

Chemical and transient spectroscopic evidence for C₂–C₃ cleavage of 2,3-diaryloxetane radical cations

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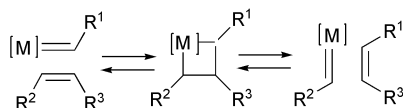
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Electron transfer cycloreversion of the methoxy substituted oxetane **1b** results in the production of *trans*-anethole and benzaldehyde through C₂–C₃ bond cleavage. *trans*-Anethole radical cation has been detected as transient intermediate by laser flash photolysis.

Oxetanes are easily available by Paterno-Büchi photoreaction of carbonyl compounds with alkenes.¹ Their cycloreversion (CR) entails cleavage of two bonds and may yield formal metathesis products. It presents clear analogies with the Chauvin mechanism operating in the metal catalyzed process (Scheme 1), which involves the interconversion of an olefin and a metal alkylidene *via* a metallacyclobutane intermediate.²



Scheme 1

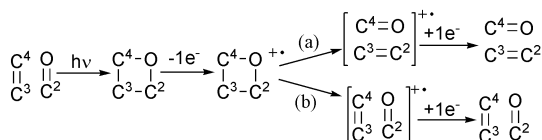
Ring opening of oxetanes can be achieved *via* chemical³ (thermolysis, hydrogenolysis or nucleophilic attack) or photochemical activation.^{4,5} The latter has been little explored and involves the use of electron transfer (ET) photosensitizers.

Theoretical calculations on the oxidative ET cycloreversion of oxetanes point to an initial C–C bond breaking, according to free energy changes estimated for the gas-phase reaction. By contrast, the anionic ET cycloreversion appears to start with C–O cleavage.⁶

Control of the regioselectivity in the CR of oxetanes by photoinduced ET (Scheme 2), besides being synthetically interesting (see above), is relevant to key biological processes. Thus, it is involved in the enzymatic repair of the (6-4) photoproducts of the DNA dipyrimidine sites by photolyase.⁷

Prior to our work,^{8,9} only two reports have appeared on the CR of oxetane radical cations.^{4,5} Preparative studies on the ET reaction of 2,2-diaryloxetanes photosensitized by cyanoaromatics suggest that CR proceeds through a stepwise mechanism with initial C–C bond breaking.⁴ The products of these reactions are the same as the reagents used to make the oxetanes.

The opposite regioselectivity has been found in the irradiation of 2,3-diphenyloxetane **1a** using 2,4,6-triaryl(thia)pyrylium salts **2a,b** as ET photosensitizers⁸ (Chart 1). The radical cation of **1a** undergoes stepwise splitting *via* initial O–C₂ cleavage;⁹ this results in the production of *trans*-stilbene and acetaldehyde (Scheme 3, pathway a). This mechanism is supported by laser flash photolysis (LFP) detection of the involved transient intermediates (*trans*-stilbene radical cation and pyryl radical).



Scheme 2

A possible strategy to control the reaction pathway could be the attachment of electron donor or electron acceptor substituents to the aryl group(s). This could favour location of the charge and the spin at different positions of the oxetane radical cation or the intermediates derived therefrom.

Methoxy substituents are known to stabilize the positive charge of aromatic radical cations.¹⁰ For example, in the oxidative ring opening of 2,2-diaryloxetanes⁴ the electron appears to be initially withdrawn from an electron-rich aryl group. This decreases the strength of the C₂–C₃ σ bond through σ–π interaction.

The aim of the present work was to introduce a methoxy substituent on the C₃-phenyl group of **1a**, the only oxetane known to undergo C–O cleavage upon oxidative ET. This could favour C₂–C₃ cleavage and lead to the reverse regioselectivity.

Oxetane **1b** was synthesized by a Paterno-Büchi photoreaction, following the procedure described in the literature.¹¹ In addition to product studies, laser flash photolysis of **1b** (Chart 1) could allow for the detection of the radical cation of anethole or 4-methoxystilbene, providing a direct mechanistic evidence for the cleavage of **1b**⁺. Such direct evidence is still missing for the C₂–C₃ cleavage of oxetane radical cations.

To generate the radical cation **1b**⁺, the pyrylium salts **2a,b** have been the photosensitizers of choice, in view of their well established photophysical, photochemical and redox properties.¹² According to simple calculations based on the Weller equation,¹³ the ET process between the ground state of **1b** and the triplet excited states of **2a** and **2b** should be thermodynamically favourable (Δ*G* ca. –13 and –7 kcal mol^{–1}, respectively).[†]

Preparative irradiation of oxetane **1b** was carried out in the presence of catalytic amounts of photosensitizers **2a,b** (Chart 1).[‡] By contrast with the behaviour reported for **1a**, *trans*-anethole and benzaldehyde were detected as the only photoproducts by direct ¹H NMR analysis of the reaction mixtures (Scheme 3, pathway b).

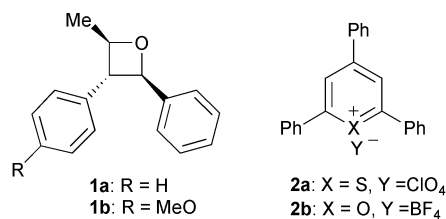
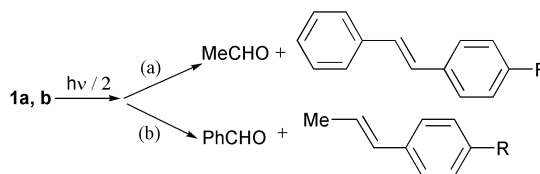


Chart 1



Scheme 3

In order to elucidate the mechanism of the observed cycloreversion, LFP experiments were conducted under different conditions. In a typical experiment, LFP (355 nm) of **2a** in the presence of **1b**, using acetonitrile as solvent, gave a transient with absorption maxima at *ca.* 380 and 600 nm (Fig. 1). These bands correspond to the same intermediate, and decay with the same rate constant. They were assigned to the radical cation of *trans*-anethole on the basis of literature data.¹⁴ To confirm the assignment, LFP of *trans*-anethole was performed in the presence of **2a**, giving rise to the same intermediate.

Another band peaking at 550 nm was also clearly observed in the LFP experiments performed using **2b** as photosensitizer (data not shown). This band is ascribed to the pyranil radical resulting from the reduction of **2b**.¹⁵ As the thiapyranil radical does not absorb in the range 500–600 nm, it does not appear in Fig. 1. Moreover, no band related to 4-methoxystilbene radical cation ($\lambda_{\text{max}} = 500 \text{ nm}$)¹⁶ was detected; this is consistent with cleavage along pathway b rather than pathway a (Scheme 3).

The insert of Fig. 1 shows the growth of the 600 nm band. It occurs with a rate constant of $2.5 \times 10^6 \text{ s}^{-1}$ (independently from the concentration of **1b**) and must be related to splitting of

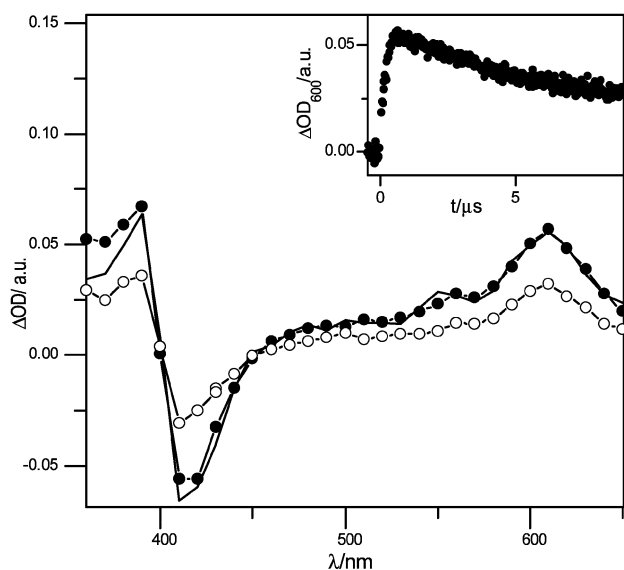
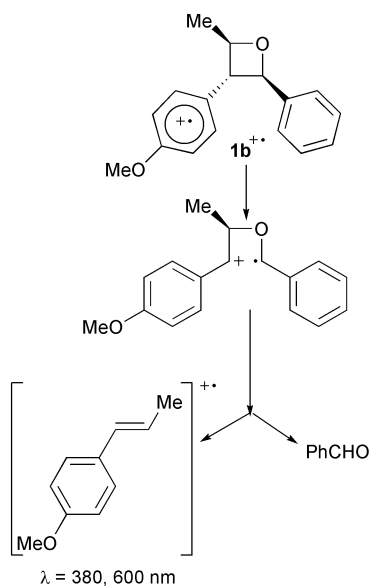


Fig. 1 Transient spectra obtained upon LFP ($\lambda = 355 \text{ nm}$) of **1b** ($1.25 \times 10^{-3} \text{ M}$) and **2a** ($7.5 \times 10^{-5} \text{ M}$) in acetonitrile under argon. Spectra were recorded 0.3 μs (line), 1 μs (filled circles) and 6 μs (open circles) after the laser pulse. Insert: growth and decay of the 600 nm band.



Scheme 4

the oxetane radical cation. Electron transfer from triplet **2a** to **1b** is much faster, as evidenced by the quenching rate constant ($4.0 \times 10^9 \text{ s}^{-1}$). This means that the initial oxetane radical cation fragments in the submicrosecond time domain, to generate *trans*-anethole radical cation and neutral benzaldehyde.

The behaviour of **1b** under ET conditions can be justified according to Scheme 4. Ionization would probably occur at the electron rich aromatic ring, to give **1b**^{•+}. Subsequent cleavage of the C₂–C₃ bond would generate a distonic 1,4 radical cation, whose C–O splitting would lead to the observed intermediate.

In summary, methoxy substitution at the 3-aryl group induces C₂–C₃ cleavage of 2,3-diaryloxetane radical cations. The reaction mechanism is supported by detection of anethole radical cations, instead of 4-methoxystilbene radical cations. Thus, the regioselectivity of ET mediated CR of oxetanes can be controlled by modifying the nature of the substituents.

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Notes and references

† The calculation of the free energy change was performed according to Weller equation: $\Delta G \text{ (kcal mol}^{-1}\text{)} = 23.06 \times [E_{\text{(D}^{\cdot+}/\text{D)}} - E_{\text{(A}^{\cdot-}/\text{A)}}] - E(T_1)_A$. The redox potentials were measured by cyclic voltammetry in acetonitrile vs SCE: $E_{\text{(D}^{\cdot+}/\text{D)}}(\mathbf{1b}) = 1.48 \text{ V}$, $E_{\text{(A}^{\cdot-}/\text{A})} = -0.21 \text{ V}$ (**2a**) and -0.29 V (**2b**). The triplet energy for **2a** and **2b** is 52 and 53 kcal mol⁻¹, respectively.¹²

‡ Irradiation conditions: oxetanes **1a,b**: $4 \times 10^{-2} \text{ M}$; **2a**: $2 \times 10^{-3} \text{ M}$; solvent: CD₃CN (0.8 ml); atmosphere: argon; time: 15 min. Irradiation in Luzchem multilamp photoreactor, using 8 W lamps (4×) with emission maxima at 350 nm. There was no reaction in the dark or in the absence of photosensitizer.

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