chloride was treated and the products were worked up in the same way as the p-cymene–toluene reaction. The low-boiling simple alkylarenes contained 7 g. (0.058 mole) of cumene, 47 g. (0.35 mole) of cymene isomers, and 38 g. (0.26 mole) of t-butyltoluene isomers. The following high boiling hydride transfer products were determined by gas chromatography and mass spectrometry. The total conversion to identified 2,2-diarylpropanes was 0.065 mole (13.0 mole % on cumene). Authentic 2-phenyl-2-tolylpropane was prepared in 75% yield from α-methylstyrene and toluene using a modification of the method reported for the preparation of 2,2-ditolylpropane.[3] It had b.p. 92–94° (0.15 mm.), $n^{20}_{D}$ 1.5643.

| Component | Estimated b.p. at 1 atm., °C. | % | Calcd. wt., g. | Moles |
|---|---|---|---|---|
| 2,2-Diphenylpropane | 280 | 4.7 | 0.75 | 0.004 |
| 2-Phenyl-2-tolylpropane | 290 | 18.8 | 2.9 | .014 |
| m,m'-Ditolylpropane | 300 | 32.5 | 5.0 | .022 |
| m,p'-Ditolylpropane | 310 | 25.5 | 3.9 | .018 |
| p,p'-Ditolylpropane | 320 | 10.5 | 1.6 | .007 |
| Unknown | 325–350 | 8.0 | 1.2 | |

*Anal.* Calcd. for $C_{16}H_{18}$: C, 91.42; H, 8.58. Found: C, 91.02; H, 8.42.

Oxidation[15] gave fine white needles (from 1:1 ethanol–water) of 2-(p-carboxyphenyl)-2-phenylpropane, m.p. 147–148°, and neutral equivalent, 238 (calcd., 240).

**Alkylation of Benzene with p-Cymene.**—Benzene, 195 g. (2.5 moles), p-cymene 67 g. (0.5 mole), t-butyl chloride, 46 g. (0.5 mole), and aluminum chloride (0.05 mole) were treated and the products worked up as described. The lower boiling alkylarenes contained 34.5 g. (0.29 mole) of unchanged cymene and 40.0 g. (0.3 mole, 60 mole %) of t-butylbenzene. The following hydride transfer products were found by gas chromatography.

| Components | Estimated b.p. at 1 atm., °C. | % | Calcd. wt., g. | Moles |
|---|---|---|---|---|
| 2,2-Diphenylpropane | 280 | 50.5 | 7.0 | 0.0360 |
| 2-Phenyl-2-tolylpropane | 290 | 14.5 | 2.0 | .0095 |
| m,m'-Ditolylpropane | 300 | 13.0 | 1.8 | .0080 |
| m,p'-Ditolylpropane | 310 | 12.2 | 1.7 | .0075 |
| Unknown | 330–350 | 9.8 | 1.2 | |

The total conversion to 2,2-diarylpropanes was 0.061 mole (12.2 mole % on cymene).

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# Polynuclear Aromatic Hydrocarbons. XI.[1] The Synthesis of Molecularly Overcrowded Benzo(c)phenanthrenes. I

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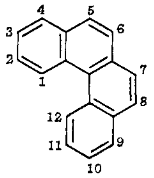
*Received November 14, 1962*

The reaction between β-methallylsuccinic anhydride and p-xylene has been examined as a means of obtaining molecularly overcrowded benzo(c)phenanthrenes. The synthesis of 1,4,5,5-tetramethyl-5,6-dihydrobenzo(c)phenanthrene (XXII) from these starting materials is described.

In an earlier communication,[4] the preparation of benzo(c)phenanthrene derivatives (I) from the Friedel–Crafts reaction products of β-methallylsuccinic anhydride (II) and benzene was outlined. In this paper, the feasibility of using p-xylene to prepare 1- and/or 12-substituted derivatives is discussed. The latter are of interest for resolution studies as well as for testing as carcinogens.



I

The starting material, β-methallylsuccinic anhydride (II), was prepared conveniently from maleic anhydride and isobutylene according to the method described by Alder and co-workers[5] and revised by Phillips and Johnson.[4] When the anhydride (II) was condensed with p-xylene in the presence of aluminum chloride, a mixture of three acids[6] (see Chart 1) and a hydrocarbon[7] was obtained. The tetralone acid (IV) usually crystallized from the acid mixture as the major product, while the other two acids (III and V) remained as an oil. However, these acids were separated easily by fractional distillation of their methyl esters. While the intramolecular acylation product (V) is of no use for the synthesis of benzo(c) phenanthrenes, III has all the carbons necessary to prepare 1,12-substituted derivatives of benzo(c)phenanthrene and IV provides a means of preparing either the 1-substituted or the 1,12-substituted derivatives.

As illustrated in Chart 1, catalytic reduction of IIIa afforded methyl α-(β-p-xylylethyl)-γ-methyl-γ-(p-xylyl)valerate (VIa), which in turn was saponified to the corresponding acid (VI). The same acid, VI, was prepared in 15% yield by condensation of p-xylene with α-(β-p-xylylethyl)-γ-methyl-γ-valerolactone (VIII), which in turn was obtained through catalytic reduction of the corresponding lactone (VII). The lactone (VII) was prepared by condensation of the anhydride (II) with p-xylene in the presence of antimony pentachloride. However, VII was obtained in a maximum yield of only 19% and consequently was a less convenient precursor to VI than was III.

Cyclization of VI with anhydrous hydrogen fluoride gave a mixture of tetralones (IX) which was subsequently reduced with lithium aluminum hydride to give a mixture of tetralols. Treatment of the tetralol

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[1] Paper X, D. D. Phillips and D. N. Chatterjee, *J. Am. Chem. Soc.*, **80**, 4364 (1958).

[2] To whom inquiries regarding this article should be sent; Shell Development Co., Modesto, Calif.

[3] From the thesis submitted by M. F. Bruno to Cornell University in partial fulfillment of the requirements for the Ph.D. degree, September, 1959.

[4] D. D. Phillips and A. W. Johnson, *J. Am. Chem. Soc.*, **77**, 5977 (1955).

[5] K. Alder, F. Pascher, and A. Schmitz, *Ber.*, **76B**, 47 (1943).

[6] A. W. Johnson, thesis, Doctor of Philosophy, Cornell University, 1957.

[7] Almost invariably, hydrocarbons were obtained in the neutral fraction when catalysts such as aluminum chloride or antimony pentachloride were used in the presence of benzene or p-xylene. These hydrocarbons will be the subject of a forthcoming publication.

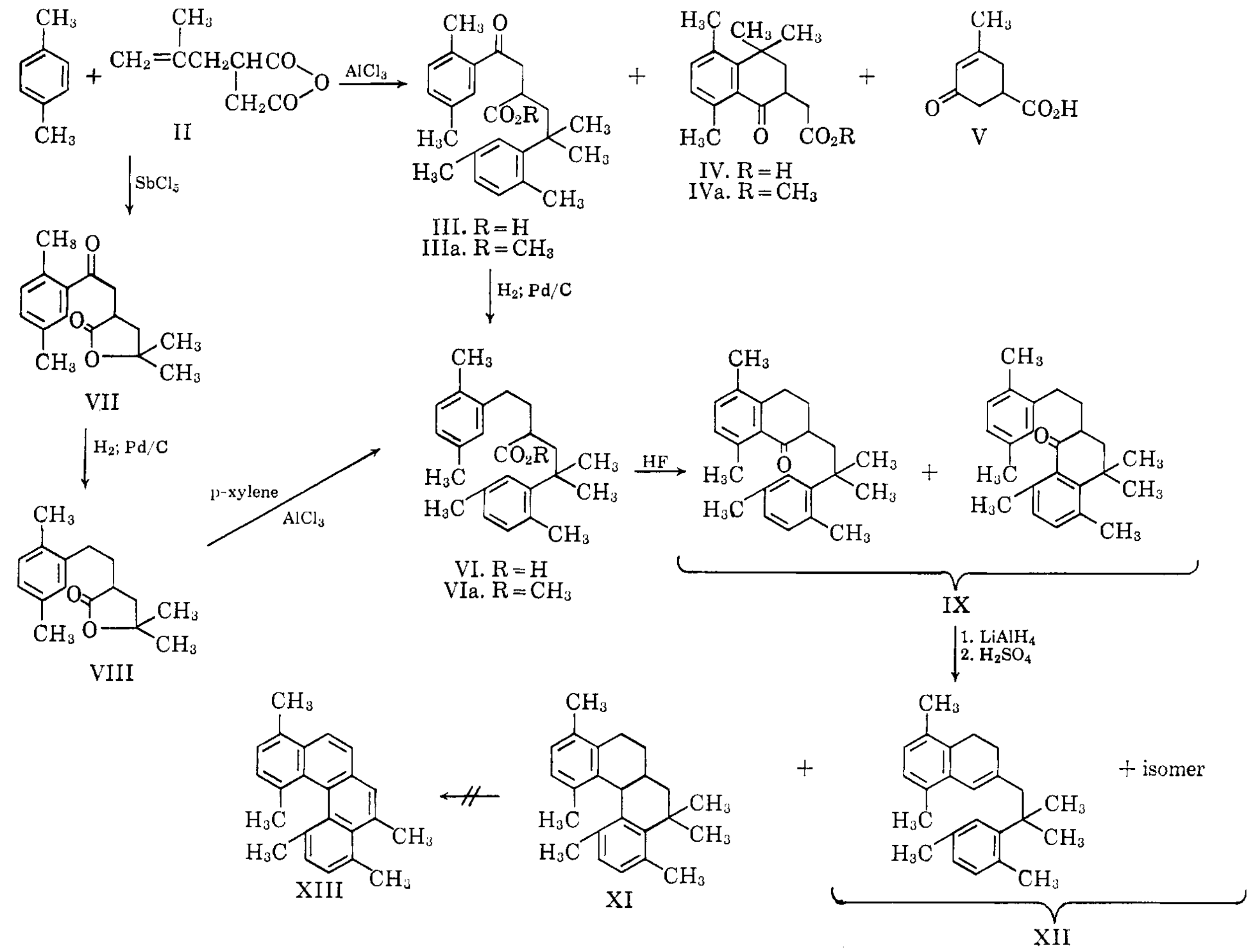
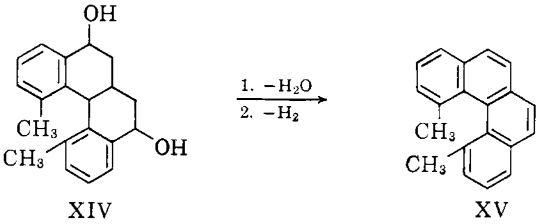


CHART 1

mixture (X) with sulfuric acid gave XI, the cyclodehydration product, and XII, the dehydration product. Attempts then were made to dehydrogenate XI and XII to 1,4,5,9,12-pentamethylbenzo(*c*)phenanthrene (XIII).

Earlier work by Phillips and Johnson[4] suggested that both XI and XII should be capable of aromatization to XIII. However, catalytic dehydrogenation with 30% palladium-on-charcoal catalyst failed to give XIII and dehydrogenation with selenium gave only an unidentified hydrocarbon. The recovery of starting material from the dehydrogenation was poor, carbonization occurring rather than aromatization. However, this was not entirely unexpected since aromatization to XIII would force two methyl groups into overcrowded positions which would result in considerable strain in the molecule. Also, complete aromatization would require the removal of one of the *gem*-dimethyl groups as methane, a reaction which is in itself difficult. Newman and Wolf[8] were able to prepare 1,12-dimethylbenzo(*c*)phenanthrene (XV) from 5,6,6a,7,8,12b-hexahydro - 1,12 - dimethylbenzo(*c*)phenanthrene - 5,8-diol (XIV). In this instance however, preliminary dehydration of the diol afforded unsaturation in each ring, and this undoubtedly facilitated the aromatization to XV.

Another route to reduced benzo(*c*)phenanthrenes, employing the available keto acid (IV), was investigated (Chart 2). In order to prepare the lactone of 1-phenyl-4,4,5,8-tetramethyl-1-tetralol-2-acetic acid (XVI), IV was treated with phenylmagnesium bromide. However, the majority of IV was recovered along with the Grignard coupling product, biphenyl. In a similar attempt to prepare XVI, the keto ester (IVa) was condensed with phenylmagnesium bromide. In this case, the neutral product contained unidentified hydrocarbons and 4,4,5,8-tetramethyl-2-phenacyl-1-tetralone (XVII), identified by its 2,4-dinitrophenylhydrazone derivative; only a small amount of crude lactone XVI was obtained.



The inability of phenylmagnesium bromide to react with the keto group of IV and IVa was probably due to the steric hindrance provided by the C-8 and/or C-4 methyl groups. Therefore, condensation of IV with phenyllithium, which has smaller steric requirements, was investigated and proved to be more successful for preparing the lactone, XVI.

Reduction of XVI to the acid (XVIII) did not proceed so easily as had been anticipated. Clemmensen reduction afforded only a trace of acid (XVIII), and catalytic reduction failed completely. Therefore, in a

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[8] M. S. Newman and M. Wolf, *J. Am. Chem. Soc.*, **74**, 3225 (1952).

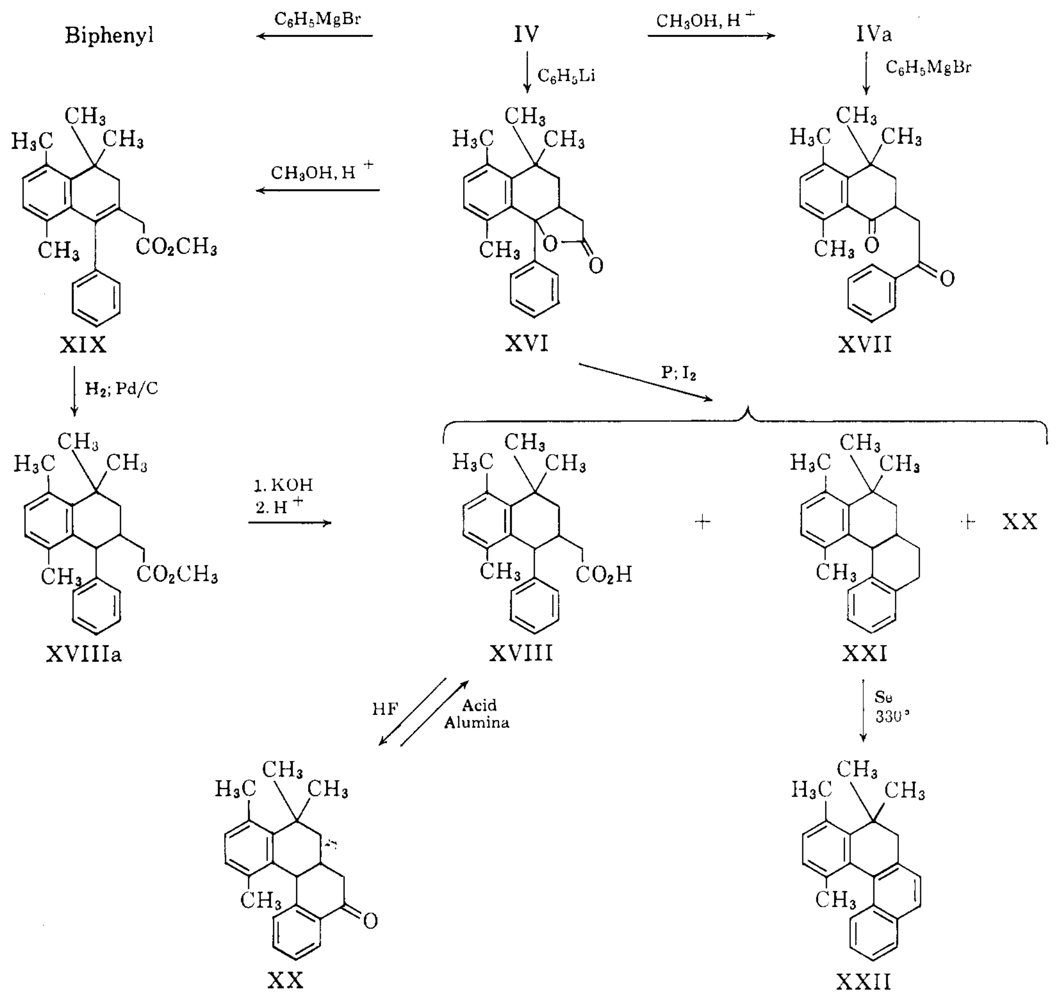


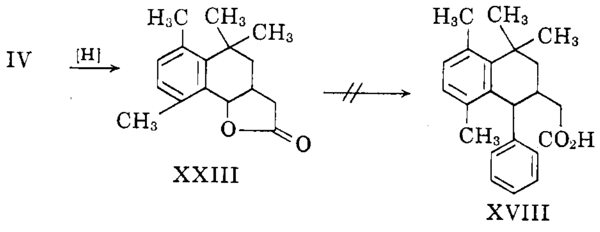
CHART 2

more circuitous route, dry hydrogen chloride was bubbled through a methanolic solution of the lactone (XVI) to give methyl 1-phenyl-4,4,5,8-tetramethyl-3,4-dihydronaphthalene-2-acetate (XIX). The ester (XIX) was catalytically reduced to give methyl 1-phenyl-4,4,5,8-tetramethyltetralin-2-acetate (XVIIIa). Saponification of XVIIIa followed by cyclization of the resultant acid (XVIII) with anhydrous hydrogen fluoride afforded the ketone (XX) as a brown viscous oil which showed infrared absorption at 5.95 $\mu$. The ketone (XX) could not be obtained in a pure condition, nor could a constant melting derivative be obtained.

At a later date it was discovered that the reduction of XVI to XVIII could be accomplished with phosphorus and iodine according to the method described by Marvel and co-workers.[9] However, the acid (XVIII) was not the only product obtained from the reduction. In one instance, the lactone (XVI) was converted almost quantitatively to a mixture containing ketone XX and hydrocarbon XXI. In an effort to separate XX and XXI, the mixture was chromatographed on acid-washed alumina to give the hydrocarbon (XXI) and the acid (XVIII). Although pure ketone XX| was not obtained from this reaction, it must have been present since the acid (XVIII) could only have come from the hydrolysis of XX on the alumina column.

Reduction of lactones to acids[10,11] and of conjugated ketones to the corresponding methylenic derivatives[12] has been accomplished with iodine (or hydriodic acid) and phosphorus. This method has also proved successful for the synthesis of $\alpha$-tetralone from $\beta$-benzoylpropionic acid.[13] In the latter case, both reduction and cyclization occurred. However, the reduction of XVI by this method seems to be the first case in which a lactone has been reduced to an acid, the acid cyclized to a ketone, and the ketone reduced to a hydrocarbon, all in one reaction.

When heated with selenium in a sealed tube at 330°, the hydrocarbon (XXI) was converted to 1,4,5,5-tetramethyl-5,6-dihydrobenzo(c)phenanthrene (XXII). Complete aromatization to 1,4,5-trimethylbenzo(c)-phenanthrene could not be accomplished.



A third route to the benzo(c)phenanthrene skeleton envisioned the use of the lactone (XXIII) derived from

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(9) C. S. Marvel, F. D. Hager, and E. C. Caudle, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1941, p. 224.

(10) B. Riegel and J. G. Burr, Jr., *J. Am. Chem. Soc.*, **70**, 1070 (1948).

(11) D. D. Phillips and E. J. McWhorter, *ibid.*, **76**, 4948 (1954).

(12) C. Graebe and F. Trümpy, *Ber.*, **31**, 375 (1898).

(13) K. Miescher and J. R. Billeter, *Helv. Chim. Acta*, **22**, 601 (1939).

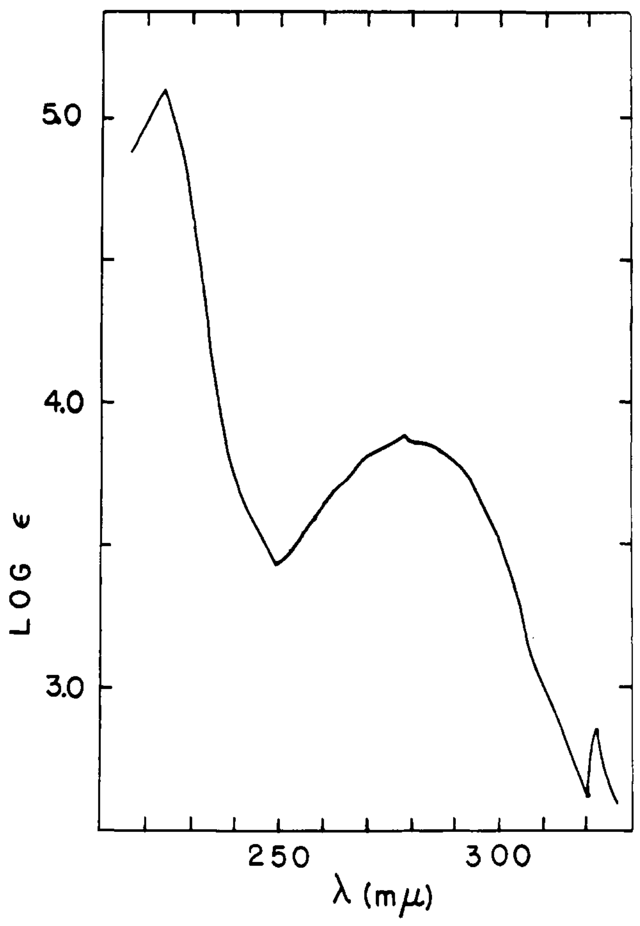

Fig. 1.—Ultraviolet absorption spectrum of XXII in 95% ethanol.

the reduction of keto acid IV. Condensation of XXIII with benzene in order to form XVIII proved abortive, however, and the route consequently was abandoned.

## Experimental[14]

**Methyl $\alpha$-($\beta$-*p*-Xylylethyl)-$\gamma$-methyl-$\gamma$-(*p*-xylyl)valerate (VIa). a. From IIIa.**—The residue (7.3 g.) obtained from the distillation of 35 g. of IVa[6] was dissolved in 150 ml. of 90% methanol containing 1.0 g. of 10% palladium-on-charcoal catalyst and heated with shaking to 60° under 48 p.s.i. of hydrogen. The catalyst was removed after 24 hr. and the solvent distilled *in vacuo* to give 7.1 g. of ester VIa as a viscous oil. Chromatography on acid-washed alumina afforded the ester (VIa) as a colorless viscous oil, $n^{25}$D 1.5300; $\lambda_{\max}^{\mathrm{NaCl}}$ 5.75 and 6.21 $\mu$.

*Anal.* Calcd. for $C_{25}H_{34}O_2$: C, 81.93; H, 9.35. Found: C, 82.23; H, 9.23.

**b. From the Lactone (VII).**—$\alpha$-(2,5-Dimethylphenacyl)-$\gamma$-methyl-$\gamma$-valerolactone (VII) was prepared by adding 62.5 ml. (0.483 mole) of antimony pentachloride over 1.5 hr. at room temperature to a mixture of 25 g. (0.162 mole) of anhydride (II) in 75 ml. of nitrobenzene and 150 ml. of *p*-xylene. The resulting brown complex was stirred under nitrogen for 12 hr. at 25°, 36 hr. at 50°, and 12 hr. at 30°. The complex then was poured into an ice–hydrochloric acid mixture at 5–10° and steam distilled for 3 hr. The residue was extracted with benzene and added to the organic portion of the distillate. This solution was extracted with several 75-ml. portions of 10% potassium hydroxide. The aqueous extract was acidified, extracted with ether, and the ethereal layer dried over magnesium sulfate. Removal of the solvent left 8.9 g. of a black tarry material. The neutral organic layer was dried over magnesium sulfate and the solvent was removed *in vacuo* to afford 23.8 g. of a brown liquid. Chromatography of the neutral material on acid-washed alumina yielded 15 g. of unidentified hydrocarbons and 8.0 g. (19%) of lactone (VII). Recrystallization from acetone–hexane afforded the lactone as colorless plates, m.p. 86.0–86.5°; $\lambda_{\max}^{\mathrm{EtOH}}$ 247 m$\mu$ (log $\epsilon$ 3.88) and 292.5 m$\mu$ (log $\epsilon$ 3.16); $\lambda_{\max}^{\mathrm{KBr}}$ 3.37, 3.42, 5.63, 5.93, 6.17, and 6.38 $\mu$.

*Anal.* Calcd. for $C_{16}H_{20}O_3$: C, 73.82; H, 7.74. Found: C, 74.00; H, 7.85.

**$\alpha$-($\beta$-*p*-Xylylethyl)-$\gamma$-methyl-$\gamma$-valerolactone (VIII).**—A solution of 16.8 g. (0.065 mole) of keto lactone VII dissolved in 160 ml. of 95% ethanol containing 1.7 g. of 10% palladium-on-charcoal catalyst was heated with shaking to 60° under 45 p.s.i. of hydrogen. The catalyst was removed after 20 hr. and the solvent distilled *in vacuo* to yield 14.1 g. (89%) of lactone VIII as a colorless viscous oil which slowly crystallized. Recrystallization from acetone–pentane afforded the lactone as colorless microcrystals, m.p. 56.5–57.0°; $\lambda_{\max}^{\mathrm{EtOH}}$ 276.5 m$\mu$ (log $\epsilon$ 2.91) and 268 m$\mu$(log $\epsilon$ 2.89); $\lambda_{\max}^{\mathrm{KBr}}$ 3.42, 3.52, and 5.69 $\mu$.

*Anal.* Calcd. for $C_{16}H_{22}O_2$: C, 78.01; H, 9.00. Found: C, 77.58; H, 8.90.

When this lactone (VIII) was treated with excess *p*-xylene and aluminum chloride at room temperature, it was converted in 15% yield to VI, identified by its infrared spectrum.

**4,4,5,8-Tetramethyl-2-(2-*p*-xylylethyl)-1-tetralone and 5,8-Dimethyl-2-(2-methyl-2-*p*-xylylpropyl)-1-tetralone (IX).**—To 4.8 g. (0.013 mole) of acid VI, obtained by saponification of ester VIa, was added 90 ml. of anhydrous hydrogen fluoride. The dark brown reaction mixture was allowed to remain for 1 hr. at room temperature, with occasional shaking, and then was decomposed by pouring onto cracked ice. The aqueous mixture was extracted with ether and the ethereal solution washed with 10% sodium carbonate solution. The neutral ethereal solution was dried over magnesium sulfate and evaporated to give 3.4 g. (78%) of tetralone mixture IX.

Chromatography of a small portion of the neutral material afforded the tetralone mixture (IX) as a colorless viscous oil which slowly crystallized, m.p. 79–81°; $\lambda_{\max}^{\mathrm{NaCl}}$ 5.95 and 6.25 $\mu$; $\lambda_{\max}^{\mathrm{EtOH}}$ 259 m$\mu$ (log $\epsilon$ 4.16) and 308 m$\mu$ (log $\epsilon$ 3.26).

*Anal.* Calcd. for $C_{24}H_{30}O$: C, 86.17, H, 9.04. Found: C, 86.01; H, 9.26.

**4,4,5,8-Tetramethyl-2-(2-*p*-xylylethyl)-1-tetralol and 5,8-Dimethyl-2-(2-methyl-2-*p*-xylylpropyl)-1-tetralol (X).**—To a stirred slurry of 0.80 g. (0.021 mole) of lithium aluminum hydride in 35 ml. of dry ether, at room temperature under nitrogen, was added, over 1.5 hr., 3.0 g. (9.0 mmoles) of tetralone mixture IX. The resulting mixture was stirred at room temperature for 24 hr. and was decomposed by the addition of a saturated solution of ammonium chloride and worked up in the usual fashion to give 2.5 g. (83%) of tetralol mixture X; $\lambda_{\max}^{\mathrm{NaCl}}$ 2.95 $\mu$.

**1,4,5,5,9,12-Hexamethyl-5,6,6a,7,8,13-hexahydrobenzo(*c*)-phenanthrene (XI) and 2-(2-*p*-Xylylethyl)-4,4,5,8-tetramethyl-3,4-dihydronaphthalene and 2-(2-Methyl-2-*p*-xylylpropyl)-5,8-dimethyl-3,4-dihydronaphthalene (XII).**—Two milliliters of concentrated sulfuric acid was added dropwise over 3 min. to 2.5 g. (7.3 mmoles) of tetralol mixture (X). The dark brown complex was stirred for an additional minute, poured into an ice–water mixture, and extracted with ether. The ethereal solution was dried and evaporated to give 2.1 g. (89%) of a yellow brown oil. Chromatography of the oil on acid-washed alumina afforded the hydrocarbon mixture (XI and XII) as a colorless, viscous oil; $\lambda_{\max}^{\mathrm{EtOH}}$ 269 m$\mu$ (log $\epsilon$ 3.19) and 277 m$\mu$ (log $\epsilon$ 3.16).

*Anal.* Calcd. for $C_{24}H_{30}$: C, 90.51; H, 9.49. Found: C, 90.40, 90.55; H, 9.55, 9.50.

**Attempted Synthesis of 1,4,5,9,12-Pentamethylbenzo(*c*)phenanthrene (XIII). a. By Catalytic Dehydrogenation of XI and XII.**—A mixture of 0.50 g. (1.57 mmoles) of XI and XII and 0.28 g. of 30% palladium-on-charcoal catalyst was heated for 4 hr. at 380° in a Pyrex tube fitted with a reflux condenser. The cooled melt was taken up in hexane an chromatographed on acid-washed alumina to give 0.3 g. of starting material.

**b. By Selenium Dehydrogenation of XI and XII.**—A mixture of 0.62 g. (7.6 mmoles) of selenium powder and 0.3 g. (0.94 mmole) of XI and XII, in a sealed tube, was heated for 19 hr. at 310° and 0.5 hr. at 360°. The mixture was cooled and the melt taken up in hexane–benzene and chromatographed on acid-washed alumina to give 50 mg. of a hydrocarbon which showed

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[14] All melting points and boiling points are uncorrected. Infrared absorption spectra of solids were taken in potassium bromide or chloroform on a Perkin-Elmer Model 21 spectrophotometer. Infrared absorption spectra of oils were taken between sodium chloride plates. Ultraviolet absorption spectra were measured in 95% ethanol with a Beckman Model DK automatic recording spectrophotometer, except where noted. Analyses were performed by the Schwarzkopf Microanalytical Laboratory, Woodside, N. Y.

ultraviolet absorption; $\lambda_{max}^{EtOH}$ 239 mμ (log ε 4.09), 249 mμ (log ε 4.17), 262 mμ (log ε 3.58), 273 mμ (log ε 3.83), 284 mμ (log ε 4.01), 307 mμ (log ε 3.25), 321 mμ (log ε 3.42), and 335 mμ (log ε 3.60). (Measured with a Cary Mode 14 automatic recording spectrophotometer using 318 as the molecular weight.)

**Lactone of 1-Phenyl-4,4,5,8-tetramethyl-1-tetralol-2-acetic Acid (XVI). a. *Via* Phenyllithium.**—To a stirred solution of 6.0 g. (0.023 mole) of keto acid IV in 200 ml. of dry ether was added dropwise, over 0.3 hour, 0.046 mole of phenyllithium prepared by heating under reflux a mixture of 7.3 g. (0.046 mole) of bromobenzene, 0.80 g. (0.115 g.-atom) of lithium, and 75 ml. of dry ether. The resulting mixture was heated under nitrogen at 55° for 40 hr., cooled, and the complex destroyed by the addition of 100 ml. of 6 *N* hydrochloric acid. The acidified mixture was stirred at room temperature for 2 hr. to ensure lactonization and worked up in the usual manner to give 3.3 g. of unchanged keto acid IV and 3.8 g. of neutral material as a brown mushy solid. Washing of the neutral material with hexane afforded 2.9 g. (49% based on the amount of acid used) of a tan solid. Recrystallization from hexane–acetone afforded the lactone as colorless, short needles, m.p. 186–187°; $\lambda_{max}^{CHCl_3}$ 5.64 and 6.25 μ; $\lambda_{max}^{EtOH}$ 274.5 mμ (log ε 2.87) and 282.7 (log ε 2.87).

*Anal.* Calcd. for $C_{22}H_{24}O_2$: C, 82.47; H, 7.55; mol. wt., 320. Found: C, 82.65; H, 7.58; mol. wt., 305.

**b. *Via* Phenylmagnesium Bromide. 1. From IV.**—To a stirred solution of 10.0 g. (0.038 mole) of keto acid (IV) in 200 ml. of dry tetrahydrofuran at room temperature was added slowly 25.6 ml. (0.077 mole) of 3 *M* phenylmagnesium bromide. The amber mixture was stirred under nitrogen at 65° for 24 hr., cooled, and the complex destroyed with 200 ml. of 6 *N* hydrochloric acid. The solvent was distilled and the mixture worked up in the usual fashion to give 9.7 g. of unchanged keto acid and 6.5 g. of neutral material identified as biphenyl.

Subsequent attempts, under various experimental conditions, to prepare the lactone (XVI) from keto acid IV were unsuccessful.

**2. From IVa.**—To a solution of 8.7 g. (0.033 mole) of keto ester IVa in 250 ml. of dry tetrahydrofuran, stirred under nitrogen at 55°, was added, over 1 hr., 22 ml. of 3 *M* (0.066 mole) phenylmagnesium bromide. The complex was destroyed and worked up in the usual way to give 12.4 g. of a brown neutral oil. The oil was taken up in 60 ml. of methanol and heated under reflux with 10 ml. of water and 6 g. of potassium hydroxide. After 4 hr. the methanolic solution was poured into 200 ml. of water and extracted with several portions of ether. Evaporation of the ethereal solution provided 6.0 g. of a brown neutral oil. The neutral oil was chromatographed on acid-washed alumina and separated into two major fractions. Fraction 1 was a mixture of unidentified hydrocarbons. Fraction 2, $\lambda_{max}^{NaCl}$ 5.94, 6.24, and 6.37 μ was the diketone, **4,4,5,8-tetramethyl-2-phenacyl-1-tetralone (XVII)**, identified by its 2,4-dinitrophenylhydrazone derivative, m.p. 209–210°.

*Anal.* Calcd. for $C_{28}H_{28}N_4O_4$: C, 67.19; H, 5.64; N, 11.14. Found: C, 67.25; H, 5.52; N, 11.32.

The aqueous solution was acidified to pH 3 with 6 *N* hydrochloric acid, heated at 60° for 2 hr., cooled, and extracted with ether. The ethereal solution was extracted with several portions of 5% sodium carbonate solution, dried, and evaporated to give 1.04 g. of crude lactone XVI. The carbonate solution was acidified and extracted with ether. Evaporation of the ethereal solution gave 4.7 g. of unchanged keto acid IV; $\lambda_{max}^{CHCl_3}$ 5.84 and 5.95 μ.

**Reduction of Lactone XVI. A. Clemmensen Reduction.**—Forty grams of mossy zinc, 4 g. of mercuric chloride, 80 ml. of water, and 1 ml. of concentrated hydrochloric acid were shaken for 10 min. The solution was decanted and the zinc washed with several portions of water. To the activated zinc was added 40 ml. of water, 20 ml. of concentrated hydrochloric acid, and 7.5 g. of crude lactone in 25 ml. of toluene. The resulting mixture was heated under reflux for 47 hr., cooled, and extracted with several portions of 5% potassium hydroxide solution. The usual work-up gave 7.2 g. of unchanged starting material and a trace of acid (XVIII).

**B. Catalytic Reduction.**—A solution of 7.1 g. of lactone XVI in 100 ml. of 95% ethanol and 40 ml. of benzene containing 0.7 g. of 10% palladium-on-charcoal catalyst was heated with shaking to 60° under 47 p.s.i. of hydrogen. The catalyst was removed after 44 hr., and the solvent distilled *in vacuo* to yield 7.0 g. of unchanged lactone.

**C. Phosphorus and Iodine Reduction. Run 1.**—To a solution of 1.35 g. (4.15 mmoles) of lactone (XVI), m.p. 186–187°, in 50 ml. of glacial acetic acid was added 1.0 g. (3.94 mmoles) of iodine, 3.0 g. (0.097 mole) of red phosphorus, and 1 ml. of water. The mixture was heated under reflux for 24 hr., cooled, and filtered. The filtered solution was added to 300 ml. of water containing 1.0 g. of sodium bisulfite and extracted with ether. The ethereal solution was extracted with 10% potassium hydroxide, dried, and evaporated to give 1.27 g. of neutral material which showed weak absorption in the carbonyl region (5.93 μ) and strong aromatic absorption. Chromatography of the neutral material on acid-washed alumina afforded 0.2 g. of hydrocarbon XXI, eluted with benzene, and 0.8 g. of acid XVIII, eluted with methanol.

Obtention of the acid (XVIII) indicates that the ketone (XX) was formed during the reduction but that it opened to the acid (XVIII) on the alumina column.

Although the hydrocarbon (XXI) was not obtained in a pure condition, it was assumed to be 1,4,5,5-tetramethyl-5,6,6a,7,8,-13-hexahydrobenzo(*c*)phenanthrene because of its ultimate conversion to 1,4,5,5-tetramethyl-5,6-dihydrobenzo(*c*)phenanthrene (XXII), identified by its ultraviolet absorption spectrum.

**Run 2.**—In a similar experiment, a mixture containing 1.55 g. (4.85 mmoles) of lactone XVI, 65 ml. of glacial acetic acid, 4.0 g. (0.13 mole) of red phosphorus, 1.1 g. (4.32 mmoles) of iodine, and 1 ml. of water was heated under reflux for 36 hr. The mixture was cooled, filtered, and worked up in the usual way to give 0.62 g. of neutral material XX and XXI and 0.45 g. (31%) of acid XVIII, m.p. 210–217°. Recrystallization from hexane–acetone afforded XVIII as colorless crystals, m.p. 227–228°; $\lambda_{max}^{CHCl_3}$ 5.87 μ; $\lambda_{max}^{EtOH}$ 264 mμ (log ε 2.73), 267 mμ (log ε 2.74), 270 mμ (log ε 2.80), and 280 mμ (log ε 2.67).

*Anal.* Calcd. for $C_{22}H_{26}O_2$: C, 81.95; H, 8.13. Found: C, 82.16; H, 8.13.

**Methyl 1-Phenyl-4,4,5,8-tetramethyl-3,4-dihydronaphthalene-2-acetate (XIX).**—Dry hydrogen chloride was bubbled for 21 hr. through a solution of 175 ml. of 90% methanol containing 3.7 g. (0.014 mole) of crude lactone XVI. Distillation of the solvent *in vacuo* afforded 3.7 g. (97%) of ester XIX as a brown viscous oil; $\lambda_{max}^{NaCl}$ 5.73 and 6.21 μ.

**Methyl 1-Phenyl-4,4,5,8-tetramethyltetralin-2-acetate (XVIIIa).**—A solution of 3.6 g. (0.011 mole) of ester XIX in 130 ml. of 90% methanol containing 0.4 g. of 10% palladium-on-charcoal catalyst was heated with shaking to 60° under 42 p.s.i. of hydrogen. The catalyst was removed after 36 hr. and the solvent distilled *in vacuo* to yield 3.5 g. (97%) of ester XVIIIa as a viscous yellow oil; $\lambda_{max}^{NaCl}$ 5.75 and 6.21 μ.

**1,4,5,5-Tetramethyl-8-keto-5,6,6a,7,8,13-hexahydrobenzo(*c*)-phenanthrene (XX).**—Forty milliliters of anhydrous hydrogen fluoride was added to 1.65 g. (5.2 mmoles) of acid XVIII in a polyethylene bottle. The complex was destroyed after 10 hr. and worked up in the usual fashion to afford 1.2 g. (77%) of ketone XX as a brown viscous oil; $\lambda_{max}^{NaCl}$ 5.95 and 6.21 μ.

**1,4,5,5-Tetramethyl-5,6-dihydrobenzo(*c*)phenanthrene (XXII).**—An intimate mixture of 0.20 g. (1.08 mmoles) of XXI and 0.30 g. (3.8 mmoles) of selenium was heated for 12 hr. at 330° in a sealed Pyrex tube. The cooled melt was taken up in benzene–hexane, treated with charcoal, and chromatographed on acid-washed alumina to give 30 mg. of hydrocarbon XXII; $\lambda_{max}^{EtOH}$ 224 mμ (log ε 5.10), 278 mμ (log ε 3.87), and 322 mμ (log ε 2.86).[15] The ultraviolet absorption spectrum of XXII was identical to that reported by Johnson,[6] except for the small peak at 322 mμ (see Fig. 1).

**Lactone of 4,4,5,8-Tetramethyl-1-tetralol-2-acetic Acid (XXIII). a. By Catalytic Reduction of IV.**—A solution of 7.8 g. (0.03 mole) of keto acid IV in 125 ml. of ethanol containing 0.3 g. of platinum oxide and 1 ml. of concentrated sulfuric acid was shaken for 24 hr. under 45 p.s.i. of hydrogen pressure. Removal of the solvent and catalyst afforded 7.8 g. of material which showed infrared absorption at 5.67 μ (lactone), 5.77 μ (ester), and 5.96 μ (ketone). This material was saponified by heating under reflux for 5 hr. with 10.0 g. (0.18 mole) of potassium hydroxide in 150 ml. of ethanol. The reaction mixture was poured into 200 ml. of 6 *N* hydrochloric acid and extracted with ether. The ethereal solution was extracted with 10% sodium carbonate, dried, and evaporated giving 2.4 g. (33%) of XVI as a colorless solid. Recrystallization from hexane–acetone afforded colorless

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[15] Measured with a Cary Model 14 recording spectrophotometer.

cubic crystals, m.p. 146–147°; $\lambda_{\max}^{\mathrm{CHCl_3}}$ 5.64, 6.82, 7.73, 8.60, 10.32, and 11.00 μ; $\lambda_{\max}^{\mathrm{EtOH}}$ 272.5 mμ (log ε 2.95) and 280.8 mμ (log ε 2.95).

*Anal.* Calcd. for $C_{15}H_{20}O_2$: C, 78.64; H, 8.26. Found: C, 78.50; H, 8.44.

b. **By Sodium Borohydride Reduction of IV.**—To a stirred, refluxing solution of 26.0 g. (0.10 mole) of keto acid IV, neutralized to the phenolphthalein end point, in 200 ml. of 50% methanol was added 1.25 g. (0.033 mole) of sodium borohydride over 0.5 hr. The reaction mixture was refluxed for 22 hr., decomposed with 6 *N* hydrochloric acid, and worked up in the usual fashion to give 12.15 g. of unchanged acid IV and 12.35 g. (47.5%) of lactone XXIII, m.p. 136–138°. Recrystallization from hexane-acetone afforded colorless microcrystals of XXIII, m.p. 146–147°, identical in all respects to the lactone prepared by catalytic reduction (see method a preceding).

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# Optical Rotatory Dispersion Studies. LXXXII.[1a] Conformational Analysis. XXXVII.[1b] Determination of the Stereochemistry and Conformation of the Four Isomeric Cyanodihydrocarvones by Optical Rotatory Dispersion and Dipole Moment Measurements[2]

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*Received December 26, 1962*

Of the four possible cyanide addition products of (−)-carvone (I), three have now been isolated in pure form and the presence of the fourth one demonstrated chromatographically. Through a combination of chemical transformations, optical rotatory dispersion measurements, and dipole moment data, it has been possible to assign the correct stereochemistry to the two newly generated asymmetric centers and to assign plausible conformations to the four isomeric 3-cyano-2,3-dihydrocarvones.

Many years ago, Lapworth[4] studied the 1,4-addition of cyanide to (+)-carvone (antipode of I[5]) and isolated two crystalline, isomeric nitriles, both of which exhibited mutarotation. Their chemistry was studied *in extenso*, but no stereochemical assignments were made, and no further work appears to have been done on these substances during the past fifty years. In the cyanide addition to carvone, two new asymmetric centers are generated, thus creating the possibility of four stereoisomers (II–V). Furthermore, since we are dealing here with a flexible ring system, eight conformers (IIA or B–VA or B) must be considered, if we restrict ourselves to chair forms; and many more, if boat and twist forms are also brought into play. It was decided, therefore, to attack this interesting stereochemical problem by attempting the isolation of as many of the dihydrocarvone isomers as possible and to subject them to optical rotatory dispersion scrutiny[6] in the light of the octant rule.[7] The latter has been shown[8] to be of considerable utility in the solution of conformation problems, and it was of interest to examine its applicability to the present cases and to confirm the conformational conclusions by dipole moment measurements.[9]

In the present work, (−)-carvone of known absolute configuration (I)[10] was employed and duplication of Lapworth's conditions[4a] (potassium cyanide in ethanol–water–acetic acid at room temperature) yielded about 70% of the highest melting isomer II (m.p. 95.5°) of 3-cyano-2,3-dihydrocarvone, the physical constants being in reasonable agreement with those reported by Lapworth[4a] for the antipode. Thin-layer chromatography on silica gel was found to be an excellent method for determining the purity of the dihydrocarvones, since a solvent system was used that effected separation of all four isomers. In fact, this method showed that the crude cyanodihydrocarvone prepared by Lapworth's first[4a] procedure consisted principally of isomer II, contaminated with some IV and traces of III.

By conducting the cyanide addition in refluxing aqueous ethanol—in the absence of acetic acid—Lapworth[4b] encountered a second isomer (m.p. 84°, now shown to be III) in high yield. Attempts in our hands to duplicate quantitatively these results failed, since thin-layer chromatography always demonstrated the existence of approximately equal amounts of isomers II and III, as well as traces of IV. By means of gradient elution chromatography, it was possible to isolate the pure second isomer III (m.p. 86.5°), with constants in reasonable agreement with those recorded[4b] for its antipode.

The question then arose whether the two cyanodihydrocarvones (now known to be II and III) of m.p. 95.5 and 86.5° were isomeric at C-2 and/or at C-3, since both these centers are invertible. In order to gain information on this point, each pure isomer was subjected to equilibration in ethyl acetate solution in the presence of *p*-toluenesulfonic acid, the course of the reaction being followed by thin-layer chromatography. Complete equilibration was reached at room tempera-

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[1] (a) For preceding paper see C. Beard, C. Djerassi, J. Sicher, F. Šipoš, and M. Tichý, *Tetrahedron*, in press; (b) for preceding paper see J. M. Conia, J. L. Ripoll, L. A. Tushaus, C. L. Neumann, and N. L. Allinger, *J. Am. Chem. Soc.*, **84**, 4982 (1962).

[2] Financial support was provided by the National Cancer Institute (grant no. CRTY-5061) of the National Institutes of Health to Stanford University, and by the National Science Foundation (grants no. 19981 and G-10346) to Wayne State University.

[3] Recipient of an undergraduate research fellowship at Stanford University from the National Science Foundation.

[4] (a) A. Lapworth, *J. Chem. Soc.*, **89**, 945, 1819 (1906); (b) A. Lapworth and V. Steele, *ibid.*, **99**, 1877 (1911).

[5] All structural formulas in this paper represent correct absolute configurations according to the steroid notation.

[6] C. Djerassi, "Optical Rotatory Dispersion: Applications to Organic Chemistry," McGraw-Hill Book Co., New York, N. Y., 1960.

[7] W. Moffitt, R. B. Woodward, A. Moscowitz, W. Klyne, and C. Djerassi, *J. Am. Chem. Soc.*, **83**, 4013 (1961).

[8] For pertinent discussion and earlier references see C. Djerassi and W. Klyne, *J. Chem. Soc.*, 4929 (1962); *Proc. Natl. Acad. Sci., U. S.*, **48**, 1093 (1962); *J. Chem. Soc.*, 2390 (1963).

[9] For discussion and earlier references of the use of dipole moment studies in conformational analysis, see N. L. Allinger, M. A. DaRooge, M. A. Miller, and B. Waegeli, *J. Org. Chem.*, **28**, 780 (1963).

[10] See A. J. Birch, *Ann. Reports Progr. Chem.*, **47**, 192 (1951).