

## On the Stability of Ozonides

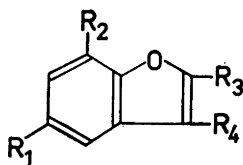
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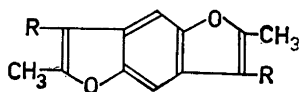
Thermal decomposition in benzene of three ozonides has been followed iodometrically. The first half of the reaction is strictly first-order with no induced decomposition. Activation energies have been calculated. The rate-controlling step is probably a homolytic cleavage of the O—O bond. It seems probable that an ozonide can transfer active oxygen to a suitable substrate.

For some time we have been concerned with the ozonolysis of certain benzofurans and benzodifurans<sup>1,2</sup>, during which work the formation of stable ozonides has been a matter of great interest.

Isolation of the ozonides in a pure crystalline state has been achieved with varying ease in the different cases chiefly due to great variations in their stability. One of the structural factors guiding the stability is the nature of the substituents at both ends of the double bond. Criegee has made a statement at variance with this<sup>3</sup>, but had perhaps only hydrocarbon substituents in mind.



I: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = H;	R <sub>3</sub> = CH <sub>3</sub> ;	R <sub>4</sub> = COOH
II: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = H;	R <sub>3</sub> = CH <sub>3</sub> ;	R <sub>4</sub> = COOCH <sub>3</sub>
III: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = H;	R <sub>3</sub> = CH <sub>3</sub> ;	R <sub>4</sub> = COOC <sub>2</sub> H <sub>5</sub>
IV: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = H;	R <sub>3</sub> = CH <sub>3</sub> ;	R <sub>4</sub> = COOC <sub>2</sub> H <sub>7</sub>
V: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = H;	R <sub>3</sub> = CH <sub>3</sub> ;	R <sub>4</sub> = COCH <sub>3</sub>
VI: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = R <sub>3</sub> = CH <sub>3</sub> ;		R <sub>4</sub> = COOC <sub>2</sub> H <sub>5</sub>
VII: R <sub>1</sub> = CH <sub>3</sub> COO;	R <sub>2</sub> = R <sub>3</sub> = CH <sub>3</sub> ;		R <sub>4</sub> = COCH <sub>3</sub>
VIII: R <sub>1</sub> = R <sub>2</sub> = H;		R <sub>3</sub> = COOCH <sub>3</sub> ;	R <sub>4</sub> = H



- IX: R = COOC<sub>2</sub>H<sub>5</sub>  
 X: R = COCH<sub>3</sub>  
 XI: R = H

Stable ozonides have on previous occasions been prepared in this laboratory from the substances III, VI and IX. An isolable, but rather unstable ozonide was obtained from X, while ozonides from V, VII and XI were too unstable to be isolated. In the experimental section of this work is described the preparation of two new benzofuran derivatives (II and IV) and their stable, monomeric ozonides. Attempts to prepare isolable ozonides from I and VIII met with no success.

Summarising these results it is seen that if only one end of the double bond in the furan ring is substituted, no ozonide can be isolated. This is in agreement with the findings that only 2,3-disubstituted indoles form stable ozonides. Furthermore, a free carboxyl group is evidently detrimental to the stability of an ozonide while an ester group enhances the stability more than does an acetyl group.

Small changes in the substituents therefore bring about great differences in stability. To get a clearer picture of their (thermal) stabilities, absolutely as well as relatively to each other, we have investigated the degradation of three closely related and easily accessible ozonides, *viz.* those of II, III and IV, at elevated temperatures.

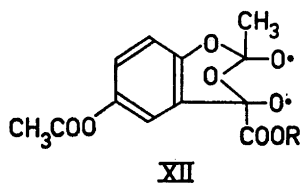
The kinetic runs were performed in benzene solution, but some degradation experiments in xylene and decalin will be discussed later in this paper. Analytically the reactions were followed by determining iodometrically the decreasing content of active oxygen. The validity of our kinetic results (*i.e.* that they truly represent the decomposition of the ozonide) is therefore based on the assumption that the rupture of the O—O bond is a rate-controlling step and that no transfer of active oxygen to the solvent or to reaction products take place. Justification of these assumptions is found in the strict adherence of the degradation to first order kinetics (however, see below), and in the rather high activation energies. The relevant kinetic results are summarised in Table 1.

The first-order rate-constants are all calculated from the first half of the reactions. From that point onwards serious deviation from first-order kinetics began to develop in the form of distinct retardation of the reaction. This may be a true kinetic effect, *i.e.* the reaction products exert a negative catalysis or it may be an analytical artefact in the sense that we are no longer measuring the real content of ozonide in solution. Such a situation could arise if the ozonide was able to transfer its active oxygen to any of the reaction products, supposing that the new peroxidic products were more stable than the ozonide itself.

Table 1. First-order rate-constants for the thermal decomposition of benzofuran ozonides in benzene.

Ozonide from	Temperature °C	$C_0 \times 10^3$ in mole/l	$k$ in $h^{-1}$
II	100.0	0.633	0.140
II	100.0	1.962	0.131
II	100.0	3.217	0.142
II	79.65	1.962	0.0147
III	100.0	0.633	0.132
III	100.0	1.962	0.126
III	100.0	3.217	0.122
III	90.0	1.962	0.0436
III	79.15	1.962	0.0127
IV	100.0	0.633	0.134
IV	100.0	1.962	0.124
IV	100.0	3.217	0.130
IV	79.15	1.962	0.0124

No significant changes in the rate-constants at 100° were observed on increasing the concentration of the reactant about five times. First-order kinetics is thus further vindicated and induced decomposition ruled out. We believe that the rate-determining step in the thermal decomposition is a homolytic splitting of the O—O bond producing a diradical like XII. Due to the special



steric situation in this diradical recombination must be frequent. The further reactions are probably of the usual radical type transformations, *viz.* decomposition, rearrangements and attack on substrates. The complexity and partly polymeric nature of the reaction products from our experiments substantiate the belief that several modes of reaction are operative. If the concept of active oxygen transfer is true, even the initial homolytic cleavage may not be entirely homogeneous but mixed with small amounts of another reaction where the O—O bond is preserved. From our kinetic data the following activation energies are calculated: Ozonide of II 28.2 kcal/mole; ozonide of III 28.7 kcal/mole; ozonide of IV 28.8 kcal/mole. These figures are well within the range of activation energies for thermal decompositions of peroxides and therefore compatible with a homolytic cleavage of an O—O bond.

In the initial search for a suitable inert solvent for the decomposition experiments xylene (*o*, *m*-, *p*-mixture) was tried. Surprisingly the content of active oxygen increased when a solution of ozonide in xylene was heated at 100° for some hours. Xylene is known to have a slight tendency to autoxidation and the amount of oxygen in the air in the ampoules was sufficient to explain the

increase in active oxygen. Controls with xylene alone, however, showed only a weak autoxidation under the experimental conditions, so the presence of an ozonide or its immediate decomposition products must be able to catalyse this process. According to our figures the reaction is accelerated at least ten times. Direct transfer of active oxygen from ozonide to the solvent can not be inferred with certainty from these experiments. Decalin has far greater tendency to formation of peroxides than xylene and some runs were made in this solvent under an oxygen-free nitrogen atmosphere. The rate of decomposition at 100° was in this case only about one third of the measured in benzene. This difference is far to large to be explained by general solvent effect, but must be due to the formation of decalin peroxides by the action of the ozonide.

## EXPERIMENTAL

*Methyl 2-methyl-5-acetoxybenzofuran-3-carboxylate (II)*. To a continuously agitated solution of anhydrous zinc chloride (35 g) in dry acetone (50 ml) and glacial acetic acid (3 ml) kept at 75°, was added during 8 h a solution of *p*-benzoquinone (27 g) in methyl acetoacetate (100 ml) and acetone (100 ml). The reaction mixture was concentrated in a stream of warm air and placed in a refrigerator when a greyish crystalline product separated which was washed with small amounts of ice-cold methanol. Yield 24.2 g (47 %). Recryst. four times from aqueous acetone (charcoal), m.p. 146.5°. (Found: C 64.1; H 5.2; OCH<sub>3</sub> 15.4. Calc. for C<sub>11</sub>H<sub>10</sub>O<sub>4</sub>: C 64.1; H 4.9; OCH<sub>3</sub> 15.1.) The product (10 g) was dissolved in acetyl chloride (50 ml), boiled for 15 min and poured into ice-water (2 l) when a dark oil separated. After about 0.5 h this solidified, was broken up and washed thoroughly with water. Recrystallised from aqueous acetone, m.p. 83°. (Found: C 63.1; H 5.0; OCH<sub>3</sub> 12.1. Calc. for C<sub>13</sub>H<sub>12</sub>O<sub>5</sub>: C 62.9; H 4.9; OCH<sub>3</sub> 12.5.)

*n*-Propyl 2-methyl-5-acetoxybenzofuran-3-carboxylate (IV). The ethyl ester I (R<sub>2</sub> = OH) (17.5 g) was dissolved in dry propanol-1 (300 ml), saturated at room temperature with hydrogen chloride, and refluxed for 8 h. The main part of the propanol (250 ml) was distilled off and the residue poured into ice-water (1 l) when a crystalline substance separated (18.3 g, 98 %). Recrystallised twice from aqueous acetone and four times from benzene, m.p. 105°. (Found: C 66.6; H 6.2. Calc. for C<sub>13</sub>H<sub>14</sub>O<sub>4</sub>: C 66.7; H 6.0.) Acetylation as for the methyl ester. Recrystallised thrice from aqueous acetone (charcoal), m.p. 45–46°. (Found: C 65.4; H 5.9. Calc. for C<sub>15</sub>H<sub>16</sub>O<sub>5</sub>: C 65.2; H 5.8.)

*Ozonisation*. The ozone generator produced at an oxygen flow of 30 l/h, 2.4 g O<sub>3</sub>/h. Methyl ester (II) (9 g) was dissolved in ethyl acetate (250 ml) and ozonised at 0° for 52 min. Most of the ethyl acetate was removed in a stream of air and the remainder *in vacuo*. The residue consisted of yellow, somewhat sticky crystals which were washed with aqueous acetic acid (1:1). Yield 8.7 g (81 %). Recrystallised twice from aqueous acetic acid (8:2) and twice from alcohol. White crystals, m.p. 88–89°. (Found: C 52.7; H 3.9; act. O 5.4; M 294 (benzene). Calc. for C<sub>13</sub>H<sub>12</sub>O<sub>8</sub>: C 52.7; H 4.1; act. O 5.4; M 296.) The propyl ester was ozonised in the same way, but at a lower temperature (solid carbon dioxide – acetone). The ozonide had m.p. 68°. (Found: C 55.1; H 4.7; act. O 5.0; M 317 (benzene). Calc. for C<sub>15</sub>H<sub>16</sub>O<sub>8</sub>: C 55.6; H 5.0; act. O 4.9; M 324.)

*Ozonolysis of 2-methyl-5-acetoxybenzofuran-3-carboxylic acid (I)*. The acid (5 g) was dissolved in ethyl acetate (200 ml) and ozonised at low temperature (solid carbon dioxide – acetone) for 30 min. To the reaction mixture was added light petroleum until turbidity occurred and a yellow oil which contained active oxygen separated. The solvent mixture was decanted and the last traces removed *in vacuo*. As soon as the oil reached about room temperature it began to decompose with evolution of gas. The residue soon solidified to a yellow crystalline mass which did not contain any active oxygen. Recrystallised from an ether-ligroin mixture (charcoal), m.p. 117–122°, white crystals. Hydrolysis with 2 N hydrochloric acid afforded white needles, recrystallised from water (charcoal), m.p. 198–200°. Blue colour with ferric chloride. Mixed m.p. with an authentic sample of gentisic acid showed no depression.

*Kinetics.* The purified ozonides were dissolved in reagent grade benzene at room temperature and 10 ml aliquots transferred to glass ampoules which were sealed and placed in a thermostat bath at the appropriate temperature. For analysis the ampoules were rapidly cooled and broken in a tall beaker whereupon glacial acetic acid (15 ml) was added. Pieces of solid carbon dioxide were placed in the mixture and sodium iodide (1 g) added. The beaker was closed with a lid and kept in a dark cupboard for 0.5 h. Recently boiled water (100 ml) was added and the heterogeneous mixture titrated under vigorous stirring with standard (0.01 N) thiosulphate. Controls with samples of the ozonide of III gave results better than 99.5 % of the theoretical value. The starting point in the runs was always a titration value of an actual sample rather than a figure calculated from the weighed amount of ozonide.

*Decomposition in xylene and decalin.* Ozonide of III was dissolved in pure xylene (free from active oxygen) and 10 ml aliquots were transferred to ampoules and sealed as before. In a typical run the titration value increased from 9.03 ml 0.01316 N sodium thiosulphate to 13.33 ml in 2 h 20 min. Roughly estimated the volume of air in the ampoules was 10 ml, *i.e.* 2 ml of oxygen. This is 0.18 mequiv. (calculated as routed through a hydroperoxide and determined iodometrically) corresponding to a consumption of 13.5 ml 0.01316 N sodium thiosulphate. Ampoules with xylene only were heated 2 h 20 min. Air volume approximately as before. Mean titration value: 0.37 ml of the usual thio-sulphate.

The runs in decalin were performed in a reflux apparatus kept in a thermostat at 100° through which a stream of dry oxygen-free nitrogen (washed with alkaline pyrogallol solution) was led. Decalin is a rather poor solvent for the ozonide (of III) and the reaction mixture was therefore made up by saturating the decalin with ozonide at room temperature. Samples of ca 25 ml were withdrawn and cooled to room temperature and from this 20 ml samples were pipetted and analysed. The reaction was not pure first order, but if calculated as such, the average rate-constant was 0.05 h<sup>-1</sup>.

#### REFERENCES

1. Bernatek, E. and Thoresen, F. *Acta Chem. Scand.* **9** (1955) 743.
2. Bernatek, E. and Bö, I. *Acta Chem. Scand.* **13** (1959) 337.
3. Criegee, R., Kerckow, A. and Zinke, H. *Chem. Ber.* **88** (1955) 1878.
4. Bailey, P. S. *Chem. Revs.* **58** (1958) 973.

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