CCCCXX.—*The Unsaponifiable Matter from the Oils of Elasmobranch Fish. Part II. The Hydrogenation of Squalene in the Presence of Nickel.*

By ISIDOR MORRIS HEILBRON, THOMAS PERCY HILDITCH, and EDWARD DAVID KAMM.

SQUALENE has already been hydrogenated by Tsujimoto (*Ind. Eng. Chem.*, 1916, **8**, 889) and by Chapman (J., 1917, **111**, 56; 1923, **123**, 769), the former using a platinum catalyst and a solution of squalene in ether under pressure, the latter a platinum catalyst and squalene alone at 190° and atmospheric pressure. Both authors appear to have obtained the same dodecahydrosqualene; the physical constants of their products are in good agreement with each other, and with those of the product now obtained by us using a nickel catalyst. We regard the obvious similarity of the completely hydrogenated hydrocarbons as conclusive evidence of the identity of squalene and spinacene (Heilbron, Kamm, and Owens, this vol., 1630).

The Physical Constants of Completely Hydrogenated Squalene.

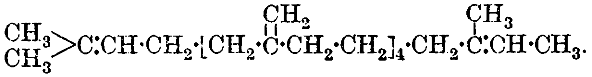
Constant.	Chapman.	Tsujimoto.	Present authors.
B. p.	280—281°/24 mm.	274°/10 mm.	224—226°/3 mm.
$n_{D}^{20°}$	1·4532	1·4525	1·4534
$d_{20°}^{20°}$	0·8119	0·8125 (at 15°/4°)	0·8107
$[R_L]_D$ ($M = 422$)	140·6	—	140·9

The hydrogenation of squalene does not, however, appear to have been studied from the point of view of selective attachment of hydrogen at the ethenoid linkings. Work in recent years has indicated that in the majority of cases where there is more than one double bond present in the molecule, the course of hydrogenation is definitely selective. An observation which is somewhat pertinent to the present case is that of Richardson, Knuth, and Milligan (*Ind. Eng. Chem.*, 1925, **17**, 80), who state that the highly unsaturated glycerides of the eicosanoic series present in whale oil are hydrogenated to the diethenoid derivatives before any fully saturated glyceride is produced.

The case of squalene is especially interesting, since it is an aliphatic hydrocarbon containing thirty carbon atoms and six ethenoid linkings. The method of hydrogenation which we have employed is to treat the oil with pure hydrogen at 130—160° in the presence of a nickel catalyst under the general conditions described by E. F. Armstrong and one of us (*Proc. Roy. Soc.*, 1919, *A*, **96**, 137; 1920, *A*, **98**, 27; 1925, *A*, **108**, 121), employing a similar type of apparatus and measuring the absorption of hydrogen continuously as therein described.

The results have proved that the hydrogenation is strongly selective and there is clear evidence that the saturation of each double bond takes place to a large extent consecutively. At the same time, a preliminary examination of the products which have been hydrogenated until only one ethenoid linking remains, indicates that a mixture of monoethylenic derivatives is left at this stage, and hence it is probable that the hydrogenation of squalene involves the simultaneous selective reduction of an original mixture of isomeric hexaolefinic hydrocarbons. This result tends to confirm the conclusions previously arrived at from a study of the squalene hexahydrochlorides (Part I).

As indicated by the curves, the selective nature of the hydrogenation process is very well marked. Whilst we have not at present sufficient knowledge of the constitution of the products definitely to correlate each intermediate compound which may be formed with a break in the curve, it seems evident that the cause of the selectivity must reside in the varying degree of substitution of the ethylene groups. Lebedev, Koblianski, and Yakubchik (J., 1925, **127**, 417) have shown the extraordinary influence exerted by differences in the degree of substitution around a double bond upon the rate of hydrogenation; and we venture to suggest, from the generalisations of these authors, that our curves indicate that certainly three, and probably four, of the unsaturated centres in squalene exist at the moment of hydrogenation in the form $CH_2{:}C<$, which is merely an isomeric form of the structure suggested in a previous paper, for example,



$$\mathrm{{}^{CH_3}_{CH_3}\!>C{:}CH\cdot CH_2\cdot[CH_2\cdot \overset{CH_2}{\overset{\|}{C}}\cdot CH_2\cdot CH_2]_4\cdot CH_2\cdot \overset{CH_3}{\overset{|}{C}}{:}CH\cdot CH_3.}$$

This idea of the dissimilarity of two of the unsaturated linkings from the remaining four is stressed, not only by the marked difference in the rate of hydrogenation, but also by the fact that ring closure in squalene itself only proceeds to the stage at which four double bonds have disappeared.

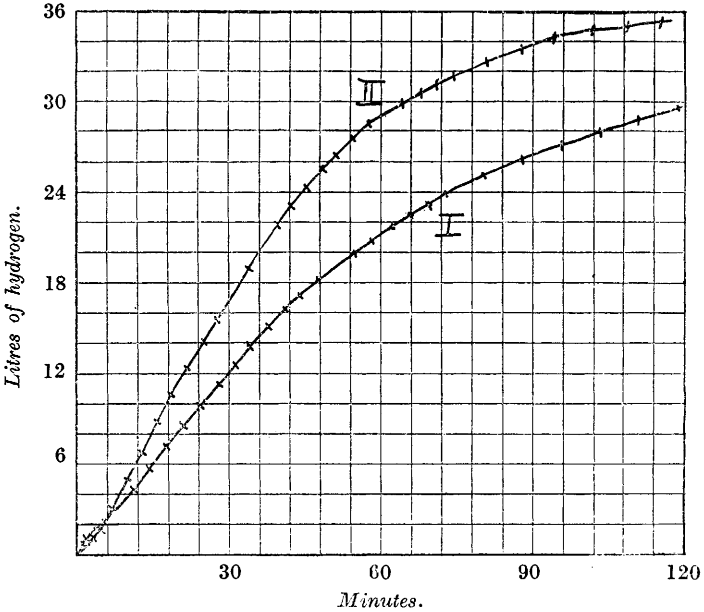
Experiments have been carried out in the direction of ring closure of the partly hydrogenated products, and it has been definitely ascertained that, unlike squalene, those products which have been hydrogenated up to the point at which 3, 4, and 5 gram-molecules of hydrogen have been absorbed are wholly incapable of intramolecular condensation when boiled with 98% formic acid. The partial condensation noted in the case of the lesser-hydrogenated product containing four double bonds, as evidenced by the change in iodine value, may be due, at least in part, to a small amount of unchanged squalene, the presence of which we have established (compare below).

We have on several occasions observed that, contrary to general experience in hydrogenations of this type, the rate of absorption is relatively slow for a short period at the commencement of the reaction, but rapidly attains a maximum value. Whilst this phenomenon has not invariably been noted, its appearance with the nickel catalyst supported both on charcoal and on kieselguhr has been sufficiently frequent to justify us in recording it as an apparent example of an induction period (see curve I). Apart from this, the absorption–time relation is of the type most commonly encountered in cases of well-marked selective hydrogenation, the variations in rate of absorption over the whole course of hydrogenation covering a wide range. Thus, on the average, taking the rate of hydrogenation of the last ethenoid linking as unity, the relative speeds for each double bond are represented approximately by the following figures :

Double bond	1	2	3	4	5	6
Rate	>10	<10	8	5·5	3	1

That the hydrogenation of squalene is indeed selective has been definitely established, since estimations of squalene by the hydrochloride method (see experimental part) have shown that after the absorption of 1 gram-molecule of hydrogen, 34% of squalene, and after the absorption of 2 gram-molecules only 1—2% of squalene, remain, and we have no doubt that if suitable methods of analysis could be devised, the same preponderance of one particular partly hydrogenated compound would be found at each intermediate stage.

FIG. 1.



I. 0·3 *G. of nickel on charcoal.* II. 0·3 *G. of nickel on kieselguhr.*

As previously stated (Part I), squalene contains in many cases a minute quantity of an oxygenated product. We have now found that after hydrogenation a very small quantity of a crystalline compound (0·2%) separated from the cooled oil and could be completely removed by fractional distillation, the hydrogenated squalene being then entirely free from oxygen. The oxygenated compound is a neutral substance, m. p. 67—68°, which appears to be oxidic in character, as it forms neither an acetyl derivative, a semicarbazone, nor an oxime.

EXPERIMENTAL.

Hydrogenation of Squalene.—The hydrogenation was effected in a narrow, closed, cylindrical steel vessel of about 400 c.c. total capacity fitted with an efficient high-speed rotary stirrer, a thermometer pocket, a hydrogen inlet-tube extending nearly to the bottom of the vessel, and a gas exit-tube almost flush with the lid. The rate of stirring was as nearly as possible 2000 revs./min., and hydrogen from a cylinder was passed at a suitable rate through a meter into the hydrogenation apparatus, from which it emerged into a second meter after passing through a catchpot to trap any traces of liquid that might be splashed over. The flow of hydrogen was adjusted so that at the maximum rate of absorption about 20—25% of unabsorbed hydrogen was passing through the second meter. The meters were of the water type and measured 2·5 litres per revolution; they were checked together before each experiment and were also frequently calibrated directly by displacement of about 10 litres of water by hydrogen from an aspirator kept strictly under atmospheric pressure.

The temperature of the squalene during the measurements of rate of hydrogenation was 150° ± 2°. The catalyst employed was metallic nickel, mounted on kieselguhr or coconut charcoal; various concentrations of catalyst were employed in different experiments and typical results are shown, in the accompanying graphs, of the hydrogenation of 100 g. of squalene at 150° in the presence of 0·3 g. of nickel on coconut charcoal and on a kieselguhr support, respectively, with hydrogen flowing at 50—60 litres per hour and with constant stirring as described above.

At the conclusion of the process, the oil was filtered from nickel while still hot, and distilled under reduced pressure.

Products of Hydrogenation.—*Dodecahydrosqualene.* The completely hydrogenated product was a colourless, odourless, mobile oil, b. p. 222—226°/3 mm., 212—213°/1 mm.; $n_{\mathrm{D}}^{20^\circ}$ 1·4534; $d_{20^\circ}^{20^\circ}$ 0·8107; $[R_L]_{\mathrm{D}}$ 140·9 (calc. for $C_{30}H_{62}$, 140·1) (Found: C, 85·5, 85·4; H, 14·8, 14·8. $C_{30}H_{62}$ requires C, 85·3; H, 14·7%).

Whereas squalene shows a remarkable exaltation of molecular refractivity ($\Sigma[R_L]_{\mathrm{D}} = 2{\cdot}1$) over the calculated value, this phenomenon completely disappears during hydrogenation.

In addition to the complete hydrogenation of squalene with simultaneous observation of the rate of absorption of hydrogen throughout the process, a number of experiments were subsequently undertaken in which the interaction was interrupted after 1, 2, 3, 4, or 5 g.-mols. of hydrogen per g.-mol. of squalene had been absorbed, and the partly hydrogenated products were examined.

1. *Absorption of* 1 *mol. of hydrogen.* The product had b. p. 235—238°/3 mm., $d^{20^\circ}_{20^\circ}$ 0·8534, and $n^{20^\circ}_{D}$ 1·4872. On treatment with dry hydrogen chloride in ethereal solution, the oil (5 g.) yielded 1·7 g. of crystalline squalene hexahydrochloride (m. p. 112—118°). This is equivalent to 34% of unchanged squalene.

2. *Absorption of* 2 *mols. of hydrogen.* A colourless oil was obtained, b. p. 235—237°/3 mm., $n^{20^\circ}_{D}$ 1·4800, $d^{20^\circ}_{20^\circ}$ 0·8443, iodine value 234·3 (calc. for $C_{30}H_{54}|_{4}^{=}$, 245). Absorption of dry hydrogen chloride yielded a quantity of squalene hexahydrochloride equivalent to 1·4% of squalene, together with an oil which could not be crystallised. Treatment of this hydrocarbon mixture with 98% formic acid for 15 hours yielded a partly cyclised product, b. p. 232—236°/ 4 mm., $n^{20^\circ}_{D}$ 1·4900, iodine value 154·2.

3. *Absorption of* 3 *mols. of hydrogen.* The product was a colourless oil, b. p. 232—234°/3 mm., $n^{20^\circ}_{D}$ 1·4710, $d^{20^\circ}_{20^\circ}$ 0·8334, iodine value 190 (calc. for $C_{30}H_{56}|_{3}^{=}$, 183). A crystalline hydrochloride could not be obtained by treatment with dry hydrogen chloride, and prolonged treatment with 98% formic acid produced no change.

4. *Absorption of* 4 *mols. of hydrogen.* The product had b. p. 229—234°/3 mm., $n^{20^\circ}_{D}$ 1·4625, $d^{20^\circ}_{20^\circ}$ 0·8211, iodine value 124·5 (calc. for $C_{30}H_{58}|_{2}^{=}$, 121·4).

5. *Absorption of* 5 *mols. of hydrogen.* The principal hydrocarbon was obtained as a colourless, mobile oil, b. p. 228—231°/3 mm., $n^{20^\circ}_{D}$ 1·4550, $d^{20^\circ}_{20^\circ}$ 0·8094, iodine value 64·8 (calc. for $C_{30}H_{60}|_{1}$, 60·4), which was recovered unchanged after prolonged treatment with formic acid.

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