Hydrogen Abstraction from 2- and 3-Methylthiophens investigated by Spin Trapping

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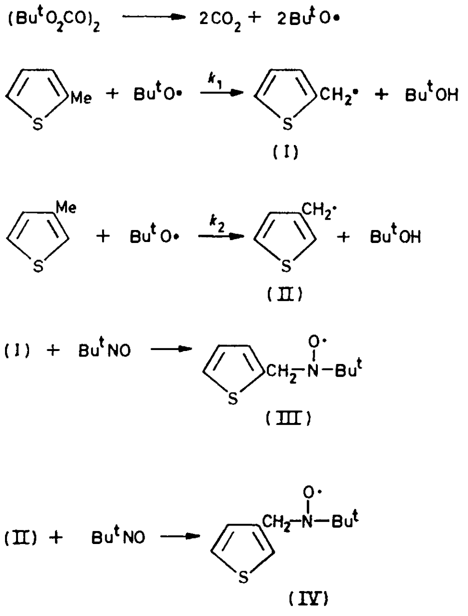
The homolytic reactivity of 2- and 3-methylthiophens towards hydrogen abstraction from the side-chain by t-butoxyl radicals has been investigated by determining the relative amount either of the coupling products of 2- and 3-thenyl radicals or of the nitroxides obtained by trapping with Bu^tNO. The conditions for the latter experiment have been explored and are discussed. Both methods showed that 2-methylthiophen is 2·2 times more reactive than the 3-isomer.

THE possibility of trapping short-lived radicals by diamagnetic scavengers and transforming them into relatively stable nitroxides which can conveniently be studied by e.s.r. offers a very powerful tool for the investigation of homolytic reactions.[1] Many cases have been reported where this technique was successfully applied to identify intermediate radicals not otherwise directly detectable,[2] although caution is needed to avoid misleading results.[3]

It has also been suggested that spin trapping might be used to measure quantitatively the relative radical reactivity;[4] this possibility has not been thoroughly tested either as regards the experimental conditions or the validity of the results, so it seemed worthwhile further to investigate the advantages and the limits of such an approach. Because of our interest in thiophens[5] and the reliability of the results available on the reactivity of many thiophen-containing molecules[6] we chose for our investigation the 2- and 3-methylthiophens with the purpose of measuring the relative reactivity towards hydrogen abstraction by t-butoxyl radicals. The results obtained by the spin trapping technique have also been compared with those obtained by an independent method.



SCHEME 1

The reactions used to produce the 2- (I) and 3-thenyl radicals (II) and subsequently to trap them as the nitroxides (III) and (IV) are shown in Scheme 1. 2-Methyl-2-nitrosopropane was chosen as scavenger instead of nitrones or other similar spin-traps owing to the simplicity of the spectral patterns of the final nitroxide radicals.

From the reaction sequence in Scheme 1 equation (1)

$$\frac{[(\text{III})]}{[(\text{IV})]} = \frac{k_1[\text{2-ThMe}]}{k_2[\text{3-ThMe}]} \qquad (1)$$

can be derived (Th = thenyl) which indicates that, with a number of assumptions, the relative intensities of the e.s.r. signals of the nitroxide radicals can be taken as a measure of the relative reactivity, k_1/k_2, of 2- and 3-methylthiophens towards the hydrogen abstraction by the t-butoxyl radicals. Essentially one must assume[4] that a high percentage of the radicals (I) and (II) are scavanged by the Bu^tNO, with very similar reaction rates, and that the resulting nitroxides do not decay during the measurements or decay at a comparable rate; this would also imply that the mechanism of decay of the nitroxides is not affected by the presence of other radicals. These assumptions represent severe restrictions to the use of spin trapping for quantitative work; it seems rather difficult that they can all be satisfied, and the composition of the reaction mixtures may therefore simply reflect the relative stabilities of the

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[3] A. R. Forrester and S. P. Hepburn, *J. Chem. Soc.* (*C*), 1971, 3322.

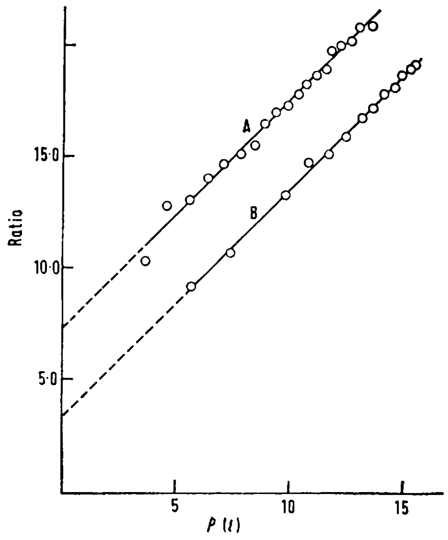
[4] M. J. Perkins, P. Ward, and A. Horsfield, *J. Chem. Soc.* (*B*), 1970, 395.

[5] L. Lunazzi, A. Mangini, G. F. Pedulli, and M. Tiecco, *Gazzetta*, 1971, **101**, 10.

[6] M. Tiecco and A. Tundo, *Internat. J. Sulphur Chem.*, in the press.

nitroxides. It is probably more reasonable to suppose that only in the early stages of the reactions are the complications due to possible different rates of consumption of the nitroxides negligible. In particular, extrapolation to zero time should yield a nitroxide ratio which might give a valid measure of the relative reactivity of the two compounds being compared. In the present work with 2- and 3-methylthiophens it has been observed that the ratio [(III)] : [(IV)] was time-dependent and only after prolonged reaction were constant values obtained. On the basis of our previous discussion we do not consider these equilibrium data as reflecting the actual value of the relative ease of formation of compounds (I) and (II), and accordingly we carried out a series of measurements at different times and assumed as k_1/k_2 the value of [(III)] : [(IV)] extrapolated to zero time. In so doing however we have not eliminated the possible source of error represented by the different rates of the trapping processes and we have assumed that they are not so different as appreciably to affect the final value of the nitroxide concentrations. Although this is obviously a gross assumption which cannot in general be satisfied, yet it can be expected that the complications due to these rate differences may be minimized when very similar radicals like 2- and 3-thenyl are compared.

Because it is not possible to distinguish directly the spectra of the two isomeric t-butylthenyl nitroxides (III) and (IV), we used as reference the nitroxide PhCHMe-N(O·)Bu^t (V) obtained from ethylbenzene, as suggested by Perkins and his co-workers.[4] The ratios [PhCHMe(O·)Bu^t] : [2-ThCH$_2$-N(O·)Bu^t] and [PhCHMe-N(O·)Bu^t] : [3-ThCH$_2$-N(O·)Bu^t] were determined as a function of time. When the reactions reached the steady-state conditions the ratios [(V)] : [(III)] and [(V)] : [(IV)] were 20·7 and 20·4 respectively, from which a value of [(III)] : [(IV)] = 1·02 can be calculated; on the other hand extrapolation to zero time affords the ratios [(V)] : [(III)] = 3·4 ± 0·1, [(V)] : [(IV)] = 7·3 ± 0·3, and [(III)] : [(IV)] = 2·15 ± 0·15. The last value seems more reasonable than the one at the equilibrium because of the expected greater stabilization of the transition state for hydrogen abstraction from 2-methyl- than from 3-methyl-thiophen. In order to have a meaningful extrapolation of the experimental curve the points were fitted with a linear monotonic polynomial giving the minimum deviation from the experimental values. The best results were reached with a third degree expression for the ratio [(V)] : [(IV)] (r.m.s. deviation = 0·29) and with a fourth-degree expression (r.m.s. deviation = 0·13) for [(V)] : [(III)], the deviations lying within the experimental uncertainty. These results are graphically summarized in the Figure where the experimental ratios are plotted against the corresponding best-fitting polynomials $P(t) = a_1t + a_2t^2 + a_3t^3 + a_4t^4$: the intercepts ($a_0$) give the mentioned values at zero time. Experiments were also carried out in order to demonstrate that the values of [(III)] : [(IV)] and hence k_1/k_2 are independent of the reference used. Other ethyl derivatives were examined such as 2-ethylthiophen and 2-ethylnaphthalene and also in these cases the concentrations of the nitroxides were found to change with time. By employing the same procedure as described for ethylbenzene, the ratios [(III)] : [(IV)] were calculated at zero time to be 2·25 and 2·17 for the 2-ethylthiophen and 2-ethylnaphthalene standards respectively.



Experimental ratios of the concentration of nitroxides A, [(V)] : [(IV)] and B, [(V)] : ([III)] as a function of the time-dependent polynomial (see text)

These results clearly support the validity of the method employed to determine the relative reactivities of the methylthiophens.

The only value available in the literature concerning the relative reactivity of 2- and 3-methylthiophens refers to hydrogen abstraction by phenyl radicals and is relative to carbon tetrachloride; in this case also the 2-isomer was found to be about twice as reactive as the 3-isomer, the appropriate values being 14·7 and 8·0.[7] No previous determination of k_1/k_2 relative to the Bu^{t}O· radical is reported and we have therefore carried out some experiments to check the reliability of the value obtained by spin trapping. For this purpose 2- and 3-methylthiophens were allowed to compete for a small amount of t-butoxyl radicals and the dithienylethanes formed according to Scheme 2 were quantitatively determined by g.l.c.

$$\text{2-ThMe} + \text{Bu}^t\text{O}\cdot \longrightarrow \text{(I)} + \text{Bu}^t\text{OH}$$
$$\text{3-ThMe} + \text{Bu}^t\text{O}\cdot \longrightarrow \text{(II)} + \text{Bu}^t\text{OH}$$
$$2\,\text{(I)} \longrightarrow (\text{2-ThCH}_2)_2$$
$$2\,\text{(II)} \longrightarrow (\text{3-ThCH}_2)_2$$
$$\text{(I)} + \text{(II)} \longrightarrow \text{2-ThCH}_2\cdot\text{CH}_2\text{Th-3}$$

SCHEME 2

The value of k_1/k_2 determined in this way is 2·2 ± 0·05. It is clear that this can be assumed to be the ratio of the

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[7] E. T. Strom, G. A. Russell, and J. H. Schoeb, *J. Amer. Chem. Soc.*, 1966, **88**, 2004.

reactivity of 2- and 3-methylthiophens only if either all the thenyl radicals formed dimerize to the dithienylethanes or both thenyl radicals are removed in similar processes at comparable rates. This assumption seems satisfied not only on the basis of the arguments put forward above but also in view of the fact that no other compound, apart from the dithienylethanes, could be identified. Moreover indirect competitive experiments with toluene as a reference compound afforded the following values of relative reactivities: 2-ThMe : PhMe = 1·9 ± 0·03 and 3-ThMe : PhMe = 0·9 ± 0·03; from these the relative reactivity of 2- and 3-methylthiophens can be derived and the value obtained is again 2·1.

In the light of the results obtained, it seems reasonable to conclude that the value (2·20 ± 0·05) determined by extrapolation to zero time of the relative concentrations of the nitroxides represents the actual value of the reactivity ratio of the two compounds being compared. It is also apparent that the use of spin trapping for quantitative purposes requires careful control of the experimental conditions.

EXPERIMENTAL

The radicals were obtained by adding t-butyl peroxyoxalate (2 mol. equiv.) to the mixture of the methylthiophen and the ethyl derivative used as reference in the presence of Bu^tNO (0·05 mol. equiv.); the spin-adduct ratios were independent of $[Bu^tNO]$ up to a concentration of 0·1 mol. equiv. The samples were previously degassed with nitrogen and kept in the dark to minimize the amount of di-t-butyl nitroxide which originates spontaneously from Bu^tNO. Different ratios of methylthiophens and reference products (ethylbenzene, 2-ethylthiophen, 2-ethylnaphthalene) were used to test that the relative amount of nitroxides were linearly dependent on the relative amount of the substrates. For instance with molar ratios ethylbenzene : 2-methylthiophen 1 : 4, 1 : 8, and 1 : 16 the ratios of nitroxides at zero time were found to be 0·81, $0{\cdot}40_5$, and $0{\cdot}19_2$ respectively.

The spectra of the nitroxides (recorded on a Varian 4502 instrument) are characterized by the hyperfine splittings shown in the Table. The splittings of the nitroxides derived from 2-ethylthiophen and 2-ethylnaphthalene are equal to those of (V).

	(III)	(IV)	(V)
a_N	15·2	15·0	14·9
a_{CH_2}	7·2	7·2	
a_{CH}			$3{\cdot}7_5$

Since the line-widths of methylthiophens (0·47 G) differ from those of the reference products (1·07 G) and the spectral lines of the two radicals partially overlap, the spectra were simulated by means of a computer programme and the relative amount of the two species was changed until the best fit with the experimental spectrum was obtained; this value was taken as the relative concentration.

The dithienylethanes and phenyl(thienyl)ethanes necessary for g.l.c. analyses were prepared as described,[8] except for 1-(2-thienyl)-2-(3-thienyl)ethane and 1-phenyl-2-(3-thienyl)ethane which were obtained by catalytic reduction of the corresponding ethenes.[9] 1-(2-*Thienyl*)-2-(3-*thienyl*)-*ethane* was obtained as a solid, m.p. 51—52 °C (from light petroleum) (Found: C, 61·8; H, 5·1; S, 32·95. $C_{10}H_{10}S_2$ requires C, 61·8; H, 5·15; S, 33·0%) and 1-*phenyl*-2-(3-*thienyl*)*ethane* was an oil, b.p. 153—154 °C at 15 mmHg (Found: C, 76·5; H, 6·4; S, 16·85. $C_{12}H_{12}S$ requires C, 76·55; H, 6·4; S, 17·0%).

Solutions of t-butyl peroxyoxalate (0·5 mol. equiv.) in equimolecular mixtures (2 ml) of the two methyl derivatives were put in a stoppered 5 ml quartz conical flask and immersed in a water-bath at 20 °C. The mixture was irradiated for 15 h with a mercury lamp, also immersed in the bath. The mixtures were then analysed by g.l.c. (Varian Aerograph 1400 instrument incorporating a 5% LAC column) without manipulation. A calibration for area–response difference between the diarylethanes formed was made for every reaction with an internal standard. Three independent reactions were carried out with each pair of methyl derivatives and the averaged results are reported in the Discussion section.

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