Tetrahedron Letters,Vol.26,No.20,pp 2387-2390,1985 0040-4039/85 $3.00 + .00
Printed in Great Britain

PHOTOOXYGENATION OF NITROAROMATIC COMPOUNDS. CATALYTIC EFFECTS IN THE REACTION OF MOLECULAR OXYGEN WITH NITROBENZYL DERIVATIVES.

Peter Wan
Department of Chemistry, University of Victoria,
Victoria, B.C., Canada V8W 2Y2

Summary: The photooxygenation reaction of several nitroaromatic compounds (1 - 8) in aqueous solution is described, the mechanism of reaction is believed to involve photogenerated nitrobenzyl carbanions.

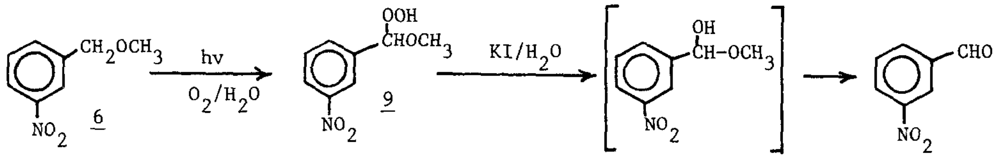
The base-catalyzed oxygenation of organic compounds (eq 1) has been extensively employed in organic synthesis and the mechanism reasonably well-understood[1,2]. In these reactions, strong bases (e.g., conc. KOH, potassium t-butoxide, NaH, etc.) are usually employed due to

$$R\text{-}CH_3 \xrightarrow{B} R\text{-}\overset{-}{C}H_2 \xrightarrow{O_2} R\text{-}CH_2\text{-}O\text{-}O^- \longrightarrow \text{product(s)} \qquad [1]$$

the very low acidity of most C-H bonds. However, many aromatic compounds have very different pK_a values in the excited state, compared to their ground state values[3]. This is especially true for those functional groups that are in direct conjugation with the aromatic system. Changes of up to 7 or 8 log units in pK_a value on photochemical excitation are not uncommon[3,4]. Conceptually, one can anticipate that if the C-H acidity of an organic compound is increased sufficiently on electronic excitation, it should be possible to carry out base-catalyzed oxygenation using much weaker bases(and hence milder conditions). Assuming that sufficient enhancement of C-H acidity is possible, it is conceivable that the photooxygenation can be carried out in the pH (aqueous) region of basicity, employing hydroxide ion as the catalyzing base. We report herein the photooxygenation of the benzylic positions of several nitroaromatic compounds in aqueous solution which is interpreted as due to the greatly enhanced C-H acidity of the benzylic methylenes of these compounds on photochemical excitation.

Zimmerman and Somasekhara[5] have reported the enhanced electron-withdrawing effect of aromatic nitro groups at the meta position on photochemical excitation. Several aromatic photosubstitution reactions of nitro compounds may be interpreted via this phenomenon[6]. Substrates 1 - 8 were chosen for study based on the postulate that the enhanced electron-withdrawing effect of the nitro group in the excited state[7] should increase the C-H acidity of the benzylic methylenes, which may be sufficient for base-catalyzed oxygenation to take place in aqueous hydroxide solution. Photolysis of 1 - 4 in oxygen purged aqueous hydroxide solution gave p-nitrobenzoic acid as the only product in conversions of up to 50%. No reaction was observed when identical solutions are kept in the dark for periods of up to several days. The reaction with oxygen was found to be strongly pH-dependent, and a plot relative quantum efficiency for reaction (loss of substrate or product formation) (Φ/Φ_o), where Φ_o = quantum yield at pH 14 (Figure 1), shows that no reaction is observed below pH 11. At pH's below 11, nearly complete (>95%) recovery of the substrate is possible after photolysis. The plot (Figure 1) resembles a titration curve, although the plateau region at high pH cannot be reached under the experimental conditions since the solubility of these organic compounds is negligible in concentrated KOH solutions, thus preventing experiments. The photooxygenation is not observed in any of the organic solvents tried so far(e.g., MeOH, EtOH, CH_3CN, benzene, diethyl ether); nearly complete recovery (>95%) of the substrate is possible after photolysis in these solvents. It appears that a catalyzing base is required for the reaction although no attempts were made to study the photooxygenation in alcohol/alkoxide solutions since thermal oxygenation is known to occur under these much more basic conditions[1,2]. The observation of base-catalysis and solvent effect argues against a photooxygenation mechanism involving substrate-oxygen complexes, or a mechanism involving radical intermediates. Additionally, we have not been able to duplicate these reactions using Rose Bengal as a sensitizer for singlet oxygen.

Photolysis of *p*-nitrotoluene (5) under similar conditions as for 1 - 4 results in decomposition of substrate without evidence for formation of oxygenation product; only intractable material was obtained after photolysis. This suggests that the reaction requires the presence of a heteroatom, which is known to enhance the acidity of adjacent C-H bonds[1]. A likely explanation is that the C-H acidity of 5 is insufficiently enhanced in the excited state, and other photochemical processes dominate the deactivation process. In contrast, photooxygenation of 6 does not require hydroxide ion catalysis. The photooxygenation takes place in neutral aqueous medium, to give the hydroperoxide 9 (eq 2) as the major product (>70%). The structure of this hydroperoxide was confirmed by its ^1H NMR and IR spectra, as well as by its quantitative reduction to *m*-nitrobenzaldehyde in aqueous KI. Hydroperoxide 9 is stable at room temperature for days if the pH is kept >4, but suffers acid-catalyzed hydrolysis to give *m*-nitrobenzaldehyde and H_2O_2 in more acidic medium. Similar photooxygenation chemistry is observed for compound 7. For 8, however, the hydroperoxide is not isolable; the only isolable product is *m*-nitrobenzaldehyde. These reactions can be accomodated in a mechanistic scheme involving formation of a nitrobenzyl carbanion from the excited state (Scheme 1), followed by trapping of the carbanion by molecular oxygen, under conditions in which the ground state ionization process does not occur. The initial photooxygenation product of these reactions is presumably a hydroperoxide (isolable only for 6 and 7), which undergoes additional reaction/photooxygenation under the basic conditions required for reaction for



[2]

1 - 4, to give p-nitrobenzoic acid as the end product. Additional evidence for α-H deprotonation in the product-forming step is provided by α-deuterium isotope effect in the photooxygenation. Thus for compound 8 and the corresponding α,α'-dideuterated compound, the isotope effect for photooxygenation was $(\Phi_H/\Phi_D)_{pH\ 13} = 1.9 \pm 0.1$, clearly indicating product-determining proton abstraction in the reaction mechanism.

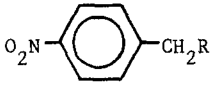
These photooxygenation reactions may be interpreted as being due to the enhanced acidity of the benzylic methylenes in the excited state. The ground state pK_a of nitrobenzyl methylenes which do not possess additional carbanion stablizing groups at the benzylic carbon is ca. 20[9], which would require bases such as potassium t-butoxide to effect ionization,and therefore oxygenation. In the excited state, the results suggest that the benzylic methylenes of the para nitro derivatives are 5 - 8 log units more acidic and for the meta nitro derivatives (6 - 8), at least 12 log units more acidic, since even neutral water (pK_a of $H_3O^+ = -1.7$) can effect ionization. The exact details of these photooxygenations have still to be worked out. For example, it is not clear at this time whether free nitrobenzyl carbanions are generated, or whether oxygen attacks a partly dissociated C-H bond. The inability to observe deuterium incorporation into unreacted material in experiments performed in D_2O/OD^- favours a mechanism not involving free carbanions.

The use of molecular oxygen to trap photogenerated transient biradicals has been extensively demonstrated[10]. In this paper, we presented evidence demonstrating that photogenerated nitrobenzyl carbanions are readily trappable with molecular oxygen. These reactions are interpreted as being examples of a photochemical process that takes advantage of the enhanced acidity/basicity of organic molecules in the excited state, and demonstrates the feasibility of applying this principle to the investigation of hitherto unknown photochemical processes. Since compounds of the type 6 - 8 react with molecular oxygen under very mild conditions, we are presently exploring the feasibility of photochemically induced oxygen activation to produce hydrogen peroxide using these substrates in a catalytic cycle[11].

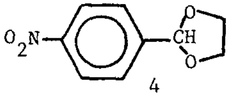
ACKNOWLEDGMENT The author thanks the Natural Sciences and Engineering Research Council of Canada (NSERC) for support of this work in the form of an operating grant and a University Research Fellowship at Victoria.

References and Notes 1. (a) J.C. Stowell,"Carbanions in Organic Synthesis"; Wiley: New York, 1979; (b) J.R. Jones,"The Ionisation of Carbon Acids"; Academic Press: London, 1973; (c) H. Pines and W.M. Stalick, "Base-Catalyzed Reactions of Hydrocarbons and Related Compounds"; Academic Press: New York, 1977. 2. (a) G.A. Russell, A.J. Moye, E.G. Janzen, S. Mak and E.R. Talaty, J. Org. Chem., 1967, 32, 137;(b) G.A. Russell and A.G. Bemis, J. Am. Chem. Soc., 1966, 88, 5491. 3. Reviews: (a) J.F. Ireland and P.A.H. Wyatt, Adv. Phys. Org. Chem., 1976, 12, 131; (b) S.C. Lahiri, J. Sci. Ind. Res. (India), 1979, 38, 492. 4. (a) P. Wan and K. Yates, Rev. Chem. Intermed., 1984, 5, 157; (b) P. Wan, S. Culshaw and K. Yates, J. Am. Chem. Soc., 1982, 104,2509. 5. H.E. Zimmerman and S. Somasekhara, J. Am. Chem. Soc., 1963, 85, 922. 6. (a) J. Cornelisse and E. Havinga, Chem. Rev., 1975, 75, 353; (b) E. Havinga and J. Cornelisse, Pure Appl. Chem., 1976, 41, 1. 7. Most nitroaromatic compounds react via their triplet excited states: D. Dopp, Top. Curr. Chem., 1975, 55, 49. 8. P. Wan and K. Yates, J. Org. Chem., 1983, 48, 136. It should be noted that 2 and 8 react via an intramolecular photoredox reaction when photolyzed under an argon atmosphere, as reported in the above paper. 9. (a) R. Schaal, J. Chim. Phys.(Paris), 1955, 52, 796; F.G. Bordwell, D. Algrim and N.R. Vanier, J. Org. Chem., 1977, 42, 1817. The pK_a of the p-nitrobenzyl alcohol methylenes should

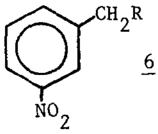
be in the range 17-19 in the ground state since the α-hydroxyl group can stabilize the carbanion by inductive effects(see ref. 1). 10. For leading references, see: W. Adam, K. Hanneman and R.M. Wilson, J. Am. Chem. Soc., 1984, 106, 7646. 11. A referee has pointed out that base-catalysis should be observable for the meta-derivatives at sufficiently high pH. We have not observed base-catalysis for these compounds up to pH 13. However, it is apparent that water is a strong enough base to catalyze the reaction.



1 R = OCH_3 ; 2 R = OH ; 3 R = NH_2 ; 5 R = H



4



6 R = OCH_3 ; 7 R = $OCH_2CH_2CH_3$; 8 R = OH

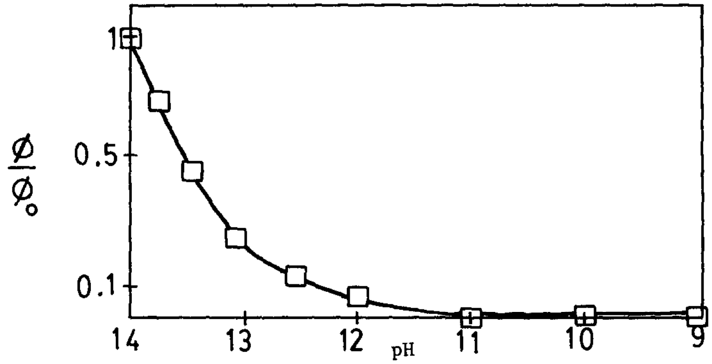
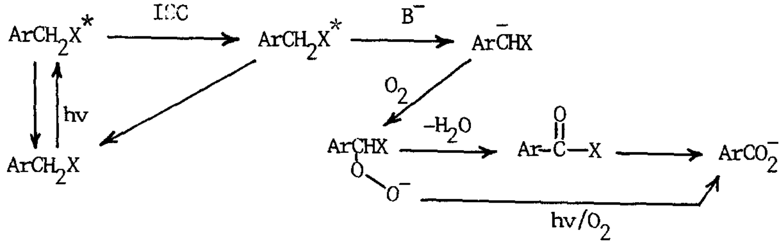


Figure 1. Relative quantum yields for photooxygenation (Φ/Φ_o) as a function of pH for compounds 1 - 4 (Φ_o = quantum yield at pH 14 defined as equal to 1.0. Determined via preparative photolyses as well as via UV spectrophotometry).



Scheme 1. Proposed mechanism for the photooxygenation of nitroaromatic compounds in aqueous solution.

(Received in USA 16 January 1985)