Autoxidation of αβ-Unsaturated Ketones.

By E. G. E. Hawkins.

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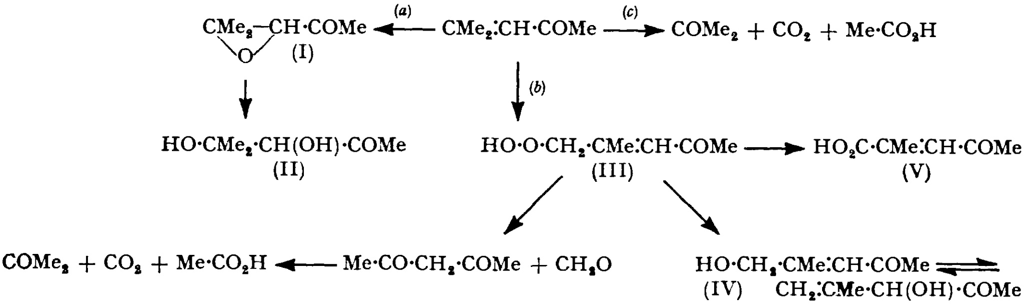
Oxidation of mesityl oxide and *iso*phorone led to products of types similar to those derived from oxidation of alkenes and *cyclo*alkenes. Mesityl oxide gives the epoxide and β-acetyl-α-methylacrylic acid, and *iso*phorone yields largely 5 : 5-dimethyl-3-oxo*cyclo*hexene-1-carboxylic acid.

The products of autoxidation of olefins have been studied in detail (Gasson, Millidge, Primavesi, Webster, and Young, *J.*, 1954, 2161, and unpublished work). They were mainly derived (*a*) by reaction at the double bond *via* epoxides, (*b*) by attack at the active methylene group *via* hydroperoxides, and (*c*) by fission at the double bond. Oxidation of two αβ-unsaturated ketones, mesityl oxide and *iso*phorone, has now been studied to find what modifying effect the carbonyl group has on the mode of reaction.

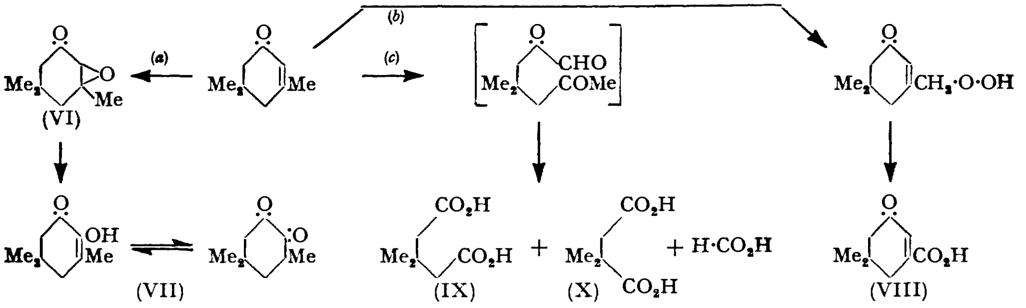
Autoxidation of mesityl oxide in acetic acid had previously been found to lead to β-acetyl-α-methylacrylic acid (Distillers Co. Ltd., Elce, Hall, and Turck, B.P. 585,527), and this acid was also found in the present work in the products obtained under neutral conditions. A major product, however, was the epoxide (I), and other products were carbon dioxide, formaldehyde, acetaldehyde, acetic acid, acetone, and 3 : 4-dihydroxy-4-methylpentan-2-one (II) : in addition there were present esters of this glycol with formic acid and α-methyl-β-acetylacrylic acid (V), and an unidentified compound containing hydroxyl, carbonyl, and unsaturated functions, cleaved by periodic acid, possibly 3-hydroxy-4 methylpent-4-en-2-one (IV). The annexed diagram represents possible stages of oxidation. These products indicate that the oxidation proceeds similarly to that of olefins.



Nicolet and Poulter's method of epoxide estimation (*J. Amer. Chem. Soc.*, 1930, **52**, 1186) was not applicable in this work since the mesityl oxide itself reacted with hydrogen chloride under the conditions used. A modified periodate method, with more concentrated acid or a higher temperature than normal, gave reasonably accurate analyses.

The epoxide was easily hydrolysed to the corresponding glycol, and when passed through activated alumina at *ca.* 250° gave poor conversion into 4-methylpentan-2 : 3-dione. This epoxide had previously been formed only by oxidation of mesityl oxide by alkaline hydrogen peroxide (Weitz and Scheffer, *Ber.*, 1921, **54**, 2327; Bunton and Minkoff, *J.*, 1949, 665; Nazarov and Akhren, *J. Gen. Chem.*, *U.S.S.R.*, 1950, **20**, 2183; Publicker Commercial Alcohol Corp., U.S.P. 2,431,718). The Russian workers also hydrolysed it to the glycol.

Autoxidation of *iso*phorone in alcoholic alkali has been described as slow by Treibs (*Ber.*, 1933, **66**, 1483), and the unsaturated ketol (VII), similar to that produced from the epoxide by alkali treatment, was apparently the only compound identified. Oxidation of some related *cyclo*alkenones was studied in greater detail (Treibs, *Ber.*, 1930, **63**, 2423; 1932, **65**, 163; 1933, **66**, 610), and the products were assumed to arise *via* the epoxides. It has now been found that autoxidation of *iso*phorone is slower than that of mesityl oxide, but gave mainly acidic materials with little epoxide—none was isolated. The main products were αα-dimethylsuccinic acid (X), ββ-dimethylglutaric acid (IX), and a compound thought to be 5 : 5-dimethyl-3-oxo*cyclo*hex-1-enecarboxylic acid (VIII); small quantities of carbon dioxide, acetone, and acetic acid were also found. In addition, derivatives of a diketone, presumably Treibs's ketol formed by isomerisation of the epoxide, were obtained from a high-boiling fraction. Oxidation was thought to follow the annexed scheme. Ozonolysis of the acid (VIII), followed by decomposition of the ozonide in acetic acid and hydrogen peroxide, yielded ββ-dimethylglutaric acid (IX). Analysis of the acid and its carbonyl derivatives, together with the above ozonolysis, agree with the suggested structure.



The products of oxidation again provided evidence of the three modes of attack, and the low yields of epoxide (VI) might have been due to (i) its rapid rearrangement to the ketol (VII) or conversion into glycol, or (ii) predominance of oxidation type (*b*) as is found with *cyclo*alkenes (unpublished work).

EXPERIMENTAL

The method of oxidation and apparatus are described by Gasson *et al.* and by Hawkins and Quin (unpublished work).

Mesityl Oxide.—Oxidations were carried out with and without metal naphthenate catalysts and basic additives, and at temperatures from 70° to 110°. The rate of oxidation was increased by the metal catalysts, decreased slightly by magnesium oxide, and decreased considerably by sodium carbonate or hydroxide. In one typical experiment, mesityl oxide (137 g.), containing cobalt naphthenate (0·1 g.), was treated with dried oxygen at *ca.* 100° for 9¾ hr. The total oxygen absorbed was 17 l., and carbon dioxide (3·3 l.) was isolated from the liquid-air trap at the end of the experiment. From a solid carbon dioxide–alcohol trap was obtained a liquid (3·9 g.) consisting of acetone (2 : 4-dinitrophenylhydrazone, m. p. and mixed m. p. 124—126°) and acetaldehyde (dimedone derivative, m. p. and mixed m. p. 139—140°). Part (71 g.) of the main liquid product (143·7 g.) was distilled to give fractions: (i) (2·7 g.), b. p. 100—126°; (ii) (36·5 g.), b. p. 126—134°; (iii) (1·2 g.), b. p. 134—150°; (iv) (8·5 g.), b. p. 150—160° (mainly 155°); (v) (2·4 g.), b. p. 64—80°/15 mm.; (vi) (3·8 g.), b. p. 80—110°/15 mm.; (vii) (5·0 g.), b. p. 110—140°/15 mm.; residue (2·8 g.). Fraction (i) contained acetic acid (*p*-bromophenacyl ester, m. p. and mixed m. p. 84—86°). Fraction (ii) was unchanged mesityl oxide. Fraction (iv) consisted mainly of the epoxide, which provided a yellow 2 : 4-dinitrophenylhydrazone, m. p. 126—128° undepressed on admixture with that from epoxide prepared by oxidation of mesityl oxide by alkaline hydrogen peroxide (Found: C, 48·7; H, 4·5; N, 18·1. Calc. for $C_{12}H_{14}O_5N_4$: C, 49·0; H, 4·8; N, 19·05%) (Nazarov and Akhren, *loc. cit.*, give m. p. 130—131°). Fraction (v) contained carbonyl, hydroxyl, and unsaturated groupings, and its infrared spectrum is consistent with the presence of a compound of the type *3-hydroxy-4-methylpent-4-en-2-one* (IV) [Found: CO equiv., 121; active H (Zerewitinov), 0·72%. $C_6H_{10}O_2$ requires CO equiv., 114; active H, 0·88%]; it reacted with periodic acid, and also yielded a *bis-2 : 4-dinitrophenylhydrazone*, m. p. 260° (decomp.) (Found: N, 23·2. $C_{18}H_{16}O_8N_8$ requires N, 23·7%). Fraction (vi) also yielded this bis-2 : 4-dinitrophenylhydrazone, m. p. 260°; hydrolysis of this fraction yielded an unresolved mixture of acids and a neutral product which provided the 2 : 4-dinitrophenylhydrazone, m. p. 160—162° (Nazarov and Akhron, *loc. cit.*, give m. p. 156—156·5°) (Found: C, 45·8; H, 5·1. Calc. for $C_{12}H_{16}O_6N_4$: C, 46·15; H, 5·1%), of the glycol (II), identical with that obtained by hydrolysis of the epoxide (see below). Fraction (vii), after hydrolysis, gave β-acetyl-α-methylacrylic acid (2·0 g.), m. p. and mixed m. p. 100—103° (from benzene).

From other oxidation experiments there were also isolated formaldehyde and formic acid (*p*-bromophenacyl ester).

The epoxide (fraction iv, or synthetic), heated for 2 hr. with aqueous ethanol, gave products which both provided identical 2 : 4-dinitrophenylhydrazones, m. p. 160—162°.

The epoxide concentrate (7·5 g.) was dropped slowly through a short column of activated alumina at *ca.* 250°. Distillation of the product gave a main, yellow fraction (3·0 g.), b. p. 100—120° [2 : 4-dinitrophenylhydrazone, m. p. 115—117° (from light petroleum, then aqueous alcohol) (Found : C, 49·4; H, 5·2; N, 21·0. Calc. for $C_{12}H_{14}O_5N_4$: C, 49·0; H, 4·8; N, 19·05%); dioxime, m. p. 153—155° (reported for 4-methylpentane-2 : 3-dione dioxime, m. p. 155—158°)]. Baker (*J.*, 1950, 1302) reported this diketone, b. p. 115—116° (2 : 4-dinitrophenylhydrazone, m. p. 120°).

iso*Phorone.*—*iso*Phorone (150 g.), magnesium oxide (10 g.), and cobalt naphthenate (0·1 g.) were treated with oxygen (12 l.) for 24 hr. at *ca.* 100°. The liquid-air trap contained carbon dioxide, and the carbon dioxide–alcohol trap a mixture (1 g.) of acetone (2 : 4-dinitrophenylhydrazone, m. p. and mixed m. p. 124—126°) and acetaldehyde (dimedone derivative, m. p. and mixed m. p. 139—140°). The main product (171·4 g.) was filtered from magnesium salts, and the filtrate, together with ether washings of the salts, distilled at 15 mm., to give fractions : (i) (3·5 g.), b. p. <85°; (ii) (108·5 g.), b. p. 85—90°; (iii) (3·8 g.), b. p. 90—110°; (iv) (0·7 g.), b. p. 110—140°; (v) (4·4 g.), b. p. 140—170°; (vi) (3·0 g.), b. p. 170—200°; residue (1·0 g.). Fraction (ii) and part of fractions (i) and (iii) were unchanged *iso*phorone, but fraction (iii) contained a compound (presumably VII) providing a *bisphenylhydrazone*, m. p. 199—200° (Found : C, 75·6; H, 7·3; N, 16·7. $C_{21}H_{26}N_4$ requires C, 75·45; H, 7·8; N, 16·8%), and a *bis*-2 : 4-*dinitrophenylhydrazone*, m. p. 276—278° (Found : C, 50·5; H, 4·2. $C_{21}H_{22}O_8N_8$ requires C, 49·0; H, 4·3%). Fractions (v) and (vi) were very viscous syrups, and analysis showed that they consisted largely of esters.

The solid magnesium salts were acidified with hydrochloric acid and extracted with ether, and the extract was distilled at 15 mm., to provide fractions : (i) (1·2 g.), b. p. 40—80°; (ii) (2·8 g.), b. p. 80—110° (mostly at *ca.* 90°); (iii) (2·3 g.), b. p. 110—140°; (iv) (6·8 g.), b. p. 140—190° (mostly at 180—190°); residue (2·8 g.). Formic and acetic acids were identified in fraction (i). Fractions (ii) and (iii) crystallised; recrystallisation from benzene gave αα-dimethylsuccinic acid, m. p. 140—141° (Found : equiv., 72·5. Calc. for $C_6H_{10}O_4$: equiv., 73). Fraction (iv) crystallised; trituration and recrystallisation from benzene gave 5 : 5-*dimethyl*-3-*oxocyclohex*-1-*enecarboxylic acid*, m. p. 153—155° (Found : C, 64·0, 64·7; H, 7·2, 7·3; active H, 0·53%; acid equiv., 169; CO equiv., 188. $C_9H_{12}O_3$ requires C, 64·3; H, 7·15; active H, 0·595%; acid and CO equiv., 168); it gave a *semicarbazone*, m. p. 224—225° (from ethanol) (Found : C, 52·3; H, 6·6. $C_{10}H_{15}O_3N_3$ requires C, 53·3; H, 6·7%), and a 2 : 4-*dinitrophenylhydrazone*, m. p. 211—212° (Found : C, 51·4; H, 4·6. $C_{15}H_{16}O_6N_4$ requires C, 51·7; H, 4·6%). After removal of the bulk of this acid, the remainder of fraction (iv) was redistilled at 15 mm., to give fractions : (iv*a*) (*ca.* 1·0 g.), b. p. <140°; (iv*b*) (0·6 g.), b. p. 140—170°; (iv*c*) (1·8 g.), b. p. 170—180°. Fractions (iv*a*) and (iv*b*) crystallised and recrystallisation from benzene–light petroleum gave ββ-dimethylglutaric anhydride, m. p. 123—125° (Found : equiv., 74·5. Calc. for $C_7H_{10}O_3$: equiv., 71). Hydrolysis provided ββ-dimethylglutaric acid, m. p. 100—101·5° (Found : equiv., 85. Calc. for $C_7H_{12}O_4$: equiv., 80). Fraction (iv*c*) provided a further quantity of the solid cyclic acid (VIII).

The acid (VIII) (0·8 g.), in methylene chloride, was treated with ozonised oxygen, the solvent removed under reduced pressure, and the ozonide decomposed by being heated for several hours with acetic acid (15 c.c.) and 30% hydrogen peroxide (10 c.c.). Ether-extraction, followed by removal of the ether and acetic acid, gave a solid residue, which after recrystallisation from benzene–light petroleum had m. p. 95—97°, undepressed on admixture with the ββ-dimethylglutaric acid obtained previously.

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