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Photogenerated Nitrenium Ions: Singlet and Triplet State Reactions of *tert*-Butyl-(2-Acetyl-4-Methyl)Phenyl Nitrenium Ion

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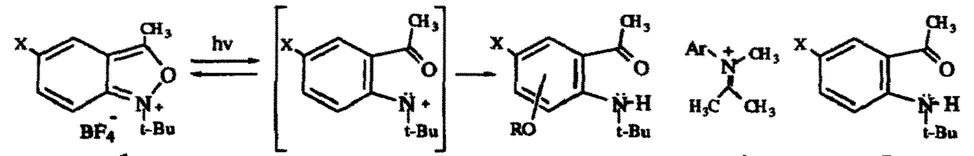
Abstract: Photolysis of an anthranilium salt, 5-methyl-3-N-*tert*-butyl-2,1-benzisoxazolium tetrafluoroborate (**1a**) gives the title nitrenium ion **2a**. Under direct photolysis of **1a**, in the presence of nucleophiles (i.e. ROH), quinone imine ethers such as (**6**) are the major product. Triplet sensitized irradiation gives both **6** and the parent amine **5**.

Nitrenium ions are cationic intermediates which contain a divalent nitrogen atom.[1,2] Like other open shell species (carbenes and nitrenes), nitrenium ions can exist in two electronic states, the singlet state, where the electrons are paired and the triplet state where both non-bonding orbitals are singly occupied. It is known that photolysis of N-alkyl anthranilium salts such as **1** give aryl nitrenium ions such as **2**. These reactive intermediates can do either singlet chemistry and give phenyl ring adducts (**3**) and/or rearranged iminium ions (**4**) or triplet chemistry where products such as **5** are expected (reduced to parent amine).[2a,3] (Scheme 1) MO calculations suggest that aryl nitrenium ions are ground state singlets.[4] The phenyl ring is thought to act as an electron donor and stabilizes the singlet relative to triplet state. The electronegativity of substituents on the aryl ring is also predicted to alter the energy gap between the nonbonding orbitals.[4] This can in turn affect the chemistry of the aryl nitrenium ion. Electron withdrawing groups are predicted to cause triplet like behavior whereas electron donating groups singlet behavior.

In this report, the photochemistry of anthranilium salt 5-methyl-3-N-*tert*-butyl-2,1-benzisoxazolium tetrafluoroborate (**1a**) is described. The objective of this investigation was to determine how inductively donating and sterically demanding substituents at the position para to the nitrenium center affect the chemistry of arylnitrenium ions. It is known that nucleophiles add to the para position of unsubstituted anthraniliums (**1d**) whereas inductively withdrawing substituents (**1b,c**) give addition ortho to the nitrenium center.[3]

Scheme 1



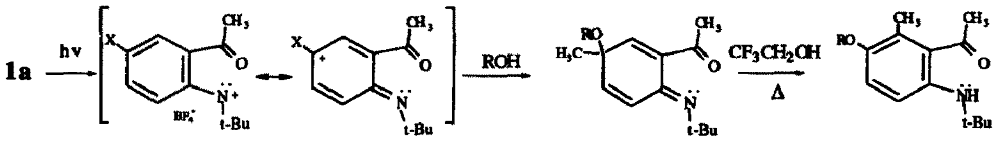
1 **2** **3** **4** **5**

a X = CH_3, **b** X = Br, **c** X = Cl, **d** X = H

Interestingly, nucleophilic addition to the aromatic ring occurs para to the nitrenium center even with the methyl substituent in that position. (Scheme 2). For example, irradiation of **1a** in the presence of a nucleophile

(4.0 M CH_3OH) generates **6f**. The quinone imine ether (**6f**) is the major product detected by ^1H NMR (87%). Traces of the ortho adduct **3a** are also observed (8%).[5] The iminium ion **4** is not detected under any of the employed photolysis conditions. The methyl substituent appears to slow down the rearrangement process relative to the other reaction pathways.

Scheme 2



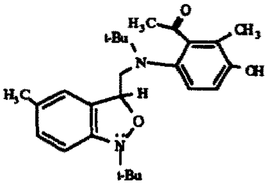
2a **6** **7**

e R=H, f R=Me, g R=Et

Confirmation of the structure of **6f** was acheived by its conversion to the tetrasubstituted benzene **7f** (24h reflux in TFE). Structural assignment of the tetrasubstituted arene **7f** was based on: (1) the ortho coupling constant (10.3 Hz) of the aromatic protons is indicative of a 1,2,3,4 substitution pattern and (2) the methyl is the substituent that shifts in an analogous reaction reported by Novak et al.[5] A similar para adduct **6g** is obtained when photolysis is performed in ethanol (4.0 M).

Photolysis of **1a** in the presence of H_2O gave the para hydroxy adduct **6e** when the concentration of H_2O was very low (residual H_2O in CH_3CN and on glassware is sufficient).[6,3a] In the presence of higher concentrations of H_2O (4.0 M), irradiation results in an unusual dimeric species **8** (Equation 1).This product results, formally, from the combination of two anthranilium ions with one molecule of water. Although the mechanism of dimer formation has not fully been characterized, it is presumed to involve a radical process. Addition of a radical inhibitor (hydroquinone), the same photolysis generates only **6e**. Compound **6e** was converted, in the presence of TFE as well as in the presence of H_2O, to the tetrasubstituted arene **7e** via a 1,2 methyl shift.[5]

$$\mathbf{1a} \xrightarrow[H_2O/CH_3CN]{h\nu}$$



8

(1)

Scheme 3

$$\begin{tikzcd}
\mathbf{1a} \arrow[r, "h\nu"] \arrow[dr, "\text{Trip. Sens.}"'] & \mathbf{1a}^{1*} \arrow[r, "\text{ring opening}"] \arrow[d, "\text{ISC}"] & \mathbf{2a}^{1} \arrow[r, "ROH"] \arrow[ll, bend right, "\text{Ring closure}"'] & \mathbf{6} \\
 & \mathbf{1a}^{3*} \arrow[r] & \mathbf{2a}^{3} \arrow[r, "R\text{-}H"] \arrow[u, "\text{ISC}"'] & \mathbf{5a}
\end{tikzcd}$$

Direct irradiation of **1a** generates only singlet-like photoproducts (**6**) however it is interesting that triplet sensitization gives triplet (**5a**) as well as singlet products. The former occur from H-atom abstraction from the solvent. Triplet-sensitized irradiation generates **1a**^{3*} which undergoes ring opening to **2a**^{3}. Intermediate **2a**^{3} can partition between H-atom abstraction to give **5a** or intersystem cross (ISC) to **2a**^{1} which will give addition product **6e** (Scheme 3).[3a]

Triplet sensitization of **1a** in the presence of H_2O (0.1 M), gives **6e** and **5a** in a 3 to 1 ratio. A similar ratio of **6f** to **5a** is obtained at low concentrations of MeOH (0.1 M). At high concentrations of MeOH (4.0 M), **5a** is obtained exclusively in quantitative yields. Because methanol acts both as a H-atom donor and as a nucleophile it can serve as either a singlet or triplet trap whereas water can only serve as a singlet trap. Therefore, once generated, **2a**^{3} abstracts a H-atom from methanol to give **5a** more rapidly than intersystem crossing to **2a**^{1}. In the presence of H_2O, which is a poor H-atom donor, **2a**^{3} can intersystem cross and give **6e** (a singlet photoproduct) as the major product. From this result, it is apparent that the singlet state nitrenium ion can be formed from its triplet state. Reduction product is not observed under direct irradiation and it is a minor product when no H-atom donors are present. These results, as well as previous work, are consistent with the generalization that arylnitreniums ions are ground state singlets.[3, 4a]

Experimental Section

N-*tert*-butyl-2-acetyl-4-methyl quinone imine methyl ether (6f) 5-methyl-3-N-*tert*-butyl-2,1-benzisoxazolium tetrafluoroborate (**1a**) (202mg, 0.694 mmol) was dissolved in 20 mL of CH_3CN (freshly distilled from CaH_2). MeOH (5.0 mL, 0.12 mol) was added to the pyrex flask (50 mL). Flask was sealed with a septum and solution was purged with N_2 for 5-7 minutes. Irradiation with a Xenon lamp while stirring for 2 hrs followed by removal of solvent gave a brown solid. Recrystallization from ethyl acetate gave tan crystals.(An isolated yield of 64%, 104 mg, 0.44 mol). mp: 148-149 °C. ^1H NMR (CD_3CN) $\delta = 8.18$-8.19 (d,1H, *J*=2.3), 7.39-7.32 (dd, 1H *J*=10.4,2.3), 7.26-7.20 (d,1H, *J*=10.4), 3.20 (s,3H), 2.60 (s,3H), 1.61 (s, 9H), 1.47 (s, 3H); ^{13}C (CD_3CN) 203.6, 168.3, 160.2, 127.4, 120.9, 75.2, 60.7, 55.5, 29.6, 28.0, 24.9; MS (EI) *m/e* 235 (M^+, 33), 202 (19), 178 (51), 164 (100), 136 (16), 120 (19); MS *m/z* calcd (M+) 235.3254, obsd 235.1572; IR 3043 cm^{-1} (m), 2980 (m), 1679 (s), 1657 (m), 1612.

N-*tert*-butyl-2-acetyl-4-methyl quinol imine (6e) **1a** (0.0213 g, 0.07 mmol) was dissolved in 10 mL CH_3CN. Reaction vessel was sealed and mixture was purged with N_2. Irradiation with a medium pressure Hg lamp for 1 hr. gave the quinol imine **6e** as the major product. ^1H NMR (CD_3CN) $\delta = 8.15$-8.14 (d,1H, *J*=2.28), 7.37-7.30 (dd, 1H *J*=10.8, 2.3), 7.05-6.99 (d,1H, *J*=10.8), 2.58 (s,3H), 1.60 (s, 9H), 1.51 (s, 3H); ^{13}C (CD_3CN) 204.5, 168.0, 160.5, 117.6, 69.3, 60.9, 29.9, 29.0, 28.3, 26.7, 26.3; MS (EI) *m/e* 221 (M^+, 98), 188 (100), 150 (82), 134 (50), 105 (43), 77 (46), 56 (85); IR 3522 cm^{-1} (br), 3038 (s), 2285 (s), 2242 (s), 1432, 1370 (s), 915.

2-Acetyl-4-hydroxy-3-methyl-N-*tert*-butyl aniline (7e): Compound **6e** was refluxed overnight in trifluoroethanol (TFE) (5mL). Solvent was removed via high vacuum. Conversion was complete; the only product detected by NMR was **7e**. It was isolated as a red oil. ^1H NMR (CD_3CN) $\delta = 7.20$-7.16 (d, 1H, *J*=8.7), 7.10-7.06 (d, 1H *J*=8.7), 2.65 (s, 3H), 2.35 (s, 3H), 1.31 (s, 9H); ^{13}C (CD_3CN) 208.2, 158.018, 136.7, 126.8, 125.9, 120.8, 66.0, 33.5, 26.4, 15.1; MS (EI) *m/e* 235 (M^+, 29), 221 (58), 163 (100), 150 (74), 91 (19), 58 (80); MS *m/z* calcd (M+) 221.2986, obsd 221.1437; IR 3038cm^{-1}(b), 2248 (s), 1670 (w), 1590 (w), 1024 (s), 924.

2-Acetyl-4-methoxy-3-methyl-N-*tert*-butyl aniline (7f) Preparation of **7f** was identical to that of **7e** described above. Conversion was clean; the only product observed by NMR was **7f** mp 255-256 °C; ^{1}H NMR (CD_3CN) δ = 7.28-7.26 (d, 1H, *J*=8.9), 7.15-7.13 (d, 1H *J*=8.9), 3.89 (s,3H), 2.63 (s, 3H), 2.33 (s, 3H), 1.31 (s, 9H); ^{13}C (CD_3CN) 208.1, 159.6, 136.4, 132.2, 125.6, 122.6, 113.9, 64.7, 57.1, 33.5, 26.9, 15.0; MS (EI) *m/e* 235 (M^+, 19), 220 (18), 179 (21), 164 (100), 137 (7), 89 (16), 77 (13); MS *m/z* calcd (M+) 235.3254, obsd 235.1572; IR 3010 cm^{-1} (br), 1685 (m), 1600, (s) 1170, 1030.

Dimer (8) 1a (0.157g, 0.54 mmoles) was dissolved in CH_3CN (7.5 mL) and H_2O (4.7 M) in RBF. The flask was sealed with a septum, N_2 was bubbled through for 5-7 minutes. Reaction vessel was then irradiated for 60 minutes while stirring with a medium pressure Hg lamp. Reaction was quenched with saturated $NaHCO_3$ and extracted with diethylether. The organic fraction was dried with $MgSO_4$, solvent was concentrated in vacuo and residue was purifed on silica using radial chromatography. (Eluent was 20% EtOAc/Hexane) mp 170-172 °C ^{1}H NMR (CD_3CN) d = 12.1 (s, 1H), 7.07-7.04 (d, 1H, *J*=8.3), 6.97 (d, 1H, *J*=1.5), 6.93-6.89 (d, 1H, *J*=8.3), 6.54-6.49 (d, 1H, *J*=10.3), 6.08-6.03 (d, 1H, *J*=10.3), 3.35-3.24 (dd, 1H, *J*=6.9, 1.5), 2.45-2.41 (d ,1H, *J*=6.9), 2.38-2.35 (d ,1H, *J*=6.9), 2.28 (s ,3H), 2.14 (s ,3H), 1.40 (s ,9H), 1.38 (s, 3H), 1.23 (s, 9H), ^{13}C (CD_3CN) 194.4, 153.6, 146.5, 133.7, 130.6, 123.7, 114.6, 118.9, 110.0, 98.7, 82.3, 61.9, 52.4, 45.3, 45.2, 31.5, 27.1, 26.5, 20.6, 1.9, 1.6; MS (EI) *m/e* 424 (M^+, 50), 408 (9), 381 (33), 293 (17), 190 (49), 178 (54), 163 (100), 148 (42), 134 (72), 106 (32); MS *m/z* calcd (M+) 424.2728, obsd 424.2726; IR 3422 cm^{-1}(b), 2975 (s), 1651 (m), 1571 (s), 1196, 754.

Triplet sensitization Triplet sensitization experiments were performed on 0.004 M - 0.006 M solutions of **1a** containing thioxanthen-9-one (5.7 - 7.5 mmole) as triplet sensitizer. (E_t = 65 kcal/mole, τ = 95 μs) solution and head volume were thoroughly purged with N_2.[7] The reaction mixture was then irradiated for 20-30 minutes with a medium pressure Hg Lamp through a 385-nm cut off filter.

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