Chloroform eluent furnished 12.5 mg (6.3%) of 9,10-phenanthraquinone identified by comparison with authentic material, mp 205 °C (lit.[13] mp 208.5–210 °C). Further elution gave 65 mg of unreacted **3**.

A reaction attempted at −20 °C gave only unchanged starting material.

6-Fluorobenzo[*c*]phenanthren-5(6*H*)-one (6). A solution of 0.21 g (0.72 mmol) of 5-(*N*-acetylamino)benzo[*c*]phenanthrene[14] in 75 ml of chloroform was treated with 2.4 g of CF_3OF according to the above procedure. After removal of residual gas and concentration on a rotary evaporator, 0.34 g of crude oil was obtained. Preparative TLC (500 μ, 20 × 5 cm slide, $CHCl_3$) showed the presence of several substances from which the major component **6** (R_f 0.39) was isolated as an oil (57.7 mg, 30%) which slowly crystallized over a period of 2 months: mp 85–88 °C (yellow crystals); ir (neat) 1730 (C=O), 730 cm^{-1}; NMR ($CDCl_3$) δ 4.43 (1 H, benzylic proton, d, J_{HF} = 48 Hz), 7.4–8.0 (10 H, m, aromatic); MS *m/e* (rel intensity) 262 (M, 100), 243 (14), 232 (21), 149 (38). Anal. Calcd for $C_{18}H_{11}FO$: C, 82.4; H, 4.2; F, 7.3. Found: C, 82.1; H, 4.5; F, 7.7.

6-Fluoro-7,12-dimethylbenz[*a*]anthracen-5(6*H*)-one (8). 6-Methoxy-7,12-dimethylbenz[*a*]anthracene[15] (0.25 g, 0.66 mmol) in 75 ml of chloroform was reacted with 1.0 g of CF_3OF. A brown solid (0.059 g) was obtained by filtration: mp >400 °C; empirical formula, C_5H_3FO; mass spectrum not attainable owing to low volatility; ir (KBr) broad, diffuse absorptions.

The concentrated filtrate furnished a dark oil which gave four fractions by TLC (300 μ, 20 × 5 cm, 1:1 $CHCl_3$–hexane): (1) R_f 0.074, 9.1 mg, identical with above described high melting point material; (2) R_f 0.50, 26 mg, unidentified; (3) R_f 0.79, 87 mg (45%) of **8**; (4) R_f 0.95, 59 mg, recovered **7**.

Compound **8** gave the following properties: mp 159–160 °C; ir (KBr) 3390 (OH), 1700 (C=O), 890, 745, 710 cm^{-1} (aromatic); NMR ($CDCl_3$) δ 1.42 (3 H, s, 7-CH_3), 2.88 (3 H, s, 12-CH_3), 4.0 (1 H, d, benzylic, J_{HF} = 84 Hz), 7.3–8.2 (8 H, m, aromatic); MS *m/e* (rel intensity) 290 (M, 7), 275 (22), 271 (7), 260 (100), 245 (50). Anal. Calcd for $C_{20}H_{15}FO$: C, 82,8; H, 5.2; F, 6.6 Found: C, 83.0; H, 5.2; F, 6.5.

Fraction 2 showed a broad melting range of 140 to >300 °C. Analytical TLC indicated the presence of **8** and the substance(s) in fraction 1.

Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research. M.H.L. was supported by a research assistantship from the Graduate School, Southern Illinois University.

Registry No.—**3,** 4235-09-0; **4,** 59830-28-3; **5,** 4176-51-6; **6,** 59830-29-4; **7,** 53306-03-9; **8,** 59830-30-7; CF_3OF, 373-91-1.

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(15) We thank Dr. Newman for the sample of **7** used in this work, ref 4.

2,4-Dihydroxyphenanthrenes and Derived Ethers. Regioselective Etherification of Acetates

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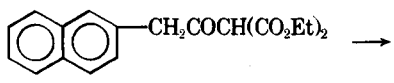
Received May 10, 1976

Etherification of the two phenanthrene diacetates **3** and **11** using a large alkyl halide in the presence of anhydrous K_2CO_3 in refluxing dry acetone is much more regioselective at the 2 position than is the direct alkylation of the monosodium salts of the corresponding phenanthrenediols **2** and **10.** However, this regioselectivity unaccountably disappears when methyl iodide is used as the alkylating agent. Also, when the steric hindrance provided by the 5 position is diminished by conversion to the nonplanar 9,10-dihydrophenanthrene system, regioselective etherification of the diacetate (i.e., **20**) no longer occurs. End products of the present work were prepared as carbocyclic analogues of the cannabinoids. Although none shows appreciable central nervous system activity, some of the chemistry used in their preparation may be useful for the syntheses of certain antifungal phytoalexins which are known to be ethers of 2,4-dihydroxy-9,10-dihydrophenanthrenes.

In extension of our work[1] in the cannabinoid field, some 2,4-disubstituted phenanthrenes and corresponding 9,10-dihydro derivatives were prepared as carbocyclic analogues of the pharmacologically potent heterotricyclic substances. Although none of the analogues exhibited appreciable central nervous system activity, some of the chemistry described here should be applicable to improved syntheses in the area of the antifungal phytoalexins, orchinol, hircinol, and loroglossol. These have been shown to be methyl ethers of 9,10-dihydro-2,4,5(7)-trihydroxyphenanthrene.[2,3]

The key intermediate **2** for this work was provided by a modification of a reported method.[4] By treating crude keto ester **1** with methanesulfonic acid at room temperature instead of polyphosphoric acid at 150 °C, the 6% reported yield of **2** was increased to nearly 60%.

Selective ether formation at the less hindered 2 position of **2** was initially approached by simple alkylation of the monosodium salt in hexamethylphosphoramide (HMPA). Under these conditions 3-*p*-fluorophenylpropyl bromide (3-FPB) gave a 53% yield of the desired monoether **4** and a 34% yield of the diether **6.** Column chromatography was necessary for the isolation of both products even though none of the mo-



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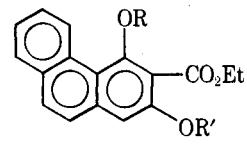


2, R = R′ = H

3, R = R′ = COMe

4, R = H; R′ = $(CH_2)_3$—C$_6$H$_4$—F

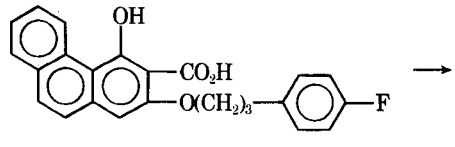
5, R = COMe; R′ = $(CH_2)_3$—C$_6$H$_4$—F

6, R = R′ = $(CH_2)_3$—C$_6$H$_4$—F

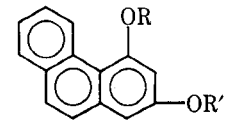
7, R = COMe; R′ = n-C_8H_{17}

8, R = COMe; R′ = CH_2Ph

noether isomeric with 4 was detected in the reaction mixture. Hydrolysis of 4 gave the corresponding acid 9 which could be smoothly decarboxylated to 12.



9



10, R = R′ = H

11, R = R′ = COMe

12, R = H; R′ = $(CH_2)_3$—C$_6$H$_4$—F

13, R = $(CH_2)_3$—C$_6$H$_4$—F; R′ = H

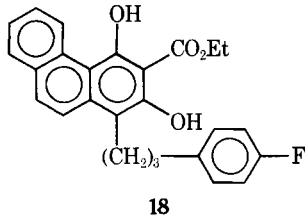
14, R = H; R′ = n-C_8H_{17}

15, R = COMe; R′ = $(CH_2)_3$—C$_6$H$_4$—F

16, R = COMe; R′ = n-C_8H_{17}

17, R = R′ = n-C_8H_{17}

Alkylation of the monosodium salt of 2,4-dihydroxyphenanthrene (10) with 3-FPB in HMPA led to only a 35% yield of the monoether 12 plus a 4.7% yield of the isomeric ether 13 as the only other isolable product. The diether, which must have been formed in appreciable amounts, was not isolated in pure form. An incidental observation possibly accounting partly for the less than satisfactory course of this direct alkylation method was encountered when an attempt was made to alkylate the disodium salt of 2 with 3-FPB in HMPA.



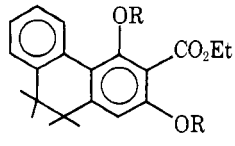
18

Under these conditions the only product isolated was a poor yield (21%) of the carbon-alkylated derivative 18. Subsequent NMR experiments clearly showed that the proton at the 1 position in 2 undergoes deuterium exchange in Me_2SO-d_6 to which sodium hydride is added.

Attention was next turned to the possibility of selective etherification of the diacetates 3 and 11 using a process discovered by Jurd in connection with regioselective alkylations of polyhydroxyflavones[5] and -flavonols,[6] and later extended to dihydroxycoumarins by Seshadri and coworkers[7]. Thus, when the diacetate 3 was heated under reflux in dry acetone for 77 h with excess 3-FPB in the presence of excess anhydrous K_2CO_3, an 85% yield of the desired ether acetate 5 was secured. In contrast, identical treatment of the corresponding dihydroxy compound 2 led to a quantitative yield of the diether 6. When n-octyl bromide was used in place of 3-FPB, the crude ether acetate 7 was obtained in good yield and, without purification, was saponified and decarboxylated to the monoether 14 in a 26% overall yield. Likewise, the alkylation of 3 with benzyl chloride produced a 78% yield of the regioselective alkylation product 8.[8] Most surprisingly, however, methyl iodide in this reaction gave a mixture containing approximately equal amounts of all three possible products: the two monoethers and the dimethyl ether. In view of the fact that methyl iodide was the reagent most often employed by the previous workers,[5-7] its total lack of regioselectivity in the present system is most puzzling.

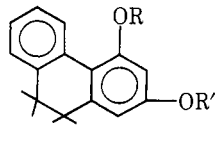
In the diacetate 3, as in most of the systems studied previously,[5-7] the phenoxide ion leaving group is stabilized by an electronegative group in conjugation with it (i.e., the 3-carbethoxy group in 3). Nevertheless, when the diacetate 11, lacking this stabilizing feature, was treated with a larger excess (5:1 vs. 2:1 for the reaction with 3) of 3-FPB, a 77% yield of the ether acetate 15 was obtained after 75 h of heating under reflux in acetone. However, the reaction with an even larger excess of n-octyl bromide required 114 h to approach the point of completion. Under these conditions, a 76% yield of the ether acetate 16 was isolated along with a 13% yield of the diether 17. Thus, the absence of the activating group (CO_2Et) appears to reduce the rate but not the regioselectivity of this reaction system.

Hydrogenation of several of these phenanthrenes to their corresponding 9,10-dihydro derivatives was accomplished by a modification of a reported[3] method using palladium–charcoal catalyst and ethyl acetate as solvent. We found that hydrogenation occurred more rapidly in the presence of a small amount of 10% $HClO_4$ in acetic acid. In this way 19 and 20 were obtained from 2 and 3, respectively; and 21, 22, and 23 were derived in turn from 12, 15, and 16.



19, R = H

20, R = COMe



21, R = H; R′ = $(CH_2)_3$—C$_6$H$_4$—F

22, R = COMe; R′ = $(CH_2)_3$—C$_6$H$_4$—F

23, R = COMe; R′ = n-C_8H_{17}

Finally, it is of interest to note that when the diacetate **20** was treated with 3-FPB in acetone–K_2CO_3, a complex mixture was produced in which **22** was only one of the components. Apparently, the out-of-plane conformation of the two benzene rings in **20** reduces the steric effect of the 5-hydrogen atom on the 4-acetate to the point where attack at the 2-acetate group is no longer favored.[9]

Experimental Section

All melting points were taken in capillary tubes and are uncorrected. Ir spectra (all in $CDCl_3$ solution) were obtained using a Perkin-Elmer Model 521 spectrophotometer. NMR spectra (all in $CDCl_3$ solution) were recorded using a Varian T-60 spectrometer. Chemical shifts are reported as δ relative to tetramethylsilane (δ 0.0 ppm) using the following abbreviations: s = singlet, d = doublet, t = triplet, q = quartet, and m = multiplet. Thin layer chromatograms (TLC) were carried out on Adsorbil-2 silica gel to a distance of 5 cm on microscope slides. Spots were detected by development with iodine vapor.

Ethyl 2,4-Dihydroxy-3-phenanthrenecarboxylate (2). To 400 ml of methanesulfonic acid cooled to 10–15 °C in an ice bath was added with stirring over a period of several minutes 85.5 g of crude 2-naphthylacetylmalonic ester **1**.[4,10] The mixture was stirred at room temperature for 18 h, then poured into 3 l. of water and vigorously stirred for 4 h. Solid product was collected at the filter, and taken up in methylene chloride (400 ml), washed once with 5% $KHCO_3$ (150 ml), and dried over $MgSO_4$. Filtration and removal of solvent by distillation left a yellow solid which was stirred vigorously for 45 min with pentane (200 ml). Collection at the filter afforded 53.7 g of crude product, mp 107–113 °C. One recrystallization from ethanol (700 ml) gave 42.7 g (58% yield based on pure starting material): mp 119–121 °C (lit.[4] mp 115–116 °C); ir 3460, 3370 (OH), 1675 cm^{-1} (bonded C=O); NMR δ 12.54 (s, 1, OH), 9.7–9.4 (m, 1, 5-H), 9.00 (s, 1, OH), 7.8–7.2 (m, 5, 6, 7, 8, 9, 10-H), 6.82 [s, 1, 1-H (exchangeable in Me_2SO-d_6 + NaH)], 4.54 (q, 2, J = 7 Hz, OCH_2CH_3), and 1.42 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Ethyl 2,4-Diacetoxy-3-phenanthrenecarboxylate (3). By heating a pyridine solution of **2** under reflux (2 h) in the presence of excess acetic anhydride there was obtained a 93% yield of **3**: mp 134–135 °C (ethanol); ir 1780, 1725 cm^{-1} (C=O); NMR δ 9.2–8.8 (m, 1, 5-H), 8.0–7.3 (m, 6, ArH), 4.43 (q, 2, J = 7 Hz, OCH_2CH_3), 2.47 (s, 3, $COCH_3$), 2.33 (s, 3, $COCH_3$), and 1.40 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{21}H_{18}O_6$: C, 68.84; H, 4.95. Found: C, 68.95; H, 4.89.

Ethyl 2-(3-*p*-Fluorophenylpropoxy)-4-hydroxy-3-phenanthrenecarboxylate (4) and Ethyl 2,4-Di-(3-*p*-fluorophenylpropoxy)-3-phenanthrenecarboxylate (6). To a cold (5 °C), stirred solution of 14.1 g (0.05 mol) of **2** and 14.0 g (0.064 mol) of 3-*p*-fluorophenylpropyl bromide[1,11] in 70 ml of hexamethylphosphoramide (HMPA) was added in nine portions over a period of 5 h 2.5 g (0.06 mol) of sodium hydride (as a 57% dispersion in mineral oil). Stirring at room temperature was continued for 57 h and the neutral reaction mixture was poured into cold water (300 ml). The precipitated oil was taken up in ether (250 ml), washed with water (150 ml), and dried over $MgSO_4$. Filtration and removal of the solvent by distillation left 25.1 g of an oil which was chromatograhed on a silica gel column (6 × 100 cm) using 4 l. of benzene for elution, and monitoring the eluate using TLC (50 C_6H_6–50 CCl_4). Four fractions were obtained: 0.19 g of an oil, 9.54 g of yellow oil (34% yield of **6**), 8.67 g of yellow solid, mp 95–100 °C, and 1.62 g of yellow solid, mp 90–95 °C (10.29 g, 53% yield of **4**). Recrystallization of a sample of the solid from ethanol gave pure **4**: mp 102–103 °C; NMR δ 10.67 (s, 1, OH), 9.7–9.2 (m, 1, 5-H), 8.0–6.8 (m, 10, ArH), 4.49 (q, 2, J = 7Hz, OCH_2CH_3), 3.90 (t, 2, J = 6 Hz, OCH_2CH_2), 3.0–2.0 (m, 4, CH_2CH_2Ar), and 1.38 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{26}H_{23}FO_4$: C, 74.63; H, 5.54. Found: C, 74.89; H, 5.65.

After standing for a month, the 9.54 g of yellow oil began to crystallize. Trituration with hexane completed the solidification. Filtration and washing with pentane yielded 7.02 g of pure **6**: mp 63–65 °C; ir no OH, 1740 cm^{-1} (C=O); NMR δ 9.7–9.2 (m, 1, 5-H), 8.0–6.7 (m, 14, ArH), 4.46 (q, 2, J = 7 Hz, OCH_2CH_3), 4.05 (t, 4, J = 6 Hz, OCH_2CH_2), 3.0–1.7 (m, 8, CH_2CH_2Ar), and 1.37 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{35}H_{32}F_2O_4$: C, 75.79; H. 5.82. Found: C, 75.50; H, 5.85.

Ethyl 2,4-Dihydroxy-1-(3-*p*-fluorophenylpropyl)-3-phenanthrenecarboxylate (18). To a stirred cold (5 °C) solution of 1.41 g (0.005 mol) of **2** in 5 ml of HMPA was added 0.42 g (0.01 mol) of sodium hydride. After stirring at room temperature for 1.5 h, a solution of 1.09 g (0.005 mol) of 3-*p*-fluorophenylpropyl bromide was added and stirring was continued for another 19 h. The reaction mixture was worked up as before to give 1.36 g of crude oil which was separated into four fractions by silica gel chromatography (benzene solvent): 0.01 g of yellow oil, 0.40 g of pale yellow solid, mp 110–125 °C (21% yield of impure **18**), 0.10 g of yellow oil, and 0.70 g of yellow oil. One recrystallization of the solid fraction from cyclohexane (10 ml) followed by another from benzene (1 ml)–ethanol (3 ml) gave pure **18** (0.17 g, mp 145–146 °C): ir 3450, 3370 (OH), and 1660 cm^{-1} (C=O); NMR δ 12.30 (s, 1, OH), 9.8–9.4 (m, 1, 5-H), 9.55 (s, 1, OH), 8.0–6.7 (m, 9, ArH), 4.59 (q, 2, J = 7 Hz, OCH_2CH_3), 3.3–2.5 (m, 4, $ArCH_2C$–CH_2Ar), 2.3–1.2 (m, 2, ArC–CH_2–CAr), and 1.45 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{26}H_{23}FO_4$: C, 74.63; H, 5.54. Found: C, 74.55; H, 5.54.

Ethyl 4-Acetoxy-2-(3-*p*-fluorophenylpropoxy)-3-phenanthrenecarboxylate (5). A stirred mixture of 1.1 g (0.003 mol) of the diacetate **3**, 1.3 g (0.006 mol) of 3-*p*-fluorophenylpropyl bromide, 1.5 g of anhydrous K_2CO_3, a few crystals of KI, and 10 ml of acetone (dried over anhydrous K_2CO_3) was heated under reflux for 77 h. TLC (99 C_6H_6–1 CH_3OH) indicated the presence of only a trace of **3** remaining. Insoluble salts were removed by filtration and washed with acetone. The combined filtrate and washings were concentrated to dryness on a rotary evaporator. Trituration of the residual oil (1.75 g) with pentane produced a solid product which was collected at the filter, washed with pentane, and dried to give 1.18 g (85% yield) of **5**, mp 107–110 °C. One recrystallization from ethanol (8–10 ml) gave pure **5**, mp 110–112 °C, identical (mixture melting point and NMR) with a sample prepared by acetylation of **4** in pyridine–acetic anhydride: NMR δ 9.7–9.3 (m, 1, 5-H), 8.2–6.8 (m, 10, ArH), 4.43 (q, 2, J = 7 Hz, OCH_2CH_3), 4.05 (t, 2, J = 6 Hz, OCH_2CH_2), 3.0–1.8 (m, 4, CH_2CH_2Ar), 2.27 (s, 3, $COCH_3$), and 1.35 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{28}H_{25}FO_5$: C, 73.03; H, 5.47. Found: C, 73.22; H, 5.46.

Subjecting the dihydroxy derivative **2** to the foregoing conditions produced no detectable amounts of the monoether (i.e., **4**). Instead, essentially a quantitative yield of the diether **6** was obtained.

Ethyl 4-Acetoxy-2-*n*-octyloxy-3-phenanthrenecarboxylate (7). A stirred mixture of 7.3 g (0.02 mol) of **3**, 19.3 g (0.1 mol) of *n*-octyl bromide, 20 g of anhydrous K_2CO_3, 1 g of KI, and 90 ml of dry acetone was heated under reflux for 64 h and worked up as in the foregoing procedure. A brown oil (8.93 g) was obtained which did not crystallize: NMR δ 9.6–9.2 (m, 1, 5-H), 8.0–7.3 (m, 6, ArH), 4.46 (q, 2, J = 7 Hz, OCH_2CH_3), 4.00 (t, 2, J = 6 Hz, OCH_2CH_2), 2.27 (s, 3, $COCH_3$), and 2.5–0.5 ppm (m, 20.5 instead of 18, C–CH). The high integration in the aliphatic C–CH region suggested the presence of octyl bromide or octanol as impurity. However, this material was usable in the next step without further purification.

Ethyl 4-Acetoxy-2-benzyloxy-3-phenanthrenecarboxylate (8). Treatment of **3** with excess benzyl chloride for 70 h in boiling acetone in the presence of anhydrous K_2CO_3 gave a 78% yield of **8**: mp 71–72 °C (from hexane); NMR δ 9.7–9.3 (m, 1, 5-H), 8.0–7.2 (m, 11, ArH), 5.03 (s, 2, $OCH_2C_6H_5$), 4.38 (q, 2, J = 7 Hz, OCH_2CH_3), 2.27 (s, 3, $COCH_3$), and 1.27 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{26}H_{22}O_5$: C, 75.34; H, 5.35. Found: C, 75.04; H, 5.35.

Reaction of 3 with Excess CH_3I. When the diacetate **3** was treated with excess CH_3I for 54 h in the usual manner, a quantitative yield of a pale yellow glass was obtained. TLC (99 C_6H_6–1 CH_3OH) showed that it contained three components (R_f 0.52, 0.62, and 0.75) none of which was **3** (R_f 0.37). The 60-Hz NMR spectrum of this material disclosed the presence of two acetyl methyl groups (2.30 and 2.42 ppm) and the 100-Hz NMR spectrum (recorded on a Varian Associates HA-100 spectrometer) revealed the presence of three *O*-methyls (3.90, 3.92, and 3.94 ppm). From the integral values of these five peaks it could be determined that the mixture consisted of 30% of one monomethoxyacetate derivative, 31% of the other monomethoxyacetate isomer, and 36% of the dimethoxy derivative, in which both acetyl groups of **3** had been displaced.

2-(3-*p*-Fluorophenylpropoxy)-4-hydroxy-3-phenanthrenecarboxylic Acid (9). A mixture of 5.4 g of the ester **4**, 24 g of KOH, 90 ml of water, and 65 ml of ethanol was stirred and heated under reflux in a nitrogen atmosphere for 21 h. The cooled mixture was poured onto ice containing 75 ml of 6 N hydrochloric acid. Precipitated oil was taken up in ether, washed to neutrality with water, and dried over $MgSO_4$. Filtration and removal of the ether by distillation yielded 4.71 g (93%), mp 110–116 °C, sufficiently pure for the next

step. Two recrystallizations of a sample from CCl_4 gave pure **9:** mp 119–120 °C; ir 3400 (broad, bonded OH) and 1690 cm^{-1} (C=O); NMR δ 12.8–12.2 (m, 1, CO_2H), 11.75 (s, 1, ArOH), 9.2–8.7 (m, 1, 5-H), 8.1–6.8 (m, 10, ArH), 4.03 (t, 2, J = 6 Hz, OCH_2CH_2), and 3.0–1.8 ppm (m, 4, C–CH_2CH_2Ar).

Anal. Calcd for $C_{24}H_{19}FO_4$: C, 73.83; H, 4.91. Found: C, 73.83; H, 4.88.

2-(3-*p*-Fluorophenylpropoxy)-4-hydroxyphenanthrene (12). The 4.71 g of crude acid **9** was mixed with 0.5 g of copper power and subjected to distillation in a Kugelrohr under a vacuum of 0.01 mm. At 160–170 °C (air bath temperature) decarboxylation began and the pressure increased to 0.1 mm. As decarboxylation neared completion the pressure decreased again to 0.01 mm and product distilled at 180–240 °C. The solid distillate (4.10 g) was redistilled in the Kugelrohr under the same conditions to give 3.41 g (82%) of product, mp 111–115 °C. Recrystallization of a sample from CCl_4 gave pure **12:** mp 116–117 °C; ir 3620 cm^{-1} (OH); NMR δ 9.9–9.5 (m, 1, 5-H), 8.0–6.5 (m, 11, ArH), 5.3–4.8 (broad, 1, OH),[12] 4.08 (t, 2, J = 6 Hz, OCH_2CH_2), 3.2–2.6 (m, 2, CH_2CH_2Ar), and 2.6–1.8 ppm (m, 2, $CH_2CH_2CH_2$Ar).

Anal. Calcd for $C_{23}H_{19}FO_2$: C, 79.75; H, 5.53. Found: C, 79.87; H, 5.63.

4-(3-*p*-Fluorophenylpropoxy)-2-hydroxyphenanthrene (13). 2,4-Dihydroxyphenanthrene,[4] mp 159–161 °C (from 2-propanol–H_2O), was alkylated with 3-*p*-fluorophenylpropyl bromide in HMPA as described above for the preparation of **4.** The crude product was chromatographed on a silica gel column using $CHCl_3$ for elution. In addition to a 35% yield of the hydroxy ether **12,** mp 115–117 °C, R_f 0.34 ($CHCl_3$), there was obtained a 4.7% yield of the isomeric hydroxy ether **13:** mp 122–124 °C; R_f 0.57 ($CHCl_3$); NMR δ 9.7–9.3 (m, 1, 5-H), 8.2–6.5 (m, 11, ArH), 5.77 (s, 1, OH),[12] 3.97 (t, 2, J = 6 Hz, OCH_2CH_2), 3.0–2.4 (m, 2, CH_2CH_2Ar), and 2.4–1.7 ppm (m, 2, $CH_2CH_2CH_2$Ar).

Anal. Calcd for $C_{23}H_{19}FO_2$: C, 79.75; H, 5.53. Found: C, 79.43; H, 5.51.

4-Hydroxy-2-*n*-octyloxyphenanthrene (14). The 8.93 g of impure acetoxy ester **7** was saponified as described above for the preparation of the acid **9.** The dark colored oil (7.2 g) thus obtained could not be crystallized so it was decarboxylated by the procedure specified previously for the preparation of **12.** Multiple trituration of the crude oily distillate with hexane produced 1.72 g (26% yield from **7**), mp 85–95%. One recrystallization from cyclohexane (60 ml) and another from CCl_4 (5 ml) gave 0.53 g of pure **14:** mp 93–96 °C; NMR δ 9.8–9.3 (m, 1, 5-H), 8.0–7.2 (m, 5, ArH), 6.82 (d, 1, J = 2 Hz, 1- or 3-H), 6.68 (d, 1, J = 2 Hz, 3- or 1-H), 5.8–5.0 (broad, 1, OH), 4.07 (t, 2, J = 6 Hz, OCH_2CH_2), and 2.2–0.3 ppm (m, 15, C–CH).

2,4-Diacetoxyphenanthrene (11). The dihydroxy ester **2** (8 g) was hydrolyzed and decarboxylated according to Hardegger et al.[4] The crude 2,4-dihydroxyphenanthrene (6.25 g, mp 155–160 °C) was directly acetylated in pyridine–acetic anhydride (see preparation of **3** above) to give 8.0 g (96% yield from **2**), mp 137–140 °C, suitable for further use. Recrystallization from methanol produced pure **11:** mp 140–142 °C; ir 1760–1790 cm^{-1} (C=O); NMR δ 9.4–8.8 (m, 1, 5-H), 7.8–6.8 (m, 7, ArH), 2.52 (s, 3, $COCH_3$), and 2.35 ppm (s, 3, $COCH_3$).

Anal. Calcd for $C_{18}H_{14}O_4$: C, 73.46; H, 4.80. Found: C, 73.53; H, 4.81.

4-Acetoxy-2-(3-*p*-fluorophenylpropoxy)phenanthrene (15). A stirred mixture of the diacetate **11** (1.77 g, 0.006 mol), 3-*p*-fluorophenylpropyl bromide (6.5 g, 0.03 mol), 6 g of anhydrous K_2CO_3, a few crystals of KI, and 40 ml of dry acetone was heated under reflux for 75 h. The usual workup led to 1.80 g (77%) of crude product, mp 94–98 °C. Recrystallization from cyclohexane gave 1.40 g of pure **15,** mp 109–110 °C, identical (mixture melting point and NMR) with the product of acetylation of **12:** NMR δ 9.9–9.6 (m, 1, 5-H), 8.0–6.8 (m, 11, ArH), 4.20 (t, 2, J = 6 Hz, OCH_2CH_2), 3.3–2.7 (m, 2, CH_2CH_2Ar), 2.33 (s, 3, $COCH_3$), and 2.7–2.0 ppm (m, 2, $CH_2CH_2CH_2$Ar).

4-Acetoxy-2-*n*-octyloxyphenanthrene (16) and 2,4-Di-*n*-octyloxyphenanthrene (17). A stirred mixture of the diacetate **11** (16.6 g, 0.0562 mol), 8.2 ml of *n*-octyl bromide, 60 g of anhydrous K_2CO_3, 5 g of KI, and 350 ml of dry acetone was heated under reflux for 114 h. The usual workup led to 13.3 g (65%) of **16,** mp 74–76 °C. Recrystallization of a sample from acetone gave pure **16,** mp 76–77 °C, identical (mixture melting point and NMR) with the product of acetylation of **14:** NMR δ 9.7–9.5 (m, 1, 5-H), 8.0–7.3 (m, 5, ArH), 7.22 (d, 1, J = 2 Hz, 1- or 3-H), 6.85 (d, 1, J = 2 Hz, 3- or 1-H), 4.15 (t, 2, J = 6 Hz, OCH_2CH_2), 2.27 (s, 3, $COCH_3$), and 2.2–0 5 ppm (m, 15, C–CH).

Anal. Calcd for $C_{24}H_{28}O_3$: C, 79.08; H, 7.74. Found: C, 79.14; H, 7.84.

A residual pentane-soluble fraction (8.15 g) was chromatographed on a silica gel column (3 × 80 cm). From 3 l. of CCl_4 eluate was obtained 3.23 g (13% yield) of **17,** mp 52–54.5 °C, R_f 0.79 (CCl_4). This was followed by 1 l. of benzene from which was obtained 2.34 g more **16,** mp 70–74 °C, R_f 0.20 (CCl_4), bringing the total yield of **16** to 76% (15.64 g). A sample (0.6 g) of the 3.23 g was recrystallized twice from acetone (1–2 ml) to give pure **17:** mp 56–57.5 °C; NMR δ 9.7–9.5 (m, 1, 5-H), 8.0–7.4 (m, 5, ArH), 6.88 (d, 1, J = 2 Hz, 1- or 3-H), 6.78 (d, 1, J = 2 Hz, 3- or 1-H), 4.4–3.9 (m, 4, OCH_2CH_2), and 2.2–0.5 ppm (m, 30, C–CH).

Anal. Calcd for $C_{30}H_{42}O_2$: C, 82.90; H, 9.74. Found: C, 82.71; H, 9.93.

Ethyl 9,10-Dihydro-2,4-dihydroxy-3-phenanthrenecarboxylate (19). A suspension of 2.8 g of 5% Pd/C in 200 ml of ethyl acetate containing 1.8 ml of 10% $HClO_4$ in glacial HOAc was prehydrogenated for 4 h. Then 2.82 g (0.01 mol) of **2** was added and hydrogenation at room temperature and 3 atm pressure was continued for 7 h after which uptake appeared to be complete. The mixture was filtered from catalyst, washed with bicarbonate solution and water, and dried over Na_2SO_4. Filtration and removal of the solvent by distillation gave a residue which solidified upon trituration with pentane, 2.0 g, mp 68–73 °C. Recrystallization of a sample from ethanol gave pure **19:** mp 71–73 °C; NMR δ 10.90 (s, 1, OH), 9.50 (s, 1, OH), 8.5–8.2 (m, 1, 5-H), 7.5–7.0 (m, 3, ArH), 6.45 (s, 1, 1-H), 4.55 (q, 2, J = 7 Hz, OCH_2CH_3), 2.70 (s, 4, $ArCH_2CH_2Ar$), and 1.27 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{17}H_{16}O_4$: C, 71.82; H, 5.67. Found: C, 71.80; H, 5.72.

Ethyl 2,4-Diacetoxy-9,10-dihydro-3-phenanthrenecarboxylate (20). Hydrogenation of 2.6 g of **3** under the above conditions led to a quantitative uptake of hydrogen in less than 2 h. Workup in the usual way gave 2.5 g of pure **20:** mp 113–114 °C (from hexane); NMR δ 8.2–7.7 (m, 1, 5-H), 7.5–7.1 (m, 3, ArH), 6.98 (s, 1, 1-H), 4.31 (q, 2, J = 7 Hz, OCH_2CH_3), 2.73 (s, 4, $ArCH_2CH_2Ar$), 2.22 (s, 3, $COCH_3$), 2.15 (s, 3, $COCH_3$), and 1.28 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{21}H_{20}O_6$: C, 68.47; H, 5.47. Found: C, 68.29; H, 5.51.

9,10-Dihydro-2-(3-*p*-fluorophenylpropoxy)-4-hydroxyphenanthrene (21). Hydrogenation of **12** in the prescribed manner gave **21:** mp 98–99.5 °C; NMR δ 8.5–8.2 (m, 1, 5-H), 7.5–6.8 (m, 7, ArH), 6.32 (s, 2, 1- and 3-H), 4.94 [s (broad), 1, OH], 3.92 (t, 2, J = 6 Hz, OCH_2CH_2) 2.67 (s, 4, $ArCH_2CH_2Ar$), and 3.2–1.7 ppm (m, 4, $CH_2CH_2CH_2Ar$).

Anal. Calcd For $C_{23}H_{21}FO_2$: C, 79.29; H, 6.08. Found: C, 79.01; H, 6.17.

4-Acetoxy-9,10-dihydro-2-(3-*p*-fluorophenylpropoxy)phenanthrene (22). Likewise, hydrogenation of **15** in the same way produced a 90% yield of **22:** mp 72.5–74 °C (from pentane); NMR δ 8.5–8.2 (m, 1, 5-H), 7.5–6.4 (m, 9. ArH), 3.97 (t, 2, J = 6 Hz, OCH_2CH_2), 2.72 (s, 4, $ArCH_2CH_2Ar$), 2.22 (s, 3, $COCH_3$), and 3.0–0.7 ppm (m, 4, $OCH_2CH_2CH_2Ar$).

Anal. Calcd for $C_{25}H_{23}FO_3$: C, 76.90; H, 5.93. Found: C, 77.10; H, 6.01.

4-Acetoxy-9,10-dihydro-2-*n*-octyloxyphenanthrene (23). Similarly, hydrogenation of **16** provided an 80% yield of **23:** mp 79–80 °C (from acetone); NMR δ 8.5–8.2 (m, 1, 5-H), 7.3–7.0 (m, 3, ArH), 6.63 (s, 2, 1- and 3-H), 3.98 (t, 2, J = 6 Hz, OCH_2CH_2), 2.72 (s, 4, $ArCH_2CH_2Ar$), 2.23 (s, 3, $COCH_3$), and 1.8–0.5 ppm (m, 15, C-CH).

Anal. Calcd for $C_{24}H_{30}O_3$: C, 78.65; H, 8.25. Found: C, 78.80; H, 8.42.

Acknowledgments. The authors wish to thank Mr. W. Washburn for the ir spectra, Dr. R. Egan and Mr. M. Cirovic for the NMR spectra, Ms. J. Hood for the elemental analyses, and Mr. W. Arnold for technical assistance.

Registry No.—**1,** 53076-43-0; **2,** 53076-42-9; **3,** 59873-09-5; **4,** 59873-10-8; **5,** 59873-11-9; **6,** 59873-12-0; **7,** 59873-13-1; **8,** 59873-14-2; **9,** 59873-15-3; **10,** 53076-41-8; **11,** 59873-16-4; **12,** 59873-17-5; **13,** 59873-18-6; **14;** 59873-19-7; **15,** 59873-20-0; **16,** 59873-21-1; **17,** 59873-22-2; **18,** 59873-23-3; **19,** 59873-24-4; **20,** 59873-25-5; **21,** 59873-26-6; **22,** 59873-27-7; **23,** 59873-28-8; 3-FPB, 24484-55-7; acetic anhydride, 108-24-7; *n*-octyl bromide, 111-83-1; benzyl chloride, 100-44-7.

References and Notes

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(8) The 5-benzyloxy derivative of **8** would obviously serve as a useful intermediate for the synthesis of hircinol: 9,10-dihydro-2,5-dihydroxy-4-methoxyphenanthrene.
(9) This steric difference is also evident in the NMR spectra of **20** vs. **3**. In **3** the 5 proton is shifted downfield to the 9.5-ppm region, a feature characteristic of the planar phenanthrene ring in which the 5 (and 4) proton is abnormally deshielded by being in the nodal plane of two benzene rings. In **20**, the 5 proton appears in the 8-ppm region, almost a normal aromatic chemical shift.
(10) Prepared by the reaction of 2-naphthylacetyl chloride with ethoxymagnesiomalonic ester according to the method of G. Reynolds and C. Hauser, "Organic Syntheses", Collect. Vol. IV, Wiley, New York, N.Y., 1963, p 708.
(11) D. Zivkovic, U.S. Patent 3 661 927 (1972).
(12) The observation that the OH peak in **12** is broad (8 Hz width at half-height) and in **13** is a sharp singlet is consistent with the expectation that proton exchange (or rotation around the Ar–O– bond) would be slower in **12** owing to the steric effect of the adjacent 5 position.

Selective Cleavage of Aryl Esters by Anhydrous Alkali Carbonates

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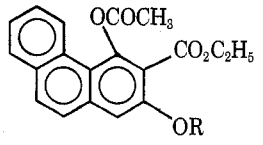
Received May 10, 1976

In the presence of a 10% excess of Cs_2CO_3 in either boiling THF (21 h) or boiling DME (10 h), the phenanthrene-2,4-diacetate **1** is converted quantitatively to the corresponding monoacetate **2**. Likewise, in boiling DME (24 h) with 50% excess Cs_2CO_3, dibenzoylresorcinol **4** gives >95% yields of monobenzoylresorcinol **5**. Provided that anhydrous conditions are maintained, no further cleavage of **5** to resorcinol is observed. The conversion of **4** to **5** was studied systematically by using varying quantities of potassium and cesium carbonates and bicarbonates in THF and DME, and by measuring the quantities of evolved CO_2. A mechanism is proposed which accounts for the observed results.

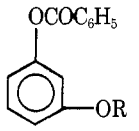
In an accompanying paper, the regioselective etherification of two phenanthrene-2,4-diacetates was described.[1] For example, heating the diacetate **1** under reflux in dry acetone for 77 h with excess 3-*p*-fluorophenylpropyl bromide (3-FPB) in the presence of excess anhydrous K_2CO_3 led to an 85% yield of the monoether **3**.



1, R = $COCH_3$
2, R = H
3, R = $(CH_2)_3$–C$_6$H$_4$–F

In an attempt to reduce the long reaction times required under the heterogeneous conditions involving K_2CO_3, the soluble Cs_2CO_3 was employed instead (Cs_2CO_3 is one of the very few carbonates, if not the only one, showing appreciable solubility in dry acetone). Although the reaction was complete in less than 10 h, the monoether **3** (~60% yield) was contaminated with excessive amounts (~40% yield) of the corresponding diether. When, however, the reaction was carried out in the absence of 3-FPB, a nearly quantitative yield of the monoacetate **2** was isolated after only 5 h (using a 7.4:1 molar ratio of Cs_2CO_3 to **1**). The structure of **2** was established by both ^1H and ^{13}C NMR (see Experimental Section), and by conversion to **3** with 3-FPB. With smaller excess amounts of Cs_2CO_3 in acetone longer reaction times again became necessary. For example, a 2:1 molar ratio gave an 85% yield of **2** only after 48 h. In order to avoid consumption of Cs_2CO_3 by acetone self-condensation reactions which seemed to be occurring, the inert solvents THF and DME were successfully employed instead. Thus, in the presence of only a 10% excess of Cs_2CO_3 a quantitative yield of **2** was obtained after either 21 h of heating under reflux in THF or 10 h in DME. Similarly, a 2:1 molar ratio of $CsHCO_3$ (also appreciably soluble) produced complete conversion of **1** to **2** in 20 h in boiling THF.

To examine further the nature of this aryl ester cleavage, the conversion of resorcinol dibenzoate (**4**) to the corresponding monobenzoate (**5**) was studied in some detail. Re-



4, R = COC_6H_5
5, R = H

actions carried out under various conditions for exactly 24 h were analyzed by NMR to determine the approach to completion, and rough estimates (±5%) were made of the amounts of CO_2 evolved.

In Table IA are summarized the results of heating 0.5 mmol of **4** in boiling THF for 24 h with varying quantities of K_2CO_3 and/or Cs_2CO_3. Comparison of the first three runs clearly shows the beneficial effect of added Cs_2CO_3. However, even a 100% excess of Cs_2CO_3 (run 3) is insufficient to effect complete cleavage in 24 h. It must be noted that when the reactions were carried out under scrupulously anhydrous conditions (runs 1–3) good material balances of **4** and **5** were obtained. When, however, the solvent was not carefully dried (run 4) a poor recovery (68%) was observed. It was established by a separate experiment using TLC for identification that the deficit could be accounted for by further cleavage of **5** to resorcinol which was lost in the aqueous washings during work-up.

Table IB lists the results of similar experiments in boiling DME. Again, the favorable effect of added Cs_2CO_3 is clearly apparent (runs 5–9). When Cs_2CO_3 is used alone, however, up to a 50% excess (run 11) is required to effect total cleavage in the 24-h time limit. Of particular interest is a comparison of run 9 with runs 5 and 10. Run 9, which is a composite of the other two, resulted in yields of both **5** (88%) and CO_2 (52%) which are almost exactly the sum of the corresponding yields