

## NRC Publications Archive Archives des publications du CNRC

### Permanganate–periodate oxidation. VI. The oxidation of various aliphatic compounds

Von Rudloff, E.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. / La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

For the publisher's version, please access the DOI link below. / Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

#### **Publisher's version / Version de l'éditeur:**

<https://doi.org/10.1139/v65-235>

*Canadian Journal of Chemistry*, 43, 6, pp. 1784-1791, 1965-06

#### **NRC Publications Archive Record / Notice des Archives des publications du CNRC :**

<https://nrc-publications.canada.ca/eng/view/object/?id=3b201b1d-9d38-49ca-85f9-e7ae2b735f3a>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=3b201b1d-9d38-49ca-85f9-e7ae2b735f3a>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

**Questions?** Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

**Vous avez des questions?** Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

# PERMANGANATE-PERIODATE OXIDATION

## VI. THE OXIDATION OF VARIOUS ALIPHATIC COMPOUNDS<sup>1</sup>

E. VON RUDLOFF

*National Research Council of Canada, Prairie Regional Laboratory, Saskatoon, Saskatchewan*

Received December 4, 1964

### ABSTRACT

A study was made of the reaction of the permanganate-periodate reagent with a wide variety of aliphatic alcohols, polyols, aldehydes, acids, oxy-acids, ketones, ethers, and esters. Saturated monols, ketones, and ethers, as well as acetic, pelargonic, pyruvic, lactic, and oxalic acids reacted only very slowly. Glycols, olefinic alcohols, and unsaturated acids were cleaved to give predictable end products. Activated alcohols and ethyl acetoacetate reacted at relatively high rates. Formic, glyoxylic, lactic, and malonic acids as well as 1,3-propanediol and 2,5-hexane dione reacted extensively and diethyl tartrate consumed as much oxidant as did tartaric acid. The oxidation of tetrahydrofurfuryl alcohol gave succinic acid instead of the expected tetrahydro-2-furoic acid. Saturated mono- and di-carboxylic acids, 3-hydroxy propionic acid,  $\gamma$ -valero lactone, and saturated esters were stable towards the reagent.

### INTRODUCTION

Since our initial reports on the permanganate-periodate reagent (1-4) this combined oxidant has found extensive use in the lipid field. Gas-liquid chromatographic (g.l.c.) analysis of the acidic oxidation products obtained from unsaturated fatty acids and esters has confirmed the quasi-quantitative oxidation to predictable end products (5-7). This aspect has made the reagent highly successful in routine analysis of lipids (6-10) as well as in locating the position of double bonds in unknown or isomeric unsaturated fatty acids (6, 7, 11-14).

In order to determine whether the reagent may be applied equally well to other fields of organic chemistry, in particular to terpenes, a systematic study of its mode of reaction at pH 7-8 and room temperature with various oxygenated compounds was carried out. The rate of reaction and amount of oxidant consumed by a variety of alcohols, ketones, aldehydes, ethers, esters, and carboxylic acids was determined by back titration of the unconsumed oxidant (1). In a few pertinent instances the reaction products were isolated and characterized.

Previously it was shown (1) that the reagent hydroxylates an olefinic double bond rapidly to give the isomeric 1,2-ketols (preferentially at pH 7-8) and 1,2-diol (preferentially at pH 9-10) and that these are cleaved by the periodate to give aldehydes and carboxylic acids. Since only catalytic amounts of permanganate are used the aldehydes are oxidized smoothly, though more slowly, to the corresponding carboxylic acids. No side reactions were detected. The mechanism of hydroxylation with permanganate was reviewed in 1958 (15) and has since been studied further by Wolfe and Lemieux (16). It was shown that a cyclic hypomanganate ester intermediate is involved which hydrolyzes either to the ketols or diol depending on the pH of the solution. The periodate cleavage step appears to follow the well-known course (17). Since one of the basic properties of the reagent is the reoxidation of permanganate by the excess periodate, care must be taken with highly reactive compounds that may reduce the permanganate beyond the  $Mn^V$  stage more quickly than reoxidation takes place, thus bringing the permanganate reaction

<sup>1</sup>Issued as *N.R.C. No. 8372*.

to a stop. Slow addition of such a reactant to the reagent or greater dilution usually prevents this extensive reduction of permanganate. The reverse order of addition (18) cannot be recommended.

### EXPERIMENTAL

Most of the compounds used were of commercial origin (reagent grade, if available). When required the compounds were purified by fractional distillation. Aldehydes were taken up in ether and washed with small aliquots of aqueous bicarbonate solution. Ethers were treated with aqueous ferrous sulfate solution to remove peroxides. Formaldehyde, *n*-butanal, *cis*-hex-3-en-1-ol, 2-methyl-hept-2-en-6-ol, and all of the acids were used without prior purification.

Gas-liquid chromatography analyses were carried out with an F & M model 500 chromatograph (F & M Scientific Corp.), using a 180 cm  $\times$  6 mm O.D. polyethylene glycol (Carbowax 20M, 15% on Gaschrom P, 60-80 mesh) column which was temperature programmed from 55 °C at 4 °C/min. The helium flow rate was 105 ml/min and the retention time of methyl hexanoate was 7.2 min (measured from the time of injection to initial emergence of the peak). Relative retention times (r.r.t) were measured relative to this standard (r.r.t = 1.00). Since methylation of acids with freshly prepared diazomethane was found to give additional peaks and was incomplete with some dicarboxylic acids, some of the free acids were methylated in methanol containing concentrated sulfuric acid (2-3%). The esters were extracted with ether in the usual manner. Esters of high volatility were not recovered quantitatively.

#### Oxidation Procedure

The compound to be oxidized (0.25 mmole; 0.5 mmole if little or no uptake of oxidant was expected) was dissolved in water (10-30 ml) and transferred quantitatively to a standard volumetric flask (100.0 ml) containing permanganate-periodate stock solution (20.0 ml), potassium carbonate (69 mg; or more if more than 1 equivalent acidic product was expected), and water (20 ml). The stock solution of oxidant consisted of 97.5 mmoles sodium periodate (20.86 g) and 2.5 mmoles potassium permanganate (25.0 ml of a 0.1 *M* standard solution) per liter. The mixture was shaken, made up to 100.0 ml, and maintained at 20 °C ( $\pm 2$  °C). At the desired intervals, aliquots (10.0 ml) were pipetted into Erlenmeyer flasks containing standard 0.1 *N* sodium arsenite solution (5.0 ml) and sodium bicarbonate (1 g). After standing for at least 10 min the excess arsenite was titrated with standard 0.025 *N* iodine solution, using starch indicator for the end point. Duplicate values for blank determinations agreed within  $\pm 0.01$  equivalents and aqueous blanks remained constant within this value for 3 to 4 days. If the compound studied was only very slightly soluble in water it was weighed into the volumetric flask. The reagent, potassium carbonate, and water were added to give about 90 ml and this mixture was shaken for 1 to 3 h before it was made up to volume and aliquots were withdrawn. Alternatively, 10 to 50% *tert*-butanol was used as solvent. The values obtained in the back titration were converted to equivalents oxidant consumed per mole of reactant and the results obtained are expressed as atoms of oxygen per mole in Tables I to VI.

Ethanol, *n*-propanol, *n*-butanol, isobutanol, *n*-hexanol, and *n*-octanol consumed 0.10 to 0.18 atoms of oxygen per mole in 24 h and 0.40 to 0.50 in 144 h. Methanol, isopropanol, *sec*- and *tert*-butanol consumed 0 to 0.10 and 0.15 to 0.22 equivalents during the same time. Pyruvic, oxalic, and acetic acid gave corresponding values of 0.02 to 0.05 and 0.06 to 0.10 whereas pelargonic acid used up 0.08 and 0.25 atoms of oxygen per mole. Glutaric, *n*-hexanoic, benzoic, and azelaic acid, methyl acetate, ethyl acetate, and  $\gamma$ -valero lactone, as well as methyl stearate and steardipalmitin (both in 30% *tert*-butanol solution) did not consume more than 0.01 to 0.05 atoms of oxygen per mole in 3 to 6 days. 3-Hydroxy propionic acid consumed 0.15 equivalents in the first hour and was not oxidized further from then on. The initial uptake appears, therefore, to be due to an impurity. Similarly, succinic acid consumed initially 0.08 equivalents without further oxidation in 5 days.

Benzyl alcohol was also oxidized in the presence of 20% *tert*-butanol. The consumption of oxidant was 0.16, 0.43, 0.80, 2.18, 2.54, and 2.84 atoms oxygen per mole after 1, 3, 6, 24, 48, and 72 h respectively.

#### Preparative Oxidations

1. *Benzyl alcohol* (108 mg) was shaken vigorously with standard oxidant (40 ml), potassium carbonate (276 mg), and water (160 ml) for 48 h. The excess oxidant was reduced with sodium bisulfite and the weakly alkaline reaction mixture was evaporated *in vacuo* to a small volume. The mixture was acidified and extracted continuously with ether. The ether extract was dried over anhydrous sodium sulfate and evaporated to give crude acid (85 mg), m.p. 118-121 °C. Recrystallization from water raised the m.p. to 121-122° (undepressed in admixture of authentic benzoic acid).

2. *n*-Butanol (74 mg) was oxidized as above for 2 weeks. The acidic product (52 mg) was worked up as above. The g.l.c. analysis of the derived methyl esters showed only one major peak (99%) corresponding to methyl butyrate (r.r.t. = 0.32) in addition to the solvent peaks (ether, methanol).

3. *Tetrahydrofurfuryl alcohol* (102 mg) was oxidized for 24 h in the same manner. After reduction of excess oxidant the alkaline solution was extracted with ether to remove neutral compounds (3.8 mg). The acidic

fraction (35.2 mg) was worked up as above to give a crystalline product, m.p. 188–191.5 °C (undepressed by admixture of authentic succinic acid). The ethereal mother liquor was methylated and the resulting methyl esters were analyzed by g.l.c. Two peaks were recorded with r.r.t. 2.30 (3%); tetrahydrofuroic acid methyl ester r.r.t. = 2.29) and 2.80 (97%); methyl succinate r.r.t. = 2.80). The purity of the starting material was found to be 90% by g.l.c.

4. *2-Methyl-hept-2-en-6-ol* (57 mg) (82% pure) was oxidized as above and gave only traces of neutral product (1.5 mg) and an acidic fraction (31.9 mg). When the latter was taken up in ether and washed with alkali virtually all material (30.5 mg) remained in the ether layer. The g.l.c. analysis gave a single peak with the r.r.t. of  $\gamma$ -valero lactone (r.r.t. = 3.05). In a separate oxidation experiment the reduced solution was evaporated to a small volume and the distillate was treated with iodine in 2 *N* sodium hydroxide solution. A yellow precipitate having m.p. 119–121 °C (undepressed by admixture of iodoform) was obtained.

5. *n-Hexanal* (100 mg, 92% pure) was oxidized as above for 24 h to give an acid fraction (75.0 mg) which was analyzed by g.l.c. after methylation. Two peaks with r.r.t. 0.93 (10%) and r.r.t. 1.00 (90%) were recorded (methyl hexanoate r.r.t. 1.00, methyl pentanoate r.r.t. = 0.60).

6. *Glutarialdehyde*. A 25% solution of glutaraldehyde (400 mg) was oxidized as above for 18 h. The acid fraction (82 mg) was obtained crystalline, m.p. 91–95° (undepressed by admixture of authentic glutaric acid). The g.l.c. analysis of the derived methyl esters of the mother liquor gave one main peak (98%) with r.r.t. 3.55 (methyl glutarate r.r.t. = 3.55).

#### Oxidation of Esters

Methyl stearate, m.p. 37.5–38.8 °C (99.20 mg) was dissolved in *tert*-butanol (30 ml) and added to the standard oxidation mixture (see above). After 24 h the excess oxidant was reduced and the reaction mixture was extracted repeatedly with ether. After evaporation of the solvent, the residue was dried *in vacuo* to constant weight (99.25 mg); m.p. 37.2–38.8 °C.

In a similar experiment oxidation of stearodipalmitin m.p. 67.5–68.3 °C (96.10 mg) gave the unreacted starting material, m.p. 67.5–68.3 °C, in almost quantitative amount (94.55 mg).

## RESULTS AND DISCUSSION

The rate of oxidation of saturated aliphatic alcohols was found to be very slow (see Experimental). No significant difference in rate was found between lower and higher homologues or between primary, secondary, and tertiary alcohols. Surprisingly, the rate for methanol was one of the lowest. The oxidation of *n*-butanol gave only *n*-butyric acid as acidic reaction product. Since it is generally accepted that alcohols are attacked only slowly by permanganate in neutral media (19), it follows that at pH 7.5–8 the permanganate–periodate reagent behaves like neutral permanganate towards saturated alcohols. This finding permits the selective oxidation of other functional groups in alcohols provided these are not adjacent to the hydroxyl group. Wall and Serota (20) made use of this property in the selective oxidation of steroidal sapogenins with the permanganate–periodate reagent.

Activated alcohols (see Table I) reacted at much higher rates than the saturated aliphatic alcohols. Thus, benzyl alcohol consumed 1 mole of oxidant in less than 6 h and 2 in just over 2 days. Since benzoic acid was isolated in 70% yield the oxidation was essentially that of the primary alcohol group. When benzyl alcohol was oxidized in the presence of 20% *tert*-butanol the rate of oxidation increased and more than 2 moles of oxidant were consumed in 1 day (see Experimental). The oxidation of tetrahydrofurfural (see Table I) did not proceed in the expected manner since the main product was succinic acid rather than tetrahydro-2-furoic acid. The reaction with cyclic ethers will have to be studied in more detail to clarify the mechanism by which the ring is opened. Allyl alcohol consumed 4 moles of oxidant very rapidly and another 1 in about an hour; oxidation continued more slowly until nearly 6 moles were consumed. This can be rationalized by assuming that allyl alcohol is hydroxylated very rapidly to glycerol, glyceraldehyde, and dihydroxy acetone and that these are cleaved quickly to give formic acid and formaldehyde. Formic acid appears to be oxidized fairly rapidly (see below); the slow oxidation of formaldehyde at pH 7–8 has been described before (1). Hydroxylation and cleavage may proceed so rapidly that oxidation of the activated hydroxyl group in allyl alcohol may take place only to a very small extent.

TABLE I  
Oxidant consumed (atoms oxygen per mole) by some activated or unsaturated alcohols

Reaction time	Allyl alcohol	Benzyl alcohol	Tetrahydrofurfural	Tetrahydro-pyran-2-methanol	<i>cis</i> -Hex-3-en-1-ol	2-Methyl-hept-2-en-6-ol
5 min	4.39	—	—	—	2.32	1.85
10 min	4.45	0.05	—	—	2.40	1.92
20 min	4.58	0.07	—	—	2.65	2.02
30 min	4.71	0.14	0.22	0.05	2.75	2.05
1 h	4.93	0.22	0.30	0.10	3.15	2.20
3 h	5.47	0.85	0.38	0.15	3.35	2.28
6 h	5.61	1.28	0.43	0.18	3.38	2.50
24 h	5.71	1.48	1.09	0.29	3.45	2.85
48 h	—	1.91	1.54	0.33	3.50	2.90
72 h	5.88	2.02	1.99	0.44	3.55	2.94
96 h	5.92	2.08	2.24	0.53	3.60	3.02
144 h	—	—	2.63	0.89	—	—

The oxidation of alcohols with an isolated double bond followed the normal pattern of hydroxylation, cleavage, and subsequent slower oxidation of the oxidizable cleavage products. The overall consumption of 3 moles of oxidant by 2-methyl-hept-2-en-6-ol (see Table I) is in agreement with formation of acetone and 4-hydroxy pentanoic acid. Acetone was characterized by the iodoform reaction and 4-hydroxy pentanoic acid was recovered (as  $\gamma$ -valero lactone) in high yield. It was shown previously (2) that acetone is oxidized only very slowly at pH 7–8 by the reagent. The consumption of almost 4 moles of oxidant by *cis*-hex-3-en-1-ol is in accord with formation of propionic and 3-hydroxy propionic acid. A commercial sample of the latter acid was found to be completely stable towards the reagent (see Experimental).

Simple  $\alpha$ -glycols (see Table II) reacted in complete accordance with the concept of periodate cleavage (17, 21, 22) and further oxidation of aldehydic products and formic acid. When the product is formaldehyde, further oxidation is slow (see e.g. ethylene glycol). The rate of oxidation after the initial cleavage of glycerol is somewhat slower than that of formic acid (see Table IV). Similarly, that of 1,2-propanediol is a little slower than the rate of oxidation of acetaldehyde as produced in the oxidation of 2,3-butanediol. This is unexpected since both compounds would also produce formaldehyde, oxidation of which (in addition to either formic acid or acetaldehyde) should lead to a somewhat faster consumption of oxidant. This may be due, at least in part, to a slightly different pH of the respective reaction mixtures. On the other hand, the rate of oxidation of erythritol did approach the expected values closely. The markedly lower rate of cleavage of pinacol is due to steric hindrance (23). Methyl  $\beta$ -L-arabopyranoside consumed slightly more than 3 moles of oxidant rather rapidly without further oxidation. Since cleavage and oxidation of the resulting formic acid require 3 moles of oxidant, the intermediate dialdehyde ether moiety appears to be stable. The formation of cyclic hemialdals (22) in periodate oxidations is well known and it is possible that these are stable towards the permanganate-periodate reagent. Methyl glucoside and free sugars reacted very extensively and their oxidation was not characterized by clearly defined stages.

Water-soluble aldehydes, except formaldehyde, were oxidized smoothly with consumption of 1 mole of oxidant in 6–24 h (see Table III). The oxidation of pelargon aldehyde to pelargonic acid is in agreement with earlier data on the behavior of this aldehyde as part of the oxidation of oleic acid (1). *n*-Octanal also required 3 h shaking to give complete oxidation. *n*-Decanal was too insoluble to give consistent data in the aqueous mixture, but addition of 40% *tert*-butanol resulted in a normal rate of oxidation. The oxidation of *n*-hexanal gave *n*-hexanoic acid in 65% yield. Since no lower homologous acids were

TABLE II  
Oxidant consumed (atoms oxygen per mole) by some polyols

Reaction time	Ethylene glycol	Glycerol	2,3-Butanediol	1,2-Propanediol	1,3-Propanediol	Erythritol	Pinacol	Methyl arabinoside
10 min	0.98	1.90	1.19	1.07	—	3.38	0.11	2.05
20 min	0.98	1.94	1.36	1.13	—	3.74	—	2.28
30 min	—	1.96	1.50	—	—	3.98	0.22	2.45
1 h	0.98	2.00	1.88	1.34	0.10	4.35	0.37	2.80
2 h	—	2.27	2.40	—	—	—	0.57	3.06
3 h	1.01	—	2.59	1.72	0.10	5.03	0.67	3.18
6 h	1.03	2.69	2.92	1.87	0.25	5.12	0.90	3.26
24 h	1.07	2.83	2.98	1.98	0.41	5.22	1.00	3.24
48 h	1.20	2.94	2.98	1.98	0.50	5.34	1.02	3.21
72 h	1.32	3.01	—	—	0.55	—	1.08	—
144 h	1.50	3.18	3.03	—	0.70	—	1.23	—

TABLE III  
 Oxidant consumed (atoms oxygen per mole) by some aldehydes

Reaction time (h)	Form-	<i>n</i> -Butyl-	<i>n</i> -Hexyl-	<i>n</i> -Octyl-	<i>n</i> -Nonyl-	<i>n</i> -Decyl-*	Glutardi-
0.25	0.0	0.45	0.35	—	—	—	—
0.5	0.01	0.60	0.62	—	—	—	0.65
1	0.01	0.81	0.91	—	—	—	1.01
3	0.01	0.88	0.94	0.75	0.48	0.53	1.52
6	0.03	0.96	0.96	0.77	0.62	0.78	1.62
24	0.24	0.98	0.96	0.90	0.91	0.83	1.73
48	—	1.00	0.96	0.94	0.94	0.83	1.76
72	0.58	1.00	—	1.00	—	0.84	—
144	—	1.06	1.10	1.02	1.12	—	1.96

\*In 40% *tert*-butanol solution.

found to be present and since some loss of these volatile acids is likely during isolation, the smooth conversion of *n*-aldehydes to the corresponding carboxylic acid is confirmed. The consumption of nearly 2 moles of oxidant by glutardialdehyde and the isolation of glutaric acid from the product indicates that dialdehydes are also oxidized in a predictable manner, except malon dialdehyde which appears to be degraded extensively (see below).

 TABLE IV  
 Oxidant consumed (atoms oxygen per mole) by some carboxylic acids

Reaction time	Formic	Malonic	Glyoxylic	Lactic	Tartaric	Diethyl tartaric	Crotonic
5 min	—	—	—	—	1.28	—	2.98
10 min	—	—	0.69	0.01	1.82	1.09	3.28
20 min	—	—	1.18	—	2.23	1.48	3.45
30 min	0.34	0.04	1.34	0.02	2.71	1.93	3.63
1 h	0.53	0.06	1.69	0.06	3.47	2.74	4.06
3 h	0.78	0.10	1.95	0.12	4.59	3.54	4.44
6 h	0.81	—	1.97	0.27	4.85	4.11	4.55
24 h	0.86	0.23	2.01	0.62	4.89	5.00	4.78
48 h	0.94	0.48	2.00	—	—	—	4.81
72 h	0.97	0.71	2.02	1.08	4.94	—	4.80
144 h	0.98	—	2.04	1.98	—	—	—

Aliphatic acids, benzoic, oxalic, glutaric, azelaic, and pyruvic acid were oxidized only very slowly by the reagent (see Experimental). The fact that oxalic acid did not react to any appreciable extent confirms that manganese is not reduced below the  $Mn^V$  level, thus preventing the well-known autocatalyzed reaction. Formic acid (see Table IV) consumed 1 mole of oxidant in 1 to 2 days. As found earlier (3), malonic acid is also oxidized slowly (see Table IV), the rate being similar to that of 1,3-propanediol. Hence, it is surprising that 3-hydroxy propionic acid was found to be much more stable. Glyoxylic acid (see Table IV) consumed 2 moles of oxidant fairly rapidly, indicating that this acid was cleaved rather than oxidized to oxalic acid. Pyruvic acid was stable towards the reagent and lactic acid was oxidized only slowly. The latter consumed 2 moles of oxidant in 6 days indicating that cleavage has taken place instead of oxidation of pyruvic acid. Tartaric acid reacted very rapidly and the consumption of almost 5 moles in 24 h suggests again that the intermediate glyoxylic acid must be cleaved, which is in agreement with the above conclusions. This is further supported by the data obtained with diethyl tartrate. Cleavage of this ester would yield 2 moles of ethyl glyoxylate. The consumption of a total of 5 moles of oxidant is in agreement with cleavage of this aldehydo ester

(possibly after hydrolysis to glyoxylic acid). Hydroxylation and cleavage of crotonic acid would yield acetaldehyde and glyoxylic acid. Further oxidation of these two products would require 3 moles of oxidant if the glyoxylic acid moiety is cleaved. Again, the values of oxidant consumed are in good agreement (see Table IV).

TABLE V  
Oxidant consumed (atoms oxygen per mole) by some aliphatic ketones

Reaction time (h)	Methyl ethyl ketone	Methyl isobutyl ketone		Methyl <i>n</i> -amyl ketone	2,5-Hexanedione	Ethyl acetoacetate
		(a)*	(b)†			
1		—	—	—	—	2.09
3	0.01	0.01	0.01	0	0.01	2.54
6	0.01	0.01	0.04	0.02	0.08	2.94
24	0.03	0.04	0.05	0.09	0.22	3.53
48	0.06	0.05	0.07	0.14	0.40	3.76
120	0.23	0.16	0.20	0.33	0.86	3.90
144	0.30	0.33	0.40	0.55	1.16	3.90

\**(a)* In aqueous solution.  
†*(b)* In 20% *tert*-butanol solution.

Ketones were oxidized only very slowly (see Table V). This was anticipated from the very low rate of oxidation of acetone at pH 7–8 (2). The rate of oxidation of methyl isobutyl ketone in the presence of *tert*-butanol was practically the same as in aqueous solution. Noteworthy, again, is the higher rate of oxidation of 2,5-hexanedione, the rate being similar to that of malonic acid and 1,3-propanediol. This would indicate a similar activation of the methylene group in 1,3-diones, although in the ketones it seems more likely that the enol form is the one that reacts. As expected, ethyl acetoacetate reacts rapidly and the consumption of almost 4 moles of oxidant is in agreement with the assumption that the enol form is hydroxylated and cleaved to give acetaldehyde and ethyl glyoxylate as intermediates. The latter two compounds would react further as described above for 2,3-butanediol, crotonic acid, and ethyl tartrate.

As noted previously (3), saturated esters are stable towards the reagent. Methyl and ethyl acetate, as well as methyl stearate and steardipalmitin, consumed less than 0.05 moles of oxidant in 3 days and the latter two esters were recovered virtually quantitatively (see Experimental).  $\gamma$ -Valero lactone also consumed no oxidant. This confirms that the saturated esters are not hydrolyzed under the ordinary oxidation conditions and this stability accounts in part for the quantitative results obtained in triglyceride analysis (6–9). Some workers have found that in the oxidation of oleic and linoleic acid or their esters a few percent of the next lower homologous monocarboxylic acid (octanoic and pentanoic acid respectively) may be formed in permanganate–periodate oxidation (6, 14, 18). Recent results obtained by Craig and Bhatti (14) indicate that this so-called overoxidation is largely due to the presence of peroxides. However, the very low rate of oxidation of pelargonic acid itself (see Experimental) suggests that a small amount of the next lower homologue may be produced by direct attack on the end products. However, since the reaction time for the oxidation of unsaturated acids and esters is usually less than 24 h, this side reaction cannot amount to more than 3%. In fact, it will normally be smaller since azelaic and hexanoic acids were found to be practically stable towards the reagent. It is also noteworthy that 9,10-epoxy stearic acid was not oxidized by the reagent (1).

TABLE VI  
Oxidant consumed (atoms oxygen per mole) by some aliphatic ethers

Reaction time (h)	Diethyl ether	<i>n</i> -Dibutyl ether	Bis-(2-methoxy ethyl)-ether	Bis-(2-ethoxy ethyl)-ether
3	0.03	0.11	0.15	0.13
24	0.41	0.40	0.18	0.42
48	0.49	0.48	0.30	0.64
72	0.70	0.58	0.42	0.78
96	0.80	0.67	0.48	1.00
168	1.30	1.11	0.89	1.17

Finally, a few ethers were investigated (Table VI). These were oxidized at a slow rate and the uptake of oxidant did not cease after 7 days. When *p*-dioxane was used as solvent (2) a slow increase in the blank titration was also noted. This confirms that the ethers are not ideal for use as solvent and *tert*-butanol and possibly also pyridine (4) are to be preferred.

#### ACKNOWLEDGMENTS

The interesting and stimulating discussions with Drs. R. U. Lemieux and A. S. Perlin are gratefully acknowledged. Thanks are also due to Mr. M. Granat for technical assistance.

#### REFERENCES

1. R. U. LEMIEUX and E. VON RUDLOFF. *Can. J. Chem.* **33**, 1701, 1710 (1955).
2. E. VON RUDLOFF. *Can. J. Chem.* **33**, 1714 (1955).
3. E. VON RUDLOFF. *J. Am. Oil Chemists' Soc.* **33**, 126 (1956).
4. E. VON RUDLOFF. *Can. J. Chem.* **34**, 1413 (1956).
5. B. M. CRAIG and E. VON RUDLOFF. Unpublished results.
6. A. P. TULLOCH and B. M. CRAIG. Abstract, Oct. Meeting Am. Oil Chemists' Soc. 1960; *J. Am. Oil Chemists' Soc.* **41**, 322 (1964).
7. T. C. LO CHANG and C. C. SWEELEY. *J. Lipid Res.* **3**, 170 (1962).
8. C. G. YOUNGS. *J. Am. Oil Chemists' Soc.* **38**, 62 (1961).
9. M. R. SUBBARAM and C. G. YOUNGS. *J. Am. Oil Chemists' Soc.* **41**, 150, 218 (1964).
10. M. R. SUBBARAM, M. M. CHAKRABARTY, C. G. YOUNGS, and B. M. CRAIG. *J. Am. Oil Chemists' Soc.* **41**, 691 (1964).
11. C. R. SMITH, T. L. WILSON, T. K. MIWA, H. ZOBEL, R. L. LOHMAR, and J. A. WOLFF. *J. Org. Chem.* **26**, 2903 (1961).
12. C. R. SMITH, T. L. WILSON, R. B. BATES, and C. R. SCHOLFIELD. *J. Org. Chem.* **27**, 3112 (1962).
13. P. A. J. GORIN, J. F. T. SPENCER, and A. P. TULLOCH. *Can. J. Chem.* **39**, 846 (1961).
14. B. M. CRAIG and M. K. BHATTY. *J. Am. Oil Chemists' Soc.* **41**, 209, 508 (1964).
15. J. W. LADBURY and C. F. CULLIS. *Chem. Rev.* **58**, 403 (1958).
16. S. WOLFE. Ph.D. Thesis, University of Ottawa, Ottawa, 1957.
17. C. A. BUNTON and V. J. SHINER. *J. Chem. Soc.* 1593 (1950).
18. E. P. JONES and J. A. STOLP. *J. Am. Oil Chemists' Soc.* **35**, 71 (1958).
19. R. STEWART. *In Oxidation mechanism*. W. A. Benjamin, Inc., New York, 1964, p. 63.
20. M. E. WALL and S. SEROTA. *J. Org. Chem.* **24**, 741 (1959).
21. F. R. DUKE and V. C. BULGRIN. *J. Am. Chem. Soc.* **76**, 3803 (1954).
22. R. D. GUTHRIE. *In Advances in carbohydrate chemistry*. Vol. 16. Edited by M. L. Wolfrom. Academic Press, New York, 1961, p. 105.
23. G. J. BUIST, C. A. BUNTON, and J. H. MILES. *J. Chem. Soc.* 4567 (1957).