

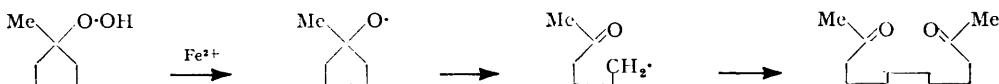
Reactions of Organic Peroxides. Part VII. Reaction of 1-Hydroxycycloalkyl Hydroperoxides with Ferrous Compounds.*

By E. G. E. HAWKINS.

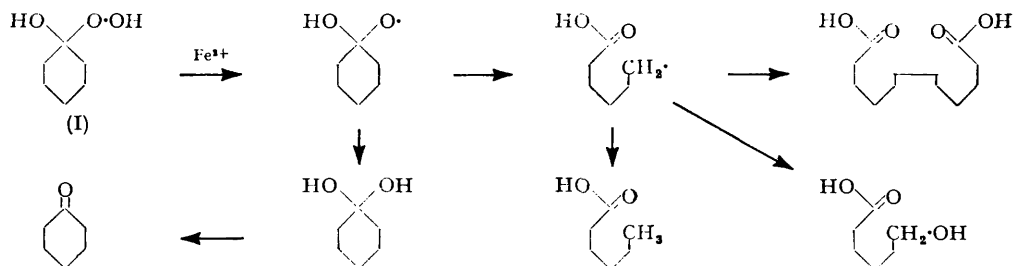
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The liquid peroxide first formed on addition of hydrogen peroxide to *cyclohexanone* reacted with ferrous sulphate solution to yield dodecane-1 : 12-dioic and hexanoic acid; solid peroxides gave much lower yields of the dicarboxylic acid. Peroxides derived from other *cycloalkanones* gave less of the corresponding dicarboxylic acids. Autoxidation of *cyclohexyl* ethers gave poor yields of the 1-hydroperoxides, which, with ferrous sulphate, provided esters of dodecane-1 : 12-dioic acid.

DURING the study of the decomposition of tertiary *cycloalkyl* hydroperoxides it was found that a diketone was produced in small yield by thermal treatment (Gasson, Hawkins, Millidge, and Quin, *J.*, 1950, 2798; Hawkins, *J.*, 1950, 2801), but in higher yield by reaction with ferrous sulphate solution (Hawkins and Young, *J.*, 1950, 2804). *E.g.* :



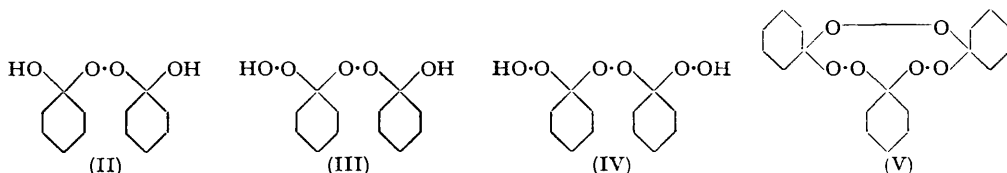
The corresponding dibasic acids, given only in low yield by thermal decomposition of 1-hydroxycycloalkyl hydroperoxides (Cooper, *J.*, 1951, 1340), were similarly produced in improved yield (*ca.* 50%) by ferrous sulphate treatment of the peroxide. After this work had been completed, Cooper and Davison (*J.*, 1952, 1180) reported that ferrous sulphate reaction led to dodecane-1 : 12-dioic acid (from *cyclohexanone*) in unspecified yield. Other products of this reaction, hexanoic acid, *cyclohexanone*, and possibly 6-hydroxyhexanoic acid, could all have been derived from a common radical, although part of the *cyclohexanone* was probably unchanged starting material. These by-products were of the same type as those obtained on decomposition of 1-methylcyclopentyl hydroperoxide (Hawkins and Young, *loc. cit.*).



The peroxides were obtained by addition of hydrogen peroxide to *cycloalkanones*. The peroxides formed under these conditions are ill-defined, and several different compounds derived from *cyclohexanone* have been reported (Milas, Harris, and Panagiotakos, *J. Amer. Chem. Soc.*, 1939, **61**, 2430; Criegee, Schnorrenberg, and Becke, *Annalen*, 1949, **565**, 7); the reaction of some of these compounds with ferrous sulphate provided evidence on this problem. When *cyclohexanone* was mixed with 90% hydrogen peroxide a slightly exothermic reaction led to a syrup which reacted smoothly with ferrous sulphate solution to give up to 55% of dodecane-1 : 12-dioic acid. This syrup gradually crystallised, and crystalline peroxides were also obtained from *cyclohexanone* and 30% or 5% hydrogen peroxide, with or without hydrochloric acid as catalyst. Such solid peroxides gave poor yields of the dicarboxylic acid when treated with ferrous sulphate solution, suggesting that the liquid peroxide was mainly (I), whilst the solid peroxides were of the type (II)—(V)

* Part VI, *J.*, 1953, 4106.

which would be expected to react with ferrous ion with greater difficulty owing to the greater stability of the $-O-O-$ linkage than that of the $-O-OH$ group. The presence of residual peroxide at the end of the reaction confirmed this increased stability.



The peroxide obtained by uncatalysed reaction of *cyclohexanone* with 5% hydrogen peroxide gave analyses correct for (II), but its m. p. (91—93°) was nearer that reported by Criegee *et al.* (*loc. cit.*) for the trimer (V) (m. p. 93°) than for the dimer (II) (m. p. 68—70°). The peroxide formed in the presence of hydrochloric acid had an analysis and m. p. (80.5—81.5°) close to that reported for the compound (IV) (m. p. 83°); this compound was decomposed by ferrous sulphate more readily than that obtained from the uncatalysed reaction.

Replacement of ferrous sulphate by ferrous chloride led to very low conversion into the C_{12} acid (cf. 1-methylcyclopentyl hydroperoxide; Hawkins and Young, *loc. cit.*), as did increase in temperature (50°).

Other ketones (*cyclopentanone*, *cycloheptanone*, 4-methylcyclohexanone) gave the corresponding dibasic acids, but in lower yields.

Direct preparation of esters of these dicarboxylic acids depended on the initial formation of 1-alkoxycycloalkyl hydroperoxides. Formation of such compounds by autoxidation of *cyclohexyl* ethers proved troublesome, and similar difficulties were encountered as during the oxidation of methylcyclopentane and methylcyclohexane (Gasson *et al.*, *loc. cit.*), *i.e.*, the peroxide concentration rose to *ca.* 10% and then fell rapidly owing to decomposition. Autoxidation of *cyclohexyl* methyl ether yielded some peroxide, difficult to isolate, together with *cyclohexanone* and adipic acid; dicyclohexyl formal also gave traces of peroxide, as well as *cyclohexanol*, *cyclohexanone*, formic and adipic acid, and *cyclohexyl* esters of these acids. Autoxidation of the *cyclohexyl* ketal of acetone (2:2-dicyclohexyloxypropane) yielded *cyclohexanol*, *cyclohexanone*, and *cyclohexyl* formate, acetate, and adipate, but very little peroxide. All these products were derived from the mesomeric radicals (A)



and (B) by oxidation or reduction. The peroxides isolated from these autoxidation reactions afforded the C_{12} acid on reaction with ferrous sulphate solution and subsequent hydrolysis.

After this work was completed (1951), details of similar experiments were reported (Du Pont, U.S.P. 2,601,223, 2,601,224; B.P. 697,506; Brown, Hartig, Roedel, Anderson, and Schweitzer, *J. Amer. Chem. Soc.*, 1955, 77, 1756).

EXPERIMENTAL

cycloHexanone.—(a) *Use of concentrated hydrogen peroxide.* *cycloHexanone* (50 c.c.) and hydrogen peroxide (90%; 20 g.) were mixed, with cooling, and used, sometimes within $\frac{1}{2}$ hr., and sometimes after being kept overnight, before crystallisation set in. The liquid mixture was added, during $\frac{1}{2}$ —1 hr., with stirring, to a suspension of powdered ferrous sulphate (250 g.) in water or 2*N*-sulphuric acid (500 c.c.), at temperatures which were varied from 0° to 50°. The product was extracted with ether, and the solvent evaporated; the residue was poured into light petroleum (b. p. 40—60°) and the solid dodecane-1:2-dioic acid (23.0 g.) filtered off. This acid had m. p. 125—126.5° (from benzene) (Found: C, 62.1; H, 9.5%; equiv., 116.5. Calc. for $C_{12}H_{22}O_4$: C, 62.6; H, 9.6%; equiv., 115). The filtrate was freed from petroleum and provided a distillate (18.0 g.), b. p. 60—150°/15 mm., and a residue (5.5 g.) from which further C_{12} acid (0.8 g.) was isolated. The distillate was separated into neutral and acid products by treatment

with alkali. The neutral product was mainly *cyclohexanone* (9.2 g.) (2:4-dinitrophenylhydrazone, m. p. and mixed m. p. 161—162°), and the acids (8.7 g.) were separated by distillation into hexanoic acid (*p*-bromophenacyl ester, m. p. and mixed m. p. 68—70°) and a high-boiling (?) hydroxy-acid. The effect of varying the temperature and reagent in further experiments is shown in Table 1.

TABLE 1.

Fe salt (g.)	Solvent (c.c.)	Temp.	Time of addition (min.)	Products (g.)			
				C ₁₂ Acid	<i>cyclo</i> - Hexanone	C ₆ Acids	Residue
FeSO₄·7H₂O							
260	H ₂ O (500)	Room	45 *	22.6	9.0	7.3	5.7
260	2N-H ₂ SO ₄ (500)	"	5 *	15.5	13.2	5.7	2.5
350	2N-H ₂ SO ₄ (500)	"	45 *	19.0	11.6	6.0	3.6
250	2N-H ₂ SO ₄ (500)	50°	30 *	6.9	15.8	4.1	2.5
250	H ₂ O (500)	0—5	45 *	23.8	6.3	9.8	4.7
250	2N-H ₂ SO ₄ (500)	0—5	45 †	25.8	7.7	5.8	2.5
125	2N-H ₂ SO ₄ (250)	0—5	45 ‡	> 8.5	17.5	7.7	5.4
FeCl₂·4H₂O							
200	H ₂ O (500)	Room	45 *	0.5	11.7	34.2	1.0

* Peroxide from *cyclohexanone* (50 c.c.) and 90% H₂O₂ (* 20 g., † 25 g., ‡ 10.5 g.).

(b) *Use of 30% hydrogen peroxide.* (i) The solid peroxide from *cyclohexanone* (50 c.c.), hydrogen peroxide (30%; 50 c.c.), and hydrochloric acid (2 c.c.), was dissolved in ethanol (100 c.c.) and added (during 1 hr.) to ferrous sulphate (250 g.) in 2N-sulphuric acid (500 c.c.). The product was separated into C₁₂ acid (5.1 g.), *cyclohexanone* (17.9 g.), hexanoic acid (7.6 g.), and residue (11.8 g.).

(ii) A mixture of *cyclohexanone* and hydrogen peroxide as in (i) but excluding hydrochloric acid, added to acidified ferrous sulphate solution within 1 hr., yielded C₁₂ acid (16.8 g.), *cyclohexanone* (13.8 g.), hexanoic acid (6.9 g.), and residue (4.3 g.).

(c) *Use of 5% hydrogen peroxide.* Addition of *cyclohexanone* (25 g.) to 5—6% hydrogen peroxide (200 c.c.) gave, on storage, a solid peroxide (A) (25—26 g.) similar to that which separated gradually from the mixture of 90% hydrogen peroxide and ketone. This peroxide had m. p. 91—93° (from benzene) [Found: C, 60.2; H, 9.7; active H (Zerewitinov), 0.64, 0.94%; peroxide equiv., 221—239. Calc. for (HO·C₆H₁₀·O)₂: C, 62.6; H, 9.6; active H, 0.87%; peroxide equiv., 230].

Addition of *cyclohexanone* (25 g.) to 6% hydrogen peroxide (200 c.c.) containing concentrated hydrochloric acid (5 c.c.) yielded, on storage, a peroxide (B) (25.7 g.), m. p. 80.5—81.5° (from aqueous methanol) [Found: C, 55.3; H, 7.9; active H (Zerewitinov), 0.75%; peroxide equiv., 88. Calc. for (HO₂·C₆H₁₀·O)₂: C, 55.0; H, 8.4; active H, 0.76%; peroxide equiv., 87.3].

TABLE 2. *Treatment of peroxides with FeSO₄·7H₂O (125 g.) in 2N-H₂SO₄ (250 c.c.).*

Peroxide used	Temp.	Products (g.)			
		C ₁₂ Acid	<i>cyclo</i> Hexanone	C ₆ Acids	Residue
A; 25 g.	0—5°	2.6	3.8	3.6	1.3
A; 25 g. in EtOH (90 c.c.)	"	4.4	6.8	2.5	2.5
A; 25 g. in acetone (170 c.c.) ...	"	3.9	5.5	2.0	2.6
B; 25 g.	"	1.3	7.3	6.0	6.6
B; 25 g. in EtOH (60 c.c.)	"	1.6	5.5	5.5	1.7
B; 25 g. in acetone (88 c.c.) ...	"	1.0	7.5	7.5	1.0
C †	Room	8.0	11.5	7.6	12.3

* The products from experiments with peroxide B could not be distilled owing to the presence of undecomposed peroxide; the quantities of *cyclohexanone*, C₆ acids, and peroxides in the residue were obtained by analysis. Peroxides A and B are described above. † A mixture of *cyclohexanone* (50 c.c.) and hydrogen peroxide (5%; 350 c.c.) added to the ferrous sulphate solution (250 g. of FeSO₄·7H₂O in 500 c.c. of 2N-H₂SO₄) before crystallisation had set in.

The results of treatment of these solid peroxides, as well as of an uncrystallised mixture of ketone and 5% hydrogen peroxide, with ferrous sulphate solution, are given in Table 2.

Other Ketones.—(i) *cyclopentanone.* The ketone (50 g.) was mixed with 90% hydrogen peroxide (23 g.), kept for 2 hr., and added to ferrous sulphate (250 g.) in 2N-sulphuric acid

(500 c.c.). Working up gave sebacic acid (5.5 g.) (m. p. and mixed m. p. 130—131.5°), *cyclopentanone* (18.1 g.), valeric acid (2.0 g.) (*p*-bromophenacyl ester, m. p. and mixed m. p. 73—74°), and residue (5.6 g.).

(ii) *cycloHeptanone*. The ketone (25 g.), 30% hydrogen peroxide (30 g.), and concentrated hydrochloric acid (1 c.c.) were set aside for 3 days and then added to ferrous sulphate (125 g.) in 2*N*-sulphuric acid (250 c.c.). Ether-extraction of the product followed by distillation gave *cycloheptanone* (8.5 g.), *n*-heptanoic acid (*p*-bromophenacyl ester, m. p. 68.5—70°), and tetradecane-1 : 14-dioic acid (3.5 g.), m. p. 122—123.5° (from benzene-light petroleum) (Found : C, 65.2; H, 9.5%; equiv., 128.3. Calc. for C₁₄H₂₆O₄ : C, 65.1; H, 10.1%; equiv., 129).

(iii) 4-Methylcyclohexanone. After the ketone (50 g.) had been kept overnight in 90% hydrogen peroxide (20 g.), the mixture was gradually added to stirred ferrous sulphate (250 g.) in 2*N*-sulphuric acid (500 c.c.). The product, on distillation, provided fractions containing 4-methylcyclohexanone (12.5 g.), 4-methylhexanoic acid (*ca.* 10 g.), b. p. 208—212° [amide, m. p. 95—96° (Found : C, 64.6; H, 11.4; N, 11.1. Calc. for C₇H₁₅ON : C, 65.1; H, 11.6; N, 10.8%); anilide, m. p. 75—76.5° (Found : C, 75.4; H, 9.1; N, 7.2. Calc. for C₁₃H₁₉ON : C, 76.1; H, 9.3; N, 6.8%); *p*-bromophenacyl ester, m. p. 45—46° (Found : C, 55.0; H, 5.75; Br, 24.7. C₁₅H₁₉O₃Br requires C, 55.0; H, 5.8; Br, 24.5%)], and high-boiling material (21 g.) from which 4 : 9-dimethyl-dodecane-1 : 12-dioic acid, m. p. 94—95.5° (from benzene-light petroleum) (Found : C, 65.3; H, 9.8%; equiv., 131. C₁₄H₂₆O₄ requires C, 65.1; H, 10.1%; equiv., 129), was isolated.

(iv) 2-Methylcyclohexanone and α -tetralone did not yield dicarboxylic acids under the conditions used.

Oxidation of cycloHexyl Ethers.—(a) *cycloHexyl methyl ether*. This ether was prepared in yields of *ca.* 50% by gradual addition of methyl sulphate (256 g.) to sodium *cyclohexyloxyde* [from reaction of sodium (46 g.) with heated and stirred *cyclohexanol* (200 g.) in *diisopropylbenzene* (256 g.)] or *ca.* 40% by addition of methyl sulphate (250 g.) to a solution of sodamide (78 g.) and *cyclohexanol* (200 g.) in diethyl ether (1500 c.c.). The crude, distilled products were refluxed over sodium and redistilled, then having b. p. 132—133°; n_D^{20} 1.4355 (lit., b. p. 135—136°, n_D^{20} 1.4344).

On oxidation at 100—110°, with or without catalyst and inorganic bases, the maximum peroxide concentration was *ca.* 14%; continued oxidation led to decomposition of peroxide and formation of *cyclohexanone* and adipic acid.

(i) The ether (50 g.), treated with oxygen at 110°, without catalyst, contained 10% of peroxide after 6 hr. Acid products were removed with sodium carbonate solution, and unchanged ether (29 g.) removed from the neutral residue at the water-pump. The product gave a distillate (1.2 g.), b. p. 55—60°/0.2 mm. (Found : peroxide equiv., 186.4. Calc. for 1-Methoxy-*cyclohexyl* hydroperoxide : peroxide equiv., 146), and a residue containing esters from which adipic acid, m. p. 149—150° [Found : equiv., 75. Calc. for C₄H₈(CO₂H)₂ : equiv., 73] (*p*-bromophenacyl ester, m. p. and mixed m. p. 154—156°), was obtained on hydrolysis. The distillate, on treatment with acidified ferrous sulphate solution, followed by hydrolysis, yielded dodecane-1 : 12-dioic acid (recrystallised; 0.3 g.), m. p. 125.5—126.5°.

(ii) The ether (100 g.) was oxidised at 100° for 20 hr., the peroxide concentration reaching 14%. Unchanged ether was removed and the crude residue (19.5 g.; 43.5% of peroxide) added to ferrous sulphate solution. There was finally obtained *cyclohexanone*, hexanoic acid (1.2 g.), C₁₂ acid (1.4 g.), and residue (1.3 g.).

(b) *cycloHexyl formal*. This was prepared by a modification of Sabetay and Schving's method (*Bull. Soc. chim. France*, 1928, 43, 1342), and had b. p. 140°/15 mm., $n_D^{19.5}$ 1.4705. Much decomposition occurred during oxidation at 100—110°, the peroxide concentration did not exceed 10%, and from the products were isolated formaldehyde, formic acid, *cyclohexanone*, *cyclohexyl* formate and adipate, and free adipic acid. Concentration of the peroxide by distillation or alkali-extraction proved difficult owing to its ease of decomposition. In one experiment, oxidation of the formal (50 g.) for 3¼ hr. at 110° was followed by dilution with light petroleum and washing with cold 50% sodium hydroxide solution (10 c.c.) to remove the peroxide. The extract was washed with benzene and light petroleum, suspended in cold water, treated with carbon dioxide, and extracted with diethyl ether. Evaporation of the ether left a residue (1.0 g.; *ca.* 50% of peroxide), which after reaction with ferrous sulphate and hydrolysis yielded a small quantity of dodecane-1 : 12-dioic acid, m. p. 122—124°.

This acid was also isolated from the products obtained by treatment of a crude oxidate with ferrous sulphate.

(c) 2 : 2-Dicyclohexyloxypropane. Ethyl orthoformate (100 g.), *cyclohexanol* (300 c.c.), and

concentrated hydrochloric acid (few drops) were heated and distilled through a short column. When the calculated quantity of ethanol had been removed, the product was distilled to give *cyclohexanol* and *cyclohexyl orthoformate* (81.0 g.; b. p. 200—205°/15 mm.), m. p. 72—73° (from benzene–light petroleum) (Found: C, 72.8; H, 11.0. $C_{15}H_{34}O_3$ requires C, 73.5; H, 11.0%). Ethyl orthoformate (100 g.), *cyclohexanol* (300 g.), and concentrated hydrochloric acid (few drops) were added to acetone (60 g.) and concentrated sulphuric acid (one drop) and set aside for 1 hr.; the product was washed with ammonia and water, dried, and distilled to provide the *ketal* (64 g.), b. p. ca. 140°/15 mm. (Found: CO equiv., 250.7. $C_{15}H_{28}O_2$ requires CO equiv., 240). The ketal was very unstable.

Oxidation of this ketal at 100—110° led to rapid formation of peroxide (25% in 1½ hr.), but this decomposed even more rapidly (to 6% in a further ½ hr.), and the peroxide could not be isolated. The oxidation products identified were *cyclohexanol*, *cyclohexanone*, *cyclohexyl formate* and *acetate*, and *adipic acid*.

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