Oxiranylmethyl radicals: EPR detection by spin trapping

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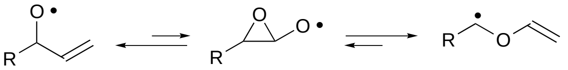
The EPR detection of oxiranylmethyl radicals, formed *via* a 3-*exo-trig* process from the corresponding allyloxyl radical, is performed with Bu^{t}ONO as a spin trap.

The 3-*exo-trig*[1] process involving allyloxyl radicals could be a useful method for synthesizing epoxides.[2] However, this reaction was usually reported to have failed because the intermediate oxiranylmethyl radical **2** can rapidly undergo either C–O bond fission (to give **1**) or C–C bond fission (to give **3**) [eqn. (1)].

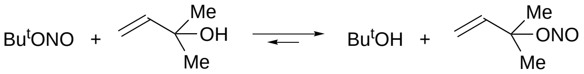


(1)

1 **2** **3**

Nevertheless, Galatsis and Millan[2c] have recently reported the preparation of α-iodo epoxides by photolysing tertiary allylic alcohols in the presence of bis(acetoxy)iodobenzene and iodine. This process is based on competition between the two possible reaction pathways that the intermediate oxiranylmethyl radical can follow (Scheme 1), and relies on the more efficient trapping by iodine.

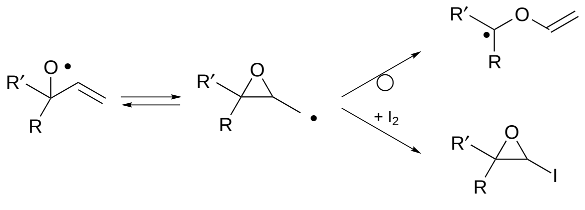
However, no direct EPR evidence for the detection of these radical species has been reported[3] and, to account for this, a fast decay process for **2** has always been claimed.[3,4] One possible method of investigation could be the spin-trap technique, *i.e.* conversion of the oxiranylmethyl radical into a more persistent radical species. Previous experiments conducted by our group had shown the ability of alkyl nitrites to act as a spin trap[5] for short-lived alkyl radicals and, in particular, *tert*-butyl nitrite seemed to be quite efficient. Moreover, since the oxiranylmethyl radicals derive from a rearrangement process involving allyloxyl radicals, it was considered convenient to generate the latter by photolysis of the corresponding nitrites. These can be prepared, in almost quantitative yield, *via* an easy exchange reaction[6] between the corresponding alcohols and *tert*-butyl nitrite, which is known to behave as a nitrosyl source [eqn. (2)].



(2)

This method could then be used also to supply the required spin trap directly into the medium. In fact, in performing the nitrosyl transfer to the alcohols with an excess of Bu^{t}ONO it was possible that a part of it could act as the trap.

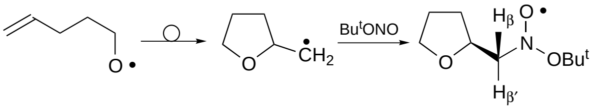
The experiments were conducted under continuous flow conditions on acetonitrile solutions of tertiary allylic alcohols in the presence of an excess of Bu^{t}ONO, which were photolysed in the EPR spectrometer cavity at different temperatures.



Scheme 1

When 2-methylbut-3-en-2-ol was investigated, two radical species were detected; the methyl *tert*-butoxy nitroxide **7** (Table 1), formed by trapping of the methyl radical which comes from the competitive β-process that the allyloxyl radical can undergo, and an alkyl alkoxy nitroxide, characterised by an alkyl group with two magnetically inequivalent β-hydrogens. The EPR spectroscopic parameters of this species suggested structure **4**, which is chiral[7] by virtue of the asymmetric oxiranyl group, and therefore justifies the detection of inequivalent β-CH$_2$ hydrogens even if there is rapid internal rotation about the N–C$_\beta$ bond. A possible reaction mechanism for the formation of both radical species could be that outlined in Scheme 2.

Since, to the best of our knowledge, this is the first spectroscopic evidence for the detection of the oxiranylmethyl radical, it was necessary to confirm the suggested structure of **4** with further experiments. The pent-4-en-1-ol–Bu^{t}ONO system was then studied using the same experimental conditions used for 2-methylbut-3-en-2-ol. It was hypothesized that the tetrahydrofurfuryl radical **8**, formed by the fast 1,5-*exo* ring closure[8] of the intermediate pent-4-enoxyl radical, would react with *tert*-butyl nitrite, leading to the formation of **9**, [eqn. (3)].



(3)

8 **9**

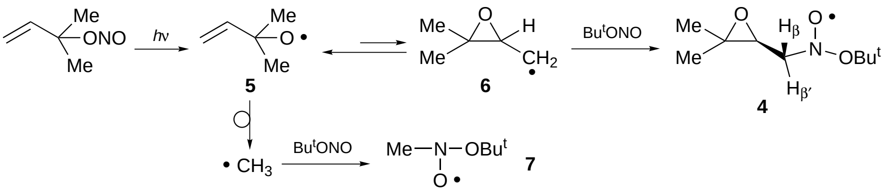
As this radical is chiral due to the presence of an asymmetric tetrahydrofuran-2-yl group, the corresponding EPR spectrum should show two magnetically inequivalent β-hydrogens; this proved to be the case. Further support came from experiments with a reduced amount of *tert*-butyl nitrite, which gave the bis(tetrahydrofurfuryl) nitroxide **10** and which confirmed the presence of the rearranged radical **8** in the medium.

Although these results strengthened our hypothesis, it was still necessary to obtain direct confirmation; for example, to

Table 1 EPR results for **4**, **7** and **9**–**13**

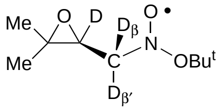
	Hyperfine coupling constant/Gauss (no. nuclei)					
Radical	a_α	$^{*}a_\beta$	$^{*}a_{\beta'}$	a_γ	a_δ	g
4	25.65 (1 N)	5.60 (1 H)	9.10 (1 H)	0.22 (1 H)	—	2.0053
7	25.75 (1 N)	8.87_5 (3 H)	—	—	—	2.0054
9	25.37_5 (1 N)	4.00 (1 H)	12.00 (1 H)	0.35 (1 H)	0.17_5 (2 H)	2.0053
10	14.25 (1 N)	6.75 (2 H)	11.25 (2 H)	—	—	2.0058
11	25.65 (1 N)	0.80 (1 D)	1.35 (1 D)	—	—	2.0053
12	25.70 (1 N)	8.12_5 (2 H)	—	0.30 (3 H)	—	2.0053
13	25.72 (1 N)	5.62_5 (1 H)	9.25 (1 H)	0.25 (1 H)	—	2.0053

* The hfc of H$_\beta$ can be attributed to H$_\beta'$ and *vice versa*.



Scheme 2

prove that the two inequivalent hydrogens of the CH_2 group of radical **4** originate from the vinyl CH_2 group in radical **5**. For this purpose, 2-methyl[3,4,4-$^{2}H_{3}$]but-3-en-2-ol was synthesized.[9] Experiments conducted on this substrate, using the same experimental conditions used for the analogous hydrogenated compound, led to the detection not only of the methyl *tert*-butoxy nitroxide, but also of the alkoxy alkyl nitroxide **11**, whose EPR spectrum showed a nitrogen coupling constant exactly matching that of the corresponding atom in radical **4**, and two inequivalent deuterium atoms with coupling constants of *ca*. 1/6 of that of the corresponding hydrogen atoms.



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Finally, support for our hypothesis was also obtained from experiments with 3-methylpent-1-en-3-ol, which gave adducts to the *tert*-butyl nitrite of all the radical species deriving from the intermediate allyloxyl radical, *i.e.* the oxiranylmethyl *tert*-butoxy nitroxide **13**, the methyl *tert*-butoxy nitroxide **7** and the ethyl *tert*-butoxy nitroxide **12**.

These results confirmed the involvement of a 3-*exo-trig* process in oxiranylmethyl radical formation from a tertiary allyloxyl radical and showed the utility of *tert*-butyl nitrite as a trap for these species. This work is currently being extended to other tertiary and secondary allylic alcohols.

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