was added a solution of 3.0 g. of sodium nitrite in 10 ml. water. The temperature of the mixture was maintained at 0–5° during the addition of the sodium nitrite solution. After a period of 10 min., 45 ml. of freshly prepared copper (I) bromide[22] solution in hydrobromic acid was added to the mixture. A vigorous reaction followed the addition of the catalyst, and the red diazotized mixture became brown. The mixture was subsequently heated on the steam-bath for 30 min. and allowed to cool. The supernatant liquid was decanted off, and the brown residue was treated with hydrobromic acid and washed with water.

The crude black material was dissolved in benzene and the solution was chromatographed on an alumina column using benzene as the eluent. From the eluate was obtained 2.0 g. (52.4%) of crude 2-bromo-10-thiaxanthenone melting at 163–167°. Crystallization from ethanol gave 1.0 g. (26.2%) of pure product melting at 166–167°. A mixture melting point of this material (II) with I showed no depression. Oxidation of 2-bromo-10-thiaxanthenone (II) with 30% hydrogen peroxide in glacial acetic acid gave 2-bromo-10-thiaxanthenone-5,5-dioxide which showed no depression in melting point when admixed with either III or IV.

2-Chloro-10-thiaxanthenone. Treatment of 10 g. (0.0648 mol.) of *o*-mercaptobenzoic acid with excess chlorobenzene and concentrated sulfuric acid in an analogous manner as that described for the preparation of 2-bromo-10-thiaxanthenone (I) gave 8.6 g. (53.4%) of yellow solid melting at 152–153°.

Anal. Calcd. for $C_{13}H_7ClOS$: C, 63.30; H, 2.86. Found: C, 63.35, 63.41; H, 3.08, 3.15.

The infrared spectrum showed absorption bands at 6.06μ, 12.4μ, and 13.4μ, characteristic of the carbonyl, 1,2,4-trisubstitution and 1,2-disubstitution, respectively.

A Sandmeyer reaction on 2-amino-10-thiaxanthenone gave a 46% yield of 2-chloro-10-thiaxanthenone, m.p. 150–151.5°, which was identical with the *x*-chloro-10-thiaxanthenone obtained by the cyclization of *o*-mercaptobenzoic acid with chlorobenzene. Oxidation of 2-chloro-10-thiaxanthenone with 30% hydrogen peroxide in glacial acetic acid gave an 85% yield of 2-chloro-10-thiaxanthenone-5,5-dioxide, m.p. 226°. Ullmann and Lehner[9] prepared 2-chloro-10-thiaxanthenone-5,5-dioxide by cyclization of 4′-chloro-2-carboxydiphenyl sulfone and reported a melting point of 222°.

x-Methyl-10-thiaxanthenone. Reaction of toluene with *o*-mercaptobenzoic acid in a manner described for 2-bromo-10-thiaxanthenone (I) gave 7.9 g. (53%) of yellow solid melting 98–110°. Several crystallizations did not improve the melting point. Smiles and Davis[6] reported a melting point of 96–97° to the product they isolated from the reaction of *o*-mercaptobenzoic acid and toluene. 2-Methyl-10-thiaxanthenone[23] has a melting point of 123°.

An infrared analysis of the isomeric mixture showed absorption bands at 6.06μ, 12.4μ, and 13.4μ, characteristic of the carbonyl, 1,2,4-trisubstitution and 1,2-disubstitution, respectively.

2-Methyl-10-thiaxanthenone-5,5-dioxide and 3-methyl-10-thiaxanthenone-5,5-dioxide. Three and seven-tenths g. (0.0164 mol.) of *x*-methyl-10-thiaxanthenone was dissolved in 25 ml. of glacial acetic acid. To the solution was added 5 ml. of 30% hydrogen peroxide and the reaction mixture heated to reflux and maintained, with stirring for 4 hr. Pouring over ice gave 4.0 g. (94.7%) of yellow crystals melting at 158–190°. Fractional crystallization from ethanol gave 3.2 g. (76%) of 2-methyl-10-thiaxanthenone-5,5-dioxide,[10] m.p. 199°, lit. 199°, and 0.5 g. (12%) of yellow powder (V), m.p. 158.5–160°. The latter substance (V) gave absorption bands at 6.06μ, 12.4μ, and 13.4μ in the infrared which are characteristic of the carbonyl, 1,2,4-trisubstitution and 1,2-disubstitution, respectively.

Anal. Calcd. for $C_{14}H_{10}O_3S$: S, 12.38. Found: S, 12.33, 12.46.

Compound V could possibly be 3-methyl-10-thiaxanthenone-5,5-dioxide since the infrared did give absorption indicative of 1,2,4-trisubstitution and no absorption for 1,2,3-trisubstitution.

Acknowledgment. Infrared spectra were obtained through the courtesy of the Institute for Atomic Research, Iowa State College.

AMES, IOWA

---

[22] A. I. Vogel, "A Textbook of Practical Organic Chemistry," Longmans, Green and Co., New York, N. Y., 2nd ed., 1951, p. 186.

[23] F. Mayer, *Ber.*, **43**, 584 (1910).

[CONTRIBUTION FROM THE RESEARCH DEPARTMENT OF THE R. J. REYNOLDS TOBACCO CO.]

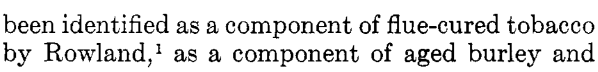
Composition of Cigarette Smoke. III. Phytadienes

ALAN RODGMAN

Received June 12, 1959

A series of isomeric conjugated phytadienes has been isolated from the cigarette smoke of a cased commercial blend of tobaccos. Evidence is presented to indicate that this series contains 3-methylene-7,11,15-trimethyl-1-hexadecene (neophytadiene), 3,7,11,15-tetramethyl-1,3-hexadecadiene, 2,6,10,14-tetramethyl-1,3-hexadecadiene, and a 1,2,4-trialkyl-1,3-butadiene and possibly as many as nine other conjugated phytadienes. Neophytadiene was the only phytadiene actually separated from the mixture. A similar series of phytadienes was observed in the cigarette smoke from flue-cured, burley, Turkish, and four other different commercial blends of tobacco.

The diterpene neophytadiene (I, $n = 3$) has



$$H(CH_2\overset{\overset{CH_3}{|}}{C}HCH_2CH_2)_nCH_2\overset{\overset{CH_2}{\|}}{C}CH{=}CH(CH_2\overset{\overset{CH_3}{|}}{C}HCH_2CH_2)_{3-n}H$$

I

been identified as a component of flue-cured tobacco by Rowland,[1] as a component of aged burley and flue-cured tobaccos and as a major component of the total volatile oils of aged burley and flue-cured tobaccos by Gladding *et al.*,[2a,2b] as a component of

---

[1] R. L. Rowland, *J. Am. Chem. Soc.*, **79**, 5007 (1957).

[2] (a) R. N. Gladding, W. B. Wartman, and H. E. Wright, Paper presented at the 11th Annual Tobacco Chemists' Research Conference, New Haven, Conn., Oct. 10–11, 1957. (b) R. N. Gladding, W. B. Wartman, and H. E. Wright, *J. Org. Chem.*, **24**, 1359 (1959).

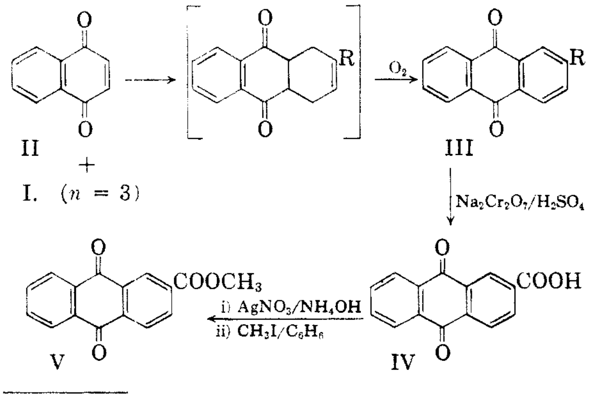
aged Japanese burley and flue-cured tobaccos by Onishi *et al.*,[3] and in the mainstream smoke of domestic cigarettes by Gladding *et al.*[2a,2b]

In a continuation of our study of the condensable portion of cigarette smoke from a cased commercial blend of tobaccos,[4,5] a hydrocarbon fraction was isolated by chromatographic separation of a base-free hexane soluble fraction of the cigarette smoke. Crystallization of this hydrocarbon fraction from acetone at −27° gave a mixture of solid saturated hydrocarbons whose melting point and infrared absorption suggested a mixture of *n*-heptacosane, *n*-nonacosane, *n*-hentriacontane, and *n*-tritriacontane. A similar mixture has been described by other investigators.[6]

Chromatography of the material in the filtrate permitted separation of a liquid unsaturated hydrocarbon fraction. Infrared studies of this fraction showed absorption at 6.07, 6.27, 7.25, 7.31, 10.10, 10.20, 10.38, 11.0, 11.1, and 11.25μ. These absorptions[1] and the order of elution on chromatography strongly suggested the presence in the hydrocarbon fraction of a mixture of phytadienes among which would be neophytadiene (I, $n = 3$).

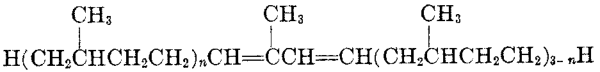
Further chromatography of this material gave seven main fractions, the fifth of which was essentially neophytadiene. The four fractions preceding the neophytadiene fraction showed infrared and ultraviolet absorption characteristics of mixtures of tri- and dialkyl-substituted 1,3-butadienes. These five fractions were designated as *Phytadiene Fractions V, W, X, Y, and Z.*

As the elucidation of the structure of neophytadiene (I, $n = 3$) was facilitated by a study of the oxidation of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl), the product obtained by air oxidation of the Diels-Alder adduct from I ($n = 3$) and 1,4-naphthoquinone (II),[1] this reaction sequence was employed in our study of the above-mentioned five phytadiene fractions.



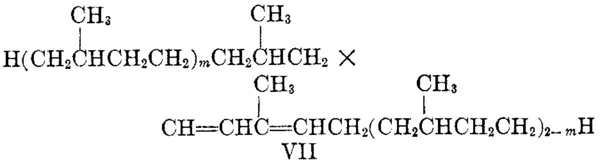
The Diels-Alder reaction of *Phytadiene Fraction V* with 1,4-naphthoquinone (II) followed by air oxidation of the adduct gave a low-melting solid derivative whose elemental analysis suggested that it was isomeric with 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl) obtained by similar treatment of neophytadiene (I, $n = 3$).[1] Further oxidation of III (R = 4,8,12-trimethyltridecyl) gave anthraquinone-2-carboxylic acid (IV),[1] whose identity was unequivocally established in our investigation by a mixture melting point study with an authentic sample, by infrared absorption analysis and by conversion to the known methyl ester.[7]

Further oxidation of the isomer of III (R = 4,8,12-trimethyltridecyl) using nitric acid yielded an acid whose identity was established by a mixture melting point study with anthraquinone-1,2,4-tricarboxylic acid (IX) and by conversion to trimethyl anthraquinone-1,2,4-tricarboxylate (X). The products obtained from this reaction sequence indicate that *Phytadiene Fraction V* probably contains phytadiene VI ($n = 1$ and/or 2) and/or VII ($m = 0$, 1, and/or 2) and the structure of the isomer of III (R = 4,8,12-trimethyltridecyl)



$$H(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_nCH{=}\overset{CH_3}{\overset{|}{C}}CH{=}CH(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_{3-n}H$$

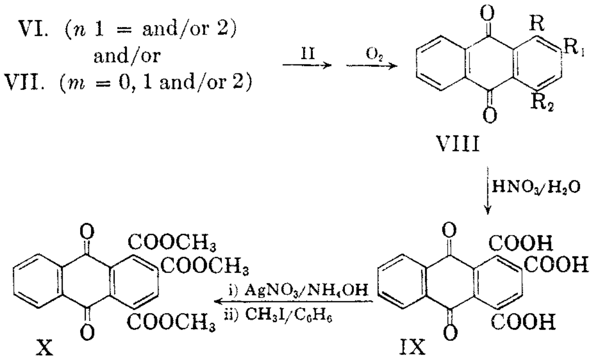
VI



$$H(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_mCH_2\overset{CH_3}{\overset{|}{C}}HCH_2 \times CH{=}CH\overset{CH_3}{\overset{|}{C}}{=}CHCH_2(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_{2-m}H$$

VII

must be such as to give a product of the general formula VIII. The melting range observed (39–42°) for the material designated as VIII suggested that a mixture was obtained. It should be noted that structures I ($n = 0$) and VI ($n = 0$) represent the same phytadiene.



The Diels-Alder reaction of *Phytadiene Fraction W* with 1,4-naphthoquinone (II) followed by air oxidation of the adduct gave an oil. Nitric acid

---

(3) I. Onishi, M. Nagamawa, H. Tomita, and T. Fukuzumi, *Bull. Agr. Chem. Soc. Japan,* **22,** 57 (1958).

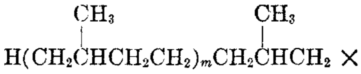
(4) A. Rodgman and L. C. Cook, *Tobacco Science,* **3,** 86 (1959).

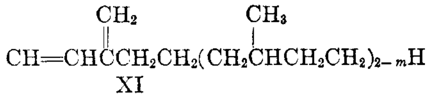
(5) A. Rodgman, L. C. Cook, and P. H. Latimer, *Tobacco Science,* **3,** 125 (1959).

(6) A. I. Kosak, J. S. Swinehart, and D. Taber, *J. Natl. Cancer Inst.,* **17,** 375 (1956).

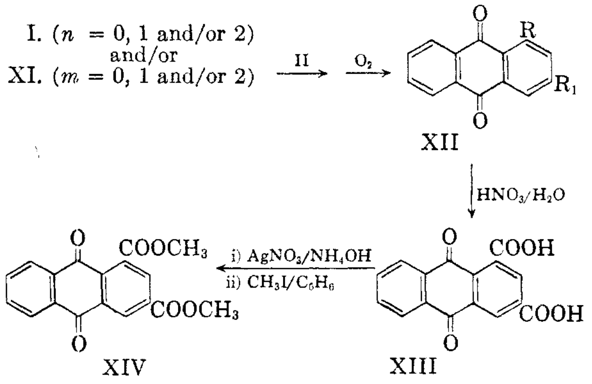
(7) P. Nawiasky and R. Robl (to I. G. Farbenind. A.-G.), Ger. Patent **609,401** (Feb. 25, 1935).

oxidation of this oil yielded a mixture of two acids which were separable by chromatography using silicic acid. One acid was anthraquinone-1,2,4-tricarboxylic acid (IX); the identity of the other acid was established by a mixture melting point study with anthraquinone-1,3-dicarboxylic acid (XIII) and by conversion to dimethyl anthraquinone-1,3-dicarboxylate (XIV). The products of this reaction sequence indicate that *Phytadiene Fraction W* contains the phytadiene I ($n=0$, 1, and/or 2) and/or XI ($m=0$, 1, and/or 2) as well as the phytadiene VI ($n=1$ and/or 2) and/or VII ($m=0$, 1, and/or 2). In addition to a substituted anthraquinone(s) represented by structure VIII, the oil arising from air oxidation of the Diels-Alder adduct must therefore contain a substituted anthraquinone(s) whose structure is represented by XII.


$\mathrm{H(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_{\mathit{m}}CH_2\overset{CH_3}{\overset{|}{C}}HCH_2}$ X

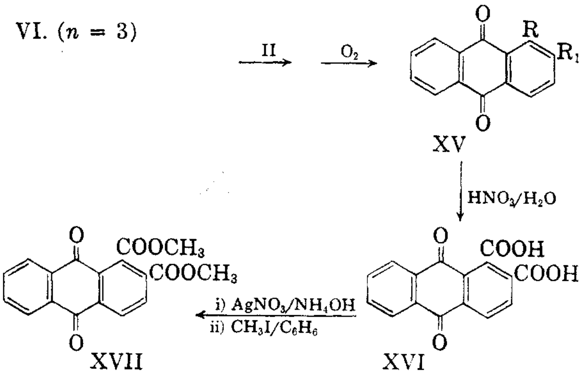

$\mathrm{CH{=}CH\overset{CH_2}{\overset{\|}{C}}CH_2CH_2(CH_2\overset{CH_3}{\overset{|}{C}}HCH_2CH_2)_{2-\mathit{m}}H}$

XI



The Diels-Alder reaction of *Phytadiene Fraction X* with 1,4-naphthoquinone (II) followed by air oxidation of the adduct yielded an oil. Nitric acid oxidation gave a mixture of three anthraquinone carboxylic acids. Two of these acids were identified as anthraquinone-1,2,4-tricarboxylic acid (IX) and anthraquinone-1,3-dicarboxylic acid (XIII). The identity of the third acid was established by a mixture melting point study with anthraquinone-1,2-dicarboxylic acid (XVI) and by conversion to dimethyl anthraquinone-1,2-dicarboxylate (XVII).

The products of this reaction sequence indicate that *Phytadiene Fraction X* probably contains phytadiene VI ($n=3$) in addition to phytadiene VI ($n=1$ and/or 2) and/or VII ($m=0$, 1, and/or 2) and I ($n=0$, 1, and/or 2) and/or XI ($m=0$, 1, and/or 2).



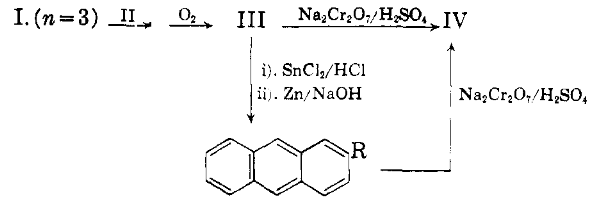
The mixture of alkyl-substituted anthraquinones obtained by air oxidation of the Diels-Alder adduct prepared from *Phytadiene Fraction X* probably contains the 1,2-dialkylanthraquinone (XV) which has to be identical with the 1-(3′, 7′,11′-trimethyldodecyl)-2-methylanthraquinone (XV, R = 3,7,11-trimethyldodecyl, $R_1 = CH_3$) described by Rowland.[1]

The Diels-Alder reaction of *Phytadiene Fraction Y* with 1,4-naphthoquinone (II) followed by air oxidation of the adduct also yielded an oil. Nitric acid oxidation of an aliquot yielded a mixture of at least three acids which were identified by mixture melting point and infrared absorption studies as anthraquinone-2-carboxylic acid (IV), anthraquinone-1,3-dicarboxylic acid (XIII), and anthraquinone-1,2-dicarboxylic acid (XVI). The 2-carboxylic acid (IV) probably arises from the Diels-Alder reaction between neophytadiene (I, $n=3$) and 1,4-naphthoquinone (II), air oxidation of the adduct and nitric acid oxidation of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl).

Chromatography of the remaining air oxidized adduct using silicic acid gave several oily fractions, three of which eventually solidified. Elemental analyses of the three solids suggested that they were isomeric. One solid fraction, melting at 47–48°, was identified by mixture melting point and infrared absorption studies as 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl). Further oxidation yielded anthraquinone-2-carboxylic acid (IV) as described previously.[1] The second solid fraction, melting at 56–57°, was shown by mixture melting point and infrared absorption studies to be identical with the compound presumed by Rowland[1] to be 1-(3′,7′,11′-trimethyldodecyl)-2-methylanthraquinone (XV, R = 3,7,11-trimethyldodecyl, $R_1 = CH_3$) arising from 3,7,11,15-tetramethyl-1,3-hexadecadiene (VI, $n=3$). Further oxidation of this dialkyl-substituted anthraquinone yielded anthraquinone - 1,2 - dicarboxylic acid (XVI).

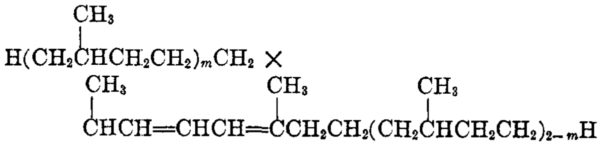
The third solid fraction, melting at 52–53°, is presumed to be 1-(2′,6′,10′-trimethyldodecyl)-3-anthraquinone (XII, R = 2,6,10-trimethyldodecyl, $R_1 = CH_3$) arising from 2,6,10,14-tetramethyl-1,3-hexadecadiene (I, $n=0$ or VI, $n=0$). Mixture melting point studies of the three isomers indicated that they were different from one another.

Phytadiene Fraction Z was shown by infrared and ultraviolet absorption studies to be neophytadiene (I, $n = 3$). Diels-Alder reaction of this fraction with 1,4-naphthoquinone (II) gave 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl). Reduction of this anthraquinone in two stages using stannous chloride-hydrochloric acid and zinc dust–sodium hydroxide[8] yielded 2-(4′,8′,12′-trimethyltridecyl)anthracene (XVIII, R = 4,8,12-trimethyltridecyl) whose ultraviolet absorption was typical of a monoalkylsubstituted anthracene. XVIII (R = 4,8,12-trimethyltridecyl) could also be converted to a hydrocarbon:trinitrofluorenone complex. Oxidation of either III (R = 4,8,12-trimethyltridecyl) or XVIII (R = 4,8,12-trimethyltridecyl) with dichromate in sulfuric acid gave anthraquinone-2-carboxylic acid (IV).



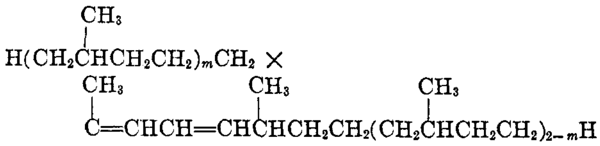
XVIII

No evidence has been obtained in our study to indicate that the six isomeric conjugated phytadienes represented by XIX and XX are present in the cigarette smoke investigated. It is felt that XIX and/or XX either would not react in the Diels-Alder reaction with 1,4-naphthoquinone or would react only slowly and incompletely. If so, these dienes would not be detected by the chemical methods used.



$$\mathrm{H(CH_2\overset{CH_3}{C}HCH_2CH_2)_{\mathit{m}}CH_2}\ \times$$
$$\mathrm{\overset{CH_3}{C}HCH{=}CHCH{=}\overset{CH_3}{C}CH_2CH_2(CH_2\overset{CH_3}{C}HCH_2CH_2)_{2-\mathit{m}}H}$$

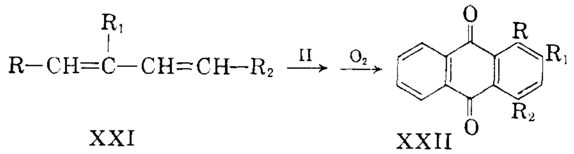
XIX



$$\mathrm{H(CH_2\overset{CH_3}{C}HCH_2CH_2)_{\mathit{m}}CH_2}\ \times$$
$$\mathrm{\overset{CH_3}{C}{=}CHCH{=}CH\overset{CH_3}{C}HCH_2CH_2(CH_2\overset{CH_3}{C}HCH_2CH_2)_{2-\mathit{m}}H}$$

XX

As the identification of the isomeric phytadienes in cigarette smoke depended to a large extent on the identity of the carboxy-substituted anthraquinones and their methyl esters, a brief study of the methyl-substituted anthraquinones and their corresponding acids and methyl esters was undertaken.



XXI XXII

$$\text{XXII } (\mathrm{R = R_2 = H,\ R_1 = CH_3}) \xrightarrow[\text{or } \mathrm{HNO_3}]{\mathrm{Na_2Cr_2O_7}} \text{IV}$$
$$\xrightarrow[\text{(ii) } \mathrm{CH_3I/C_6H_6}]{\text{(i) } \mathrm{AgNO_3/NH_4OH}} \text{V}$$

$$\text{XXII } (\mathrm{R_2 = H,\ R = R_1 = CH_3}) \xrightarrow{\mathrm{HNO_3}} \text{XVI}$$
$$\xrightarrow[\text{(ii) } \mathrm{CH_3I/C_6H_6}]{\text{(i) } \mathrm{AgNO_3/NH_4OH}} \text{XVII}$$

$$\text{XXII } (\mathrm{R = H,\ R_1 = R_2 = CH_3}) \xrightarrow{\mathrm{HNO_3}} \text{XIII}$$
$$\xrightarrow[\text{(ii) } \mathrm{CH_3I/C_6H_6}]{\text{(i) } \mathrm{AgNO_3/NH_4OH}} \text{XIV}$$

$$\text{XXII } (\mathrm{R = R_1 = R_2 = CH_3}) \xrightarrow{\mathrm{HNO_3}} \text{IX}$$
$$\xrightarrow[\text{(ii) } \mathrm{CH_3I/C_6H_6}]{\text{(i) } \mathrm{AgNO_3/NH_4OH}} \text{X}$$

2-Methylanthraquinone (XXII, $\mathrm{R = R_2 = H,\ R_1 = CH_3}$) has been prepared by intramolecular condensation of *o*-(4-methylbenzoyl)benzoic acid,[9,10] by condensation of 2-carbomethoxybenzoyl chloride and toluene,[11] and by air oxidation of the Diels-Alder adduct obtained from isoprene (XXI, $\mathrm{R = R_2 = H,\ R_1 = CH_3}$) and 1,4-naphthoquinone (II).[12] The anthraquinone-2-carboxylic acid (IV)[13,14] and its methyl ester (V)[7] have been described previously. 1,2-Dimethylanthraquinone (XXII, $\mathrm{R_2 = H,\ R = R_1 = CH_3}$) has been prepared by intramolecular condensation of *o*-(3,4-dimethylbenzoyl)benzoic acid[15,16] or *o*-(2,3-dimethylbenzoyl) benzoic acid[17] and by air oxidation of the Diels-Alder adduct from 1,2,6,6-tetramethyl-1,3-cyclohexadiene (β-pyronene) and 1,4-naphthoquinone.[18] The 1,2-dicarboxylic acid (XVI)[16,19] and its di-

---

(8) G. M. Badger and J. W. Cook, *J. Chem. Soc.*, **802** (1939).

(9) L. F. Fieser, *Org. Syntheses*, **4**, 43 (1925).

(10) L. Gresly, *Ann.*, **234**, 234 (1886).

(11) M. E. Smith, *J. Am. Chem. Soc.*, **43**, 1922 (1921).

(12) O. Diels, K. Alder, and G. Stein, *Ber.*, **62B**, 2337 (1929).

(13) M. A. Il'inskii, L. G. Gindin, and V. A. Kazakova, *Compt. Rend. Acad. Sci., U.R.S.S.*, **20**, 555 (1938).

(14) M. A. Il'inskii and V. A. Kazakova, *J. Gen. Chem.*, (*U.S.S.R.*), **11**, 16 (1941); *Chem. Abstr.*, **35**, 5487 (1941).

(15) E. D. Barnett and F. C. Morrison, *Ber.*, **64B**, 535 (1931).

(16) O. Fairbourne, *J. Chem. Soc.*, 1573 (1921).

(17) G. M. Badger, J. W. Cook, and F. Goulden, *J. Chem. Soc.*, 16 (1940).

(18) G. Dupont and R. Dulou, *Atti X° Congr. Internat. Chim.*, **3**, 129 (1939); *Chem. Abstr.*, **33**, 9312 (1939).

(19) R. Scholl and E. Schwinger, *Ber.*, **44**, 2992 (1911).

methyl ester (XVII)[20] have been described previously. 1,3-Dimethylanthraquinone (XXII, $R = H$, $R_1 = R_2 = CH_3$) has been prepared by intramolecular condensation of 2-benzoyl-4,6-dimethylbenzoic acid,[21] by rearrangement and intramolecular condensation of *o*-(2,5-dimethylbenzoyl)benzoic acid,[22] by intramolecular condensation of *o*-(2,4-dimethylbenzoyl)-benzoic acid,[10,23] and by air oxidation of the Diels-Alder adduct obtained from 2-methyl-1,3-pentadiene (XXI, $R = H$, $R_1 = R_2 = CH_3$) and II.[12] The 1,3-dicarboxylic acid (XIII) has been described.[24] 1,2,4-Trimethylanthraquinone (XXII, $R = R_1 = R_2 = CH_3$) has been prepared by intramolecular condensation of *o*-(2,4,5-trimethylbenzoyl)benzoic acid,[22] and by oxidation of 1,2,4-trimethylanthracene obtained by condensation of *p*-xylene and 2,3,4,5-tetramethyl-2,5-hexanediol.[25] Nitric acid oxidation of either XXII ($R = R_1 = R_2 = CH_3$)[20,23] or 1-formyl-2,4-dimethylanthraquinone[26] yields the 1,2,4-tricarboxylic acid (IX). The trimethyl ester (X) of IX has been described.[27]

In the preparation of the necessary reference compounds, we elected to employ the Diels-Alder reaction between II and XXI, followed by air oxidation of the adduct,[12] oxidation of the methyl-substituted anthraquinone to the acid[10,14,23] and esterification to the methyl ester by the method described by Cook.[20,28]

1,2-Dimethyl-(XXII, $R_2 = H$, $R = R_1 = CH_3$) and 1,2,4-trimethylanthraquinone (XXII, $R = R_1 = R_2 = CH_3$) were prepared by air oxidation of the adduct obtained from II and 3-methyl-1,3-pentadiene (XXI, $R_2 = H$, $R = R_1 = CH_3$) and 3-methyl-2,4-hexadiene (XXI, $R = R_1 = R_2 = CH_3$), respectively. 2-Methyl-(XXII, $R = R_2 = H$, $R_1 = CH_3$) and 1,3-dimethylanthraquinone (XXII, $R = H$, $R_1 = R_2 = CH_3$) were prepared by air oxidation of the adduct obtained from II and isoprene (XXI, $R = R_2 = H$, $R_1 = CH_3$) and 2-methyl-1,3-pentadiene (XXI, $R = H$, $R_1 = R_2 = CH_3$), respectively, as described by Diels *et al.*[12]

It has been suggested that neophytadiene (I, $n = 3$) arises from the breakdown of phytol (*ex* chlorophyll) in the tobacco leaf.[1,2b] The isomeric conjugated phytadienes indicated in our study are presumed to result from the thermal isomerization of neophytadiene during the smoking process. When neophytadiene (I, $n = 3$) is heated at 180° for 2.5 hr., the changes observed in the infrared absorption indicate the formation of a mixture of isomers similar to the phytadienes described by Rowland.[1] The infrared absorption of the thermally isomerized neophytadiene is quite similar to that of the gross phytadiene fraction obtained from the cigarette smoke. A similar alteration in the infrared absorption may be observed when a benzene solution of neophytadiene containing a catalytic amount of *p*-toluene sulfonic acid is refluxed. Treatment of a hexane solution of neophytadiene with dilute hydrochloric acid in a procedure analogous to that employed in the isolation of the phytadiene fraction from cigarette smoke did not result in isomerization of the neophytadiene.

As the infrared absorption indicated that the mixture of isomeric phytadienes was present in the cigarette smoke fraction prior to reaction with 1,4-naphthoquinone in the Diels-Alder addition, it was felt that isomerization did not occur during this reaction. However, further confirmation of this point was desired. A solution of neophytadiene (I, $n = 3$) and 1,4-naphthoquinone (II) in ethanol was refluxed and aliquots were withdrawn after 4, 8, 16, and 32 hr. Air oxidation yielded only 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (III, R = 4,8,12-trimethyltridecyl) determined by melting point, by infrared absorption and by conversion to anthraquinone-2-carboxylic acid (IV).

Discounting the optical isomers and the *cis*, *trans*, *cis-cis*, *trans-trans*, *cis-trans*, and *trans-cis* isomers, consideration of the isomerism of the conjugated phytadienes indicates that nineteen isomers are possible. These are described by structures I, VI, VII, XI, XIX, and XX. The reaction sequence employed in this study would not differentiate between the *cis* and *trans* isomers.

The evidence obtained in this study indicates that at least four of these isomers are present in cigarette smoke. These are (a) 3-methylene-7,11,15-trimethyl-1-hexadecene (neophytadiene) (I, $n = 3$), (b) 3,7,11,15-tetramethyl-1,3-hexadecadiene (VI, $n = 3$), (c) 2,6,10,14-tetramethyl-1,3-hexadecadiene (I, $n = 0$ or VI, $n = 0$), and (d) a 1,2,4-trialkyl-1,3-butadiene. The evidence herein presented could be presumed to indicate the presence in cigarette smoke of as many as thirteen of the isomeric conjugated phytadienes; namely, I ($n = 0,1,2,3$), VI ($n = 1,2,3$), VII ($m = 0,1,2$), and XI ($m = 0,1,2$). Again it should be noted that I ($n = 0$) and VI ($n = 0$) are identical. No evidence has been obtained to indicate the presence of the remaining six isomeric conjugated phytadienes, XIX ($m = 0,1,2$) and XX ($m = 0,1,2$).

No attempt was made to estimate the quantities in cigarette smoke of the phytadienes, I ($n = 3$), VI ($n = 3$), and I ($n = 0$), because of the uncertainty of the yields in the reaction sequence employed.

---

(20) J. W. Cook, *J. Chem. Soc.*, 1592 (1933).

(21) E. Louise, *Ann Chim. Phys.*, [6] **6**, 232 (1885).

(22) G. Baddely, G. Holt, and S. M. Makar, *J. Chem. Soc.*, 2415 (1952).

(23) K. Elbs, *J. Prakt. Chem.*, [2] **41**, 1, 121 (1890); *Bull. Soc. Chim.*, [2] 532 (1890).

(24) L. F. Fieser and E. L. Martin, *J. Am. Chem. Soc.*, **58**, 1443 (1936).

(25) B. J. Abadir, J. W. Cook, and D. T. Gibson, *J. Chem. Soc.*, 8 (1953).

(26) H. Diesbach, P. Lachat, M. Poggi, B. Baldi, R. Friderich, and H. Walker, *Helv. Chim. Acta*, **23**, 1232 (1940).

(27) A. Dansi, *Gazz. Chim. Ital.*, **67**, 85 (1937); *Chem. Abstr.*, **31**, 6227 (1937).

(28) J. W. Cook, *J. Chem. Soc.*, 2529 (1931).

EXPERIMENTAL[29]

Isolation of phytadienes. The smoking apparatus and smoking procedure have been described previously.[4,5] Two separate lots of cigarettes fabricated from the same commercial blend of tobaccos were smoked. Cigarettes A consisted of 20,000 cigarettes, Cigarettes B consisted of 32,000 cigarettes. After chemical fractionation, the so-called hexane soluble neutral acidic fraction[4,5] from Cigarettes A and the hexane soluble neutral fraction from Cigarettes B[4] were chromatographed in 15- to 16-g. aliquots using alumina. The material (3.0–3.5 g.) eluted by hexane (600 ml.) was combined to yield 9.0- to 10.0-g. samples and rechromatographed using alumina. Elution with hexane (275 ml.) gave 7.0 to 9.0 g. of a mixture of saturated and unsaturated hydrocarbons and an unsaturated alcohol. Combination of similar fractions from all the chromatograms gave 115 g. of this mixture. Two crystallizations from acetone at −27° gave 26.5 g. of normal saturated hydrocarbons, m.p. 62.5–64.5°. This mixture probably contains *n*-heptocosane, *n*-nonacosane, *n*-hentriacontane, and *n*-tritriacontane.[6]

The filtrate was concentrated at 40° using a water aspirator to yield 88 g. of a mixture of unsaturated hydrocarbons and alcohol(s) containing a trace of saturated hydrocarbons. Chromatography of this material on alumina using hexane as eluant yielded in order of elution: (a) 50.5 g. of a colorless free-flowing oil consisting of a mixture of unsaturated hydrocarbons, predominantly phytadienes; (b) 7.8 g. of a viscous unsaturated hydrocarbon mixture; (c) 8.2 g. of a viscous unsaturated hydrocarbon mixture; and (d) 11.35 g. of a viscous oil with infrared absorption indicative of an unsaturated alcohol.

Fractionation of phytadienes. The 50.5-g. sample described above was repeatedly chromatographed on alumina using pentane and hexane as eluants to give seven main fractions with the following weights: Fr. 1, 2.05 g.; Fr. 2, 6.85 g.; Fr. 3, 8.25 g.; Fr. 4, 6.70 g.; Fr. 5, 4.05 g.; Fr. 6, 10.60 g.; and Fr. 7, 7.22 g. In several instances, benzene and methanol were used to elute Fr. 6 and 7, respectively, as the major emphasis of this study is on Fr. 1 to 5.

On the basis of the similarity of their infrared absorption spectra to those of the phytadienes described by Rowland,[1] Fr. 1–5 were chosen for further study.

Fr. 1 was crystallized from acetone (10 ml.) at −27° to yield 0.23 g. of normal saturated hydrocarbons, m.p. 61–63°. The filtrate, designated as *Phytadiene Fraction V*, was concentrated to give a colorless, free-flowing oil with weak infrared absorption at 6.07, 11.0, and 11.28μ and moderately strong absorption at 10.38μ indicative of a *trans*-CH=CH grouping. Absorption was also present at 7.25 and 7.31μ. The ultraviolet absorption showed a maximum at 233 mμ, log ϵ 4.32.

Anal. Calcd. for $C_{20}H_{38}$: C, 86.25; H, 13.75. Found: C, 86.14; H, 13.56.

Fr. 2, designated as *Phytadiene Fraction W*, was a colorless oil with infrared absorption at 6.08, 6.25, 7.25, 7.31, 10.1, 10.38, 11.0, 11.1, and 11.23μ. The ultraviolet absorption showed a broad maximum from 228 to 232 mμ, log ϵ 4.25.

Fr. 3, designated as *Phytadiene Fraction X*, was a colorless oil with infrared absorption at 6.08, 6.25, 7.25, 7.31, 10.1, 10.35 (very weak), 11.1, and 11.22μ. The ultraviolet absorption showed a broad maximum from 225 to 228 mμ, log ϵ 4.28.

Fr. 4, designated as *Phytadiene Fraction Y*, was a colorless oil with infrared absorption at 6.07 (s), 6.25 (w), 7.25, 7.32, 10.1, and 11.2μ. The ultraviolet absorption showed a maximum at 225 to 228 mμ, log ϵ 4.30.

Fr. 5, designated as *Phytadiene Fraction Z*, was a colorless oil with infrared and ultraviolet spectra essentially the same as neophytadiene.[1,2b] Some infrared absorption was observed at 12.25μ. This was due to one of the main components of Fr. 6. Chromatography on alumina gave 3.76 g. of material with infrared absorption identical with that of neophytadiene.[1,2b]

Phytadiene Fraction V. Diels-Alder reaction with 1,4-naphthoquinone. A solution of 1.0 g. of *Phytadiene Fraction V* and 1.0 g. of 1,4-naphthoquinone in 35 ml. of ethanol was refluxed for 20 hr. A solution of 0.10 g. of potassium hydroxide in 10 ml. of ethanol was added and air was bubbled through the mixture for 6.0 hr. The mixture was concentrated under reduced pressure. Extraction with 35 ml. of hexane followed by chromatography using silicic acid gave (a) a diene mixture (0.75 g.), eluted by hexane, with infrared absorption essentially the same as the starting material; and (b) a pale yellow oil, the oxidized adduct (0.11 g.), eluted by 25:1 hexane:benzene. This oil subsequently solidified, m.p. 35–38°. Crystallization from methanol at −27° raised the melting point to 39–42° but did not reduce the melting range.

Anal. Calcd. for $C_{30}H_{40}O_2$: C, 83.28; H, 9.32. Found: C, 83.40; H, 9.30.

Anthraquinone-1,2,4-tricarboxylic acid (IX). A. *From the air oxidized adduct.* The air oxidized adduct (50 mg.), m.p. 39–42°, was oxidized with 3.0 ml. of 22% nitric acid at 250° for 3.5 hr. to yield 15 mg. of anthraquinone-1,2,4-tricarboxylic acid, m.p. softened at 195°, resolidified at 210°, melted at 316–318° (dec.).

Anal.[30] Calcd. for $C_{17}H_8O_8.H_2O$: C, 56.99; H, 2.81; neut. equiv., 119. Found: C, 56.02; H, 2.82; neut. equiv., 126, 127.[31a,31b]

A mixture melting point with an authentic sample of the 1,2,4-tricarboxylic acid gave melting characteristics identical with those of the authentic sample. The infrared absorption spectrum of this material was essentially the same as that of the authentic sample.

B. *From 1,2,4-trimethylanthraquinone.* 3-Methyl-2,4-hexadiene was prepared from 3-methyl-2-hexen-4-ol in 90% yield by the method of Abelmann.[32] A solution of 1,4-naphthoquinone (3.5 g., 0.022 mol.) and 3-methyl-2,4-hexadiene (6.0 g., 0.062 mol.) in 60 ml. of ethanol was refluxed for 12.0 hr. Addition of a solution of 1.1 g. of potassium hydroxide in 15 ml. of ethanol followed by air oxidation for 6.0 hr. yielded 2.7 g. (51%) of crude 1,2,4-trimethylanthraquinone, m.p. 157–158°. Crystallization from meth-

---

[29] All melting points were determined on a Fisher-Johns melting point apparatus. Elemental analyses were performed either by the Clark Microanalytical Laboratory, Urbana, Ill., or by the Huffman Microanalytical Laboratories, Wheatridge, Colo. Ultraviolet absorption spectra were determined using a Beckman DK2 Ratio Recording Spectrophotometer. Infrared absorption spectra were determined using a Perkin-Elmer Model 21 Spectrophotometer. The alumina employed was Aluminum Oxide Merck (Cat. No. 71707); the silicic acid was obtained from Mallinckrodt Chemical Works (Cat. No. 2844). Chromatograms involving material in excess of 1.0 g. employed approximately 45 mm. (diam.) × 200 mm. of adsorbent; those involving less than 1.0 g. employed approximately 24 mm. (diam.) × 100 mm. of adsorbent.

[30] Considerable difficulty was encountered in obtaining a satisfactory analytical sample of the 1,2,4-tricarboxylic acid prepared either from the air oxidized Diels-Alder adduct or from 1,2,4-trimethylanthraquinone. Diesbach *et al.* (ref. 26) reported the following analysis: Calcd. for $C_{17}H_8O_8$: C, 60.00; H, 2.37. Found: C, 60.25; H, 2.63.

[31] (a) R. H. Cundiff and P. C. Markunas, *Anal. Chem.*, **28**, 792 (1956). (b) This tribasic acid gave three inflections as expected on titration with tetrabutylammonium hydroxide in pyridine. (c) This dibasic acid gave two inflections as expected on titration with tetrabutylammonium hydroxide in pyridine. (d) This monobasic acid gave one inflection as expected on titration with tetrabutylammonium hydroxide in pyridine.

[32] P. Abelmann, *Ber.*, **43**, 1574 (1910).

anol raised the melting point to 161.5–162.0°. Melting points of 161°,[10] 162°,[22,23] and 155–158°[25] have been reported.

Anal. Calcd. for $C_{17}H_{14}O_2$: C, 81.59; H, 5.64. Found: C, 82.01; H, 5.58.

Chromatography on alumina of the material obtained in the mother liquor from the crystallization gave two fractions. In order of elution, these were (a) 0.11 g. of a pale yellow solid, m.p. 105–106°, and (b) 0.25 g. of a pale yellow crystalline solid, m.p. 161.5–162.0°. The low melting material gave an analysis compatible with $C_{17}H_{16}O_3$. No attempt was made to characterize this compound.

Anal. Calcd. for $C_{17}H_{16}O_3$: C, 76.69; H, 5.95. Found: C, 76.10; H, 6.01.

The second material was a further crop of 1,2,4-trimethylanthraquinone.

Anal. Calcd. for $C_{17}H_{14}O_2$: C, 81.59; H, 5.64. Found: C, 81.18; H, 5.53.

A suspension of 1,2,4-trimethylanthraquinone (0.4 g.) in 7.0 ml. of 22% nitric acid was heated at 255° for 6.0 hr. in a sealed tube to give 0.35 g. (64%) of the 1,2,4-tricarboxylic acid,[10,22] m.p. softened at 197°, resolidified at 212° and melted at 310–312° (dec.). Crystallization from 4:1 methanol:water raised the decomposition point to 317–318°. The 1,2,4-tricarboxylic acid has been prepared previously by the nitric acid oxidation of 1,2,4-trimethylanthraquinone[22,23] and of 1-formyl-2,4-dimethylanthraquinone.[26]

One oxidation of the 1,2,4-trimethyl derivative conducted at 210° gave a yellow crystalline product, m.p. 320–325°, whose analysis suggested a methylanthraquinone–dicarboxylic acid.

Anal. Calcd. for $C_{17}H_{10}O_6$: C, 65.81; H, 3.25; neut. equiv., 155. Found: C, 66.45; H, 3.28; neut. equiv., 150, 152.[31a,31e]

Trimethyl anthraquinone-1,2,4-tricarboxylate. The anthraquinone-1,2,4-tricarboxylic acid obtained from the air oxidized Diels-Alder adduct from *Phytadiene Fraction V* was converted to the trimethyl ester, m.p. 188–189°, employing the method of Cook.[28] Trimethyl anthraquinone-1,2,4-tricarboxylate (115 mg., 80%), m.p. 188–189°, was prepared from the 1,2,4-tricarboxylic acid obtained from 1,2,4-trimethylanthraquinone. Crystallization from methanol raised the melting point to 192–193°. A mixture melting point determination using the two samples described above gave no depression. The infrared absorption spectra of the two samples were identical. A melting point of 193° has been reported[27] for this ester.

Anal. Calcd. for $C_{20}H_{14}O_8$: C, 62.82; H, 3.69. Found: C, 62.46; H, 3.62.

Phytadiene Fraction W. Diels-Alder reaction with 1,4-naphthoquinone. A solution of *Phytadiene Fraction W* (3.0 g.) and 1,4-naphthoquinone (2.5 g.) in 75 ml. of ethanol was refluxed for 10 hr. The reaction mixture was treated with a solution of potassium hydroxide (0.15 g.) in ethanol (10 ml.) and air was bubbled through the mixture for 6.0 hr. The mixture was concentrated under reduced pressure. Extraction with 75 ml. of hexane followed by chromatography using silicic acid gave (a) a diene mixture (1.58 g.), eluted by hexane, and (b) the oxidized adduct (0.37 g.), eluted by 25:1 hexane:benzene. This material was a pale yellow oil with an infrared absorption spectrum typical of an anthraquinone.

Anthraquinone-1,3-dicarboxylic acid. A. *From the air oxidized adduct.* Oxidation with 20% nitric acid (sealed tube, 215°, 4.5 hr.) gave a mixture of acids, wt. 0.15 g. Chromatography of the acid mixture using silicic acid gave 0.09 g. of a pale yellow crystalline solid, m.p. 320–322°, eluted by ether. Crystallization from methanol at −27° raised the melting point to 325–326°.

Anal. Calcd. for $C_{16}H_8O_6$: C, 64.87; H, 2.72; neut. equiv., 148. Found: C, 65.23; H, 2.67; neut. equiv., 152, 154.[31a,31c]

A mixture melting point with an authentic sample of anthraquinone-1,3-dicarboxylic acid gave no depression. The infrared absorption spectrum of this material was identical with that of an authentic sample.

A second acid fraction (0.011 g.), m.p. softened at 196°, resolidified at 212°, melted at 310–314° (dec.), was obtained from the chromatogram. This material gave an infrared absorption spectrum identical with that of authentic anthraquinone-1,2,4-tricarboxylic acid.

B. *From 1,3-dimethylanthraquinone.* 2-Methyl-2,4-pentanediol (Carbide and Carbon Chemicals Co.) was dehydrated using sulfuric acid to yield 2-methyl-1,3-pentadiene, b.p. 78° (75%). A solution of 1,4-naphthoquinone (4.2 g., 0.027 mol.) and 2-methyl-1,3-pentadiene (12.3 g., 0.15 mol.) in 65 ml. of ethanol was refluxed for 6.0 hr. The 1,3-dimethylanthraquinone (4.9 g., 77%), m.p. 158–160°, was prepared and isolated as described previously.[12] Crystallization from ethanol raised the melting point to 161.5–162.0°. 1,3-Dimethylanthraquinone has been reported as melting at 162°.[12]

Anal. Calcd. for $C_{16}H_{12}O_2$: C, 81.33; H, 5.12. Found: C, 81.40; H 5.01.

The 1,3-dimethylanthraquinone (0.5 g.) was heated at 180° for 6.0 hr. with 7.0 ml. of 20% nitric acid in a sealed tube[24] to yield 0.48 g. (76%) of the 1,3-dicarboxylic acid, m.p. 320–323°. Crystallization from methanol raised the melting point to 326–328°.

Dimethyl anthraquinone-1,3-dicarboxylate. Employing the method of Cook,[28] the dimethyl ester of anthraquinone-1,3-dicarboxylic acid from *Phytadiene Fraction W* was prepared, m.p. 188–189°. Crystallization from methanol did not alter the melting point.

Anal. Calcd. for $C_{18}H_{12}O_6$: C, 66.66; H, 3.73. Found: C, 66.72; H, 3.63.

A mixture melting point with an authentic sample, m.p. 188.5–189.5°, prepared from the 1,3-tricarboxylic acid obtained by nitric acid oxidation of 1,3-dimethylanthraquinone gave no depression. The infrared absorption spectra of the two esters were identical.

Phytadiene Fraction X. Diels-Alder reaction with 1,4-naphthoquinone. A solution of *Phytadiene Fraction X* (3.0 g.) and 1,4-naphthoquinone (3.0 g.) in 75 ml. of ethanol was refluxed for 6.5 hr. The reaction mixture was treated with a solution of potassium hydroxide (0.15 g.) in ethanol (15 ml.) and air was bubbled through the mixture for 6.0 hr. The mixture was concentrated under reduced pressure and the residue was extracted with 75 ml. of hexane. Chromatography using silicic acid gave (a) a diene mixture (1.88 g.) and (b) the oxidized adduct (0.52 g.) which was a pale yellow oil. The infrared absorption spectrum of this oil indicated a substituted anthraquinone.

Anthraquinone-1,2-dicarboxylic acid. A. *From the air oxidized adduct.* Nitric acid oxidation (20% nitric acid solution, sealed tube, 210°, 6.0 hr.) was accomplished as before to give a mixture of acids (0.19 g.). Chromatography using silicic acid with hexane-ether solutions and ether as eluants gave 0.041 g. of anthraquinone-1,3-dicarboxylic acid, m.p. 321–323°, 0.060 g. of a second acid, m.p. 320–321°, and 0.011 g. of anthraquinone-1,2,4-tricarboxylic acid, m.p. softened at 192°, resolidified at 210°, melted at 315–317° (dec.). The acid, m.p. 320–321°, was shown by mixture melting point and infrared absorption studies to be anthraquinone-1,2-dicarboxylic acid.

Anal. Calcd. for $C_{16}H_8O_6$: C, 64.87; H, 2.72; neut. equiv., 148. Found: C, 64.02; H, 2.52; neut. equiv., 152.[31a,31c]

B. *From 1,2-dimethylanthraquinone.* 3-Methyl-1,3-pentadiene, b.p. 77–78°, was prepared from 3-methyl-3-penten-2-ol *via* 2-chloro-3-methyl-3-pentene by dehydrochlorination of the latter compound using the method of Abelmann.[32]

A solution of 1,4-naphthoquinone (3.5 g., 0.022 mol.) and 3-methyl-1,3-pentadiene (7.5 g., 0.09 mol.) in 60 ml. of ethanol was refluxed for 4.0 hr. A solution of 0.4 g. of potassium hydroxide in 15 ml. of ethanol was added. The reaction mixture was aerated for 16 hr. Filtration gave 3.63 g. (70%) of 1,2-dimethylanthraquinone, m.p. 147–148°. Crystallization from ethanol gave bright yellow needles, wt. 2.8 g., m.p. 151.0–152.0°. A melting point of 154° has been reported for this compound.[17]

Anal. Calcd. for $C_{16}H_{12}O_2$: C, 81.33; H, 5.12. Found: C, 81.76; H, 5.07.

Oxidation of the 1,2-dimethylanthraquinone using the method of Fieser and Martin[24] gave the 1,2-dicarboxylic acid monohydrate,[16] m.p. 266°, in 67% yield. Crystallization from methanol followed by prolonged drying at 80° *in vacuo* gave the diacid, m.p. 322–325°.

Dimethyl anthraquinone-1,2-dicarboxylate. Employing the method described by Cook,[28] the dimethyl ester of anthraquinone-1,2-dicarboxylic acid from *Phytadiene Fraction X* was prepared, m.p. 202–203°. Crystallization from methanol raised the melting point to 204.5–205.5°. A melting point of 208° has been reported.[20]

Anal. Calcd. for $C_{18}H_{12}O_6$: C, 66.66; H, 3.73. Found: C, 66.18; H, 3.62.

Dimethyl anthraquinone-1,2-dicarboxylate, m.p. 203–204°, was prepared in 76% yield from the 1,2-dicarboxylic acid obtained from 1,2-dimethylanthraquinone. A mixture melting point of the two samples gave no depression. The infrared absorption spectra were identical.

Phytadiene Fraction Y. Diels-Alder reaction with 1,4-naphthoquinone. A solution of *Phytadiene Fraction Y* (3.0 g.) and 1,4-naphthoquinone (3.0 g.) in 75 ml. of ethanol was refluxed for 6.0 hr. A solution of potassium hydroxide (0.15 g.) in ethanol (15 ml.) was added and air was bubbled through the mixture for 6.0 hr. The mixture was concentrated under reduced pressure. The residue was extracted with hexane (60 ml.) and chromatographed using silicic acid to give (a) a diene mixture (1.45 g.) eluted by hexane and (b) the oxidized adduct (0.68 g.), eluted by carbon tetrachloride. Nitric acid oxidation of an aliquot (0.25 g.) of this material gave a mixture of acids (0.16 g.) which were separable by chromatography using silicic acid. Anthraquinone-2-carboxylic acid (0.045 g.), m.p. 291.5–293.0°, anthraquinone-1,3-dicarboxylic acid (0.038 g.), m.p. 321–323°, and anthraquinone-1,2-dicarboxylic acid (0.051 g.), m.p. 320–322°, were isolated from the mixture. These acids were identified by mixture melting point studies and by comparison of infrared absorption spectra with those of authentic samples.

Chromatography of the remaining oxidized adduct (0.43 g.) on silicic acid using hexane, hexane-carbon tetrachloride solutions, and carbon tetrachloride as eluants gave five fractions as follows:

Fr. A: oily solid, m.p. 48–51°, wt. 0.045 g.
Fr. B: yellow oil, wt. 0.016 g.
Fr. C: yellow solid, m.p. 54.5–56.5°, wt. 0.061 g.
Fr. D: yellow oil, wt. 0.021 g.
Fr. E: yellow solid, m.p. 46–48°, wt. 0.039 g.

Crystallization of Fr. A from methanol at −27° gave 0.028 g. of a pale yellow solid, m.p. 52–53°. This material was considered to be 1-(2′,6′,10′-trimethyldodecyl)-3-methylanthraquinone.

Anal. Calcd. for $C_{30}H_{40}O_2$: C, 83.28; H, 9.32. Found: C, 83.33; H, 9.09.

Crystallization of Fr. C from methanol at −27° gave 0.041 g. of a pale yellow solid, m.p. 56–57°. This material had an infrared absorption spectrum identical with that of the compound presumed by Rowland[1] to be 1-(3′,7′,11′-trimethyldodecyl)-2-methylanthraquinone.

Anal. Calcd. for $C_{30}H_{40}O_2$: C, 83.28; H, 9.32. Found: C, 83.38; H, 9.50.

After crystallization from methanol at −27°, Fr. E gave a pale yellow solid, m.p. 47.0–48.0°. The infrared absorption spectrum of this material was identical with that of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone obtained from neophytadiene.[1]

Mixture melting point studies using approximately 1:1 mixtures of Fr. A plus Fr. C, Fr. A plus Fr. E, and Fr. C plus Fr. E gave an appreciable depression of the melting point in each instance.

Anthraquinone-carboxylic acids. Nitric acid oxidation (20% nitric acid solution, sealed tube, 210°, 3.5 hr.) of the material from Fr. A and from Fr. C gave anthraquinone-1,3- and 1,2-dicarboxylic acids, respectively. Chromic acid oxidation of the material from Fr. E gave anthraquinone-2-carboxylic acid. Mixture melting point determinations and infrared absorption studies were employed to establish the identity of these acids.

Phytadiene Fraction Z. Neophytadiene. The infrared absorption spectrum of *Phytadiene Fraction Z*, n_D^{27} 1.4600, was identical with that of neophytadiene reported by Rowland.[1] The ultraviolet absorption spectrum determined in cyclohexane at 25° showed a maximum at 225 mμ, log ε 4.37 with a weaker maximum at 278 mμ, log ε 2.78.

Anal. Calcd. for $C_{20}H_{38}$: C, 86.25; H, 13.75. Found: C, 86.16; H, 13.84.

Reduction of neophytadiene using palladium-charcoal catalyst gave phytane, n_D^{27} 1.4403.

Anal. Calcd. for $C_{20}H_{42}$: C, 85.03; H, 14.97. Found: C, 85.27; H, 14.73.

2-(4′,8′,12′-Trimethyltridecyl)anthraquinone. 2-(4′,8′,12′-Trimethyltridecyl)anthraquinone (0.21 g., 22%), m.p. 47–48°, was prepared from 0.6 g. of neophytadiene and 0.6 g. of 1,4-naphthoquinone in 15 ml. of ethanol as described by Rowland.[1] Crystallization from methanol at −27° raised the melting point to 48.5–49.0°.

Anal. Calcd. for $C_{30}H_{40}O_2$: C, 83.28; H, 9.32. Found: C, 83.21; H, 9.18.

2-(4′,8′,12′-Trimethyltridecyl)anthracene. A mixture of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone (0.10 g., 0.23 mmol.), stannous chloride (0.22 g., 0.116 mmol.), acetic acid (3.0 ml.), and 37% hydrochloric acid (0.5 ml.) was refluxed for 2.0 hr., a procedure described by Badger and Cook.[8] The reaction mixture was cooled, diluted with water (30 ml.), and extracted with three 50-ml. portions of ether. Concentration of the extract gave 0.10 g. of a pale yellow oil.

This oil, suspended in 5 ml. of 2*N* sodium hydroxide, was treated with 0.30 g. of zinc dust and the suspension refluxed for 4.0 hr.[8] The initial red color of the reaction mixture faded to pale yellow within 30 min. Dilution of the reaction mixture with water (50 ml.) followed by acidification with 37% hydrochloric acid caused a pale yellow solid to separate. Filtration gave 0.10 g. of this material, m.p. 85–86°. Chromatography on alumina using 3% benzene-hexane solutions as eluant gave 0.09 g. of a highly fluorescent solid. Crystallization from 4:1 ethanol:water gave 0.08 g. of 2-(4′,8′,12′-trimethyltridecyl)anthracene, m.p. 92.0–93.0°.

Anal. Calcd. for $C_{30}H_{42}$: C, 89.48; H, 10.52. Found: C, 90.02; H, 9.98.

The ultraviolet absorption of this material at 25° (ethanol) showed typical anthracenoid maxima as follows: 246.5 mμ, log ε 5.35; 255 mμ, log ε 5.67; 322 mμ, log ε 3.59; 337 mμ, log ε 3.78; 356 mμ, log ε 3.90; 376 mμ, log ε 3.84.

This hydrocarbon gave a 1:1 *2,4,7-trinitrofluorenone:hydrocarbon complex* which crystallized from 4:1 methanol:-benzene as deep violet needles, m.p. 104.5–105.5°.

Anal. Calcd. for $C_{30}H_{42}\cdot C_{13}H_5N_3O_7$: C, 71.94; H, 6.60. Found: C, 72.01; H, 6.52.

Anthraquinone-2-carboxylic acid. A. *From 2-(4′,8′,12′-trimethyltridecyl)anthraquinone.* As reported previously,[1] chromic acid oxidation of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone gave anthraquinone-2-carboxylic acid, m.p. 295–296°. A melting point of 291–292° has been reported.[13,14]

Anal. Calcd. for $C_{15}H_8O_4$: C, 71.43; H. 3.19; neut. equiv., 252. Found: C, 71.67; H, 3.25; neut. equiv., 260.[31a,31d]

A mixture melting point with an authentic sample gave no depression. The infrared absorption spectrum was identical with that of an authentic sample.

B. *From 2-(4′,8′,12′-trimethyltridecyl)anthracene.* 2-(4′,8′,-12′-Trimethyltridecyl)anthracene (0.030 g.) was dissolved in 2.0 ml. of glacial acetic acid. A solution of 0.25 g. of sodium dichromate in 0.5 ml. of concentrated sulfuric acid was added and the resulting solution was heated at 100° for

2.0 hr. Dilution with water, followed by ether extraction, yielded 0.014 g. of anthraquinone-2-carboxylic acid, m.p. 292–293°. A mixture melting point with an authentic sample gave no depression.

C. *From 2-methylanthraquinone.* 2-Methylanthraquinone, m.p. 178.5–179.0°, was prepared in 95% yield from isoprene and 1,4-naphthoquinone as described previously.[12]

Anal. Calcd. for $C_{15}H_{10}O_2$: C, 81.07; H, 4.54. Found: C, 81.20; H, 4.52.

Oxidation of 2-methylanthraquinone by the method of Il'inskii and Kazakova[14] gave the 2-carboxylic acid, m.p. 290–292°, in 95% yield. Crystallization from 4:1 ethanol:-water raised the melting point to 295–296°.

Methyl anthraquinone-2-carboxylate. Methyl anthraquinone-2-carboxylate, m.p. 169°, was prepared using the method of Cook[28] in 77% yield from anthraquinone-2-carboxylic acid obtained by oxidation of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone. Crystallization from methanol raised the melting point to 171.0–171.5°. A melting point of 170° has been reported.[7]

Anal. Calcd. for $C_{16}H_{10}O_4$: C, 72.21; H, 3.78. Found: C, 72.08; H, 3.77.

A mixture melting point study of this material with an authentic sample of the ester prepared from the 2-carboxylic acid obtained by oxidation of 2-methyl-anthraquinone gave no depression. The infrared absorption spectra of the two ester samples were identical.

Isomerization of neophytadiene. A. Thermal isomerization. Neophytadiene (0.65 g.) was heated in an oil bath at 182° for 2.5 hr. Examination of the infrared spectrum indicated that the absorption at 6.27μ had lessened, the absorption at 11.1μ had shifted to 11.0μ, the ratio of the absorption at 11.1μ to that at 11.2μ had markedly altered and strong absorption at 10.38μ had appeared. These data are consistent with the migration of the conjugated system toward the center of the phytadiene molecule. The appearance of infrared absorption at 10.38μ is indicative of the formation of a *trans*-CH=CH grouping.

The ultraviolet absorption of the isomerized material showed a broad maximum at 230–233 mμ, log ϵ 4.22.

B. *Catalytic isomerization.* A solution of neophytadiene (0.65 g.) in 20 ml. of benzene containing 0.025 g. of *p*-toluenesulfonic acid was refluxed for 3.3 hr. The solution was cooled, extracted with 25 ml. of water, and concentrated under reduced pressure. The residue was chromatographed using alumina to give a diene mixture with strong infrared absorption at 10.38μ. The infrared absorption at 6.07 and 6.27μ had almost completely disappeared. The infrared absorption spectrum of this material was almost identical with that of the hydrocarbon obtained by *p*-toluenesulfonic acid–phthalic anhydride dehydration of phytol.[1]

C. *Dilute hydrochloric acid.* Neophytadiene (0.45 g.) was dissolved in 200 ml. of methanol, diluted with 300 ml. of 0.2*N* hydrochloric acid, and extracted with six 75-ml. portions of hexane. This procedure is essentially that employed in the isolation of the phytadiene fraction from cigarette smoke.[4,5] The hexane extract was washed with 100 ml. of 9:1 methanol:water, dried over sodium sulfate and concentrated to yield 0.43 g. of neophytadiene, identical with the starting material in respect to infrared and ultraviolet absorption. No evidence of infrared absorption at 10.38μ was obtained.

Study of Diels-Alder reaction between neophytadiene and 1,4-naphthoquinone. A solution of neophytadiene (1.0 g., 2.3 mmol.) and 1,4-naphthoquinone (0.55 g., 3.5 mmol.) in 25.0 ml. of ethanol was refluxed for 4.0 hr. The reaction mixture was chilled rapidly in ice water and 5.0 ml. were withdrawn using a pipette. The remaining reaction mixture was refluxed for an additional 4.0 hr., at which time the chilling and pipetting were repeated. This procedure was repeated at the end of 16.0 and 32.0 hr.

Each aliquot was treated with a solution of 0.05 g. of potassium hydroxide in 5.0 ml. of ethanol and air was bubbled through the mixture for 3.0 hr. The residue was extracted with 55 ml. of hexane and the hexane extract was chromatographed using silicic acid. In each instance, the air oxidized adduct was further oxidized to anthraquinone-2-carboxylic acid. Table I shows the results obtained. No other acid could be detected during examination of the oxidation products of the air oxidized adduct. The air oxidized adduct showed infrared absorption identical with that of 2-(4′,8′,12′-trimethyltridecyl)anthraquinone.

TABLE I

DIELS-ALDER REACTION BETWEEN NEOPHYTADIENE AND 1,4-NAPHTHOQUINONE

		Air Oxidized Adduct		Anthraquinone-2-carboxylic Acid	
Aliquot No.	Reaction Time, Hr.	Wt., mg.	M.p.	Wt., mg.	M.p.
1	4	55	41–44	25	292–293
2	8	71	40–43	32	292–293.5
3	16	106	45–46	47	295–296
4	32	149	43–45	75	294–296

Phytadienes in smoke from different tobacco types and blends. The smoke condensate from 3600 cigarettes of each of the following tobacco types was examined for phytadienes: (a) Turkish tobacco, (b) flue-cured tobacco, and (c) burley tobacco. The smoke condensate was collected and processed as described previously.[4,5] Infrared absorption studies indicated that the phytadiene mixture was present in the smoke from each tobacco type as evidenced by absorption at 6.07, 6.27, 7.25, 7.32, 10.1, 10.35, 11.0, 11.1, and 11.2μ. No attempt was made to show conclusively that the total series of phytadienes was present in each instance. However, neophytadiene was isolated from the smoke of cigarettes fabricated from Turkish, from flue-cured, and from burley tobacco.

Essentially the same phytadiene mixture was indicated by infrared absorption studies of four blends of cased commercial tobaccos different from the blend employed in our study.

Acknowledgment. I am indebted to Mr. John J. Whalen and Mr. John L. Stewart for the infrared spectra and to Mr. Robert H. Cundiff and Mr. W. T. Robinson, Jr. for certain analytical determinations. I also wish to acknowledge the capable assistance of Mr. Bruce W. Woosley and Mr. Max A. Wagoner.

WINSTON-SALEM, N. C.