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THE IPSO-NITRATION OF p-CRESOL

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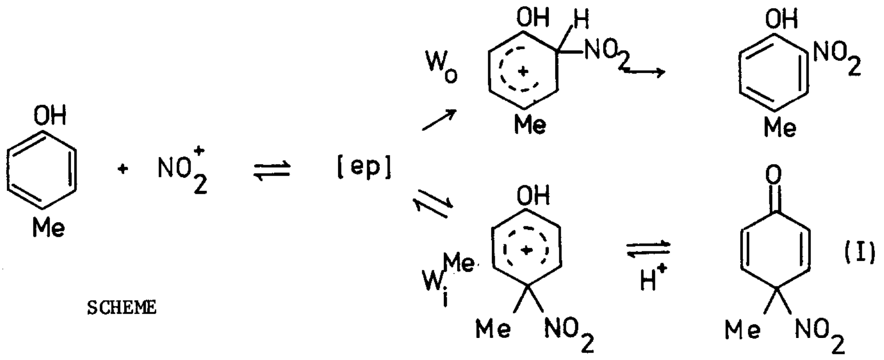
Summary The nitration of p-cresol by nitric acid in aqueous sulphuric acid involves ~ 40% ipso-substitution at C^{Me}. The 4-methyl-4-nitrocyclohexa-2,5-dien-1-one (I) formed undergoes an acid-catalysed rearrangement to 4-methyl-2-nitrophenol.

A RECENT report[1] concerns the mechanism of rearrangement of 4-methyl-4-nitrocyclohexa-2,5-dienone into 4-methyl-2-nitrophenol under non-acidic conditions, where a radical dissociation-recombination mechanism is indicated. This prompts us to report our study of the nitration of p-cresol, which provides evidence concerning another pathway for this conversion under highly acidic conditions. Ipso-nitration of aromatic compounds at activated positions bearing alkyl groups is of interest as an example of a non-conventional pathway in electrophilic aromatic substitution.[2] The phenomenon has usually been detected by the formation of products which result from initial nucleophilic trapping of the ipso-substituted Wheland intermediate. When the concentration of nucleophilic species is low, normal nitration products may arise by nitro group shifts in such intermediates, bringing into question the validity of many partial rate factors.

For the nitration of p-cresol by nitric acid in 56-78% sulphuric acid at 25°C a quantitative (99-101%) yield of the sole product, 4-methyl-2-nitrophenol, was observed when nitrosation was precluded. Amounts of 4-methyl-3-nitrophenol greater than 0.2% would have been detected in our experiments. Measurements of the change in absorbance at 380 nm gave a rate vs acidity profile in the region 56-73% sulphuric acid which was parallel to that of mesitylene (k_2(obs) in 68.0% sulphuric acid = 0.88 $dm^3\ mol^{-1} s^{-1}$ for p-cresol), and characteristic of a substrate reacting at or very near the encounter rate.[3,4]

However, observation of the extinction curve change in the ultraviolet region during the course of reactions in 68-73% sulphuric acid revealed the formation of an intermediate species absorbing at λ_{max} = 240 nm, which is formed transiently during the course of a reaction. This absorption is in the region expected for that of a cyclohexa-2,5-dien-1-one,[5,6] and, particularly in view of recent studies,[1,6] is clearly due to the formation of 4-methyl-4-nitrocyclohexa-2,5-dienone (I) via W_i^{Me}, as shown in the scheme. It forms 40-45% of the initial nitration product. Species (I) is now well established as a product of the nitration of some other p-substituted toluenes on nitration by nitric acid in acetic anhydride.[1,6]

Suitable increase of the nitric acid concentration allows the first-order rate coefficient for the acid catalysed conversion of (I) into 4-methyl-2-nitrophenol to be studied as a function of the acidity of the medium. Measurements were taken at 380 nm over about two half-lives and a calculated final spectrum was used, as the rate of nitration of 4-methyl-2-nitrophenol was



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significant under these circumstances. The results are shown in the table. A plot of $\log_{10}k_1$ vs $-H_o$ (from ref. 7) gives a line of slope 0.9, indicating that (I) behaves quite like a Hammett base and that the rate limiting step in the rearrangement involves the protonated cyclohexadienone, W_i^{Me}. Reaction via W_i^{Me} is unlikely to involve C-N bond homolysis, as this process should be more facile for the unprotonated cyclohexadienone.

TABLE

First order rate coefficients for the conversion of (I) into 4-methyl-2-nitrophenol at 25°C

H_2SO_4(%)[a]	$[HNO_3]10^{-2}$ mole dm^{-3}	$k_1/10^{-3}s^{-1}$
67.9[b]	5.5	0.98
69.1[c]	5.5	1.68
71.2[b]	1.18	3.43
72.5[c]	0.25	3.90

(a) [Sulphamic acid] = 2×10^{-2}; b) [p-Cresol] = 1.23×10^{-3}; c) [p-Cresol] = 1.23×10^{-4} (mol dm^{-3}).

The likely pathway would involve rate-limiting reversion of W_i^{Me} to the encounter pair, and fast formation of W_o and subsequent proton loss (see the Scheme). These three steps have also been postulated as part of the pathway for demethylative nitration of p-methylanisole,[4] and here isotopic labelling experiments[8] have shown that some leakage from the encounter pair must occur in 66.8%, but not 71.3%, sulphuric acid. Our arguments mean that (I) should be observed as a transient intermediate in the reaction of p-methylanisole also, and this has been shown to be so.[9] The possible nucleophilic capture of W_i^{Me}, at the position para to the sp^3-carbon, by water at low acidities will remain undetected, and significant capture at the ortho-position is precluded by the quantitative yields of 4-methyl-2-nitrophenol.

We conclude that the above mechanism for rearrangement of (I) via W_i^{Me} supplants the radical dissociation-recombination mechanism at high acidities.

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