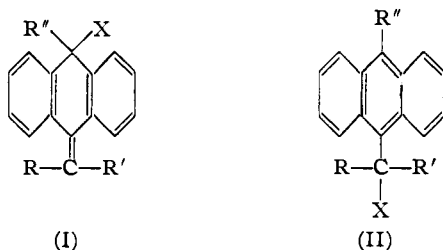


[CONTRIBUTION FROM THE RESEARCH LABORATORIES OF THE GLIDDEN COMPANY, SOYA PRODUCTS DIVISION]

Conjugated Systems. VI. 1,5-Anionotropic Shifts in the Anthracene Series

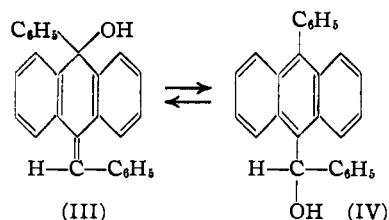
BY PERCY L. JULIAN, WAYNE COLE, GERHARD DIEMER AND J. G. SCHAFFER

The present investigation arose out of the need for a more satisfactory method for determining whether certain anthracene derivatives under investigation possessed structures I or II. The principal criteria for assignment of structures to such isomers have hitherto been (a) that the dihydroanthracene derivatives (I) are colorless in the crystalline state and non-fluorescent in solution while (b) their isomeric anthracene derivatives are colored in the crystalline state and fluoresce rather strongly in solution. Obviously



such bases for decision are not comforting, and various workers have been inclined to assign structures to such compounds with reservations. Thus, for example, Sandin, Kitchen and Fieser¹ place question marks after the structures of two isomeric 1,2-dimethyl derivatives of I and II above ($R, R' = H; R'' = CH_3; X = OCH_3$) because color and fluorescence did not satisfy them as sufficient evidence for distinguishing between the isomeric pair. Moreover, most such pairs of anionotropic tautomers have been obtained by synthetic methods which left considerable doubt as to their structure. Thus replacement reactions on compounds of structure (I) might well lead to compounds of structure (II) or to mixtures and *vice versa*. Similarly additions across the ring to compounds of structure (II), followed by elimination, or additions to compounds with the ring distribution of double bonds represented by I, with or without subsequent elimination, might lead to indeterminate structures (*cf.* ref. 1).

Julian and Cole² pointed out several years ago that despite the numerous researches on this isomerism up to that time,³ compound III of the isomeric pair, (III) and (IV), which they were studying, represented the only 9,10-dihydroanthracene derivative of fairly indisputable structure included in an investigation of this isomerism. 9-Phenyl-10-benzylidene-9,10-dihydroanthranol-9 (III) was prepared by treating benzal-



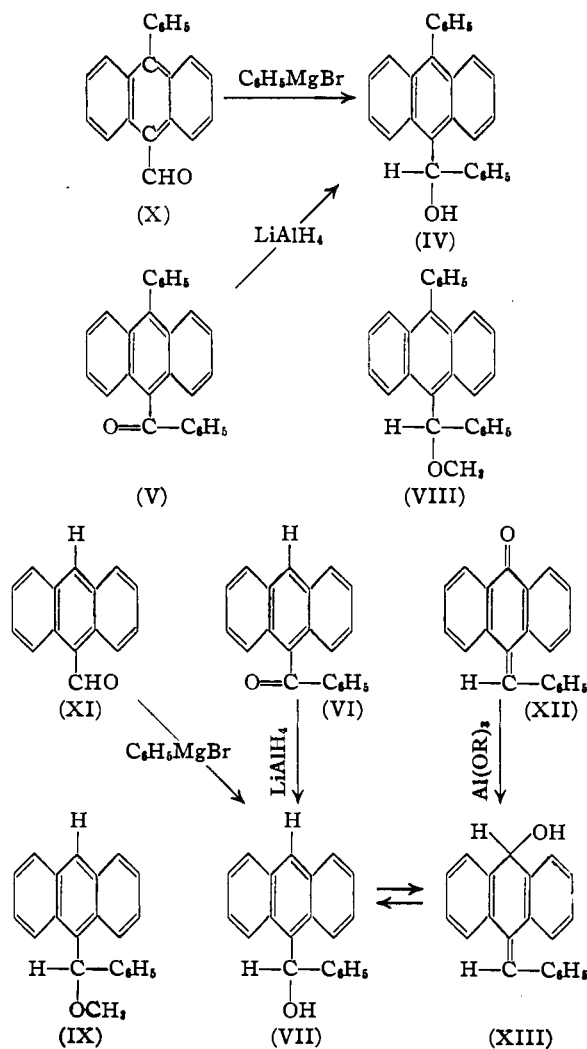
anthrone with phenylmagnesium bromide and working the product up under the mildest possible conditions. On warming with mineral acids it was converted into 9-phenyl-10- ω -hydroxybenzylanthracene (IV). While the method of preparation and the reactions of (III) left no doubt as to its structure, the evidence for the structure of (IV) was not equally as satisfying, especially if such evidence as we employed were to be used as generally applicable procedure for elucidation of structures corresponding to IV. For example, both compounds (III) and (IV) gave phenylanthranol on oxidation with chromic oxide. Both likewise, on treatment with bromine, gave 9-phenyl-10-bromoanthracene. Both likewise gave the same acetoxy-, chloro- and bromo-derivatives on treatment with acetic anhydride, thionyl chloride and hydrogen bromide, respectively. Moreover, attempts to reduce 9-phenyl-10-benzoylanthracene (V) or 10-benzoylanthracene (VI) itself to (IV) or its corresponding analog (VII), respectively, by the usual methods failed. Indeed, it was later shown⁴ that even the Grignard reagent does not add to the carbonyl group of either of these highly hindered ketones. Aluminum isopropoxide in isopropyl alcohol likewise fails to reduce V or VI to the corresponding carbinols. We were therefore forced again to rely upon the old criteria for the structure of (IV), namely, its distinctly yellow color in contradistinction to (III) and its strong fluorescence in solution. When, however, what we thought to be the corresponding ether (VIII) and its analog (IX) were both almost colorless, and in the case of IX only faintly fluorescent in solution, the need became all the more apparent for better diagnostic methods in structure determination. The results reported in this paper fill that gap and give procedures whereby the structures of such isomers can be accurately determined.

Both (IV) and (VII) have been synthesized by the action of phenylmagnesium bromide on the appropriate aldehydes (X) and (XI), which were prepared by the formamide method of Fieser.⁵ Since this method seems generally applicable for

(1) Sandin, Kitchen and Fieser, *THIS JOURNAL*, **65**, 2019 (1943).(2) Julian and Cole, *ibid.*, **57**, 1609 (1935).(3) Barnett, *et al.*, *Ber.*, **59**, 2864 (1926); **60**, 2353 (1927); **62**, 423, 1969, 3063, 3072 (1929); **64**, 49, 1573 (1931); Cook, *ibid.*, **60**, 2366 (1927); *J. Chem. Soc.*, 2798 (1928).(4) Julian, Cole and Wood, *THIS JOURNAL*, **57**, 2510 (1935).(5) Fieser, *Org. Syn.*, **20**, 11 (1940).

the preparation of anthracene aldehydes, it appears that the hydroxyl derivatives corresponding to structure (II) are readily available by such a procedure.

The carbinols (IV) and (VII) were prepared by another interesting method. Although reduction with aluminum alkoxides as well as reduction with metals and alcohols or metals and acids failed to convert the hindered benzoyl anthracenes (V) and (VI) into (IV) and (VII), respectively, lithium aluminum hydride⁶ smoothly effected this conversion. This is another illustration of the usefulness of this unique reagent, and is indicative of the probable accessibility of several hydroxyl derivatives hitherto unattainable by reduction of hindered carbonyl groups.



Turning to the isomeric carbinols of general structure (I) we found that the simpler derivatives ($R, R' = H$) could be readily produced by the Meerwein-Ponndorf reduction of the appropriate arylidene anthrones. Thus benzalanthrone

(6) Nystrom and Brown, *THIS JOURNAL*, **69**, 1197 (1947).

(XII) was readily converted into 9-hydroxy-10-benzylidene-9,10-dihydroanthracene (XIII), which in turn was converted on warming with mineral acids into its tautomer (VII), identical with the compound secured on treatment of 9-anthracene aldehyde with phenylmagnesium bromide. It is interesting to note here that reduction of benzalanthrone with lithium aluminum hydride led to a mixture of compounds difficult to separate.

These synthetic procedures make it possible to assign accurate structures to anthranols corresponding to the general structures (I) and (II) ($X = \text{OH}$). There remains, however, the uncertainty as to the structures of products formed by replacement reactions on these carbinols.

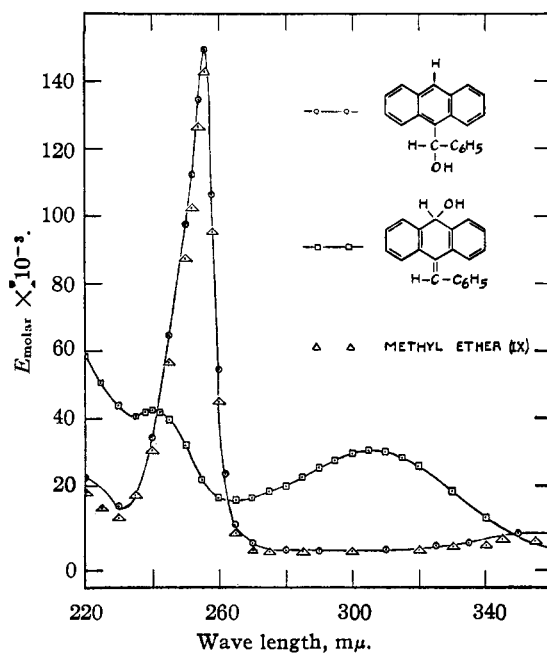


Fig. 1.

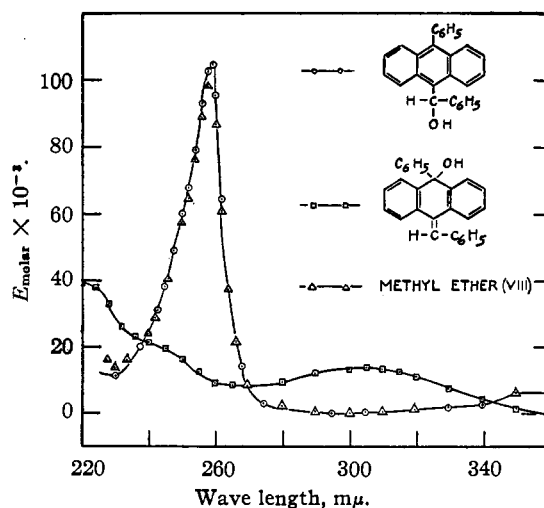


Fig. 2.

Thus, as mentioned above, all attempts to secure a methyl ether from (III) and (IV) led to a single substance, which for some time was thought to possess the general structure (I), ($R = H$, $R'' = C_6H_5$, $X = OCH_3$). Likewise carbinols (VII) and (XIII) gave only one methyl ether which was colorless and only slightly fluorescent. Final proof that the structures of these ethers were (VIII) and (IX) came from examination of their ultraviolet absorption spectra. Figures 1 and 2 give the absorption curves for the isomeric carbinols and the methyl ethers. Up to the present we have not succeeded, despite numerous trials, in preparing a methyl ether from either carbinol (III) or (XIII), which has the dihydroanthracene structure (I).

The ultraviolet absorption curves show a distinct difference between those compounds possessing structures (I) and (II). In Fig. 1 the principal peak of anthracene ($255\text{ m}\mu$)⁷ is seen to be prominent and identical for both 10- ω -hydroxybenzylanthracene (VII) and its methyl ether (IX), while completely absent from the absorption curve of the isomeric dihydroanthranol. In spite of the apparent sharpness of the peak at $256\text{ m}\mu$, an interesting fine structure exists, and it is possible to observe distinct maxima at 255.0 , 255.6 and $256.0\text{ m}\mu$. The usual fine structure in the 330 – $390\text{ m}\mu$ region, which is characteristic of anthracene, is also observable with our substituted anthracenes, but the effect is subdued and not of primary value in diagnosing molecular structure. Figure 2 similarly shows an identical absorption pattern for 9-phenyl-10- ω -hydroxybenzylanthracene (IV) and its methyl ether (VIII) in contrast with the dihydroanthranol isomer (III). The effect of increased substitution on the shift of the anthracene peak to longer wave length and lower intensity is in agreement with the general rules discussed by Jones.^{7b}

Experimental Part⁸

9-Phenylanthracene.⁹—A solution of 38.8 g. (0.2 mole) of anthrone in dry thiophene-free benzene was added to the phenylmagnesium bromide prepared from 52 g. of bromobenzene and 7.2 g. of magnesium. After decomposing the Grignard complex with ice and dilute hydrochloric acid, and extracting with ether, the extracts were washed with 12% alkali and water, concentrated, and steam distilled. The residue was taken up in ether, concentrated to a sirup, and heated with 12% sodium hydroxide and about 10 g. of sodium hydrosulfite. After cooling and diluting with ether, the alkaline layer was separated and the ether solution washed thoroughly with water and then concentrated. The phenylanthracene was crystallized from acetic acid, giving 36 g., m. p. 152 – 153° .

9-Phenyl-10-anthraldehyde (X).—A mixture of 11.2 g. of 9-phenylanthracene, 10 ml. of *o*-dichlorobenzene, 17.5

g. of *N*-methylformanilide and 17.5 g. of phosphorus oxychloride was stirred and heated under reflux at 90° for eighty minutes. Seventy grams of sodium acetate in about 125 ml. of water was added, and the mixture was steam distilled briefly to remove dichlorobenzene and methylaniline. The residue was extracted with ether, and the extract was washed with dilute hydrochloric acid and water. Concentration gave the aldehyde as yellow crystals from ether: first crop, 6 g., m. p. 168 – 170° ; second crop, 2.3 g., m. p. 158 – 166° . Recrystallization from benzene gave yellow crystals, m. p. 168 – 169° .

Anal.^M Calcd. for $C_{21}H_{14}O$: C, 89.36, H, 4.96. Found: C, 88.78; H, 5.31.

9-Phenyl-10- ω -hydroxybenzylanthracene (IV). (A) From Phenylanthraldehyde.—A benzene solution of 3.8 g. of phenylanthraldehyde was added to the Grignard reagent prepared from 2.4 g. of magnesium and 16 g. of bromobenzene in ether. The reaction proceeded during two hours at room temperature, after which it was poured onto ice and dilute sulfuric acid. (In another run ammonium chloride was used in place of the sulfuric acid, the results being the same.) The washed ether extract was concentrated to a crystalline mass, which was then washed with ethanol onto a filter. This crude product was 4.8 g. of the carbinol, m. p. 184 – 185° . Recrystallization from ethanol gave 3.5 g. of the pure carbinol (IV), m. p. 187 – 188° . This gave no depression in melting point when mixed with a sample prepared by the rearrangement of 9-phenyl-9-hydroxy-10-benzylidene-9,10-dihydroanthracene as previously described.²

(B) From Phenylbenzoylanthracene.—Two grams of 9-phenyl-10-benzoylanthracene in 50 ml. of dry ether was added dropwise to a stirred solution (under nitrogen) of 1 g. of lithium aluminum hydride in 180 ml. of dry ether. One-half hour after the addition, ice-water was added to decompose the excess reagent, and then the solution was transferred to a separatory funnel, washed with dilute sulfuric acid and water. Concentration gave yellow crystals from ether; yield 1.7 g., m. p. 182 – 184° . These crystals showed no depression in melting point when mixed with the phenylhydroxybenzylanthracene described above.

9-Phenyl-10- ω -methoxybenzylanthracene (VIII).—When 2 g. of 9-phenyl-10- ω -hydroxybenzylanthracene (IV) was refluxed for five minutes in methanol containing one drop of sulfuric acid, it was converted into the methyl ether. The crude product, 2 g., was recrystallized from ether-methanol, giving 1.6 g. of straw-colored crystals which melt at 146 – 147° .

Anal.^B Calcd. for $C_{27}H_{22}O$: C, 89.80; H, 5.92. Found: C, 89.23; H, 5.76.

This methyl ether shows melting point depression when mixed with the parent carbinol or when mixed with 9-phenyl-9-hydroxy-10-benzylidene-9,10-dihydroanthracene of m. p. 147° . Solutions of the methyl ether are blue fluorescent; its ultraviolet absorption peak is at $259\text{ m}\mu$ (E molar = 98,000).

The same methyl ether has been prepared also from the 147° carbinol (III) by five-minute treatment with hot methanol containing a drop of sulfuric acid. The product so obtained crystallized from methanol as straw-colored flakes, m. p. 144 – 145° , which showed no melting point depression when mixed with the methyl ether described above.

9-Hydroxy-10-benzylidene-9,10-dihydroanthracene (XIII).—A solution of 5 g. of benzalanthrone and 22 g. of aluminum isopropoxide in 140 ml. of dry isopropyl alcohol was distilled very slowly through a column to remove acetone together with as little isopropyl alcohol as possible, until the fresh distillate gave a negative test for acetone (Legal test) (about eight hours). The residue was then poured into a separatory funnel containing 300 cc. of 3% potassium hydroxide and extracted with ether. The ether extract was washed with alkali and with distilled water but *not* with acid, since acid isomerizes the product. The material was concentrated and crystallized from hexane, giving a first crop of about 0.5 g. of pale yellow crystals, m. p. 135 – 139° , of a fluorescent by-product. (This

(7) (a) Radulescu and Ostrogovich, *Ber.*, **64**, 2233 (1931); (b) Jones, *This Journal*, **67**, 2127 (1945).

(8) Analyses marked M are by Dr. T. S. Ma, University of Chicago. Those marked B are by Mr. Charles Beazley, Micro-Tech. Laboratory, Skokie, Illinois.

(9) For preparation of sizable quantities of phenylanthracene in good yield, the above procedure is strongly recommended (*cf.* Barnett and Cook, *J. Chem. Soc.*, **123**, 2638 (1923); Cook, *ibid.*, 2170 (1926); Bradsher, *This Journal*, **62**, 486 (1940)).

by-product, m. p. 141° when purified, is still under investigation.) The filtrate from these crystals was concentrated and crystallized from about 20 ml. of pentane containing a few drops of absolute ether (to prevent oiling), whereby about 2.5 g. of nearly white crystals separated during forty-eight hours at 10°. These were recrystallized first from hexane, then from acetone-water, yielding 2.0 g. of nearly white crystals of m. p. 118–119°.

Anal.^B Calcd. for C₂₁H₁₆O: C, 88.70; H, 5.67. Found: C, 88.56; H, 5.70.

9- ω -Hydroxybenzylanthracene (VII). (A) From Anthraldehyde.—Five grams of 9-anthraldehyde was dissolved in benzene and added to a stirred ether solution of the Grignard reagent from 5 g. of magnesium and 35 g. of bromobenzene. After four hours at about 45°, the solution was poured into ice-cold ammonium chloride solution, and the ether-benzene layer was washed with water, sodium hydroxide solution and water. The material was concentrated, steam distilled briefly to remove bromobenzene and biphenyl, then crystallized from ether-hexane. The crude product, 5 g., m. p. 109–115°, was recrystallized from ether-hexane giving 3.3 g. of straw-colored crystals, m. p. 114°.

Anal.^B Calcd. for C₂₁H₁₆O: C, 88.70; H, 5.67. Found: C, 88.70; H, 5.70.

(B) From Benzoylanthracene.—Two grams of 9-benzoylanthracene¹⁰ was dissolved in anhydrous ether and added to a solution of 1 g. of lithium aluminum hydride in 160 ml. of anhydrous ether with stirring under nitrogen. After twenty minutes water was added to decompose the excess hydride, after which the ether solution was washed with ice-cold 10% sulfuric acid and water. The product which crystallized from the ether concentrate was 1.6 g. of straw-yellow crystals melting at 111–114°. The melting point was not depressed by admixture with the material prepared from anthraldehyde.

Samples of 9- ω -hydroxybenzylanthracene have remained stable for several weeks, but year-old samples have decomposed to benzaldehyde and anthraquinone, apparently by air oxidation.

Rearrangement of XIII to VII.—A solution of 2.6 g. of 9-hydroxy-10-benzylidene-9,10-dihydroanthracene in 15 ml. of alcohol-free acetone containing 1.5 ml. of 10% sulfuric acid (in water) was refluxed on the steam-bath for one hour, cooled, diluted with water and extracted with alcohol-free ether. After washing with sodium carbonate and water, the product crystallized from the concentrate as 1.7 g. of straw-yellow crystals of 9- ω -hydroxybenzylanthracene melting at 112–114° and showing no melting point depression with the sample prepared from anthraldehyde.

9- ω -Methoxybenzylanthracene (IX).—Two grams of 9- ω -hydroxybenzylanthracene was dissolved in hot methanol and treated with one drop of sulfuric acid (which was diluted with methanol before addition). After ten minutes refluxing, the product was precipitated with water, extracted with ether, washed with alkali and with water,

then concentrated and crystallized from a small volume of methanol. The methyl ether, 1.9 g., m. p. 125–129°, was recrystallized from ether-methanol, which gave white plates, m. p. 129–130°. The solutions are blue-fluorescent.

Anal.^B Calcd. for C₂₂H₁₈O: C, 88.55; H, 6.08. Found: C, 88.09; H, 5.98.

The same methyl ether has been prepared by treating 9-hydroxy-10-benzylidene-9,10-dihydroanthracene with methanol containing a drop of sulfuric acid. When 9- ω -hydroxybenzylanthracene was treated with thionyl chloride at room temperature in ether solution, and the crude chloride so obtained treated with sodium methoxide in methanol, the same 129–130° methyl ether resulted.

Oxidations of 9-Hydroxy-10-benzylidene-9,10-dihydroanthracene (XIII).—An Oppenauer oxidation using 1 g. of the dihydroanthranol, 35 ml. of toluene, 8 ml. of cyclohexanone and 3 g. of aluminum isopropoxide at refluxing temperature for eight hours gave 0.8 g. of benzalanthrone. When 2 g. of the dihydroanthranol in carbon tetrachloride was treated with 3% ozone at 2 l./m. for eight minutes and then steam distilled, only benzaldehyde and anthraquinone could be identified.

Oxidations of 9- ω -Hydroxybenzylanthracene (VII).—Two attempts to convert this substance to benzoylanthracene by the Oppenauer method using cyclohexanone and aluminum isopropoxide left it as recovered 9- ω -hydroxybenzylanthracene. A mild chromic acid oxidation, using 1 g. of 9- ω -hydroxybenzylanthracene, 0.4 g. of chromic oxide and 200 ml. of acetic acid for one hour at room temperature, gave anthraquinone (0.4 g.) but no benzoylanthracene could be found.

Summary

A study of methods for ascertaining the structures of isomeric pairs involved in the rearrangement of dihydroanthranols into meso-substituted anthracenes is reported.

Generally applicable synthetic procedures have been proposed and demonstrated for the dihydroanthranols as well as for their isomers, the meso-substituted anthracenes.

The ultraviolet absorption curves of the dihydroanthranols and of the isomeric meso-substituted anthracenes have been shown to be entirely different and to offer a ready method for distinguishing between these structural types.

Reductions of such highly hindered aroyl anthracenes as benzoyl- and phenylbenzoylanthracene to secondary alcohols with lithium aluminum hydride are reported, such reductions having hitherto failed with all other reducing media.

(10) Cook, *J. Chem. Soc.*, 1282 (1926).