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ANOMALOUS OZONOLYSIS PRODUCTS IN THE ADDITION OF SINGLET OXYGEN TO METHOXYMETHYLFURANS

by

Ben L. Feringa and Robert J. Butselaar

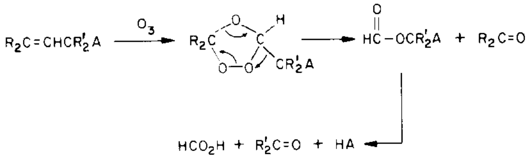
KONINKLIJKE/SHELL-LABORATORIUM, AMSTERDAM

(Shell Research B.V.), The Netherlands

The rearrangement of cyclobutadiene ozonides, related to "anomalous ozonolysis", has been elucidated.

In the ozonolysis of allylic compounds varying amounts of products are formed that are due to cleavage of both the carbon-carbon double bond and the adjacent carbon-carbon single bond, the so-called "abnormal" or "anomalous" products[1]. Contradicting results have been obtained concerning "normal" and "abnormal" ozonolysis.

The influence of the work-up procedure and the exact mechanism are points of debate although the studies of Young and co-workers[2] strongly suggest a rearrangement of the ozonide according to Scheme 1[1].



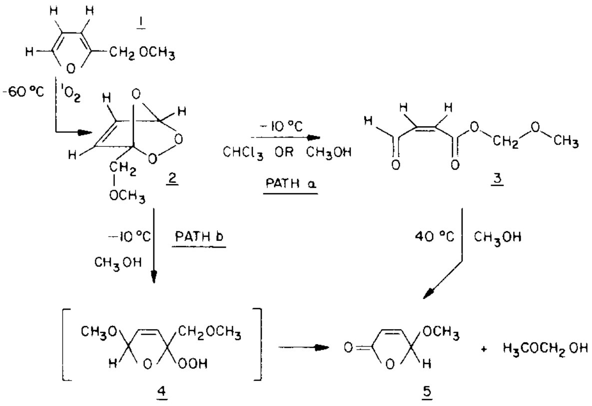
(A = OH, OR, NR$_2$, R AND R' = H, ALKYL, ARYL)

SCHEME I

A similar Baeyer-Villiger-like rearrangement has been proposed[3] as one of the possible mechanisms in the breakdown of the cyclobutadiene ozonides formed in the photo-oxidation of certain 2-substituted furans as investigated by Schenk and co-workers[4].

We here wish to report direct evidence for the breakdown according to the mechanism pictured in Scheme 1 of the ozonides formed upon photo-oxidation of 2-(methoxymethyl)- and 2,5-di-(methoxymethyl)furan and the isolation of the primary rearrangement products.

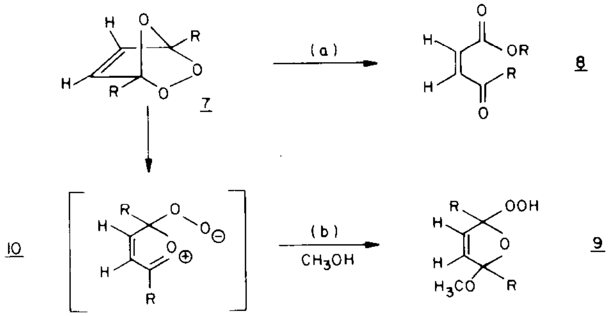
When a solution of 2-(methoxymethyl)furan 1 (17.8 mmol) in $CDCl_3$ with Rose Bengal/18-crown-6 (0.2 mmol) as the sensitizer was photo-oxidized at -60 °C, ozonide 2 was formed quantitatively. 2: ^{1}H-NMR ($CDCl_3$): 6.58 (m, 2 H); 6.51 (s, 1 H), 4.08 (s, 2 H), 3.49 ppm (s, 3 H). When the temperature of the solution was raised to -10 °C 2 rearranged quantitatively to 3 (Scheme 2, path a) by a first-order process (k (-10 °C) = 1.17×10^{-4} s^{-1}, E^a = 80.3 kJ/mole). Pure compound 3, containing the peculiar γ-keto-α,β-unsaturated-methoxymethyl ester functionality, was isolated by chromatography over alumina ($CHCl_3$) as a colourless oil (17.3 mmol, 96 % yield). Spectroscopic data confirmed structure 3 of the rearranged product. ^{1}H-NMR ($CDCl_3$): 10.62 (d, J = 7 Hz, 1 H), 6.41 (d.d., J = 7 Hz, 12 Hz, 1 H), 6.72 (d., J = 12 Hz, 1 H), 5.42 (s, 2 H), 3.55 ppm (s, 3 H); ^{13}C-NMR: 57.7, 91.2, 133.0, 140.7, 163.5, 191.8 ppm;
MS: (E.I) m/e 113, 83, 61, 55, 28; (CI) (methane). $[M+1]^+$ at m/e 145, 83; NCI (OH^-) M^- at m/e 144.



SCHEME 2

Upon photo-oxidation of 1 in the manner described above but with methanol as the solvent the ozonide 2 was again formed quantitatively. However, two concurrent processes occurred when the temperature was raised to -10 °C. The main process was the rearrangement of 2 to 3 in 82 % yield, while 18 % of 2 was decomposed into lactone 5 and formaldehyde hemiacetal. This decomposition probably proceeds via hydroperoxide 4. Schenck and co-workers[4] isolated 5 as the only distillable product from the photo-oxidation of 1 in methanol. We did not observe any conversion of 3 to 5 at -10 °C in CH_3OH, but when 3 was stirred in CH_3OH at 40 °C for 3 hours it was converted into lactone 5 in more than 85 % yield. On the basis of our results we conclude that (a) the breakdown of ozonide 1 proceeds in $CHCl_3$ exclusively and in CH_3OH predominantly via the Baeyer-Villiger-type rearrangement shown in Scheme 1, and (b) the fact that lactone 5 is isolated (by distillation) as the main product in the photo-oxidation of 1 in methanol is due to solvolysis of the major rearrangement product 3 (Scheme 2).

"Anomalous ozonide" rearrangements similar to that for 1 were also found in the photo-oxidation of 2,5-di(methoxymethyl)furan (6a) and 2,5-di(hydroxymethyl)furan (6b). The ozonides 7a and 7b were formed quantitatively at -60 °C in both $CHCl_3$ and CH_3OH. (see preceding paper). Upon warming the solutions of 7a and 7b in $CHCl_3$ to room temperature quantitative rearrangements to 8a and 8b[8] occurred. In CH_3OH, attack on the ozonide by the solvent to give 9 is a minor pathway for 7a, a major pathway for 7b and the exclusive pathway for 7c (see Scheme 3).



			8 (%)	9 (%)
a	R = CH_2OCH_3	$CDCl_3$	100	–
		CD_3OD	84	16
b	R = CH_2OH	$CDCl_3$	100	–
		CD_3OD	46	54
c	R = CH_3	$CDCl_3$	–	– (cf ref.7)
		CD_3OD	–	100

SCHEME 3

Thus, oxymethylene substitution seems to be essential for the ozonide rearrangement via path a to occur. It is remarkable that the course of the reaction, i.e. via methanol addition or Baeyer-Villiger-type rearrangement, is so largely determined by the nature of the substituents. As methanol addition involves carbon-oxygen bond breaking, probably via dipolar species 10, assistance of the OH via hydrogen bridging or protonation of 10 might favour the methanol addition in the case of ozonide 7b.

On the basis of our results we conclude that a rearrangement similar to that observed for the bicyclic ozonides is reponsible for the formation of anomalous products in the ozonation of allylic compounds. That the rearrangement occurs quantitatively in the case of 2, 7a and 7b in contrast to ozonides of allylic compounds[9] might be due to release of ring strain or to electronic effects in the cyclobutadiene ozonides.

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Notes and References

1. P.S. Bailey, "Ozonation in Organic Chemistry", Volume I, "Olefinic Compounds", Academic Press, New York, 1978, Chapter IX.
2. W.G. Young, A.C. Mc. Kinnis, I.D. Webb and J.D. Roberts, J. Amer. Chem. Soc., **68**, 293 (1946).
3. H.H. Wasserman and B.H. Lipshutz, in: "Singlet Oxygen" (H.H. Wasserman and R.W. Murray, eds.), Academic Press, New York, 1979, Chapter 9.
4. G.O. Schenck, Angew. Chem., **64**, 12 (1952); G.O. Schenck, Justus Liebigs Ann. Chem., **584**, 156 (1953).
5. Compound 5 was independently synthesized via photo-oxidation of furfural[4,6] or furan in methanol.
6. G.J. Koomen, F. van Alewijk, D. Blok and U.K. Pandit, Heterocycles, **12**, 1535 (1979).
7. The ozonide decomposes slowly at room temperature into diacetylethylene.
8. All spectroscopic data of the new compounds were in agreement with their structures.
9. Young et al. report, for instance, 25 % abnormal product in the ozonolysis of 1-ethoxy-2-butene[2].

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