THE CHEMISTRY OF RETENE

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CONTENTS

I. INTRODUCTION

It is interesting to note the cycle through which the organic chemist has passed in a century of progress during which he has synthesized several hundred thousand new compounds and has unravelled, step by step, many of nature's secrets that had long been considered insolvable. At first the organic chemist was concerned chiefly with the isolation of naturally occurring materials, some simple and some complex in structure, and the establishment of their structures by synthetic and degradative methods. This task being well on the way to solution, he busied himself with the synthesis and the proof of the structure of several hundreds of thousands of new compounds. In recent years, however, the discovery of the pres-

ence of the phenanthrene nucleus in the sterols, bile acids, cardiac poisons, sex hormones, alkaloids of the morphine and aporphine groups, many carcinogenic hydrocarbons and in a variety of other materials has prompted the organic chemist to investigate once again naturally occurring substances. As a result of this revival of interest in products of natural occurrence, much synthetic activity has been undertaken involving such substances as intermediates or as starting materials.

Because of the current interest in naturally occurring compounds, this review of the chemistry of retene has been written. Retene is itself of further interest on account of its structural relationship to the resin acids. The hydrocarbon is worthy of additional consideration by virtue of its possession of the biologically significant methyl and isopropyl groups in positions similar to their occurrence in many terpenes, camphor, and the p-cymenes.
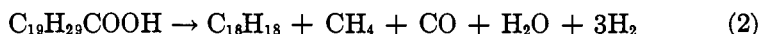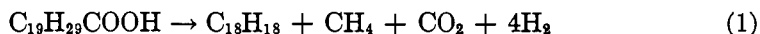
II. NATURAL SOURCES OF RETENE

Retene (Greek, *rhētinē*, pine resin) was first described by Fikentscher and Trommsdorf (140) a century ago. Their source of the hydrocarbon was fossilized pine wood in a peat bed of the Fichtelgebirge region of Bavaria. In 1858 retene was further investigated by Fehling (55) and Fritzsche (67, 69), who studied a sample of the relatively pure hydrocarbon obtained by Knauss from the oil resulting from the distillation of pine wood. Wahlforss (146) and Ekstrand (51) secured retene by allowing the oil from the higher boiling fractions of various wood-tar oils to deposit the hydrocarbon and then pressing the cold oil. In 1887 processes were developed and patented for the production of retene by heating resin oils with sulfur until the evolution of hydrogen sulfide had ceased and recovering the hydrocarbon from the product by distillation or extraction with suitable solvents (7, 37, 94).

Vesterberg (143) obtained retene by treating abietic acid with sulfur and distilling the product at reduced pressure. Virtanen (145) secured the hydrocarbon in similar fashion from pinabietic acid. The work of Vesterberg and Virtanen served not only to introduce a method for the dehydrogenation of a hydroaromatic compound to an aromatic one, a procedure that has been adapted to many studies of natural products in recent years, but also to cast light on the structure of resin acids of the abietic type. Since the starting material contains twenty carbon atoms, the dehydrogenation to retene ($C_{18}H_{18}$) is accompanied by a loss of two carbon atoms and is probably that represented by the following equation:

$$C_{19}H_{29}COOH + 5S \rightarrow C_{18}H_{18} + CH_3SH + 4H_2S + CO_2$$

Abietic acid   Retene
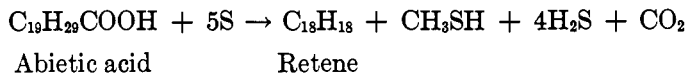
An extensive study of the action of sulfur on rosin was made by Li Man Cheung (103), who encountered considerable difficulty in isolating in pure condition the retene thus formed.

Other dehydrogenating agents, such as selenium (46) and palladium charcoal (127), gave better yields of retene. Thus, while Vesterberg (143) using sulfur was able to get a yield of only 8 per cent, based on the abietic acid, the selenium treatment gave a yield of 55 per cent of the pure hydrocarbon. The palladium charcoal dehydrogenation, carried out by Ruzicka and Waldmann (127) at 300–330°C., gave a 71 per cent yield of fairly pure retene together with approximately 4 moles of hydrogen, 1 mole of methane, 0.75 mole of carbon dioxide, and 0.25 mole of carbon monoxide. These authors postulated the following dehydrogenation reactions as taking place simultaneously, reaction 1 taking place to a much greater extent than reaction 2:

$$C_{19}H_{29}COOH \rightarrow C_{18}H_{18} + CH_4 + CO_2 + 4H_2 \qquad (1)$$

$$C_{19}H_{29}COOH \rightarrow C_{18}H_{18} + CH_4 + CO + H_2O + 3H_2 \qquad (2)$$

III. PRODUCTION OF RETENE FROM NATURAL SOURCES

Two of the processes mentioned above have been adapted to large-scale production and have been patented. The essential difference between these two methods consists in the fact that one involves the use of sulfur as a dehydrogenation agent, while the second employs only a metallic halide as a catalyst in accomplishing the same end.

The sulfur dehydrogenation process (85) involves heating rosin, abietic acid, esters of abietic acid, abietine, abietene, or abietane with sulfur at about 250°C. for a short time and then distilling the reaction mass under reduced pressure (25 to 28 in. of mercury) and at an elevated temperature (250° to 275°C.) with steam. The oily distillate is dissolved in alcohol, and retene crystallizes out on cooling. A further quantity of retene may be obtained by evaporating the mother liquors, combining the residue with the highest boiling fractions of the original distillation, and subjecting the whole once more to the sulfur treatment.

The second process (113) comprises condensing pine-tar oils (the water-insoluble portion of the liquid obtained by destructive distillation of the wood) by heating them to about 250°C. with a metallic halide catalyst, of which aluminum chloride was found to be the best, and then distilling under a pressure of about 2 in. of mercury. The distillate is agitated with 10 per cent caustic soda solution, and the oily layer is separated and distilled at atmospheric pressure. The last 25 per cent of the distillate contains retene and other hydrocarbons. This is allowed to crystallize, and the retene is recovered by removing the admixed oil by hydraulic pressure of about 400 pounds per square inch.

IV. PHYSICAL CONSTANTS AND PROPERTIES OF RETENE

Retene crystallizes from alcohol in large, colorless plates, melting at 98.5–99°C. (133); it boils at 390°C. (29). It is characterized by its picrate $(C_{18}H_{18} + C_6H_3O_7N_3)$, which forms orange-yellow needles melting at 123–124°C. (53, 68), and by its *sym*-trinitrobenzene adduct $(C_{18}H_{18} + C_6H_3O_6N_3)$, which is obtained as yellow needles melting at 139–140°C. (139).

Retene forms a complex with 2-chloro-1,3,5-trinitrobenzene $(C_{18}H_{18} + C_6H_2O_6N_3Cl)$, m. p. 53.5°C. (89). It forms two eutectic mixtures melting at 45.5°C. and 47.5°C. and containing 28.8 and 65.5 per cent of retene, respectively. Thermal analysis of the systems retene–2-chloro-1,3,5-trinitrobenzene, retene–2,4,6-trinitrophenol (88), retene–2,4,6-trinitroresorcinol (91), and retene–2,4,6-trinitroaniline (90) have been reported in the literature.

The hydrocarbon is somewhat volatile with steam (66, 67, 68). It sublimes in a vacuum of cathode light intensity at 135°C. (99); when maintained in such a vacuum for 14 hr. at 36°C., 2.2 per cent of the retene present will sublime (71). Its refractive power in benzene solution is given by Chilesotti (41). Its luminescence phenomena under the influence of cathode rays have been described by Pochettino (118). The fluorescence phenomena of retene under the influence of x-rays have been studied by Straus (138). When irradiated with ultraviolet light at the temperature of liquid air, retene emits a band spectrum (72). Wiedemann and Schmidt (152) observed in retene vapor a blue or violet fluorescence; in solution retene showed absorption in the extreme violet.

Ekstrand (51, 52, 53) gives the density of retene in crystalline form as 1.13, and after melting and supercooling as 1.08. In 100 parts of 95 per cent alcohol 69 parts of retene dissolve at the boiling point, while 3 parts dissolve at room temperature. The hydrocarbon is soluble in ether, carbon bisulfide, petroleum ether, benzene, and hot acetic acid.

The molar heat of combustion of retene at constant volume and at constant pressure has been measured by several investigators (30, 31, 137).

The behavior of retene in concentrated sulfuric acid in the presence of formaldehyde has been investigated by Ditz (49).

V. PROOF OF THE STRUCTURE OF RETENE

A. Oxidative degradation

Determination of the structure of retene proved to be a most perplexing problem, because of the great difficulty with which retene and its deriva-

tives burn when subjected to combustion in the ordinary way. This phenomenon, which was unnoticed for years, led to erroneous results which, in turn, furnished contradictory evidence as to the structure of the hydrocarbon. The combustion problem was solved by Bamberger and Hooker (19, 20, 21, 22), who burned a mixture of the material and lead chromate in a tube packed with lead chromate. Other investigators (5, 74) have found the analysis of retene derivatives to be both difficult and troublesome.

Retene (I) is 1-methyl-7-isopropylphenanthrene. It may be regarded as

I
Retene
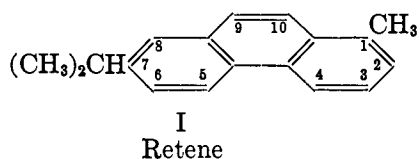
a methyl isopropyl homolog of biphenyl with an ethylene bridge inserted between the o- and o'-positions, one of these being adjacent to the carbon atom carrying the methyl group. Retene being a phenanthrene homolog, the arrangement of its double bonds is similar to that of phenanthrene, whose structure has been determined by Fittig and Ostermayer (62) and by Schultz (132).

Analyses indicate that retene possesses the empirical formula $C_{18}H_{18}$. Inasmuch as much of the early work on the proof of structure of the hydrocarbon led to unreliable conclusions because of erroneous analytical results and other difficulties, that work will not be included in this review.

After surmounting the combustion difficulties mentioned above, Bamberger and Hooker (15, 19) oxidized retene and obtained retenequinone (II), which had previously been prepared by Wahlforss (146). This was evidently an ortho-quinone, since Bamberger was able to form a quinoxaline derivative from it and to reduce it to a colorless hydroquinone. Distillation of the quinone with zinc dust yielded retene. Retenequinone (II) was further shown to be similar to an open chain α-diketone because of its sensitivity to alkali. When boiled with 10 per cent methyl alcoholic potassium hydroxide, it underwent the benzilic acid rearrangement to yield reteneglycolic acid (III) (104), and when fused with potassium hydroxide and lead peroxide, it gave 4'-isopropyl-3-methylbiphenyl-2-carboxylic acid (IV). The latter yielded retene ketone (V) when treated with thionyl chloride or when its barium salt was distilled with sodium methoxide.

V	IV	II	III
Retene ketone	4′-Isopropyl-3-methylbiphenyl-2-carboxylic acid	Retenequinone	Reteneglycolic acid
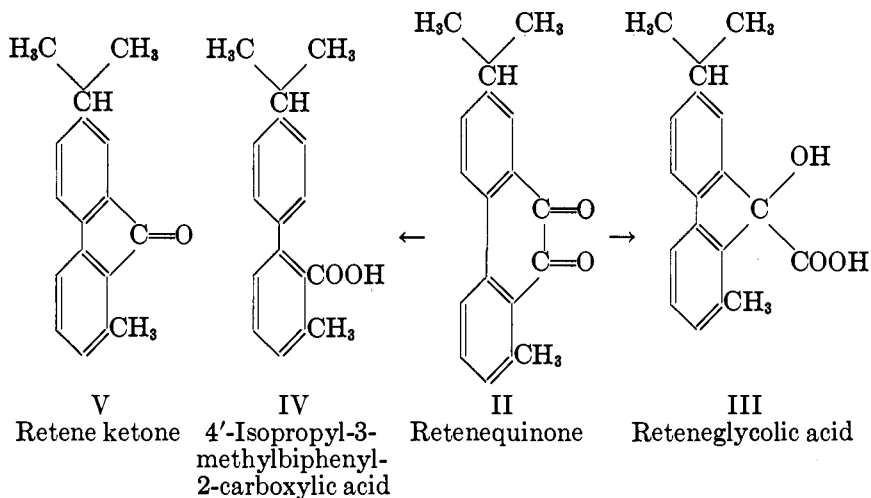
Bamberger and Hooker (19, 20, 21, 22) oxidized retenequinone (II) by means of alkaline potassium permanganate and secured a hydroxyisopropyldiphenyleneketonecarboxylic acid (VI), $C_{17}H_{14}O_4$. Further oxidation of VI by means of potassium dichromate in acid solution gave rise to a diphenyleneketonedicarboxylic acid (VII), which lost a molecule of carbon dioxide on distillation to give a diphenyleneketonecarboxylic acid (VIII).

II	VI	VII	VIII
Retenequinone	7-(α-Hydroxyisopropyl)fluorenone-1-carboxylic acid	Fluorenone-1,7-dicarboxylic acid	Fluorenone-7-carboxylic acid
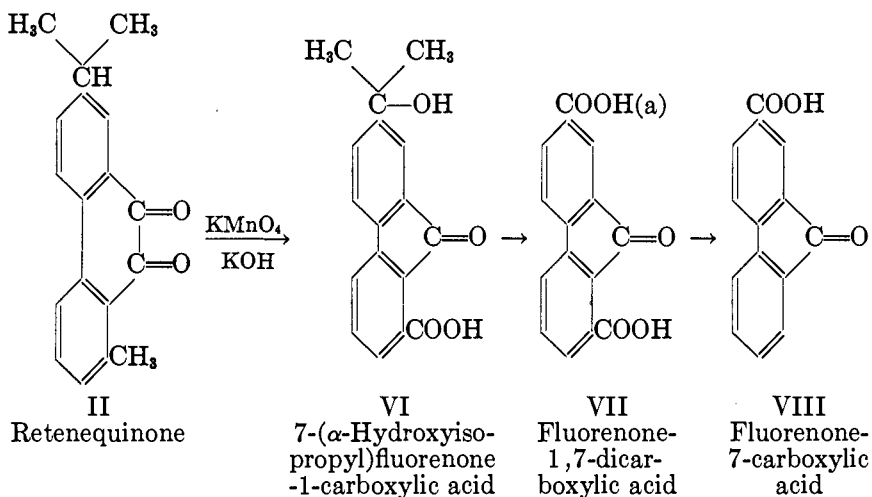
When the diphenyleneketonedicarboxylic acid (VII) was fused with potassium hydroxide, a diphenyltricarboxylic acid (IX) was formed, and when

reduced with sodium amalgam, a fluorenedicarboxylic acid (X) was obtained. Distillation of the latter with lime yielded fluorene (XI). The

COOH   COOH   COOH

$\longleftarrow$ C=O $\longrightarrow$ CH$_2$ $\longrightarrow$ CH$_2$

COOH

COOH   COOH   COOH

    IX   VII   X   XI
Biphenyl-2,   Fluorenone-   Fluorene-1,   Fluorene
3,4'-tricar-   1,7-dicar-   7-dicarbox-
boxylic acid   boxylic acid   ylic acid
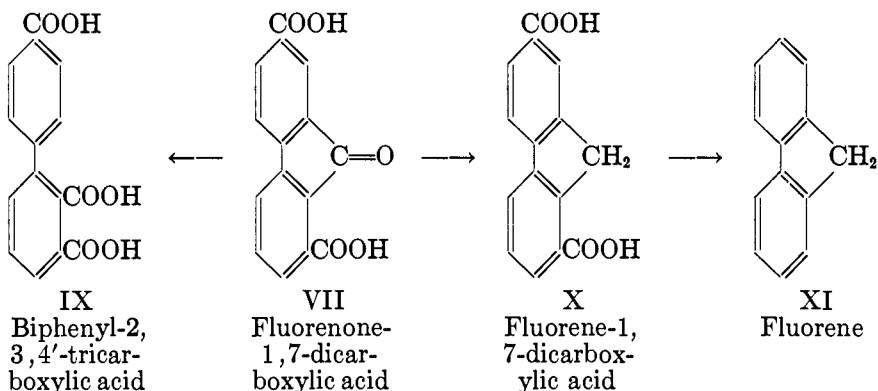
dicarboxylic acid (VII) yielded fluorenone (XII) on complete decarboxylation, and the tricarboxylic acid (IX) gave biphenyl (XIII) on similar treatment.

               C=O

      XII   XIII
   Fluorenone   Biphenyl
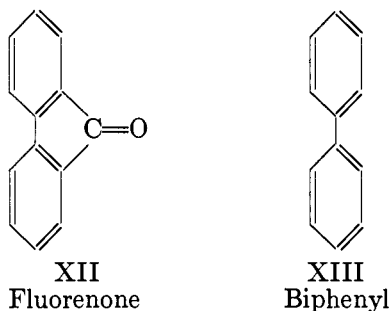
While the work of Bamberger and Hooker did not establish the exact structure of retene, it served to define certain important facts. The formation of a dicarboxylic acid (VII) showed that the C$_4$H$_{10}$-residue of retenequinone (II) must be in the form of two alkyl side chains. The possibilities are diethyl, methyl n-propyl, and methyl isopropyl. The production of the hydroxyisopropyldiphenyleneketonecarboxylic acid (VI) removed the first two possibilities. Since VI can be converted to fluorenone (XII), it is apparent that the oxidation of retenequinone, C$_{18}$H$_{16}$O$_2$ (II), to C$_{17}$H$_{14}$O$_4$ (VI) left the four carbon atoms of the two original alkyl groups intact. The carboxyl group of VI could not have come from an ethyl or propyl group without the loss of carbon, and it must therefore have arisen from the oxidation of a methyl group. The other alkyl group in retenequinone (II) is therefore n-propyl or isopropyl. The keto acid

(VI), however, contains one oxygen atom not accounted for in the keto and carboxyl groups. Since the *n*-propyl group is not susceptible to partial oxidation, whereas alkaline permanganate is known to hydroxylate an isopropyl group, the second alkyl group is an isopropyl group. The product of the oxidation of retenequinone (II) by means of alkaline potassium permanganate is therefore a hydroxyisopropyldiphenyleneketonecarboxylic acid (VI). The tricarboxylic acid (IX) readily forms an anhydride, while the dicarboxylic acid (VII) does not. One carboxyl group of the acid (IX) must be ortho to the carbonyl group of VII, and thus ortho to the carboxyl group which is produced in IX by fusion of VII with alkali. It follows that one alkyl group of retenequinone (II) is attached to C_1, adjacent to one of the quinoidal carboxyl groups.

Bamberger and Hooker therefore established retene as a methylisopropylphenanthrene in which one of the alkyl groups is at C_1. Their work did not indicate whether or not the second alkyl group was in the same benzene nucleus or in a different one.

Fortner (64) oxidized fluorene-2-carboxylic acid with chromic acid and obtained Bamberger and Hooker's diphenyleneketonecarboxylic acid (VIII). This showed further that one of the alkyl groups in retene was at C_7.

By fusion of retene ketone (V) with potassium hydroxide, Lux (104) obtained two methylisopropylbiphenylcarboxylic acids, XV and XVI. One of these acids, presumably XV, did not esterify easily, and he concluded that it must contain two substituting groups in the positions ortho to the carboxyl group. This lent further proof to the presence of one alkyl group in retene at C_1.

XIV
Trimellitic acid

XV

XVI
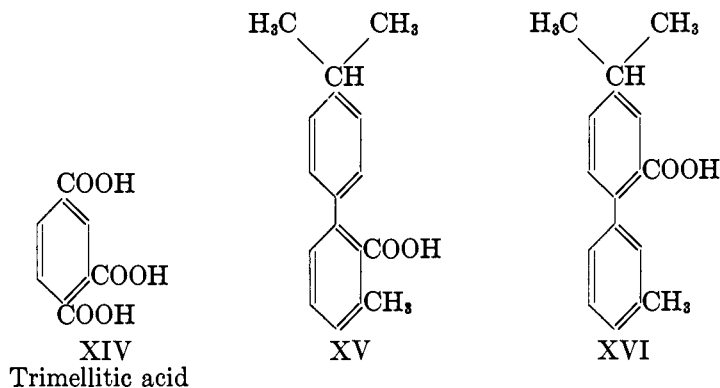
Schultze (133) oxidized hydrogenated retenes to trimellitic acid (XIV), thus proving that the two alkyl groups in retene cannot be in the same benzenoid ring. Since one of the alkyl groups in retene had already been shown to be at C_1, the work of Schultze indicated that the second alkyl

group was at C_7. Thus the observations of Fortner, Lux, and Schultze showed that the methyl and isopropyl groups in the retene molecule are probably located at C_1 and C_7, respectively, or at C_7 and C_1.

It remained for Bucher to complete the task of determining the structure of retene. Retenequinone (II) is oxidized by means of potassium permanganate in pyridine solution to yield 4'-(α-hydroxyisopropyl)-3-carboxydiphenic acid (XVII). This acid (XVII) loses water very easily upon heating, leaving a residue which is still soluble in sodium carbonate solution. This shows the acid to be tribasic. Its formation from retenequinone establishes the positions of two of the carboxyl groups at C_2 and $C_{2'}$ (XVII). The loss of water on heating fixes another carboxyl group in an adjacent ortho position (C_3, formula XVII), for substances of the diphenic acid type sublime unchanged when heated. Inasmuch as the isopropyl group remains in the compound, it is certain that the carboxyl group attached to C_3 must have come from the methyl group present in the original quinone (II) at C_1.

II	XVII	XVIII
Retenequinone		3,4'-Dicarboxydiphenic acid
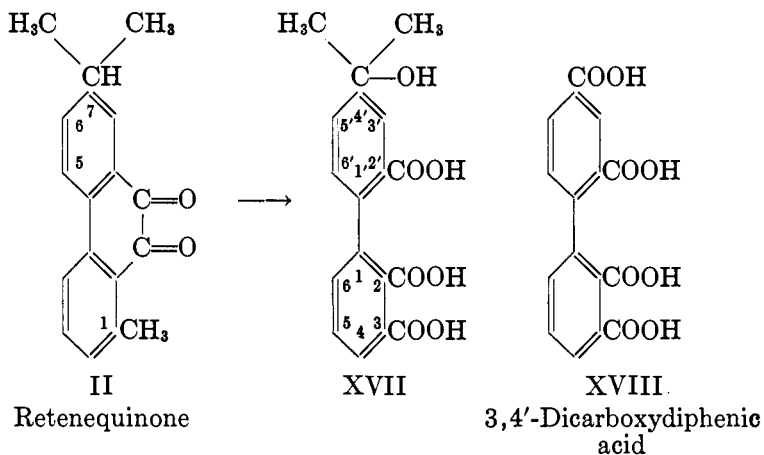
Further oxidation of the tribasic hydroxy acid (XVII) yields the corresponding tetrabasic acid (XVIII), 3,4'-dicarboxydiphenic acid, which gives biphenyl (XIII) on complete decarboxylation. This tetrabasic acid, on heating, gives off water to form an anhydride which is still soluble in sodium carbonate solution with effervescence of carbon dioxide. The acid (XVIII) therefore does not contain a carboxyl group at $C_{3'}$. In this oxidation a small quantity of hemimellitic acid (XIX) was obtained, proving that in retene the alkyl groups must be attached to different benzene rings. These results show that the isopropyl group in retenequinone (II) must be at C_5, C_6, or C_7.

Additional evidence concerning the location of the isopropyl group was obtained by Bucher in his oxidation of the diphenyleneketonedicarboxylic

acid (VII) of Bamberger and Hooker to hemimellitic acid (XIX) and trimellitic acid (XIV). This further proves that the original alkyl groups in retene are in different benzene nuclei and that the unlocated carboxyl group (a) in the fluorenonedicarboxylic acid (VII), and hence the isopropyl group in retene, is at C_6 or C_7.

COOH (a)

C=O

COOH

VII
Fluorenone-1,7-dicarboxylic acid

COOH

COOH
COOH

XIV
Trimellitic acid

COOH
COOH

COOH

XIX
Hemimellitic acid
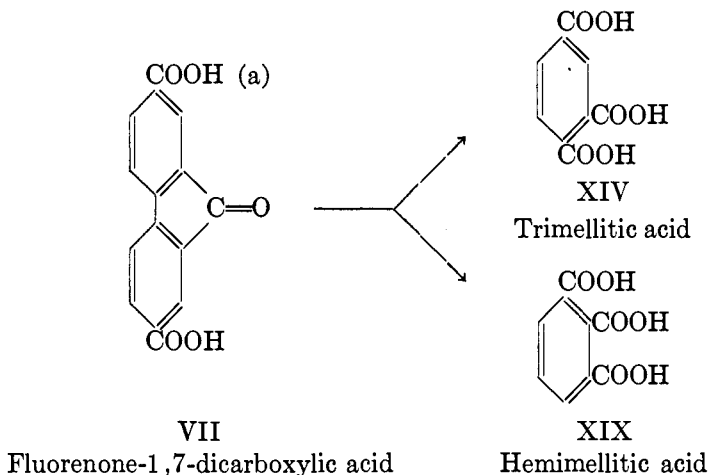
The isopropyl group in retene was finally established at C_7 by the degradation of the hydroxyisopropylfluorenonecarboxylic acid (VI) of Bamberger and Hooker to the known p-phenylbenzoic acid (biphenyl-4-carboxylic acid). Fusion of VI with potassium hydroxide gives the hydroxyisopropylbiphenyldicarboxylic acid (XX), which yields the isopropylbiphenyldicarboxylic acid (XXI) upon reduction with hydriodic acid. The position of the carboxyl group formed by opening the fluorenone ring of VI by alkali and represented at $C_{2'}$ in formulas XX and XXI is

H₃C   CH₃
C—OH

C=O

COOH

VI
7-(α-Hydroxyiso-
propyl)fluorenone-
1-carboxylic acid

⟶

H₃C   CH₃
C—OH

2'COOH (?)

COOH

XX
4'-(α-Hydroxyisopro-
pyl)biphenyl-2',3-
dicarboxylic acid

⟶

H₃C   CH₃
CH

COOH (?)

COOH

XXI
4'-Isopropylbiphe-
nyl-2',3-dicarboxylic
acid

⟶

XXII
4-Isopropylbiphenyl

XXIII
Biphenyl-4-carbox-
ylic acid

problematical; it may be at C_2. The exact position of this carboxyl group is of no serious consequence in the proof of structure in question, for this carboxyl group disappears, together with the other carboxyl group, upon decarboxylation of XXI. Oxidation of the 4-isopropylbiphenyl (XXII) thus formed gives p-phenylbenzoic acid (biphenyl-4-carboxylic acid) (XXIII), proving that the isopropyl group of retene is at C_7. Retene (I) is therefore 1-methyl-7-isopropylphenanthrene.

I
Retene

B. Synthesis

The structure of retene as established by Bucher has been further corroborated by the synthesis of the hydrocarbon from simpler materials of known constitution. Aside from their structural contribution, these syntheses have no practical value as a source of retene.

The succinic anhydride synthesis of Haworth (76) was adapted by that author, in collaboration with Letsky and Mavin (78), to the synthesis of retene (I). β-Isopropylnaphthalene condenses with succinic anhydride in the presence of aluminum chloride to yield β-(6-isopropyl-2-naphthoyl)-propanoic acid (XXIV). Methylmagnesium iodide reacts selectively with the keto group of the methyl ester of the keto acid (XXIV) to give γ-(6-isopropyl-2-naphthyl)-β-pentenoic acid (XXV), which is reduced with phosphorus and hydriodic acid to γ-(6-isopropyl-2-naphthyl)valeric acid (XXVI). Cyclization of the latter by means of sulfuric acid yields
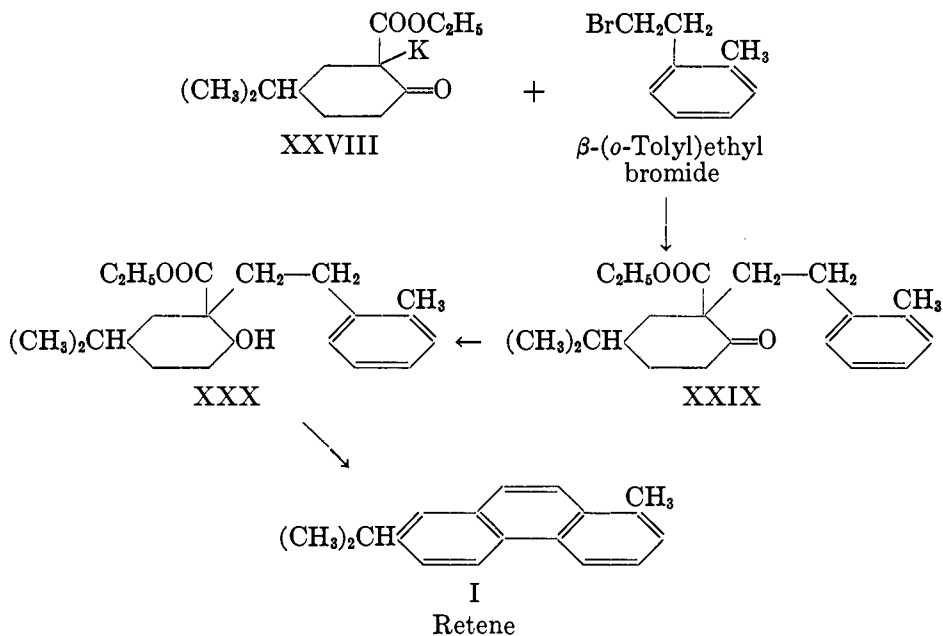
4-keto-1-methyl-7-isopropyl-1,2,3,4-tetrahydrophenanthrene (XXVII). The Clemmensen reduction of the ketone followed by selenium dehydrogenation gives retene (I).

β-Isopropylnaphthalene

XXIV
β-(6-Isopropyl-2-naphthyl)-
propanoic acid

XXV
γ-(6-Isopropyl-2-naphthyl)-β-
pentenoic acid

XXVI
γ-(6-Isopropyl-2-naphthyl)valeric
acid

I
Retene

(two steps)

XXVII
4-Keto-1-methyl-7-isopropyl-
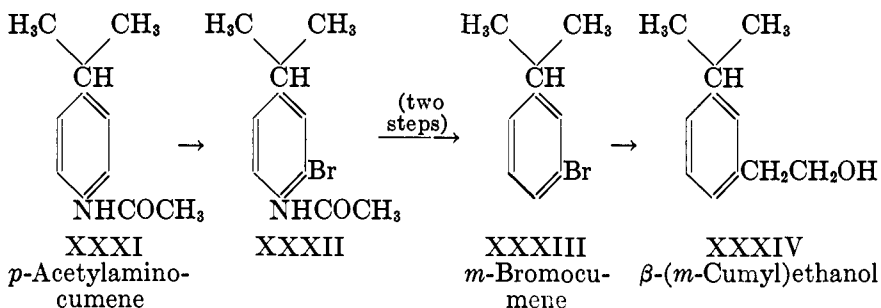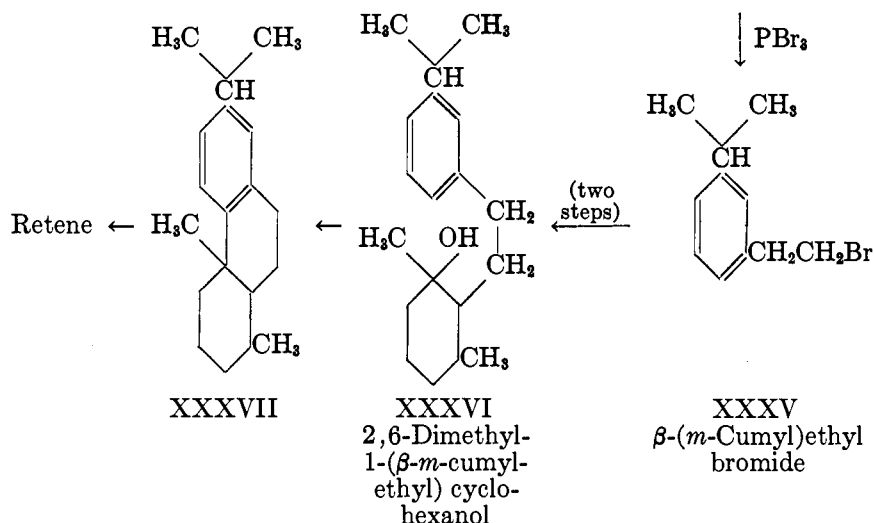1,2,3,4-tetrahydrophenanthrene
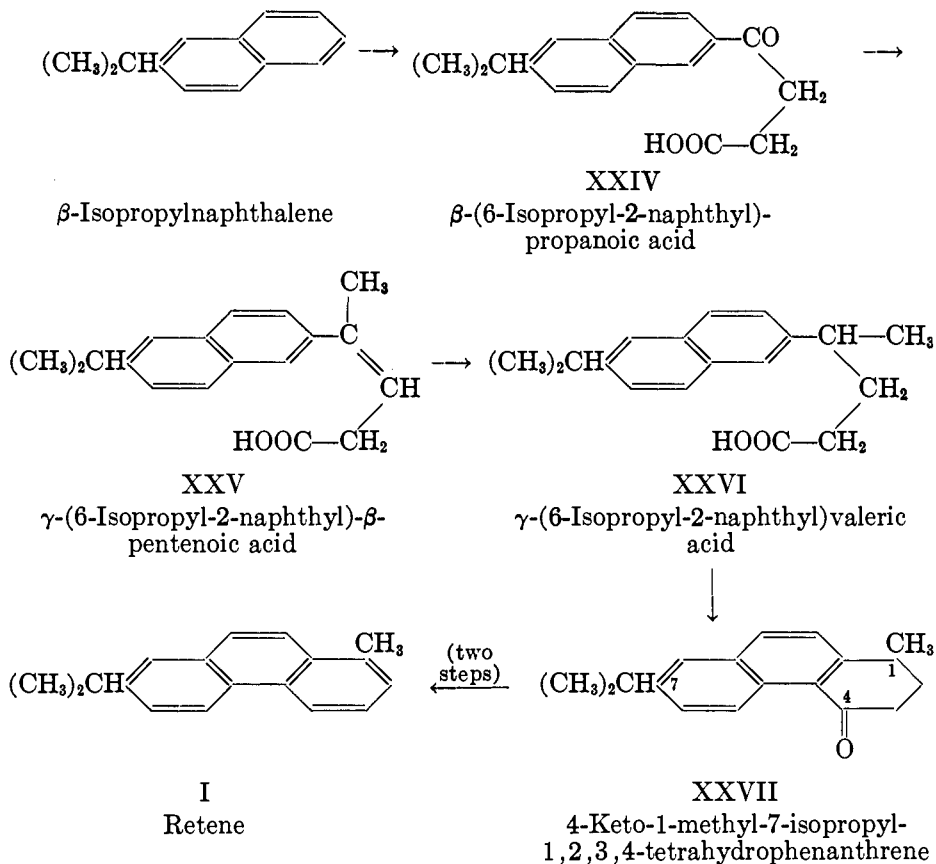
The Bardhan and Sengupta synthesis of phenanthrene (25) was adapted with equal success by the Indian chemists in the synthesis of retene (26). The potassium derivative of ethyl 4-isopropylcyclohexan-1-one-2-carboxylate (XXVIII) reacts with β-o-tolylethyl bromide to give ethyl 4-isopropyl-2-(β-o-tolylethyl)cyclohexan-1-one-2-carboxylate (XXIX). Sodium amalgam reduces the keto ester (XXIX) to ethyl 4-isopropyl-2-(β-o-tolylethyl)-cyclohexan-1-hydroxy-2-carboxylate (XXX). This hydroxy ester (XXX) is heated with phosphorus pentoxide and the product dehydrogenated by selenium to yield retene (I).

More recently Bogert and Sterling (35) have adapted the Perlman–Davidson–Bogert synthesis of phenanthrene (116) to the synthesis of retene. This method starts with the known p-acetylaminocumene

$$COOC_2H_5$$

(CH$_3$)$_2$CH

XXVIII

$+$

BrCH$_2$CH$_2$ ... CH$_3$

β-(o-Tolyl)ethyl bromide

C$_2$H$_5$OOC CH$_2$—CH$_2$

(CH$_3$)$_2$CH ... OH ... CH$_3$

XXX

$\leftarrow$

C$_2$H$_5$OOC CH$_2$—CH$_2$

(CH$_3$)$_2$CH ... =O ... CH$_3$

XXIX

(CH$_3$)$_2$CH ... CH$_3$

I

Retene

(XXXI), which is converted to the monobromo derivative. Hydrolysis of the latter, followed by removal of the amino group through the diazo reaction, gives *m*-bromocumene (XXXIII). The bromo compound reacts with magnesium, then with ethylene oxide to yield β-(*m*-cumyl)ethanol (XXXIV). The alcohol (XXXIV) gives the corresponding bromide (XXXV) when treated with phosphorus tribromide. The magnesium compound of this bromide undergoes the Grignard reaction with 2,6-dimethylcyclohexanone to form 2,6-dimethyl-1-(β-*m*-cumylethyl)cyclohexanol (XXXVI). Cyclization of the latter by means of sulfuric acid furnishes 12-methyl-1,2,3,4,9,10,11,12-octahydroretene (XXXVII), which is smoothly dehydrogenated by means of selenium to retene (I).

H$_3$C   CH$_3$
CH

NHCOCH$_3$
XXXI
p-Acetylamino-
cumene

$\rightarrow$

H$_3$C   CH$_3$
CH

Br
NHCOCH$_3$
XXXII

$\xrightarrow{\text{(two steps)}}$

H$_3$C   CH$_3$
CH

Br
XXXIII
m-Bromocu-
mene

$\rightarrow$

H$_3$C   CH$_3$
CH

CH$_2$CH$_2$OH
XXXIV
β-(*m*-Cumyl)ethanol

$$H_3C\diagdown CH_3 \qquad H_3C\diagdown CH_3 \qquad \downarrow PBr_3$$

Retene ← H$_3$C ← H$_3$C OH $\overset{\text{(two}}{\underset{\text{steps)}}{\longleftarrow}}$ H$_3$C CH$_3$

CH$_2$CH$_2$Br

XXXVII	XXXVI	XXXV
	2,6-Dimethyl-1-(β-m-cumyl-ethyl) cyclo-hexanol	β-(m-Cumyl)ethyl bromide

VI. HYDROGENATION PRODUCTS OF RETENE

A. Various hydrogenated retenes

The study of the hydrogenation products of retene has been of interest chiefly in connection with attempts to establish the structure of abietic acid. Retene having been defined as a dehydrogenation product of this acid, the ring skeleton of abietic acid is known. Many investigators (100, 133, 141) believed that, in order to determine whether hydrogenated retenes or their methyl homologs are obtained from resin acids, it was important to prepare the different hydrogenated retenes and determine their properties.

The earliest work on the hydrogenation of retene was done by Bamberger and Lodter (23), who reduced retene by means of sodium and amyl alcohol and obtained a tetrahydroretene. By prolonged action of phosphorus and hydriodic acid on the hydrocarbon, Liebermann and Spiegel (101) obtained a dodecahydroretene, $C_{18}H_{30}$. This compound was later prepared by Ipatiev (87), who hydrogenated retene at an elevated temperature in the presence of nickel oxide. Prolonged hydrogenation of this dodecahydroretene yielded perhydroretene, $C_{18}H_{32}$. The latter did not prove to be identical with fichtelite, in disagreement with the views of Spiegel (136) and of Bamberger and Strasser (24). In 1904 Easterfield and Bagley (50) heated abietic acid with hydriodic acid in a sealed tube and obtained a hydrocarbon which they reported to be a decahydroretene, $C_{18}H_{28}$.

In 1920 Virtanen (144) prepared six hydrogenated compounds from

retene and recorded their physical constants. Dihydroretene and tetra-hydroretene (table 1) were made by reducing retene with sodium and amyl alcohol; the others were obtained by the action of phosphorus and hydriodic acid on the hydrocarbon at elevated temperatures in a sealed tube filled with carbon dioxide. None of these hydrogenated retenes formed picrates.

Czerny (45) obtained an octahydroretene, $C_{18}H_{26}$, by prolonged treatment of pine oil with caustic potash at 50–60°C.; its physical constants differed somewhat from those of the octahydroretene described by Virtanen (144). Orlov (115) investigated the pyrolytic dissociation of retene in the presence of hydrogen under pressure. The hydrogenation of retene and hydroretenes has been studied by Hasselstrom and Hull (75).

In 1932 Bogert and Hasselstrom (33) reduced retene-6-carboxylic acid, the synthesis of which will be described in a later section, and obtained an

TABLE 1

Physical properties of retene and of its hydrogenation products

COMPOUND	FORMULA	APPEARANCE	MELT-ING POINT	BOILING POINT AT 10 MM.	$d_4^{20°}$	$n_D^{20°}$
			°C.	°C.		
Retene.............	$C_{18}H_{18}$	White plates	98.5	208–210		
Dihydroretene.......	$C_{18}H_{20}$	White plates	64–65	188–190		
Tetrahydroretene....	$C_{18}H_{22}$	Pale yellow oil		180–183	1.0057	1.56061
Hexahydroretene....	$C_{18}H_{24}$	Colorless oil		175–177	0.9802	1.54705
Octahydroretene.....	$C_{18}H_{26}$	Colorless oil		163–165	0.9578	1.53023
Decahydroretene....	$C_{18}H_{28}$	Colorless oil		155–158	0.9342	1.51501
Dodecahydroretene..	$C_{18}H_{30}$	Colorless oil		148–150	0.8985	1.48510

octahydroretene-6-carboxylic acid. Its sodium salt behaved as a true resinate, being soluble in hot water but not in aqueous alkali. This octahydroretene-6-carboxylic acid is the nearest approach so far achieved synthetically to a true aporesin acid of the abietic series.

Owing to the difficulty encountered in the preparation of retene derivatives, Nyman (114) studied substitution in 9,10-dihydroretene and found that it occurred more readily than in retene. The dihydro compound was prepared in 60 per cent yield by reduction of retene with sodium and amyl alcohol. Nyman investigated the acetylation of 9,10-dihydroretene and prepared a number of new derivatives.
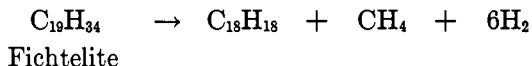
B. Relation to fichtelite

Fichtelite (XXXVIII), m. p. 46.5°C., is a completely saturated hydrocarbon which is decidedly inert in both chemical and physical properties. First isolated by Bromies (38) from peat beds of pine forests in Bavaria,

its structure and composition were long in question. Early investigators (17, 24, 84, 101, 136) regarded it as a perhydroretene, $C_{18}H_{32}$.

Prompted by the discovery that fichtelite yields retene upon dehydrogenation with sulfur (120), Ruzicka and Waldmann (128) studied a quantitative dehydrogenation of the material with palladium charcoal at 330–370°C. Were fichtelite a perhydroretene, $C_{18}H_{32}$, the gas evolved in this dehydrogenation should consist only of hydrogen:

$$C_{18}H_{32} \quad \rightarrow \quad C_{18}H_{18} \quad + \quad 7H_2$$
Perhydroretene
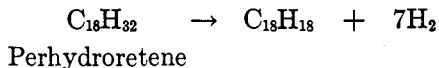
The gases actually evolved were found to consist of one volume of methane and six volumes of hydrogen:

$$C_{19}H_{34} \quad \rightarrow \quad C_{18}H_{18} \quad + \quad CH_4 \quad + \quad 6H_2$$
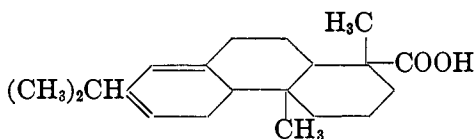Fichtelite

This indicated the presence of an additional tertiary methyl group. In order to show its relationship to abietic acid (XXXIX), from which it probably arises in the process of decay, Ruzicka and Waldmann have proposed for fichtelite the structure given in formula XXXVIII.

In an effort to clear up the structure of fichtelite, Bogert and Sterling (35) synthesized 12-methyl-1,2,3,4,9,10,11,12-octahydroretene (XXXVII), which was catalytically hydrogenated at 225°C. and 150 atm. pressure by Dr. Homer Adkins. There was obtained a hydrocarbon, $C_{19}H_{34}$, which was an oil, boiling at 179–181°C. at 12 mm. pressure. As fichtelite is a white crystalline solid, m. p. 46.5°C., this hydrocarbon was not identical therewith. It may be that the difference between the two is a stereochemical one (120) or that the hydrocarbon of Bogert and Sterling requires further purification.

It is of interest to point out at this point that the so-called "methylretene" obtained by Ruzicka and Meyer (124) in their degradation of ethyl abietate to "methylretene" has been identified as 1-ethyl-7-isopropylphenanthrene (XLII). Upon oxidation with alkaline potassium ferricyanide, retene yielded phenanthrene-1,7-dicarboxylic acid (XL) and biphenyl-2,2',3,4'-tetracarboxylic acid (XLI) (121). A "methylretene" should yield a tribasic acid under similar conditions.

Instead, Ruzicka, de Graaf, and Müller obtained phenanthrene-1,7-dicarboxylic acid (XL), identical with the product obtained from retene. This evidence indicates that the additional methyl group in "methylretene" is not attached directly to the phenanthrene ring. Ruzicka, de Graaf, and Müller postulated that the methyl group in question was in a side chain, probably united with the methyl group of retene (I) at C_1 in the form of an ethyl group. In other words, "methylretene" is 1-ethyl-7-isopropylphenanthrene (XLII).

XXXIX
Abietic acid
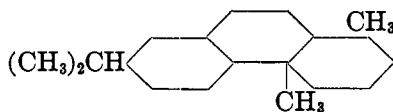
XXXVIII
Fichtelite
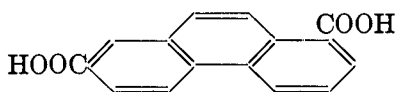
XL
Phenanthrene-1,7-dicarboxylic acid

XLI
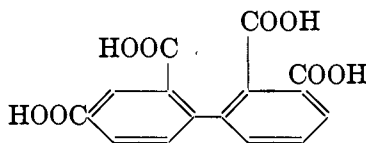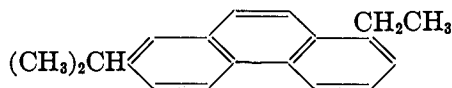Biphenyl-2,2',3,4'-tetracarboxylic acid

XLII
1-Ethyl-7-isopropylphenanthrene

This hypothesis was established as a fact by Haworth (77), who synthesized the hydrocarbon by a series of reactions similar to those used in his synthesis of retene (I) (see above). In the transformation from the methyl ester of the keto acid (XXIV to XXV), he used ethylmagnesium iodide instead of the methyl compound. The synthetic 1-ethyl-7-isopropylphenanthrene (XLII) was found to be identical with the "methylretene" obtained from the degradation of ethyl abietate (124).

VII. DERIVATIVES OF RETENE

Nearly one hundred years had elapsed since the preliminary report of Fikentscher and Trommsdorf (140) before systematic synthesis of retene derivatives was undertaken. Prior to the publication of Fieser and Young (61), no retene derivatives had been reported in which the exact position of all the substituent groups in the molecule was given. The unique work of these authors in establishing the structures of the two retenols of Komppa and Wahlforss (97) has largely made possible recent expansion in the retene field by other investigators. The matchless contribution of Fieser and Young (61) is discussed in detail below.

A. Hydroxy derivatives

By alkaline fusion of the ammonium salts of A- and B-retenesulfonic acids, Komppa and Wahlforss (97) prepared the corresponding monohydroxy derivatives. The term "retenol' was suggested for monohydroxyretene, $C_{18}H_{17}OH$, in analogy with the corresponding term for

monohydroxyphenanthrene. The A- and B-retenols of Komppa and Wahlforss (97) were characterized as 2- and 6-retenol, respectively, by the research of Fieser and Young (61).

Inasmuch as no promising method of degradation could be found to establish the structure of the two retenols, Fieser and Young tackled the problem from an entirely different angle. Since it is possible to oxidize suitable A- and B-retenol derivatives to 9,10-retenequinones without affecting the new substituents, these groups must occupy the 2-, 3-, 4-, 5-, 6-, or 8-positions. The 8-position is ruled out by the Dimroth test (47, 48) for α-hydroxyquinones. 8-Hydroxyretenequinone should give an intense coloration with boroacetic anhydride, but neither the A- nor the B-quinone displays such behavior. The 8-position is definitely ruled out by subsequent work of Adelson and Bogert (3, 4), who synthesized 3'-methyl-5,6-cyclopentenoretene from 6-acetylretene. The structure of 6-acetylretene had previously been established by these authors (1) by conversion of the ketone into the 6-retenol of Fieser and Young. Had the 8-position been the one involved, the cyclopenteno ring could not have been formed. The synthesis of 5,6-benzoretene by Adelson and Bogert (5) furnishes another example in substantiation of this point.

The next significant fact is that B-retenol couples with diazotized amines, while A-retenol does not. The double bonds of phenanthrene occupy fixed positions as in the case of naphthalene. C_2 and C_3 are connected by a single bond and hence a 2-phenanthrol cannot couple with diazonium salts if C_1 is blocked, as is the case with retene, for a double bond is required for the formation of the intermediate addition product. Stated in more general terms, this rule asserts that only those phenanthrols can couple which have a free position para to the hydroxyl group or have free an ortho position which is connected by a double bond to the carbon carrying the hydroxyl group. In the case of retene, there is only one possible hydroxyl derivative which does not fulfil the requirement. Since A-retenol does not couple, it must be 2-retenol (XLIII).

XLIII   XLIV
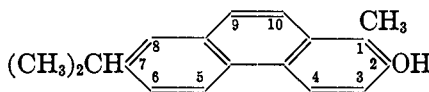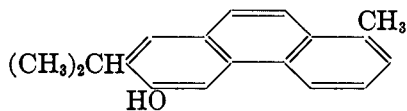
2-Retenol   6-Retenol

Four possible locations remain for the hydroxyl group in B-retenol, namely, 3, 4, 5, or 6. By a comparison of the reduction potentials of the 2- and B-hydroxyretenequinones, positions 4 and 5 are eliminated. Fieser (57) has shown that there is considerable difference in the effect of the

hydroxyl group on the potential of phenanthraquinone according to whether the substituent occupies a position which is meta or ortho-para to one of the ketonic oxygen atoms. A single hydroxyl group at C_2 or C_4 is without influence, while such a group at C_1 or C_3 lowers the potential 51 millivolts. In the case of the hydroxyretenequinones the situation is slightly altered by the fact that there must be present in one of the terminal benzene rings two substituents (hydroxyl and alkyl) which produce a lowering in the potential of the parent quinone. Comparing the mono- and di-hydroxyphenanthraquinones it is seen that the effect of a second hydroxyl group introduced into the ring carrying the first such group produces a somewhat greater potential lowering: 28 millivolts for a group in the meta position and -77 millivolts for a group in the ortho-para position. It is reasonable to expect that a hydroxyl group would have a similar effect upon the potential of retenequinone. The potentials of the three compounds concerned are:

	POTENTIALS	Δ
	volts	*millivolts*
Retenequinone............................	0.421	
A(2)-hydroxyretenequinone.................	0.385	−36
B-hydroxyretenequinone....................	0.348	−73

The differences, which show the effect of the added hydroxyl groups, clearly indicate that the class A compounds contain the hydroxyl group in the meta position to one of the ketonic oxygen atoms in the appropriate quinone, and the class B compounds contain it in the ortho-para position. This confirms the structure already assigned to the A-compound (2-retenol) and shows that in B-retenol the hydroxyl group must be located at either C_3 or C_6 (C_8 is excluded by the Dimroth test). A choice between C_3 and C_6 can be made by a consideration of orientation principles. The retenols, it will be recalled, were made by alkali fusion of the corresponding sulfonates. It is highly improbable that an alkyl group (at C_1 or C_7) would direct a sulfonic acid group to a meta position (C_3 or C_5) when a position ortho to such a group is available. Since C_8 and C_4 are ruled out by other considerations, it is very probable that the hydroxyl group in B-retenol is at C_6 (XLIV).

9-Retenol has been made by the reduction of retenequinone with zinc dust and acetic acid (61). Its structure is established by a study of the 9,10(or 10,9)-hydroxyazo derivatives of retene. In the case of phenanthrene such a compound may be prepared in two ways: by coupling 9-phenanthrol with a diazotized amine or by condensing phenanthraquinone with phenylhydrazine. Werner and Frey (149) have shown that the same

product is obtained in each case. With retene, however, the two reaction products are different. 9-Retenol couples readily with diazotized *p*-nitroaniline to give 9-hydroxy-10-(*p*-nitrophenylazo)retene (XLV). The isomeric compound, 10-hydroxy-9-(*p*-nitrophenylazo)retene (XLVI) has been prepared by Li Man Cheung (103) from retenequinone and *p*-nitrophenylhydrazine. Since this last reaction is probably one involving an

$$\text{HO} \quad \text{N}{=}\text{NC}_6\text{H}_4\text{NO}_2$$

(CH₃)₂CH ... CH₃

XLV
9-Hydroxy-10-(*p*-nitrophenylazo)-
retene

$$\text{O}_2\text{NC}_6\text{H}_4\text{N}{=}\text{N} \quad \text{OH}$$

(CH₃)₂CH ... CH₃

XLVI
10-Hydroxy-9-(*p*-nitrophenylazo)-
retene
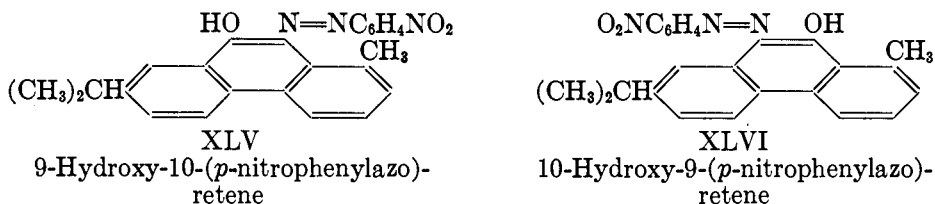
addition, and since it is known to be subject to steric influence, it is reasonable to assume that condensation at the ketonic group closest to the methyl group is retarded and that the product formed has the structure given in formula XLVI. The compound obtained from the retenol, being isomeric with this substance, must have the alternate structure of XLV, whence the new hydroxyretene is 9-retenol. Fieser and Young (61) assume that it is the methyl group at C_1 in retenequinone that causes the condensing agent (here *p*-nitrophenylhydrazine) to attack the ketonic group at C_9 rather than the one at C_{10}. Analogous experiments with 1-methylphenanthraquinone support this assumption.

The remarkable reasoning of Fieser and Young (61) that it is the oxygen atom closest to the methyl group in retenequinone that is eliminated on reduction has recently been confirmed by synthesis. Keimatsu, Ishiguro, and Sumi (93) have synthesized 9-methoxyretene (LIII) by a process similar to that used by Ruzicka and Waldmann (126) in the preparation of 1,7-dimethyl-9-methoxyphenanthrene. Isopropylbenzene and succinic anhydride react in the presence of aluminum chloride in tetrachloroethane solution to give β-(*p*-isopropylbenzoyl)propanoic acid, which undergoes the Clemmensen reduction to yield γ-(*p*-isopropylphenyl)butanoic acid. The latter is converted into 1-keto-7-isopropyl-1,2,3,4-tetrahydronaphthalene (XLVII) by treatment with sulfuric acid. This keto compound (XLVII) furnishes 1-hydroxy-7-isopropylnaphthalene (XLVIII) when heated with sulfur and cupric sulfide. 1-Methoxy-7-isopropylnaphthalene (XLIX), prepared by the action of dimethyl sulfate on the hydroxy compound (XLVIII), yields β-(1-methoxy-7-isopropylnaphthoyl-(4))-propanoic acid (L) when subjected to the Friedel–Crafts reaction with succinic anhydride. This keto acid (L) undergoes the

Clemmensen reduction to γ-(1-methoxy-7-isopropylnaphthyl-(4))-butanoic acid (LI), the acid chloride of which furnishes 1-keto-7-isopropyl-9-methoxy-1,2,3,4-tetrahydrophenanthrene (LII) upon vacuum distillation. The ketone (LII) is reacted with methylmagnesium iodide and the reaction product is dehydrogenated with selenium to yield 9-methoxyretene (LIII), identical with that prepared by Fieser and Young (61) by methylation of 9-retenol.

XLVII

XLVIII
1-Hydroxy-7-isopropylnaphthalene

XLIX
1-Methoxy-7-isopropylnaphthalene

LI

L

LII

LIII
9-Methoxyretene
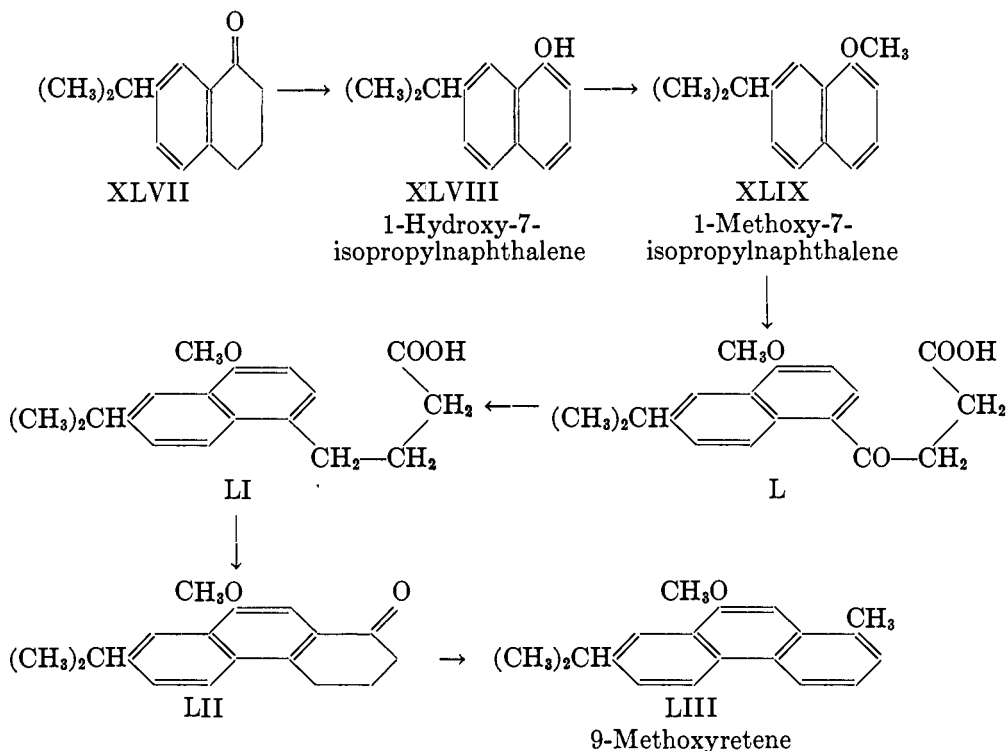
In 1933 Japanese chemists published the first of a series of papers concerning the isolation of a natural product which they subsequently described as possessing the retene nucleus. From the ether extract of the middle, red part of Japanese hinoki wood, Yoshiki and Ishiguro (154) obtained an oil which separated into two layers on standing. The upper layer, a viscous, bright yellow oil, yielded a crystalline substance which they called hinokiol. Subsequent work by Keimatsu and Ishiguro (92) gave $C_{19}H_{28}O_2$ as the molecular formula for hinokiol. Dehydrogenation of hinokiol with selenium gave three compounds which the authors state

to be retene, a hydroxyretene, $C_{18}H_{18}O$, and a dihydroxyretene, $C_{18}H_{18}O_2$. Various derivatives were prepared in support of these views by Keimatsu and Ishiguro, who then proposed tentative structures for the compounds in question. The hydroxyretene, the dihydroxyretene, and hinokiol were assigned the structures LIV, LV, and LVI, respectively, where R is CH_3 and R′ is CH_2OH, or R is CH_2OH and R′ is CH_3. The position of the phenolic hydroxyl group in LV and LVI was also uncertain; in addition, the double bond linkage and the position of the angular methyl group in hinokiol (LVI), which is a dihydroxyoctahydromethylretene, were not definite. Until a more comprehensive study of this problem appears, these structures are to be regarded as provisional.

LIV   LV

LVI
Hinokiol

9,10-Dihydroxyretene has been prepared by Bamberger (16) and by Knesch (96); the latter prepared it by reduction of the sodium bisulfite compound of retenequinone with iron or zinc dust and water, no acid or alkali being required. This hydroquinone is extremely sensitive to oxidation and is best isolated in the form of its diacetyl or dibenzoyl derivatives. Its instability had also been noticed by Ekstrand (53).

B. Carboxylic acids

Liebermann and Zsuffa (102) were the first to describe a retenecarboxylic acid. They synthesized it by the usual Friedel–Crafts reaction, from retene and oxalyl chloride, and reported its melting point as 121–123°C. It is possible that this melting point is a misprint for 221–223°C. This work was repeated by Komppa and Wahlforss (98), who obtained an acid, m. p. 229–231°C. (uncorrected) and oxidized it to the corresponding quinonecarboxylic acid, thus proving that the carboxyl group was not attached to C_9 or C_{10}. Bogert and Hasselstrom (33) obtained this retenecarboxylic acid, m. p. 237.5–238.5°C. (corrected), by the oxidation of acetylretene by sodium hypobromite.

The structure of this retenecarboxylic acid was established by Adelson and Bogert (1), who determined the position of the acetyl group in acetyl-retene as C_6 (see below). These authors (1) also simplified the synthesis of retene-6-carboxylic acid from 6-acetylretene by the use of an alkaline iodine–potassium iodide solution as the oxidant.

C. Sulfonic acids

The action of sulfuric acid on retene has been studied by a number of investigators. Fehling (55) noted that sulfur dioxide was evolved when retene was heated with concentrated sulfuric acid above 100°C., but could isolate no sulfonic acid. Fritzsche (70) was successful in isolating the barium salt of a retenedisulfonic acid, $C_{18}H_{16}(SO_3H)_2$, obtained by the action of a mixture of concentrated and fuming sulfuric acids on retene. Ekstrand (53) was able to identify the free disulfonic acid and its chloride. All his attempts to prepare a monosulfonic acid, in spite of the use of the most diversified experimental conditions, were fruitless.

In 1930 Komppa and Wahlforss (98) prepared two isomeric retene-sulfonic acids, $C_{18}H_{17}SO_3H$, designated as A-retenesulfonic acid and B-retenesulfonic acid, by adding concentrated sulfuric acid to vigorously stirred melted retene. At 100°C. the formation of the A-acid was favored, while at 200°C. the B-acid predominated. Fusion of the ammonium salts of these acids with potassium hydroxide gave the A- and B-retenols, whose structures have been established as 2- and 6-retenol, respectively, by Fieser and Young (61) (see above). Hence the acids in question are retene-2-sulfonic acid and retene-6-sulfonic acid.

The work of Komppa and Wahlforss (98) on the retenesulfonic acids has been extended by Komppa and Fogelberg (97) to 9,10-dihydroretene. Sulfonation of 9,10-dihydroretene yields two well-defined sulfonic acids whose ethyl esters give upon oxidation the ethyl 2-retenequinonesulfonate and ethyl 6-retenequinonesulfonate of Komppa and Wahlforss (98). This defines the dihydroretenesulfonic acids as 9,10-dihydroretene-2-sulfonic acid and 9,10-dihydroretene-6-sulfonic acid. Attempts to replace the sulfonic acid group of these acids by the hydroxyl group results in simultaneous dehydrogenation and consequent formation of the corresponding retenols, the 2- and 6-retenols.

Hasselstrom and Bogert (74) have been interested in opening a path to a successful synthesis of thioindigoids from retene. 6-Retenesulfonyl chloride (98) was reduced by zinc and sulfuric acid to 6-thioretenol (6-retyl mercaptan), and this mercaptan was condensed with chloroacetic acid to 6-retylthioglycolic acid (LVII). When this thioglycolic acid was subjected to the action of chlorosulfonic acid, there resulted a very un-

stable thioindoxyl (LVIII) and a disulfonic acid of the corresponding thioindigo. In alkaline solution the thioindoxyl (LVIII) was oxidized to an amorphous dark solid, presumably 6-retenethioindigo (LIX), which resisted purification and which, therefore, could not be positively identified. The retenethioindoxyl (LVIII) condensed readily at $C_{1'}$ (formula LVIII) with various aldehydes to yield thioindogenides and with isatin to yield 6-retothiophene-3-indoleindigo. These condensation products, which also could not be purified, exhibited tinctorial properties.

LVII
6-Retylthioglycolic acid

LVIII

LIX
6-Retenethioindigo (?)

D. Nitro and amino derivatives

Attempts by various investigators to obtain crystalline nitro derivatives by the direct nitration of retene itself have not been very successful, the results in most cases having been either tars or oxidation products (22, 55, 68, 103). Ekstrand (53) obtained a yellow, flocculent precipitate when he diluted the acid mixture upon completion of the nitration of retene, but it resinified when crystallization was attempted. Arnot (9) obtained a similar product, which he stated to be a dinitroretene, for he reduced it to a base (10) from which azo dyes were prepared by the usual reactions. He claimed also the production of a nitroretenesulfonic acid by nitration of retene dissolved in a 20 per cent oleum, and of a dinitro-retenequinone from the quinone, but none of these products appears to have been either crystalline or analytically pure. A dinitroretenequinone has been reported by Li Man Cheung (103).

Heiduschka and Scheller (83) have reported a nitrotribromoretenequinone, and Bogert and Hasselstrom (32) a crystalline dinitro-6-acetylretene. The latter authors (34) have also prepared mononitro derivatives of 6-acetoxyretene and of retene ketone (1-methyl-7-isopropylfluorenone), both of which were reduced to the corresponding amines. The amino-6-acetoxyretene was very unstable, but yielded a stable, crystalline acetyl derivative. Fieser and Young (61) found that 5-amino-6-retenol was similarly unstable, and they also resorted to acetylation to obtain a crystalline pure product. Bamberger and Hooker (22, page 144) have shown that 1-methyl-7-isopropylfluorene (retenefluorene) yields without difficulty a dinitro derivative. More recently Komppa and Wahlforss (98) have reported unsuccessful attempts to prepare a crystalline nitro derivative of retene.

From the foregoing it is apparent that, while retene itself yields no good nitration products, substituted retenes can be nitrated with success.

Only one amino derivative of retene is known, 6-aminoretene (LXXIX) (1), a stable crystalline substance which is made by hydrolysis of 6-acetylaminoretene (LXXVIII), a compound resulting from the Beckmann rearrangement of 6-acetylretene oxime (LXXVII) (see below).

E. Halogenated derivatives

The recorded literature contains but little systematic work on the halogen derivatives of retene. Such work was initiated by Ekstrand (53) in 1877. Ekstrand discussed the formation of additive compounds of retene with chlorine and bromine, and stated that the dichloride produced with chlorine appeared to be convertible into a monochlororetene. A dibromoretene was prepared by the action of bromine on retene in aqueous suspension, while a tetrabromo derivative was produced when excess bromine was used hot. Heiduschka and Scheller (83) oxidized tetrabromoretene and obtained a tribromoretenequinone, thus indicating that one of the bromine atoms in the original compound was at C_9 or C_{10}. These authors prepared a number of derivatives of this quinone.

By passing chlorine into a carbon tetrachloride solution of retene in the sunlight and in the presence of iodine, Heiduschka and Grimm (80) obtained a retenenonachloride, $C_{18}H_9Cl_9$. This was a white, amorphous powder, m. p. 98–100°C., which was soluble in the usual organic solvents and which was stable toward chromic acid and nitric acid in acetic acid solution.

Chlorination of retene in carbon tetrachloride solution gave 9(or 10)-chlororetene (98), which yielded retenequinone upon oxidation. Boiling the chlorinated product with alcoholic potassium hydroxide or with quinoline did not split off hydrogen chloride, nor could the chlorine atom

be replaced by iodine by treatment with sodium iodide in acetone or in glacial acetic acid solution. No crystalline products were obtained when the 9(or 10)-chlororetene was nitrated or sulfonated. Attempts to obtain a monohydroxyretene from this monochlororetene by Grignard's reaction gave no identifiable products. Attempts to prepare a methylretene from this monochlororetene and methyl iodide with sodium in absolute ether were likewise unsuccessful. The foregoing indicates the stability of the C—Cl linkage and the unreactivity of the chlorine atom in 9(or 10)-chlororetene.

A mixture of mono-, di-, tri- and hexa-chlororetenes has recently been recommended for use in petroleum lubricants (148). Such a mixture of chlorinated retenes is added to a hydrocarbon lubricating base and has been proposed for high pressure or other purposes.

F. Retenequinone

Retenequinone (II) was first recognized as the quinone obtained by the oxidation of retene by Bamberger and Hooker (19, 20). Earlier workers had published confusing accounts of the nature of the quinone (15, 52, 54, 146).

Retenequinone crystallizes in flat, orange prisms, m. p. 197°C. Valeur (142) has measured its heat of formation and its heat of combustion at constant volume and at constant pressure. The quinone is best prepared by oxidizing retene with chromic anhydride in acetic acid solution (22, page 116). Fieser and Young (61) have recommended that retenequinone be purified through its sodium bisulfite addition compound (53), which liberates the quinone upon acidification. Its sodium bisulfite addition compound is also described by Knesch (96).

Retenequinone reacts with o-phenylenediamine to give the quinoxaline (22, page 123). Its product with ethylenediamine has been described by Mason (107). With arylhydrazinesulfonic acids it yields dyes whose shades vary from orange-red to blue-red (8).

The monophenylhydrazone of retenequinone has been prepared by Bamberger and Grob (18). Its p-nitrophenylhydrazone has been reported by Li Man Cheung (103), and its semicarbazone and aminoguanidine derivatives by Heiduschka and Scheller (83). The dioxime of retenequinone has been described by Bamberger (16).

In an effort to cast light on the structure of retene, Lux (105) studied the Beckmann rearrangement of the monoöxime of retenequinone (LX) (22, page 122). When treated with hydrogen chloride in a mixture of acetic acid and acetic anhydride, the oxime yielded chiefly a methylisopropylbiphenylenenitrilocarboxylic acid (LXI), m. p. 112–114°C.,

together with a small amount of the corresponding methylisopropyl-diphenamic acid (LXII). The latter was also obtained by boiling the nitrilocarboxylic acid (LXI) with alcoholic potassium hydroxide. Thionyl chloride converted the nitrilocarboxylic acid (LXI) into the corresponding acid chloride, which furnished methylisopropylbiphenylenenitriloamide (LXIII) when treated with ammonium hydroxide. Dilute alcoholic potassium hydroxide hydrolyzed the nitriloamide (LXIII) to the methyl-isopropylbiphenylenediamide (LXV). In one experiment Lux obtained the isomeric methylisopropyldiphenamic acid (LXIV) by the action of alcoholic potassium hydroxide on the nitriloamide (LXIII). The positions of the methyl and isopropyl groups relative to the other substituting groups in these compounds are uncertain. R = $(CH_3)_2CH$— and R' = CH_3—, or *vice versa*, in formulas LX through LXV.

$$RC_6H_3C{=}NOH$$
$$R'C_6H_3CO$$
LX
Retenequinone monoöxime

$\longrightarrow$

$$RC_6H_3CN$$
$$R'C_6H_3COOH$$
LXI

(Two steps)
$\longrightarrow$

$$RC_6H_3CN$$
$$R'C_6H_3CONH_2$$
LXIII

$\longrightarrow$

$$RC_6H_3CONH_2$$
$$R'C_6H_3CONH_2$$
LXV

$$RC_6H_3CONH_2$$
$$R'C_6H_3COOH$$
LXII

$$RC_6H_3COOH$$
$$R'C_6H_3CONH_2$$
LXIV
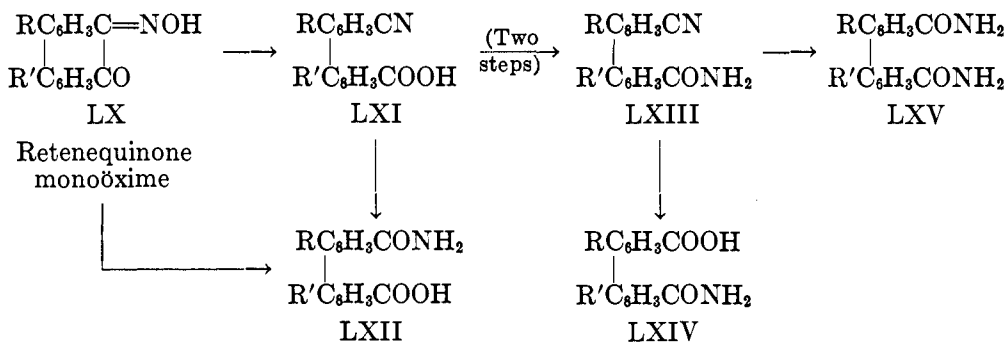
Werner and Piquet (151) obtained in poor yield a methylisopropyl-biphenylenenitrilocarboxylic acid, m. p. 195°C., by the action of benzene-sulfonyl chloride on retenequinone monoöxime in pyridine solution. This nitrilocarboxylic acid was evidently isomeric with that (LXI) of Lux (105).

Bucher's brilliant work (39) establishing the structure of retene appeared almost simultaneously with Lux's (105) studies on the Beckmann rearrangement of retenequinone monoöxime. A few months later Lux published a more lengthy account of his work (106), together with the results of an extension of his experiments. By assuming that the iso-nitroso group (=NOH) in retenequinone monoöxime is at C_9 (1-methyl-7-isopropylphenanthraquinone-9-monoöxime), Lux assigned structures to the previously described compounds (LX through LXV). In formulas LX through LXV, Lux regarded R as $(CH_3)_2CH$— and R' as CH_3—. His assumption was based on the observation that neither the nitrilo-carboxylic acid (LXI) nor the diphenamic acid (LXII) could be esterified

by means of alcohol and concentrated sulfuric acid. From this he concluded that the carboxyl group in LXI and LXII must be ortho to both the methyl group (R') and the biphenyl linkage, and therefore could not be esterified because of steric hindrance. This additional evidence does not seem to be of sufficient weight to establish the structures of the compounds in question (LX through LXV), and the definition of R as $(CH_3)_2CH—$ and R' as $CH_3—$ must be regarded as provisional.

The Hofmann degradation of the diamide (LXV) yielded the expected 2,2'-diamino-3-methyl-4'-isopropylbiphenyl (LXVI). When Lux tetrazotized this diamino compound and decomposed the tetrazonium salt thus produced under conditions usually employed for hydrocarbon formation, he did not obtain the expected 3-methyl-4'-isopropylbiphenyl. Instead, 1-methyl-7-isopropylcarbazole (LXVII) was secured.

LXVI
2,2'-Diamino-3-methyl-4'-
isopropylbiphenyl

LXVII
1-Methyl-7-
isopropylcarbazole
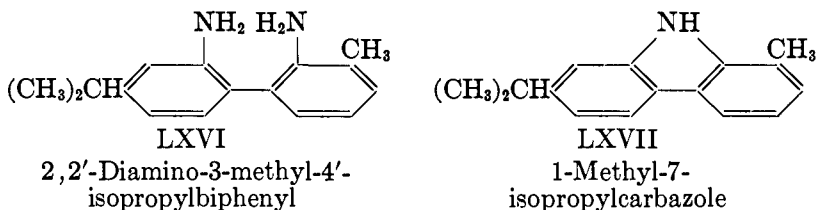
Bamberger and Hooker (22, page 145) have reported the behavior of retenequinone on further oxidation. Potassium permanganate oxidation yielded 7-(α-hydroxyisopropyl)fluorenone-1-carboxylic acid (VI), fluorenone-1,7-dicarboxylic acid (VII), 1-methyl-7-isopropylfluorenone, oxalic acid, and other products. The quinone was reduced to retene by phosphorus and hydriodic acid.

Retenequinone yields reteneglycolic acid (III) when boiled with strong aqueous alkali (22, page 132) or with 10 per cent methyl alcoholic potassium hydroxide (104). By fusion of the quinone with potassium hydroxide and lead peroxide, Lux (104) obtained 4'-isopropyl-3-methylbiphenyl-2-carboxylic acid (IV).

By the action of suitable organomagnesium halogen compounds on retenequinone, Heiduschka and Grimm (80) have prepared a number of 9,10-dihydroxy-9,10-diaryl(or dialkyl)-9,10-dihydroretene derivatives. 9,10-Dihydroxy-9,10-diphenyl-9,10-dihydroretene (LXVIII) yielded an anhydride (LXIX) when treated with acetyl chloride. When the dihydroxy compound (LXVIII) was heated with zinc dust, 9,10-diphenylretene was formed. Reduction of LXVIII with hydriodic acid and red phosphorus yielded a 9,10-diphenylhexahydroretene, and finally a retenedodecahydride (101).
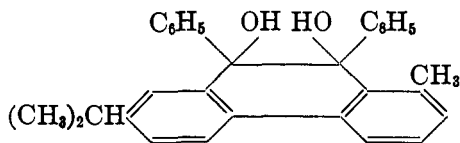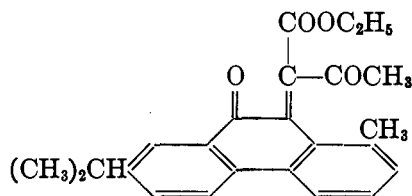
LXVIII
9,10-Dihydroxy-9,10-diphenyl-
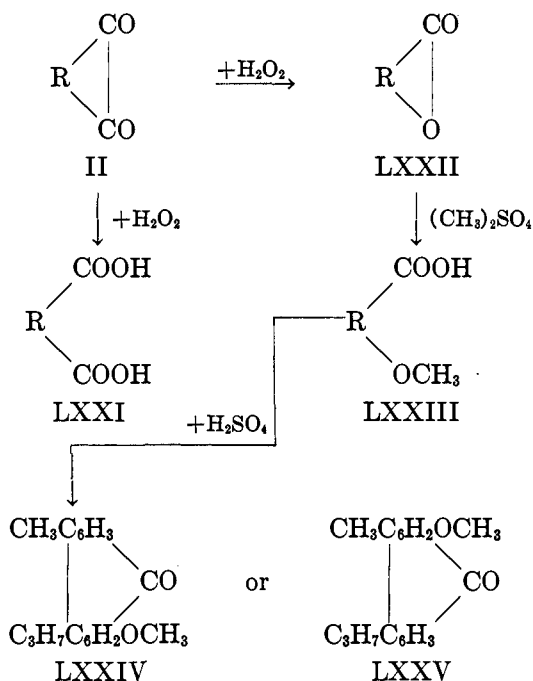9,10-dihydroretene
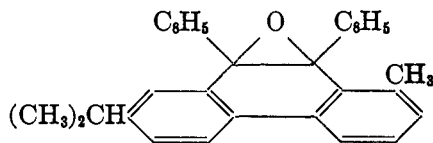
LXIX

LXX
Ethyl retoxyleneacetoacetate

Retenequinone condenses with ketones in the presence of aqueous or alcoholic potassium hydroxide (81). Heiduschka and Khudadad have prepared a wide variety of such condensation products. The structures of the latter have not been absolutely established. When retenequinone is boiled with acetoacetic ester in alcoholic solution in the presence of a little piperidine or potassium hydroxide, ethyl retoxyleneacetoacetate (LXX) is formed (82). A number of reactions and derivatives of this product have been investigated.

Adelson, Hasselstrom, and Bogert (6) have studied the oxidation of retenequinone in glacial acetic acid by means of 30 per cent hydrogen peroxide. Two substances were obtained, retenediphenic acid (LXXI) and a small amount of a lactone by-product. The latter, a methyliso-propylhydroxybiphenylcarboxylic lactone (LXXII), was identified as such by conversion into the methylisopropylmethoxybiphenylcarboxylic acid (LXXIII), and this in turn into the methylisopropylmethoxyfluo-renone-9 (LXXIV or LXXV). In the formulas shown at top of next page, the residue $CH_3C_6H_3C_6H_3C_3H_7$ is represented by R.

Retenediphenic acid was found to behave as a true diphenic acid and to resemble phthalic acid in the formation of artificial resins with glycerol or borneol. The acid had previously been obtained by Fogelberg (63) as a syrupy oxidation product when retenequinone was oxidized with hydrogen peroxide. The desired acid could be obtained in crystalline condition only by conversion to the anhydride, followed by purification and hydrolysis of the latter.

$$R\underset{CO}{\overset{CO}{\diagup}}\Big| \qquad \xrightarrow{+H_2O_2} \qquad R\underset{O}{\overset{CO}{\diagup}}\Big|$$

II   LXXII

$$\Big\downarrow +H_2O_2 \qquad\qquad\qquad \Big\downarrow (CH_3)_2SO_4$$

$$R\underset{COOH}{\overset{COOH}{\diagup}} \qquad\qquad R\underset{OCH_3}{\overset{COOH}{\diagup}}$$

LXXI   +H₂SO₄   LXXIII

$$\underset{C_3H_7C_6H_2OCH_3}{\overset{CH_3C_6H_3}{\Big|}}CO \qquad or \qquad \underset{C_3H_7C_6H_3}{\overset{CH_3C_6H_2OCH_3}{\Big|}}CO$$

LXXIV   LXXV

G. 6-Acetylretene

Of all the derivatives of retene which have been prepared to date one of the most important is 6-acetylretene (LXXVI). As a synthetic intermediate, 6-acetylretene has proven to be of inestimable value. Its worth as a point of departure in proof of structure work is equally great, and it can be stated without reservation that this important compound has been very instrumental in guiding the course of much synthetic activity in progress during the past year.

6-Acetylretene (1, 32) is the only acetylated retene of established structure that is known at present. The acetylation of 9,10-dihydroretene (114) has been investigated by Nyman. Freund and Fleischer (65) have reported a "retenediethylindandione" from retene, diethylmalonyl chloride, and aluminum chloride. Neither Freund and Fleischer nor Nyman have proven the structure of their products. Another acetylated compound of unestablished structure was obtained by Perrier (117). He reported that the compound $(C_6H_5COCl)_2Al_2Cl_6$, obtained by heating benzoyl chloride with aluminum chloride in carbon bisulfide, reacted with retene to form a compound, $(C_6H_5COC_{18}H_{17})_2Al_2Cl_6$.

The preparation of a condensation product of retene with formaldehyde, said to be suitable for tanning, has been patented (14).

The synthesis of 6-acetylretene was developed by Bogert and Hasselstrom (32). It involved the Friedel–Crafts reaction between retene, acetyl chloride, and aluminum chloride in carbon bisulfide solution. The yield and technique of the synthesis were improved by Adelson and Bogert (1), who also established the structure of the compound by a sequence of reactions discussed in the following paragraph. Recently a patent (147) has appeared in which nitrobenzene is used as a solvent in the acetylation of retene.

6-Acetylretene oxime (LXXVII) (32) was rearranged to 6-acetylaminoretene (LXXVIII) (1) by means of the well-known Beckmann rearrangement. The latter compound was hydrolyzed by alcoholic potassium hydroxide, and the 6-aminoretene (LXXIX) thus formed was converted into 6-retenol (XLIV) through the agency of the diazo reaction. 6-

LXXVI
6-Acetylretene

LXXVII
6-Acetylretene oxime

LXXVIII
6-Acetylaminoretene

LXXX
6-Acetoxyretene

XLIV
6-Retenol

LXXIX
6-Aminoretene
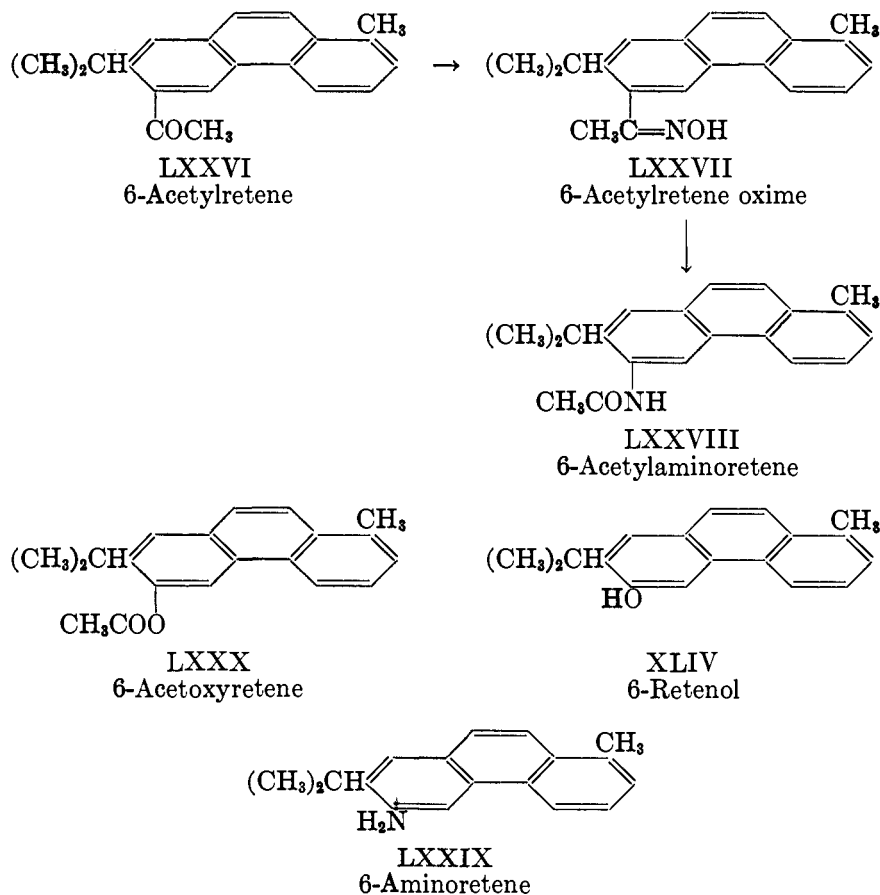
Retenol (XLIV) was acetylated, and both the acetylated product, 6-acetoxyretene (LXXX), and the parent phenol were found to be identical with authentic specimens of the materials prepared by other means (61, 98).

The Beckmann rearrangement of a ketoxime has been applied very recently and independently by several investigators to the preparation of phenanthryl amines (1, 12, 112).

As in acetophenone, the terminal group of 6-acetylretene was very reactive and condensed smoothly with various aldehydes to chalcone types, some of which possessed tinctorial properties (32). Bromination of 6-acetylretene gave 6-ω-bromoacetylretene and 6-ω-dibromoacetyl-retene (5). 6-Acetylretene was also found to undergo the Reformatsky reaction (3, 4) (see below).

By the method of Wolff (153) 6-acetylretene semicarbazone was easily reduced to 6-ethylretene (32).

The oxidation of 6-acetylretene to retene-6-carboxylic acid (1, 33) has been discussed above.

H. Polynuclear compounds

By fusion with selenium the so-called "Diels' hydrocarbon" (3'-methyl-1,2-cyclopentenophenanthrene) has been obtained from such biologically interesting and chemically important compounds as cholesterol, ergosterol, lumisterol, isopyrovitamin, pyrocalciferol, cholic acid, strophanthidin, gitogenin, anhydrouzarigenin, sarsasapogenin, and pseudobufotalin.

Since retene is itself a natural product containing the methyl and iso-propyl groups, two radicals which are frequently found associated in natural products and which seem to have some significant function in nature, Adelson and Bogert (3, 4, 5) have launched a program involving the synthesis of polynuclear hydrocarbons derived from retene. This has thus far included the synthesis of 3'-methyl-5,6-cyclopentenoretene (LXXXV) (3, 4) and 5,6-benzoretene (XCII) (5). The former is of significance because it is a methyl isopropyl homolog of the Diels' hydro-carbon; the latter, 5,6-benzoretene (XCII), is of considerable interest because it is a methyl isopropyl homolog of 3,4-benzophenanthrene (42), which possesses considerable carcinogenic activity and which is the simplest carcinogenic substance yet encountered (27).

(1)   3'-Methyl-5,6-cyclopentenoretene

This hydrocarbon has been synthesized by Adelson and Bogert (3, 4). The Reformatsky reaction involving 6-acetylretene (LXXVI), ethyl bromoacetate, and zinc dust yielded a hydroxy ester which was hydrolyzed to β-hydroxy-β-6-retylbutanoic acid (LXXXI). The hydroxy acid

(LXXXI) was dehydrated by means of acetic anhydride to β-6-retyl-crotonic acid (LXXXII), which was then reduced to β-6-retylbutanoic acid (LXXXIII). Cyclization of the acid chloride of the latter through the agency of aluminum chloride in benzene solution gave 1'-keto-3'-methyl-5,6-cyclopentenoretene (LXXXIV). This cyclic ketone was converted into 3'-methyl-5,6-cyclopentenoretene (LXXV) by means of the Clemmensen reduction.

$(CH_3)_2CH$ ⟨ ... CH_3 ⟩ (two steps) → $(CH_3)_2CH$ ⟨ ... CH_3 ⟩
CH_3CO CH_3CCH_2COOH
             OH

LXXVI   LXXXI
6-Acetylretene   β-Hydroxy-β-6-retylbutanoic acid

$(CH_3)_2CH$ ⟨ ... CH_3 ⟩ ← $(CH_3)_2CH$ ⟨ ... CH_3 ⟩
CH_3CHCH_2COOH $CH_3C{=}CHCOOH$

LXXXIII   LXXXII
β-6-Retylbutanoic acid   β-6-Retylcrotonic acid

$(CH_3)_2CH$ ⟨ ... CH_3 ⟩ → $(CH_3)_2CH$ ⟨ ... CH_3 ⟩
CH_3CH CO CH_3CH CH_2
$\underset{(3')}{}$ $\underset{(1')}{}$
CH_2 CH_2
(2')

LXXXIV   LXXXV
          3'-Methyl-5,6-cyclopentenoretene
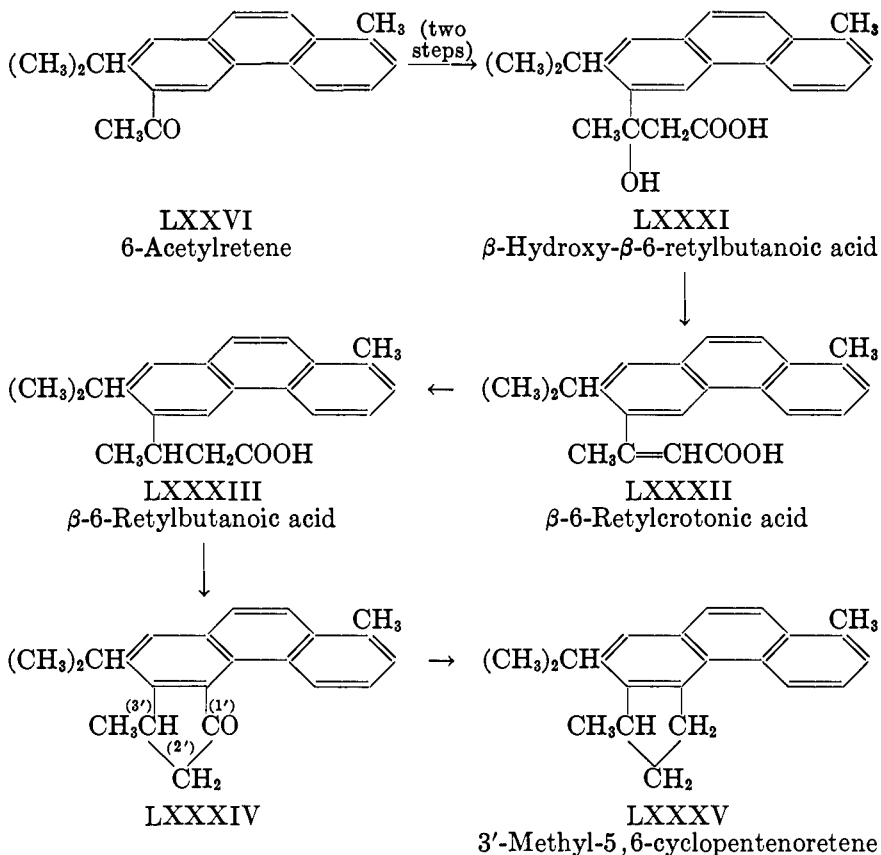
Inasmuch as 6-acetylretene was used as the starting material, the structure of 3'-methyl-5,6-cyclopentenoretene (LXXXV) was defined at once. Since C_7 was occupied by the isopropyl group, only C_5 was available for ring closure. The same reasoning applies to 5,6-benzoretene, which is discussed below.

$(CH_3)_2CH$ [structure] CH_3

I
Retene

(two steps) →

$(CH_3)_2CH$ [structure] CH_3

CH_2BrCO

LXXXVI
6-ω-Bromoacetylretene

(two steps) →

$(CH_3)_2CH$ [structure] CH_3

OC — CH_2—CH $\begin{array}{c} COOH \\ COOH \end{array}$

LXXXVII
6-Retacylmalonic acid

$(CH_2CO)_2O$
$AlCl_3$

$(CH_3)_2CH$ [structure] CH_3

OC $COOH$
CH_2—CH_2

LXXXVIII
β-6-Retoylpropanoic acid

→

$(CH_3)_2CH$ [structure] CH_3

H_2C $COOH$
CH_2—CH_2

LXXXIX
γ-6-Retylbutanoic acid

→

$(CH_3)_2CH$ [structure] CH_3

O

XC

(two steps)

$(CH_3)_2CH$ [structure] CH_3

XCI
1′,2′,3′,4′-Tetrahydro-5,6-benzoretene

←

$(CH_3)_2CH$ [structure] CH_3

XCII
5,6-Benzoretene

(2) 5,6-Benzoretene

5,6-Benzoretene (XCII) has been synthesized by Adelson and Bogert (5) by a series of steps, starting with retene (I). The bromination of 6-acetylretene (LXXVI) gave 6-ω-bromoacetylretene (LXXXVI) and a small amount of 6-ω-dibromoacetylretene. The monobromo compound (LXXXVI) was condensed with sodiomalonic ester, and the resulting retacylmalonic ester was hydrolyzed to the corresponding 6-retacylmalonic acid (LXXXVII). Decarboxylation of the latter yielded β-6-retoyl-propanoic acid (LXXXVIII), which was identical with the keto acid obtained by the interaction of succinic anhydride, retene, and aluminum chloride in benzene solution. The keto acid (LXXXVIII) was reduced by the modified Clemmensen method to γ-6-retylbutanoic acid (LXXXIX). Treatment of the latter with phosphorus pentachloride followed by aluminum chloride gave 1'-keto-1', 2', 3', 4'-tetrahydro-5,6-benzoretene (XC); this keto compound was also obtained by the action of anhydrous stannic chloride on the acid (LXXXIX). The semicarbazone of this cyclic ketone (XC) was reduced by the method of Wolff (153) to 1', 2', 3', 4'-tetrahydro-5,6-benzoretene (XCI). The latter was smoothly dehydrogenated by sulfur to 5,6-benzoretene (XCII).

When retene was treated with pyrotartaric anhydride in the presence of aluminum chloride, α-methyl-β-6-retoylpropanoic acid (XCIII) resulted (5). Its structure was established by its synthesis from 6-ω-bromoacetyl-retene (LXXXVI) and sodio-methylmalonic ester in a manner similar to that described above for β-6-retoylpropanoic acid (LXXXVIII). The α-methyl-β-6-retoylpropanoic acid (XCIII) from both syntheses was identical. It was reduced by means of the modified Clemmensen method to α-methyl-γ-6-retylbutanoic acid (XCIV), which was cyclized by sulfuric acid to 1'-keto-2'-methyl-1',2',3',4'-tetrahydro-5,6-benzoretene (XCV). The ultimate goal is 2'-methyl-5,6-benzoretene.

In the course of experimental work on the synthesis of 5,6-benzoretene (XCII), Adelson and Bogert (5) investigated an alternate route leading to this hydrocarbon. The method involved was a modification of the von Auwers and Möller (11) adaptation of the Bougault synthesis (36) as employed by Fieser and Hershberg (58). Methyl γ-6-retylbutanoate (XCVI) was condensed with ethyl oxalate in the presence of sodium ethylate. The sodium salt of the reaction product was treated with 10 per cent sulfuric acid to yield the free keto ester (XCVII), which was subsequently cyclized by means of 3',4'-dihydro-5,6-benzoretene-1',2'-dicarboxylic acid anhydride (XCVIII). Dehydrogenation of the latter with sulfur gave 5,6-benzoretene-1',2'-dicarboxylic acid anhydride (XCIX), which could not be successfully decarboxylated.
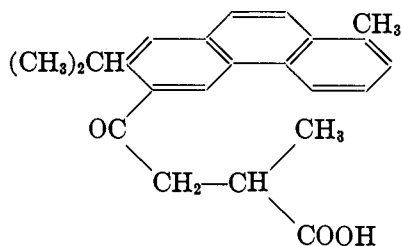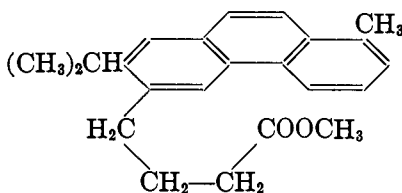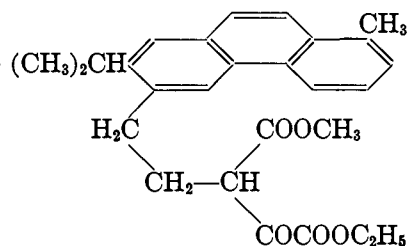
XCIII

α-Methyl-β-6-retoylpropanoic acid
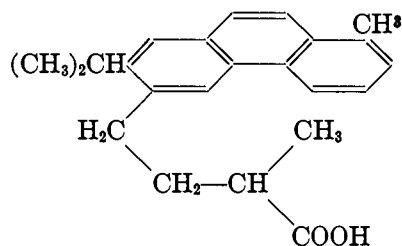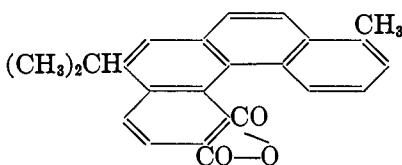
XCIV

α-Methyl-γ-6-retylbutanoic acid
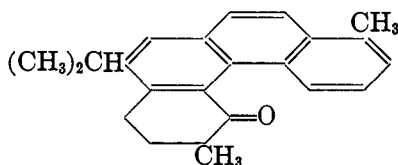
XCV
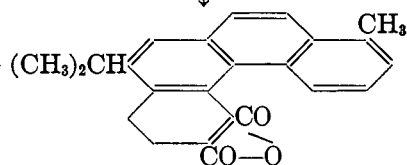
1'-Keto-2'-methyl-1',2',3',4'-tetrahydro-5,6-benzoretene

XCVI

Methyl γ-6-retylbutanoate

XCVII

XCIX

5,6-Benzoretene-1',2'-dicarboxylic
acid anhydride ·

XCVIII

VIII. CONCLUSION

A. Relation of retene to the terpenes

The sulfur dehydrogenation method first employed by Vesterberg (143) in obtaining retene from abietic acid has been of the greatest importance

in the investigation of other natural products. This method was highly instrumental in the determination of the structures of the dicyclic sesquiterpenes ($C_{15}H_{24}$), which have been found to yield either cadalene ($C_{15}H_{18}$; 1,6-dimethyl-4-isopropylnaphthalene) or eudalene ($C_{14}H_{16}$; 1-methyl-7-isopropylnaphthalene) (119, 123, 125). These two hydrocarbons, cadalene and eudalene, thus occupy key positions in relating the dicyclic sesquiterpenes and the naphthalene series.

It has also been shown that the monocyclic terpenes, such as terpinene and limonene, give *p*-cymene upon dehydrogenation with sulfur (125). *p*-Cymene stands in the same relationship to the monocyclic terpenes and the benzene series as do eudalene and cadalene in the case of the dicyclic sesquiterpenes and the naphthalene series.

It is highly probable that retene occupies a similar position in phenanthrene chemistry in relation to the diterpenes. Abietic acid, which may be regarded as a diterpene type, yields retene when heated with sulfur. Unfortunately, in this instance the sulfur dehydrogenation has not proven to be as fruitful in elucidating the structure of the parent compound as in the case of the sesquiterpenes. It is possible that the recent work on hinokiol (92, 154) may throw additional light on the relationship between retene and diterpenes.

B. Comparison of retene and phenanthrene

Retene does not generally behave as one would expect a methyl isopropyl homolog of phenanthrene to behave.

While retene itself yields only resinous products upon nitration, the nitration of phenanthrene in glacial acetic acid solution with diacetyl ortho nitric acid yields 9-nitrophenanthrene as the chief product, together with smaller amounts of the 2- and 4-nitro derivatives and a very small amount of the 3-nitro isomer (95, 130).

Only one amino derivative of retene is known, 6-aminoretene (1). Aminophenanthrenes, prepared as in the case of 6-aminoretene by hydrolysis of the product of the Beckmann rearrangement of the appropriate acetylphenanthrene oxime, have been synthesized where the amino group is at C_1, C_2, C_3, and C_9 (12, 112).

No systematic work has been done on the halogen derivatives of retene. Perhaps the only definitely known retyl halide is 9(or 10)-chlororetene (98). 9-Bromophenanthrene is an easily accessible compound. Other phenanthryl halides (1-, 2-, and 3-chloro, -bromo, and -iodo) have been prepared by diazotization of the appropriate amines (13, 60).

Sulfonation of retene gives acids with the sulfonic acid group at C_2 and C_6 (61, 98). The isomers formed in largest amount on sulfonating phenanthrene are the 2-sulfonic and the 3-sulfonic acids (the latter may also

be called the 6-sulfonic acid); the 1-sulfonic and the 9-sulfonic acid are also known (56, 86, 129, 150).

The acetylation of retene by means of the Friedel–Crafts reaction, using carbon bisulfide or nitrobenzene as the solvent, gives 6-acetylretene (1, 32, 147). Under similar conditions phenanthrene is converted mainly into resinous products. If nitrobenzene is used as the solvent, 2- and 3-acetylphenanthrenes are obtained in good yield (110).

In the presence of aluminum chloride, succinic anhydride and pyrotartaric anhydride condense smoothly with retene in benzene solution and give exclusively products containing substituents in the 6-position (5). When condensed with phenanthrene in nitrobenzene solution, these anhydrides yield principally the C_3 compounds (43, 79). In general, the results with phenanthrene indicate that C_3 (which may also be regarded as C_6) is particularly favored in the Friedel–Crafts reaction.

6-Retenecarboxylic acid is most conveniently prepared by the action of alkaline iodine–potassium iodide solution on 6-acetylretene (1). The 2- and 3-carboxylic acids of phenanthrene are formed in quantitative yield by the action of aqueous sodium hypochlorite solution on the appropriate acetyl compound (110, 111).

No retylaldehydes or retylnitriles are known. Distillation of potassium retene-6-sulfonate with potassium ferrocyanide in an attempt to prepare a nitrile gave no good product (61).

The readily available phenanthrols, 2- and 3-phenanthrols, are prepared from the sulfonates (56). 2- and 6-Retenols are synthesized in similar fashion (61, 98). While other phenanthrols are known, namely, 1-phenanthrol (56, 109, 135), 4-phenanthrol (28), and 9-phenanthrol (40, 44, 59, 71, 131, 134), the corresponding possible retenols are not known.

From the foregoing it is evident that substitution in the retene molecule takes place with far less formation of isomers than in the case of phenanthrene. Fieser and Young (61) state: "The alkyl groups (of retene) serve only to promote substitution at an adjacent position and thus to hinder the formation of a large number of isomers."

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