

### 38. Isomerisation Reactions. Part I.

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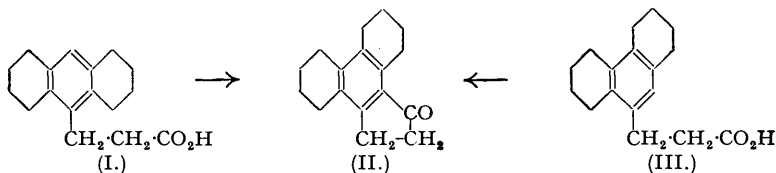
9-Chloromethyl-s-octahydroanthracene was converted by standard reactions into  $\beta$ -(9-s-octahydroanthranyl)propionic acid (I), which on treatment with anhydrous hydrogen fluoride underwent rearrangement and cyclisation to 1'-keto-9:10-cyclopenteno-s-octahydrophenanthrene (II). The same ketone was prepared also from  $\beta$ -(9-s-octahydrophenanthryl)propionic acid (III) by cyclisation with aluminium chloride, and its constitution was proved by its conversion into the known 9:10-cyclopentenophenanthrene, and by its oxidation to mellitic acid. The acid (III) was prepared by reduction of  $\beta$ -(9-phenanthryl)propionic acid with hydrogen and copper chromite. Chloromethylation of phenanthrene gave 1-chloromethylphenanthrene in addition to the known 9-chloromethyl derivative.

VERY many examples have been recorded of rearrangement of the carbon skeletons of organic compounds, particularly among hydrocarbons of all classes (aliphatic, alicyclic, aromatic). The conversion of straight-chain hydrocarbons into isomeric branched-chain compounds is now, in fact, an important process in petroleum technology. Numerous catalysts have been employed for isomerisation, as also has heat (for bibliography, see Egloff, Hulla, and Komarewsky, "Isomerisation of Pure Hydrocarbons", New York, 1942). Aluminium halides are outstandingly

efficacious, and may cause rearrangement under very mild conditions of temperature and pressure. An interesting example is the action of aluminium chloride on tetralin at or below 50—70°, which gives a mixture of hydrocarbons from which have been isolated, *inter alia*, *s*-octahydroanthracene, *s*-octahydrophenanthrene, and a non-crystalline fraction consisting essentially of 1-phenyl-4-tetralylbutane. This last-named compound is clearly an intermediate in the formation of the other two, which have been shown to be interconvertible under the influence of aluminium chloride (Schroeter, *Ber.*, 1924, 57, 1990; cf. Kennaway, *Biochem. J.*, 1930, 24, 497).

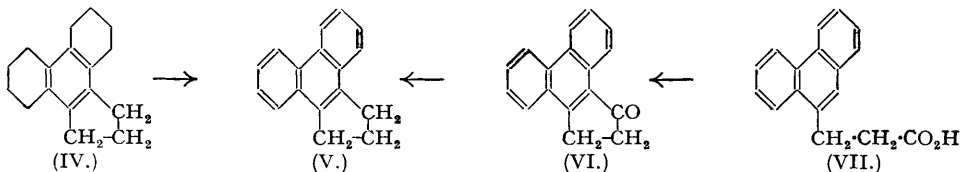
At first sight, the transformation of *s*-octahydroanthracene-9-sulphonic acid into *s*-octahydrophenanthrene-9-sulphonic acid by means of sulphuric acid (Schroeter and Götzky, *Ber.*, 1927, 60, 2035) seems closely allied to the interconversion of the related hydrocarbons by aluminium chloride, and may indeed be an analogous process. The sulphonic acid conversion is, however, a special case of the Jacobsen rearrangement of polyalkylbenzenes, which requires the presence of the sulphonic acid group in order that the reaction may occur. Thus, durenepulphonic acid rearranges into prehnitenepulphonic acid and other products in presence of phosphoric oxide, which does not affect durenene itself (Smith and Cass, *J. Amer. Chem. Soc.*, 1932, 54, 1614). Moreover, pentamethylbenzenepulphonic acid undergoes spontaneous rearrangement when it is kept in a desiccator over sulphuric acid (Smith and Lux, *ibid.*, 1929, 51, 2994; see also Moyle and Smith, *J. Org. Chem.*, 1937, 2, 112).

In the treatment of  $\beta$ -(9-*s*-octahydroanthranyl)propionic acid (I) with anhydrous hydrogen fluoride at room temperature we have found a reaction which has features both of the Jacobsen reaction and of aluminium chloride-catalysed rearrangements. Isomerisation and cyclisation took place, so that the product, 1'-*keto*-9:10-cyclopenteno-*s*-octahydrophenanthrene (II), was obtained in good yield.



Neither *s*-octahydroanthracene nor its 9-carboxylic acid underwent isomerisation under the same conditions. This suggests that cyclisation is an integral part of the rearrangement mechanism in the case of the propionic acid (I). Possibly there is an equilibrium between the octahydroanthracene structure (I) and the octahydrophenanthrene structure (III) which is disturbed by cyclisation of (III) with the result that conversion of (I) into (III) becomes greatly accelerated. This new type of rearrangement is being further examined and extended to other examples.

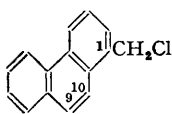
The ketone (II) was prepared also from  $\beta$ -(9-*s*-octahydrophenanthryl)propionic acid (III) by cyclisation with aluminium chloride. Its constitution was rigidly proved (*a*) by its oxidation with dilute nitric acid to mellitic acid, and (*b*) by its reduction by Clemmensen's method to 9:10-cyclopenteno-*s*-octahydrophenanthrene (IV), followed by dehydrogenation to the known 9:10-cyclopentenophenanthrene (V). This was compared with an authentic specimen prepared by cyclisation of  $\beta$ -(9-phenanthryl)propionic acid (VII) followed by reduction of the ketone (VI) (Weizmann, Bergmann, and Berlin, *J. Amer. Chem. Soc.*, 1938, 60, 1331; Bachmann and Kloetzel, *ibid.*, 1937, 59, 2207).



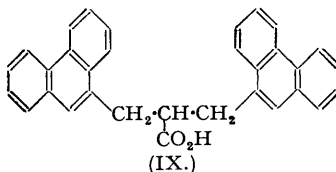
The desired propionic acids were prepared from the corresponding chloromethyl derivatives. For the chloromethylation of phenanthrene the method of Cook *et al.* (*J.*, 1935, 1323) and of Tarbell and Wystrach (*J. Amer. Chem. Soc.*, 1943, 65, 2149) was slightly modified. Satisfactory yields were never obtained, however, the bulk of the material invariably being converted into

an intractable resin. The main crystalline product was 9-chloromethylphenanthrene, but we also isolated a small amount of 1-chloromethylphenanthrene (VIII) characterised by reduction with hydrogen and palladium to 1-methylphenanthrene. This method for the reduction of chloromethyl derivatives gives very satisfactory results, the hydrocarbon being obtained almost quantitatively. Chemical methods of reduction, on the other hand, are often unsatisfactory owing to the formation of bimolecular derivatives (cf. Badger, Cook and Crosbie, *J.*, 1947, 1432). Von Braun (*Ber.*, 1937, 70, 979) mentioned the formation of the 1-chloromethyl derivative during the chloromethylation of phenanthrene, but gave no details or description.

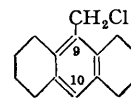
9-Chloromethylphenanthrene was condensed with ethyl malonate to give the desired malonic acid derivative previously prepared by Bachmann and Kloetzel (*loc. cit.*) from 9-bromomethylphenanthrene.  $\beta$ -(9-Phenanthryl)propionic acid (VII) was readily formed from the malonic acid by decarboxylation, and some bimolecular *product*, evidently (IX), was also isolated. Hydrogenation with hydrogen in dioxan, over copper chromite under pressure, gave the desired  $\beta$ -(9-*s*-octahydrophenanthryl)propionic acid (III). It is of some interest that in spite of numerous experiments under a variety of different conditions of temperature and pressure we were unable to prepare the lower hydrides. Under milder conditions only inseparable mixtures containing both the unchanged acid and its octahydrate were obtained.



(VIII.)



(IX.)



(X.)

For the preparation of  $\beta$ -(9-*s*-octahydroanthryl)propionic acid (I), advantage was taken of the fact that *s*-octahydroanthracene readily undergoes mono-chloromethylation, to give 9-chloromethyl-*s*-octahydroanthracene (X). In presence of excess of paraformaldehyde, 9 : 10-bis-chloromethyl-*s*-octahydroanthracene was also formed. The corresponding chloromethylation of anthracene yields only the bischloromethyl derivative (Badger and Cook, *J.*, 1939, 802). Both chloromethyl derivatives were catalytically reduced in good yield to the corresponding hydrocarbons, 9-methyl-*s*-octahydroanthracene and 9 : 10-dimethyl-*s*-octahydroanthracene; the constitution of the dimethyloctahydroanthracene was proved by its dehydrogenation to the known 9 : 10-dimethylanthracene.

Condensation of monochloromethyloctahydroanthracene, in benzene solution, with ethyl sodiomalonate gave the desired substituted malonic acid, which on decarboxylation gave  $\beta$ -(9-*s*-octahydroanthryl)propionic acid (I). In one condensation with ethyl sodiomalonate in alcoholic solution some bimolecular product, evidently *ethyl di*-(9-*s*-octahydroanthrylmethyl)-malonate, was isolated.

#### EXPERIMENTAL.

*Chloromethylation of Phenanthrene.*—A rapid stream of hydrogen chloride was introduced, with stirring, into a boiling suspension of powdered phenanthrene (300 g.) in concentrated hydrochloric acid (750 c.c.) and aqueous formaldehyde (40% ; 750 c.c.), for 12 hours. After cooling, the aqueous layer was decanted and the dark oil washed with water, and then twice with dilute sodium carbonate. The product was treated with ether, filtered from some insoluble material, and then thoroughly washed first with dilute sodium carbonate and then water. After 48 hours' drying ( $K_2CO_3$ ), the solvent was removed and the oil distilled. There was a forerun of unchanged phenanthrene (110 g.), b. p. 170—190°/4 mm., and the main fraction (155 g.) was collected as a yellow oil, b. p. 190—210°/4 mm. On standing, crystals were deposited which, after recrystallisation from benzene-light petroleum and from alcohol, formed colourless needles of 9-chloromethylphenanthrene (60 g.), m. p. 100° (lit. 101—101.5°). Its identity was confirmed by oxidation with sodium dichromate to 9-phenanthroic acid and phenanthraquinone, and comparison with authentic specimens. Hydrogenation of 9-chloromethylphenanthrene, in acetone, over palladium black proceeded smoothly to give 9-methylphenanthrene, m. p. 90—91° (lit. 90—91°), picrate, m. p. 153° (lit. 152—153°).

Evaporation of the benzene-light petroleum mother liquors gave a yellow oil, which was redistilled, the fraction, b. p. 210°/4 mm., being collected and dissolved in benzene-light petroleum. After 2 days, the crystals which had separated were collected, washed with ether, and recrystallised from alcohol. 1-Chloromethylphenanthrene (VIII) (5 g.) formed colourless lustrous plates, m. p. 89—90° (Found : C, 79.5 ; H, 4.8.  $C_{15}H_{11}Cl$  requires C, 79.4 ; H, 4.9%). Its *picrate* formed fine yellow needles, m. p. 110—111°, from alcohol (Found : C, 55.5 ; H, 3.0 ; N, 9.4.  $C_{15}H_{11}Cl.C_6H_3O_7.N_3$  requires C, 55.3 ; H, 3.1 ; N, 9.3%). Reduction of 1-chloromethylphenanthrene with hydrogen and palladium proceeded rapidly to give 1-methylphenanthrene, m. p. 121° [lit. 123° (corr.)] (Found : C, 93.6 ; H, 6.2. Calc. for  $C_{15}H_{12}$  : C, 93.8 ; H, 6.2%). The picrate formed orange-yellow needles from alcohol, m. p. 136° [(lit. 139° (corr.)] (Found : N, 10.2. Calc. for  $C_{15}H_{12}.C_6H_3O_7.N_3$  : N, 10.0%).

$\beta$ -(9-Phenanthryl)propionic Acid (VII).—9-Chloromethylphenanthrene (50 g.) was added to a solution prepared from sodium (5.4 g.), ethyl malonate (44 c.c.), and ethanol (180 c.c.); the mixture was refluxed for 2 hours. Potassium hydroxide (60 g.) in water (150 c.c.) was then added, and boiling continued for a further 3 hours. The acidic product was isolated in the usual way, dried, and decarboxylated at 190°. After extraction with dilute sodium carbonate and crystallisation from acetic acid, a small amount of sparingly soluble material was isolated. This product, evidently  $\omega\omega$ -di-(9-phenanthryl)isobutyric acid (IX) (6 g.), crystallised from xylene in glistening colourless plates, m. p. 224° [Found : C, 87.4; H, 5.4;  $M$  (Rast), 430.  $C_{32}H_{24}O_2$  requires C, 87.3; H, 5.5%;  $M$ , 440]. The methyl ester, prepared with diazomethane in acetone-ether, crystallised from methanol-ethyl acetate in fluffy colourless needles, m. p. 165—166° (Found : C, 87.3; H, 6.0.  $C_{33}H_{26}O_2$  requires C, 87.2; H, 5.7%). The main bulk of the acidic material, phenanthrylpropionic acid, was crystallised from benzene, and formed colourless needles (40 g.), m. p. 174° (lit. 173—174°). The methyl ester formed colourless needles, m. p. 71—72° (lit. 72—73°).

In one run in which crude chloromethylphenanthrene had been used, the propionic acid was found to be impure even after removal of the sparingly soluble diphenanthrylisobutyric acid. By fractional crystallisation a small quantity of  $\beta$ -(1-phenanthryl)propionic acid was obtained. It formed colourless crystals, m. p. 186—188° (Bachmann and Kloetzel, *loc. cit.*, give m. p. 189—189.5°) (Found : C, 81.6; H, 5.4. Calc. for  $C_{17}H_{14}O_2$  : C, 81.7; H, 5.6%). The methyl ester, prepared from the acid with diazomethane, was shown by mixed m. p. to be identical with an authentic specimen kindly supplied by Professor W. E. Bachmann.

$\beta$ -(9-s-Octahydrophenanthryl)propionic Acid (III).—The above 9-phenanthrylpropionic acid (6 g.) was reduced in dioxan by treatment for 5 hours with hydrogen at 180—190°/170 atmospheres, in the presence of copper chromite (4 g.).  $\beta$ -(9-s-Octahydrophenanthryl)propionic acid (5 g.) formed small colourless needles, m. p. 179°, from benzene (Found : C, 79.6; H, 8.4.  $C_{17}H_{22}O_2$  requires C, 79.2; H, 8.5%). The methyl ester, prepared in ether with diazomethane, formed fine colourless needles, m. p. 40—41°, from methanol (Found : C, 79.8; H, 8.8.  $C_{18}H_{24}O_2$  requires C, 79.5; H, 8.8%).

9-Chloromethyl-s-octahydroanthracene (X).—Hydrogen chloride was passed into a suspension of paraformaldehyde (3.9 g.) in glacial acetic acid (60 c.c.) until a clear solution was obtained. s-Octahydroanthracene\* (18.6 g.) was then added, and the passage of hydrogen chloride continued, at 60°. After some hours the voluminous crystalline product which had separated was collected, and the filtrate again treated with hydrogen chloride. After a total of 7 hours the product was collected and recrystallised from glacial acetic acid. 9-Chloromethyl-s-octahydroanthracene (12 g.) formed colourless needles, m. p. 91—92° (Found : C, 76.7; H, 7.8; Cl, 15.0.  $C_{15}H_{16}Cl$  requires C, 76.8; H, 8.1; Cl, 15.1%). Reduction with hydrogen and palladium, in ethanol, proceeded readily, to give 9-methyl-s-octahydroanthracene, which formed colourless plates from ethanol, m. p. 52° (Found : C, 90.3; H, 9.8.  $C_{15}H_{20}$  requires C, 90.0; H, 10.0%).

9 : 10-Bischloromethyl-s-octahydroanthracene.—To the filtrate from the experiment just described, paraformaldehyde (2.5 g.) was added, and passage of hydrogen chloride at 60° continued for several hours. The precipitate was collected, and recrystallised first from acetic acid and then from ethanol. 9 : 10-Bischloromethyl-s-octahydroanthracene formed colourless transparent scales, m. p. 214—215° (Found : C, 68.0; H, 7.3; Cl, 24.85.  $C_{18}H_{20}Cl_2$  requires C, 67.8; H, 7.1; Cl, 25.1%). Reduction with hydrogen and palladium, in ethanol, gave 9 : 10-dimethyl-s-octahydroanthracene, almost quantitatively. It formed colourless lustrous scales, m. p. 145—146° (Found : C, 89.6; H, 10.1.  $C_{16}H_{22}$  requires C, 89.7; H, 10.3%). Dehydrogenation with palladium black in an atmosphere of nitrogen, at 270—290° for 3 hours, gave a yellow strongly fluorescent substance which crystallised from light petroleum in yellow needles, m. p. 181—182°, not depressed by admixture with authentic 9 : 10-dimethylanthracene.

$\beta$ -(9-s-Octahydroanthranlyl)propionic Acid (I).—Ethyl malonate (3.2 g.) was treated with atomised sodium (0.46 g.) in dry benzene (15 c.c.), and the mixture refluxed for 3 hours. After cooling, monochloromethyloctahydroanthracene (4.6 g.) was added, and, after being left overnight, the mixture was refluxed for 7 hours. The liquid product was hydrolysed by being warmed for an hour with methanolic potassium hydroxide on the water-bath. The acid was purified by crystallisation of its sparingly soluble sodium salt; the regenerated malonic acid formed colourless micro-crystals, m. p. 184° (decomp.), from aqueous methanol (Found : C, 71.9; H, 7.2.  $C_{18}H_{22}O_4$  requires C, 71.5; H, 7.3%). This acid was decarboxylated by being heated at 180—200° for a few minutes.  $\beta$ -(9-s-Octahydroanthranlyl)-propionic acid crystallised from light petroleum in colourless needles, m. p. 167—168° (Found : C, 79.3; H, 8.5.  $C_{17}H_{22}O_2$  requires C, 79.1; H, 8.5%).

In another experiment, monochloromethyloctahydroanthracene (2.34 g.) was added to an ethanolic solution of ethyl sodiomalonate [from sodium (0.23 g.), ethyl malonate (1.6 g.), and ethanol (2.5 c.c.)], and the whole boiled for an hour. The product was warmed with methanolic potassium hydroxide, and extracted with benzene after dilution with water. The benzene, on evaporation, gave a neutral product (which had resisted hydrolysis) evidently ethyl di-(9-s-octahydroanthranlylmethyl)malonate. It formed colourless rods from benzene-light petroleum, m. p. 174°, after softening [Found : C, 80.1; H, 8.5;  $M$  (Rast), 507.  $C_{37}H_{48}O_4$  requires C, 79.8; H, 8.7%;  $M$ , 554].

1'-Keto-9 : 10-cyclopenteno-s-octahydrophenanthrene (II).—(a) The above octahydroanthranlylpropionic acid (0.5 g.) was treated with anhydrous hydrogen fluoride (*ca.* 20 c.c.), and the solution kept for 16 hours. The crude ketone was obtained in good yield by evaporation of the solution, followed by extraction of the residue with dilute sodium carbonate to remove unchanged acid. In another experiment, which was worked up after only 4 hours, some ketone was obtained, but much acidic material was recovered. 1'-Keto-9 : 10-cyclopenteno-s-octahydrophenanthrene was purified by chromatography on alumina, in benzene solution, and then sublimation at 137°/0.4 mm. It crystallised from light petroleum in colourless needles, m. p. 197—198° [Found : C, 84.8; H, 8.3;  $M$  (Rast), 230.  $C_{17}H_{20}O$  requires C, 85.0; H, 8.3%;  $M$ , 240]. The 2 : 4-dinitrophenylhydrazones formed orange needles, m. p. 298° (decomp.), from glacial acetic acid (Found : C, 65.75; H, 5.7; N, 13.4.  $C_{23}H_{24}O_4N_4$  requires C, 65.7; H, 5.7; N, 13.3%).

\* Kindly gifted by Dr. E. de Barry Barnett.

(b) Octahydrophenanthrylpropionic acid (1 g.) was treated with thionyl chloride (5 c.c.) and warmed to *ca.* 50–60° for an hour, by which time evolution of hydrogen chloride had ceased. The excess of thionyl chloride was then removed at 50° under reduced pressure. The solid product, dissolved in nitrobenzene (3 c.c.), was cooled in ice and added to an ice-cold solution of aluminium chloride (1 g.) in nitrobenzene (10 c.c.), and the mixture left overnight at room temperature. After hydrolysis with hydrochloric acid, and steam distillation to remove the nitrobenzene, the product was crystallised from ethanol. It formed colourless needles, m. p. 195° after slight sintering, not depressed by mixture with a specimen prepared as under (a).

*Oxidation with nitric acid.* The aforementioned ketone (160 mg.) was oxidised with dilute nitric acid in a sealed tube at 175–180° by the method used by Cook and Hewett (*J.*, 1934, 371) in another case. The acidic product was converted, *via* the silver salt, into the methyl ester, which formed colourless prisms, from methanol, m. p. 187–188° (Found: C, 50·6; H, 4·2. Calc. for  $C_{18}H_{16}O_{12}$ : C, 50·7; H, 4·2%). Its identity with the hexamethyl ester of mellitic acid (lit. m. p. 187–188°) was confirmed by mixed m. p. with the ester obtained by oxidation of 9:10-bischloromethyl-*s*-octahydroanthracene under the same conditions.

9:10-cycloPenteno-*s*-octahydrophenanthrene (IV).—The above ketone (0·8 g.) was added to a mixture of amalgamated zinc (8 g.), hydrochloric acid (40 c.c.), glacial acetic acid (10 c.c.), and toluene (10 c.c.). The mixture was refluxed for 24 hours, a further quantity (10 c.c.) of hydrochloric acid being added after 12 hours. The solid product (0·7 g.) was sublimed at 170°/14 mm., and recrystallised from ethanol. 9:10-cycloPenteno-*s*-octahydrophenanthrene formed long colourless needles, m. p. 156–158°, after sintering. Repeated crystallisation from various solvents, and passage through a column of alumina, did not result in a sharper definition of the m. p. (Found: C, 90·3; H, 9·6.  $C_{17}H_{22}$  requires C, 90·3; H, 9·7%).

Dehydrogenation of the above cyclopenteno-octahydrophenanthrene (0·1 g.) with palladium black (0·02 g.) at 290–300° for 30 minutes proceeded smoothly. After sublimation, and recrystallisation from ethanol, 9:10-cyclopentenophenanthrene (V) had m. p. 150° (lit. 149–150°; 154°); the picrate had m. p. 161° (lit. 161·5–162°). Both compounds were identified by comparison with authentic specimens prepared by cyclisation of  $\beta$ -(9-phenanthryl)propionic acid (VII) followed by reduction by the Clemmensen method, as described by Weizmann, Bergmann, and Berlin (*loc. cit.*).

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