The Mechanism of Nitration by 4-Methyl-4-nitro-2,3,5,6-tetrabromocyclohexa-2,5-dienone

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Nitration of phenol by 4-methyl-4-nitro-2,3,5,6-tetrabromocyclohexa-2,5-dienone in diethyl ether is a radical process involving reaction between the phenoxyl radical and $NO_2^{\cdot}$ that has escaped from a radical pair in which it was formed by homolytic fission of the C–N bond.

In recent years there has been increasing use of nitrocyclohexadienones and, in particular, the tetrabromoderivative **1** for the selective nitration of naphthols, phenols and amines under mild conditions.[1,2] Addition of this reagent to a solution of phenol in dry diethyl ether at room temperature has been reported[2] to give a 72% yield of *o*- and *p*-nitrophenols ($o:p = 1:3$). The reagent **1** can be regenerated by nitration of tetrabromo-*p*-cresol making this reaction particularly attractive.

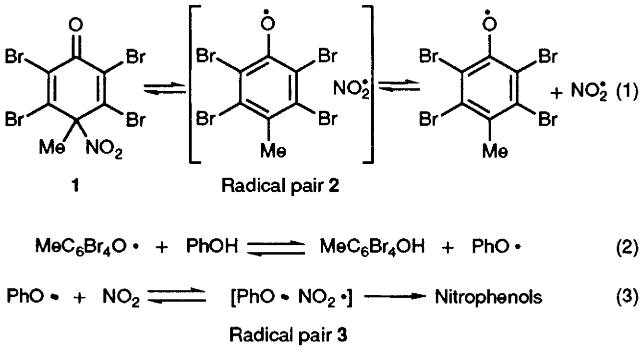
There is, however, no agreement on the mechanism of these reactions. The suggestion that **1** undergoes heterolysis to form a nitronium ion[1] can be supported by reference to the electronegative substituents present. Other authors[2] have suggested that the reactions involve ion pairs or a synchronous transfer of a nitro group and a hydrogen atom within a hydrogen-bonded complex formed by the reactants. However, since 4-nitrocyclohexa-2,5-dienones without electronegative substituents are well known to undergo homolytic fission of the C–N bond in a wide range of solvents,[3–5] even when the protonated species is involved,[4–7] we have followed up an earlier suggestion of homolysis[8] using the ^{15}N-labelled cyclohexadienone **1** to determine from CIDNP (chemically induced dynamic nuclear polarisation) effects whether radicals are involved.

^{15}N-labelled **1** was prepared by nitration of tetrabromo-*p*-cresol with $H^{15}NO_3$ in acetic acid. Solutions of phenol in diethyl ether (0.1–0.3 mol dm^{-3}) were nitrated by equimolar amounts of **1** rapidly at room temperature giving 60–80% yields of nitrophenols (56% *o*, 44% *p*), and tetrabromo-*p*-cresol. For the CIDNP experiment, the initial mixing of the reactants was carried out at −1 °C and the reaction mixture was rapidly brought to 30 °C within the NMR spectrometer. [^{15}N]-Nitrobenzene in [$^2H_6$]-acetone was used as an external reference. A series of ^{15}N NMR spectra taken during the kinetic run are shown in Fig. 1.

Comparison with the noise level and with the signal for the standard [too small to be seen with amplitude settings in spectra (*b*) and (*c*)] shows that **1** exhibits enhanced absorption in spectrum (*b*) and that the nitro products give strong emission signals in spectra (*b*), (*c*) and (*d*) with a maximum enhancement factor >200. The final spectrum shows the unpolarised products at the end of reaction.

These results can be understood by the application of Kaptein's rules[9] to the reaction mechanism shown in Scheme 1. The enhanced absorption of **1** in the second spectrum is as expected from the polarisation deriving from the radical pair **2** and accords with that observed in the rearrangement of 4-nitrocyclohexadienones to 2-nitrophenols.[4] However, if the partition of this radical pair between dissociation and recombination were the sole source of the CIDNP effects, the polarisation in the products should then be far less persistent. This arises because, by the time of the third spectrum, the absorption of **1** has disappeared; the reaction is, therefore, effectively over with all of the ^{15}N atoms transferred to the products. Hence, if there were no other source of CIDNP effects, the ^{15}N spin distribution in the products should then be close to a normal distribution. We suggest that the other source is the partitioning of the radical pair **3** between dissociation and radical combination; this, by analogy with the work on *p*-nitrophenol,[10] should give rise to strong emission signals in the nitro products formed. The hydrogen-atom transfer in reaction (2) of Scheme 1 accords with previous studies,[5] and the overall process is similar to that proposed for the nitrosation of phenols by thionitrites.[11]

This mechanism is supported by the product isomer proportions. The ratio of the intensities of the emission signals for the *o*-nitro and *p*-nitro products (1.11)‡ is close to the corresponding ratio for the product composition (1.27) and so there is no reason to believe that any additional heterolytic mechanism contributes significantly to the product composition. Although in our hands the product proportions were



Scheme 1

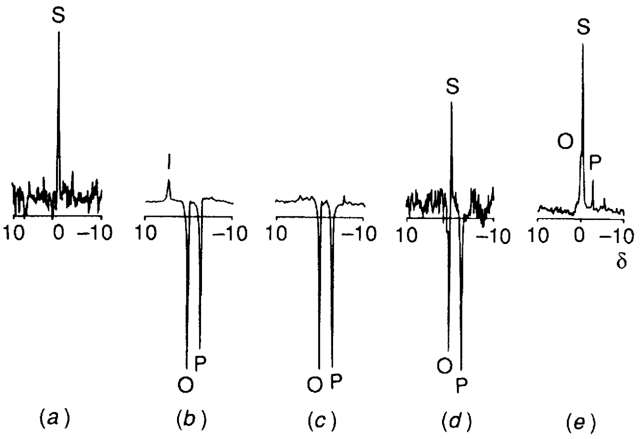


Fig. 1 ^{15}N NMR spectra taken during the nitration of phenol by the ^{15}N-labelled nitrocyclohexadienone **1** under the conditions described in the text: (*a*) before addition of **1**; (*b*) 3–7 min after addition; (*c*) 8–12 min after addition; (*d*) 13–17 min after addition; (*e*) at the end of the reaction. Peaks: S, standard ($Ph^{15}NO_2$); I, the cyclohexadienone **1**; O, *o*-nitrophenol; P, *p*-nitrophenol. The spectra involved 24 pulses [(*e*), 1240 pulses], pulse repetition time 10 s, pulse width 20 μs.

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‡ Taken from spectrum (*b*) to minimise the effects of any difference in the ^{15}N relaxation times for the two nitro products.

different from those previously reported,[2] they are similar to those reported by Al-Obaidi and Moodie[12] for the nitrous acid catalysed nitration of phenol in aqueous sulfuric acid (57% *o*, 43% *p*), and those reported for reaction of low concentrations of NO_2/N_2O_4 with phenol in CCl_4 (56% *o*, 44% *p*).[13] In both these cases, the product-determining stage of reaction is believed to involve reaction of $NO_2^{\bullet}$ with the phenoxyl radical.

We conclude that the nitrocyclohexadienone **1** provides a very convenient way of carrying out homolytic nitrations of phenols and related compounds.

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