Tetrahedron Letters, Vol. 34, No. 52, pp. 8557-8560, 1993
Printed in Great Britain

0040-4039/93 $6.00 + .00
Pergamon Press Ltd

The Mechanism of Nitration of 2,4,6-Trialkylphenols by Nitrogen Dioxide in Solution

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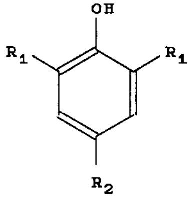
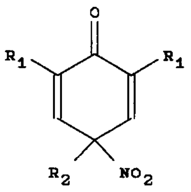
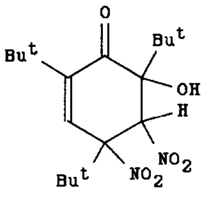
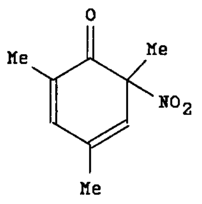
Abstract: *The apparent rate of reaction of 2,4,6-trialkylphenols with nitrogen dioxide in solution is that of a 6-nitrocyclohexa-2,4-dien-1-one to 4-nitrocyclohexa-2,5-dien-1-one isomerisation unless the 2- and 6-alkyl groups are sufficiently bulky when the rate limiting stage may involve reaction between the appropriate phenoxy radical and* $NO_2\cdot$.

We have previously reported[1] that the reaction of 2,6-di-t-butyl-4-methylphenol (**1,a**) with nitrogen dioxide in cyclohexane to form 2,6-di-t-butyl-4-methyl-4-nitrocyclohexa-2,5-dien-1-one (**2,a**) has a second order dependence of rate on the concentration of $NO_2\cdot$ ($k_3 = 6 \times 10^5$ dm^6 mol^{-1}s^{-1} at 25°C), but that the apparent rate of the reaction of 2,4,6-trimethylphenol **1,b** to form **2,b** is independent of the concentration of nitrogen dioxide









1 2 3 4

a $R_1 = Bu^t$, $R_2 = Me$
b $R_1 = R_2 = Me$
c $R_1 = R_2 = Bu^t$

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($k_{obs} = 0.11\ s^{-1}$ at 25°C). It was recognised that the behaviour of **1,a** could be accommodated by a previously proposed[2] mechanism (Scheme 1) if a pre-equilibrium preceded rate limiting reaction of the phenoxy radical with $NO_2^{\cdot}$. It is also necessary for the concentration of nitrous acid to remain effectively constant during

$$ArOH + NO_2^{\cdot} \rightleftarrows ArO^{\cdot} + HNO_2$$

$$ArO^{\cdot} + NO_2^{\cdot} \rightarrow \mathbf{2}$$

Scheme 1

reaction.[3] It was recognised that the behaviour of **1,b** could be explained by the rate limiting formation of **2,b** from a rapidly formed intermediate. We now report a study of 2,4,6-tri-t-butylphenol (**1,c**), the corresponding phenoxy radical (2,4,6-tri-t-butylphenoxyl)[4] and some further studies of **1,b**.

1,c (0.14 mol dm^{-3}) reacts rapidly with nitrogen dioxide ($[N_2O_4] + ½[NO_2^{\cdot}] = 0.091$ mol dm^{-3}) in carbon tetrachloride at 25°C to give **2,c** (67%), 2,6-di-t-butyl-*p*-benzoquinone (3%) and **3** (22%).[5] **3** is also formed in 42% yield from reaction of **1,c** and nitrogen dioxide in carbon tetrachloride solution. The formation of 3 was not observed in an earlier study involving reaction of **1,c** with an excess of nitrogen dioxide in benzene solution.[6] The ultraviolet extinction curve change on mixing equivalent amounts of **1,c** and nitrogen dioxide in cyclohexane at 25°C is consistent with **2,c** as the major product of reaction. Below 3.2×10^{-4} mol dm^{-3} $NO_2^{\cdot}$ the reaction is second order in $NO_2^{\cdot}$ and $k_3 = 9 \times 10^5\ dm^6\ mol^{-2}s^{-1}$ (see the **Figure**). However, as the concentration of $NO_2^{\cdot}$ is increased the order in $NO_2^{\cdot}$ decreases and in the region of concentrations of $NO_2^{\cdot}$, $5.0 - 8.3 \times 10^{-4}$ mol dm^{-3}, the reaction rate becomes independent of $NO_2^{\cdot}$ concentration with $k_{obs} = 0.16 \pm 0.01\ s^{-1}$.

The rate of reaction of the 2,4,6-t-butylphenoxy radical with nitrogen dioxide[7] was determined under similar conditions, when the ultraviolet extinction curve of the product solution was identical to that of the dienone **1,c**. Here the reaction rate was independent of the concentration of nitrogen dioxide over the observed range ($1.6 - 5.5 \times 10^{-4}$ mol dm^{-3} $NO_2^{\cdot}$) as shown in the **Figure**. The k_{obs} value of $0.160 \pm 0.005\ s^{-1}$ is identical to the value for **1,c** at high concentrations of NO_2.

The behaviour of **1,c** is consistent with Scheme 2. At low concentrations of $NO_2^{\cdot}$ the first stage is a

$$ArOH + NO_2^{\cdot} \rightleftarrows ArO^{\cdot} + HNO_2$$

$$ArO^{\cdot} + NO_2^{\cdot} \rightarrow \mathbf{2} + \text{Intermediate}$$

$$\text{Intermediate} \rightarrow \mathbf{2}$$

Scheme 2

pre-equilibrium and the subsequent rate limiting stage gives a second order dependence on $NO_2^{\cdot}$ concentration.

At high concentrations of the latter the intermediate is formed rapidly in bulk and the observed rate is that of conversion into product. The behaviour of the 2,4,6-tri-t-butylphenoxy radical makes it likely that the radical does indeed lie on the reaction path from **1,c** to the intermediate. The reaction with $NO_2^{\cdot}$, as in the second stage of Scheme 2, is rapid under all concentration conditions and so the reaction of the intermediate is always rate limiting.

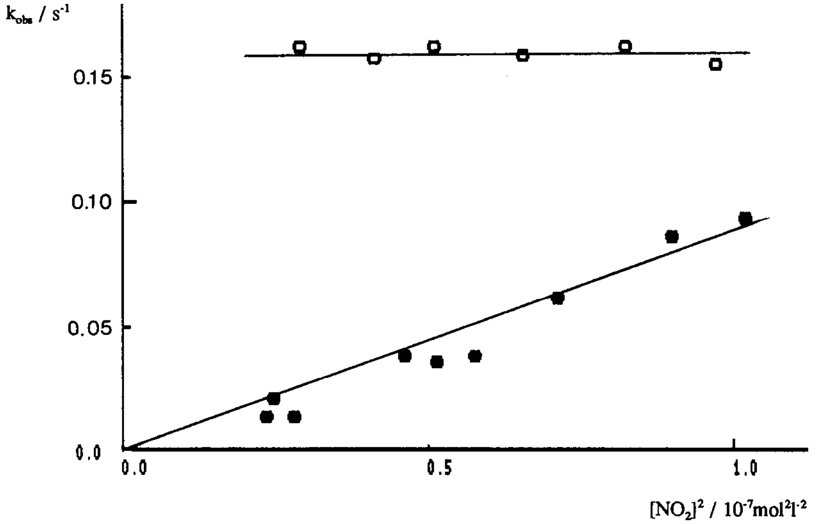

Figure Plot of first-order rate coefficients (k_{obs}) *versus* $[NO_2^{\cdot}]^2$ for reactions of **1,c** (●) and the 2,4,6-tri-t-butylphenoxy radical (□), each ≲ 5 x 10^{-5} mol dm^{-3}, with nitrogen dioxide at 25°C in cyclohexane.

Evidence concerning the nature of the intermediates present in the reactions of **1,b** and **1,c** has been obtained by further study of **1,b**. When **1,b** reacts with nitrogen dioxide in deuteriochloroform at -60°C both **2,b** (45%) and 2,4,6-trimethyl-6-nitrocyclohexa-2,4-dien-1-one (**4**) (55%) were formed, although on warming **4** isomerised to **2,b**. **4** has been identified previously as a transient intermediate in the nitration of **1,b** in acetic anhydride at low temperatures.[8] The rates of the isomerisation reaction in deuteriochloroform were measured at -20°C (k_{obs} = 7 x 10^{-4} s^{-1}) and -10°C (k_{obs} = 4 x 10^{-3} s^{-1}) by ^1H n.m.r. spectroscopy. This enables an estimate for the rate coefficient for isomerisation at 25°C to be made of 0.2 ± 0.15 s^{-1}. This shows acceptable agreement with the observed[1] rate of reaction of **1,b** with nitrogen dioxide (k_{obs} = 0.11 ± 0.01 s^{-1}). Contrary to our previous statement[1] it is possible to calculate the ultraviolet extinction curve immediately after mixing solutions of **1,b** and nitrogen dioxide by extrapolation of the stopped-flow kinetic traces back to the time of mixing. The resulting curve has λ_{max} 320nm and is clearly different from that of **1,b** above 290 nm. The difference is ascribed to the presence of the intermediate and is consistent with it having a 2,4-dien-1-one structure (*c.f.* 6-t-butylperoxy-6-methyl-2,4-di-t-butylcyclohexa-2,4-dien-1-one,[9] λ_{max} 309 nm).

We conclude that Scheme 2 rationalises the behaviour of **1,a**, **1,b** and **1,c** and that the intermediate is a 2,4-dien-1-one the isomerisation of which to a 2,5-dien-1-one may be the reaction of which the rate is observed.

In the case of **1,a** and **1,c** the steric hindrance offered to reaction between the 2- and 6-t-butyl groups can, however, lead to the isomerisation reaction becoming relatively fast.

Acknowledgement
The award of an SERC CASE studentship to AWD is gratefully acknowledged.

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(Received in UK 13 October 1993; accepted 22 October 1993)