Tetrahedron Vol 39, No 1, pp 159 to 163, 1983
Printed in Great Britain

0040-4020/83/010159-05$03.00/0

REACTIONS OF ALKANETHIYL AND ALKOXYL RADICALS WITH UNSATURATED CYCLIC ETHERS

LODOVICO LUNAZZI and GIUSEPPE PLACUCCI
Istituto di Chimica Organica, Università, Viale Risorgimento 4, 40136 Bologna, Italy

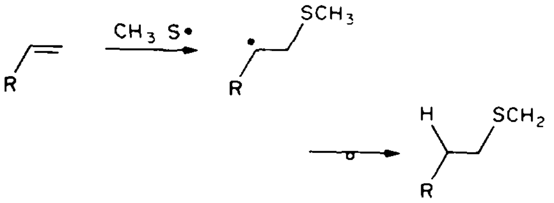
and

LORIS GROSSI*
Istituto Chimico, Politecnico, Piazza L. da Vinci, Milano, Italy

(*Received in the U.K.* 26 *January* 1982)

Abstract—Methanethiyl radicals ($CH_3S^\cdot$) are shown to react with cyclic ethers containing double bonds to give addition and hydrogen abstraction from the allylic positions. The esr spectra of the corresponding radicals have been determined. In some cases radicals arising from a rearrangement (probably 1,4 H-shift) were observed. t-Butoxyl radicals also give abstraction and addition with the same substrates. In two cases the barriers to ring inversion for six-membered ring radicals have been determined.

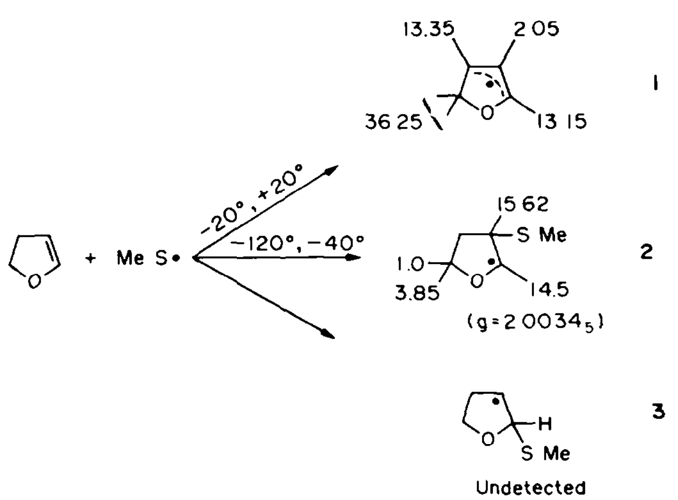
It has been previously reported that alkanethiyl radicals can either abstract[1] hydrogens from allylic systems or add to double bonds, depending on the experimental conditions.[2,3] On the other hand alkoxyl radicals normally abstract hydrogen,[4] although in some cases addition is the preferred pathway.[5,6] It has been also shown that addition of methanethiyl radical is sometimes followed by a rearrangement[3] (H-shift) leading to radicals of the type $R\text{-}S\dot{C}H_2$:



Although rearrangement involving H-shifts are known to occur,[7,8] this particular migration would require a 1,4 H-shift that is quite unusual.[9] Since this migration has been observed *via* ESR in cyclic unsaturated hydrocarbons,[3] in the present paper were investigated reactions of $RS^\cdot$ with unsaturated cyclic ethers in order to find additional examples of the existence of such an effect. The same substrates were also allowed to react with alkoxyl radicals for comparison.

RESULTS AND DISCUSSION

Photolysis of MeSSMe gives methanethiyl radicals $MeS^\cdot$, allowed to react with 2,3-dihydrofuran within the cavity of an ESR spectrometer. As reported for cyclopentene[2] and other heterocyclic derivatives,[1] the cycloallylic radical (in this case radical **1**) is detected at temperatures higher than −20°, as shown in Scheme 1:



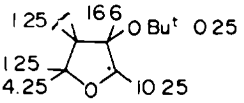
Scheme 1.

(The figures on the formulas represent the hyperfine splitting constants in gauss for the hydrogen atoms: formulas not bearing these figures correspond to radicals that were not detected at the ESR.) The same radical is also observed when abstraction is carried out with Bu^tOOBu^t, as source of $Bu^tO^{\cdot}$. In the latter case, however, radical **1** can be produced also at much lower temperatures (down to −130°). This indicates that the free energy of activation for H abstraction is lower for $Bu^tO^{\cdot}$ than for $MeS^{\cdot}$; in other words alkoxyl are better abstractors than thiyl radicals. The splittings we observed for **1** are substantially equal to those reported for the same radical generated by addition of an hydrogen atom to furan[10] and by H abstraction with $^{\cdot}OH$ radicals in aqueous solutions.[11]

When photolysis of MeSSMe, in presence of 2,3-dihydrofuran, is carried out at temperatures lower than required for H abstraction ($< -20°$), two radicals different from **1** can be observed. One of them is due to addition of $MeS^{\cdot}$ to double bond (**2**) whereas the other (**6**, Scheme 2) has three different hydrogens ($a_4 = 2.9$, 17.0 and 17.9 respectively) and has a much higher g-factor ($g = 2.0048_5$).

Clearly at low temperature the system does not attain the free energy of activation for H abstraction, so that **1** disappears.

Contrary of what happens with the corresponding cyclic hydrocarbons, the heteroatom makes the two ethylenic carbons non equivalent and two addition radicals (**2** and **3**) could, in principle, be obtained. The experimental a_H values indicate that addition of $MeS^{\cdot}$ only occurs in position 3, giving radical **2**, and not in position 2. For, the observed radical (Scheme 1) has two large splittings (one for H_α and one for H_β) whereas a radical like **3** would give a greater number of large a_H values since has one H_α and three H_β. At low temperature (−130°) also $Bu^tO^{\cdot}$ adds to 2,3 dihydrofuran, yielding radical **4** whose a_H values show that addition occurs at position 3.



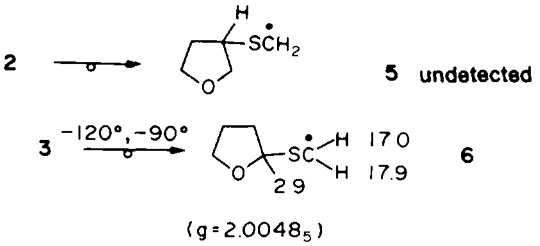
4

These values are actually quite similar to those reported[11] for addition of $^{\cdot}OH$ to 2,3 dihydrofuran in position 3 and very different from those of the radical due to addition of $^{\cdot}OH$ in position 2.

As mentioned before, when reaction is carried out with Bu^tOOBu^t radical **1** does not disappear at low temperature, so that **1** and **4** (i.e. the abstraction and the addition radicals) are simultaneously present at −130°.

The non-equivalence of the hydrogens in position 5 in both **2** and **4** indicates that these radicals are not planar. Studies carried out on analogous tetrahydrofuranyl radicals confirm that they are likely to adopt an envelope conformation, with fast ring reversal even at very low temperatures.[12] The non equivalence we observe in **2**, **4** is therefore due to the existence of a preferred conformation having the substituents (MeS or Bu^tO) mainly in a pseudo-axial or pseudo-equatorial position. Calculations[12] carried out on the unsubstituted tetrahydrofuran-2-yl radical indicate that, in a C-4 envelope arrangement, a_{H_3} is expected to be 38.3G when pseudo-axial and 18.7 when pseudo-equatorial. ESR spectra in solid state of 5-methyl tetrahydrofuran-2-yl radical give 33 G and 16.3 G respectively:[13] being in solids these a_H values are likely to refer to a fixed preferred conformation.[13] Even allowing for the geometrical modifications and electronic effects[14] brought about by the two substituents (MeS and Bu^tO), there is little doubt that the a_{H_3} splittings of **2** (15.6 G) and of **4** (16.6 G) indicate that these hydrogens are almost completely pseudo-equatorial and the substituents are thus pseudo-axial.

The features of the second spectrum (superimposed to that of radical **2** in the −120°, −90° range), observed when $MeS^{\cdot}$ reacts with 2,3 dihydrofuran are very similar to those reported for the same reaction with cyclopentene.[3] This spectrum was assigned to a radical deriving from the mentioned rearrangement and leading to a structure of the type $R{-}SCH_2$: these α-hydrogens are in fact known[15] to be diastereotopic at low temperature (Scheme 2). However, although we assigned structure **2** to the addition radical we cannot assume structure **5** for the rearranged radical:



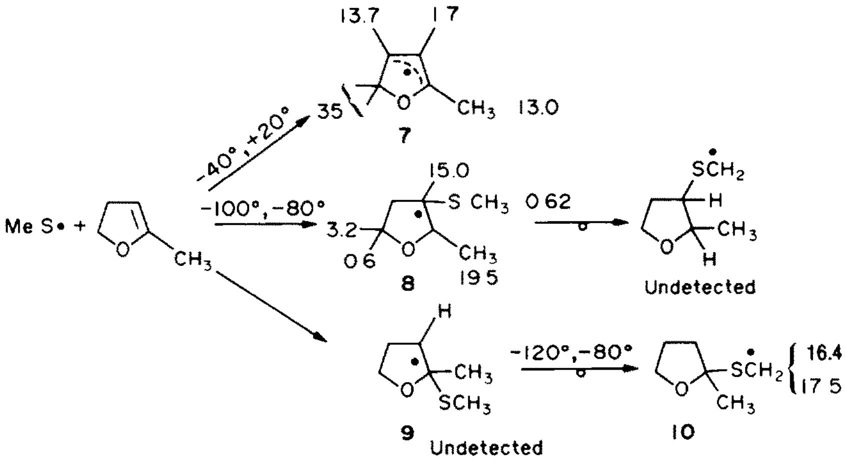
Scheme 2.

For, addition of $MeS^{\cdot}$ leading to **3** can in principle occur, but the latter could immediately rearrange to **6**. Actually migration seems to occurr in **3** to give **6**: this indication was obtained by studying the reaction of MeSSMe with 2-methyl-4,5-dihydrofuran. Again at higher temperature ($> -40°$) was observed the H-abstraction process yielding the allylic radical **7**, whereas at lower temperature the radicals due to addition (**8**) and to rearrangement (**10**) were detected (Scheme 3).

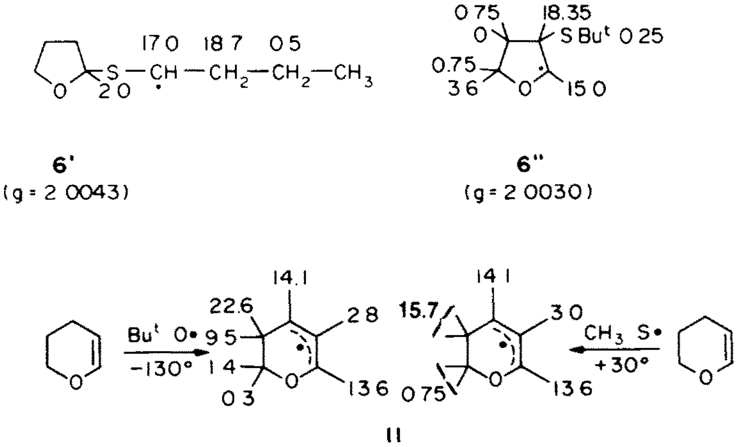
The a_H values confirm that addition occurs in position 3 (radical **8**). The presence of the methyl group now allows to decide which of the two possible structures (**5** or **6**) corresponds to the $S\dot{C}H_2$ rearranged radical. If radical **8** was the precursor, we would obtain a spectrum for the rearranged radical with the same three splittings, as in the case of 1,2-dihydrofuran (i.e. two large for the diastereotopic CH_2 hydrogens and one small for the CH hydrogen in γ position).

On the other hand, if the rearranged radical derives from the undetected addition radical **9**, then its structure must be structure **10**, where the small γ-splitting is expected to disappear, owing to the substitution of the γ-hydrogen with a methyl group. Actually the observed radical only has the two large splittings, thus confirming that the rearranged radical has structure **10** (Scheme 3).

An additional experiment can be also performed to check that radical **6** is really due to a rearrangement. If 2,3-dihydrofuran is allowed to react with $(n\text{-}BuS)_2$, the features of the rearranged radical should be different, whereas those of radicals due to abstraction (**1**) should be identical and those due to addition similar to radical **2**. This was actually the case: radical **6′** has completely different spectral features. Finally the same reaction was carried out with $(Bu^tS)_2$, where the lacking of hydrogens



Scheme 3.



Scheme 4.

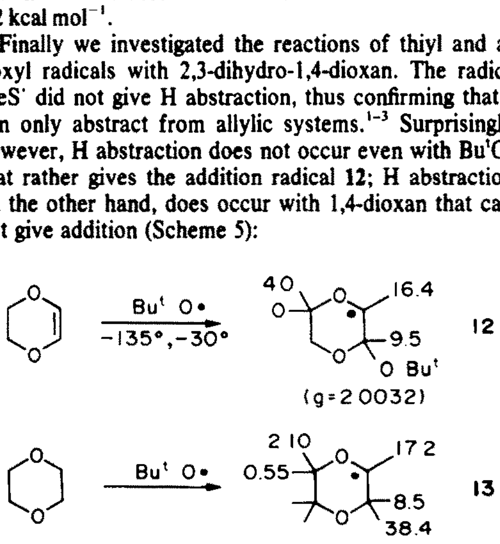
able to migrate should prevent the observation of the rearranged radical. Indeed in this case only the abstraction (1) and addition radical (**6''**) were observed.

It is also noteworthy that the g-factor of radicals **6**, **6'** and **10** are typical of radicals with sulphur close to the radical center ($g \geq 2.004$).

Analogous reactions, carried out with MeS˙ on the six-membered derivative (2,3-dihydropyran), only yield H abstraction and no addition or rearrangement were observed. On the contrary of the case of 2,3-dihydrofuran, also Bu^{t}O˙ does not give addition but only abstraction. Again CH_3S˙ turns out to be a poorer abstractor than Bu^{t}O˙; in fact the reaction yielding **11** only occurs at room temperature, whereas, even at −130°, Bu^{t}OOBu^t produces the radical **11** (Scheme 4).

As a consequence, whereas with MeS˙ one can only observe the range where ring reversal is fast, with Bu^{t}O˙ also the situation where ring reversal is slow could be attained. By line shape analysis the rate constants for this process were determined at various temperatures. The simulation of the whole spectrum was not attempted, since the two large exchanging splittings (22.6 G, axial and 9.5 equatorial) made the lines so broad as to be almost insensitive to the choice of the rate constants. Accordingly only the first four lines, depending upon the two small exchanging splittings, were monitored in the whole interval: from the slow to the fast exchanging region. The shape also depends on the relative sign of the a_H values and could be reproduced only assuming opposite sign (+1.4 and −0.3 G respectively). The free energy of activation was independent on the temperature within the errors and turned out to be $5.2 \pm 0.2\ \text{kcal mol}^{-1}$.

Finally we investigated the reactions of thiyl and alkoxyl radicals with 2,3-dihydro-1,4-dioxan. The radical MeS˙ did not give H abstraction, thus confirming that it can only abstract from allylic systems.[1-3] Surprisingly, however, H abstraction does not occur even with Bu^{t}O˙, that rather gives the addition radical **12**; H abstraction, on the other hand, does occur with 1,4-dioxan that cannot give addition (Scheme 5):



Scheme 5.

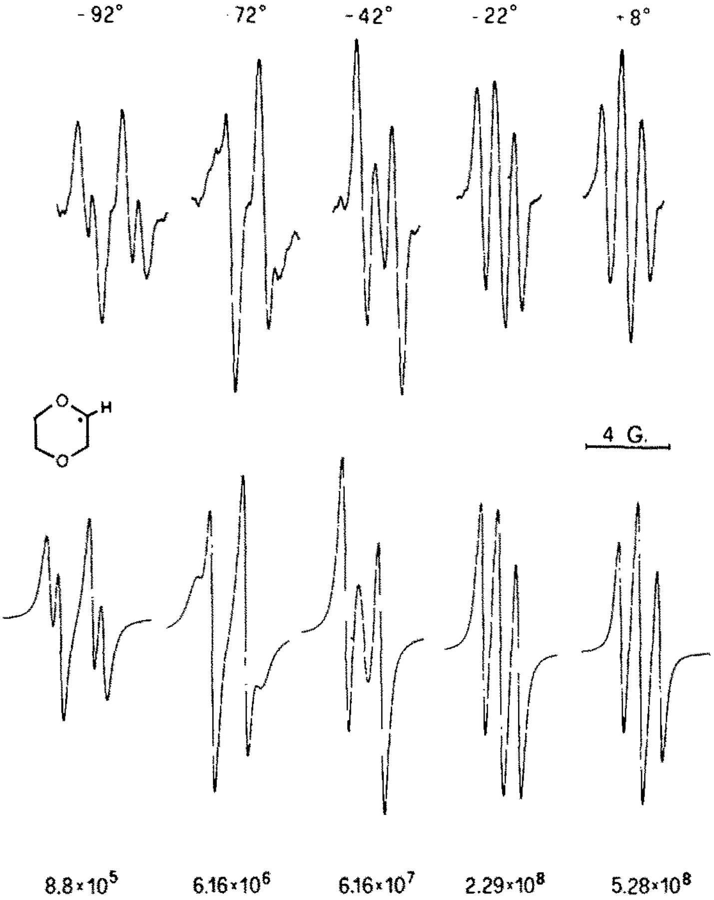
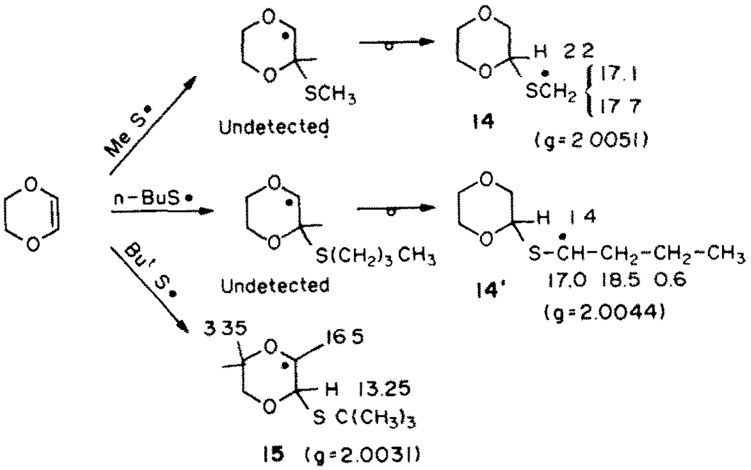


Fig. 1. Experimental ESR lines (upper) corresponding to the smallest hfs constants i.e. hydrogens in γ position) of radical 13 at various temperatures (°C). Underneath the lines computed using the first order rate constants (sec^{-1}).

The lack of reactivity for H-abstraction culd be connected with peculiar CH arrangements, as suggested by Malatesta and Ingold for other six membered rings.[16]

A comparison between the β-splittings of 12 with those of 13 shows that the smaller a_H values are quite similar (9.5 G in 12 vs 8.5 G in 13). The small H_β splitting corresponds to an equatorial position[17] in a chair-like arrangement and therefore the substituent is essentially in an axial position. We could also detect two different a_H for the two diastereotopic γ-hydrogens of 13 (a feature not noticed in previous investigations[17,18]) and we used these values (0.55 and 2.10 G) for the line shape analysis. The study of this ring reversal process, carried out as mentioned before (radical 11), gave a $\Delta G^{\neq}$ value (5.1 ± 0.2 kcal mol^{-1}) larger than reported in the literature[17,18] (Fig. 1).

Reaction of MeSSMe with the 2,3-dihydro-1,4-dioxan did not produce the addition radical, but only the rearranged radical 14 (Scheme 6). Since, on the contrary of the case of 2,3-dihydrofuran, only one type of radical can



Scheme 6.

be formed, the failure of observing its ESR signals supports the hypothesis that it rearranges immediately to **14**. Again, if the reaction is carried out with (n-BuS)$_2$ a different spectrum is observed whose splittings correspond to those of a rearranged radical **14'**. Additional evidence that the rearrangement occurs after the addition has taken place, is given by the reaction with (Bu^{t}S)$_2$. In this case one cannot have 1,4-H shift because all the hydrogens have been replaced by methyls; consequently the spectrum of the addition radical **15** was observed.

Although further evidences are certainly required to reach a definite proof of the proposed 1,4-H shift, nonetheless the data collected do not seem in disagreement with this hypothesis.

EXPERIMENTAL

The compounds employed were commerically available and were purified (distillation or chromatography) before use. 1,4-Dioxan was synthesized according to the photochemical procedure described in Ref. 19.a

Samples were prepared by mixing the reactants in suprasil quartz tubes that were connected to a vacuum line; gaseous cyclopropane was subsequently introduced by using liquid nitrogen. The samples were then sealed off in vacuum. Photoysis was carried out with a 500-W high-pressure mercury lamp carefully focused into the ESR cavity.

In the case of radical 1 second order splitting, as reported in Ref. 10, has been observed. In our conditions the accidental degeneracy reported[10] for the a_H values of the allylic hydrogens has been removed. The temperatures were measured by a thermocouple inserted in a blank tube before each spectral determination.

Acknowledgements—The authors thank Dr. K. U. Ingold (NRC, Ottawa, Canada) and Dr. J. Fossey (CNRS, Thiais, France) for helpful discussions. This work has been carried out with the financial support of Italian CNR (Rome).

REFERENCES

[1] L. Grossi, L. Lunazzi and G. Placucci, *Tetrahedron Letters* **22**, 251 (1981).

[2] L. Lunazzi, G. Placucci and L. Grossi, *J.C.S. Chem. Comm.* 533 (1979).

[3] L. Lunazzi, G. Placucci and L. Grossi, *J.C.S. Perkin II* 703 (1981).

[4] L. Lunazzi, G. Placucci and L. Grossi, *Ibid.* 1063 (1980).

[5] [a] M. Kira, M. Watanabe and H. Sakurai, *J. Am. Che. Soc.* **99**, 7780 (1980); [b] A. G. Davies, *Ann. Rep. Prog. Chem. Section B* **76** (1979), p. 75.

[6] [a] B. C. Gilbert, P. D. R. Marshall, R. O. C. Norman, N. Pineda and P. S. Williams, *J. Chem. Soc. Perkin II* 1392 (1981); [b] L. Lunazzi, G. Placucci and L. Grossi, *Ibid.* 875 (1982).

[7] J. W. Wilt, In *Free Radicals* (Edited by J. K. Kochi), Vol. 1, Chap. 8. Wiley, New York (1973). A. L. J. Beckwith, K. U. Ingold, In *Rearrangement in Ground and Excited States* (Edited by P. De Mayo), Vol. 1, Chap. 4, p. 162. Academic Press, New York (1980).

[8] J. Fossey and J. Y. Nedelec, *Tetrahedron* **37**, 2967 (1981).

[9] P. J. Krusic and J. K. Kochi, *J. Am. Chem. Soc.* **93**, 846 (1971).

[10] R. H. Schuler, G. P. Laroff and R. W. Fessenden, *J. Phys. Chem.* **77**, 456 (1973).

[11] B. C. Gilbert, R. O. C. Norman and P. S. Williams, *J. Chem. Soc. Perkin* II 647 (1980).

[12] C. Gaze and B. C. Gilbert, *Ibid.* 503 (1978).

[13] A. C. Ling and L. Kevan, *J. Phys. Chem.* **80**, 592 (1976); G. C. Dismurker and J. E. Willard, *Ibid.* **80**, 1435 (1976).

[14] L. Lunazzi, G. Placucci, L. Grossi and M. Guerra, *J. Chem. Soc. Perkin* II 43 (1982).

[15] I. Biddles, A. Hudson and T. J. Whiffen, *Tetrahedron* **28**, 867 (1972).

[16] V. Malatesta and K. U. Ingold, *J. Am. Chem. Soc.* **103**, 609 (1981).

[17] C. Gaze and B. C. Gilbert, *J. Chem. Soc. Perkin* II 754 (1977).

[18] B. C. Gilbert, R. O. C. Norman and M. Trenwith, *J. Chem. Soc. Perkin* II 1033 (1974).

[19] M. B. Rubin, *Synthesis* 266 (1977).