenetrione (1b). To a solution of alcohol **19** (1.55 g, 4.78 mmol) in methylene chloride (175 mL) was added pyridinium chlorochromate (2.06 g, 9.57 mmol), and the mixture was vigorously stirred. After 4 h a TLC of the reaction showed complete consumption of the starting material. 2-Propanol (10 mL) was added to the reaction mixture, and stirring was continued for another 1 h. Water (100 mL) was added to the reaction mixture, and the aqueous phase was separated. The methylene chloride solution was washed with brine (3 × 100 mL), dried ($MgSO_4$), and filtered. The solvent was evaporated at reduced pressure, and the residue was purified by column chromatography on silica gel with methylene chloride–ethyl acetate (4:1) as the eluent. Recrystallization of the eluted material gave 1.40 g (91%) of pure triketone **16**, mp 256–258 °C (lit.[9a] mp 258–259 °C). The spectral (^{1}H NMR, IR, and UV) characteristics and TLC behavior of this

product were identical with both the material produced in the other sequence and with the sample supplied by Dr. Kende. A mixed melting point was undepressed.

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Registry No. *cis*-**5**, 80727-33-9; *trans*-**5**, 84810-55-9; *cis*-**7a**, 84810-56-0; *trans*-**7a**, 84810-57-1; *cis*-**7b**, 84810-58-2; *trans*-**7b**, 84810-59-3; **8**, 81838-64-4; **9**, 78-94-4; *cis*-**10a**, 84810-60-6; *trans*-**10a**, 84810-61-7; **10b**, 84810-62-8; **10c**, 84810-63-9; *cis*-**11**, 84810-64-0; *trans*-**11**, 84810-65-1; **12a**, 84810-66-2; **12b**, 84810-67-3; *cis*-**13**, 84810-68-4; **14**, 84810-69-5; **15**, 84810-70-8; **16**, 77219-86-4; **17**, 84810-71-9; **18**, 84810-72-0; **19**, 84810-73-1.

Reaction of Diazonium Salts with Transition Metals. 8. Palladium-Catalyzed Carbon–Carbon Coupling of Arenediazonium Salts with Organotin Compounds[1]

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Arenediazonium salts are effectively functionalized with a methyl or vinyl group by palladium-catalyzed coupling with organotin compounds in acetonitrile at room temperature. Fairly good yields were obtained irrespective of the nature of a substituent on the aromatic ring, including a nitro group. Transformation of the diazonium group can proceed chemoselectively even in the presence of halogen substituents.

Although the diazonium group is useful to introduce various functional groups into an aromatic ring, simple alkyl groups have rarely been introduced. Unlike heteroatom nucleophiles, carbon nucleophiles such as active methylene compounds,[2] Grignard reagents,[3] and active aromatic rings react with diazonium salts to give azo compounds. The conventional C–C bond-forming reactions via diazonium salts have been achieved under copper catalysis (Meerwein arylation and Sandmeyer cyanation) or under basic conditions (Gomberg reaction), in which the mechanism is believed to take a radical pathway.[4] Recent palladium-catalyzed reactions of diazonium salts with alkenes[5] or carbon monoxide,[6] in which arylpalladium species are assumed to be intermediates, afforded a simple method for transformation of the C–N bond to a C–C bond. The palladium-catalyzed reactions have several advantages over the conventional methods such as higher yields and less restriction of substituents on both substrates.

We now report a simple C–C coupling of arenediazonium salts (ArN_2X) utilizing metathesis between in situ formed arylpalladium species and tetraorganotin compounds.

Results and Discussion

Methylation of ArN_2X. Addition of a palladium catalyst to a solution of an ArN_2X and Me_4Sn in acetonitrile afforded a methylarene (ArMe) with gas evolution (eq 1).

$$ArN_2X + Me_4Sn + PdL_2 \rightarrow ArMe\ (+\ Ar\text{–}Ar + EtH) \quad (1)$$

The effects of reaction conditions to the methylation of $4\text{-}BrC_6H_4N_2X$ are shown in Table I. Presence of chloride ion (by the use of ArN_2Cl or an addition of LiCl) in the reaction produced Me_3SnCl and decreased the yield drastically (entry 1 and 3). In the presence of Me_3SnCl, ArN_2X formed intractable tarry materials. Both zero- and divalent palladium complexes acted as catalysts effectively, albeit palladium(II) acetate showed an induction period of about 15 min as shown in Figure 1. Since palladium(II) acetate does not react with ArN_2X, the induction period (and also the deviation between the course of ArMe formation and gas evolution) may be explained in terms of formation of dimethylpalladium followed by reaction with ArN_2X to give ethane and ArPdX as a preceding step of the reaction (eq 2). A GLC analysis of the gas evolved

$$Pd(II) + 2Me_4Sn \rightarrow [Me\text{—}Pd\text{—}Me] \xrightarrow[N_2]{ArN_2X} Ar\text{—}Pd\text{—}X + EtH \quad (2)$$

under the normal reaction conditions revealed that it contained about 8 vol % of hydrocarbon composed of ethane (~95%) and methane (~5%).

In the absence of ArN_2X, the reaction of Me_4Sn and $Pd(OAc)_2$ at 25 °C also gave gaseous products along with precipitation of palladium black. However, the composition of hydrocarbons in the gas was very different, i.e.: methane, 57%; ethane, 36%; ethylene, 7%.[7] Thus, the dimethylpalladium may react directly with ArN_2X to form ethane and ArPdX.[8]

(1) Part 7: Kikukawa, K.; Kono, K.; Wada, F.; Matsuda, T. *Chem. Lett.* **1982**, 35.
(2) Parmerter, S. M. *Org. React.* **1959**, *10*, 1.
(3) Durtin, D. Y.; Ursprung, J. A. *J. Org. Chem.* **1956**, *21*, 1221.
(4) March, J. "Advanced Organic Chemistry"; 2nd ed.; McGraw-Hill/Kogakusha, Ltd.: Tokyo, 1977; pp 653, 655, 662.
(5) Kikukawa, K.; Nagira, K.; Wada, F.; Matsuda, T. *Tetrahedron* **1981**, *37*, 31.
(6) Nagira, K.; Kikukawa, K.; Wada, F.; Matsuda, T. *J. Org. Chem.* **1980**, *45*, 2365. Kikukawa, K.; Kono, K.; Nagira, K.; Wada, F.; Matsuda, T. *Ibid.* **1981**, *46*, 4413.
(7) The yield of ethylene depended on $Pd(OAc)_2$ concentration (7.5% based on Pd at $[Pd(OAc)_2]$ = 0.032 M and 13% at 0.098 M), while those of methane and ethane did not (methane 59% and ethane 37.5% at 0.032 M and methane 57% and ethane 37% at 0.098 M). Although there is no other evidence, the formation of ethylene and its dependence on $Pd(OAc)_2$ concentration suggest the presence of α-elimination process for decomposition of dimethylpalladium complex in the absence of ArN_2X.[20]
(8) These results suggest electron transfer from dimethylpalladium for the present reductive coupling reaction,[21] i.e.: $Pd^{II}Me_2 + ArN_2X \rightarrow [Pd^{III}Me_2]^+ + ArN_2\cdot + X^- \rightarrow EtH + Pd(I) + Ar\cdot + X^- + N_2 \rightarrow EtH + ArPdX + N_2$

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