

Ozonolysis in Ester Solvents: Synthesis of Alkoxy Ozonides

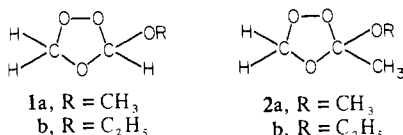
Helmut Keul and Robert L. Kuczkowski*

Department of Chemistry, University of Michigan
Ann Arbor, Michigan 48109

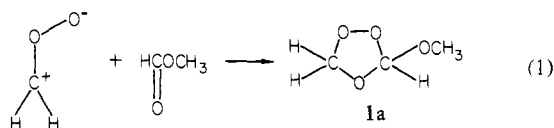
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Ozonide systems derived from alkenes with electronegative substituents at the double bond are uncommon.¹ Recently several simple fluoroozonides² and a few complex ozonides containing chlorine have been characterized.³ An interest in such systems has led us to explore the synthesis of ozonides containing the OR moiety. We have been successful in identifying 3-methoxy-1,2,4-trioxolane (**1a**) in yields of 5–10% from the ozonolysis of



styrene in methyl formate solvent. In a similar fashion, ozonides **1b**, **2a**, and **2b** have been obtained in the solvents ethyl formate, methyl acetate, and ethyl acetate, respectively. These ozonides are presumably formed by the reaction of the ester with the formaldehyde oxide produced from the breakdown of the primary ozonide (reaction 1). This trapping reaction is especially note-

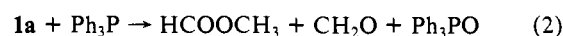


worthy since ester solvents are ordinarily considered nonparticipating and ozonolyses are frequently conducted in them.^{3d,4}

Ozonolysis of styrene in the presence of ester was undertaken for several reasons. Styrene would produce the $\text{H}_2\text{C}^+\text{OO}^-$ intermediate which has been shown to react with poor dipolarophiles such as HCOF and COF_2 .² In addition, most normal products from styrene such as benzaldehyde and styrene ozonide⁵ could be readily identified and separated from any low molecular weight ozonide. The ester needed to trap $\text{H}_2\text{C}^+\text{OO}^-$ was also chosen as the solvent because of the expected low dipolarophilicity of esters. Therefore, a high effective concentration would enhance the prospects to trap $\text{H}_2\text{C}^+\text{OO}^-$. Moreover, a formate ester seemed to be a very propitious choice since it can be formally regarded as an alkoxy formaldehyde and aldehydes are good trapping agents for carbonyl oxides. The employment of a poor dipolarophile as a solvent to produce ozonides which are difficult to obtain by normal procedures has precedence in the use of ketonic solvents (acetone, for example) to form tri- and tetra-substituted ozonides.⁶ In this context, the ability of both formate and acetate esters, when used as solvents, to react with some of the ozonolysis cleavage product ($\text{H}_2\text{C}^+\text{OO}^-$) may not appear so unusual.

In a typical reaction, 5.57 g of styrene in 55 mL of methyl formate was ozonized at -78°C with 1 equiv of ozone. The workup consisted of three distillations. The solvent was removed via the first distillation at room temperature and 200 torr. In the second distillation (room temperature, <0.01 torr), all the volatile products including benzaldehyde, ethylene ozonide, 3-methoxy-1,2,4-trioxolane, and residual HCOOCH_3 were separated from the involatile residue, which consisted mainly of styrene ozonide and some minor unidentified products. The third distillation (trap to trap on a vacuum line) separated the methoxy ozonide from the less volatile benzaldehyde and more volatile ethylene ozonide and HCOOCH_3 . The purity of the methoxy ozonide was 95–96%. It was analyzed by spectroscopic methods.⁷ The other three ozonides (**1b**, **2a**, **2b**) were purified and analyzed similarly.⁸ All four ester solvents gave the parent ozonide, styrene ozonide, in yields of $75 \pm 5\%$ and the respective alkoxy ozonide in yields of 5–10%. The alkoxy ozonide yield from the alkyl formate ester was higher than that from the analogous alkyl acetate ester.

Methoxy ozonide (**1a**) is a colorless liquid with a vapor pressure of ~ 0.3 torr at room temperature. Small amounts of it have been relatively stable in a high-vacuum apparatus or in solution at room temperature. Under these conditions it does not appear hazardous but normal precautions in handling ozonides should be followed. The ozonide was also reduced with Ph_3P in CDCl_3 (reaction 2).



This reaction was monitored by NMR. The characteristic signals of **1a** disappeared while new signals for HCOOCH_3 and CH_2O grew as expected for the reaction between an ozonide and Ph_3P . The analogous behavior was observed with **1b**, **2a**, and **2b**.

We believe that the formation of these ozonides from the ozonolysis of styrene in ester solvents is in accord with the Criegee mechanism¹ and occurs via trapping of the $\text{H}_2\text{C}^+\text{OO}^-$ intermediate. Additional labeling experiments and synthetic tests will be needed to confirm this postulate. Nevertheless a viable route to the class of OR substituted ozonides has been identified and follow-up experimentation will hopefully lead to higher yield syntheses.

Since the yields of the ozonides in ester solvents have been $<10\%$ and since only the reactions of the simplest carbonyl oxide species with esters have been presumably investigated, there is little reason to criticize or invalidate the conclusions of previous ozonolysis studies in such solvents. In fact, several of these studies were specifically designed using TCNE^{4c} or $\text{CH}_3\text{OH}^{4e}$ which readily react with primary ozonides or fragmentation products so that little opportunity for reaction with the ester solvent was afforded. Nevertheless, the inertness of ester solvents in ozonolysis reactions should no longer be taken for granted in view of the present findings.

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(7) 3-Methoxy-1,2,4-trioxolane; $^1\text{H NMR}$ (360 MHz, CDCl_3) δ 3.42 (s, 3 H), 4.93 (s, 1 H), 5.49 (s, 1 H), 6.05 (s, 1 H); $^{13}\text{C NMR}$ (CDCl_3) δ 51.49 (q, $J = 144.94$ Hz), 94.06 (dd, $J = 166.98, 173.80$ Hz), 112.23 (d, 200.60 Hz); IR (in CDCl_3) 3000 (s), 2970 (s), 2925 (s), 2880 (w), 1740 (sh), 1715 (w), 1460 (w), 1375 (w), 1295 (w), 1220 (s), 1165 (s), 1145 (s), 1120 (vs), 1085 (vs), 1045 (s), 1025 (s). GC-MS (70 eV), m/e (relative intensity) 106 (M^+ , 9.4%), 75 ($\text{M}^+ - \text{CH}_3\text{O}$, 86.5), 74 ($\text{M}^+ - \text{CH}_3\text{OH}$, 100), 61 (16.5), 60 (16.1), 59 (8.1), 47 (14.9), 46 (25.3), 45 (83.5), 44 (51.5).

(8) **1b**: $^1\text{H NMR}$ 1.26 (t, 3 H, $J = 7.10$ Hz), 3.73 (m, 2 H), 4.93 (s, 1 H), 5.47 (s, 1 H), 6.08 (s, 1 H); $^{13}\text{C NMR}$ 14.89 (q, $J = 127.11$ Hz), 60.71 (t, $J = 144.70$ Hz), 93.88 (dd, $J = 167.10, 173.35$ Hz), 111.91 (d, $J = 199.91$ Hz); GC-MS⁷ 120 (12.4), 105 (1.7), 92 (39.3), 88 (60.1), 75 (100), 74 (4.9), 64 (58.3), 63 (11.8), 62 (29.0), 60 (44.8), 59 (9.6), 47 (38.4), 46 (16.6), 45 (76.5), 44 (15.1). **2a**: $^1\text{H NMR}$ 1.65 (s, 3 H), 3.41 (s, 3 H), 5.05 (s, 1 H), 5.44 (s, 1 H); $^{13}\text{C NMR}$ 21.30 (q, $J = 129.27$ Hz), 50.27 (q, $J = 144.25$ Hz), 94.74 (dd, $J = 165.48, J = 172.67$ Hz), 119.71 (s); GC-MS⁷ 120 (1.5), 105 (0.5), 89 (26.8), 88 (32.1), 75 (1.2), 74 (1.9), 59 (5.5), 58 (7.5), 45 (9.3), 44 (6.2), 43 (100), 42 (9.8). **2b**: $^1\text{H NMR}$ 1.20 (t, 3 H, $J = 7.10$ Hz), 1.66 (s, 3 H), 3.75 (m, 2 H), 5.04 (s, 1 H), 5.41 (s, 1 H); $^{13}\text{C NMR}$ 15.07 (q, $J = 126.92$ Hz), 21.63 (q, $J = 129.41$ Hz), 58.56 (t, $J = 145.46$ Hz), 94.62 (dd, $J = 165.58, 172.25$ Hz), 119.64 (s); GC-MS⁷ 134 (2.2), 119 (0.4), 102 (15.9), 91 (4.4), 90 (1.6), 89 (45.9), 77 (2.2), 75 (4.1), 74 (4.6), 73 (6.5), 61 (6.4), 60 (1.0), 59 (2.3), 58 (3.4), 47 (1.7), 46 (2.2), 45 (13.7), 44 (5.9), 43 (100), 42 (6.5).

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