Reaction of Carbonyl Oxides and Thioketones. [3 + 2] Cycloaddition *vs.* Oxygen Atom Transfer

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The ozonolysis of vinyl ethers (**1a, b**) in the presence of thioadamantan-2-one (**4a**) gave in each case the corresponding thio-ozonide (**5a, b**) in around 70% yield, whilst ozonolysis of a mixture of vinyl ethers (**1a—c**) and thiobenzophenone derivatives (**4b—d**) gave the corresponding thione-*S*-oxides (**8b—d**) in 15—30% yields, together with the benzophenones (**6b—d**).

Cycloaddition[1] and oxygen atom transfer[2] are the main pathways involved in the reactions of carbonyl oxides. We report here that in the reaction with thioketones both of these mechanistic alternatives participate and, moreover, the structure of the thioketone plays an important role in determining the course of the reaction.

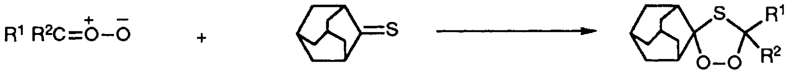
A solution of vinyl ether (**1a**) (8 mmol) and thioadamantan-2-one (**4a**) (4 mmol) in methylene chloride or ether (20 ml) was treated with ozone (4 mmol) at −70 °C. The ^{1}H NMR spectra of the crude products showed the formation of the thio-ozonide (**5a**) in around 70% yield, suggesting that [3 + 2] cycloaddition of formaldehyde *O*-oxide (**2a**) with (**4a**) is a

$$\underset{(1)}{R^1R^2C{=}CHOR^3} \xrightarrow{O_3} \underset{(2)}{R^1R^2C{=}\overset{+}{O}{-}\overset{-}{O}} + \underset{(3)}{HCO_2R^3} \qquad (1)$$

a; $R^1 = R^2 = H$, $R^3 = CH_2CHMe_2$
b; R^1 = cyclohexylmethyl,
$R^2 = H$, $R^3 = Me$
c; $R^1, R^2 = -(CH_2)_5-$, $R^3 = Me$

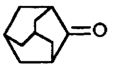
a; $R^1 = R^2 = H$
b; R^1 = cyclohexylmethyl,
$R^2 = H$
c; $R^1, R^2 = -(CH_2)_5-$

a; $R^3 = CH_2CHMe_2$
b; $R^3 = Me$
c; $R^3 = Me$

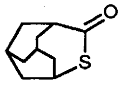


(2a, b) **(4a)** **(5)** (2)

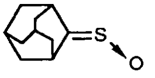
a; $R^1 = R^2 = H$
b; R^1 = cyclohexylmethyl, $R^2 = H$



(6a)



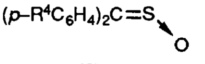
(7)



(8a)

$(p\text{-}R^4C_6H_4)_2C{=}S$

(4)



$(p\text{-}R^4C_6H_4)_2C{=}S{\to}O$

(8)

$(p\text{-}R^4C_6H_4)_2C{=}O$

(6)

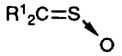
b; $R^4 = Me$
c; $R^4 = Me$
d; $R^4 = H$

b; $R^4 = OMe$
c; $R^4 = Me$
d; $R^4 = H$

b; $R^4 = OMe$
c; $R^4 = Me$
d; $R^4 = H$

$R^1{}_2C{=}S$

(4e) $R^1 = Bu^t$



$R^1{}_2C{=}S{\to}O$

(8e) $R^1 = Bu^t$

$$\underset{(A)}{R^1R^2\overset{+}{C}{-}\overset{-}{S}} \longleftrightarrow \underset{(B)}{R^1R^2C{=}S} \longleftrightarrow \underset{(C)}{R^1R^2\overset{-}{C}{-}\overset{+}{S}}$$

facile process [equations (1) and (2)].[3] Perhaps in accordance with this, the ozonolysis of (**1a**) in the presence of a 1:1 mixture of (**4a**) and adamantan-2-one (**6a**) in ether at −70 °C resulted in exclusive formation of the thio-ozonide (**5a**) (around 70% yield) by selective capture of (**4a**) with formaldehyde *O*-oxide (**2a**). Compound (**5a**), however, was labile on silica gel and hence was isolated in low yield (10%) by silica gel column chromatography, together with adamantanone (**6a**) (40%) and the thioester (**7**) (40%). From the ozonolysis of a mixture of vinyl ether (**1b**) and (**4a**), the corresponding thio-ozonide (**5b**) was isolated in *ca.* 70% yield without significant decomposition during column chromatography. However, neat (**5b**) decomposed gradually even at 0 °C, giving unidentified high melting-point materials; consequently, the melting point of (**5b**) was not determined. In the case of the more bulky vinyl ether (**1c**), no evidence was obtained for the formation of the corresponding cycloadduct.†

A remarkably different trend was observed for the reaction with thiobenzophenone derivatives (**4b**—**d**). The reaction of a mixture of a vinyl ether (**1c**) (4 mmol) and 4,4′-dimethoxythiobenzophenone (**4b**) (2 mmol) with ozone (2 mmol) in methylene chloride at −70 °C gave the corresponding sulphine (**8b**) (33%), together with 4,4′-dimethoxybenzophenone (**6b**) (37%) and the unreacted thioketone (**4b**) (30%). Also, in the ozonolysis of a mixture of (**1a**, **b**) and (**4b**), the thione-*S*-oxide (**8b**) was obtained, albeit in a lower yield (*ca.* 15%), together with the ketone (**6b**) (*ca.* 60%). Thus, the most bulky cyclohexanone *O*-oxide (**2c**) was the most effective oxygen-atom transfer agent. The same trends were observed for the ozonolysis of a mixture of vinyl ethers (**1a**—**c**) and thioketones (**4c**, **d**).

When the reaction of a mixture of (**1c**) and (**4b**) with ozone was undertaken in the 'participating' solvent system, methanol–methylene chloride (1:1 v/v), the production of (**8b**) was completely suppressed. The reaction of (**4b**) with ozone in methylene chloride at −70 °C was also very fast, but

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† The reaction of (**4a**) with ozone in methylene chloride or ether at −70 °C gave mainly adamantan-2-one (*ca.* 70% yield); there was no evidence of formation of the thione-*S*-oxide (**8a**).[4] In contrast, 3,3-dimethyl-1,2-dioxirane (the isomer of acetone *O*-oxide), generated *in situ* from the reaction of acetone and 'oxone' ($2KHSO_5$–$KHSO_4$–K_2SO_4),[5] could transfer an oxygen atom to (**4a**), yielding after 4.5 h reaction at room temperature (**8a**) in 29% yield, together with the unreacted (**4a**) (33%). A similar oxygen-atom transfer from 3,3-dimethyl-1,2-dioxirane was observed for thioketones (**4b**, **e**).

ketone (**6b**) was the sole product.[4] These results suggest that ozone attacks mainly the vinyl ether (**1c**) to yield the corresponding carbonyl oxide (**2c**), which in turn transfers an oxygen atom to the thioketone (**4b**) in methylene chloride or is captured by the protic solvent in methanol–methylene chloride.

The remarkable difference in behaviour between thioadamantan-2-one (**4a**) and thiobenzophenones (**4b**—**d**) is due to the substituent electronic effects on the structure of the resonance hybrid of these thioketones. Of the three possible structures (**A**)—(**C**), the contribution of structure (**A**) is important for (**4a**), while in the case of (**4b**—**d**) structure (**C**) has the major contribution.[6] Thus, in the case of (**4a**), which has a high 1,3-dipolarophilicity, cycloaddition with the 1,3-dipole (**2**) is predominant, while in the case of (**4b**—**d**) the nucleophilic oxygen-transfer agent (**2**)[2] attacks preferentially at the terminal sulphur atom.

It is noteworthy that the reaction of bulky di-t-butyl thioketone (**4e**) with ozone in methylene chloride at −70 °C gave the thione-*S*-oxide (**8e**) in 71% yield.[7] When this reaction was undertaken in the presence of the vinyl ether (**1c**) (2 mol equiv.), however, the formation of (**8e**) was significantly suppressed; (**8e**) was obtained in 7% yield, together with the unreacted (**4e**) (84%). In the ozonolysis in methanol–methylene chloride, (**8e**) was isolated in 6% yield, suggesting that (i) the reaction of ozone with (**1c**) is significantly faster than that with (**4e**), and (ii) the formation of small amounts of (**8e**) is probably the result of the direct attack of ozone on the thioketone (**4e**).

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