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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.

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(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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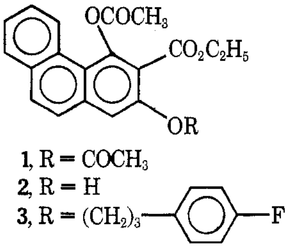
Received May 10, 1976

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.

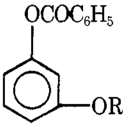
In an accompanying paper, the regioselective etherification of two phenanthrene-2,4-diacetates was described.[1] For example, heating the diacetate **1** under reflux in dry acetone for 77 h with excess 3-*p*-fluorophenylpropyl bromide (3-FPB) in the presence of excess anhydrous K_2CO_3 led to an 85%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



1, R = $COCH_3$
2, R = H
3, R = $(CH_2)_3$

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. Reactions 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.



4, R = COC_6H_5
5, R = H

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 workup.

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

Table I. Carbonate Cleavage of Dibenzoyl- to Monobenzoylresorcinol

$$\mathbf{4}\ (0.5\ \text{mmol}) \xrightarrow[\text{THF or DME}]{M_2CO_3} \mathbf{5} + CO_2\uparrow$$

reflux 24 h

Run no.	K_2CO_3, mmol	Cs_2CO_3, mmol	Yield, % **5**	**4**	CO_2
		A. Solvent THF			
1	3.6	0	18	81	5
2	3.6	0.5	48	51	34
3	0	1.0	58	41	44
4[a]	3.6	0.5	45	23	41
		B. Solvent DME			
5	3.6	0	21	79	11
6	3.6	0.1	41	53	15
7	3.6	0.2	52	43	26
8	3.6	0.3	70	29	38
9	3.6	0.5	88	12	52
10	0	0.55	68	29	42
11	0	0.75	95	0	57
12[b]	0.6	0	29	74	10
13[a]	3.6	0.1	74	12	

[a] Solvent was dried only by passing through a column of basic alumina (activity grade I). [b] Reaction mixture included 0.05 mmol of $C_6H_5CH_2N^+(C_2H_5)_3{\cdot}Cl^-$.

(89% and 53%) of runs 5 and 10. This suggests that the K_2CO_3 and Cs_2CO_3 reactions are essentially independent processes, the former occurring heterogeneously on the surface of the insoluble carbonate, and the latter in solution. Moreover, essentially, no cation exchange between the K_2CO_3 and soluble cesium salts (either Cs_2CO_3 or product salts) can be taking place. This is further supported by the observation (run 12) that a soluble phase-transfer agent has little effect on the K_2CO_3 reaction.

Run 13 again illustrates the damaging effect of moisture. Although the yield (74%) of **5** produced in the 24-h period is higher than that obtained under dry conditions (41% in run 6), the material balance (86%) is poor. Relatively rapid conversion of both **4** to **5** and **5** to resorcinol clearly occurs under these conditions.

The high selectivity of the reaction when conducted under completely anhydrous conditions was demonstrated more plainly by means of a preparative run. In the presence of a 35% excess of Cs_2CO_3 in boiling DME, cleavage of **4** to **5** was complete in 16 h, as revealed by TLC. Another 30% excess of Cs_2CO_3 was nevertheless added and the reaction was continued for another 7 h after which there was no indication (TLC) of any change in the composition of the reaction mixture. A 95.5% yield of essentially pure **5** was obtained on workup.

In Table II are listed the results of using potassium and cesium bicarbonates instead of the carbonates in boiling DME. Although an equivalent of $CsHCO_3$ (run 14) produces a good yield (96%) of **5** in the 24-h period, an excess (run 15) gives a lower yield and a poor material balance. Thus, the reaction with bicarbonate clearly does not stop at **5**, even under anhydrous conditions. Also of interest is the observation (run 16) that excess $KHCO_3$ alone gives twice the yield of excess K_2CO_3 (run 5) in the 24-h reaction period. However, neither phase-transfer agents (runs 17, 18) nor a specific potassium ion solvator (run 19) radically improves the $KHCO_3$ reaction even though, unlike K_2CO_3, a uni-univalent salt is here involved.

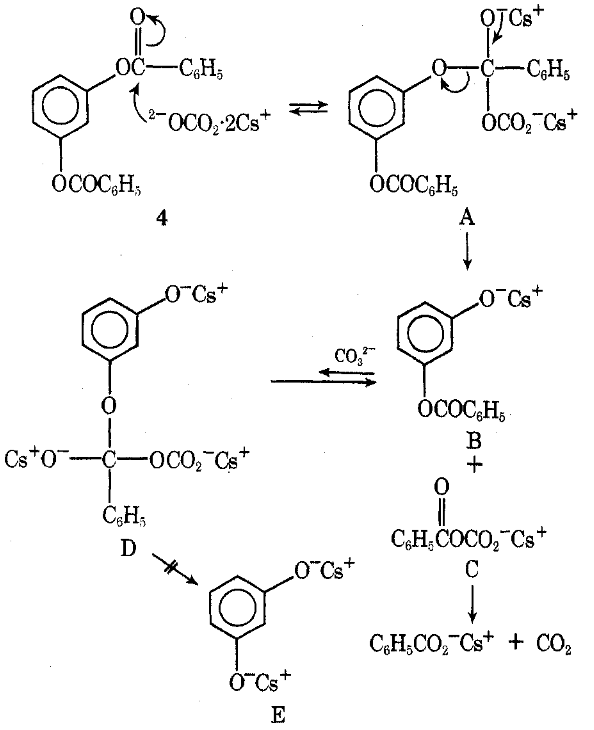
The experimental results described above can be accommodated by the following mechanism.

Table II. Bicarbonate Cleavage of Dibenzoyl- to Monobenzoylresorcinol

$$\mathbf{4}\ (0.5\ \text{mmol}) \xrightarrow[\text{DME, reflux 24 h}]{MHCO_3} \mathbf{5} + CO_2\uparrow$$

Run no.	$KHCO_3$, mmol	$CsHCO_3$, mmol	Yield, % **5**	**4**	CO_2
14	0	0.95	96	0	79
15	0	1.3	68	0	80
16	5.0	0	43	55	41
17[a]	1.2	0	48	51	39
18[b]	1.2	0	41	50	37
19[c]	1.2	0	58	39	57

[a] Reaction mixture included 0.05 mmol of $C_6H_5CH_2N^+(C_2H_5)_3{\cdot}Cl^-$. [b] Included 0.05 mmol of Hyamine 10X. [c] Included 0.1 mmol of dicyclohexyl-18-crown-6 ether.



Carbonate ion attack at a carbonyl carbon atom in **4** leads reversibly to the tetrahedral intermediate A which collapses irreversibly to B, the cesium salt of **5**, plus C, the cesium salt of a mixed benzoic carbonic acid anhydride. Intermediate C undergoes further decomposition to cesium benzoate and CO_2, but in the absence of a proton source, is sufficiently stable to account for the observation (Table I) that the yield of CO_2 is consistently less than the yield of **5**. Further attack of B by carbonate ion is not favored because combination of a monoanion with a dianion is necessarily involved. Moreover, even if a small equilibrium concentration of the resulting intermediate D were formed, it would not collapse rapidly to dicesium resorcylate (E) because the doubly charged anion is a relatively poor leaving group. Hence, under anhydrous conditions, the reaction stops after only one ester group is removed.

However, in the presence of a proton source (H_2O or HCO_3^-), equilibrium concentrations of **5** will be formed from B and attack of carbonate at the second carbonyl group can proceed (runs 4, 13, and 15).

Experimental Section

Reagent grade acetone was dried over anhydrous K_2CO_3. Tetrahydrofuran (THF) and 1,2-dimethoxyethane (DME) were dried over anhydrous K_2CO_3 for several days, then distilled from $LiAlH_4$, and stored over CaH pellets. Finely powdered $KHCO_3$, K_2CO_3, $CsHCO_3$, and Cs_2CO_3 were heated at 240–245 °C[2] for 20 h, allowed to cool in a desiccator over P_2O_5, and stored in stoppered bottles in the same desiccator. Resorcinol dibenzoate was recrystallized from ethanol to constant melting point (117 °C) and dried at 60 °C in vacuo. For the ^1H NMR solvent-shift studies a Varian HA-100 spectrometer was used. ^{13}C NMR spectra were measured on an XL-100-15A/TT-100 spectrometer system in the pulse/Fourier transform mode; 8K data points were used. Off-resonance single frequency decoupling (orsfd) experiments were used to assist in assignments. All ^{13}C NMR spectra were of $CDCl_3$ solutions at ambient temperature and chemical shifts are in parts per million relative to tetramethylsilane. For other general experimental conditions, see ref 1.

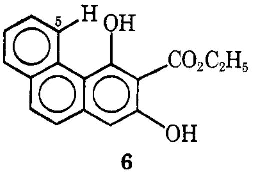
Ethyl 4-Acetoxy-2-hydroxy-3-phenanthrenecarboxylate (2). A stirred mixture of 0.37 g (1 mmol) of ethyl 2,4-diacetoxy-3-phenanthrenecarboxylate (1),[1] 2.4 g (7.4 mmol) of Cs_2CO_3, and 20 ml of acetone was heated under reflux for 5 h, at which time TLC (1% CH_3OH in C_6H_6) showed a single spot at R_f 0.75 and nothing at R_f 0.47 corresponding to 1. The cooled reaction mixture was poured into cold water (200 ml) containing excess HCl. The precipitated solid was collected at the filter, washed with water, and dried to give 0.33 g (100%) of cream-colored powder, mp 148–154 °C. Several recrystallizations from ethanol produced pure 2: mp 153–154 °C; NMR δ 13.60 (s, 1, OH), 9.8–9.5 (m, 1, 5-H), 8.1–7.4 (m, 5, ArH), 7.03 (s, 1, 1-H), 4.46 (q, 2, J = 7 Hz, OCH_2CH_3), 2.28 (s, 3, $COCH_3$), and 1.37 ppm (t, 3, J = 7 Hz, OCH_2CH_3).

Anal. Calcd for $C_{19}H_{16}O_5$: C, 70.35; H, 4.97. Found: C, 70.13; H, 4.98.

When a similar excess (7.4:1) of dry K_2CO_3 was used instead of the Cs_2CO_3 in the above procedure, reaction was incomplete after 72 h of reflux and NMR analysis of the crude product indicated a 70:30 ratio of 2 to 1. When Cs_2CO_3 was used in only a 2:1 molar ratio in acetone an 85% yield of 2 was obtainable after 48 h of heating. Yields of 90–100% of 2 were also obtainable under the following sets of conditions: (1) a 1.12:1 molar ratio of Cs_2CO_3 to 1 in refluxing THF for 21 h, (2) a 2:1 molar ratio of $CsHCO_3$ to 1 in boiling THF for 20 h, and (3) a 1.12:1 molar ratio of Cs_2CO_3 to 1 in boiling DME for 10 h.

Ethyl 4-Acetoxy-2-(3-*p*-fluorophenylpropoxy)-3-phenanthrenecarboxylate (3) from 2. To an ice-cold, stirred solution of 0.324 g (1 mmol) of 2 and 0.25 ml (~1.25 mmol) of 3-*p*-fluorophenylpropyl bromide in 2 ml of hexamethylphosphoramide was added 0.046 g (1.1 mmol) of a 57% mineral oil dispersion of sodium hydride. The mixture was stirred at room temperature for 20 h and then poured into cold water (150 ml). Precipitated product was taken up in ether, washed with water, and dried over anhydrous $MgSO_4$. Filtration and concentration to dryness left an oily solid (0.52 g) which was triturated with cold pentane (5 ml), and collected at the filter to give 0.34 g (74%) of 3, mp 110–113 °C, identical (mixture melting point, TLC, and NMR) with the material, mp 110–112 °C, prepared[1] directly from the diacetate 1.

^{1}H NMR Spectral Evidence for the Structure of 2. In preliminary solvent effect experiments, it was found that the peak corresponding to the 5 proton in 6 shifted downfield 0.40 ppm (9.55 to 9.95 ppm) in going from $CDCl_3$ to pyridine-d_5 solution.



6

The corresponding shift in compound 1, in which an acetate group is near the 5-H, was only 0.18 ppm (9.02 to 9.20 ppm). In 2 this shift was even smaller (9.93 to 9.98 ppm = 0.05 ppm) indicating that the acetate group is also at the 4 position in 2.

^{13}C NMR Spectral Evidence for the Structure of 2. In the ^{13}C NMR spectrum of compound 6 the hydroxylated C-2 and C-4 carbon atoms can easily be differentiated from the other ring carbons. On the basis of resonance assignments for phenanthrene itself[4] combined with known substituent shifts for benzene,[5] the lower field resonance (163.6 ppm) could be assigned to C-2 and the other (155.7 ppm) to C-4. In the diacetate 1, both peaks shift upfield to 148.0 and 145.8 ppm, respectively. In the monoacetate 2, only the C-4 peak shifts upfield to 147.0 ppm. The C-2 peak in 2 actually shifts slightly downfield to 165.2 ppm, again indicating that the hydroxyl group is attached to C-2 and the acetate to C-4.

Resorcinol Monobenzoate (5) from Resorcinol Dibenzoate (4). A stirred mixture of 1.6 g (5 mmol) of 4, 2.2 g (6.75 mmol) of Cs_2CO_3, and 15 ml of DME was heated under reflux for 16 h. Although TLC (0.5% CH_3OH in C_6H_6) indicated that the reaction was complete, another 0.5 g (1.5 mmol) of Cs_2CO_3 was added and heating was continued for another 7 h. TLC indicated that no change in composition of the reaction mixture occurred during this additional period. The mixture was concentrated to dryness under a stream of dry nitrogen, and ice was added to the pink solid, followed by an excess of 6 N HCl and ether. The ether layer was separated and washed with 2 N $KHCO_3$ (2 × 20 ml). Acidification of the bicarbonate extract precipitated 0.34 g (56% of theory) of benzoic acid, mp 124–125 °C. The ether layer was washed with water to neutrality and dried over anhydrous $MgSO_4$. Filtration and removal of the ether by distillation gave 1.05 g (95.5% yield) of good quality 5, mp 133–136 °C (lit.[3] mp 135–136 °C).

When the foregoing reaction was conducted in boiling acetone for 24 h using a 2:1 molar ratio of Cs_2CO_3 to 4, a 77% yield of pure 5 was obtained. When a 7:1:1 molar ratio of K_2CO_3 to Cs_2CO_3 to 4 was heated in boiling DME for 30 h, only a 70% yield of pure 5 was isolated.

Systematic Study of the Reaction 4 → 5. The data for the reactions summarized in Tables I and II were obtained under the following standard conditions: 0.16 g (0.5 mmol) of the dibenzoate 4 in 5.0 ml of the indicated solvent was heated under reflux with magnetic stirring with the indicated amount of alkali carbonate or bicarbonate for exactly 24 h. The apparatus consisted of a 10-ml round-bottom flask fitted with a reflux condenser and $CaCl_2$ drying tube attached by heavy rubber tubing to a 25-ml pipet immersed in a water-filled 500-ml graduate. Heating was accomplished by means of a magnetically stirred oil bath kept in the appropriate temperature range (73–75 °C for THF and 93–96 °C for DME), and attachment of the reaction system to the gas-measuring pipet was not made until reflux equilibrium was established (5–10 min after immersion of the reaction vessel in the preheated oil bath). In several experiments it was established that 0.5 mmol of an alkali carbonate or bicarbonate on treatment with excess acid produced an average of 13.5 ± 0.5 ml of CO_2 under the above reaction conditions. The percent yields of CO_2 listed in the table are based on this experimental volume and not on a corrected one.

At the end of the 24-h reaction time, solvent was blown off under a stream of N_2 and the cooled residue was treated with ice and excess 6 N HCl. Insoluble material was taken up in 5 ml of CH_2Cl_2 (ether, when $C_6H_5CH_2N^+(C_2H_5)_3 \cdot Cl^-$ was used as an additive) and separated. The organic layer was washed with 2 N $KHCO_3$ (2 × 4 ml) and water (3 × 4 ml), and concentrated to dryness in a warm water bath under a stream of N_2. (All separations and liquid transfers were carried out using disposable capillary pipets.) The residue was dried overnight at 60 °C in vacuo before weighing and submitting for NMR analysis. The relative amounts of 4 and 5 in the product could be determined within ±5% by virtue of the fact that, whereas 5 absorbs in the aromatic region between 6.3 and 6.9 ppm, 4 shows nothing below 7.0 ppm. Furthermore, the upfield resonance in 5 (i.e., 6.3–6.9 ppm) exhibits baseline separation from the rest of its aromatic resonance further downfield, and constitutes 29% of the total. This value was taken as the standard for pure 5.

Acknowledgments. The author is indebted to Dr. R. Egan, Ms. R. Stanaszek, and Mr. M. Cirovic for the ^{13}C and ^1H NMR spectra, to Ms. J. Hood for the elemental analysis, and to Professor Peter Beak, University of Illinois, for helpful discussions.

Registry No.—1, 59873-09-5; 2, 59873-29-9; 3, 59873-11-9; 4, 94-01-9; 5, 136-36-7; $KHCO_3$, 298-14-6; K_2CO_3, 584-08-7; $CsHCO_3$, 15519-28-5; Cs_2CO_3, 534-17-8; 3-FPB, 24484-55-7.

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