[CONTRIBUTION FROM THE GEORGE HERBERT JONES LABORATORY OF THE UNIVERSITY OF CHICAGO]

DETECTION OF FREE RADICALS IN SOLUTION. III. FORMATION OF LONG-CHAIN α,ω-DICARBOXYLIC ACIDS

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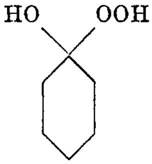
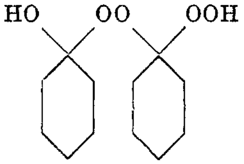
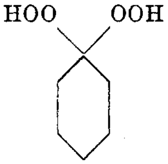
It has long been known that aliphatic aldehydes and ketones (1) react with hydrogen peroxide to form peroxidic compounds of type RCHOH(OOH). But the peroxide formed from cyclohexanone and hydrogen peroxide (2) has been shown (3) to have Structure II instead of the simple Structure I. The authors (3) also consider that, in solution, II may break down to give cyclohexanone and 1,1-dihydroperoxycyclohexane (III). The solid peroxide (II) when shaken with an aqueous solution of ferrous sulfate gives "mainly hexanoic and dodecane-1,12-dioic acid" and cyclohexanone (4). The yields of the individual products are not indicated in the article cited.[1]



I



II



III

The work here reported had two objectives. First, to learn whether the free radical **A,** formed by the reaction of ferrous salts on the hydroperoxide (I or II) adds to butadiene in the manner that the free *tert*-butoxy radical[2] adds to buta-

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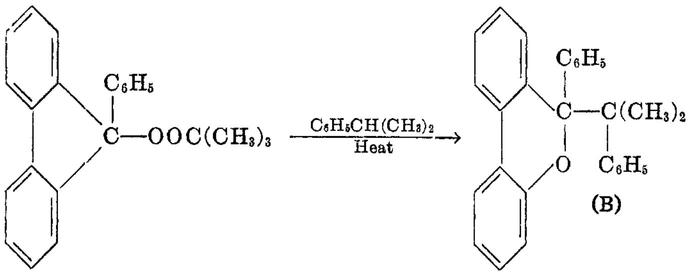
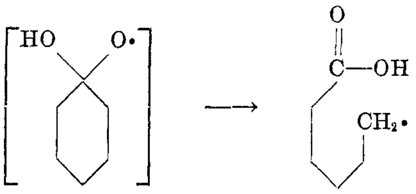
[1] Cf. Kharasch, Fono, and Nudenberg, *J. Org. Chem.*, **15**, 763 (1950); Kharasch, Poshkus, and Nudenberg, *J. Org. Chem.*, **16**, 1458 (1951). Note also that the peroxide (see below) when heated in cumene gives a benzopyran compound. (Kharasch, Roginsky, and Nudenberg, unpublished work.)



(B)

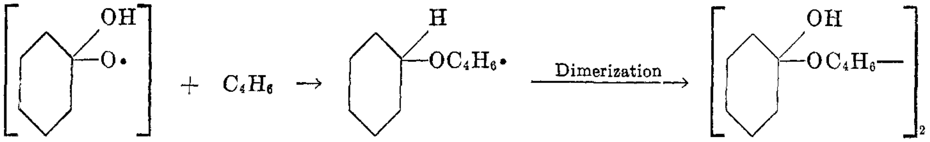
[2] It has been stressed in some of our publications that, in many reactions of this type, the data at hand do not permit the unequivocal statement that free *tert*-butoxy radicals are actually formed in solution. It may be that the radical adds to butadiene at the moment when the ferrous ion donates an electron to the hydroperoxide molecule. This latter reaction would obviously be a sort of a "concerted" reaction and no free RO• radicals would be generated in solution.



(A) (B)

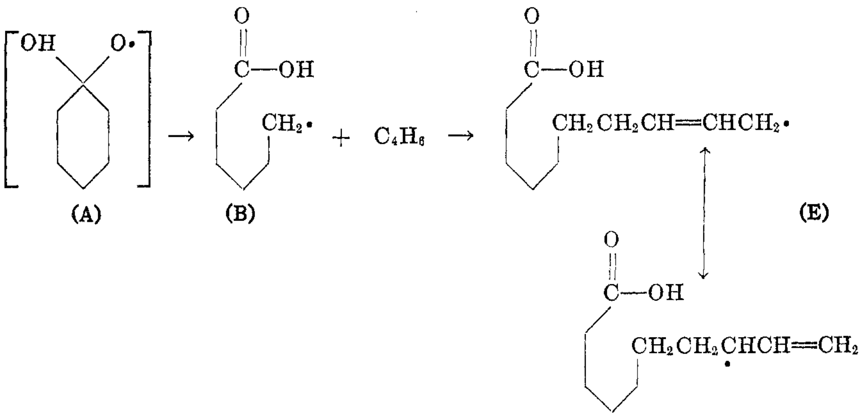
diene. Second, to ascertain whether the free radical **B**, if formed, adds to butadiene, isoprene, and chloroprene.[3]

Insofar as the free radical **A** is concerned, none of the product **D** has been isolated; neither have any products which might conceivably be explained by the prior addition of the radical **C** to butadiene. The major reaction product

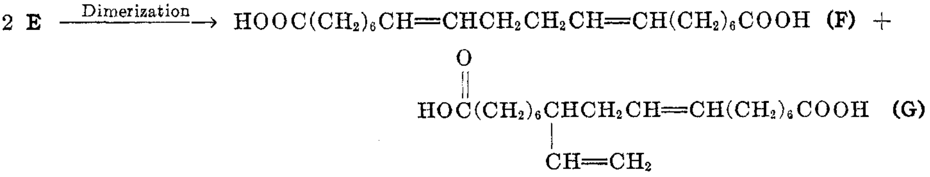


(A) (C) (D)

(85–95%) appears to be that formed by the addition of the free radical **B** to butadiene and dimerization of the new free radical[4] thus produced.



(A) (B) (E)



$$2\ E \xrightarrow{\text{Dimerization}} HOOC(CH_2)_6CH{=}CHCH_2CH_2CH{=}CH(CH_2)_6COOH\ \text{(F)} + HO\overset{\overset{O}{\|}}{C}(CH_2)_6\underset{\underset{CH=CH_2}{|}}{C}HCH_2CH{=}CH(CH_2)_6COOH\ \text{(G)}$$

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[3] It has been found (unpubl. work, Kharasch and Nudenberg) that treatment of triphenylmethyl hydroperoxide with ferrous salts in the presence of butadiene gives rise to an adduct of the following type:

$(C_6H_5)_3COOH + Fe^{++} \rightarrow [(C_6H_5)_3CO\bullet] \rightarrow (C_6H_5)_2\bullet COC_6H_5$

$(C_6H_5)_2\bullet COC_6H_5 + C_4H_6 \rightarrow [(C_6H_5)_2(C_6H_5O)CC_4H_6]\bullet \xrightarrow{\text{Dimerization}}$

$(C_6H_5)_2(C_6H_5O)CC_4H_6C_4H_6C(C_6H_5O)(C_6H_5)_2.$

[4] The argument dealing with the independent existence of free RO• radicals (see footnote

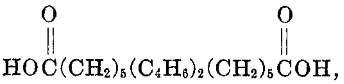
The acids **F** and **G** are very difficult to separate quantitatively. From previous experience with the addition of RO• radicals to butadiene, (and the amount of succinic acid formed upon ozonolysis of the adducts) it is estimated that the mixture contains about 85% of **F**.

Analyses of the mixture of these acids are in accord with the empirical formula. Furthermore, when the mixture is hydrogenated two moles of hydrogen per mole of acid are absorbed. Ozonolysis of the mixture gave succinic acid and suberic acid [$HOOC(CH_2)_6COOH$]. No extensive search was made for the tricarboxylic acid which would result from ozonolysis of **G**.

The acids **F** and **G** can not be separated by distillation. However, when these acids, dissolved in methanol, are gently heated for eight hours in the presence of a small amount of *p*-toluenesulfonic acid, and the product is worked up in the usual way, esters which could be distilled at reduced pressure were obtained. The analyses (C and H) of these esters were in good agreement with the values calculated for the methyl esters of **F** and **G**.

EXPERIMENTAL

Into a three-necked flask equipped with a Tru-bore stirrer, dropping-funnel, and Dry Ice condenser, and provided with a means for maintaining a nitrogen atmosphere, was introduced a solution of 75 g. of urea in 150 ml. of redistilled water. The flask was cooled to −10° and 75–100 g. of butadiene was added, followed by 0.2 mole (26.4 g.) cyclohexanone peroxide (Lucidol Corp.). To this mixture was added dropwise 0.2 mole of ferrous ammonium sulfate hexahydrate dissolved in 350–400 ml. of distilled water. The ferrous ammonium sulfate solution was added over a period of two hours while the whole was stirred vigorously. The butadiene was allowed to evaporate off and there remained a suspension of the iron salts of the reaction products. The residue, after evaporation of the butadiene, was treated with 4 *N* HCl, ethanol, and ether to recover the organic acids and other products from the ferric salts. The alcohol ether extract was washed with water to remove the ferric chloride. The ether extract was then extracted with 4 *N* sodium hydroxide to remove the organic acids. The alkaline extract was acidified with 4 *N* HCl and the liberated acids were extracted with ether. After washing and drying the ether solution, the solvent was removed, a residue of the organic acids remained (which, in part, crystallized). If allowed to stand longer (3–4 days), the whole solidified, m.p. 114–116°. The weight of acids varied between 18–22 g. The yield of C_{20} diethylenic dibasic acid,



$$HO\overset{\overset{\displaystyle O}{\|}}{C}(CH_2)_5(C_4H_6)_2(CH_2)_5\overset{\overset{\displaystyle O}{\|}}{C}OH,$$

based on the cyclohexanone peroxide used, was 65–75%. The same products were formed when hydrogen peroxide (1 mole) was added to a mixture of cyclohexanone (2 moles), water, urea, and butadiene (in the amounts stated above), followed by slow addition of ferrous ammonium sulfate, or a suspension of ferrous pyrophosphate (one mole-equivalent on the basis of the hydrogen peroxide used). The reaction is preferably carried out at 0° to −10°.

For analyses the mixture of the acids was dried at reduced pressure. The acids still contained a trace of ash.

Anal. Calc'd for $C_{20}H_{34}O_4$: C, 70.98; H, 10.1.
Found: C, 70.3; H, 9.84.

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2) applies equally well to the reaction which the free radical designated schematically as **B** is indicated. This, too, may be a "concerted" reaction and no free radicals corresponding to **B** may ever be present in solution.

Ozonolysis. The C_{20} acids were ozonized in the usual way in ethyl acetate. The ozone absorption indicated the presence of two double bonds. When the reaction mixture was worked up in the usual way a 96% yield of crude suberic acid, and 100% yield of crude succinic acid were obtained. The acids thus obtained did not depress the melting points of authentic samples of suberic and succinic acids, respectively.

The high yield of succinic acid indicates that by far the largest amount (over 80%) of the C_{20} acids must be compound **F**, namely 8,12-eicosadiene-1,20-dioic acid.

Preparation of dimethyl 8,12-eicosadiene-1,20-dioate. It is more advantageous to carry out the reaction in methanol (or *tert*-butanol) than in water, particularly when the diolefin (isoprene, chloroprene) is little soluble in water. A further advantage results when acid is used in the reaction to prevent precipitation of the iron salts of the C_{20} dicarboxylic acid. The preparation of the esters of the acids is carried out as follows:

1,1′-Dihydroxydicyclohexyl peroxide was prepared by adding, in portions, 50 g. of 34% hydrogen peroxide (0.5 mole) to 98 g. of cyclohexanone (1 mole) while maintaining the temperature below 40° by intermittent cooling with an ice-bath, and then dissolving in 750 ml. of methanol containing 25 g. of concentrated sulfuric acid. The solution was cooled to 0° in a 2-liter 3-neck round-bottom flask equipped with mechanical stirrer, Dry Ice-acetone condenser, thermometer, and dropping-funnel. The dropping-funnel was removed and 81 g. (1.5 moles) of butadiene was dissolved in the solution. The funnel was replaced and filled with a solution of 147 g. (0.53 mole) of ferrous sulfate heptahydrate and 25 g. of concentrated sulfuric acid in 250 ml. of water. The ferrous solution was added with stirring to the peroxide solution at 0° over a period of 1½ to 2 hours. After completion of the addition the mixture was warmed to 65° and the excess butadiene (52 g., 0.96 mole) was collected in a Dry Ice-acetone trap. The mixture was then cooled, diluted with two liters of water, and extracted with a 300-ml. portion of benzene. The benzene solution was dried over sodium sulfate and distilled through a two-foot packed column. After removal of the benzene there was obtained 44 g. of cyclohexanone (0.45 mole), b.p. 83–85° (85 mm.). The pressure was reduced to 1 mm. and the bath temperature was raised to 200°, but no other product distilled. The light brown bottoms weighed 84 g. (92% yield based on hydrogen peroxide; calculated as C_{20} dimethyl ester). The residue was dissolved in 300 ml. of methanol containing 3 g. of *p*-toluenesulfonic acid catalyst and the mixture was allowed to reflux gently overnight. After dilution with one liter of water and extraction with 300 ml. of benzene, the benzene solution was washed with dilute sodium carbonate solution, water, and dried over sodium sulfate. Claisen distillation afforded the following fractions after removal of solvent:

Fraction I: 95–190°/1 mm. (6 g.); Fraction II: 190–220°/1 mm. (69 g.); n_D^{20} 1.4693. Residue, 7 g.

Analysis of Fraction II gave the following results:

Anal. Calc'd for $C_{22}H_{38}O_4$: C, 72.1; H, 10.4.

Found: C, 71.6; H, 10.3.

Fraction II represents a 75% yield of dimethyl ester based on the hydrogen peroxide used.

Preparation of dimethyl 7,11-octadecadiene-1,18-dioate. Cyclopentanone peroxide produced by reacting cyclopentanone and hydrogen peroxide in a mole ratio of 2:1, reacted in methanol solution with butadiene (3 moles per mole of peroxide) at $-10°$ to $-5°$ in the presence of 1.1 moles of ferrous sulfate per mole of peroxide, gives under acid conditions, as the chief product after esterification, dimethyl 7,11-octadecadiene-1,18-dioate together with a small amount of dimethyl 7-vinyl-9-hexadecene-1,16-dioate (19% total yield).

Anal. Calc'd for $C_{20}H_{34}O_4$: C, 71.0; H, 10.1.

Found: C, 71.0; H, 10.1.

SUMMARY

1. A procedure for the preparation of long-chain α,ω-dicarboxylic acid is described.

2. The mechanism of the formation of the long-chain α,ω-dicarboxylic acid from cyclohexanone, hydrogen peroxide, and butadiene is suggested.

CHICAGO 37, ILLINOIS

REFERENCES

(1) RIECHE, *Alkylperoxide and Ozonide*, Verlag von Theodor Steinkopff, Leipzig (1931).
(2) MILAS, HARRIS, AND PANAGIOTAKOS, *J. Am. Chem. Soc.*, **61**, 2430 (1939).
(3) CRIEGEE, SCHNORRENBERG, AND BECKE, *Ann.*, **565**, 7 (1949).
(4) COOPER AND DAVISON, *J. Chem. Soc.*, 1180 (1952). See also COOPER, *J. Chem. Soc.*, 1340 (1951) on the thermal decomposition of hydroperoxide (II). A small amount of dodecane-1,12-dioic acid was isolated from the reaction mixture.