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FORMATION OF DIENONES ON THE REACTION OF CRESOLS, XYLENOLS, AND 2-NAPHTHOL WITH NITROGEN DIOXIDE: OBSERVATION OF KETO TAUTOMERS OF NITROPHENOLS

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Abstract: Reaction of *o*- and *p*-cresol, the xylenols, and 2-naphthol with nitrogen dioxide gives nitrocyclohexadienones and nitrophenols. Secondary nitrodienones, the keto tautomers of the nitrophenols, have been observed in several cases and are intermediates in the formation of the nitrophenols.

2,4,6-Trisubstituted and polysubstituted phenols give nitrocyclohexa-2,5-dienones on reaction with nitrogen dioxide.[1,2,3] In a few instances formation of the 2,4-dienone has been observed or proposed.[3] Other phenols on reaction with nitrogen dioxide are reported to give nitrophenols.[4] The mechanism for formation of the dienones involves abstraction of the phenolic hydrogen by the nitrogen dioxide followed by combination of the resulting phenoxy radical at an ortho or para position with a second molecule of nitrogen dioxide.[2] Recent kinetics studies suggest that the mechanism may be more complicated.[5] It has been suggested that the formation of dienones is associated with sterically hindered phenols.[2] However there is no apparent reason why simple phenols should not react similarly to form tertiary or secondary nitrodienones, depending upon the presence or absence of a substituent at the position where the nitrogen dioxide adds. The reason for the failure to observe dienones in the case of simple phenols would then be that such dienones are labile and this would be especially so in the case of secondary nitrodienones, the keto tautomers of the nitrophenols, which readily undergo prototropy to the phenol tautomers. In this communication we show that cresols and xylenols containing at least one methyl substituent in an ortho or para position form the tertiary nitro dienone(s) on reaction with nitrogen dioxide. We also report the first observation of the formation of secondary nitrodienones from xylenol precursors and thus confirm that in these systems, and by implication in the reactions of other phenols with nitrogen dioxide the keto tautomer of the nitrophenol is an intermediate on the pathway between phenol and nitrophenol.

Reactions were carried out by adding a solution of nitrogen dioxide (2 mmol) in chloroform-*d* (0.3 cm^3) to a solution of the phenol (1 mmol) in chloroform-*d* (5 cm^3) at -60 °C. The reaction products were determined from the ^1H and ^{13}C nmr spectra measured at -60 °C in conjunction with variable temperature studies which aided in the distinction between the products labile at temperatures below 0 °C, generally secondary nitrodienones and ortho tertiary nitrodienones, and the more stable products: nitrophenols and para tertiary nitrodienones.

o-Cresol gave a mixture of 2-methyl-4-nitro- and 2-methyl-6-nitro-phenol (53%), 6-methyl-6-nitrocyclohexa-2,4-dienone[6] (34%) and 2-methyl-*p*-benzoquinone (13%). The dienone isomerized to the 6-nitrophenol at -20 °C. *m*-Cresol gave a mixture of nitrocresols (80%) and 2-methyl-*p*-benzoquinone (20%). *p*-Cresol gave a mixture of 4-methyl-2-nitrophenol (57%) and 4-methyl-4-nitrocyclohexa-2,5-dienone (43%).

2,3-Dimethylphenol gave 2,3-dimethyl-4-nitrocyclohexa-2,5-dienone (δ_H 2.09 (s, 3, 2-CH_3), 2.13 (s, 3, 3-CH_3), 5.77 (bs, 1, 4-H), 6.61 (d, 1, J = 9.9 Hz, 6-H), 7.08 (dd, 1, J = 9.9 and 3.5 Hz); δ_C 18.2 (2-CH_3), 21.4 (3-CH_3), 85.6 (C-4), 136.1 (C-6), 144.2 (C-5), 185.1 (C-1)) (31%),[7] 5,6-dimethyl-6-nitrocyclohexa-2,4-dienone[6] (22%), 2,3-dimethyl-6-nitrophenol (18%), 2,3-dimethyl-4-nitrophenol (16%), and 2,3-dimethyl-*p*-benzoquinone (13%). The 2,4-dienone isomerized to the 6-nitrophenol at -10 °C and the 2,5-dienone tautomerized to the 4-nitrophenol at 0 °C.

2,4-Dimethylphenol gave 2,4-dimethyl-4-nitrocyclohexa-2,5-dienone[6] (40%), 4,6-dimethyl-6-nitrocyclohexa-2,4-dienone[6] (36%), and 2,4-dimethyl-6-nitrophenol (24%). The 2,4-dienone isomerized at -40°C over 45 min resulting in a mixture of nitrophenol (45%) and 2,5-dienone (55%). The 2,5-dienone rearranged to the nitrophenol at ambient temperature over 1 h.

2,5-Dimethylphenol gave 2,5-dimethyl-4-nitrocyclohexa-2,5-dienone (δ_H 2.04 (s, 3, 2-CH_3), 2.16 (s, 3, 5-CH_3), 5.72 (s, 1, 4-H), 6.42 (s, 1, 6-H), 6.87 (s, 1, 3-H); δ_C 84.9 (C-4), 185.9 (C-1)) (42%), 3,6-dimethyl-6-nitrocyclohexa-2,4-dienone[6] (24%), 2,5-dimethyl-1,4-benzoquinone (13%), 2,5-dimethyl-6-nitrocyclohexa-2,4-dienone (δ_H 1.97 (s, 3, 2-CH_3), 2.41 (s, 3, 5-CH_3); δ_C 92.9 (C-6), 190.1 (C-1)) (10%), 2,5-dimethyl-4-nitrophenol (7%), and 2,5-dimethyl-6-nitrophenol (4%). The secondary ortho nitrodienone tautomerized to the 6-nitrophenol at -60 °C and the secondary para nitrodienone tautomerized to the 4-nitrophenol at 0 °C. The tertiary nitrodienone was stable up to ambient temperature.

2,6-Dimethylphenol gave 2,6-dimethyl-6-nitro-cyclohexa-2,4-dienone[6] (52%), 2,6-dimethyl-4-nitrocyclohexa-2,5-dienone (δ_H 2.04 (s, 6, 2- and 6-CH_3), 5.74 (t, 1, J = 1.6 Hz, 4-H), 7.0-7.6 (m, 2, 3- and 5-H); δ_C 16.7 (2- and 6-CH_3), 79.5 (C-4), 131.9 (C-3 and C-5), 137.7 (C-2 and C-6), 185.8 (C-1)) (37%), and 2,6-dimethyl-4-nitrophenol (11%). The 2,5-dienone tautomerized to the nitrophenol at 0 °C over 15 min. The 2,4-dienone isomerized to the nitrophenol on warming the reaction mixture to ambient temperature.

3,4-Dimethylphenol gave 3,4-dimethyl-4-nitrocyclohexa-2,5-dienone[8] (52%), 4,5-dimethyl-2-nitrophenol (32%), and 3,4-dimethyl-2-nitrophenol (16%). The dienone survived in the reaction mixture at ambient temperature.

3,5-Dimethylphenol gave 3,5-dimethyl-2-nitrophenol (54%), 3,5-dimethyl-4-nitrophenol (23%), 2,6-dimethyl-*p*-benzoquinone (15%), and 3,5-dimethyl-4-nitrocyclohexa-2,5-dienone (δ_H 2.17 (s, 6, 3- and 5-CH_3), 5.65 (s, 1, 4-H), 6.42 (s, 2, 2- and 6-H); δ_C 21.4 (C-2 and C-6), 88.6 (C-4), 129.6 (C-2 and C-6), 184.3 (C-1) (8%). The dienone tautomerized to the 4-nitrophenol over 45 min at -60 °C.

2-Naphthol gave 1-nitro-2-oxo-1,2-dihydronaphthalene (δ_H 6.27 (s, 1, 1-H), 6.36 (d, 1, J = 10 Hz, 3-H), 7.4-7.6 (m, 4, 5-, 6-, 7-, and 8-H), 7.68 (d, 1, J = 10 Hz, 4-H); δ_C 88.9 (C-1), 124 (C-3), 128.4 (C-6), 129.2 (C-10), 130.4 (C-8), 130.8 (C-9), 131 (C-5), 131.2 (C-7), 148.1 (C-4), 187.7 (C-2)) in quantitative yield. The dienone tautomerized to 1-nitro-2-naphthol over 15 min at ambient temperature.

It is evident that para nitrodienones are more stable than ortho nitrodienones and tertiary nitrodienones are more stable than secondary nitrodienones. All of the possible tertiary nitrodienones were observed, i.e nitrogen dioxide added to all of the ortho and para positions in the cresols and xylenols which carried a methyl group. We were not able to observe the para secondary dienone (the keto tautomer of the nitrophenol) for either *o*-cresol or *m*-cresol but we were able to observe the corresponding dienone for all of the appropriate xylenols. It appears that the second methyl group confers additional stability on the dienone. Stability is enhanced when at least one of the methyl groups is at the 2 position. In the methylphenols we were able to observe an ortho secondary nitrodienone only in the case of 2,5-dimethylphenol and this dienone isomerized at -60 °C. 2-Naphthol formed the secondary nitrodienone in quantitative yield reflecting the general observation that polycyclic aromatics have a greater tendency to lose the aromaticity of one ring than does benzene. The secondary nitrodienones tautomerized to the corresponding phenols. It seems most likely that all of the nitrophenols were formed via the intermediate dienone, even in those cases where we could not observe the appropriate dienone at the lowest temperature at which we made observations (-60 °C). The formation of secondary 4-nitrocyclohexa-2,5-dienones, in addition to the tertiary 6-nitrocyclohexa-2,4-dienones, has previously been observed in the acetyl nitrate nitration of 2,3,6-trimethyl- and 2,3,5,6-tetramethyl-phenol.[6] Under the electrophilic nitration conditions secondary nitrodienones are even more labile than in chloroform and it is not surprising that their formation in the electrophilic nitration of cresols and xylenols was not observed. Nevertheless, their formation in the cases cited coupled with the observations for the nitrogen dioxide reactions suggests that generally in the nitration of phenols the keto tautomer is the first formed product and this rapidly tautomerizes to the nitrophenol.

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