Attempted Preparation of New Phenanthrenequinone Types[1,2]

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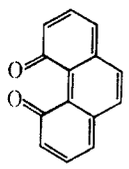
The syntheses of 4,5-, 2,7-, and 2,5-dihydroxyphenanthrenes are described as well as unsuccessful attempts to oxidize these to the corresponding phenanthrenequinones. Instead 5-hydroxy-1,4-phenanthrenequinone (IV), 7-hydroxy-1,2-phenanthrenequinone (VI), and 7-hydroxy-1,4-phenanthrenequinone (X) resulted when Fremy's salt was the oxidant. Spectral evidence for the formation of 1,8-dibromo-2,7-phenanthrenequinone (XIV), formed by the lead tetraacetate oxidation of 1,8-dibromo-2,7-dihydroxyphenanthrene (XII), is presented, but isolation was unsuccessful.

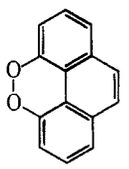
Of the 15 possible phenanthrenequinones only four are known, namely 1,2-,[4] 1,4-,[5] 3,4-,[6] and 9,10-phenanthrenequinone.[7] The other 11 possibilities are 1,6-, 1,8-, 1,9-, 2,3-, 2,5-, 2,7-, 2,10-, 3,6-, 3,9-, 4,5-, and 4,10-P.[8]

Phenanthrenehydroquinones corresponding to six of the 11 unknown quinones are known[9-14] but attempts to oxidize three of these (1,6-, 2,7-, and 3,6-PH_2) with silver oxide failed.[9]

The prime objective of the present work was the preparation of 4,5-phenanthrenequinone (I) to find out if it would exist as the quinone (I) or as the cyclic peroxide (II) and if the two forms could be interconverted. In addition, attempts were made to oxidize the known 2,7-PH_2 and 2,5-PH_2 to the corresponding quinones.

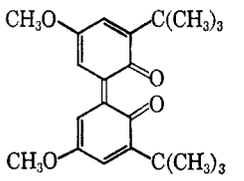


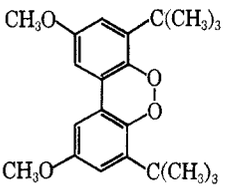
I



II

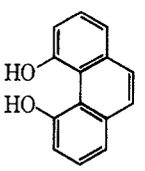
Isomeric structures corresponding to a quinone and peroxide have been reported once, to our knowledge,[15] *e.g.*, the following structures.



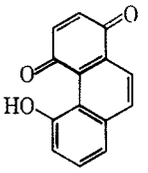


The unknown 4,5-PH_2 (III) was prepared from the known 9,10-dihydro-4,5-dimethoxyphenanthrene[16] by heating with sulfur and demethylation of this product to III by heating with pyridine hydrochloride.[17] Demethylation of 2,5-dimethoxy- and 2,7-dimethoxyphenanthrene in the same way afforded the known 2,5-PH_2[12] and 2,7-PH_2.[13]

Oxidation of 4,5-PH_2 (III) with Fremy's salt[18] afforded a purple compound in 56% yield to which we assign the structure 5-hydroxy-1,4-phenanthrenequinone (IV) on the basis of analysis and spectral data (see the Experimental Section). The purple color is perhaps due to the effect of intramolecular hydrogen bonding as the corresponding 5-acetoxy-1,4-phenanthrenequinone was yellow. Other attempts at oxidation with silver,[19] lead dioxide,[20] potassium ferricyanide,[15,21] silver benzoate and triethylamine,[22] and 2,3-dicyano-5,6-dichloro-*p*-benzoquinone[23] either failed to oxidize III or gave tarry materials.



III



IV

Oxidation of 2,7-PH_2 (V) with Fremy's salt[18] afforded in high yield a dark red hydroxyquinone to which we assign the structure 7-hydroxy-1,2-phenanthrenequinone (VI) on the basis of spectral data and conversion into 1,2,7-triacetoxyphenanthrene (VII) by reductive acetylation and into 1,2,4,7-tetraacetoxyphenanthrene

(1) The fact that there were many types of quinones in the naphthalene and phenanthrene systems that had never been prepared was pointed out to M. S. Newman by Dr. Richard Weiss of the Van Ameringen Haebler Co., many years ago. These remarks have stimulated the present research and other work as yet unpublished.

(2) Supported by a Type C grant from the American Chemical Society Petroleum Research Fund and by the U. S. Army Research Office at Durham, N. C.

(3) Holder of the Goodyear Foundation Fellowship. This work formed part of the Ph.D. thesis presented by R. L. Childers in 1965.

(4) L. F. Fieser, *J. Am. Chem. Soc.*, **51**, 1896 (1929).

(5) L. F. Fieser, *ibid.*, **51**, 2460 (1929).

(6) G. Barger, *J. Chem. Soc.*, **113**, 218 (1918); L. F. Fieser, *J. Am. Chem. Soc.*, **51**, 940 (1929).

(7) R. Fittig and E. Ostermeyer, *Ann.*, **166**, 361 (1873); C. Graebe, *ibid.*, **167**, 131 (1873).

(8) Throughout this paper the symbol P will stand for a phenanthrenequinone molecule and the symbol PH_2 will stand for a phenanthrenehydroquinone molecule.

(9) 1,6-PH_2: L. F. Fieser, *J. Am. Chem. Soc.*, **51**, 2471 (1929).

(10) 1,9-PH_2: A. Burger, *ibid.*, **60**, 1533 (1938).

(11) 2,3-PH_2: E. Mosettig and A. Burger, *ibid.*, **52**, 2988 (1930).

(12) 2,5-PH_2: W. S. Rapson and R. Robinson, *J. Chem. Soc.*, 1533 (1935).

(13) 2,7-PH_2: J. W. Cornforth and R. Robinson, *ibid.*, 684 (1942).

(14) 3,6-PH_2: P. Hugelshofer, J. Kalvoda, and K. Schaffner, *Helv. Chim. Acta*, **43**, 1322 (1960).

(15) J. Battes and F. Volbert, *Fette Seifen Anstrichmittel*, **57**, 660 (1955); see also S. Goldschmidt and H. Wesskecher, *Ber.*, **61**, 372 (1928).

(16) D. M. Hall and E. E. Turner, *J. Chem. Soc.*, 3072 (1951). The picrate of III was reported but not III.

(17) L. F. Fieser, "Experiments in Organic Chemistry," 3rd ed, D. C. Heath and Co., Boston, Mass., 1957, p 337.

(18) Fremy's salt, potassium nitrosodisulfonate, $(KOSO_2)_2NO$, has been used often by H. J. Teuber and associates: see H. J. Teuber and G. Jellinek, *Ber.*, **85**, 95 (1952); H. J. Teuber and W. Rau, *ibid.*, **86**, 1036 (1953); H. J. Teuber and N. Gotz, *ibid.*, **87**, 1236 (1954).

(19) R. Willstatter and A. Pfannenstiel, *ibid.*, **37**, 4744 (1904).

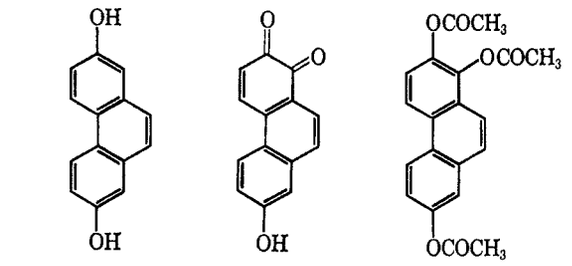
(20) R. Kuhn and I. Hammer, *ibid.*, **83**, 413 (1950).

(21) B. S. Thyragarajan, *Chem. Rev.*, **58**, 439 (1958).

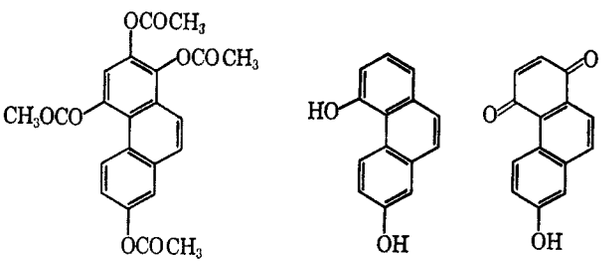
(22) M. S. Newman and P. F. Beal, *J. Am. Chem. Soc.*, **72**, 5163 (1950).

(23) E. A. Braude, A. G. Brook, and R. P. Linstead, *J. Chem. Soc.*, 3569 (1954).

(VIII) by the Thiele reaction.[24] The nmr spectra of these compounds were consistent with the assigned structures.



V VI VII



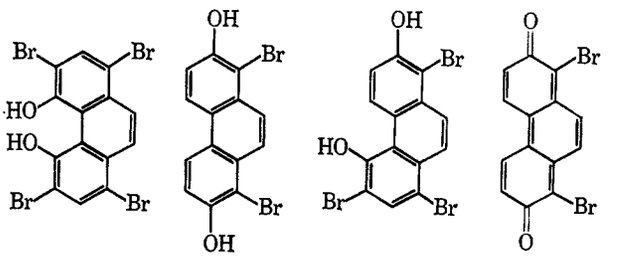
VIII IX X

Oxidation of 2,5-PH_2 (IX) with Fremy's salt[18] gave a small amount of a red product to which we assign the structure of 7-hydroxy-1,4-phenanthrenequinone (X), mainly on the basis of similarity of the ultraviolet absorption spectrum to that of 1,4-P. Also, we have shown that oxidation of 4-phenanthrol with Fremy's salt yields 1,4-P.

In attempting to assign structures to hydroxyquinones IV, VI, and X, above described, we studied the reaction of these quinones with *o*-phenylenediamine as quinoxaline formation takes place readily with *o*-quinones.[25] We examined the number of spots (shown in parentheses) other than those from starting materials, obtained by thin layer chromatography on silica gel of the reaction mixtures of *o*-phenylenediamine with 1,2-P[26] (1), 3,4-P[26] (2), 1,4-P (0), IV (3), and X (0). From these results only 1,2-P, 1,4-P, and X gave the expected result. Hence we conclude that such a test to prove or disprove the presence of a 1,2-quinone may be misleading. Only the isolation of a homogeneous solid product having the correct analysis should be taken as evidence for an *o*-quinone.

We next turned to the oxidation of quinones by lead tetraacetate in acetic acid[27] with the thought that *o*-quinones might react and *p*-quinones not. Also oxidation of certain hydroquinones to quinones by this reagent has been reported.[28] This work shows that in general hydroxyquinones are much more rapidly acted on than *o*-quinones which in turn are more rapidly acted on than *p*-quinones. Although several *o*-quinones consumed more reagent more rapidly than did *p*-quinones, the results leave much to be desired on a quantitative basis.[29]

Since the attempted oxidations of III, V, and IX to the corresponding quinones failed because of introduction of an hydroxyl group at another reactive position in the nucleus or over oxidation, we attempted to prevent such side reactions by bromination prior to oxidation. Bromination of III, V, and IX in acetic acid yielded 4,5-dihydroxy-1,3,6,8-tetrabromophenanthrene (XI), 2,7-dihydroxy-1,8-dibromophenanthrene (XII), and 2,5-dihydroxy-1,6,8-tribromophenanthrene (XIII), respectively. These structures were assigned by assuming that bromination would occur only *ortho* or *para* to an hydroxyl group and were confirmed by nmr spectral analysis (see the Experimental Section for details).



XI XII XIII XIV

Oxidation of XI and XII with Fremy's salt did not occur, but on oxidation with lead tetraacetate evidence for the formation of 1,8-dibromo-2,7-phenanthraquinone (XIV) from XII was obtained, although we were unable to isolate XIV. The evidence consists of the fact that the ultraviolet spectrum of XII on oxidation changed to give a 2,7-diphenoquinone-like spectrum.[29] On catalytic reduction, a spectrum identical with that of the starting XII was obtained. Interestingly the log ϵ values for the supposed 1,8-dibromo-2,7-phenanthraquinone (XIV) were higher than those for the corresponding maxima for the diphenoquinones reported. All attempts to isolate XIV failed as tarry materials were obtained on concentration, even at low temperatures. Oxidation of V in dioxane produced a yellow solution with a maximum at 420 mμ (log ϵ 3.88) but the quinone formed, possibly 2,7-P, was very unstable so that in 2 hr at room temperature most of the absorbances had disappeared. On reduction, the above yellow solution was decolorized and some V was present.

An attempt to determine the oxidation potentials of III, V, IX, XI, and XIII by electrometric titration with ceric ion[30] was made.[31] Three factors indicated that the potentials determined were not significant: (a) curves obtained by plotting cell voltage against volume of oxidant were not similar to that for hydroquinone; (b) the amount of oxidant varied from 1 to 4 equiv rather than the expected 2 equiv; (c) the potential values were not precisely reproducible. These data suggest that the oxidations by ceric ion are not reversible reactions and that more complicated oxidations or other reactions are occurring.[29]

(24) L. F. Fieser and M. Fieser, "Advanced Organic Chemistry," Reinhold Publishing Corp., New York, N. Y., 1961, p 855.

(25) A. I. Vogel, "Practical Organic Chemistry," Longmans, Green and Co., London, England, 1956, p 749.

(26) We thank Professor L. F. Fieser for samples of these quinones.

(27) See R. C. Hockett and W. S. McClenahan, *J. Am. Chem. Soc.*, **61**, 1667 (1939), for use of this method in oxidation of glycols; see also R. Criegee, *Ann.*, **495**, 211 (1932).

(28) K. H. Konig, W. Schulse, and G. Moeller, *Ber.*, **93**, 554 (1960).

(29) The data can be found in the Ph.D. thesis of R. L. Childers.[3]

(30) J. B. Conant and L. F. Fieser, *J. Am. Chem. Soc.*, **44**, 2480 (1922).

(31) We thank Professor J. Collat of this department for help in setting up the required apparatus.

Experimental Section[32]

2-Nitro-3-methylanisole.[33]—To a stirred solution of 65 g of *m*-cresol in 220 ml of 15% fuming sulfuric acid in a 1-l. flask was added during 8 hr a solution of 18 ml of 90% nitric acid in 60 ml of 15% fuming sulfuric acid so as to maintain the temperature below 50°. After stirring overnight the mixture was poured into a steam distillation apparatus,[34] which contained 100 ml of water, and the exothermic desulfonation reaction was effected by passing in 120° steam. The reaction temperature increased to about 140° and 2-nitro-*m*-cresol distilled from the mixture and condensed as a yellow oil.

The yield of this oil depended upon the conditions of sulfonation and nitration of the *m*-cresol, and especially upon the control of the desulfonation reaction. The best results were obtained when the fuming sulfuric acid was no stronger than 15%, the temperature was held below 50° during nitration, and no more than 65 g of *m*-cresol was nitrated per run. Desulfonation was best accomplished by passing in steam rapidly until the reaction started, as indicated by yellow droplets in the condenser, and then reducing the flow so as to maintain the internal temperature at about 140°. At lower steam flow the desulfonation reaction would stop and at higher flow the reaction became so vigorous that the material decomposed almost explosively to form a spongy resin. After the desulfonation reaction had subsided, separation of the undistilled product was accomplished by steam distillation.

The yellow 2-nitro-*m*-cresol was extracted from the steam distillate with 500 ml of xylene fraction and the extracts from four similar runs were combined in a 5-l. flask fitted with stirrer, condenser, and addition funnel. On addition of 220 g of anhydrous potassium carbonate and heating to reflux the mixture turned red. The color faded as 200 ml of dimethyl sulfate was added during 2 hr. After working up in the usual manner crystallization from 400 ml of ethanol yielded 211 g (55%) of colorless 2-nitro-3-methylanisole, mp 49–50°.

3-Methoxyanthranilic Acid.—The above nitroanisole was oxidized to 3-methoxy-2-nitrobenzoic acid, mp 252–253°, in 49% yield as described.[16] A solution of 50 g of ferrous sulfate heptahydrate in 1.5 l. of water was stirred and held at 80° in a 4-l. beaker during the addition of a solution of 50 g of the above acid in 300 ml of concentrated ammonium hydroxide. More ammonium hydroxide was added as needed to cause the reaction mixture to remain black. The mixture was filtered hot and the filter cake was extracted with dilute ammonia and refiltered. The combined filtrates were acidified when cool and the crude acid was purified to yield 37.8 g (87%) of 3-methoxyanthranilic acid,[35] mp 168–170°.

2,2′-Bisbromoethyl-6,6′-dimethoxybiphenyl.—Diazotization of the above anthranilic acid as described[16] yielded 6,6′-dimethoxydiphenic acid which was reduced by lithium aluminum hydride in tetrahydrofuran to the corresponding 2,2′-bishydroxymethyl-6,6′-dimethoxybiphenyl, 155–157°, in 81% yield.[16] Treatment of this diol with phosphorus tribromide as described[16] yielded the dibromo compound, mp 111–112°, in 83% yield.

4,5-Dimethoxy-9,10-dihydrophenanthrene.—A solution of 57 g of the above dibromide in 2 l. of ether was added during 1 hr to a phenyllithium solution. The latter was prepared by adding 47 g of bromobenzene in 100 ml of ether to 4.2 g of lithium suspended in 1 l. of ether, filtration of the reaction mixture through glass wool under nitrogen, and dilution with 2 l. of ether. After being held at reflux for 1 hr and overnight at room temperature, 200 ml of dilute sulfuric acid was added. After the usual work-up distillation afforded two fractions, bp 145–160 and 160–200° (1 mm). Crystallization of these separately from methanol yielded 13.7 g, mp 129–130°, and 5.0 g, mp 125–128°, of colorless 4,5-dimethoxy-9,10-dihydrophenanthrene[16] (55%) suitable for dehydrogenation.

4,5-Dimethoxyphenanthrene.—A mixture of 1.4 g of sulfur and 10.0 g of the above dihydrophenanthrene was heated at 225° for 2 hr. The product was taken up in 300 ml of ethanol and the solution was decolorized with charcoal (Darco G-60). Addition of 9.5 g of picric acid yielded 14.9 g of picrate,[16] mp 187–188°. By chromatography over alumina with benzene, there was obtained 6.0 g (61%) of 4,5-dimethoxyphenanthrene. Recrystallization from ethanol with slight loss afforded the analytical sample: mp 126–127°; ultraviolet absorption $\lambda_{max}^{ethanol}$ at 254 mμ (log ε 4.67), 289 (4.54), 318 (4.05).

Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.7; H, 5.9. Found: C, 80.5; H, 5.9.

4,5-Dihydroxyphenanthrene (III).—After heating a mixture of 5.2 g of 4,5-dimethoxyphenanthrene and 6.6 g of pyridine hydrochloride[17] at 210° for 1.5 hr the melt was ground with 300 ml of water. An ether–benzene solution of the organic products was washed with three 50-ml portions of 10% sodium hydroxide. Acidification of the alkaline extract followed by the usual work-up afforded 3.6 g (79%) of slightly colored III, mp 181–184°. Repeated crystallization from benzene afforded pure nearly colorless elongated prisms of III: mp 182.5–183.5° with darkening; ultraviolet absorption $\lambda_{max}^{dioxane}$ at 286 mμ (log ε 4.39), 315 (3.98), 346 (3.20), and 364 (3.02).

Anal. Calcd for $C_{14}H_{10}O_2$: C, 80.0; H, 4.8. Found: C, 80.2; H, 4.8.

2,7-Dihydroxyphenanthrene (V).—This compound was prepared by the following sequence of reactions. Lithium aluminum hydride reduction of 3-methoxybenzaldehyde[36] gave 3-methoxybenzyl alcohol. Treatment with thionyl chloride and coupling of the resulting benzylic chloride with magnesium yielded 3,3′-dimethoxydibenzyl, which was iodinated with mercuric acetate and iodine to 2,2′-diiodo-5,5′-dimethoxydibenzyl as described.[37] Coupling of the latter (five parts) by means of heating with copper bronze[38] (seven parts) yielded 2,7-dimethoxy-9,10-dihydrophenanthrene which on heating with sulfur as described afforded pure V: mp 260–262° with darkening; ultraviolet absorption $\lambda_{max}^{dioxane}$ at 258 mμ (log ε, 4.57), 281 (3.93), 295 (3.93), 350 (3.04), and 368 (2.94).

2,5-Dihydroxyphenanthrene (IX).—A mixture of 0.5 g of 2,5-dimethoxyphenanthrene, prepared as described,[14] and 3.0 g of pyridine hydrochloride was heated at 210° for 2 hr. After a work-up similar to that described for III, 0.27 g (61%) of IX,[12] mp 174–176°, was obtained. The ultraviolet spectrum had $\lambda_{max}^{dioxane}$ at 254 mμ (log ε 4.70), 261 (4.72), 280 (4.31), 293 (4.10), 305 (4.02), 328 (3.45), 344 (3.51), and 362 (3.56).

5-Hydroxy-1,4-phenanthrenequinone (IV).—A solution of 0.30 g of III in 50 ml of acetone was stirred at room temperature for 30 min with a solution of 1.00 g of Fremy's salt[39] in 75 ml of 0.05 *M* potassium dihydrogen phosphate. The resulting purple solution was diluted with 100 ml of water and extracted with chloroform. This extract, after the usual work-up, afforded a residue which was chromatographed on 150 g of silica gel. Elution with benzene followed by removal of the benzene on a rotary evaporator and crystallization from petroleum ether (bp 90–100°) (Skellysolve C) yielded 0.18 g (56%) of purple IV, mp 163–165° dec. The ultraviolet spectrum had $\lambda_{max}^{ethanol}$ at 222 mμ (log ε 4.51), 260 (3.95), 310 (4.11), 386 (3.15), and 510 (2.85).

Anal. Calcd for $C_{14}H_8O_3$: C, 75.0; H, 3.6. Found: C, 75.1; H, 3.5.

A solution of 0.05 g of IV and 0.10 g of fused sodium acetate in 10 ml of acetic anhydride changed from purple to yellow on warming on a steam bath for 1 hr. Chromatography of the product on 50 g of silica gel with elution by 9:1 benzene–ether yielded 0.05 g of yellow crystals, mp 124–127°. Recrystallization from petroleum ether (bp 60–68°) (Skellysolve B) afforded 0.031 g (53%) of pure (by tlc) 5-acetoxy-1,4-phenanthrenequinone, mp 133–135°. The ultraviolet spectrum had $\lambda_{max}^{ethanol}$ at 228 mμ (log ε 4.68), 262 (4.18), 282 (4.23), 360 (3.43), and 410 (3.28).

Anal. Calcd for $C_{16}H_{10}O_4$: C, 72.2; H, 3.8. Found: C, 72.1; H, 3.7.

(32) All melting points are uncorrected. Analyses were by Galbraith Laboratories, Knoxville, Tenn. All nmr spectra were taken on a Varian A-60 instrument. We are indebted to the National Science Foundation for aid in the purchase of this instrument. The term "worked up on the usual manner" means that an ether–benzene solution was washed successively with dilute acid and/or base and with saturated salt solution and was filtered through anhydrous magnesium sulfate. The solvent was then distilled or removed on a rotary evaporator.

(33) G. P. Gibson, *J. Chem. Soc.*, **123**, 1269 (1923); R. D. Haworth and A. Lapworth, *ibid.*, 2982 (1932).

(34) L. F. Fieser, "Experiments in Organic Chemistry," D. C. Heath and Company, Boston, Mass., 3rd ed., Revised, 1955, p 256 ff.

(35) The method is that of R. Pschorr [*Ann.*, **381**, 23 (1912)] with modifications.

(36) R. B. Woodward, *J. Am. Chem. Soc.*, **62**, 1478 (1940).

(37) J. W. Cornforth and R. Robinson, *J. Chem. Soc.*, 684 (1942).

(38) The type of copper bronze used is important. The one we used with success was No. 5743, O. Hommel Co. The ratio of Cu to diiodide compound is best not less than that described. If less is used exothermic release of iodine and large loss of product may result.

(39) Obtained from the Aldrich Chemical Co., Milwaukee, Wis.

1,4-Phenanthrenequinone.—A solution of 20 mg of 4-phenanthrol[40] in 30 ml of acetone was oxidized with 90 mg of Fremy's salt in 75 ml of 0.17 *M* potassium dihydrogen phosphate to yield 1,4-P, mp 148–149°. The ultraviolet spectrum had $\lambda_{max}^{ethanol}$ at 223 mμ (log ε 4.86), 258 (4.37), 280 (4.33), 289 (4.33), and 360 (3.65). This melting point is lower than that reported (153°).[5] However, as no quinoxalin derivative was formed on treatment with *o*-phenylenediamine, we believe that a polymorphic form was at hand. No other quinone was found by chromatographic analysis.

7-Hydroxy-1,2-phenanthrenequinone (VI).—A solution of 1.30 g of Fremy's salt in 150 ml of 0.05 *M* potassium dihydrogen phosphate was added to a stirred solution of 0.50 g of V in 100 ml of acetone at room temperature. Within 5 min 0.51 g (94%) of dark red elongated prisms separated and were collected by filtration. Recrystallization from ethanol with little loss provided pure (tlc) VI, mp 247–250° dec. The ultraviolet spectrum had $\lambda_{max}^{ethanol}$ at 218 mμ (log ε 4.37), 250 (4.98), 312 (4.19), and 412 (3.84).

Anal. Calcd for $C_{14}H_8O_3$: C, 75.0; H, 3.6. Found: C, 74.8; H, 3.8.

1,2,7-Triacetoxyphenanthrene (VII).—A mixture of 0.080 g of VI, 0.1 g of fused sodium acetate, 0.3 g of powdered zinc, and 30 ml of acetic anhydride was heated on a steam bath for 5 min. After 1 hr 20 ml of acetic acid and 30 ml of water were added and the mixture was filtered and neutralized with sodium carbonate. The product was isolated in the usual way to yield 0.12 g of colorless product. Recrystallization from Skellysolve C–benzene afforded pure (tlc) VII, mp 155–156°, with little loss. The ultraviolet spectrum had $\lambda_{max}^{ethanol}$ at 210 mμ (log ε 4.15), 255 (4.85), 278 (4.26), 286 (4.15), and 297 (4.10).

Anal. Calcd for $C_{20}H_{16}O_6$: C, 68.2; H, 4.6. Found: C, 68.2; H, 4.6.

1,2,4,7-Tetraacetoxyphenanthrene (VIII).—A red solution of 0.100 g of VI in 30 ml of acetic anhydride became nearly colorless in 15 min at room temperature after the addition of 1 drop of concentrated sulfuric acid. By a work-up similar to that for VII, there was isolated 0.130 g (72%) of colorless product, mp 173–175°. Recrystallization from ethanol with little loss afforded pure (tlc) VIII: mp 184–185°; ultraviolet absorption $\lambda_{max}^{ethanol}$ at 212 mμ (log ε 4.30), 258 (4.18), 281 (4.12), 291 (4.02), and 303 (4.06).

Anal. Calcd for $C_{22}H_{18}O_8$: C, 64.4; H, 4.4. Found: C, 64.3; H, 4.2.

7-Hydroxy-1,4-phenanthrenequinone (X).—A solution of 0.40 g of Fremy's salt in 75 ml of 0.05 *M* potassium dihydrogen phosphate was added to a solution of 0.150 g of IX in 50 ml of acetone at room temperature. As much IX remained after 30 min, an additional 1.00 g of Fremy's salt was added in 150 ml of buffer. After 1 hr the mixture was worked up as described for IV and VI to yield, after chromatography over 30 g of silica gel, 25 mg (16%) of red X: mp about 222° dec; ultraviolet absorption $\lambda_{max}^{ethanol}$ at 233 mμ (log ε 4.75), 303 (4.10), and 396 (3.68).

Anal. Calcd for $C_{14}H_8O_3$: C, 75.0; H, 3.6. Found: C, 74.8; H, 3.7.

4,5-Dihydroxy-1,3,6,8-tetrabromophenanthrene (XI).—To a stirred solution at 80° of 0.21 g of III in 25 ml of acetic acid was added 80 ml of 0.1 *M* bromine in acetic acid. After 30 min, cooling caused 0.37 g (70%) of colorless XI to crystallize. Recrystallization from ethanol with little loss yielded a sample which melted with marked darkening in the range of 220–260°. The ultraviolet spectrum had $\lambda_{max}^{dioxane}$ at 220 mμ (log ε 4.44), 242 (4.42), 261 (4.64), 307 (4.36), 330 (4.23), 343 (4.20), 366 (3.65), and 384 (3.99).

Anal. Calcd for $C_{14}H_6Br_4O_2$: C, 32.0; H, 1.2; Br, 60.8. Found: C, 32.0; H, 1.5; Br, 60.8.

The nmr spectrum of XI showed only two aromatic hydrogen bands, equal and unsplit. The one at τ 2.0 is assigned to the 2 and 7 protons and the one at 1.95 to the 9 and 10 protons. The hydroxyl proton band was at τ −3.5.

2,7-Dihydroxy-1,8-dibromophenanthrene (XII).—Bromination of 0.2 g of V in 50 ml of acetic acid with 40 ml of 0.1 *M* bromine as above yielded 0.25 g (71%) of XII. Recrystallization from ethanol with little loss afforded pure XII: mp 267–270° with darkening; ultraviolet absorption $\lambda_{max}^{chloroform}$ at 246 mμ (log ε 4.62), 271 (4.81), 291 (4.34), 298 (4.29), 311 (4.17), 339 (3.34), 355 (3.52), and 374 (3.61).

Anal. Calcd for $C_{14}H_8Br_2O_2$: C, 45.7; H, 2.2; Br, 43.4. Found: C, 45.7; H, 2.0; Br, 43.3.

The nmr spectrum of XII showed the 4 and 5 protons as a doublet at τ 1.2 (J = 10 cps) and the 3 and 6 protons as a doublet at 2.4 (J = 10 cps).[41] A singlet at τ 1.7 was due to the 9 and 10 protons and the hydroxyl protons were at −0.8.

2,5-Dihydroxy-1,6,8-tribromophenanthrene (XIII).—Bromination of 0.155 g of IX in 25 ml of acetic acid with 15 ml of 0.3 *M* bromine as above (except for 1 hr before cooling) yielded 0.260 g (79%) of XIII: mp 218–220°; ultraviolet absorption $\lambda_{max}^{dioxane}$ at 264 mμ (log ε 4.68), 292 (4.45), 309 sh (4.19), 324 (4.19), 355 (3.31), and 372 (3.36).

Anal. Calcd for $C_{14}H_7Br_3O_2$: C, 37.6; H, 1.6; Br, 53.6. Found: C, 37.9; H, 1.8; Br, 53.7.

The nmr spectrum of XII showed the 4 proton as a doublet at τ 0.2 (J = 10 cps) and the 3 proton as a doublet at 2.5 (J = 10 cps). No *meta* coupling was observed for the resonance assigned to the 3 proton, a fact which argues for a bromine at the 1 position. A multiplet at τ 1.7 (3 H) was assigned to protons at the 7, 9, and 10 positions. The hydroxyl protons were at τ −1.5.

1,8-Dibromo-2,7-phenanthraquinone (XIV).—The ultraviolet spectrum[42] of a 2.72 × 10^{-5} *M* chloroform solution of 1,8-dibromo-2,7-phenanthrenediol (XII) was recorded. The equivalent amount of 2 × 10^{-4} *M* lead tetraacetate in chloroform was added and the resulting solution became light yellow. The spectrum of this solution was recorded then, and after standing 24 hr. A blank containing lead tetraacetate in chloroform showed the oxidant did not interfere with spectral observation of the diol or products.

A three-step spectral examination of a 3.36 × 10^{-5} *M* dioxane solution of XII was carried out as follows: (a) the spectrum of the diol solution was recorded; (b) the solution was oxidized by the equivalent amount of a 2 × 10^{-4} *M* lead tetraacetate in dioxane solution and the spectrum of the resulting solution was recorded; (c) the oxidized solution was reduced under 10 psi, of hydrogen over a platinum catalyst and the spectrum of the resulting solution was recorded. These spectral data are listed under the corresponding step letters in Table I.

A similar three-step spectral examination of a 4.57 × 10^{-4} *M* 2,7-phenanthrenediol in dioxane gave the data presented in Table II.

TABLE I

a		b		c	
$\lambda_{max}^{dioxane}$, mμ	Log ε	$\lambda_{max}^{dioxane}$, mμ	Log ε	$\lambda_{max}^{dioxane}$, mμ	Log ε
246	4.58	247	4.54	246	4.54
271	4.77	254	4.51	271	4.72
291	4.25	264	4.55	291 sh[a]	4.25
298	4.18	294	4.38	297 sh	4.18
311	4.13	443	4.30	311	4.06
354	3.43			356	3.43
373	3.52			374	3.47

[a] sh stands for shoulder.

TABLE II

a		b		c	
$\lambda_{max}^{dioxane}$, mμ	Log ε	$\lambda_{max}^{dioxane}$, mμ	Log ε	$\lambda_{max}^{dioxane}$, mμ	Log ε
		241	4.47	242	4.25
		244	4.47	248	4.28
		249 sh[a]	4.21	254	4.30
258	4.57	285 sh	4.21	258	4.33
		359	3.83	262	4.31
281	3.93	420	3.88	281 sh	4.01
295	3.93			295	3.93
350	3.04				
368	2.94				

[a] sh stands for shoulder.

(40) We thank W. S. Gaugh for preparing the 4-phenanthrol from 4-keto-1,2,3,4-tetrahydrophenanthrene by dehydrogenation over 10% palladium on charcoal as described by W. O. Foye, M. Weitzenhoff, and A. M. Stranz, *J. Am. Pharm. Assoc.*, **41**, 312 (1952).

(41) L. M. Jackman ["Nuclear Magnetic Resonance Spectroscopy," Pergamon Press, London, 1959, p 85] lists coupling of *ortho* aromatic protons at 7–10 cps and *meta* at 2.3 cps. This *meta* coupling was observed in the case of 2,7-diacetoxyphenanthrene.

(42) Spectra were taken on a Cary Model 14 recording spectrometer from 200 to 650 mμ.

Similar three-step spectroscopic examinations[43] were carried out for 4,5-phenanthrenediol and 1,6,8-tribromo-2,5-phenanthrenediol which were oxidized to purple and yellow solutions, respectively, but the spectra of these solutions were without character. Reduction afforded colorless solutions with spectra identical to that before reduction.

1,3,6,8-Tetrabromo-4,5-phenanthrenediol and 2,5-phenanthrenediol were oxidized to afford purple and yellow solutions, respectively. Both solutions gave spectra without character and no reduction experiments were attempted.

Assignment of Structures.—In our assignment of structure to the Fremy's salt oxidation products we bank heavily on the assumption that oxidation in which a new hydroxyl group results always occurs *ortho* or *para* to an existing hydroxyl group in the compound being oxidized. This assumption, to date, is supported by all available evidence.[18] Furthermore, if the hydroxyl group is present in the 2 position (or equivalent 7 position) we assume that oxidation will occur preferentially in the 1 position rather than the 3 position.

4,5-Dihydroxyphenanthrene (4,5-PH_2).—In addition to the method of synthesis[16] the hydroxyl groups are undoubtedly in the 4 and 5 positions because of the absence of proton resonances between τ 1.0 and 1.5 in the nmr spectrum[44] and that of the precursor, 4,5-dimethoxyphenanthrene.[45]

5-Hydroxy-1,4-phenanthrenequinone (IV).—This structure was assigned to the Fremy's salt oxidation product of 4,5-PH_2 (III) on the assumption that oxidation would take place *para* to one of the hydroxyl groups. We have shown that 4-phenanthrol yields 1,4-phenanthrenequinone. The failure to obtain a quinoxaline derivative on treatment with *o*-phenylenediamine is evidence against an *o*-quinone structure for IV. The nmr spectrum[44] is also consistent with the assigned structure but does not rule out the 5-hydroxy-3,4-phenanthrenequinone structure. The structure of 5-acetoxy-1,4-phenanthrenequinone follows from IV.

7-Hydroxy-1,2-phenanthrenequinone (VI).—The Fremy's salt oxidation product of V was assigned structure VI on the assumption (stated above) that Fremy's salt oxidizes hydroxy compounds in the *ortho* or *para* positions,[18] and on the nature of the acetylation reactions and nmr spectral data. Fieser[4] showed that 1,2-phenanthrenequinone yields 1,2,4-triacetoxyphenanthrene under Thiele conditions (acetic anhydride and H_2SO_4) and 1,2-diacetoxyphenanthrene on reductive acetylation. On comparable treatment VI yields the tetraacetate VIII and triacetate VII (see above).

The nmr spectrum of VIII had one proton as a doublet centered at τ 0.9. This is attributed to splitting of the 5 proton by the 6 proton. The remaining protons need no comment.[44] The nmr spectrum of VII had two protons as four peaks centered at τ 1.7. This is attributed to the fact that the 4 and 5 protons are nonequivalent and each is split by the 3 and 6 protons, respectively. The remaining protons need no comment.[44]

Finally, the ultraviolet spectrum of VI (see above) is similar to that of 1,2-phenanthrenequinone which has λ_{max} at 222 mμ (log ϵ 4.62), 282 (4.38), 315 (385), and 375 (3.43).

7-Hydroxy-1,4-phenanthrenequinone (X).—This oxidation product of 2,5-dihydroxyphenanthrene (IX) might be 7-hydroxy-1,2-P, 5-hydroxy-1,2-P, or 7-hydroxy-3,4-P on the basis of our assumptions concerning Fremy's salt oxidations. We believe structure X is correct because the ultraviolet spectrum is similar to that of 1,4-phenanthrenequinone and, also, because 4-phenanthrol is oxidized by Fremy's salt to 1,4-phenanthrenequinone rather than to 3,4-phenanthrenequinone.

For the assignment of structure to the brominated dihydroxyphenanthrenes, we assume that bromination occurs only in positions *ortho* and *para* to the existing hydroxyl groups. Furthermore, hydroxyl groups in the 2 and 7 positions direct only to the 1 and 8 positions, respectively. The analogy for this argument is that 2-naphthol brominates in the 2 position but not in the 3 position.

(43) Spectra data of diols are listed with description of syntheses.

(44) The nmr spectral data are in the Ph.D. thesis of R. L. Childers.

(45) J. A. Pople, W. G. Schneider, and H. J. Bernstein ["High Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., Inc., New York, N. Y., 1959, p 248–250] list the 4,5 protons of phenanthrene in the τ 1.0–1.5 region.

The Syntheses of 3,4-Dimethoxy-9,10-dimethyl-1,2-benzanthracene and 9,10-Dimethyl-1,2-benzanthra-3,4-quinone[1]

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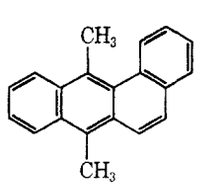
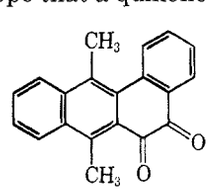
The synthesis of 3,4-dimethoxy-9,10-dimethyl-1,2-benzanthracene (V) started with the condensation of *o*-acetylbenzoic acid with 1,2-dimethoxynaphthalene in 90% methanesulfonic acid to yield 3-methyl-3-(3,4-dimethoxy-1-naphthyl)phthalide (VI), followed by conventional steps to yield V. The synthesis of 9,10-dimethyl-1,2-benzanthra-3,4-quinone (II) was accomplished by hydroxylation of 9,10-dimethyl-1,2-benzanthracene (I) to 3,4-dihydro-3,4-dihydroxy-9,10-dimethyl-1,2-benzanthracene (VIII), followed by treatment of VIII with acetic anhydride and dimethyl sulfoxide to yield II. Other attempts to prepare II by more traditional methods failed.

One of the most powerful carcinogenic hydrocarbons is 9,10-dimethyl-1,2-benzanthracene (I), but little information as to the mechanism by which it induces cancer is available.[3] In the hope that a quinone related to I might prove to be an inhibitor or a promoter of the production of cancer by I, we have attempted to develop routes for the synthesis of such quinones. Herein is reported the synthesis of 9,10-dimethyl-1,2-benzanthra-3,4-quinone (II).



I



II

Our first attempt to prepare II was by oxidation of 3-methoxy-9,10-dimethyl-1,2-benzanthracene (III), prepared essentially as described,[4] as oxidation of 9-methoxyphenanthrenes to 9,10-phenanthraquinones has been effected.[5] When oxidation of III to II proved unsuccessful, attempts were made to demethylate III to 3-hydroxy-9,10-dimethyl-1,2-benzanthracene (IV) prior to oxidation. However, we were unable to isolate IV. Actually IV has never been isolated although re-

(1) This research was supported by funds from the U. S. Public Health Service Grant No. CA-07394.

(2) This research is taken from the Ph.D. thesis of C. C. Davis, The Ohio State University, 1966.

(3) See N. H. Cromwell, *Am. Scientist*, **53**, 213 (1965), for references and discussion.

(4) W. M. Smith, Jr., E. F. Pratt, and H. J. Creech, *J. Am. Chem. Soc.*, **73**, 319 (1951).

(5) L. Ruzicka and H. Waldman, *Helv. Chim. Acta*, **15**, 907 (1932).