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The Phenoxylium Ion from α-Tocopherol Spirodimer and its Significance for the Mechanism of Oxidative Coupling in Phenols

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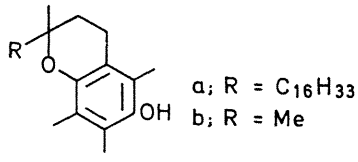
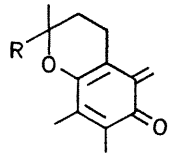
Summary The characteristic n.m.r. behaviour shown by the spirodimer (IIIa) from α-tocopherol, and its behaviour in ascorbic acid reductions, shows a dependence upon acid catalysis explicable in terms of a phenoxylium ion (X) and designates one area in which oxidative coupling of phenols would have ionic rather than radical mechanisms.

The evidence is persuasive that ferricyanide oxidation of α-tocopherol (Ia) gives first a quinone methide[1] (IIa) which dimerises to a spiran of structure[2-4] (IIIa). The simpler analogue (Ib) similarly yields spiran (IIIb), the n.m.r. spectrum of which indicates, surprisingly, that the aromatic methyl groups can exchange their identity with the vinylic methyl groups.[5] Thus at −5° in chloroform separate bands are observed for each type of methyl group, but as the temperature rises these bands broaden and coalesce eventually at about 70°. We have confirmed these observations and shown that the tocopherol dimer (IIIa) behaves similarly.

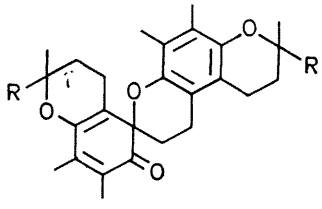
The original authors[5] tentatively suggested that the spiran nucleus might be a fluxional system as indicated in (IV). The idea is of doubtful validity (as its originators recognise) because the orbital overlap is inadequate and can be made good only by utilising orthogonal orbitals. They also considered the possibility that there might be an equilibrium between the spirans (IIIa,b) and their quinone methides (IIa, b) but rejected it because the two spirans yield no new spiran when mixed. However, other results[6] appear to sustain the idea. We examined the spiran (V) which, on general grounds, was expected to dissociate relatively easily into the quinone methide (VI); this happened, and the product was trapped smoothly by stilbene as the adduct (VII). But temperatures above 150° were necessary, and at lower temperatures there was little dissociation, while the



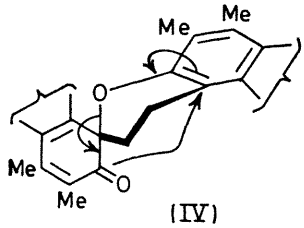
(I)



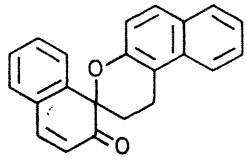
(II)



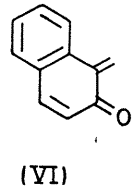
(III)



(IV)



(V)

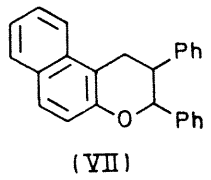


(VI)

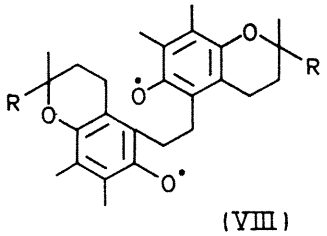
n.m.r. spectrum at 70° showed no signs of collapse in the vinylic resonances [τ 2·76 (d), 3·96 (d); *J* 10 Hz] or in the

multiplets between τ 6·8 and 8·0 corresponding to the methylene groups. These facts dispose of both the fluxional and the quinone methide explanations.

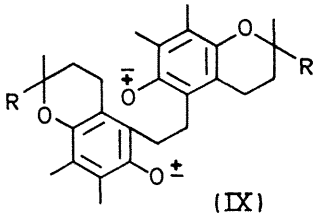
The behaviour of spiran (V) also eliminates dissociations giving biradicals such as (VIIIa), since (V) should give a biradical quite as readily as spiran (III). As a further check, spiran (IIIa) was examined under conditions in which methyl interchange was active but we failed to detect any e.s.r. signals or CIDNP effects.



(VII)



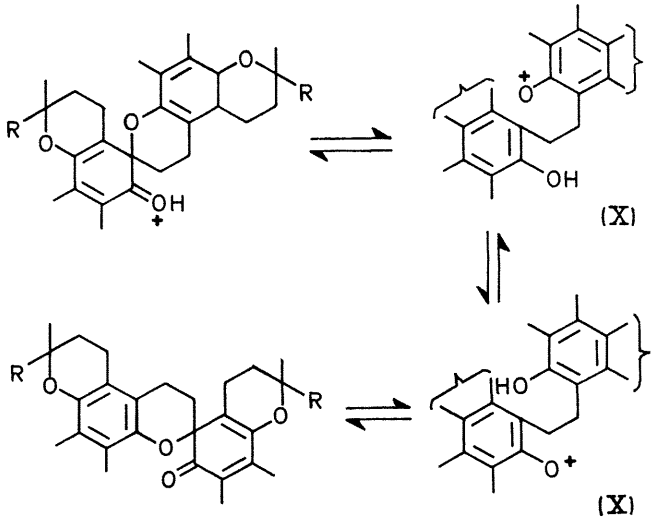
(VIII)



(IX)

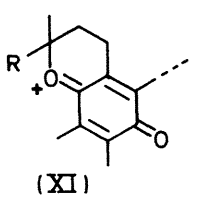
Simple heterolytic dissociation into zwitterions (IXa,b) must also be eliminated since the coalescence is virtually unaffected by the type of solvent in a range including benzene, phenyl cyanide, and nitromethane, or even by the presence of methanol in the solution.

This disposed of all non-catalysed mechanisms, so we sought catalysts, and found that acids induce methyl interchange at constant temperature, coalescence being attained with 0·2M-trichloroacetic acid in benzene. Addition of pyridine at once restored the original spectrum. The simplest explanation can be expressed thus:

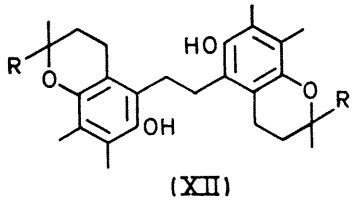


The phenoxylium ion (X) is produced in conditions much milder than those needed for other such ions,[7] probably because the charge can be shared as shown in (XI) by the additional oxygen atoms. The inert character of the naphthalene analogue (V) is thus easily accounted for. Conversely, the special role assigned to the additional oxygen atoms is further evidence that the intermediates are ionic and not radical in nature, for it is known that alkoxy-groups confer little stability upon radicals.[8]

The spirans (IIIa,b) are slowly reduced by ascorbic acid[3] to the bisphenols (XIIa,b). The exceptional ease of this ether scission seems never to have been commented upon, but can now be seen as a consequence of the formation of the phenoxylium ion (X) ⟷ (XI) which must be a rather powerful oxidising agent. Accordingly, the reaction of (IIIa) with ascorbic acid in aqueous ethanol takes about 12 h, but is complete in 5 s in 0·1N-aqueous ethanolic hydrochloric acid. Other oxidation reactions[6] and fissions to quinonoid compounds[3] can also be easily explained in terms of phenoxylium ion (X), while the relative stability of spiran (V) is again understandable.



(XI)



(XII)

The bisphenols (XII) can be re-oxidised to the spirans (III) in reactions typical of the oxidative coupling reactions believed to have biosynthetical importance.[9] Such reactions are commonly written as radical reactions,[10] though ionic ones are sometimes suggested.[11] The present observations provide the first *direct* test of mechanism, for they make it clear that, in the tocopherol series, the phenoxylium ion (X) must take precedence over the biradical (VIII). This view is supported by the anodic oxidation[12] of quinol and its derivatives, where two electrons are abstracted with equal ease to give, in a single step, ions equivalent to (X). Martius and Eilingsfeld[13] were the first to interpret tocopherol oxidations in terms of phenoxylium ions, but presumably because the evidence was limited and because alkaline ferricyanide and other 'one-electron' oxidising agents have been employed, other workers[14,15] have reverted to radical hypotheses. For phenols where two electrons are easily removed, however, the nature of the oxidising agent cannot be critical, and we consider it legitimate to regard the formation of bistocopheryl ethers from β- and γ-tocopherols[14] as examples of electrophilic substitution by phenoxylium ions.

Phenoxylium ions should also be stabilised to some extent by *o*-alkoxy-groups and might therefore play a part in the formation of some varieties of alkaloid. They have the particular merit that they can account simultaneously for the production of certain dienone intermediates[16] and for the acid catalysis which nearly always rearranges these into aromatic products.

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