Regioselectivity of Hydride Transfer to and between NAD^+ Analogues[1a]

R. M. G. Roberts,*[1b] D. Ostović, and M. M. Kreevoy*

Chemical Dynamics Laboratory, Department of Chemistry, University of Minnesota, Minneapolis, Minnesota 55455

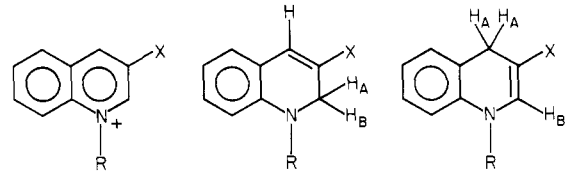
Received November 15, 1982

The reaction of 1-methyl- or 1-benzylquinolinium compounds, also bearing an electron-withdrawing substituent in the 3-position, with $NaBH_4$, gives mixtures of the corresponding 1,2-dihydroquinolines and 1,4-dihydroquinolines in which the 1,2-dihydro derivatives usually predominate. The 1,2-derivatives can be isolated. The 1,2-isomers react with the quinolinium salts, giving the 1,4-isomers and regenerating quinolinium salts. This bimolecular isomerization can be used to convert a mixture of isomers to the 1,4-isomer on a preparative scale. 3-Cyano-1,2-dihydro-1-methylquinoline also isomerizes to the 1,2-isomer in the crystalline solid. The major first product of $NaBH_4$ reduction of 3-(aminocarbonyl)-1-benzylpyridinium ion is the 1,6-dihydro derivative. This also isomerizes to the 1,4-dihydro compound in the presence of the pyridinium ion. Reduction of quinolinium derivatives with $Na_2S_2O_4$ or a dihydropyridine directly produces the 1,4-isomer predominantly. Reduction of 3-(aminocarbonyl)-1-benzylpyridinium ion with $Na_2S_2O_4$ in D_2O gives the 1,4-dihydro derivative, but 8% of the deuterium is in the 2-position; presumably by reversible isomerization. This deuterium redistribution may have important consequences for the interpretation of isotope effects.

The biochemically important oxidizing agent, nicotinamide adenine dinucleotide, NAD^+, is a 3-(aminocarbonyl)pyridinium ion. This has generated a great deal of interest in the chemistry of these and related substances.[2] The reduction, in nature, gives a 1,4-dihydropyridine, and it is of interest to know if this is the most stable of the three isomeric reduction products, the generality of the thermodynamic preference, and the results of various chemical reductions. Effective synthetic procedures for particular isomers are also needed. A good deal of such information is already available.[3-7] In the present paper we describe, primarily, the reduction of certain quinolinium ions. We also describe a bimolecular reaction between a dihydropyridine or a dihydroquinoline and a quinolinium ion and some consequences of the analogous reaction of pyridine derivatives. Synthetic procedures are given for either the 1,4- or the 1,2-dihydroquinolines. An interesting isomerization that appears to take place in the crystalline state is also noted.

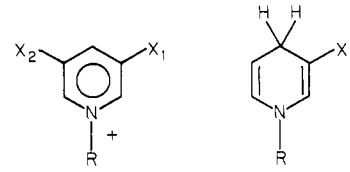
Results

Reduction Products. Reduction of quinolinium ions (1) with $NaBH_4$ in water or a water–methanol mixture generally gives mixtures of substituted 1,2- (2) and 1,4-dihydroquinolines (3) in which the 1,2-isomers predominate. The relative amounts of the isomers present in the initial product mixture were determined from its ^1H NMR spectrum, as described in the Experimental Section. Sometimes no 1,4-isomer at all could be detected. Smaller numbers of reductions were also carried out with 3-(aminocarbonyl)-1-benzyl-1,4-dihydropyridine (5) and sodium dithionite as reducing agents. As previously observed in related systems,[3,8] these reductions gave predominantly



1 2 3

a, R = CH_3; X = CN
b, R = CH_3; X = $CONH_2$
c, R = CH_3; X = Br
d, R = $CH_2C_6H_5$; X = CN
e, R = $CH_2C_6H_5$; X = $CONH_2$



4 5

a, R = CH_3; X_1 = Cl; X_2 = Cl
b, R = $CH_2C_6H_5$; X_1 = $CONH_2$; X_2 = H

R = $CH_2C_6H_5$; X = $CONH_2$

1,4-dihydroquinolines. The proportions of the two isomers, along with the reduction products of **4a** and **4b** are given in Table I.

The structures of the isomers were assigned from their spectroscopic properties. The methylene groups in compounds **2** should give ^1H NMR bands downfield from those in compounds **3**, because of the adjacent nitrogen in the former. In contrast, the methyl resonances in compounds **2a–c** should be upfield from those in compounds **3a–c** because the former has a CH_2 group adjacent to nitrogen while the latter has an olefinic double bond in this position. Consistent with this assignment, coupling constants, J_{24}, of ~1 Hz, were observed for compounds **2**, but those for compounds **3** were less than 0.5 Hz and were generally not observed.[4,9] The various coupling constants and chemical shifts are given in Table II. Also, in the initial (mixed) products of reduction with $NaBH_4$ and in the purified compounds to which structures **2** were assigned, there is an electronic absorption with λ_{max} ~420 nm and ϵ_{max} ~10^3. The corresponding band appears at ~360 nm in compounds to which structures **3** were assigned. Long-wave-

(1) (a) This work was supported by the National Science Foundation through Grant CHE79-25990 to the University of Minnesota. (b) Department of Chemistry, University of Essex, Colchester, England, U.K.

(2) Klinman, J. P. *Crit. Rev. Biochem.* **1981**, *10*, 39.

(3) Karrer, P.; Schwartzenbach, G.; Benz, F.; Solmssen, U. *Helv. Chim. Acta* **1936**, *19*, 811.

(4) Diekmann, H.; Engbert, G.; Wallenfels, K. *Tetrahedron* **1964**, *20*, 281.

(5) Chaykin, S.; King, L.; Watson, J. G. *Biochim. Biophys. Acta* **1966**, *124*, 13.

(6) Van Bergen, T. J.; Mulder, T.; van der Veen, R. A.; Kellogg, R. M. *Tetrahedron* **1978**, *34*, 2377.

(7) A great deal of additional information on these topics is also available in literature on related topics, much of which can be located through ref 2–6.

(8) Shinkai, S.; Hamada, H.; Kusano, Y.; Manabe, O. *J. Chem. Soc., Perkin Trans. 2* **1979**, 699.

(9) Bramley, R.; Johnson, M. D. *J. Chem. Soc.* **1965**, 1372.

0022-3263/83/1948-2053$01.50/0

Table I. Product Distribution in Reduction of Quinolinium and Pyridinium Compounds

compound reduced	reducing agent	1,4-dihydro product,[a] %
1a	$NaBH_4$	27
1b	$NaBH_4$	33
1c	$NaBH_4$	<5[b]
1d	$NaBH_4$	45
1e	$NaBH_4$	57[c]
4a	$NaBH_4$	31
4b	$NaBH_4$	40[d]
1a	5	>95[e,f]
1c	5	83
4a	5	>95[e]
1c	$Na_2S_2O_4$	92
4b	$Na_2S_2O_4$	>95[e]

[a] For the variants of 1 the remaining product was the 1,2-isomer. [b] Not detected. [c] There appears to be a base-catalyzed isomerization giving the 1,4-isomer. [d] The other product is predominantly the 1,6-isomer. [e] No other product was detected. [f] The result was the same when the mixture of isomers produced by $NaBH_4$ reduction of 4b was used as the reducing agent.

Table II. NMR Parameters of Dihydroquinoline and Pyridine Derivatives

compd	δ CH_3 or CH_2 (C_6H_5)	δ CH_2[a]	J_{24}, Hz
2a	2.73	4.03	1.2
3a	3.16	3.07	b
2b	2.77	4.19	0.8
3b	3.18	3.77	0.4
2c	2.76	4.21	1.6
3c	3.05	3.93	b
2d	4.38	4.17	1.4
3d	4.71	3.77	b
2e	~4.4[c]	~4.4[c]	1.4
3e	4.78	3.83	b
reduced 4a[d]	2.65	3.91	b
reduced 4a[e]	2.83	3.38	b
reduced 4b[f]	4.19	3.97	3.5[g] (1.7[h])
5	4.27	3.17	3.2[i] (1.7[j])

[a] Endocyclic methylene group. [b] Not observed. [c] These peaks overlap and exact δ values could not be obtained. [d] 3,5-Dichloro-1,2-dihydro-1-methylpyridine. [e] 3,5-Dichloro-1,4-dihydro-1-methylpyridine. [f] 3-(Aminocarb onyl)-1,6-dihydro-1-methylpyridine. [g] J_{56}. [h] Either J_{46} or J_{26}. [i] J_{45}. [j] J_{24} or J_{46}.

length bands have been previously reported for 1,6- and 1,2-dihydro derivatives of pyridinium salts.[10,11]

Unexpectedly, the principal product of the reduction of **4b** by $NaBH_4$ appears to be 3-(aminocarbonyl)-1-benzyl-1,6-dihydropyridine (60%). This material was not isolated but was identified by the strong coupling of the downfield methylene hydrogens to another proton (J = 3.5 Hz) along with an electronic absorption ~420 nm.

Reduction of **4b** with dithionite in aqueous carbonate gives principally **5**.[12] However, when the analogous reaction is carried out in D_2O and the chemically pure product examined by ^2H NMR, 8% of the D is found in the 2-position. This probably results from bimolecular isomerization and reisomerization, taking place during the rather prolonged reaction period. Base-catalyzed isomerization may also be involved.

Small-Scale Preparations. The reduction with $NaBH_4$ can be used as a preparative method for 1,2-dihydroquinolines. As an example, **2a** was prepared from the corresponding quinolinium bromide in 50% yield. The pure product was isolated from the initial product mixture by recrystallization. On the other hand the 1,4-dihydro isomers could be prepared by equilibrating the first-formed product mixture from the $NaBH_4$ reduction with a fresh portion of the oxidized form. For example, **3d** was prepared in this way, in 80% yield. This isomerization is a bimolecular reaction involving hydride transfer, with rate constants of $\sim 10^{-2}$ M^{-1} s^{-1}, so that a concentration of oxidizing agent above $\sim 10^{-2}$ M is needed to give practically useful isomerization rates. The reduction of quinolinium salts by **5** is another example of this same family of reactions and also gives the 1,4-dihydro isomers as the major products. As previously reported,[8] this reaction can serve as a preparative method for the 1,4-dihydro isomers. The mixed product from the $NaBH_4$ reduction of **4b** can also be used for this purpose. These reactions are faster than the isomerization **2** → **3** because they are strongly spontaneous.[13]

Solid-State Isomerization. Solid samples of **2a** isomerize to **3a**. The conversion is shown by changes in the IR, ^1H NMR, and electronic spectra. Is is more than 90% complete on standing overnight at room temperature. Among the compounds we have examined, this is the only one in which this transformation has been observed in the solid state. By contrast, **2d** appears to be stable indefinitely in the crystalline state. The X-ray diffraction pattern of solid **2a** was obtained and definitely established its crystalline character. The diffraction pattern was consistent with the assigned structure, although it was not sufficiently refined to establish that structure.[14,15]

Isomerization in Solution. When **2a** and **1a** are dissolved together in a 1:4 2-propanol–water mixture, bimolecular isomerization to **3a** takes place, as judged by the loss of ~95% of the intensity from the 420-nm band in the electronic spectrum. An equilibrium constant of ~20 and a rate constant of $\sim 5 \times 10^{-2}$ M^{-1} s^{-1} could be estimated. The reaction of **2d** with **1d** proceeds similarly, as does the reaction of **4b** with **5**, which has a rate constant $\sim 2.5 \times 10^{-2}$ M^{-1} s^{-1}. A rate constant of $\sim 1.5 \times 10^{-2}$ M^{-1} s^{-1} can be estimated for the reaction of NAD^+ with the products of its reduction by $NaBH_4$ from spectral changes with time shown by Werner, Huang, and Aminoff.[11] Equilibrium constants were not estimated for the pyridine derivatives, but it is clear that the 1,4-isomers are more stable. Equilibrium constants between 10 and 20 would be consistent with the observed rate constants.[13]

For **1e** there is also an isomerization that appears to be base catalyzed, which converts the first-formed product to the 1,4-isomer on standing for 75 min in contact with the solution in which the $NaBH_4$ reduction was carried out. This solution had a pH ~9.3. Such isomerizations were not observed for the other compounds we studied, but they are not excluded.

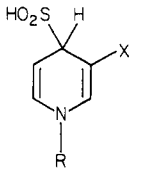
Discussion

In the examples we have studied the isomerization **2** → **3** is clearly spontaneous, with equilibrium constants of >10. The results appears to be general for quinolinium ions with electron-withdrawing substituents in the 3-position. It

(10) Wallenfels, K.; Schully, H.; Hofmann, D. *Justus Liebigs Ann. Chem.* **1959**, *621*, 106.
(11) Werner, D. A.; Huang, C. C.; Aminoff, D. *Anal. Biochem.* **1973**, *54*, 554.
(12) Sutter-Kostic, K.; Karrer, P. *Helv. Chim. Acta* **1956**, *39*, 677.
(13) Roberts, R. M. B.; Ostović, D.; Kreevoy, M. M. *Faraday Discuss. Chem. Soc.*, in press.
(14) We are indebted to Prof. J. Z. Gougoutas of the University of Minnesota for the crystallographic work.
(15) Mauzerall, D.; Westheimer, F. H. *J. Am. Chem. Soc.* **1955**, *77*, 2261.

should be noted, however, that 3,5-disubstituted pyridinium ions give a quite different result.[6] The first-formed products of reduction with **5** appear to reflect the thermodynamic preference. The reaction of 4b with dihydroquinolines is thermodynamically quite unfavorable,[13] so that the observed products cannot be the result of multiple transfers in both directions. Other evidence indicates that this reaction is a one-step hydride transfer and that the transition state for such reactions partially reflect the stability of the products.[13] On the other hand the reductions with BH_4^- generally give product mixtures in which an *unstable* isomer predominates, although this reaction also appears to be a one-step hydride transfer. Reaction with BH_4^-, however, is much faster than that with the dihydropyridine, so that the regionality may be established at a transition state that resembles the products only very weakly. Since BH_4^-, and also its likely cascade products, BH_3OH^-, etc., are negatively charged while the oxidizing agents are positively charged at the pyridinium or quinolinium nitrogen, 1,2-addition of hydride would be favored by coulombic forces that would be entirely absent in the products. Reduction of 1-methylquinolinium iodide by $LiAlH_4$ gives principally 1,2-dihydro-1-methylquinoline,[12] as this logic suggests it should.

The mechanism of reduction by dithionite is different and appears to involve **6** as an intermediate.[16] If the



6

product were formed in an intramolecular reaction of **6**,[10] its regionality would be determined by that of the C–S bond, which appears to show the thermodynamic preference for the 4-position. It would be harder to understand the regioselectivity if the product were formed by hydride transfer from HSO_2^- to the pyridinium ion.[16]

The results of the reduction with $S_2O_4^{2-}$ in D_2O are mainly important because they show that the isomerization is at work even when only one product is observed. This reaction has been used to make deuterated 3-(aminocarbonyl)-1-aryl-1,4-dihydropyridines.[17] It has been supposed that these materials had one deuterium in the 4-position and none elsewhere and retained that regionality while reacting with the methyl acridinium ion.[17] It now seems most unlikely that such was really the case. Since this assumption underlies the conclusion that the hydride transfer has a multistep mechanism, the conclusion must be considered unproven.[18] A one-step mechanism is indicated by relative reactivity studies.[13]

The spontaneous isomerization of **2a** joins a rather small number of examples of crystalline solids that undergo chemical transformation under mild conditions without melting or exposure to high-energy radiation. This behavior clearly depends on the specifics of the crystal structure of **2a**; crystalline **2d** does not behave similarly, though it readily isomerizes in solution in the presence of **1d**. We speculate that the crystal isomerization is initiated by a small amount of **1a**, either present as a contaminant originally or generated by air oxidation at the surface of the crystal.

(16) Blankenhorn, G.; Morre, E. G. *J. Am. Chem. Soc.* **1980**, *102*, 1092.
(17) Ohno, A.; Shio, T.; Yamamoto, H.; Oka, S. *J. Am. Chem. Soc.* **1981**, *103*, 2045.
(18) Powell, M. F.; Buice, T. C. *J. Am. Chem. Soc.* **1982**, *104*, 5834.

Experimental Section

$NaBH_4$ was purchased from Baker Chemical Co., originally specified 98% active. This material is extremely hygroscopic, ultimately forming a solid dihydrate. The real $NaBH_4$ content of reaction mixtures must be considered somewhat lower than their nominal content, in spite of the usual precautions to avoid contact with moisture. In our hands analysis of this material has generally shown 90–95% activity. $Na_2S_2O_4$ was purchased from Matheson Coleman and Bell and was of practical grade.[19] No better grade of this material is available. It is generally contaminated with a variety of partially oxidized materials. Its real concentration in reaction mixtures must, therefore, also be considered somewhat lower than its nominal concentration.

Rate and equilibrium constants were measured by standard spectrophotometric techniques,[13] using the visible part of the electronic spectrum.

IR spectra were obtained with a Perkin-Elmer Model 297 infrared spectrophotometer, periodically calibrated with a thin film of polystyrene. Electronic spectra were obtained with a Cary Model 17DX spectrophotometer. ^1H NMR spectra were made with a Varian Model CFT80 spectrophotometer.

Compound **5** was prepared by reduction of **4b** with $Na_2S_2O_4$, by the method of Mauzerall and Westheimer:[15] mp 120 °C (lit.[5] mp 120–122 °C). It had the expected spectroscopic properties. It was stored at 0 °C under an atmosphere of N_2.

The 1-methylquinolinium iodides were prepared by dissolving the appropriate quinoline (purchased from Aldrich Chemical Co.) in a minimum quantity acetone (ACS grade[19]), filtering the solution to remove small amounts of undissolved impurities, and then adding a 2–3-fold molar excess of methyl iodide. Typically about 25 mL of acetone was required per gram of quinoline. The reaction mixture was allowed to stand at room temperature 14–40 h. The crystalline product was deposited as it formed and collected by filtration. This method was also used to prepare **4a**. Yields ranged from 45% to 90%, generally improving with the length of the reaction period. No particular effort was made to optimize them. Compounds **1a–c** and **4a** had melting points of 250, 280, 294, and 295 °C, respectively. These salts melt with decomposition, so that their melting points depend on the rate of heating, and are, thus, not very useful for characterization.

Benzylquinolinium bromides were prepared by refluxing the quinoline with a 10% molar excess of benzyl bromide in absolute ethanol (~10 mL of ethanol per gram of quinoline) for 4–6 h. Ethanol was removed under vacuum at ~30 °C until crystals appeared. Then the solution was chilled to induce precipitation of most of the rest of the product. Alternatively, the quinoline and a 10% molar excess of benzyl bromide were heated at 130 °C until crystals appear (15–20 min). In either case the product was recrystallized from ethanol. The first of these methods was also used to prepare **4b**, which is a well-known compound.[15] Compound **1e** is also previously known.[8] Compounds **1d**, **1e**, and **4b** had melting points of 185, 223, and 187 °C, respectively.

^1H NMR spectra of these compounds were obtained in solution in perdeuteriodimethyl sulfoxide, and IR spectra were obtained from KBr pellets. All had the expected characteristics. The important characteristics of the NMR spectra are given in Table II.

Compound **2a** was prepared from 0.5 g (1.7 mmol) of **1a** dissolved in a minimum volume of a 3:2 mixture of H_2O–methanol. The solution was cooled to 10 °C, and a freshly made solution of $NaBH_4$ (0.064 g, 1.7 mmol) in 5 mL of water was added dropwise with stirring under N_2. A flocculant yellow precipitate appeared immediately. The mixture was stirred for 1 h under N_2. Then the precipitate (presumably a mixture of **2a** and **3a**) was filtered off and air-dried. It weighed 0.24 g (1.4 mmol, 85% yield). Recrystallization from ethanol–water gave bright yellow crystals; mp 55 °C. It was not possible to obtain an elemental analysis of this compound before it isomerized.

The IR spectrum of **2a**, obtained from a melted film, showed peaks at 2200, 2185, and 1650 cm^{-1} in addition to the expected absorptions in the neighborhood of 3000 cm^{-1} and in the fingerprint region. The 2185-cm^{-1} band may belong to the 1,4-isomer,

(19) "Reagent Chemicals"; American Chemical Society: Washington, D.C., 1974.

present as a contaminant. The essentials of the ^1H NMR spectrum taken in $DCCl_3$ are given in Table II. The electronic spectrum, obtained in 4:1 2-propanol–water, contains bands with maxima (extinction coefficients in parentheses) at 416 nm (2.8×10^3), 295 nm (5.6×10^3), and 248 nm (2.6×10^4). There were also inflections at 355 and 339 nm.

On 14 h of standing at room temperature, crystalline **2a** became sticky. After recrystallization from a methanol–water mixture this material melted at 90 °C and had spectroscopic properties indistinguishable from those of **3a**, described below.

3a was prepared from 0.5 g (1.6 mmol) of **1a** mixed with 20 mL of methanol, in which it is not soluble. With vigorous stirring, 0.4 g (1.9 mmol) of **5** or the mixed reaction produce of **4b** with $NaBH_4$ was added. After 5 min at room temperature no undissolved **1a** remained. The solution was allowed to stand for a further 10 min and then poured into 100 mL of distilled water cooled in an ice bath. Pale yellow crystals separated from solution and were filtered off, washed with more water, and air-dried. The yield was 0.23 g (1.35 mmol, 77%); mp 91–92 °C.

The IR spectrum of **3a** (a thin film of melt) included bands at 2185 and 1645 cm^{-1} in addition to the expected absorptions around 3000 cm^{-1} and in the fingerprint region. The fingerprint region was substantially different from that of **2a**. The electronic spectrum showed maxima at 334 nm (1.2×10^4), 241 nm (8.8×10^3), and 233 nm (1.1×10^4) in 4:1 2-propanol–water. The NMR spectrum of the nonaromatic protons is described in Table II.

3d was prepared by equilibrating a mixture of **2d** and **3d** with **1d**. The mixture was prepared by reducing 1.0 g (3.0 mmol) of **1d** with $NaBH_4$ as described above for **1a**. The mixed reduction product and 0.1 g (0.3 mol) of **1d** were dissolved in a minimum volume of ethanol (~50 mL) and allowed to stand at room temperature for 14 h. The alcohol was then removed under vacuum and the product taken up in CH_2Cl_2. Most of the **1d** was left behind as an insoluble solid. The CH_2Cl_2 was washed with water, the CH_2Cl_2 was removed under vacuum, and the product, **3d**, was purified by recrystallization from an ethanol–water mixture. The yield was 0.56 g (2.3 mmol, 75%); mp 133 °C. The ^1H NMR spectrum, reported in Table II, confirmed its structure.

Compounds **1a–d**, **4a**, **3a**, and **3d** all gave satisfactory elemental analyses for C, H, and N, none differing from the calculated value by more than 0.25%.

The reduction of **4b** with $Na_2S_2O_4$ in D_2O and isolation of the deuterated product was carried out as previously described. The ^2H NMR spectrum was obtained in $DCCl_3$, with a Nicolet NT-300 NMR spectrophotometer operating at 46 MHz and by using 5000 transients and an acquisition time of 0.64 s. Bands were observed at ~3.7 and ~7.7 ppm; positions previously associated with the CH_2 group in the 4-position and the vinylic proton of **5**. Exact band positions were not obtained because no standard was included. No other absorptions were observed. The band at 7.7 ppm had ~8% of the total absorption while that at 3.7 ppm had ~92%.

Other $NaBH_4$ reductions were carried out as described above for **1a**, except that pure water was sometimes used in place of the water–methanol mixture as solvent and slurries of the less soluble quinolinium salts were reduced in place of solutions. Generally the products were not isolated. They were separated from the reaction mixture in which they were produced (10 mL of aqueous or aqueous alcohol solution) by extraction into 1–2 mL of $CDCl_3$. The $CDCl_3$ layer was washed with two 10-mL portions of water, dried, and the H NMR spectrum obtained. The product composition was deduced from the relative intensities of the methyl bands (of methyl derivatives) or the benzylic methylene bands (of benzyl derivatives).

Registry No. **1a**, 46176-64-1; **1b**, 84811-85-8; **1c**, 21979-27-1; **1d**, 85289-84-5; **1e**, 47072-02-6; **2a**, 50741-33-8; **2b**, 85749-92-4; **2c**, 85749-93-5; **2d**, 85749-95-7; **2e**, 85749-96-8; **3a**, 72594-76-4; **3b**, 20224-92-4; **3c**, 85749-94-6; **3d**, 73184-18-6; **3e**, 17260-79-6; **4a**, 49865-82-9; **4b**, 16183-83-8; **5**, 952-92-1; NAD^+, 53-84-9; 3-(aminocarbonyl)-1-benzyl-1,6-dihydropyridine, 2288-38-2; $NaBH_4$, 16940-66-2; $Na_2S_2O_4$, 7775-14-6; 3,5-dichloro-1,2-dihydro-1-methylpyridine, 85749-97-9; 3,5-dichloro-1,4-dihydro-1-methylpyridine, 85749-98-0; 3-(aminocarbonyl)-1,6-dihydro-1-methylpyridine, 23338-78-5.

Photolysis of *p*-Toluenesulfonyl Azide and Its Charge-Transfer Complex with Aniline

C. E. Hoyle,† R. S. Lenox,* P. A. Christie, and R. A. Shoemaker

Armstrong World Industries, Lancaster, Pennsylvania 17604

Received September 3, 1982

Photolysis of *p*-toluenesulfonyl azide (1) in *p*-xylene and cyclohexane gives primarily the products derived from insertion of (*p*-tolylsulfonyl)nitrene into the solvent. For *p*-xylene, an unstable intermediate product is formed which decomposes in the dark at room temperature to give both the ring-insertion product and the corresponding *p*-toluenesulfonamide (2). Photolysis of the ground-state charge-transfer complex between *p*-toluenesulfonyl azide and aniline gives six products, the major product being the sulfonyl hydrazide 7. Futhermore, formation of the insertion product by reaction with the solvent provides evidence for production of (*p*-tolylsulfonyl)nitrene from the excited charge-transfer complex.

Since the pioneering work of Curtius,[1-3] a large number of papers, summarized in several recent reviews,[4-6] have dealt with the decomposition of arenesulfonyl azides. While most of the reports on sulfonyl azides have been concerned with their thermal decomposition in organic solvents,[7-10] a few have included results of photolysis experiments.[11-17] In general, it has been found that photolysis of arenesulfonyl azides in alcohol solvents yields the corresponding sulfonamide. Thus, Reagan and Nickon[14] found that photolysis of arenesulfonyl azides in either

† Present address: Department of Polymer Science, The University of Southern Mississippi, Hattiesburg, MS 39406.

(1) Curtius, T. *J. Prakt. Chem.* **1930**, *125*, 303.
(2) Curtius, T. *J. Prakt. Chem.* **1930**, *125*, 323.
(3) Curtius, T. *Z. Angew Chem.* **1913**, *26*, 134.
(4) Abramovitch, R. A.; David, B. A. *Chem. Rev.* **1964**, *64*, 149.
(5) Breslow, D. S. In "Nitrenes"; Lwowski, W., Ed.; Interscience: New York, 1970; p 245.
(6) Abramovitch, R. A.; Kyba, C. P. In "The Chemistry of the Azido Group"; Patai, S., Ed.; Interscience: New York, 1971; p 279.
(7) Sloan, M. F.; Breslow, D. S.; Renfrow, W. B. *Tetrahedron Lett.* **1964**, 2905.

0022-3263/83/1948-2056$01.50/0