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DIARYL AND TRIARYL OXAZIRIDINES

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ABSTRACT

A study of the rates of rearrangement of 2,3-diaryl and 2,3,3-triaryloxaziridines to the corresponding amides has been made. From the effects of solvent and from the behavior of a series of substituted compounds, it can be concluded that rearrangement involves heterolytic N-O bond fission with synchronous migration of a group from the carbon to the nitrogen. Aryl migration in the 2,3-diaryloxaziridines involves a significant amount of charge separation while hydrogen migration in the diaryl system and aryl migration in the triaryl system involve considerably less charge. The high enthalpies for phenyl migration (ΔH = 24 kcal/mole, ΔS = -3-1/2 e.u.) and for hydrogen migration (ΔH = 24 kcal/mole, ΔS = -1-1/2 e.u.) for the rearrangement of 2,3-diphenyloxaziridine in acetonitrile can be explained in terms of conformational restrictions in the three-membered ring and the instability of the developing positively charged nitrogen species.

The isolation of stable crystals of suitably substituted 2,3-diaryloxaziridines and 2,3,3-triaryloxaziridines from the photolysis of the corresponding nitrones firmly establishes the oxaziridines as the primary photoproduct from irradiation of N-arylnitrones.

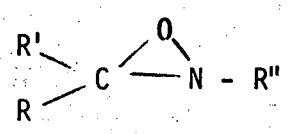
The rate of nitrogen inversion of N-aryloxaziridines has been found to be extremely slow when compared with the inversion rate of other previously investigated N-aryl compounds. At room temperature the half-time for nitrogen inversion in the 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine is about 100 minutes. The activation parameters

for nitrogen inversion in 3-methyl-2,3-diphenyloxaziridine has been measured in carbontetrachloride. The very high activation energy for inversion in this system (ΔH = 26-1/2 kcal/mole, ΔS = 10 e.u.) demonstrates the great retarding effect of the oxaziridine ring on the inversion of the nitrogen.

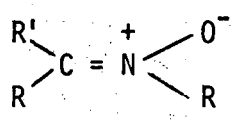
INTRODUCTION

Historical

The existence of three-membered carbon-nitrogen-oxygen ring (I)* has been hypothesized for many years. For instance, nitrones (II)** were first thought to have the oxaziridine ring structure[3] but this structure was discarded on the basis of spectra and the inability to resolve the compound.[4]



(I)



(II)

Allesandri[5] found that, under the influence of the warm Italian sun, acetone solutions of the α,N-diarylnitrone (II, R=R"=Ø, R'=H) rearranged to benzanilide. This is probably the first example of a reaction where an oxaziridine intermediate was actually involved.

Since then, the three-membered carbon-nitrogen-oxygen ring has had a long and illustrious career as a useful intermediate in many chemical reactions.

For instance, there are a number of examples of photochemical reactions involving the photoaddition of an aromatic nitro group to

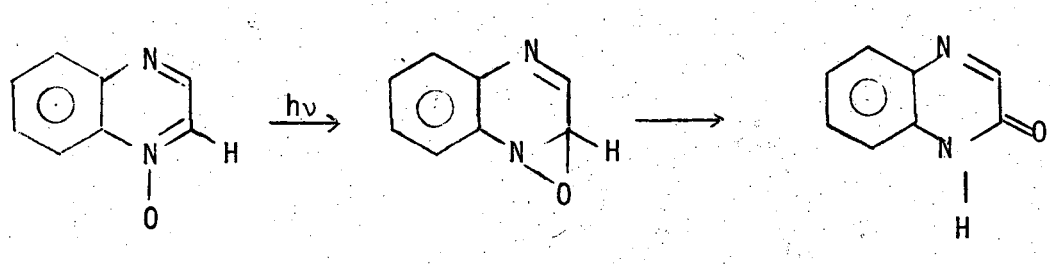
---

* For general surveys of oxaziridines see references 1a-c.

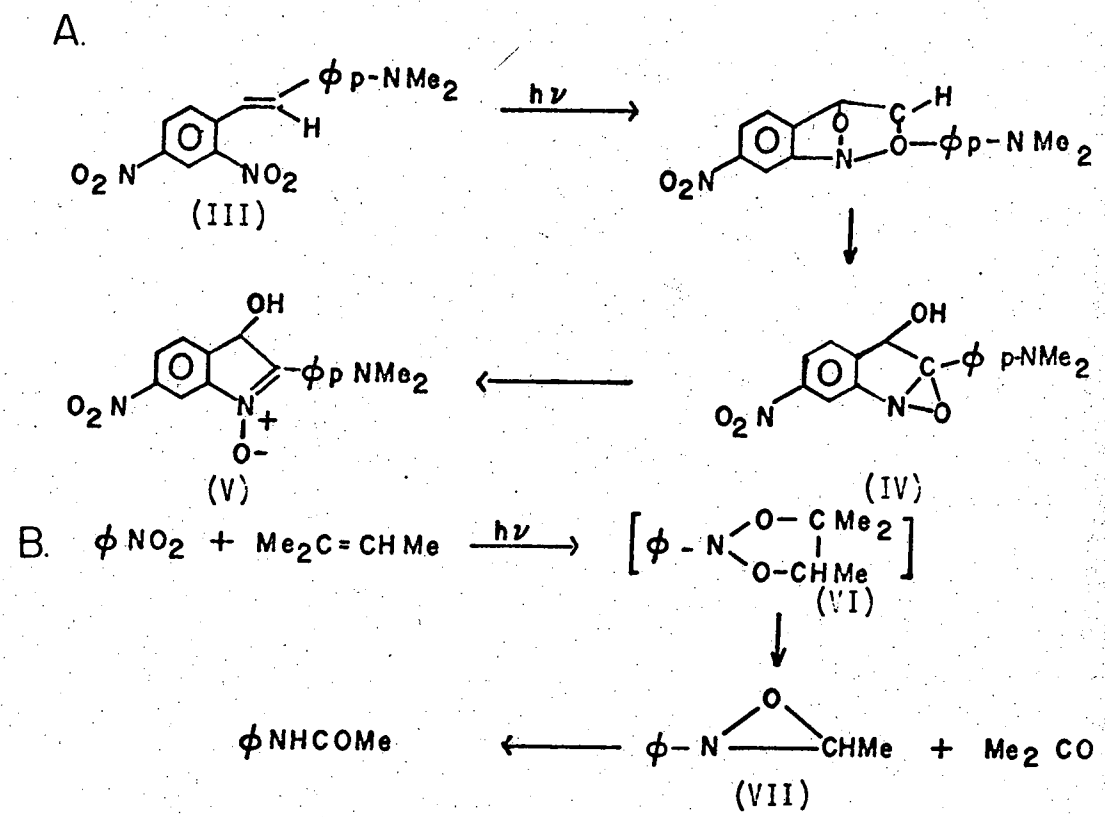
** For general reviews of nitrones see references 2a-c.

double bonds which may involve oxaziridine intermediates. Splitter and Calvin[6] hypothesized the intermediacy of an oxaziridine (IV) in the photoconversion of ortho-nitro-stilbene (III) to substituted isotogens (V). Somewhat later, Buchi and Ayers[7] hypothesized the intermediacy of a 1,3-dioxazolidine (VI) in the photoreaction of nitrobenzene with olefins. This, in turn, can yield an oxaziridine (VII) which rearranges to the final product (see page 3). The recent isolation of a stable cis 1,3-dioxazolidine as the primary product in the photolysis of nitrobenzene with cyclohexene adds credence to the proposed mechanism and leaves the oxaziridine as the likely product of isoxazolidine fragmentation.[8] Other reports of similar reactions have been made by Scheinbaum[9] and Taylor.[10a,b]

In the early 1950's Landquist[11] reported that irradiation of quinoline-N-oxide (VIII) yielded the corresponding amide (X) in good yield. This reaction again proceeded through a presumed oxaziridine intermediate (IX).



VIII IX X



The mechanism of the photoaddition of nitrobenzenes to olefins according to Splitter and Calvin (A) and Buchi and Ayers (B).

Besides these examples, oxaziridines have been hypothesized as intermediates in such reactions as the photolysis of oximes[12,13*] the reaction of nitrenes with aldehydes[15], photolysis of quinone anil-N-oxides[16], and the mass spectral fragmentation of aromatic nitro compounds[17] to mention a few. But in all these cases, oxaziridines were only inferred and not detected.

These previously mentioned reactions where oxaziridines are presumed intermediates raises question about the isolability of these systems. Since photochemical rearrangements provide a very effective method of producing high-energy compounds under very mild conditions, the fact that these compounds, under these conditions, were not observable indicated that they may be too unstable to be isolated. In particular, it seemed probable that under any more drastic conditions of acidity, basicity, or temperature, no hope existed for obtaining oxaziridines. Therefore, it was quite surprising when the synthesis of stable oxaziridines was eventually announced.

In the 1950's, three groups[18,19,20] independently found that the oxaziridine ring could be formed by the peracid oxidation of certain imines. Contrary to what might have been expected, these oxaziridines proved to be extremely stable. In many cases they were distillable oils which showed no significant decomposition on standing.

From a cursory glance, the stability of this system is very unexpected.

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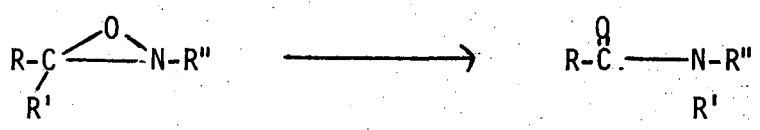
* Chemical evidence for the intermediate oxaziridines has recently been presented.

To get some feeling for the energetics of this system, a rough calculation can be made, comparing it with its rearrangement product, the amide.



(XI) (XII)

	Bond energy (kcal/mole)[21]		Bond energy (kcal/mole)
C-O	86	C=O	179
N-O	53	N-R'	73*, 93**
C-R'	83*, 99**		
	222,* 238**		252*, 272**

Thus, by bond energies alone, the amide is more stable than the corresponding oxaziridine by 30*-34** kcal/mole. In addition, the strain energy of the three-membered oxaziridine ring must be included. A reasonable estimate of 14 kcal/mole can be made based on the measured strain energy in aziridine (14 kcal/mole) and ethylene oxide (13 kcal/mole).[22] Thus, oxaziridines are, in general, much less stable (by 44 to 49 kcal/mole) than the corresponding amide. Thus, on a thermodynamic basis, the oxaziridine would be expected to be very reactive.

---

* For R' = alkyl, or aryl

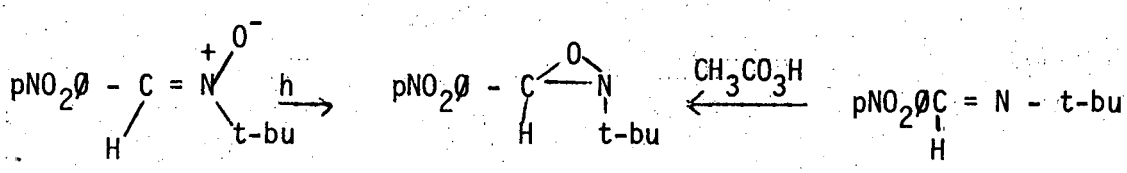
** For R' = H

The ring itself contains a weak, easily cleaved nitrogen-oxygen bond (ca. 53 kcal/mole[21]) and, in addition, strain energy inherent in the ring system should make this bond even weaker. The ring carbon has two electronegative groups attached to it. This 'hemi-acetal" structure should be very sensitive to traces of acid or base and yet the compound is produced in the presence of acids and peracids! Thus, its stability is undeniable.*

Soon after the original peracid synthesis of oxaziridines, the question of their production in nitrone photolysis quickly arise. Kamlet and Kaplan[23] suggested that the photosensitivity of α,N-diarylnitrones was due to the production of oxaziridines but no experimental evidence was offered. Finally, Splitter and Calvin[24] photolyzed the p-nitrophenyl-N-t-butylnitrone (XII) and obtained an isolable product. They showed that it was identical in all respects to the product from the peracid oxidation of p-nitrophenyl-N-t-butylimine (XV). This production of the 3-p-nitrophenyl-2-t-butyloxaziridine (XIV) proved conclusively that the oxaziridine was the photoproduct from nitrone irradiation.

---

* Another, more philosophical question is raised: "If these compounds are so stable, why weren't they found long ago?" One of the main pasttimes of organic chemists is to react all possible organic systems with all possible reagents. Since peracids have been used to oxidize ketones (Baeyer-Villiger Reaction), olefins (epoxidation), aldehydes, and many other unsaturated systems, it seems odd that the peracid oxidation of imines was bypassed.

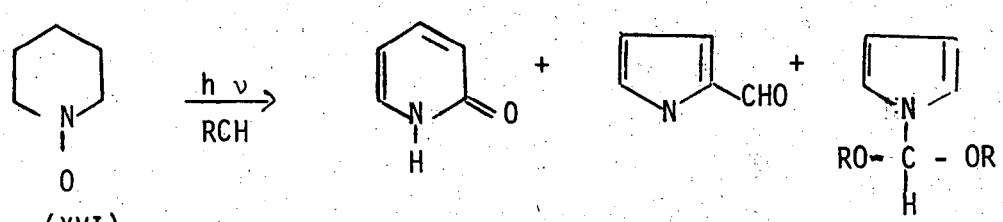


(XIII) (XIV) (XV)

Similar results were later obtained in the photolysis of 5,5-dimethylpyrroline-N-oxide[25] and the tranquilizer, Librium (7-chloro-2-methylamino-5-phenyl-3H-1,4-benzodiazepine-4-oxide).[26]

Since the original observation by Landquist[11], the photolysis of N-oxides has been intensively investigated. Because of the similarity between the structures of the nitrones and n-oxides, it appeared that the N-oxide photolyses too could be explained in terms of oxaziridine intermediates.

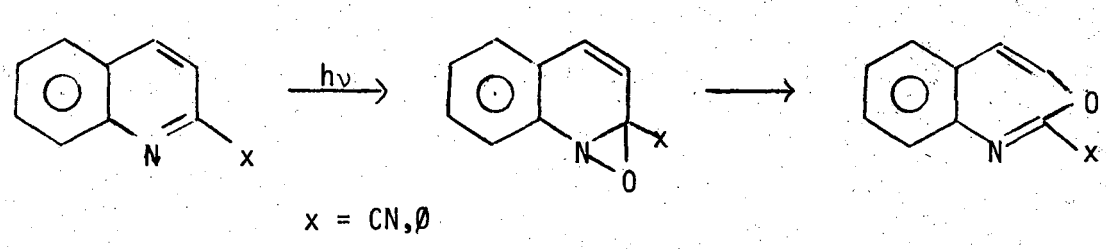
Photolysis of the parent compound, pyridine N-oxide (XVI) has been found to lead to a number of products,[27,28] most of which can be attributed to oxaziridine-type intermediates.



(XVI)

Since the strong oxidizing power of the oxaziridines is well known[18], the ability of irradiated aromatic N-oxides to act as oxidizing agents may be another indication of oxaziridine intermediates. For instance, Hata and Tanaka[29] have reported the formation of pyridine and oxygen in the gas phase photolysis of pyridine-N-oxide. Recently, Streith[30] obtained phenol in the photolysis of pyridine N-oxide in benzene and Alkaitis and Calvin[31] have detected cyclohexene oxide and cyclohexanone when pyridine N-oxide is irradiated in the presence of cyclohexene. Likewise, irradiation of pyridazine N-oxide in the presence of benzene yields phenol.[32]

However, attempts to isolate the oxaziridines derived from aromatic N-oxides have so far proved fruitless although, considering the high energy of these species, this is not surprising. Kaneko et al.[33,34] reported that the irradiation of 2-substituted quinoline N-oxides (XVII) yielded the corresponding stable oxaziridines (XIV) but it was later

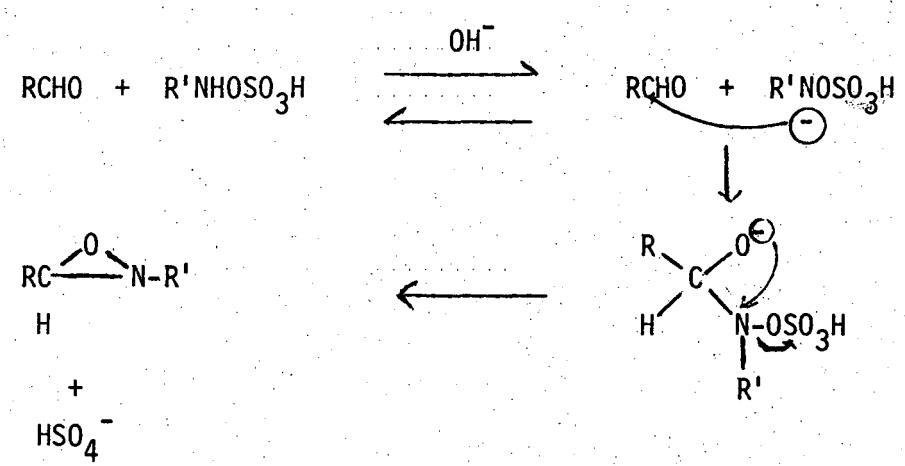


XVII XVIII XIX

shown that the product was instead the benzo-ozazepine (XIX), the rearrangement product from the oxaziridine.[35,36,37]

Many other examples of aromatic N-oxide photolyses have appeared in the last few years. In all cases, the rearrangements appear to proceed through an intermediate oxaziridine although the oxaziridine has never been detected. A partial list of those N-oxides that have been found to rearrange photochemically is given below: quinoline N-oxides[38,39], isoquinoline N-oxides[40,41], pyrezine-N-oxides[42], 4-phenylquinazoline-3-oxides[43], quinoxaline-di-N-oxide[44], 2,6-dicyanopyridine-1-oxide[45], 1,4-diphenylphthalizine-N-oxide[46]. 2-phenylisatogen(2-phenyl-3H-indol-3-one-N-oxide)[47], phenanthridine-N-oxides[10b, 48,49] and adenine N-oxide.[50,51]

The third general method of oxaziridine formation is the reaction of substituted hydroxylamine-O-sulfonic acids ($RNHOSO_3$) or chloroamine with carbonyl compounds in the presence of base. The reaction presumedly proceeds via the mechanism shown below:



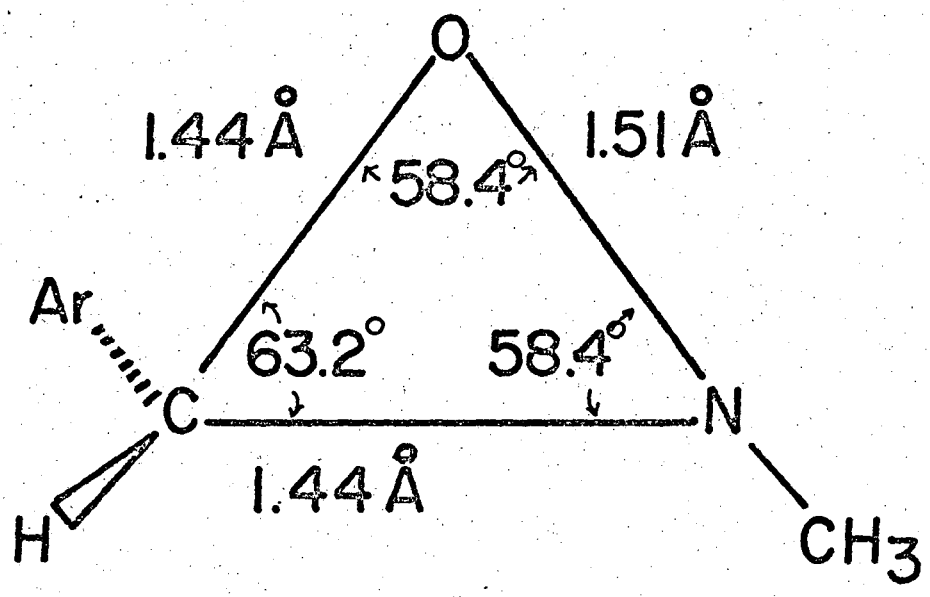
Using this technique, Schmitz has been able to synthesize both N-alkyl and N-unsubstituted (iso-oxime) oxaziridines and by acylation on the unsubstituted compound he has prepared the N-acyl derivatives.[52]

A final definitive identification of the oxaziridine ring structure was reported in 1967 when Jerslev[53a,b] reported the x-ray crystal structure of (RS) trans-2-methyl-3(2,6-dimethyl-4-chlorophenyl)-oxaziridine (XX), see page 11. The crystallographic dimensions are given on the following page. Thus, the structure and stability of the carbon-nitrogen-oxygen three-membered ring system has been definitely established in a number of independent syntheses.

The oxaziridines themselves are relatively stable to base but are slowly hydrolyzed by acids to the corresponding carbonyl compound and hydroxylamine. They are very strong oxidizing agents and in the presence of acidic iodide, iodine and the corresponding imine are produced.[54] In act, oxaziridines have been known to oxidize chloride to chlorine.[55]

Photolysis of the oxaziridines results in photofragmentation to yield the carbonyl compound plus products derivable from nitrenes. For instance, Meyer and Griffith[56] reported that the photolysis of 3,3-pentamethylene-2-phenyloxaziridine in the presence of diethylamine as a trapping agent yielded 2-diethylamino-3H-azepine in 10% yield and aniline in 9%. Likewise, Splitter and Calvin have shown that the photolysis of triphenyloxaziridine yields triplet phenylnitrene and benzophenone.[57]

Thermally, the oxaziridines undergo two rearrangement reactions, one caused by carbon-oxygen bond cleavage and one caused by nitrogen-oxygen bond cleavage. C-O cleavage results in the isomerization of the oxaziridine to the isomeric nitrone while N-O bond cleavage is followed by migration of a group from the carbon atom to the adjacent nitrogen atom to yield amides.

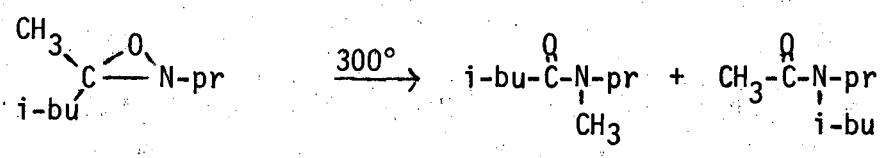


∠ Ar-C-O	117.2°
Ar-C-N	118.4°
CH_3-N-O	107.4°

X-ray crystal structure of (RS) trans-2-methyl-3-(2,6-dimethyl-4-chlorophenyl)oxaziridine (XX).

For example, Emmons has reported that the 3-phenyl-2-alkyl oxaziridines rearrange thermally to the corresponding nitrone.[18*] Thus, 3-phenyl-2-t-butyl oxaziridine rearranges quantitatively to the corresponding 3-phenyl-2-t-butyl nitrone in refluxing acetonitrile.[58]

On the other hand, 2,3-di- and 2,3,3-trialkyloxaziridines have proved exceedingly stable. However, when heated to high temperatures, they too rearrange to the corresponding amides. For example, when 2-n-propyl-3-methyl-3-isobutyl oxaziridine (XXI) is heated at 300°, a 64:36 mixture of N-methyl-N-n-propyl isovaleramide (XXII) and N-isobutyl-N-n-propyl acetamide (XXIII) is produced.



(XXI) (XXII) (XXIII)

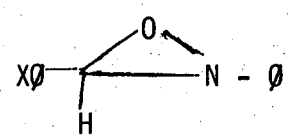
This reaction presumably proceeds in the gas phase and probably occurs via a free radical reaction. Liquid phase reaction (168°) of the same compound yields methyl isobutyl ketone, ammonia and black tar with very little amide products. Again, considering the large amounts of intractable material produced, it seems likely that a complex radical (probably a chain transfer) process is occurring. The rather drastic conditions necessary to effect these rearrangement reactions attest to the remarkable stability of the oxaziridine ring system.

---

* Emmons[18] reported that of the 3-phenyl compounds only the 2-5-alkyl ones were stable, but it was found that only their sensitivity to acids reduced their stability.[59,60]

The implication given in the last few pages is that oxaziridine rings are all stable. This is not correct. The di- and trialkyl oxaziridines are stable as are the 3-phenyl-2-alkyl compounds (see footnote, page 12). But in contrast to these very stable ring systems, the 2,3-diaryloxaziridines are unstable and have only been detected in solution.

Allesandri's[5] irradiation of α,N-diphenylnitrone by sunlight to yield benzanilide is probably one of the earliest examples of the intermediacy of the α,-N-diphenyl oxaziridine. Wheeler and Gore[61] attempted to measure the UV spectra of a series of diaryl nitrones. However, their results were inconsistent. Since their solution preparations apparently were done without adequate precautions against light exposure, their inconsistencies were probably due to photochemical rearrangement of the nitrone to the oxaziridine (XXIV). Attempts to



(XXIV)

prepare the diaryl oxaziridine system by the standard method of the peracid oxidation of the corresponding N-arylamine have not been successful.* On oxidation of p-nitrobenzaldehyde anil with peracetic acid, only trace amounts of p-nitrobenzanilide were obtained.[62] Padwa[63]

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* For an exception, see Krimm.[20]

has reacted several monoarylimines of benzil with peracetic acid and obtained N,N-dibenzoylamines as the principal products with no evidence of a stable oxaziridine intermediate. Even milder air oxidations of benzil monoarylimines and benzaldehyde imines have given no evidence of stable oxaziridine production but have yielded products that can be derived from oxaziridine rearrangements.[64,65]

Thus, it appears that under conditions where 2-alkyloxaziridines are very stable, the 2-aryl compounds can be prepared in situ but they undergo further rearrangement reactions.

By irradiating diarylnitrones in solution the diaryloxaziridines can be produced in solution. Using this technique, Splitter and Calvin[62] have investigated some of the properties of the system. Although the photoproducts of the nitrone were not isolated, they could be identified as oxaziridines by the following criteria:

1) Their production from nitrones in analogy to the production of 2-t-butyl-3-phenyl oxaziridine by the photolysis of 2-t-butyl-3-phenyl nitrone[10];
2) their high active oxygen content;
3) their UV spectrum;
4) their thermal rearrangement to stable amides.

The diaryloxaziridines studied were found to have lifetimes of from a few seconds to several weeks in solution at room temperature. Like the di- and trialkyloxaziridines, they normally rearrange cleanly to yield the corresponding amides and formamide while appropriately sub-

stituted compounds gave significant yields of the corresponding nitrone, a reaction similar to that found in 3-aryl-2-alkyloxaziridines.

When one considers the structure of the 2-aryloxaziridines it is not surprising that they are substantially less stable than their 2-alkyl analogs. The 2-aryl substituent would be expected to stabilize any radical or ion developing on the nitrogen resulting from cleavage of the weak nitrogen-oxygen bond; thus the products of N-O bond cleavage, the amides, would be expected to form.

From the brief summary of oxaziridines it can be seen that there is a great diversity of stabilities and reactivities present in the system, from very stable to unisolatable.

The purpose of this present work is to gather information about the properties of these three-membered carbon-nitrogen-oxygen ring systems. In particular, it would be desirable to know what factors govern the thermal stability of the ring. Although a wide spectrum of subjects are available for investigation, we have chosen to investigate the di- and triaryl compounds. This choice of a system was based on both convenience and on the probability of obtaining useful information.

Since the dialkyl and trialkyl systems are very stable, thermal rearrangement reactions only occur under very drastic conditions. Under these conditions many complicating radical reactions appear to take place which may mask much of the desired results. Also, Emmons[18] has investigated this area in fair detail and any further new information would be of dubious value. The 3-aryl-2-alkyl system, on the other hand, shows one clean reaction-rearrangement to the corresponding nitrone.

However, only a limited amount of information can be gleaned from the system since only one reaction can be investigated.

In the di- and triaryl systems, on the other hand, the aryl groups have sufficiently destabilized the oxaziridine ring so that N-O and C-O bond cleavage leading to rearrangement occur at reasonable rates. The di- and triaryl systems are also excellent subjects for investigation for more practical reasons. They can be formed cleanly in a photochemical reaction so the chances of contamination by other compounds are relatively small. As shown by Splitter[62] and others, the formation of the oxaziridine by irradiation of the corresponding nitrone is essentially quantitative.

The oxaziridines themselves are high-energy species so that rearrangement is always a thermodynamically favored process which is free of complications from back reactions. Likewise, the products from rearrangement (nitrones and amides) are all very stable.

Unlike many other analogous rearrangements systems -- the pinacol rearrangement[66], and the rearrangement of trityl hydroxylamines (the Stieglitz rearrangement)[67] for instance -- the oxaziridine rearrangement does not require external reagents such as strong mineral acid to promote the reaction. The uncatalyzed rearrangement takes place readily at accessible temperatures (0-100°C).

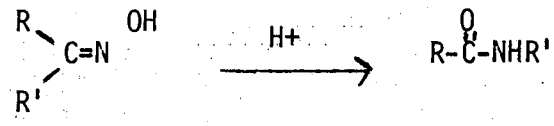
These oxaziridines also have several inherent properties which make monitoring them simple. One of these properties is quantitative active oxygen content. Thus, the diaryl oxaziridines can liberate iodine from

an acidic iodide solution, quantitatively and instantaneously at room temperature. This property is possessed neither by the starting nitrone nor any of the rearrangement products. Since iodimetric titrations are both simple and sensitive, this provides an effective method for following the disappearance of oxaziridine. A second monitoring property is the ultraviolet spectrum of the oxaziridines. Since the three-membered carbon-nitrogen-oxygen ring effectively prevents conjugation between the substituents on the ring, the oxaziridines under investigation show only short wavelength absorption. On the other hand, all the possible reaction products -- the nitrone, anilide, formamide, imine and even the aldehyde -- have longer conjugated systems. Thus the products all have absorption at longer wavelength than the oxaziridine and the appearance of product can be easily monitored by ultraviolet spectroscopy.

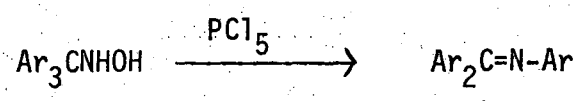
Finally, the rearrangement of N-aryl oxaziridines has one major advantage over other reactions of "electron deficient" nitrogens. In the rearrangements listed on page 18 the most direct way of investigating the reaction mechanisms is to vary reaction conditions, or to vary substituents on the migrating group. But determinations of the charge localized on the electron deficient nitrogen is difficult because there are no groups attached directly to the nitrogen which can be varied. However, in the rearrangement of the di- and triaryloxaziridines, there is an aryl group directly attached to the nitrogen. Thus by using substituted phenyl groups, a sensitive probe is available for investigating the electronic nature of the reacting nitrogen.

MIGRATIONS TO ELECTRODEFICIENT NITROGEN

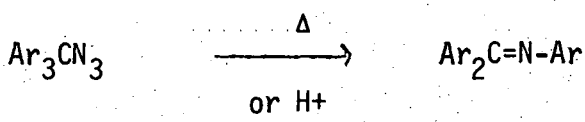
Beckmann Rearrangement



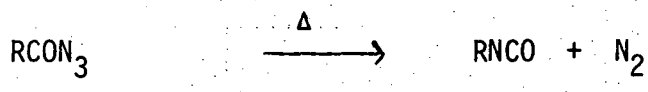
Stieglitz Rearrangement



Azide Rearrangement



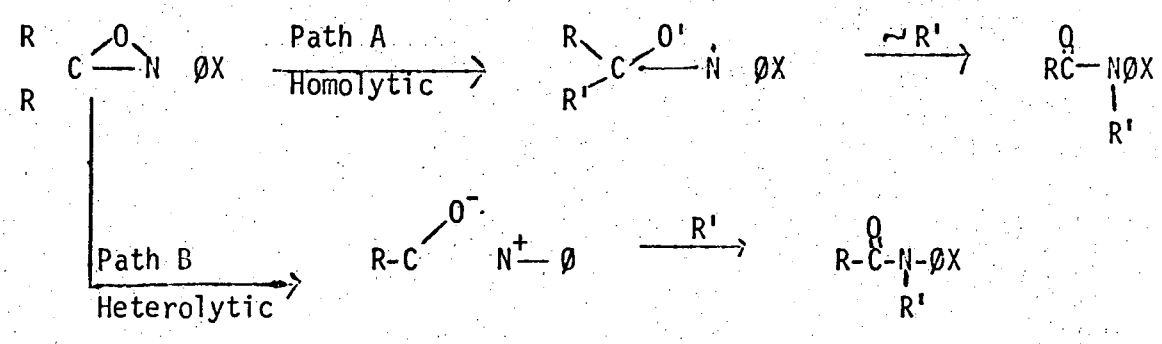
Curtius Rearrangement



The Experimental Approach

One of the questions that has not been adequately answered in the 2-aryl system is what is the mechanism of the N-O bond cleavage. Does it, as found in the 2-alkyl compound, occur via a homolytic cleavage to yield an oxy radical and a nitrogen radical? The N-aryl group would surely stabilize the radical nitrogen, thus possibly accounting for the great instability of the compound. On the other hand, the heterolytic N-O bond cleavage is also possible, which would result in an alkoxide oxygen plus a nitrenenium ion, R_2N^+. Stabilization of this electron deficient nitrogen by the N-aryl group should be quite substantial. To distinguish between these two forms of reaction, the following experimental approach will be employed.

A variety of di- and triarylnitrones will be synthesized. Irradiation of these nitrones, following the method of Splitter and Calvin[62], should produce the desired oxaziridines in solution.



Substituents on the aryl group attached to the nitrogen should provide sensitive probes to test the two major modes of nitrogen-oxygen cleavage -- homolytic (Path A) and heterolytic (Path B).

Heterolytic cleavage should be facilitated by electron releasing substituent and should be retarded by electron withdrawing substituents.

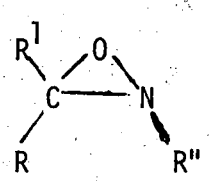
Hence some type of Hammett correlation should be obtained with a negative ρ.[68] On the other hand, homolytic cleavage should be facilitated by most para-substituents. In particular, both p-nitro and p-methoxy substituents should accelerate the reaction while with heterolytic bond cleavage, the p-nitro group should greatly retard the rate of rearrangement. Thus kinetics done on the rate of rearrangement as a function of N-phenyl substituent should allow a definite determination of the method of N-O bond cleavage. Further evidence can be obtained from the effect of solvents on the rate of reaction, since homolytic cleavage should not be appreciably affected by solvent while heterolytic cleavage, where charge separation is occurring, should show a marked rate increase in more polar solvents.

The effect of substituents on the carbon-phenyl can also give us important information on the structure of the transition state for the rearrangement. The rate of aryl migration should be substituent dependent: heterolytic cleavage will favor migration of electron-donating groups[69] while, generally, electron-withdrawing groups are favored in radical rearrangements.[70] Thus, the kinetics of the C-phenyl substituted oxaziridines should sitinguish between the two mechanisms. In particular, the product ratio of aryl migration to H migration in the diaryl system and aryl migration to phenyl migration in the triaryl system should markedly depend on the charge on the nitrogen and the extent of aryl migration in the transition state leading to rearrangement.

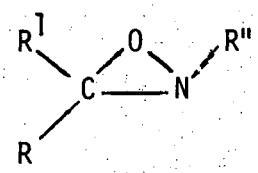
Splitter and Calvin[62] have previously looked at the rates of rearrangement of several C-phenyl substituted diaryloxaziridines and have noted

variations in the distribution of the product with substituent. However, it would be desirable to investigate a more complete series of compounds so more definitive conclusions can be drawn about the mechanism of the rearrangement.

An additional problem that is inseparable from any kinetic analysis of the rearrangement reactions is the conformational orientation of the rearranging oxaziridine. In particular, do there exist two separate conformers of the oxaziridines (XXV) and (XXVI) whose reactions may be quite different?



(XXV)



(XXVI)

It is hoped that by the use of spectral instrumentation, particularly nuclear magnetic resonance spectrometry, the existence of stable isomers may be confirmed or disproved.

One more point about the experimental approach deserves comment. In this study we intend to investigate the reactivity and characteristics of unstable compounds which cannot be isolated. The evidence for the existence of the diaryloxaziridine system is very compelling, and evidence for the intermediacy of triaryloxaziridines is also strong. However, it is aesthetically more pleasing to be able to isolate and char-

acterize the compounds under investigation. One of the hopes of this work is that by studying the kinetics of the reaction, we will be able to determine the factors governing the stability of the ring. From this knowledge it is hoped that we will be able to construct and isolate suitable substituted diaryl and possibly triaryloxaziridines and firmly establish the identity of the system.

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EXPERIMENTAL

I. SYNTHESIS

SYNTHESES OF DIARYL AND TRIARYLNITRONES

Known α-aryl-N-phenylnitrones

The following known diarylnitrones were synthesized by condensing phenylhydroxylamine[1,2,3] with the appropriate substituted benzaldehyde in ethanol:[4,5]

α-N-diphenylnitrone. mp 113.8-114.2° (Lit. 116°[4]); uv max (cyclohexane) 322 m μ(ε18,700), (benzene) 322 m μ(ε 20,200); ms (70 eV) m/e (relative intensity) 197 (M^+, 50), 196 (34), 181 (22), 180 (33), 105 (17), 91 (100), 77 (46).

α-(4-chlorophenyl)-N-phenylnitrone. mp 151.3-153° (Lit. 152°[4]); uv max (cyclohexane) 327 m μ(ε 22,000), (benzene) 321 mμ (20,400).

α -(4-nitrophenyl)-N-phenylnitrone. mp 190-1° (Lit. 190°[4]); uv max (benzene) 367 m μ (ε19,800); ms (70 eV) m/e (relative intensity) 242 (M^+, 33), 226 (23), 225 (8), 195 (6), 179 (91), 167 (6), 97 (7), 94 (8), 92 (8), 91 (100), 77 (18).

α-(4-anisyl)-N-phenylnitrone. mp 116.3-117.5° (Lit. 116°[4]); uv max (cyclohexane 335 mμ (ε 22,300); ms (70 eV) m/e (relative intensity) 227 (M^+,100) 226 (32), 211 (45), 210 (47), 198 (35), 184 (20), 135 (36), 91 (100), 77 (41).

α-(4-dimethylaminophenyl)-N-phenylnitrone. mp 138° (Lit. 138°[5]); uv max (benzene) 374 mμ (ε 27,300); ms (70 eV) m/e (relative intensity) 240 (M^+, 48), 225 (16), 224 (100), 223 (86), 207 (13), 150 (10), 149 (100), 148 (53), 145 (7), 91 (7), 77 (21).

α-D-α,N-diphenylnitrone

In a similar manner, the α-deuterium compound was prepared from α-D-benzaldehyde and phenylhydroxylamine. The α-D benzaldehyde was prepared by a Rosemund reduction of benzoyl chloride with deuterium gas (>95% pure) using a palladium-barium sulfate catalyst poisoned with a trace of quinoline sulfur following the procedure of Hershberg and Cason.[6] (NMR analysis showed that the benzaldehyde was 95% deuterated.) NMR of the deuterated nitrone showed a complete disappearance of the α-H resonance at τ2.25.

ms (70 eV) m/e (relative intensity) 199 (2), 198 (M^+, 17), 197 (15), 182 (14), 180 (13), 105 (17), 91 (100), 71 (28), It appears that under these mass spectral conditions significant exchange of the nitrone α-hydrogen resulted. For evidence that the irradiated nitrone is still specifically labelled, see the section on product analysis.

α -(3-nitrophenyl)-N-phenylnitrone

3-Nitrobenzaldehyde (4.2 g) and 7.3 g phenylhydroxylamine (not very pure) were combined in 150 ml 95% ethanol and heated until the aldehyde dissolved, and allowed to stand 18 hours at room temperature. The crude product was collected on a buchner funnel (yield 7.84 g) and recrystallized from ethanol-water, 5.53 g. mp 146.2-147.8° (Lit. 154°[4]); uv max (absolute ethanol) 315 mμ (ε14,720); ms (70 eV) m/e (relative intensity) 242 (M^+, 56), 226 (17), 197 (38), 168 (13), 167 (22), 151(33), 150 (89), 120 (11), 119 (19), 105 (100), 104 (31), 103 (24), 93 (41), 91 (19), 77 (78).

α -(2,6-dichlorophenyl)-N-phenylnitrone

2,6-Dichlorobenzaldehyde (2.24 g) and 1.34 g phenylhydroxylamine were dissolved in 20 ml ethanol and allowed to stand for 12 hours at room temperature. The oily solution was combined with water and the mixture was extracted with 80 ml ether. The ethereal solution was dried ($MgSO_4$) and the ether was removed by rotary evaporation. The resulting oil solidified upon cooling to a white crystalline material. Yield 2.67 g. mp 116-117.5°. Recrystallization from chloroform-petroleum ether yielded white crystals. mp 118.2-118.7°; uv max (acetonitrile) 284 m μ(ε 8970); ms (70 eV) m/e (relative intensity) 267 (M^+, 3), 265 (5), 251 (21), 250 (20), 249 (24), 232 (34), 230 (100), 173 (14), 104 (14), 91 (39), 77 (71).

N-tolyl-α-phenylnitrone

4-Tolylhydroxylamine (7.00 g) synthesized according to Utzinger[2] and 6.31 g benzaldehyde were combined in 50 ml ethanol. The solution was allowed to stand overnight. The precipitate was collected. Yield 4.86 g. mp 124-125.5° (Lit. 123°[4]). A second crop was collected on adding water to the filtrate until cloudy and allowing the solution to stand. Yield 2.04 g. Total yield 6.90 g; uv max (absolute ethanol) 316 m μ (ε20,900);

ms (70 eV) m/e (relative intensity) 211 (M^+, 82), 195 (6), 183 (7), 118 (6), 106 (16), 105 (100), 91 (9), 77 (39).

N-(p-chlorophenyl)-α -phenylnitrone

4-chlorophenylhydroxylamine[2] (8.12 g) and 9.07 g benzaldehyde were combined in 100 ml ethanol, and allowed to stand for 12 hours. The resulting crystals were collected and washed with ethanol-water. Yield 10.88 g. mp 174-175°. A second crop was collected by adding water to the filtrate until cloudy and allowing the solution to stand. Yield .39 g. Total yield 11.3 g (86%). mp (recrys. from ethanol-water) 179-181° (Lit. 181°[4]); uv max (absolute ethanol) 319 m μ(ε 21,200); ms (70 eV) m/e (relative intensity) 233 (M^+, 18), 231 (58), 215 (13), 214 (8), 203 (9), 167 (7), 127 (9), 125 (9), 111 (8), 106 (16), 105 (100), 94 (9), 77 (32).

N-(4-biphenylyl)-α -phenylnitrone[7]

4-Nitrobiphenyl (5.39 g), 230 ml ethanol, 50 ml water, 5 g ammonium chloride and 5 g powdered zinc were placed in a 500 ml flask. The mixture was stirred with ice cooling to maintain the temperature at less than 20°C. After stirring 1/2 hour, the product was filtered into 15 cc glacial acetic acid and the resulting solution was poured into 300 ml water. The yellow precipitate was collected (6.93 g) and combined with 4.67 g benzaldehyde in 80 ml ethanol which was heated until the p-phenylphenylhydroxylamine dissolved. After sitting for 12 hours, the resulting precipitate (2.94 g) was collected and recrystallized from ethanol-water. Yield 2.25 g (40%). mp 175-178° (Lit. 174-175°[7]); uv max (absolute ethanol) 324 mμ (ε 25,800); ms (70 eV) m/e (relative intensity) 273 (M^+, 65), 257 (50), 256 (20), 245 (30), 180 (35), 170 (48), 169 (100), 167 (67), 154 (43), 153 (34), 152 (45), 106 (74), 105 (95), 77 (66).

N-(4-anisyl)-α-phenylnitrone

4-Nitroanisole (11.1 g), 5 g ammonium chloride and 75 ml 1:1 ethanol: water were placed in a 200 ml round bottomed flask equipped with a magnitic stirrer.[2] The solution was cooled to 5°C with an icebath. 17 g powdered zinc was added in small portions over 1 1/2 hours. The temperature was maintained at less than 15°C. After the addition was completed, the solution was filtered and the ZnO was washed with 100 ml hot ethanol. 10 ml benzaldehyde was added to the ethanolic solution and the solution stood at room temperature for 18 hours. The resulting precipitate was collected and dried on a buchner funnel. 7.033 g. mp 114-121°. Recrystallized from benzene-pentane 6.49 g. For analysis, recrystallized from chloroform-pentane. mp 130-131°. uv max (absolute ethanol) 320 mμ (ε 23,500); ms (70 eV) m/e (relative intensity) 227 (M^+, 90), 211 (7), 184 (10), 105 (100), 77 (40), 51 (8),

Anal. Calcd. for $C_{14}H_{13}NO_2$: C, 74.01; H, 5.73; N, 6.17. Found: C, 73.96; H, 5.68; N, 6.34.

α-(4-bromophenyl)-N-phenylnitrone

4-Bromophenylhydroxylamine[8] (4.66 g) and 5 ml benzaldehyde were dissolved in 20 ml of ethanol. After sitting for several hours, the resulting precipitate was collected and recrystallized from ethanol. Yield. 4.41 g. mp 183-184°; uv max (acetonitrile) 321 m μ(ε 24,200); ms (70 eV) m/e (relative intensity) 277 (M^+, 35), 275 (M^+, 39), 261 (4), 260 (3), 259 (4), 173 (3), 171 (4), 168 (4), 167 (8), 106 (15), 105 (100), 94 (8), 77 (31).

N-(3-fluorophenyl)-α-phenylnitrone

3-Fluoronitrobenzene (10.40 g), 15 g powdered zinc and 50 ml 1:1 ethanol-water were placed in a 100 ml 3-necked flask equipped with a thermometer, reflux condenser, magnetic stirrer and dropping funnel. 2 ml of saturate ammonium chloride solution was added through the dropping funnel as the solution began to reflux.[2] Reflux was maintained by the addition of more ammonium chloride solution. After 20 minutes, the solution was filtered and the residue was washed with 20 ml of hot ethanol. 100 ml water and 8 ml benzaldehyde were added to the filtrate and the solution stood at room temperature for 4 hours. The resulting white precipitate (11.47 g) was collected and recrystallized from ethanol-water (11.19 g, 67.5%). For analysis, the product was recrystallized from benzene-hexane. uv max (absolute ethanol) 319 mμ (ε 18,600) and 231 mμ (ε 10,600); ms (70 eV) m/e (relative intensity) 215 (M^+, 100), 199 (7), 198 (6), 187 (13), 106 (26), 105 (100), 94 (20), 77 (85), 51 (22). Anal. Calcd. for $C_{13}H_{10}NOF$: C, 72.56; H, 4.65; N, 6.51. Found: C, 72.88; H, 4.53; N, 6.39. mp 109-110°.

N-(4-nitrophenyl)- α-phenylnitrone

Procedure A[9]

4-dinitrobenzene (0.46 g) was added to a solution of 10 ml water, 50 ml 95% ethanol, 1.57 g ascorbic acid and 10 ml 2N sodium bicarbonate. The red solution was stirred for 10 minutes and glacial acetic acid was added dropwise until the solution turned yellow-orange. 2 ml benzaldehyde were added and the solution sat at room temperature for 12 hours. The resulting yellow crystals were collected and recrystallized from ethanol-water. Yield, 187 mg (28%). mp 184-189°. uv max (acetone) 352 m μ(ε13,600); (acetonitrile 352 m μ(ε13,600); ms (70 eV) m/e (relative intensity) 242 (M^+, 9), 226 (55), 225 (37), 196 (25), 180 (26), 167 (25), 135 (20), 105 (95), 77 (100),

Procedure B

4-nitrophenylhydroxylamine (.311 g) was synthesized according to Kuhn and Weygand[9] (mp 96-99°) .235 g benzaldehyde and 1 ml ethanol were placed in a test tube. The ethanol was heated to boiling in a water bath for 1/2 hour, more ethanol being added to maintain the volume at about 1.5 ml. After cooling the solution solidified. The yellow precipitate was collected on a buchner funnel and washed with cold ethanol. Yield 0.486 g. mp 180-183°. Recrystallized from chloroform-petroleum ether. Yield .302 g. mp 188-189°

α-(4-cyanophenyl)-N-phenylnitrone

4-Nitrobenzonitrile (8.56 g), 11 g powdered zinc, 50 ml ethanol and 50 ml water were placed in a 250 ml flask equipped with a reflux condenser and magnetic stirrer. 10 ml of saturated ammonium chloride was added dropwise. The temperature of the solution rose to 80° and the reaction was terminated when the temperature dropped to 55°C. The solution was filtered. 5 ml of benzaldehyde were added to the solution. After sitting overnight, the precipitate was collected and dried. Yield 3.73 g. mp 144-148°. A second crop was collected by adding water to the filtrate. Yield 3.57 g. uv max (acetonitrile) 335 mμ (ε17,700) and 246 m μ(ε15,500). ir (heat) 3100 (C-H), 3045 (C-H), 2230 (C≡N), 1585 (C=C), 1544, 1440, 1418, 1293, 1194, 1080, 1064, 890, 850, 820, 755, 686 cm^{-1}.; ms (70 eV) m/e (relative intensity) 222 (30), 206 (32), 205 (22), 194 (9), 129 (5), 119 (5), 118 (91), 106 (20), 105 (100), 102 (12), 94 (13), 77 (43). (The α-D compound was prepared in the same way.)

α-(4-dimethylaminophenyl)-N-(4-nitrophenyl)nitrone

4-Dinitrobenzene (0.4 g) was added over a period of 10 minutes to a solution containing 10 ml water, 40 ml 95% ethanol, 1.2 g ascorbic acid and 10 ml 2N sodium carbonate.[9] The solution turned a brilliant red and was stirred for an additional 10 minutes. Glacial acetic acid was added dropwise until the solution turned yellow-orange. 0.9 g p-dimethylaminobenzaldehyde was added and the solution was heated slightly until all the aldehyde dissolved. After standing 4 days at room temperature, the resulting red-brown precipitate was collected and recrystallized from boiling benzene. Yield 0.26 g (39%). mp (sublimed sample) 243-244° with decomposition. uv max (absolute ethanol) 466 mμ(ε20,200). Anal. Calcd for $C_{15}H_{15}N_3O_3$; C, 63.14; H, 5.26; N, 14.74. Found: C, 62.73; H, 5.04; N, 14.45.

N-phenyl-α-styrylnitrone

Phenylhydroxylamine[1] (1.512 g) was combined with 2.508 g of freshly distilled cinnamaldehyde. It reacted immediately giving a yellow precipitate. Yield 3.072 g (99%); mp 151-152° (Lit. 155[10]); uv max (benzene) 367 mμ (ε24,000); (acetonitrile) 360 mμ (ε25,700); ms (70 eV) m/e (relative intensity) 233 (M^+,85), 222 (100), 206 (15), 195 (25), 146 (36), 105 (18), 104 (24), 103 (22), 91 (53), 78 (20), 77 (40), 51 (16).

α-(4-phenylbutadienyl)-N-phenylnitrone

1) 5-phenylpentadienal[11]

Magnesium turnings (10 g) and 110 ml tetrahydrofuran were placed in a 500 ml round-bottom flask equipped with a reflux condenser, magnetic stirrer and dripping funnel. Freshly distilled ethyl bromide (50 ml) was added over one hour with ice cooling. The solution was then heated to reflux for one-half hour. After cooling to room temperature, 33 g 4-methoxy-butenyne was added dropwise and the solution was stirred for 1 1/2 hours. 32 g benzaldehyde was added with cooling. The solution was then stirred at room temperature for 3 hours. Finely powdered lithium aluminum hydride (8 g) was added and the solution stirred for an additional 15 hours. The solution was poured into an ammonium chloride-ice water solution, neutralized with 6N H_2SO_4 to pH .5, and the aqueous solution was extracted with 200 ml ether. The ether solution was washed with 100 ml 2N sodium carbonate solution and with 100 ml water, dried over anhydrous sodium sulfate and the ether removed at reduced pressure. The residue was distilled under vacuum. 20.74 g of a thick oil was obtained; bp 105-120° (3-5 min.), (43% yield).

2) Reaction of 5-phenylpentadienal with phenylhydroxylamine.

5-Phenylpentadienal[11] (3.3 g) and 2.2 g phenylhydroxylamine[1] were combined in 50 ml ethanol. A solid formed after 10 minutes. 3.82 g Recrystallized from ethanol-water. 2.83 g. mp 169-171°; uv max (acetonitrile) 379 mμ (ε40,300), and 286 mμ (ε13,700); ms (70 eV) m/e (relative intensity) 249 (M^+, 62), 233 (51), 232 (65), 158 (100), 157 (68), 143 (19), 112 (22), 106 (21), 98 (25).

α,α,N-triphenylnitrone

N-phenylbenzophenone ketoxime was synthesized according to Johnson[12] and Aurich[13]. mp (recrystallized from ethanol-water) 222-224° (Lit. 223-225°[12]). uv max (ethanol) 311 mμ (ε11,000); uv max (acetonitrile) 312 mμ (ε11,400) and 230 m μ(ε15,300); ms (70 eV) m/e (relative intensity) 273 (M^+, 100), 272 (32), 257 (60), 180 (64), 105 (45), 91 (90), 77 (40).

α-(4-methoxyphenyl)-α,N-diphenylnitrone

4-Methoxybenzophenone hydrazone[14] (4.0 g), 10 g silver oxide and .5 g magnesium sulfate were stirred at room temperature for 1 1/2 hours in 125 ml petroleum ether.[15] The purple solution was filtered and the solvent was removed by rotary evaporation. To the 2.7 g of oily purple crystals (p-methoxydiphenyldiazomethane)[16] in 100 ml petroleum ether and 25 ml ether was added 1.0 g nitrobenzene. Gas was evolved and the solution turned yellow. The white precipitate formed was collected and washed with petroleum ether. Yield 1.83 g. mp 123-140°. Recrystallization from ethanol-water (50 ml:200 ml) yielded 1.72 g. mp 128-146°; uv max (acetonitrile) 318 mμ(ε14,100) and 262 mμ (ε11,600); ir (CCl_4) 3060, 2950, 2840, 1601, 1510, 1440, 1238, 1175, 1037, 956 and 690 cm^{-1}; ms (70 eV)

m/e (relative intensity) 303 (74), 287 (68), 286 (25), 225 (11), 212 (20), 210 (44), 180 (24), 135 (100), 105 (63), 77 (44).

The wide melting range is caused by the presence of two isomers. The NMR spectrum (CCl_4) shows widely spread aromatic hydrogens centered at δ6.9 (m, 14). Two methoxy peaks appear at δ3.66 and 3.76 with areas of 1.3 and 1.7 respectively. The lower field peak is probably due to the methoxy group on the phenyl group trans to the nitrone oxygen. A similar observation has been made by others.[17]

α-(4-nitrophenyl)-α,N-diphenylnitrone

4-Nitrodiphenyldiazomethane (2.98 g) synthesized according to Huttel[15] and .136 g nitrosobenzene[1] were placed in 2 ml ether and 2 ml petroleum ether in a test tube. As the mixture was stirred, gas was evolved and the red color of the solution disappeared leaving a yellow precipitate. The precipitate was collected on a Hirsch funnel and washed with petroleum ether. Yield 240 mg. mp 70-80°. Recrystallized from ether-petroleum ether. mp 78-82°. uv max (acetonitrile) 361 mμ (ε10,300), 300 mμ (sh,ε12,700), and 253 m μ(ε16,500); ms (70 eV) m/e (relative intensity) 318 (M^+, 28), 302,(55), 272 (50), 255 (32), 225 (28), 195 (32), 180 (43), 150 (49), 120 (35), 105 (100), 77 (72). Anal. Calcd for $C_{19}H_{14}N_2O_3$: C, 71.70; H, 4.40; N, 8.81. Found: C, 71.75; H, 4.81; N, 8.46.

α-(4-bromophenyl)- α,N-diphenylnitrone

1) 4-Bromobenzophenonehydrazone

4-Bromobenzophenone (14.4 g) (synthesized by reaction to bromobenzene with benzoylchloride in the presence of aluminum chloride)[18] and 17 ml 85% hydrazine hydrate and 150 ml absolute methanol were placed in a 250 ml standard taper-round bottomed flask. The flask was equipped

with a soxhlet extractor containing a thimble with 20 g of calcium oxide, a condenser and heating mantle. The solution was refluxed for 20 hours. The ethanol was removed by rotary evaporation, yielding an oil which solidified on standing at 0°. The solid was collected, washed with petroleum ether and air dried. Yield 9.16 g. mp 74-80°.[19]

2) Reaction of 4-bromodiphenyldiazomethane with nitrosobenzene.

4-Bromobenzophenonehydrazone[19] (3.26 g) and 7.4 g silver oxide were stirred for 4 hours in 10 ml petroleum ether. The purple solution was filtered and the solvent removed by rotary evaporation. There appeared to be a mixture of purple 4-bromodiphenyldiazomethane and traces of unreacted hydrazone. 80 ml of 2:1 petroleum ether-ether solution were added and the purple solution decanted from the white precipitate. .82 g nitrosobenzene[1] was added to the solution of 4-bromodiphenyldiazomethane. After gas evolution was complete, the white precipitate was collected and washed with petroleum ether. mp 180-181°. Total yield 1.03 g. uv max (acetonitrile) 316 mμ (ε13,100) and 244 mμ (ε17,300); ms (70 eV) m/e (relative intensity) 353 (51), 352 (15), 351 (59), 337 (94), 335 (100), 260 (30), 258 (25), 185 (41), 183 (42), 180 (21), 131 (38), 105 (56), 77 (25).

N-(4-nitrophenyl)-α,α -diphenylnitrone

4-Nitronitrosobenzene (.69 g) synthesized according to Ashley and Berg[20] and .66 g diphenyldiazomethane[21] in 50 ml ether were stirred overnight. The yellow precipitate was collected and washed with petroleum ether. Yield .37 g. mp 180-185°; uv max (acetonitrile) 350 mμ (sh,ε 6850), 300 m μ(ε12,800) and 249 m μ(ε16,700); ms (70 eV) m/e (relative intensity) 318 (M^+, 16), 302 (10), 225 (8), 182 (6), 105 (100), 77 (40). Anal. Calcd for $C_{19}H_{14}N_2O_3$: C, 71.70; H, 4.40; N, 8.81. Found: C, 71.40; H, 4.54, N, 8.91.

N-(4-anisyl)-α,α-diphenylnitrone

4-Methoxynitrosobenzene[22] (.60 g) and .72 g diphenyldiazomethane[21] were combined in 40 ml petroleum ether. After the gas evolution ceased, the white precipitate was collected and washed with petroleum ether. Yield .93 g. Recrystallized from ethanol-water. Yield. .84 g. mp 178-179°. uv max (acetonitrile) 313 mμ (ε19,300) and 238 mμ (ε28,100); ms (70 eV) m/e (relative intensity) 303 (M^+, 2), 287 (49), 272 (30), 210 (38), 182 (11), 167 (20), 141 (21), 115 (18), 105 (30), 92 (27), 77 (100). Anal.Calcd for $C_{20}H_{17}NO_2$: C, 79.21; H, 5.61: N, 4.62. Found: C, 78.97; H, 5.45; N, 4.64.

N-(4-bromophenyl)-α,N-diphenylnitrone

4-Bromonitrosobenzene (0.86 g) (synthesized according to Mijs[8]) was placed in 100 ml ether and 0.41 g diphenyldiazomethane[21] was added portion-wise with stirring. After the gas evolution ceased, the solution was placed in a refrigerator overnight. The yellow crystals were collected. Yield 0.29 g. mp 170-174°. Concentration of the ethereal filtrate to 25 ml and addition of 25 ml petroleum ether afforded an additional 0.30 g mp 172-174°. Total yield 0.59 g. mp (recrystallized from benzene-petroleum ether) 175-177°. uv max (acetonitrile) 313 mμ (ε12,300) and 239 m μ(ε20,100); ir (CCl_4) 3060 (C-H), 1482, 1470, 1435, 1238, 1066, 1011, 957, 850, 822, 698, 685; ms (70 eV) m/e (relative intensity) 353 (23), 351 (24), 337 (25), 335 (22), 260 (30), 258 (30), 182 (15), 180 (12), 171 (100), 169 (95), 165 (50), 157 (21), 155 (32), 105 (50), 90 (35) 77 (60).

α,α-Fluorenyl-N-phenylnitrone

1) Fluorenone hydrazone[23]

Fluorenone (0.8 g), 15 ml 85% hydrazine hydrate and 75 ml of ethanol were heated to reflux overnight. The solution was cooled and the precipitate was collected. Yield. 10.2 g.

2) Reaction of 9-diazofluorene with nitrosobenzene

Fluorenone hydrazone (3.57 g) and 4.0 g silver oxide in 50 ml petroleum ether and 50 ml ether were stirred together for 4 hours. The red solution was filtered and 1.75 g nitrosobenzene[1] was added to the filtrate and stirred for 12 hours. The yellow precipitate was filtered and washed with petroleum ether. Yield 2.85 g. mp 192-195° (Lit. 194.5-196.5[12]); uv max (acetonitrile) 355 mμ (ε24,200), 343 mμ (sh,ε18,600), 270 m μ(sh, ε17,600), 263 mμ (ε20,900) and 239 mμ (ε4,800); ms (70 eV) m/e (relative intensity) 271 (M^+,100), 270 (77), 255 (25), 254 (22), 180 (18), 91 (19).

α-(4-methoxyphenyl)-α-(4-nitrophenyl)-N-phenylnitrone

4-Methoxy-p'-nitrobenzophenone hydrazone[24] (.70 g), 3.45 g silver oxide, 50 ml ether and 25 ml petroleum ether were stirred for one hour.[15] The red solution was filtered and .46 g nitrosobenzene[1] were added to the solution. Gas was evolved and the resulting precipitate was collected and washed with petroleum ether. Yield .31 g. mp 165-170°; uv max (acetonitrile) 368 mμ (ε9,200), 304 mμ (sh,ε 11,300), 287 mμ (sh,ε12,200), 258 m μ(ε15,600) and 221 m μ(ε18,200).

N-(4-anisyl)-α-(4-nitrophenyl)-α-phenylnitrone

4-Methoxynitrosobenzene (.75 g) synthesized according to Rising[25]

and .69 g freshly prepared 4-nitrodiphenyldiazomethane[15] were placed in 30 ml petroleum ether. Bubbles were evolved and the red solution turned brown. After stirring for one hour, the yellow precipitate which was formed was collected. Yield .51 g. mp 154-164°. The compound was photosensitive. Recrystallization from ethanol-water did not change the wide melting point. This is consistent with the presence of cis- and trans-isomers as found in the case of the 3-(4-methoxyphenyl)-2,3-diphenylnitrone uv max (acetonitrile) 368 m μ(ε9150), 304 mμ (sh,ε 11,300), 287 mμ (sh, ε12,200), 258 mμ(ε15,600), 221 mμ (ε18,230); ms (70 eV) m/e (relative intensity) 348 (M^+, 43), 332 (38), 318 (10), 317 (12), 270 (33), 227 (36), 225 (56), 210 (35), 198 (32), 150 (16), 139 (21), 123 (18), 120 (20), 112 (88), 105 (100), 83 (40), 77 (40).

α-cyclohexyl-N-phenylnitrone

Cyclohexylcarboxaldehyde (.98 g) and 1.05 g phenylhydroxylamine[1] (and about .5 g anhydrous calcium sulfate) were placed in 20 ml of ether. The solution was refluxed overnight. The cooled solution was filtered and the calcium sulfate was washed with 20 ml of acetone. The solvent from the combined solutions were removed by rotary evaporation. Some of the remaining oil crystallized upon standing for 3 weeks. Yield .193 g. mp 112°; uv max (acetonitrile) 243 mμ (ε13,700); ms (70 eV) m/e (relative intensity) 203 (M^+, 38), 148 (4), 119 (10), 94 (10), 93 (100), 92 (3), 91 (3), 84 (30), 77 (4).

α-phenyl-N-methylnitrone[26]

Methylhydroxylaminehydrochloride (1.09 g) in 5 ml of water and 1.32 g benzaldehyde in 15 ml 2N sodium hydroxide solution were stirred together for 10 minutes. The solution was extracted four times with 50 ml chloroform.

The chloroform solution was dried over anhydrous magnesium sulfate. The solvent was removed under reduced pressure. The resulting oil crystallized on standing. Recrystallized from 1:1 benzene-petroleum ether (30°-60°). Yield 1.10 g (65%). mp 90-91°. ms (70 eV) m/e (relative intensity) 135 M^+,80) 134 (70), 120 (38), 106 (30), 105 (98), 77 (100).

α-benzoyl-α,N-diphenylnitrone

1) Desyl pyridimium chloride[27]

Desyl chloride (4.53 g) and 4 ml pyridine were placed in 25 cc of benzene. The solution sat for one month in a dessicator containing Drierite. The white crystals formed were washed with benzene and petroleum ether. Yield 6.04 g. mp 130°.

2) Reaction of desyl pyridinium chloride with nitrosobenzene.

Desyl pyridimium chloride (2.0 g) and 1 g of nitrosobenzene were placed in 25 ml of ethanol which was heated to 40°. 2N sodium carbonate was added dropwise until the solution was no longer red. The solution was diluted with 75 ml water. The tan precipitate was collected and washed with petroleum ether. Yield. 1.02 g. mp 155-157° (Lit.157°[28]). ms (70 eV) m/e (relative intensity) 301 (21), 300 (6), 285 (2), 197 (3), 196 (14), 181 (16), 180 (100), 168 (5), 165 (5), 91 (19), 77 (25).

α-methyl-α,N-diphenylnitrone

Acetophenone hydrazone (2.39 g) (synthesized according to Lock and Stach[29]) and 3.77 g silver oxide were stirred in 50 ml petroleum ether for 5 hours. The resulting red solution was filtered and treated with small portions of nitrosobenzene until gas evolution ceased and the red color disappeared. The resulting white precipitate was collected and washed with 3 x 25 ml petroleum ether. Yield 2.52 g. mp 85-89°. Recrystallization of petroleum ether mp 93-96°. The material appeared to

be quite unstable at room temperature, occasionally becoming a thick oil. By washing the crystals with petroleum ether-ether, the impurities can be removed. uv max (acetonitrile) 291 mμ (ε8,800); ir (CCl_4) 3060 (C-H), 1590 (C=C), 1535 , 1480, 1240, 1173, 1160, 1070, 695, 688, 643 cm^{-1}; ms (70 eV) m/e (relative intensity) 211 (M^+,27), 210 (8), 195 (10), 194 (4), 180 (18), 169 (10), 118 (7), 105 (8), 103 (11), 92 (12), 91 (100), 77 (40), 64 (8), 51 (10). NMR (CCl_4) τ7.47 (s,3),τ 2.9 (m, 10).

α-cyano-α,N-diphenylnitrone

The α and β isomers of α-cyano-α,N-diphenylnitrone were synthesized by the reaction of α-chlorobenzonitrile[30] and nitrosobenzene in base following the synthesis of Barrows and Thorneycraft[31]. α -isomer mp 165-170° (Lit. 170°[31]); β-isomer mp 141-143° (Lit. 143°[31]).

ANILIDES

The following anilides were prepared for comparison with the products from the thermal rearrangements of di- and triaryloxaziridines. They were prepared by the general method of Shriner, Fuson and Curtin[32], except that chloroform was generally used as the reaction solvent instead of benzene.

4-nitrobenzanilide	mp 215-216°	(Lit. 214°)[33]
4-methoxybenzanilide	mp 172-173°	(Lit. 168°)[34]
4-chlorobenzanilide	mp 199-200°	(Lit. 199-199.5°)[35]
4'-methoxybenzanilide	mp 157.5-158°	(Lit. 153-154°)[36]
4'-methylbenzanilide	mp 158-158.3°	(Lit. 158°)[37]
4'-chlorobenzanilide	mp 191-192°	(Lit. 192°)[32]
4'-nitrobenzanilide	mp 201-201.3°	(Lit. 199°)[38]
4'-phenylbenzanilide	mp 234-235°	(Lit. 227-228°)[39]
benzoyldiphenylamine	mp 177-179°	(Lit. 180°)[32]
4-anisoyldiphenylamine	mp 130-133°	(Lit. 139-140°)[40a]
4-nitrobenzoyldiphenylamine	mp 157-158°	(Lit. 156-157°)[40b]
benzoyl- 4-nitrodiphenylamine[41]	mp 126°	(Lit. 129°)[41]

SYNTHESIS OF DIARYL AND TRIARYLOXAZIRIDINES

Unstable Substituted 2,3-diphenyloxaziridine

The diaryloxaziridines were prepared by irradiating the corresponding diarylnitrone.[42] They were characterized by their ultraviolet spectra, active oxygen, their production from nitrones, and their rearrangement products. Experimental details are given below:

Ultraviolet spectra: Known concentrations of ca. 10^{-4} M nitrone solutions in a 1 cm quartz cell were irradiated for about one minute with two General Electric Photo-DBX photospots placed about 4 inches on either side of the cell. The cell was cooled in a Pyrex beaker of ice water. Irradiation was continued until no further change in the spectrum occurred. Extinction coefficients were calculated assuming quantitative conversion of the nitrone to the oxaziridine. Measurements were taken on a Cary Model 14 spectrometer.

Active oxygen content;[43] (See the Kinetic Experimental section for irradiation procedure). 1 ml of saturated potassium iodide solution and 0.5 ml glacial acetic acid were placed in the bottom of a 125 ml Erlenmeyer flask. To this is added 10 ml of an ethanol or acetonitrile solution containing 2-10 mg of the oxaziridine. The solution is swirled for a few seconds and diluted to 75 ml with water. 1 ml of starch solution[44] is added and the solution is titrated to clearness with .01 N sodium thiosulfate solution.[44] The diaryloxaziridines react almost immediately in all cases.

	uv max (mμ)	Active Oxygen
unsubstituted	222 (ethanol) (ε13,600)	100%
	219 (acetonitrile) (ε13,600)	
3-(4-methoxy)	237.5 (acetonitrile) (ε23,300)	100%
	238 (ethanol) (ε23,200)	
3-(4-nitro)	268 (acetonitrile) (ε14,000)	100%
	266 (ethanol (ε11,800)	
3-(4-dimethylamino)	275 (acetonitrile) (ε26,000)	57%
	450 (acetonitrile) (sh, ε1,300)	
3-(4-chloro)	229 (ethanol) (ε19,000)	100%
3-(3-nitro)	248 (ethanol) (sh, $\varepsilon\sim$14,000)	100%
2-(4-methyl)	end absorption at 230 (acetonitrile) (ε12,680)	50%
	279 (sh, ε2,380)	
	262 (sh, ε3,360)	
	255 (sh, ε3,920)	
2-(4-chloro)	221 (ethanol) (ε15,600)	96%
2-(3-fluoro)	231 (ethanol) (ε10,000)	100%
2-(4-bromo)	239 (acetonitrile) (ε18,500)	100%
2-(4-phenyl)	265 (acetonitrile) (ε24,900)	71%
3-(2,6-dichloro)	end absorption at 220 (acetonitrile) (ε15,000)	100%
	280 (sh,ε1,930)	
	271 (sh,ε2,360)	
3-(4-phenyl-butadienyl)-2-phenyloxaziridine	292 (acetonitrile (ε40,300)	
	236 (ε12,800)	
	228 (ε17,600)	
	222 (ε18,200)	
3-(4-dimethyl-aminocinnamyl)-2-phenyloxaziridine	380 (acetonitrile) (ε12,700)	
	314 (ε17,700)	
	238 (ε13,200)	

Isolation of Stable Diaryl and Triaryloxaziridines

The stable oxaziridines were formed by irradiation of 30-80 mg of the corresponding nitrone in 100 ml of redistilled methylene chloride. Unless otherwise stated, the irradiations were done in a water-cooled photochemical immersion apparatus of 100 ml capacity equipped with a 450-watt Hanovia high-pressure mercury lamp, Pyrex filter, and a magnetic stirrer and an air bubbler (for more complete stirring). It was found that use of nitrogen gas led to less oxaziridine formation and a darkening of the reaction mixture. The irradiation times listed include the warm-up time for the mercury lamp (ca. 1 1/2 min.), when the lamp is not at full intensity.

The active oxygen contents were measured in the same way as the unstable diaryloxaziridines. However, it was found that in the triaryloxaziridines the solution had to be heated for about five minutes at 50-60° before complete iodine liberation occurred.

2-(4-cyanophenyl)-3-phenyloxaziridine

A solution of 46.1 mg N-(4-cyanophenyl)-α-phenylnitrone in 100 ml methylene chloride was irradiated for 3 minutes. The solvent was removed and the crystals collected. mp 82-84°. uv max (acetonitrile) 252 mμ (ε19,500), 272 (sh,ε7,200); ir (CCl_4) 3065 (C-H), 3035 (C-H), 2230 (C≡N), 1600, 1490, 1457, 1407, 1390, 1310, 1203, 1147, 862, 825, 690 cm^{-1}; active oxygen 98%; ms (70 eV) m/e (relative intensity) 222, (M^+,5), 206 (30), 152 (18), 118 (65), 106 (55), 105 (80), 91 (33), 90 (19), 77 (100), 51 (80). NMR (CCl_4) δ7.42 (m,9) and δ4.62 (s,1).

2-(4-nitrophenyl)-3-phenyloxaziridine

A solution of 54 mg of N-(4-nitrophenyl)-α-phenylnitrone in 70 ml methylene chloride was placed in a water-cooled 1 cm Pyrex "lollipop" of 70 ml capacity. The solution was irradiated for 3 minutes with two GE-DBX photospots placed 4 inches on either side of the cell. The solution was then placed in a 200 ml flask and the solvent removed by rotary evaporation at room temperature. The remaining orangish crystals were dissolved in 2 ml methylene chloride. Petroleum ether (10 ml) was added until the solution became opaque and the solution was then stored at 0°C. After several hours, an orangish crystalline material precipitated from the solution. Collection on a sintered glass funnel and washing with petroleum ether yielded 46 mg of crystals, mp 95-102°. uv max (acetonitrile) 290 mμ (ε12,600); active oxygen 94%; ir (CCl_4) 1588, 1520, 1340, 1252, 1105, 868 and 690 cm^{-1}; ms (70 eV) m/e (relative intensity) 242 (M^+,5), 226 (58), 225 (22), 196 (19), 179 (15), 138 (23), 106 (70), 105 (80), 77 (100).

3-styryl-2-phenyloxaziridine

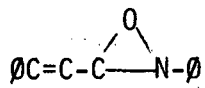
A solution of 65 mg α-styryl-N-phenylnitrone in 100 ml methylene chloride was irradiated for 3 minutes with nitrogen bubbling. The solution was immediately transferred to a 500 ml flask. After two freeze-dry cycles, the solvent was vacuum transferred off. Total time was about one hour and the maximum temperature of the solution was about -10°C. There remained off-white crystals. mp 62-64°. Active oxygen 78%. The crystals could also be obtained by stripping of the solvent of a rotary evaporator at low temperature. Ethanol or carbon tetrachloride as solvent gives a brown oil. uv max (heptane) 256 mμ, (acetonitrile)260 mμ

(ε26,800); ir (CCl_4) 6.78, 6.94, 7.21, 10.39 and 14.50 microns; NMR (CCl_4) 4.30 (d, 1, J=8cps), 6.05 (q, 1, J=7 and 16 cps), 6.98 (d, 1, J=16 cps) and ∿7.3 (m, 10); ms (70 eV) m/e (relative intensity) 233,(M^+; 8), 207 (20), 206 (30), 132 (80), 131 (70), 104 (57), 103 (65), 77 (100). The material is quite unstable, decomposing to a dark oil after two hours at room temperature. However, it can be kept for several weeks at dry ice temperature. Because of the instability, the mass spectral pattern (taken at 80°) is probably not that of the pure compound.*

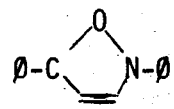
Triphenyloxaziridine

A solution of 67 mg α,α,N-triphenylnitrone in 100 ml methylene chloride was irradiated for 4 1/2 minutes. After solvent removal on a rotary evaporator at room temperature, 67 mg (100%) of a cream-colored crystal was isolated. mp 125° (The melting point was difficult to determine because the material melted and resolidified and then remelted at 150-160° (presumably impure benzoyldiphenylamine)); uv (acetonitrile) only end absorption with ε12,400 at 230 mμ, 273 mμ (sh,ε 1,890), and 266 mμ (sh, ε2,700); active oxygen 99%; ir (CCl_4) 360 (C-H), 3030 (C-H), 1449 , 1245, 1070, 945 and 690 cm^{-1}; ms (70 eV) m/e (relative intensity) 273 (M^+,5), 257 (1.6), 182 (32), 180 (9), 152 (5), 106 (11), 105 (100), 93 (16), 91 (12), 77 (100), 51 (75), 50 (25). Anal. Calcd for $C_{19}H_{25}NO$: C, 83.52; H, 5.50; N, 5.13. Found: C, 83.52; H, 5.65; N, 5.47.

* Two reasonable structures can be drawn for the nitrone photoproduct, one an oxaziridine structure (I) and the other an isoxazole (II). The oxaziridine structure (I) is favored for three reasons: First, in analogy



(I)



(II)

with other nitrones, an oxaziridine would be the expected photoproduct from irradiation of the N-phenyl-α-styrylnitrone. Second, the uv spectra favors the oxaziridine structure. The long wavelength absorption of the photoproduct at 260 mμ (in acetonitrile, ε27,000) is typical of a substituted styryl residue (styrene max 244 mμ). On the other hand, the isoxazole structure (II) would not be expected to show any long wavelength absorption since it contains no long conjugated system. Finally, in the NMR spectra there are four nonaromatic hydrogen resonances, a doublet at τ5.70 (J=8 cps), a quartet at τ3.95 (J=8 and 16 cps), and a doublet at τ3.02 (J= 16 cps) of relative areas 1:1:1. The doublet at τ5.70 is consistent with an oxaziridine ring proton in analogy with other oxaziridine systems that have been investigated; (3-phenyl-2-t-butyl-oxaziridine,τ5.49; 3-p-nitrophenyl-2-t-butyloxaziridine,τ 5.12; 2-(p-cyanophenyl)-3-phenyloxaziridine, τ5.38.) Likewise, the other two resonances are consistent with a trans- styryl moiety. (α-H 3.31, trans-β-H 4.27 for styrene.)[45]

On the other hand, it is difficult to rationalize the observed resonances with an isoxazole structure. In addition, this photoproduct has a high active oxygen content. Isoxazoles have not been reported to be strongly oxidizing compounds while oxaziridines are very strong oxidizers.

2-(4-bromophenyl)-3,3-diphenyloxaziridine

N-(4-bromophenyl)-α,α-diphenylnitrone (47.7 mg) were irradiated for 3 minutes in 100 ml methylene chloride. The solvent was removed under rotary evaporation. An oil was obtained which solidified upon cooling with dry ice. Yield 28.4 mg (60%). mp 88-89°; active oxygen 95%; uv (acetonitrile) only end absorption, shoulder at 250 mμ(ε14,600); ir 3060 (C-H), 1477, 1447, 1265, 1070, 1008, 946, 830 and 696 cm^{-1}; ms (70 eV) m/e (relative intensity) 353 (M^+,7), 351 (7), 337 (11), 335 (15), 260 (8), 258 (8), 182 (60), 173 (18), 171 (18), 105 (100), 77 (46).

3-(4-nitrophenyl)2,3-diphenyloxaziridine

α-(4-nitrophenyl)-α,N-diphenylnitrone (58.4 mg) were irradiated for 3 minutes in 100 ml methylene chloride. The solvent was removed by rotary evaporation at room temperature. The oil was taken up in a small amount of methylene chloride and petroleum ether and the solution was stored at 0°C. As the solvent evaporated, yellow crystals formed. These crystals were collected and washed with petroleum ether. Yield 12.3 mg (21%). mp 106-109°; Active oxygen 98%; uv max (acetonitrile) 267 mμ (ε14,500); ms (70eV) m/e (relative intensity) 318 (M^+,100), 302 (10), 227 (35), 225 (16), 150 (36), 105 (47), 93 (6), 77 (11).

3-(4-anisyl)-2,3-diphenyloxaziridine

A solution of 127 mg α-anisyl-α,N-diphenylnitrone in 100 ml methylene chloride were irradiated for 5 minutes. The solvent was removed by rotary evaporation and the resulting oil was redissolved in a minimum amount of petroleum ether. The solution sat at 0° for several weeks.

A white precipitate crystallized out. Yield 92.9 mg (73%). mp 103-106°. Active oxygen 96%; uv max (acetonitrile) 234 mμ (ε20,900); ir (CCl_4) 3065 (C-H), 2960 (C-H), 2837 (C-H), 1608 (C=C), 1510, 1250, 1172, 1038, 974 and 690 cm^{-1}; ms (70 eV) m/e (relative intensity) 303 (M^+,1.5), 287 (2.3), 273 (9), 257 (3), 212 (24), 182 (11), 180 (13), 135 (60), 105 (70), 93 (26), 92 (21), 91 (5), 77 (100), 51 (55).

3,3-fluorenylidine-2-phenyloxaziridine

A solution of 61.4 mg N-phenylfluorenylketoxime in 70 ml methylene chloride was irradiated in a water-cooled 1 cm Pyrex "lollipop" of 70 ml capacity. The irradiation was performed by 2 GE-DBX photospots placed 4 inches on either side of the cell. After 25 minutes, the nitrone was completely irradiated. The solvent was removed by rotary evaporation at low temperature (<0°C). The oily material was run through a 2" x 1/4" supercel column, eluting with 3:1 petroleum ether-methylene chloride. After removing the solvent and refrigerating, 34.9 mg of a yellowish crystal were obtained. mp 102-104°; uv max (acetonitrile) 296 mμ (ε 8,300); 283 mμ (ε10,900), 272 mμ(ε 11,500), 243 mμ (ε 51,000), 237 mμ(ε 44,600); ir (CCl_4) 3067 (C-H), 1612 (C=C), 1590 (C=C), 1483, 1450, 1322, 930 and 690 cm^{-1}; (no fluorenone carbonyl (1713 cm^{-1}) nor nitrone N-O (1260 cm^{-1})); ms (70 eV) m/e (relative intensity) 271 (M^+, 32), 276 (29), 255(9), 180 (100), 152 (25), 151 (16), 93 (16).

3-(4-bromophenyl)-2,3-diphenyloxaziridine

A solution of 51 mg of α-(4-bromophenyl)-α,N-diphenylnitrone in 100 ml methylene chloride was irradiated for 5 minutes. The solvent was removed by rotary evaporation leaving a dark oil which partially solidified at

dry ice temperature. uv max (acetonitrile) 228 mμ (ε23,300); active oxygen 100%. (After 4 days in acetonitrile at room temperature the active oxygen was 91%). ms (70 eV) m/e (relative intensity) 353 (M^+,56), 352 (15), 351 (58), 337 (96), 335 (100), 260 (30), 258 (25), 185 (41), 183 (42), 131 (38), 105 (56), 77 (25).

2-(4-nitrophenyl)-3,3-diphenyloxaziridine

A solution of 50 mg of N-(4-nitrophenyl)-α,α, -diphenylnitrone in 70 ml of methylene chloride was placed in a water-cooled 1 cm Pyrex "lollipop" of 70 ml capacity. The solution was irradiated for 70 seconds with two GE-DBX photospots placed 4 inches on either side of the cell. The solvent was then removed by rotary evaporation at room temperature. The resulting crystals were recrystallized from 1 ml methylene chloride and 10 ml petroleum ether at 0°C. Collection of the resulting orange precipitate resulted in a yield of 41 mg of crystalline product. mp 110-115°; uv max (acetonitrile) 257 mμ(ε16,200); active oxygen 94%; ms (70 eV) m/e (relative intensity) 318 (M^+, 1), 302 (2), 182 (40), 181 (9), 152 (7), 138 (6), 106 (14), 105 (100), 77 (93).

3-methyl-2,3-diphenyloxaziridine

A solution of freshly prepared α-methyl-α,N-diphenylnitrone was irradiated for 3 minutes in methylene chloride. The solvent was removed by rotary evaporation at low temperature. A dark oil remained. uv only end absorption at 230 mμ(ε9,400) (acetonitrile); ir (CCl_4) 3015, 2950, 1588, 1480, 1444, 1372, 1300, 1252, 1058, 1022, and 688 cm^{-1}; ms (70 eV) m/e (relative intensity) 211 (M^+,16), 198 (7), 195 (42), 180 (75), 120 (19), 105 (100), 93 (63), 91 (12), 77 (86), 51 (14); active oxygen 100%; NMR (CCl_4) (see section on NMR) after equilibration, δ 7.1 (m,10) δ 1.95 (s,∿1) and δ1.57 (s, ∿2).

REARRANGEMENT OF DIARYL AND TRIARYLOXAZIRIDINES

Kinetic Procedure

The di- and triaryloxaziridines proved to be very obliging systems for kinetic study. Irradiation of the corresponding nitrone produced the oxaziridines in high yield and the oxaziridine rearrangement was both clearly first-order and quite reproducible. The general kinetic procedure used is described below:[42]

30-70 mg of the corresponding nitrone was dissolved in approximately 75 ml of acetonitrile. The solution was placed in a water-cooled Pyrex immersion apparatus of 100 ml capacity equipped with a 450-watt Hanovia high-pressure mercury lamp, a magnetic stirrer and an air or nitrogen bubbler (for more complete stirring). The solution was irradiated for 4 to 5 minutes and then transferred to a 100 ml volumetric flask. The solution was then diluted to 100 ml with acetonitrile and the volumetric flask was placed in 25.00° ± .01° constant temperature bath. At various intervals 10 ml aliquots were pipetted out and delivered into a 200 ml erlenmeyer flask containing 1 ml saturated potassium iodide and 1/2 ml glacial acetic acid. After swirling for a few seconds to liberate the iodine, 50 ml water was added and the solution was titrated to a starch-iodide endpoint with 0.01 N sodium thiosulfate solution.[43,44]

8 to 9 points were taken during a run, and the runs were generally followed for 2 to 3 half-lives. First-order rate constants were obtained from least square fits calculated using the LSKIN 1 program of DeTars.[46]

In the case of the compound with N-(4-nitrophenyl) or N-(4-biphenylyl) groups, the oxaziridines themselves were found to be photosensitive. To prevent irradiation of the oxaziridines, the irradiations were performed in a 1 cm pathlength, water-jacketed Pyrex cell of 70 ml capacity. Irradiation

was done for 5-15 minutes with two GE-DBX photospots placed 4 inches on either side of the cell.

Runs using ethanol as solvent were performed in a similar manner. For the kinetics at different temperatures, constant temperature baths were used which were calibrated using NBS standardized thermometers. The solutions at higher temperatures were allowed to equilibrate for 15 minutes before the first point was taken. Tests indicate that the flask is within 1° of the equilibrium temperature in 15 minutes.

In the case of the kinetic run done in benzene, a modified procedure was used. After the benzene aliquot was added to the KI-acetic acid mixture, acetonitrile was poured into the mixture until one phase resulted. After swirling for a few seconds, 50 ml of water was added and the solution titrated to a starch-iodide endpoint with .01 N sodium thiosulfate. The solution had to be stirred quite rapidly since two phases were present during the titration.

For the triaryloxaziridine a similar procedure was employed except that the solution of KI-acetic acid and oxaziridine solution had to be heated for 5 minutes at 50-60° before the iodine liberation occurred.

The acetonitrile was reagent grade which was refluxed for several days over calcium hydride, distilled and stored over molecular sieves. The ethanol (absolute) was continually refluxed over anhydrous magnesium ethoxide and distilled immediately before use.

To guard against the possibility that traces of acids on the wall of the reaction vessel were catalyzing the decomposition of the oxaziridines, the following procedure was employed. The volumetric flasks were washed with soapy water, rinsed and transferred into an ethanolic potassium hydroxide bath. After sitting overnight the flasks were removed and rinsed thoroughly with tap water and then distilled water and dried.

Kinetic Results

Run Number	Compound (Oxaziridine)	Solvent/ Temperature	Amount of Compound mg/100 ml)	Time of Irradiation (min.)	First Order Rate Constant ($\times 10^4$ sec^{-1})
D-61	2,3-diphenyl	acetonitrile/25°	52.8	4	4.78 ± .2
D-62	2-(4-chlorophenyl)-3-phenyl	"	53.6	3 1/2	5.59 ± .2
D-64	2,3-diphenyl	"	47.5	4	4.86 ± .1
D-65	2-(4-chlorophenyl)-3-phenyl	"	47.5	4	5.41 ± .8
D-66	2-(4-methylphenyl)-3-phenyl	"	50.2	4 1/2	41.0 ± 3
D-69	" "	"	50.4	4	42.6 ± 2
D-70	2,3-diphenyl	"	46.1	5	4.45 ± .1
D-71	2,3-diphenyl-α-D	"	47.3	4	3.48 ± .2
D-74	2,3-diphenyl	" /45°[a]	43.9	5	57.0 ± 1
D-75	2,3-diphenyl-α-D	" /25°	45.8	4	3.49 ± .1
D-76	2,3-diphenyl	" /45°[a]	51.8	5	54.9 ± 2
D-78	2,3-diphenyl-α-D	" /25°	45.8	4	3.46 ± .3
D-79	2-(3-fluorophenyl)-3-phenyl	"	44.4	4	1.43 ± .03
D-81	2,3-diphenyl	ethanol/25°	42.4	3	90.0 ± 4

D-82	2,3-diphenyl-α-D	ethanol/25°	47.2	4	70.3 ± 3
D-83	2,3-diphenyl	"	51.9	4	83.4 ± 3
D-84	2,3-diphenyl-α-D	"	45.7	4	88.0 ± 2
D-88	"	acetonitrile/25°	45.7	4	3.34 ± .2
D-89	2,3-diphenyl	ethanol/25°	40.1	4	82.1 ± 1
D-90	2.3-diphenyl-α-D	"	47.3	4	80.4 ± 3
D-92	2-(4-methylphenyl)-3-phenyl	acetonitrile/25°	44.7	4	41.1 ± 2
D-95	2-(3-fluorophenyl)-3-phenyl	"	40.3	4	1.34 ± .02
D-97	2-(4-biphenylyl)-3-phenyl	"	51.2	3 1/2	58.7 ± 2
D-98	2,3-diphenyl	90% acetonitrile -2% water /25°	48.8	4	6.03 ± .6
D-99	2-(4-biphenylyl)-3-phenyl	acetonitrile/25°	60.7	15[b]	63.0 ± 1
D-100	2-(4-nitrophenyl)-3-phenyl	"	35.4	5[b]	0.661 ± .021
E-36	3-(4-methoxyphenyl)-2-phenyl	"	51.2	5	4.22 ± .10
E-37	3-(4-nitrophenyl)-2-phenyl	"	52.5	5	5.97 ± .14
E-47	3-(4-chlorophenyl)-2-phenyl	"	52.8	3 1/2	4.14 ± .13

E-48	3-(3-nitrophenyl)-2-phenyl	acetonitrile/25°	56.5	5	5.08 ± .12
E-73	2-(4-nitrophenyl)-3-phenyl	"	43.8	6[b]	0.524 ± .009
F-5	2,3,3-triphenyl	"	61.1	4	0.344 ± .0077
F-15	2-(4-cyanophenyl)-3-phenyl	"	57.7	6	0.472 ± .011
F-18	2,3-diphenyl	" /35°	89.9[c]	5	15.6 ± 0.53
F-19	"	"	"	"	15.9 ± 0.39
F-24	"	" /40°	50.2	4	31.9 ± 0.89
F-25	"	" /30°	55.6	3	8.60 ± 0.15
F-26	2-(4-bromophenyl)-3-phenyl	" /25°	67.6	3 1/2	4.60 ± .078
F-29	3-(4-methoxyphenyl)-2,3-diphenyl	"	70.0	4	0.441 ± .028
F-32	2,3-diphenyl + triethylamine	" /23°	63.4[d]	4	151 ± 7.9
F-37	2,2,3-triphenyl	ethanol/25°	69.5	4	0.702 ± .067
F-41	2,3-diphenyl	benzene/25°	55.7	3 1/2	1.36 ± .054
F-42	2-(4-chlorophenyl)-3-phenyl	ethanol/25°	48.6	3 1/2	596 ± 26
F-43	2-(3-fluorophenyl)-3-phenyl	"	61.3	4	6.11 ± .10

F-45A	2,3-diphenyl	ethanol/25°	48.0	4	74.8 ± 0.73
F-45B	2,3-diphenyl-α-D	"	49.9	3 1/2	73.5 ± 2
F-47	2-(4-cyanophenyl)-3-phenyl	"	53.7	4	2.37 ± .034
F-53	3,3-fluorenylidine-2-phenyl	acetonitrile/25°	46.4	3	1.09 ± .0075
F-61A	2,3-diphenyl	"	58.8	3 1/2	4.23 ± .03
F-61B	2,3-diphenyl-α-D	"	54.2	3 1/2	3.24 ± .058
F-66	3-(4-dimethylaminophenyl)-2-phenyl	"	60.5	6[b]	68.2 ± 3.7
F-67A	3-(4-nitrophenyl)-2-phenyl	"	47.6	3 1/2	6.09 ± .19
F-67B	"	ethanol/25°	61.3	3 1/2	146 ± 4
F-68	3-(4-methoxyphenyl)-2-phenyl	"	58.4	4	193 ± 5.7
G-15	2-(nitrophenyl)-2,3-diphenyl	acetonitrile/25°	54.4	3[a]	< .05

[a]Equilibrate 15 minutes at 45° before the first point taken.

[b]Irradiated in 70 ml acetonitrile in a water-cooled 1 cm cell with two GE-DBX photospots, 20 cm apart. After the irradiation, the solution was diluted to 100 ml.

[c]The solution was divided into two 50 ml fractions and separate kinetic measurements were taken on each.

[d]Experimental details are given elsewhere in the experimental section.

Calculation of the Activation Parameters for the Rearrangement of 2,3-Diphenyloxaziridine in Acetonitrile.

The rate of rearrangement of the 2,3-diphenyloxaziridine was determined at five different temperatures ranging between 25° and 45°C. (See the kinetic section for general procedures.) All temperatures were checked with an NBS calibrated thermometer. The results of the temperature runs are listed below.

Temperature (°C)	Total Rate ($x10^4$ min^{-1})
25° [a]	4.58 [c]
30° [b]	8.6
35° [b]	15.7
40° [b]	31.9
45° [a]	56.0 [c]

a. ± .01

b. ± .1 A constant temperature bath was employed. Because of the small volume of water in the bath, noticible fluctuations in the temperature occurred.

c. Average value for duplicate runs.

A plot of the log of the reaction rate against the inverse of the temperature (see results section) yielded a good straight line. From this a value of ΔH of 24.2 kcal/mole was obtained. Gas chromatographic analysis of the products from the reaction showed only two components, benzanilide and diphenylformamide, resulting from hydrogen and aryl migration respectively. Determination of the ratio of products at 25° and 45°C indicated that

identical product distributions (73 ± 0.5% benzanilide and 27 ± 0.5% diphenylformamide) were obtained at 25° and 45°C. Thus ΔH calculation for both reactions were the same, ΔH=24 kcal. From the partial rate factors a value of -1 1/2 eu and -3 1/2 eu were calculated for the ΔS for the formation of benzanilide and diphenylformamide respectively.

ISOMERIZATION OF 3-METHYL-2,3-DIPHENYLOXAZIRIDINE

Kinetic Run at 22°C

The 3-methyl-2,3-diphenyloxaziridine was prepared by irradiating 50 mg of the 3-phenyl-2,3-diphenylnitrone for 3 1/2 minutes in methylene chloride. The solvent was removed by rotary evaporation at low temperature (<0°) and the remaining oil was taken up in carbon tetrachloride and placed in an NMR tube. The total elapsed time since irradiation was about 50 minutes. NMR spectra were taken on a Varian T-60 NMR at about 90 minute intervals. Between scans, the sample was maintained at ambient temperature (22 ± 1°C). The relative areas of the methyl peaks are given as a function of time. The first order rate constant was calculated by plotting log [% $Methyl_1$ —% $Methyl_1$ (at t= ∞)] as a function of time.

Time (min.)	% $Methyl_1$ (upfield)	$\%M_1-\%M_\infty$
0	25.7	42.3
84	39.8	28.2
185	50.0	18.0
226	54.5	13.5
∞	68.0	--

The value for $t_{1/2}$ was measured as 140 minutes, $k = 8.2 \times 10^{-5}$ $sec.^{-1}$

Kinetic Run at 0°C.

About 50 mg of 3-methyl-2,3-diphenyloxaziridine was prepared as above. The sample was stored at dry ice temperature until used. The kinetics were run in an ice filled dewar. At various intervals, the tube was removed and placed in a Varian A-60 NMR thermostatted to 0°C. The spectra was taken and the sample returned to the dewar. After it became apparent that the reaction was very slow, further spectra were performed on the Varian T-60 NMR. At various intervals the sample was placed in the T-60 NMR and the two methyl resonances were quickly integrated and the sample returned to the ice water bath. Since each measurement took on the order of 30 seconds, it was felt that short periods in the T-60 NMR (ambient temperature 30°C) did not appreciably affect the kinetics since the kinetics were taken over a period of 8 days. The relative areas of the methyl resonances are given below as a function of time. The first order rate constant was calculated by plotting log (% upfield Methyl - % upfield Methyl at $t=\infty$) as a function of time.

Time (hours)	% Upfield Methyl M_1	% Upfield Methyl at time t $-\%M_1$ at $t=\infty$
0	20.1	47.9
3	22.0	46
4.3	25.7	42.3
5.5	24.2	43.8
6.5	24.1	43.7
8.5	25.5	42.5
10	27.3	40.7
23	29.0	39.0
76	41.4	26.6
104.5	46.5	21.5

119	46.2	21.8
129	50.5	18.0
142.5	53.1	14.9
153.5	51.2	16.8
176.5	56.5	11.5
∞	68.0	

At t=∞ , slight amounts of acetophenone, acetyldiphenylamine and an unknown methyl-containing constituent were present in the solution (totalling about 20% of the methyl-containing compound).

Properties of the Oxaziridine Solution

A series of experiments were performed to verify the fact that both methyl resonances were from the oxaziridine and not from any rearrangement or decomposition product.

1) Methyl resonances. The NMR spectra of the major decomposition products are given below:

Acetophenone (commercial) (CCl_4) τ7.55 (s,3),τ∿ 2.6 (m,3),τ∿ 7.8 (m,2).

Acetophenone anil (synthesized by the method of Claisen[47]) (CCl_4) τ7.83 (s,2.8), τ∿6.7 (m,2),τ∿ 7.4 (m,6)τ∿ 8.0 (m,2).

N-methylbenzamide (CCl_4) τ6.49 (s) (from the thermal rearrangement of the oxaziridine in acetonitrile).

Acetyldiphenylamine (CCl_4) τ 8.12 (s) (from the thermal rearrangement of the oxaziridine in acetonitrile).

None of the methyl resonances of these compounds corresponded to the high field methyl resonance encountered in the oxaziridine solution.

2) Spectral Changes. A freshly prepared solution of 3-methyl-2,3-diphenyloxaziridine (50 mg) in 100 ml of methylene chloride was allowed to stand at room temperature for 8 hours. Active oxygen measurement showed a 98% content. NMR measurements of the solution (in CCl_4) indicated that the percentage of the low field methyl signal had decreased from 80% to 45%. Thus a large drop in the amount of the low field methyl signal did not result in a lowering of active oxygen content. The ir showed no noticible change except for a slight increase in carbonyl absorption at 1680 cm^{-1} and a slight increase in two peaks at about 1290 and 1302 cm^{-1}. The uv was unchanged.

3) The thermal rearrangement of 3-methyl-2,3-diphenyloxaziridine. When kinetic measurements were attempted in acetonitrile, it was found that the reaction occurred very slowly. After 6 days at room temperature over 90% of the compound was still present. Samples, each containing 50 mg of the oxaziridine formed by irradiation of the nitrone were refluxed in three different solvents for several days. Gas chromatography of the resulting solutions indicated that two products were formed. They were idenfified as the expected rearrangement products--acetyldiphenylamine and N-methylbenzanilide--by mass spectrometry (see product identification section). The results are summarized below:

Solvent	% CH_3 Migration	% Phenyl Migration
Carbon tetrachloride*	76%	24%
Acetonitrile**	68%	32%
Ethanol**	56%	44%

*The product composition was determined by NMR. The acetyldiphenylamine had a characteristic methyl resonance at τ8.12, while the N-methylbenzanilide had a methyl resonance at τ3.65. Small amounts of acetophenone were also detected.

**The product composition was determined by gas chromatography.

Calculation of Product Distributions

After the kinetic run was finished, the remaining 10-20 ml of oxaziridine solution was allowed to remain at bath temperature for an additional 5 to 10 half-lives. The solution was concentrated and the product distribution was determined by gas chromatography on an Aerograph 204 or an Aerograph 665.

The columns employed were 10 ft x 1/16 in stainless steel packed with 3% OV-1 or 3% SE-30 phase on 60/80 Chromsorb Q. The machine was generally linearly programmed from 75 to 300°C at 6°C/min. (He flow 30cc/min) and the components were measured using a hydrogen flame detector. In rare cases, when peak separation was poor, separation was achieved using a 50 or 100 ft x .01 in (I.D) stainless steel capillary column coated with Apiezon L, programmed at 2°C/min from 90° to 300°C (He flow 2ml/min).

In certain instances when insufficient material remained after the kinetic run, a fresh solution of the oxaziridine was prepared, allowed to stand for 5-10 half-lives and analyzed as above.

The peak areas were measured by two general techniques--triangulation (peak height times half-width) and cutting and weighing. It was found that results obtained by the two procedures were very similar and since the latter was more convenient, it was generally used. (Xeroxed copies of the spectra were cut and weighed to preserve the original spectra.)

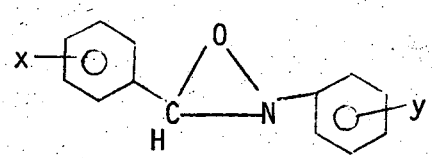
Since a hydrogen flame detector was being used, it was assumed that the peak area per mole of isomeric materials would be equal. This seems reasonable since the response of a hydrogen flame detector is roughly proportional to the number of carbon atoms in the component. In particular, the two

components that we are concerned with here are anilides and the corresponding formamides. Since both compounds contain the same functional groups, their peak area per mole should be very close.

However, measurements have shown that this was not entirely correct. In all cases where sufficient product was available for comparison the formamide had a peak area per mole of from 13% (p-H) to 30% (p-NO_2) higher than the anilide in our chromatographic system.

To alleviate time consuming synthetic effort, an average normalization factor of 1.2 was employed throughout this work. This approximation should cause an error of no greater than $\pm$ 4% for the measurement being made if we assume the 13% and 30% are extremes. Since our kinetics are probably accurate to only 5-10% it was felt that this additional error would not invalidate the results of the work, particularly since we are only interested in orders of magnitude effects.

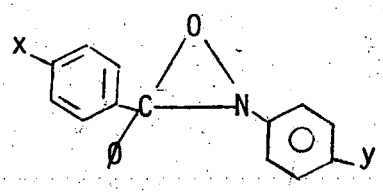
Product Distribution in the Thermal Reaction of Diaryloxaziridines



x	y	Solvent	Rearrangement Products		
			%Anilide	% Formamide	
H	H	Acetonitrile	73	27	
		Ethanol	16	61	20% others
H (α-D)	H	Acetonitrile	73	27	
		Ethanol	15	65	∿ 6% imine, 3% diphenylamine 11% others
p-methoxy	H	Acetonitrile	85	15	
		Ethanol	0	100	
p-Cl	H	Acetonitrile	73	27	
m-nitro	H	Acetonitrile	88	6	6% imine
p-nitro	H	Acetonitrile	85	9	6% imine
		Ethanol	31	19	40% hydrolysis[42]
p-NMe_2	H	Acetonitrile	53	27	8% imine, 13% nitrone* (*by uv spectra)
		Ethanol	0	100	

H	p-methoxy	Acetonitrile	100	0	
		Ethanol	100	0	
H	p-phenyl	Acetonitrile	74	26	
H	p-CH_3	Acetonitrile	87	13	
		Ethanol	<5	>95	
H	p-Cl	Acetonitrile	81	19	
H	p-bromo	Acetonitrile	83	17	
H	m-fluoro	Acetonitrile	100	0	
		Ethanol	38	5	53% imine, 3% azo.
H	p-cyano	Acetonitrile	100	0	
		Ethanol	40	5	53% imine
H	p-nitro	Acetonitrile	100	0	
		Ethanol	100	0	
H	H	Benzene	83	11	6% imine
H	H	Isooctane	90	0	10% hydrolysis[42]

Product Distribution in the Thermal Reaction of Triaryloxaziridines



x	y	Solvent	Rearrangement Products[a]	
			% phenyl migration	% phenyl-x migration
H	H	Acetonitrile	100	--
H	OMe	Acetonitrile	100	--
NO_2	H	Acetonitrile	55	45[b]
		Ethanol	60	40
OMe	H	Acetonitrile	~ 40	~ 60
		Ethanol	~ 40	~ 60
NO_2	OMe	Benzene	58	42
		Acetonitrile	80	20
		Ethanol	90	10
H	NO_2	Acetonitrile	< 5	--[c]

a. In all cases the two amide products represented greater than 85% of the total products.

b. In addition there was about 10-15% of an unidentified component.

c. The major detectable product was benzophenone (by gc coinjection).

Absolute Product Yield

It has been found previously[42] that the yield of rearrangement product in the thermal reactions of oxaziridines is quite high. The yields vary from 70% to quantitative. Although absolute product yields were not calculated for all the reactions, a sufficient number were done to indicate that near quantitative yields (>70%) were obtained in almost all reactions. In all reactions done, unless otherwise noted, only traces <10% of other products were visible in the glpc trace of the product solution.

Three compounds were investigated in detail. Known quantities of kinetic solutions were injected into the glpc and were compared with known quantities of synthesized products by comparing recorder peak areas. With the three compounds investigated, the p'CH_3, p'Ø and p'OMe diphenyloxaziridines in acetonitrile, absolute product yields of 90,83 and 100% were obtained.

Product Isolation

All products were isolated by preparative gas chromatography on an Aerograph A-90-P gas chromatograph (thermal conductivity detector) equipped with a 10 ft x 1/4 in,or a 25 ft x 1/4 in 3% SE-30 column. Helium flow 50 ml/min. Injector temp. 275°C. Detector temp. 255°-295°C. The machine was linearly programmed from 90°-300°C at 6°C/min. 20-50 microliters of a 1-10% solution was injected and the products collected in capillary tubes. In several instances products were collected on an F&M 5750 gas chromatograph equipped with a 10 ft x 1/4 in 3% OV-1 on 60-80 mesh Gaschrom Q under the same conditions given above. The machine was equipped with a splitter so that 20% of the sample went to a hydrogen flame detector and 80% was collected.

Some rearrangement reactions were sufficiently specific that only one predominant product was formed which could be isolated preparatively. The conditions and results of these isolations are given below:

2,3,3-triphenyloxaziridine in acetonitrile

A solution of 90.8 mg α,α,N-triphenylnitrone in 100 ml acetonitrile was irradiated for 6 min. The solution was refluxed for 22 hours. Evaporation of the solvent gave 79.5 mg of a crystalline solid. Recrystallization from ethanol-water yielded 57.8 mg (64%) of benzoyldiphenylamine. mp 177-178°.

2-tolyl-3-phenyloxaziridine in ethanol

A solution of 74 mg N-tolyl-α-phenylnitrone inl 100 ml ethanol was irradiated for 3 1/2 min. Rotary evaporation of the solvent and washing with petroleum ether yielded a total of 53.3 mg (72%) of 4-methyldiphenylformamide. mp 74-77°. glpc of the material indicated the presence of a trace (<5%) 4'-methylbenzanilide.

2-(3-fluorophenyl)-3-phenyloxaziridine in acetonitrile

A solution of 53.2 mg N-(3-fluorophenyl)-α-phenylnitrone was irradiated for 5 min. in 100 ml acetonitrile. Active oxygen on 10 ml of the solution showed 100+%. The remaining 90 ml stood at room temperature for several months. The solvent was removed by rotary evaporation yielding 40.2 mg (84%) of a tan crystalline material. mp 128-133°. Recrystallization from chloroform-petroleum ether yielded 26.3 mg (55%) (mp 141-142°) of 3'-fluorobenzanilide.

2-(4-methoxyphenyl)-3-phenyloxaziridine in ethanol

A solution of 47.2 mg N-(4-methoxyphenyl)-α-phenylnitrone in 100 ml ethanol was irradiated for 4 min. The solvent was removed by rotary evaporation. glpc of the product showed only one product having the same retention time as 4'-methoxybenzanilide. Column chromatography in a 2" x 1/2" silica gel column with 1:1 chloroform-hexane as eluent yielded 33.7 mg (72%) of 4'-methoxybenzanilide. mp 157.5-158°. A similar irradiation in acetone yielded a 75% yield of 4'-methoxybenzanilide.

2-(4-cyanophenyl)-3-phenyloxaziridine in acetonitrile

A solution of 48.3 mg N-(4-cyanophenyl)-α-phenylnitrone in 100 ml acetonitrile was irradiated for 4 min. The solution was heated to reflux for 16 hours. Rotary evaporation of the solvent yielded 44.1 mg of an orangish solid. Recrystallization from chloroform yielded 35.9 mg (74%) 4'-cyanobenzanilide. mp 165-167°.

2-(methoxyphenyl)-2,3-diphenyloxaziridine in acetonitrile

A solution of 39.9 mg α-(methoxyphenyl)-α,N-diphenylnitrone in 100 ml acetonitrile was irradiated for 3 min. The solution was refluxed for 2 days. (The uv indicated that the rearrangement was over immediately after irradiation). The solvent was removed by rotary evaporation.

Addition of petroleum ether and cooling yielded 18.8 mg 4'-methoxybenzoyl-diphenylamine.

2-(4-nitrophenyl)-3-phenyloxaziridine in acetonitrile

A solution of 33.1 mg N-(4-nitrophenyl)-α-phenylnitrone was irradiated in 2 batches in a 1 cm water-jacketed Pyrex cell of 70 ml capacity for 1 min. each. The irradiation was done with 2 GE-DBX photospots placed 1 in. on either side of the cells. The solution was refluxed under nitrogen for 2 days. 20% of the solution was saved for glpc analysis. The solvent form the remaining 80% of the solution was removed by rotary evaporation. The remaining orange precipitate was collected and washed with petroleum ether. Yield 22.0 mg (82%). mp ca. 180°. A careless recrystallization from chloroform-petroleum ether yielded 8.1 mg (31%) of 4'-nitrobenzanilide. mp 195-197°. ms (70 eV) m/e (relative intensity) 242 (M^+,27), 226 (6), 222 (4), 212 (5), 138 (17), 112 (25), 105 (100), 83 (15), 77 (26), 70 (77), 55 (45).

3-(4-dimethylamino)-2-phenyloxaziridine

A uv solution of α-(4-dimethylaminophenyl)-N-phenylnitrone in acetonitrile was prepared and the optical density at the λ max of the solution (374 mμ) was determined. The solution was irradiated with GE-DBX photospots for 1/2 minute as previously described until the 374 mμ peak disappeared and the spectrum of oxaziridines was obtained. After allowing the solution to stand for one day (> 12 half-lives) the O.D. at 374 mμ was again measured and the solution reirradiated for 1/2 minute. The loss in O.D. at 374 mμ after the irradiation indicated the presence of 3-(4-dimethylamino)-2-phenylnitrone from the rearrangement reaction of the oxaziridine. From the O.D. change upon reirradiation a yield of 13% nitrone was calculated from the thermal rearrangement of the oxaziridine.

For the product analysis of amide and formamide from oxaziridine rearrangement, a solution of about 20 mg in 100 ml of acetonitrile was irradiated in the usual manner (see kinetic procedures) and reirradiated twice, at about 12 hour intervals. The uv of the final solution showed no evidence of the nitrone. The solvent was then removed and the remaining sample was subjected to glpc analysis as before.* No other compound investigated gave noticible yield of the nitrones.**

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*The nitrone decomposed when injected into the gas chromatograph giving mainly imine as product.

**Splitter and Calvin[42] report a 20% yield of the nitrone in acetone.

Product Identification

The products isolated by preparative gas chromatography were routinely identified by mass spectrometry. Supplementary evidence for the structural assignment was obtained by glpc coinjection with an authentic sample prepared by other means (when possible), melting point, and infrared spectrometry.

Mass spectrometry provided a clean differentiation between the isomeric anilides and formamides since the anilides showed characteristically intense aroyl ($x\text{-}\emptyset CO^+$) peaks, while the formamides showed a very characteristic peak at m-28 which corresponds to a loss of carbon monoxide from the parent fragment. In the infrared spectra anilides show a characteristic carbonyl frequency at 6.05-6.10 microns while the formamide carbonyl absorbed at 5.93-5.97 microns.

In all cases, the anilides and formamides constituted the largest amount of product with occasional amounts of the corresponding imine.

2,3-diphenyloxaziridine

1) Benzaldehyde imine. Identified by glpc coinjection with an authentic sample.

2) N,N-diphenylformamide. Identified by glpc coinjection with a sample of authentic material. ms (70 eV) m/e (relative intensity) 197 (M^+,100), 169 (M-28,75), 168 (70), 167 (50), 104 (11), 77 (23), (Identical with ms of an authentic sample.)

3) Benzanilide. Identified by glpc coinjection with a sample of authentic material. mp 159-161° (Lit. 161°[32]). ms (70 eV) m/e (relative intensity) 197 (M^+, 50), 168 (52), 105 (100), 77 (44), (Identical with ms of an authentic sample.)

3-(4-chlorophenyl)-2-phenyloxaziridine

1) N-(4-chlorophenyl)-N-phenylformamide. glpc retention time is the same as the corresponding formamide from 2-(4-chlorophenyl)-N-phenylformamide. ms (70 eV) m/e (relative intensity) 233 (35), 231 (100), 203 (M-28,65), 168 (30), 167 (48).

2) 4-chlorobenzanilide. Identified by glpc coinjection with an authentic sample. mp 199-200° (authentic sample mp 199-200°) (Lit. 199-199.5°[35]); ir 3.02 (C-H), 3.29 (C-H), 5.18, 6.10 (C=C), 7.00, 7.19, 7.58, 7.82, 9.19, 9.35, 10.31, 11.09, 11.33, 11.90, 13.37 and 14.70 microns. The ir spectra was identical with that of an authentic sample. ms (70 eV) m/e (relative intensity) 233,(35), 231 (100), 141 (75), 139 (100), 111 (54), 77 (12).

2,3-diphenyloxaziridine (α-D)

1) Benzaldehyde imine. Identified by glpc coinjection with an authentic sample.

2) N-N-diphenylformamide. Identified by glpc coinjection with an authentic sample. ms (70 eV) m/e (relative intensity) 198 (M^+,100), 197 (8.5), 170 (20), 169 (21), 168 (95), 167 (70), 105 (21), 91 (13), 77 (22). (The large 198 peak indicates that the compound is still specifically deuterated.)

3) Benzanilide. Identified by glpc coinjection with a sample of authentic material. ms (70 eV) m/e (relative intensity) 198 (M^+,6), 197 (37), 169 (9), 168 (11), 105 (100), 77 (38).

2-(4-chlorophenyl)-3-phenyloxaziridine

1) N-(4-chlorophenyl)-N-phenylformamide. glpc retention time is consistent with the proposed structure. ir 3.42 (C-H), 5.95 (C=O), 6.30 (C=C), 6.73, 7.93, 9.17, 9.89, 12.52 and 14.50 microns. The ir spectrum is very similar to that of N,N-diphenylformamide. ms (70 eV) m/e (relative intensity) 233 (41), 231 (23), 205 (5), 203 (M-28, 16), 197 (32), 104 (100), 77 (36).

2) 4'-chlorobenzanilide. Identified by glpc coinjection with an authentic sample. mp 191-192° (authentic sample mp 191-192°) (Lit. 192°[32]); ir 2.99 (N-H), 3.26 (C-H), 6.08 (C=O), 6.20 (C=C), 6.61, 7.18, 9.13, 9.36,10.83, 12.19, and 14.02 microns. The ir spectrum is the same as that of an authentic sample. ms (70 eV) m/e (relative intensity) 233 (8), 231 (25), 169 (4), 168 (3), 105 (100), 77 (32).

2-(4-methoxyphenyl)-3-phenyloxaziridine

1) 4'-methoxybenzanilide. Identified by glpc coinjection with an authentic sample. mp 157.5-158° (authentic sample 157.5-158°) (Lit. 153-154°[36]); uv max (ethanol) 281 mμ(ε11,700); ms (70 eV) m/e (relative intensity) 228 (18), 227 (M^+,100), 207 (3), 245 (3), 106 (7), 105 (80), 77 (18), 55 (6),

2-(4-cyanophenyl)-3-phenyloxaziridine

1) 4'-cyanobenzanilide, mp 165-167° (Lit. 170°[48]). ms (70 eV) m/e (relative intensity) 222 (M^+,38), 112 (16), 105 (100), 83 (5), 77 (30), 70 (59), 55 (27).

2-(3-fluorophenyl)-3-phenyloxaziridine

1) 3,3'-difluoroazobenzene. ms (70 eV) m/e (relative intensity) 218 (100),123 (30), 111 (10), 109 (7), 97 (11), 96 (15), 95 (128), 83 (11), 75 (12).

2) 3'-fluorobenzaldehyde anil. ms (70 eV) m/e (relative intensity) 199 (M^+,100), 198 (92), 122 (6), 95 (14).

3) 3'-fluorodiphenylformamide. glpc retention is consistent with the proposed structure. ms (70 eV) m/e (relative intensity) 215 (M^+,100), 188 (6), 187 (M-28,55), 186 (36), 185 (24), 96 (6), 84 (6).

4) 3'-fluorobenzanilide. mp 141-142°; ms (70 eV) m/e (relative intensity) 215 (M^+,38), 105 (100), 83 (3), 78 (3), 77 (4), 70 (10), 55 (7), 51 (9).

3-(4-dimethylaminophenyl)-2-phenyloxaziridine

1) 4-dimethylaminodiphenylformamide. Identified by glpc coinjection with an authentic sample.[42] ms (70 eV) m/e (relative intensity) 240 (M^+, 100),212 (M-28,16), 211 (M-29,34), 197 (10), 167 (15), 77 (4).

2) 4-dimethylaminobenzanilide. Identified by glpc coinjection with an authentic sample.[42] mp 175-180° (authentic sample mp 177-180°)[42] ir major peaks 1625, 1588, 1435, 1315 and 1230 cm^{-1}. uv max (ethanol) 314 m μ. ms (70 eV) m/e (relative intensity) 240 (M^+,27), 197 (4), 149 (11), 148 (100), 135 (7), 134 (3), 77 (4).

2-(4-tolyl)-3-phenyloxaziridine

1) 4-methyldiphenylformamide. glpc retention is consistent with the proposed structure. mp 74-77°, uv max (ethanol) 239 mμ (ε13,000). ir 3.29 (C-H), 3.50 (C-H), 5.93 (C=O), 6.30 (C=C), 6.65, 6.72, 7.17, 7.63, 7.73 and 7.96 microns. ms (70 eV) m/e (relative intensity) 211 (M^+,100), 183 (M-28,57), 182 (46), 167 (23), 77 (15).

2) 4'-methylbenzanilide. Identified by glpc coinjection with an authentic sample. mp 155.5-157° (Lit. 158°[49]). ms (70 eV) m/e (relative intensity) 211 (M^+,50), 168 (2), 167 (2), 105 (100), 77 (48).

3-(4-methoxyphenyl)-2-phenyloxaziridine

1) 4-methoxydiphenylformamide. glpc retention time is consistent with the proposed structure. ir. 3.29 (C-H), 3.43 (C-H), 5.97 (C=O), 5.31 (C=C),6.67, 6.73, 8.06, 8.54, 8.85, 9.76, 12.04 and 14.50 microns. ms (70 eV) m/e (relative intensity) 227 (M^+,100), 199 (m-28,20), 184 (M-28,15,60), 124 (10), 77 (6).

2) 4-methoxybenzanilide. Identified by glpc coinjection with an authentic sample. mp 171-173° (authentic sample mp 172-173°) (Lit. 168°[34]). ir 3.03 (N-H), 3.44 (C-H), 6.08 (C=O), 6.29 (C=C), 6.58, 7.00, 7.58, 8.02, 8.51, 9.81, 11.32, 11.89, 13.38 and 14.60 microns. The ir spectrum is identical with that of an authentic sample. ms (70 eV) m/e (relative intensity) 227 (M^+,28), 135 (100), 107 (4), 92 (8). The mass spectrum is identical with that of an authentic sample.

3-(3-nitrophenyl)-2-phenyloxaziridine

1) 3-nitrobenzaldehyde anil. glpc retention time is consistent with this structure. ms (70 eV) m/e (relative intensity) 226 (M^+,100), 196 (50), 195 (40), 180 (25(, 104 (28), 93 (30), 77 (60).

2) 3-nitrodiphenylformamide. glpc retention time is consistent with the proposed structure. uv max (ethanol) 242 mμ. ir 3080 (C-H), 2860,1675 (C=O), 1588 (C=C), 1518, 1488, 1340, 1250, 1135 and 1070 cm^{-1}. ms (70 eV) m/e (relative intensity) 242 (M^+,100), 214 (M-28,90), 212 (90), 184 (12), 167 (80), 120 (10), 77 (15).

3) 3-nitrobenzanilide. glpc retention time is consistent with this structure. mp 143-146° (Lit. 153°[50]). ir 3.04 (N-H), 3.28 (C-H), 6.09 (C=O), 6.29 (C=C), 6.59, 6.99, 7.46, 7.58, 7.96, 9.38, 11.11, 11.63, 12.41 and 13.33 microns. ms (70 eV) m/e (relative intensity) 242 (M^+,68), 212 (100), 150 (45), 120 (45), 104 (32), 92 (22), 77 (20).

3-(4-nitrophenyl)-2-phenyloxaziridine

1) 4-nitrodiphenylformamide. Identified by glpc coinjection with an authentic sample.[33] ir major peaks at 1680, 1580 and 1487 cm^{-1}. ms (70 eV) m/e (relative intensity) 242 (M^+,100), 214 (M-28,21), 184 (13), 167 (55), 77 (14).

2) 4-nitrobenzanilide. Identified by glpc coinjection with an authentic sample. mp 208-212° (authentic sample mp 213-214°) (Lit. 214°[33,51]); uv max 295 mμ and 230 m μ ir 3300 (C-H), 1650 (C=O), 1590 (C=C), 1510, 1435, 1345, 1310, 868 and 753 cm^{-1}.

2-(4-bromophenyl)-3-phenyloxaziridine

1) 4-bromodiphenylformamide. The glpc retention time is consistent with this structure. uv max (ethanol) 240 mμ. ms (70 eV) m/e relative intensity) 277 (99), 275 (100), 249 (M-28,47), 247 (M-28,50), 168 (48), 167 (82), 166 (25), 97 (21), 77 (20).

2) 4-bromobenzanilide. The glpc retention time is consistent with this structure. mp 201-204° (Lit. 202°[52]). ir 3080, 2860, 1675, (C=O), 1588 (C=C), 1518, 1488, 1340, 1250, 1135 and 1070 cm^{-1}. uv max (ethanol) 296 and 230 mμ . ms (70 eV) m/e (relative intensity) 277 (22), 275 (21), 166 (5), 165 (5), 111 (5), 106 (8), 105 (100), 97 (8), 77 (35).

2-(4-biphenylyl)-3-phenyloxaziridine.

1) 4-phenyldiphenylformamide. The glpc retention time is consistent with this structure. mp 86-88°. ir 3.30 (C-H), 3.47 (C-H), 5.96 (C=O), 6.30 (C=C), 6.75, 7.55, 7.97, 13.17 and 14.50 microns. The ir spectrum is very similar to that of diphenylformamide. ms (70 eV) m/e (relative intensity) 273 (M^+,100), 246,(12), 245 (M-28,60), 170 (14), 105 (4), 77 (3).

2) 4'-phenylbenzanilide. Identified by glpc coinjection with an authentic sample. mp 230-233° (authentic sample 232-234°) (Lit. 227-228°[39]). The ir spectrum is the same as an authentic sample. ms (70 eV) m/e (relative intensity) 273 (M^+,100), 169 (5), 105 (100), 77 (40), The mass spectrum is the same as an authentic sample.

3-(4-methoxyphenyl)-2,3-diphenyloxaziridine

1) N-benzoyl-4-methoxydiphenylamine. Identified by coinjection with an authentic sample obtained from the rearrangement of 2-(4-methoxyphenyl)-3,3-diphenyloxaziridine.in acetonitrile. Quantitative separation was not achieved on a 10 ft x 1/16 in column used in most analyses. One peak with a slight shoulder resulted. Instead, the components were separated on a 100 ft x .01 in Apiezon L-coated stainless steel capillary column; temperature programmed at 2°C/min from 100-300°; helium flow 2 ml/min. On the capillary column, two well separated peaks were observed. each identified by coinjection.

2) anisoyldiphenylamine. Identified by coinjection with an authentic sample. The samples could not be separated by preparative glpc. Both compounds emerged as one peak. Three fractions were taken of the peak (at about 1/4, 1/2 and 3/4 way through the peak) and the important peaks in the mass spectrum of each fraction are shown below:

m/e	(relative intensity)		
	#1	#2	#3
303	60	53	50
198	6	5	01
180	18	13	03
167	10	8	10
135	6	100	100
105	100	89	20
92	4	4	9
77	20	23	20

Thus it appears that the N-benzoyl-4-methoxydiphenylamine (large $\overset{+}{\text{ØCO}}$ m/e 105 peak) appears in the early part of the peak and the anixoyldiphenylamine (large $CH_3O\overset{+}{\text{ØCO}}$ m/e 135 peak) appears in the latter half of the peak. This substantiates the results from the coinjection with authentic sample.

2-(4-methoxyphenyl)-3,3-diphenyloxaziridine

1) N-benzoyl-4-methoxydiphenylamine. Identified by coinjection with the similar product from the rearrangement of 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine. mp 120° (Lit. 121°[53]). ms (70 eV) m/e (relative intensity) 303 (M^+,85), 198 (10), 180 (28), 167 (7), 155 (5), 154 (7), 106 (9), 105 (100), 77 (23).

3-(4-nitrophenyl)-2-(4-methoxyphenyl)-2-phenyloxaziridine

1) N-(4-nitrobenzoyl)-4-methoxydiphenylamine. ms (70 eV) m/e (relative intensity) 349 (5), 348 (M^+,16), 225 (25), 199 (25), 198 (36), 184 (34), 183 (21), 167 (22), 155 (22), 154 (22), 150 (12), 149 (12), 120 (100), 109 (37), 105 (30), 92 (44), 81 (57), 77 (44).

2) N-benzoyl-(4-methoxy-4'-nitrodiphenylamine. ms (70 eV) m/e (relative intensity) 349 (3), 348 (M^+,8), 270 (36), 245 (26), 240 (25), 210 (47), 197 (52), 149 (48), 120 (100), 105 (100), 77 (100).

An ir of a mixture of the two products containing 1) and 2) in a ration of 10:1 showed the following predominant peaks; 3080 (C-H), 3000 (C-H), 2930, 2830, 1659 (C=O) (s), 1600 (s), 1520 (s), 1510 (s), 1342,

1307, 1300, 1247, 1170, 1102, 1032, 850 and 688 cm^{-1}. Separation was poor by preparative gas chromatography and it appears that a mixture of products is present in both mass spectra. Therefore, the identification of both compounds is still tentative.

3-methyl-2,3-diphenyloxaziridine

1) acetyldiphenylamine.[53] ir 3060 (C-H), 2930 (C-H), 1640 (C=O), 1592 (C=C), 1492, 1364, 1302, 1110, 1025, 727, 697. ms (70 eV) m/e (relative intensity) 211 (M^+,22), 170 (M-41,13), 169 (100), 168 (20), 167 (14), 166 (4), 118 (3), 105 (2), and 77 (11).

2) N-benzoyl-N-methylaniline.[54] ir 3060 (C-H), 1668 (C=O), 1590 (C=C), 1485, 1448, 1365, 1330, 1303, 1073, 1030, 760, 690. ms (70 eV) m/e (relative intensity) 211 (30), 169 (4), 106 (7), 105 (100), 77 (38).

3-(4-nitrophenyl)-2,3-diphenyloxaziridine

1) 4-nitrobenzoyldiphenylamine. Identified by glpc coinjection with an authentic sample.[41] ms (70 eV) m/e (relative intensity) 318 (M^+,15), 288 (21), 225 (8), 169 (12),168 (10), 167 (12), 150 (13), 120 (100), 105 (5), 92 (8), 77 (4).

2) N-(4-nitrophenyl)-benzanilide. Identified by glpc coinjection with an authentic sample.[41] ms (70 eV) m/e (relative intensity) 318 (M^+,67), 288 (42), 183 (36), 167 (20), 105 (100), 77 (84).

Instrumentation

NMR: All NMR spectra were taken on a Varian A-90-P or a Varian T-60 instrument using carbon tetrachloride as solvent with TMS as an internal standard unless otherwise note.

uv: All uv spectra were taken on a Cary Model 14 recording spectrophotometer.

ir: All ir were taken on a Perkin-Elmer Model 257 recording spectrophotometer. Generally cells of .05 mm pathlength were used with carbon tetrachloride solutions of the compounds to be measured. When minute amounts of purified compound were available (as with many rearrangement product analyses) the sample was deposited as a thin film on a small sodium chloride plate, and the spectrum was taken using a Perkin-Elmer beam condenser attachment on the Model 257 spectrophotometer.

ms: Mass spectra were routinely run by Miss Sherri Firth on a CEC Model 103 mass spectrometer at 70 eV, using a glass inlet system at about 180°. A few samples were also run on an AEI MS-12 and a CEC-110 machine. The oxaziridines proved sensitive to temperature and their spectra were obtained on the above machines using a metal direct inlet system where the temperature was maintained at 80-100°C.(CEC-103), 80-120°C (MS-12) and under 70°C (CEC-110).

Elemental Analysis: All elemental analyses were performed at the Microanalysis Laboratory, University of California, Berkeley.

IV. MISCELLANEOUS REACTIONS

Reaction of 2,3-diphenyloxaziridine with triethylamine.

To see if the presence of a strong base has any effect on the rate of rearrangement of oxaziridines, the effect of triethylamine on 2,3-diphenyloxaziridine was investigated. 63.4 mg of α,N-diphenylnitrone were irradiated for 4 minutes in about 90 ml acetonitrile. 1.5 ml triethylamine was added and the solution diluted to 100 ml with acetonitrile. Active oxygen measurements on 100 ml aliquots taken at various times indicated a rate of $1.5 \times 10^{-2} min^{-1}$ at 23°C. (Active oxygen at the beginning of the run was 95%.) The rate of rearrangement of diphenyloxaziridine in the absence of triethylamine is about $4 \times 10^{-4} min^{-1}$. Thus triethylamine increases the rate of oxaziridine disappearance by a factor of about 40. After the reaction was allowed to go to completion, uv spectra (acetonitrile) showed a λ max at 250 mμ with a slight shoulder at 320 mμ. Analysis by glpc of the concentrated solution showed the presence of greater than 90% benzaldehyde anil with traces of benzanilide, benzaldehyde, and aniline. By quantitative glpc, the total amount of anil, aldehyde and aniline accounted for about 50% of the starting material. This implies that the triethylamine was being oxidized to triethylamine oxide analogous to the oxidation of brucine to brucine 4-oxide as found by Emmons.[55]

Triethylamineoxide synthesized according to Dustan,[56] was not stable under gas chromatographic conditions, giving triethylamine as the only peak observable.

The reaction of 2,3-diphenyloxaziridine with diethylamine.

1,1-diethylphenylhydrazine

A solution of 48.3 mg α,N-diphenylnitrone in 80 ml acetonitrile was irradiated for 4 minutes. Two ml diethylamine were added and the solution diluted to 100 ml with acetonitrile. After one hour, no active oxygen was detectable. Analysis by glpc indicated the presence of only two components one coinjecting with benzaldehyde (and showing similar mass spectral fragmentation) and one appearing later. Collection of the second component by preparative glpc yielded a liquid. ms (70 eV) 80°) m/e (relative intensity) 165 (14), 164 (M^+,100), 149 (13), 135 (52), 121 (18), 93 (21), 92 (75); ir (CCl_4) 2975 (C-H), 2812 (C-H), 1598 (C=C), 1492 and 1250 cm^{-1}, with no carbonyl peaks; NMR (CCl_4) δ6.7 (m,5),δ 2.57 (q,4, J=6Hz),δ 1.04 (t,6,J=6Hz). The physical data is consistent with the structure of 1,1-diethylphenylhydrazine.[57]

Oxaziridine Photolysis

2-(4-methoxyphenyl)-3-phenyloxaziridine

A solution of 57.1 g N-(4-methoxypehnyl)-α-phenylnitrone in 100 ml reagent benzene was irradiated for 10 minutes through a Pyrex filter in the Hanovia immersion apparatus. Nitrogen gas was bubbled through the solution during the irradiation. During the irradiation the solution darkened to orangish-brown. The solvent was removed by rotary evaporation and the residue was chromatographed on an 8 in x 1/2 in silica gel column. The material was eluted successively with the following amounts of methylene chloride-hexane solution: (%methylene chloride given): 0%-150 ml, 5%-75 ml, 10%-50 ml, 20%-75 ml, 40%-75 ml, 100%-50 ml. From the 40% methylene chloride fraction, 12 mg of a yellow crystal was obtained. mp 162.5-164°.

(All other fractions yielded <4 mg of products.) Final washing of the column with acetone yielded 27.7 mg of dark solid, probably polymeric material.) ms (70 eV) m/e (relative intensity) 242 (78), 135 (33), 121 (4), 107 (100), 92 (24), 77 (30). uv max (ethanol) 354 mμ.

The physical data is consistent with the structure of 4,4'-dimethoxyazobenzene.[58] mp 165°.[58] Molecular weight 242. uv max (ethanol) 360 mμ. (log ε2.57) and 490 mμ (log ε.230).[59]

2-(4-nitrophenyl)-3-phenyloxaziridine

A solution of 30.2 mg N-(4-nitrophenyl)-α-phenylnitrone in 100 ml acetone was irradiated for 6 minutes through a Pyrex fliter with the Hanovia immersion apparatus. The dark solution was concentrated and the residue was chromatographed on a 6 in x 1/2 in silica gel column using methylene chloride-hexane as solvent. A red crystalline material (6.5 mg) was obtained. mp 220-221.5°. The uv max (ethanol) was at 337 mμ. ms (70 eV) m/e (relative intensity) 272 (M^+,100), 242 (6), 150 (66), 138 (12), 122 (76), 92 (28), 83 (25). The properties of this material were identical to those reported for 4,4'-dinitroazobenzene.[60] mp 221-2°, uv max (benzene) at 338 mμ. (ε26,800).[61] Molecular weight 272.

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RESULTS

I. The Thermal Rearrangement of Diaryl and Triaryloxaziridines

A. Kinetics of the Thermal Rearrangement of 2,3-Diaryloxaziridines

The 2,3-diaryloxaziridines proved to be a very easy system for kinetic analysis. The desired 2,3-diarylnitrones were synthesized easily by condensation of the properly substituted benzaldehyde with the appropriate phenylhydroxylamine. Irradiation of the nitrone solution yielded a solution of the corresponding oxaziridine[1] in high yield based on uv and active oxygen determinations.* The thermal reactions of the 2,3-diaryloxaziridines, as followed by active oxygen titration, was first-order in all cases. A typical run is shown in Figure 1. The major products from the reaction were the expected formamides and anilides resulting from aryl and hydrogen migrations from the oxaziridine carbon to the nitrogen.

To investigate the nature of the rearrangement reaction, a series of kinetic experiments were performed, each varying one particular component of the system. The three major variables investigated were the effects of solvent, N-phenyl substituents and C-phenyl substituents on the course of the reaction. From these experiments, in conjunction with a similar investigation of the triaryloxaziridines, a general mechanism for the thermal rearrangement of 2-aryloxaziridines will be presented.

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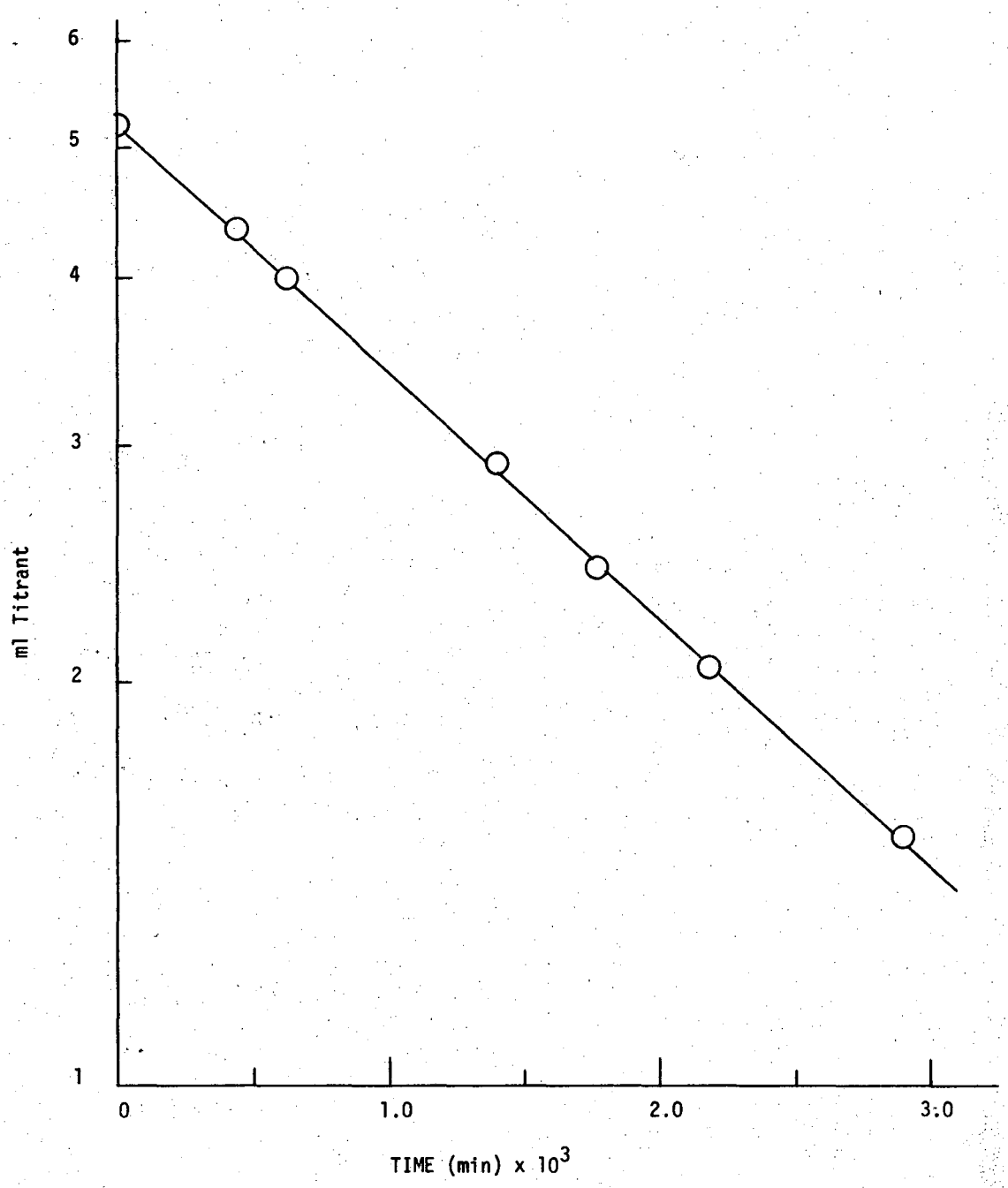
*Irradiation of the nitrones under nitrogen appears to lead to colored solutions with reduced yields of oxaziridine. It appears that the oxaziridine itself can undergo photofragmentation[2] to yield carbonyl products plus phenylnitrenes. For examples, see the experimental section.



XBL 695-4261

Figure 1. Kinetic Run F-61. The thermal rearrangement of 2,3-diphenyloxaziridine in acetonitrile at 25°C.

1. Solvent Effects on the Rearrangement of 2,3-Diphenyloxaziridine

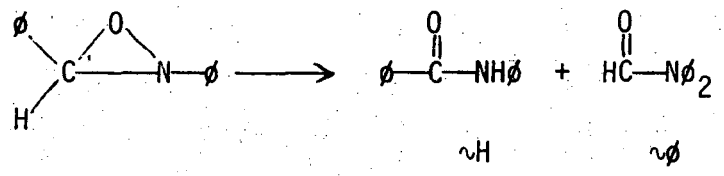
In Table I is shown the effect of solvent variation of the rate of 2,3-diphenyloxaziridine rearrangement. In going from iso-octane to ethanol, a rate increase of over 200 is observed. This large rate increase is not consistent with a homolytic N-O fragmentation where the sensitivity of the reaction to solvent would be expected to be very low. On the other hand, the rate increase with increasing solvating properties of the solvent is consistent with a heterolytic N-O bond cleavage. Here, charge separation is being developed in the transition state and the solvents that tend to stabilize charge will stabilize the transition state and hence increase the rate of rearrangement.

Another important point that must be recognized is the quite different sensitivities that phenyl migration and hydrogen migration show toward solvent. While a change from iso-octane to ethanol causes a 3,000 fold increase in the rate of phenyl migration, the rate of hydrogen migration is accelerated by only a factor of 30. This implies that there is significantly more charge separation in the transition state leading to phenyl migration than for hydrogen migration. This again is consistent with the formulation of a heterolytic N-O bond cleavage. In the transition state for phenyl migration some degree of bonding exists between the phenyl group and the nitrogen. If there is a positive charge generated on the nitrogen, some of the charge can be delocalized on the migrating

TABLE I

Solvent Effects on the Rearrangement of

2,3-Diphenyloxaziridine at 25°*



Solvent	Rate ($\times 10^4$ min^{-1})		
	Total*	H Migration	Phenyl migration
Iso-octane	~0.4[1]	0.4[1]	<.02[1]
Benzene	1.36**	1.18	0.18
Acetonitrile	4.7	3.4	1.3
Ethanol	68**	12	56

*In this and in the following tables, the total rate refers to the sum of the partial rate factors for H and phenyl migration. For other side reactions see the Experimental Section. Although the dielectric constant for ethanol is appreciably lower than for acetonitrile (24.3 vs 37.5),[3] this may not be a suitable criterion for predicting solvating properties. The ion solvating ability of ethanol is appreciably higher than that of acetonitrile based on its large Z value (79.6 vs 71.3 kcal/mole).[4]

**Similar results were obtained in reference 1.

phenyl group. As the polarity of the solvent increases, the ease of charge separation increases because of the better ion solvating properties of the medium. Thus more charge can be delocalized out onto the migrating phenyl ring, resulting in a lowering of the energy required for phenyl migration. The hydrogen migration cannot be affected as much by solvent since additional charge separation cannot result. Thus, phenyl migration increases relative to hydrogen migration as the polarity of the solvent increases.

2. Substituent Effects in 2-Aryl-3-Phenyloxaziridine Rearrangements

The most definitive test for differentiating between heterolytic and homolytic N-O bond cleavage is the use of the sensitive probe available in the 2-phenyl group. Electron-donating and withdrawing -roups on this aryl group would directly conjugate with the developing electron-deficient center on the nitrogen. If, as the solvent effects indicate, heterolytic cleavage occurs, electron-withdrawing groups should greatly slow the rate of rearrangement while electron-donating groups would greatly accelerate the rate. If, however, homolytic cleavage is occurring, the p-nitro compound would be expected to react faster than the p-H or p-methoxy compound.[5]

The rates of rearrangement for a series of nine N-phenyl-substituted diphenyloxaziridines have been measured in acetonitrile at 25°C. The substituents were varied from strong electron-donators such as p-methoxy, to strong electron-withdrawers such as p-nitro

and p-cyano. These are shown in Table II. From a quick glance at the table we find a great variation in the stability of the n-aryl oxaziridines, the half-lives for the reaction varying from less than a few seconds to many days. In going from the p-nitro to the p-methoxy-substituted compound, a rate increase of over 10^4 is observed. In going from the p-nitro to the p-methyl and p-phenyl-substituted compounds where measingful rate data can be obtained, one finds a rate increase of over 10^2. Thus, there appears to be a definite positive correlation between the rate of rearrangement and the electron-donating power of the N-aryl substituents. This is conclusive evidence for the existence of heterolytic N-O bond cleavage and corroborates what was initially indicated in the solvent studies.

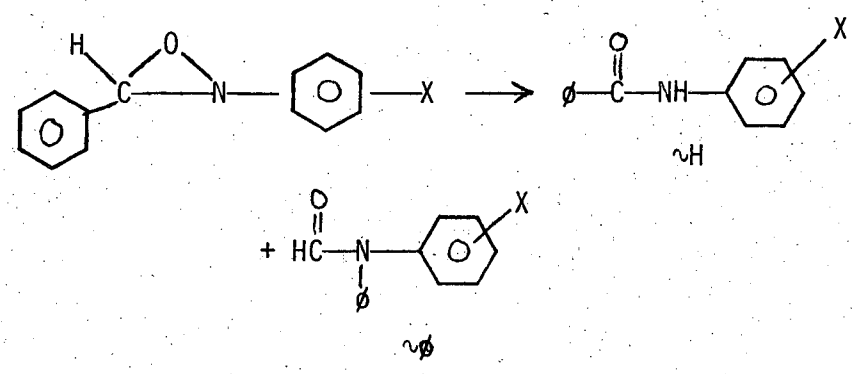
When positive charge development takes place adjacent to an aryl group, there should be a linear correlation between the log of the rate of reaction with σ^{+6} which is a measure of the electron donating ability of the aryl substituent. A plot of the log of the rearrangement rate against the substituent constant σ^+ is shown in Figure 2.

As can be observed, there is a consistent increase in the rate of rearrangement with increased electron-donating ability of the substituent. However, the relation is not a perfectly linear one. A noticeable upward curvature exists with the strongly electron-withdrawing substituents reacting faster than anticipated. However, since there is a competition between hydrogen and phenyl migration,

TABLE II

Rearrangement of 2-Aryl-3-Phenyloxaziridines

in Acetonitrile at 25°



Substituent - X	Rate (x 10^4 min^{-1})		
	Total	H Migration	Phenyl Migration
p-methoxy	$>10^4$	$>10^4$	---
p-phenyl	60.9	45	16
p-methyl	41.3	36	5
p-H	4.70	3.4	1.3
p-chloro	5.50	4.4	1.1
p-bromo	4.6	3.8	0.8
m-fluoro	1.39	1.4	<0.02
p-cyano	0.47	0.5	<0.01
p-nitro	0.6	0.6	<0.01

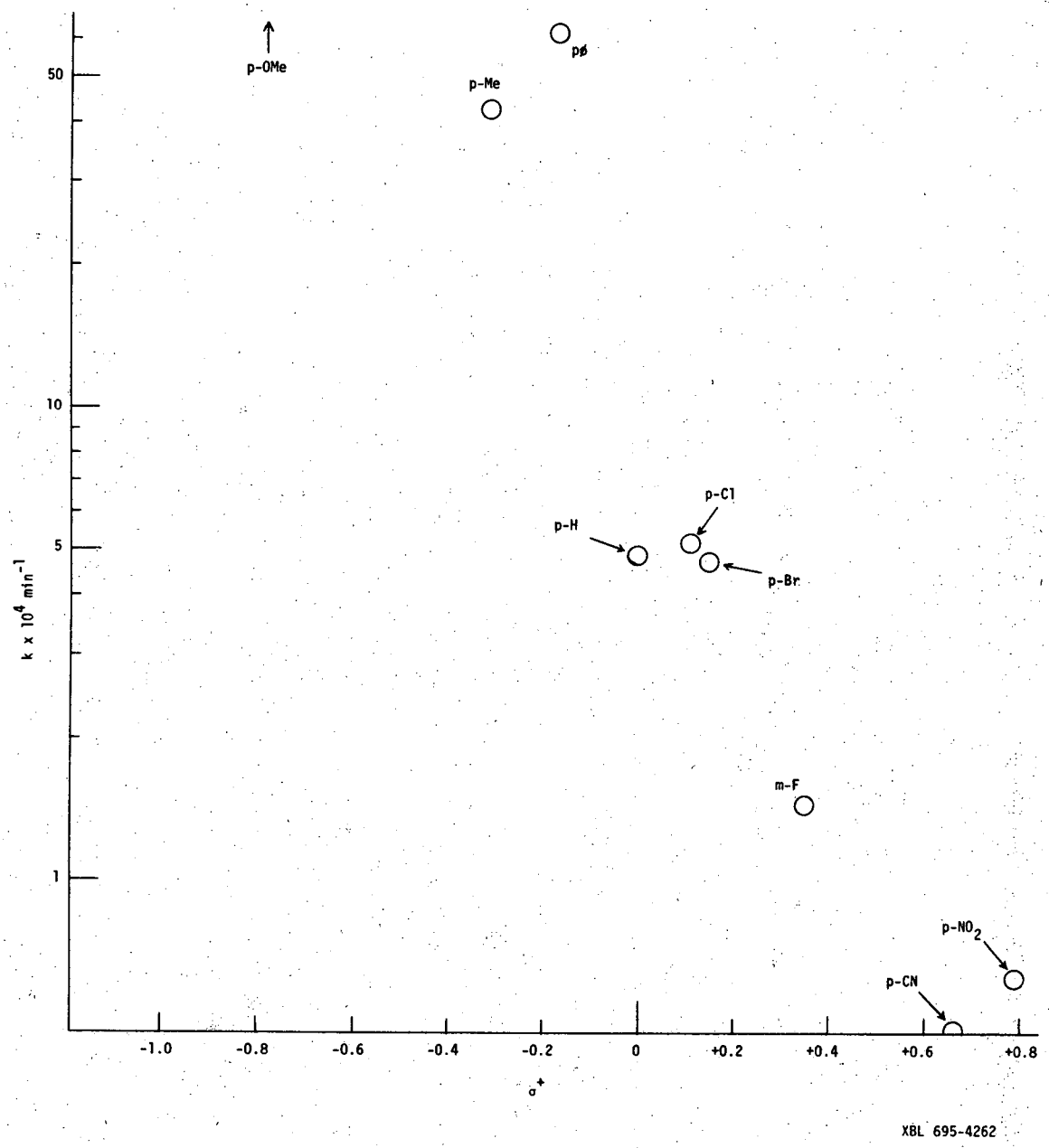


Figure 2. Plot of the total rearrangement rate of monosubstituted 2-aryl-3-phenyloxaziridines in acetonitrile at 25°C against the substituent constant σ^+

it would be more appropriate to plot the partial rate factor for hydrogen migration versus σ^+. This is done in Figure 3. Again, a slight upward curvature is noted.

Okamoto and Brown[6] have developed a general relationship for estimating the amount of positive charge generated at an atom immediately adjacent to an aromatic ring. Using the general Hammett equation,[7] $\log \frac{k}{ko} = \rho\sigma$, Brown has developed a set of substituent constants σ^+ which measures the ability of a given substituent to stabilize a positive charge capable of direct resonance interaction with the ring. ρ then is a measure of the sensitivity of a particular reaction to the aryl substituent. Since the more positive charge generated, the more responsive the rate of the reaction should be toward the aryl substituent, ρ represents a measure of the degree of positive charge developed during the reaction. The value of ρ ion varies significantly. For instance, it has a low value of -0.6 for the Diels-Alder addition of 1-arylbutadienes[8] to maleic anhydride, a reaction that is thought to proceed through an almost concerted reaction with very little charge separation. At the other extreme a value of -12 is obtained in the bromination of substituted benzenes in acetic acid.[9] Here electrophilic attack by a bromonium ion generates a positive charge directly on the aromatic ring.

In the rearrangement of the diaryloxaziridines, a rough value for ρ of about -2 can be calculated from Figures 2 or 3. This figure is near the lower end of the values of ρ that have been

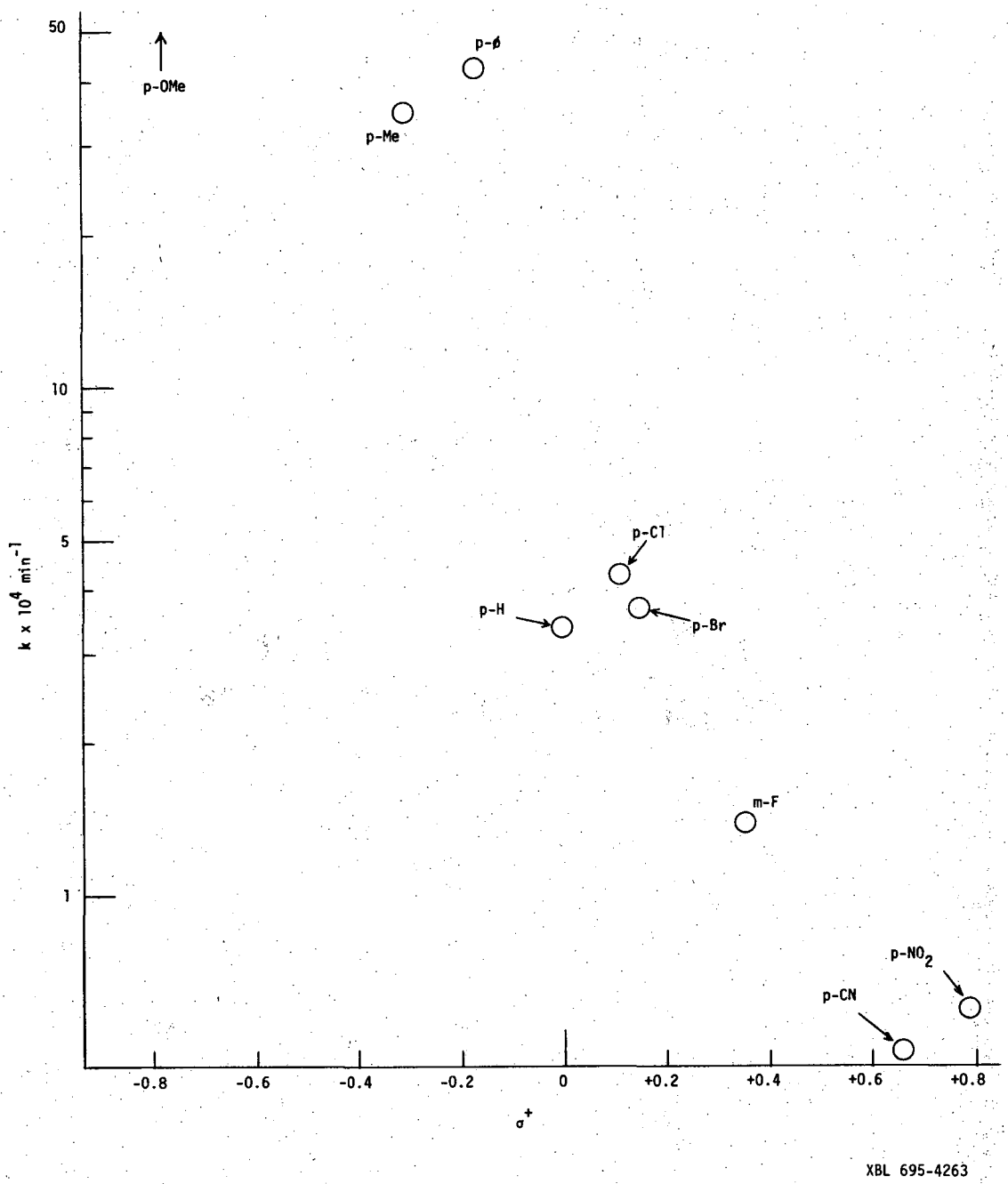


Figure 3. Plot of the rate of hydrogen migration of monosubstituted 2-aryl-3-phenyloxaziridines in acetonitrile at 25°C against the substituent constant σ^+.

measured in $\rho\sigma^+$ correlations and is in keeping with a mechanism involving a slight degree of positive charge in the transition state for the reaction. As a comparison, the solvolysis of cumyl chlorides in 90% acetone shows a ρ of -4.5.[6] In these solvolysis reactions, it is expected that a high degree of positive charge is generated at the α-carbon during the reaction. Since our value of ρ is considerably smaller than the values for these solvolyses, the amount of positive charge generation on the nitrogen during the transition state of the reaction must be much less. Thus the simplified picture of the reaction proceed via simple heterolytic N-O bond cleavage to yield a high energy switterionic species followed by rearrangement, cannot be correct. Instead, a much less polar transition state is probably involved in the reaction.

The result to be noticed about phenyl migration is the fact that it is not observed in systems with strongly electron-withdrawing groups. This is consistent with what we have learned from the solvent effects on aryl migration (Table I). Then conditions are favorable for charge separation, aryl migration occurs. In this case, the strongly electron-withdrawing groups, by destabilizing positive charge development on the nitrogen, retards heterolytic N-O bond cleavage. Since polarization of the N-O bond is hindered, there should be considerably less charge separation in transition state for these compounds than in compounds with more electron-donating substituents. With less positive charge on the nitrogen, less aryl migration occurs. Thus it appears that the sensitivity

of the aryl migration to charge on the nitrogen is significantly higher ($\rho \sim -3$ to -4) than the sensitivity of hydrogen migration.*

The data points in the $\rho\sigma+$ correlation plot shows a large amount of scatter from any line drawn through them. However, this scatter may be due to the selection of σ^+ as a measure of the charge donating ab ility of the substituent. These values of σ^+ are based on the solvolysis of substituted t-cumyl chloride in acetone-water in which, presumably, a carbonium ion-like species is involved.[6] However, we are not dealing with carbonium ions. Instead, we are concerned with a R_2N^+ intermediate which, because of energetic differences and the presence of an unshared pair of electrons on the nitrogen, may not exactly follow a σ^+ correlation. It would be desirable to construct a new $\rho\sigma$ system for R_2N^+ species but, at present the data on these intermediates is too sparse to make such a system feasible.

Two conclusions can be drawn from the previous results on 2-aryl-3-phenyloxaziridines and solvent effects: 1) the N-O cleavage is heterolytic, and 2) the likelihood of greater charge separation favors aryl migration.

From these two results we should be able to predict the effect of increasing the ionizing power of the solvent on the course of the rearrangement of N-phenyl-substituted-diaryloxaziridines. The oxaziridines with electron-donating groups should react even faster and should give more aryl migration. The oxaziridines with strong

*The one anomaly, the p-methoxy group, will be discussed later.

electron-withdrawing groups should be less affected by the solvent change, since there is appreciably less charge-separation in these cases. Although their overall rates won't be affected as much, there should be more aryl migration than was seen in less ionizing solvent.

The rearrangements of N-phenyl-substituted diaryloxaziridines in ethanol is shown in Table III. Changing solvent from acetonitrile to ethanol affects the rearrangement exactly as predicted. The p-H compound increases in rate by 15 and the p-methyl compound increases by at least 250, while the electron-withdrawing m-fluoro and p-cyano compounds show an increase in rate of only 2 and 5. Aryl migration is increased as the percent of aryl migration in the p-H compound goes from 30 to 83% and the p-CH_3 increases from 15 to 95%. Though the rates of rearrangement of the m-fluoro and p-cyano compounds do not increase appreciably, the amount of phenyl migration, though still very small, becomes detectable.

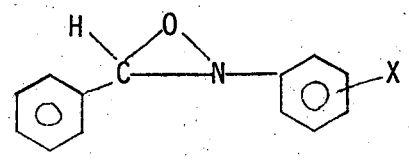
3. Substituent Effects in 2-Phenyl-3-Aryloxaziridine Rearrangements

From what has been concluded about the rearrangement reaction so far, it would be expected that a substituent on the C-phenyl group would have an appreciable effect on the migrating ability of that aryl group. In the migrations to analogous carbonium ion centers, the difference in migratory aptitude of substituted-phenyl groups is significant. For example, in the pinacol rearrangement of symmetrical

TABLE III

Rearrangement of 2-Aryl-3-Phenyloxaziridines

in Ethanol at 25°



Substituent	Rate ($\times 10^4$ min^{-1})		
X	Total	H Migration	Phenyl Migration
p-methoxy	$>10^4$	$>10^4$	---
p-methyl	$>10^4$	$>5 \times 10^2$	$>10^4$ *
H	68	12	56
m-fluoro	2.2	1.8	0.4
p-cyano	2.4	2.1	0.3

*95% phenyl migration and ca. 5% hydrogen migration were observed.

tetra-aryl glycols, the p-anisyl group migrates 700 times faster than phenyl, which in turn migrates 10 times faster than m-chlorophenyl.[10] An even closer analogy can be found in migratory aptitudes in the acid catalyzed rearrangement of diphenylmethyl carbinyl azide[10] (x $\phi_2(CH_3)C\text{-}N_3$) to acetophenoneimines. Since this reaction superficially presumably involves rearrangement to an electron deficient $R\text{-}NH^+$ species, there should be some correlation with the oxaziridine rearrangement system. Ege[11] found that methoxyphenyl migrates at least 100 times faster than the phenyl and the p-bromophenyl migrates 1/3 as fast as the phenyl. Thus this reaction too shows a high sensitivity to substituent.

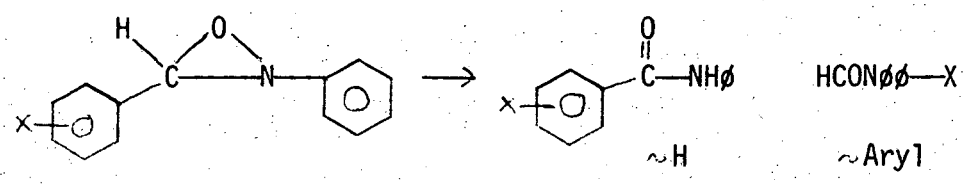
Therefore, in analogy to migrations to electron deficient centers of this type, we would expect the electron donating substituents on the C-phenyl in the oxaziridine would cause 1) the reaction to proceed faster and 2) more aryl migration to occur. Table IV shows the results of kinetics on the rates of rearrangements of C-phenyl substituted diaryl oxaziridines in acetonitrile at 25°C. As one can easily observe, our predictions were completely wrong. It appears, that to a first approximation, the rate of rearrangement (except for the dimethylamino case) is independent of the substituent. This insensitivity to substituent is difficult to rationalize.

Two possible explanations can be put forward. One can argue that the aryl migration is of a radical nature. Then the effects of substituents would be expected to be much less. But this

TABLE IV

Rearrangement of 2-Phenyl-3-Aryloxaziridines

in Acetonitrile at 25°

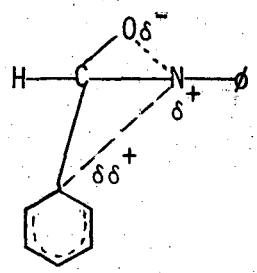


Substituents - X	Rate ($\times 10^4$ min^{-1})		
	Total	H Migration	Aryl Migration
p-dimethylamino	51*	34	17
p-methoxy	4.2	3.5	0.7
p-H	4.7	3.4	1.3
p-chloro	4.1	3.0	1.1
m-nitro	4.8	4.3	0.5
p-nitro	5.6	5.1	0.5

*In addition, 13% of the total reaction is rearrangement to the corresponding nitrone.

contradicts all the previous results we have obtained which substantiates the heterolytic N-O bond cleavage. In addition, even in radical rearrangements, there is migratory specificity with phenyl groups with electron withdrawing substituents such as the p-nitro group migrating significantly faster than the phenyl group itself.[12] This is not found.

The other possible rationale is that, first, not much charge separation is generated in the transition state for aryl migration; and second, the migrating aryl group does not delocalize much of the charge in the transition state leading to aryl migration. Thus a transition state like the one pictured below (I) can explain the results.



(I)

Here aryl migration is not very advanced in the transition state; and hence, the amount of positive charge delocalized onto the aryl ring is quite small. Thus, sensitivity to the substituents on the aryl ring would be expected to be low. This is in general agreement with Hammond's Postulate,[13] which states that the transition state for a reaction should more closely resemble the higher energy species. Since in the oxaziridine to anilide reaction, the oxaziridine is

definitely the higher energy species, the transition state should be fairly close to the oxaziridine structure. Hence a transition state where very little aryl to nitrogen bonding takes place, is to be expected.

The fact that generally no sensitivity at all is seen with substituent may indicate the existence of an "isokinetic effect",* as that observed in the thermal rearrangement of triaryl methylazides[14] and in a great number of other diverse reactions.**

As the ion stabilizing power of the the solvent increases, one would, as previously, expect greater aryl migration since charge separation will be more stabilized. This is what is found, as shown in Table V.

When the solvent is changed from acetonitrile to ethanol, the rate of aryl migration increases (compare Tables IV and V), 40-fold with the p-nitro compound, 50-fold with the unsubstituted compound and 300-fold with the p-methoxy compound while hydrogen migration is much less affected. Again the accelerating effect of more polar solvents on aryl migration is seen. The most significant change, however, is the increased sensitivity of the aryl migration to the substituent on the migrating aryl ring.

In ethanol, the p-methoxyphenyl group migrates 10 times faster than the p-nitrophenyl, whereas in acetonitrile they migrated at

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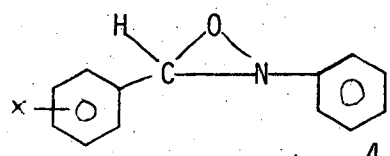
*The isokinetic effect indicates some proportionality between the enthalpy and entropy of a reaction. Thus $\Delta H = \beta \Delta S$.

**Reference 7, Chapter 9.

TABLE V

Rearrangement of 2-Phenyl-3-Aryloxaziridines

in Ethanol at 25°



Substituent	Rate ($\times 10^4$ min^{-1})		
X	Total	H Migration	Aryl Migration
p-dimethylamino	2×10^5 (1)	$<10^3$	2×10^5 (1)
p-methoxy	193	< 2	193
p-H	68	12	56
p-nitro	50	31 (1)	19 (1)

approximately the same rate. This increased sensitivity to substituent probably indicates that more positive charge is being delocalized in the aryl ring during the migration. This in turn implies that the degree of bonding between the migrating aryl group and the electron-deficient nitrogen in the transition state for migration is increased, thus increasing the sensitivity of the reaction to the aryl substituent.

When one sees a series of aryl groups migrating to an electron-deficient center, the question of the possibility of anchimeric assistance arises.* Anchimeric assistance indicates an accelerated ionization caused by neighboring group participation.[16] In the oxaziridine system, this would involve the participation of the C-aryl group in the heterolytic cleavage of the nitrogen-oxygen bond. This participation should be apparent experimentally in an unexpectedly high rate of reaction. For instance, Norlander found that the solvolysis of α-phenethyl tosylate in trifluoroacetic acid is 3000 times faster than the solvolysis of the unsubstituted ethyl tosylate.[17] This acceleration is due to the participation of the phenyl group in the ionization of the tosylate.[18]

One of the characteristics of aryl participation of this form is that the stronger the electron-donating ability of the participating group, the more stabilization that will result, and hence the faster the reaction will occur.[19] For instance, in the solvolyses of substituted benzonorborenyl-9-arenesulfonates, Tanida[20] found that the methoxy-xubstituted compound reacted 5×10^5 times

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*For a general review of anchimeric assistance see the survey of Bartlett.[15]

faster than the nitro-substituted compound. Although we would not expect a rate difference of such magnitude, we would expect to see some effect.

If significant anchimeric assistance to N-O bond cleavage by an aryl group is occurring, the result should be visible as an increase in the total rate of both reactions. Changes in the migratory ratio between aryl and hydrogen migration without an increase in the total reaction rate would indicate only that the migrating aryl group competes more effectively with hydrogen for reaction with the electron-deficient center without anchimeric assistance.

In Table IV we see that in going from the p-nitro to the p-methoxy-substituted C-phenyl group in acetonitrile no increase in the rate of aryl migration or in the total rate is observed. Obviously no anchimeric assistance is occurring. However, with the strongly electron-donating dimethylamino group, a rate increase of over 10 is seen.* This may be an indication of some degree of aryl participation. In ethanol this effect is even more noticible. The p-dimethylaminophenyl group in ethanol migrates 10^4 times faster than the unsubstituted phenyl.

This effect can be seen even more dramatically in Figure 4, where the log of the rate of aryl migration in ethanol is plotted against the substituent constant σ^+. From the effect of substituent on the aryl migrations of the p-methoxy, p-H and p-nitro substituted

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*The accelerating effect of the p-dimethylamino substituent on hydrogen migration (Table IV) probably reflects its stabilizing effect on the positively charged transition state for hydrogen migration.

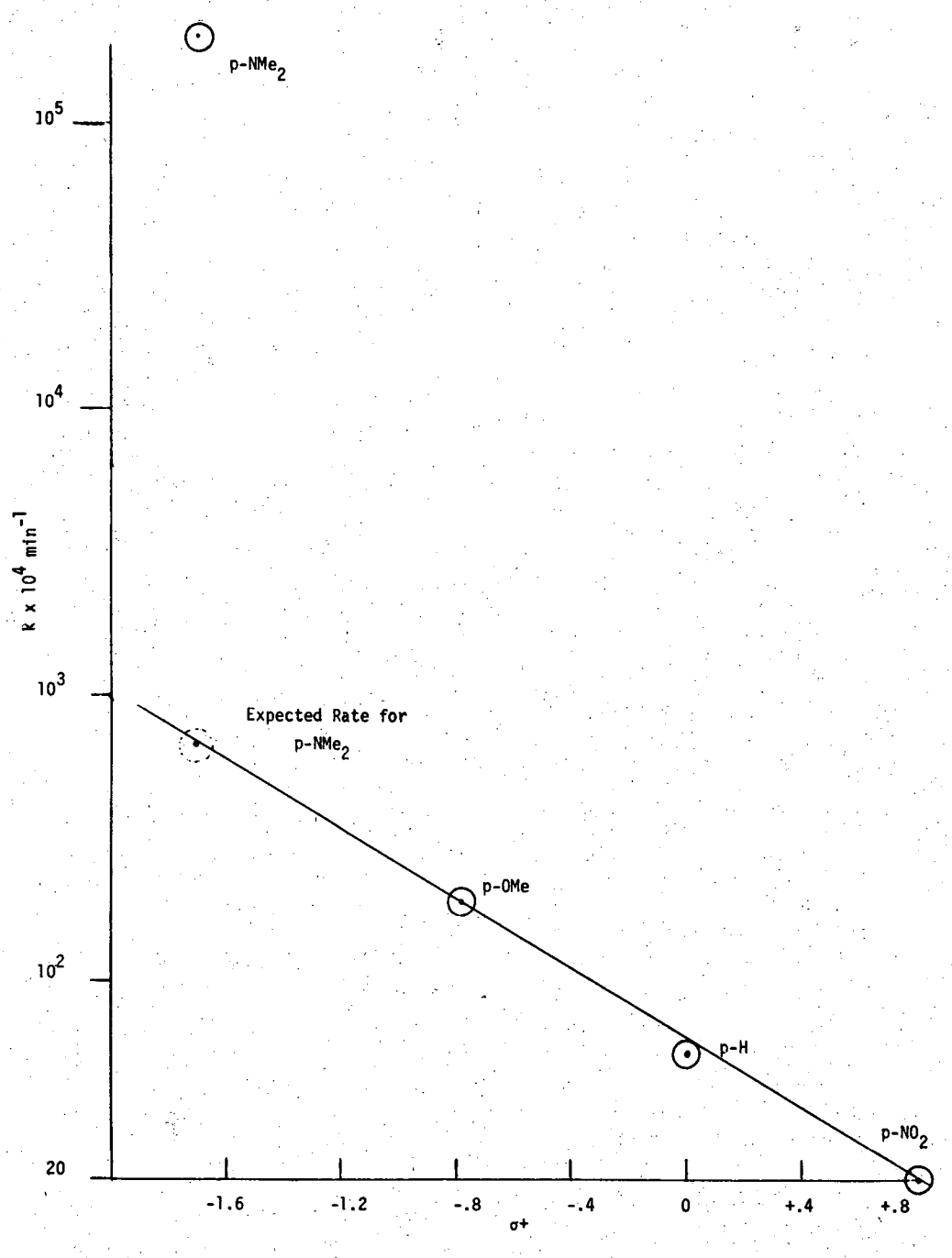

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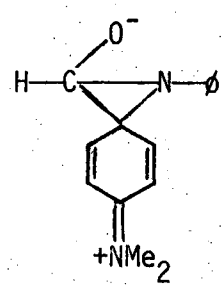
Figure 4. A plot of the rate of aryl migration in 3-aryl-2-phenyloxaziridines in ethanol at 25°C against the substituent constant σ^+.

phenyl groups, a value of ρ for the rearrangement of about -0.7 can be calculated. It is apparent that the p-dimethylamino compound deviates significantly from this line, reacting about 300 times faster than would be expected from an extension of the $\rho\sigma^+$ line for the other substituents.

This suggests the possible existence of a discrete phenonium ion-type intermediate (II) in this reaction. Thus it appears that in ethanol at least anchimeric assistance to bond cleavage does



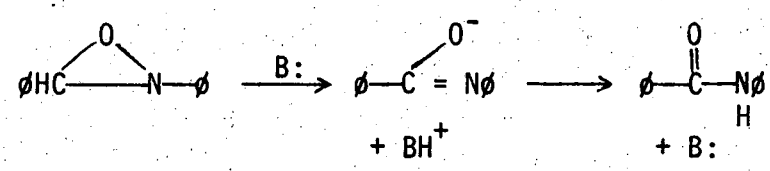
(II)

occur when the migrating phenyl group is substituted with a very strongly electron-donating group such as the p-dimethylamino.

Judging by the low value of ρ (ca. -0.7) for aryl migration that can be estimated from the rates of rearrangement of p-methoxy, p-H, and p-nitro compounds in ethanol, only a limited participation can exist. In contrast, in the rearrangement of acetophenone oxime picrates where significant anchimeric assistance is thought to exist, a value for ρ of -4.1 is calculated.[21] Likewise, in acid catalyzed rearrangements of substituted benzhydrylazides where an electron-deficient nitrogen is involved, a value of over -2 is found for ρ.[22]

4. Effect of Added Bases on the Rearrangement of 2,3-Diphenyloxaziridine

The rearrangement of hydrogen has continually been discussed in terms of a hydride migration to the nitrogen. However, there are several other possible mechanisms that must be considered. The main alternate theory is a proton absraction reaction to give the corresponding enolate type ion (IV), followed by isomerization to the corresponding amide.

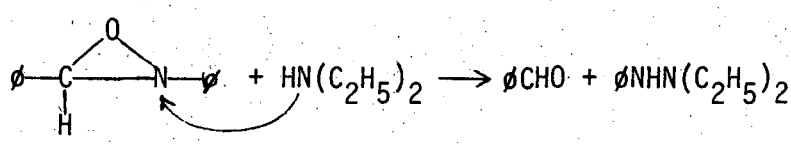


(IV)

In solution the presence of trace amounts of water may provide the base necessary for the reaction to proceed. To eliminate this possibility, the effect of base concentrations on the rate of rearrangement migration was investigated.

The addition of 2% water to an acetonitrile solution of the diphenyl oxaziridine results in a 30% increase in rate. It is obvious from this result that water is not serving as a base for oxaziridine proton removal since a many-fold increase in water content causes only a slight rate change. This small rate increase can be fully rationalized as an acceleration due to the existence of a more polar solvent system.

An attempt to determine the effect of stronger amine bases on the rearrangement reaction was also made. When 100 ml of an acetonitrile solution of the 2,3-diphenyloxaziridine is reacted with 1-1/2 ml of triethylamine, the oxaziridine disappears at a rate 40 times faster than normal. Analysis of the resulting solution indicates that the only major product is not the benzanilide, but benzaldehyde anil. Thus it appears that instead of acting as a weak base, the triethylamine is being oxidized by the oxaziridine to triethylamineoxide. Similar results were found by Emmons,[23] who noted that alkyloxaziridines oxidize brucine to brucine-4-oxide. Reaction of diethylamine with the diphenyloxaziridine results in the rapid disappearance of the oxaziridine. Product isolation shows only two major components, benzaldehyde and a product with the characteristics consistent with the structure of 1,1-diethylphenylhydrazine (III), the product that would result from amine attack on the oxaziridine nitrogen.



(III)

Schmitz[24] has reported similar results in the reaction of isoximes (oxaziridines with a hydrogen on the nitrogen) where reaction with aniline yields the corresponding phenyl hydrazine. Thus it appears that nucleophilic attack on the ring system generally occurs on the nitrogen and not on the carbon, thus again indicating the polarized

nature of the N-O bond.* Benzanilide formation is independent of the presence of bases, and therefore, in the presence of oxaziridines, the strong nitrogen bases appear to act only as reducing agents and nucleophiles. Thus, benzanilide formation appears to be a rearrangement reaction and not a proton abstraction.

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*Schmitz has also reported that hydrolysis of isoximes with acidic H_2O^{18} yields labeled hydroxylamine,[24] again indicating a nucleophilic attack on the ring nitrogen.

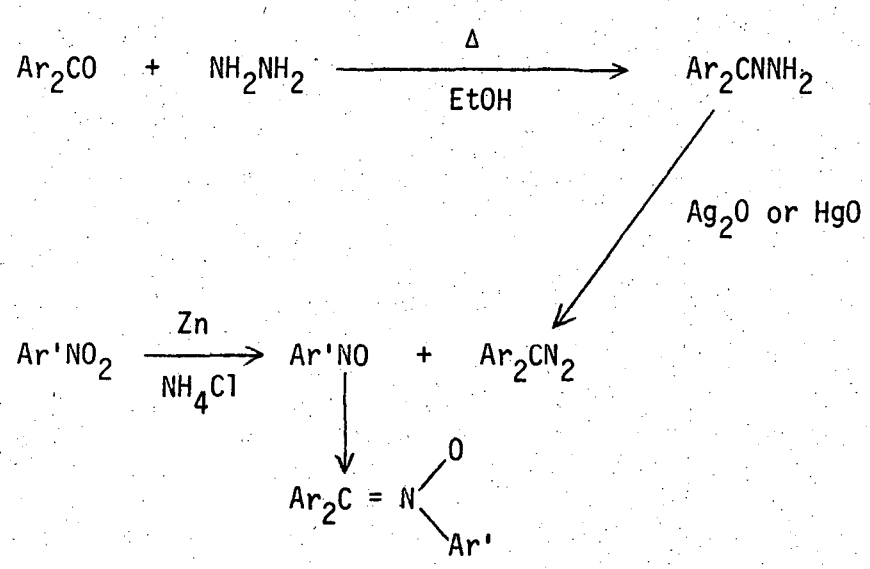
B. Kinetics of the Thermal Rearrangement of 2,3,3-Triaryloxaziridines

It seems fairly certain from the kinetic results of the 2,3-diaryloxaziridine rearrangements, that N-O bond cleavage is heterolytic. Substantiating evidence for this mechanism may also be obtainable from an investigation of the rates of rearrangement of the triaryloxaziridines -- assuming that their rates can be measured.

In one respect the triaryloxaziridines have an inherent advantage over the diaryl system. In the diaryl system, conformational effects may be important. Thus the N-aryl group is capable of being either on the same side of the ring as the C-aryl group or as the oxaziridine hydrogen but because of steric interactions, the N-aryl group would probably spend most of its time "cis" to the hydrogen. This could, in turn, influence the migratory behavior of the aryl group relative to the hydrogen. Thus any phenyl to hydrogen migration ratio may not indicate true migratory preferences, but instead reflect the effect of the favored conformer of the oxaziridine ring. With the triphenyl system, these conformational effects are eliminated. The phenyl groups are of the same general size and facile interconversion between the conformers should occur, retaining an approximately 50:50 mixture of "cis" and "trans" isomers. Thus migratory aptitudes instead of conformational stabilities should determine the course of the rearrangement.

Unfortunately, triaryloxaziridines have never been detected, let alone isolated. If previous workers are correct (see Introduction), they may be too unstable to even be detected in solution.

But even if they are not detectable, studies of the rearrangement products from the oxaziridines should give us valuable information about the charge on the nitrogen during the rearrangement. With this in mind we attempted the synthesis of these triaryloxaziridines by irradiation of the appropriate triarylnitrone, following the same approach as that used in the diaryl system. Unlike the α,N-diarylnitrones, the α,α,N-triarylnitrones cannot be synthesized by a simple condensation of a ketone with a hydroxylamine. Instead, the general method of Johnson[25] was adapted involving the reaction of a diazo compound with a nitroso compound as shown below:

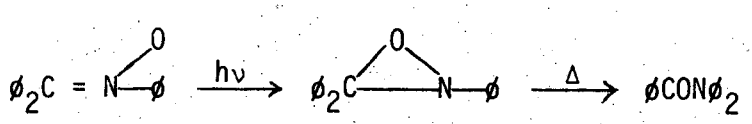


By this method a variety of N- and α-substituted triarylnitrones could be prepared.

Irradiation of the nitrones results in the complete disappearance of the long wavelength nitrone absorption and the appearance of a short wavelength absorption indicative of a nonconjugated system.

For instance, irradiation of an ethanol solution of the triphenylnitrone (V) (λ_{max} [ethanol] 311 nm [ϵ 11,000]) in a uv cell for one minute with GE-DBX photospots results in a product with a uv spectra showing only end absorption (at 230 nm [ϵ 12,600]). This spectrum changes only slowly (over days) upon standing, and comparison with the spectrum of the expected product, benzoyldiphenylamine (VII) shows they are not the same. An active oxygen titration of an acetonitrile solution of the irradiated triphenylnitrone prepared in the same manner as the diaryloxaziridines shows a 100% yield of active oxygen. Finally, reflux of the acetonitrile solution resulted in a high yield (75%) of benzoyldiphenylamine (VII), the expected product from rearrangement of the phenyloxaziridine. Thus, it appears that the same characteristics used to identify the diphenyloxaziridines are also found in the photoproduct from the triphenylnitrone.

On this basis, the photoproduct from triphenylnitrone irradiation was identified as the triphenyloxaziridine (VI). Other irradiated nitrone solutions showed similar characteristics. Summarized below in Table VI are the spectral and active oxygen properties of some of the triaryloxaziridine solutions that were prepared.

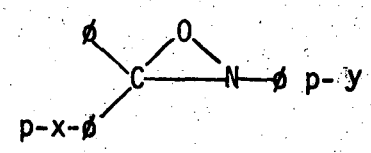


(V) (VI) (VII)

Thus it appears, contrary to expectations, that the 2,3,3-triaryloxaziridines can be prepared and characterized in solution. It was

TABLE VI

Properties of Triaryloxaziridine Solutions



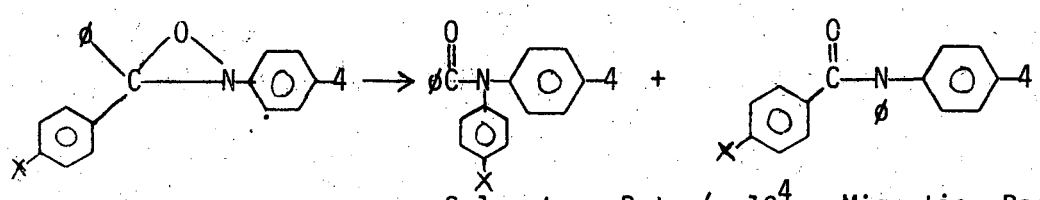
x	y	uv λ_{max} of the nitrone (acetonitrile)	uv λ_{max} of the oxaziridine (acetonitrile)	Active oxygen
-	-			
H	H	314 nm (ε11,400)	end absorption at 230 nm (ε12,400)	99%
NO_2	H	361 nm (ε10,300)	267 nm (ε14,500)	92%
OMe	H	318 nm (ε14,100)	234 nm (ε20,900)	100%
Br	H	318 nm (ε13,060)	228 nm (ε23,300)	100%
H	OMe	313 nm (ε19,300)	*	*
H	NO_2	300 nm (ε12,800)	251 nm (ε16,200)	100%
H	Br	313 nm (ε12,300)	(sh) 250 nm (ε14,600)	100%
NO_2	OMe	368 nm (ε9200)	**	**

*Only the anilide was observed, 243 nm (ε 23,400)

**Only the anilide was observed, 243 nm (ε18,600) · (sh) 324 nm (ε5,760).

TABLE VII

Rearrangement of Triaryloxaziridines at 25°



x	y	Solvent	Rate (x 10^4 min^{-1})	Migration Ratio phenyl/aryl
H	H	Acetonitrile	0.34	---
p-nitro		"	∿0.6	1.2
p-methoxy	H	"	0.44	1.5
H	p-methoxy	"	>10^4	---
H	p-nitro	"	< .01[a]	---
H	H	Ethanol	0.70	---
p-methoxy	H	"	∿1.2	1.5
p-nitro	H	"	---	1.5

[a]After one month, the compound still showed a 75% active oxygen content. Analysis of the solution refluxed for several days showed benzophenone as the major product with only traces of the desired anilide.

also found that the oxaziridines were generally stable enough for kinetic data to be obtained.

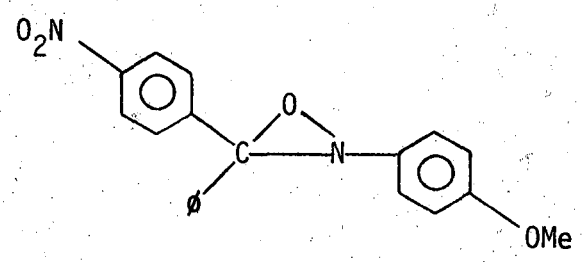
In Table VII is shown the results from kinetic measurements on several of the oxaziridine solutions. As can be seen from the table, the triaryloxaziridines are extremely stable. For instance, the triphenyloxaziridine has a half-life of about 10 days in acetonitrile -- about ten times as long as the corresponding diphenyloxaziridine. In ethanol its half-life is 100 times longer than its diphenyl counterpart.

The reason for its stability does not lie in the absence of a hydrogen capable of migration, since phenyl migration is also a relatively facile process. Rather, it appears to lie in the inability of the N-phenyl group to adequately stabilize developing positive charge on the neighboring nitrogen. Molecular models indicate that there are serious steric interactions between the three groups in the system. It appears that the two phenyl rings attached to the carbon force the nitrogen phenyl to assume a conformation where it cannot effectively stabilize the N-O bond cleavage.

The effect of substituents on the N-phenyl is quite marked (Table VII). While the p-methoxy compound is too fast to measure, the unsubstituted compound has a half-life of about 2 weeks. At the other extreme, the p-nitro substituted compound rearranges at a rate too slow to measure and instead, another reaction takes place which slowly yields benzophenone as the predominant product. Only a trace of what could be the desired product was visible by

TABLE VIII

Solvent Effects on the Migratory Aptitude in the Rearrangement of 2-(4-methoxyphenyl)-3-(4-nitrophenyl)-3-phenyloxaziridine



Solvent	Rate (x 10^4 min^{-1})	Migration Ratio phenyl/p-nitrophenyl
Benzene	$>10^4$	1.3
Acetonitrile	$>10^4$	4
Ethanol	$>10^4$	10

using a more polarizing solvent doesn't appreciably affect the amount of charge separation. This is similar to the rearrangement of 2-(4-nitrophenyl)-3-phenyloxaziridine (Tables II and III) where solvent variation had very little effect on the rate.

However, the effects of solvent on the 2-(4-methoxyphenyl)-3-(4-nitrophenyl)-3-phenyloxaziridine is more significant. The results of solvent changes with this compound are shown in Table VIII. Like the 2-(4-methoxyphenyl)-3,3-diphenyloxaziridine, the compound rearranges too fast to be isolated. This high rate implies that because of the presence of a p-methoxy group, the transition state for this reaction is much more polar than for the normal triaryloxaziridines with an unsubstituted N-phenyl.

However, there appears to be a definite trend in the migratory behavior of the two 3-aryl groups. In benzene, which is a poor charge stabilizing solvent, there seems to be very low selectivity in the relative migratory ability of phenyl vs p-nitrophenyl. In acetonitrile, a better charge stabilizing solvent, the phenyl migration becomes appreciably faster than the p-nitrophenyl. In ethanol, the most polar solvent used, the phenyl group migration is responsible for over 90% of the overall reaction.

This again is in keeping with a greater and greater development of charge separation as more polar solvents are used. As the reaction becomes more ionic, the aryl group most capable of stabilizing a positive charge is the one that preferentially migrates.

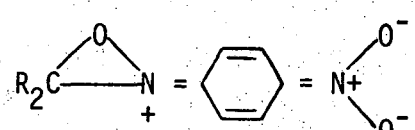
The added stabilization of the ground state of the p-nitro and p-H compound due to interaction with the nitrogen electrons and the conformational stabilization of the p-methoxy transition state both tend to exaggerate the value of ρ found for the reaction. Thus the large negative ρ observed can occur without invoking an extremely high degree of positive charge on the oxaziridine nitrogen during rearrangement. Additional evidence for a low degree of positive charge on the nitrogen can be found by noting the migratory aptitudes in the triaryl system.

The migratory abilities of the C-phenyl groups seem to be quite insensitive to phenyl substituent. For example, in acetonitrile and ethanol the phenyl and p-nitrophenyl groups migrate with about equal facility. This parallels the same insensitivity found for the rearrangements of the diaryloxaziridines in acetonitrile. In fact, in the case of the 3-(4-methoxyphenyl)-2,3-diphenyl compound, the phenyl seems to migrate in preference to the methoxyphenyl. This may indicate some type of conformational effect but a more adequate explanation for this strange migratory preference is still lacking. This insensitivity to substituent indicates that very little positive charge is being delocalized into the migrating aryl group during rearrangement.

The solvent effect on the rate of rearrangement in the unsubstituted and the 3-p-methoxyphenyl compound is very minor, as the rate in each is only doubled when ethanol replaces acetonitrile as solvent. This adds credence to the idea that very little charge separation is actually involved in these rearrangements and even

charge on the nitrogen in the transition state can still explain the observed large negative ρ for the rearrangement.

A second factor possibly responsible for the high sensitivity to substituent is the presence of the unshared pair of electrons on the oxaziridine nitrogen.* The tendency of the N-aryl group to interact with the unshared electron pair is proportional to the ability of the aryl group to stabilize a negative charge. The p-nitrophenyl, with its strongly electron withdrawing nitro group would most effectively interact with the unshared pair as shown in IX. The phenyl group would interact but less strongly, and the 4-methoxyphenyl group would interact very little because of the electron repulsion between the methoxy group and the unshared electron pair.**



(IX)

*This resonance interaction of the N-phenyl group with the unshared electron pair should also occur in the diaryl system.

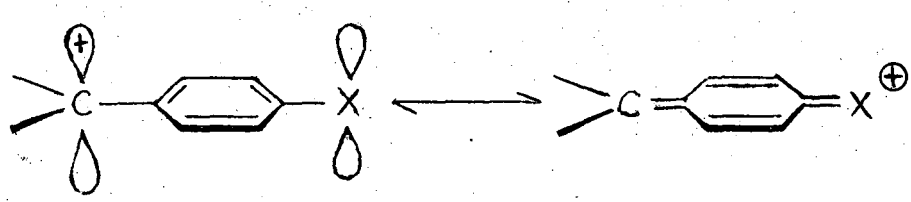
**A good estimate of this effect could be obtained by determining the inversion rates of N-aryl aziridine where increased aryl interaction with the nitrogen unshared electron pair would increase the rate of nitrogen inversion. Unfortunately, this work has not been done. An estimate of this effect can be made from the work of Curtin et al.[26] who found in the isomerization of N-substituted triarylimines that a p-dimethylamino substituent decreased the rate by 10 while a p-carboethoxy group increased the inversion rate by 15.

of the aromatic rings. Because of this twisting, the N-phenyl group is not in an orientation to effectively stabilize the developing positive charge on the nitrogen, caused by N-O bond cleavage. Instead of being aligned with the N-O bond, the pi-lobes on the phenyl ring are at some angle θ to the breaking bond. Thus, as an approximation, the effective resonance stabilizing power of the phenyl group is reduced by a factor of roughly cos θ. This reduction in resonance stabilizing power results in a greatly decreased rate of N-O bond cleavage for the triaryloxaziridines. On the other hand, the diaryloxaziridines do not have this great steric interference, hence the resonance stabilizing power of the substituted N-phenyl is not decreased.

The p-methoxyphenyl compound should suffer the same fate but the strong electron donating ability of the p-methoxy group may help alleviate this problem. The electron donation of the p-methoxy group allows greater N-O bond stretching by stabilizing the positive charge which is developing on the oxaziridine nitrogen. This lengthening of the N-O bond causes loosening of the three-membered ring, which in turn reduces the steric interactions between the aryl groups. Since the aryl groups are less severely crowded, the N-aryl group can rotate to more effectively stabilized N-O bond cleavage. The end result is more rapid rearrangement. The effect of the p-methoxy group, thus, is much greater than normal ρ relationships would predict. A small degree of stabilization can thus lead to a conformational change in the molecule which itself greatly accelerates the reaction. Thus only a small positive

glpc. Thus again we find evidence consistent with a heterolytic cleavage of the N-O bond to leave a positive charge on the nitrogen, the p-methoxy group greatly accelerating the reaction and the p-nitro greatly decelerating it. The great sensitivity of rate to substituent (ρ is estimated to be >-6) indicates that the amount of positive charge on the nitrogen is very substantial. However, this substantial positive charge on the nitrogen may be illusionary. Judging by other results, the charge density is probably not nearly as large as indicated. Instead, complicating conformational effects may account for the great substituent sensitivity.

We find the p-methoxy group greatly stabilizing the transition state of the reaction. In a normal Brown $\sigma\rho^+$ plot,[6] we are measuring the effect of substituent on a planar molecule (VIII) where resonance stabilization of the charge is not affected by differing conformations.



(VIII)

However, in the oxaziridine system, we are dealing with a three-membered ring substituted with three aryl groups. Molecular models indicate that there is a significant degree of steric interaction between the phenyl rings, resulting in a twisted orientation

It appears that in the triaryloxaziridines, aryl migration proceeds via a much less polar transition state than the corresponding aryl migration in the 2,3-diaryloxaziridines. Neither the sensitivity to substituents on the migrating aryl group nor the sensitivity of the rearrangement to solvent polarity indicate a very polar reaction Even with a strong electron donating group such as the p-methoxy group on the N-phenyl, the rearrangement shows only modest sensitivity toward the substituent on the migrating aryl group. Only with highly polar solvents in addition to the presence of the p-methoxy group on the N-phenyl does the rearrangement begin to show the migratory selectivity expected for rearrangements to electron deficient centers. Again, conformational restrictions seem the most reasonable way of explaining these results. Since the N-aryl group is conformationally in an orientation where it cannot effectively stabilize a developing electron deficient center at the nitrogen, a high degree of N-O bond polarization cannot occur. Thus the reaction is slowed down appreciably and must take place via a less ionic process than found in the 2,3-diaryloxaziridines.

C. Summary of the Kinetic Data

In order to help extract the salient points from this voluminous amount of kinetic data, the general results of the data are briefly summarized below:

1) Solvent effects on the rearrangement of 2,3-diphenyloxaziridine.

The rate of 2,3-diphenyloxaziridine rearrangement seems to be very solvent dependent, increasing in rate by 150 as the solvent is varied from iso-octane to ethanol. Phenyl migration is exceptionally sensitive, increasing over 3×10^3 as the solvent is varied from iso-octane to ethanol, while hydrogen migration increases about 30-fold over the same range.

2) Substituent effects in 2-aryl-3-phenyloxaziridine rearrangements.

In acetonitrile, as the substituent on the N-aryl group is varied from p-nitro to p-phenyl, the total rate increases continuously with a $\rho^{ca.}$-2 (using σ^+ values). Hydrogen migration shows the same rate increase with $\rho^{ca.}$-2 while the rate of phenyl migration is more sensitive to substituent, not even being observed with strongly electron withdrawing substituents (ρ>-3). In ethanol, a similar trend is found with hydrogen migration appearing less sensitive to substituent ($\rho^{ca.}$-2) than phenyl migration (ρ>-3). The strong electron-donating substituents appear to accelerate the reaction more than predicted by a simple $\sigma^+\rho$ relationship in both solvents. In both solvents there is a trend toward greater aryl migration with the increased electron

donating ability of the substituent.

The p-methoxy substituted appears to react anomolously fast, and, in contrast to other electron donating substituents, favors H migration to the exclusion of phenyl migration.

3) Substituent effects in 2-phenyl-3-aryloxaziridine rearrangements.

In acetonitrile, the substituent on the C-phenyl appears to have no effect on either the rate of hydrogen migration or the rate of aryl migration. Only with the p-dimethylamino substituent does appreciable acceleration (by 10 x) of both H and aryl migration appear. In ethanol, however, the effect of substituent is greater, p-methoxy group increasing the rate of aryl migration by a factor of 10 over the p-nitro group ($\rho^{ca.}$-0.7) while hydrogen migration appears to be faster with electron withdrawing substituents ($\rho^{ca.}$+0.7). In ethanol the p-dimethylamino substituted compound reacts with complete aryl migration at a rate 10^3 times faster than predicted by a simple $\sigma^+\rho$ correlation.

4) Rearrangement of triaryloxaziridines.

The triaryloxaziridines appear to react at a much slower rate than their counterpart diaryloxaziridines. (The triphenyloxaziridine reacts more slowly than the diphenyl by a factor of 10 in acetonitrile and 100 in ethanol.) The migratory aptitudes of the 3-aryl groups seem to be independent of substituent on the migrating group in both ethanol and acetonitrile. The rate of rearrangement shows a great sensitivity to N-aryl substituents (ρ<-6)

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in acetonitrile. However, the reaction appears to be very insensitive to changes in solvent ionizing capabilities. In the 2-(4-methoxyphenyl)-3-(4-nitrophenyl)-3-phenyloxaziridine (p-NO_2ø ø$\overset{O}{\triangle}$N-øpOMe) the reaction shows a sensitivity to substituent on the migrating aryl group whose magnitude varies directly with the polarity of the solvent.

D. Discussion

1. The Nature of the N-O Bond Cleavage

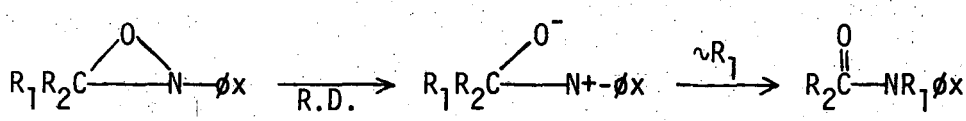
It appears from all the kinetic results that heterolytic cleavage of the N-O bond is occurring in contrast to the homolytic cleavage that occurs in thermal reactions of 2-alkyloxaziridines.[23] The 2,3-diphenyloxaziridine shows over a 100-fold increase in rate as the solvent is varied from a hydrocarbon solvent to ethanol. In all the series of compounds investigated, similar rate accelerations due to an increase in solvent polarity are observed, indicating a polar transition state for the rearrangements.

The effect of substituents on the rate of oxaziridine rearrangement indicates that, in the transition state for rearrangement, positive charge is developed on the oxaziridine nitrogen. For example, in the reaction of 2-aryl-3-phenyloxaziridines, electron-donating substituents accelerated the reaction while electron-withdrawing groups slowed it down (Table II and III). Since the substituents on the N-aryl group are directly attached to the developing positive charge on the nitrogen, the rate should give a correlation with Brown σ^+ substituent constants. A satisfactory correlation is obtained and the calculated value for $\rho(\underline{ca.}\text{-}2)$ conclusively indicates the presence of a fair degree of positive charge on the nitrogen in the transition state for rearrangement. This same trend is found in the 2-aryl-3,3-diphenyloxaziridines (Table VII). Secondly, the effect of

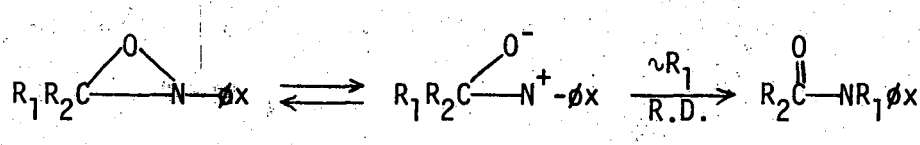
substituents on the migrating aryl group in reaction of 3-aryl-2-phenyloxaziridines in ethanol (Table V) indicates a trend in which the more electron-donating substituents accelerate the rate of aryl migration. This again is typical of migrations to electron-deficient centers. Thus the evidence seems conclusive that in the rearrangement of the 2,3-diaryl- and triaryloxaziridine heterolytic N-O bond fission is occurring leaving a positively charged nitrogen species. However, the exact energetics and transition state for this bond breaking is unclear.

There are three major possibilities for the mechanism, if one assumes heterolytic fission occurs. These are illustrated below.

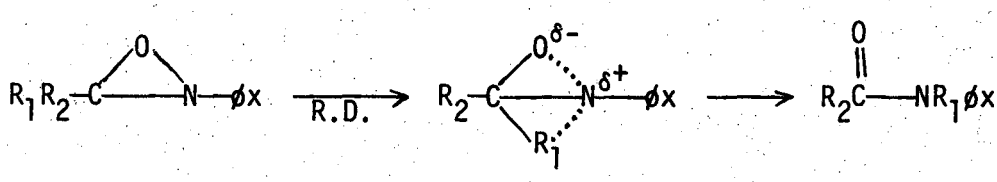
I. <u>Unassisted N-O Bond Cleavage</u>



II. <u>Equilibrium N-O Bond Cleavage</u>



III. <u>Concerted N-O Bond Cleavage and Migration</u>



In mechanism I, the first step, to form a high energy zwitterion must be the slow step of the reaction. From a chemical standpoint, it seems unlikely that a free R_2N^+ ion would be formed. As Tietz and McEwen[27] have indicated, the R_2N^+ is a very high energy species relative to the isoelectronic carbonium ion. Therefore, there should be a great drive for rearrangement in this system to be synchronous with N-O bond breaking. For instance, Smith has shown that while loss of nitrogen from $Ar_2CH\text{-}CH_2N_2^+$ followed by aryl migration proceeds without participation, the rearrangement of the corresponding nitrogen analog $Ar_2CH\text{-}NHN_2^+$ probably occurs with synchronous aryl migration.[28] In the oxaziridine system, in addition to the high energy of the R_2N^+ ion species, a large degree of charge separation would be involved in its production.

The unassisted N-O bond cleavage should show a great sensitivity to substituent on the N-aryl group since a high degree of positive charge should be developed on the nitrogen in the transition state. By Hammond's Postulate,[13] the transition state for this complete N-O bond heterolysis should resemble the high energh zwitterionic intermediate more than the starting material. This would imply a high degree of positive charge on the nitrogen at the transition state, and hence a large negative ρ for the overall reaction. The overall value of ρ for this reaction, estimated at -2 (Figure 2), indicates a relatively moderate degree of positive charge on the nitrogen in the transition state for rearrangement. Thus the complete bond heterolysis seems unlikely.

However, this arguement does not eliminate the possibility that an equilibrium exists between the open and closed form of the molecule (mechanism II), the open form of the molecule then rearranging to products. The ρ for this reaction would be expected to be lower because the transition state for this rearrangement is changed from N-O bond breaking to rearrangement of the zwitterion, a process whose sensitivity to substituent should be less. However, NMR evidence, to be presented later indicates that inversion about nitrogen is slow. This argues against rapid equilibrium since the equilibrated open zwitterionic structure should allow rapid nitrogen inversion.

In both the aforementioned mechanisms, it would also seem probable that the migratory aptitude of the aryl groups to the positively charged nitrogen would be very sensitive to substituents on the migrating aryl ring. Since both aryl and hydrogen migration are occurring at the same time, this sensitivity to substituents should be visible in differences in the relative proportions of the two migrations. This is not found.* As shown in Table IV, the ratios of aryl to hydrogen migration are about

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*A similar insensitivity to migrating groups has been found in processes where a highly energetic cationic center is produced. For instance, in the nitrous acid deamination of 1-phenyl-1-anisyl-2-aminoethanol, the ratio of anisyl to phenyl migration is only 1.56:1.[29] This has been explained both in terms of the highly reactive carbonium ion[29] and in terms of conformational effects.[30] It appears that neither of these effects are applicable in the oxaziridine system.

the same in all cases (except for the p-dimethylamino case).

If complete unassisted N-O bond cleavage does not occur, there must be some degree of migration of the rearranging group before complete N-O bond breaking occurs. This would indicate the existence of an intermediate similar to the one illustrated in mechanism III. However, the exact degree of N-O bond breaking and group migration at the transition state is still unknown.

2. The Geometry of the Transition State

a. Activation Parameter. Some indication of the energetics of the transition state can be made by calculating the activation parameters for the rearrangement. The ΔH and ΔS for the rearrangement of 2,3-diphenyloxaziridine in acetonitrile was determined by plotting the log of the reaction vs 1/T for five different temperatures between 25° and 45°C, as shown in Figure 5.

It is found that the ratio of hydrogen to aryl migration was consistant throughout the temperature range investigated. Therefore, their values of ΔH are the same, both being about 24 kcal/mole. From the partial rate factors, the entropies calculated are -1-1/2 e.u. and -3-1/2 e.u. for hydrogen migration and phenyl* migration. The value of ΔH for the two rearrangements is

*This can be compared with the values of ΔH = 25.3 kcal/mole and ΔS = 7-1/2 e.u. calculated by Shinzawa and Tanaka[31] for the corresponding reaction in cyclohexane where only hydrogen migration is observed.

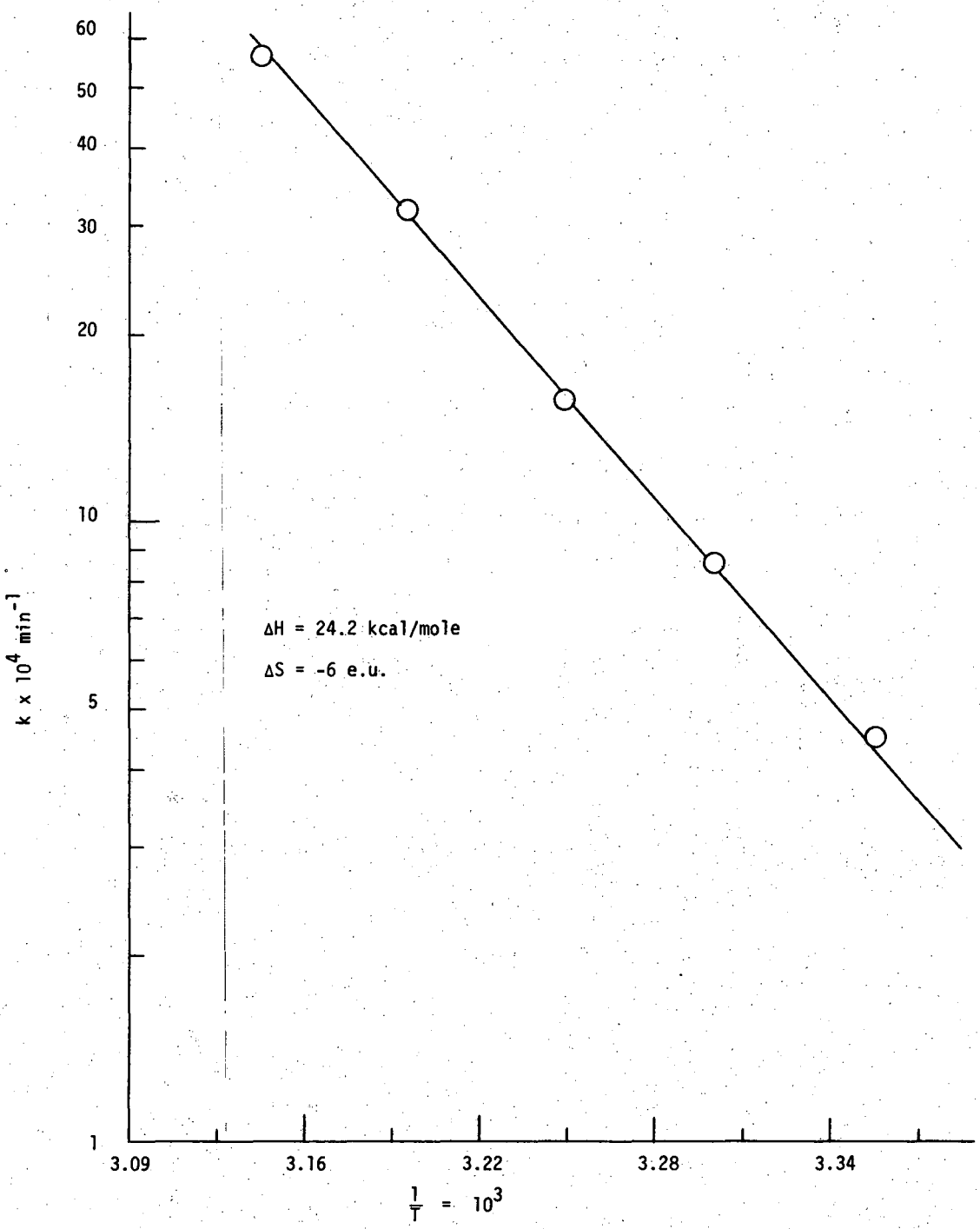

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Figure 5. Dependence of the first-order rate constant k on temperature for the rearrangement of 2,3-diphenyloxaziridine in acetonitrile.

surprisingly high considering that a very energetic species is being converted into a much more stable one. It is likely that the high energy of any positively charged nitrogen species that is produced as an intermediate contributes significantly to this high ΔH. The extremely low value of ΔS indicates that no appreciable overall entropy change is occurring between the ground state and transition state of the reaction. This value probably precludes a "tight" transition state where considerable group migration has occurred with little N-O bond stretching. These very ordered intermediates would be expected to have a large negative entropy. Likewise, the entropy values are probably not consistent with a complete N-O bond cleavage which, because the rigidity of the ring is eliminated, should result in a positive S.* It appears, therefore, that the rigidity of the transition state lies somewhere between these two extremes.

b. Hydrogen Isotope Effect. The question of the degree of migration of the hydride during the N-O bond cleavage is more difficult to assess since there are no longer the range of substituents available when investigating the aryl group migration. However, the presence of a heavy isotope of hydrogen, deuterium, allows some comparisons to be made. In reactions where hydrogen transfer occurs, the presence of an appreciable hydrogen isotope

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*The ordering of the solvent to stabilize the developing charges will probably cancel much of this effect.

effect (k_H/k_D = 1) has been taken to indicate that the hydrogen transfer occurs in or before the rate determining step for the reaction.[32] The values of k_H/k_D for reactions where hydrogen transfer occurs in the rate determining step vary from about 5 to 15, depending on the reaction.[32]

The deuterium analog of 2,3-diphenyloxaziridine has been prepared and the isotope effect measured. The results are shown below, in Table IX.

TABLE IX

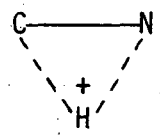
Hydrogen Isotope Effect in the Rearrangement of 2,3-Diphenyloxaziridine at 25°C

Solvent	k_H/k_D
CH_3CN	1.35 ± .05*
EtOH	1.05 ± .1

*The rate retarding effect of the α-D on the aryl migration still has not been adequately explained.

In ethanol, the α-H and α-D compounds react at approximately the same rate. This is understandable since only 20% of the reaction involves hydrogen migration (i.e. a primary isotope effect).

In acetonitrile the isotope effect k_H/k_D for the <u>total</u> reaction rate is about 1.35. This value is much smaller than the 5-15 rate noted earlier for other reactions. However, hydrogen rearrangement in the oxaziridine system involves a "triangular" transition state (VI). In these systems where only the bending



(VI)

modes of the carbon hydrogen and nitrogen-hydrogen bonds are important in hydrogen migration, the k_H/k_D is generally much smaller with a maximum value of about 3.[32] For instance, Collins and Bowman found a k_H/k_D of about 3 in the pinacol rearrangement of 1,1,2-triphenylethylenediols.[33] The maximum values of k_H/k_D are observed when, at the transition state, the migrating hydrogen is about equidistant from the migrating terminals.*

For less symmetrical transition states, considerably lower values for the isotope effect are obtained. For instance, Cram and Tadanier[34] found a value of 1.8 for the hydrogen migration in the solvolysis of 3-cyclohexyl-2-butyl-3-α-tosylates, and Bartlett and McCollum[35] found a value of 1.84 for the reduction of carbonium ions by alcohols. As a rule, the more unsymmetrical the transition state, the lower the observed kinetics isotope effect. Our value

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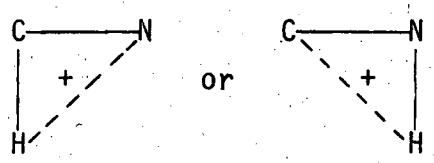
*More correctly, it is when the energies of the hydrogen bonds to the two terminals are isoenergetic.[32]

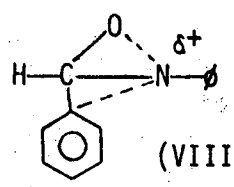
of approximately 1.35 is at the low end of observed primary isotope effects and indicates a rather unsymmetrical transition state for the reaction (VII). However, its non-unity value implies that the hydrogen is migrating in the rate determining step of the rearrangement. Thus it seems inconsistent with a mechanism involving rate determining ring opening followed by rapid phenyl or hydrogen migration.



(VII)

c. Transition State for Aryl Migration. In phenyl migration, the structure of the transition state is fairly polar as indicated by the great sensitivity of phenyl migration to solvent polarity (Table I). In addition, the relatively large values of $\rho(\sim -3$ to $-4)$ for phenyl migration in 3-phenyl-3-aryloxaziridines (Table I) both indicate a reasonable degree of charge development in the transition state for aryl migration. However, the aryl migration in the rearrangement of 2-aryl-3-phenyloxaziridines is independent of the substituent on the migrating group (Table IV). As stated previously, this implies a transition state where only a small amount of charge is delocalized into the migrating aryl ring.

This implies a transition state like the one shown below (VIII),



(VIII)

where only a weak interaction exists between the migrating group and the electron-deficient nitrogen. When ethanol is used as a solvent, there is a corresponding increase in sensitivity to substituent. This implies that the increased solvent polarity of the medium allows more charge delocalization to occur into the migrating aromatic ring, thus indicating a stronger interaction between the aryl ring and the electron-deficient nitrogen.

d. Conformational Effects. The information obtained thus far about the nature of the transition state for oxaziridine rearrangement leads to three general conclusions: 1) Positive charge is generated at the oxaziridine nitrogen. 2) A concerted reaction without complete heterolytic N-O bond cleavage occurs. 3) Aryl migration occurs more readily under more ionic conditions while hydrogen migration shows less sensitivity to the ionic nature of the reaction.

A fourth conclusion, although not as clearly defined as the previous three, seems to underlie much of the interpretations given so far. This is the fact that the existence of long weak bonds are necessary to explain many of the results--the low hydrogen isotope effect, the low negative ΔS, the general insensitivity of the rearrangement to substituents on the migrating aryl group. However, an *a priori* reason has not been advanced to explain this conclusion.

However, a different view of the system should help clarify these results and show why the presence of long, weak bonds are

consistent with the structure of the oxaziridine ring.

So far, we have been describing the aryl group and hydrogen, without considering the geometric requirements of an oxaziridine ring system. With the constraining nature of the three membered oxaziridine ring, geometry becomes a very important consideration as shown in Figure 6. A represents a diagram of the ground state oxaziridine molecule looking along the N-C bond. From this view of the oxaziridine molecule, it immediately becomes clear why rearrangement is so difficult. For R_1 to migrate most effectively, it must assume a trans-orientation relative to the breaking N-O bond as shown in B. Obviously, this is geometrically impossible if the integrities of the C-O and N-O bonds are to be maintained. The assumed high energy of the R_2N^+ species prevents complete heterolytic N-O bond cleavage. Thus, as our results indicate, a concerted rearrangement must occur. For R_1 to migrate, it must assume some compromise conformation such as illustrated in C. For this rearrangement to occur there must be severe distortions in the oxaziridine ring. To allow this distortion, there must be significant stretching of the nitrogen-oxygen bond coupled with twisting around the C-N bond. In addition, the bond between the migrating group and the nitrogen, at the transition state, must be relatively long and weak.

This is consistent with what was observed in the results of Table IV, where the rate of aryl migration is only weakly responsive to the substituent on the migrating aryl group. Since the

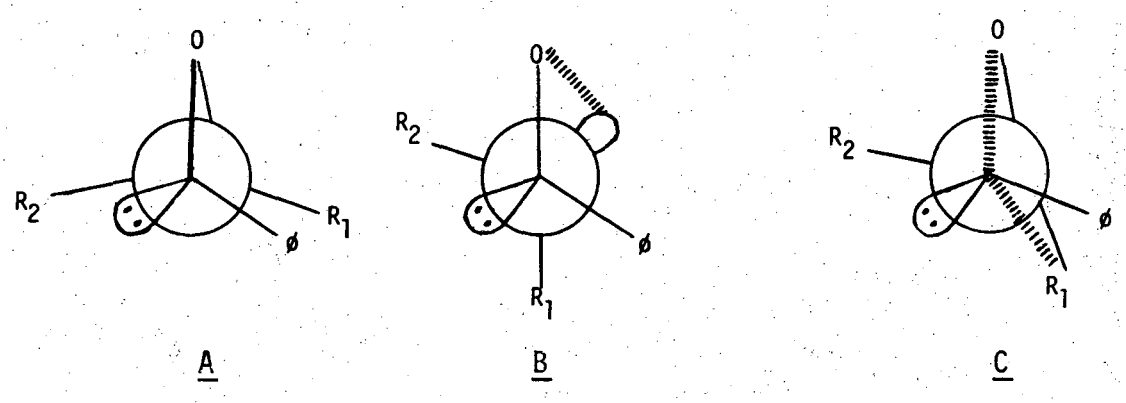


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Figure 6. Oxaziridine conformations.

bonding between the migrating group and the nitrogen is very weak, selectivity should also be low. In more ionizing solvents where greater heterolytic N-O bond cleavage occurs, selectivity is enhanced for three reasons. First, there is a higher positive charge on the nitrogen available for interacting with the migrating group. Secondly, the greater solvation allows more charge distribution into the migrating aromatic ring. Thirdly, the greater N-O bond cleavage reduces the rigidity of the system, thus allowing the migrating group to assume a configuration where it can more effectively interact with the developing positive charge on the nitrogen.

The reason for the general absence of significant anchimeric assistance is clear. Geometric requirements prevent the aryl groups from participating substantially in N-O bond cleavage. However, when a p-dimethylamino group is on the migrating carbon, the great electron donating power of the substituent allows significant interaction to occur between the electron-deficient nitrogen and the migrating aryl group. It is clear, however, that even in this case where anchimeric assistance seems to occur, the interaction must take place via relatively long bonds and in a relatively unfavorable conformation.

The results obtained in this study thus suggest a concerted rearrangement similar to the rearrangement of α,β-epoxyketones as studied by House and Rief.[36]

e. Nitrenium Ions.* To explain the concerted nature of the reaction, it seems necessary to assume the high energy nature of the nitrenium ion (R_2N^+), without clearcut proof. Much experimental evidence in the past has indicated that this species is generally not formed.** Instead, rearrangements and other reactions appear to take place synchronously.[28, 37] ‡

Tietz and McEwen[27] have stated that the $R\text{-}\overset{+}{N}H$ should be much less stable than the RCH_2^+, the corresponding carbon analog. Undoubtedly their conclusion was based on the greater electron negativity of the nitrogen. Since these species are not stable, it is impossible to get a good experimental value for the relative stabilities of the two ions. However, with the current refinement in molecular orbital theory, it is now possible to roughly estimate the energetics of theoretical molecules.

It may be instructive to use the most refined *ab initio* SCF calculations available to estimate the relative stability of N^+ and C^+. To do this, we take the simplest analogous systems where

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*The term "nitrenium ion" as advocated by Gassman[42] is used here since it appears to be more descriptive than the term "imidonium ions" used by others.[37]

**For possible exceptions, see References 38-40.

‡Several recent papers have appeared on the rearrangements of dialkylnitrenium ions,[41-43] but these too probably occur in a concerted manner.[44]

fairly reliable data is available, methane and ammonia.

Comparison of energetics of the reactions listed below should give us some idea of the relative stability of CH_3^+ and NH_2^+ relative to the parent compound. These calculations are shown below.

$$CH_4 \longrightarrow CH_3^+ + H^-$$

$E = -40.1983$ au[45] $\quad -39.2346$ au[46] $+ E_{H-}$

$\Delta E - .9637$ au $+ E_{H^-}$

$$NH_3 \longrightarrow NH_2^+ + H-$$

$E = -56.2015$ au[47] $\quad -55.0932$ au[46]

$\Delta E = -1.1083$ au $+ E_{H-}$

One thus calculates that the process to form the NH_2^+ is less energetically favorable than the CH_3^+ formation by .1446 au which is equal to about 90 kcal/mole.

Although the current crude state of molecular orbital calculation makes this calculation inexact, the number should be accurate to within $\pm$ 30 kcal. The size of the difference in energy indicates that, as predicted by Tietz and McEwen, the RNH^+ is of much higher energy than the RCH_2^+. However, the levelling effect of substituents should reduce this difference. This energy difference is <u>not</u> caused by the energy difference between the C-H and N-H bonds which are

being broken in the ionization reaction since the bonds are of comparable energy (i.e. 98 kcal/mole and 93 kcal/mole, respectively).

It can be concluded therefore that the nitrenium ion is significantly higher in energy than the corresponding carbonium ion. Thus, the difficulty in forming the Free R_2N^+ species is understandable and the reason this reaction must react by concerted means is apparent.*

3. Charge Distribution in the Transition State

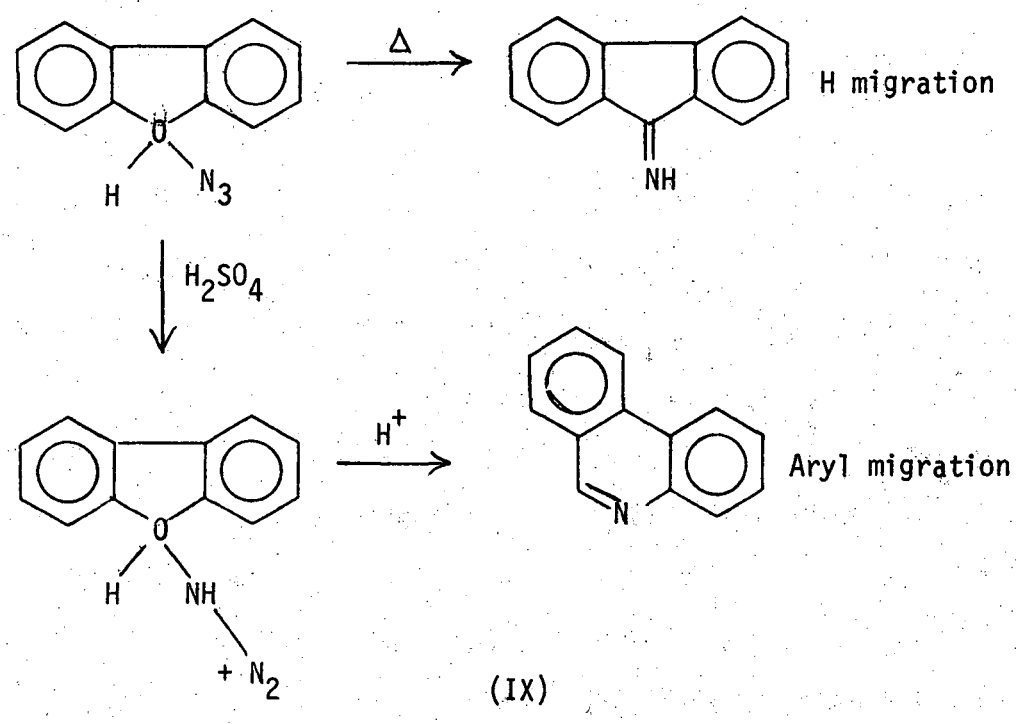
The fact that hydrogen migration exceeds aryl migration in the oxaziridine rearrangement in acetonitrile is quite unusual since in most migrations to electron-deficient systems, the aryl groups migrate much more readily than hydrogen.[28] It appears that in non-ionizing solvents such as acetonitrile and carbon tetrachloride, even methyl groups seem to migrate more readily than

*The fact that the thermal rearrangement of the 2-(4-methoxyphenyl)-3-phenyloxaziridines results in only rapid hydrogen migration is a major anomoly in these results since electron donating groups on the N-phenyl generally favor phenyl migration. As shown in other systems by Collins,[48] Gassman[49] and others, the anisyl group can so stabilize a positive charge that participation by other groups can be eliminated. Therefore, it is possible that in this case the presence of the anisyl group adjacent to the developing electron-deficient nitrogen, eliminates stabilization due to aryl migration. Thus the reaction may take place through an open nitrenium ion.

phenyl! (See the experimental section.) However, in more ionizing solvents, aryl migration appears to predominate. In addition, the migration of a hydrogen is characterized by a relatively small value of $\rho^{(-2)}$. The implication from both of these results if that the migration of a hydrogen in the rearrangement is not a highly ionic process. Hydrogen migration can occur in iso-octane at a rate that is still one tenth the rate in acetonitrile (Table I). The fact that the reaction can occur at such a rate in such a nonpolar environment imlies that even the low value of ρ found may exaggerate the ionic nature of the reaction. In fact, the results can be interpreted to mean that hydrogen migration is more of an internal 1,2-hydride shift which requires very little charge separation.[50,51]

The fact that the rate of hydrogen migration is in some way proportional to the amount of charge on the electron-deficient nitrogen may be interpreted in another manner. Instead of changing the charge density on the nitrogen, the effect of the substituent is to lengthen or shorten the N-O bond. This in turn would effect the ability of the hydrogen to migrate. As the N-O bond is stretched, the hydrogen can more effectively orient itself into a conformation conducive to migration. Electron-donating substituents by stabilizing heterolytic N-O bond cleavage allow more stretching of the N-O bond and thus the hydrogen can more effectively migrate. The value of ρ of -2 for hydrogen thus may represent a sensitivity to conformation effects caused by N-O bond stretching rather than an inherent sensitivity to charge densities. Some evidence supporting the internal character of the hydrogen rearrangement can

be found in the results of Arcus and coworkers,[52] who found that in the rearrangement of 9-phenyl-9-fluorenyl azide (IX), thermal hydrogen migration occurs while in the acid catalyzed reaction,



(IX)

aryl migration occurs. Thus it appears that when a high positive charge is present as in the protonated azide, aryl migration predominates while with little positive charge, the hydrogen migration is preferred. Similar results have been observed in other systems.[53]

Phenyl migration shows a high degree of sensitivity to substituent on the N-phenyl group as shown by the substantial values of ρ for the phenyl migration in the N-substituted diphenyloxaziridines (ρ ca. -3 to -4 in acetonitrile) (Table II). Likewise, its greater sensitivity to solvent polarity indicates that the phenyl migration is probably significantly more ionic in character than the

corresponding hydrogen migration. This is an indication of a fairly ionic reaction, comparable to many solvolyses reactions in carbonium ion chemistry. But again, the effect of the substituent is felt in two separate ways. One, it affects the degree of positive charge on the nitrogen by stabilizing or destabilizing the degree of heterolytic N-O bond cleavage. This in turn should affect the strength of bonding that should exist between the migrating phenyl group and the electron-deficient nitrogen. However, as in the case of hydrogen migration, the substituent, in altering the amount of N-O bond cleavage alters the conformation of the molecule. As the N-O bond is stretched, the phenyl again can assume a conformation where it can more effectively interact with the electron deficient nitrogen.*

Therefore, the ρ calculated for the reaction cannot be compared with ρ's for other carbonium and nitrenium ion reactions to estimate the degree of positive charge on the nitrogen at the transition state for phenyl migration. Instead, a modified $\sigma\rho+$ correlation must be assumed: $\log {}^{k}/_{ko} = \sigma^{+} (\rho_1 + \rho_2)$.**

*Phenyl migration has been shown to be very sensitive to the geometry of the migrating phenyl group relative to the developing electron-deficient center.[55]

**Separation of these two factors would be difficult since there should be some rough proportionality between the charge on the nitrogen and the amount of N-O bond stretching. For example, Jones[54a] and Rao[54b] have found a reasonable correlation between σ^{+} and the changes in the carbonyl stretching frequency in substituted acetophenone.

Here, ρ_1 is related to the effect of substituent on the amount of positive charge present on the oxaziridine nitrogen. ρ_2, on the other hand, is related to effect of the substituent on the conformation of the oxaziridine ring caused by N-O bond stretching, and hence on the ability of the migrating group to assume an orientation conducive to migration.*

Quite probably the actual amount of positive charge on the nitrogen is substantially lower than the ρ value of -3 or -4 indicates. However, the evidence seems conclusive that there exists a polar transition state for aryl migration. From a comparison of the rates of phenyl to hydrogen migration in 2,3-diphenyloxaziridine in various solvents (Table I), it is apparent that phenyl migration is much more sensitive to solvent polarity than the hydrogen migration. In fact, in iso-octane where charge delocalization is difficult, no phenyl migrations occur while in ethanol, a quite good solvating medium, phenyl migration predominates over hydrogen migration. This sensitivity to solvent polarity indicates that a fair degree of positive charge must be present on the nitrogen before aryl migration occurs. Likewise, its sensitivity to N-aryl substituents indicates that a greater degree of charge must be

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*The slight curvature observed in $\sigma\rho^+$ plots of the rearrangements of N-substituted diaryloxaziridines (Figure 1) may reflect the fact that a change in the length of the nitrogen-oxygen bond may not cause a linearly proportional change in the conformation of the migrating group.

generated on the nitrogen for aryl migration than for the corresponding hydrogen migration.

In the rearrangements of 3-aryl-2-phenyloxaziridines in acetonitrile (Table IV), the lack of sensitivity of the reaction rate to substituents on the migrating aryl group implies that in this case the amount of positive charge delocalized to the aryl ring is small. However, when a more polar solvent such as ethanol is used, the rate increase and increased sensitivity indicate a more polar transition state, and hence more positive charge on the nitrogen. Again, all this evidence indicates that aryl migration involves a quite polar transition state.

In the triaryloxaziridines, two factors indicate only a slightly ionic transition state. First, the insensitivity of the reaction to substituents on the migrating aryl group (as shown in Table VII) argues for only a slight degree of ionic character. Second, the solvent effects are minimal on the rate of rearrangement. As shown in Table VII, a change from acetonitrile to ethanol causes a rate increase of only a factor of <u>two</u> in the rate of rearrangement of triphenyloxaziridine. This is even less than the effect of the solvent change on hydrogen migration in the 2,3-diphenyloxaziridine (4 x)! Yet an estimate of ρ for the rearrangement of 2-aryl-3,3-diphenyloxaziridines (Table VII) indicates a value of >-6!

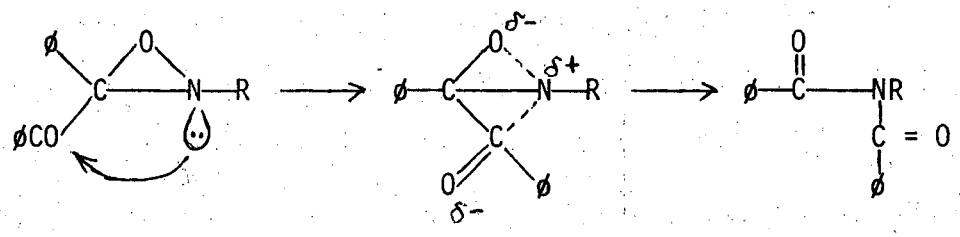
Thus it appears that the value of ρ is much less than implied by the sensitivity to substituents. Two factors dealing with the orientation of the N-aryl ring have been used to explain this

anomoly (see section on Triaryloxaziridine Kinetics). In addition, the same conformational arguements used in discussing hydrogen and phenyl migration can be applied here. Because of the high degree of steric interactions, the orientation of the migrating aryl group in this case will be even more dependent on the amount of N-O bond stretching. The negative value of ρ and the meager sensitivity to solvent indicate that the reaction probably occurs through a mechanism involving only slight stretching and polarization of the N-O bond followed by aryl migration. Again, it appears that caution must be used in assuming charge densities from calculated ρ values. If conformational changes are occurring as the reaction proceeds, the ρ values may give an exaggerated indication of charge densities.

Thus it is proposed that the rate of rearrangement of diaryl- and triaryloxaziridines is increased by two factors: one, an increase in the amount of positive charge on the oxaziridine nitrogen and the other, a greater degree of stretching of the nitrogen-oxygen bond. The former increases the electrophilic properties of the nitrogen toward the aromatic ring or hydride ion and the latter allows a better conformation for interaction between the electron deficient nitrogen and the migrating group. Unfortunately, these two effects are difficult to separate since there is a rough proportionality between the two factors, i.e. the higher the degree of positive charge, the more the nitrogen-oxygen bond is stretched. However, recently a system has been investigated where positive

charge and the degree of nitrogen-oxygen bond stretching have opposite effects on the rate of reaction, one retarding and one accelerating the reaction.

Padwa[56] has proposed that in the rearrangement of 3-benzoyl-2-cyclohexyl-3-phenyloxaziridine (X) in acetonitrile, the rearrangement proceeds via attack of the unshared electron pair of the oxaziridine nitrogen on the carbonyl to give a "bicyclobutane-type" of intermediate (XI). This then rearranges to the final product, a dibenzoylamine (XII). Considering the relatively high



(X) Ia. R = cyclohexyl (XI) (XII)

Ib. R = ø

entropy for the rearrangement (-21 e.v.),[56] this type of a transition state seems quite likely. The fact that the N-phenyl derivative (Xb)* reacts instantaneously at room temperature while the N-cyclohexyl compound (Xa) must be heated to 80-90° before the reaction occurs implies that the N-phenyl group has a substantial accelerating effect on the reaction. This effect is not on the unshared pair of electrons on the nitrogen, however, since the phenyl group, being electron withdrawing relative to the

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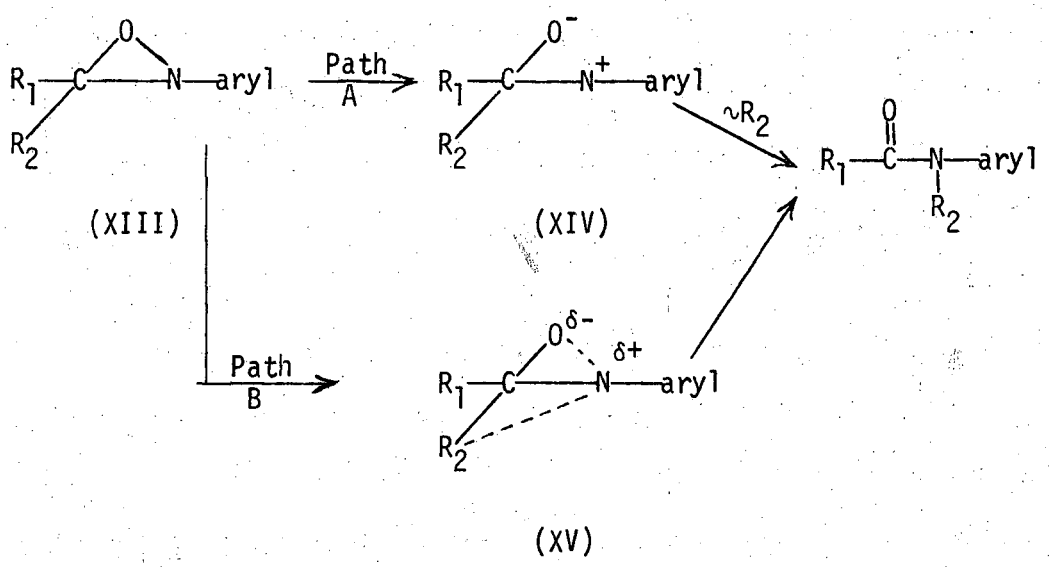
*Produced by the irradiation of the corresponding α-benzoyl-α,N-diphenylnitrone.

cyclohexyl group, would tend to reduce the free electron density on the nitrogen. This should, in turn, reduce the rate of nitrogen attack on the benzoyl group. Therefore, the accelerating effect on the phenyl group must be due to its stabilization of heterolytic N-O bond cleavage as found in the rearrangements of diaryl- and triaryloxaziridines. Heterolytic bond cleavage should generate positive charge on the oxaziridine nitrogen, which should reduce the nucleophilicity of the nitrogen and hence reduce the rate of benzoyl migration. On the other hand, it should lengthen the N-O bond reducing the constraints of the three-membered ring, allowing the benzoyl group to assume a position more conducive to migration. Thus, unlike the di- and triaryloxaziridines, in this system, these two factors operate in opposite directions, positive charge generation reducing the reaction rate while N-O bond lengthening accelerating it. Since the overall effect of the N-phenyl group is to greatly accelerate the rearrangement, it is apparent that N-O bond lengthening is the dominant factor in determining the rate of rearrangement in the 3-benzoyloxaziridine systems. Thus conformational effects can be extremely important in oxaziridine rearrangements, and a combination of charge distribution <u>and</u> conformational effect must be considered when discussing the mechanism of the reaction.

4. Summary

From a general survey of the results of this kinetic study it appears that the rearrangement of the 2,3-diaryloxaziridines to amides involves a heterolytic process. However, with the possible exception of the 2-p-methoxyphenyl compound, it does not seem to occur by a simple process of nitrogen-oxygen bond cleavage (Path A) to give a zwitterionic intermediate (XIV). The instability of a



free nitrenium ion (R_2N^+) prevents the formation of the intermediate (XIV). Instead, the reaction probably occurs via a concerted bond cleavage and rearrangement (Path B) to give the final rearrangement products.

Because of the geometric constraint placed on the system by the oxaziridine ring, the migrating group cannot easily assume a conformation conducive to migration. Thus, before migration can occur there must be considerable stretching of the nitrogen-oxygen bond, probably with a small amount of polarization. As an additional

consequence of the poor orientation of the migrating group for rearrangement, the transition state for rearrangement appears to involve only a long, weak interaction between the migrating group and the electron deficient nitrogen.

The migration of a hydrogen atom seems to be much less sensitive to positive charge development at the nitrogen than does the migration of the aryl group. This indicates that hydrogen migration probably occurs by a fairly concerted 1,2 hydride transfer where little actual charge separation is involved. On the other hand, the migration of an aryl group appears to involve a significantly more polar transition state with a greater degree of heterolytic N-O bond cleavage being necessary for the rearrangement to occur. However, because of the geometric constraints of the system, again, in the transition state for aryl migration, generally only a weak interaction exists between the migrating aryl group and the electron deficient nitrogen. Only in the case of the 3-p-dimethylaminophenyl and possible the 2-p-methylphenyl compound does a resonance stabilized phenonium-type ion appear to be formed.

Similar considerations appear to apply to the rearrangement of the triaryl compounds. Because of the steric interactions between the three aryl rings, it appears that the N-aryl group is forced to assume a conformation where it cannot effectively stabilize the developing positive charge resulting from N-O bond cleavage. Therefore the rearrangement of triaryloxaziridines (I,R_1 = R_2 = aryl) to substituted benzoyldiphenylamines appears to be a less

polar process than in the diaryl system. This inability to stabilize N-O bond cleavage is apparently responsible for the unexpectedly high stability of the triaryloxaziridines.

These general conclusions on the mechanism of oxaziridine rearrangement seem to be consistent with the few previous investigations of these types of reactions. For instance, Splitter and Calvin,[1] on the basis of solvent effects and the reactions of several substituted 2,3-diaryloxaziridines felt that the rearrangement proceeded via a heterolytic N-O bond cleavage. Mauser and Bokranz[57] have recently reported a study of the rearrangement of 2,3-diphenyloxaziridine in methanol and find products resulting from nucleophilic attack of the solvent on the N-phenyl ring. This too implies the intermediacy of a positively charged nitrogen during the reaction.*

A comparison of our results with the acid catalyzed reactions of N-alkyl oxaziridines indicates some consistency in the migratory behavior of the phenyl and hydrogen in rearrangements to electron deficient centers.

When 2-(1-phenylethyl)-3-isopropyloxaziridine (XVI) is hydrolyzed in acidic alcohol, only phenyl migration to the electron deficient nitrogen occurs, giving aniline as a major hydrolysis product.[23] When the corresponding N-butyl compound was reacted,

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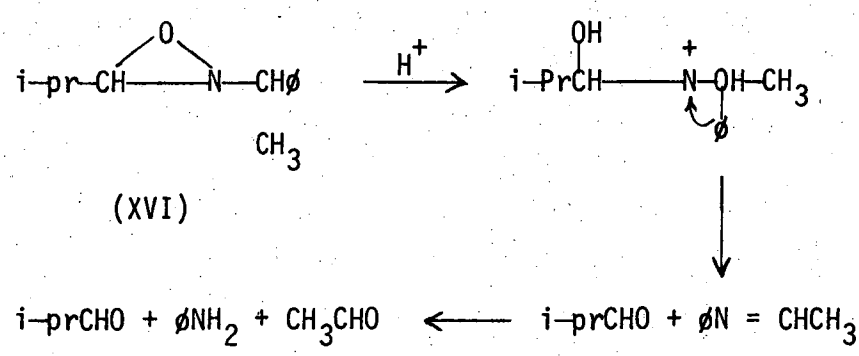
*The possibility still exists that these types of nucleophilic solvent attack on the aromatic rings are acid catalyzed reactions similar to the acid catalyzed rearrangement of phenylhydroxylamine.[58]

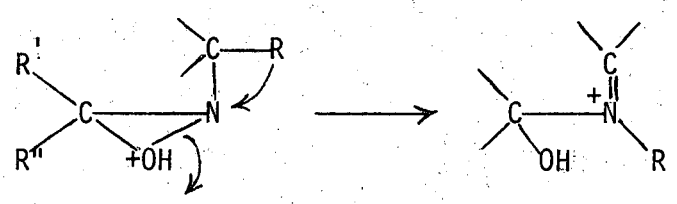


hydrogen migration occurred exclusively to the exclusion of alkyl migration (although with N-t-butyl compounds, methyl migration does occur.) Thus it appears that the migratory aptitudes to the nitrogen follow the order phenyl>>H>alkyl.

In our studies we have observed a trend that the greater the positive charge on the nitrogen, the more aryl migration occurs. Since in these acid catalyzed reactions, a very high degree of positive charge resides on the nitrogen, we would expect, as is found, that phenyl migration is much faster than hydrogen migration.

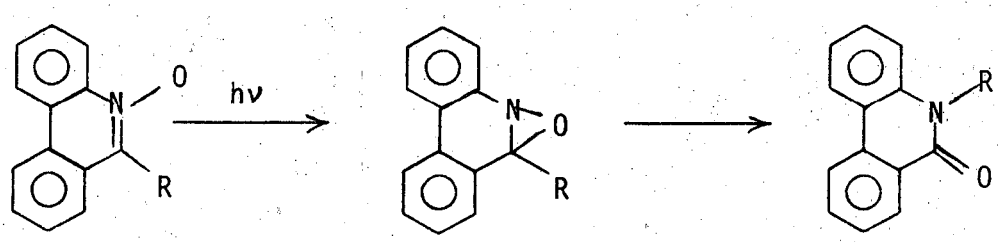
It is interesting to note that acid catalyzed migration of a group from the oxaziridine carbon does not occur, and instead migration occurs from a carbon <u>exo</u>- to the ring. There are two very substantial reasons for this. In the thermal rearrangements of aryl oxaziridines, there is a carbonyl formed upon group migration. The driving force for carbonyl formation should lower the energy barrier for group migration. However, in the acid catalyzed rearrangement, the proton already on the oxygen neutralizes any negative charge on the oxygen and hence reduces the push for carbonyl formation.

The second reason is what Schmitz calls the "stereoelectronic" effect.* In essence, it is the ability of the migration group to assist N-O bond cleavage. As the diagram below shows groups exo- to the oxaziridine ring can be oriented into a position where group migration can occur synchronously with bond breaking. On the other hand, the substituents on the oxaziridine carbon are in a poor position to migrate. Thus exo-migration is preferred.



This again substantiates the necessity for the concerted rearrangement and N-O bond cleavage which was indicated in our work.

One other recent example of oxaziridine rearrangements deserves comment. Taylor and Spence[59] found that irradiation of 6-substituted phenanthridine 5-oxides (XVII) yields the corresponding 5-substituted phenanthridin-6(5H)-ones (XIX) presumably via an intermediate oxaziridine (XVIII). When an optically active alkyl



(XVII) (XVIII) (XIX)

*Reference 24, p. 107.

migrating group was used (R = $CH(C_2H_5)\emptyset$) the product after rearrangement showed complete loss of optical activity. Likewise, side-products of the reaction could most easily be explained in terms of a radical rearrangement mechanism. This implies that in the phenanthridine system, a radical process is occurring in which the migrating group becomes completely dissociated or only very weakly bound to the oxaziridine carbon and nitrogen. This is consistent with our findings that hydrogen and possibly methyl migration occur via a "radical-like" mechanism involving long weak bonding between the nitrogen and the migrating group.

A. Stable 2,3-diaryloxaziridines.

We have seen that electron-withdrawing groups on the N-phenyl greatly retard the rearrangement of the diaryloxaziridines. This fact may help answer one of the basic questions of this research: Can stable diaryloxaziridines be isolated? If sufficiently electron-withdrawing groups are placed on the N-phenyl it would seem possible to isolate these species.

Since the half-life for rearrangement in acetonitrile of the p-cyano substituted compound is so long (on the order of 10 days), this compound seems like the most reasonable choice for an isolable diaryloxaziridine. Hence, an effort was made to collect and identify it. Our task then is to irradiate the corresponding nitrone in a suitable solvent, remove the solvent and determine if the remaining product is the desired oxaziridine.

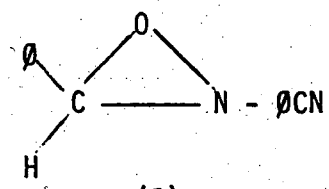
The solvent used must satisfy five criteria:

1) It must dissolve the nitrone; 2) it must be low boiling so elevated temperature will not have to be used to remove it; 3) it must not absorb light used to irradiate the nitrone; 4) it must be stable to uv irradiation and 5) it must be unreactive with either the nitrone or oxaziridine. Methylene chloride appeared to satisfy all the requirements and thus it was used in all further isolation attempts.

When the corresponding nitrone is irradiated in methylene chloride and the solvent removed under reduced pressure, a solid remains. Purification on a super-cel column yields a light orange crystalline material, mp 82-84°. The solid is fairly stable at room temperature and could be stored indefinitely at 0°C. It shows a high active oxygen content of 98%, a very strong indication of an oxaziridine ring. The mass spectrum shows a parent peak at m/e 222, the same molecular weight as the starting nitrone. Additional peaks

at m/e 206, 105 and 118 are also characteristic of the oxaziridine ring. The infrared spectrum (Fig. 1) shows no carbonyl peak nor a peak consistent with a carbon nitrogen double bond. The uv spectra (Fig. 2) shows no extended conjugation as found in the starting nitrone. Finally, the material when refluxed overnight in acetonitrile is converted in 75% yield to the corresponding benzanilide.

These properties of the compound are completely consistent with the structure of 2-(4-cyanophenyl)-3-phenyloxaziridine (I).



(I)

The isolation of this compound firmly establishes the fact that oxaziridines are indeed the photoproduct from the irradiation of diarylnitrones. Also, it verifies our contention that the kinetics that are being measured are those of the diaryloxaziridines. Although the evidence, as shown by Splitter and Calvin[1], for the existence of the diphenyloxaziridines is very compelling, the oxaziridines themselves have never been isolated.*

Similar results were obtained for the 2-(4-nitrophenyl)-3-phenyloxaziridine and the 3-styryl-2-phenyloxaziridine and some of their properties are summarized in Table I.

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*C. Kaneko[59] had earlier claimed the isolation of a diaryloxaziridine from the photolysis of 2-phenylquinoline N-oxide,but this was later proved to be in error.[60]

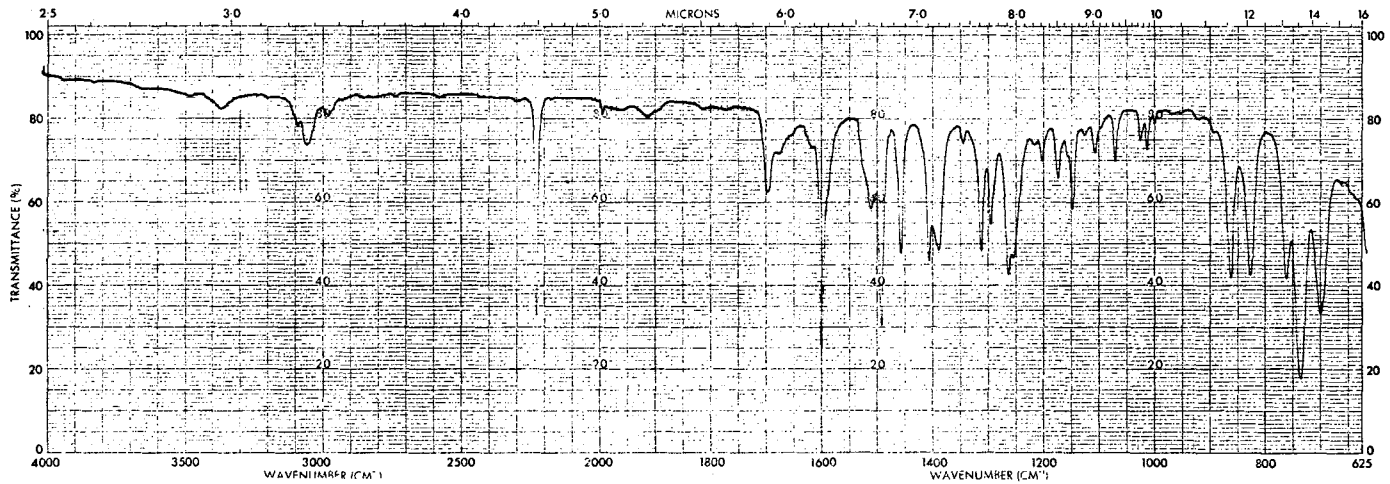
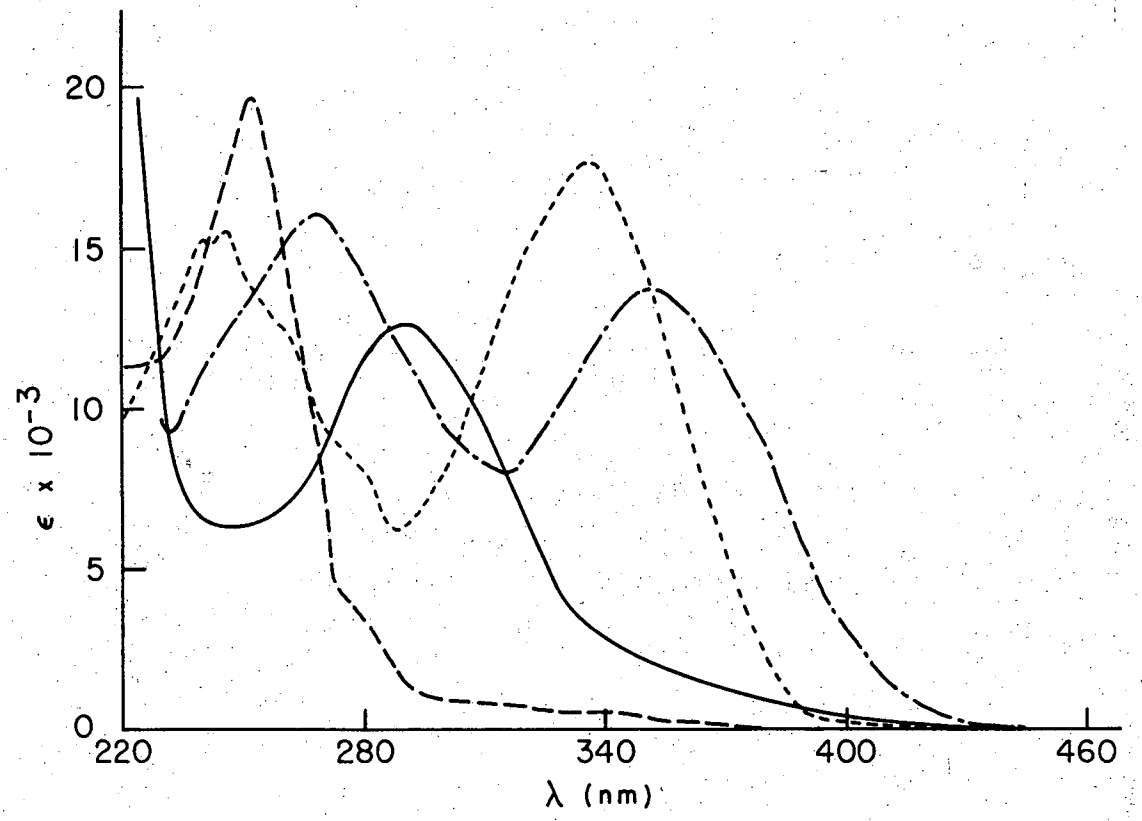


Figure 1. IR spectrum of 3-phenyl-2-(4-cyanophenyl)oxaziridine (neat). (A trace of benzaldehyde is present (C=O at 1700 cm^{-1}).)



XBL 695-4268

Figure 2a. UV spectra of stable diaryloxaziridines and the corresponding diarylnitrones (in CH_3CN).

1 a. N-(4-cyanophenyl)-α-phenylnitrone ---------

b. 2-(4-cyanophenyl)-3-phenyloxaziridine — — — — —

2 a. N-(4-nitrophenyl)- -phenylnitrone — - — - —

b. 2-(4-nitrophenyl)-3-phenyloxaziridine ————

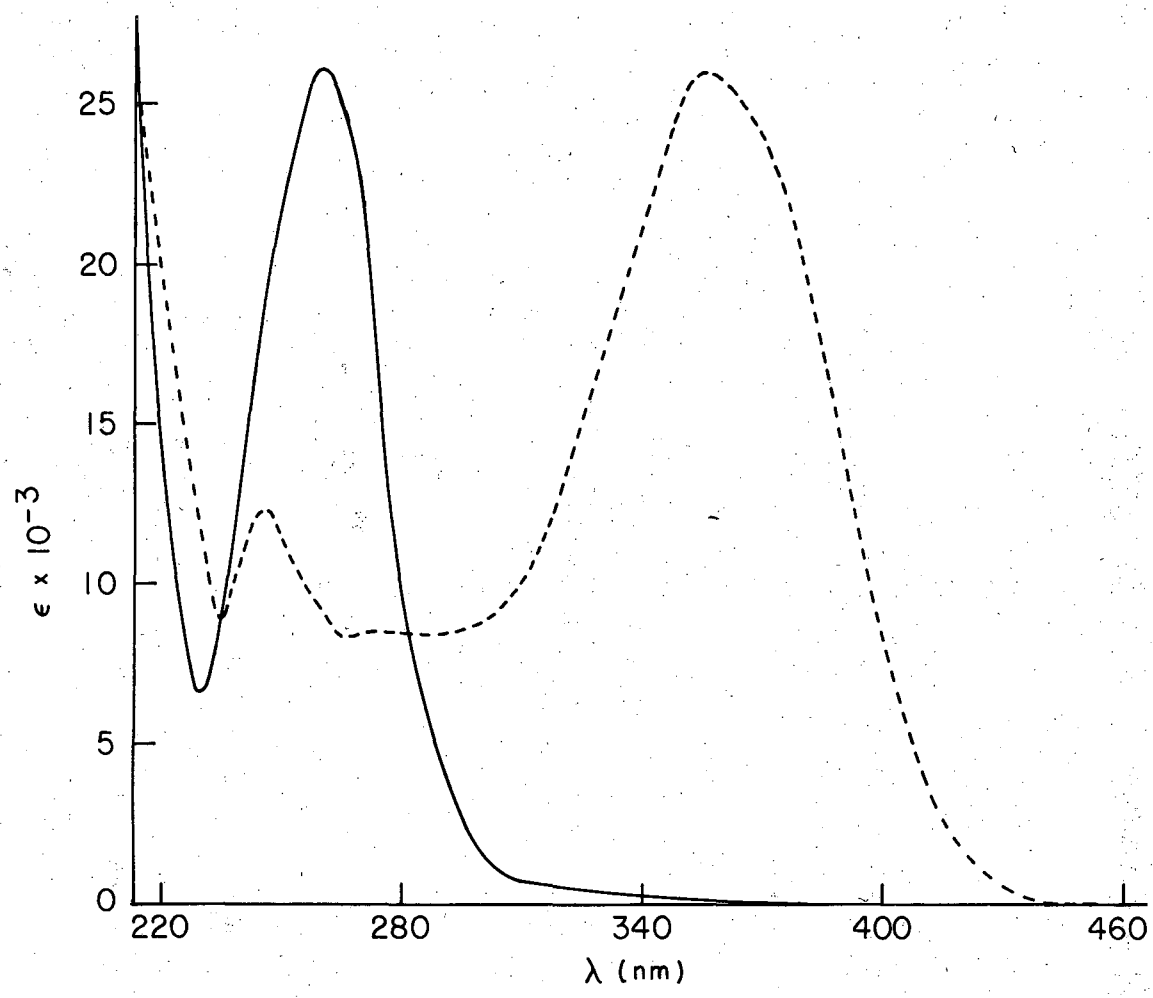


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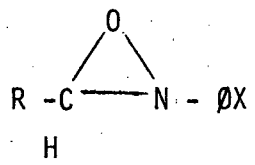
Figure 2b. UV spectra of stable diaryloxaziridines and the corresponding diarylnitrones (in CH_3CN).

3 a. α-styryl-N-phenylnitrone --------

b. 3-styryl-2-phenyloxaziridine ————

TABLE I

Stable Diaryloxaziridines



R	X	mp	λ max (ε)[a] (acetonitrile)	Active Oxygen
phenyl	p-CN	82-84°C	252 mμ (ε19,500)	98%
phenyl	p-NO_2	95-102°C	290 mμ (ε12,600)	94%
styryl	H	63-64°C [b]	260 mμ (ε26,800)	80% [c]

a. See Figures 2a and 2b.

b. Solvent removal must be carried out at low temperatures <0°C or product decomposition will take place.

c. The low active oxygen observed for the styryl compound is probably due to its great instability. At room temperature it decomposed in a few hours to a dark oil.

Figures 2a & b show the absorption spectra of the three isolated diaryloxaziridines and the corresponding diarylnitrones. It is apparent that the oxaziridines show none of the long wavelength absorptions characteristic of the extended conjugated system present in the parent nitrones.

The 3-styryl-2-phenyloxaziridine is quite unstable, decomposing in a few hours at room temperature to a dark oil. However, at dry ice temperatures it can be stored for days. The question remains, why is it isolable at all? uv Studies indicate that the styryl compound is only

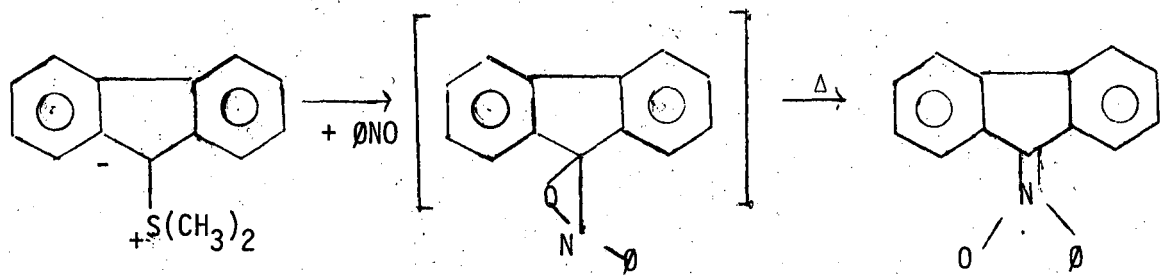
slightly more stable than the diphenyl compound. This is reasonable since both compounds have unsubstituted phenyl groups adjacent to the nitrogen. Attempts to isolate the diphenyloxaziridine by the technique used above result in a very unstable oil which darkened very rapidly. Shinzawa and Tanaka[31] have similarly reported the instability of the diphenyloxaziridine and their failure to isolate it. However they were able to obtain ir spectra by photolyzing the nitrone in a KBr disc at liquid nitrogen temperatures.[31]

Instead of attempting to explain the isolability of the 3-styryl-2-phenyloxaziridine in terms of chemical reactivity, a physical explanation may be more appropriate. The ability to isolate the oxaziridine may be due to its facile crystallization at low temperatures. As an oil, it can still undergo complex intermolecular decomposition reactions. In keeping with this, Shinzawa and Tanaka have reported that the diphenyloxaziridine is very sensitive to concentrations decomposing rapidly at high concentrations.[31] However, the 3-styryl-2-phenyloxaziridine crystallizes at moderate temperatures. In the crystalline state, further reactions may very well be slowed down because of the rigid lattice structure inherent in the crystal.

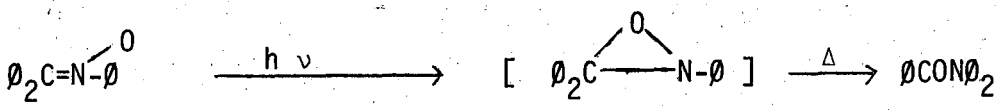
B. Stable triaryloxaziridines.

The unexpected stability of the triaryloxaziridine system in solution immediately brought forth the possible isolation and characterization of these unknown compounds. Although triaryloxaziridines had never been isolated, their intermediacy had been proposed.

Johnson[25] has hypothesized the existence of a triaryloxaziridine (III) in the reaction of dimethylsulfonium (diphenyl) methylide (II) with nitrosobenzene to give N-phenyl fluorenone ketoxime (IV). He also found that irradiation of the produced nitrone gave unchanged starting material.



(II) (III) (IV)



(V) (VI) (VII)

Scheinbaum[61] found that irradiation of 2,3,3-triphenylnitrone (IV) in dioxane gave high yields of benzoyldiphenylamine (VII), presumably through the intermediacy of the triphenyloxaziridine (VI). No direct evidence for the existence of the oxaziridine could be found, although his irradiation conditions (0.55 g of nitrone in 5 ml dioxane, irradiated through Pyrex for 2 days with a 550-watt high pressure mercury arc lamp) were so drastic, that detection of the intermediate oxaziridine would be difficult.

Irradiation of the triphenylnitrone for 4 1/2 minutes in methylene chloride, followed by solvent removal by rotary evaporation yields a quantitative yield of a tan-white crystalline material, mp 125°. The elemental analysis and parent ion in the mass spectra indicate that the compound is isomeric with the starting nitrone. The major peaks in the mass spectrum of the oxaziridine are shown below. The main peaks can be accommodated in the mass spectral fragmentation pattern shown in Fig. 3. m/e (relative intensity) 273 (M^+), 257 (1.6), 182 (32), 191 (7), 180 (9), 167 (2), 165 (3), 152 (5), 106 (11), 105 (100), 93 (16), 91 (12), 77 (100), 51 (75).

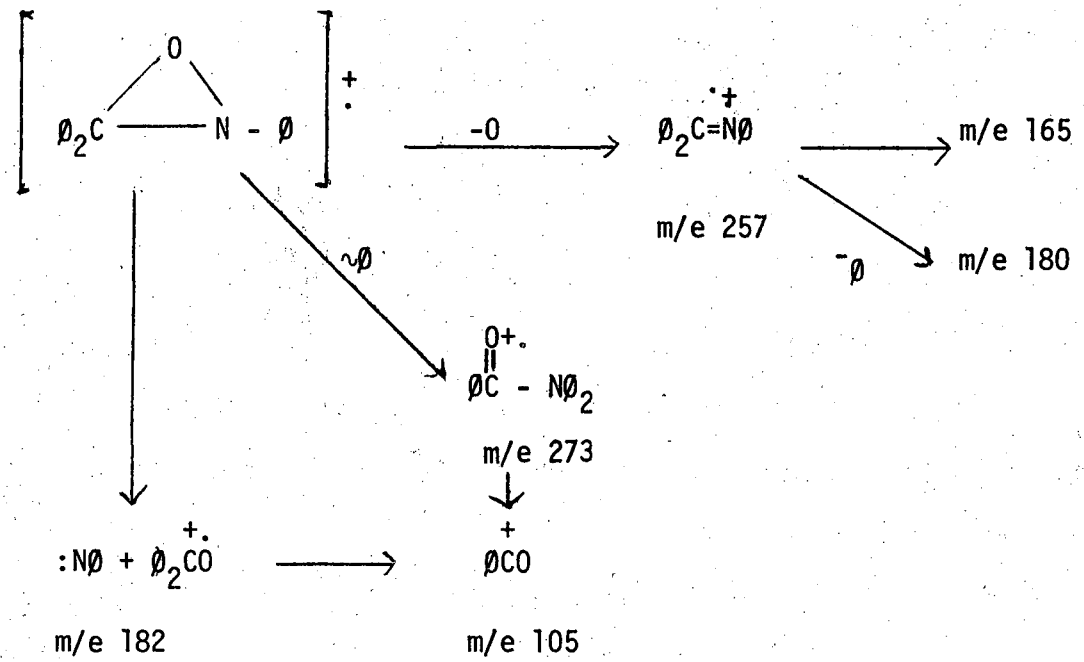


Figure 3

The ir spectrum of the unknown shows neither carbonyl nor imine absorptions (Fig. 4) while the uv (Fig. 5) shows only end absorption typical of the non-conjugated oxaziridine ring. Quantitative active oxygen content, a definite indication of the oxaziridine structure is also observed. In addition, refluxing of an acetonitrile solution of the unknown results in an 88% yield of the corresponding benzoyldiphenylamine. All this evidence is consistent with a triphenyloxaziridine structure.

By similar procedures a number of other triaryloxaziridines were isolated as stable solids. Some of their properties are shown in Table II and the uv spectra of the parent triphenyloxaziridine and the 2-(4-nitrophenyl)-3,3-diphenyloxaziridine and their respective nitrones are shown in Fig.5 .

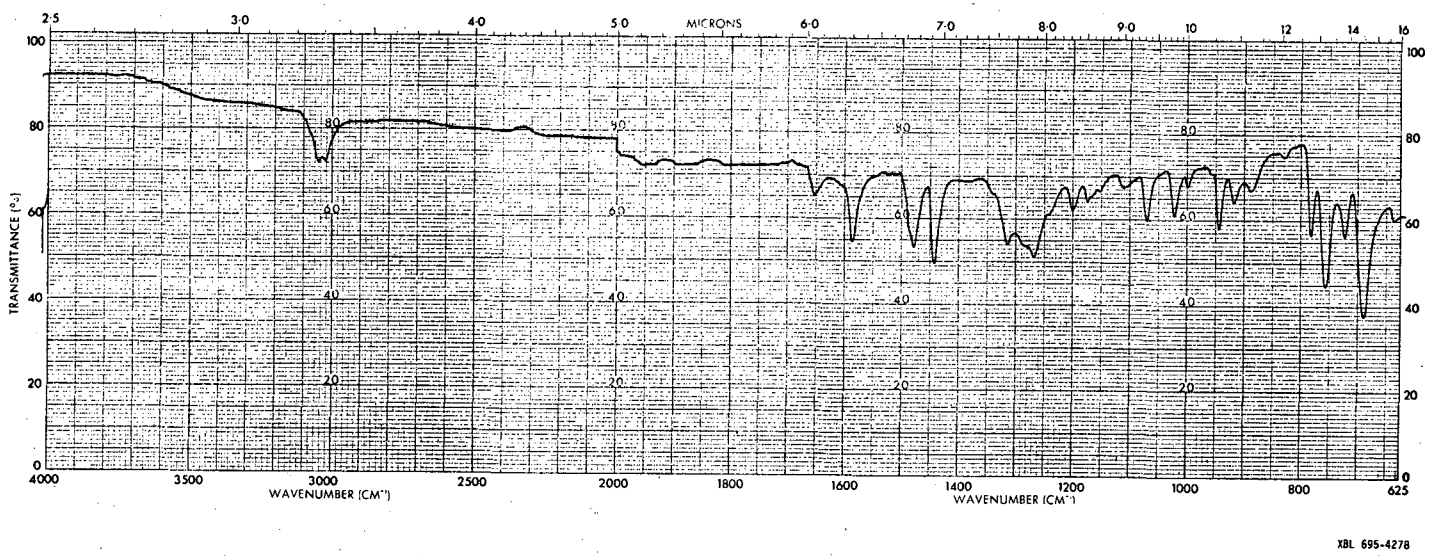
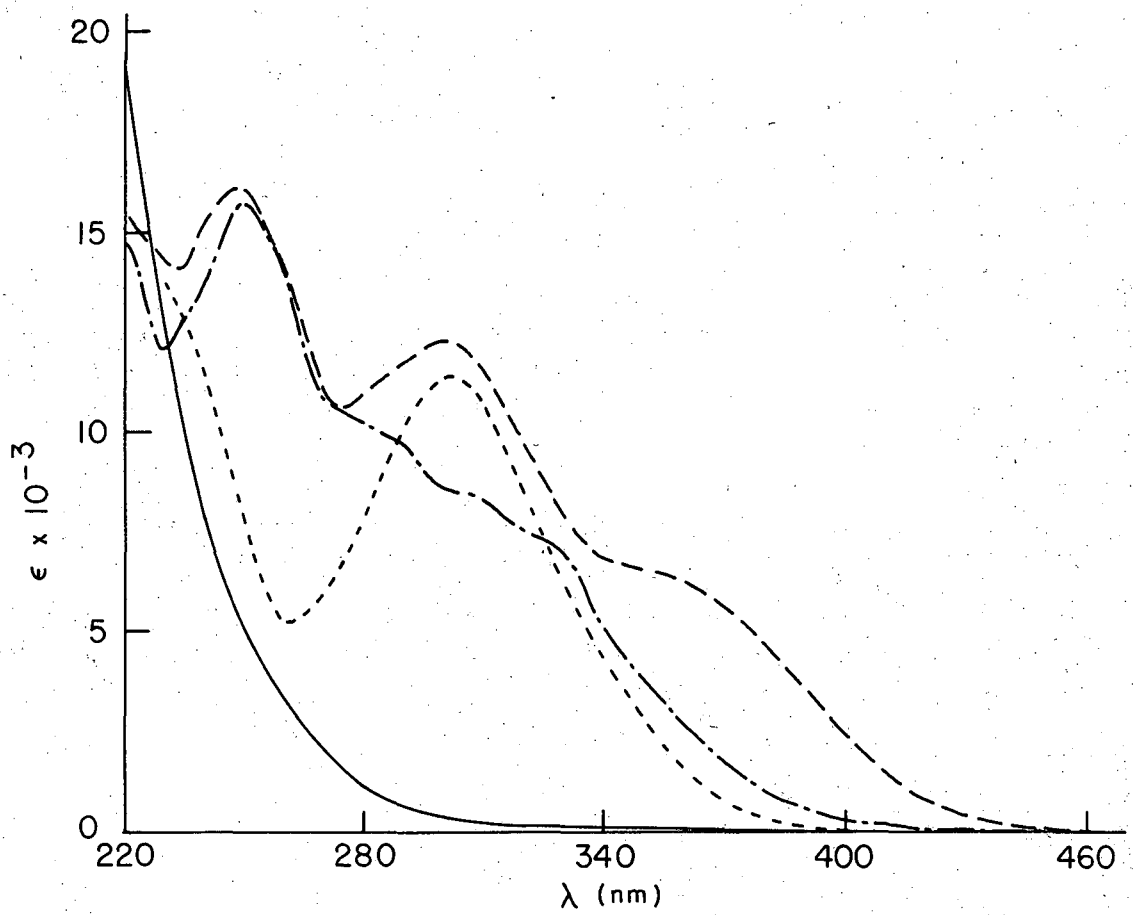


Figure 4. IR spectrum of 2,3,3-triphenyloxaziridine (neat).



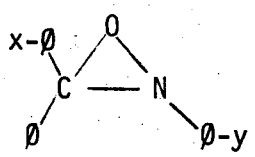
XBL 695-4267

Figure 5. UV spectra of stable triaryloxaziridines and the corresponding triarylnitrones.

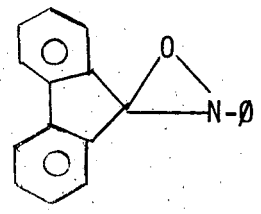
4	a.	α,α,N-triphenylnitrone	---------
	b.	2,3,3-triphenyloxaziridine	————
5	a.	N-(4-nitrophenyl)-α,α-diphenylnitrone	— — — — —
	b.	2-(4-nitrophenyl)-3,3-diphenyloxaziridine	— - — - —

TABLE II

Stable Triaryloxaziridines



(1)



(2)

	x	y	mp	λ max (mμ) in CH_3CN, (ε)	active oxygen (%)	isolated yield (%)
(1a)	H	H	125[a]	b	99[c], 99[d]	100
(1b)	p-OMe	H	103-5°	234 (20,900)	100[c], 96[d]	73
(1c)	p-NO_2	H	110-115°	267 (14,500)	92[c], 98[d]	21
(1d)	H	p-Br	88-90°	250 (sh)(14,600)	100[c], 95[d]	60
(1e)	H	p-NO_2	110-115°	251 (16,200)	100[c], 94[d]	82
(1f)	p-Br	H	e	228 (23,300)	100[c]	--
(2)	--	--	102-104°	f	96[d]	57

a. The melting point was difficult to determine because the material melted and resolidified and then remelted 150-160° (presumably impure benzoyl diphenylamine).

b. Showed only end absorption with ε12,400 at 230 mμ, shoulders at 273 mμ (ε1,890) and 266 mμ (ε2,700).

c. Active oxygen liberated from an irradiated solution of the nitrone in acetonitrile.

d. Active oxygen of the isolated oxaziridine.

e. A thick oil.

f. The uv spectrum resembled the complex uv spectrum of fluorene with peaks at 296 (ε8,300), 283 (ε10,900), 272 (ε11,500), 243 (ε51,000), and 237 mμ (ε44,600).

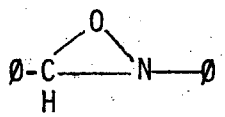
These stable triaryloxaziridines can be stored for weeks at 0°C with little decomposition. In the systems where thermal reactions were investigated (see the kinetic section) the corresponding amides were the primary reaction product, again substantiating the hypothesized oxaziridine structure.

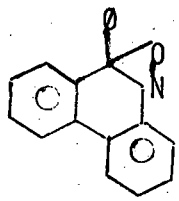
The isolation of the fluorenyl-N-phenyloxaziridine is in marked contrast to the observation of Johnson[25] that irradiation of the fluorenyl-N-phenylnitrone (IV) results in no reaction. It appears that his irradiation conditions were not adequate for significant reaction to occur. Likewise, the stability of this oxaziridine (half-life in CH_3CN is about 4 days) probably excludes the oxaziridine as a possible intermediate in the reaction of dimethylsulfonium(diphenyl)methylide with nitrosobenzene (II $\longrightarrow$ VI).

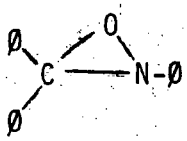
The isolation of these diaryl and triaryloxaziridines is important for two reasons. First, and most importantly, they prove conclusively the assertion that irradiation of arylnitrones does indeed produce oxaziridines as the primary photoproduct. Secondly, the existence of these stable isomers allows us to test a number of hypotheses which have recently been put forward which require the intermediacy of this type of system. In particular, recent reports[62a,b,c] concerning the mass spectral rearrangement of diaryl and triarylnitrones have hypothesized oxaziridines as intermediates. However, no oxaziridines were available for comparison. Unless the mass spectral fragmentation pattern of the oxaziridine is known, its hypothesized intermediacy in the nitrone fragmentation is tenuous. Investigations of the mass spectral fragmentation of the oxaziridines and nitrones are currently in progress.[63]

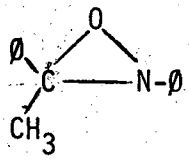
The stability of the triaryloxaziridines is, as has been explained, quite unexpected. Considering the probable severe steric interaction between the aryl groups, it would have been expected that they would be particularly unstable. But molecular models indicate that the steric interaction between the aryl groups forces the nitrogen phenyl into a conformation where it cannot appreciably stabilize a developingg charge on the nitrogen resulting from N-O bond cleavage. Thus, in effect, it acts partially as an "alkyl-like" substituent with reduced resonance stabilizing ability.

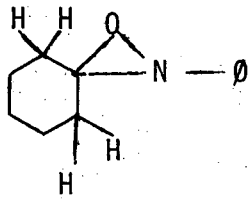
When one examines the stabilities of some of the N-phenyloxaziridines which have been investigated, there seems to be a direct relationship between stability and N-phenyl conformations. For example, consider the five compounds listed below:

(A) 

(B) 

(C) 

(D) 

(E) 

In (A), because of the lack of any steric interactions, the N-phenyl group can assume a configuration where it can stabilize ionic N-O bond cleavage. Thus it is unstable and has been observed only in solution.

Compound (B)[58] has an N-phenyl rigidly fixed in a conformation where it can stabilize the N-O bond cleavage and it cannot even be observed in solution. However, according to molecular models, compounds (C), (D), and (E)[64] have severe steric interactions which prevent the N-phenyl group from stabilizing the developing charge on the nitrogen. All of them are isolable . Thus it appears that in N-aryloxaziridines and in the triaryloxaziridines in particular, conformation is an important factor in determining stability.

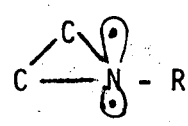
One of the basic assumptions made in the study of the di- and triaryl oxaziridine rearrangements is that, within a series, the configurations of the molecules are the same. In particular, it is assumed that inversion at the nitrogen is rapid at the temperatures used in this study.

The equilibration of isomers in the diaryl system should lead to similar isomeric distributions in all the diaryl oxaziridines since the steric conditions are almost identical in all of them. It would also be expected that there would be a predominance of the trans form of the oxaziridine (i.e., the two aryl groups trans to each other) in the equilibrium mixture since the phenyl group is considerably larger than the unshared electron pair on the nitrogen.

In the triaryl systems, an approximately 50:50 mixture of the two isomers should be present. With rapid equilibration of the two isomeric forms, the distribution of the rearranged products should given an accurate indication of the relative migratory aptitudes of the two C-aryl groups since conformational effects should be unimportant.

The assumption of rapid nitrogen inversion is a reasonable one. Swalen and Ibers[65] have reported an activation energy of only 5.8 kcal for the inversion of ammonia, whereas one would need an estimated activation energy of 25 kcal before resolution of stable optical antipodes can be effected.[66] While the prediction of rapid nitrogen inversion seems valid, two properties of the oxaziridine ring structures may be cause for concern. One is the constricting nature of the three-membered ring. The second is the effect of the electronegative oxygen group directly attached to the inverting nitrogen moiety.

Very early, several groups[67,68] suggested that suitably substituted aziridines, three-membered carbon-carbon-nitrogen rings, may exist in isomeric forms. Kincaid and Henriques[69] calculated that the activation energy of inversion of the nitrogen atom of 1-methyl aziridine would be approximately 25 kcal/mole. Gutowsky[70] reported an activation energy of 19 kcal/mole for the inversion of nitrogen in 1-methylaziridine. Lowenstein, Neumer and Roberts[71] reported an activation energy of 10 kcal/mole for inversion in 1,2,2-trimethylaziridine but have recently revised the figure to 24 kcal/mole.[72] The relatively high activation energies found in nitrogen inversion of aziridines can be attributed to the strain energy required to read the planar transition state (I). In



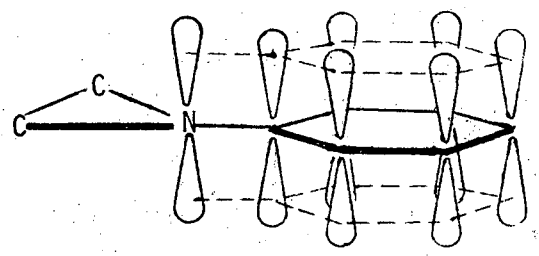
(I)

aziridines the C-N-C bonds are constrained to an angle of 60°. In the ground state the nitrogen is sp^3 hybridized so the preferred C-N-C bond angle is about 104°. However, in the planar transition state for inversion (I) the nitrogen assumes an sp^2 hybridization with a preferred C-N-C bond angle of 120°. Since the C-N-C bond is constrained to a 60° angle, the increase in bond angle strain on going from sp^3 to sp^2 hybridization causes a marked decreases in rate of nitrogen inversion.

With larger groups attached to the nitrogen, it might be expected the inversion rate would decrease because of ponderal effects. But as Kincaid and Henriques[69] observed, the increased weight of a group would have little effect when compared with the increase in steric repulsion caused by the larger groups. But even with the bulky 1-t-butyl group,

Brois[73], in contrast to earlier results of Roberts[66], reported that the two isomers can be detected at room temperature by NMR.

Because of the ability of the aryl group to stabilize the planar transition state for nitrogen inversion (II), we would expect a large



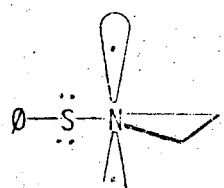
(II)

increase in inversion rate relative to the N-alkyl compounds. Anet and coworkers[74,75] have investigated a large number of aziridines with N-substituents which could stabilize, by resonance, the transition state for nitrogen inversion. They found for the 1-phenylaziridine a ΔF^* of 12.9 kcal/mole at -40°C. (For more highly conjugating sustems such as a 1-carbomethoxyaziridine they found a ΔF^* as low as 7.6 kcal/mole.) They also found that neighboring electronegative groups such as sulfur retard the rate of nitrogen inversion in the aziridines.[75]

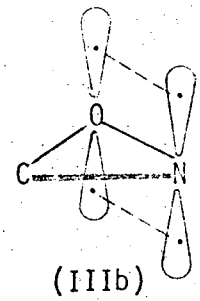
They concluded[75] that the retardation of nitrogen inversion rates by neighboring electronegative groups is caused by a combination of inductive and electron repulsion effects. A rationale for this effect has been proposed by Bent[76] who states that: "....as the electronega-

tivity of the substituent increases, the central atom diverts increasing amounts of s character to the orbital or orbitals occupied by the lone-pair electrons." Since in the planar transition state (I), the electron pair must be in a p-orbital, this tends to raise the energy of the transition state and hence reduce the rate of nitrogen inversion. The electron repulsion effect comes about because of the existence of unshared electrons on the neighboring group. For instance, in the 1-benzenesulfenyl aziridine the neighboring sulfur has an unshared pair of electrons.

In the transition state for nitrogen inversions, the filled p-lobe of the nitrogen would interact with the electron-rich lobe of the sulfur (IIIa). This electron repulsion would be much less in the ground



(IIIa)



(IIIb)

state. A similar effect should be found in the transition state for nitrogen inversion in the oxaziridine ring system (IIIb). As an example of this repulsion, the preferred conformation of hydrazine has the two-electron pairs in orbitals which are at 90° to each other.[77] Griffith and Roberts[78] has presented experimental evidence that the effect of a neighboring group in the inversion of nitrogen is substantial. They found in studies of N-benzyl-N-O-dimethylhydroxylamine an inversion barrier of 12.9 kcal/mole in n-hexane.

If we take Griffith's and Roberts' data for the inversion barrier of N-benzyl-N,O-dimethylhydroxylamine and extrapolate it to 25°C, we find a rate constant of approximately 2×10^3 sec^{-1}. This compares with a value of $2 \pm 1 \times 10^5$ sec^{-1} for the inversion rate of the similar N,N-dibenzyl-N-methylamine as calculated by Saunders and Yamada.[79*] Thus, a rate decrease of over 10^2 might be expected if an N-alkyl group is replaced by an oxygen.

Curtin, Grubbs and McCarthy[26] have tabulated data on the uncatalyzed syn-anti isomerization of imines, oxime ethers and halomines. Some of the results are shown in Table I. The substitution of a chloro group for an N-alkyl group causes a marked decrease ($>10^4$) in the inversion rate in imines. The effect of an alkoxy group is even more marked, causing a rate decrease of greater than 10^9. On the other hand, the N-aryl group causes an increase in the rate of N-inversion of about 10^5 relative to an N-alkyl group. According to Curtin[26] these imines are thought to isomerize via a "shift of the substituent attached to the nitrogen from one side of the molecule through a linear transition state, the nitrogen atom adopting linear sp bonds, the π bond remaining intact, and the unshareed electron pair occupying the perpendicular p-orbital of nitrogen in the transition state." Thus, the nitrogen inversion in imines bears a great resemblance to isomerization in aziridines and the effect of substituents in imine inversion may also have the same effect in the aziridine system.

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* The solvent used in this work was water as compared with hexane used by Griffith and Roberts.[78] If hexane were used, we would expect an even higher rate since the strongly hydrogen-bonding solvent, water, should have caused a marked decrease in nitrogen inversion rate relative to the rate in a hydrocarbon solvent.

TABLE I

Data on the Unimolecular cis-trans (syn.-anti) Isomerization of Imines

Structure	$k^{60°}$	Ea	Solvent
$C_6H_5CH{=}NC_6H_5$	20[a]	16.5	ethanol
p-X C_6H_4 $C{=}NC_6H_5$ p-X' C_6H_4	10[b]	17-20	CCl_4, cyclohexane
pxC_6H_5 $C{=}NCH_3$ p'xC_6H_4	10^{-4}[c]	25-27	cyclohexane
o-CH_3NHAr $C{=}NCH_3$ C_6H_5	—[d]	—	isomer isolated
o-RNHAr $C{=}NCH_2CH_2NR_2$ C_6H_5	$<< 10^{-4}$[e]		isomer isolated
p-ClC_6H_5 $C{=}NBr$ C_6H_5	$< 10^{-5}$		cyclohexane
p-ClC_6H_5 $C{=}NCl$ C_6H_5	$< 10^{-8}$[b]		cyclohexane
p-ClC_6H_5 $C{=}NCOCH_3$ C_6H_5	$< 10^{-13}$[b]		decane

a. D.G.Anderson and G. Wettermark, J. Am. Chem. Soc. 87, 1433 (1965).

b. Reference 26.

C. D.Y. Curtin and J. W. Hausser, J. Am. Chem.Soc. 83, 3474 (1961).

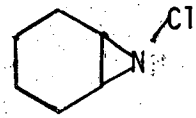
d. G. Saucy and L. H. Sternbach, Helv. Chim. Acta, 45, 2226 (1962).

e. S. C. Bell, G. L. Conklin and S. J. Childress, J. Am. Chem. Soc. 85, 2868 (1963); J. Org. Chem. 29, 2368 (1964).

Recently, a number of papers have appeared which substantiate the view that a combination of an aziridine ring and an adjacent electronegative group greatly reduces nitrogen inversion rates. Brois[80], and Lehn and Wagner[81] have examined the nuclear magnetic resonance (NMR) of N-chloroaziridine and several dimethyl substituted N-chloroaziridines. In contrast to a recent report[82], they found nitrogen inversion exceedingly slow with no peak coalescence even at 180°.[66] Thus a free energy ΔF^* of well over 23 kcal/mole must be assigned to this inversion. Mannschreck et al.[83] reported a similarly high activation energy to nitrogen inversion in diaziridines. Brois[84] and Atkinson[85] reported exceedingly slow inversion in N-amino aziridines.

Finally, two groups reported the isolation of invertomers of N-chloroaziridines! Brois[86] reported the isolation of 1-chloro-2-methylaziridine (IV) while Felix and Eschenmoser[87a] isolated the invertomers of 7-aza-7-chlorobicyclo (4.1.0)heptane (V)

(IV)



(V)

Very recently, the optical isomers of some N-halo-2-alkylaziridines were reported.[87b]

Thus, the extreme stability to inversion of some suitably substituted aziridines was demonstrated. Therefore, our original assumption about the rapid inversion of the nitrogen in oxaziridines may not be

valid. Reducing the rate of inversion are the restricting effects of the three-membered ring and the electronegative effects of the oxaziridine oxygen. Increasing the inversion rate is the effect of the N-aryl group in stabilizing the transition state for isomerization. Whether this stability can be extrapolated to oxaziridines was a matter of conjecture until quite recently.

Emmons[23] reported the existence of two ring hydrogen resonances in the NMR of 2-t-butyloxaziridine, implying a slow inversion about the nitrogen.* Brois and Pews** reported that 3-phenyl-2-alkyloxaziridines show two ring hydrogen resonances in its NMR spectrum, implying a slow rate of nitrogen inversion.

Final conclusive evidence for the stability of oxaziridine invertomers came in two recent reports. Boyd[88a] reported that oxidation of unsymmetrical imines with optically-active peracids yields optically active oxaziridines. The optical activity is most likely due to the asymmetric carbon. But Boyd reports that several compounds gave <u>two</u> oxaziridines of differing optical activities. This implies that diastereomeric forms exist which are caused by the two <u>stable</u> configurations of the oxaziridine nitrogen. Similarly, Montanari, Moretti and Torke[88b] reported that oxidation of N-diphenylmethylene-methylamine with optically active peracids yielded an optically active oxaziridine (VI), 2-methyl-3,3-diphenyloxaziridine.

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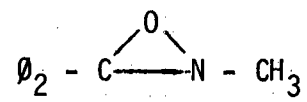
* W. D. Emmons, unpublished results, as quoted in Reference 66.

** S. J. Brois and R. G. Pews, unpublished results quoted in Reference 86.



(VI)

With the symmetrically substituted carbon, the only source of optical activity lies in the nitrogen. For optical activity to exist, the nitrogen configuration must be extremely stable. In fact, the molecule is configurationally stable at 90°, where it can be vacuum distilled with no detectable loss of optical activity.

Thus, as implied by previous work on analogous sytems, the n-alkyl oxaziridine contains an extremely stable configuration at nitrogen. Whether the N-phenyl group on the diaryl- and triaryloxaziridines causes rapid N-inversion is a question that must be resolved before any interpretation of the kinetic data can be attempted. The complications that would result if two stable isomers of each oxaziridine existed in solution are appalling.

To determine whether there were two stable isomers of any of the oxaziridines we were investigating, the nuclear magnetic resonance spectra were taken of a number of stable oxaziridines (see Table II and Figure 1-3). From these results it appears that two different isomers are not present in any of the spectra, since the oxaziridine hydrogen absorptions should be greatly different in the <u>cis</u> and <u>trans</u> isomers of the oxaziridines.[89*]

The fact that only one oxaziridine hydrogen peak is seen implies that two stable isomers are not present. To be sure, this is a very encouraging result.

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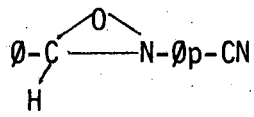
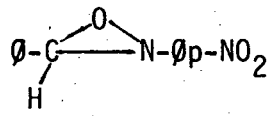
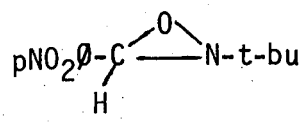
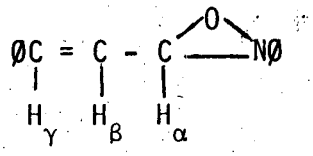
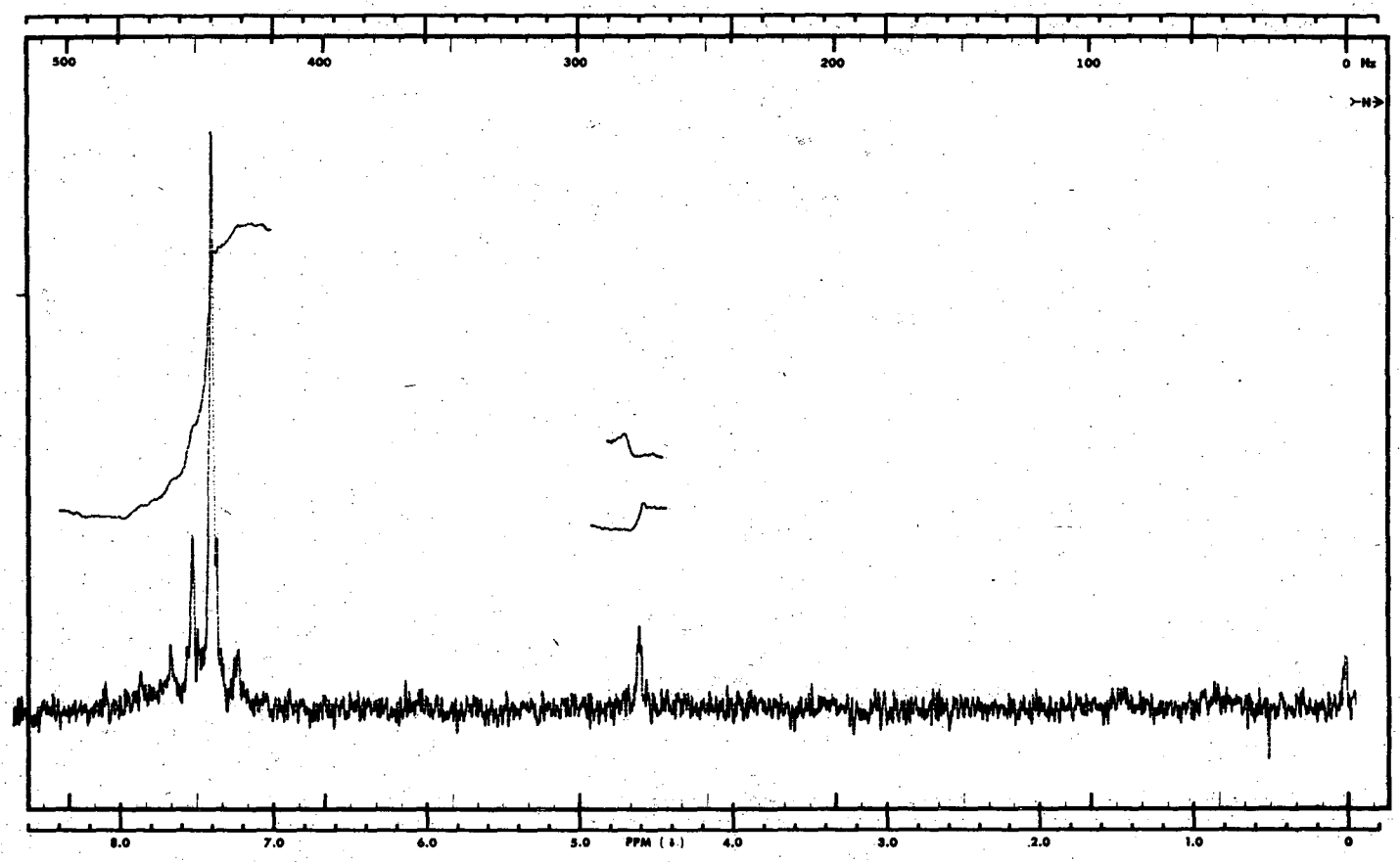
* Here <u>cis</u> and <u>trans</u> refer to the orientation of the two aromatic groups with respect to each other.

Table II

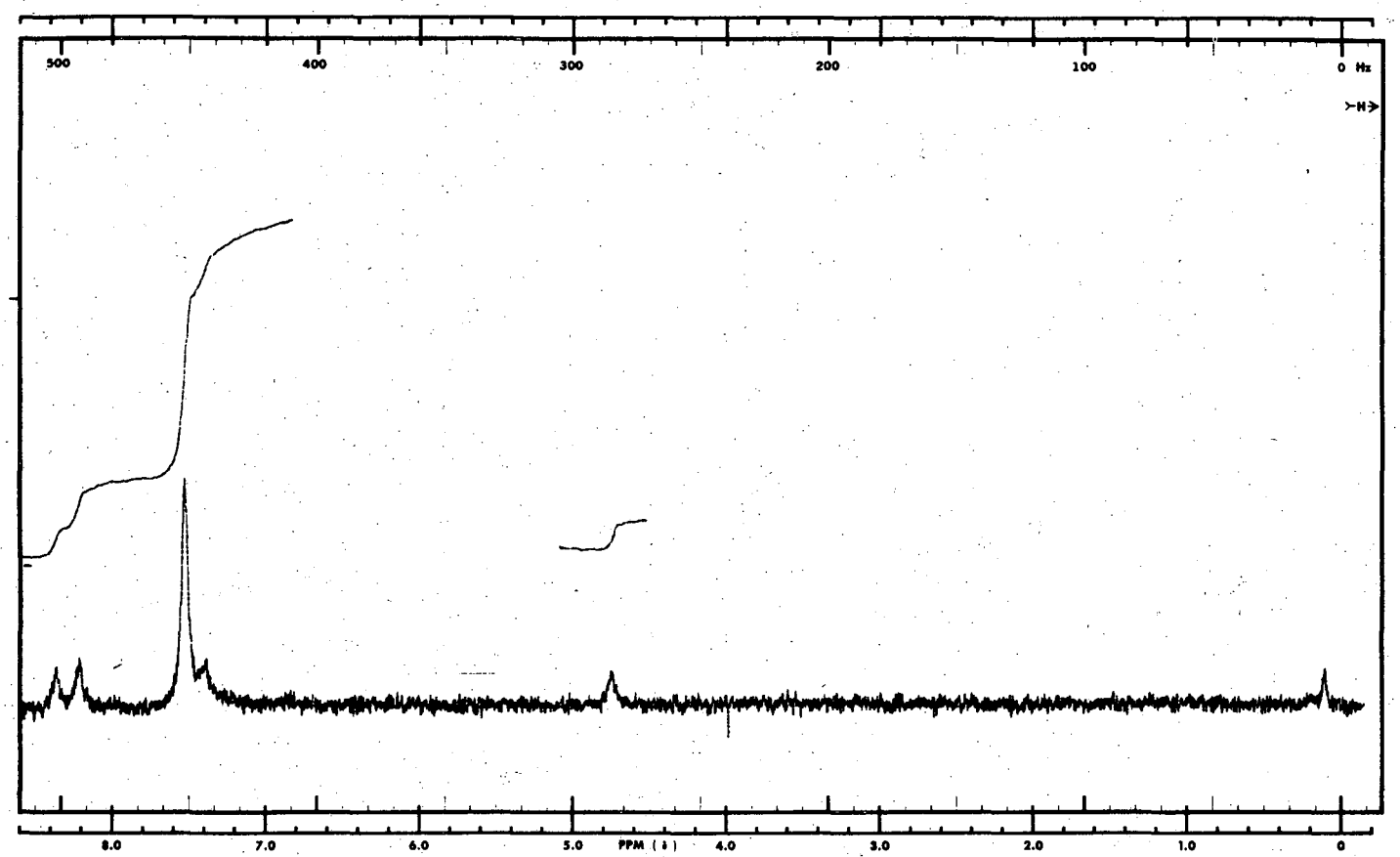
Non-Aromatic Protons in the NMR of Oxaziridines

Oxaziridine	Non-aromatic Resonances (τ)
1) 	H τ 5.55 (singlet)
2) 	H 5.37 (singlet)
3) 	H 5.55 (singlet)
4) 	H α 5.70 (doublet) H β 3.95 (quartet) H γ 3.02 (doublet)



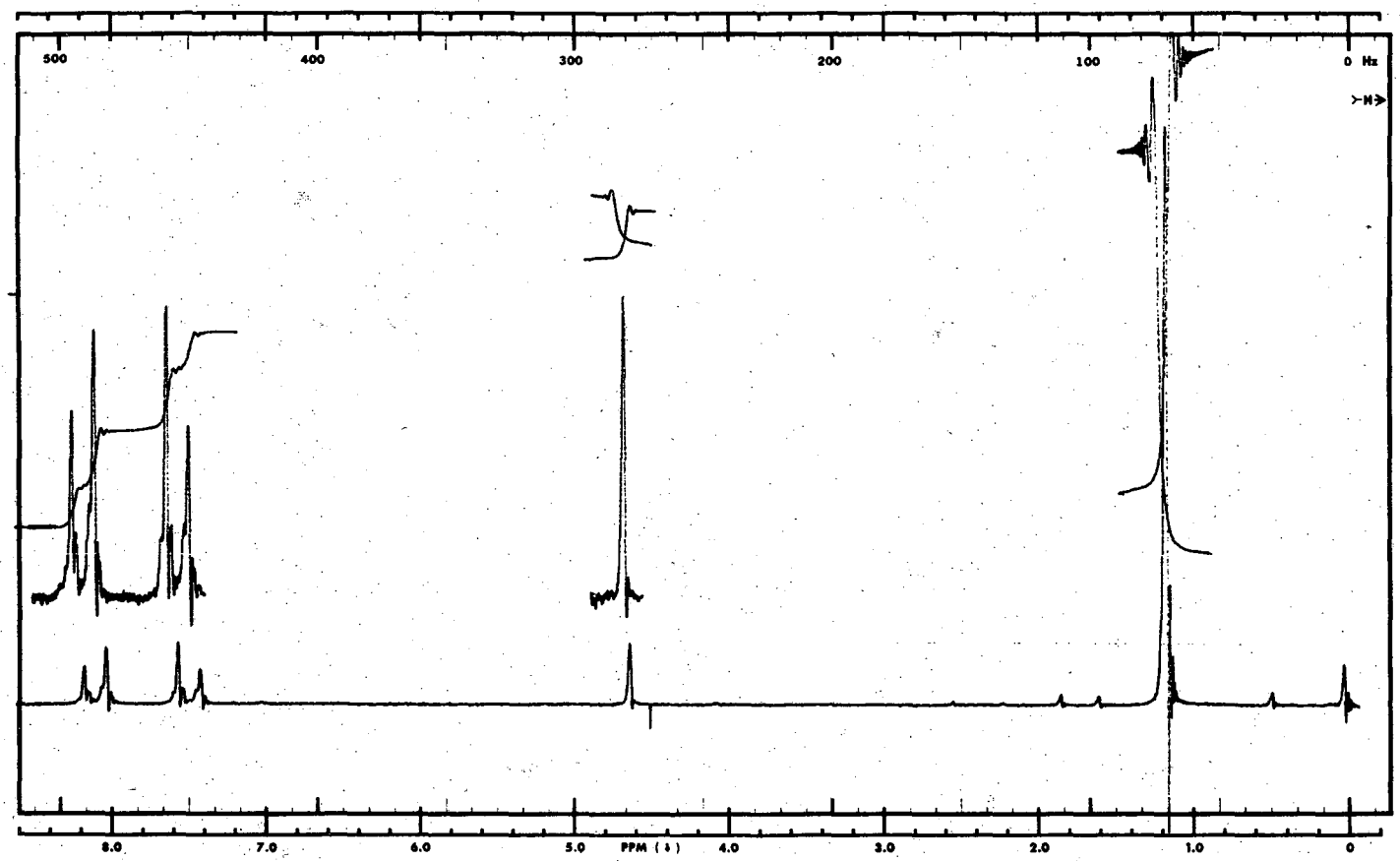
XBL 696-4282

Figure 1. NMR spectrum of 2-(4-cyanophenyl)-3-phenyloxaziridine in CCl_4 (TMS internal standard).



XBL 696-4284

Figure 2. NMR spectrum of 2-(4-nitrophenyl)-3-phenyloxaziridine in CCl_4 (TMS internal standard).



XBL 695-4266

Figure 3. NMR spectrum of 3-(4-nitrophenyl)-2-t-butyloxaziridine in CCl_4 (TMS internal standard).

The single oxaziridine hydrogen resonance can be explained in two ways: either there is a rapid equilibrium between the two isomeric oxaziridines or just one stable isomer of the oxaziridine is produced by photochemical irradiation. In the former, if isomerization between the two isomers occurs more rapidly than about 10 times per second, the NMR would average the two signals into one sharp peak. In the latter, the photolysis of the nitrone would presumably form the trans isomer where the steric interactions between the phenyl groups would be minimized. NMR spectra taken very soon after irradiation and a considerable time later both show no evidence of another isomer. Thus, the possibility of the photochemical formation of one isomer which slowly isomerizes to the other is eliminated. Although all our kinetic data would not be complicated by either result, it would be preferable to be able to distinguish between the two.

In our studies on the rearrangement of the 3-methyl-2,3-diphenyl-oxaziridine, we found that the oxaziridine from the irradiation of the corresponding nitrone could be isolated as a thick oil by the procedure used earlier. The NMR spectra taken of the compound shows two separate methyl resonances at 89 and 111 cps downfield from TMS. The integrated peak areas show the expected 10:3 ratio between aromatic and the total methyl protons. Thisimplies that there are two separate isomers of the oxaziridine that do not interconvert rapidly.

To verify the existence of two separate isomers rigorously, it must be shown that the solution does actually contain only the oxaziridine compounds and that the two methyl resonances are attributable only to these oxaziridines. In Table III are shown the methyl resonances of

TABLE III

Methyl Resonances of Possible Products from the Thermal Reaction of 3-Methyl-2,3-Diphenyloxaziridine

Compound	Methyl Resonance (cps from TMS in CCl_4)
$Ø(CH_3)C{=}N(O)Ø$	151
$Ø(CH_3)C{=}NØ$	129
$ØCOCH_3$	147
$ØCON(CH_3)Ø$	206
$CH_3CONØ_2$	113

Of the normally expected products, only the acetyldiphenylamine has an absorption near either oxaziridine absorptions. This product, however, forms only slowly in solution, over a matter of weeks. Also, this rearrangement product is formed in conjunction with the N-methylbenzanilide.* No methyl resonance for the N-methylbenzanilide can be found. Thus, it appears the two methyl resonances are not from oxaziridine rearrangement products but, indeed, are from the primary irradiation product of the nitrone.

In addition, the UV spectrum (with only short wavelength end absorption) is that expected for an oxaziridine structure and the IR shows no carbonyl nor C=N absorptions. Finally, the solution shows quantitative active oxygen content, a strong indication of oxaziridine structure.

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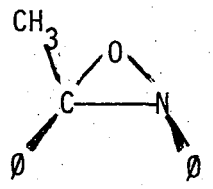
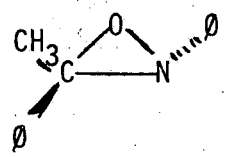
* Reflux of a carbon tetrachloride solution of the oxaziridine for several days resulted in the formation of a mixture of N-methylbenzanilide, acetophenone and acetyldiphenylamine in a ratio of about 6:3:2.

Thus, the oxaziridine structure of both isomers appears confirmed.



"cis"

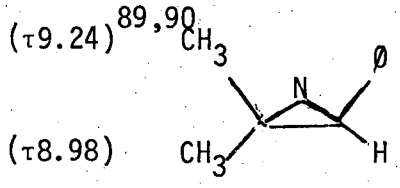
(VII)

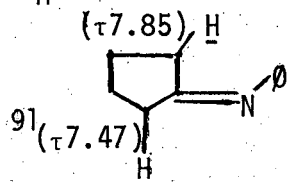


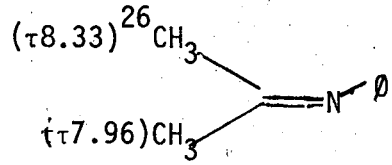
"trans"

(VIII)

The assignment of the low field methyl resonance to the "cis" isomer (VII)* and the higher field resonance to the "trans" isomer (VIII) is based on an analogy with similar systems. For example, the proton resonances have been assigned for the compounds noted below:







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* The cis and trans terminology refer to the orientation of the two phenyl groups with respect to one another.

From these examples we see that the methyl group trans to the phenyl appears upfield relative to the methyl group cis to the phenyl. Apparently the phenyl group shields the cis-methyl and causes an upward shift in its absorption. The chemical shift difference between the cis and trans is on the order of .3 to .4 ppm,* in fair agreement with the value of .40 ppm found in the oxaziridine system.

Generally, to determine the inversion rate for interconverting species, etc., the effect of increased temperature on the peak separation is measured. However, in our system, heating causes rearrangement of the compound. Thus, any measurement of inversion rates would be difficult. An interesting phenomenon was noticed, however, which made line-broadening techniques of this type unnecessary. Different preparations of the 3-methyl-2,3-diphenyloxaziridine resulted in different relative amounts of the two methyl peaks, the ratio of low field to high field peaks varying from 30:70 to 80:20. Further investigation indicated that the ratio of the two peaks is time dependent! If measurements are taken early (Figure 4) the high field peak accounts for ca. 20% of the total and if the solution stands a day at room temperature, this percentage increases until it accounts for about 70% of the total (Figure 5). Thus, it appears thatphotochemical irradiation of the nitrone yields a non-equilibrium mixture of the two oxaziridine isomers which slowly equilibrates (with a half-life of several hours at room temperature).

The UV spectra taken immediately after irradiation and a day later are identical. The IR shows very little change and the active oxygen con-

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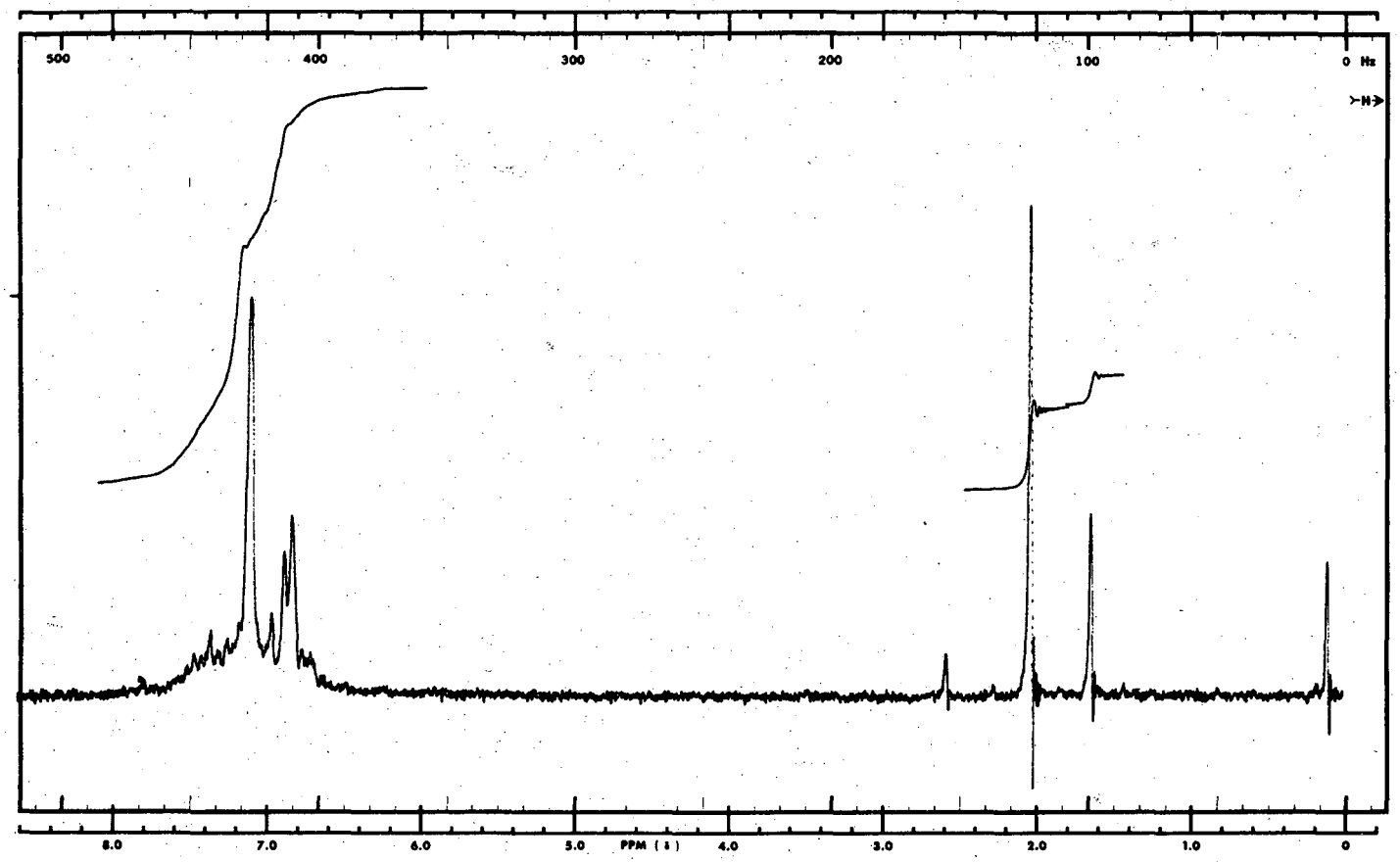
* However, the methyl resonances of the cis and trans isomers of 1-phenyl-propene are almost identical (τ 8.15 and τ 8.17, respectively).[92]



XBL 695-4257

Figure 4. NMR spectrum of 3-methyl-2,3-diphenyloxaziridine in CCl_4 taken as soon as possible after preparation (TMS internal standard).

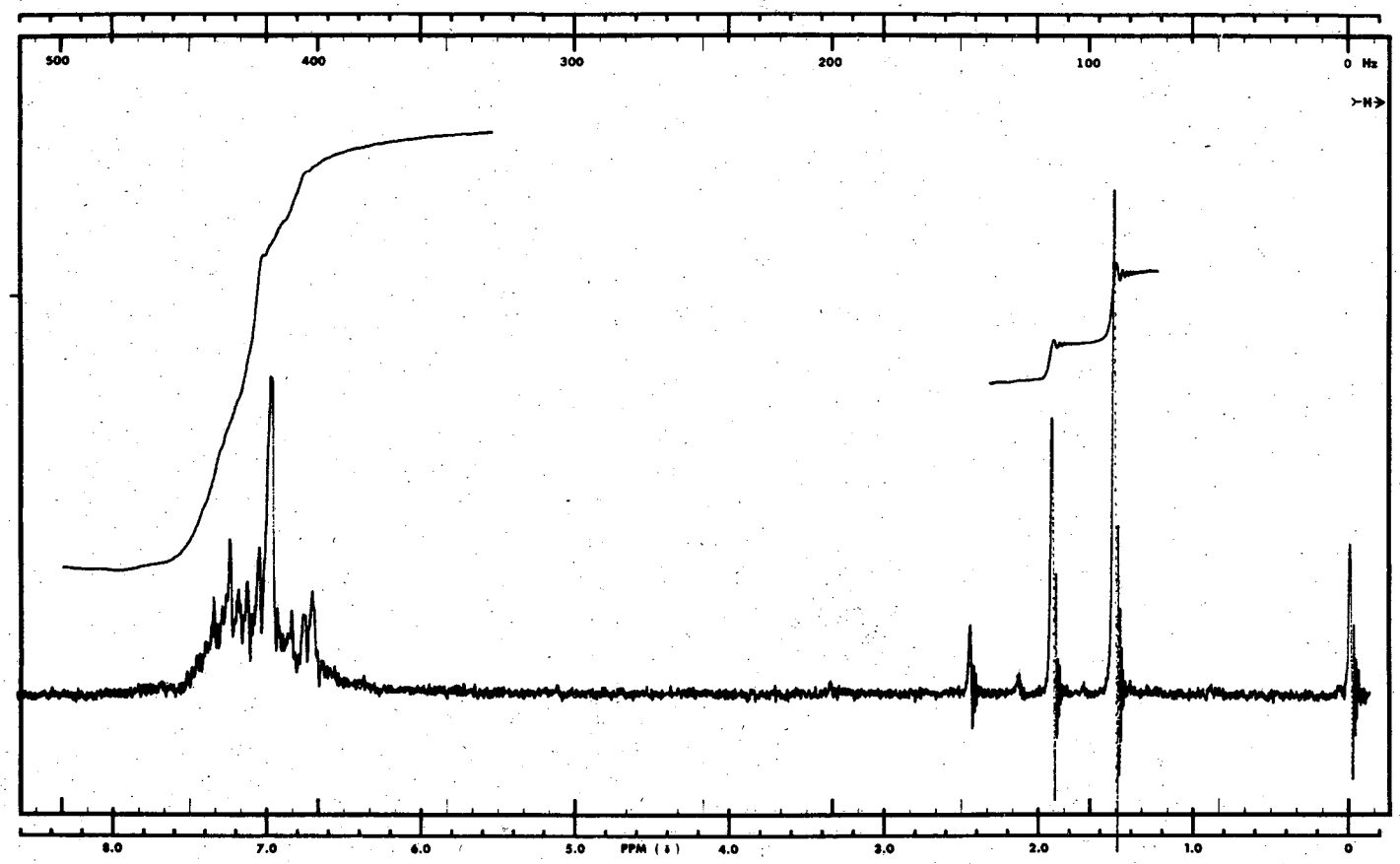


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Figure 5. NMR spectrum of 3-methyl-2,3-diphenyloxaziridine in CCl_4 about eight hours after preparation (TMS internal standard). (A trace of acetophenone is present, τ 7.55)

tent remains quantitative after 8 hours (98%). Thus, again it appears that this slow reaction is isomerization between the two oxaziridines.

From a thermodynamic standpoint, we would expect that the equilibrium mixture of the two oxaziridines would have a preponderance of the "trans" isomer (VIII) since steric interactions in this system would be less than in the corresponding "cis" form (VII). In the cis form (VII) the phenyl-phenyl interactions would tend to destabilize the structure while in the trans form, (VIII) there would be a less everer methyl-phenyl interaction. If we apply this thermodynamic reasoning to this system, we would assign the "trans" form (VIII) to the higher field methyl group since it is the dominant species at equilibrium. This, in turn, would imply that the photochemical irradiation of the nitrone predominantly produces the cis isomer (VII) which slowly isomerizes to the trans form (VIII). This structural assignment is the same as thatobtained previously using structural analogies.

The fact that the α-methyl-α,N-diphenylnitrone, on irradiation, produces a non-thermodynamic distribution of oxaziridines, is worthy of note. In our studies, we found the cis isomer produced in 80% yield with 20% trans. However, our experimental technique to produce the oxaziridine involves a fair amount of time (at least 50 minutes) before the first NMR spectra is taken. During this time, conversion of some cis isomer to trans must undoubtedly take place. Thus, the actual percentage of cis isomer originally formed is greater than 80%; 90% may be a more reasonable figure.

The starting nitrone itself has proven to be unusual. Unlike the triaryl- and diarylnitrones which are extremely stable, the α-methyl-αN-

diphenylnitrone is extremely unstable. Even at 0°C it slowly decomposes to an oily mixture which, by NMR (and olefactorally) consists in large part of acetophenone. In contrast, all of the diaryl- and triarylnitrones prepared in this work are completely stable at room temperature. NMR spectra of the nitrone shows only one methyl resonance* at τ 2.50 (see Figure 6). Thus, as found in the diphenyl case [93-96], only one isomer is present. This is, however, in contrast to the finding that the preparation of α-cyano-α,N-diphenylnitrone results in both the cis and trans isomer.[97]** Likewise, in the present synthesis of α-(4-methyoxyphenyl)-α,N-diphenylnitrone, two isomers were formed in about a 1:1 mixture (see Experimental Section). Since the method of synthesis is exactly the same as in the compound in question (reaction of di-substituted diazomethane with nitrosobenzene), the lack of isomeric α-methyl-α,N-diphenylnitrones is unexpected. The actual configuration of this nitrone is unknown, although, judging by the unusual instability, the cis configuration is probable.***

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* J. Hamer and S. Macaluso, unpublished results as quoted in Reference 95.

** Although the reaction forming these nitrones is somewhat different than the one used in the present case, similar steric considerations should hold in the two cases.

*** Attempts to isomerize the nitrone to the other isomer, either thermally or with iodine, have failed.

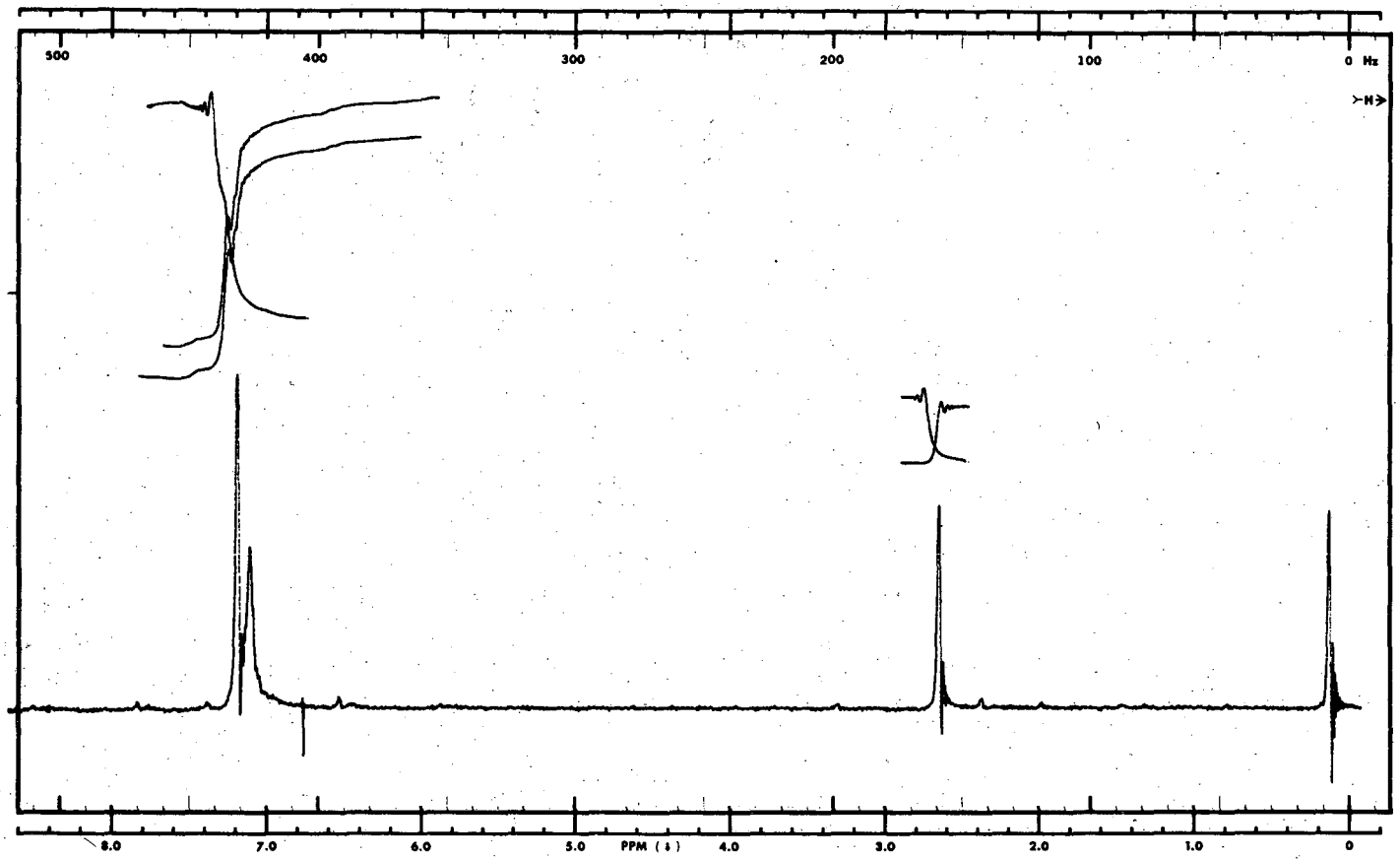

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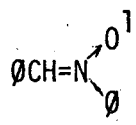
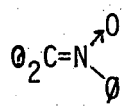
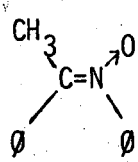
Figure 6. NMR spectrum of α-methyl-α,N-diphenylnitrone in CCl_4 (TMS internal standard).

Further evidence for the cis orientation of the nitrone can be found if the UV spectra is compared with other nitrones. Listed below in Table IV are the UV maxima and extinction coefficients of the α-methyl-α,N-diphenylnitrone, the diphenylnitrone and the triphenylnitrone.

TABLE IV

Compound	UV Max (Acetonitrile)(mμ)	Extinction Coefficient
	317*	18,500
	312**	11,400
	291	8,800

* max (ethanol) 322 mμ (ε 18,700

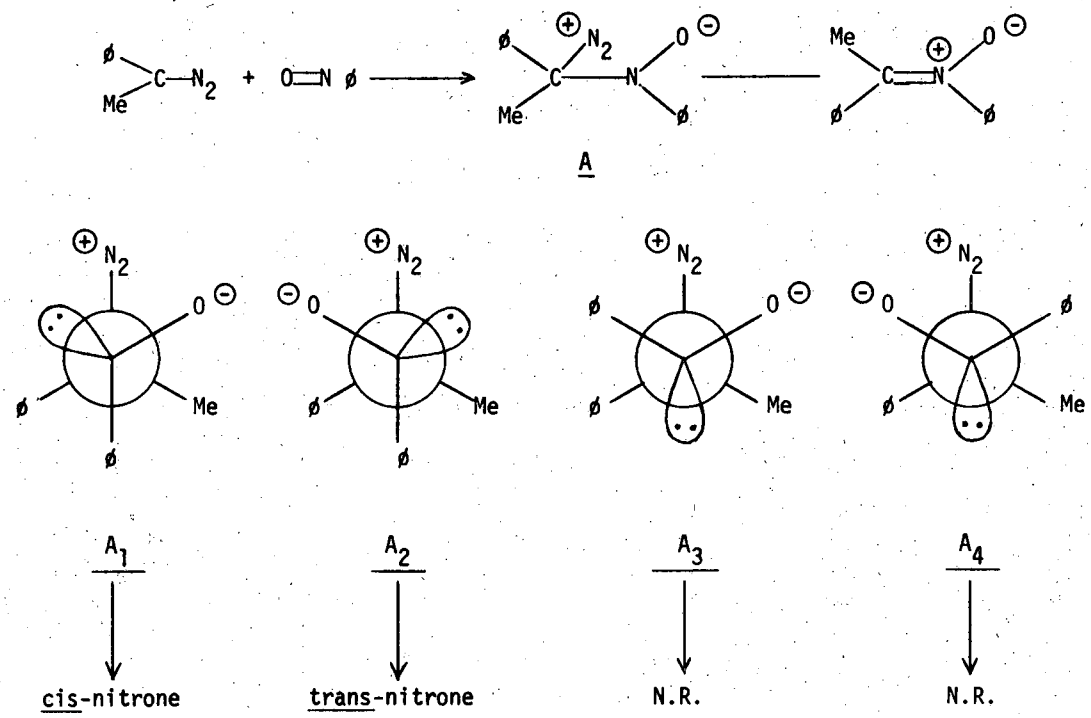
** max (ethanol) 311 mμ (ε11,000).

The much shorter wavelength absorption of the α-methyl-α,N-diphenylnitrone indicates the absence of a trans-conjugated aromatic ring system as found in the other two compounds. Likewise, the lower extinction coefficient is typical of cis-conjugated aromatic systems where non-coplanarity of the aromatic ring exists. For example, trans stilbene has λ_{max} at 294 mμ

(ε 24,000) while the cis isomer has a λ_{max} at 278 mμ (ε 9350).[98]

A possible post hoc rationalization of the formation of the cis isomer in the reaction of nitrosobenzene with phenylmethyldiazomethane can be made, if the reaction proceeds as in Figure 7.

Conformational preferences of the intermediate may determine the favored product. Because of electrostatic attraction we would expect the intermediate A to be most stable when the positively charged diazo group is near the negative oxygen. In Figure 4 are shown the four possible conformers with the diazo group and the negative oxygen gauche to one another. In cis elimination[99], the unshared pair of electrons on the nitroso nitrogen directly overlaps with the developing electron deficient carbon lobe formed as the N_2 departs. This should be the favored course of reaction. If diazo elimination can only occur by this expected cis elimination, conformers A_3 and A_4 cannot lead to product. But both conformers A_1 and A_2 can. Since the unshared electron pair is smaller than the negative oxygen, structure A_1 is more stable than structure A_2 since in A_2 the C-phenyl is gauche to a phenyl and the negative oxygen while in A_2 it is gauche to a phenyl and the smaller unshared electron pair. Cis elimination from A_1, the more stable conformer, yields the cis nitrone, which is the product obtained in the reaction. In the triaryl system, where the methyl group is replaced by a substitued phenyl, conformers A_1 and A_2 are energetically equivalent and thus a mixture of isomers would be expected. This rationale is not completely compelling, and a further investigation of this and similar systems seems in order.



XBL 695-4258

Figure 7. The mechanism of nitrone formation in the reaction of 1-methyl-1-phenyldiazomethane with nitrosobenzene.

If the nitrone isomer we are dealing with is indeed the cis isomer, we have a consistent result with respect to nitrone irradiation: the cis nitrone yields a cis oxaziridine stereospecifically. A corollary to this result is that irradiation of a trans nitrone should lead to trans oxaziridine.

The diarylnitrones have been shown to be trans.[93-96] Irradiation of the nitrone produces one oxaziridine as shown by the occurrence of only one oxaziridine hydrogen resonance in the NMR. The absence of any other oxaziridine hydrogen signals with time indicates that the oxaziridine originally formed is the trans isomer, the thermodynamically more stable one. (In this case, the trans-oxaziridine should be significantly more stable than its cis counterpart since strong phenyl-phenyl interactions occur in the cis compound, which are absent in the trans compound.) As a consequence, negligible amounts of the cis-oxaziridine should exist in the equilibrium mixture. There is reason to believe that no cis-oxaziridine is produced in the irradiation mixture at all. Since the half-life for cis $\longrightarrow$ trans isomerizations is relatively long, of the order of several hours, we should be able to observe any cis isomer that was originally formed, but none was seen. It therefore appears that the "trans" diarylnitrones on irradiation produce only trans-diaryloxaziridines.*

From a closer investigation of the photochemical ring closure occurring in the nitrone photolysis, the stereospecific synthesis of oxaziridines is not surprising. If we consider the rearrangement to take place through a concerted ring closure, the following sequence, as shown in Figure 8,

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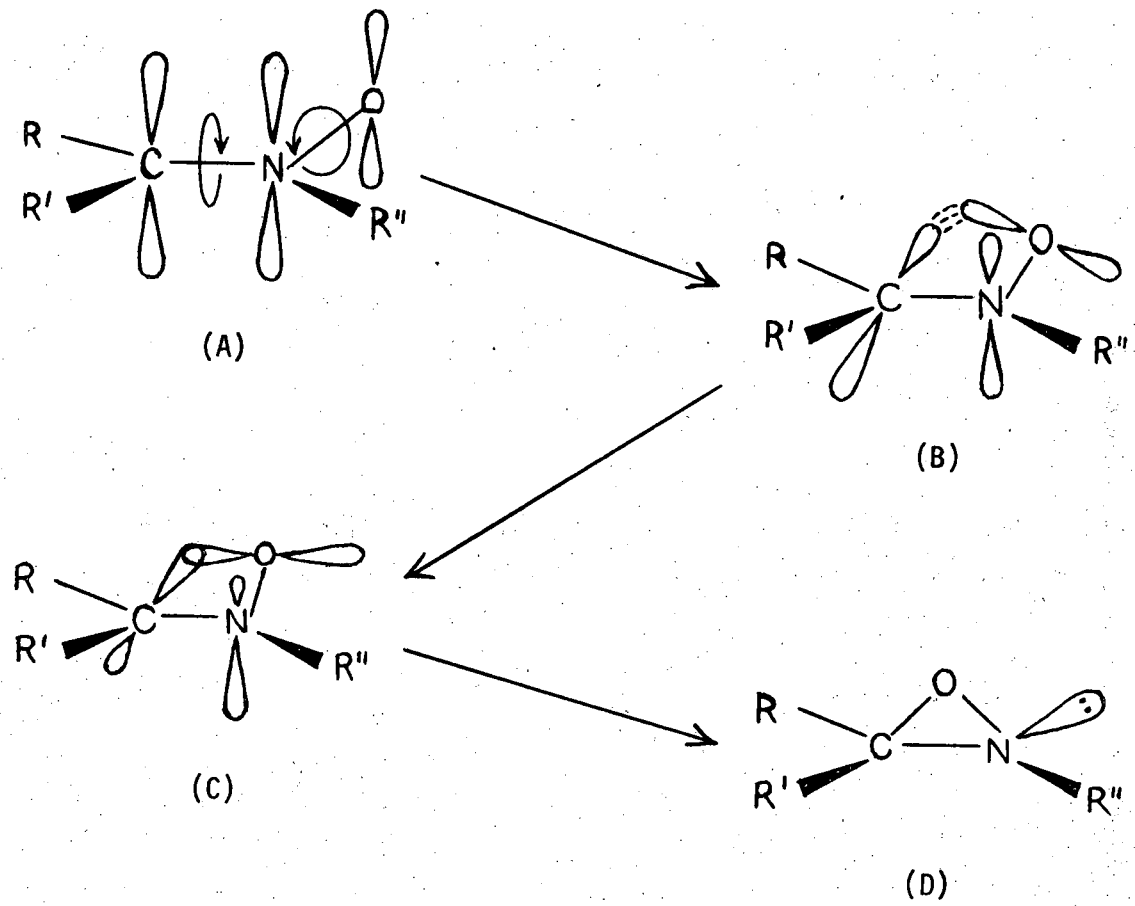
* The absence of a noticeable induction time in the 2,3-diaryloxaziridine kinetics also argues against a significant cis $\longrightarrow$ trans reaction.



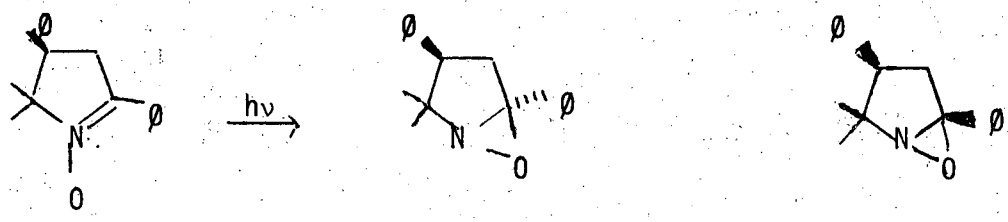
XBL 695-4264

Figure 8. The stereospecific pathway for oxaziridine formation in the photolysis of the corresponding nitrone.

should occur. In the ground state nitrone, the carbon,nitrogen and oxygen atoms occupy one plane with their conjugating p-lobes perpendicular to the plane (A). Because of the conjugated system, rotation around the C-N and N=O bonds are restricted. In the electronically-excited state of the molecule, these restrictions are reduced, allowing freer rotation about the two bonds. Rotation about both the C-N and N-O bond occurs, allowing a partial overlap of the p-orbitals of the carbon and oxygen. As this overlap becomes more pronounced, and a sigma bond forms, the carbon p-lobe rehybridizes to an sp^3 lobe (B). Concomitantly, electron repulsion from this partially formed sigma bond, coupled with a loss of conjugation stabilization, causes the p-lobe on the nitrogen to assume a more stable sp^3 hybridization with the larger lobe on the side of the plane opposite to the developing carbon-oxygen bond, (C). The end result is an oxaziridine (D) that has retained the configuration of the starting nitrone. Thus, we see that irradiation of cis nitrone can very likely lead to cis-oxaziridine and, conversly, trans nitrone can lead to trans-oxaziridine.

This is in contrast to the results of Koyano and Tanaka[100] who report that both cis and trans α-cyano-α,N-diphenylnitrone produce the same oxaziridine. However, their conclusion was based on the fact that photoproducts of both isomers have the same UV spectra. Since both oxaziridine isomers should have very similar spectra anyway, their conclusion is not convincing. Bapat[101] has recently shown that irradiation of a substituted 1-pyroline 1-oxide (IX) leads to a single oxaziridine (X) (the thermodynamically stable isomer), while peracid treatment of the correspond-

ing 1-pyrroline produces the opposite isomer (XI). Therefore, some type of



(IX) (X) (XI)

specificity is not unexpected in this irradiation. Furthermore, as has been shown by Shinzawa and Tanaka[31], the nitrone irradiation proceeds via a singlet state. Since the lifetime of a singlet state is short[102], it is very possible that ring closure to the oxaziridine occurs before full rotation around the C-N bond to give the opposite isomer can compete. On the other hand, with a long-lived triplet state[102], rotation around the C-N bond should have sufficient time to occur, leading to a mixture of isomers. This has been confirmed by Koyano and Tanaka[100] who found that triplet sensitization of nitrone irradiation resulted in cis-trans isomerization about the C=N bond. Singlet/reactions gave none of this isomerization.*,**

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* By UV spectra, Splitter and Calvin[1], have also found that the thermal isomerization of the 3-(4-dimethylaminophenyl)-2(3-nitrophenyl)oxaziridine (presumably trans) yields what appears to be the "cis" nitrone which then slowly isomerizes to the starting "trans" nitrone. The process where a trans nitrone photochemically yielding a trans oxaziridine which termally referts to the cis nitrone may be following the electrocyclic rules of Woodward and Hoffman.[50]

** For a stereospecific photochemical rearrangement of aziridines that appears to obey the Woodward-Hoffmann rules, see Reference 103.

One consequence of this predicted stereospecific rule is that, when cis and trans isomers of the corresponding nitrones exist, photolysis of the separate isomers should lead to isomeric products. In the cis and trans α-cyano-α,N-diphenylnitrones, the irradiation should produce separate cis and trans oxaziridines. But, as our work shows, isomerization proceeds quite rapidly. Thus identification of the isomers may be difficult. However, the cis and trans isomers of the nitrone (XII) shown below have been separated..

(XIIa) (XIIb)

X = p-NO_2 [104,105]

X = p-CH_3 [106]

Irradiation of these nitrones should lead to stable photoproducts. As shown by Montanari [88b] inversion about the nitrogen of an N-methyloxaziridine is very slow. Therefore irradiation of the cis nitrone should lead to a stable cis oxaziridine and irradiation of the trans nitrone should produce the trans oxaziridine. These oxaziridines should be non-interconverting, isolable, and characterizable. In particular, NMR of the oxaziridine methyl group should easily distinguish between the two. This is a very important confirmatory experiment that should be carried out in the near future.

The kinetics of the 3-methyl-2,3-diphenyloxaziridine isomerization were measured at two temperatures, 0°C and 22°C. The isomerization followed first order kinetics with first order rate constants of 2.18×10^{-6} sec^{-1} and 8.21×10^{-5} sec^{-1} respectively. From the two rates, a value

of the activation energy E_a for nitrogen inversion was calculated to be about 26 1/2 kcal/mole (ΔH 26=kcal/mole) and ΔS = + 10 e.u. Since only two points were employed, these values are only approximate and an E_a of 26 1/2 kcal/mole + 10% seems more appropriate. As far as can be found, no activation energy has ever been calculated for a trivalent N-phenylamine and therefore comparisons are difficult to make. However the E_a found is significantly higher than the 17-21 kcal/mole calculated by Curtin for the cis-trans isomerization of substituted triarylimines.[26] Anet[75] has measured the ΔF^* for nitrogen inversion of 1-phenylaziridine at -40°C and has obtained a value of 12.9 kcal/mole. If we extrapolate our data to -40°C we obtain a ΔF^* of 24 kcal/mole. Thus in the oxaziridine system, inversion is 11 kcal/mole less favorable than in the phenylaziridine system. This confirms the awesome rate-retarding effect of the oxaziridine ring on the rate of nitrogen inversion.* The fairly significant positive ΔS for nitrogen inversion is in fair agreement with the value of +15-20 e.u. found by Jautelat and Roberts[72] for the inversion of 1,2,2-trimethylaziridine. They theorized that constraining steric interactions may be present in the ground state which are absent in the transition state for nitrogen inversion. Such an explanation also seems applicable in this system.

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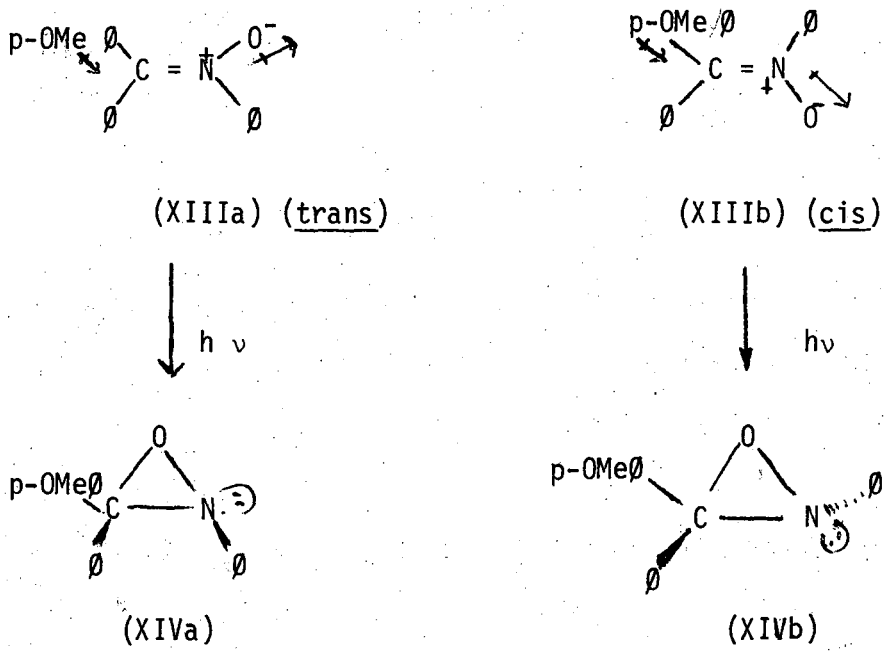
*Since the ground state of this oxaziridine system is probably destabilized by steric interactions, the ΔF^* for the hypothetical unsubstituted N-phenyloxaziridine should probably be even higher. Thus the retarding effect of the oxaziridine on nitrogen inversion relative to the aziridine is probably greater than the 11 kcal/mole which was calculated.

A similar result is observed in the NMR spectrum of 3-(4-anisyl)-2,3-diphenyloxaziridine (XIV) which was synthesized by the photolysis of the corresponding α-(4-anisyl)-α,N-diphenylnitrone (XIII).



The NMR spectrum of the nitrone itself (Figure 9) shows two distinct methoxy methyl resonances at τ 6.24 (area 1.7) and 6.34 (area 1.3) plus a complex multiplet of aromatic hydrogen resonances centered at τ 3.1 (area 14) . The existence of two distinct methyl resonances implies the presence of both the trans and cis isomers of the nitrone, XIIIa and XIIIb respectively.* The wide melting range of the nitrone (128-146°) is also indicative of a mixture of isomers.

A tentative assignment of the methyl resonances can be made. Because of the great shielding power of the negatively charged oxygen, it is expected that the methyl group of the trans isomer (XIIIa) would appear

*The terms cis and trans refer to the orientation of the p-methoxyphenyl ring with respect to the N-phenyl group.

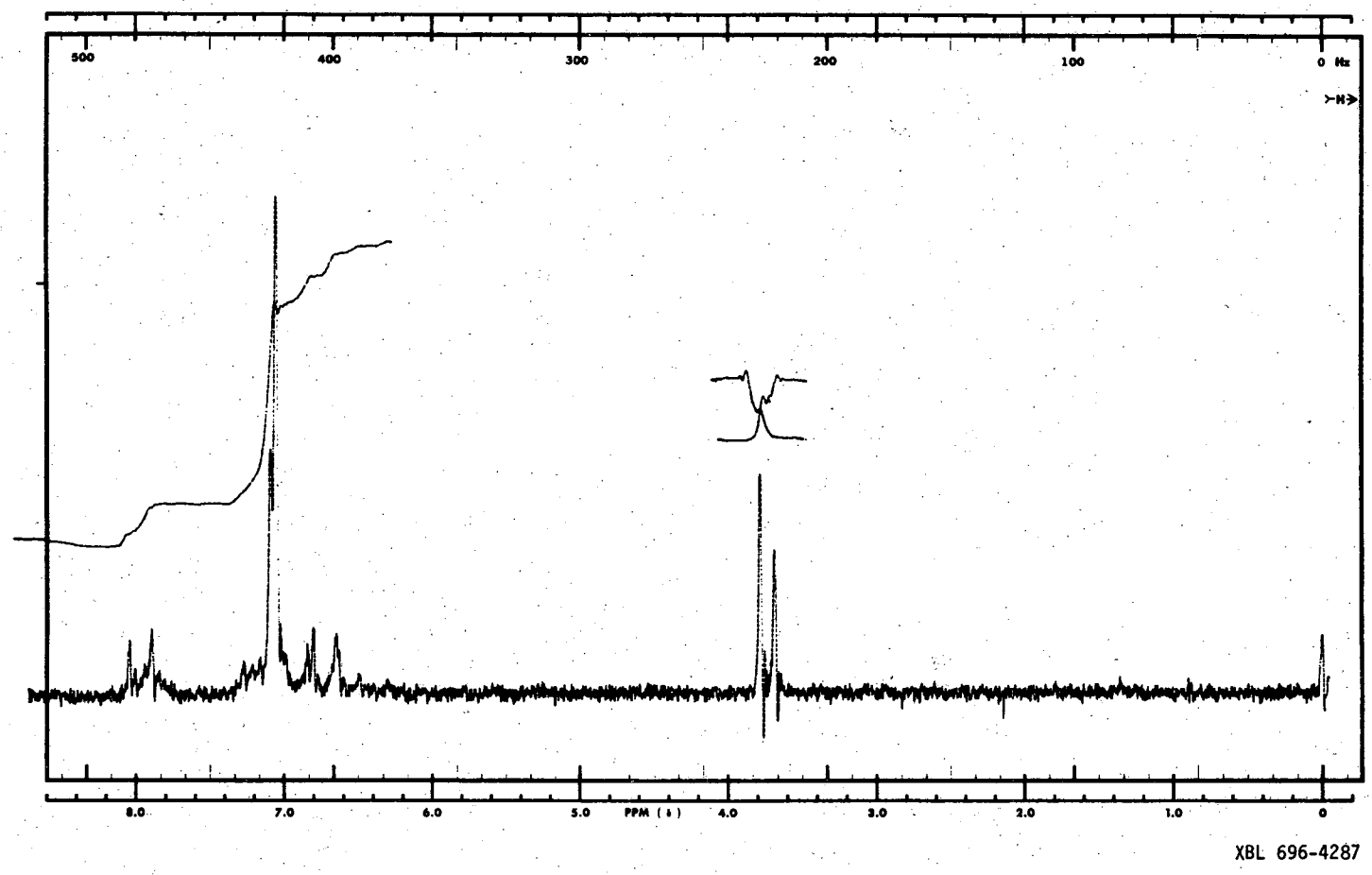
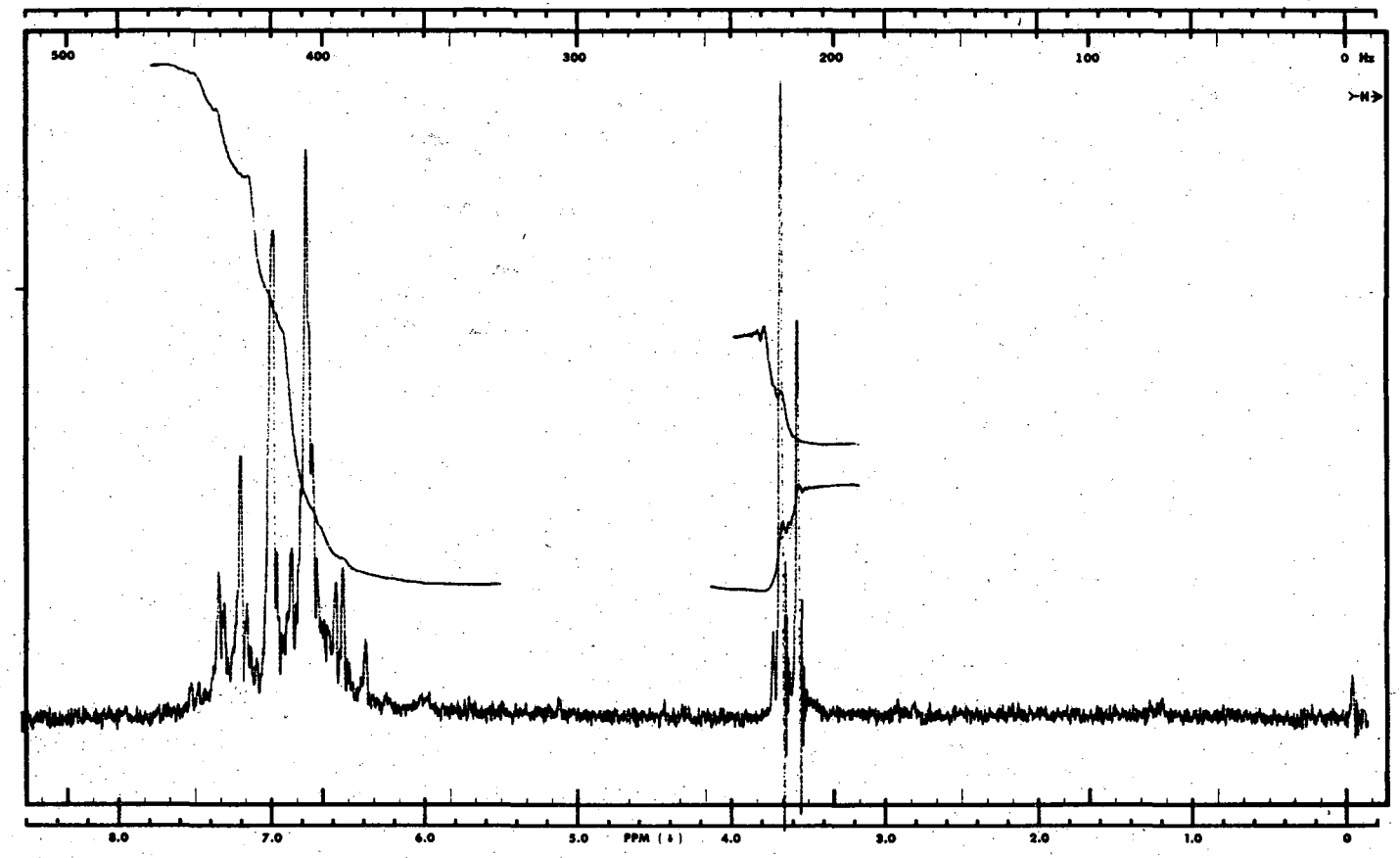


Figure 9. NMR spectrum of α-(4-methoxyphenyl)-α,N-diphenylnitrone in CCl_4 (TMS internal standard).

at a higher field than the cis isomer. Since both α-aryl groups are similar in size, one isomer should not be favored over the other on steric grounds and thus only electronic effects should be important in determining the relative populations of the two conformers. When one considers the electron-donating ability of the p-methoxy group, one would expect a sizeable dipole directed from the methoxy group toward the aromatic ring. Likewise there should exist a substantial charge dipole directed from the nitrone nitrogen toward the oxygen. Dipole-dipole interactions will be most favorable when these two dipoles are pointed in the same direction. Thus, on the basis of dipolar interactions, isomer XIIb would be expected to be the most stable and hence the most abundant isomer, i.e., the low field methyl resonance. Therefore, on the basis of stabilities as well as on the basis of structural effects on NMR resonances one would assign the high field resonance (τ6.34) to the trans isomer (XIIIa) and the low field resonance (τ6.24) to the cis isomer (XIIIb).[26]

Irradiation of this mixture of nitrone isomers in methylene chloride yields a solution of the corresponding oxaziridines (XIV). An NMR spectrum of the irradiated solution in carbon tetrachloride (Fig. 10) (the methylene chloride being removed in vacuo) again shows two methoxy methyl resonances at τ6.27 (57%) and τ6.38 (43%) whose relative ratio does not vary with time. This is the same ratio of methyl resonances as found in the starting nitrone (57%:43%). This again indicates, as found in the 3-methyl-2,3-diphenyloxaziridine, that inversion about the oxaziridine nitrogen is slow compared to the NMR time scale. If, as hypothesized for the irradiation of the α-methyl-α,-diphenylnitrone, the



XBL 696-4285

Figure 10. NMR spectrum of a freshly prepared solution of 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine in CCl_4 (TMS internal standard).

photochemical rearrangement of the nitrone to oxaziridine is stereospecific we would expect the trans nitrone (XIIIa) to give trans oxaziridine (XIVa) and cis nitrone (XIIIb) to give cis oxaziridine (XIVb). If interconversion between the oxaziridine isomers is slow,* the predominant oxaziridine isomer with a methyl resonance at τ6.24 should be produced stereospecifically from the predominant nitrone isomer (the cis form XIIIb). Therefore the methyl resonances at τ6.24 is tentatively assigned to the cis oxaziridine (XIVb) and the less populated high field resonance at τ6.34 is assigned to the trans oxaziridine (XIVa).** These assignments are very tentative and other model systems should be investigated to confirm the proposed structures.

Because the oxaziridine appears to represent an equilibrium mixture of the two isomers, no useful kinetic data can be obtained. However, a physical phenomenon is observed which allows an estimation of isomerization rates. Very crystalline 3-(p-methoxyphenyl)-2,3-diphenyloxaziridine (mp 103-106°) can be formed (see the experimental section) by allowing the oily residue from the nitrone irradiation to slowly crystallize over several weeks from a methylene-chloride-petroleum ether solution. An NMR spectrum (Fig.11) taken of a dissolved sample of this crystalline oxaziridine is very different from the NMR spectrum of freshly prepared sample. Instead of two methyl resonances of approximately equal intensities, the low field methyl resonance (τ6.24) is over

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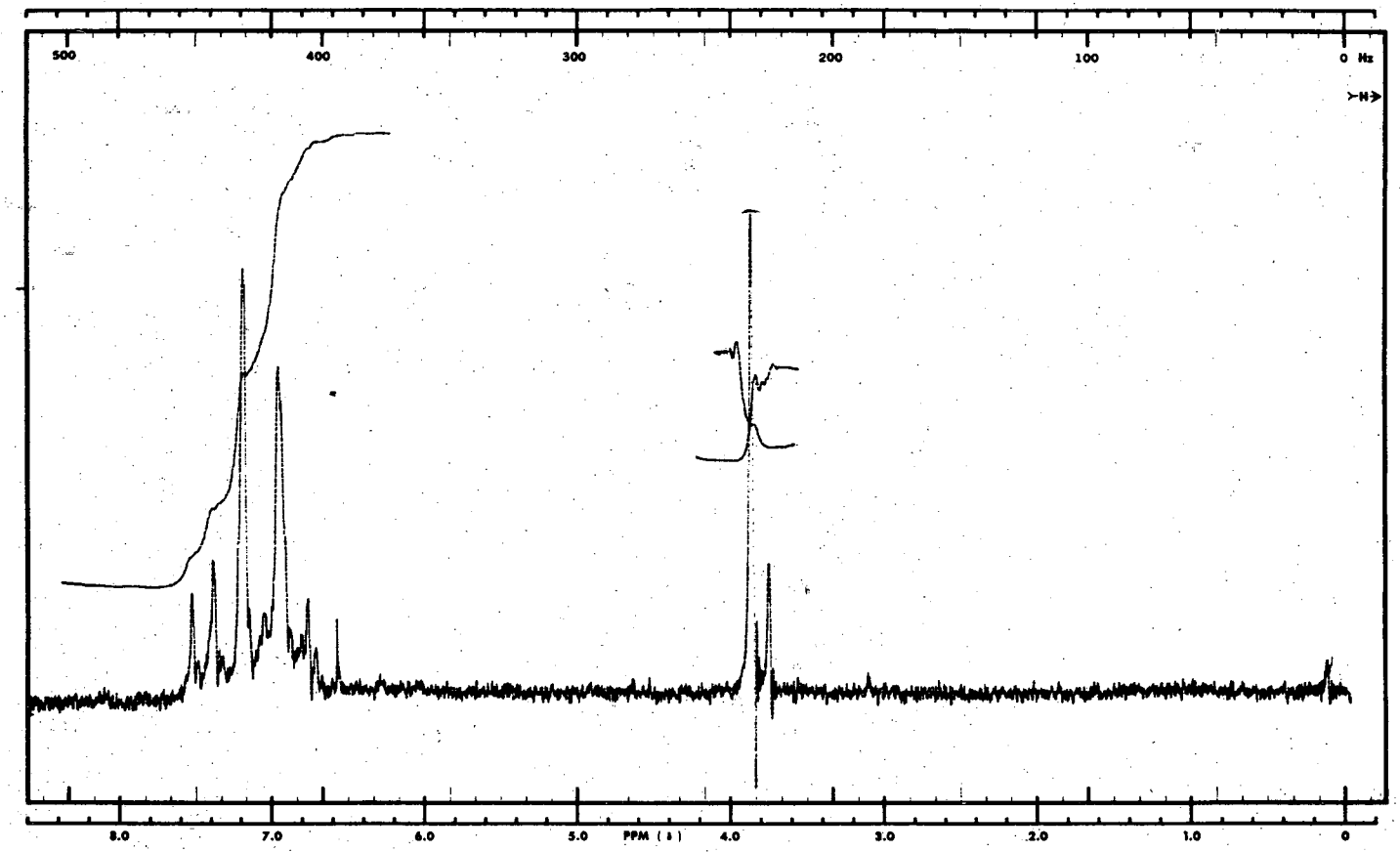
* The sample took about the same length of time to prepare as the 3-methyl-2,3-diphenyloxaziridine (about 50 minutes). Since only a slight amount of isomerization occurred int the latter case, probably only slight isomerization also took place in the system under investigation during preparation.

** This contradicts the conclusions obtained by extrapolating the results of Curtin, Grubbs and McCarthy[26] on unsymmetrical triarylimines to the oxaziridine system. Further work must be done to clarify these results.



XBL 696-4288

Figure 11. NMR spectrum of a freshly prepared solution of crystalline 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine in CCl_4 (TMS internal standard).

five times larger than the high field methyl resonance (τ6.34).* These results suggest that the oxaziridine crystallizes out as a single isomer! Similar results have been found in crystallizations of unsymmetrical triarylimines.[26] With time, the low field methyl resonance decreases with a corresponding increase in the high field methyl resonance. Upon standing, the solution eventually reaches the same equilibrium (Fig. 12) mixture of isomers (57%-43%)** as found in the freshly prepared oxaziridine solution. Because of the selective isolation of one isomer of the oxaziridine, the rate of equilibration between the two isomers can be measured. At room temperature (22°) the halftime for this isomerization is about 1 3/4 hours. Thus it appears that in the triaryloxaziridine system, as well as in the 3-methyl-2,3-diphenyloxaziridine system, inversion of the oxaziridine nitrogen is very slow.

The rearrangement of the oxaziridines to amides which we have studied must be considered in the light of this slow inversion rate of the N-phenyl group. In the 2,3-diaryl system, it appears that in the cases that have been investigated, only the trans form of the oxaziridine is produced

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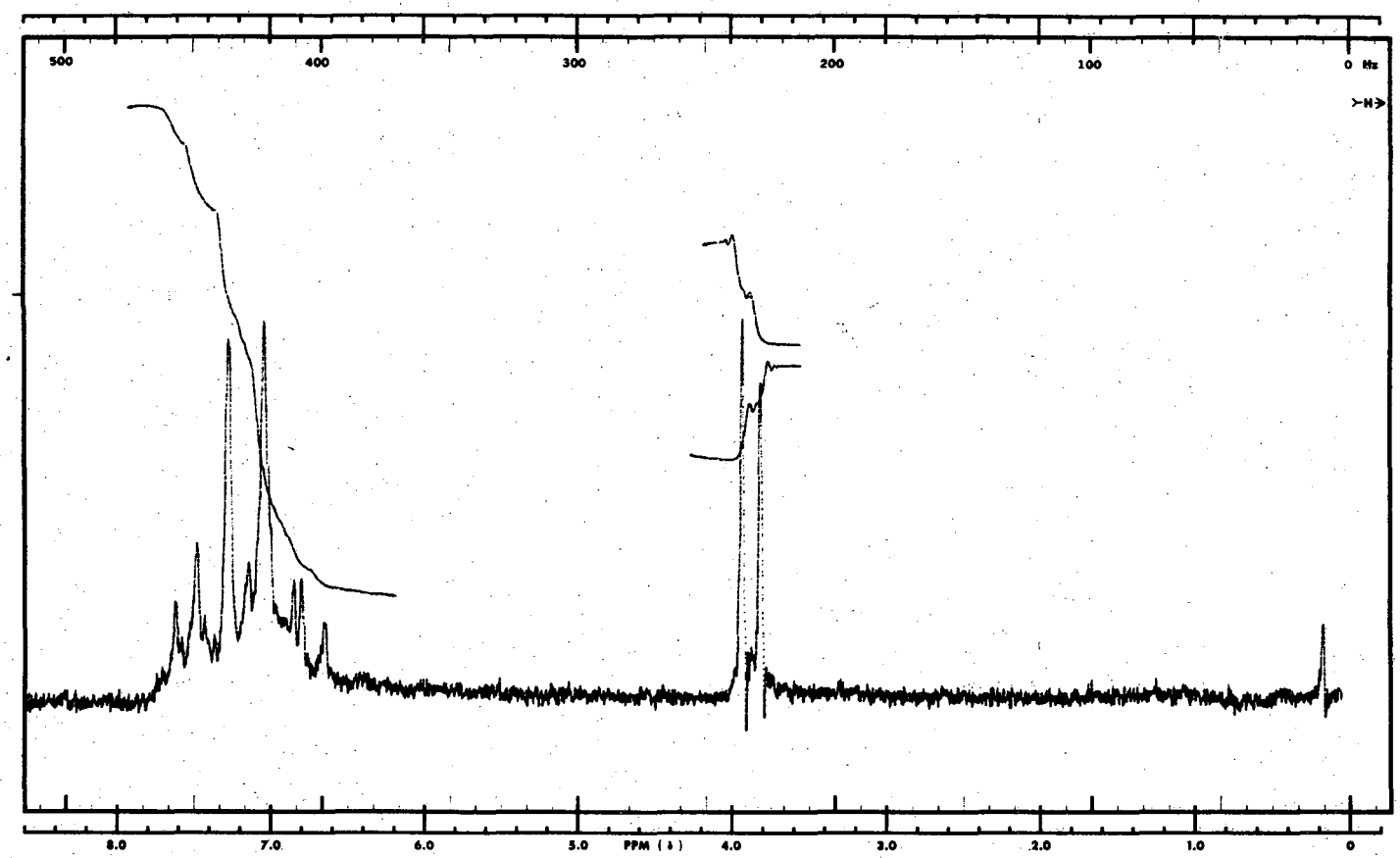
* To dissolve the oxaziridine crystals in carbon tetrachloride for NMR analysis, the solution was heated to ca. 40° for several minutes. Therefore, significant isomerization undoubtedly occurred before the first spectra was taken.

** A crystalline sample of the oxaziridine (mp ca.95-105°) from rapid crystallization from methylene chloride-petroleum ether has an NMR spectrum showing an equilibrium mixture of the two oxaziridine isomers.



XBL 696-4286

Figure 12. NMR spectrum of a solution of crystilline 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine in CCl_4 after standing for 24 hours (TMS internal standard).

by irradiation of the corresponding trans nitrone. Since the trans-2,3-diaryloxaziridine would be expected to be much more stable than the cis form, it appears that all interpretations of data must be based on the existence of only the trans form in solution. This existence of only one isomer in this large series of substituted 2,3-diaryloxaziridines greatly simplifies interpretation of data.

In the triaryl system, the interpretations are slightly more complex. From the results of the 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine, it appears that the oxaziridine solution contains a mixture of cis and trans isomers. Since the thermal reaction rates for most of the triaryloxaziridines are very slow ($t_{1/2}$ ca. 10 days), sufficient time is available for complete thermodynamic equilibration of the cis and trans isomers to occur. (The $t_{1/2}$ for cis $\rightarrow$ trans isomerization of the 3-methyl-2,3-diphenyloxaziridine is about 2-3 hours at room temperature, while that of the 3-(4-methoxyphenyl)-2,3-diphenyloxaziridine is about 1 3/4 hours). In addition, it appears that in the preparation (without isolation) of the unsymmetrical triaryloxaziridines in solution, irradiation of the correspondingn nitrone produces a near-equilibrium mixture of the oxaziridine isomers. Thus in the triaryl system, data must be interpreted in terms of a mixture of two isomers. Only in the 2-(4-methoxyphenyl)oxaziridine compounds where rearrangement occurs very fast can there be rearrangement of a non-equilibrium mixture of triaryloxaziridines.

This does not, however, mean that rearrangement must take place in a static system where the N-aryl group is fixed rigidly on one side of the ring system. On the contrary, we might expect that, in the transition state for rearrangement, N-O bond stretching occurs which, by relieving ring strain, allows nitrogen inversion to occur at a much more rapid rate.

IV. SUMMARY OF RESULTS

The thermal stabilities of diaryl and triaryloxaziridines have been investigated. As first indicated by Splitter and Calvin[1], the stability of diaryloxaziridines is very sensitive to substituents on the aromatic rings and, with the appropriate choice of substituents, the lifetimes of the compounds in solution can be varied from less than a few seconds to indefinitely long. They appear to rearrange via a heterolytic nitrogen-oxygen bond cleavage with simultaneous migration of a group from the oxaziridine carbon to the nitrogen to yield amides (although in rare cases, isomeric nitrones are also formed with an activation energy of about 24 kcal/mole and with a very low negative entropy change.

There appears to be a continuum in the mechanism of the rearrangements of the oxaziridines. On one end are the highly ionic, anchimerically assisted rearrangements of the 3(-4-dimethylaminophenyl)-2-phenyloxaziridine in ethanol, and on the other end are the fairly nonpolar rearrangements of the triphenyloxaziridines. The position of a particular compound in this continuum is dependent on the ease of charge development in the compound. This, in turn, is dependent both on the substituents present in the molecule and on the ionizing properties of the solvent. Electron donating substituents and highly ionizing solvents increase the amount of ionic character in the rearrangement while electron withdrawing substituents and nonpolar media favor a slower, more concerted and less ionic rearrangement.

Although the existence of the diaryloxaziridines in solution had been firmly established, their isolation had not been accomplished previously.

This investigation found that with strongly electron withdrawing groups on the nitrogen phenyl group of 2-aryl-3-phenyloxaziridines, the nitrogen-oxygen bond cleavage can be retarded sufficiently so that these oxaziridines can be isolated as crystalline solids. This definitely establishes that oxaziridines are the photoproduct from α,N-diarylnitrone irradiations.

The triaryloxaziridines from the irradiation of triarylnitrones were shown to be, in general, very stable compounds which rearranged to substituted benzoyldiphenylamines in a manner similar to the 2,3-diaryloxaziridines. They could be isolated and characterized as very stable crystalline solids. This again confirms the fact that the triaryloxaziridine is the primary product from the photolysis of triarylnitrones.

Lastly, evidence has been presented to show that inversion about the nitrogen in the 3-methyl-2,3-diphenyloxaziridine is very slow, $\Delta H \sim 26$ kcal/mole and $\Delta S \sim 10$ e.u. for the inversion process. Comparison with nitrogen inversion, in the analogous N-phenylaziridines, indicates that the oxaziridine ring has a destabilizing effect of about 12 kcal/mole on the rate of nitrogen inversion. In addition, the 2,3-diaryloxaziridines appear to exist in a configuration where the aryl groups are "trans" to each other. This trans orientation is attributed to a stereospecific formation from the trans-α,N-diarylnitrone.

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