

181. Polycyclic Aromatic Hydrocarbons. Part XXXIII. Synthesis of Naphtho(1' : 2'-1 : 2)fluorene and Naphtho(2' : 1'-2 : 3)fluorene.

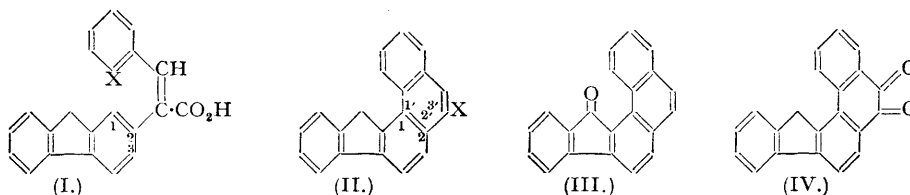
By J. W. COOK and (Miss) E. F. M. STEPHENSON.

1 : 2 : 7 : 8-Dibenzanthracene (VI; X = H) has been synthesised by an improved method and transformed, through its 3 : 4-quinone (VIII), into naphtho(2' : 1'-2 : 3)fluorene (X). The isomeric naphtho(1' : 2'-1 : 2)fluorene (II; X = H) has been synthesised from fluorene-2-acetic acid by the Pschorr method and found to be carcinogenic and also to inhibit tumour-growth. Indane-1 : 2-dicarboxylic acid has been prepared in *cis*- (XVII) and *trans*-forms (XVIII), characterised as their *methyl* esters.

As part of a study of the inhibitory effects on tumour growth of polycyclic aromatic compounds related to the carcinogenic hydrocarbons, it was desired to synthesise naphtho(2' : 1'-2 : 3)-fluorene (X). Some preliminary experiments towards this objective were recorded by Cook and Preston (*J.*, 1944, 553). After further exploratory work summarised below, methods were devised by which we have been able to obtain the required hydrocarbon (X), and also the isomeric naphtho(1' : 2'-1 : 2)fluorene (II; X = H). In tests carried out by Professor A. Haddow, which will be reported elsewhere, (II; X = H) has given clear evidence of inhibition of growth of transplanted tumours in rats and has also given malignant tumours of the skin in mice. The isomeric hydrocarbon is still under test.

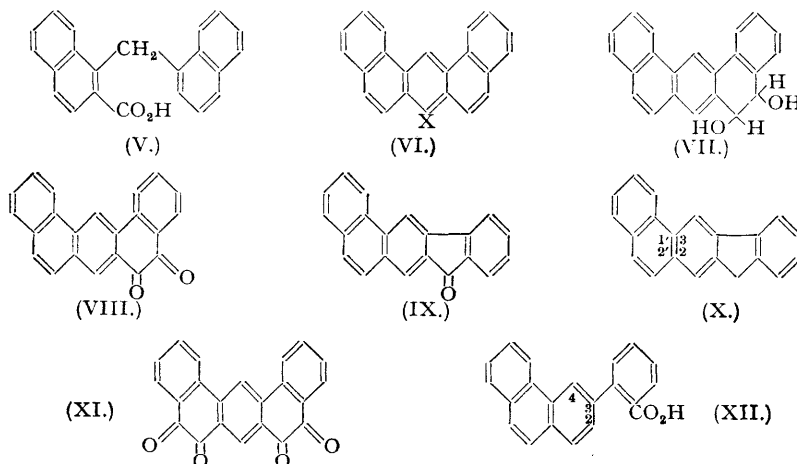
Naphtho(1' : 2'-1 : 2)fluorene (II; X = H) was obtained by a series of reactions by which it had been hoped to prepare the isomer (X). For this purpose, the Pschorr phenanthrene synthesis was adopted. Fluorene-2-acetic acid was condensed with *o*-nitrobenzaldehyde to give *o*-nitro- α -2-fluorenylcinnamic acid (I; X = NO₂), which was reduced to the corresponding amino-acid (I; X = NH₂). Diazotisation of this was troublesome, but was accomplished with

amyl nitrite and ethanolic hydrochloric acid. The resulting diazonium salt underwent cyclisation to *naphtho(1' : 2'-1 : 2)fluorene-3'-carboxylic acid* (II; X = CO₂H) when its suspension in ethanol was treated with copper powder. The acid was decarboxylated by heating it with copper powder, the hydrocarbon (II; X = H) being sublimed under reduced pressure. Oxidation of (II; X = H) with sodium dichromate in boiling acetic acid gave a mixture, which was separated by chromatography into *naphtho(1' : 2'-1 : 2)fluorenone* (III) and the *quinone* (IV). In an attempt to adapt the method developed by Hewett (*J.*, 1938, 1286; 1940, 293) to the synthesis of benzologues of phenanthrene, fluorene-2-acetic acid was condensed with *o*-chlorobenzaldehyde to give *o*-chloro- α -2-fluorenylcinnamic acid (I; X = Cl). However, this acid could not be cyclised by fusion with alkali.



The Pschorr ring-closure of the diazonium salt from the amino-acid (I; X = NH₂) could take place at positions 1 or 3 of the fluorene system. Only one of these positions was attacked, for the product was homogeneous. The actual direction of cyclisation, *i.e.*, at position 1, was unexpected, for both ω -2-fluorenyl-*o*-toluic acid (Barnett, Goodway, and Watson, *Ber.*, 1933, 66, 1880) and γ -2-fluorenylbutyric acid (Koelsch, *J. Amer. Chem. Soc.*, 1933, 55, 3885) undergo cyclisation at position 3 of the fluorene system. The structures assigned to the products which we obtained are based on the finding that the hydrocarbon (II; X = H) and its oxidation product (III) differ from *naphtho(2' : 1'-2 : 3)fluorene* (X) and the corresponding fluorenone (IX), which would have been obtained if cyclisation had occurred at position 3 of the fluorene nucleus in (I).

The starting point in the synthesis of *naphtho(2' : 1'-2 : 3)fluorene* (X) was 1 : 2 : 7 : 8-dibenzanthracene (VI; X = H), two syntheses of which have been recorded (Cook, *J.*, 1932, 1472; *cf.* Waldmann, *J. pr. Chem.*, 1932, 135, 1). In order to obtain this hydrocarbon in quantity adequate for our present purpose, it was found necessary to improve the method selected for its preparation. To this end, 2-carboxy-1 : 1'-dinaphthyl ketone, an intermediate used by Cook (*loc. cit.*) in one route to (VI) was reduced by Huang-Minlon's modification (*J. Amer.*

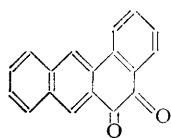


Chem. Soc., 1946, 68, 2487) of the Wolff-Kishner method. This led to 1 : 1'-*dinaphthylmethane-2-carboxylic acid* (V), now obtained crystalline and analytically pure, which with a boiling mixture of acetic acid and acetic anhydride, containing a little zinc chloride (compare Fieser and Hershberg, *ibid.*, 1937, 59, 1028), was converted in good yield into 10-acetoxy-1 : 2 : 7 : 8-dibenzanthracene (VI; X = OAc). For hydrolysis to the anthranol (VI; X = OH) the procedure of Fieser and Hershberg (*loc. cit.*) was used, whereby the acetate was treated with

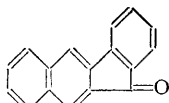
n-butylmagnesium bromide. The final reduction, of the anthranol to 1 : 2 : 7 : 8-dibenzanthracene, (VI; X = H) was effected with zinc dust and aqueous alkali in presence of toluene (compare Martin, *ibid.*, 1936, 58, 1438.)

Osmium tetroxide in benzene-pyridine reacted by addition with 1 : 2 : 7 : 8-dibenzanthracene (compare Criegee, Marchand, and Wannowius; *Annalen*, 1942, 550, 99) to give a coloured complex which was then hydrolysed to a diol; this, from the work of Cook and Schoental (*J.*, 1948, 170), should have the structure (VII). The diol was difficult to purify, but was characterised by the preparation of its *diacetate* and by conversion into 3-(or 4-)*methoxy*-1 : 2 : 7 : 8-dibenzanthracene. Oxidation of the diol (VII) with sodium dichromate in acetic acid gave 1 : 2 : 7 : 8-dibenz-3 : 4-anthraquinone (VIII) as the main product, together with 1 : 2 : 7 : 8-dibenz-3 : 4 : 5 : 6-anthradiquinone (XI). (VIII) reacted with *o*-phenylenediamine to give a *phenazine* derivative, and the presence of two *ortho*-quinonoid groups in (XI) was shown by its reaction with two molecules of *o*-phenylenediamine. The monoquinone was obtained free from diquinone when the diol (VII) was oxidised by means of ethyl azodicarboxylate (Diels and Fritzsche, *Ber.*, 1911, 44, 3022).

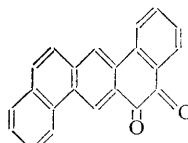
1 : 2 : 7 : 8-Dibenz-3 : 4-anthraquinone (VIII) was smoothly converted into *naphtho*-(2' : 1'-2 : 3)*fluorenone* (IX) by being heated with lead monoxide, and the formation of a coloured ketone in this way confirms the structures assigned to the diol (VII) and its oxidation products. The ketone was finally reduced to *naphtho*(2' : 1'-2 : 3)*fluorene* (X) by heating it in a sealed tube with hydrazine hydrate. The degradation of (VIII) to (IX) probably involves a benzylic acid transformation, in which case the structure of the product is not in doubt. If, however, the acid (XII) were formed as an intermediate, then its cyclisation to a fluorenone could take place not only at position 2 of the phenanthrene system, but also at position 4, and the latter position might be preferentially attacked. This would lead to a ketone of the structure (III). Nevertheless, it seems certain that the transformation of (VIII) into (IX) has been correctly interpreted, for parallel degradations have been carried out in which all of the possible products are known compounds of established structure. Thus, 1 : 2-benz-3 : 4-anthraquinone (XIII), on being heated with lead monoxide, gave exclusively 2 : 3-benzfluorenone (XIV) and not the isomeric 1 : 2-benzfluorenone, and in experiments which will be reported later we have found that 1 : 2 : 5 : 6-dibenz-3 : 4-anthraquinone (XV) is converted into *naphtho*(1' : 2'-2 : 3)*fluorenone* (XVI) (Cook *et al.*, *J.*, 1935, 1319) and not the alternative *naphtho*(2' : 1'-1 : 2)*fluorenone* (Cook *et al.*, *J.*, 1934, 1727).



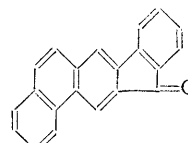
(XIII.)



(XIV.)



(XV.)

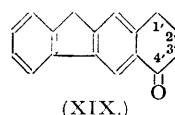
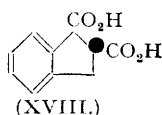
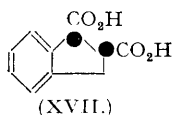


(XVI.)

One of the methods considered by Cook and Preston (*loc. cit.*) for the synthesis of *naphtho*-(2' : 1'-2 : 3)*fluorene* (X) involved the use of indane-1 : 2-dicarboxylic anhydride, and, although this anhydride was prepared, the work was interrupted before the subsequent stages of the synthesis could be examined. We have now attempted the condensation of this anhydride with β -*naphthylmagnesium* bromide, and also with tetralin by aluminium chloride in nitrobenzene. In view of the small amounts of acidic products obtained in these reactions the method was abandoned. In the course of this work, however, we have made some observations which correct and extend those of Cook and Preston relating to indane-1 : 2-dicarboxylic anhydride. This anhydride was obtained, with some difficulty, by the action of boiling acetyl chloride on the known dicarboxylic acid, m. p. 228°, and, as the anhydride must have the *cis*-configuration and was found to be hydrolysed by alcoholic potassium hydroxide to the acid from which it was prepared, this acid was assumed also to have the *cis*-configuration. This conclusion has now been shown to be erroneous, for a change of configuration takes place under the influence of alkali, and the acid, m. p. 228°, is the *trans*-acid (XVIII). The *cis*-acid (XVII), m. p. 197—198°, was obtained by hydrolysing the anhydride with water. This *cis*-acid was reconverted into the anhydride in good yield by boiling acetyl chloride, or even by distilling its solution in tetrachloroethane. The *cis*-acid was also formed by catalytic hydrogenation of indene-2 : 3-dicarboxylic acid over palladium. These stereoisomeric dicarboxylic acids were characterised by conversion into their *methyl* esters.

In another approach to the synthesis of (X) the action of 1-diethylaminobutan-3-one

methiodide on the keto-tetrahydro-2 : 3-benzfluorene (XIX) was examined (compare du Feu, McQuillin, and Robinson, J., 1937, 53; Cornforth and Robinson, J., 1946, 676; Wilds and



Shunk, J. *Amer. Chem. Soc.*, 1943, **65**, 469). This led to no useful result. The ketone (XIX) underwent the Reformatsky reaction with ethyl bromoacetate to give the expected unsaturated acid, but no crystalline product could be isolated when a similar condensation was carried out with methyl γ -bromocrotonate.

EXPERIMENTAL.

(All m. p.s are uncorrected. Light petroleum refers to the material, b. p. 40–60°, and ligroin to that boiling at 80–100°.)

Fluorene-2-acetic Acid.—(a) Dry hydrogen chloride was passed into a suspension of paraformaldehyde (6 g.; 0.2 mol.) in glacial acetic acid (200 c.c.) until a clear solution was formed. Fluorene (13.3 g.; 0.08 mol.) and powdered anhydrous zinc chloride (0.5 g.) were then added and the passage of hydrogen chloride was continued for $\frac{1}{2}$ hour. The flask was stoppered and kept at room temperature for 5 days. After dilution with ice-water the precipitate was collected and washed with water, then with dilute sodium carbonate solution, and finally with water. The product was largely a mixture of 2-chloromethylfluorene, which could not be isolated in a pure state, with unchanged fluorene. If the reaction was allowed to proceed until all the fluorene was used, the chloromethyl compound was mostly polymerised. The mixture was drained from moisture as far as possible and treated immediately with excess of concentrated aqueous potassium cyanide and sufficient acetone to effect solution. This solution was boiled for 3 hours, the acetone was removed, and the residual oil was diluted with water, whereupon it solidified. In order to hydrolyse the cyanide this solid was refluxed with a mixture of acetic acid and concentrated hydrochloric acid (3 : 1). After the mixture had been diluted with water, the crude product was collected and digested with dilute sodium carbonate solution and the filtered solution was clarified with charcoal and acidified. The precipitated fluorene-2-acetic acid (1.9 g.) had m. p. 178–180°. Sublimation, at 0.4 mm., of the neutral material insoluble in sodium carbonate gave 7.8 g. of unchanged fluorene. The residue from this sublimation was heated at 225–240°/0.015 mm., and gave a crystalline sublimate of 2 : 2'-difluorenylmethane, m. p. 201–202° (after recrystallisation from acetic acid and then light petroleum) (Found : C, 94.1; H, 5.8. Calc. for $C_{27}H_{20}$: C, 94.2; H, 5.8%). Dzewiński and Panek (*Bull. Acad. Polonoise, A*, 1927, 745), who obtained this hydrocarbon by the action of phosphoric oxide on a solution of fluorene and methylal in chloroform, give m. p. 201–202°.

(b) Much better results were obtained by the Willgerodt reaction with 2-acetylfluorene (Bachmann and Sheehan, *J. Amer. Chem. Soc.*, 1940, **62**, 2687), taking advantage of the finding of De Tar and Carmack (*ibid.*, 1946, **68**, 2028) that a reproducible ammonium sulphide reagent can be prepared by suspending in concentrated ammonia solution one-tenth of its weight of sulphur and passing in hydrogen sulphide until this just dissolves. A mixture of 2-acetylfluorene (3 g.), ammonium sulphide reagent (12.5 c.c.), and dioxan (peroxide-free; 15 c.c.) was heated for 8 hours at 160–170° in a small stainless-steel autoclave. The contents of the autoclave were washed out with ethanol and the solution evaporated on the steam-bath. A solution of the residual crude amide in acetic acid (40 c.c.) and concentrated hydrochloric acid (12 c.c.) was boiled for 7 hours and then poured into water. The precipitate was dissolved in hot dilute sodium carbonate solution, filter aid was added, and the filtered solution was acidified. The precipitated fluorene-2-acetic acid was recrystallised from 50% ethanol (charcoal), m. p. 175–177° (1.8 to 2.0 g.). When the acid was further purified by sublimation at 0.003 mm. and then crystallised from benzene, it had m. p. 183°. Bachmann and Sheehan (*loc. cit.*) give m. p. 186–187°, whereas von Braun and Engel (*Ber.*, 1924, **57**, 194) give m. p. 178° for a recrystallised acid prepared by hydrolysis of the cyanide.

o-Nitro- α -2-fluorenylcinnamic Acid (I; X = NO₂).—In the Perkin condensation of fluorene-2-acetic acid with *o*-nitrobenzaldehyde the triethylamine salt was found to give better yields than did the sodium salt (compare Kalnin, *Helv. Chim. Acta*, 1928, **11**, 977; Bakunin and Peccerillo, *Gazzetta*, 1935, **65**, 1145). A mixture of fluorene-2-acetic acid (5.6 g.; dried at 110°), *o*-nitrobenzaldehyde (4 g.), triethylamine (2.52 g. = 3.45 c.c.; dried over potassium hydroxide), and "Analar" acetic anhydride (30 c.c.) was heated for 11 hours in an oil-bath at 85–95°. The pale-brown solution was poured, while still warm, into vigorously stirred cold water (250 c.c.), and the whole kept for 12 hours and then heated on the water-bath until the viscous precipitate was completely solid (1–2 hours). This was collected, washed, and, without drying, dissolved in hot benzene (*ca.* 230 c.c.). The solution was cooled, filtered to remove a little *o*-nitrocinnamic acid, and then exhaustively extracted with dilute sodium carbonate solution. The alkaline extract was warmed with charcoal and filtered, and the crude acid was precipitated with hydrochloric acid (yield, 8.75 g.). After recrystallisation from 50% acetic acid, then 50% ethanol, and finally benzene-ligroin, *o-nitro- α -2-fluorenylcinnamic acid* formed bright yellow needles, m. p. 215–216° (decomp.) (Found : C, 74.2; H, 4.3; N, 3.9. $C_{22}H_{15}O_4N$ requires C, 73.9; H, 4.2; N, 3.9%).

o-Chloro- α -2-fluorenylcinnamic Acid (I; X = Cl).—A mixture of sodium fluorene-2-acetate (1.35 g.), *o*-chlorobenzaldehyde (0.77 g.), and acetic anhydride (7.5 c.c.) was heated for 8 hours in an oil-bath at 130–140°. After decomposition with water as in the previous example, the product was washed with hot water. The washings, on cooling, deposited crystals of *o*-chlorocinnamic acid. The insoluble residue was purified by dissolution in sodium carbonate solution and reprecipitation, followed by

recrystallisation from aqueous acetone and then benzene. The *acid* (I; X = Cl) formed colourless needles, m. p. 229—231° (Found : C, 76.1; H, 4.4; Cl, 10.3. $C_{22}H_{15}O_2Cl$ requires C, 76.2; H, 4.4; Cl, 10.2%). From the material insoluble in sodium carbonate there was isolated a neutral compound which formed pale yellow crystals (from ligroin), m. p. 138—139° (Found : C, 83.4; H, 4.8; Cl, 11.2. $C_{21}H_{15}Cl$ requires C, 83.3; H, 5.0; Cl, 11.7%); this was evidently *trans-2-o-chlorostyrylfluorene*.

o-Amino- α -2-fluorenylcinnamic Acid (I; X = NH_2).—A solution of the finely powdered crude nitro-acid (I; X = NO_2) (2.7 g.) in water (100 c.c.) and concentrated ammonia (140 c.c.) was added to a solution of ferrous sulphate (22 g.) in warm water (50 c.c.). The suspension so formed was heated on the water-bath for 2 hours. After dilution with hot water, the whole was boiled and filtered. The precipitate was extracted with hot 1% ammonia solution until the washings were free from amino-acid. The combined filtrate and washings were acidified with acetic acid, and the precipitated *amino-acid* was collected (1.9 g.; m. p. 217.5—219.5°), purified by redissolution in sodium carbonate solution, heating with charcoal on the water-bath, reprecipitation with acetic acid and then recrystallisation from ethanol and finally benzene. It formed yellow needles, m. p. 217.5—219.5° (Found : C, 80.9; H, 5.05; N, 4.1. $C_{22}H_{17}O_2N$ requires C, 80.7; H, 5.25; N, 4.3%). This acid formed sparingly soluble sodium and ammonium salts.

Naphtho(1' : 2')fluorene-3'-carboxylic Acid (II; X = CO_2H).—Diazotisation of the foregoing amino-acid in aqueous solution was always incomplete, and, as both the diazonium salt and the salts of the amino-acid were sparingly soluble in water, it was not feasible to separate them. For complete diazotisation with amyl nitrite it was found advisable to use hydrochloric rather than sulphuric acid and to work at room temperature. A solution of the amino-acid (I; X = NH_2) (1.58 g.) in warm ethanol (250 c.c.) was cooled to 10—15°. Concentrated hydrochloric acid (32 c.c.) was rapidly added, and then, after shaking, redistilled amyl nitrite (3.5 c.c.) was added immediately in one portion. If the temperature rose above 20°, it was brought to this level by cooling and kept there for 1½ hours. Separation of the yellow diazonium chloride began after a few minutes. For decomposition of the diazonium salt, freshly prepared copper powder (Gattermann, *Ber.*, 1890, **23**, 1219) was added and the mixture was shaken at room temperature until a colour was no longer developed with alkaline β -naphthol. The reaction mixture was diluted with cold water to 1200 c.c., and the precipitate was collected and extracted with dilute sodium carbonate solution, and the acid reprecipitated from the filtered solution. After recrystallisation from acetic acid it had m. p. 250—251° (0.9 g.). For analysis, it was recrystallised twice from acetic acid and then from benzene containing 10% of ethanol (Found : C, 85.0; H, 4.4. $C_{22}H_{14}O_2$ requires C, 85.2; H, 4.55%). *Naphtho(1' : 2'-1 : 2)fluorene-3'-carboxylic acid* formed small cream-coloured needles, m. p. 251—252.5° (decomp.). It was sparingly soluble in benzene and moderately soluble in acetic acid. In the purification of this acid a less soluble acid, m. p. 269—271° was isolated in amount insufficient for investigation (Found : C, 71.4; H, 4.8%).

Naphtho(1' : 2'-1 : 2)fluorene (II; X = H).—Decarboxylation of the acid (II; X = CO_2H) proved troublesome. A pure compound could not be isolated after heating it with copper powder in quinoline; heating it with copper powder without a solvent gave the hydrocarbon, but it was found best to work with batches of acid not exceeding 0.2 g. An intimate mixture of the acid with 2 parts of dry copper powder was heated at 260—280° for a few minutes in a metal-bath. The mass was then sublimed at 300—320° (0.2—0.4 mm.), and the sublimate (yield, ca. 20%) was digested with hot 1% sodium hydroxide solution to remove unchanged acid. The residue was dissolved in light petroleum and the solution passed through a column of alumina. Red by-products were strongly adsorbed. The hydrocarbon, which slowly passed down the column, was eluted with light petroleum. Evaporation of the eluate gave *naphtho(1' : 2'-1 : 2)fluorene* (II; X = H), which crystallised from light petroleum as colourless plates, m. p. 158.5—159.5° (Found : C, 94.7; H, 5.2. $C_{21}H_{14}$ requires C, 94.7; H, 5.3%). Crystallisation from alcohol gave needles of somewhat lower m. p. Neither a picrate nor a *s*-trinitrobenzene complex could be obtained.

Oxidation of Naphtho(1' : 2'-1 : 2)fluorene.—A solution of the hydrocarbon (1 part) and sodium dichromate (2 parts) in acetic acid was boiled for 15 minutes and poured into water. The yellow precipitate was dissolved in benzene and the solution was washed with aqueous sodium carbonate, dried (Na_2SO_4), and passed through a column of alumina. The less strongly adsorbed material from a benzene eluate was *naphtho(1' : 2'-1 : 2)fluorenone* (III) which formed orange needles (from ethanol), m. p. 152—153° (Found : C, 90.0; H, 4.4. $C_{21}H_{12}O$ requires C, 90.0; H, 4.3%). A more strongly adsorbed red band was eluted with chloroform; evaporation of this solution gave *indeno(3' : 2'-3 : 4)-phenanthra-9 : 10-quinone* (IV), which formed yellow plates (from benzene), m. p. 243—244° (Found : C, 84.4; H, 4.0. $C_{21}H_{12}O_2$ requires C, 85.1; H, 4.1%). Analysis suggested slight contamination with a compound of higher oxygen content, but there was insufficient material for further purification.

1 : 1'-Dinaphthylmethane-2-carboxylic Acid (V).—A mixture of 2-carboxy-1 : 1'-dinaphthyl ketone (Cook, *J.*, 1932, 1476) (3.26 g.), 90% hydrazine hydrate solution (2.2 c.c.), potassium hydroxide (1.9 g.), and diethylene glycol (bis-2-hydroxyethyl ether) (25 c.c.) was boiled under reflux for 1½ hours. The condenser was then removed and the temperature of the mixture (thermometer in liquid) was allowed to rise to 190—195°. The condenser was then replaced and boiling continued for 6 hours. The solution was poured into water (500 c.c.), whereupon the very sparingly soluble sodium salt (0.6 g.) of the *azine* of the keto-acid was precipitated; this was collected and converted into the free acid which crystallised from acetic acid as cream coloured plates, m. p. 301—303° (Found : C, 81.6; H, 4.5; N, 4.4. $C_{44}H_{28}O_4N_2$ requires C, 81.5; H, 4.3; N, 4.3%). The alkaline filtrate from which the sodium salt had been separated was acidified and extracted with benzene. The benzene extract was freed from resinous impurities by passage through a column of silica, and the solvent was removed. The residue was washed with light petroleum; the acid (1.83 g.) was then almost pure. After several recrystallisations from benzene, 1 : 1'-*dinaphthylmethane-2-carboxylic acid* (V) formed colourless crystals, m. p. 207—208° (Found : C, 84.9; H, 5.3. $C_{22}H_{16}O_2$ requires C, 84.6; H, 5.2%). The substance partly fused at 150—170°, but resolidified at a higher temperature.

10-Acetoxy-1 : 2 : 7 : 8-dibenzanthracene.—For cyclisation of the acid (V) with zinc chloride in acetic anhydride and acetic acid the procedure of Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1937, **59**, 1032;

1938, 60, 1895) was used. The acetate (VI; X = OAc), obtained in 85% yield, crystallised from benzene containing 15% of ethanol in colourless needles, m. p. 255—256°, in agreement with Cook (*loc. cit.*).

1 : 2 : 7 : 8-Dibenzanthracene (VI; X = H).—The powdered acetate (VI; X = OAc) (3.6 g.), suspended in pure dry benzene (60 c.c.), was added to a Grignard solution from magnesium turnings (2.06 g.), *n*-butyl bromide (10.25 c.c.), and absolute ether (50 c.c.). The mixture was boiled for an hour, during which the ether was allowed to distil. Toluene (170 c.c.) was added while the mixture was still warm, and the magnesium complexes were decomposed by addition of dilute hydrochloric acid. The benzene-toluene layer was washed twice with warm water and then immediately treated with zinc dust (8 g.) and 2*N*-sodium hydroxide (200 c.c.). The whole was boiled under reflux for 8 hours. The mixture was acidified with hydrochloric acid, the benzene-toluene layer was separated, and the aqueous solution and excess of zinc were extracted with benzene. The combined solutions were washed with water and the solvents removed under diminished pressure. The residue was recrystallised from acetic acid, and gave 1 : 2 : 7 : 8-dibenzanthracene (2.17 g.), m. p. 190—191°. After purification by passage through a column of alumina and crystallisation from methanol-benzene; it melted at 197—198° (*lit.*, 196°).

3 : 4-Dihydroxy-3 : 4-dihydro-1 : 2 : 7 : 8-dibenzanthracene (VII).—A solution of 1 : 2 : 7 : 8-dibenzanthracene (1.64 g.) and osmium tetroxide (1.53 g.) in pure dry benzene (62 c.c.) and pyridine (1.44 c.c.) was kept at room temperature until separation of the coloured osmium complex was complete (12 days). The precipitate was collected, washed with benzene, and shaken with methylene chloride (60 c.c.) and 1% potassium hydroxide solution (150 c.c.) containing 10% of mannitol. When hydrolysis of the complex was complete, the diol which had separated (1.41 g.) was filtered from the emulsified mixture, washed with water, and dried. A further quantity (0.1 g.) was recovered from the filtrate. The diol (VII), a colourless solid, m. p. 226—228° (decomp.), crystallised with difficulty and was acetylated with pyridine-acetic anhydride (2 days at room temperature and then 20 minutes at 100°). After chromatographic purification on silica of a benzene solution, 3 : 4-diacetoxy-3 : 4-dihydro-1 : 2 : 7 : 8-dibenzanthracene was obtained as fine colourless needles [from benzene-ethanol; (1 : 1)], m. p. 225—226.5° (Found: C, 78.7; H, 5.05. C₂₆H₂₀O₄ requires C, 78.8; H, 5.1%).

The diol was dehydrated by brief boiling of its solution in acetic acid containing a few drops of concentrated hydrochloric acid. The crude phenolic product was methylated with methyl sulphate and sodium hydroxide solution to give 3-(or 4-)methoxy-1 : 2 : 7 : 8-dibenzanthracene which, after passage through a column of alumina of its solution in light petroleum, formed colourless crystals (from ligroin), m. p. 182.5—183.5° (Found: C, 89.4; H, 5.4. C₂₂H₁₆O requires C, 89.2; H, 5.4%).

1 : 2 : 7 : 8-Dibenz-3 : 4-anthraquinone (VIII).—(a) A mixture of the diol (VII) (0.52 g.) and sodium dichromate (0.5 g.) in water (2 c.c.) and acetic acid (75 c.c.) was boiled for 10 minutes. As the diol dissolved, the red quinone was precipitated. The suspension was diluted with warm water and the precipitate collected and washed with water. By crystallisation from tetrachloroethane this (0.44 g.) was separated into a small amount of the diquinone (see below) and a larger amount of the more soluble monoquinone, m. p. 310°. In order to obtain the latter in a state of analytical purity the crude product was cautiously sublimed at 0.3 mm. Pure 1 : 2 : 7 : 8-dibenz-3 : 4-anthraquinone (VIII) sublimed first as bright red needles, m. p. 310° (decomp.) (Found: C, 85.8; H, 3.9. C₂₂H₁₂O₂ requires C, 85.7; H, 3.9%). By heating with *o*-phenylenediamine in acetic acid this yielded the corresponding phenazine derivative as small yellow needles (from tetrachloroethane), m. p. 327—329° (decomp.) (Found: C, 83.8; H, 3.9; N, 7.1. C₂₄H₁₆N₂ requires C, 88.4; H, 4.2; N, 7.4%). The analytical discrepancy was accounted for by retention of tetrachloroethane (Found: Cl, 5.6%), even after drying at 140°/10 mm. There was insufficient material for further purification.

The crude diquinone which had been separated during the purification of the oxidised diol was re-treated with sodium dichromate in boiling acetic acid to complete oxidation of the adherent monoquinone. The resulting material was extracted with hot tetrachloroethane, and the insoluble residue was crystallised from diethylene glycol. 1 : 2 : 7 : 8-Dibenz-3 : 4 : 5 : 6-anthradiquinone (XI) formed small orange needles, m. p. above 340° (decomp.) (Found: C, 78.1; H, 3.2. C₂₂H₁₀O₄ requires C, 78.1; H, 3.0%). The corresponding *bis*-phenazine derivative, prepared by treatment with *o*-phenylenediamine in boiling acetic acid, crystallised from *o*-dichlorobenzene in very small yellow crystals, m. p. above 360° (Found: C, 84.7; H, 3.7. C₃₄H₁₈N₄ requires C, 84.6; H, 3.8%).

(b) A mixture of the diol (VII) (0.16 g.) and ethyl azodicarboxylate (3 g.) was heated in an oil-bath for 11 hours, first at 100—110° and then at 105—115°. The cooled mixture was diluted with ethanol and the suspended product (75 mg.) was collected and washed with ethanol. The 1 : 2 : 7 : 8-dibenz-3 : 4-anthraquinone so obtained had m. p. 300° (decomp.), raised to 310° by recrystallisation from tetrachloroethane.

Naphtho(2' : 1'-2 : 3)fluorenone (IX).—An intimate mixture of the purified quinone (VIII) (0.28 g.) and lead monoxide (2 g.) was divided into 3 portions. Each portion was separately introduced into an apparatus fitted for vacuum sublimation and heated in a metal-bath at 260—270° under atmospheric pressure. After 2 minutes the brisk reaction had subsided, and the pressure was reduced to 0.3 mm. The resulting orange sublimate (110 mg. in all) had m. p. 250.5—251.5°. Recrystallisation from benzene-ethanol (1 : 2) gave small orange needles, m. p. 252—253°, of *naphtho*(2' : 1'-2 : 3)fluorenone (Found: C, 90.0; H, 4.2. C₂₁H₁₂O requires C, 90.0; H, 4.3%).

Naphtho(2' : 1'-2 : 3)fluorene (X).—The ketone (IX) (75 mg.) and 50% hydrazine hydrate solution (0.2 c.c.) were heated in a sealed tube at 200—210° for 7½ hours. The product was purified by passing its solution in light petroleum through a column of alumina and the material recovered by evaporation was recrystallised from ethanol. *Naphtho*(2' : 1'-2 : 3)fluorene formed colourless, almost cubic crystals, m. p. 171.5—173° (Found: C, 94.8; H, 5.35. C₂₁H₁₄ requires C, 94.7; H, 5.3%). Another preparation crystallised in plates, m. p. 178.5—179.5°.

Degradation of 1 : 2-Benz-3 : 4-anthraquinone to 2 : 3-Benzfluorenone.—1 : 2-Benz-3 : 4-anthraquinone (XIII), prepared as described by Cook and Schoental (*loc. cit.*), was treated with lead monoxide under the conditions used for the quinone (VIII). The resulting yellow ketone (XIV) had m. p. 150.5—152.5° after recrystallisation from ethanol, and gave an oxime, m. p. 230—231°. 2 : 3-Benzfluorenone has

m. p. 152° and its oxime has m. p. 231°, whereas the alternative 1 : 2-benzfluorenone has m. p. 132·5° and its oxime has m. p. 202° (decomp.).

cis-Indane-1 : 2-dicarboxylic Acid (XVII).—(a) The *cis*-anhydride (Cook and Preston, *loc. cit.*) (0·5 g.) was boiled with water. The molten anhydride dissolved in the course of a few minutes. The cooled solution was kept for a few days during which *cis-indane-1 : 2-dicarboxylic acid* crystallised as colourless leaflets, m. p. 197—198° with evolution of gas (Found : C, 64·15; H, 4·8. $C_{11}H_{10}O_4$ requires C, 64·0; H, 4·9%). The *methyl ester*, obtained by treatment with ethereal diazomethane, was distilled at 0·1 mm. from a bath at 100°. The viscous distillate slowly crystallised and had m. p. 71—72°, depressed to 55—60° by admixture with the isomer described below (Found : C, 66·35; H, 6·0. $C_{13}H_{14}O_4$ requires C, 66·6; H, 6·0%). Recrystallisation from hexane gave thick colourless rhombs, m. p. 72—73°. The monoethyl ester described by Cook and Preston (*loc. cit.*) is clearly also a derivative of the *cis*-acid.

(b) *Indene-2 : 3-dicarboxylic acid* (Bougault, *Compt. rend.*, 1914, **159**, 745) (5·1 g.) was hydrogenated in ethanolic suspension (400 c.c.) with palladised charcoal or palladium-black until absorption of hydrogen ceased. The filtered solution was evaporated and the viscous residue rubbed with a little ethyl acetate. The residual solid (2·5 g.) was recrystallised from water and had m. p. 190—192° (decomp.). This was identical with the *cis*-acid, obtained as described under (a). A further 1·2 g. of less pure material was obtained by acid hydrolysis of the oil obtained by evaporation of the ethyl acetate washings.

(c) Ethyl *indene-2 : 3-dicarboxylate* (2·6 g.) was hydrogenated as described by Cook and Preston (*loc. cit.*). The liquid product was dissolved in a mixture of acetic acid (3 parts) and concentrated hydrochloric acid (1 part), and the solution was boiled for 4 hours, after which no turbidity resulted from dilution with water. Crystalline material had separated, and the amount was augmented by diluting with water. It (1·9 g.) had m. p. 187—189° (decomp.) and was essentially *cis-indane-1 : 2-dicarboxylic acid*.

trans-Indane-1 : 2-dicarboxylic acid (XVIII).—The known dicarboxylic acid, m. p. 228°, was formed when the *cis*-anhydride (0·5 g.) was heated on the water-bath for an hour with aqueous potassium hydroxide (2 g. in 10 c.c.). After acidification with hydrochloric acid, the higher-melting acid separated. This is clearly the *trans*-acid, and its m. p. was depressed to 186—188° by admixture with the pure *cis*-acid. Esterification with ethereal diazomethane or with boiling methanolic hydrogen chloride gave *methyl trans-indane-1 : 2-dicarboxylate*, which formed colourless needles (from methanol), m. p. 73—74° (Found : C, 66·8; H, 6·0. $C_{13}H_{14}O_4$ requires C, 66·6; H, 6·0%).

Condensation of 4'-Keto-1' : 2' : 3' : 4'-tetrahydro-2 : 3-benzfluorene (XIX) with *Ethyl Bromoacetate*.—A mixture of the tetracyclic ketone (XIX; Koelsch, *J. Amer. Chem. Soc.*, 1933, **55**, 3885; Lothrop and Coffman, *ibid.*, 1941, **63**, 2566) (4·7 g.), arsenic-free granulated zinc (2·6 g.) [activated as described by Fieser and Johnson (*ibid.*, 1940, **62**, 575)] ethyl bromoacetate (4·5 c.c.), and dry thiophen-free benzene (120 c.c.) was heated under reflux on the water-bath for 4 hours. After cooling, methanol (75 c.c.) was added, together with more benzene (75 c.c.). When the zinc complex had dissolved the solution was shaken with dilute hydrochloric acid, and the benzene solution was washed, dried, and then heated with phosphoric oxide for 3 hours to ensure complete dehydration of the hydroxy-ester expected as a product. The solution was then decanted, washed with water, and dried, and the solvent removed. The residue was boiled for 5 hours with ethanolic potassium hydroxide (3 g. potassium hydroxide, 25 c.c. ethanol, 5 c.c. water) in an atmosphere of nitrogen. The crude acid (3 g.) was purified through its sparingly soluble potassium salt, and the regenerated acid was crystallised from benzene and then light petroleum. The resulting unsaturated *acid* (1·4 g.) formed colourless needles, m. p. 167—168° (decomp.) (Found : C, 82·9; H, 5·6. $C_{18}H_{16}O_2$ requires C, 82·6; H, 5·8%).

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