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Reactions of Nitrenium Ions with Arenes: Laser Flash Photoylsis Detection of a σ-Complex between *N*,*N*-Diphenylnitrenium Ion and Alkoxybenzenes

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Nitrenium ions are a family of electrophilic reactive intermediates that are defined by a divalent nitrogen having a formal positive charge ($RR'N^+$).[1−3] Typical members of this family are highly reactive and have solution lifetimes rarely exceeding 1 ms. Interest in the possible roles of nitrenium ions in carcinogenic DNA-damaging reactions,[4−6] the synthesis of conducting poly(aniline) derivatives,[7,8] and the development of methods for the synthesis of complex molecules[9] have motivated much recent work. All of these processes are thought to involve the addition of the nitrenium ion to an aromatic ring. Despite the wide interest, a general picture of nitrenium ion/arene reactions has yet to emerge.

One unresolved issue concerns the importance of various intermediates on the pathway to the products. Most electrophilic substitution reactions are considered to involve π and/or σ complexes between the electrophile and the arene.[10,11] The only systematic examinations of this question relative to the nitrenium ions are studies by McClelland,[12] Novak,[13] and Guengerich[14] on the addition of arylnitrenium ions to guanosine nucleosides. All of these researchers agree that some intermediate is formed, but they differ on its structure and/or the pathway leading to the final products. One reason for this controversy is that the guanine itself is a fairly complex nucleophile having at least 6 possible sites for electrophilic attack.[15]

N,N-Diphenylnitrenium ion (**Ph$_2$N$^+$**) is an attractive candidate for further examination of these reactions as it has been extensively characterized by theoretical calculations,[16] time-resolved IR,[17] and UV−vis spectroscopy.[18,19] Many of its decay reactions are well-known and it can be generated cleanly in a variety of solvents from the photolysis of 1-(*N,N*-diphenylamino)-2,4,6-triphenylpydinium ions (**2**).[20] Described herein are laser flash photolysis (LFP) studies which show that **Ph$_2$N$^+$** reacts rapidly with both 1,3,5-trimethoxybenzene (**TMB**) and 1,3-dimethoxybenzene (**DMB**). An intermediate is detected in these reactions, which is attributed to the corresponding σ-adducts. A product analysis shows that **Ph$_2$N$^+$** is trapped by these arenes to give the predicted adducts.

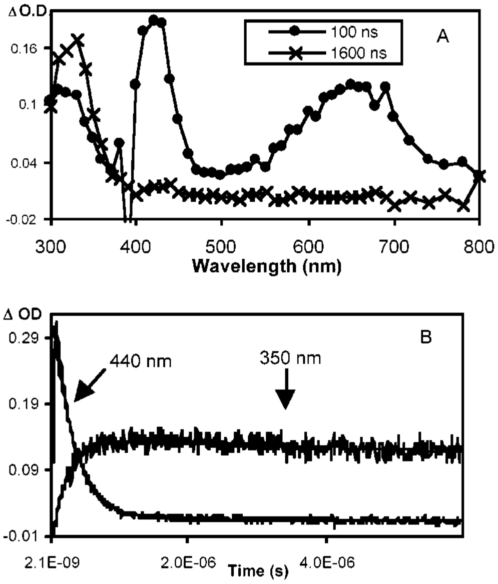

Figure 1. Panel A: Transient absorption spectra from laser flash photolysis (390 nm, 8−10 mJ/pulse, 4−6 ns) of **Ph$_2$N$^+$** precursor **2** in the presence of 24 mM **DMB** in N$_2$-purged CH$_3$CN taken 100 ns (circle) and 1.6 μs (cross) following the laser pulse. Panel B: Kinetic traces taken at 350 and 440 nm from a LFP experiment (355 nm, 10−12 mJ, 4−6 ns) where **2** was irradiated in the presence of 7.6 mM **DMB**

The two arenes employed in this study efficiently trap **Ph$_2$N$^+$**. Compound **2** was photolyzed in the presence of 87 mM **TMB** (CH$_3$CN solvent N$_2$-purged) and the products were isolated by silica gel chromatography, characterized by the usual spectroscopic methods, and quantified by GC analysis. Three isomers were characterized. The most abundant (44%) was an adduct joining a *para* carbon on **Ph$_2$N$^+$** to an unsubstituted carbon on **TMB** (**7**). Also formed were adducts joining the nitrenium ion center (**11**, 30%) and an *ortho* carbon (**9**, 24%). **DMB** also traps **Ph$_2$N$^+$** to produce adducts. In this case the major products are the *ortho* adduct (**10**, 39%), the *para* adduct (**8**, 34%), and the parent amine (**Ph$_2$NH** 36%). A GC/MS analysis also shows trace amounts of a third isomer, which we tentatively identify as the *N*-adduct (*m/z* 305).

Both arenes show high rate constants (k_{trap}) for reaction with **Ph$_2$N$^+$** with **TMB** being more reactive than **DMB.** LFP (355 or 390 nm, 8−10 mJ/pulse, 4−6 ns) was used to generate **Ph$_2$N$^+$** and its pseudo-first-order decay rate constant k_{obs} was measured with varying concentrations of either **TMB** or **DMB** (N$_2$-purged, CH$_3$CN solutions). Rate constants (k_{trap}) of 3.1×10^9 (**TMB)** and 3.4×10^8 M^{-1} s^{-1} (**DMB**) were determined in this manner.

These trapping reactions result in the formation of a longer lived intermediate following the decay of **Ph$_2$N$^+$**. Figure 1A shows the transient absorption spectra that result from pulsed laser excitation of **2** in the presence of 24 mM **DMB**. The same

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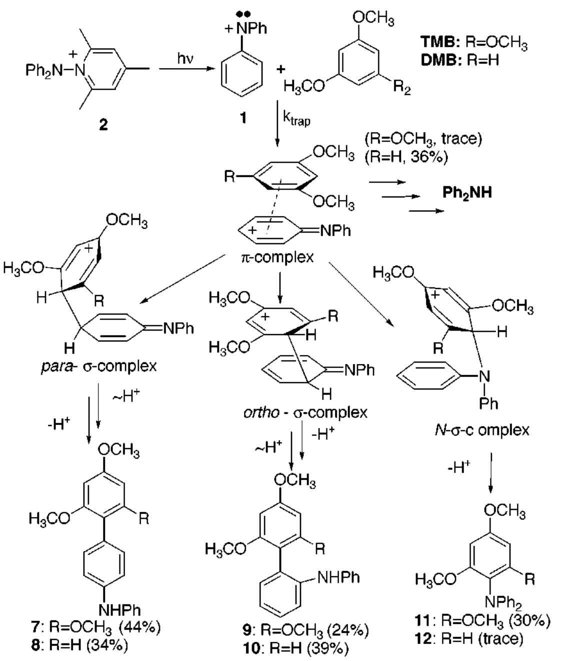
Scheme 1



experiment with **TMB** (10 mM) gives nearly identical spectra. In both cases the characteristic spectrum of **Ph$_2$N$^+$** ($\lambda_{max} = 420$, 660 nm) is observed immediately following the excitation pulse. Upon decay of this species a new absorption band grows in with $\lambda_{max} = 330$ nm , $\tau = 125$ μs (**TMB**) or $\lambda_{max} = 330$ nm, $\tau = 30$ μs (**DMB**).

The long-lived species are assigned to the σ-adducts shown in Scheme 1 on the basis of the following observations:

1. All of the stable products in the case of **TMB** and the majority of the stable products in the case of **DMB** are consistent with the formation of the σ-complexes.

2. The growth of the new species corresponds to the decay of **Ph$_2$N$^+$** (Figure 1B). The growth rates for the long-lived species were monitored at 350 nm and a similar pseudo-first-order analysis provides second-order rate constants (k_{gro}) in reasonable agreement with those measured from the decay of the nitrenium ion (**TMB**: $k_{gro} = 3.1 \times 10^9$ M^{-1} s^{-1}; **DMB**: $k_{gro} = 3.5 \times 10^8$ M^{-1} s^{-1}).[21] No growth was observed in the absence of trap. Thus, it is reasonable to conclude that the long-lived species forms as a result of **Ph$_2$N$^+$** reacting with the traps.

3. The new species absorbs in a region of the spectrum typical for σ-complexes. Steenken and McClelland[22,23] as well as other groups[11] have characterized several related σ-complexes where either a proton or a carbocation is bonded to **TMB** or **DMB**. These complexes absorb in the range of 315−345 nm. The σ-complexes leading to **7**−**12** have a similar benzenium ion chromophore, which should absorb near these wavelengths. Perfect agreement is not expected. The observed bands are also influenced by the nitrenium ion residue as well as depletion of the starting material, which also absorbs in this region.

4. They are quenched when a nonnucleophilic base (2,4,6,-trimethylpyridine, **TMP**) is added to the solution. LFP experiments provide quenching rate constants of 4×10^6 M^{-1} s^{-1}for the **TMB** adducts and 5.4×10^7 M^{-1} s^{-1} for the **DMB** adducts.[24] As shown in Scheme 1, the proposed σ-complexes must suffer a deprotonation to form the stable products. Isotope exchange experiments by Kresge et al.[25] also indicate that σ-complexes derived from **DMB** are more kinetically acidic than those derived from **TMB**. Thus reaction with base is consistent with the assignment of this intermediate to the σ-complex.

5. The π-complex is excluded. This intermediate might also be expected to react with **TMP** via a nucleophilic attack on the nitrenium ion, displacing the arene. However, reaction with the complex would occur more slowly than addition to a free **Ph$_2$N$^+$**. The rate constant for addition of **TMP** to free **Ph$_2$N$^+$** was measured by LFP and found to occur more slowly (2.0×10^7 M^{-1} s^{-1}) than the reaction of **TMP** with the **DMB** complex. Therefore, we favor assignment of the observed signal to the σ-complex.

6. Intermediates from a simple electron-transfer reaction are excluded. The trap cation radicals are known to have absorptions in the high-wavelength visible region of the spectrum (**TMB**: $\lambda_{max} = 613$ and 645 nm; **DMB**: $\lambda_{max} = 477$ and 505 nm).[26] No new long-lived peaks are observed in this region.

These experiments have resulted in the first direct characterization of a σ-complex in the reaction between an arylnitrenium ion and a simple arene (i.e., other than guanosine).[12] While **TMB** traps the nitrenium ion in nearly quantitative yield, **DMB** trapping produces substantial yields of the parent amine, **Ph$_2$NH**. The reason for this striking difference in product distributions is not entirely clear. A simple electron-transfer pathway in the case of **DMB** can be ruled out. First, the radical ions that would result from such a reaction are not observed in the LFP experiment. Second, both traps have nearly the same oxidation potential (1.49 V vs SCE).[27] Inasmuch as the parent amine appears to be formed at the expense of the *N*-adduct, it is tempting to suggest that both products can originate from a common intermediate, possibly the *N*-σ adduct. Additional investigations, aimed at resolving this issue, are currently underway.

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[21] The signal at 350 nm was fit to a first-order growth and decay model. While the slopes of the pseudo-first-order plots show excellent agreement with the decays at 440 nm, the intercept for the 350 nm plots was consistently higher by ca. 25%. The source of this quantitative discrepancy is not clear at this time. However, two causes are probable: (a) systematic distortions of the 350 nm growths by the time characteristics of the laser pulse and scattered excitation light and (b) the more complex kinetic equations used to fit the 350 nm data.

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