

Application of a Lanthanide Shift Reagent in ^{17}O N.M.R. Spectroscopy to determine the Stereochemical Course of Oxidation of Cyclic Sulphite Diesters to Cyclic Sulphate Diesters with Ruthenium Tetroxide

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Cyclic sulphite diesters are rapidly oxidized to cyclic sulphate diesters with ruthenium tetroxide in good yield; diastereotopically labelled cyclic [^{17}O]sulphate diesters obtained by oxidation of diastereoisomeric cyclic sulphite diesters with ruthenium [^{17}O]tetroxide are shown, by the effect of a lanthanide shift reagent on their ^{17}O n.m.r. signals, to be formed with retention of configuration at sulphur.

2-Oxo-1,3,2-dioxathiolanes (**1**) and 2-oxo-1,3,2-dioxathianes (**3**) are generally prepared in good yield by treatment of 1,2- and 1,3-diols with thionyl chloride.¹ By contrast their oxidation to the related 2,2-dioxo-1,3,2-dioxathiolanes (**2**) and 2,2-dioxo-1,3,2-dioxathianes (**4**) by any of the multifarious reagents hitherto investigated leaves much to be desired.^{2,3} Our attempts to oxidize 2-oxo-1,3,2-dioxathiolanes (**1a–e**) with barium permanganate in acetone solution, apparently the reagent of choice,³ led to extensive product decomposition and it quickly became evident that an efficient general method for the preparation of 2,2-dioxo-1,3,2-dioxathiolanes (**2**) was required. We now report that ruthenium tetroxide generated *in situ* from sodium periodate, and ruthenium(IV) oxide,⁴ oxidizes the 2-oxo-compounds (**1**) and (**3**) to their respective 2,2-dioxo-compounds (**2**) and (**4**) in good yield (Table 1).

Table 1. Oxidation of 2-oxo-1,3,2-dioxathiolanes (**1**) and 2-oxo-1,3,2-dioxathianes (**3**) with ruthenium tetroxide.

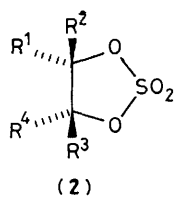
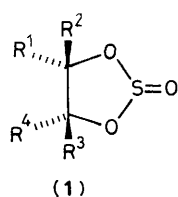
Substrate	Product ^a	% Yield ^b
(1a)	(2a)	75
(1b)	(2a)	75
(1c)	(2c)	77
(1d)	(2c)	81
(1e)	(2e)	72
(3a)	(4a)	87
(3b + c)	(4b)	90
(3d)	(4d)	78

^a All products were satisfactorily characterised by ^1H n.m.r., i.r., and mass spectroscopy. ^b The 2,2-dioxo-1,3,2-dioxathiolanes are unstable at room temperature and were kept at -20°C .

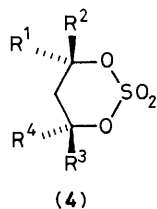
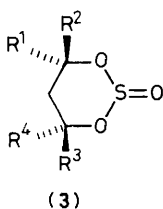
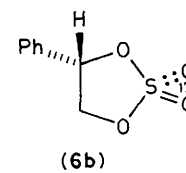
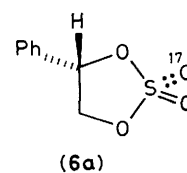
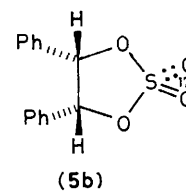
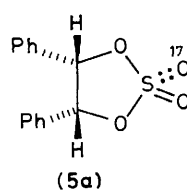
Table 2. ^{17}O N.m.r. chemical shifts^a of the diastereotopic 2,2-[^{16}O , ^{17}O]dioxo-1,3,2-dioxathiolanes before and after addition of one equivalent of $\text{Eu}(\text{fod})_3$.

Starting material (% in mixture)	Product	δ (^{17}O) (integration %)	δ (^{17}O) with $\text{Eu}(\text{fod})_3$ (integration %)	$\Delta\delta$ /p.p.m.
(1a) (88)	(5a)	153.1 (88)	152.6 (88)	0.5
(1b) (12)	(5b)	167.5 (12)	163.5 (12)	4.0
(1c) (66)	(6a)	161	158.0 (66)	3.0
(1d) (34)	(6b)	161	154.9 (34)	6.1

^a All spectra were recorded at 40.687 MHz on a Bruker WH-300 WB Fourier transform spectrometer and the chemical shifts (δ) are expressed in p.p.m. downfield from external ^{17}O -water. Field frequency locking was provided by the deuterium resonance of solvent CDCl_3 . Each spectrum consists of about 10^4 transients recorded at ambient temperature and had line widths (at half height) of 50–70 Hz; the chemical shifts are accurate to ± 0.5 p.p.m. The concentration of (5a) + (5b) was 126 mM with 25 atom % ^{17}O . The concentration of (6a) + (6b) was 259 mM with 21 atom % ^{17}O . Parameters: sweep width 50 000 Hz, 40 transients/s, Gaussian multiplication (line broadening –250 Hz, Gaussian broadening 0.28) in 4K and Fourier transform in 16K.



	R ¹	R ²	R ³	R ⁴
a;	Ph	H	H	Ph
b;	H	Ph	Ph	H
c;	Ph	H	H	H
d;	H	H	Ph	H
e;	H	H	H	H



	R ¹	R ²	R ³	R ⁴
a;	H	H	H	H
b;	Me	H	H	H
c;	H	H	H	Me
d;	H	Me	H	Me

All the cyclic sulphite esters (1a–e) and (3a–d) used in this study were prepared by established procedures from the appropriate 1,2- or 1,3-diol.^{1,5} A typical oxidation was conducted as follows (chloroform was freshly distilled from P_2O_5). To a solution of sodium periodate (1.60 mmol) in water (0.5 ml) was added chloroform (4 ml) and ruthenium(IV) oxide hydrate (0.70 mmol) with rapid stirring. The black ruthenium(IV) oxide was converted into a pale green solution of ruthenium tetroxide in about 15 min after which the solution was cooled to 0 °C. The cyclic sulphite diester (0.70 mmol) in chloroform (1 ml) was then added rapidly and with stirring. After 45 s, propan-2-ol (1 ml) in chloroform (24 ml) was added, the solution filtered and dried (Na_2SO_4), and the solvent removed *in vacuo* (< 20 °C) to give the product; (2a–e) and (4a–d) are all crystalline.

Although there is extensive evidence that the oxidation of trico-ordinate to tetraco-ordinate phosphorus compounds occurs with retention of configuration at phosphorus, there appears to be only one investigation concerning the stereochemical course of oxidation of a trico-ordinate to a tetraco-

ordinate sulphur compound.⁶ Thus in the pioneering studies on the chiroptical properties of [^{16}O , ^{18}O]sulphones,⁷ and in subsequent related investigations,⁸ it was assumed that oxidation proceeded with retention of configuration at sulphur. In order to verify this expectation in the conversion of cyclic sulphite diesters into cyclic sulphate diesters, 2-oxo-4,5-diphenyl-1,3,2-dioxathiolanes (1a and b) and 2-oxo-4(*S*)-phenyl-1,3,2-dioxathiolanes (1c and d) were oxidized with ruthenium [^{17}O]tetroxide [prepared *in situ* from ruthenium(IV) oxide, sodium periodate, and 40 atom % ^{17}O -water]. The ^{17}O n.m.r. spectrum of the diastereotopic 2,2-[^{16}O , ^{17}O]dioxo-4,5-diphenyl-1,3,2-dioxathiolanes (5a and b) showed two resonances separated by 14.4 p.p.m. The ratio of intensities (see Table 2) established that the high field resonance (153.1 p.p.m.) was derived from the *trans*-cyclic sulphite diester (1a) and the low field resonance (167.5 p.p.m.) from the *cis*-cyclic sulphite diester (1b), since the *trans*-isomer (1a) had been identified as the major isomer from the diamagnetic anisotropy of its S=O group on the chemical shift of the ring protons.⁹

1,1,1,2,2,3,3-Heptafluoro-7,7-dimethyloctane-4,6-dionato-europium(III) [$\text{Eu}(\text{fod})_3$] binds to (1a) (*trans*) more strongly than to (1b) (*cis*),¹⁰ and consequently it should preferentially ligate the least hindered diastereotopic oxygen of (2). Addition of $\text{Eu}(\text{fod})_3$ (1 equiv.) to the mixture of the diastereotopic compounds (5a and b) differentially shifted the ^{17}O resonances to higher field: the product derived from the *cis*-stereoisomer (1b) shifted 4.0 p.p.m. upfield [and hence was (5b)] whilst that derived from the *trans*-stereoisomer (1a) shifted only 0.5 p.p.m. [and hence was (5a)], thus demonstrating that 2-oxo-4,5-diphenyl-1,3,2-dioxathiolanes are oxidized by ruthenium tetroxide with retention of configuration at sulphur.

In a similar experiment a mixture of the stereoisomers (1c and d)¹¹ was oxidized with ruthenium [^{17}O]tetroxide to the diastereotopic (4*S*)-2,2-[^{16}O , ^{17}O]dioxo-4-phenyl-1,3,2-dioxathiolanes (6a and b). Only one ^{17}O n.m.r. signal was

observed for this diastereotopic pair, but addition of $\text{Eu}(\text{fod})_3$ (1 equiv.) split the signal into a smaller ^{17}O resonance, for the product derived from the *cis*-cyclic sulphite diester (**1d**), shifted by 6.1 p.p.m. and a larger resonance for the product derived from the *trans*-isomer (**1c**), shifted by 3.0 p.p.m. This confirms that oxidation of 2-oxo-1,3,2-dioxathiolanes (and presumably sulphite diesters generally) are oxidized by ruthenium tetroxide with retention of configuration at sulphur.

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