

PHOTODEBROMINATION OF BROMOQUINOLINES AND BROMOISOQUINOLINES

Cyril Párkányi* and Yong J. Lee**

Department of Chemistry, The University of Texas at El Paso,

El Paso, Texas 79968

(Received in USA 15 January 1974; received in UK for publication 18 February 1974)

Over the past few years, the number of papers on photochemical reactions of nitrogen-containing π -electron heterocycles has shown a steady increase.¹ However, only limited attention has been paid to photosubstitution reactions in these systems. It has been shown that ultraviolet irradiation of 3-bromopyridine in aqueous sodium hydroxide leads to a smooth photochemical substitution with the formation of 3-hydroxypyridine as the main reaction product.^{2,3} Similarly, 2-bromopyridine is photohydrolyzed to 2-pyridone and 2-bromoquinoline gives carbostyryl (2-quinolone).³ On the other hand, 3-bromoquinoline and bromoquinolines with the bromine atom attached to one of the carbon atoms of the benzene ring do not undergo photohydrolysis in the presence of aqueous alkali hydroxide.³ Nasielski and co-workers have shown that the ultraviolet irradiation of 2-methoxy-, 2-phenyl- and 2-dimethylamino-5-bromopyrimidine in methanol yields, among other compounds, the corresponding dehalogenated 2-substituted pyrimidines as reaction products and that the reaction rate is strongly increased in the presence of aliphatic amines.⁴⁻⁶ Quite recently, the ultraviolet irradiation of chlorobenzene in cyclohexane has been reported to give benzene as one of the reaction products.⁷ These recent disclosures prompt us to report our studies of the photodebromination of bromoquinolines and bromoisoquinolines carried out in the presence of an electron donor (a nucleophile) and a hydrogen donor (usually the solvent).

The ultraviolet irradiation of 3-bromo-, 4-bromo-2-methyl-, 6-bromo-, 7-bromo-, and 8-bromoquinoline in aqueous methanol in the presence of sodium hydroxide, potassium cyanide, or aliphatic amines (methylamine, triethylamine) gives quinoline (or 2-methylquinoline in the case of the above-mentioned 4-bromo compound) as the main reaction product.⁸ In an analogous reaction, 4-bromoisoquinoline affords isoquinoline. In some experiments, ethanol

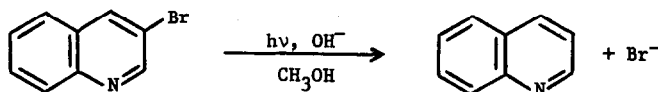
*To whom correspondence should be addressed.

**R. A. Welch Postdoctoral Fellow, 1971-1972. Present address: Department of Chemistry, The University of Oklahoma, Norman, Oklahoma 73069.

or 2-propanol were used instead of methanol with similar results. In the absence of a nucleophile, the reaction does not take place and it does not occur when acetonitrile is used as the solvent in combination with sodium hydroxide as the nucleophile. Thus, the reaction requires the presence of both an electron donor and of a hydrogen donor. In protic solvents, solvent molecules provide the needed hydrogen atoms. In an aprotic solvent (acetonitrile), the amine serves not only as an electron donor but it also plays the role of a hydrogen donor.

To determine the source of hydrogen atoms, photodebromination of 4-bromoisoquinoline was carried out in a $\text{CH}_3\text{OD}-\text{D}_2\text{O}$ mixture, with NaOD as base. After the reaction, isoquinoline formed as the product was found by mass spectrometric and nmr analysis to contain no deuterium. Thus, the hydrogens must have been removed from the methyl group of methanol. Because tertiary aliphatic amines can be used as electron and hydrogen donors in the photodebromination, also in the case of amines the hydrogen atoms are abstracted from the alkyl group of the amine. It has been shown that hydrogen α to the heteroatom is important for high reactivity of alcohols and amines in the photoreduction of aromatic ketones, and that in amines the $\alpha\text{-C-H}$ bond is weaker than the N-H bond.⁹

In the case of 3-bromoquinoline as an example, the reaction can be schematically represented as follows:



Some initial quantum yields of photodebromination of the bromoheterocycles are shown in Table I.

Table I. Quantum Yields of Photodebromination^a

Compound	ϕ	
	254 nm	300 nm
3-Bromoquinoline	0.065	0.062
4-Bromo-2-methylquinoline	—	0.031
6-Bromoquinoline	0.023	0.018
8-Bromoquinoline	0.025	0.015
4-Bromoisoquinoline	0.042	0.025

^a 1.5×10^{-3} M substrate, non-degassed samples, in 0.1 N aqueous NaOH-methanol (4:1, vol.).

There is a linear dependence of the reciprocal value of the quantum yield, $1/\Phi$, on the reciprocal concentration of the nucleophile, e.g., $1/[\text{OH}^-]$ or $1/[(\text{C}_2\text{H}_5)_3\text{N}]$, which indicates a bimolecular process between the excited bromosubstituted heterocycle and the nucleophile in the rate-determining step. It is assumed that the nucleophiles act as an electron donor toward the excited state of the bromoheterocycles giving rise to the corresponding radical anions. It is known that amines, but not hydroxides, possess a strong tendency to form charge-transfer complexes.^{4-6,9,10} However, the hydroxide ion has been shown to react as an electron donor in the catalytic dehalogenation of aliphatic halides¹⁰ and in the photo-reduction of N,N'-dimethyl-4,4'-bipyridinium diiodide.¹¹ The radical ion formed by the electron transfer then loses a bromide ion with the formation of a heterocyclic radical which abstracts a hydrogen atom from the protic solvent and gives the debrominated quinoline or isoquinoline.

The photodebromination reaction in the case of 3-bromoquinoline is quenched by oxygen and the quantum yields are considerably higher in degassed solutions (under conditions analogous to those in Table I, the quantum yield for 3-bromoquinoline at 300 nm is 0.33). On the other hand, the reaction is sensitized by Michler's ketone.

Bromoquinolines and other halosubstituted azaheterocycles were shown to give phosphorescence spectra.¹² In most cases, the lowest triplet states of pyridine-like heterocycles are π, π^* states.

The above information indicates that the most likely excited state of the bromoheterocycles undergoing the reaction is the first excited π, π^* triplet state. The reaction mechanism may be similar to the mechanism of the base-catalyzed thermal dehalogenation of aryl halides studied by Bunnett and co-workers.^{13,14}

No noticeable photodechlorination was observed with chloroquinolines (2-chloroquinoline, 6-chloroquinoline, and 8-chloroquinoline) under the conditions analogous to those used in the case of the bromo compounds.

A discussion of these and further results, the experimental details, a study of the emission spectra of bromoquinolines and bromoisoquinolines, the results of PPP (LCI-SCF-MO) calculations of these systems, and the mechanistic aspects of the photodebromination will be the subject of a forthcoming publication.

Acknowledgement

We are grateful to the Robert A. Welch Foundation, Houston, Texas for financial support of this work (Grant No. AH-461).

References

1. P. Beak and W. R. Messer, in: *Organic Photochemistry* (O. L. Chapman, Ed.), Vol. 2, p. 117, M. Dekker, New York (1969).
2. G. H. D. van der Stegen, E. J. Poziomek, M. E. Kronenberg, and E. Havinga, *Tetrahedron Letters*, 6371 (1966).
3. G. H. D. van der Stegen, Dissertation, Rijksuniversiteit Leiden, Leiden (1972).
4. J. Nasielski, A. Kirsch-Demesmaeker, P. Kirsch, and R. Nasielski-Hinkens, *Chem. Comm.*, 302 (1970).
5. J. Nasielski, A. Kirsch-Demesmaeker, and R. Nasielski-Hinkens, *Tetrahedron*, **28**, 3767 (1972).
6. J. Nasielski and A. Kirsch-Demesmaeker, *Tetrahedron*, **29**, 3153 (1973).
7. M.-A. Fox, W. C. Nichols, Jr., and D. M. Lemal, *J. Amer. Chem. Soc.*, **95**, 8164 (1973).
8. The irradiations were carried out in a Rayonet photochemical reactor, model RPR-208. Some experiments were performed in an immersion-well type Ace Glass photochemical reactor. The course of the reaction was followed spectrophotometrically and a merry-go-round unit, model MGR-100, was used for the determination of quantum yields. The ultraviolet, nmr, and mass spectra and gas chromatography were used to identify the reaction products.
9. S. G. Cohen and H. M. Chao, *J. Amer. Chem. Soc.*, **90**, 165 (1968).
10. M. G. Reinecke, *J. Org. Chem.*, **29**, 299 (1964).
11. I. S. Shchegoleva, *Khim. Vys. Energ.*, **6**, 380 (1972).
12. R. M. Hochstrasser, *Can. J. Chem.*, **38**, 233 (1960).
13. J. F. Bunnett and C. C. Wamser, *J. Amer. Chem. Soc.*, **89**, 6712 (1967).
14. J. F. Bunnett, *Acct. Chem. Res.*, **5**, 139 (1972).