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OXIDATION OF ARYL KETOXIMES AND HYDRAZONES WITH CERIUM(IV) SALTS

by

Samuel Paul Thackaberry

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1968

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INTRODUCTION

Reports of the use of cerium(IV) as an oxidant of organic compounds were made as early as 1905, in which were summarized the uses of ceric oxide in sulfuric acid for the oxidation of toluene to benzaldehyde, anthracene to 9,10-anthraquinone, and naphthalene to 1,4-naphthaquinone (1,2). The procedures used to effect these conversions, and the yields obtained, were not reported. The use of cerium(IV) as an analytical reagent for the determination of organic compounds has since gained prominence, and has been the subject of several review articles (3,4,5).

Kinetic studies of the oxidation of a variety of organic compounds by cerium(IV) constitute a sizeable proportion of the chemical literature which is concerned with cerium(IV) oxidation in organic chemistry. However, the majority of those kinetic studies are only of limited usefulness because the products of the reactions are not known. Only in recent years has any significant interest been shown in possible synthetic applications of the oxidation reactions which organic compounds undergo with cerium(IV). The investigations reported in this dissertation fall mainly within the area of the synthetic applications of the cerium(IV) oxidation of organic molecules.

It was observed by D. C. Heckert that ceric ammonium nitrate rapidly oxidized 9-fluorenone oxime in methanol solution to give 9-fluorenone and lesser amounts of 9,9-dinitrofluorene and 9-fluorenone azine monoxide. A study of the scope of the ceric ammonium nitrate oxidation of oximes to give geminal-dinitro compounds has been made and is reported here. In general, only diaryl and arylalkyl ketoximes are converted to geminal-dinitro compounds in significant yields. Of the aryl ketoximes studied, only 9-xanthenone oxime and anthraquinone monoxime did not yield gem-dinitro derivatives when oxidized by ceric ammonium nitrate. Ketones are generaally the major products of the cerium(IV) oxidation of ketoximes in alcohol solution. The factors influencing the formation of gem-dinitro compounds from aryl ketoximes by ceric ammonium nitrate oxidation have been elucidated in part and are discussed. The oxidation of 9-fluorenone oxime by other cerium(IV) salts has been conducted, and the results are compared to the results obtained in the oxidation of that oxime by ceric ammonium nitrate.

The preparation of gem-dinitro compounds has been accomplished in the past by several methods, all of which are either severely limited in scope or involve long, tedious procedures for the separation of the desired materials from other reaction products in low yields. The facile oxidation of aryl and diaryl ketoximes by ceric ammonium nitrate to produce aryl and diaryl-substituted dinitromethanes affords a convenient route for the preparation of a novel class of compounds, one which may be carried out under extremely mild conditions to give products which are readily separable by column chromatography. Little is known concerning the chemistry of gem-dinitro compounds, primarily as a result of the lack of general methods for the preparation of the materials. The physical and spectroscopic properties of eight gem-dinitro compounds are reported here, but the chemistry of those compounds has not been studied.

The conclusion has been reached from kinetic studies on the cerium(IV) oxidation of alcohols that oxidation occurs by way of formation of a 1:1 alcohol cerium(IV) complex, and rate determining oxidative decomposition of the complex. It is probable that the cerium(IV) oxidation of oximes proceeds similarly through an oxime-cerium(IV) complex, but kinetic evidence for the intermediacy of such a complex in the reaction has not been obtained. Nitrogen-15 isotopic labeling experiments have shown that the origin of one of the two nitro groups present in the gem-dinitro compounds derived from ketoximes by ceric ammonium nitrate oxidation originates from the nitrate ion bound initially to cerium(IV). The results indicate that the ceric ammonium nitrate oxidation of oximes is in part a ligand transfer oxidation, and resembles the reactions which alkyl radicals undergo with copper(II) complexes and other metal ion complexes.

The transfer of the elements of nitrate ion from cerium(IV) to an oxime molecule would indicate that an oxime-cerium(IV) complex, or a complex of cerium(IV) with an intermediate derived from the oxime, is involved in the reaction. The possibility exists that oxidation of other compounds (e.g., alcohols) by ceric ammonium nitrate may also involve oxidation by ligand transfer producing nitrated intermediates which are not sufficiently stable to allow detection and isolation. This is important in that an oxidant which is believed to be a simple one-electron oxidant may in fact function as a two-electron in its initial attack on an organic molecule.

A stable class of nitrogen radicals known as iminoxyl radicals have been generated from oximes by oxidation with various reagents and have been characterized by electron spin resonance techniques by several groups of workers. Some electron spin resonance studies on the oxidation of aryl ketoximes by ceric ammonium nitrate have been conducted and are reported here. Iminoxyl radicals derived from 9-fluorenone oxime, benzophenone oxime, and anthraquinone monoxime have been characterized. The data suggests that iminoxyl radicals are reactive intermediates in the cerium(IV) oxidation of aryl ketoximes to form ketones, *gem*-dinitro derivatives, and other materials.

Limited studies on the oxidation of aryl ketoximes by nitric acid to give *geminal*-dinitro compounds have been conducted. At the present time, this method appears to be generally less useful for the preparation of *gem*-dinitro compounds than ~~is~~ the method of oxidizing the oximes with ceric ammonium nitrate. An exception is the nitric acid oxidation of 9-fluorenone oxime, which results in the production of 9,9-dinitrofluorene in yields greater than those obtained in the ceric ammonium nitrate oxidation of the oxime. The scope of the reaction remains to be determined.

A number of methods for the preparation of symmetrical ketazines by the oxidation of the respective hydrazones have been reported in the literature. The cerium(IV) oxidation of diaryl ketohydrazones has been found to give symmetrical ketazines and ketones. The preliminary results in this area are described in this dissertation.

Interest in mass spectrometry and its applications to organic chemistry has increased rapidly in recent years, as is evidenced by the almost overwhelming number of reports to be found in the current literature concerning the mass spectra of organic compounds. Extensive use of mass spectrometry was made in the investigations reported here, as an aid in the determination of the structures of reaction products. Inclusion of a separate section dealing with the mass spectra of *geminal* dinitro compounds has been made so that the fragmentations observed for the individual compounds could be placed within the context of fragmentation pathways which were found to be characteristic for this interesting class of compound. The observation of some novel modes of fragmentation of azines and azine monoxides in the mass spectrometer has prompted the inclusion of separate sections dealing with the mass spectra of those materials.

The results of the cerium(IV) oxidation of oximes and hydrazones illustrate the novel reactions which organic compounds can undergo with cerium(IV) reagents. Other systems may be found in which synthetically useful products are formed. Investigations of the chemistry and photochemistry of *geminal*-dinitro compounds can be conducted now that a convenient method for the preparation of those materials has been developed. Improvements in the synthetic method itself will probably be made once the factors influencing product formation become more completely understood.

HISTORICAL

Oxidation of Organic Compounds with Cerium(IV)

Research in the area of the chemistry and reactions of cerium(IV) has been confined mainly to the fields of analytical and inorganic chemistry. The use of cerium(IV) as an oxidant for organic molecules has been given limited attention, particularly from a synthetic point of view. Recent investigations in the area of the cerium(IV) oxidation of organic molecules, both from a kinetic and a synthetic point of view, have been conducted under the direction of Dr. W. S. Trahanovsky in the laboratories at Iowa State University. Portions of the findings of Trahanovsky and co-workers will be presented at various points throughout this review. Use of cerium(IV) as an analytical reagent in organic chemistry has been reviewed by Smith (3). Later reviews are available (4,5), which are concerned mainly with cerium(IV) oxidation as an analytical tool in organic chemistry.

Primary consideration in this review will be given to the synthetic applications of cerium(IV) oxidation to organic chemistry. Several kinetic studies of the cerium(IV) oxidation of alcohols, glycols, aldehydes, ketones, and other organic compounds have appeared in the chemical literature (6). The majority of reports on the oxidation of organic compounds with cerium(IV) have been concerned with the kinetics and mechanism of the various reactions, and are of limited usefulness since the products of these reactions are not known. The oxidation of a number of organic materials by cerium(IV) has been reviewed by Richardson (6), together with detailed kinetic evidence and reaction mechanisms. The reader is referred to that review for more detailed descriptions of many of the reactions which are included here. Since reactions of other reagents (e.g., lead tetraacetate, potassium ferricyanide, manganese dioxide) with oximes and hydrazones are similar to those observed with cerium(IV) salts, sections reviewing those reactions are included.

Before describing cerium(IV) oxidations of organic compounds, a brief review of the inorganic chemistry of cerium(IV) seems appropriate. The common oxidation states of cerium are III and IV (7). The most probable electronic configurations are $5s^2\ 5p^6\ 4d^{10}\ 4f^1$ (for trivalent cerium) and $5s^2\ 5p^6\ 4d^{10}$ (for tetravalent cerium) (8). Cerium(IV) would be a one-electron oxidant. The oxidation potential of the cerium(IV)-(III) couple is strongly ligand dependent, varying from -1.71 volts in 1N perchloric acid to -1.28 volts in 1N hydrochloric acid (6 and references cited therein). The oxidation potentials in 1N nitric acid and 1N sulfuric acid are -1.61 and -1.44 volts, respectively (6). Increasing the acid concentration from 1N to 8N increases the oxidation potential in perchloric acid, but results in a decrease in the oxidation potential in nitric and sulfuric acids. The decrease in the potentials in nitric and sulfuric acids with increasing acid concentration has been attributed to complexing of cerium(IV) with sulfate and nitrate (9).

Oxidation of alcohols

The commonly accepted view of the cerium(IV) oxidation of alcohols is that they proceed through initial formation of an alcohol-cerium(IV) complex, which then decomposes through one or several steps to produce cerium(III) and product. Kinetic data has been obtained (10) which confirms that initial cerium(IV)-alcohol complex formation is involved in the oxidation of ethanol in aqueous solution (Equations 1 and 2 (10)). Acetaldehyde is produced in the reaction in 90% yield.

$$Ce(IV)(H_2O)_8^{+4} + C_2H_5OH \rightleftarrows Ce(IV)(H_2O)_7(C_2H_5OH)^{+4} + H_2O$$

1

$$Ce(IV)(H_2O)_7(C_2H_5OH)^{+4} \longrightarrow \text{products}$$

2

Kinetic and spectrophotometric evidence for complex formation has been obtained in the cerium(IV) oxidation of many compounds in nitric and perchloric acid media (11-15). However, recent reports (16-18) present contradictory viewpoints as to the intermediacy of cerium(IV)-alcohol complexes in the oxidation of alcohols in nitric and perchloric acids.

The kinetics of the oxidation of benzyl alcohol to benzaldehyde with cerium(IV) in 1N perchloric acid have been studied (16). At a 3:8 molar ratio of alcohol to cerium(IV), measureable rates were obtained. The reaction was first order with respect to cerium(IV) and the alcohol (second order overall). No complexing between the alcohol and cerium (IV) was detected, as indicated by a "normal" salt effect. The postulated mechanism of the reaction is summarized in Equations 3 and 4 (16). The absence of cerium(IV)-alcohol complexing was

$$\mathrm{PhCH_2OH + Ce(IV) \xrightarrow{slow} Ph\dot{C}H{-}OH + Ce(III) + H^+} \qquad \underline{3}$$

$$\mathrm{Ph\dot{C}H{-}OH + Ce(IV) \xrightarrow{fast} PhCH{=}O + Ce(III) + H^+} \qquad \underline{4}$$

explained by "the effect of the phenyl group as an electron-withdrawer, which prevents coordination and weakens the O—H bond of the alcohol" (16).

The validity of the results obtained by Rangaswamy and Santappa (16) is to be seriously questioned in the light of results recently obtained by Young (19). Qualitatively, Young has shown that cerium(IV)-alcohol complex formation is involved in the oxidation of benzyl alcohol by ceric perchlorate in perchloric acid medium. On mixing a solution of 0.05 M ceric perchlorate in 0.5 M perchloric acid and benzyl alcohol, the orange color of cerium(IV) changes immediately to an extremely deep red, the color of a cerium(IV)-alcohol complex (19). One must conclude that there is in fact complex formation in the benzyl alcohol-cerium(IV) system. In this light, the partial mechanism for the reaction as shown in Equation 3 (16) must certainly be in error.

The oxidation of allyl alcohol (I) by ceric nitrate in 1N nitric acid has been studied (17). Results which were consistent with initial alcohol-cerium(IV) complex formation were obtained. The reaction is summarized in Equations 5-7 (17). As the reaction proceeds, the aldehyde II is further oxidized by

$$\underset{\text{I}}{CH_2{=}CH{-}CH_2OH} + Ce(NO_3)_4 \cdot 2H_2O \rightleftarrows \text{1:1 complex} \qquad \underline{5}$$

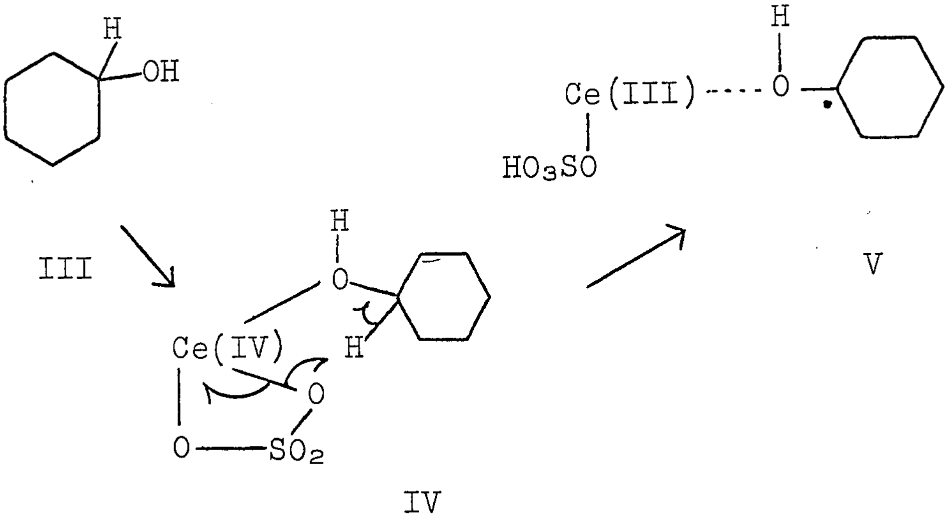
$$\text{1:1 complex} \xrightarrow[\text{slow}]{} CH_2{=}CH{-}\dot{C}H{-}OH + Ce(NO_3)_3 \qquad \underline{6}$$

$$CH_2{=}CH{-}\dot{C}H{-}OH + Ce(IV) \xrightarrow[\text{fast}]{} \underset{\text{II}}{CH_2{=}CH{-}CH{=}O} + Ce(III) \qquad \underline{7}$$

cerium(IV). Sen Gupta and Aditya (18) have studied the oxidation of malonic acid by ceric perchlorate, ceric nitrate, and ceric sulfate. The oxidation proceeds through the formation of an initial cerium(IV) complex with the acid in the case of all three cerium(IV) salts. The products of the reactions are carbon dioxide and formic acid. The rates of oxidation of malonic acid by the perchlorate, nitrate, and sulfate salts were in the order perchlorate > nitrate > sulfate (18).

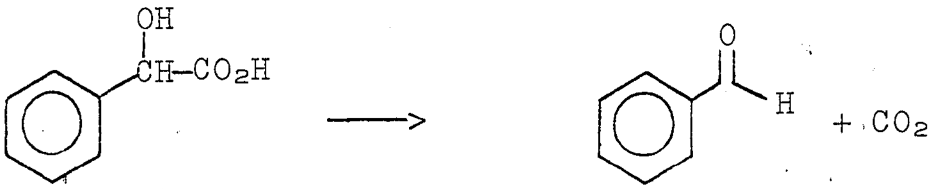
The kinetics of the cerium(IV) oxidation of benzyl and substituted benzyl alcohols in 75% aqueous acetonitrile-1 M nitric acid have been studied (19). It has been concluded that the oxidation proceeds by way of rapid 1:1 alcohol-cerium(IV) complex formation and rate determining unimolecular decomposition of the complex. A substituent effect and a deuterium isotope effect have indicated that an α—C—H bond is being broken in the transition state of the rate determining step and that the amount of charge development on the α-carbon varies with the nature of the substituent. A mechanism involving varying amounts of charge development at the α-carbon and on oxygen in the alcohol is thought to best explain the results (19). The formulation of mechanisms for the cerium(IV) oxidation of alcohols involving discrete radical intermediates, as shown in Equations 3 and 4 for the oxidation of benzyl alcohol (16), and in Equations 5-7 for the oxidation of allyl alcohol (17), is backed by little or no experimental evidence. Discrete radical intermediates may not be involved to any major extent at all in the cerium(IV) oxidation of alcohols. Young's results (19) would suggest that intermediates such as $PhCH_2O\cdot$ (or $Ph\dot{C}H—OH$) are not involved in the oxidation of benzyl alcohol to any significant extent, since the reaction exhibits the characteristics of an ionic reaction (at least in part; e.g., a polar substituent effect). Reaction mechanisms have been proposed which account for the observed polar substituent effect in the oxidation of benzyl alcohols by cerium(IV). The reader is referred to reference 19 for detailed descriptions of the possible mechanisms for the reaction. Mechanisms involving radical intermediates are written throughout the remainder of this section for illustrative purposes only, and not because evidence is available for such mechanisms. The majority of such mechanisms represent at best pure speculation on the part of this author, or on the part of the authors of the work being reviewed.

Complex formation has been detected in cerium(IV) oxidations in sulfuric acid media in only a few instances (18, 20, 21). Reactions in sulfuric acid often follow second-order kinetics (14, 15, 22-24). A direct oxidation mechanism, without complex formation, has been suggested for oxidations in that acid (14). However, Littler and Waters (25) have shown that alcohol-cerium(IV) complex formation is involved in the oxidation of cyclohexanol (III) with ceric sulfate in sulfuric acid medium. In an attempt to resolve the problem of the structure of the organic radical produced by the initial one-electron oxidation of cyclohexanol, the deuterium isotope effect for ceric sulfate oxidation of alpha-deuterocyclohexanol was measured (20). An isotope effect of (k_H/k_D) 1.9 was observed, indicating some breakage of the alpha-carbon-hydrogen bond in the rate determining step. An activated complex, such as IV, was suggested to explain the low value of k_H/k_D (20, 25). The nature of the "activated" complex is unknown. The possibility of attack at the oxygen-hydrogen bond seems unlikely since no isotope effect was observed for the cerium(IV) oxidation of other secondary alcohols in D_2O (25). Data on the oxidation of cyclohexanol in D_2O is necessary before attack at the oxygen-hydrogen bond can be ruled out completely. Further oxidation of V by cerium(IV) gives cyclohexanone (25, yield not reported).

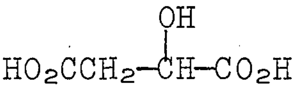


The majority of kinetic studies on the oxidation of alcohols by cerium(IV) have been carried out under conditions where the presence of an excess of the oxidant resulted in the conversion of first-formed products into carbon dioxide, formic acid, or acetic acid; or under conditions where an excess of organic reagent was used which effectively prevented further oxidation of first-formed products. Studies on the oxidation of ketones and aldehydes with cerium(IV) (to be reviewed shortly) have been conducted under similar conditions.

Krishna and Tewari (26) have investigated the kinetics and mechanism of oxidation of mandelic acid (VI), malic acid (VII), and lactic acid (VIII), by ceric sulfate. Mandelic acid (VI) is degraded to benzaldehyde and CO_2, while VII and VIII are completely oxidized to form CO_2 and formic acid. Under more carefully controlled conditions, VI was found to

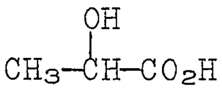


VI



$$HO_2CCH_2-\overset{OH}{\underset{|}{C}}H-CO_2H$$

VII



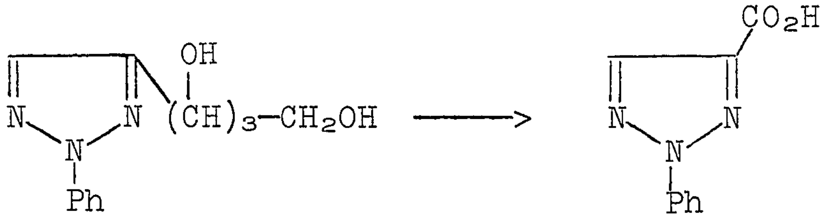
$$CH_3-\overset{OH}{\underset{|}{C}}H-CO_2H$$

VIII

require two equivalents of cerium(IV) per mole of acid, indicating that the oxidation proceeded only to the *alpha*-keto acid (26). *Alpha*-Hydroxybutyric acid has been oxidized by cerium(IV) in aqueous sulfuric acid (27), resulting in complete degradation to form CO_2 and formic acid. The oxidation of *alpha*-hydroxy acids was proposed to proceed through initial complex formation wherein the acid was bound to the cerium(IV) in a cyclic transition state through the *alpha*- and carboxyl OH groups (26, 27).

The use of cerium(IV) as an effective reagent for the cleavage of polyhydric alcohols has been known for some time. Pinacol (IX) is quantitatively cleaved by ceric sulfate to produce acetone (22). Glucose phenylosotriazole (X) is quantitatively oxidized to 2-phenyl-1,2,3-triazole-4-carboxylic acid (XI) (28). In general, hydroxyl groups at primary

IX



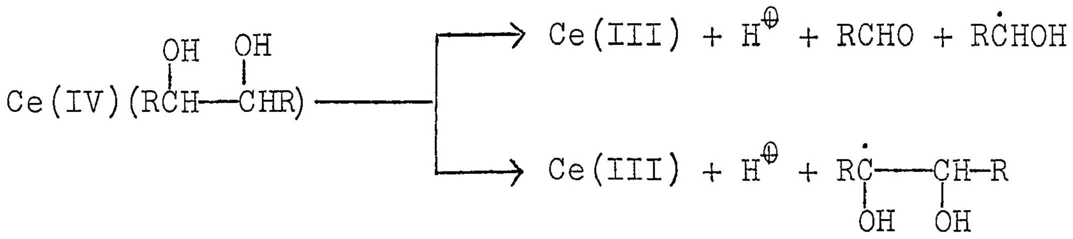
X XI

and secondary positions give acids, while hydroxyl groups at tertiary positions give ketones.

The complex formed in the cerium(IV) oxidation of a 1,2-glycol may be either a chelate complex or an acyclic complex in which only one hydroxyl is coordinated with cerium(IV). Littler and Waters (25) have concluded from studies of the relative rates of oxidation of certain glycols and the corresponding monomethyl ethers by ceric sulfate that cerium(IV) oxidation of 1,2-glycols proceeds by way of an acyclic mechanism. By contrast, Duke and Forist (11) assumed that both hydroxyls of 2,3-butanediol coordinated with cerium(IV). Complex formation appears to be dependent on the anion associated with the cerium(IV) and on the type of glycol. Evidence has been obtained that complex formation is _not_ involved in the ceric sulfate oxidation of 2,3-butanediol or pinacol (25). Oxidation of glycerol by ceric sulfate does not proceed through complex formation (15).

Oxidation of 2,3-butanediol with ceric nitrate has been found to proceed through complex formation (11). Kinetic evidence is available which indicates that both 2,3-butanediol (12) and glycerol (15) are oxidized by ceric perchlorate through complex formation. Doubt exists as to whether the complexes involved are acyclic or chelate in nature.

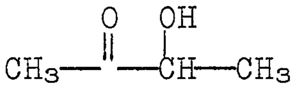
Two possible reaction pathways exist once a glycol-cerium(IV) complex has formed (Equations _8_ and _9_). One pathway depends on carbon-carbon bond rupture (Equation _8_), while the other depends on carbon-hydrogen bond rupture (Equation _9_).



$$\mathrm{Ce(IV)(R\underset{}{\overset{OH}{C}}H\text{—}\overset{OH}{C}HR)} \longrightarrow \mathrm{Ce(III)} + \mathrm{H}^{\oplus} + \mathrm{RCHO} + \mathrm{R\dot{C}HOH} \qquad \underline{8}$$

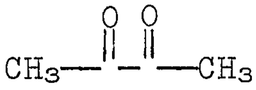
$$\mathrm{Ce(IV)(R\overset{OH}{C}H\text{—}\overset{OH}{C}HR)} \longrightarrow \mathrm{Ce(III)} + \mathrm{H}^{\oplus} + \mathrm{R\underset{OH}{\dot{C}}\text{—}\underset{OH}{C}H\text{—}R} \qquad \underline{9}$$

Oxidation of 2,3-dideutero-2,3-butanediol with ceric sulfate has been conducted (25). An isotope effect of (k_H/k_D) 1.18 ± 0.12 at 50°C was observed. Although the effect is small, a primary isotope effect, and hence Equation 9, cannot be eliminated. Product studies (25) have confirmed Equation 8 as the pathway for cerium(IV) oxidation of glycols. Oxidation of 2,3-butanediol by the pathway shown in Equation 9 would result in the formation of acetoin (XII). Oxidation of acetoin with cerium(IV) gives biacetyl (XIII). Neither XII nor XIII was



$CH_3-\overset{O}{\overset{\|}{C}}-\overset{OH}{\overset{|}{C}H}-CH_3$

XII



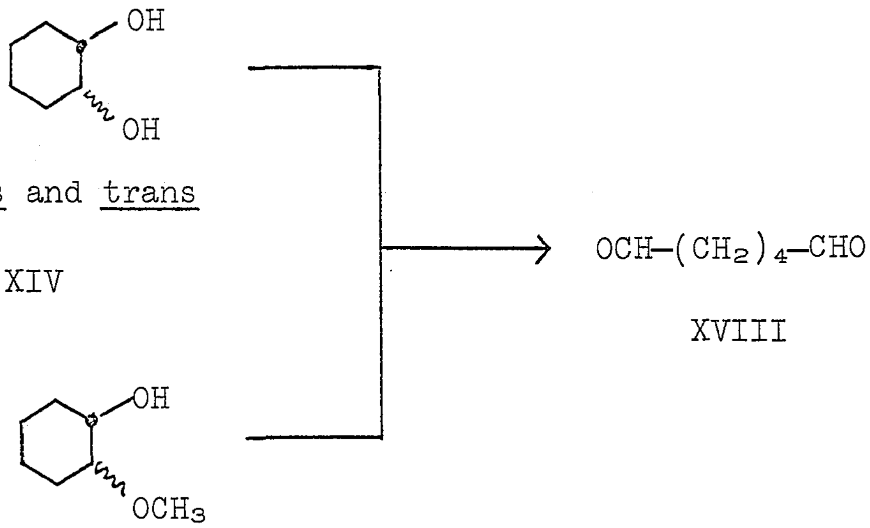
$CH_3-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CH_3$

XIII

detected in the product mixture from 2,3-butanediol. Essentially pure acetaldehyde was the product (25), as predicted by Equation 8.

Hintz and Johnson (29) have obtained definite evidence for the formation of cerium(IV) complexes with cis- and trans-1,2-cyclohexanediols (XIV), cis- and trans-2-methoxycyclohexanols (XV), cyclohexanol, and cyclopentanol in perchloric acid and mixed perchloric-sulfuric acids. Definitive evidence for the formation of cerium(IV) complexes with cis- and trans-1,2-cyclopentanediols (XVI) and cis- and trans-2-methoxycyclopentanols (XVII) was not obtained due to the rapidity of the reaction.

The 1,2-cyclopentanediols were oxidized 200-1000 times faster than the corresponding cyclohexanediols at 30°C. Oxidation of XIV and XV proceeded by C—C bond cleavage to give adipaldehyde (XVIII). Oxidation of XVI and XVII gave glutaraldehyde (XIX). Oxidation of _trans_-XV gave some formaldehyde, also. In the oxidations of XIV and XV, small amounts of an unknown material were obtained, which apparently arose from further oxidation of the dialdehyde XVIII.



cis and trans

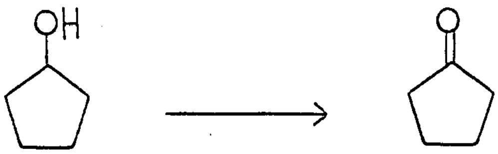
XIV

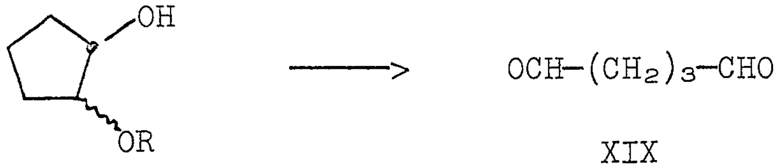
$OCH{-}(CH_2)_4{-}CHO$

XVIII

cis and trans

XV





$OCH-(CH_2)_3-CHO$

XIX

cis and trans

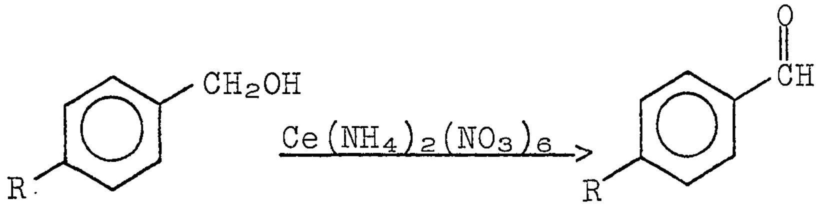
XVI R = H
XVII R = CH_3

Cyclopentanol and cyclohexanol were oxidized to the respective ketones (50-60% yield). Only very approximate yield data is available. The reactions were conducted using at least a 10:1 molar ratio of organic substrate to cerium(IV).

The complexes of XIV with cerium(IV) were determined to be chelate complexes (both O—H groups bound to cerium(IV)) (29). Monomethyl ether XV was oxidized at about the same rate as the diol XIV. An acyclic complex was detected for XV with cerium(IV). It becomes obvious from these facts that the nature of the complexes formed in cerium(IV)-glycol oxidations cannot be determined from measurements of relative rates of oxidation. A reinvestigation of cerium(IV) oxidation of some acyclic glycols and the intermediate complexes involved seems necessitated in view of the data (29).

Young and Trahanovsky (30, 31) have found that benzyl alcohols (XX) are oxidized by ceric ammonium nitrate in aqueous acetic acid to benzaldehydes (XXI) in greater than 90% yields.

Cyclopropylmethanol (XXII) has been oxidized by ceric ammonium nitrate in aqueous solution to cyclopropanecarboxaldehyde (XXIII) in 64% yield (32). Of the known methods of preparation of XXIII, the method of controlled oxidation of XXII by cerium(IV) appears to be the most convenient.



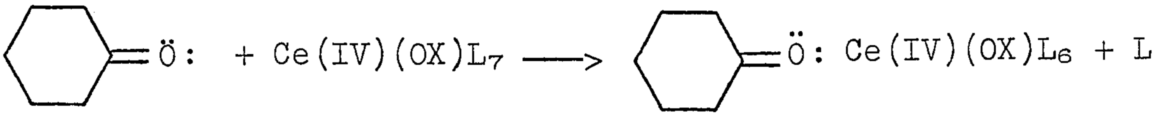
XX R = H, OCH_3, Br, NO_2 XXI

XXII XXIII

Oxidation of aldehydes and ketones

Considerable effort has been devoted to elucidation of the mechanism of cerium(IV) oxidation of aliphatic ketones (13, 33-36). The oxidation rate has been found to be dependent on the concentrations of both ketone and cerium(IV) in all cases. Littler (36) has obtained evidence that enol formation is not involved in the oxidation of aliphatic ketones. The rate of oxidation of cyclohexanone by ceric sulfate was found to be 61-fold faster than enolization (36). An isotope effect of (k_H/k_D) 6.0 was observed when

2,2,6,6-tetradeuterocyclohexanone was oxidized in water, indicating that alpha-carbon-hydrogen bond breakage was involved in the rate-determining step. Equations 10-12 summarize the mechanism which was proposed to account for the data (36). The ligand O-X may be hydroxyl, sulfate ($—O—SO_3^-$), or bisulfate ($—O—SO_3H$), while the nature of the ligand L is unspecified. The products of the reaction were not specified. The reaction was carried out on a scale so small that product analysis was impractical. By analogy to the oxidation of cyclohexanone by manganese(III) (36, oxidation 40-fold faster than enolization, $k_H/k_D = 4.0$), the products of the oxidation



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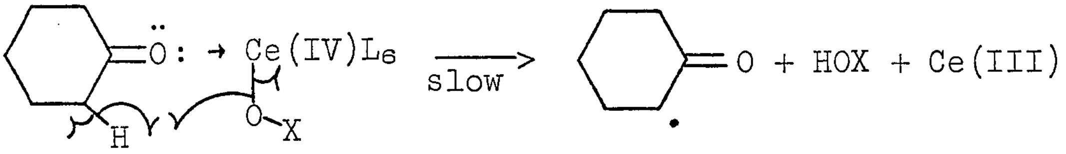

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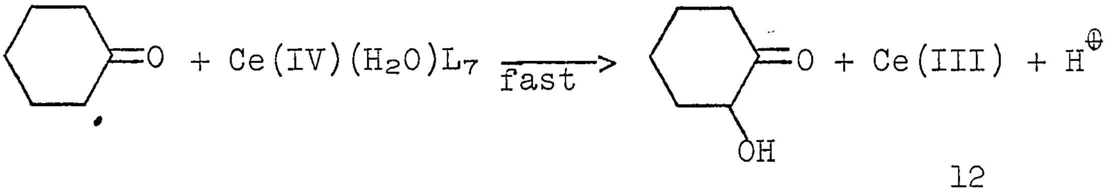
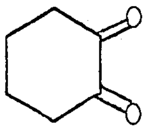


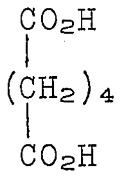
12

of cyclohexanone by cerium(IV) might be the diketone XXIV and adipic acid (XXV). Both XXIV and XXV were isolated from the manganese(III) reaction.

The oxidation of acetone by ceric sulfate in sulfuric acid medium at 70°C resulted in the formation of formic acid and CO_2 (33), and required 8.6 equivalents of ceric sulfate per mole of acetone. At 25°C, one mole of acetone required 6.01 equivalents of ceric nitrate, and acetic acid and formic acid were formed (35). At 70°C, methyl n-amyl ketone was degraded by ceric sulfate to form acetic acid, formic acid, and some CO_2 (34). Generally, ceric sulfate degrades aliphatic ketones to acetic acid, formic acid, and CO_2.



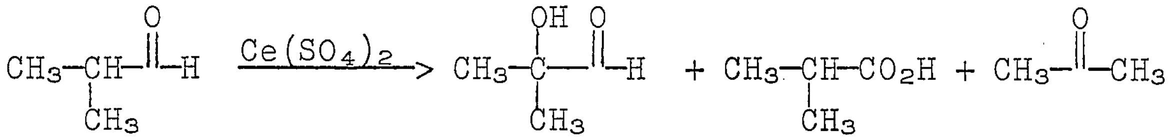
XXIV



$$\mathrm{CO_2H}-(\mathrm{CH_2})_4-\mathrm{CO_2H}$$

XXV

As is the case with aliphatic ketones, aliphatic aldehydes are degraded by ceric sulfate to form acetic acid, formic acid, and CO_2. Acetaldehyde was found to require 5.75 equivalents of ceric sulfate and was oxidized to formic and acetic acids (34). More closely controlled oxidation of isobutyraldehyde (XXVI) by ceric sulfate resulted in the isolation of <u>alpha</u>-hydroxyisobutraldehyde (XXVII, 14% yield), isobutyric acid (XXVIII, 22% yield), and acetone (37). For acetaldehyde, the rate of oxidation by ceric sulfate was found to be about 14 times faster than enolization (34), further indicating that aldehydes are oxidized by the *alpha*-oxidation mechanism previously described for ketones (Equations *10*-*12*).

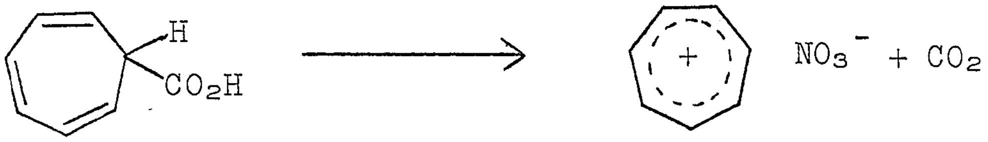


$$CH_3CH(CH_3)CHO \xrightarrow{Ce(SO_4)_2} CH_3C(OH)(CH_3)CHO + CH_3CH(CH_3)CO_2H + CH_3COCH_3$$

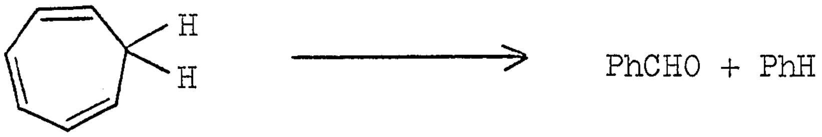
XXVI XXVII XXVIII

Oxidation of hydrocarbons

Although cyclohepta-2,4,6-trienecarboxylic acid (XXIX) is not a hydrocarbon in the strictest sense, its reactions with oxidizing agents are worthy of note at this point. The oxidative decarboxylation of XXIX to give tropylium salts has been observed with various oxidizing agents, including ceric ammonium nitrate (38). With ceric ammonium nitrate, tropylium nitrate (XXX) was reported to be produced in 30% yield. No other products were identified, although with other oxidizing agents, benzaldehyde and benzoic acid were isolated in addition to the tropylium salts. Recently (19), the oxidation of cycloheptatriene (XXXI) by ceric ammonium nitrate was studied, and was found to give only benzaldehyde and benzene. It has also been found that tropylium salts are rapidly oxidized by cerium(IV) (19), leading one to question the claim that tropylium nitrate is a product of the cerium(IV)-induced



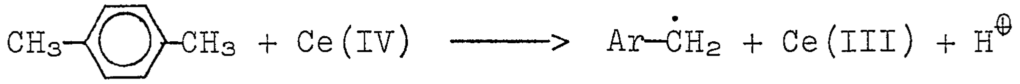
XXIX XXX



XXXI

decarboxylation of XXIX. Investigations in this area are being continued.

Ramaswamy, et al. (39), have investigated the ceric sulfate oxidation of p-xylene (XXXII) to p-tolualdehyde (XXXIII). The reaction is first order in both reactants. The yield of XXXIII was about 50%. An interesting feature of the reaction was that it was rendered continuous, or nearly so, by electrolytic regeneration of cerium(IV) at a lead oxide anode operating at 70% efficiency. The mechanism which was proposed (Equations 13-17) required four equivalents of cerium(IV) for the oxidation of one mole of XXXII to XXXIII. Although it is not known whether Ce(IV)(OH) or Ce(IV)(H_2O) is the oxidant in Equations 14 and 16, it seems likely that it



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XXXII

$$Ar{-}\dot{C}H_2 + Ce(IV)(H_2O) \longrightarrow Ar{-}CH_2{-}OH + Ce(III) + H^{\oplus} \qquad \underline{14}$$

$$Ar{-}CH_2{-}OH + Ce(IV) \longrightarrow Ar{-}\dot{C}H{-}OH + Ce(III) + H^{\oplus} \qquad \underline{15}$$

$$Ar{-}\dot{C}H{-}OH + Ce(IV)(H_2O) \longrightarrow Ar{-}CH(OH)_2 + Ce(III) + H^{\oplus} \qquad \underline{16}$$

17

XXXIII

would be the latter, since the reaction was conducted in strongly acidic medium.

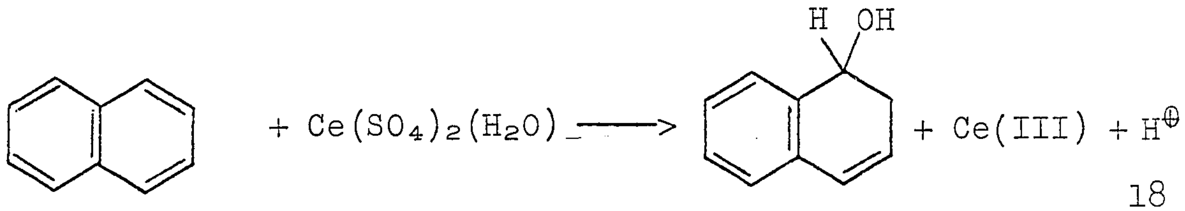
The kinetics of the oxidation of toluenes with cerium(IV) in 50% aqueous acetic acid containing some perchloric acid have been investigated (40). The reaction was second order overall and was acid catalyzed. The rate determining step was assumed to be one-electron transfer to give a benzyl radical (Equation 13), which then underwent rapid decomposition to the aldehyde *via* the alcohol (Equations 14-17). Substituent effects were observed: Nitro (*meta* and *para*) was found to retard the reaction, as did *ortho* and *meta*-chloro; *para*-chloro increased the rate of oxidation.

Syper (41) has conducted an extensive study on the utility of the oxidation of aliphatic sidechains to the corresponding carbonyl compounds using ceric ammonium nitrate.

Table 1 (41) summarizes a portion of the results which were obtained in this work. In all cases, the reactions were conducted in aqueous acid medium. A 4 to 1 molar ratio of cerium(IV) to hydrocarbon was used in all reactions. Temperatures ranging from 10° to 100°C, and reactions times of 1 to 9 hours, were employed. The method is undoubtedly of value for the syntheses of aromatic aldehydes which are difficult to prepare by other means.

Miscellaneous oxidations

Although ceric sulfate oxidation of naphthalene in aqueous acetic-sulfuric acid medium has been reported (42), the stoichiometry and products are not known. The oxidation has been viewed as being initiated by hydroxylation of naphthalene (XXXIV) to form alpha-naphthol (6, Equations 18 and 19). Oxidation at a carbon-hydrogen bond to give an aryl radical has been discounted (6).



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XXXIV

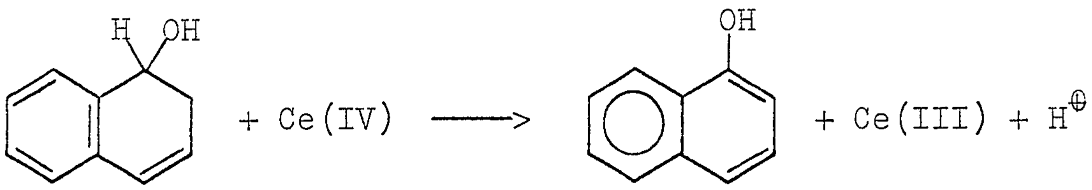

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Table 1. Oxidation of aliphatic sidechains with ceric ammonium nitrate

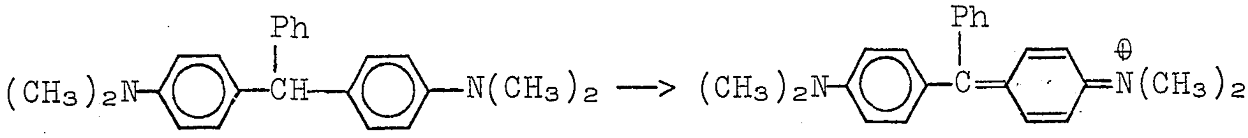
Compd.	Subst.[a]	Acid[b]	Prod.	Yield (%)[c]
Toluene	None	Perchloric	Benzaldehyde	92
	p-Methyl	Acetic	---, p-Methyl	Quant.
	2,4-Dimethyl	Acetic	---, 2,4-Dimethyl	Quant.
	o-Chloro	Perchloric	---, o-Chloro	74
	o-Nitro	Perchloric	---, o-Nitro	43
	p-Nitro	Perchloric	---, p-Nitro	47
	p-N-acetyl-amino	Acetic	---, p-N-acetyl-amino	94
	o-Methoxy-	Acetic	---, o-Methoxy-	63
	p-Methoxy-	Acetic	---, p-Methoxy-	Quant.
	p-Phenyl-sulfonyl-	Nitric	---, p-Phenyl-sulfonyl-	Quant.
	α-Methyl-	Nitric	Acetophenone	77
	α-Phenyl-	Nitric	Benzophenone	76
Indane	None	Nitric	1-Indanone	78
Tetralin	None	Nitric	1-Tetralone	76

[a] Substituent on the basic nucleus given in column 1.

[b] Aqueous acid solution.

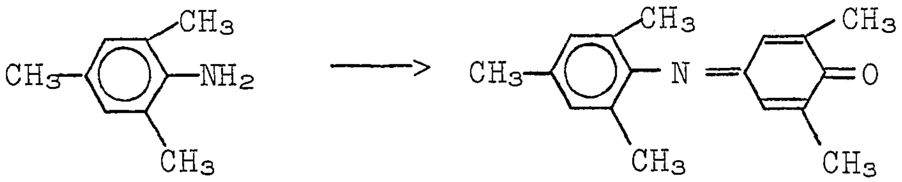
[c] Yields are based on the 2,4-dinitrophenylhydrazones.

Studies on the oxidation of nitrogen-containing compounds with cerium(IV) have been limited to aromatic amines, with the exception of some electron spin resonance studies on the cerium(IV) oxidation of oximes (which are reviewed in a separate section). Cerium(IV) oxidation of leuco malachite green (XXXV) has been found to give malachite green (XXXVI) (43, 44). Mesidine (XXXVII) yields the quinone-imine (XXXVIII) (70% yield) when reacted with cerium(IV) (45).



XXXV

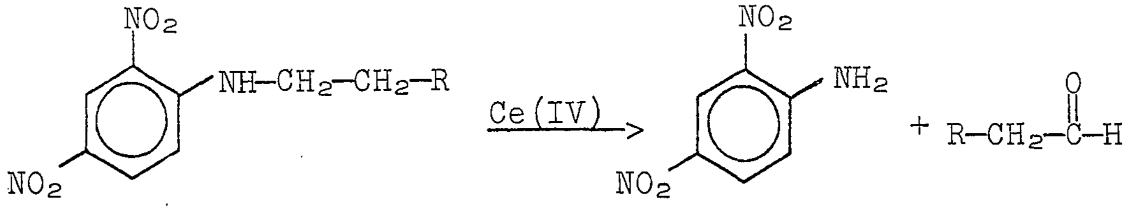
XXXVI



XXXVII

XXXVIII

The oxidation of some N-substituted-2,4-dinitrophenylamines (XXXIX) with ceric ammonium sulfate in aqueous acetic acid has recently been reported (46). The reaction product (isolated) was 2,4-dinitrophenylamine (XL). Aldehydes of the general structure $O{=}CH{-}CH_2{-}R$ were presumed to be formed from the remaining portion of XXXIX, but the aldehydes were not isolated and identified. Three equivalents of cerium(IV) per mole of XXXIX were used in the reactions. The yields of XL for several compounds in the series were as follows (R group, % yield): SO_3K, 95%; CH_2-SO_3K, 88%; $N(CH_3)_2$, 75%; and $-\overset{\oplus}{N}(CH_3)_2-(CH_2)_3-SO_3K$, 70% (46).



XXXIX

XL

Mechanistically, the reaction was viewed as an initial one-electron transfer to give XLI (Equation 20, R′ = 2,4-dinitrophenyl), followed by a second oxidation to give an enamine of the structure XLII. Acid hydrolysis of XLII would then give XL and aldehyde. An equally acceptable second oxidation step would be the hydroxylation of XLI by cerium(IV)

$$R'{-}NH{-}CH_2CH_2R \xrightarrow{Ce(IV)} R'{-}NH{-}\dot{C}H{-}CH_2{-}R + Ce(III) + H^{\oplus} \qquad \underline{20}$$

XXXIX XLI

$$R'{-}NH{-}\dot{C}H{-}CH_2{-}R \xrightarrow{Ce(IV)} R'{-}NH{-}CH{=}CH{-}R + Ce(III) + H^{\oplus} \qquad \underline{21}$$

XLII

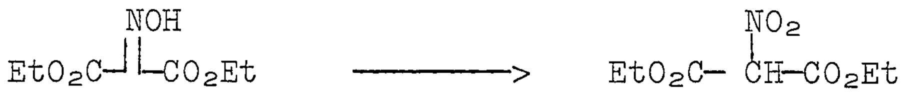
$$R'{-}NH{-}\dot{C}H{-}CH_2{-}R \xrightarrow{Ce(IV)(H_2O)} R'{-}NH{-}\overset{\overset{OH}{|}}{C}H{-}CH_2{-}R + Ce(III) + H^{\oplus} \qquad \underline{22}$$

XLIII

to give an iminoacetal XLIII (Equation 22), which would then decompose to XL and aldehyde. Either mechanism requires only two equivalents of cerium(IV). A rapid primary oxidation to give a precipitate of XL was observed which required two equivalents of cerium(IV). Continued consumption of cerium(IV) was probably due to a slower oxidation of the aldehydes formed.

Oxidation of oximes

The oxidation of oximes to mononitro compounds has been effected through the use of manganese dioxide (47) and trifluoroperacetic acid (48). With manganese dioxide, XLIV yielded 88% of the mononitro compound XLV, while the yield of XLVII (from XLVI) was somewhat lower (30%) (47). With trifluoroperacetic acid, XLV was obtained in 66% yield (48). The method utilizing the peroxy acid seems to be the most generally



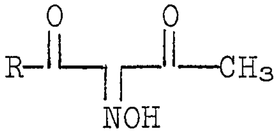
$$EtO_2C-C(=NOH)-CO_2Et \longrightarrow EtO_2C-CH(NO_2)-CO_2Et$$

XLIV XLV

$$Me-C(=O)-C(=NOH)-CO_2Et \longrightarrow NO_2-CH_2-C(=O)-OEt$$

XLVI XLVII

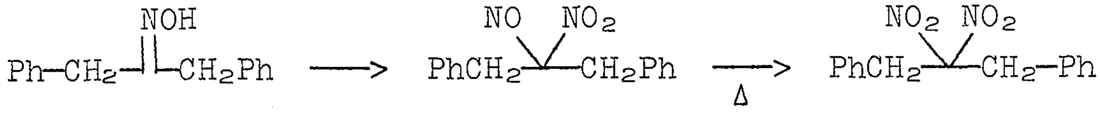
useful of the two reactions. A wide variety of mononitro alkanes were prepared by this technique in 40-75% yields (48). With both reagents, alpha-keto oximes of the general structure XLVIII suffered partial degradation, resulting in a loss of the acetyl group, as is illustrated by the conversion of XLVI to XLVII (47, 48).

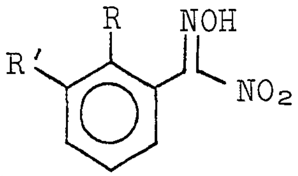


$$R-\overset{O}{\overset{\|}{C}}-\underset{NOH}{\underset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CH_3$$

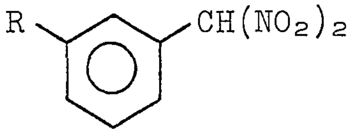
XLVIII $R \neq CH_3$

The nitration of some ketoximes and aldoximes by nitric acid has been reported to form geminal-dinitro compounds and nitrolic acids (49). Dibenzyl ketoxime (XLIX) reacted with nitric acid or alkyl nitrites to form L, which on heating in ethanol was converted to the dinitro compound LI. Benzil monoxime was converted to benzaldehyde and phenylnitrolic acid (LIIa) by nitric acid. Benzaldoxime yielded a mixture of benzaldehyde and α,α-dinitrotoluene (LIIIa), while only the dinitrotoluene LIIIb was reported to be formed from m-methylbenzaldehyde. Nitrolic acids LIIb and LIIc were the only reported products of the nitric acid oxidation of o- and m-nitrobenzaldoximes. On heating, both LIIb and c decomposed to form the respective benzoic acids. Only p-nitrobenzoic acid was obtained from the oxidation of p-nitrobenzaldoxime by nitric acid.


XLIX L LI



LIIa $R = R' = H$
b $R = NO_2, R' = H$
c $R = H, R' = NO_2$

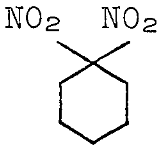


LIIIa $R = H$
b $R = CH_3$

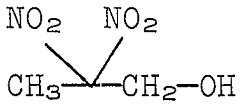
The preparation of geminal-dinitro compounds has been accomplished by a variety of methods, most of which are severely limited in scope. As early as 1876, Ter Meer (50) reported the preparation of 1,1-dinitroethane (LIV) by treatment of the potassium salt of nitroethane with inorganic nitrites in the presence of silver ion. Yields were low, and although other mononitroalkanes were found to give small amounts of gem-dinitro compounds in the reaction, it received little further attention until recent years. Shechter and Kaplan (51, 52) have found that the conversion of salts of primary and secondary nitro compounds to geminal-dinitro compounds by inorganic nitrites in the presence of silver or mercuric ions (neutral or alkaline aqueous solution) is indeed a general process. In addition to LIV, compounds such as LV, LVI, LVII, and LVIII have been prepared in yields of 60-95% (51). However, the method appears to be limited mainly to aliphatic compounds. The yields of _geminal_-dinitro compound are drastically reduced when an aryl group is substituted on the carbon atom bearing the nitro group in the starting material. Yields of the carbonyl compound and oxidative dimers increase: phenylnitromethane (LIX) is converted to α,α-dinitrotoluene (LIIIa) in 19% yield, in addition to benzaldehyde (36% yield) and 1,2-dinitro-1,2-diphenylethane (LX) (37% yield); and 9-nitrofluorene (LXI) is converted to 9,9-dinitrofluorene (LXII) (8%), 9-fluorenone (LXIII) (8%), and 9,9′-dinitro-9,9′-bifluorene (LXIV) (76%) (51).

$CH_3CH(NO_2)_2$

LIV



LV

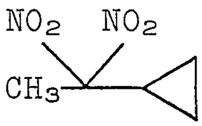


$CH_3C(NO_2)_2CH_2{-}OH$

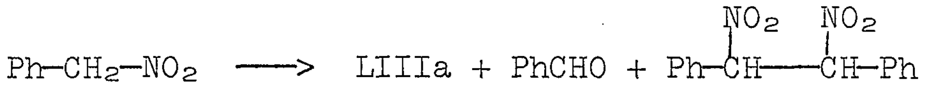
LVI

$(NO_2)_2CH{-}CH_2{-}CO_2CH_3$

LVII

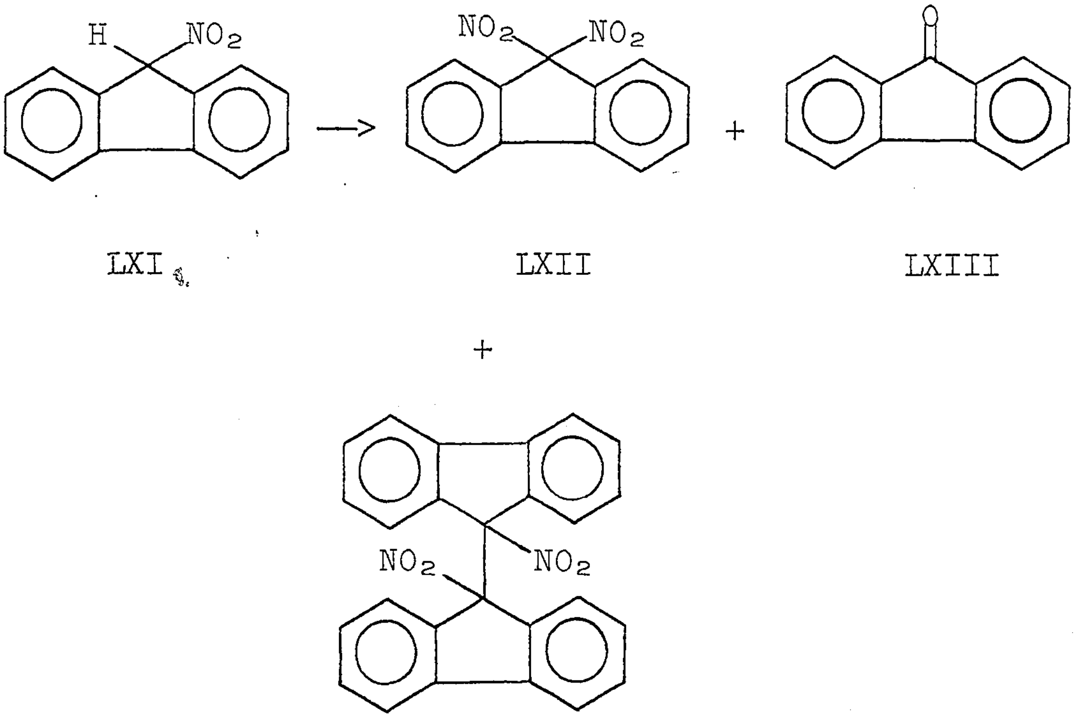


LVIII



$$\mathrm{Ph{-}CH_2{-}NO_2 \longrightarrow LIIIa + PhCHO + Ph{-}\overset{NO_2}{\overset{|}{C}}H{-}\overset{NO_2}{\overset{|}{C}}H{-}Ph}$$

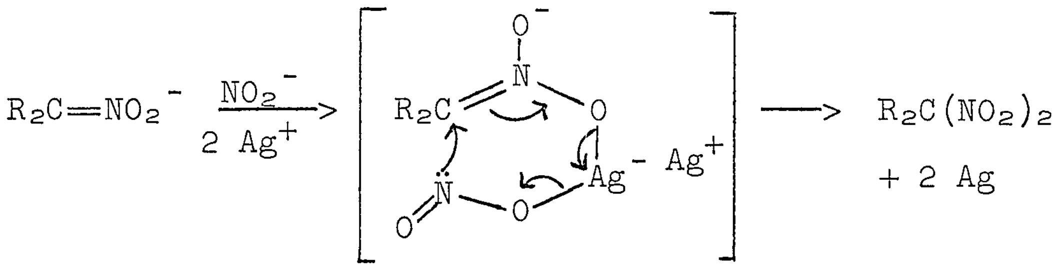
LIX LX



LXI LXII LXIII

LXIV

The proposed mechanism of the oxidative nitration of mononitro compounds to form <u>geminal</u>-dinitro derivatives is of interest. The reaction is viewed as proceeding through an intermediate complex salt such as LXV, which decomposes to the observed product and the reduced metal (Equation <u>23</u>).



23

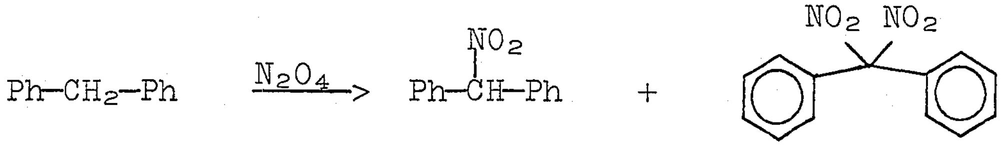
The reaction is effectively a ligand-transfer oxidation, and in that sense it strongly resembles the ceric ammonium nitrate oxidation reaction which has been observed with oximes.

Ponzio (53) found that benzaldoxime could be converted to α,α-dinitrotoluene (LIIIa) by the action of excess nitrogen dioxide (as dinitrogen tetroxide) in ether solution. The yield of LIIIa was low. Further investigations of the reaction, now known as the Ponzio reaction, were conducted by Fieser and Doering (54). In addition to LIIIa (in 38% yield), benzaldehyde and a material formulated as "benzaldoxime hydroperoxide" (LXVI) were isolated. Nitric oxide was also identified as a

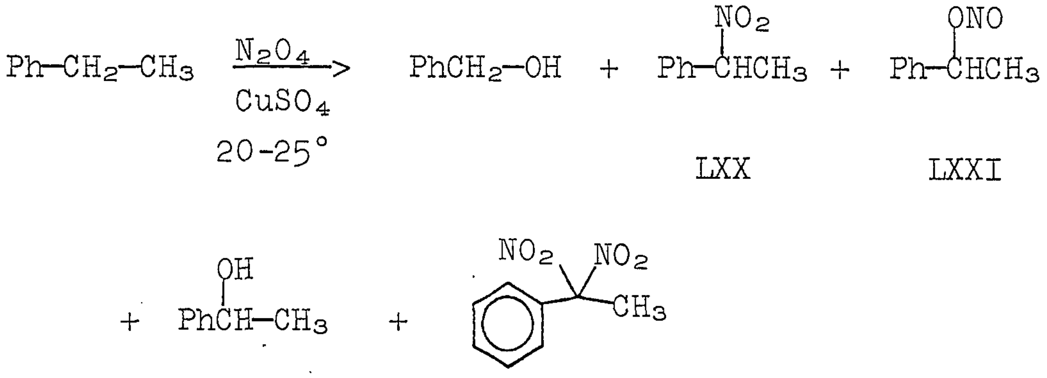
$$\mathrm{PhCH{=}NOH} \xrightarrow{N_2O_4} \mathrm{LIIIa} + \mathrm{PhCHO} + \underset{\mathrm{LXVI}}{\mathrm{PhCH{=}N{-}O{-}O{-}N{=}CHPh}}$$

reaction product. A series of substituted benzaldoximes were subjected to the reaction, but the yields of the corresponding gem-dinitro compounds were either very low or non-existent (54).

The nitration of hydrocarbons with nitric acid and nitrogen (or dinitrogen tetroxide) has resulted in the formation of gem-dinitro compounds in some instances. Diphenylmethane (LXVII) has been found to react with dinitrogen tetroxide in carbon tetrachloride at 20-70° to produce nitrodiphenylmethane (LXVIII) and dinitrodiphenylmethane (LXIX, m.p. 79°) (55). The yields of LXVIII and LXIX were 22% and 28%, respectively, at 20°. The mononitro compound LXVIII was the major product at 70°. Ethylbenzene reacted with dinitrogen tetroxide in the presence of copper sulfate to give benzyl alcohol, α-nitroethylbenzene (LXX), α-phenylethyl nitrite (LXXI), α-phenylethyl alcohol, and 1,1-dinitro-1-phenylethane (LXXII, ca. 12% yield, m.p. 6°) (56).



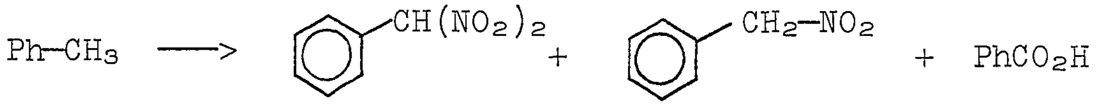
LXVII LXVIII LXIX



LXXII

The procedure used for the separation of the reaction mixture was complicated, and involved several steps where loss of LXXII might have occurred. Variations in the reaction conditions, and in the separation procedure, gave lower yields of LXXII (56).

Nitration of toluene with nitrogen dioxide and nitric acid has been extensively studied. Titov (57) found that both nitrogen dioxide and nitric acid with toluene gave α-nitrotoluene (LIX), α,α-dinitrotoluene (LIIIa), and benzoic acid in yields of 49-52%, 3-4%, and 24-27%, respectively. These results led to several investigations of the mechanism of nitration by nitric acid.



LIIIa LIX

It has become well established that nitrogen dioxide ($\cdot NO_2$) is the active species in radical nitration reactions. Materials such as para-formaldehyde were found to facilitate the decomposition of nitric acid to form nitrogen oxides (57). Oxygen was observed to play an important role in nitrations using nitric acid or nitrogen dioxide (58). Products analogous to those obtained in the nitration of toluene were obtained in the nitration of m-xylene (58). In the absence of oxygen, the yields of gem-dinitro compound, mononitro compound, and the benzoic acid were 33%, 6%, and 20%, respectively. In the presence of oxygen, the yields were (in the same order) 7%, 54%, and 7%, respectively (58).

In the absence of nitrogen oxides, nitric acid did not attack hydrocarbons such as toluene and m-xylene (59). Under conditions which facilitated the decomposition of nitric acid, nitration commenced immediately. Titov proposed the following mechanism to account for the data (59) (Equations 24-27).

$$RH + \cdot NO_2 \longrightarrow R\cdot + HNO_2 \qquad \underline{24}$$

$$HNO_2 + HNO_3 \rightleftarrows 2\ \cdot NO_2 + H_2O \qquad \underline{25}$$

$$2\ HNO_3 + \cdot NO \rightleftarrows 3\ \cdot NO_2 + H_2O \qquad \underline{26}$$

$$R\cdot + \cdot NO_2 \longrightarrow R\text{—}NO_2 + R\text{—}ONO \qquad \underline{27}$$

The difficulty with the mechanism is that the origins of $\cdot NO_2$ (Equation 24) and $\cdot NO$ (in Equation 26) are not specified. Presumably, the nitrogen oxides arise by reaction of nitric acid with materials such as para-formaldehyde. Oxygen was thought to act as a scavenger for nitric oxide by reaction to form nitrogen dioxide (Equation 28) (59), which facilitated nitration due to the increased concentration of $\cdot NO_2$.

$$2\ \cdot NO + O_2 \rightleftarrows 2\ \cdot NO_2 \qquad \underline{28}$$

Conversion of α-nitrotoluene (LIX) to α,α-dinitrotoluene (LIIIa) by nitrogen dioxide was not observed. To account for the formation of LIIIa in the nitration of toluene, Titov (59) proposed the following reaction sequence (Equations 29 and 30).

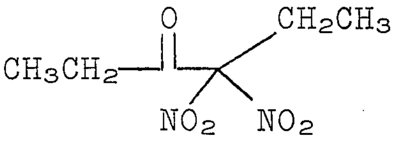
$$PhCH_3 + \cdot NO_2 \longrightarrow PhCH_2\cdot \xrightarrow{\cdot NO} PhCH_2NO \qquad \underline{29}$$

$$PhCH_2NO \rightleftarrows PhCH{=}NOH \xrightarrow{\cdot NO_2} PhCH(NO_2)_2 \qquad \underline{30}$$

LIIIa

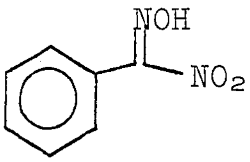
The last step in the sequence represents the Ponzio reaction, which has been reviewed. Evidence for the involvement of NO in producing LIIIa comes from the following facts: (1) the nitration reaction is retarded by added NO; and (2) the yield of LIIIa increases while the yield of LIX decreases in the presence of NO (59).

Isolated reports of the formation of gem-dinitro compounds in the addition of dinitrogen tetroxide to unsaturated compounds have been made. One reaction was the addition of N_2O_4 to diethylacetylene at 0-10° in ether solution (60). Cis and trans-3,4-dinitro-3-hexene (35.5%), propionic acid (60%), 3,4-hexanedione (16%), and 4,4-dinitrohexan-3-one (LXXIII) (8%) were the reaction products.

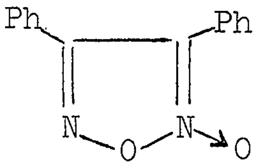


LXXIII

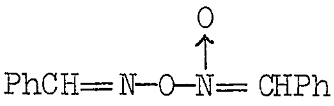
The oxidation of benzaldoxime by dinitrogen tetroxide has been found to give a number of products (61). The geminal-



LIIa



LXXIV



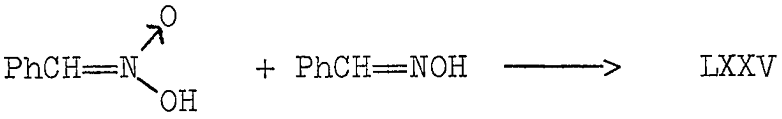
$$PhCH{=}N{-}O{-}\overset{O}{\overset{\uparrow}{N}}{=}CHPh$$

LXXV

Table 2. Oxidation of benzaldoxime with dinitrogen tetroxide

Temp.	Reaction time	Yields (%)		
		LIIa	LXXIV	LXXV
36°	6 min.	50	10	0
0°	1 hr.	22	18	42
0°	72 hrs.	18	42	8
-60°	72 hrs.	8	20	45

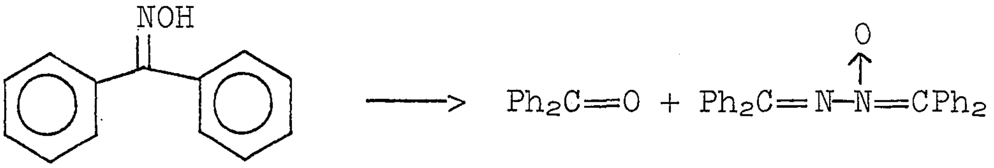
dinitro compound LIIIa was not formed in the reaction. The products were phenylnitrolic acid (LIIa), diphenylfuroxan (LXXIV), benzaldehyde (traces), and benzaldoxime anhydride N-oxide (LXXV). The reaction was conducted at temperatures between -60° and 36° using a molar ratio of oxime to N_2O_4 of 2:1, in contrast to previous reports where excess N_2O_4 was employed (53, 54). Temperature and reaction time were found to have considerable effect on product ratios. Some temperatures, reaction times, and the yields of the products obtained are shown in Table 2 (61). Nitrolic acid LIIa slowly converted to LXXIV (57% yield) and benzoic acid (10% yield) on standing at 0° for 72 hours, indicating that LXXIV was probably a secondary reaction product. Anhydride N-oxide LXXV was postulated to arise from a dehydration reaction between phenyl-aci-nitromethane (LXXVI) (not isolated) and the oxime. Furoxans and anhydride-N-oxides were not detected in the reactions of alkyl aldoximes with N_2O_4. Nitrolic acids, <u>aci</u>-nitroalkanes, and aldehydes were formed (61).



$$\mathrm{PhCH{=}N}\begin{smallmatrix}\nearrow O\\ \searrow OH\end{smallmatrix} + \mathrm{PhCH{=}NOH} \longrightarrow \mathrm{LXXV}$$

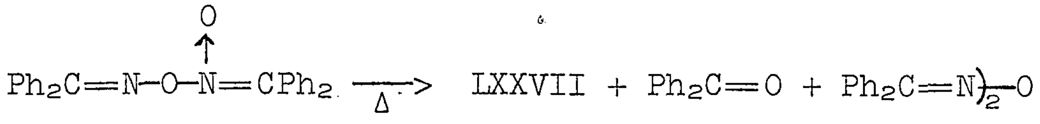
LXXVI

Auwers and Wunderling (62, 63) found that the oxidation of benzophenone oxime (LXXVII) with potassium ferricyanide gave benzophenone, benzophenone azine monoxide (LXXVIII), and other materials which were not characterized. Hunter and Dyer (64) showed that the conversion of LXXVII to benzophenone and LXXVIII occurred with either potassium ferricyanide or silver oxide. A third product was isolated which was erroneously formulated as $(C_{13}H_{10}NO)_4$. A detailed study of the potassium



LXXVII LXXVIII

ferricyanide oxidation of LXXVII in aqueous ethanol containing potassium hydroxide was conducted by Lauer and Dyer (65). The third product of the reaction was shown to be anhydride N-oxide LXXIX, which was thermally unstable and decomposed on heating in solution to form oxime LXXVII, benzophenone, and trace amounts of the diimine oxide LXXX. Product ratios in the oxidation in basic solution were found to be temperature dependent (65). At 35°, the yields of azine monoxide LXXVIII, benzophenone, and LXXIX were 34%, 34%, and 5%, respectively. At -3° to -8°, the yield of LXXIX was 15-20%; no yield for benzophenone was given, but it was the major reaction product. Azine monoxide LXXVIII was not formed at the lower temperatures (65). Thermal



$$Ph_2C{=}N{-}O{-}\overset{\overset{O}{\uparrow}}{N}{=}CPh_2 \xrightarrow[\Delta]{} LXXVII + Ph_2C{=}O + Ph_2C{=}N)_2{-}O$$

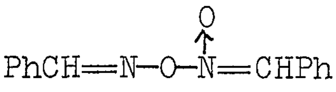
LXXIX LXXX

decomposition of LXXVIII resulted in the formation of benzophenone azine, benzophenone, and nitrogen (65).

The potassium ferricyanide oxidation of benzaldoxime has been reported to give "benzaldoxime hydroperoxide" (LXVI) (66). "Hydroperoxide" LXVI was also reported as the product from the oxidation of benzaldoxime with nitric oxide in ether solution (67). As has already been mentioned, a similar compound (formulated as benzaldoxime anhydride N-oxide, LXXV) was later isolated from the oxidation of benzaldoxime with N_2O_4 (61). Recently (68), the potassium ferricyanide and nitric oxide reactions with benzaldoxime were reinvestigated. The product of the reactions was found to be benzaldazine-bis-oxide (LXXXI), rather than LXVI or LXXV. Since the reported properties of LXXV (61) were the same as those found for LXXXI, it is likely that LXXV is the azine-bis-oxide LXXXI. Azine-bis-oxide LXXXI has been

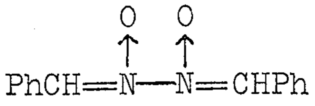
$PhCH{=}N{-}O{-}O{-}N{=}CHPh$

LXVI



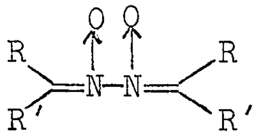
$$PhCH{=}N{-}O{-}\overset{\overset{O}{\uparrow}}{N}{=}CHPh$$

LXXV



$PhCH{=}\overset{O}{\overset{\uparrow}{N}}{-}\overset{O}{\overset{\uparrow}{N}}{=}CHPh$

LXXXI



R and R′ =
alkyl or aryl

LXXXII

isolated in high yield from the oxidation of benzaldoxime with ceric ammonium nitrate (69). Substituted benzaldoximes undergo oxidation by ceric ammonium nitrate to give analogous products (69). Ketazine-bis-oxides (LXXXII, R and R′ = alkyl or aryl) are an unknown class of compounds. The structure LXXIX proposed by Lauer and Dyer (65) for the third product of the potassium ferricyanide oxidation of benzophenone oxime is thus probably correct.

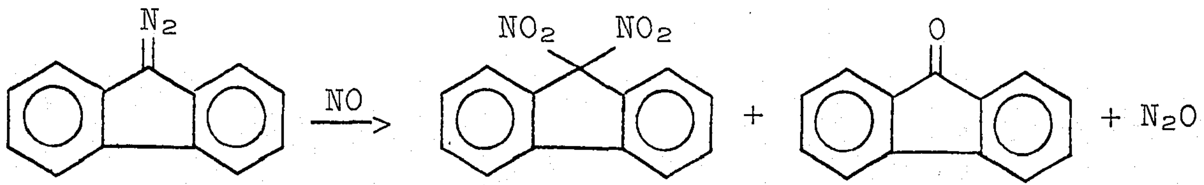
The formation of azine-bis-oxides such as LXXXI by the reaction of nitric oxide (·NO) with phenyldiazomethanes (LXXXIII) has been reported by Horner, et al. (70). Nitrimines (LXXXIV), carbonyl compounds, and dinitrogen oxide (N_2O) are also formed in the reaction. Diaryldiazomethanes give only nitrimines and carbonyl compounds when treated with nitric oxide. Diazodiphenylmethane (LXXXV) reacts with nitric oxide to give nitrimine LXXXVI and benzophenone (70, 71). 9-Diazofluorene (LXXXVII) was reported to yield 9-nitriminofluorene and 9-fluorenone (LXIII) on treatment with nitric oxide (70). However, Heckert (68) has recently shown that 9,9-dinitrofluorene (LXII) is the product, rather than the nitrimine. Dialkyl and arylalkyldiazomethanes yield the corresponding ketazines and nitrogen when treated with nitric oxide (70).

$$PhCH{=}N_2 \xrightarrow{NO_2} LXXXI + PhCH{=}N{-}NO_2 + PhCH{=}O + N_2O$$

LXXXIII LXXXIV

$$Ph_2C{=}N_2 \xrightarrow{NO} Ph_2C{=}N{-}NO_2 + Ph_2C{=}O + N_2O$$

LXXXV LXXXVI



LXXXVII LXII LXIII

Chapman and Heckert (72) have characterized the reactive intermediate in the reactions of nitric oxide with diazo compounds by electron spin resonance (esr) techniques. Observation of the esr spectra of solutions of diphenyldiazomethane, methylphenyldiazomethane, and phenyldiazomethane which had been treated with nitric oxide led to the characterization of the respective iminoxyl radicals (LXXXVIII). The intermediacy of LXXXVIII in the reaction had been suggested previously (70). A mechanism has been proposed which accounts for all of the data (70, 72) (see Figure 1). The initial reaction of nitric oxide with diazomethanes (LXXXIX) results in the formation of iminoxyl radicals (LXXXVIII) and nitrogen. The iminoxyl radicals may undergo further reaction with nitric oxide to give XC, or the radicals may dimerize to form azine-bis-oxides XCI. The azine-bis-oxides are isolated only when R = aryl and R′ = hydrogen. When R = aryl and R′ = alkyl or aryl, the bis-oxides (if formed at all) decompose to regenerate LXXXVIII. The intermediate XC may rearrange by one of two pathways to give either carbonyl compound or nitrimine (XCII). Dinitrogen oxide is produced when XC rearranges to the carbonyl compound.

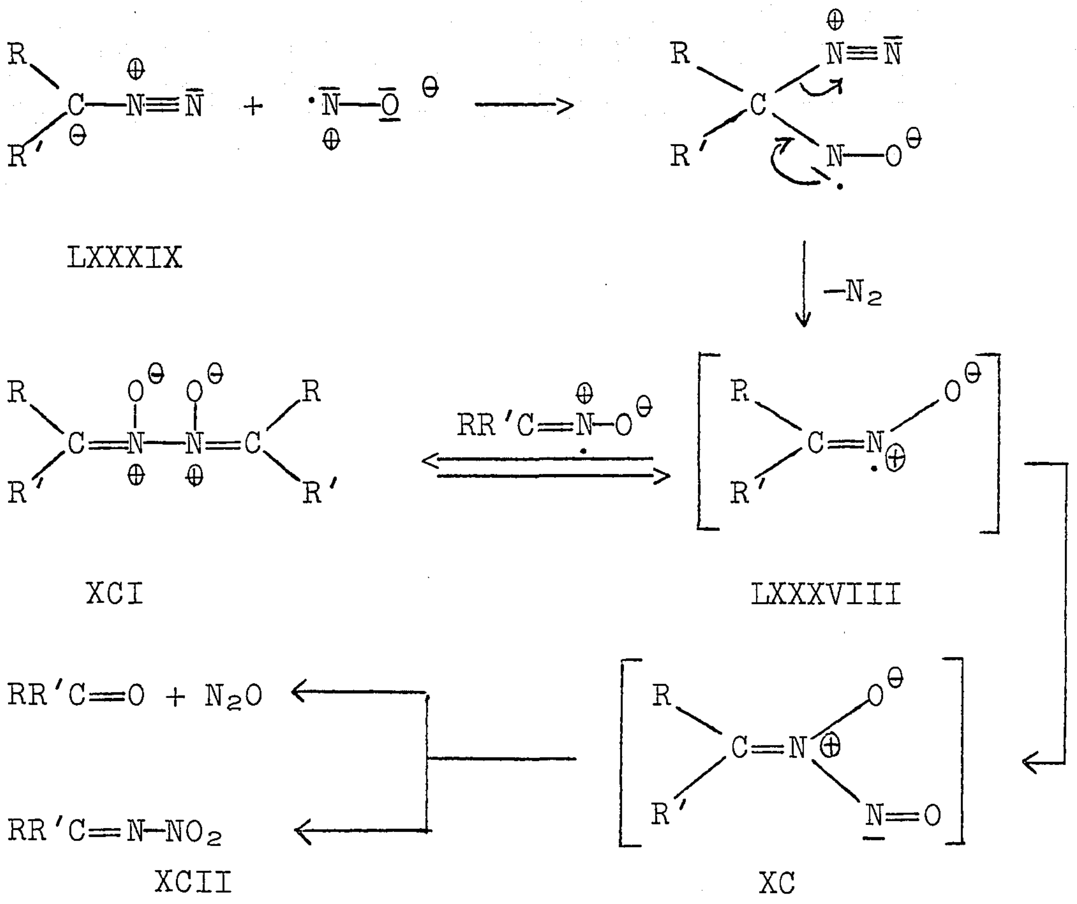
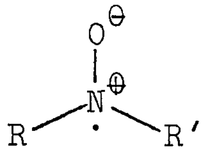


Figure 1. Reaction of diazomethanes with nitric oxide.

Nitrimines have been isolated from the reactions of a wide variety of nitrosating agents (such as NOCl and $(NO)_2SO_4$) with aldoximes and ketoximes (73, and references cited therein). In most instances, intermediates such as XC have been postulated to precede nitrimine formation. Several methods for the preparation of nitrimines from oximes have been reported. One method is the treatment of an oxime with an inorganic nitrite in ether-acetic acid solution at low temperatures (conditions similar to those used in the diazotization of amines) (74). Pinacolone nitrimine has been prepared from pinacolone oxime by the action of N_2O_4 at 0° in ether solution (75). The scope of the N_2O_4 reaction with ketoximes has not been investigated.

Iminoxyl radicals (LXXXVIII) have been generated by the one-electron oxidation of oximes by several methods and have been characterized by electron spin resonance techniques. The esr spectra of some iminoxyl radicals generated by ceric ammonium nitrate oxidation of oximes in methanol in a fast-flow system have been reported by Thomas (76). The gamma-irradiation of single crystals of dimethylglyoxime has been reported to give the corresponding iminoxyl radical (77). Electron spin resonance studies on the lead tetra-acetate oxidation of a wide variety of ketoximes in methylene dichloride (78, 79) and benzene (80, 81), and the ceric sulfate oxidation of aldoximes in acetone-water (82, 83) have been reported. Selected aryl ketoximes which have been studied, the oxidants and solvents employed, and the nitrogen and hydrogen hyperfine splitting constants observed for the respective iminoxyl radicals are shown in Table 3. Similar data relating to the oxidation of aryl aldoximes is shown in Table 4. The references from which the data was taken are included for convenience.

Iminoxyl radicals (LXXXVIII) are generally characterized by a large splitting due to nitrogen, which is in the range of 28-33 gauss. This is to be compared to the more stable class of nitrogen free radicals, the nitroxyl radicals (XCIII). Nitroxyl radicals are generally characterized by nitrogen coupling constants of 10-16 gauss (84-86), and are thus readily distinguished from iminoxyl radicals by esr techniques. The radical formed in the gamma-irradiation of dimethyl glyoxime has a nitrogen coupling constant of 31.7 gauss (77), which is



XCIII

intermediate between that of nitric oxide (87, a_N = 10.6 gauss) and nitrogen dioxide (88, a_N = 47.1 gauss), but nearer to the value of nitrogen dioxide. Calculations based on the radical from dimethylglyoxime have indicated that about 45% of the

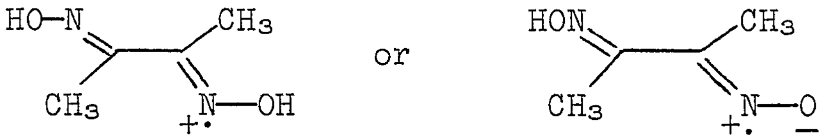


Table 3. Coupling constants of iminoxyl radicals derived from aryl ketoximes

Oxime	Oxidant	Solvent	a_N[a]	a_H[a]	No. of Protons[b]	Ref.
Benzophenone	CAN[c]	CH_3OH	31.6	---[d]		76
	$Pb(OAc)_4$	CH_2Cl_2	31.4	1.4	(2)	79
	$Pb(OAc)_4$	C_6H_6	32.0	1.4	(2)	80
Fluorenone	$Pb(OAc)_4$	CH_2Cl_2	30.8	2.7	(1)	79
	$Pb(OAc)_4$	C_6H_6	31.2	2.7	(1)	80
Acetophenone	CAN	CH_3OH	30.6	---[d]		76
Quinone-monoxime	CAN	CH_3OH	33.0	1.2 3.7	(1) (1)	76
Anthraquinone monoxime	$Pb(OAc)_4$	CH_2Cl_2	29.8	2.5	(1)	79
α and β-Benzil-monoxime	$Pb(OAc)_4$	CH_2Cl_2	(α)32.6 (β)29.9	1.4 ---	(2) -	79
2,3,4,5,6-Pentadeuterobenzophenone	$Pb(OAc)_4$	CH_2Cl_2	(1)31.6 (2)31.6	1.4 ---	(2) -	79
Dibenzyl ketone	$Pb(OAc)_4$	CH_2Cl_2	29.3	1.25	(4)	78

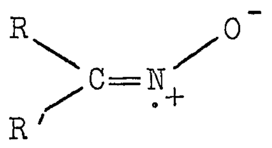
[a] Hyperfine splitting constants are given in gauss.

[b] Number of equivalent nucleii interacting with the unpaired spin center.

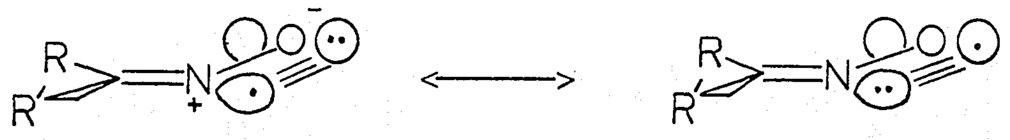
[c] CAN = ceric ammonium nitrate.

[d] The values of hydrogen hyperfine splitting constants were not reported.

unpaired spin is on nitrogen in a hybrid orbital which has about 19% s character (89). The C=N–O bond angle is about 140° (89). The radicals (LXXXVIII) are best represented as hybrids of the structures LXXXVIIIa and b. The unpaired electron is in a π-type orbital which was derived from a nitrogen sp^2-orbital and an oxygen p-orbital, and which lies in the nodal plane of the C–N π-bond. The π-type hybrid orbital is orthogonal to the molecular π-system, and little or no interaction with the molecular π-system occurs. Consequently the radicals have been described as σ-radicals (81, 90), as opposed to π-radicals where the odd electron interacts with the molecular π-system (91).



LXXXVIII

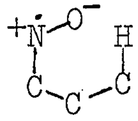


a

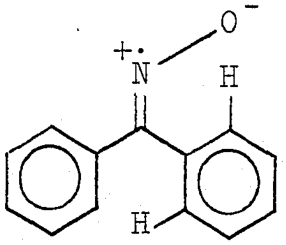
b

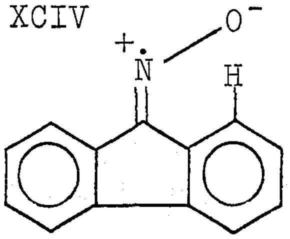
Thomas observed that the interaction of the odd electron with protons in iminoxyl radicals derived from aromatic aldoximes had stereochemical requirements (76). Similar results have been obtained for radicals derived from aromatic ketoximes (78-81). The esr spectrum of benzophenone oxime showed a 1:2:1 hyperfine splitting ($\underline{a}_H$ = 1.4 gauss, Table 3), indicating that the radical was coupled to two protons. The spectrum of 2,3,4,5,6-pentadeuterobenzophenone oxime (Table 3) did not contain doublet splitting (one proton), but consisted of the superimposition of a singlet (relative intensity 4) on the central line of a 1:2:1 triplet (79), a situation made possible only if both interacting protons were on the same aromatic ring. Spectra which were identical to that given by benzophenone oxime were obtained from 4,4′-dinitro- and 3,3′-dimethoxybenzophenone oximes (79), a fact from which two conclusions may be drawn. First, the protons interacting with the odd electron must be the ortho protons on the same ring. The other is that the radicals are of the σ-type described previously. If the radicals were of the π-type, no differentiation between the protons on the two rings would be expected, and the para-protons in benzophenone oxime might be expected to couple more strongly than the ortho-protons. The latter phenomenon has been observed for benzyl and related radicals (91), which are π-radicals.

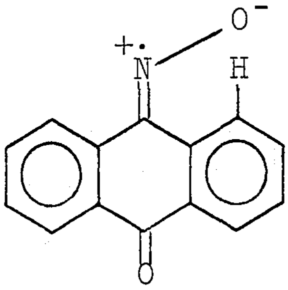
The geometry of the fragment H—C—C—C—N—O has an effect on the magnitude of the interaction of the unpaired electron with the ortho-protons of an adjacent aromatic ring. The hydrogen splitting values ($\underline{a}_H$) shown in Table 3 for benzophenone oxime, fluorenone oxime, and anthraquinone monoxime serve to illustrate the effect. In benzophenone oxime, free rotation about the C(aliphatic)-C(aromatic) bond may lead to a variety of conformations, the result of which is the observation of an average value for the hydrogen splitting of 1.4 gauss. In fluorenone oxime and anthraquinone monoxime, the aromatic rings are geometrically fixed in a planar (or nearly planar) conformation. The hydrogen splitting values (Table 3) for



XCIV

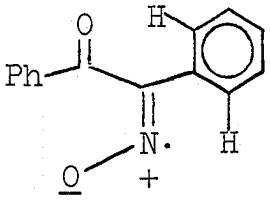




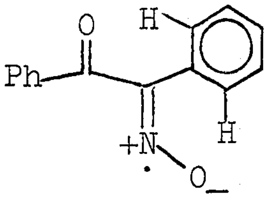


fluorenone oxime and anthraquinone monoxime are 2.7 gauss and 2.5 gauss, respectively, which are approximately twice as large as $\underline{a}_H$ for benzophenone oxime. It appears that maximum interaction arises when the iminoxyl oxygen and the interacting proton are eclipsed or nearly so (arrangement XCIV). For a $C{=}N{-}O$ bond angle of 140°, as suggested by Symons (89), spatial interactions might be expected to be small, and calculations have been made which confirm this (92). Other mechanisms of interaction cannot be ruled out.

The question of whether the protons interacting with the unpaired electron are on the aromatic ring which is <u>cis</u> to the iminoxyl oxygen or <u>trans</u> to it appears to be resolved by the data available for benzil α-monoxime (anti) and benzil β-monoxime (syn). Oxidation of either of the two isomers of benzil monoxime with lead tetra-acetate in methylene dichloride gave the same mixture of radicals (79). In one radical (anti), coupling between the unpaired electron and two protons, of the same magnitude as that in the radical from benzophenone oxime, was observed, whereas in the other isomer (syn) no such interaction could be detected.



syn



anti

Rassat and co-workers (81) found that oxidation of benzil α-monoxime by lead tetra-acetate in benzene resulted in the formation of only one radical, in which coupling to two protons was observed (a_H = 1.4 gauss). Interconversion of the isomeric radicals was apparently not observed under the conditions employed by Rassat (81). The structure of the radical was assigned to the α-isomer (benzoyl group and iminoxyl oxygen anti (trans) to each other) (81).

The arguments relating to the stereochemical requirements for hyperfine splitting in the iminoxyl radicals derived from aryl aldoximes (Table 4) are similar to those given for the

Table 4. Coupling constants of iminoxyl radicals derived from aryl aldoximes

Oxime	Oxidant	Solvent	a_N[a]	a_{H_i}[a,b]	a_H[a]	No. of Protons[c]	Ref.
Benzaldoxime							
anti-	CAN[d]	CH_3OH	29.2	26.9	---	---	76
syn-			31.6	6.2	1.4	(2)	
anti-	$Ce(SO_4)_2$	acetone-H_2O	30.0	27.0	---	---	83
syn-			32.6	6.5	1.4	(2)	
p-Nitrobenzaldoxime							
anti-	$Ce(SO_4)_2$	acetone-H_2O	30.4	27.0	---	---	83
syn-			32.0	6.4	1.4	(2)	
o-Nitrobenzaldoxime							
anti-	$Ce(SO_4)_2$	acetone-H_2O	30.4	29.1	---	---	83
syn-			33.3	7.05	2.4	(1)	

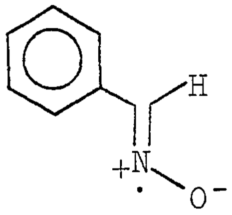
[a] Hyperfine splitting constants are given in gauss.

[b] Hyperfine splitting constants for the imino hydrogen (H_i).

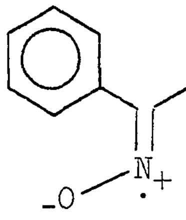
[c] The number of equivalent ring hydrogens interacting with the unpaired spin center.

[d] CAN = ceric ammonium nitrate.

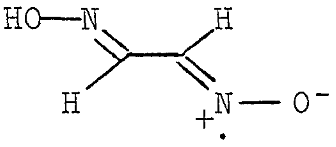
aryl ketoximes. Oxidation of benzaldoxime (either isomer, *anti* or *syn*) with ceric ammonium nitrate in methanol (76), lead tetraacetate in benzene (81), or ceric sulfate in acetone-water (83), has been found to give the same mixture of radicals. Thomas (76) and Rassat (81) assigned the *anti*-structure (aromatic ring and iminoxyl oxygen *trans* to each other) to the iminoxyl radical from benzaldoxime which showed the larger aldehydic (imino) hydrogen splitting and no coupling with protons on the aromatic ring. The *syn*-structure (aromatic ring and oxygen *cis* to each other) was assigned to the radical with smaller aldehydic proton coupling and measurable coupling to the *ortho*-protons on the aromatic ring. A single-crystal study of the iminoxyl radical from glyoxime confirmed the assignments by showing that the coupling constant



anti



syn



for the aldehydic proton *cis* to the iminoxyl oxygen was 22 gauss (93). In the radicals summarized in Table 4, and in numerous others (83), the *anti*- radicals show smaller nitrogen splitting (a_N) and larger aldehydic proton splitting (a_{H_i}) than the corresponding *syn*-isomers, and only in the *syn*- isomers are couplings to the aromatic protons ($\underline{a}_H$) observed. The smaller aldehydic proton coupling in the syn- isomers can be rationalized in part as arising due to twisting of the CNO fragment out of a plane with the aldehydic proton by interaction of the oxygen with the ortho-protons on the aromatic ring.

The data summarized in Table 4 for the isomeric radicals generated from ortho- and para- nitrobenzaldoximes illustrates the remaining features of the stereochemical requirements for hyperfine splitting in aryl aldoximes. Two protons interact with the odd electron in the syn- isomer of p-nitrobenzaldoxime, while only one proton interacts with the odd electron in the syn- isomer of o-nitrobenzaldoxime. Thus, the ortho- protons on the aromatic ring are the ones which are coupled with the odd electron in the syn-isomers of aryl aldoximes. Furthermore, the invariance of the hyperfine splitting constant when both ortho-protons are present ($\underline{a}_H = 1.4$ gauss for both syn-benzaldoxime and syn-p-nitrobenzaldoxime) indicates that the interaction is not affected by changes in the aromatic π-system. The hyperfine splitting constant for the ortho-proton in syn-o-nitrobenzaldoxime ($\underline{a}_H = 2.4$ gauss) indicates that there is restricted rotation about the C (aldehydic)-C (aromatic) bond, and the magnitude of the interaction is very nearly the same as that observed for fluorenone oxime (Table 3, $\underline{a}_H = 2.7$ gauss) where no rotation is possible. The value of the coupling constant for the ortho-protons when both are present represents the average value for a number of conformations made possible by unrestricted rotation of the aromatic ring.

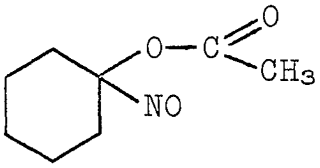
To summarize the major conclusions which have been made about the transmission of spin in iminoxyl radicals derived from aryl ketoximes and aldoximes, the following points are made.

1. Spin is more effectively transmitted to one side of an iminoxyl radical than the other (illustrated by the data for fluorenone and benzophenone oximes, and for _syn_- and _anti_-benzaldoximes).

2. The interaction with _gamma_-protons (O—N=C—C—C—H) is angular-dependent and strongest when the interconnecting σ-bond system is coplanar (e.g., fluorenone oxime versus benzophenone oxime). The data included in Table 3 for quinone monoxime and dibenzyl ketoxime indicates that the interaction with _beta_-protons (O—N=C—C—H) is similarly angular-dependent.

3. In aryl substituted iminoxyl radicals, interaction is observed with only the _ortho_-protons, and is not affected by substituents such as _p_-nitro which interact with the π-system.

Product studies in the oxidation of oximes by lead tetraacetate have received less attention than have studies on the intermediates produced in the reaction. Iffland and Criner (94) reported that the oxidation of cyclohexanone oxime by Pb-$(OAC)_4$ resulted in the formation of 1-acetoxy-1-nitrosocyclohexane (XCV) and the corresponding nitroso dimer. Kropf (95) has since shown that the oxidation of aliphatic ketoximes by $Pb(OAC)_4$ to form <u>geminal</u>-nitrosoacetates (XCVI) is apparently a general reaction. The reaction has been interpreted by an ionic mechanism, passing through an intermediate



XCV

complex such as XCVII (see Figure 2). The observation of radicals in the oxidation of oximes by $Pb(OAC)_4$ has been dismissed as a secondary effect (95, 96).

Lown (97) has investigated the oxidation of some aliphatic ketoximes by $Pb(OAC)_4$ and has isolated geminal-nitrosoacetates (XCVI) also. A mechanism was proposed which involves the rapid addition of two acetoxyl groups to the oximino double bond (accompanied by either one two-electron oxidation or two one-electron oxidations) to give an intermediate XCVIII (see Figure 2). Elimination of acetic acid from XCVIII results in the formation of the observed product, XCVI. Support for the involvement of an intermediate such as XCVIII was given by some electron spin resonance studies (94). The oxidation of cyclohexanone oxime by $Pb(OAC)_4$ in methylene dichloride at 0°

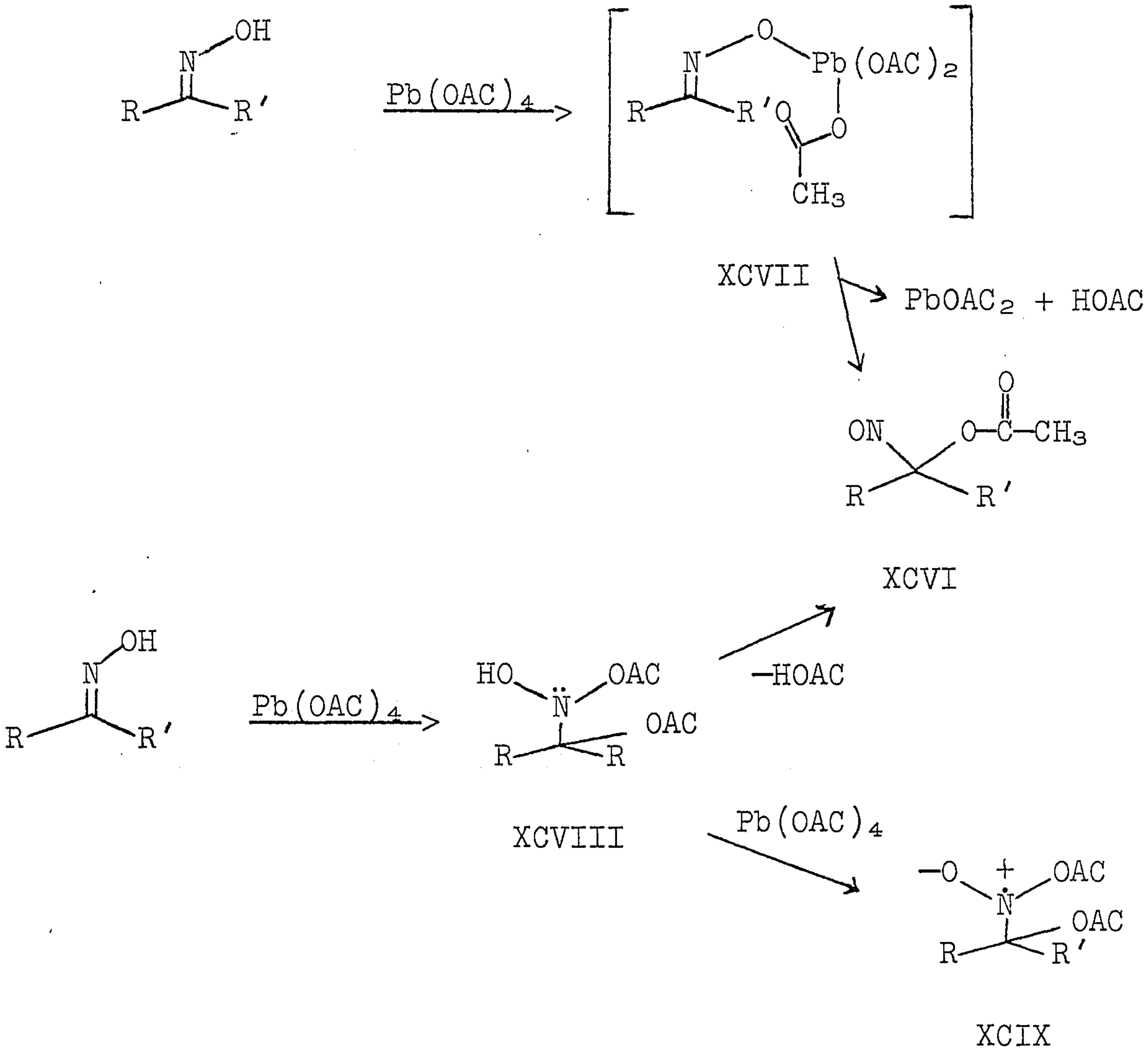
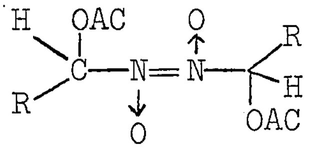


Figure 2. Mechanisms for the oxidation of aliphatic ketoximes by lead tetraacetate.

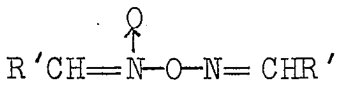
in a flow system resulted in the observation of a radical with a nitrogen coupling ($\underline{a}_N$) of 16.2 gauss (1:1:1 triplet), which was assigned the nitroxyl structure XCIX (RR′ = $\leftarrow CH_2 \rightarrow_5$. No signal due to an iminoxyl radical was observed. The conditions employed in the esr study were identical to those reported by Rassat (80, 81) for the oxidation of cyclohexanone oxime, and no iminoxyl radical was observed in that instance, either. A radical with $\underline{a}_N$ = 15.2 gauss was observed (80). Secondary radicals with nitrogen coupling constants in the range of 13-16 gauss were observed by Rassat with a number of aliphatic and aromatic ketoximes, which were apparently not observed by other workers (81). The nitroxyl radical (XCIX) was presumed by Lown (97) to arise by one-electron oxidation of the intermediate XCVIII. The yields of the geminal-nitrosoacetates (XCVI) from the oxidation of cyclopentanone oxime, cyclohexanone oxime, and 4-t-butylcyclohexanone oxime were 40.3%, 35.0%, and 71.5%, respectively.

Nitroxyl radicals were also formed when cyclopentanone oxime and 4-t-butylcyclohexanone oxime were oxidized by $Pb(OAC)_4$, with $\underline{a}_N$ = 15.5 gauss and 16.0 gauss, respectively. Iminoxyl radicals were generated from cyclohexanone oxime and cyclopentanone oxime by ceric ammonium nitrate oxidation in a flow system for comparison to the nitroxyl radicals, and were found to have nitrogen coupling constants of 32.1 gauss and 31.2 gauss, respectively. A complex esr spectrum was observed when 4-heptanone oxime was treated with $Pb(OAC)_4$, which slowly changed a triplet (1:1:1) with a_N = 14.3 gauss; the radical was assigned structure XCIX (R = R′ = *n*-propyl) (97).

The oxidation of aliphatic aldoximes with lead tetraacetate results in the formation of diacetates of the structure C (R = *n*-propyl, *n*-pentyl, *n*-heptyl, and $-CH_2-Ph$) (95). The oxidation products from α, β-unsaturated and aromatic aldoximes were formulated as oxime anhydride N-oxides (CI) (96). The formation of CI requires one-half mole of $Pb(OAC)_4$ per mole of the aldoxime oxidized (96). Dahl[1] has found that aldazine-*bis*-oxides (CII), and not oxime anhydride N-oxides are formed in the low temperature (-78°) $Pb(OAC)_4$ oxidation of aromatic *anti*-aldoximes. The aldazine-*bis*-oxides thus formed were identical to the anhydride N-oxides formulated by Kropf (96). Benzaldazine-*bis*-oxide (LXXXI) which was isolated from the cerium(IV) oxidation of benzaldoxime (69) was found to be identical to the azine bis-oxide formed in the low temperature oxidation of *anti*-benzaldoxime[1]. It would appear then that the oxime anhydride N-oxides formulated by Kropf are in fact the corresponding azine-*bis*-oxides (CII). It is interesting to



C R=alkyl



$$R'CH{=}\overset{O}{\overset{\uparrow}{N}}{-}O{-}N{=}CHR'$$

CI R′=aryl or Ar—CH=CH—

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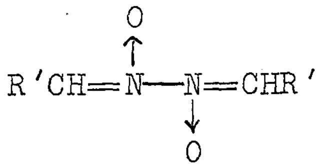
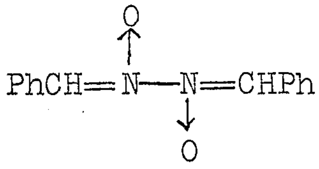
[1] K. Dahl, Department of Chemistry, McGill University, Montreal, Canada. Lead tetraacetate oxidation of oximes. Private communication. 1966.



$$\mathrm{R'CH{=}\overset{\overset{O}{\uparrow}}{N}{-}\underset{\underset{O}{\downarrow}}{N}{=}CHR'}$$

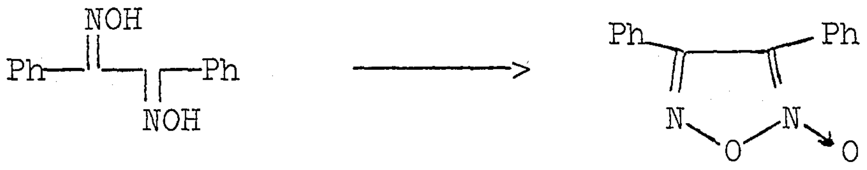
CII



$$\mathrm{PhCH{=}\overset{\overset{O}{\uparrow}}{N}{-}\underset{\underset{O}{\downarrow}}{N}{=}CHPh}$$

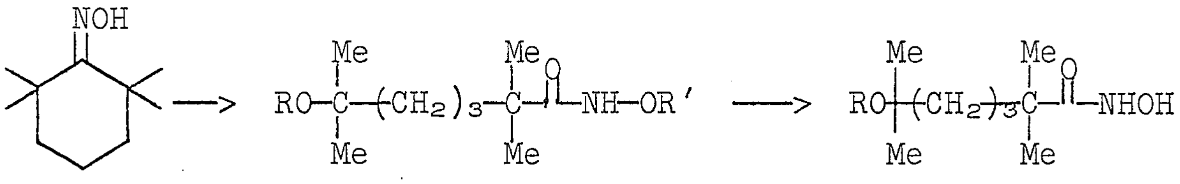
LXXXI

note that the oxidation of benzil dioxime (CIII) by $Pb(OAC)_4$ resulted in the formation of diphenylfuroxan (LXXIV) (96), which is in effect an oxime anhydride N-oxide although cyclic in nature. The analogy between this reaction and the oxidation of other aromatic aldoximes may have been drawn, which led to the assignment of the structures of the reaction products as oxime anhydride N-oxides (CI) (96).



CIII LXXIV

Just and Dahl (98) have investigated the oxidation of some hindered ketoximes and aldoximes with lead tetra-acetate. Oxidation of 2,2,6,6-tetramethylcyclohexanone oxime (CIV) with one equivalent of $Pb(OAC)_4$ in acetic acid gave the hydroxamic acid derivative CVa, which was hydrolyzed by methanolic potassium carbonate to the hydroxamic acid CVIa (84% yield overall). A similar reaction with CIV in trifluoroacetic acid yielded CVb in 30% yield. Hydrolysis of CVb with hot water gave CVIb (94% from CVb). The oxidation of



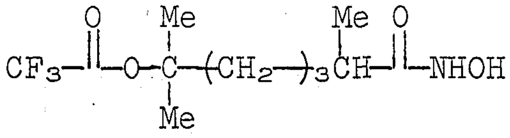
CIV

CVa, R = R′ = $\mathrm{CH_3}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-$

b, R = $\mathrm{CF_3}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-$, R′ = H

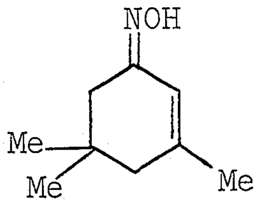
CVIa, R = $\mathrm{CH_3}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-$

b, R = H



$\mathrm{CF_3}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\mathrm{O}-\underset{\mathrm{Me}}{\overset{\mathrm{Me}}{\mathrm{C}}}-(\mathrm{CH_2})_3-\overset{\mathrm{Me}}{\mathrm{C}}\mathrm{H}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\mathrm{NHOH}$

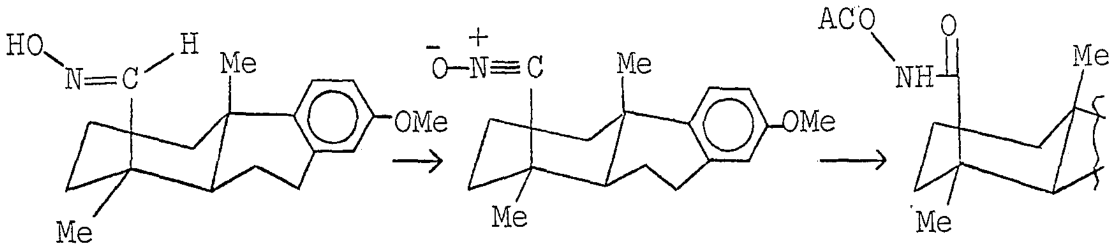
CVII



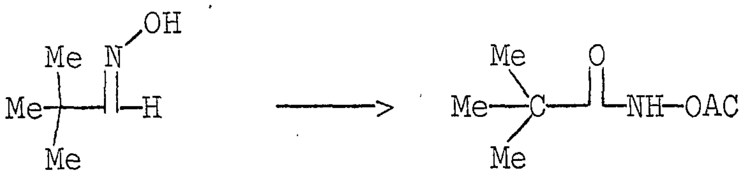
CVIII

2,2,6-trimethylcyclohexanone oxime in trifluoroacetic acid gave hydroxamic acid CVII (54%). Cyclohexanone oxime, 3-methylcyclohexanone oxime, and 3,5,5-trimethylcyclohex-2-enone oxime (CVIII) gave geminal-nitrosoacetates, carbonyl compounds, and nitric oxide. No hydroxamic acid derivatives were formed. Hydroxamic acid (40%) and ketone (60%) were obtained from the oxidation of 2-methylcyclohexanone oxime.

Oxidation of syn-O-methylpodocarpinaldoxime (CIX) with $\mathrm{Pb(OAC)_4}$ gave nitrile oxide CX in 94% yield (98). On heating in acetic acid, CX was quantitatively converted to the hydroxamic derivative CXI (partial structure shown).



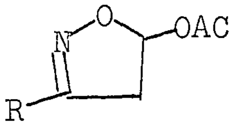
CIX CX CXI



Syn CXII

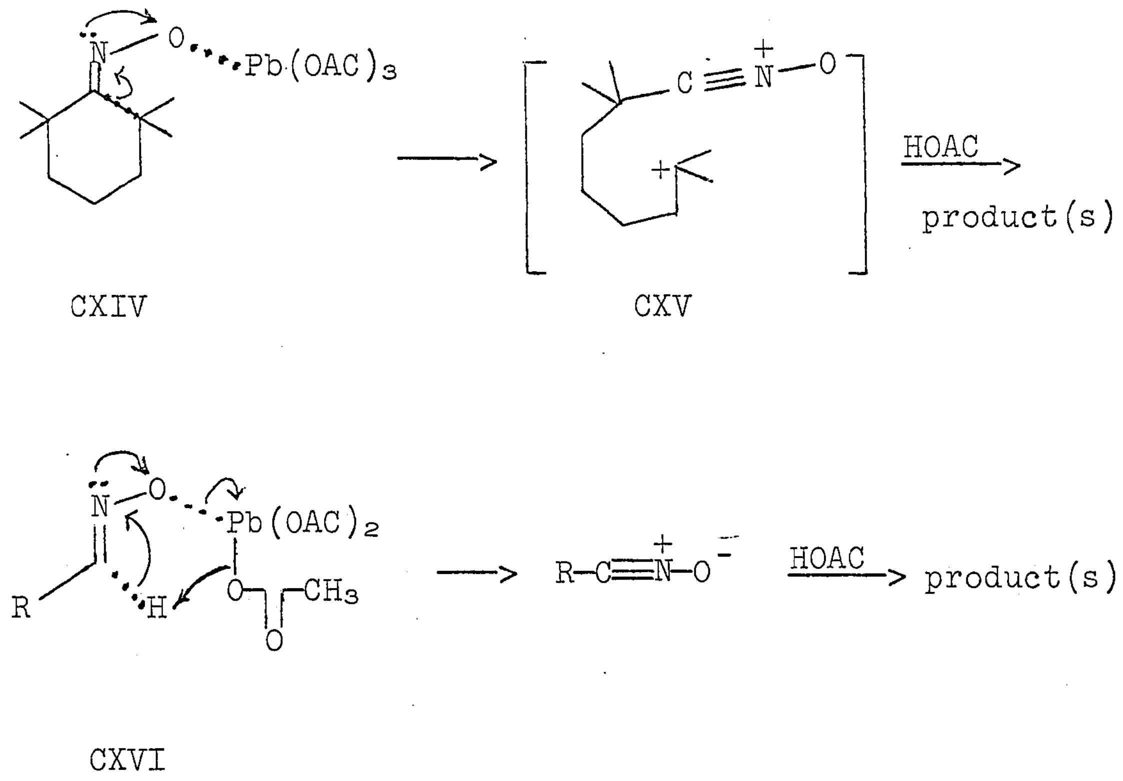
Syn-trimethylacetaldehyde gave the hydroxamic acid derivative CXII directly without prior isolation of a nitrile oxide. *Syn*-aldoximes generally gave high yields of products derivable from nitrile oxides, while *anti*-aldoximes gave low yields of products derivable from nitrile oxides, in addition to aldehydes. *Anti*-aldoximes also reacted considerably slower than the *syn*-isomers with $Pb(OAC)_4$.

Scavenger experiments using vinyl acetate were performed (98). Generally, oxidation of *syn*-aldoximes with $Pb(OAC)_4$ in the presence of the olefin led to the formation of isoxazoline derivatives (CXIII) in high yields. An example was the oxidation of *syn*-trimethylacetaldehyde to form the derivative CXIII (R = *t*-butyl) in 80% yield. Isoxazoline derivatives were also formed when *anti*-aldoximes were oxidized in the



CXIII

presence of vinyl acetate, but the yields were very low. Mechanisms involving the formation of nitrile oxides were presented for both the ketoximes and aldoximes (98) (see Figure 3). For ketoximes such as CIV, initial carbon-carbon bond rupture within the complex CXIV, coupled with a two-electron oxidation by Pb(IV), would give an intermediate CXV. Capture of a solvent molecule by CXV, and acetolysis of the nitrile oxide grouping, would result in the formation of product. The involvement of a free carbonium ion (CXV) is unnecessary since it is equally likely that direct (or nearly direct) transfer of an acetoxyl group from Pb(IV) to the developing positive center occurs as the alpha-carbon-carbon bond ruptures. Intermediate nitrile oxides are certainly involved in the oxidation of syn-aldoximes, as evidenced by the trapping experiments with vinyl acetate and by the isolation of CX in high yield from the oxidation of CIX. The cyclic transition state CXVI for the oxidation of aldoximes readily accounts for the fact that anti-aldoximes react more slowly than the syn isomers and yield products other than those derived from nitrile oxides.



CXIV

CXV

CXVI

Figure 3. Mechanisms for the lead tetraacetate oxidation of hindered ketoximes and aldoximes.

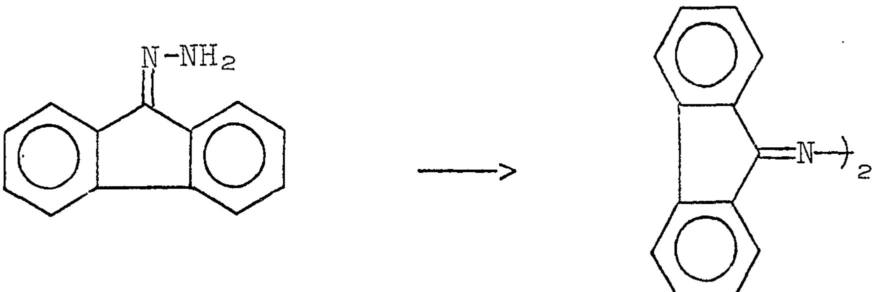
Oxidation of hydrazones

A wide variety of syntheses for symmetrical and unsymmetrical azines are to be found in the chemical literature, one means of which is the oxidation of hydrazones ($R_2C{=}N{-}NH_2$). Oxidation of hydrazones with mercuric oxide to produce diazo compounds, which undergo nitrogen elimination to form symmetrical azines, has been known for years (99, Equation 31). In some instances, however, the diazo compounds initially generated are sufficiently stable that forcing conditions are necessary to induce azine formation, and unwanted side reactions become important.

$$R_2C{=}N{-}NH_2 \xrightarrow{HgO} R_2C{=}N{-}N{=}CR_2 + N_2 \qquad \underline{31}$$

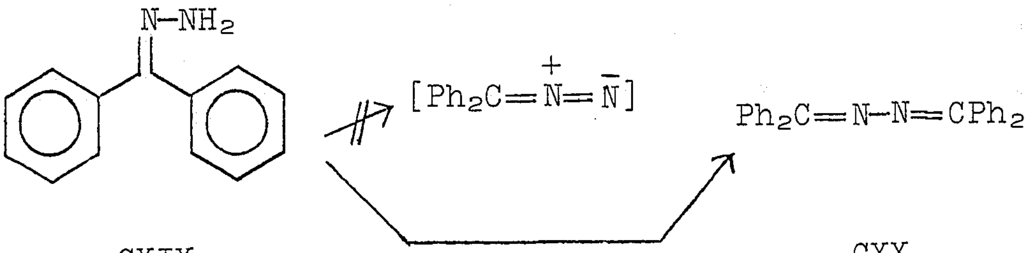
In Table 5 are summarized some methods of oxidation of hydrazones which have found limited use in the preparation of symmetrical azines, and in the preparation of some unsymmetrical azines. Fluorenone hydrazone, xanthone hydrazone, and, to a lesser extent, benzophenone hydrazone, form stable diazo derivatives when oxidized with mercuric oxide, which has resulted in a search for other means of preparing the respective sym-azines from those hydrazones.

Oxidation of 9-fluorenone hydrazone (CXVII) with N-bromosuccinimide was found to give 9-fluorenone azine (CXVIII) in 81% yield (100). Benzophenone hydrazone (CXIX) yielded benzophenone azine (CXX) in good amounts (90%). The reaction was not a rapid reaction, but the evolution of nitrogen was detectable. Diazodiphenylmethane was discounted as an intermediate in the formation of CXX from CXIX on the grounds that



CXVII

CXVIII



CXIX

CXX

the distinct violet color of the diazo compound was not observed when CXIX was oxidized by NBS in ether or benzene in an atmosphere of carbon dioxide.

The yields of the azines CXVIII and CXX (Table 5) were considerably lower on oxidation of the respective hydrazones with manganese dioxide (101) than were realized with NBS. No mechanism was proposed to account for azine formation in the MnO_2 reaction, and other products were not reported (101). The most limited of the methods shown in Table 5 for the preparation

Table 5. Oxidation of hydrazones ($R_2C{=}NNH_2$)

	Azine Yields (%)[a]				
Hydrazone	NBS[b]	MnO_2[c]	THBQ[d]	PBQ[e]	PBQ[e,f]
Fluorenone	81	58		---[g]	60
Benzophenone	90	52	90		75
Benzil	85				
Xanthone				---[g]	80

[a] Yields of the symmetrical azines except for the last column; see footnote f.

[b] NBS = N-bromosuccinimide; reference 100.

[c] Manganese dioxide; reference 101.

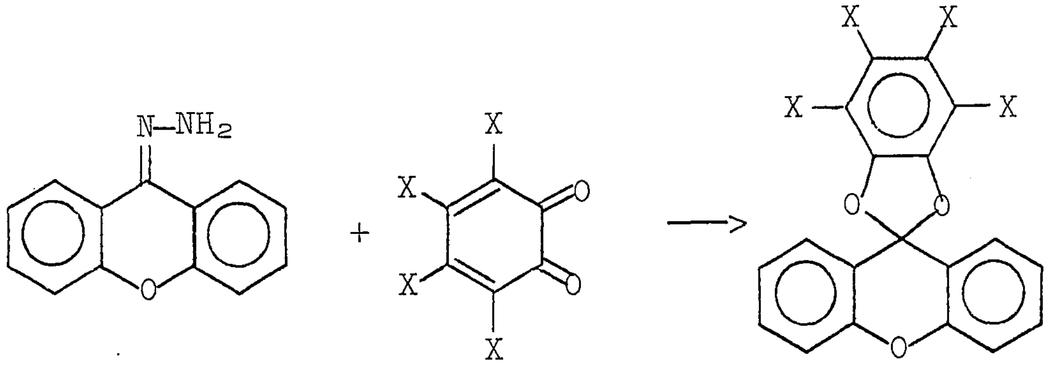
[d] THBQ = tetrahalo-o-benzoquinone, halogen = Cl or Br; reference 102.

[e] PBQ = p-benzoquinone; reference 102.

[f] Yields given in the column are for the mixed p-benzoquinoazines ($p{-}BQ{=}N{-}N{=}CR_2$).

[g] Yields were not given, but were reported to be "high".

of azines was that of the oxidation of hydrazones with tetrachloro- and tetrabromo-o-benzoquinones (102). The yield of CXX was high, but CXIX was the only hydrazone found which reacted to give an azine. Fluorenone hydrazone (CXVII) and xanthone hydrazone (CXXI) formed the cyclic ethers CXXII (shown for xanthone hydrazone) when treated with the reagent (102). The reaction with benzophenone hydrazone (CXIX) was postulated to take place through the formation of bis-diphenylmethane tetrazene (CXXIII) which then decomposed, with elimination of nitrogen, to form azine CXX.



CXXI

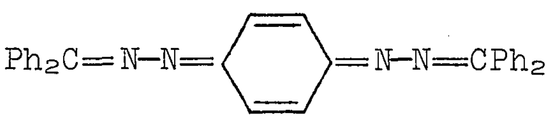
X = Cl or Br

CXXII

$$Ph_2C{=}N{-}N{=}N{-}N{=}CPh_2$$

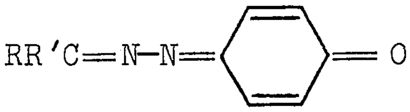
CXXIII

When hydrazones CXVII and CXXI were treated in dry benzene with two equivalents of p-benzoquinone, the corresponding sym-azines were formed in good yields (102). Hydrazone CXIX gave the diazine CXXIV when reacted with two equivalents of the quinone. A similar reaction using one equivalent of



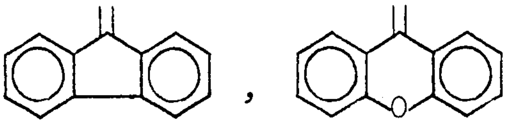
CXXIV

the quinone per equivalent of hydrazone resulted in the formation of the mixed p-benzoquinoazines CXXV (condensation, not oxidation products) (Table 5). The p-benzoquinoazines (CXXV) were subsequently found to be satisfactory oxidants for the respective hydrazones, and gave good yields of sym-azines when heated in benzene with the hydrazones. The molar



CXXV

RR′ =



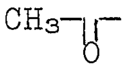
R = R′ = Ph

proportions of p-benzoquinone to hydrazone had no effect on the reaction in alcohol solution, as only symmetrical ketazines were formed (102).

Horner and Fernekess (103) have shown that hydrazones such as CXVII, CXIX, and benzaldehyde hydrazone, are quantitatively converted to the corresponding carbonyl compounds and nitrogen when treated with two equivalents of peracetic acid. The observation that one equivalent of the peracid was necessary to effect the quantitative conversion of 9-diazofluorene to 9-fluorenone and nitrogen (104) made it seem unlikely that diazo compounds were involved in the peracid oxidation of hydrazones to analogous products. Carbonyl compounds were not formed when hydrazones were oxidized with one equivalent of peracetic acid in the presence of alcohols and acids (103). To illustrate, the oxidation of benzophenone hydrazone (CXIX) with one equivalent of peracetic acid in ethanol or acetic acid resulted in the formation of the adduct CXXVI in good yield. Subsequently, it was found that N,N-dialkylhydrazines were oxidized

CXIX CXXVI R = CH_3CH_2-

or

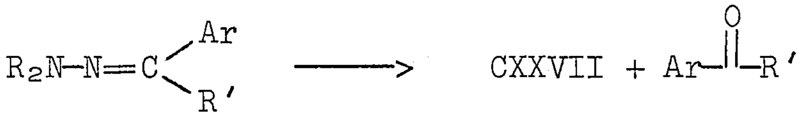


$CH_3C(=O)-$

$$R_2N-NH_2 \longrightarrow R_2N-N=N-NR_2$$

R = alkyl

CXXVII

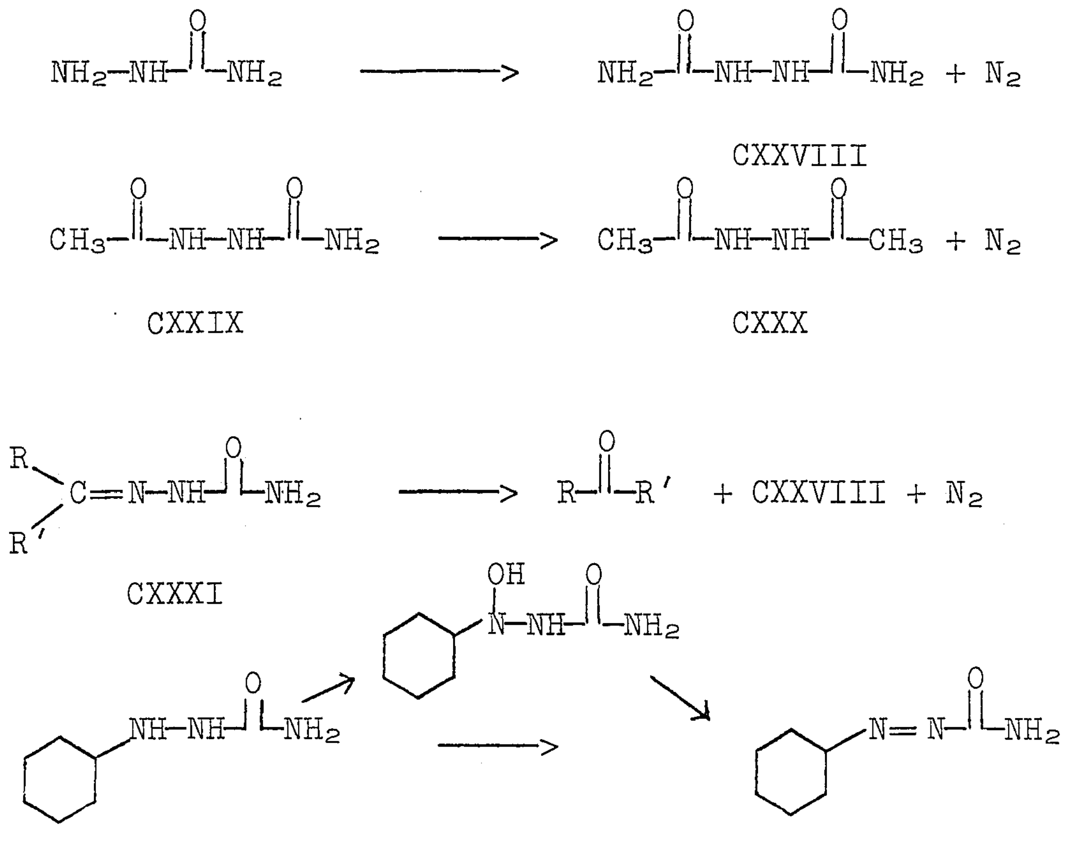


R = alkyl

R′ = aryl, alkyl, or H

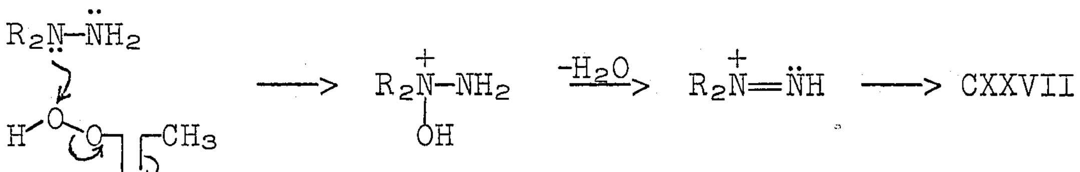
by peracetic acid to form symmetrical tetrazenes (CXXVII), and that dialkylhydrazones were oxidized by the reagent to form symmetrical tetrazenes and the corresponding carbonyl compounds in good yields (103).

Intermediates similar to tetrazenes (CXXVII) were important in explaining the products formed when semicarbazide, N,N′-diacylhydrazines, and ketone semicarbazones were oxidized with peracetic acid (103). Semicarbazide was oxidized to form CXXVIII (81% yield) and nitrogen. Unsymmetrical diacylhydrazines, such as 4-acetylsemicarbazide (CXXIX) gave N,N′-diacetylhydrazine (CXXX) (94% yield) and nitrogen. Oxidation of ketone semicarbazones (CXXXI) yielded the respective ketones, CXXVIII, and nitrogen. Dehydrogenation of 4-cyclohexylsemicarbazide



(CXXXII) by peracetic acid to give CXXXIII furnished conclusive evidence that the initial point of attack by the peracid was at the center of highest electron density (103). Attack at position 4 of CXXXII would give an intermediate hydroxyhyrazino derivative, which would then lose water to form CXXXIII.

Hydroxylation of N,N-dialkylhydrazines by peracetic acid would result in a hydrazine oxide, which would then lose a molecule of water to form CXXXIV. When sodium hypochlorite (NaOCl) was used to oxidize N,N-diethylhydrazine, the perchlorate salt of CXXXIV (R = ethyl) was isolated, and was found to dimerize readily to form tetraethyl tetrazene (CXXVII) (103). Thus, the generation of CXXXIV from N,N-dialkylhydrazines with peracetic acid, and subsequent dimerization of CXXXIV to form tetrazenes, is a reasonable mechanism for the reaction. Similar mechanisms can be written for the oxidation of hydrazones and other hydrazine derivatives with peracetic acid. For hydrazones (Figure 4) the initial formation of CXXXV is reasonable (and not $RR'C{=}\overset{+}{N}{=}\overline{N}$). If the diazo compound were formed, it would be detectable in the reaction of fluorenone hydrazone with one equivalent of peracetic acid, where additional peracid is not available for further oxidation. Diazofluorene reacts very slowly, if at all, with alcohols and acids to give products of the type CXXVI. Further reaction of CXXXV with either peracetic acid or solvent is apparently rapid by comparison to the dimerization to form tetrazenes. Products (azines)



CXXXIV

resulting from the formation and decomposition of tetrazenes were not observed (103).

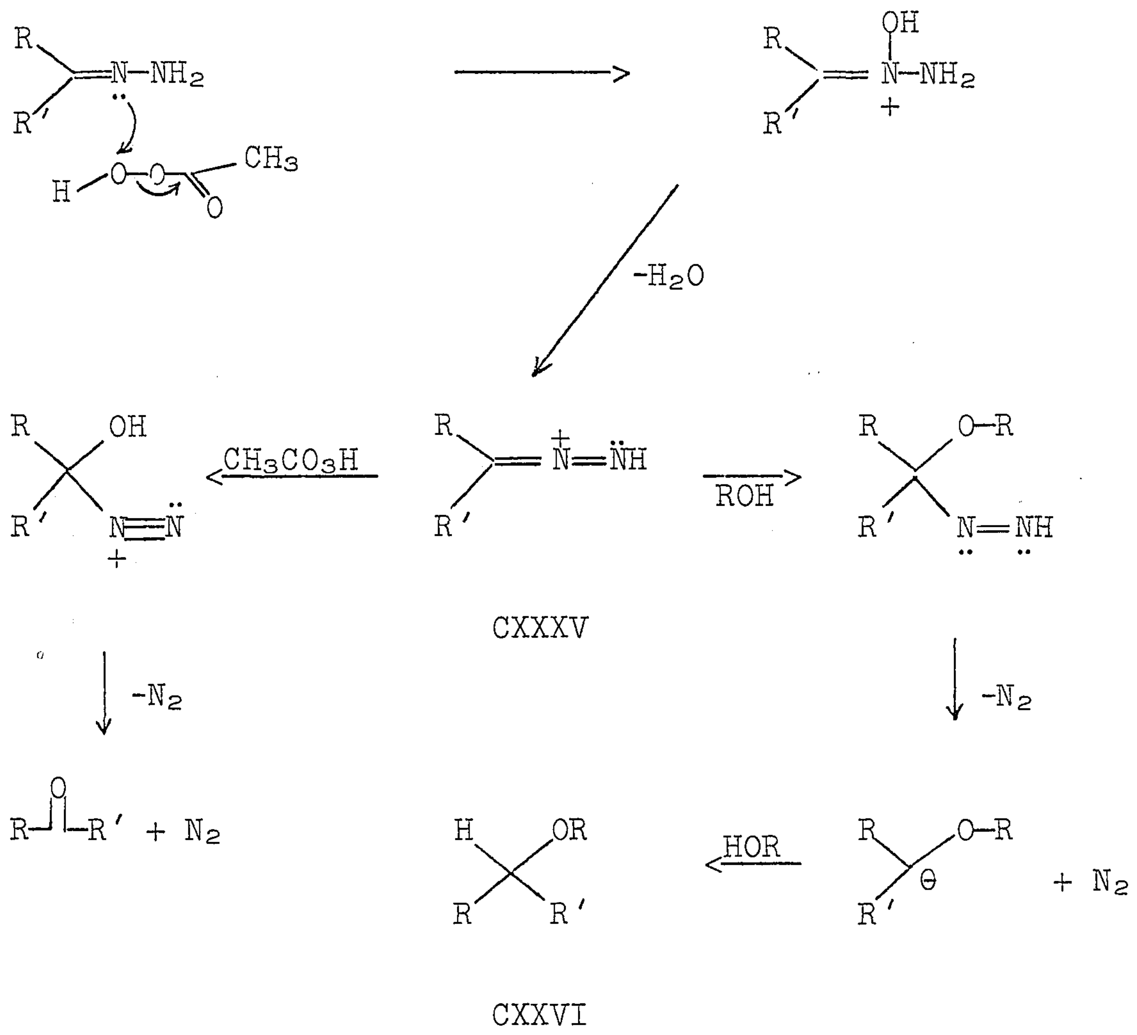
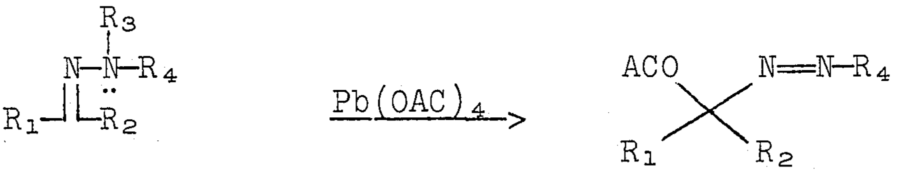


Figure 4. Mechanism for the peracetic acid oxidation of hydrazones.

The oxidation of substituted hydrazones (CXXXVI) by lead tetra-acetate to form azoacetates of the general structure CXXXVII has been widely investigated. Among the hydrazones which have been found to undergo the reaction are N-alkyl and N-arylhydrazones (R_3 = H, R_4 = alkyl or aryl) (105), N-carbethoxyhydrazones (R_3 = H, R_4 = $CO_2CH_2CH_3$) (106), N-acetylhydrazones (R_3 = H, R_4 = $COCH_3$) (107), and N,N-disubstituted ketohydrazones (R_3 = alkyl, R_4 = alkyl or aryl) (108). One equivalent of lead tetra-acetate was sufficient to give good



CXXXVI CXXXVII

yields of CXXXVII from all hydrazones except the N,N-disubstituted ketohydrazones, which required two equivalents of the oxidant to produce CXXXVII (108). When benzophenone N-methyl-N-phenylhydrazone (CXXXVI, R_1 = R_2 = R_4 = phenyl, R_3 = methyl) was treated with one equivalent of $Pb(OAC)_4$, benzophenone phenylhydrazone was formed, while the reaction with two equivalents of $Pb(OAC)_4$ gave the expected azoacetate (CXXXVII), R_1 = R_2 = R_3 = phenyl). Oxidation of benzophenone N-benzyl-N-t-butylhydrazone (CXXXVI, R_3 = Ph—CH_2-, R_4 = t-butyl) with one equivalent of the reagent gave benzophenone N-t-butylhydrazone and benzaldehyde. In no cases were aryl or t-butyl groups removed in the initial C—N bond cleavage reaction (108).

Although no mechanism was proposed to account for the facile C(alkyl)—N bond cleavage of N,N-disubstituted ketohydrazones by lead tetraacetate (108), it is probable that a sequence such as that shown in Figure 5 was involved. Formation of an organo-lead derivative, followed by a loss of an

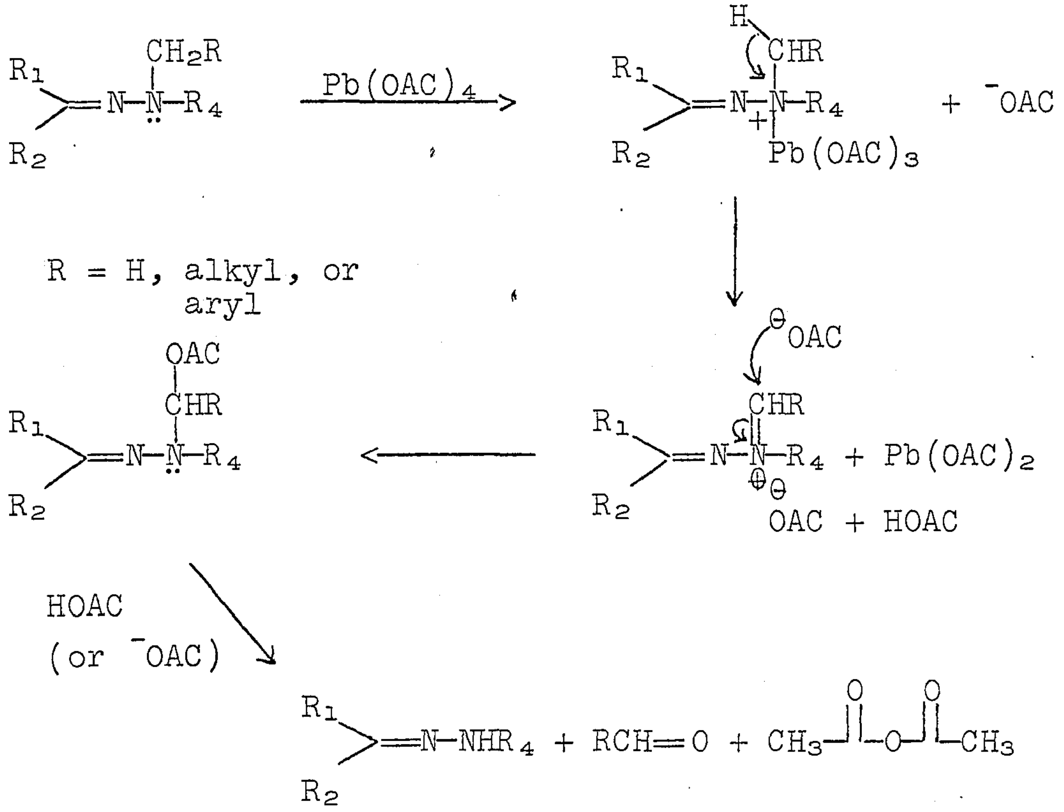


Figure 5. Mechanism for the lead tetraacetate oxidation of N,N-disubstituted ketohydrazones.

alpha-proton in an alkyl residue, and decomposition of the organo-lead species, would give the imino salt CXXXVIII. Attack of acetic acid (or acetate ion) at the alpha-carbon in CXXXVIII would give an iminoacetoxy acetal, which decomposes to form the monosubstituted hydrazone, an aldehyde, and acetic anhydride. Acetic anhydride was not detected in the product mixtures from the oxidation, but its formation in the reaction remains an open question (108).

Iffland (105) had originally proposed that the initial step in the oxidation of N-alkyl and N-aryl-hydrazones by $Pb(OAC)_4$ was a one-electron oxidation to give the intermediate CXXXIX. Norman, et al. (109), have recently shown that the

$$R_1R_2C{=}\underset{\alpha}{N}{-}\underset{\beta}{\ddot{N}}HR_4 \longrightarrow R_1R_2C{=}N{-}\dot{N}HR_4$$

CXXXIX

initial point of attack by $Pb(OAC)_4$ is indeed the β-nitrogen in the hydrazone residue, but have discounted the intermediacy of free radicals such as CXXXIX. Rate studies on the oxidation of benzophenone phenyl- and p-nitrophenylhydrazones by $Pb(OAC)_4$ have shown that the rate determining step involves the displacement of acetate ion from $Pb(OAC)_4$ by the β-nitrogen of the hydrazone residue (109) (see Figure 6). An organo-lead derivative (CXL) would be formed, followed by the uptake of an acetoxy group at the ketone carbon, which probably occurs through an intramolecular transfer reaction within CXL. The incorporation of solvent (ROH) can occur intermolecularly before an acetate ion is incorporated. Both azoacetates and azoethers are formed in the reaction (109). The oxidation rate was dependent on

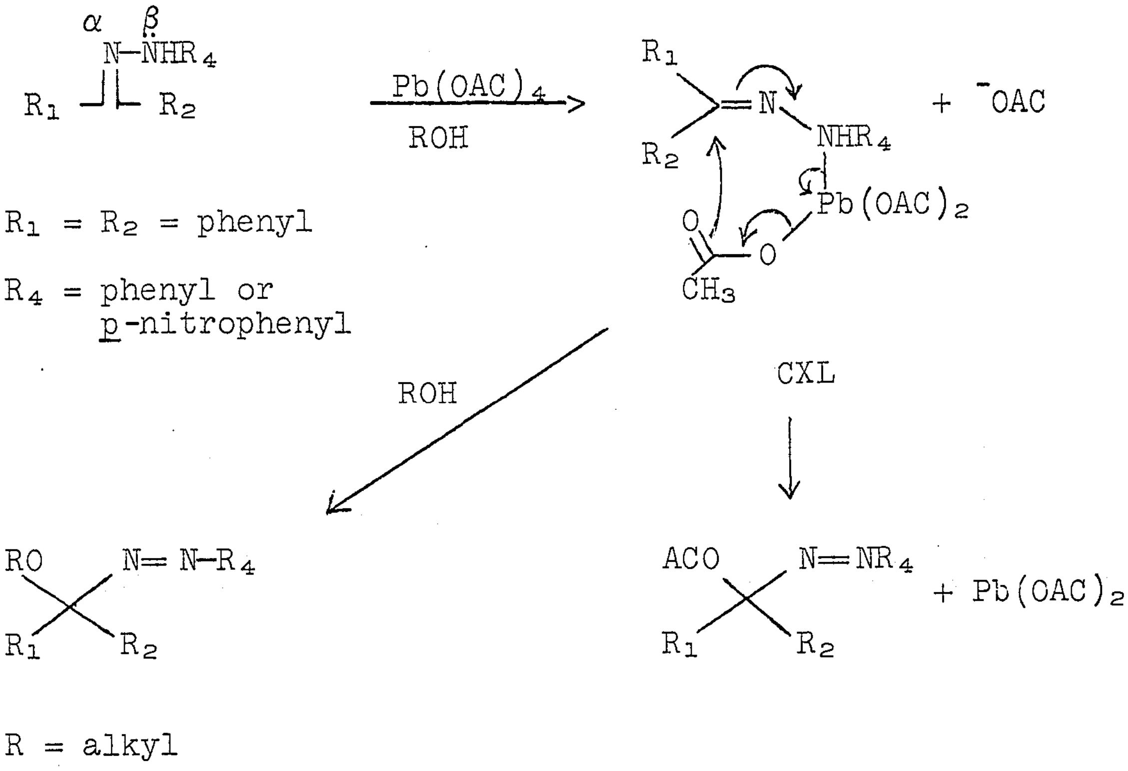
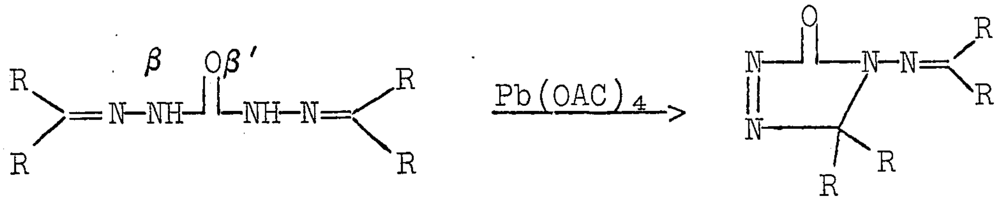


Figure 6. Mechanism for the lead tetraacetate oxidation of N-alkyl and N-arylhydrazones.

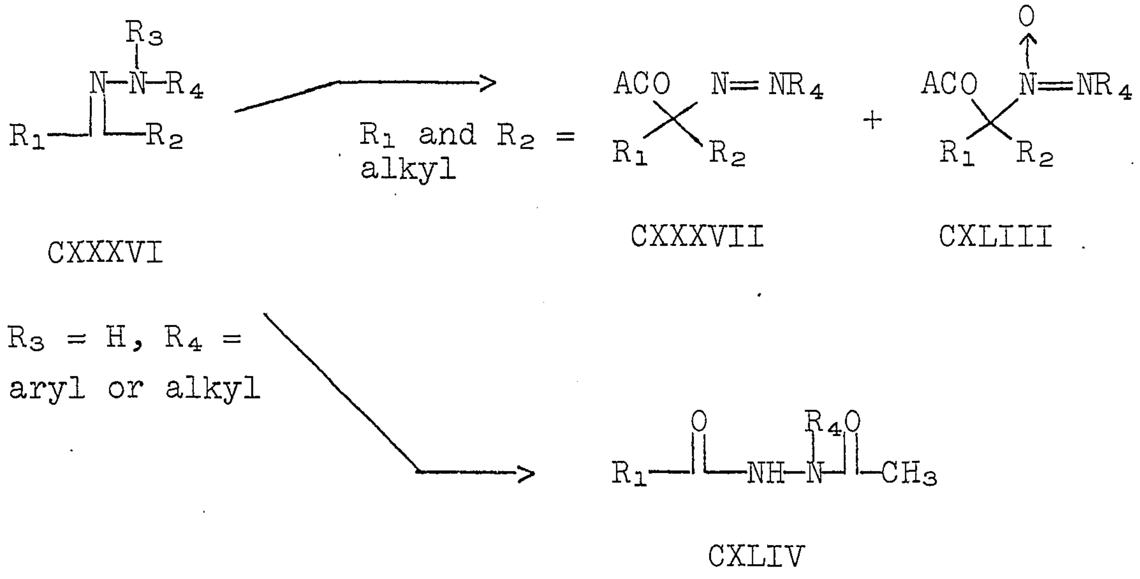
the polar effects of substituents in the arylhydrazine group, and to a lesser extent substituents in the parent ketone (109). Benzophenone p-nitrophenylhydrazone was oxidized much more slowly than the corresponding phenylhydrazone, indicating that the availability of the unshared electron pair on the β-nitrogen of the hydrazone residue played an important role in the reaction.

The oxidation of ketocarbohydrazones (CXLI) by lead tetra-acetate results in the formation of triazolinones (CXLII) (110). For example, the oxidation of acetone and carbohydrazone (CXLI, R = methyl) gives 4-isopropylimino-5,5-dimethyl-Δ^1-1,2,4-triazolin-3-one (CXLII, R = methyl) in good yield. The triazolinones are probably formed by way of an initial organo-lead derivative similar to CXL, which decomposes by an intramolecular attack by the $\underline{\beta}'$-nitrogen at the ketone carbon rather than by attack of an acetate ion or solvent molecule as shown previously (see structure CXL).

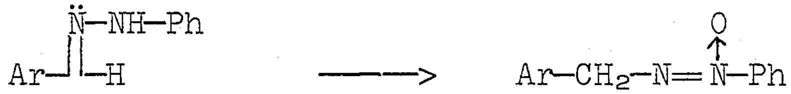


CXLI CXLII

The peracetic acid oxidation of aliphatic ketone aryl- and alkylhydrazones (CXXXVI, R_1 and R_2 = alkyl, R_3 = H, R_4 = aryl or alkyl) has been shown to give azoacetates, similar to CXXXVII obtained in the Pb(OAC)$_4$ oxidation of hydrazones, and acetoxyazoöxides (CXLIII) (111). Aliphatic aldehyde aryl- and alkylhydrazones (CXXXVI, R_1 = alkyl, R_2 = H, R_3 = H, R_4 = aryl or alkyl) yield N,N'-diacylhydrazines (CXLIV) on oxidation with peracetic acid (111). Aromatic aldehyde phenylhydrazones give azoöxides CXLV when oxidized with peracetic acid (112). The acetoxyazoöxides (CXLIII) isolated from the oxidation of

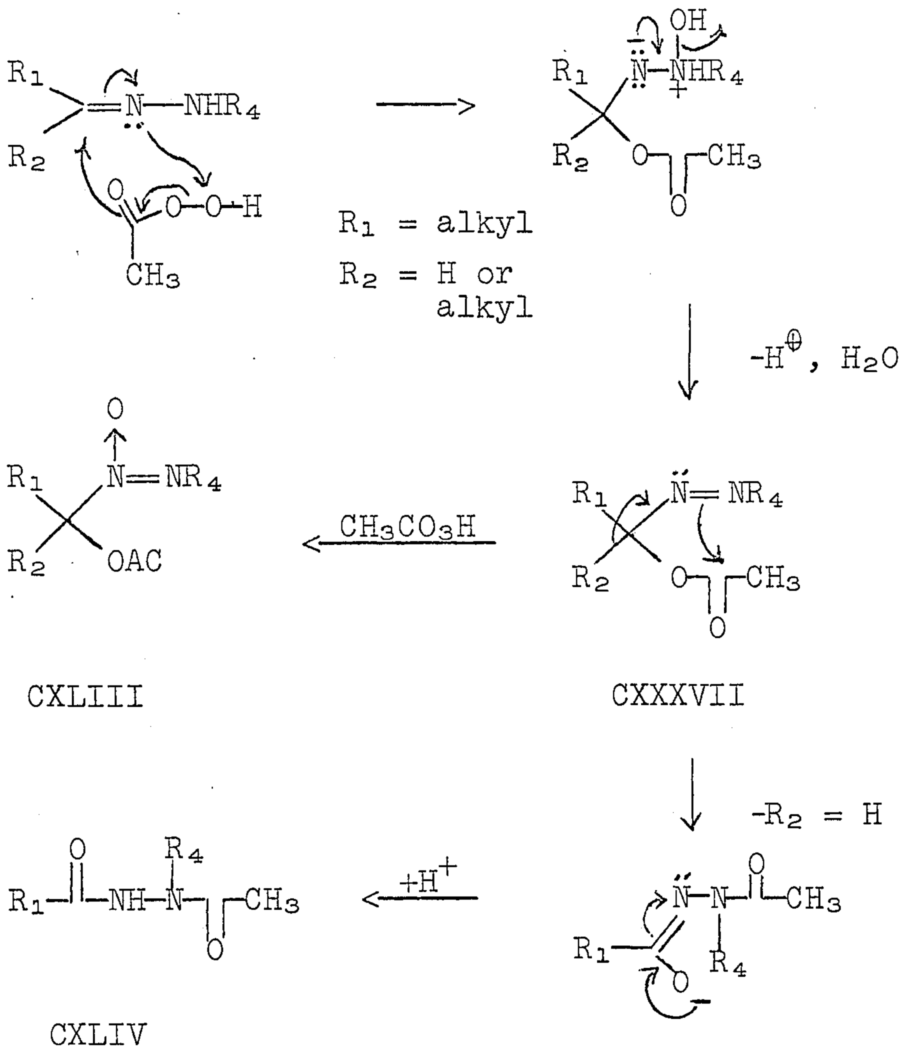


CXXXVI CXXXVII CXLIII CXLIV



CXLV

aliphatic ketone aryl- and alkylhydrazones with the peracid were formed as a result of a reaction between the first-formed azoacetates (CXXXVII) and another molecule of peracetic acid (111). Mechanistically, the products formed in the reactions could be rationalized in terms of an initial attack by peracetic acid at the β-nitrogen of the various hydrazones, followed by decomposition of the intermediate oxides in different ways depending on the structural type of hydrazone being oxidized (Figure 7 and Figure 8).

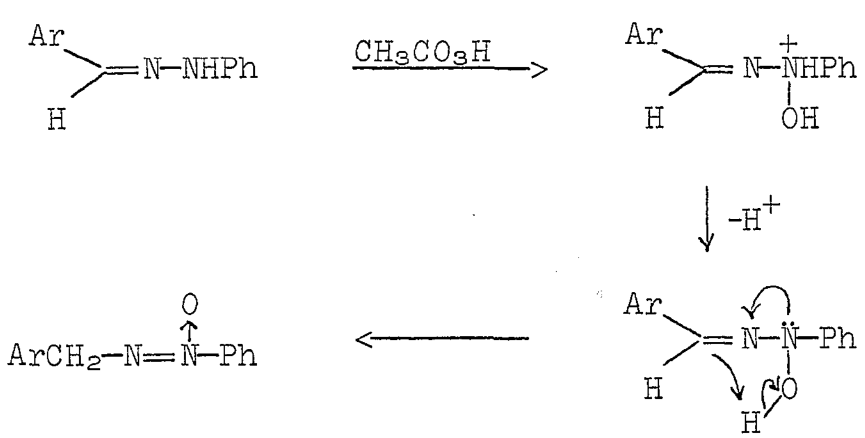


CXLIII

CXXXVII

CXLIV

Figure 7. Mechanism for the peracetic acid oxidation of aliphatic ketone- and aldehyde-N-aryl- and N-alkylhydrazones.



CXLV

Figure 8. Mechanism for the peracetic acid oxidation of aromatic aldehyde phenylhydrazones.

The use of lead tetra-acetate and peracetic acid as reagents for the oxidation of substituted hydrazones has received considerable attention, as is apparent from the preceding discussion. Both reagents are two-electron oxidants, and as such give reactions with hydrazones which might be expected to be somewhat different than the reactions of hydrazones with one-electron oxidants such as cerium(IV). Although manganese dioxide is strictly speaking a two-electron oxidant, many of the reactions which organic compounds undergo with MnO_2 are viewed as a series of one-electron oxidation steps (Mn (IV) → Mn (III) → Mn (II)) involving free radical intermediates.

Recently (113), the oxidation of some ketone phenylhydrazones by MnO_2 in benzene solution has been shown to give the corresponding ketones and biphenyl (CXLVI). Oxidation of aldehyde phenylhydrazones with MnO_2 resulted in the formation of a mixture of oxidative dimers, aldehydes, triazoles, and CXLVI, depending on the reaction conditions (113). The dependence of product formation on temperature is illustrated in the summary shown in Figure 9 for benzophenone and benzaldehyde phenylhydrazones.

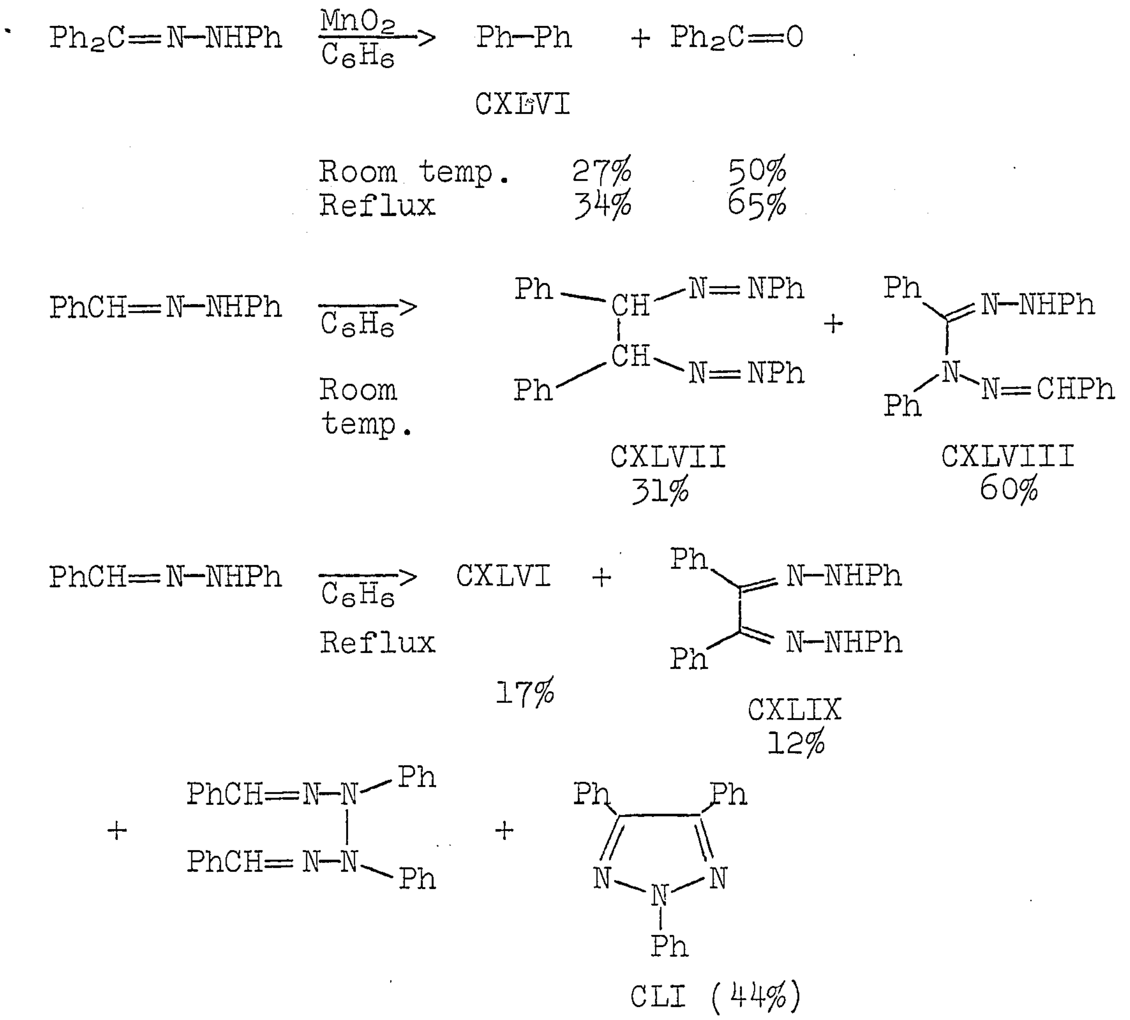
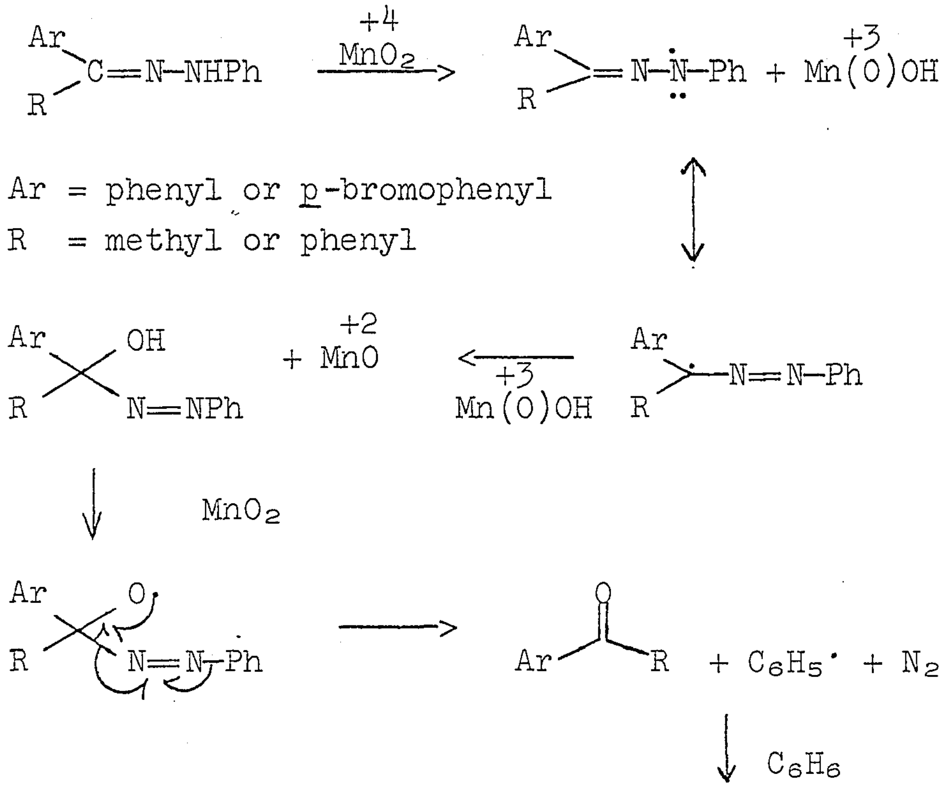


Figure 9. Dependence of product formation on temperature in the manganese dioxide oxidation of benzophenone and benzaldehyde phenylhydrazones.

A mixture of methylbiphenyls was obtained when benzophenone phenylhydrazone was oxidized in toluene, indicating that the origin of CXLVI was by generation of phenyl radical which then reacted with solvent. Identical results were obtained when cumene was used as the solvent for the oxidation.

The mechanism of the oxidation of ketone phenylhydrazones by MnO_2 was viewed as a series of one-electron oxidation steps which led to the formation of ketone, phenyl radical, and nitrogen (113) (see Figure 10). Reaction of phenyl radical with solvent (benzene) gave biphenyl. The mechanism of the oxidation of aldehyde phenylhydrazones was necessarily more



CXLVI

Figure 10. Mechanism for the manganese dioxide oxidation of ketone phenylhydrazones.

complex due to the observation of products which were not formed in the ketone phenylhydrazone oxidations.

The initial oxidation step in the case of the aldehyde phenylhydrazones was viewed as occurring at the β-nitrogen of the hydrazone residue as before (113) (Figure 11). Dimerization of the intermediate radicals produced accounted for the formation of the dimers CXLVII, CXLVIII, and CL. The formation of benzil osazone (CXLIX) resulted from a secondary thermal (or acid-catalyzed) isomerization of the dimer CXLVII initially produced. Benzil osazone (CXLIX) was oxidized with MnO_2 in an effort to determine the origin of the triazole CLI, and was found to give triazole CLI and a small amount of azobenzene (113). The mechanism of oxidation of benzaldehyde phenylhydrazone is summarized in Figure 11. Evidence that the isomerization of CXLVII to CXLIX, and the subsequent oxidation of CXLIX to CLI, were occurring in the reaction came from the oxidation of p-methoxybenzaldehyde phenylhydrazone. At room temperature, the p-methoxy analog of CXLVII was the only reaction product, in 84% yield. At reflux, biphenyl (10%), p-methoxybenzil osazone (12%), and the p-methoxy analog of triazole CLI (7%) were formed. Presumably, p-methoxybenzaldehyde was also formed, since the decomposition of the type shown for the ketone phenylhydrazones to form phenyl radical requires the formation of carbonyl compound.

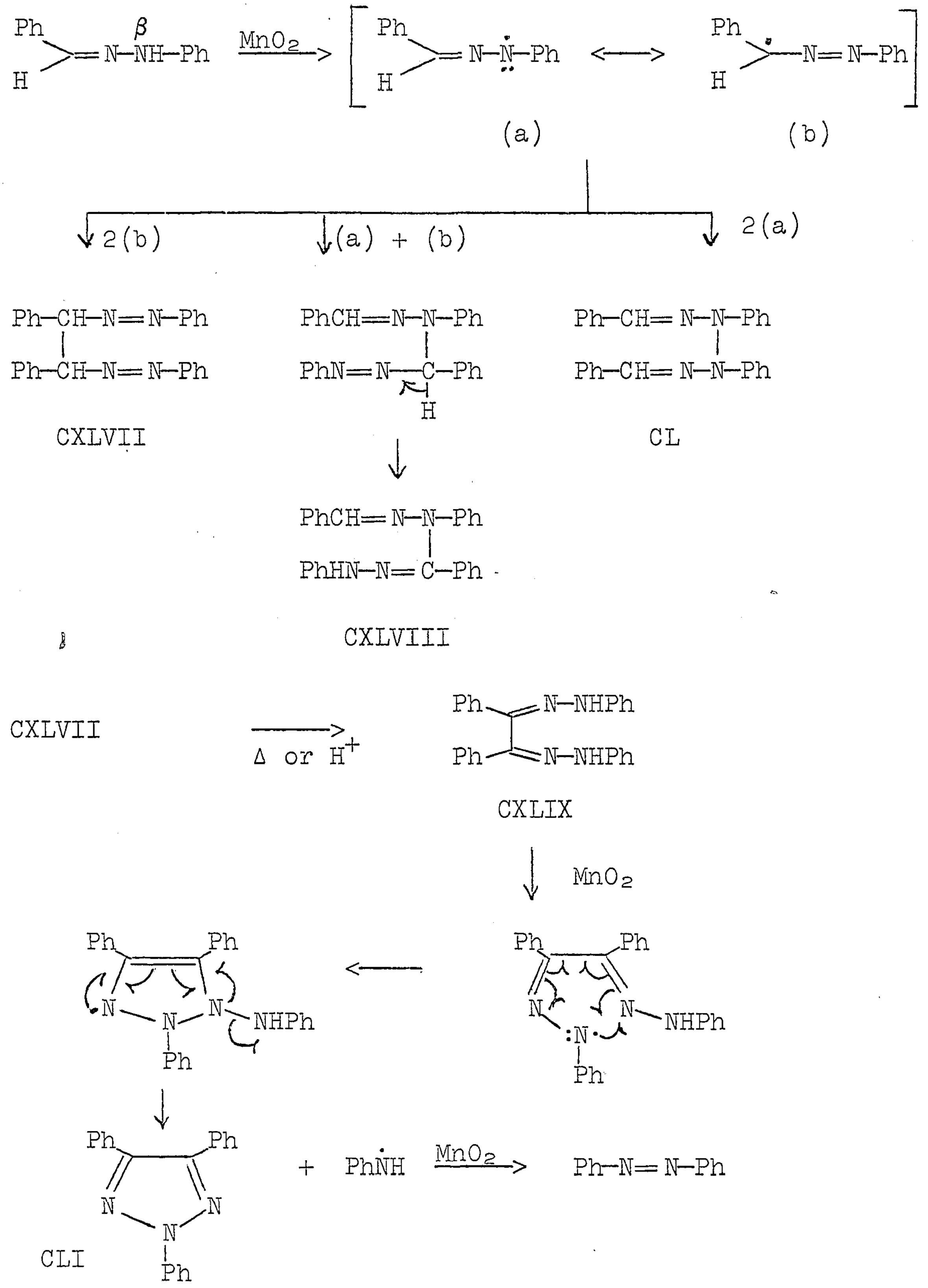


Figure 11. Mechanism for the manganese dioxide oxidation of benzaldehyde phenylhydrazone.

An attempt has been made in the preceding pages to summarize an almost overwhelming volume of chemical literature which relates directly or indirectly to the work to be discussed in later sections. Of necessity, some reports have not been included. Others will be summarized in the following sections as the need arises for analogies to, and precedents for, the reactions of cerium(IV) with oximes and hydrazones, and the reaction of nitric acid with oximes. The results of several of the investigations previously mentioned will be recalled at the appropriate times for illustrative purposes.

RESULTS AND DISCUSSION

The investigation of the oxidation of oximes by cerium(IV) salts came about as an extension of studies on the photochemical conversion of ketoximes to ketones in the presence of nitric oxide (·NO)[1]. In the course of an investigation of the photochemistry of 9-nitroanthracene (CLII) (114), it was found that anthraquinone monoxime (CLIII) was rapidly converted to anthraquinone (CLIV) by irradiation in deoxygenated acetone in the presence of nitric oxide.

Irradiation of 9-nitroanthracene (CLII) in deoxygenated solvent resulted in the isolation of 10,10′-bianthrone (CLV) and anthraquinone (CLIV). When CLII was irradiated in deoxygenated acetone, with the rapid passage of an inert gas through the solution, anthraquinone monoxime (CLIII) was obtained in yields up to 26%, in addition to 10,10′-bianthrone (CLV) in yields up to 81%, and anthraquinone (CLIV) in yields up to 8%. When solutions of CLII were irradiated while ·NO was passed through the solution, anthraquinone was obtained in yields of 55-77%. Small quantities of CLV were also obtained, but the monoxime CLIII was not isolated. Irradiation of 9-nitroanthracene in carbon tetrachloride gave CLV (86%) and anthraquinone (6%). The lower solubility of CLV in carbon tetrachloride than in acetone accounted for the high yields of CLV in that solvent. When oxygen was passed through solutions of CLII

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[1] O. L. Chapman and D. C. Heckert. Photolysis of ketoximes in the presence of nitric oxide. Unpublished observations. Iowa State University of Science and Technology, Ames, Iowa. 1966.

during irradiation, high yields (88%) of anthraquinone were obtained. When 10,10′-bianthrone was photolyzed in the presence of oxygen, high yields (72%) of quinone CLIV were also obtained. The scheme shown in Figure 12 illustrates the known facts concerning the photochemistry of 9-nitroanthracene (114). The nitro → nitrite rearrangement shown in the first step of the scheme has been given ample justification (114).

The conversion of ketoximes to ketones by irradiation in the presence of nitric oxide was found to be a general process[1].

Among the ketoximes which were studied in the reaction were benzophenone oxime (LXXVII), 9-fluorenone oxime (CLVI), methylphenylglyoxal α-monoxime (CLVII), and pinacolone oxime (CLVIII). Benzophenone oxime was found to give nitriminodiphenylmethane (LXXXVI) and benzophenone (CLIX) when irradiated with nitric oxide present. It is worthy of note that the reaction of LXXVII with ·NO in the dark gave the dinitro compound (LXIX), rather than the nitrimine LXXXVI. Irradiation of 9-fluorenone oxime (CLVI) in the presence of ·NO gave 9,9-dinitrofluorene (LXII) and 9-fluorenone (LXIII). Monoxime CLVII yielded predominantly diketone CLX, although some evidence for the formation of acetic acid was obtained. Pinacolone oxime (CLVIII) gave a mixture of pinacolone nitrimine (CLXI) and pinacolone.

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[1] Chapman and Heckert, ibid.

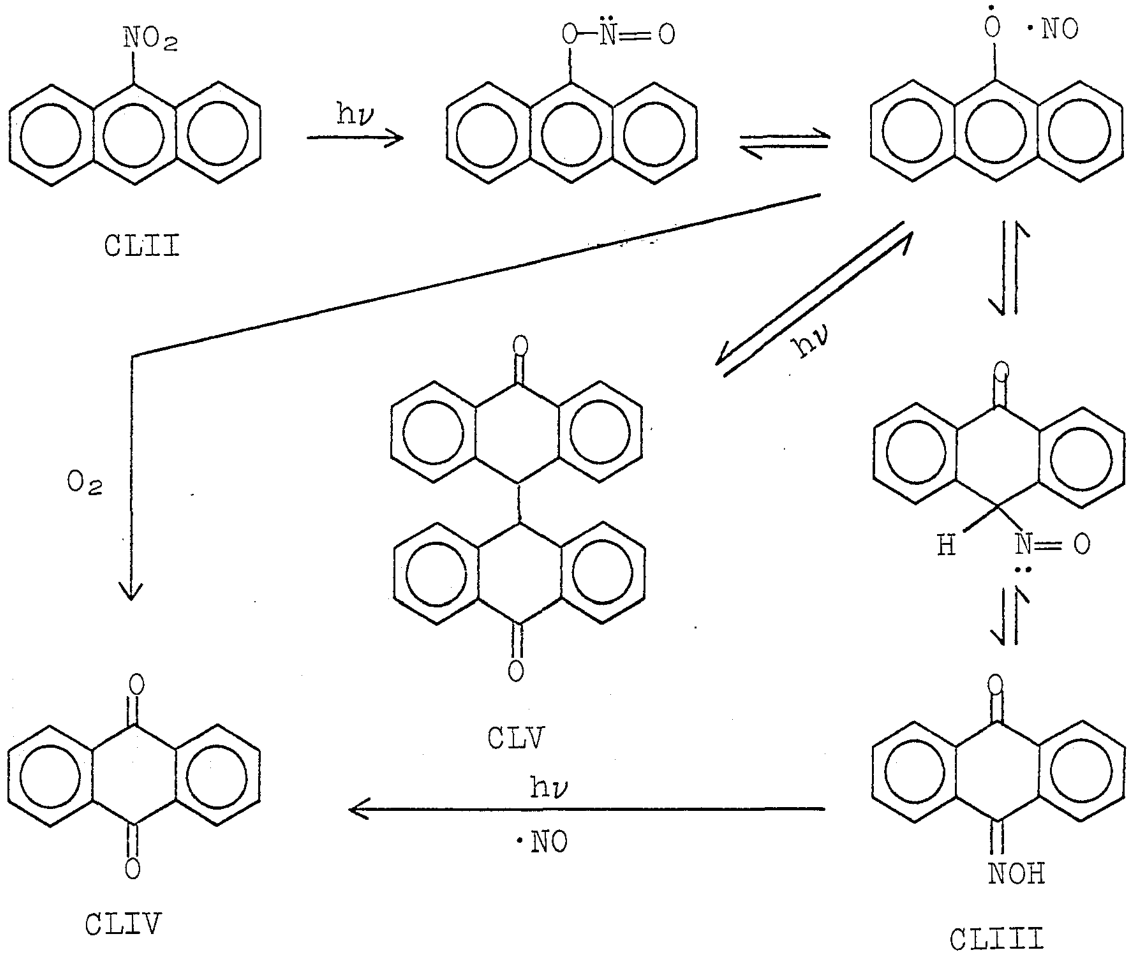
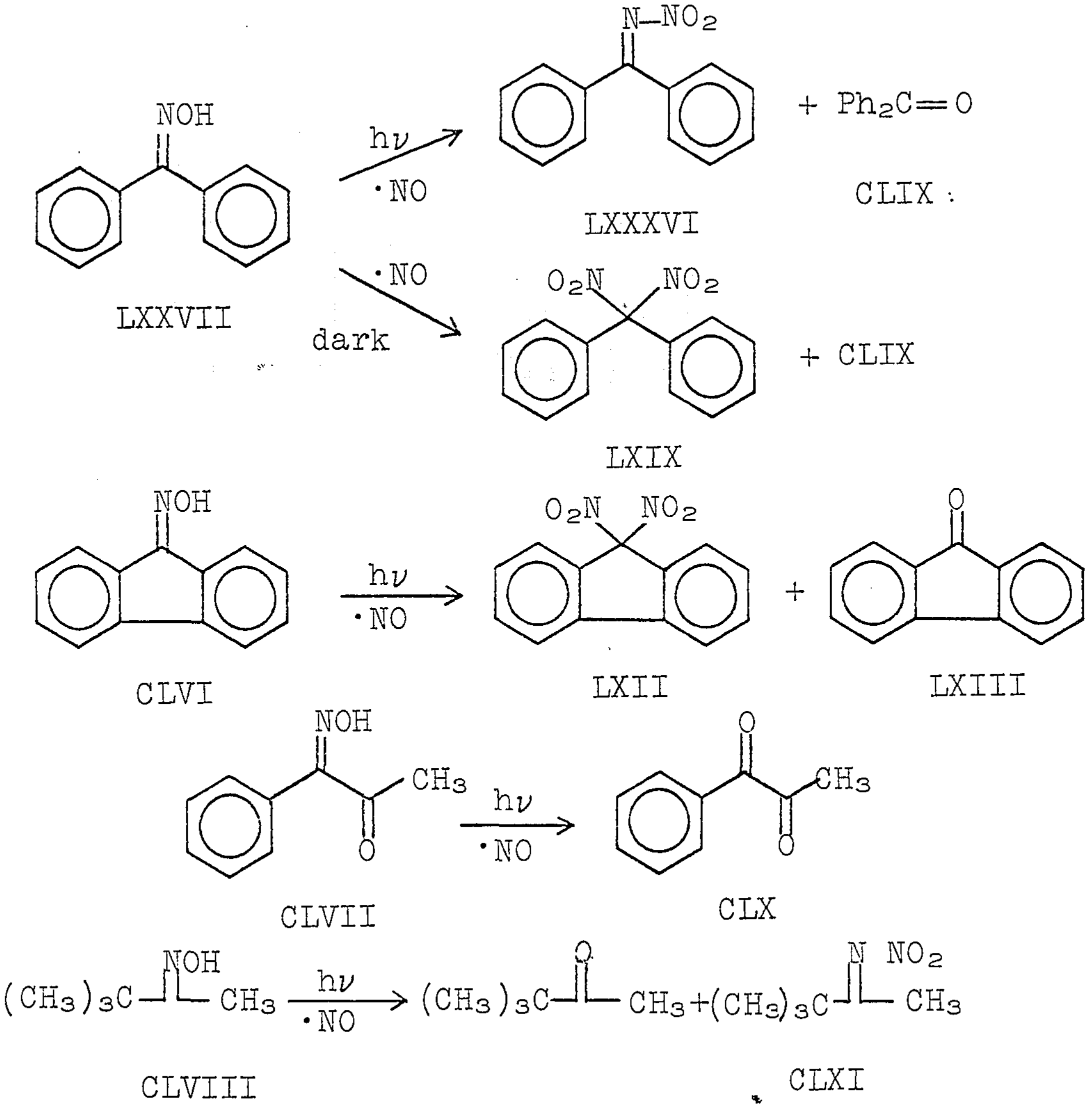


Figure 12. Photochemistry of 9-nitroanthracene (CLII).

In all reactions, the ketones were the major products, and the yields of gem-dinitro compounds or nitrimines were low. Figure 13 summarizes a scheme which has been proposed to account for the reactions of nitric oxide with ketoximes (114).

Irradiation of 9-fluorenone oxime (CLVI) in acetone in the presence of nitric oxide and nitrate-^{15}N labeled ammonium nitrate led to the same products and product ratios as had been observed in the reaction in the absence of labeled nitrate.



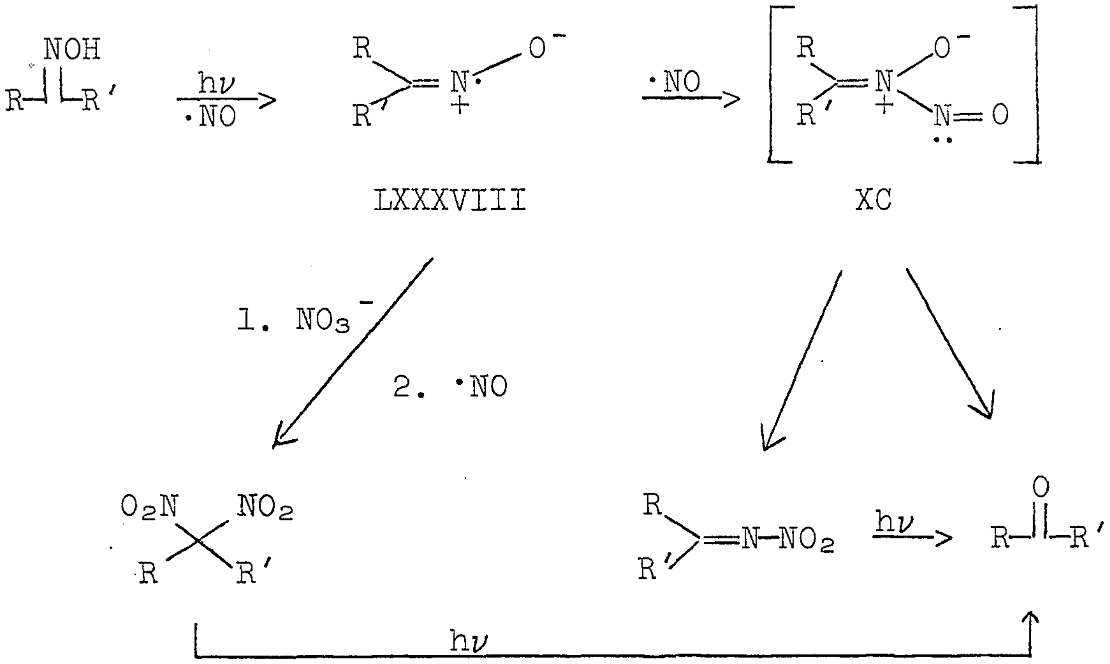


Figure 13. Photochemistry of ketoximes in the presence of nitric oxide.

However, the mass spectrum of the dinitro compound LXII which was isolated from the reaction with ^{15}N-labeled nitrate present indicated that a 14.5% incorporation of ^{15}N into LXII had taken place[1]. Irradiation of solutions of ·NO in acetone, which had been rigorously deoxygenated prior to saturation with ·NO, led to the detection of nitrite ion and nitrate ion in the reaction mixtures (analysis of the salts when the solutions were neutralized with sodium carbonate). No nitrogen dioxide (as N_2O_3) was trapped when the exit gases from the irradiation were passed

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[1] Chapman and Heckert, ibid.

through Dry Ice-acetone traps. The detection of nitrate formation by reaction of ·NO with acetone, and the observed incorporation of ^{15}N into LXII, lend support to the suggestion (114) that nitrate is involved in the formation of gem-dinitro compounds when oximes are irradiated with ·NO in acetone.

An attempt was made to generate an iminoxyl radical from 9-fluorenone oxime (CLVI) by means other than the photochemical nitric oxide oxidation for purposes of a study of the photochemical behavior of the radical once formed. The ceric ammonium nitrate oxidation of CLVI was chosen as a possible means of doing this, since Thomas (76) had shown that iminoxyl radicals were formed when oximes were oxidized by ceric ammonium nitrate. Irradiation of a solution of excess CLVI and ceric ammonium nitrate in methanol was conducted[1]. The ketone LXIII and a small amount of 9,9-dinitrofluorene (LXII) were obtained, in addition to unreacted oxime. It was then found that ketoximes (and aldoximes) react rapidly with ceric ammonium nitrate to form a variety of well-defined products.

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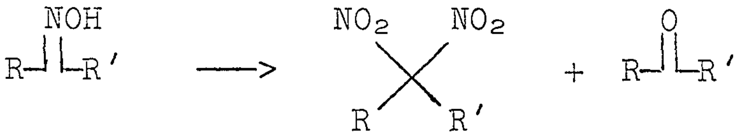
[1] Chapman and Heckert, ibid.

Oxidation of Aryl Ketoximes by Cerium(IV) Salts

General considerations

The oxidation of aryl ketoximes by cerium(IV) salts has been found to result in the formation of a number of stable products. The products formed, and the respective yields, were found to be dependent upon several factors, such as the specific cerium(IV) salt employed as the oxidant, and the solvent in which the reaction was conducted. All reaction mixtures were separable by means of column chromatography using silica gel as the adsorbent. Yields are based on recrystallized products which had satisfactory melting points (or boiling points) and spectroscopic properties. Yields are based on recovered starting material. The use of special apparatus was not required except in those cases where the oxidation was studied in deoxygenated solution.

Ceric ammonium nitrate (CAN) was given extensive study as an oxidant for ketoximes, in an attempt to develop the reaction to a point where it would be of synthetic utility in the production of *geminal*-dinitro compounds. The oxidation of aryl ketoximes with ceric ammonium nitrate generally yielded *geminal*-dinitro derivatives and the parent ketones (Equation 32). To a lesser extent, azine monoxides were obtained. Other



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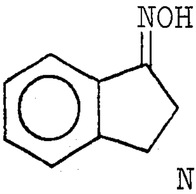
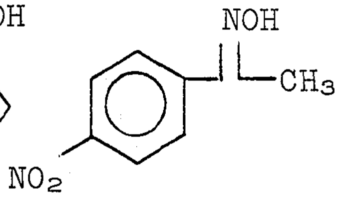
products, such as ring-nitrated ketones, were also formed in some reactions. Ceric potassium nitrate (CPN) was found to give virtually the same ratio of products as was obtained with CAN. Ceric ammonium sulfate (CAS) and ceric sulfate (CHS) were given only limited study as oxidants for aryl ketoximes. Both salts gave ketones and azine monoxides as reaction products. Ceric sulfate was not well-suited as an oxidant in neutral organic solvents due to its extreme insolubility in the solvents employed.

The oxime which was selected for a detailed study in the oxidation reaction with ceric ammonium nitrate was 9-fluorenone oxime (CLVI). The choice of CLVI was governed by the fact that the products, geminal-dinitro compound (LXII), ketone (LXIII), and azine monoxide (CLXII), were stable compounds with relatively high melting points, and were readily separable by column chromatography. In addition, the factors which were observed to influence the formation of 9,9-nitrofluorene (LXII) in the oxidation of CLVI by CAN were the same as those observed to influence the production of geminal-dinitro derivatives from other aryl ketoximes. Investigations of the reactions of other cerium(IV) salts (ceric potassium nitrate, ceric ammonium sulfate, ceric sulfate) with ketoximes were limited to 9-fluorenone oxime, since the interest in the oxidation by salts other than ceric ammonium nitrate was mainly to aid in the determination of some of the gross mechanistic features of the CAN reaction.

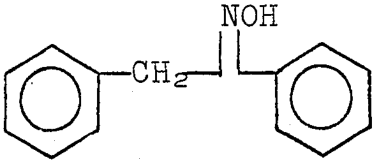
Ten oximes were oxidized by ceric ammonium nitrate under a variety of conditions. Among the ketoximes studied were 9-fluorenone oxime, benzophenone oxime (LXXVII), 1-indanone oxime (CLXIII), p-nitroacetophenone oxime (CLXIV), α-phenylacetophenone (CLXV), acetophenone oxime (CLXVI), p-methylacetophenone oxime (CLXVII), 2,4-dimethylacetophenone oxime (CLXVIII), 9-xanthenone oxime (CLXIX), and anthraquinone monoxime (CLIII).The oximes were found to fall into two categories: 1) oximes which formed geminal-dinitro derivatives on oxidation by ceric ammonium nitrate; and 2) oximes which did not yield gem-dinitro derivatives on oxidation with CAN. Eight of the ten ketoximes investigated gave gem-dinitro derivatives. The two which did not were 9-xanthenone oxime



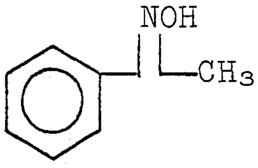
CLXIII



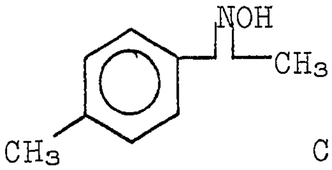
CLXIV



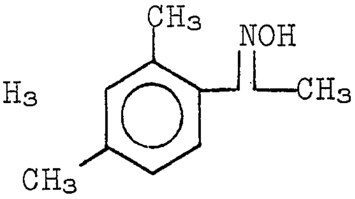
CLXV



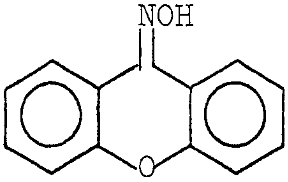
CLXVI



CLXVII



CLXVIII



CLXIX

(CLXIX) and anthraquinone monoxime (CLIII). Consequently, the results of the ceric ammonium nitrate oxidation of CLXIX and CLIII are discussed separately from the rest.

The procedure used for the oxidation of the ketoximes with ceric ammonium nitrate was essentially the same irrespective of the ketoxime being studied. The ketoxime was dissolved in a measured volume of solvent sufficient to dissolve it. A solution of one equivalent of ceric ammonium nitrate in a measured volume of solvent was then added to the ketoxime solution with rapid stirring. The rate of addition of the CAN solution was generally rapid (5-15 seconds), although in some instances slower addition rates were used in an effort to ascertain what effect the rate of addition of CAN had on product ratios. The length of time reaction mixtures were allowed to stir after addition of the reagent was varied depending upon the solvent being used for the specific reaction. With the exception of some reactions involving oxidation of 9-fluorenone oxime with CAN, distinct color changes were observable. The red color of ceric ammonium nitrate was in most cases discharged rapidly to give bright green or blue solutions, the color and intensity of which depended upon the solvent used and the ketoxime being oxidized. After removal of solvent and separation of the organic materials from the inorganic salts, crude reaction mixtures were resolved by column chromatography.

The organic solvents used for the oxidation of aryl ketoximes with ceric ammonium nitrate were methanol and acetone.

The choice of solvents was limited to begin with. First of all, a solvent was needed in which both the ketoxime to be oxidized and the cerium(IV) salt to be used as oxidant exhibited appreciable solubility. Secondly, the inertness of the solvent to oxidation by salts such as ceric ammonium nitrate was important. Methanol has been found to undergo oxidation by cerium(IV) at room temperature at a rate which is difficult to measure due to the slowness of the reaction (25). Although the rate of oxidation of acetone by cerium(IV) is somewhat faster than the rate of oxidation of methanol at room temperature, the reaction has been shown to be slow (33). The cerium(IV) salts of primary interest here, ceric ammonium nitrate and ceric potassium nitrate, both exhibit appreciable solubility in methanol, and, to a lesser extent, in acetone. The problem of solvent oxidation was avoided by preparing solutions of the oxidants in the respective solvents and using the solutions immediately after preparation. When it is considered that the reactions of CAN and CPN with ketoximes were extremely fast reactions, it is reasonable to assume that, at room temperature, the cerium(IV) used in any given reaction was reacting with ketoxime and not solvent. However, secondary solvent oxidation, induced by the initial oxidation of ketoxime by cerium(IV), cannot be discounted.

The yields of geminal-dinitro compounds, ketones, azine monoxides, and other products obtained by the oxidation of aryl ketoximes with ceric ammonium nitrate (CAN) using methanol as solvent are shown in Table 6. The results obtained when 9-fluorenone oxime (CLVI) was oxidized in methanol with ceric potassium nitrate (CPN) are included in Table 6 for purposes of comparison to the CAN reaction. Table 7 summarizes the results obtained when the ketoximes which formed gem-dinitro derivatives on oxidation in methanol were oxidized with ceric ammonium nitrate in acetone solution. Methanol-water was investigated as a possible reaction medium for the oxidation of several ketoximes which were found to give geminal-dinitro compounds with CAN in methanol and acetone solutions. The results of some reactions conducted in 80%-methanol-20% water are summarized in Table 8, page 109. A comparison of the yield data given in Table 6, Table 7 and Table 8 for the respective gem-dinitro compounds indicates that water has a gross effect on the reaction of ketoximes with ceric ammonium nitrate. The yields of the dinitro compounds fall off dramatically when 80% methanol-20% water is used as solvent. The data illustrates at this point the third factor to be considered when a solvent choice is made in which to oxidize ketoximes with CAN: if geminal-dinitro compounds are the desired product, the solvent must be anhydrous.

The reactions

The oxidation of 9-fluorenone oxime (CLVI) in methanol or acetone with one equivalent of ceric ammonium nitrate (CAN) resulted in the formation of 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and 9-fluorenone azine monoxide (CLXII). The average yields of the three products from the reaction in methanol were 33% LXII, 40% LXIII, and 10% CLXII, as shown in Table 6. The highest yield of LXII which was obtained in the room temperature oxidation of CLVI in methanol was 38%. The yields of LXIII and CLXII were 40.6% and 5.8%, respectively, in that reaction. The yield of 9,9-dinitrofluorene (LXII) increased considerably when CLVI was reacted with one equivalent of ceric ammonium nitrate in anhydrous acetone at room temperature. The average yields of LXII and fluorenone (LXIII) for the reaction in acetone were 55.5% and 34.3%, respectively, as shown in Table 7. Azine monoxide CLXII was not formed in appreciable amounts when the oxidation was carried out in acetone solution. In an isolated instance, less than 1% of CLXII was found in the product mixture. Subsequently, it was shown that higher yields of <u>geminal</u>-dinitro compounds and lower (if any) yields of azine monoxides were generally obtained when aryl ketoximes were oxidized with CAN in acetone solution at room temperature than were obtained from the reactions in methanol solution.

Of the eight aryl ketoximes which yielded <u>gem</u>-dinitro derivatives when oxidized by ceric ammonium nitrate in methanol or acetone, the diaryl ketoximes, 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII), were found to give generally cleaner reactions than the other ketoximes. Both CLVI and LXXVII were oxidized in methanol to form azine monoxides, in

Table 6. Oxidation of aryl ketoximes by ceric ammonium nitrate in methanol

		YIELDS (%)[a]				
Oxime	Addition Rate[b]	*geminal*-dinitro compound	Ketone	Azine monoxide	Nitrated ketone[c]	Recovered oxime
9-Fluorenone		33[d]	40[d]	10[d]		
	1 min.	28.3	28.3	21.3		
	1 hr.	26.2[d]	47.2[d]	19.1[d]		
		29[e]	46.8[e]	13.7[e]		
Benzophenone		21.8	46.7	3.1		
1-Indanone		26.8	24.7			
p-Nitroacetophenone		1.4	75.5	3.3		13.5
α-Phenylacetophenone		13	64.3		1.2	
Acetophenone		27	39.6[f]		1[g]	
p-Methylacetophenone		27	50.8[f]			
2,4-Dimethylacetophenone		20	51.1[f]			

[a] Yields based on recovered oxime.

[b] A rapid addition of CAN solution (5-15 seconds) unless otherwise noted.

[c] Nitrated ketone = the *para*-nitrated ketone.

[d] Average yields of two or more reactions.

[e] Ceric potassium nitrate was used as the oxidant.

[f] Yield based on a *p*-nitrophenylhydrazone or a 2,4-dinitrophenylhydrazone derivative.

[g] Crude yield.

Table 7. Oxidation of aryl ketoximes by ceric ammonium nitrate in acetone

	YIELDS (%)[a]			
Oxime	*geminal*-Dinitro compound	Ketone	Azine monoxide	Nitrated ketone[b]
9-Fluorenone	55.5[c]	34.3[c]	---[d]	
Benzophenone	44.2	45.7		2.3
1-Indanone	37.8	36.6		
p-Nitroacetophenone	18.6	71.3		
α-Phenylacetophenone	20.6	52.7		2.3
Acetophenone	25.2	41.8[e]		2-3[f]
p-Methylacetophenone	34.3	48.9[e]		
2,4-Dimethylacetophenone	31.4	39.4		

[a] Yields based on recovered oxime.

[b] Nitrated ketone = *para*-nitrated ketone.

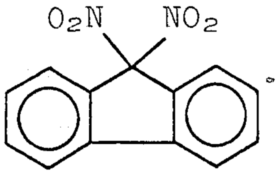
[c] Average yields of two or more reactions.

[d] Azine monoxide isolated in one instance in less than 1% yield.

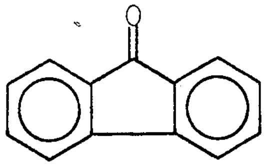
[e] Yields based on a 2,4-dinitrophenylhydrazone or a *p*-nitrophenylhydrazone derivative.

[f] Crude yield.

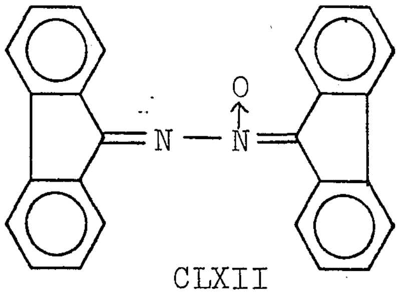
addition to dinitro derivatives and ketones. However, the quantity of benzophenone azine monoxide (LXXVIII) obtained from benzophenone oxime was much smaller than the quantity of CLXII obtained from the oxidation of fluorenone oxime in methanol (Table 6). The recovery of material in the form of well-defined products was also higher from the reactions of fluorenone oxime in methanol than from similar reactions of benzophenone oxime, as is evidenced by a comparison of the data given in Table 6 for fluorenone oxime and benzophenone oxime (reactions involving the rapid addition of one equivalent of CAN to solutions of the respective oximes (83% recovery (average) versus 70% recovery). The recovery of material was high for both diaryl ketoximes (about 90%) when the oximes were oxidized with one equivalent of CAN in acetone solution (Table 7). The yields of gem-dinitro compounds were significantly different in the oxidations in acetone. Benzophenone oxime gave dinitrodiphenylmethane (LXIX) in 44.2% yield and benzophenone (CLIX) in 45.7% yield when oxidized in acetone, as compared to fluorenone oxime, where the dinitro compound LXII was the major product (55.5% LXII to 34.3% LXIII, Table 7). In addition, a small amount of the nitrated ketone, p-nitrobenzophenone (CLXX), was isolated from the reaction of LXXVII with CAN in acetone. Nitrated products similar to CLXX could not be detected in the product mixtures from the oxidation of fluorenone oxime in acetone, or any other solvent or solvent mixture.



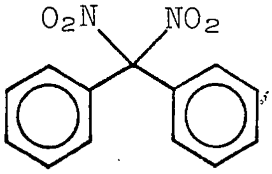
LXII



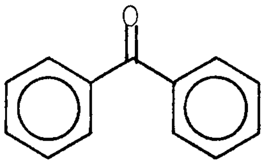
LXIII



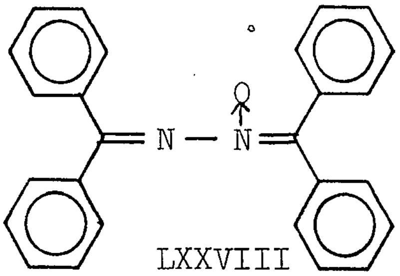
CLXII



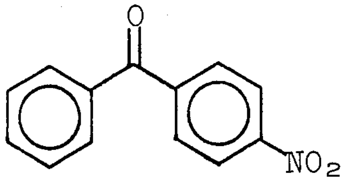
LXIX



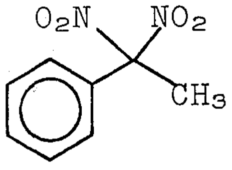
CLIX



LXXVIII



CLXX



LXXII

Arylalkyl ketoximes generally gave lower yields of *geminal*-dinitro compounds than the diaryl ketoximes when oxidized with one equivalent of ceric ammonium nitrate in acetone solution (Table 7). The effect was not as apparent in methanol solution, as can be seen for instance by a comparison of the data summarized in Table 6 for benzophenone oxime and acetophenone oxime (CLXVI). The dinitro compound, 1,1-dinitro-1-phenylethane (LXXII) was formed in slightly greater yield than was dinitrodiphenylmethane (LXIX) from benzophenone oxime (27% for LXXII compared to 21.8% for LXIX). Several other arylalkyl ketoximes were also found to give yields of gem-dinitro compounds which were slightly greater than the yields obtained for LXIX (see Table 6) in methanol. The increase in the yields of dinitro derivatives in going from methanol to acetone as the oxidation solvent were generally not as great for arylalkyl ketoximes as they were for the diaryl ketoximes (about 5-10% for arylalkyl ketoximes versus 20-25% for the diaryl ketoximes, Tables 6 and 7, excluding p-nitroacetophenone oxime).

The recovery of well-defined products from the oxidation of arylalkyl ketoximes with CAN was usually lower than the recovery of the same from reactions of diaryl ketoximes. In addition, oxidation of arylalkyl ketoximes gave product mixtures which were considerably more complex than those obtained from benzophenone oxime and fluorenone oxime. The presence of alpha-hydrogens in the arylalkyl ketoximes probably accounted for the observed complexity of the product mixtures by providing a point of attack for cerium(IV) (or another similar oxidant) other than the oxime group common to all the compounds.

The presence of water in the solvent in which an oxidation was conducted was found to have several effects on product ratios. Not only were the yields of geminal-dinitro compounds reduced, but the yields of ketones and azine monoxides were increased (again, p-nitroacetophenone oxime is excluded from the considerations). The effect can be illustrated by a comparison of the yield data for the oxidation of fluorenone oxime in methanol (Table 6) with the data obtained when 80% methanol-20% water was the solvent for the reaction (Table 8.) The yields of LXII, LXIII, and 9-fluorenone azine monoxide (CLXII) were 33%, 40%, and 10%, respectively, in methanol. In 80% methanol-20% water, the yields of LXII, LXIII, and CLXII were 4%, 53.9%, and 60.9%,[1] respectively. Unreacted oxime was not recovered in the reactions in methanol, whereas a 29.8% recovery of CLVI was realized for the reaction in 80% methanol-20% water. A similar effect of water on the oxidation of benzophenone oxime with CAN was also observed (Table 8), although unreacted oxime was not recovered. If there was oxime remaining in the product mixture, the quantity was too small to allow isolation. The effect of water on the oxidation reaction with ceric ammonium nitrate was not restricted to changes in product yields. Electron spin resonance studies on the iminoxyl radicals produced by the CAN oxidation of fluorenone oxime and benzophenone oxime in a fast-flow system qualitatively indicated that the radicals so produced had significantly longer lifetimes in 80% methanol-20% water than in methanol.

The possibility that oxygen was involved in the formation of _geminal_-dinitro compounds led to the investigation of the oxidation of aryl ketoximes in deoxygenated solutions. The

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[1] The yield CLXII was based on one-half of the oxime which reacted, since the material is a dimer requiring two equivalents of oxime for formation.

Table 8. Oxidation of aryl ketoximes by ceric ammonium nitrate in 80% methanol-20% water

		YIELDS (%)[a]			
Oximes	*geminal*-Dinitro compound	Ketone	Azine monoxide[b]	Other	Recovered oxime
9-Fluorenone	4	53.9	60.9		29.8
Benzophenone	1.2	79.6	8		
p-Nitroacetophenone	<1	56.1	5	--[c]	23.9

[a] Yields based on recovered oxime.

[b] Yields based on one-half of the starting material which reacted.

[c] Two other materials were isolated and partially characterized. See text.

The results of reactions of 9-fluorenone oxime (CLVI), benzophenone oxime (LXXVII), and 1-indanone oxime (CLXIII) with ceric ammonium nitrate in deoxygenated solvents are summarized in Table 9. Reactions were conducted using both prepurified nitrogen and helium as the inert gas in deoxygenation procedures. With the exceptions of the three reactions footnoted in the column headed "Inert gas" in Table 9, the reactions were carried out in a specially designed apparatus (see Experimental, Figure 55, page 469) which allowed simultaneous deoxygenation of solution of the reactants prior to mixing, and which could be sealed immediately upon completing the deoxygenation procedure. Addition of the ceric ammonium nitrate solution to the oxime solution could then be made within seconds after the flow of inert gas through the solutions had been terminated, eliminating the possibility of air leaking back into the system before the reaction was run. The tightness of the apparatus to gas leaks was attested by the fact that in all cases, significant pressure release was noted when the system was opened to the air after extended periods of time (30 minutes to one hour). Helium was chosen as an inert carrier gas due to its availability in a higher state of purity (lower oxygen content) than prepurified nitrogen.

A comparison of the data summarized in Table 9 with that given in Tables 6 and 7 for the oxidation of 9-fluorenone oxime, benzophenone oxime, and 1-indanone oxime in methanol and acetone shows that oxygen has no effect on the formation of <u>geminal</u>-dinitro compounds. Oxidation of 9-fluorenone oxime with CAN in deoxygenated methanol gave LXII in 33.6% (Table 9, line 3), while the reaction in non-degassed solution gave LXII in 33% yield (Table 6). In the reactions of CLVI with CAN in methanol where nitrogen was bubbled through the solutions during the reactions (lines 1 and 2, Table 9), the yields of LXII were not changed significantly (26.2% and 34.8% compared to 33% in non-degassed solution.)

The larger fluctuations in yields in the oxidation of CLVI in going from methanol to deoxygenated methanol were in the yields of azine monoxide CLXII. Azine monoxide CLXII was formed in deoxygenated methanol in somewhat greater amounts (by a factor of ca. 2) than were formed in non-degassed methanol (23.6% and 15.9%, Table 9, lines 1 and 2, and 23.1%, line 3; compared to 10%, Table 6, line 1). The yields of fluorenone showed small decreases (from 40% in methanol to 37.5%, 36.8%, and 33.6% in degassed methanol), but the significance of the decreases is doubtful. Some variation in the yields of LXII and CLXII was noted when the rate of addition of CAN solution to oxime solution was changed for the oxidation in methanol (Table 6). When an addition time of one minute was used for the addition of CAN solution to the oxime solution, yields for LXII, LXIII, and CLXII of 28.3%, 28.3%, and 21.3%, respectively, were obtained. Using an addition time of one hour, the yields of LXII, LXIII, and CLXII were 26.2%, 47.2%, and 19.1%, respectively. The low yield of 9-fluorenone (LXIII) in the reaction involving a CAN addition time of one minute was the result of considerable loss of material on attempted purification of the crude ketone. The crude yield of LXIII in that instance was about 44%. Generally, the lower yields of LXII observed in the isolated case in deoxygenated methanol (Table 9, line 1), and in the reactions where a slower addition rate of oxidant was employed in methanol (Table 6, lines 2 and 3), were not sufficiently different from the yields of LXII in the standard reaction involving rapid addition of CAN in non-degassed methanol to be attributed to any special effect

Table 9. Oxidation of aryl ketoximes by ceric ammonium nitrate in deoxygenated solution

			YIELDS (%)[a]				
Oxime	Solvent	Inert gas	*geminal*-Dinitro compound	Ketone	Azine monoxide[b]	Nitrated ketone	Recovered oxime
9-Fluorenone	Methanol	N_2[c]	26.2	37.5	23.6		
		N_2[c]	34.8	36.8	15.9		
		He	33.6	33.6	23.1		
	Acetone	He	52.4	36.5	1.5		3.5
Benzophenone	Methanol	He	24.9	58.6			
	Acetone	He	45.3	45.4		---[d]	
1-Indanone	Acetone	He	36.2	37.2			
		He[e]	27.7	35.6			

[a] Yields based on recovered oxime.

[b] Yields based on one-half of the oxime which reacted.

[c] Nitrogen was bubbled through the solution during the reaction in an open reaction vessel.

[d] Less than 1% of p-nitrobenzophenone was isolated.

[e] Addition of the ceric ammonium nitrate solution was made dropwise over a 20 minute period; reaction was conducted in an open reaction vessel.

other than small variations in the water content of the methanol being used for solvent.

The oxidation of 9-fluorenone oxime (CLVI) in deoxygenated acetone with ceric ammonium nitrate gave virtually the same yields of LXII and LXIII as were obtained in the reaction in non-degassed acetone. In deoxygenated acetone, LXII and LXIII were formed in 52.4% and 36.5% yields, respectively, (Table 9, line 4), as compared to 55.5% for LXII and 34.3% for LXIII in non-degassed acetone (Table 7, line 1). However, azine monoxide CLXII was formed in 1.5% yield in deoxygenated acetone, whereas only traces, if any, of CLXII were formed in acetone which was not deoxygenated. Some unreacted oxime (3.5%) was also recovered in the deoxygenation experiment in acetone.

The results of the oxidation of benzophenone oxime and 1-indanone oxime with ceric ammonium nitrate in deoxygenated solutions (Table 9) substantiate the fact that oxygen was not required for the formation of geminal-dinitro derivatives. Oxidation of benzophenone oxime in degassed methanol gave dinitrodiphenylmethane (LXIX) and benzophenone in 24.9% and 58.6% yields, respectively, as compared to yields of 21.8% for LXIX and 46.7% for the ketone from the reaction in non-degassed solution. Small amounts of benzophenone azine monoxide (LXXVIII) and unreacted oxime LXXVII were detected in the product mixture from the degassing experiment, but the materials could not be isolated due to the small quantities present.

Oxidation of LXXVII in deoxygenated acetone gave yields for LXIX and CLIX of 45.3% and 45.4%, respectively (yields in non-degassed solution: LXIX, 44.2%, and CLIX, 45.7%; Table 7, line 2). Less than 1% of p-nitrobenzophenone (CLXX) was isolated from the product mixture. Evidence for the presence of azine monoxide LXXVIII in the product mixture was not obtained.

The oxidation of 1-indanone oxime (CLXIII) with CAN in degassed acetone gave 1,1-dinitroindane (CLXXI) and 1-indanone (CLXXII) in 36.2% and 37.2% yields, respectively (Table 9, line 7). The reaction in non-degassed acetone gave CLXXI and CLXXII in yields of 37.8% and 36.6%, respectively (Table 7, line 3). As was the case in other solvents (methanol, acetone), the oxidation of CLXIII with CAN in deoxygenated acetone gave only two well-defined products, CLXXI and CLXXII. Considerable amounts of gums and oils accounted for the remainder of the product mixtures in reactions involving CLXIII, which resisted all efforts at characterization.

Concentration effects in the oxidation of aryl ketoximes with ceric ammonium nitrate were investigated within a narrow range of concentrations due to the fact that deoxygenation studies were conducted using more dilute oxime solutions than were used in reactions in non-degassed solution. At concentrations of 9-fluorenone oxime (CLVI) of 0.0625 M, oxidation using a standard 0.25 M solution of ceric ammonium nitrate in methanol gave product yields which were virtually identical to those obtained when an 0.125 M solution of CLVI was treated with an

0.25 M solution of CAN. When the concentration of oxime solution was 0.125 M in CLVI, reaction with solutions of CAN which were either 0.25 M or 1.00 M resulted in the same product yields. The lack of effect of initial oxidant concentration was to be expected, since solutions of CAN were added to oxime solutions in one portion in all instances. Product yields from the oxidation of benzophenone oxime were also unchanged within the concentration ranges given above for 9-fluorenone oxime and CAN. The concentration range studied was narrow, but the lack of effect within that narrow range justified any comparison between the results of any two reactions which were run using slightly different concentrations either of oxidant or oxime.

Oxidation of 9-fluorenone oxime (CLVI) with ceric ammonium nitrate in methanol at 0° resulted in the isolation of 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and 9-fluorenone azine monoxide (CLXII) in yields of 38.5%, 35.1%, and 13.9%, respectively (Table 10) (compared to average yields of 33% for LXII, 40% for LXIII, and 10% for CLXII in the reaction at room temperature). The highest yield of LXII which was obtained in the room temperature oxidation was 38%, as mentioned previously. A comparison of the data indicates that the change in temperature from room temperature (22-27°) to 0° had little effect on the reaction. Heckert[1] had previously oxidized CLVI

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[1] Dr. David Heckert. Private communication, final report. Iowa State University of Science and Technology, Ames, Iowa. 1966.

in methanol with CAN at -50° (Dry Ice-acetone). A yellow solid was filtered from the reaction mixture which was shown by an infrared spectrum to be predominantly 9-fluorenone. On standing for a short time, the solid decomposed with the evolution of nitrogen oxides of undescribed nature, and the remaining material was found to be almost pure fluorenone.[1] Fluorenone (major) and LXII (minor) were reported as the reaction products, but yield data for the two compounds was not available.

Reactions of 9-fluorenone oxime with ceric ammonium nitrate in the presence of added nitrate, nitric acid, and ammonium hydroxide were conducted. Benzophenone oxime was also oxidized with CAN in the presence of nitric acid. The results of the reactions are summarized in Table 10. Oxidation of CLVI with one equivalent of CAN in the presence of one equivalent of ammonium nitrate gave yields of LXII, LXIII, and CLXII of 26.9%, 45%, and 15.7%, respectively. The reaction was performed on a small scale using nitrate-^{15}N labeled ammonium nitrate in an attempt to ascertain whether ^{15}N incorporation into LXII occurred during the reaction. The results concerning ^{15}N incorporation are discussed in a later section. Oxidation of CLVI with CAN in methanol containing four equivalents of lithium nitrate gave yields for LXII, LXIII, and CLXII of 30.5%, 45.5%, and 11.5%, respectively, indicating that added nitrate had no effect on the reaction.

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[1] Heckert, ibid.

Table 10. Oxidation of aryl ketoximes by ceric ammonium nitrate: effect of temperature, acid, base and added nitrate

				YIELDS (%)[a]			
Oxime	Solvent	Salt, acid, or base[b]	Temp.[c]	geminal-dinitro compound	Ketone	Azine monoxide[d]	Recovered oxime
9-Fluorenone	Methanol		0°	38.5	35.1	13.9	
	Methanol	NH_4NO_3 (1)		26.9	45	15.7	
	Methanol	$LiNO_3$ (4)		30.5[e]	45.5[e]	11.5[e]	
	90% Acetone-10% Water			46.6	35.9	8.2	
	90% Acetone-10% Water	NH_4NO_3 (1)		44.3	37.9	8.9	
	Methanol	HNO_3 (4)		7.7	54.2	23.5	46
	Methanol	NH_4OH (2)			52	5	59
Benzophenone	Methanol	HNO_3 (4)		1.1	76.3	2	1
1-Indanone	Methanol	NH_4NO_3 (1.2)		25.3	59[f]		

[a] Yields based on recovered oxime.

[b] Number in brackets = the equivalents of material per equivalent of oxime oxidized.

[c] Reactions conducted at room temperature unless otherwise noted.

[d] Yields based on one-half of the oxime which reacted.

[e] Results obtained by Dr. David Heckert, Iowa State University, Ames, Iowa, 1966

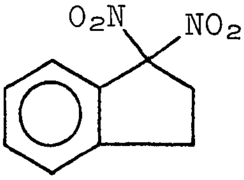
[f] Yield based on the 2,4-dinitrophenylhydrazone derivative.

Oxime CLVI was oxidized by CAN in 90% acetone-10% water to ascertain the effect of water on product yields in acetone solution. The yields of LXII, LXIII, and CLXII were 46.6%, 35.9%, and 8.2%, respectively. The same reaction with one equivalent of ammonium nitrate added to the solution gave yields for LXII, LXIII, and CLXII of 44.3%, 37.9%, and 8.9%, respectively. The added ammonium nitrate had no effect on the reaction. Water was found to have an effect on the reaction similar to that observed for the oxidation in methanol, but the effect was not as great. The yields of LXII in anhydrous acetone were about 55% (Table 7), as compared to about 45% in 90% acetone-10% water. Although the reactions in aqueous methanol (Table 8) were performed using 80% methanol-20% water as solvent, a smaller amount of water (10%) in the methanol gave yields which were nearly identical to those obtained when 20% of the solvent was water. The other effect of water in the reaction in acetone solution was to increase the yield of azine monoxide CLXII from approximately zero (Table 7) to about 8.5% (Table 10). A similar effect of water was observed when aqueous methanol was the solvent, as a comparison of Table 6 with Table 8 shows. A six-fold increase (from 10% to about 61%) in the yield of CLXII was observed in that instance.

Nitric acid had similar effects on the oxidation of 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII) with CAN in methanol. The oxidation of CLVI in methanol containing four equivalents of nitric acid resulted in yields for LXII, LXIII, and CLXII of 7.7%, 54.2%, and 23.5%, respectively. Oxime CLVI was recovered from the reaction in considerable quantity (46% recovery, Table 10), which was partially an effect of water in the nitric acid. The yield of CLXII increased by a factor of about two (from 10% in anhydrous methanol to 23.5%) in the presence of nitric acid, which could again be viewed as an effect of water. The higher recovery of CLVI (46%) from the reaction with added nitric acid than from the reaction in aqueous methanol (Table 8, 29.8%) suggested however that nitric acid was influencing the reaction in ways other than just being a source of water. Benzophenone oxime (LXXVII) gave yields of dinitrodiphenylmethane (LXIX), benzophenone (CLIX), and benzophenone azine monoxide (LXXVIII) of 1.1%, 76.3%, and 2%, respectively, when oxidized with CAN in the presence of nitric acid. In addition, about 1% of LXXVII was recovered. The yield of LXIX was much lower than was observed in methanol in the absence of nitric acid (1.1% compared to 21.8% in methanol), but the yields in the reaction were about the same as those which were obtained when LXXVII was oxidized in 80% methanol-20% water (Table 8, 1.2% LXIX, 79.6% CLIX, and 8% LXXVIII). The fact that some of the oxime LXXVII was isolable from the product mixture indicated that again water was not the only influencing factor in the oxidation in the presence of nitric acid. Oxime LXXVII was generally quite difficult to recover due to facile decomposition by light in air to form benzophenone. The recovery of only 1% of LXXVII is misleading in respect that ca. 2-4% more of the oxime was present in a chromatography fraction which was decomposed to benzophenone before isolation could be completed. One potential effect that nitric acid might have had on the oxidation was oxime protonation which would inhibit initial cerium(IV)-oxime complex formation and thus inhibit oxime oxidation. The gross effect, however, appeared to be one of water rather than nitric acid itself.

Oxidation of 9-fluorenone oxime (CLVI) in methanol in the presence of two equivalents of ammonium hydroxide resulted in very complex reactions. The recovery of materials from the reaction was characteristically poor, regardless of variations in the work-up. The geminal-dinitro compound LXII was not formed in the reactions. Fluorenone (LXIII) and azine monoxide CLXII were formed in yields of 52% and 5%, respectively, while a 59% recovery oxime was obtained (Table 10, line 7). The results shown in Table 10 were obtained in a reaction where a solution of CLVI, two equivalents of ammonium hydroxide, and one equivalent of CAN, was stirred for 22 hours at room temperature. Shorter reaction times (20 minutes and 4 hours) gave virtually identical results. Solutions of oxime and ammonium hydroxide when treated with CAN immediately formed red-brown precipitates which could not be induced to redissolve. Ceric ammonium nitrate in methanol when treated with ammonium hydroxide gave a similar precipitate. The formation of various cerium(IV) oxides and alkoxides which were insoluble in methanol presumably accounted for the observed precipitates, and for the failure of ceric ammonium nitrate to oxidize CLVI with the facility observed in the absence of ammonium hydroxide. It is known that strongly complexing ligands stabilize the higher valence state of a metal ion relative to the lower valence state (115). Hydroxide ion was apparently serving in that capacity at least in part when the attempt to oxidize CLVI with cerium(IV) in the presence of ammonium hydroxide was made. The poor recovery of materials cannot be accounted for.

The final entry in Table 10 summarizes the results obtained when 1-indanone oxime (CLXIII) was oxidized with CAN in the presence of nitrate-^{15}N labeled ammonium nitrate. The reaction was performed on a small scale as a part of the experiments concerning ^{15}N incorporation into <u>geminal</u>-dinitro compounds from labeled nitrate. The results concerning ^{15}N incorporation are discussed in a later section. The yield of 1,1-dinitroindane (CLXXI) in the reaction was essentially the same as was



CLXXI

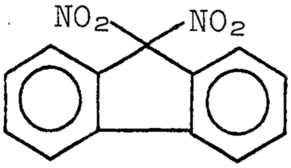
obtained in the oxidation of CLXIII in methanol in the absence of added nitrate (26.8%, Table 6, line 6). The yield (59%) of 1-indanone in the reaction was the highest obtained in any oxidations involving CLXIII. The yield was based on the 2,4-dinitrophenylhydrazone derivative of the ketone, which was prepared from a chromatography fraction the infrared spectrum of which had indicated that the fraction was practically pure ketone. Preparation of the derivative was carried out because of the small quantity of ketone present and difficulty in inducing crystallization. The presence of another material in the fraction, which reacted to form 1-indanone 2,4-dinitrophenylhydrazone when treated with the hydrazine reagent, cannot be discounted. The important fact concerning the reaction at this point is that added nitrate did not influence the yield of dinitro compound CLXXI to any extent. Anthraquinone monoxime (CLIII) and 9-xanthenone oxime (CLXIX) did not give *geminal*-dinitro compounds when oxidized by ceric ammonium nitrate in methanol or acetone. The products and the respective yields of the reactions of anthraquinone monoxime and 9-xanthenone oxime are shown in Table 13, page 217. Discussion of the factors influencing the oxidation of CLIII and CLXIX by ceric ammonium nitrate is conveniently deferred until that point where the evidence for the structures of products is presented.

The products

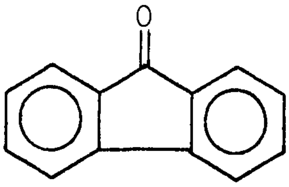
The oxidation of 9-fluorenone oxime (CLVI) with ceric ammonium nitrate in anhydrous methanol or acetone results in the formation of 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and 9-fluorenone azine monoxide (CLXII). The yields of LXII were higher in acetone solution than in methanol solution. The yield of LXII was drastically reduced when CLVI was oxidized with CAN in aqueous methanol, while the yield of azine monoxide CLXII was significantly increased. The effect of water was found to be somewhat less in the oxidation of CLVI in acetone, although the effect was qualitatively the same as was observed in methanol. Yields of 9-fluorenone (LXIII) were slightly lower in acetone than in methanol, and were not as strongly affected by factors such as added water as were the yields of LXII and CLXII. The yields of LXIII increased when yields of LXII were reduced by added water.

The dinitro compound, 9,9-dinitrofluorene (LXII), was isolated as very light yellow, finely-divided needles, m.p. 139-140° (dec.) after several recrystallizations from hexane. The compound was stable at room temperature in the dark, but was slowly decomposed upon exposure to light with the evolution of nitrogen dioxide. The compound decomposed at its melting point with the evolution of nitrogen dioxide. On cooling a sample of LXII which had been heated above the melting point, new yellow crystals were obtained which melted in the range of 155-65°, suggesting that some 9-nitrofluorene (m.p. 177-8°) was formed from the decomposition of LXII. Purification of LXII could be performed readily by recrystallization from hexane (b.p. 60°). The use of solvents, such as methanol or heptane, with boiling points higher than hexane led to extensive decomposition of LXII on recrystallization. Extensive heating of solutions of LXII in any solvent led to the decomposition of LXII to form $\cdot NO_2$ and unidentified materials.

The infrared spectrum of LXII (KBr, Figure 16, page145) showed absorptions due to the nitro groups at 6.41 μ and 7.40μ. The peak at 6.41μ was about twice as intense as the 7.40μ. The infrared spectra of other geminal-dinitro compounds showed absorptions in the ranges of 6.35-6.50μ and 7.35-7.50μ also, with nearly identical intensity relationships to that shown in the spectrum of LXII. The solubility of LXII in chloroform was quite limited. The nuclear magnetic resonance (n.m.r.) spectrum of LXII in deuteriochloroform (saturated solution) showed only aromatic protons. The general shape of the aromatic splitting pattern was exactly as expected for an ortho-disubstituted aromatic compound. The mass spectrum gave a molecule ion at m/e 256 and fragmentation which was consistent with 9,9-dinitrofluorene (LXII, $C_{13}H_8N_2O_4$). The mass spectral data for LXII is summarized in Table 15, page 291. The fragmentation observed will be discussed with the mass spectra of other geminal-dinitro compounds.



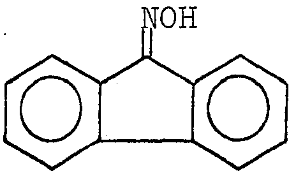
LXII



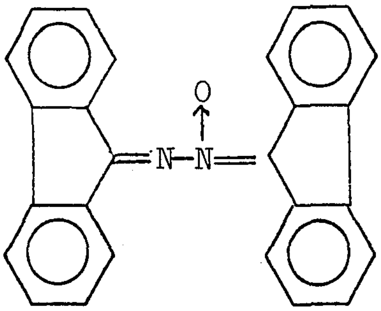
LXIII

The ketone LXIII was isolated as a solid and characterized by the i r spectra. In every case, the i r spectrum of the sample of LXIII in question was compared to the i r spectrum of an authentic sample of the ketone. In a number of reactions, reasonably pure LXIII was obtained directly from a chromatography column. Mixed melting points with authentic 9-fluorenone were found to give no depression. In reactions where the ketone was not obtained in an acceptable state of purity, the material was recrystallized from either a minimum amount of ethanol or an ethanol-benzene mixture until a satisfactory melting point was obtained.

Complete separation of 9-fluorenone azine monoxide (CLXII) and 9-fluorenone oxime (CLVI) was not always obtained in the reactions where CLXII was formed and unreacted CLVI remained in the product mixture. The difference in the solubilities of CLXII and CLVI in chloroform provided a means by which the two compounds could be separated. Recrystallization of chromatography fractions containing both materials from chloroform gave 9-fluorenone oxime (CLVI) essentially free of CLXII, with a satisfactory melting point. Mixed melting points were performed in some cases to insure that the compound was unreacted CLVI. Azine monoxide CLXII was then isolated by recrystallization of the remaining material from ethanol to give a red solid which was free from oxime CLVI.



CLVI



CLXII

Fluorenone azine monoxide (CLXII) was isolated as a product from a number of different oxidation reactions of CLVI with cerium(IV) salts. Azine monoxide CLXII is a bright red or red-orange solid depending upon the particle size of the crystals. The compound could be purified by recrystallization from ethanol to give red needles, m.p. range 172-175°. The authentic compound was prepared from 9-fluorenone azine by oxidation of the azine with peracetic acid in cold chloroform solution, a technique which was developed by Horner and coworkers (116) for the preparation of azine monoxides. The authentic material had a melting point of 174-5° and other physical properties which were identical to CLXII isolated from the cerium(IV) oxidations of CLVI. A mixed melting point of CLXII, m.p. 174-5°, with authentic azine monoxide, m.p. 174-5°, gave no depression (m.m.p. 174-5°).

The infrared (i r) spectrum of CLXII (KBr) is shown in Figure 20, page 153. The important features of the i r.

spectrum are the absorptions at 6.50μ and 7.94μ. Horner (116) found that azine monoxides generally showed i.r. absorptions in the 6.40-6.45μ and 8.0μ regions of the spectrum, which were attributed to various vibrational modes of the $C=\overset{+}{N}<^{O^-}$ grouping. The observation of similar absorptions in the i.r. spectrum of CLXII further substantiated the structure shown. The n.m.r. spectrum of CLXII ($CDCl_3$) showed only the expected absorptions due to aromatic protons. The mass spectrum gave a molecule ion at m/e 372 and fragmentations which were consistent with the structure CLXII ($C_{26}H_{16}N_2O$). The mass spectral data for CLXII is summarized in Table 19, page 315, and will be discussed with the mass spectra of other azine monoxides.

The azine monoxide CLXII partially precipitated from reaction mixtures where CLVI was oxidized with cerium(IV) salts in methanol and in methanol-water. Secondary oxidation of CLXII by cerium(IV) could not be discounted though because the material partially precipitated from solution when formed. The possibility of oxidation of CLXII by cerium(IV) was confirmed in part by the results obtained when fluorenone oxime (CLVI) was reacted with two equivalents of ceric ammonium nitrate in methanol. When the CAN solution was rapidly added to the oxime solution, a bright yellow precipitate formed, rather than the red-orange precipitate observed when one equivalent of CAN was used. The results were as follows: LXII, 27.8%; LXIII, 66.1%; and CLXII, 3%. The results should be compared to the reactions of one equivalent of CAN with CLVI

(Table 6, lines 1-3). The yield of CLXII was lowered considerably, while the yield of 9-fluorenone (LXIII) showed a considerable increase. Formation of 9,9-dinitrofluorene (LXII) was apparently not grossly affected by the excess CAN used in the reaction, since the yield for LXII of 27.8% was within the range observed (26-38%) for reactions in anhydrous methanol with one equivalent of CAN. Oxidation of CLXII with ceric ammonium nitrate was investigated using acetone as the solvent for the reaction, since CLXII exhibited somewhat greater solubility in acetone than in methanol. A slurry of CLXII (in acetone) was treated with one equivalent of CAN. The remaining azine monoxide immediately dissolved to give a dark red solution. The reaction mixture was given the same work-up as used for oxime oxidations, and the product mixture was separated on a silica gel column. Fluorenone (LXIII) was obtained in 71.1% yield, in addition to a 39.4% recovery of CLXII. Traces of 9,9-dinitrofluorene (LXII) were detectable in the early chromatography fractions, but the quantity was too small to allow isolation. The oxidation of CLXII by ceric ammonium nitrate may account in part for why CLXII was not formed in significant amounts when oxime CLVI was oxidized by CAN in anhydrous acetone. The stoichiometry of the oxidation of CLXII with CAN in acetone was not determined, but it is interesting to note that the aqueous solution obtained in the work-up was completely colorless. Ceric ammonium nitrate imparts a distinct orange color to water solutions of the material, and is visually detectable in fairly small concentrations in water.

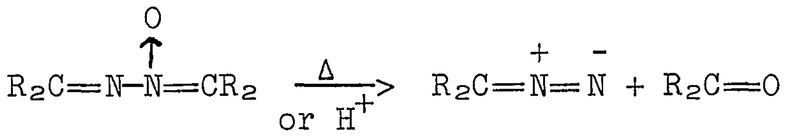
The dinitro compound LXII also partially precipitated from solution upon formation in the oxidation of CLVI with CAN in methanol. The possibility of a cerium(IV)-induced decomposition of LXII was checked by treating a slurry of LXII in methanol with one equivalent of ceric ammonium nitrate. A slurry of LXII in methanol was used in an attempt to approximate as closely as possible the conditions present in an oxime oxidation reaction. The dinitro compound LXII was recovered nearly quantitatively from the reaction (about 96%). The recovered material had an i.r. spectrum which was identical to that of authentic LXII, in addition to a satisfactory melting point (m.p. 136-8° (dec)). Dinitro compound LXII was stable to the conditions of the oxidation of oxime CLVI in methanol.

In order to qualitatively determine whether the nitrate in ceric ammonium nitrate was the origin of a nitro group in 9,9-dinitrofluorene (LXII), the oxidation of 9-fluorenone oxime (CLVI) with ceric ammonium sulfate (CAS) was conducted. The products of the oxidation of CLVI with CAS were 9-fluorenone (LXIII) and 9-fluorenone azine monoxide (CLXII) in yields of 46.7% and 45.8%, respectively. None of the dinitro compound LXII was detectable in the product mixture. A 62% recovery of oxime CLVI was also obtained in the reaction. However, the solubility of ceric ammonium sulfate in methanol required that the reaction be run in aqueous methanol. The effect of water in lowering the yields of LXII in the CAN oxidation of CLVI has already been discussed. Although no LXII was detected when CLVI was oxidized by CAS, the results could not be used as conclusive evidence for the involvement of nitrate ion in dinitro compound formation due to the aqueous medium used for the reaction. Another reaction was run using aqueous methanol. An i r spectrum of the crude product mixture from the reaction showed that ketone LXIII, unreacted oxime CLVI, and azine monoxide CLXII, but no LXII, were present in the mixture. A slurry (due to the insolubility of the oxime) of the product mixture in benzene (ca. 50 ml.) was then allowed to stand for six weeks on the desk top prior to chromatography. Over the six week period, the oxime CLVI slowly dissolved in the solution, accompanied by a slow loss of the deep red color of azine monoxide CLXII. The faint odor of $\cdot NO$ or $\cdot NO_2$ became noticeable over the solution after several weeks. At the end of six weeks, the orange solution was warmed to dissolve all remaining solids, and the solution was chromatographed in the normal manner. The materials isolated from the column were 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and azine monoxide CLXII in yields of 31.7%, 58.2%, and ca. 1%, respectively. The dinitro compound was identical in all respects to LXII isolated from the oxidations of CLVI with ceric ammonium nitrate. Oxime CLVI was not recovered, and was not detected at any point in the work-up of the reaction. The small amount of azine monoxide CLXII isolated was quite impure. In addition, a trace amount of a tan solid, m.p. 205-210°, was obtained in the chromatography which was not characterized beyond its melting point.

The formation of LXII by what was apparently a reaction between oxime CLVI and azine monoxide CLXII was investigated further. A slurry of 9-fluorenone oxime (CLVI) and 9-fluorenone azine monoxide (CLXII) in benzene was prepared and was allowed to stand on the desk top at room temperature for five weeks in an attempt to approximate as closely as possible the conditions present previously. Control solutions containing CLVI and CLXII were prepared and allowed to stand for five weeks under the same conditions. After five weeks, the mixture of CLVI and CLXII was chromatographed. A fraction (0.01 g.) was obtained which showed absorptions at 4.86μ and 5.85μ in the infrared ($CHCl_3$), and which were assigned to 9-diazofluorene and 9-fluorenone, respectively. The i r spectrum ($CHCl_3$) (Figure 52) of authentic 9-diazofluorene showed a strong absorption at 4.86μ, which supported the assignment of the absorption in the spectrum of the fraction to that compound.

A second fraction containing practically pure 9-fluorenone (0.008 g.) was obtained (as shown by an i r spectrum). Oxime CLVI (86.8% recovery) and azine monoxide CLXII (88.6% recovery) accounted for nearly all of the remaining material recovered from the column. A trace (0.006 g.) of brown gum was isolated when the column was stripped with methanol, which was not characterized further. The *gem*-dinitro compound LXII was not detected in the fractions. The control solution containing oxime CLVI was found to contain only oxime after five weeks (i.r analysis, melting point, and mixed melting point). The control solution containing azine monoxide CLXII was found to contain only CLXII (i r analysis, melting point, and mixed melting point).

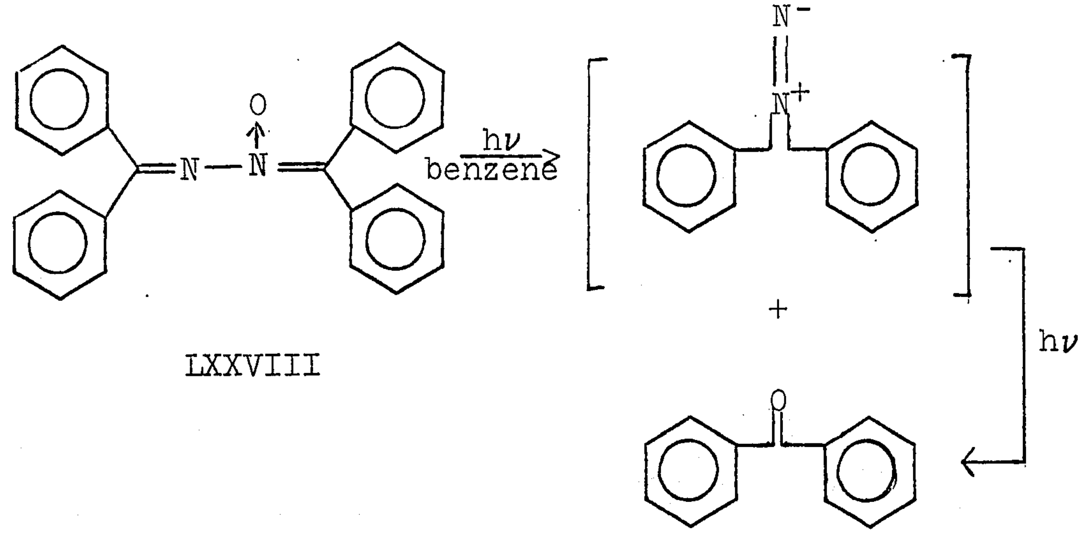
An attempt was made to decompose 9-fluorenone azine monoxide (CLXII) by refluxing a solution of the compound in benzene for 4 hours. The azine monoxide was recovered unchanged from the experiment. Benzophenone azine monoxide (LXXVIII) and several aldazine monoxides are known to rearrange on heating in solution to the respective diazo compounds and carbonyl compounds (Equation 33)(116). The suggestion has been made that the rearrangement occurs by way of an intermolecular



$$R_2C{=}\overset{\overset{O}{\uparrow}}{N}{-}N{=}CR_2 \xrightarrow[\text{or } H^+]{\Delta} R_2C{=}\overset{+}{N}{=}\overset{-}{N} + R_2C{=}O \qquad \underline{33}$$

oxygen shift. The rearrangement of 9-fluorenone azine monoxide to analogous products is apparently more difficult to induce thermally, as evidenced by the fact that the azine monoxide was recovered intact from an experiment which was similar to those performed with other azine monoxides (116).

Photolysis of azine monoxides in benzene solution gives diazo compounds and carbonyl compounds (116). The diazo compounds once formed are converted in part to the respective carbonyl compounds in a secondary photochemical reaction. Irradiation of benzophenone azine monoxide (LXXVIII) in benzene in a pyrex vessel gave benzophenone in 50% yield. The reaction is summarized below. The phoeochemical behavior of



LXXVIII

9-fluorenone azine monoxide is not known at this time, but it is possible that the azine monoxide undergoes a light-induced rearrangement to 9-diazofluorene and 9-fluorenone (see Figure 14) in a manner analogous to that observed for benzophenone azine monoxide and other azine monoxides.

The role of 9-fluorenone oxime (CLVI) in the decomposition of 9-fluorenone azine monoxide (CLXII) is not obvious. It is apparent that under the experimental conditions employed, 9-fluorenone azine monoxide does not decompose in the absence oxime CLVI. Conversion of CLXII to 9-diazofluorene and 9-fluorenone (LXIII) does occur to some extent in the presence of the oxime. The oxime could function as an acid catalyst for the rearrangement of CLXII (Figure 14). Rearrangement of azine monoxides to the respective diazo compounds and carbonyl compounds does occur when azine monoxides are treated with acid reagents (116). Once 9-diazofluorene is formed, a reaction with nitric oxide (·NO) could lead to the formation of 9,9-dinitrofluorene (LXII) (Figure 14), as has been shown to occur when 9-diazofluorene reacts with nitric oxide (68). The source of ·NO could be the oxime group of 9-fluorenone oxime (CLVI). Nitric oxide (or nitrogen dioxide) was detectable in the flask in which the product mixture from the oxidation of CLVI by ceric ammonium sulfate was stored.

Oxime CLVI may function as a sensitizing agent for a photochemical rearrangement of 9-fluorenone azine monoxide to 9-diazofluorene and 9-fluorenone. Energy transfer mechanisms for a light-induced rearrangement of CLXII cannot be discounted at this time. Involvement of oxime CLVI in this manner does not account for the observed destruction of the oxime in the reaction. Irradiation of 9-fluorenone oxime (CLVI) in deoxygenated solution for 6 hours results in the recovery of the oxime unchanged (68). Oxime CLVI does not serve as a source of nitric oxide through a light-induced decomposition in the absence of oxygen. Photochemical conversion of CLVI to 9-fluorenone (LXIII) and nitric oxide may occur in the presence of oxygen, however (Figure 14). Since oxygen was not excluded from the reaction vessel in which the conversion of CLXII and CLVI to 9,9-dinitrofluorene (LXII) and 9-fluorenone took place,

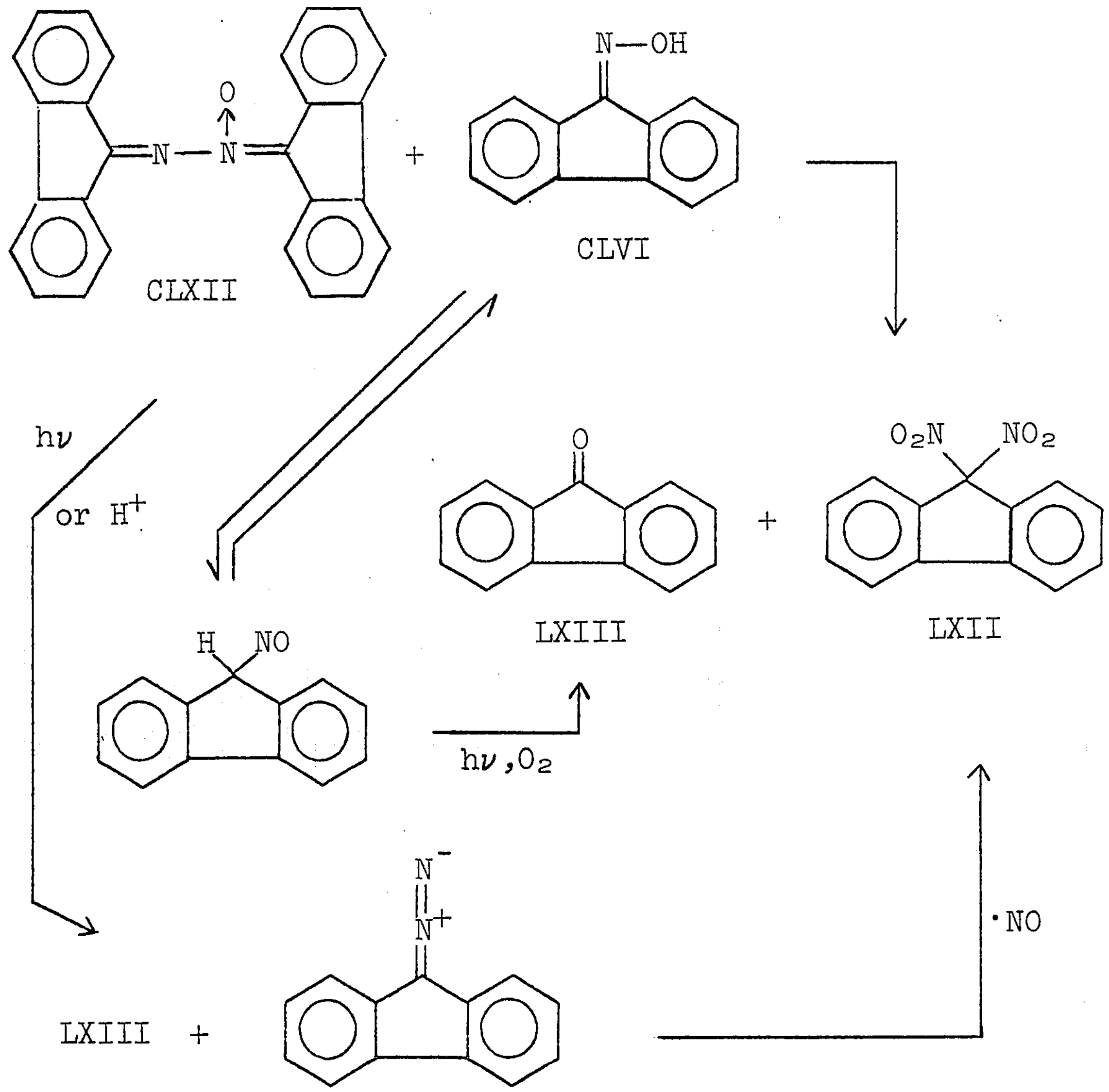


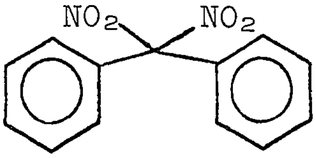
Figure 14. Reaction of 9-fluorenone azine monoxide (CLXII) with 9-fluorenone oxime (CLVI).

this possibility cannot be eliminated.

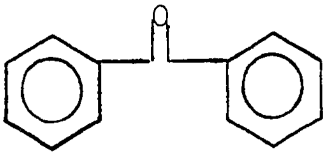
The oxidation of 9-fluorenone oxime by ceric sulfate (as $Ce(HSO_4)_4$) in aqueous methanol was studied. The solubility of ceric sulfate in methanol was very low, and was not increased significantly by the use of water. As a result, the reaction was conducted by stirring a slurry of the oxime and ceric sulfate for one week. Ketone LXIII, azine monoxide CLXII, and unreacted oxime CLVI were obtained on chromatography of the product mixture, in yields of 68%, 24.6%, and 61.4% (recovery), respectively. The dinitro compound LXII was not detected in the reaction mixture. The oxidation of CLVI with CHS in 13% concentrated sulfuric acid-87% methanol was conducted in an attempt to improve the solubility of the oxidant and shorten the reaction time. The products obtained were 9-fluorenone (90.9% yield) and unreacted oxime CLVI (65.7% recovery). The absence of azine monoxide CLXII in the product mixture, and the observed high yield of ketone LXIII, suggested that the reaction was one of hydrolysis of oxime CLVI rather than an oxidation by CHS. Oxidations of oximes with ceric sulfate were not investigated further as a result of the solubility properties of the salt.

Product formation in the oxidation of benzophenone oxime (LXXVII) with ceric ammonium nitrate was influenced by the factors which influenced the formation of products in the oxidation of fluorenone oxime with CAN. The oxidation of LXXVII in anhydrous methanol gave dinitrodiphenylmethane (LXIX), benzophenone (CLIX), and benzophenone azine monoxide (LXXVIII) in yields of 21.8%, 46.7%, and 3.1%, respectively (Table 6, page 103). Dinitrodiphenylmethane (LXIX) could be purified by recrystallization from hexane and was obtained as a white powder, m.p. 75-6°. Unlike 9,9-dinitrofluorene, LXIX was stable on standing in the room light and was not decomposed on excessive heating in solvents such as methanol or hexane. The dinitro compound LXIX was also stable at its melting point, as evidenced by the fact that samples of LXIX on melting could be induced to resolidify by cooling in an ice bath and when remelted showed no melting point depression.

The i r spectrum of LXIX (CCl_4, Figure 16, page 145) showed a broad absorption at 6.35μ and a sharp, slightly less intense absorption at 7.44μ, corresponding to the nitro groups in the molecule. The nmr spectrum (CCl_4) of LXIX showed only a strong aromatic singlet (somewhat broadened) as expected for the mono-substituted aromatic rings. The mass spectrum of LXIX gave a molecule ion at m/e 258 and fragmentation consistent with LXIX ($C_{13}H_{10}N_2O_4$). The mass spectral data for LXIX is summarized in Table 15, page 291.



LXIX



CLIX

Benzophenone (CLIX) was the major product of the oxidation of oxime LXXVII in methanol. The ketone was isolated as crystalline material with a satisfactory melting point. The i r spectrum of LXIX (CCl_4) was identical to that given by an authentic sample of benzophenone.

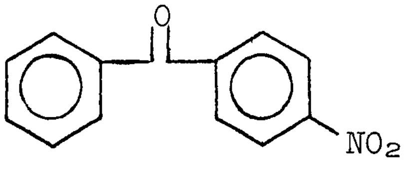
Benzophenone azine monoxide (LXXVIII) was difficult to isolate from chromatography fractions, due to decomposition on attempted recrystallization. Initial isolation of LXXVIII was accomplished by triturating fractions containing the compound with carbon tetrachloride and removing the insoluble yellow solid by filtration. The material thus isolated was recrystallized from ethanol to give a yellow powder, m.p. 157-8° (dec.). Authentic benzophenone azine monoxide was prepared from benzophenone azine by oxidation with peracetic acid (116) in 57% yield. The compound thus prepared had an i r spectrum and melting point which were identical to those given by LXXVIII from the oxidation of oxime LXXVII. A mixed melting point of LXXVIII with the authentic material gave no depression.

In the oxidation of LXXVII by CAN in methanol, the isolated yield of azine monoxide LXXVIII was probably lower than the amount of LXXVIII actually formed in the reaction. The brown gum from which LXXVIII was recovered was observed to slowly turn red as the isolation procedure was carried out. The i r spectrum of the crude chromatography fraction before trituration with CCl_4 showed only absorptions due to azine monoxide LXXVIII. After LXXVIII was isolated, an i.r. spectrum ($CHCl_3$) of the residual red gum showed absorptions at 4.90μ and 6.05μ (both strong), which were assigned to diazodiphenylmethane and benzophenone, respectively. Azine monoxide LXXVIII decomposed to a red oil on melting, which was found to be a mixture of diazodiphenylmethane and benzophenone by i.r. analysis.

The i.r. spectrum of LXXVIII (KBr, Figure 20, page 153) showed absorptions at 6.44μ and 8.10μ, which were assigned to the $\mathrm{C{=}N}{<}^{\mathrm{O}}$ grouping in the molecule, in addition to absorptions due to the aromatic nuclei in the compound. The nmr spectrum ($CDCl_3$) of LXXVIII showed only aromatic protons. The mass spectrum of LXXVIII gave a molecule ion at m/e 376 and fragmentation which was consistent with structure LXXVIII ($C_{26}H_{20}N_{2}O$) (See Table 19, page 315 and accompanying text).

Oxidation of benzophenone oxime (LXXVII) in acetone by CAN resulted in the isolation of dinitrodiphenylmethane (LXIX), benzophenone (CLIX), and p-nitrobenzophenone (CLXX) in yields of 44.2%, 45.7%, and 2.3%, respectively (Table 7). Evidence for the formation of azine monoxide LXXVIII was not obtained in the acetone reaction, nor was any of the oxime LXXVII recovered. The physical and spectroscopic properties of LXIX were identical to those of the compound obtained from the oxidation of benzophenone oxime in methanol.

In addition to the increased yield of LXIX in the reaction in acetone, the formation of p-nitrobenzophenone (CLXX) was observed for the first time in oxidations of oxime LXXVIII with CAN. The i r spectrum of CLXX showed a carbonyl absorption at 6.07μ, and absorptions due to an aromatic nitro group at 6.60μ and 7.37μ. The appearance of the asymmetric stretching frequency of the nitro group at 6.60μ (as compared to 6.41μ in aliphatic nitro compounds) indicated that the



CLXX

nitro group was on an aromatic ring. Further, the nitro group absorption was shifted below that observed for nitrobenzene (117, 6.55μ), which indicated that the ν_{as} was being influenced by another strongly electron-withdrawing substituent. The symmetric stretching frequency at 7.37μ was in about the normal position for an aromatic nitro group (117, ν_s in nitrobenzene, 7.42μ), suggesting that the nitro group occupied a position on an aromatic ring where maximum coplanarity could be achieved between the ring and the nitro group. The nmr spectrum of CLXX ($CDCl_3$, Figure 29, page 187) showed an A_2B_2 splitting pattern centered at about 1.87τ (J_{AB} = *ca*. 9 c.p.s.), the high-field portion of which was partially obscured by complex absorptions due to protons on the other aromatic ring. The observation of an A_2B_2 pattern in the spectrum of CLXX confirmed the fact that the nitro group occupied a *para*-position on an aromatic ring.

The mass spectrum of CLXX gave a molecule ion at m/e 227. The base peak of the spectrum was observed at m/e 105, corresponding to the ion $[C_6H_5CO]^+$. Fragmentation observed in the mass spectrum of CLXX is summarized in Figure 15. Ion intensities are expressed (in parentheses) as percent of the base peak (Figure 15.) The fragmentation and relative intensities of

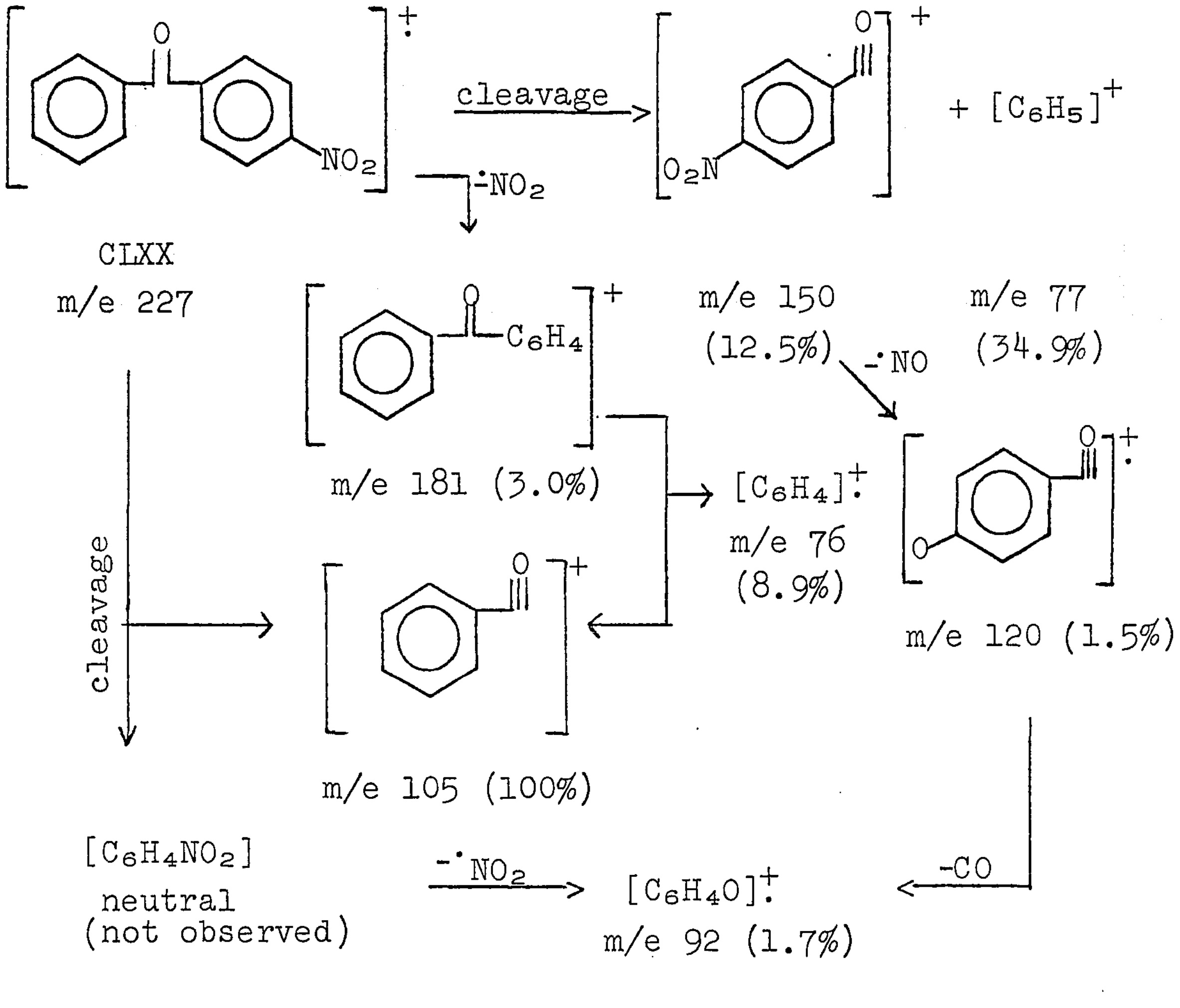


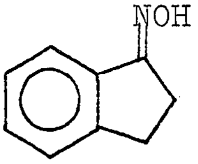
Figure 15. Mass spectral fragmentation of p-nitrobenzophenone (CLXX).

the respective ions were in good agreement with the reported data for authentic CLXX (118).

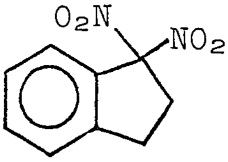
Nitrated ketone CLXX was apparently not formed when oxime LXXVII was oxidized with ceric ammonium nitrate in methanol, deoxygenated methanol, and aqueous methanol. If CLXX was formed in those solvents and under those conditions, the quantity was too small to allow detection. Ketone CLXX was isolated from the oxidation of LXXVII in deoxygenated acetone, but the yield (_ca_. 1%) was somewhat lower than in the reaction in the presence of oxygen.

Both 9,9-dinitrofluorene (LXII) and dinitrodiphenylmethane (LXIX) were stable to the conditions used when the respective oximes were oxidized in methanol containing nitric acid. The control reactions were required by the fact that the dinitro compounds were found in only trace amounts in the product mixtures from the oxidations with nitric acid added. A solution of LXII in methanol containing excess nitric acid was stirred for 9 hours at room temperature. The dinitro compound was recovered from the reaction unchanged in 95.6% yield. Only a trace amount of 9-fluorenone was detected in the residue remaining after LXII had been isolated. A solution of dinitrodiphenylmethane (LXIX) in methanol containing excess nitric acid was stirred for 8 hours at room temperature. Dinitro compound LXIX was recovered in 95% yield. A small amount of benzophenone was detected in the product mixture (i r analysis). The amounts of the respective ketones obtained were insufficient to account for the lowering of the yields of the dinitro compounds in anhydrous methanol (33% for LXII; 21.8% for LXIX, Table 6) to those obtained in methanol containing nitric acid (7.7% for LXII; 1.1% for LXIX, Table 10) by reaction of the dinitro compounds with nitric acid.

Oxidation of 1-indanone oxime (CLXIII) by ceric ammonium nitrate in anhydrous methanol or acetone gave 1,1-dinitroindane (CLXXI) and 1-indanone (CLXXII) as the only well-defined products. The yield of CLXXI was higher in acetone solution than in methanol solution, but the yield increase in going from methanol to acetone was smaller (about 10%) than similar increases observed with the diaryl ketoximes, 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII) (20-25%). The recovery of material from oxidations of CLXIII was also usually lower than from oxidations of the diaryl ketoximes. Only 80-85% recovery by weight of material was obtained in the oxidations of CLXIII (based on one gram of oxime initially oxidized. The loss of organic material apparently occurred in the work-up of the reactions, since recovery of material from silica gel chromatography columns was usually high (94-96%). Use of a non-aqueous work-up for the reactions gave no improvement in

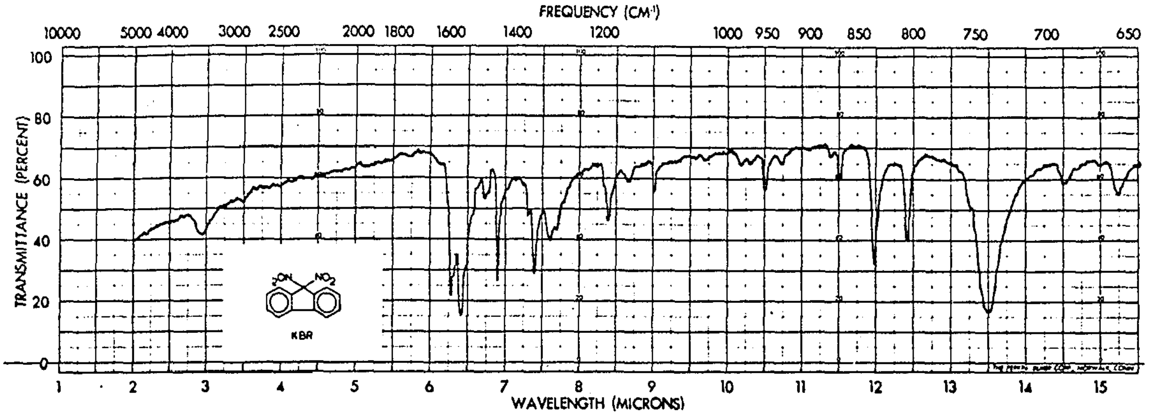


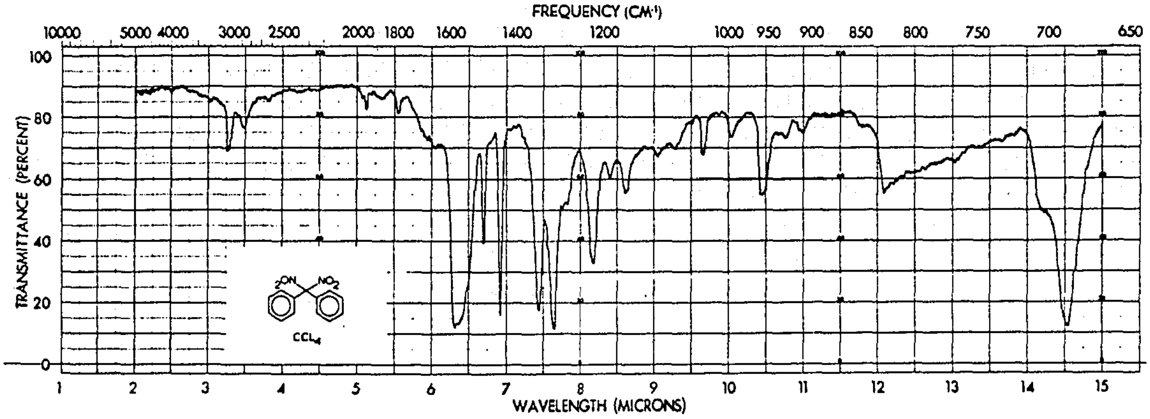
CLXIII



CLXXI

Figure 16. Infrared spectra.
Top: 9,9-Dinitrofluorene (LXII).
Middle: Dinitrodiphenylmethane (LXIX).
Bottom: 1,1-Dinitroindane (CLXXI).


FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O2N NO2
KBR


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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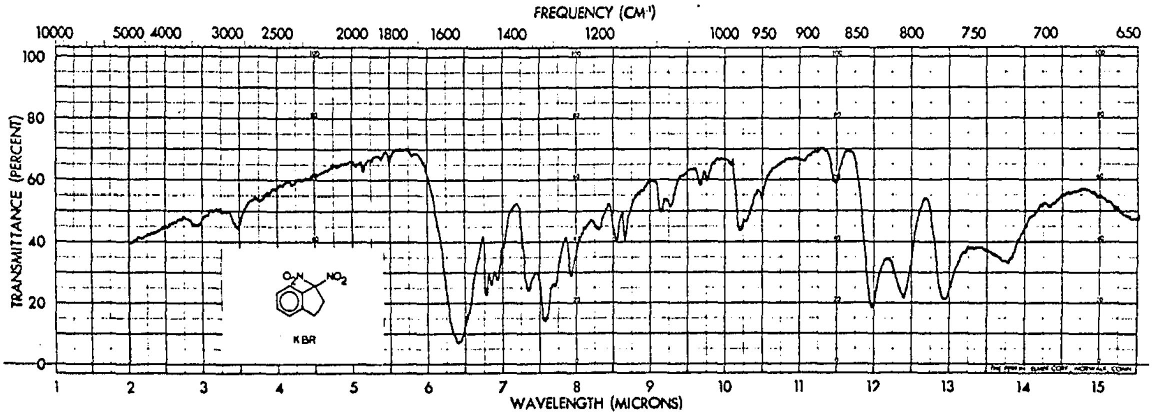
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O2N NO2
CCl4


FREQUENCY (CM⁻¹)
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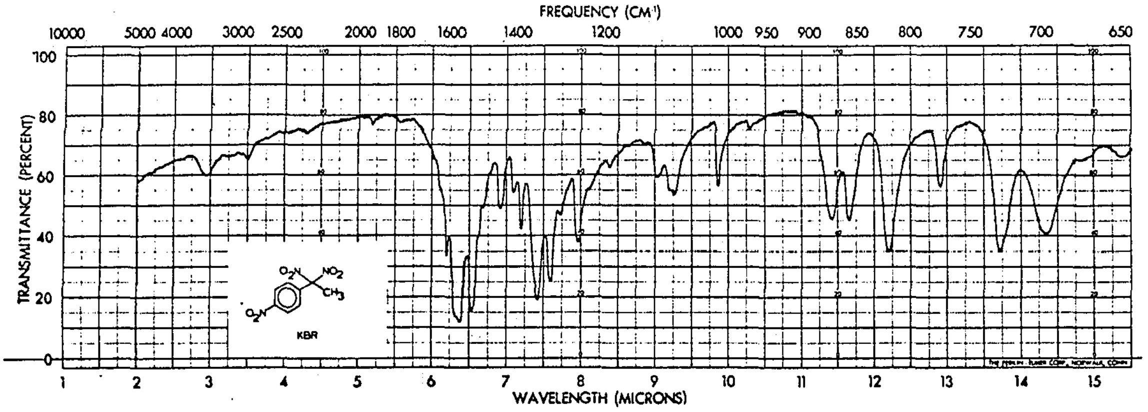
TRANSMITTANCE (PERCENT)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O2N NO2
KBR

Figure 17. Infrared spectra.
Top: 1,1-Dinitro-1-(p-nitrophenyl)-ethane, (CLXXIII).
Middle: 1,1-Dinitro-1,2-diphenylethane (CLXXVI).
Bottom: Chromatography fraction 2.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TRANSMITTANCE (PERCENT)
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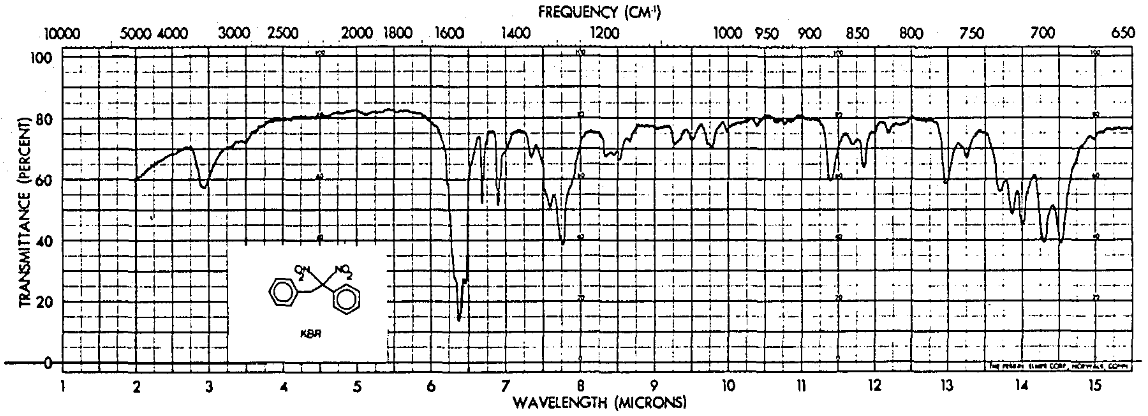
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O2N
NO2
CH3
O2N
KBR


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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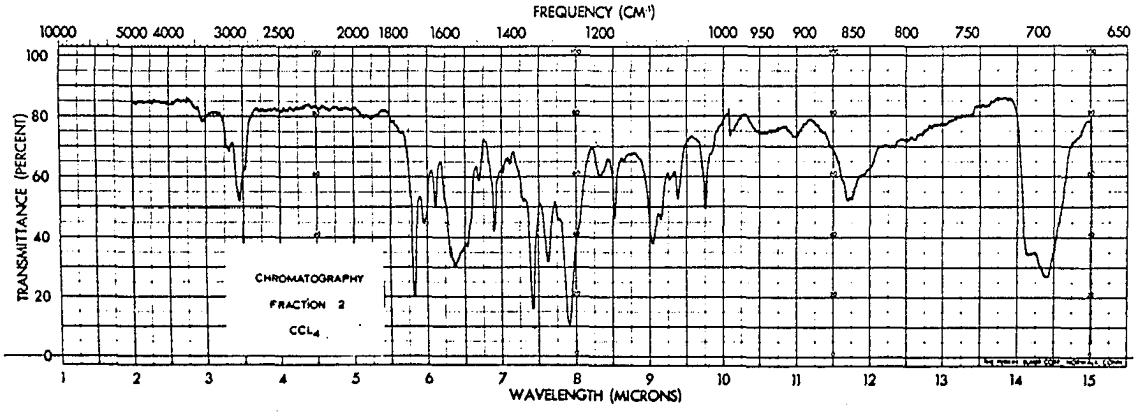
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O2N
NO2
KBR


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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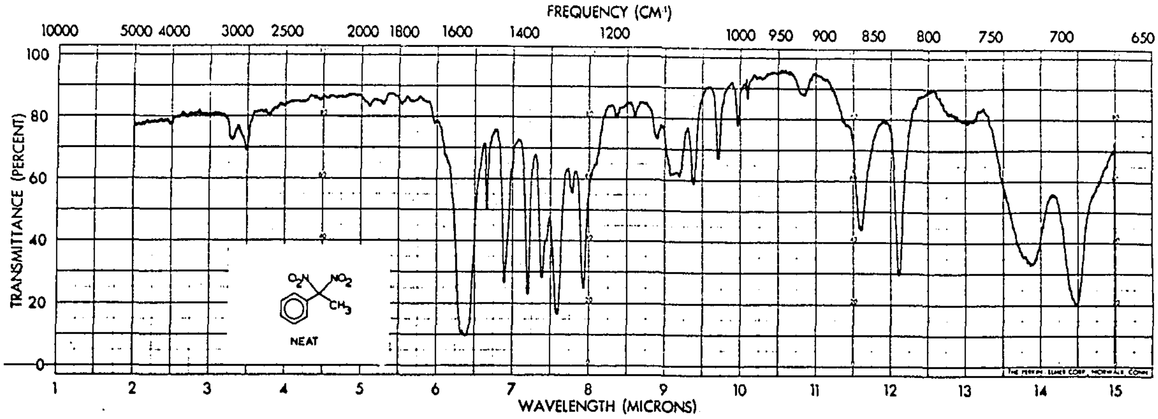
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
CHROMATOGRAPHY
FRACTION 2
CCL4

Figure 18. Infrared spectra.
Top: 1,1-Dinitro-1-phenylethane (LXXII)
Middle: 1,1-Dinitro-1-(p-tolyl)-ethane (CLXXXI).
Bottom: 1,1-Dinitro-1-(2,4-dimethylphenyl)-ethane, (CLXXXIII).


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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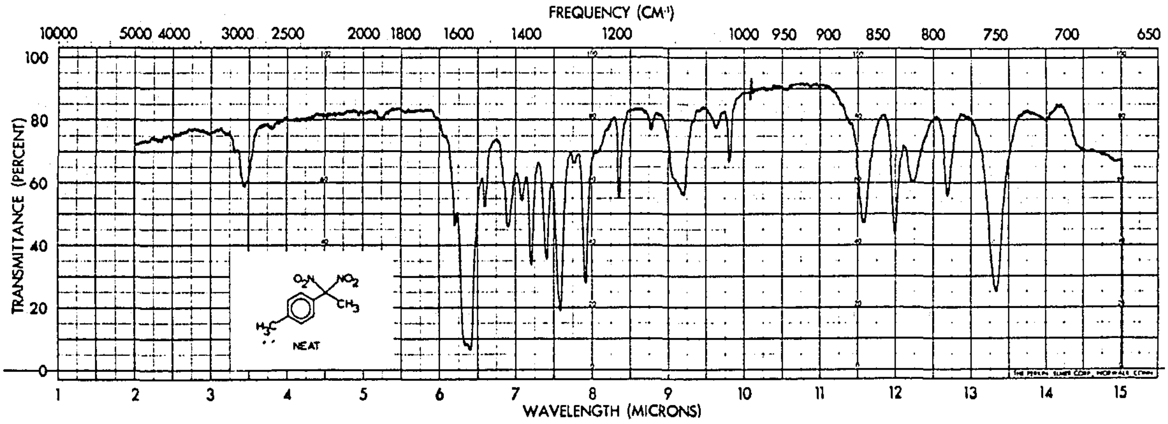
O_2N NO_2 CH_3
NEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)


FREQUENCY (CM⁻¹)
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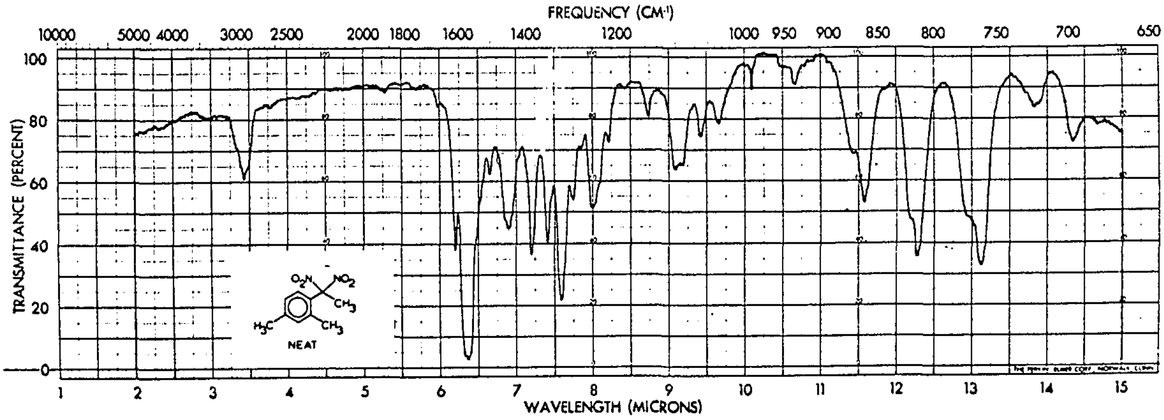
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
O_2N NO_2 CH_3 H_3C
NEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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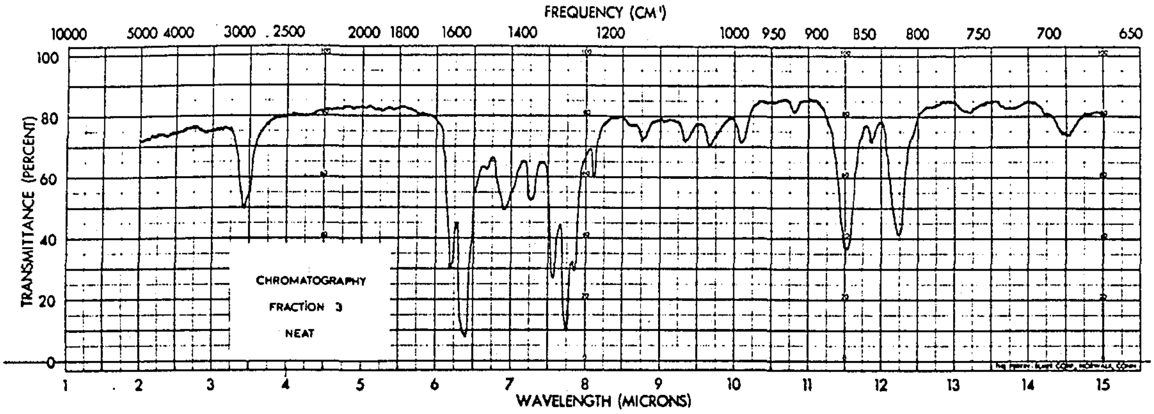
O_2N NO_2 CH_3 H_3C CH_3
NEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)

Figure 19. Infrared spectra.
Top: Chromatography fraction 3.
Middle: Unknown A.
Bottom: Unknown B.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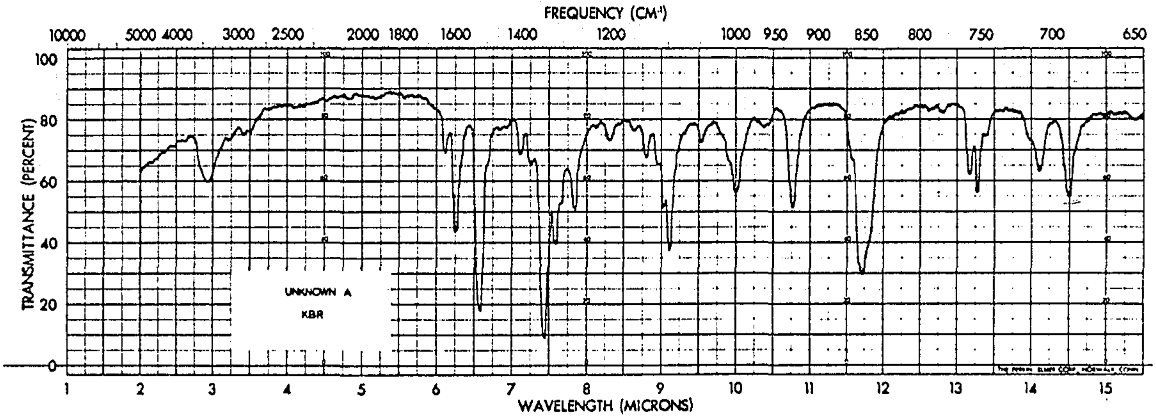
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
CHROMATOGRAPHY
FRACTION 3
NEAT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)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1000
950
900
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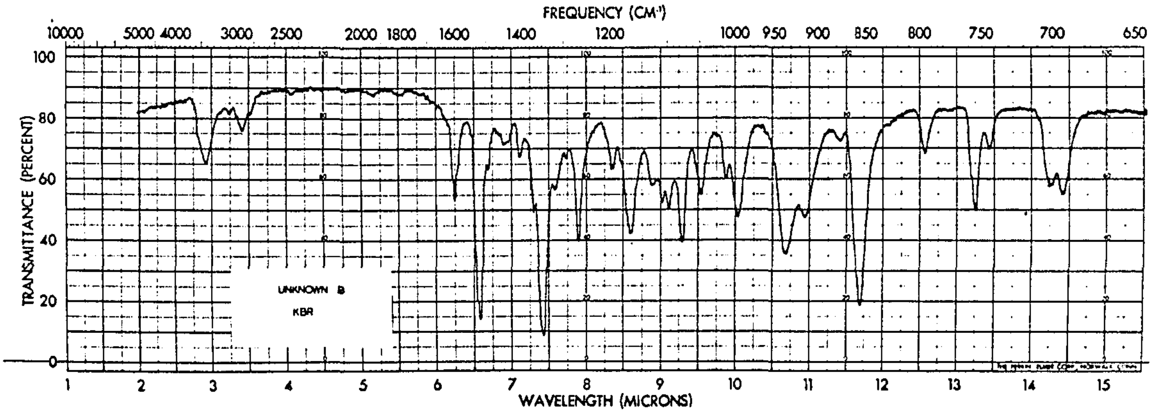
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
UNKNOWN A
KBR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)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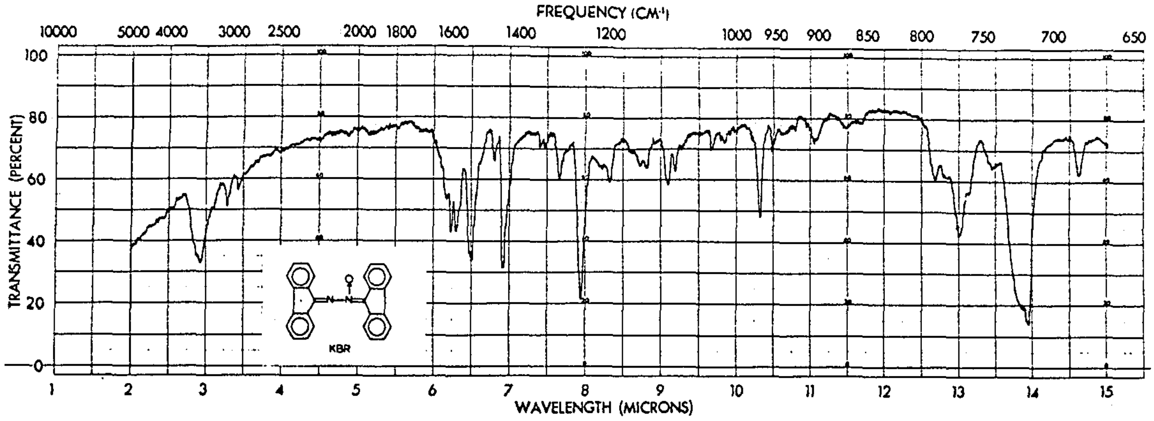
1800
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
UNKNOWN B
KBR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)

Figure 20. Infrared spectra.
Top: 9-Fluorenone azine monoxide (CLXII).
Middle: Benzophenone azine monoxide (LXXVIII).
Bottom: p-Nitroacetophenone azine monoxide (CLXXV).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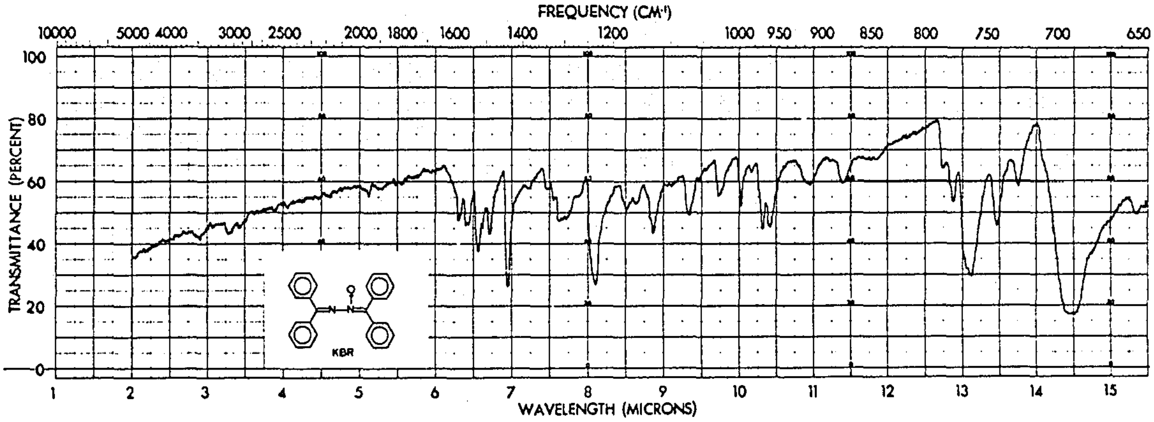
2500
2000
1800
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)
KBR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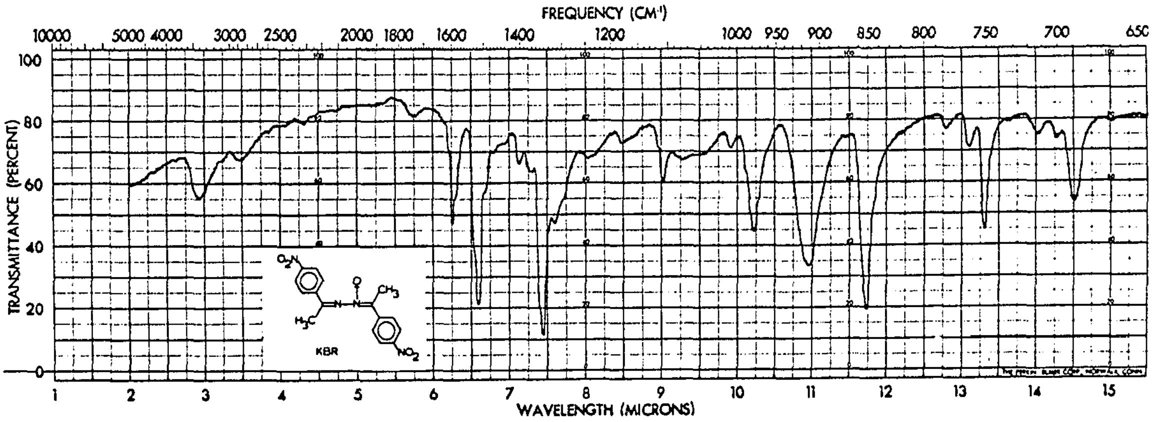
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)
KBR


FREQUENCY (CM⁻¹)
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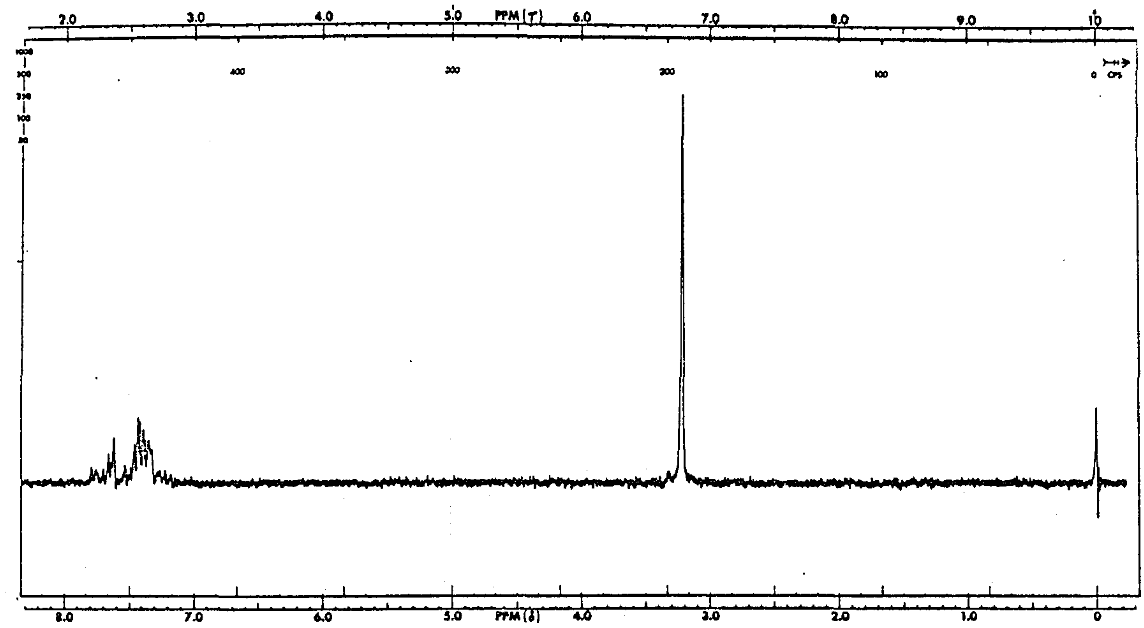
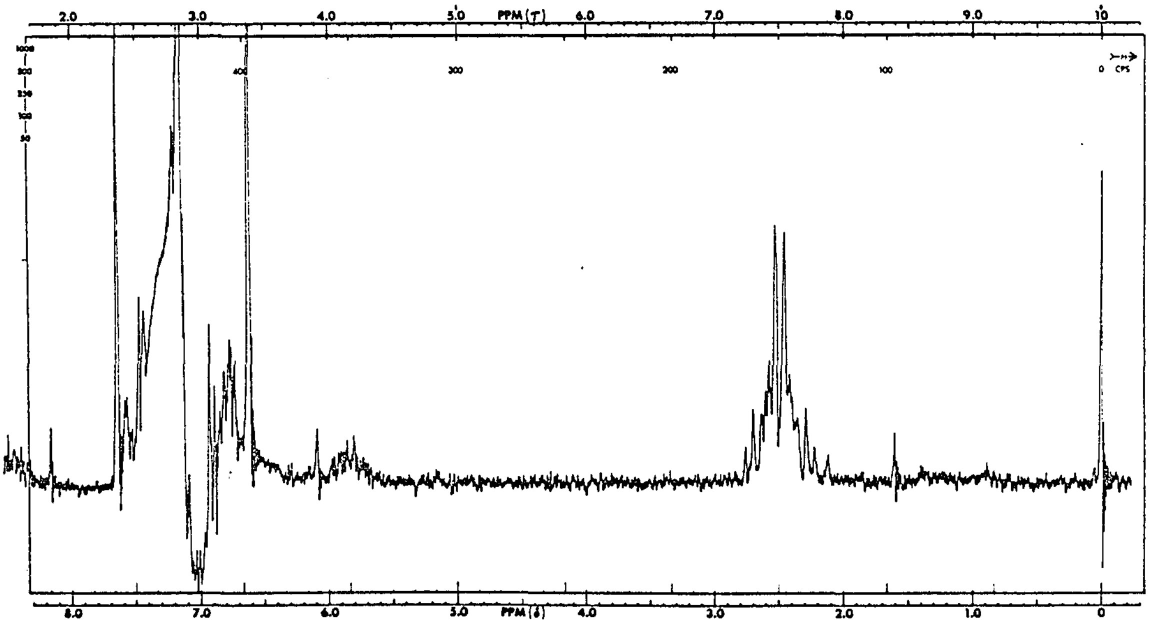
3000
2500
2000
1800
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)
O₂N
CH₃
H₃C
NO₂
KBR

Figure 21. Nuclear magnetic resonance spectra.
Top: 1,1-Dinitroindane (CLXXI) in CCl_4.
Bottom: 1,1-Dinitroindane (CLXXI) in benzene.


2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0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3.0
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PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
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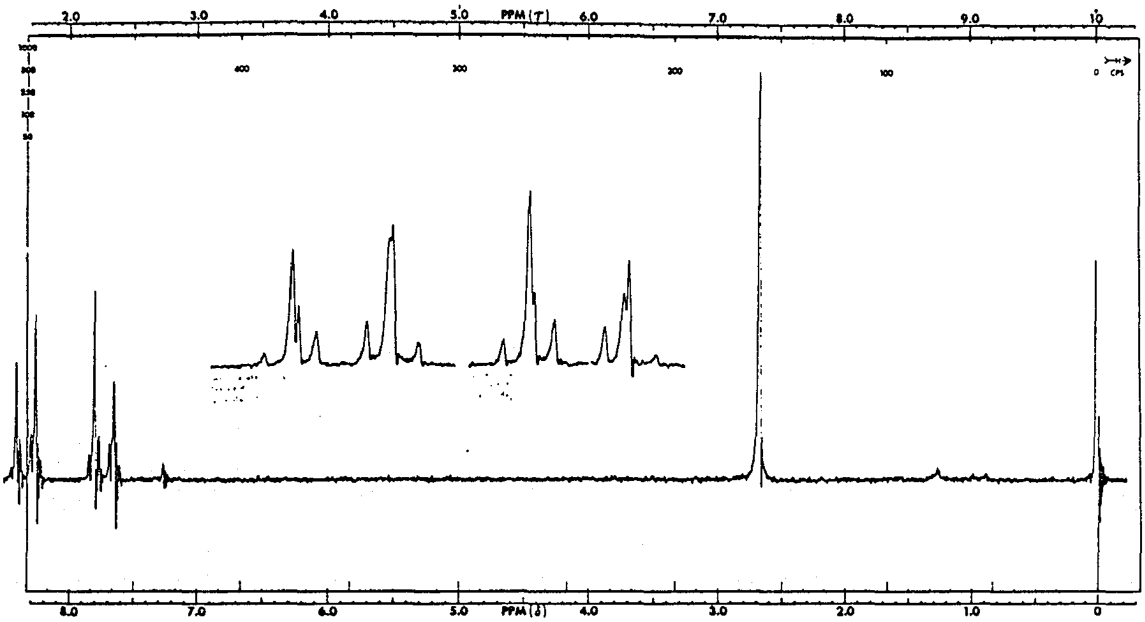
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

Figure 22. Nuclear magnetic resonance spectra.
Top: 1,1-Dinitro-1-(p-nitrophenyl)-ethane, (CLXXIII).
Bottom: 1,1-Dinitroindane (CLXXI) in benzene: methylene expansion.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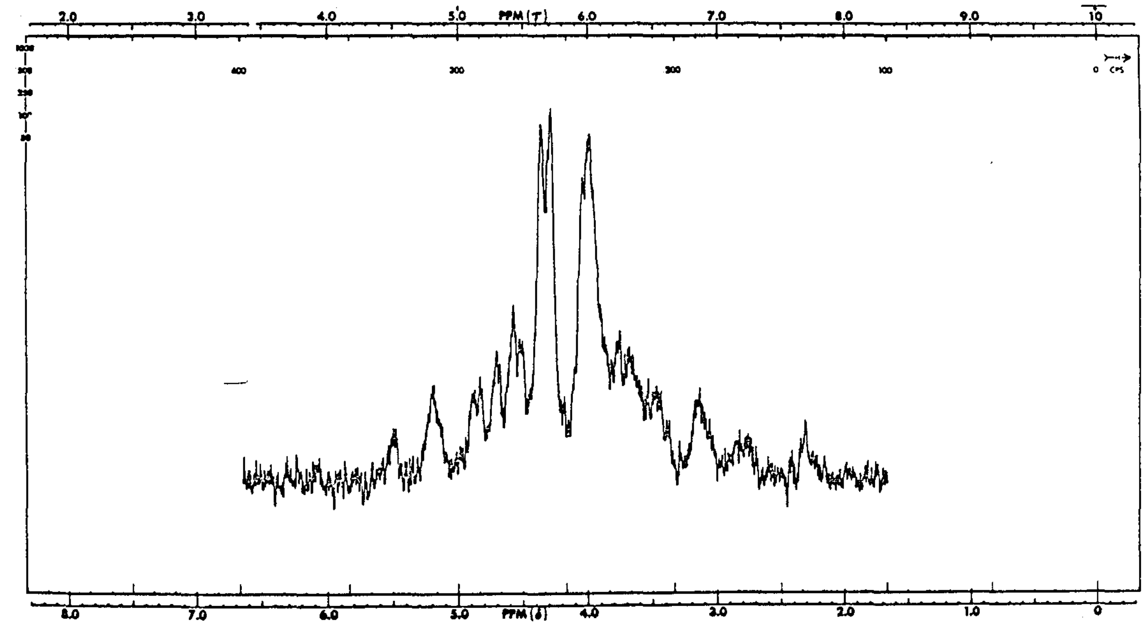
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0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3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
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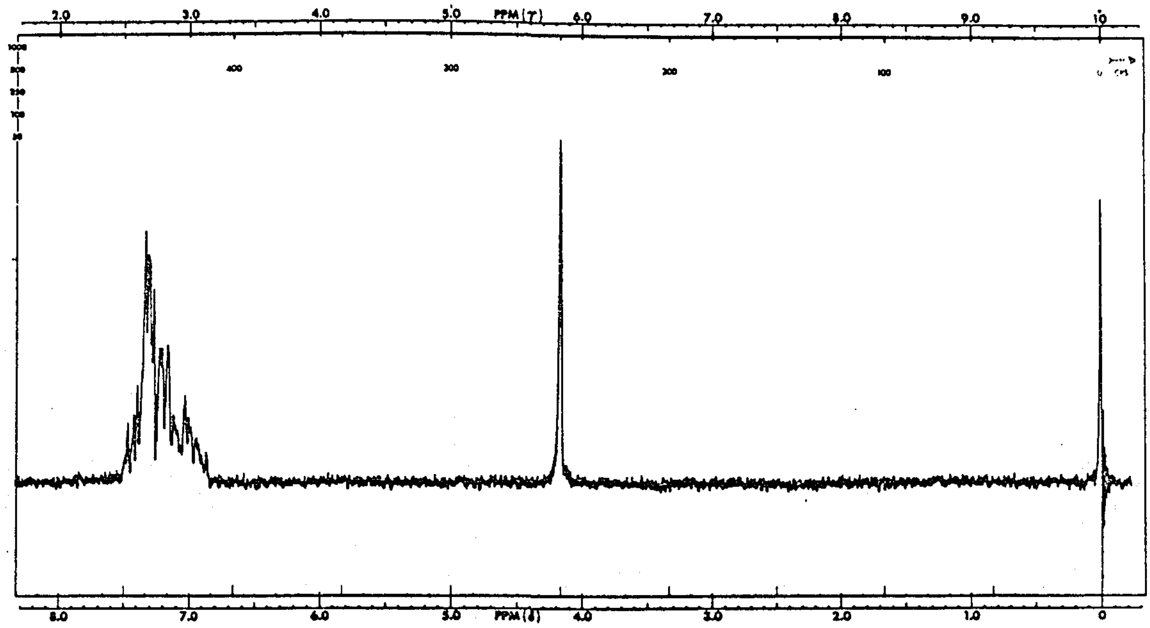
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

Figure 23. Nuclear magnetic resonance spectra.
Top: 1,1-Dinitro-1,2-diphenylethane (CLXXVI).
Bottom: Chromatography fraction 2.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3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

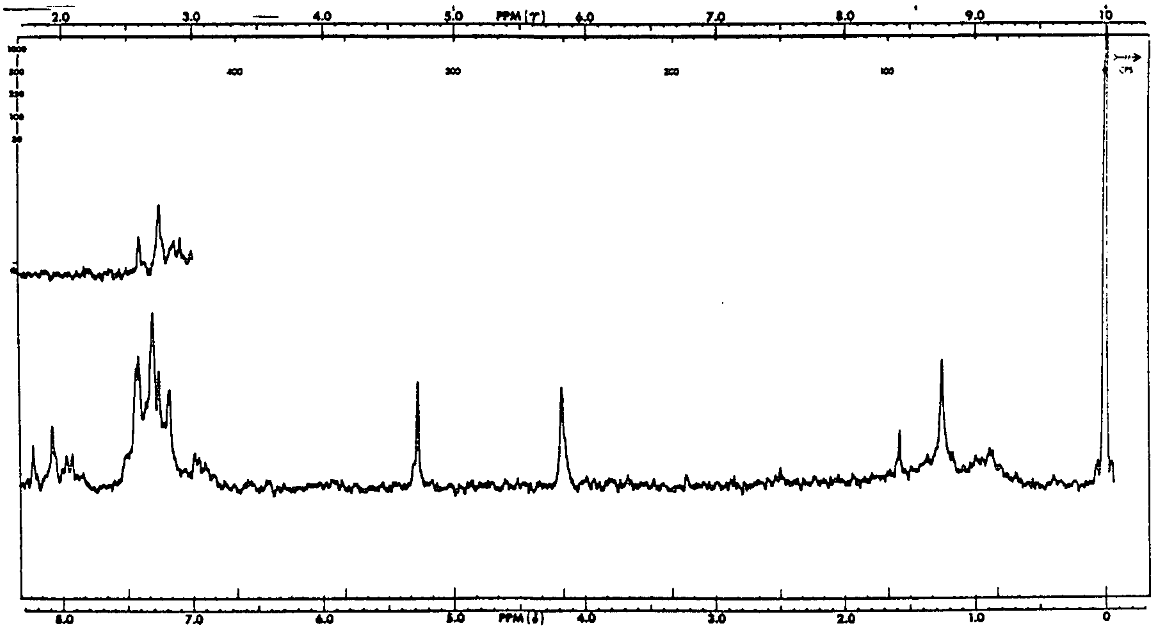
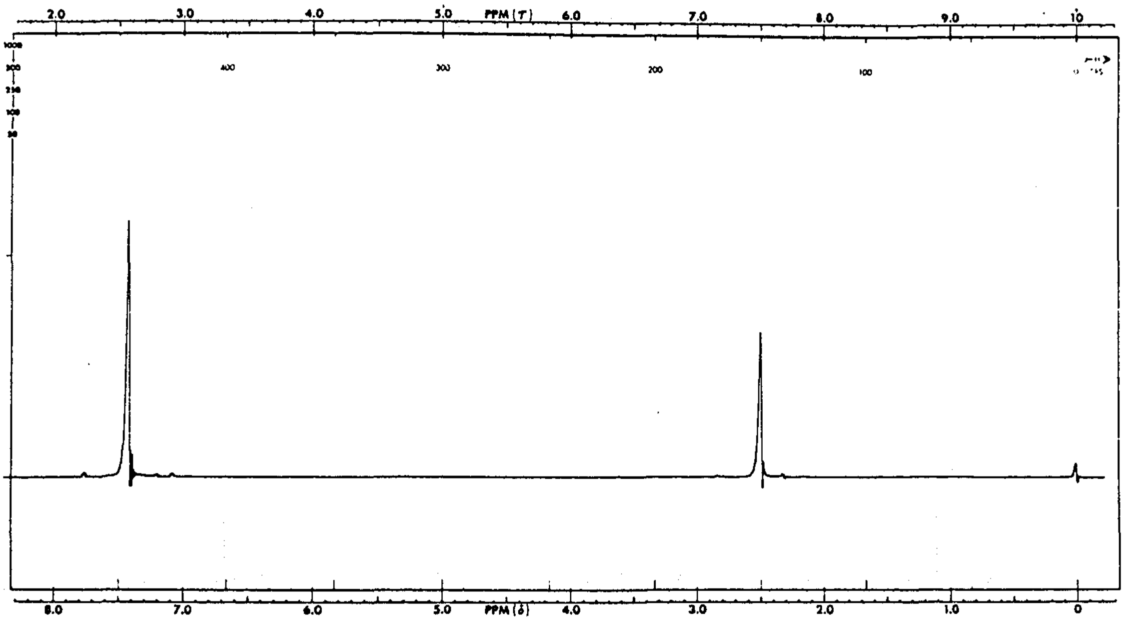

2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

Figure 24. Nuclear magnetic resonance spectra.
Top: 1,1-Dinitro-1-phenylethane (LXXII).
Bottom: 1,1-Dinitro-1-(p̲-tolyl)-ethane (CLXXXI).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3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
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PPM (δ)
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3.0
2.0
1.0
0

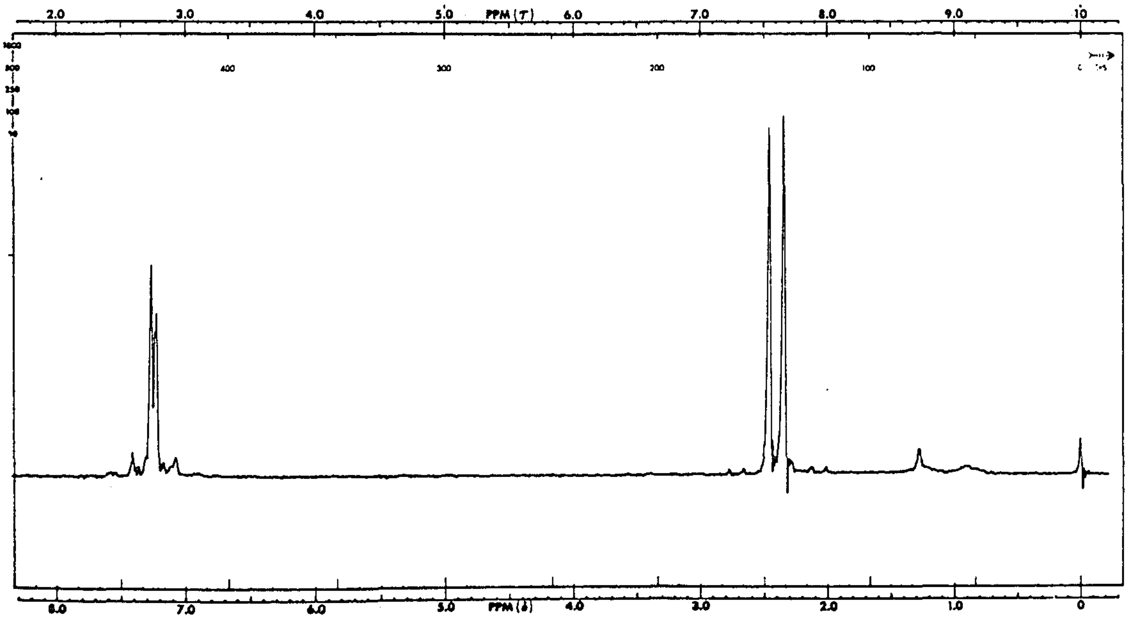
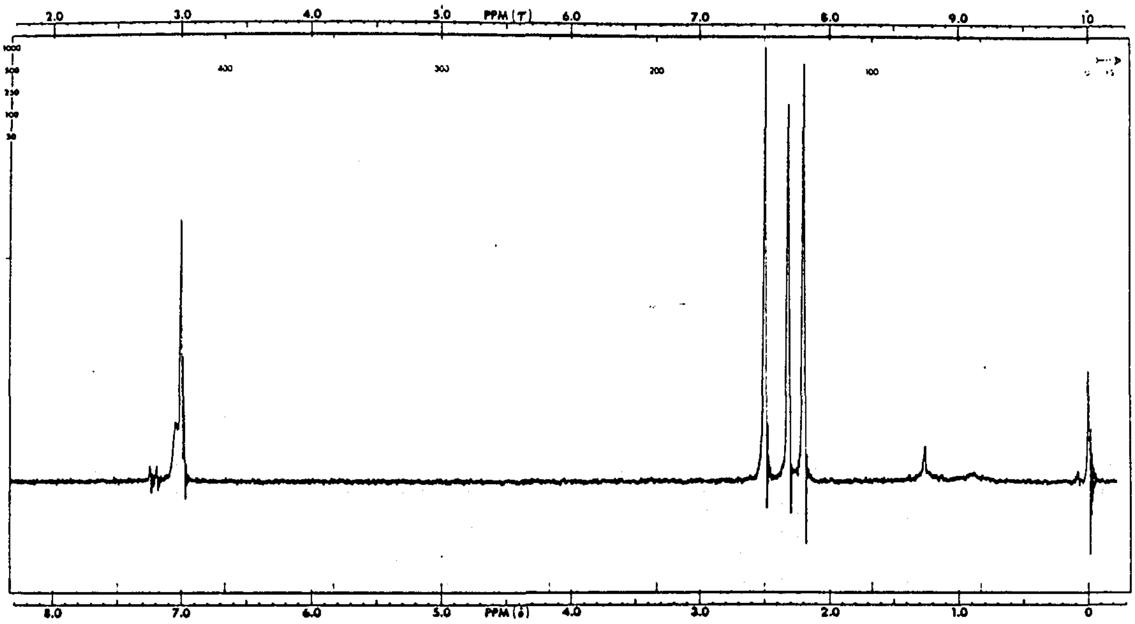

2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

Figure 25. Nuclear magnetic resonance spectra.
Top: 1,1-Dinitro-1-(2,4-dimethylphenyl)-ethane, (CLXXXIII).
Bottom: Chromatography fraction 3.


PPM (τ)
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10
1000
500
250
100
50
400
300
200
100
PPM (δ)
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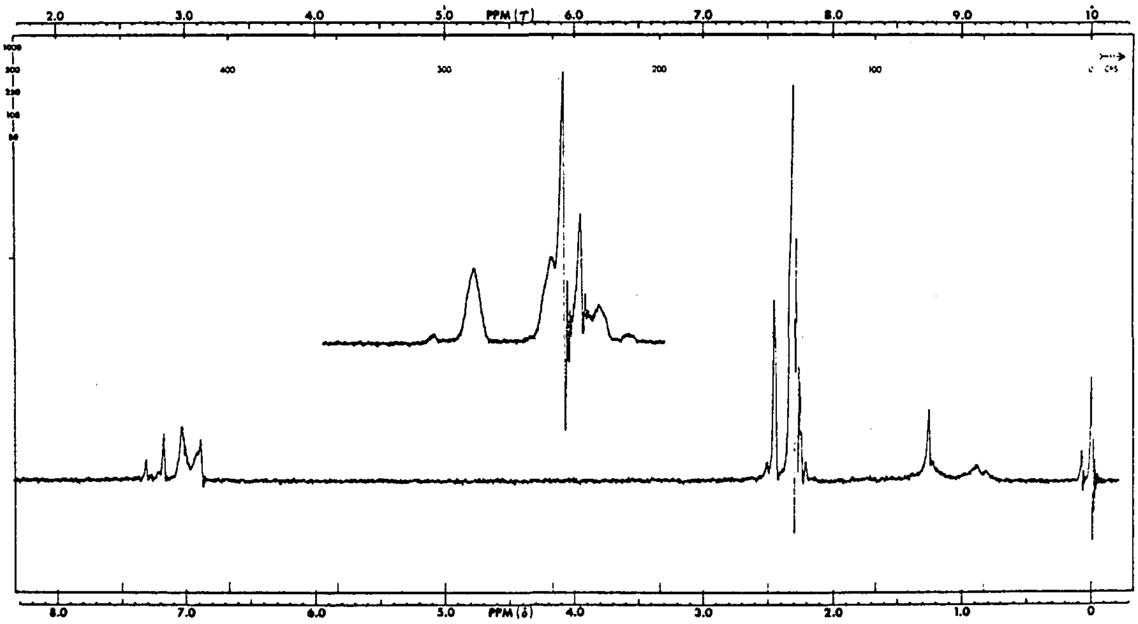
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0


PPM (τ)
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3.0
4.0
5.0
6.0
7.0
8.0
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1000
500
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100
50
400
300
200
100
PPM (δ)
8.0
7.0
6.0
5.0
4.0
3.0
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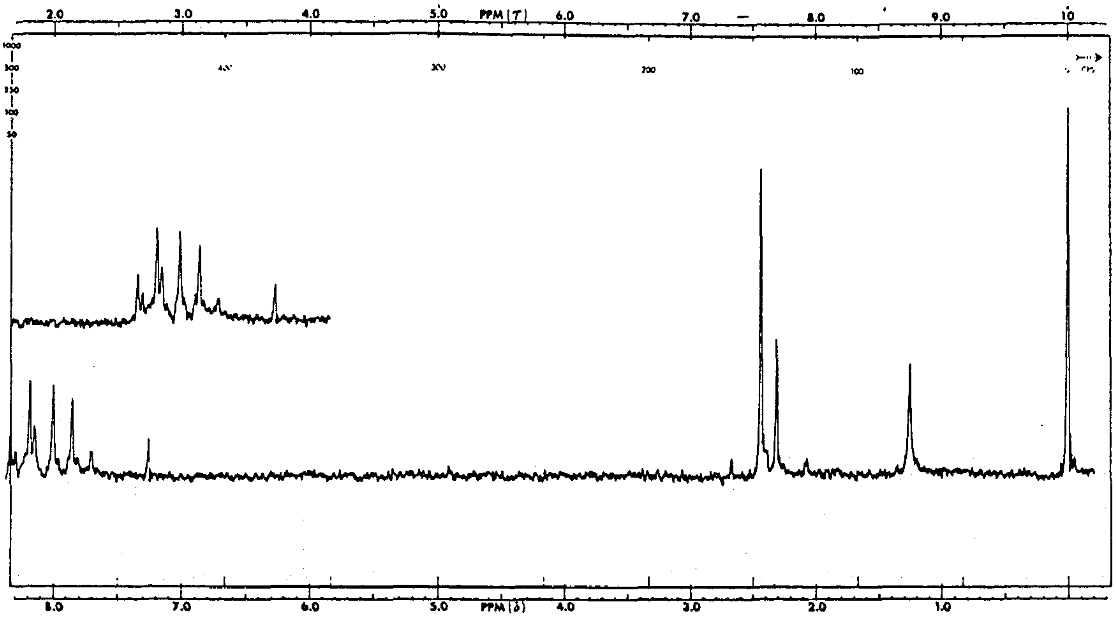
Figure 26. Nuclear magnetic resonance spectra.
Top: p-Nitroacetophenone azine monoxide (CLXXV).
Bottom: p-Nitroacetophenone oxime (CLXIV).


2.0
3.0
4.0
5.0
PPM (τ)
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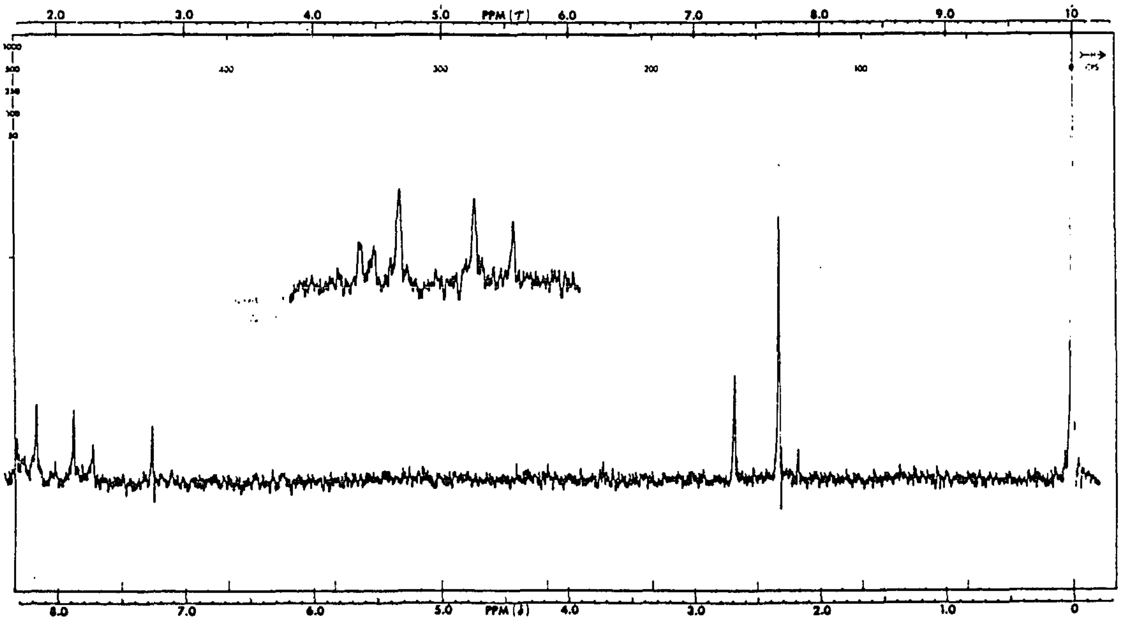
7.0
8.0
9.0
10
400
300
200
100
0
CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0


2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
0
CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

the overall recovery, suggesting that loss of materials with high solubility in water was not important.

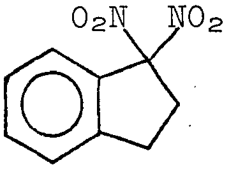
Oxidation of CLXIII by one equivalent of ceric ammonium nitrate in methanol gave CLXXI and CLXXII in yields of 26.8% and 24.7%, respectively (Table 6). Intractable gum accounted for about 29% by weight of the material recovered from the chromatography. The gums yielded a small amount of a yellow solid, m.p. >300°, on stirring with ether. The solid was not characterized beyond observation of an i r spectrum which was ill-defined in nature.

The dinitro compound, 1,1-dinitroindane (CLXXI), was purified by recrystallization from hexane (or pentane) to give white needles, m.p. 42-3°. Upon heating CLXXI above 130°, decomposition was observed accompanied by evolution of nitrogen dioxide. The dark yellow oil remaining after decomposition could not be induced to resolidify. Unlike 9,9-dinitrofluorene (LXII), 1,1-dinitroindane (CLXXI) was stable indefinitely on standing in the room light at room temperature. The i r spectrum of CLXXI (KBr, Figure 16, page 145) showed a broad 6.41μ absorption and a less intense absorption at 7.35μ, which were assigned to the nitro groups in the compound.

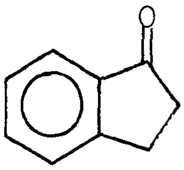
The nmr spectrum of CLXXI (CCl_4, Figure 21, page 155) showed aromatic protons between 2.2-2.8τ and a singlet at 6.79τ, in the ratio of 1:1, respectively. The observation of a singlet at 6.79τ for the four methylene protons in CLXXI was unexpected, and suggested that the nitro groups were on the 2-position of the indane nucleus rather than the 1-position. The singlet at 6.79τ was observed to break up into a complex A_2B_2 pattern when the nmr spectrum of CLXXI was recorded in benzene (Figure 21, page 155), which confirmed that the compound was 1,1-dinitroindane and not the 2,2-dinitro compound. The A_2B_2 multiplet was centered at 7.52τ in the spectrum of CLXXI in benzene, a shift of 0.73 p.p.m. upfield from the position of the methylene singlet in carbon tetrachloride.

The use of benzene as an nmr solvent and the effects which benzene and other aromatic compounds have on the chemical shifts of aliphatic protons have been described by Pople, Bernstein, and Schneider (119). In summary, the aromatic ring with its mobile π-electrons acts as a secondary magnetic field when placed in another magnetic field. Thus, protons in close proximity to an aromatic ring are acted on by the secondary magnetic field and undergo a shift in resonance frequency from that observed in the absence of the aromatic solvent. The magnitude of the shift is a function of the concentration of the aliphatic material in the aromatic solvent. The higher the concentration of the aromatic material (or the lower the concentration of the compound containing the aliphatic protons) the more pronounced is the shift of the resonance frequency of the aliphatic protons in an <u>upfield</u> direction (119). The large shift (0.73 p.p.m.) observed for the center of gravity of the methylene resonance in CLXXI in changing from carbon tetrachloride to benzene is consistent with the facts.

Coupling constants and chemical shifts for the respective protons in the methylene multiplet from CLXXI in benzene were not calculated due to the complexity of the pattern. Assignments of the high and low field portions of the A_2B_2 multiplet were possible by comparison of the spectrum of CLXXI in benzene to the nmr spectrum of 1-indanone.[1] The protons adjacent to the carbonyl in CLXXI showed a better resolved, more complex pattern than that observed for the benzylic methylene protons. An expansion (Figure 22) of the methylene absorptions in the spectrum of CLXXI in benzene showed that the low field portion of the A_2B_2 was better resolved and more complex than the high field portion. It was reasonable to expect that benzene would induce a larger shift in the resonance frequency of the benzylic methylene protons. The bulky nitro groups in the 1-position of the indane nucleus would at least partially shield the 2-position from the approach of molecules of benzene, reducing the effectiveness of the solvent in causing a



CLXXI



CLXXII

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[1] This spectrum can be found in NMR catalog, Vol. 1, Varian Associates, Inc., 1962, No. 229.

shift in the resonance frequency of those protons. The low field portion of the A_2B_2 pattern was assigned to the methylene group adjacent to the carbon bearing the nitro groups (position 2) and the high field portion was assigned to the benzylic methylene group.

The mass spectrum of CLXXI gave a weak molecule ion at m/e 208 and fragmentation which was consistent with CLXXI ($C_9H_8N_2O_4$) (Table 16, page 292). The mass spectral data for CLXXI is discussed in a later section.

The ketone, 1-indanone (CLXXII), was normally isolated as an oil which could be crystallized after drying and treatment with charcoal. The i r spectrum of the solid was identical to that given by authentic 1-indanone. The ketone was further identified by its melting point and mixed melting point with authentic 1-indanone.

Oxidation of 1-indanone oxime (CLXIII) in acetone by one equivalent of ceric ammonium nitrate gave CLXXI and CLXXII in yields of 37.8% and 36.6%, respectively (Table 7). The gums found in the later chromatography fractions accounted for about 22% by weight of the material recovered from the reaction, and about 15% by weight of the crude product mixture before chromatography. Practically the same yields of CLXXI and CLXXII were obtained when CLXIII was oxidized in deoxygenated acetone by CAN (36.2% for CLXXI, 37.2% for CLXXII). The contents of the later chromatographic fractions again accounted for about

15% by weight of the crude product mixture. Dinitro compound CLXXI and ketone CLXXII were obtained in yields of 27.7% and 35.6%, respectively (Table 9) when oxime CLXIII was oxidized in deoxygenated acetone using a dropwise addition of the CAN solution to the oxime solution (over a 20 minute period). In addition to a lower yield of CLXXI in the slow addition reaction, the overall recovery of material (about 75%) was the lowest obtained in any reaction involving oxime CLXIII. Further, the contents of later chromatographic fractions accounted for only 14% by weight of the material recovered, and about 10% by weight of the crude product mixture.

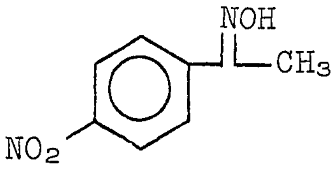
The dinitro compound CLXXI was treated with ceric ammonium nitrate in acetone solution in an effort to determine the stability of the compound to the conditions used for the oxidation of oxime CLXIII. About 67% of CLXXI initially reacted with CAN was recovered in the work-up. Attempts to improve the recovery of CLXXI by variation in the work-up procedure were unsuccessful, with the recovery for several attempts averaging about 65%. Unreacted CLXXI accounted for all of the material recovered in any reaction. Products resulting from degradation of CLXXI were not isolated.

Although CLXXI apparently reacted with CAN in some manner, the loss of material in the oxidation of oxime CLXIII by CAN using a dropwise addition of the reagent was not due only to reaction between CLXXI and CAN. The yield of CLXXI was about the same when CLXIII was titrated with excess CAN as it was in the oxidation of CLXIII with one equivalent of CAN using a slow addition rate. Samples of CLXIII were titrated in acetone with a standard ceric ammonium nitrate solution. Approximately two moles of CAN were consumed per mole CLXIII, with the first 0.7 mole of CAN reacting more rapidly than the remainder of the two moles. The product mixture from the titration of CLXIII with two equivalents of CAN was analyzed as before. The yields of CLXXI and ketone CLXXII were 29% and 57.5% (based on the 2,4-dinitrophenylhydrazone), respectively. The marked effect observed in the titration was the increase in the yield of CLXXII from 35.6% to 57.5% (slow addition of one equivalent compared to the reaction with two equivalents of CAN). However, the significance of this increase is questionable, as was pointed out previously.

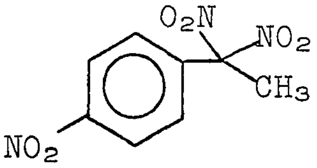
Oxime CLXIII was also titrated with a standard solution of ceric ammonium nitrate in methanol. The stoichiometry of the oxidation in methanol was found to be about three moles of CAN per mole of oxime, which presents a contrast to the titration results in acetone solution (two moles of CAN per mole of oxime). Product analysis was not performed on the methanol titration samples, but the difference between the reactions of CLXIII with CAN in methanol acetone is apparent from the different stoichiometries of the reactions. It is interesting to note that titration of 9-fluorenone oxime (CLVI) in methanol in the exact manner used for the titration of CLXIII led to a stoichiometry for the reaction of two moles of CAN per mole of oxime

CLVI. The presence or absence of hydrogens *alpha* to the oxime group undergoing oxidation thus appears to have a quantitative effect on the reactions, since the gross structural change in going from 1-indanone oxime (CLXIII) to 9-fluorenone oxime is one of replacement of the aliphatic hydrogens in CLXIII with a fused aromatic ring. The difference in the stoichiometries for the oxidation of CLXIII with CAN in methanol and acetone is not readily explainable.

Oxidation of *p*-nitroacetophenone oxime (CLXIV) by one equivalent of ceric ammonium nitrate in methanol resulted in the isolation of 1,1-dinitro-1-(*p*-nitrophenyl)-ethane (CLXXIII), *p*-nitroacetophenone (CLXXIV), and *p*-nitroacetophenone azine monoxide (CLXXV) in yields of 1.4%, 75.5%, and 3.3%, respectively (Table 6). Oxime CLXIV was recovered in 13.5% yield. The reaction of CLXIV with CAN in 80% methanol-20% water was considerably more complex. In addition to CLXXIII, CLXXIV, and CLXXV (in yields of <1%, 56.1% and 5%, respectively, Table 8), small amounts of two other compounds were obtained. Oxime CLXIV was recovered in 23.9% yield. Dinitro compound CLXXIII and ketone CLXXIV were obtained in yields of 18.6% and 71.3%, respectively (Table 7), when *p*-nitroacetophenone oxime was



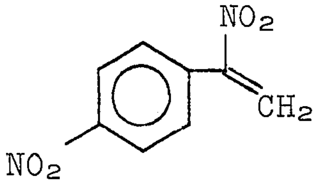
CLXIV



CLXXIII

reacted with CAN in anhydrous acetone. Unreacted oxime CLXIV was not detected in the reaction mixture. The azine monoxide CLXXV was apparently not formed in the reaction. The increase in the yield of CLXXIII upon changing the solvent for the oxidation of CLXIV from methanol to acetone was the largest increase (about 17%) observed for the yield of a dinitro compound in the oxidation of any arylalkyl ketoxime. In terms of absolute magnitude, however, the yield of CLXXIII was the lowest for any ketoxime oxidation in acetone solution (see Table 7, page 104).

In addition to the compounds mentioned above, trace amounts of an olefinic material (or materials) were found in the early fractions of the chromatography of the product mixtures from the oxidation of CLXIV in methanol and acetone. A similar compound was not detected in the product mixture from the oxidation of CLXIV in 80% methanol-20% water. The evidence for the olefinic materials was obtained from infrared spectra. The i r spectrum of the fraction containing crude dinitro compound CLXXIII from the reaction in methanol showed a band of medium intensity at 6.09μ, in addition to absorptions due to CLXXIII. Only the dinitro compound was isolated from the fraction, however. The second fraction of the chromatography of the product mixture from the oxidation of CLXIV in acetone contained 0.018 g. of a yellow oil, which showed absorptions at 6.14μ, 6.45-6.60μ (broad), and 7.45μ in the i r spectrum. The i r was consistent with a nitro olefin of the structure

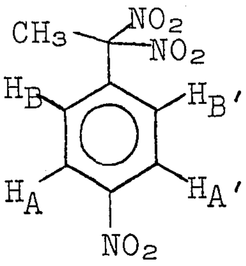


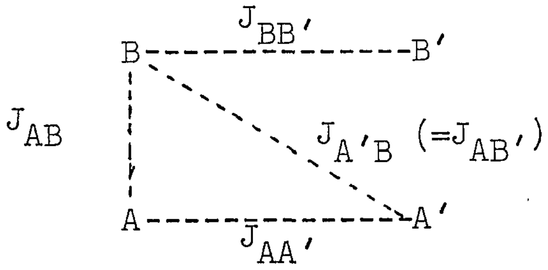
but further characterization was not made due to the small amount of material in the fraction. Dinitro compound CLXXIII was found to be stable to all phases of the work-up of the reactions, indicating that unsaturated materials similar to that just described were not artifacts of the decomposition of first-formed products.

The i r spectrum (KBr, Figure 17) of 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII) showed absorptions at 6.37μ (aliphatic nitro groups, broad), 6.53μ (aromatic nitro group), and 7.42μ (broad, aliphatic and aromatic nitro groups), in addition to absorptions characteristic of an aromatic nucleus. The compound was initially isolated as an oil, which yielded white needles, m.p. 41.5-42.5°, on successive recrystallizations from pentane (or hexane). On melting, CLXXIII could be recrystallized by cooling the colorless oil below 0° to give a white solid which had the same melting point as observed previously. The compound appeared to be stable indefinitely on standing in the room light in air.

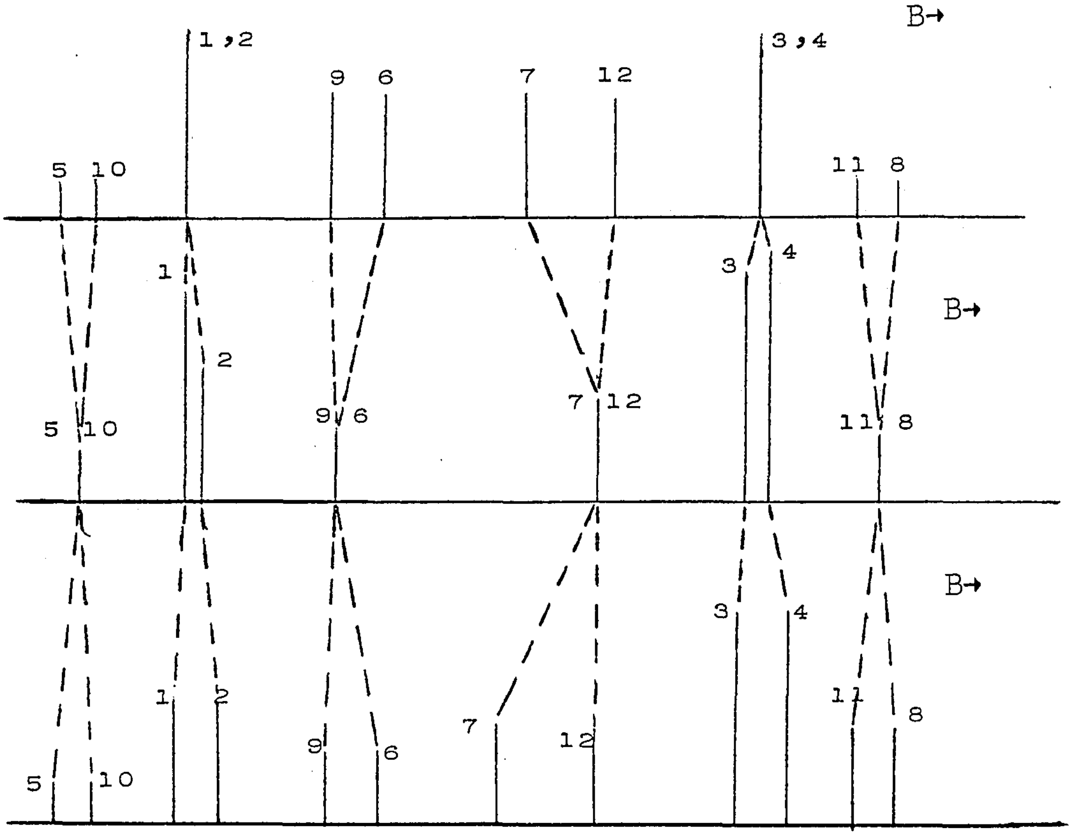
The nmr spectrum of CLXXIII ($CDCl_3$, Figure 22) showed a singlet at 7.33τ (3H, aliphatic methyl group) and a complex A_2B_2 pattern centered at 1.94τ (4H). An expansion of the A_2B_2

pattern showed the presence of 16 lines in the multiplet (Figure 22). The multiplet was best explained by the boundary conditions for the various coupling constants of $J_{AB} >> J_{AB'} > 0$, with $J_{AB'}$ small, and $J_{BB'} >> J_{AA'} = 0$ or nearly so (119) (see following page). The boundary conditions are illustrated in the accompanying diagrams for the A portion of an A_2B_2 multiplet. In an A_2X_2 multiplet, where $J_{AB} >> J_{AB'} > 0$ and $J_{BB'} >> J_{AA'} > 0$ (upper diagram), two strong lines, representing degenerate pairs of lines (1, 2 and 3, 4), and two quartets (lines 5, 6, 7, 8 and 10, 9, 12, 11) would comprise the spectrum. As the chemical shift of the protons A and B decreases in magnitude, the spectrum shown in the lower diagram would be observed, again with the boundary conditions $J_{AB} >> J_{AB'} > 0$ and $J_{BB'} >> J_{AA'} > 0$. The degenerate pairs of lines, 1, 2 and 3, 4, split slightly. The inner pairs of lines (9, 6 and 7, 12) also separate further. The portion of the A spectrum closest to the B spectrum becomes more intense, accompanied by a decrease in the intensity of the outer lines (119). If $J_{AA'}$ is zero or small, the pairs of lines [5, 10], [9, 6], [7, 12], and [11, 8] collapse to form single lines. Further, if $J_{A'B}$ is small, the lines 7, 12 are separated very little. The middle diagram reproduces the A portion of the A_2B_2 pattern for CLXXIII (from the expansion shown in Figure 22). Although lines [5,10], [9, 6], [7, 12], and [11, 8] are broad in the spectrum of CLXXIII, the boundary conditions $J_{AA'} = 0$, and $J_{AB'}$ = small, best explain the observed 16 lines in the multiplet. The


CH3
NO2
NO2
HB
HB'
HA
HA'
NO2

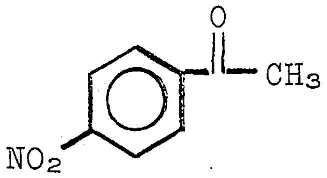

JBB'
B
B'
JAB
JA'B (=JAB')
A
A'
JAA'

CLXXIII


B→
1,2
3,4
9 6
7 12
5 10
11 8
1
2
3
4
B→
5 10
9 6
7 12
11 8
B→
3
4
1 2
9 6
7
12
11
8
5 10

coupling constant J_{AB} was calculated by the method of Pople (119) to be about 10 c.p.s. for CLXXIII.

The mass spectrum of CLXXIII (70 ev.) gave no ion at m/e 241, although the fragment ions were consistent with the structure CLXXIII ($C_8H_7N_3O_6$). Even at low ionization energies, a molecule ion for CLXXIII (m/e 241) was not observed. The mass spectral data for CLXXIII is summarized in Table 16, page 292.



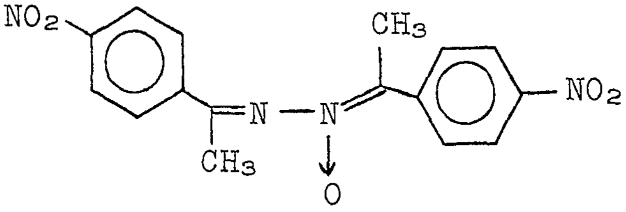
CLXXIV

The ketone, p-nitroacetophenone (CLXXIV), was isolated as a yellow solid which was purified by recrystallization from ethanol. The compound was identified by its melting point and mixed melting point with authentic p-nitroacetophenone. An i r spectrum (KBr) of CLXXII was identical to that given by the authentic ketone.

The isolation of p-nitroacetophenone azine monoxide (CLXXV) from the oxidation of oxime CLXIV by CAN in methanol provided the third example of azine monoxide formation in the CAN oxidation of aryl ketoximes in methanol. Difficulty was experienced in separating azine monoxide CLXXV from unreacted oxime CLXIV by chromatographic techniques. The materials were separable, however, as a result of the differing solubilities in chloroform. Fractional recrystallization of mixtures containing oxime CLXIV and azine monoxide CLXXV from chloroform gave unreacted oxime CLXIV. The material remaining after removal of CLXIV was recrystallized from ethanol to give azine monoxide CLXXV. The azine monoxide was difficult to purify due to decomposition on heating in any solvents. A satisfactory combustion analysis for CLXXV was not obtained, apparently as a result of decomposition of the material in recrystallization procedures. The compound decomposed on melting (m.p. 140-2°) to give a red oil.

The i r spectrum (KBr) of p-nitroacetophenone azine monoxide (CLXXV) is shown in Figure 20, page 153. The absorptions characteristic of azine monoxides in the 6.40-6.45μ and *ca*. 8μ regions of the spectrum (116) were either masked by other absorptions or had been shifted to new positions. The shoulder on the absorption at 6.60μ and either the absorption at 7.60 or the shoulder at 7.71μ were the most likely assignments for absorptions due to the $C{=}N{<}^{O}$ grouping, but the lack of i r data for other arylalkyl azine monoxides makes the assignments only tentative. The presence of an aromatic nitro group (or groups) in the compound was confirmed by absorptions at 6.60μ and 7.45μ (Figure 20).

The mass spectrum of CLXXV gave a molecule ion at m/e 342 (see Table 19, page), and fragmentation which was similar to that observed for 9-fluorenone azine monoxide and benzophenone azine monoxide. The observed molecular weight for the



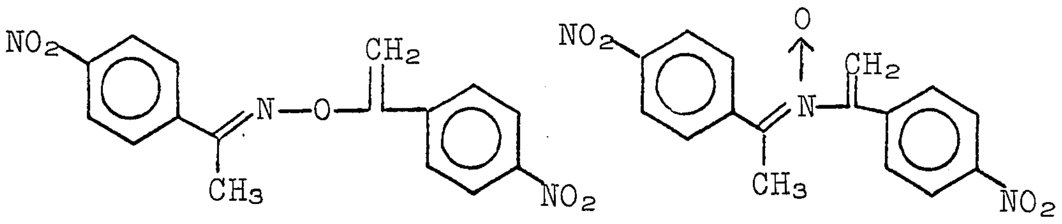
CLXXV

material was consistent with CLXXV ($C_{16}H_{14}N_4O_5$). The mass spectral data for CLXXV is discussed in a later section.

The nmr spectrum ($CDCl_3$) of an impure sample of azine monoxide CLXXV is shown in Figure 26, page 165. The nmr spectrum of p-nitroacetophenone oxime ($CDCl_3$, saturated solution) is also shown in Figure 26 for purposes of comparison, since the oxime was the major contaminant in the azine monoxide spectrum. The assignments of the various peaks in the spectrum of azine monoxide CLXXV follow. An A_2B_2 splitting pattern due to the two aromatic disubstituted rings of CLXXV was centered at 1.91τ, with J_{AB} = ca. 9 c.p.s. The A_2B_2 pattern due to CLXXV was superimposed on an A_2B_2 multiplet due to the para-disubstituted ring of oxime CLXIV centered at 1.98τ, with J_{AB} = ca. 9.2 c.p.s., the same position and coupling constant as obtained from the nmr spectrum of the oxime itself. The small peak at 7.32τ in the spectrum of the mixture disappeared on addition of D_2O to the sample, and was assigned to the hydroxyl proton of oxime CLXIV. The intense singlet at 7.56τ was assigned to the methyl groups of CLXXV; the singlet at 7.67τ

was assigned to the methyl group of oxime CLXIV. The integral indicated that the composition of the mixture was about 72% azine monoxide CLXXV and 28% oxime CLXIV. A peak at 8.74τ in the spectrum of the mixture was due to an additional impurity.

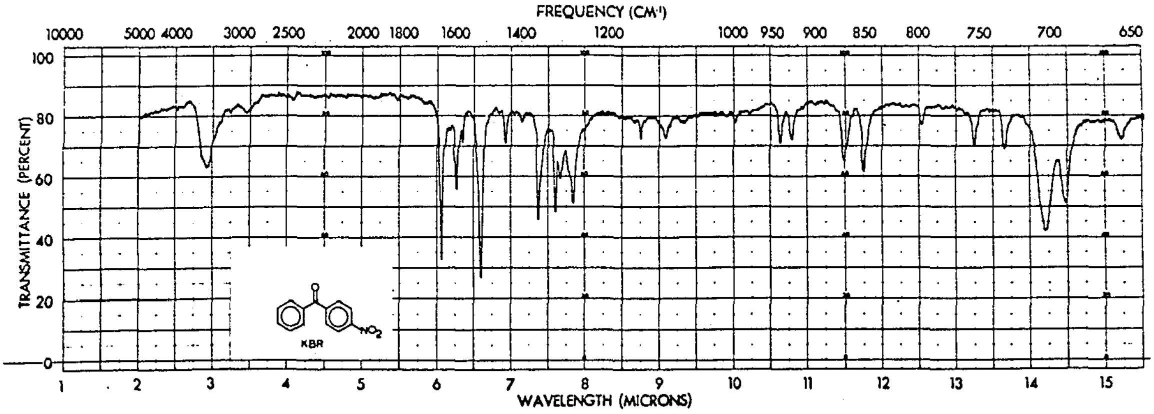
The oxidation of oxime CLXIV in 80% methanol-20% water gave small quantities of two other compounds, in addition to dinitro compound CLXXIII, ketone CLXXIV, azine monoxide CLXXV, and unreacted oxime. The first of the compounds was obtained in the second fraction of the chromatography of the product mixture, as a mixture with a small amount of ketone CLXXIV. Recrystallization of the fraction from ethanol gave 0.009 g. of yellow-orange needles, m.p. 162-3° (dec.). The i r spectrum (KBr) of the material is shown in Figure 19, page 151, labeled Unknown A. The spectrum was generally similar to that of oxime CLXIV, but lacked the characteristic absorption due to the hydroxyl group of CLXIV. Some changes in the 11.7-15.0μ region of the spectrum indicated that some alteration in the nature of one of the two para substituents on the aromatic ring of CLXIV had taken place. The presence of an aromatic nitro group (or groups) in the compound was indicated by absorptions at 6.58μ and 7.44μ. The apparent molecular weight of the material was 327 (mass spec.). The base peak of the mass spectrum was observed at m/e 180. The molecular weight of the ion corresponding to the base peak of the spectrum is the same as that of oxime CLXIV (m.w. 180). At low electron energy (18 ev.), the peak at m/e 327 became one of the most intense peaks in the spectrum. The odd molecular weight of 327 indicated that the material contained an odd number of nitrogen atoms. Further characterization was not possible due to the small amount isolated, but speculation based on the data relating to Unknown A results in the formulation of possible structures such as are shown below.

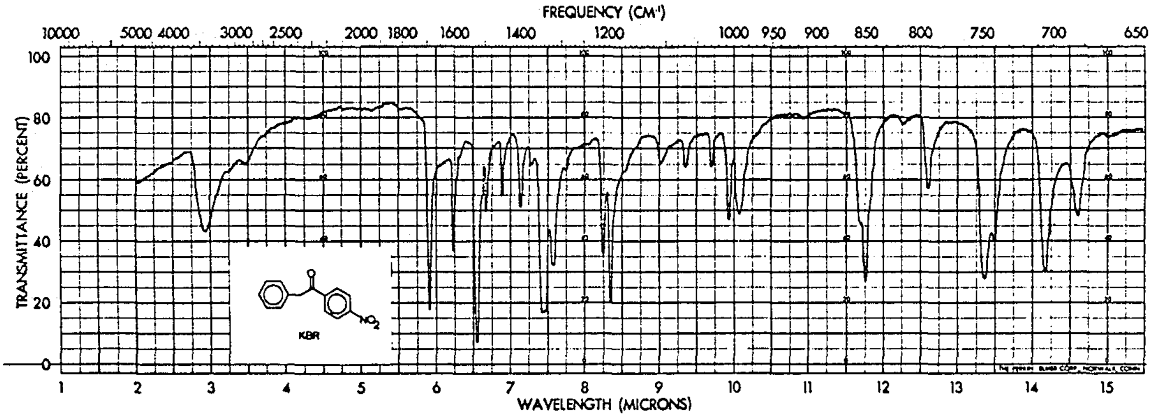


Unknown A

Recrystallization (ethanol) of the fourth fraction of the chromatography of the product mixture from the oxidation of CLXIV in 80% methanol-20% water gave 0.05 g. of a tan solid, m.p. 92-6°. The i r spectrum (KBr) is shown in Figure 19, page 151, titled Unknown B. Absorptions at 6.59μ and 7.43μ in the i r spectrum indicated the presence of an aromatic nitro group in the molecule. An nmr spectrum of the material (CCl_4, Figure 31, page 191) showed (to a first approximation) superimposed AB (or A_2B_2) multiplets in the 1.67-2.50τ region. In addition, six singlets appeared at 6.80τ, 6.90τ, 7.60τ, 7.79τ, 8.22τ, and 8.37τ, respectively. The ratio of the aromatic protons to aliphatic protons was 1:1.04. The singlets between 6.80τ and 8.37τ occurred in two sets. The smaller peaks (6.90τ,

Figure 27. Infrared spectra.
Top: p-Nitrobenzophenone (CLXX).
Middle: α-Phenyl-p-nitroacetophenone (CLXXVIII).
Bottom: p-Nitroacetophenone (CLXXIV).


FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
NO₂
KBR


FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
NO₂
KBR

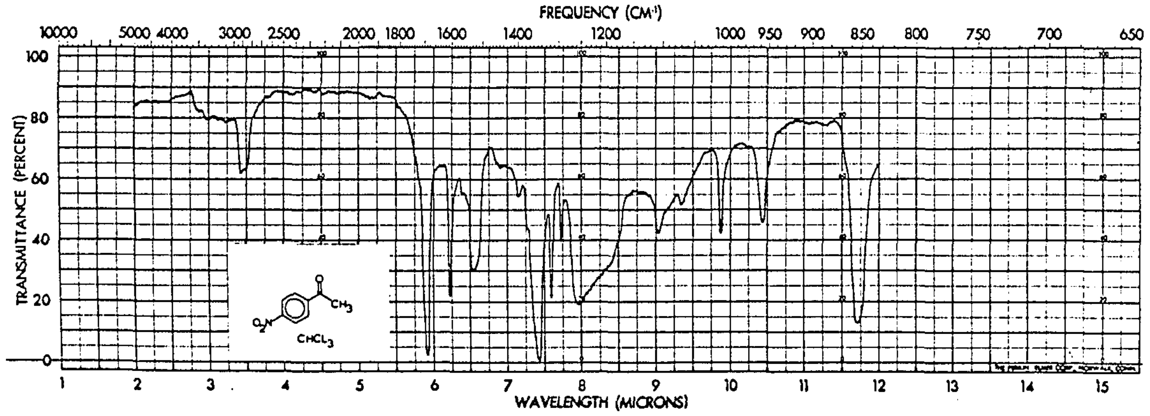
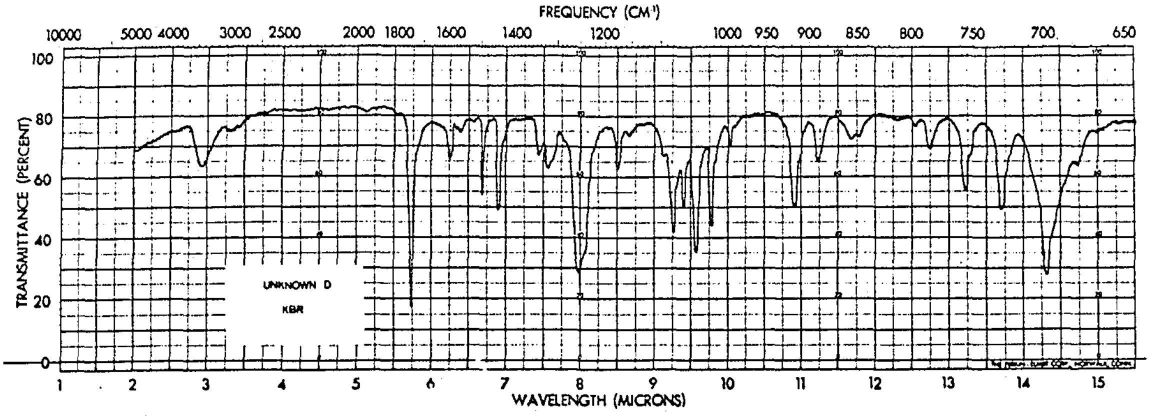
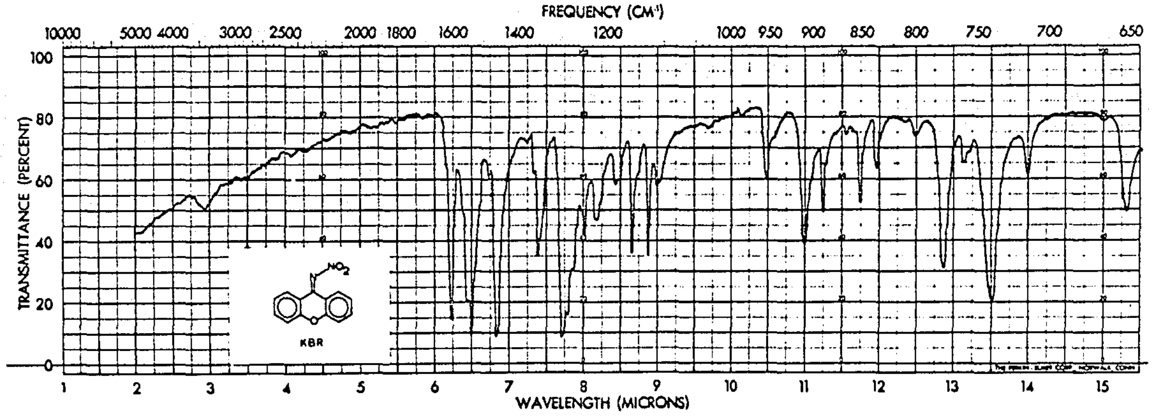

FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)
O₂N
CH₃
CHCl₃

Figure 28. Infrared spectra.
Top: Unknown D.
Middle: 9-Nitriminoxanthene (CLXXXVI).
Bottom: Unknown E.


FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
0 20 40 60 80 100
UNKNOWN D
KBR
WAVELENGTH (MICRONS)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


FREQUENCY (CM⁻¹)
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TRANSMITTANCE (PERCENT)
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NO2
KBR
WAVELENGTH (MICRONS)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

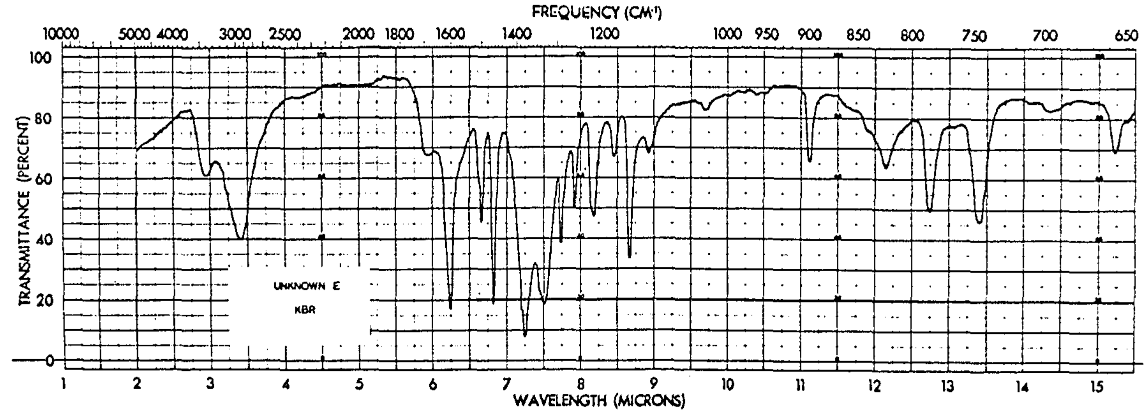

FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
0 20 40 60 80 100
UNKNOWN E
KBR
WAVELENGTH (MICRONS)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Figure 29. Nuclear magnetic resonance spectra.
Top: p-Nitrobenzophenone (CLXX).
Bottom: α-Phenyl-p-nitroacetophenone (CLXXVIII).

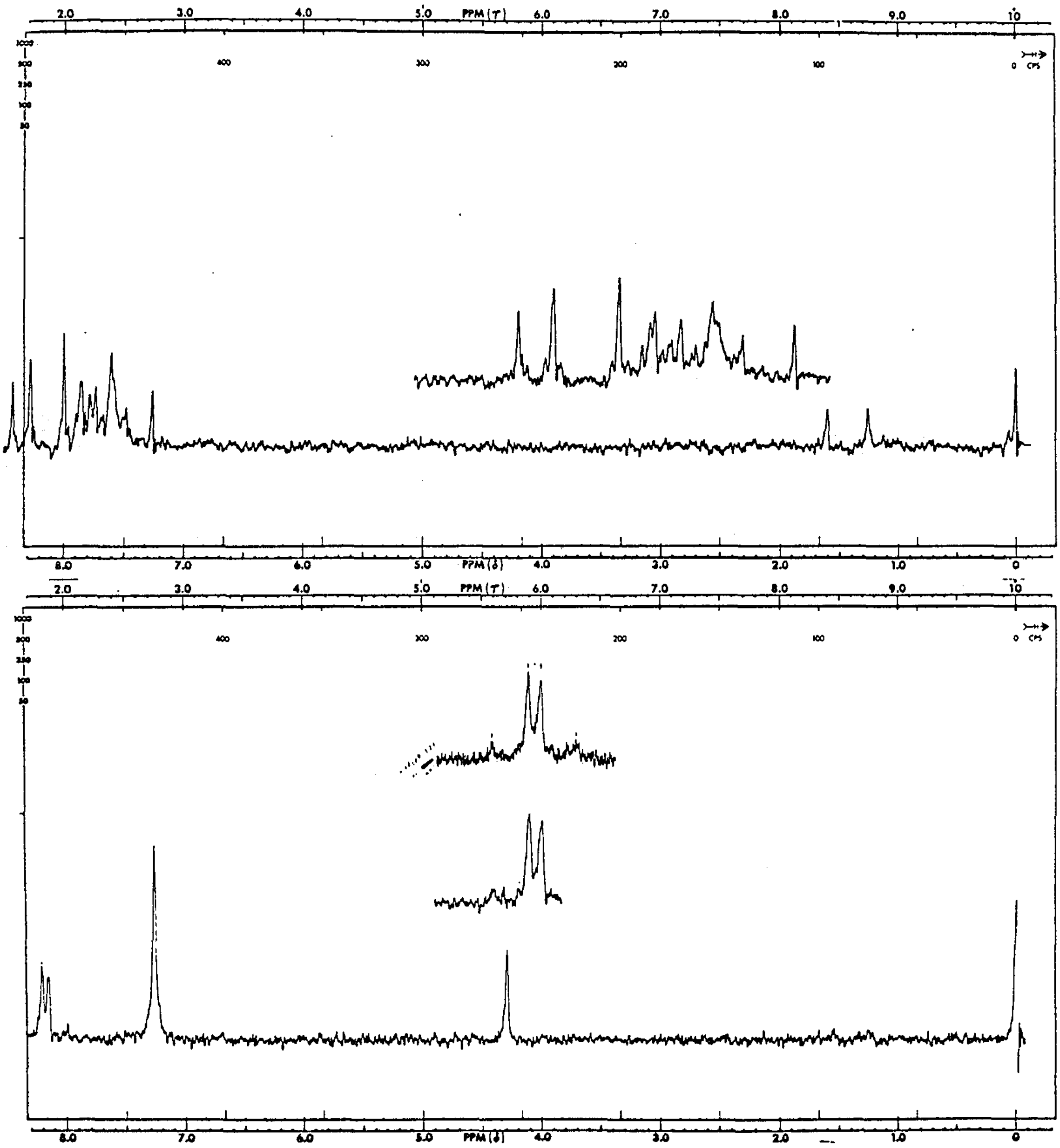
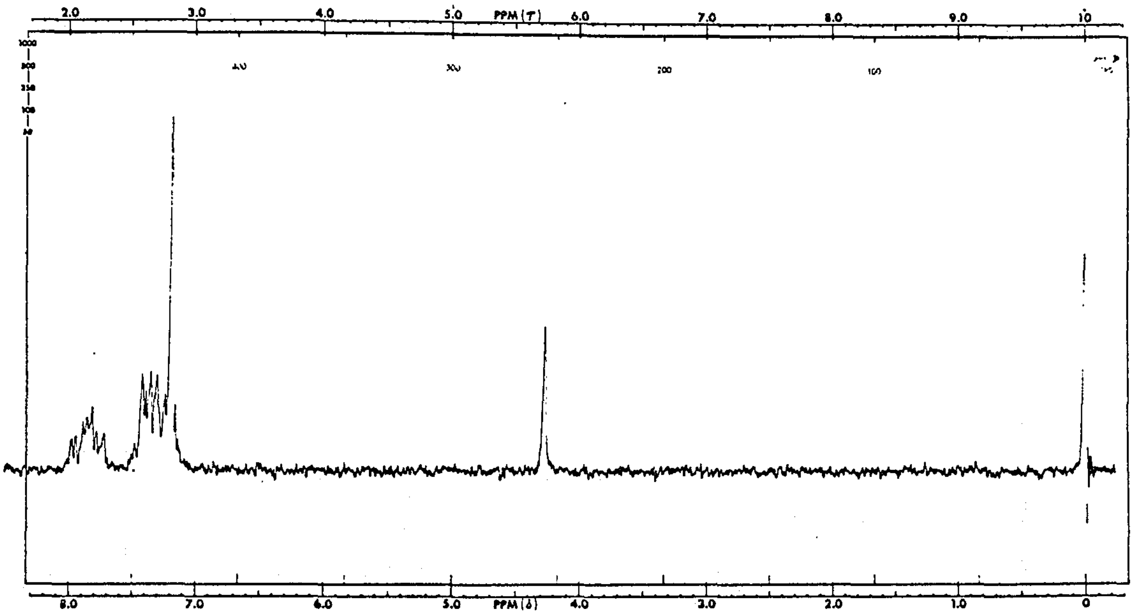

PPM (τ)
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10
400
300
200
100
0 CPS
PPM (δ)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1000
500
250
100
50

Figure 30. Nuclear magnetic resonance spectra.
Top: Unknown D.
Bottom: α-Phenylacetophenone (CLXXVII).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3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

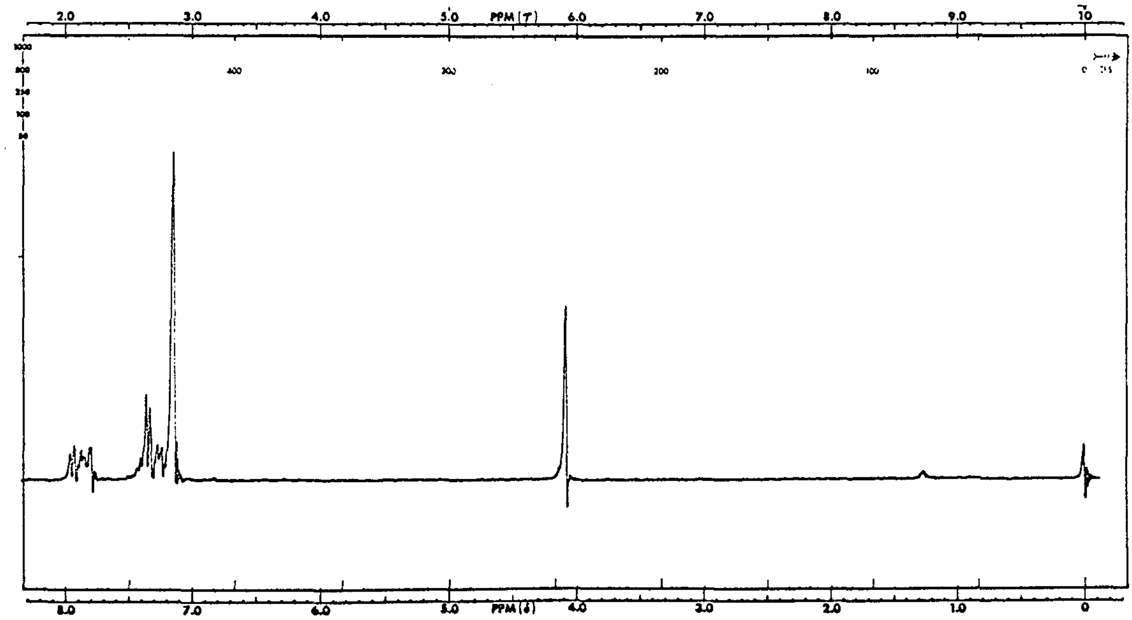
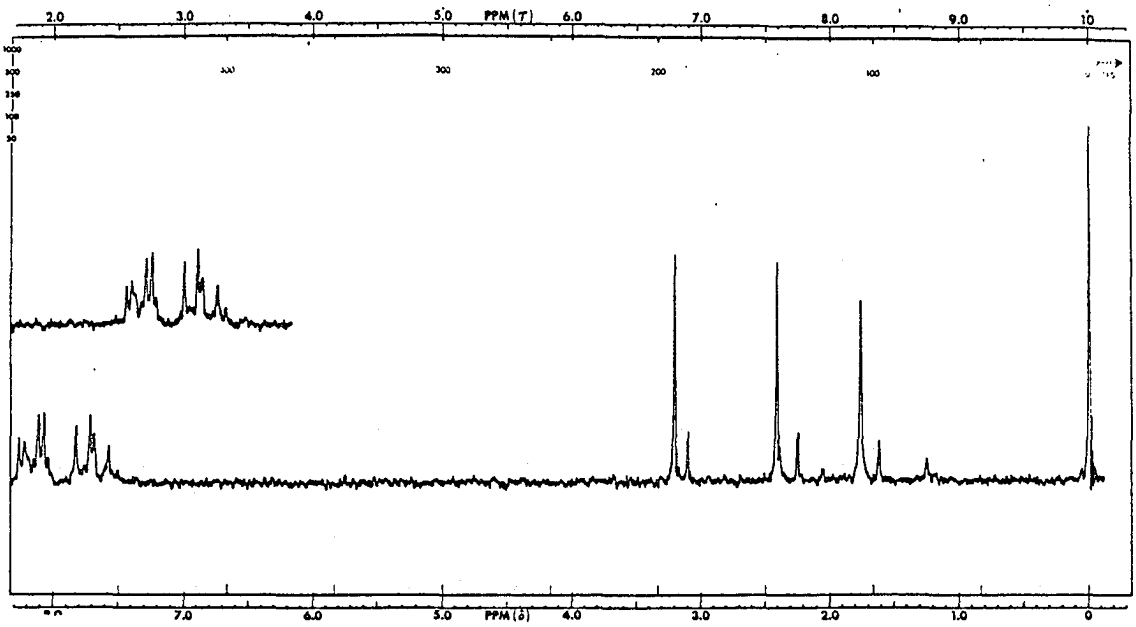
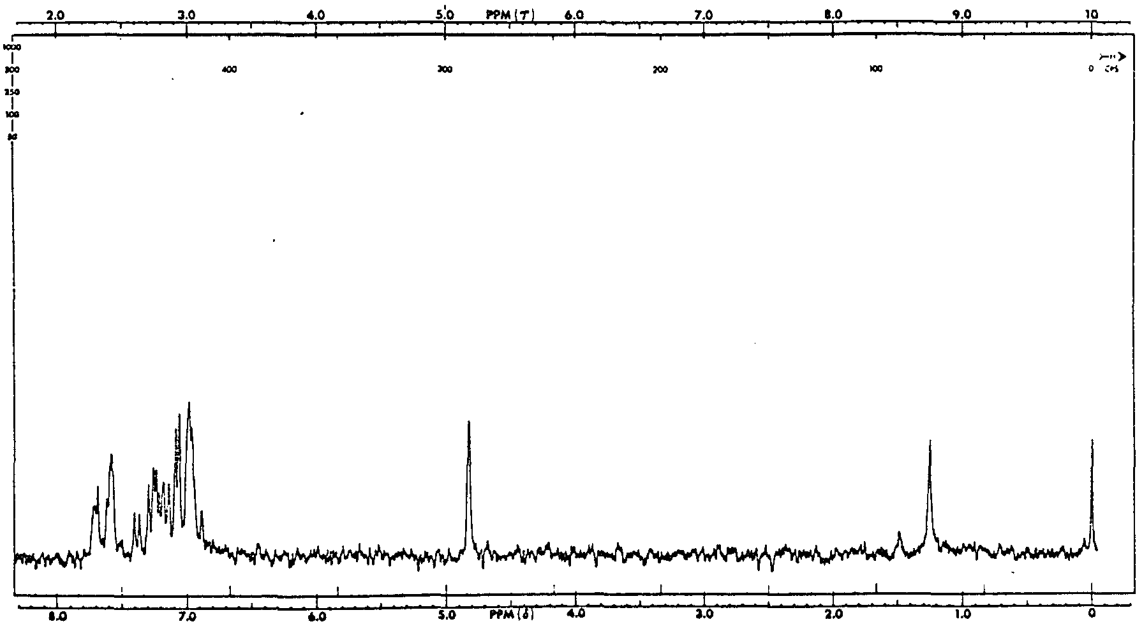

2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
400
300
200
100
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

Figure 31. Nuclear magnetic resonance spectra.
Top: Unknown B.
Bottom: 9,9'-Bifluorene (CCXV).


2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
1000
500
250
100
50
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0


2.0
3.0
4.0
5.0
PPM (τ)
6.0
7.0
8.0
9.0
10
1000
500
250
100
50
400
300
200
100
0 CPS
8.0
7.0
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
0

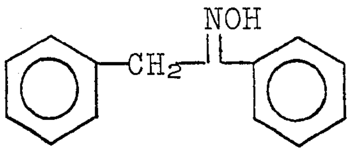
7.79τ, and 8.37τ) integrated in the ratio 1:5 with the larger peaks (6.80τ, 7.60τ, and 8.22τ), and the peaks within each set integrated in the ratio 1:1:1. Recrystallization of Unknown B from hexane by cooling the solution below 0° resulted in a white solid, m.p. 105-8° (Unknown C). The nmr (CCl_4) and i r (CCl_4) spectra of Unknown C were identical to those given by Unknown B, suggesting that Unknown C was a different crystalline modification of Unknown B. A mixture of B and C enriched in B may have been obtained when the solid was recrystallized from ethanol, whereas a mixture enriched in C may have been obtained on recrystallization from hexane. An equilibration between isomeric materials in solution to give the same mixture would account for why B and C had identical i r and nmr spectra.

The mass spectral data for Unknowns B and C has been summarized in the Experimental section (see Table 24, page 425). Both materials gave an apparent molecule ion at m/e 180 (70 e.v.), which was also the base peak of both spectra. The fragmentation patterns for B and C differed somewhat, however. An inspection of Table 24 shows the differences in fragmentation. Loss of a hydrogen atom from m/e 180 to give m/e 179 was more prominent for C (43.7%) than it was for B (2.0%). Loss of hydroxyl from m/e 180 (derived from Unknown B) to give m/e 163 was supported by a metastable ion at m/e 147.6. Some loss of hydroxyl from Unknown C was suggested by an ion at m/e 163, but an apparent loss of CH_3 to give m/e 165 was more prominent. A peak at m/e 152 in the spectrum of C apparently arose by loss of 28 from the molecule ion, as suggested by a strong metastable ion at m/e 128.4. However, the origin of a fragment of mass 28 was not obvious as no carbonyl absorption was observed in the i r spectrum of C. An ion at m/e 150 in the spectrum of Unknown B suggested a loss of ·NO from m/e 180, which was supported by a metastable ion at m/e 125.0. Loss of ·NO from Unknown C was apparently important, as suggested by an ion at m/e 150 (25.5%). Fragmentation by loss of ·NO from either of the two materials was reasonable, since the presence of nitro groups in the compounds was indicated by the i r spectra. The occurrence of ions at m/e 91 and m/e 92 in the spectra of B and C indicated that species such as $[C_6H_3O]^+$ and $[C_6H_4O]^{\dagger}$ were formed by degradation of the compounds, as would arise from substituted aromatic nitro compounds.

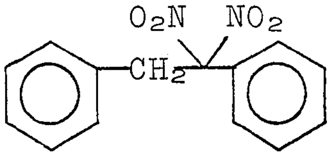
At an ionization energy of 18 ev., only ions at m/e 150, 165, 179, 180, and 181 remained in the mass spectrum of Unknown C. At 13 ev. and 14 ev., only ions at m/e 179, 180 and 181 remained. The apparent molecular weights of Unknowns B and C corresponded to that of oxime CLXIV, but the melting points of B and C were considerably lower than the melting point of CLXIV (m.p. 174-6°). The unknown materials contained the p-nitrophenyl group originally present in oxime CLXIV, and were apparently isomeric with CLXIV through some arrangement of atoms in the alkyl sidechain. The structures of Unknowns B and C were not determined, as the amount of material initially isolated was too small to allow further characterization.

Oxidation of α-phenylacetophenone oxime (CLXV) in methanol by one equivalent of CAN gave 1,1-dinitro-1,2-diphenylethane (CLXXVI), α-phenylacetophenone (CLXXVII), and α-phenyl-p-nitroacetophenone (CLXXVIII) in yields of 13%, 64.3%, and 1.2%, respectively (Table 6). A small amount of a fourth material was isolated which was only partially characterized. Oxime CLXV was not recovered from the reaction, although some evidence suggested that a small amount of the oxime was present in later chromatography fractions. Oxidation of oxime CLXV in anhydrous acetone solution by CAN gave CLXXVI, CLXXVII, and CLXXVIII in yields of 20.6%, 52.7%, and 2.3%, respectively (Table 7) in addition to a small amount of the same unknown material as isolated from the oxidation in methanol. Oxime CLXV was not recovered from the reaction in acetone.

The dinitro compound, 1,1-dinitro-1,2-diphenylethane (CLXXVI), was obtained as white needles, m.p. 71-72°, after successive recrystallizations from pentane. The compound appeared to be stable indefinitely on standing at room temperature in the room light. The i r spectrum of CLXXVI (KBr, Figure 17, page 147) showed an absorption at 6.38μ due to the asymmetric stretching vibrations of a nitro group, and a weak absorption due to the symmetric stretching vibrations of a nitro group at 7.35μ or between 7.50-7.60μ. Assignment of the latter absorption was difficult, since the normal region for appearance of the symmetric vibrations of the nitro groups in



CLXV



CXLLVI

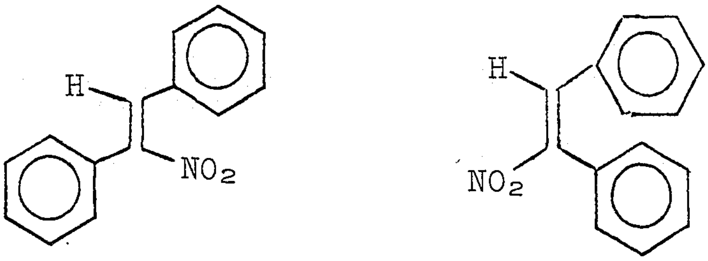
geminal-dinitro compounds was between 7.40-7.50μ, and the absorption was usually more intense than either the peak at 7.35μ or the broad peak between 7.50-7.60μ. The mass spectrum of CLXXVI gave a molecule ion at m/e 272, and fragmentation which was consistent with CLXXVI ($C_{14}H_{12}N_2O_4$). The mass spectral data for CLXXVI is summarized in Table 16, page 292.

The nmr spectrum of CLXXVI (CCl_4, Figure 23, page 159) showed a broad aromatic band between 2.50-3.17τ, and a singlet at 5.83τ corresponding to the methylene protons. The absorptions integrated in the ratio 5:1 (aromatic:aliphatic).

Small amounts of olefinic material were formed in the oxidation of oxime CLXV in both methanol and acetone. An absorption at 6.10μ was observed in the i r spectrum (CCl_4) of the crude fraction containing CLXXVI from the oxidation in methanol, which was not accounted for by compound CLXXVI. The material responsible for the i r band was not isolated. A fraction containing 0.047 g. of a yellow semisolid was obtained in the chromatography of the product mixture from the oxidation of CLXV in acetone, which showed a 6.10μ absorption in the i r (CCl_4, Figure 17, page 147), in addition to 5.82μ and

5.95μ absorptions due to an unknown material and α-phenylacetophenone (CLXXVII), respectively. A broad band at 6.37μ, with a 6.55μ shoulder, and a band at 7.42μ, suggested the presence of compounds in the mixture containing aliphatic and olefinic (or aromatic) nitro groups.

The nmr spectrum (CCl_4, Figure 23, page 159) of the mixture showed peaks at 1.92τ and 1.77τ, which were tentatively assigned to the olefinic protons of cis- and trans-α-nitrostilbene (CLXXIX). The assignments of the absorptions at 1.92τ and 1.77τ to cis and trans CLXXIX were not unreasonable, since the chemical shifts of the olefinic protons in cis- and trans-stilbene are 3.45τ and 2.90τ,[1] respectively, and a downfield shift in the resonance frequencies of the olefinic protons of CLXXIX (cis and trans) relative to the respective parent stilbenes might be expected due to additional deshielding of the protons by the nitro group. The lack of an absorption at 5.71τ corresponding to the methylene group of α-phenyl-p-nitroacetophenone (CLXXVIII) indicated that the low field absorptions



CLXXIX

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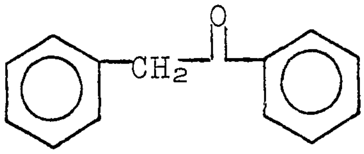
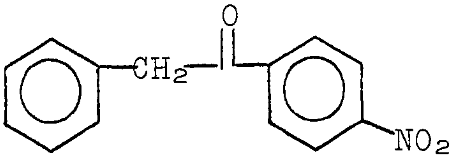
[1] This spectrum can be found in NMR catalog, Vol. 1, Varian Associates, Inc., 1962, No. 229.

were not a part of the A_2B_2 multiplet observed for the aromatic protons in CLXXVIII. Other absorptions in the nmr spectrum of the crude fraction (Figure 23) were assigned as follows. The broad singlet at 5.82τ was assigned to the methylene protons of dinitro compound CLXXVI and ketone CLXXVII. The singlet at 4.72τ was tentatively assigned to the unknown material which had contributed the 5.82μ carbonyl band to the i r spectrum of the mixture. The dinitro compound CLXXVI was stable to all phases of the work-up of the reaction, indicating that the olefinic materials were not artifacts arising from decomposition of CLXXVI. The components of the mixture could not be separated due to the small amount of material present.

The ketone, α-phenylacetophenone (CLXXVII), was recrystallized from ethanol to give a light yellow solid which had a satisfactory melting point and i r spectrum (identical to that shown by the authentic ketone). A mixed melting point



CLXXVII



CLXXVIII

of CLXXVII with authentic ketone gave no depression. The nmr spectrum (CCl_4) of CLXXVII (Figure 30) showed a singlet at 5.92τ, in addition to aromatic protons in the ratio 1:5, respectively. The nmr spectrum is shown in Figure 30 for purposes of comparison for other nmr spectra.

The isolation of α-phenyl-p-nitroacetophenone (CLXXVIII) from the oxidation of oxime CLXV provided a second example of the formation of a nitrated ketone in the oxidation of ketoximes by ceric ammonium nitrate. The formation of CLXXVIII in methanol and acetone was the first instance, however, where a nitrated ketone was formed in both solvents. Formation of p-nitrobenzophenone from benzophenone oxime by oxidation with CAN was observed to occur only in acetone solution, at least in quantities sufficient to allow isolation.

The i r spectrum of CLXXVIII (KBr, Figure 27, page 183) showed a carbonyl absorption at 5.92μ, and absorptions at 6.56μ and 7.45μ (aromatic nitro group). The mass spectrum of CLXXVIII gave a molecule ion at m/e 241. The base peak of the spectrum was observed at m/e 150. Portions of the mass spectral fragmentation of CLXXVIII are summarized in Figure 32. Ion intensities relative to the base peak (base peak = 100%) are given in parentheses. A weak metastable ion at m/e 93.4 indicated that the molecule ion was cleaved as shown in Figure 32 to give the ions of m/e 150 and m/e 91. A strong metastable ion at m/e 96.0 accompanied the conversion m/e 150 → m/e 120 (loss of ·NO). Fragmentation of the ion m/e 120 to give an ion at m/e 92 was supported by the appearance of a weak metastable ion at m/e 70.5. Only the major fragmentation of CLXXVIII is shown in Figure 32. Less prominent means of degradation of

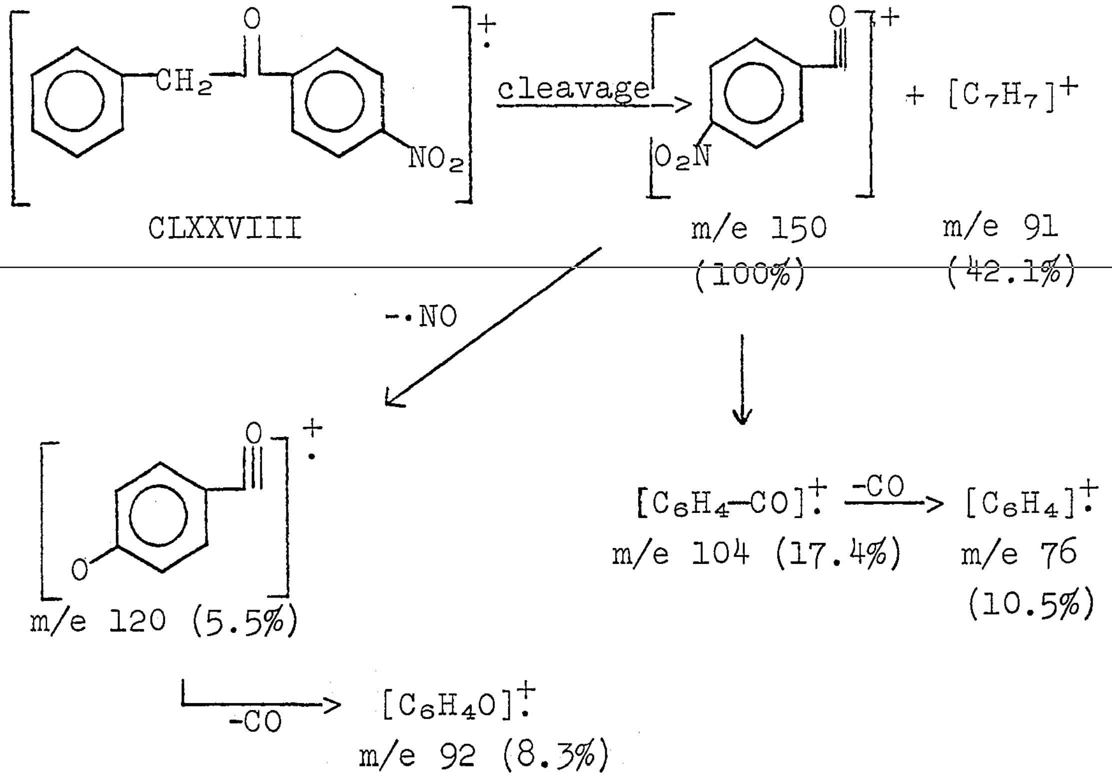


Figure 32. Mass spectral fragmentation of α-phenyl-p-nitroacetophenone (CLXXVIII).

CLXXVIII were consistent with the structure.

The nmr spectrum of CLXXVIII ($CDCl_3$, Figure 29, page 187) showed an A_2B_2 multiplet centered at 1.82τ (4H), a singlet at 2.73τ (5H), and another singlet at 5.71τ (2H). The chemical shifts of the protons A and B were calculated (119) to be about 1.75τ and 1.90τ, respectively with a coupling constant J_{AB} of about 9 c.p.s. The presence of the A_2B_2 multiplet in the spectrum of CLXXVIII indicated that the nitro group was <u>para</u> to the carbonyl group.

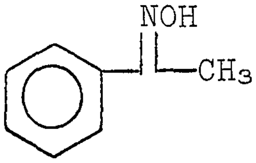
The fourth compound obtained in the oxidation of oxime CLXV by CAN was found in the product mixtures from reactions in both methanol and acetone. A chromatography fraction from the reaction in methanol contained material which showed a 5.75μ absorption in the i r spectrum ($CHCl_3$). Successive recrystallizations of the material from hexane gave an almost white solid, m.p. 83-4°. The sixth fraction of the chromatography of the product mixture from the oxidation of CLXV in acetone yielded, after successive recrystallizations from hexane, an equal amount of a white solid, m.p. 82-4°, which gave an i r spectrum ($CHCl_3$) superimposable with that of the solid from the methanol reaction. A mixed melting point of the two materials showed no depression.

The i r spectrum of the solid (KBr, Figure 28, page 185, titled Unknown D) showed a 5.74μ carbonyl absorption and no absorptions due to a nitro group. An intense absorption at 2.99μ (broad) was not readily assignable to any structural feature, although the absorption was the most prominent of several which distinguished the compound from other reaction products. The nmr spectrum of Unknown D (CCl_4, Figure 30, page 189) showed complex absorptions at 1.92-2.35τ and 2.45-2.90τ (with a superimposed singlet at 2.83τ), and a singlet at 5.73τ, in the ratio 2:5.5:1, respectively. No change in the ratio of the absorptions was observed on addition of D_2O to the nmr sample. The absorptions in the region between 1.92τ and 2.90τ in the spectrum of Unknown D were similar to those observed for α-phenylacetophenone (CLXXVII) (compare Unknown D with CLXXVII, Figure 30), but were more complex and more symmetrical than those of ketone CLXXVII. A downfield shift in the resonance frequency due to the methylene protons from 5.92τ in CLXXVII (Figure 30) to 5.73τ in Unknown D was also to be noted.

A combustion analysis indicated an empirical formula for Unknown D of $C_{20}H_{17}NO_2$ (calculated $C_{19.9}H_{16.8}NO_2$), which required a molecular weight of 303. The ion of highest mass observed in the mass spectrum of D (70 ev.) appeared at m/e 224, which could not be the true molecular weight if Unknown D contained a nitrogen atom. Ions at higher m/e were not observed at low electron energies. As the ionization potential was lowered, the peak at m/e 224 increased in intensity relative to other peaks, until it was the only peak remaining in the spectrum at 16 ev. At 20 ev., weak ions at m/e 193, 194, 195, and 211 were observable. An apparent metastable ion at m/e 159.5 also remained in the spectrum of D at 20 ev., which was not explainable by the fragmentations m/e 224 → m/e 193, 194 or 195; m/e 224 → m/e 180; m/e 211 → m/e 193, 194 or 195; or m/e 211 → m/e 180. A conversion m/e 303 → m/e 224 for a material of molecular weight 303 required a metastable ion at m/e 165.6, which was not observed. The base peak of the spectrum was found at m/e 105 ($[C_6H_5CO]^+$), and was accompanied by other ions of lower mass at m/e 91 ($[C_7H_7]^+$) and m/e 77 ($[C_6H_5]^+$), with intensities relative to the base peak of 20.6% and 28.2%, respectively.

The available data (i r, nmr, mass spec.) suggested that the basic structure of ketone CLXXVII ($C_{14}H_{12}O$) was incorporated in Unknown D with only slight modification. If the molecular weight of 303($C_{20}H_{17}NO_2$) suggested by the analysis data was correct or nearly so, it follows that a group with an empirical formula such as C_6H_5NO was also incorporated in Unknown D. The general shape of the aromatic absorptions observed in the nmr spectrum of D (Figure 30) strongly suggested that *ortho*-disubstitution was present on an aromatic ring or rings in D. The structure of Unknown D remains to be determined.

Oxidation of acetophenone oxime (CLXVI) by one equivalent of ceric ammonium nitrate in anhydrous methanol gave 1,1-dinitro-1-phenylethane (LXXII) and acetophenone (CLXXX) in yields of 27% and 39.6%, respectively (Table 6). The yield of CLXXX was based on the 2,4-dinitrophenylhydrazone derivative of CLXXX, which was prepared directly from a chromatography fraction. The i r spectrum (neat) of the ketone before preparation of the derivative was superimposable with that of the authentic ketone. Oxidation of CLXVI by CAN in anhydrous acetone gave LXXII and CLXXX in yields of 25.2% and 41.8%, respectively (Table 7). The yield of CLXXX again was based on the 2,4-dinitrophenylhydrazone derivative. Small amounts of *p*-nitroacetophenone (CLXXIV) were formed in the oxidation of CLXVI in methanol and acetone, but the ketone was not isolable in pure form. The i r spectrum ($CHCl_3$) of the crude ketone CLXXIV obtained in the reaction in methanol is shown in Figure



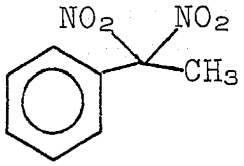
CLXVI

27, page 183 . . The i r spectrum of CLXXIV was identical to that given by the authentic ketone. The ketone was identified in the same manner as a product of the reaction in acetone. The approximate yields of CLXXIV in the reactions in methanol and acetone, based on the weights of crude chromatography fractions and their infrared spectral properties were 1% and 3%, respectively. The detection of p-nitroacetophenone in the product mixtures from the oxidation of oxime CLXVI provided the third (and last) example of the formation of nitrated ketones in the oxidation of ketoximes by CAN.

Unlike the geminal-dinitro compounds described previously, 1,1-dinitro-1-phenylethane (LXXII) was not a crystalline material at room temperature. The compound was obtained from chromatography columns as a light yellow, viscous oil, which was stable on distillation at reduced pressure. Distillation gave a nearly colorless liquid, b.p. 85-7°/0.13 mm., which crystallized on cooling below 0° and remelted in the range 5-8°. The reported melting point for the material is 6° (56). The compound was indefinitely stable to ordinary room light.

The i r spectrum of LXXII (neat, Figure 18, page 149) showed a broad absorption at 6.39μ and a less intense absorption at 7.38μ, corresponding to the nitro groups in the molecule. The nmr spectrum of LXXII (CCl_4, Figure 24, page 161) showed singlets at 2.58τ (aromatic protons) and 7.51τ (methyl group), in the ratio 5:3, respectively. The mass spectrum gave no molecule ion for LXXII even at low electron energies. The observed fragment ions were consistent with LXXII ($C_8H_8N_2O_4$). The mass spectral data for LXXII is summarized in Table 17, page 293 .

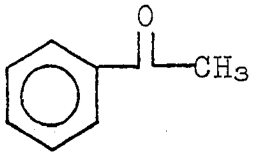
Evidence was obtained for the formation of an olefinic material in the oxidation of CLXVI in methanol. The second fraction of the work-up of the crude reaction mixture gave an



LXXII

i r spectrum (CCl_4) which showed a strong 6.10μ absorption, in addition to bands at 6.40μ (broad) and 7.46μ of medium intensity. The small amount of oil (0.017 g.) prohibited further identification. Olefinic materials were not detected in the product mixture from the oxidation of CLXVI in acetone. The dinitro compound LXXIX was stable to all phases of the work-up, which eliminated secondary decomposition of LXXIX as a possible means of formation of an olefinic compound containing a nitro group.

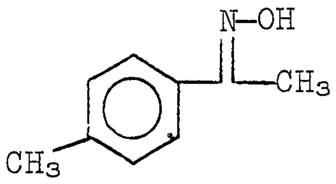
Acetophenone 2,4-dinitrophenylhydrazone was prepared from ketone CLXXX once the ketone had been separated from other materials. Before yields based on the hydrazone derivative were calculated, the material was recrystallized from ethanol-ethyl acetate until a satisfactory melting point was obtained. Mixed melting points with authentic acetophenone 2,4-dinitrophenylhydrazone were taken, and the derivative prepared from product ketone CLXXX gave no depression.



CLXXX

Infrared evidence was obtained which suggested that some unreacted oxime CLXVI was present in the later fractions of the chromatography of the acetone reaction mixture. The i r spectrum ($CHCl_3$) of the later fractions showed a broad absorption between 2.9-3.1μ. Oxime CLXVI was not isolated from the mixture. Evidence for unreacted oxime in the product mixture from the reaction in methanol was not obtained.

The substituted acetophenone oximes, p-methylacetophenone oxime (CLXVII) and 2,4-dimethylacetophenone oxime (CLXVIII), were oxidized by ceric ammonium nitrate in an attempt to determine what effects the ring substituents had on product yields,

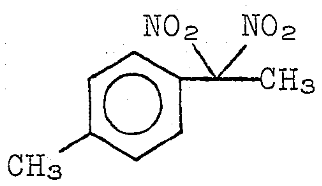


CLXVII

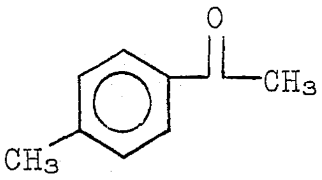
as compared to the results obtained with acetophenone oxime. Oxidation of p-methylacetophenone oxime (CLXVII) by one equivalent of ceric ammonium nitrate in anhydrous methanol gave 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI) and p-methylacetophenone (CLXXXII) in yields of 27% and 50.8%, respectively (Table 6). The yield of ketone CLXXXI was based on the p-nitrophenylhydrazone derivative, which was prepared from a chromatography fraction containing nearly pure ketone (i r (neat)). Oxidation of oxime CLXVII by CAN in anhydrous acetone gave CLXXXI and CLXXXII in yields of 34.3% and 48.9%, respectively (Table 7). Again, the yield of ketone CLXXXII was based on the p-nitrophenylhydrazone derivative.

The formation of ketones containing a nitro group on the aromatic ring was not observed in the oxidation of CLXVII in either methanol or acetone. The para-methyl group in oxime CLXVII accounted for the fact that no nitration in the para position was observed, since that position was blocked. The interesting point is that an ortho-nitrated ketone was also not formed.

The dinitro compound, 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI), was isolated as a viscous oil, which did not crystallize at room temperature. The compound crystallized on cooling below 0° and remelted in the range 6-10°. Distillation of CLXXXI at reduced pressure gave a light yellow, viscous liquid, b.p. 92-4°/0.07 mm., which when cooled below 0° crystallized to give a material which remelted in the range 7-10°. The



CLXXXI



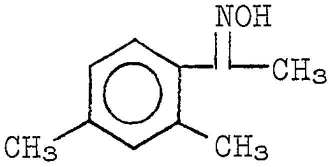
CLXXXII

compound was stable on standing in ordinary room light at room temperature.

The i r spectrum of CLXXXI (neat, Figure 18, page 149) showed a broad absorption at 6.37μ and a less intense absorption at 7.41μ (nitro groups). The nmr spectrum of CLXXXI (CCl_4, Figure 24, page 161) showed a complex A_2B_2 multiplet centered at about 2.75τ (δ_A and δ_B not very different), and singlets at 7.53τ (aliphatic methyl) and 7.67τ (aromatic methyl), in the ratio 4:3:3, respectively. The mass spectrum gave a weak molecule ion at m/e 210, and fragmentation which was consistent with CLXXXI ($C_9H_{10}N_2O_4$). The mass spectral data for CLXXXI is summarized in Table 17, page 293.

The third fraction of the chromatography of the product mixture from the oxidation of CLXVII in acetone contained 0.028 g. of an oil which was found to be a mixture of CLXXXI and an olefinic material (by an i r spectrum, neat). Evidence for an olefinic material came from a medium intensity absorption at 6.11μ. Insufficient material was available to allow isolation. Olefinic compounds were not detected in the product mixture from the oxidation of CLXVII in methanol.

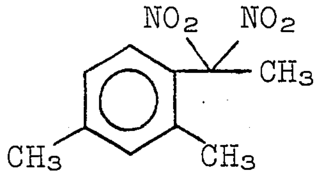
A p-nitrophenylhydrazone derivative was prepared from ketone CLXXXII after an i r spectrum (neat) was found to be identical to authentic p-methylacetophenone. A mixed melting point of the p-nitrophenyl hydrazone derivative with authentic p-methylacetophenone p-nitrophenylhydrazone gave no depression.



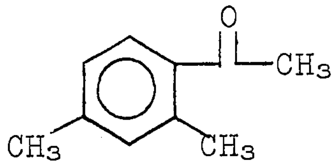
CLXVIII

Oxidation of 2,4-dimethylacetophenone oxime (CLXVIII) by one equivalent of ceric ammonium nitrate in anhydrous methanol gave 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) and 2,4-dimethylacetophenone (CLXXXIV) in yields of 20% and 51.1%, respectively (Table 6). The yield of ketone CLXXXIV was based on the p-nitrophenylhydrazone derivative. The oxidation of CLXVIII by CAN in anhydrous acetone gave CLXXXIII and CLXXIV in yields of 31.4% and 39.4%, respectively (Table 7). The yield of CLXXIV was again based on the p-nitrophenylhydrazone derivative. Evidence for the formation of nitrated ketones in the oxidation in either methanol or acetone was not obtained. Unreacted oxime CLXVIII was not detected in the product mixtures.

The dinitro compound, 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII), was isolated as a yellow, viscous oil which could be crystallized at Dry Ice-acetone temperatures. Distillation of CLXXXIII gave a light yellow, viscous oil, b.p. 110-113°/0.25 mm., which on freezing remelted in the range 0-5°. The compound was stable on standing indefinitely at room temperature in the room light. The i r spectrum of CLXXXIII (neat, Figure 18, page 149) showed absorptions at 6.36μ (broad) and



CLXXXIII

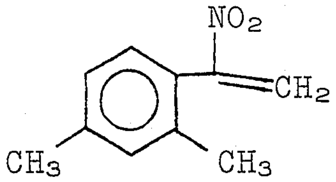


CLXXXIV

7.41μ (nitro groups). The nmr spectrum of CLXXXIII (CCl_4, Figure 25, page 163) showed aromatic protons at $2.9\text{-}3.0\tau$, and singlets at 7.51τ, 7.68τ and 7.80τ, in the ratio 1:1:1:1, respectively. A comparison of the spectrum with those given by dinitro compounds LXXII and CLXXXI permitted assignments of the singlets at 7.51τ, 7.68τ and 7.80τ, to the aliphatic methyl, the para-methyl, and the ortho-methyl group, respectively. The mass spectrum gave a molecule ion at m/e 224, and fragmentation which was consistent with CLXXXIII ($C_{10}H_{12}N_2O_4$). The mass spectral data for CLXXXIII is summarized in Table 17, page 293 .

The i r spectrum (neat) of chromatography fraction 3 from the oxidation of oxime CLXVIII in methanol is shown in Figure

19, page 151. The 6.20μ absorption was broadened and was more intense than that observed in the i r spectrum (neat) of dinitro compound CLXXXIII, relative to the peak due to the nitro group. Absorption maxima due to a nitro group were observed at 6.40μ and 7.57μ, as compared to 6.36μ and 7.41μ for CLXXXIII (Figure 18). The nmr spectrum of the unknown material (CCl_4, Figure 25, page 163) confirmed the fact that the unknown compound was different from the dinitro compound CLXXXIII. An expansion of the 7.4-8.0τ region (shown on the spectrum in Figure 25) revealed (to a first approximation) an AB quartet, with J_{AB} = ca. 7 c.p.s. The quartet is partially obscured by absorptions due to the methyl groups in CLXXXIII and the aromatic methyl groups of the unknown material. A modification in the aliphatic methyl group originally present in the oxime was evidenced by the decreased intensity of the absorption at 7.54τ in relation to the intense peak just upfield. The shape of the aromatic absorptions between 2.3-3.1τ in the spectrum of the unknown indicated that modification had occurred on a para-substituent on the aromatic ring of oxime CLXVIII. An AB multiplet (J_{AB} = ca. 8 c.p.s.), partially obscured by other aromatic absorptions, appeared in the 2.3-3.1τ region. The nmr spectrum (Figure 25) was consistent with a mixture containing some dinitro compound CLXXXIII and a vinyl benzene, such as α-nitro-2,4-dimethylstyrene (CLXXXV). Absorptions observed in the i r spectrum were also consistent with a nitro group situated on a double bond. The fraction contained 0.08 g.



CLXXXV

of the mixture, but attempts to separate the components were unsuccessful. Although much of the spectral data for the mixture is described through comparison with the dinitro compound CLXXXIII, the proposed nitro olefin CLXXXV did not arise by secondary decomposition of CLXXXIII. Compound CLXXXIII was stable to all phases of the work-up of the reaction. Compound CLXXXV, or any similar material, was not detected in the product mixture from the oxidation of oxime CLXVIII in acetone.

The i r spectrum of ketone CLXXXIV (neat) as obtained from chromatography columns was identical to that shown by the authentic ketone. The p-nitrophenylhydrazone derivative of CLXXXIV was prepared as mentioned before. A mixed melting point with authentic 2,4-dimethylacetophenone p-nitrophenylhydrazone showed no depression.

The infrared spectral properties and physical properties of geminal-dinitro compounds are summarized in Table 11 as a means of bringing together some of the data which has been presented in the preceding pages. Only the i r absorptions due to the nitro groups are included in the Table. Nuclear magnetic resonance data for the geminal-dinitro compounds is summarized in Table 12.

It should be recalled that oxidation of the diaryl ketoximes anthraquinone monoxime (CLIII) and 9-xanthenone oxime (CLXIX) did not give geminal-dinitro derivatives. The major products of the oxidation of oximes CLIII and CLXIX were the respective ketones in every solvent. The yield data for the oxidation of CLIII by CAN in methanol and acetone is summarized in Table 13, page 217. The results of the oxidation of CLXIX by CAN in methanol, 80% methanol-20% water, and acetone, are also summarized in Table 13. As can be seen from Table 13, anthraquinone (CLIV) was the only product isolated from the oxidation of anthraquinone monoxime in methanol and acetone. Oxidation of 9-xanthenone oxime by CAN resulted in more complex reactions, as evidenced by the fact that 9-nitriminoxanthene (CLXXXVI), 9-xanthenone (CLXXXVII), and 9-xanthenone azine (CLXXXVIII) were isolated from product mixtures under varying conditions. Ketone CLXXXVII was the major product.

Oxidation of anthraquinone monoxime (CLIII) by CAN in methanol (containing some benzene to improve the solubility of CLIII) gave anthraquinone (CLIV) in 84.2% yield. The quinone CLIV was characterized by its melting point and i r spectrum, which was identical to that given by authentic anthraquinone. A mixed melting point of CLIV with authentic anthraquinone gave no depression. The reaction has been reported to give CLIV in 81% (114), a yield which has since been improved

Table 11. Infrared spectra and physical properties of <u>geminal</u>-dinitro compounds

		Infrared Spectra			Physical Properties	
		$\nu_{\text{Nitro}}(\mu)$[a]				
Compound	Phase	$\nu_{\text{asym.}}$	$\nu_{\text{sym.}}$	Fig.[b]	Form[c]	Melting point or boiling point[d]
9,9-Dinitrofluorene (LXII)	KBr	6.41	7.40	16	v.l. yellow needles	m.p. 139-140° (dec.)
Dinitrodiphenylmethane (LXIX)	CCl_4	6.35	7.44	16	white powder	m.p. 75-76° (dec. 115°)
1,1Dinitroindane (CLXXI)	KBr	6.41	7.35	16	white needles	m.p. 42-43° (dec. 130°)
1,1-Dinitro-1-(p-nitrophenyl)-ethane (CLXXIII)	KBr	6.37 6.53 (ar)	7.42[e]	17	white needles	m.p. 41.5-2.5°
1,1-Dinitro-1,2-diphenylethane (CLXXVI)	KBr	6.38	7.35 or 7.5-7.6	17	white needles	m.p. 71-72°
1,1-Dinitro-1-phenylethane (LXXII)	neat	6.39	7.38	18	colorless liq.	b.p. 85-87°/0.13 mm. m.p. 5-8°
1,1-Dinitro-1-(p-tolyl)-ethane (CLXXXI)	neat	6.37	7.41	18	liquid	b.p. 92-94°/0.07 mm. m.p. 7-10°
1,1-Dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII)	neat	6.36	7.41	18	liquid	b.p. 110-113°/0.25 mm. m.p. 0-5°

[a] Asymmetric and symmetric vibrational frequencies for the nitro groups.

[b] The figure in which the i r spectrum is shown.

[c] Physical form at room temperature.

[d] Temperature at which decomposition (dec.) occurred given in parentheses beside the melting point.

[e] Symmetric vibrational frequency for the aliphatic and aromatic nitro groups.

Table 12. Nuclear magnetic resonance spectra of <u>geminal</u>-dinitro compounds

Compound	Solvent	Chemical Shift (τ)[a] Ar[b]	-CH_2-[c]	-CH_3[c]	Fig.[d]
9,9-Dinitrofluorene (LXII)	$CDCl_3$	2.5-3.0(o)			
Dinitrodiphenylmethane (LXIX)	CCl_4	2.7-2.9(m)			
1,1-Dinitroindane (CLXXI)	CCl_4	2.2-2.8(o)	6.79(s)[e]		21
1,1-Dinitro-1-(p-nitrophenyl)-ethane (CLXXIII)	$CDCl_3$	1.94(p)[f]		7.33(s)	22
1,1-Dinitro-1,2-diphenylethane (CLXXVI)	CCl_4	2.50-3.17(m)	5.83(s)		23
1,1-Dinitro-1-phenylethane (LXXII)	CCl_4	2.58(m)		7.51(s)	24
1,1-Dinitro-1-(p-tolyl)-ethane (CLXXXI)	CCl_4	2.75(p)[f]		7.53(s) 7.67(s,Ar)	24
1,1-Dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII)	CCl_4	2.9-3.0		7.51(s) 7.68(s,Ar) 7.80(s,Ar)	25

[a] Chemical shifts in <u>tau</u>-values (τ) relative to TMS.

[b] Ar = aromatic protons; <u>o</u> = ortho-disubstituted; <u>p</u> = <u>para</u>-disubstituted; and m = mono-substituted.

[c] Methylene or methyl protons adjacent to carbon bearing the nitro groups; (Ar) indicates a group on an aromatic ring; s = singlet.

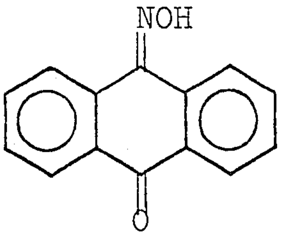
[d] Figure in which full spectrum is shown.

[e] Corresponds to both methylene groups.

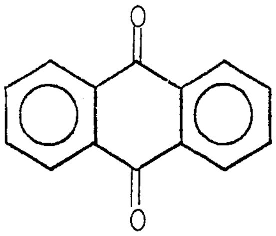
[f] Center of gravity of an A_2B_2 multiplet.

(slightly). The yield of 84.2% for CLIV from the oxidation of CLIII in methanol-benzene represents a minimum yield. Additional CLIV was obtained in later chromatography fractions in mixtures with a red solid. The ketone could not be separated from the red solid, a fact which was partially due to facile decomposition of the red material to form anthraquinone. Including ketone CLIV isolated from later chromatography fractions, the yield of CLIV in the reaction in methanol-benzene was about 90%.

The unknown red substance mentioned above decomposed on heating with loss of all red color to give ketone CLIV. The material was found to undergo a distinct rearrangement of crystalline form, accompanied by loss of red color, at 144-8°, leaving in its place a light yellow solid, m.p. 270-75° with sublimation (CLIV). The mass spectrum of the red material gave an apparent molecule ion at m/e 208 (70 ev.), and fragmentation which was consistent with anthraquinone (CLIV), suggesting the rearrangement to form CLIV on observing the melting point was also occurring in the mass spectrometer. At ionization energies of 18 ev. and 22 ev., the peak at m/e 208 was intensified relative to peaks of lower mass. Nothing was observed at m/e higher than 208. Attempts at removing CLIV from the material only led to decomposition to form more CLIV. An i r spectrum ($CHCl_3$) of the red material was similar, but not identical to the i r ($CHCl_3$) of CLVI. Further characterization of the red material was not made.



CLIII



CLIV

Oxidation of CLIII in deoxygenated acetone gave anthraquinone in 89% yield. The red material was not isolated from the reaction. When the oxidation of CLIII was conducted in acetone which had not been deoxygenated, the crude product mixture (light yellow solid) underwent a mild exothermic decomposition accompanied by the evolution of nitrogen dioxide (NO_2). Decomposition was not observed when deoxygenation of solutions of reactants was performed. The nature of the material which was decomposing was not determined. The yield of anthraquinone (CLIV) from the reaction in non-degassed solution was 94%.

Oxidation of 9-xanthenone oxime (CLXIX) by one equivalent of ceric ammonium nitrate in methanol gave 9-nitriminoxanthene (CLXXXVI) and 9-xanthenone (CLXXXVII) in yields of 3.1% and 90.4%, respectively. The reaction was conducted by a rapid addition of CAN reagent to the oxime solution. Virtually identical results were obtained in a second run. When a dropwise addition of the CAN reagent to the oxime solution was made, 9-xanthenone azine (CLXXXVIII) was formed, in addition to nitrimine CLXXXVI and ketone CLXXXVII, in yields

Table 13. Oxidation of anthraquinone monoxime (CLIII) and 9-xanthenone oxime (CLXIX) by ceric ammonium nitrate

Oxime	Solvent	Addn. rate[b]	YIELDS (%)[a] Ketone[c]	Nitrimine	Azine[d]
Anthraquinone monoxime	methanol-benzene[e]		84.2		
	acetone[f]		89		
	acetone		94		
9-Xanthenone	methanol		90.4	3.1	
	methanol	30 min.	88.4	1.3	4.2
	80% methanol-20% water		86.7	1	1.2
	acetone		88.7	1.7	

[a] Yields based on recovered oxime.

[b] A rapid addition of CAN solution (5-15 seconds) unless otherwise noted. If noted, addition was dropwise over the time given.

[c] Ketone = anthraquinone or 9-xanthenone.

[d] Yields based on one-half of the oxime which reacted.

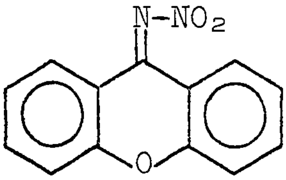
[e] Benzene added to the reaction mixture to improve monoxime solubility.

[f] Solutions of reactants degassed with nitrogen before mixing. A nitrogen atmosphere was maintained throughout the reaction.

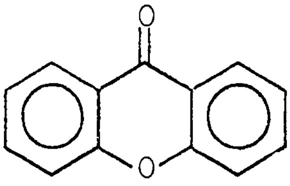
of 4.2%, 1.3%, and 88.4%, respectively. Azine CLXXXVIII was not formed in the oxidation of oxime CLXIX employing a fast addition of CAN solution, for reasons which are not known. Oxidation of CLXIX by CAN in 80% methanol-20% water resulted in the isolation of CLXXXVI, CLXXXVII, and CLXXXVIII in yields of

1%, 86.7%, and 1.2%, respectively. Oxidation of CLXIX in acetone gave CLXXXVI and CLXXXVII in yields of 1.7% and 88.7%, respectively. Azine CLXXXVIII was not formed in acetone.

The formation of 9-nitriminoxanthene (CLXXXVI) in the oxidation of CLXIX represented the first and only instance where a nitrimine was formed in the oxidation of an aryl ketoxime by CAN. The compound was obtained as light yellow needles, m.p. 145-6°, on recrystallization from hexane. In reactions where CLXXXVI and azine CLXXXVIII were formed, the materials were separated by fractional recrystallization, since only partial separation was achieved in chromatographic procedures. Azine CLXXXVIII crystallized readily from ethyl acetate. Mixtures of the azine and the nitrimine were separated by recrystallizing the mixture first from ethyl acetate to give azine, and then from hexane to give nitrimine.



CLXXXVI

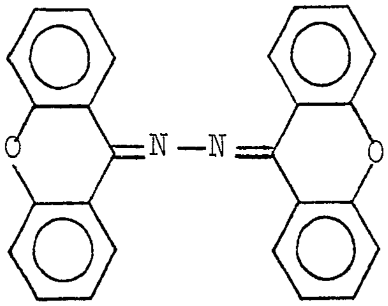


CLXXXVII

The i r spectrum of nitrimine CLXXXVI (KBr, Figure 28, page 185) showed absorptions at 6.50μ and 7.38μ corresponding to the nitro group in the molecule. The nmr spectrum of CLXXXVI ($CDCl_3$) showed only aromatic protons. The general appearance of the broad absorptions due to the aromatic protons in the nmr was consistent with an <u>ortho</u>-disubstituted aromatic compound. The mass spectrum of CLXXXVI gave a molecule ion at m/e 240, and fragmentation which was consistent with CLXXXVI ($C_{13}H_8N_2O_3$). The mass spectral data for CLXXXVI is summarized in Table 15, page 291.

The ketone, 9-xanthenone (CLXXXVII), accounted for the major portion of product mixtures from the oxidation of CLXIX. The ketone was recrystallized from ethanol to give a white solid, m.p. 173-4°. A mixed melting point of CLXXXVII with authentic 9-xanthenone gave no depression. The i r spectrum (KBr) of CLXXXVII was identical to that given by the authentic ketone.

After separation of azine CLXXXVIII from nitrimine CLXXXVI by recrystallization from ethyl acetate, the azine was again recrystallized from ethyl acetate to give red-orange needles, m.p. 287.5-9°. The i r spectrum of CLXXXVIII (KBr, Figure 46, page 326) had few distinguishing features. A broad absorption at 13.46μ indicated the presence of the xanthene nucleus in CLXXXVIII. The nmr spectrum of CLXXXVIII ($CDCl_3$) showed only



CLXXXVIII

aromatic protons in a pattern indicative of ortho-disubstitution on an aromatic ring (or rings). The mass spectrum of CLXXXVIII gave a molecule ion at m/e 388, and fragmentation consistent with the structure ($C_{26}H_{16}N_2O_2$). The mass spectral data for CLXXXVIII is summarized in Table 21, page 350 and is discussed with the mass spectra of other azines.

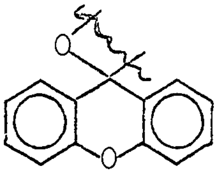
Small quantities of an unknown material were isolated from the later chromatography fractions of several oxidations of CLXIX. A light yellow solid, m.p. 227-37° (subl.), insoluble in chloroform, was isolated from the product mixture of the oxidation of CLXIX in methanol. The compound gave an i r spectrum (KBr) which was nearly identical to that shown by a small quantity of tan needles (0.01 g.), m.p. 232-4° (subl.), isolated from the product mixture of the oxidation of CLXIX in methanol using a 30 minute addition of CAN reagent. The i r spectrum (KBr) of the material from the latter reaction is shown in Figure 28, page 185, titled Unknown E. A broad absorption at 13.41μ in the i r suggested the presence of an xanthene nucleus in the compound. A trace amount (0.006 g.) of an analogous material, m.p. 248-52° (dec. and subl.), isolated from the oxidation of CLXIX in 80% methanol-20% water. The i r spectrum of the latter solid was also nearly identical to that shown by Unknown E, even though the melting points were different. Trace materials of this type were not formed in the oxidation of CLXIX in acetone solution.

The mass spectrum of Unknown E gave an apparent molecule ion at m/e 356 (intensity relative to the base peak, 5%) (70 ev.). The base peak in the spectrum appeared at m/e 195, flanked by peaks at m/e 194 (16%) and m/e 196 (14%). Other peaks which were observed in the spectrum of E were as follows (ion (% base peak)): m/e 169 (3.7%), 168 (11%), 167 (3.5%), 166 (3%), 165 (<1%), 140 (4%), 139 (8%), 97 (5%), 84 (5%), and 77 (4%). A weak ion at m/e 279 (<0.5%) was also noted. Doubly-charged ions appeared at m/e 82.5, 83.5, 97.5 and 69.5, corresponding to singly-charged species at m/e 165, 167, 195 and 139, respectively. At 15 ev., only peaks at m/e 195 (100%), 196 (14%), and 356 (7%) remained in the spectrum. The conversions m/e 195 (or 196 and 194) → m/e 168 (or 167) (loss of 27 or 28) and m/e 168 (or 167) → m/e 140 (loss of 27 or 28) were supported by the appearance of broad metastable ions at m/e 143-145 and m/e 116-118, respectively.

The appearance of ions at m/e 194, 195, and 196 in the mass spectrum suggested that an xanthene nucleus was present in Unknown E. The fragmentation pattern in the spectrum below m/e 196 was essentially that shown by an authentic sample of 9-xanthenone, with the exception of a peak at m/e 84. Loss of hydrogen to give an ion at m/e 195 occurred in the mass spectrum of 9-xanthenone, although the base peak was the parent ion (m/e 196), suggesting that an ion at m/e 195 in the spectrum of E was formed directly from the molecule ion by loss of species of mass 161. A weak ion at m/e 279 in the spectrum of

E suggested that a loss of an aromatic ring from E, followed by a loss of 84 to give an ion at m/e 195, accounted for an overall loss of 161. The occurrence of an ion at m/e 84 also suggested such a fragmentation.

In order for Unknown E to have a molecular weight of 356 and contain one xanthene nucleus intact, some degradation of a xanthene nucleus in the oxidation reaction and recombination of the fragments in such a way as to give a nucleus with a mass of 176 must have occurred (180 + 176 = 356). Since 9-xanthenone was apparently formed by fragmentation of E in the mass spectrometer, it follows that 9-xanthenone was incorporated into Unknown E structurally, but not necessarily functionally, intact. The lack of a carbonyl absorption in the i r spectrum of E suggests that Unknown E, in light of the other facts, contains the structural unit



with the remainder of the compound attached in the manner suggested by the partial structure.

Isotopic labeling experiments

The oxidation of aryl ketoximes by nitrate-^{15}N labaled ceric ammonium nitrate was conducted in order to determine the origin of the nitro groups in geminal-dinitro compounds. Oxidation of 9-fluorenone oxime (CLVI) and 1-indanone oxime (CLXIII) by nitrate-^{15}N labeled CAN in anhydrous methanol was conducted in the same manner as used for previously described reactions.

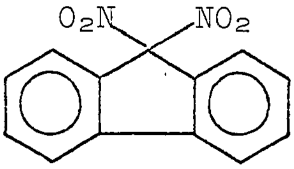
Solutions of ceric ammonium nitrate-^{15}N in methanol were added in one portion to solutions of the respective oximes in methanol with rapid stirring. Product mixtures were separated by column chromatography on silica gel. The respective *geminal*-dinitro compounds were purified by recrystallization to a satisfactory melting point prior to mass spectral analysis of the compounds.

Nitrate-^{15}N labeled ceric ammonium nitrate was prepared as follows. Ceric ammonium nitrate (Fischer Reagent, minimum 99.7% purity), equal to one equivalent per equivalent of the oxime to be oxidized, was weighed out and dissolved in absolute methanol. A weighed portion of nitrate-^{15}N labeled ammonium nitrate (Bio-rad Laboratories, 95.7% ^{15}N-nitrate) was added to the CAN solution. The reagent was allowed to stand, with occasional swirling, until the ammonium nitrate had dissolved and equilibration of the labeled nitrate with unlabeled nitrate had presumably taken place. The nitrate-^{15}N labeled CAN solution was then added to a solution of an oxime.

The percent incorporation of ^{15}N into the *geminal*-dinitro compounds, 9,9-dinitrofluorene (LXII) and 1,1-dinitroindane (CLXXI), was determined by mass spectrometry. The intensities of the isotope satellite peaks of a molecule ion (M) are directly related to the intensity of the molecule ion in ratios determined by the relative abundances of isotopes of the elements in the compound. The ratios $(M + 1)/M$, $(M + 2)/M$, and higher (M + N)/M can be calculated from the natural isotopic abundances of elements in an organic molecule. The calculations are laborious, and the method by which the ratios are calculated has been summarized by Beynon (120). Enrichment of an isotope of an element in a compound over that present due to natural occurence is reflected in an increase in the intentisy of one or more of the isotope satellite peaks of the molecule ion. The extent of incorporation of ^{15}N into a compound can be determined if the (M + 1)/M ratio of the unlabeled compound is known, and the magnitude of the increase in the (M + 1)/M ratio in going from unlabeled to labeled material can be measured with accuracy. Since nitrate ion which was only enriched in nitrate-^{15}N content was used in the experiments, the percent of nitrate-^{15}N in the total nitrate ion was required information. The incorporation of ^{15}N from nitrate ion into a <u>geminal</u>-dinitro compound would occur statistically, and the maximum increase in the (M + 1)/M ratio would be determined by the percent of the nitrate which was labeled to begin with.

If two ^{15}N atoms were incorporated into a molecule containing nitrogen, an increase in the intensity of the M + 2 satellite peak would be observed, accompanied by an increase in the (M + 2)/M intensity ratio from that observed for the unlabeled compound. In the instance where one or two ^{15}N atoms might be incorporated into a compound in the same reaction a comparison of the increases in the intensity ratios (M + 1)/M and (M + 2)/M would allow a distinction to be made. If the (M + 1)/M ratio showed a maximum increase, incorporation of two ^{15}N atoms could not be important, since for every second ^{15}N atom incorporated per molecule, a corresponding decrease in (M + 1)/M from its maximum value and an increase in (M + 2)/M would occur. The lower limit of (M + 1)/M would be the normal ratio measured for the unlabeled material, and a maximum (M + 2)/M ratio would be observed. Intermediate situations would be detectable, since neither of the ratios would show maximum increases, but would show values between 0% and 100%.

Oxidation of 9-fluorenone oxime (CLVI) with nitrate-^{15}N labeled ceric ammonium nitrate in methanol gave 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and 9-fluorenone azine monoxide (CLXII) in yields of 26.9%, 45%, and 15.7%, respectively (Table 10, page 117, line 2). The dinitro compound was recrystallized from hexane to give very light yellow needles, m.p. 137-8° (dec.), identical in all respects to LXII previously obtained. The reaction was conducted on a small scale, using 0.0011 mole of oxime CLVI. A solution containing 0.0011 mole of CAN and 0.0013 mole of nitrate-^{15}N labeled ammonium nitrate in methanol was used for the oxidation.

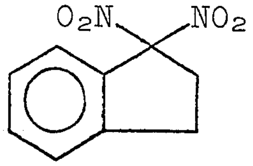


LXII

The mass spectrum of a sample of LXII from another source was obtained, and the (M + 1)/M intensity ratio was measured as 15.22%. Using the method of Beynon (120), the theoretical (M + 1)/M ratio for a compound of the formula $C_{13}H_8N_2O_4$ was calculated to be 15.09%, in good agreement with the observed value. The mass spectrum of LXII from the oxidation in the presence of nitrate-^{15}N was observed. The mass spectral data for both unlabeled LXII and the labeled compound has been summarized in the Experimental Section, Table 25, page 460. An intensity ratio (M + 1)/M of 30.58% (an average of four measurements of M (m/e 256) and M + 1 (m/e 257)) was found in the mass spectrum of the "labeled" compound. The observed increase in the (M + 1)/M ratio over that observed for unlabeled LXII was 15.36%, based on the M + 1/M ratio measured from the control spectrum of LXII, which corresponded to a percent incorporation of one ^{15}N atom per molecule of LXII of 94.2%. On the basis of the theoretical value of (M + 1)/M calculated for LXII (120), the percent incorporation of ^{15}N was found to be 95.0% of one ^{15}N atom per molecule of LXII. The high value observed for the percent incorporation of one ^{15}N atom into LXII indicated that incorporation of two ^{15}N atoms in the reaction had not taken place.

The fact that 9,9-dinitrofluorene fragmented in the mass spectrometer by a loss of $\cdot NO_2$ to give an ion at m/e 210 was used as a means of confirming the percent of ^{15}N-incorporation in LXII as follows. Assuming an equal probability for the loss of either of the two nitro groups from LXII, equivalent to a loss of one-half of the ^{15}N-label in the molecule, the percent of ^{15}N-incorporation into LXII could be calculated from the relative intensities of the M-46 + 1 and M-46 peaks by the method that was employed using the intensities of the M + 1 and M peaks. A loss of NO_2 from $C_{13}H_8N_2O_4$ would result in a species $C_{13}H_8NO_2$. The ratio (M-46 + 1)/(M-46) taken from the control spectrum of LXII was 15.08%, in reasonable agreement with the value of 14.63% given by Beynon (120) as the theoretical (M + 1)/M ratio for a compound $C_{13}H_8NO_2$. The percent incorporation of ^{15}N into LXII was calculated to be 94.7% of one ^{15}N atom per molecule of LXII (based on the (M-46 + 1)/(M-46) ratio obtained from the control spectrum), and 100% of one ^{15}N atom per molecule of LXII (from the data given by Beynon (120)).

The results of the oxidation of 1-indanone oxime (CLXIII) in methanol with nitrate-^{15}N labeled ceric ammonium nitrate confirmed the results of the labeling experiment with 9-fluorenone oxime (CLVI). Oxidation of CLXIII (0.0027 mole) with CAN (0.0027 mole) containing 0.0031 mole of nitrate-^{15}N labeled ammonium nitrate (95.7% ^{15}N-nitrate) gave 1,1-dinitroindane (CLXXI) and 1-indanone (CLXXII) in yields of 25.3% and 59%, respectively (Table 10, page 117, line 9). The dinitro compound CLXXI was recrystallized from pentane-ether to give off white needles, m.p. 40-2°, which were analyzed by mass spectrometry in the manner described previously. The mass spectral



CLXXI

data recorded for both labeled and unlabeled CLXXI is shown in Table 26, page 465(Experimental Section).

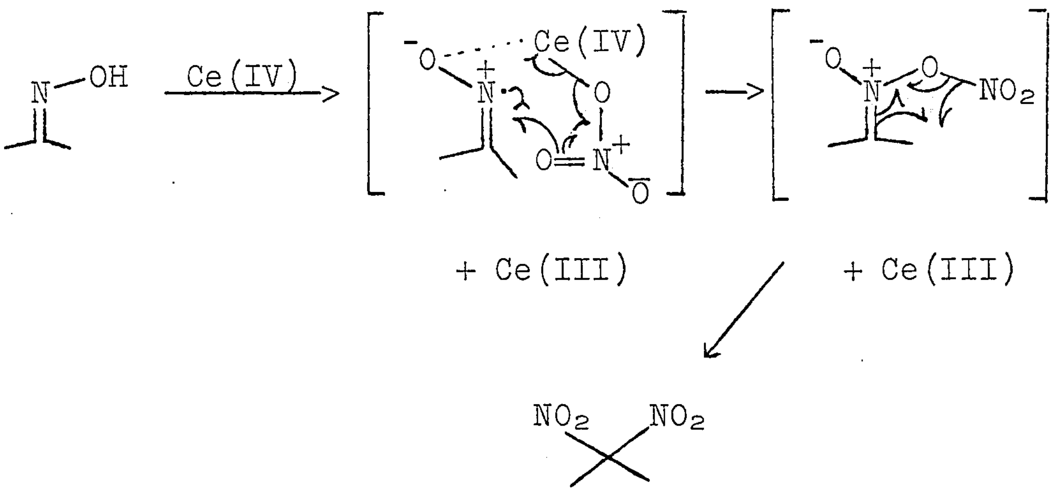
The percent incorporation of ^{15}N from the labeled nitrate into CLXXI based on the (M + 1)/M intensity ratios obtained from a control spectrum of CLXXI (11.13%) and the spectrum of the "labeled" compound (27.06%) was found to be >100% of one ^{15}N atom per molecule of CLXXI. A theoretical intensity ratio ((M + 1)/M) of 10.77% was given by Beynon (120) for a compound $C_9H_8N_2O_4$, in reasonable agreement with the value obtained from the control spectrum. The molecule ion (M = m/e 208) and the M + 1 peak (m/e 209) were weak in the mass spectrum of CLXXI, which made accurate measurement of peak intensities difficult. Difficulty was also experienced in eliminating an M-1 (m/e 207) peak from the spectrum of the labeled compound, which was necessary before a true value of the (M + 1)/M ratio could be obtained. Although only recordings of the M, M + 1 set of peaks where the M-1 peak was practically non-existent were used in obtaining the (M + 1)/M ratios, the low intensity of the molecule ion (M) and the presence of any M-1 peak at all would result in an apparent (M + 1)/M ratio which would be larger than the actual value. The net result would be the calculation of a percent incorporation of ^{15}N into CLXXI of greater than 100% if the percent incorporation was in fact nearly quantitative. The M + 2 peaks in the mass spectra of unlabeled and labeled CLXXI were almost non-existent, and could not be measured with accuracy.

The difficulty experienced in obtaining a percent incorporation of ^{15}N into CLXXI using the (M + 1)/M ratios due to the presence of a finite M-1 peak in the spectrum of labeled CLXXI was avoided through the use of (M-46 + 1)/(M-46) intensity ratios. The assumption was again made that an equal probability of the loss of either of the two nitro groups in CLXXI existed, corresponding to a loss of one-half of the labeled nitrogen in the molecule. The maximum increase in the (M-46 + 1)/(M-46) ratio in going from unlabeled to labeled CLXXI would then be one-half of the maximum value of the increase in the (M + 1)/M ratio. An increase in the (M-46 + 1)/(M-46) ratio of 7.49% was observed in the mass spectrum of labeled CLXXI, with the maximum possible increase being 7.705% (one-half of 15.41%). The percent of ^{15}N-incorporation into CLXXI was found to be 97.2% of one ^{15}N atom per molecule of CLXXI. The theoretical value of (M + 1)/M for a compound of the formula $C_9H_8NO_2$ (arising from a loss of NO_2 from $C_9H_8N_2O_4$) was given by Beynon (120) as 10.31%, in good agreement with the value of (M-46 + 1)/(M-46) obtained from the control spectrum of CLXXI (10.46%).

Possible reactions between the oximes and ammonium nitrate to form *geminal*-dinitro compounds were eliminated from consideration as an explanation for the incorporation of ^{15}N. A solution of 9-fluorenone oxime (CLVI) in methanol containing a 30-molar excess of ammonium nitrate was stirred for 67 hours at room temperature. Oxime CLVI was recovered nearly quantitatively (96.2%) from the reaction. Dinitro compound LXII was not formed. A solution of 1-indanone oxime (CLXIII) and ammonium nitrate (slight excess) was stirred for 45 minutes at room temperature. The oxime was recovered nearly quantitatively (97%). Dinitro compound CLXXI was not formed.

In summary, the oxidation of aryl ketoximes by ceric ammonium nitrate to form *geminal*-dinitro compounds involves the incorporation of nitrate nitrogen into one of the two nitro groups, but not both nitro groups. A percent incorporation of ^{15}N into 9,9-dinitrofluorene (LXII) of 94-95% of one ^{15}N atom per molecule of LXII was observed in the cerium(IV) oxidation of 9-fluorenone oxime in the presence of ^{15}N labeled nitrate. A percent incorporation of 97-100% of one ^{15}N atom per molecule of 1,1-dinitroindane (CLXXI) was observed when 1-indanone oxime was oxidized with ceric ammonium nitrate in the presence of ^{15}N-labeled nitrate. The origin of the nitrogen atom in the second nitro group of the dinitro compounds LXII and CLXXI was apparently the nitrogen atom originally present in the respective oximes.

The high percent of ^{15}N-incorporation from nitrate ion into 9,9-dinitrofluorene (LXII) and 1,1-dinitroindane (CLXXI) established the mechanism by which _geminal_-dinitro compounds were formed in the oxidation of oximes by CAN. A ligand transfer of nitrate ion from a coordination site on cerium(IV) to some intermediate derived from the oxime by cerium(IV) oxidation appeared to be occurring, presumably within a complex formed between the oxime and cerium(IV). The fact that 9-fluorenone oxime and 1-indanone oxime were stable to ammonium nitrate treatment in the absence of cerium(IV) supports the involvement of an oxime-cerium(IV) complex, and indicates that incorporation of nitrate ion into an intermediate derived from the oxime (and not the oxime itself) occurs within that complex. The transfer of nitrate (originally bound to cerium(IV)) to some intermediate derived from an oxime may be an oxidative transfer, the net result being the reduction of cerium(IV) to cerium(III) accompanied by a one-electron oxidation of the intermediate to which nitrate is transferred. Schematically, with the specification that the intermediate described above is an iminoxyl radical (see following section), the suggestions may be represented as follows. As can be seen, the nitrogen atom of the oxime has undergone a formal two-electron oxidation, which is in fact what must occur if the nitrogen atom of the oxime is to be incorporated into one of the two nitro groups found in a _geminal_-dinitro compound. The intermediate formed by the transfer of nitrate to the iminoxyl radical could decompose by arrangement as shown to produce _geminal_-dinitro



compound.

The scheme shown above illustrates only one possible means by which *geminal*-dinitro compounds may be formed in the oxidation reaction. It should be noted at this point that, although ligand-transfer oxidations involving cerium(IV) as shown in the scheme are not well-documented, indirect oxidation reactions with cerium(IV) are not unknown. The reaction between cerium(IV) and bromide ions in the presence of butadiene has been found to give additive dimerization (121a). The suggested mechanism of the reaction is summarized in Equations 34-36.

$$\mathrm{Ce(IV)} + \mathrm{Br}^- \longrightarrow \mathrm{Ce(III)} + \mathrm{Br}\cdot \qquad \underline{34}$$

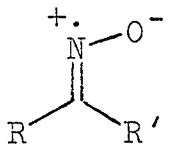
$$\mathrm{Br}\cdot + \qquad \longrightarrow \mathrm{Br{-}C_4H_6}\cdot \qquad \underline{35}$$

$$2\mathrm{Br{-}C_4H_6}\cdot \longrightarrow (\mathrm{Br{-}CH_2{-}CH{=}CH{-}CH_2}\!)_2 \qquad \underline{36}$$

The 1,8-dibromide was the major product. The oxidation of butadiene with cerium(IV) and bromide ions, however, represents an extreme case of a ligand-transfer oxidation by cerium(IV), in the sense that the bromide ion is not strictly a ligand which is transferred to the butadiene molecule within a coordination complex. Ceric bromide ($Ce(Br)_4$) is an unknown compound due to the facility with which cerium(IV) oxidizes bromide ion. The cerium(IV) is thus involved only in the production of bromine atoms, and does not function as a complexing agent to bring the butadiene molecules and bromide ions into close proximity prior to reaction.

Electron spin resonance studies

Iminoxyl radicals (LXXXVIII) have been generated by the one-electron oxidation of oximes by several methods and have been characterized by electron spin resonance (esr) techniques. Among the methods of generation of iminoxyl radicals is the oxidation of oximes by ceric ammonium nitrate in methanol in a fast flow system (76). This interesting class of radical and the methods used to generate the species for electron spin resonance studies were discussed previously (see Historical, pages 48-58).



LXXXVIII

Thomas (76) observed that the interaction of the odd electron with protons in iminoxyl radicals had stereochemical requirements, an observation substantiated by several other groups of workers (78-81). Spin is more effectively transmitted to one side of an iminoxyl radical than the other, and the direction in which the spin is most effectively transmitted is to the portion of the molecule which is adjacent to the iminoxyl oxygen atom. The magnitude of the interaction of protons with the odd electron center is angular dependent, with the strongest interaction occurring when a proton is in a coplanar arrangement with the iminoxyl function through an interconnecting σ-bridge. Interactions of the aromatic protons with the odd electron center in aryl substituted iminoxyl radicals are restricted to the ortho-protons of the aromatic ring, indicating that the iminoxyl radicals are σ-radicals and not π-radicals.

Gilbert and Norman (83) have reported the esr spectra of iminoxyl radicals derived from aryl aldoximes by oxidation with ceric sulfate in acidified aqueous acetone. It was found (83) that the oxidation of aldoximes by ceric sulfate in acidified aqueous acetone gave in general more intense esr spectra than was given by ceric ammonium nitrate oxidation of the aldoximes in methanol (76). Iminoxyl radicals generated by the lead tetraacetate oxidation of aryl ketoximes in methylene dichloride (78, 79) and benzene (80, 81) showed longer lifetimes than those generated by cerium(IV) oxidation, which permitted the use of a static system in the esr studies. The radicals generated from aryl aldoximes by lead tetraacetate oxidation in methylene dichloride were too short-lived for study in a static system, which led to the use of ceric sulfate in acidified aqueous acetone for generation of the radicals in a fast flow system (83).

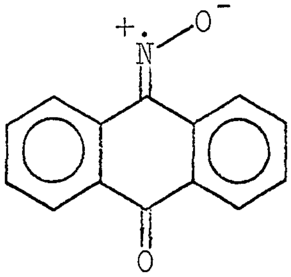
The observation of iminoxyl radicals in the oxidation of oximes by lead tetraacetate has been dismissed as a secondary effect (95, 96). The reactions of lead tetraacetate are generally accepted to proceed by way of ionic mechanisms, involving two-electron changes (Pb(IV) —> Pb(II)), rather than one-electron changes (Pb(IV) —> Pb(III) —> Pb(II)). Cerium(IV) has been viewed as a one-electron oxidant (Ce(IV) —> Ce(III)). The observation of an iminoxyl radical generated from an oxime by cerium(IV) oxidation may be a primary effect. However, the fact that cerium(IV) is generally thought to be a one-electron oxidant does not prove that the formation of iminoxyl radicals in the cerium(IV) oxidation of oximes is a primary effect. Although an iminoxyl radical may be the initial reactive intermediate in the cerium(IV) oxidation of an aryl ketoxime, conclusive evidence relating an iminoxyl radical to the formation of products has not been obtained. The evidence presented in the following discussion only suggests that iminoxyl radicals are important intermediates in the cerium(IV) oxidation of aryl ketoximes.

Electron spin resonance studies on the oxidation of aryl ketoximes by ceric ammonium nitrate were conducted using a static system, and to a lesser extent, a fast flow system. The apparatus employed in esr studies in a static system consisted of an inverted U-tube (121b) and a quartz esr cell. The fast flow system (see Experimental, Figure 55, page 469) was a modification of a system previously described by Janzen (121b) for the study of short-lived radical species by esr.

The use of a static system to generate iminoxyl radicals from aryl ketoximes by ceric ammonium nitrate oxidation for esr studies proved to be a generally unsatisfactory technique. The aryl ketoximes oxidized by CAN in a static system were anthraquinone monoxime (CLIII), 9-fluorenone oxime (CLVI), benzophenone oxime (LXXVII), 1-indanone oxime (CLXIII), p-nitroacetophenone oxime (CLXIV), α-phenylacetophenone oxime (CLXV), and acetophenone oxime (CLXVI). Of the oximes listed, only anthraquinone monoxime (CLIII) gave an esr spectrum, corresponding to the iminoxyl radical CLXXXIX.

The esr spectrum of iminoxyl radical CLXXXIX derived from anthraquinone monoxime (CLIII) by CAN oxidation in degassed methanol has been reported (114). The spectrum of CLXXXIX contained the expected 6 lines, with nitrogen ($\underline{a}_N$) and hydrogen ($\underline{a}_H$) hyperfine splitting constants of 30.3 gauss and 3.4 gauss, respectively. The observed values for $\underline{a}_N$ and $\underline{a}_H$ were in reasonable agreement with the values $\underline{a}_N$ = 29.8 gauss and $\underline{a}_H$ = 2.5

gauss given by Gilbert and Norman (79) for CLXXXIX. The concentrations of solutions of CLIII and CAN were 2.5×10^{-2} $\underline{M}$ and 1.25×10^{-2} $\underline{M}$, respectively. When the concentration of the CAN solution was increased by a factor of two (to 2.5×10^{-2} $\underline{M}$), the decay of the signal due to radical CLXXXIX was more rapid than was observed using the lower oxidant concentration, and observation of a signal was difficult. The buildup and decay of the signal due to CLXXXIX was rapid in both instances, with no signal remaining in the esr spectrum after 8-10 minutes from the time the reactant solutions were mixed and the cell was transferred to the cavity of the spectrometer. The elapsed time between mixing the solutions of reactants and transfer of the cell to the instrument cavity, and the initial observation of a signal varied in the range of 4-7 minutes. The signal due to CLXXXIX was always in the last stages of decay, and the lifetime of the radical could not be determined.

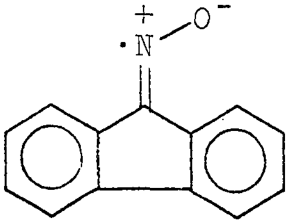


CLXXXIX

The CAN oxidation of anthraquinone monoxime could not be readily investigated in a static esr system using acetone as solvent due to gas formation which resulted in an excessive pressure buildup in the apparatus. None of the oximes listed previously gave esr spectra due to iminoxyl radicals when oxidized by CAN in degassed acetone in a static system. As before, the time which elapsed between the mixing of the reactants and the initial observation of the esr spectrum was in the range of 4-7 minutes, ample time for the concentration of a short-lived radical species to build up and decay before detection could be made.

A preliminary esr study of the oxidation of 9-fluorenone oxime (CLVI) by CAN in 80% methanol-20% water was made. A weak signal was initially observed, which was apparently the remainder of a more intense signal undergoing rapid decay. An approximate nitrogen hyperfine splitting constant ($\underline{a}_N$) of 29-32 gauss was estimated from the spacing of three broad lines in the spectrum. Resolution was not good enough to allow estimation of a hydrogen splitting constant. The value of $\underline{a}_N$ was consistent with an iminoxyl radical such as CXL. The esr spectrum of a solution of benzophenone oxime (LXXVII) and CAN in 80% methanol-20% water was observed. No signal was obtained. The initial concentrations of solutions of CLVI and LXXVII in the above experiments were 2.5×10^{-2} $\underline{M}$. The initial concentration of the CAN solutions was 1.25×10^{-2} $\underline{M}$. Using equimolar quantities of CLVI and CAN (2.5×10^{-2} $\underline{M}$) in a similar experiment, even a weak signal due to CXC could not be detected.

A fast flow system was employed in a study of the iminoxyl radicals derived from 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII) by CAN oxidation in degassed methanol and 80% methanol-20% water. Studies in the flow system were conducted using solutions of the oximes and CAN which were 2.5 x 10^{-2} M, respectively. The esr results obtained through the use of the fast flow system are summarized in Table 27, page 475 (Experimental Section).

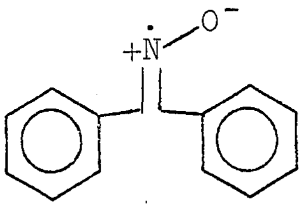


CXC

A six-line spectrum corresponding to iminoxyl radical CXC was observed when the esr spectrum of a solution of 9-fluorenone oxime and CAN in methanol was recorded. The hyperfine splitting constants for CXC were a_N = 30.9 gauss and a_H = 3.0 gauss, in good agreement with literature values (a_N = 30.8 gauss and a_H = 2.7 gauss (79); and a_N = 31.2 gauss and a_H = 2.7 gauss (81). An approximate half-life (t 1/2) for CXC of 2 minutes was obtained from the experiments in methanol, based on the decay of the radical. Radical CXC was also observed using the flow system for the oxidation of 9-fluorenone oxime by CAN in 80% methanol-20% water, with a_N = 30.8 gauss and a_H = 3.0 gauss. Although the decay of signal due to CXC was rapid in 80% methanol-20% water, the half-life of the radical was somewhat longer than that measured in anhydrous methanol. An approximate half-life (t 1/2) of 3.5 minutes was measured in 80% methanol-20% water. The intensity of the signal due to

CXC in the aqueous methanol was somewhat greater than the signal intensity in anhydrous methanol.

The esr spectrum of iminoxyl radical CXCI was observed when benzophenone oxime was oxidized by CAN in methanol in the flow system.



CXCI

The spectrum contained 9-lines (three sets of three lines, relative intensity 1:2:1), corresponding to the interaction of two equivalent protons with the unpaired spin on nitrogen. The measured hyperfine splitting constants were $\underline{a}_N = 31.6$ and $\underline{a}_H = 1.6$ gauss, in good agreement with literature values (76, $\underline{a}_N = 31.6$ gauss; 79, $\underline{a}_N = 31.4$ gauss, $\underline{a}_H = 1.4$ gauss). Formation of CXCI on oxidation of benzophenone oxime by CAN in methanol has been reported by Thomas (76). The half-life (t 1/2) of CXCI was found to be about 1 minute, based on the decay of the radical. Oxidation of benzophenone oxime by CAN in 80% methanol-20% water in the flow system resulted in an esr spectrum due to CXCI, with $\underline{a}_N = 31.6$ gauss and $\underline{a}_H = 1.6$ gauss. The half-life of the radical in 80% methanol-20% water was approximately 1.5 minutes. The intensity of signal due to CXCI was somewhat higher in 80% methanol-20% water than in anhydrous methanol.

The observation of iminoxyl radicals CLXXXIX, CXC, and

CXCI by esr techniques when the respective oximes were oxidized by CAN in methanol and 80% methanol-20% water was expected in the light of previous reports (75, 82). The interest in iminoxyl radicals has been from a theoretical standpoint as a new class of stable nitrogen radicals. The potential role of iminoxyl radicals as reactive intermediates in the oxidation of oximes by cerium(IV) to form well-defined products has not been investigated. It is the possible involvement of iminoxyl radicals as reactive intermediates in the oxidation of aryl ketoximes by ceric ammonium nitrate to form gem-dinitro compounds, ketones, and other products that was of primary interest in this investigation.

The reactions of aryl ketoximes with ceric ammonium nitrate were found to be rapid reactions in the sense that the color of CAN in the respective solvents was generally discharged quickly when solutions of CAN and ketoximes were mixed. The same product mixtures were generally obtained from reactions regardless of the length of time reaction mixtures were stirred. The generation of a short-lived intermediate such as an iminoxyl radical by a one-electron cerium(IV) oxidation of an oxime at least qualitatively accounts for the facts that cerium(IV) (red or orange) was rapidly reduced to cerium(III) (colorless) and that product formation occurred within a short period of time. However, the approximate half-lives of the radicals CXC and CXCI provide only circumstantial evidence that the iminoxyl radicals are involved in product formation in the CAN oxidation of the respective oximes.

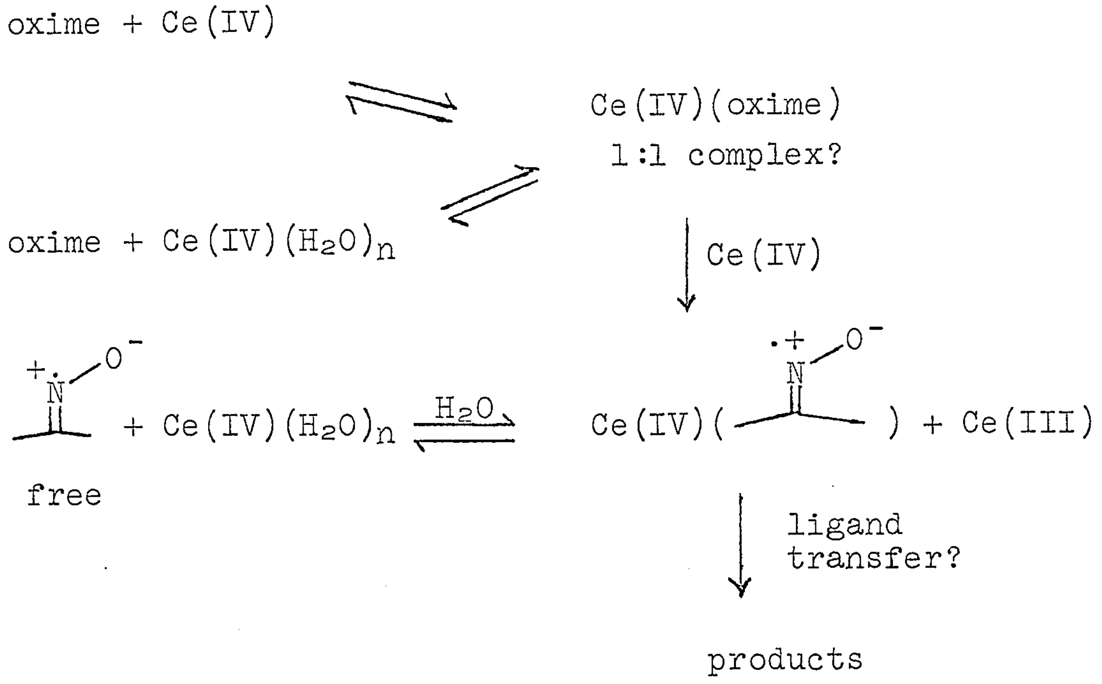
Some analogy exists between the behavior of the iminoxyl radicals CXC and CXCI in methanol and aqueous methanol and the results of the product analyses of the CAN oxidations of the respective oximes. This analogy again only implies that iminoxyl radicals are intermediates in the formation of products in the CAN oxidation of aryl ketoximes, and does not provide direct evidence for the involvement of the radicals in the reactions. A possible correlation between iminoxyl radical behavior and product formation can be illustrated by the data obtained from the CAN oxidation of 9-fluorenone oxime (CLVI).

The oxidation of CLVI by CAN in methanol gave 9,9-dinitrofluorene (LXII), 9-fluorenone (LXIII), and 9-fluorenone azine monoxide (CLXII) in yields of 33%, 40%, and 10%, respectively (Table 6, page 103) while in 80% methanol-20% water yields for LXII, LXIII, and CLXII were 4%, 53.9%, and 60.9%, respectively (Table 8, page 109). Oxime was not recovered from the methanol reaction, whereas a 29.8% recovery of the oxime was obtained from the reaction in aqueous methanol. The lifetime of the radical CXC was somewhat longer in 80% methanol-20% water (t 1/2 = <u>ca</u>. 3.5 minutes) than in methanol (t 1/2 = <u>ca</u>. 2 minutes). Assuming for the moment that complex formation between CLVI and cerium(IV) was involved in the CAN oxidation of the oxime, the effect of water could be accounted for as follows. Water could compete with the oxime for a coordination site on cerium(IV) as shown on the following page. The net result would be a decrease in the apparent ease with which cerium(IV) initially oxidizes the oxime. Cerium(IV) might then react in other ways before oxime oxidation occurs. In the event that an iminoxyl radical is formed by the cerium(IV) oxidation of the oxime, water might serve to displace the radical from a complex before further reaction occurs (ligand transfer, all or in part). The lower yield of the ligand transfer product, 9,9-dinitrofluorene, in aqueous methanol suggests such an effect, as does the longer lifetime of radical CXC in aqueous methanol.

The scheme on the following page represents at best a gross simplification of a mechanism for a complex reaction. The available evidence concerning possible mechanisms for the reaction is summarized and discussed in a later section. The possibility that iminoxyl radicals are intermediates in cerium(IV) oxidations of oximes does exist, but additional information is required before any conclusions can be drawn.

Oxidation of aryl ketoximes by nitric acid

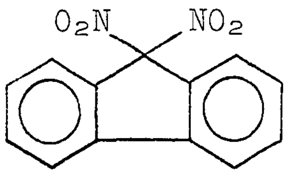
Nitric acid was found to oxidize several of the aryl ketoximes investigated in the oxidation reactions with cerium(IV) salts. Entry into the area was made by chance when a control reaction for the oxidation of 9-fluorenone oxime (CLVI) by CAN in methanol in the presence of nitric acid was conducted and 9,9-dinitrofluorene (LXII) was found in the product mixture. Solutions of aryl ketoximes in methanol were allowed to react with a 30 molar excess of nitric acid (70%) at room



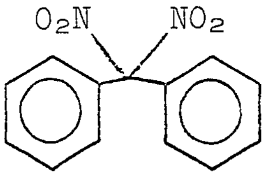
temperature for periods of 14-15 hours in an attempt to determine the scope of the reaction. Product mixtures were separated by chromatography on silica gel. The results obtained in the reactions of five aryl ketoximes with 70% nitric acid in methanol are summarized in Table 14, page 246.

Methanol was chosen as the solvent for the nitric acid oxidations of aryl ketoximes solely because that was the solvent used for the oxidation of 9-fluorenone oxime (CLVI). Variations in the molar ratio of nitric acid to oxime and in the length of reaction time were not made, as only a preliminary study of the reaction was conducted. An attempt was made to use nitric acid which had not undergone decomposition to various nitrogen oxides. However, no effort was made to insure that nitrogen oxides were not present in the acid before use.

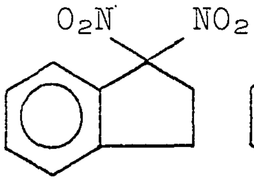
Formation of geminal-dinitro compounds was observed when four of five aryl ketoximes were oxidized by nitric acid. The respective ketones accounted for nearly all of the remaining material recovered from the reactions. Oxidation of 9-fluorenone oxime (CLVI) gave 9,9-dinitrofluorene (LXII) and 9-fluorenone (LXIII) in yields of 75.2% and 16.8%, respectively (Table 14). Benzophenone oxime (LXXVII) gave dinitrodiphenylmethane (LXIX) and benzophenone (CLIX) in yields of 29% and 67.1%, respectively, while the oxidation of 1-indanone oxime (CLXIII) resulted in the formation of 1,1-dinitroindane (CLXXI) and 1-indanone (CLXXII) in yields of 17.3% and 49%, respectively. Acetophenone oxime (CLXVI) gave 1,1-dinitro-1-phenylethane (LXXII) and acetophenone (CLXXX) in yields of 2.7% and 61% (based on the 2,4-dinitrophenylhydrazone derivative), respectively. Oxidation of 9-xanthenone oxime (CLXIX) gave only 9-xanthenone (CLXXXVII), in 97.6% yield. Small amounts of ill-defined gums were obtained in the chromatographic separations of the product mixtures from the four ketoximes which gave gem-dinitro compounds but nothing was isolated from the gums.



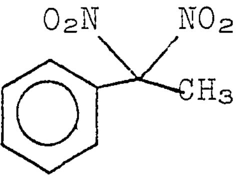
LXII



LXIX



CLXXI



LXXII

The recovery of material from the reactions of 1-indanone oxime and acetophenone oxime was poor, for reasons which are unknown.

Table 14. Oxidation of aryl ketoximes by nitric acid in methanol

Oxime	YIELDS (%)[a] *geminal*-Dinitro compound	Ketone
9-Fluorenone (CLVI)	75.2	16.8
Benzophenone (LXXVII)	29	67.1
1-Indanone (CLXIII)	17.3	49
Acetophenone (CLXVI)	2.7	61[b]
9-Xanthenone (CLXIX)	---	97.6

[a] Yields based on recovered starting material. A 30 molar excess of nitric acid (70%, sp. gr. 1.42) was used for all reactions.

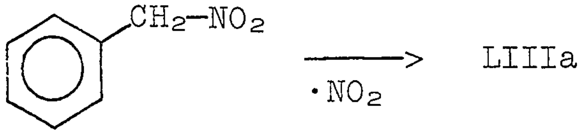
[b] Yield based on the 2,4-dinitrophenylhydrazone derivative.

The dinitro compounds were identical in every respect to the dinitro compounds obtained from the oxidation of the respective oximes by CAN. Oxime was not recovered in any of the reactions.

The yields of the ketones appeared to increase in the oxidation of the ketoximes shown in Table 14 roughly in the order in which the relative ease of hydrolysis of the ketoximes might be expected to fall. Oxime CLXIX is hydrolyzed very rapidly by dilute acid, which perhaps accounts for why only ketone CLXXXVII was formed in the "oxidation" of CLXIX by nitric acid. It is possible that competing reactions, oxidation and hydrolysis, were taking place in all of the reactions. Ketone formation is not required to occur solely by hydrolysis, however. It is probable that some ketone is also formed by oxidation of the respective oxime. The dinitro compounds are certainly products of an oxidation of the respective ketoximes by nitric acid. It is not known at this time whether one or both of the nitro groups in the dinitro compounds originated from the nitric acid. It is possible that only one of the nitro groups originated from nitrate, while the other nitro group had as its origin the nitrogen atom of the oxime.

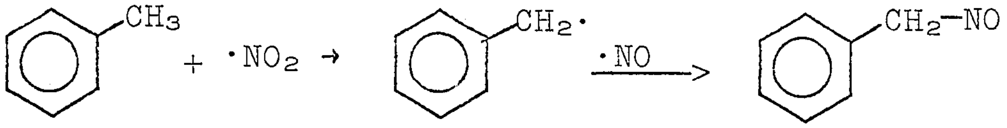
Oxidation of ketoximes by nitric acid to form *geminal*-dinitro comounds is not an unknown reaction. A method of preparation of *geminal*-dinitro compounds from steroid ketoximes has been reported (73). The steroid ketoximes were dissolved in a mixture of fuming nitric and sulfuric acids. After the solutions had been allowed to stand for some time, hydrogen peroxide was added dropwise to the reaction mixtures. Yields in the range of 50% were obtained by this procedure. The conditions used in this preparation of *gem*-dinitro compounds are more drastic than those used in the reactions summarized in Table 14. The role of hydrogen peroxide in the above procedure is probably one of facilitating the decomposition of nitric acid to nitrogen oxides, which then react with ketoxime to give a *gem*-dinitro compound.

Some aspects of the nitration of hydrocarbons by nitric acid, and nitrogen oxides such as nitric oxide (·NO) and nitrogen dioxide ($\cdot NO_2$), have been reviewed in the Historical section (pages 36-40). The nitration of toluene (and similar aromatic compounds) with either nitric acid or nitrogen dioxide gives the same products in practically the same yields (57). It is known that $\cdot NO_2$ is the active species in nitrations involving nitric acid (57). Materials such as *para*-formaldehyde are known to facilitate the decomposition of nitric acid to various nitrogen oxides. Nitration of hydrocarbons by nitric acid does not take place in the absence of nitrogen oxides (59). The dinitro compound, α,α-dinitrotoluene (LIIIa) is formed as a minor product in the nitration of toluene by nitric acid, but does not arise by a secondary nitration of the mononitro compound LIX (57). The following reaction sequence (Equations 29 and 30) was proposed to account for the formation of LIIIa in the nitration of toluene (59). The last step in Equation 30 represents the Ponzio reaction, which is the reaction of benzaldoxime with $\cdot NO_2$ to give LIIIa and benzaldehyde (53).



LIX

It is possible that $\cdot NO_2$ is involved in the formation of *geminal*-dinitro compounds from ketoximes by oxidation with nitric acid. Methanol and *para*-formaldehyde are quite similar



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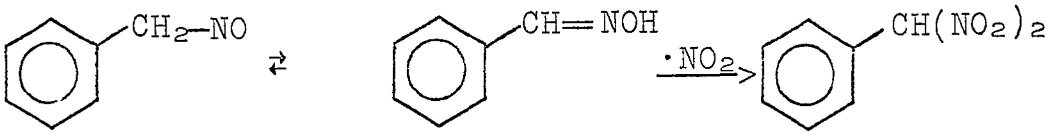


30

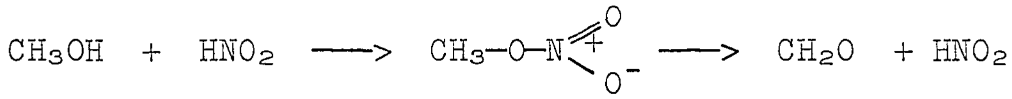
LIIIa

structurally, and since p-formaldehyde is capable of inducing the decomposition of nitric acid to nitrogen oxides, it is possible that methanol is also capable of inducing HNO_3 decomposition. The mechanism for such a reaction is unknown at the present time. If methanol can serve in such a capacity, whether or not nitrogen oxides are present in the nitric acid initially added to a solution of a ketoxime is unimportant, since those nitrogen oxides will be generated by the methanol-induced decomposition of nitric acid anyway. It is doubtful that geminal-dinitro compounds are formed in the oxidation of aryl ketoximes solely by a reaction such as the Ponzio reaction. The Ponzio reaction has been found to be restricted in scope mainly to benzaldoxime and some substituted benzaldoximes (54). Ketoximes have been found to give mainly nitrimines rather than geminal-dinitro compounds when treated with $\cdot NO_2$ (as N_2O_4) (74, 75).

Possible ways in which *geminal*-dinitro compounds and ketones might be formed in the oxidation of aryl ketoximes by nitric acid are shown in Figure 33, page 251. The equations shown at the top of Figure 33 represent means by which the decomposition of nitric acid may take place. The representation of the initial methanol-induced decomposition of HNO_3 to give $\cdot NO_2$ and a hydroxyl radical ($\cdot OH$) is purely schematic, as the existence of $\cdot OH$ is highly doubtful in the methanol solution. Equation 24′ represents a variation of Equation 24 for the propagation of nitric acid decomposition.

$$RH + \cdot NO_2 \longrightarrow R\cdot + HNO_2 \qquad \underline{24}$$

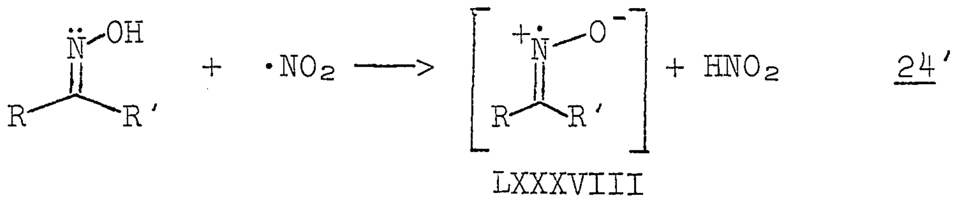
The variation is in the nature of the species RH, which represents a hydrocarbon molecule in Equation 24. In Equation 24′, RH has been replaced by an oxime molecule, which gives an iminoxyl radical (LXXXVIII) on reaction with $\cdot NO_2$, rather than an alkyl radical R·. Equations 25 and 26 illustrate the furthur decomposition of nitric acid to $\cdot NO_2$ and $\cdot NO$. A source of the nitrous acid shown in Equation 25 could be the formation and decomposition of methyl nitrate (below).



$$CH_3OH + HNO_2 \longrightarrow CH_3{-}O{-}\overset{+}{N}\begin{smallmatrix}{=}O\\ {-}O^-\end{smallmatrix} \longrightarrow CH_2O + HNO_2$$

Figure 33 has been formulated on the assumption that iminoxyl radicals are involved in the oxidation of aryl ketoximes by nitric acid. This assumption is based on no

$$HNO_3 \xrightarrow{CH_3OH} \cdot NO_2 + [\cdot OH]$$



$$HNO_3 + HNO_2 \rightleftharpoons 2\ \cdot NO_2 + H_2O \qquad \underline{25}$$

$$2\ HNO_3 + \cdot NO \rightleftharpoons 3\ \cdot NO_2 + H_2O \qquad \underline{26}$$

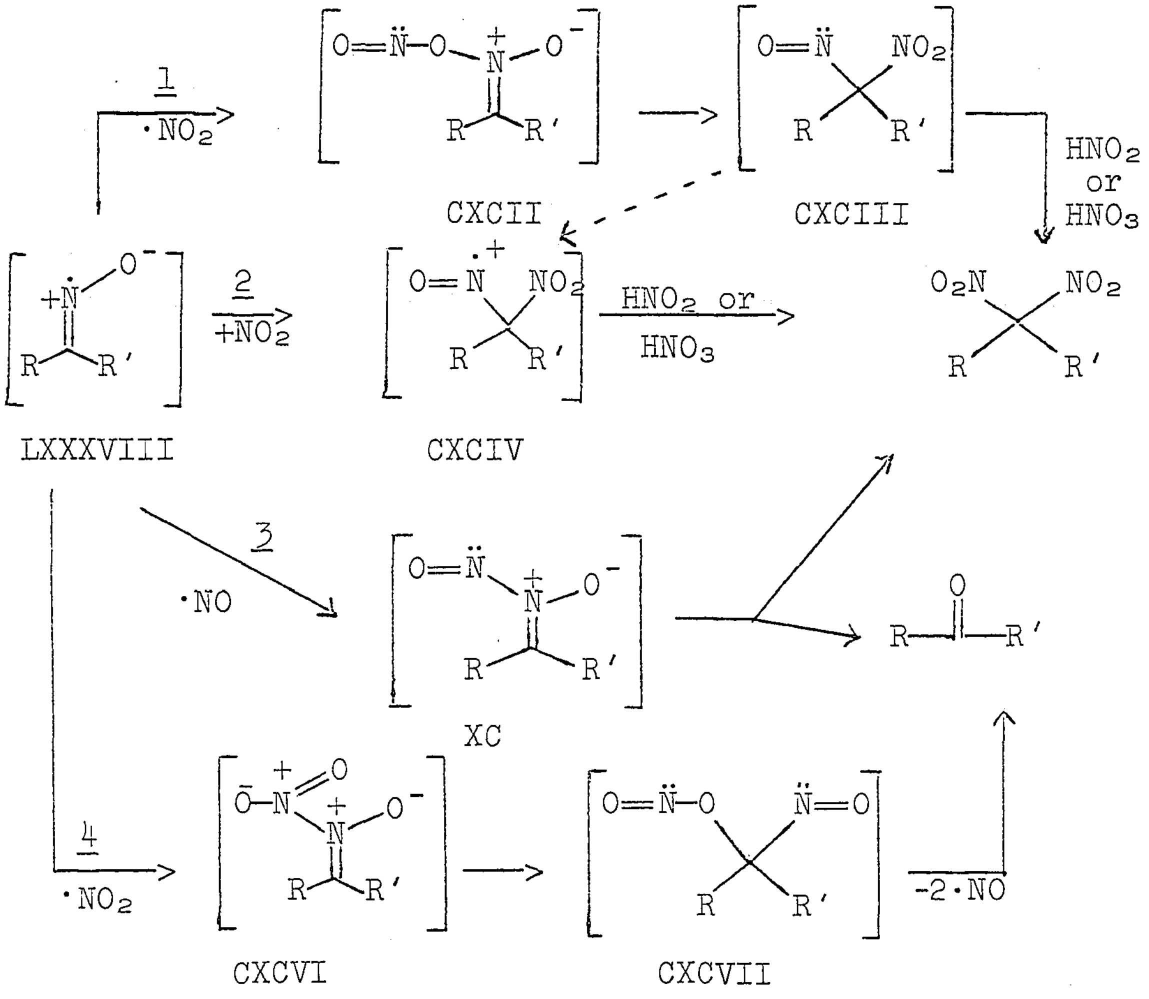
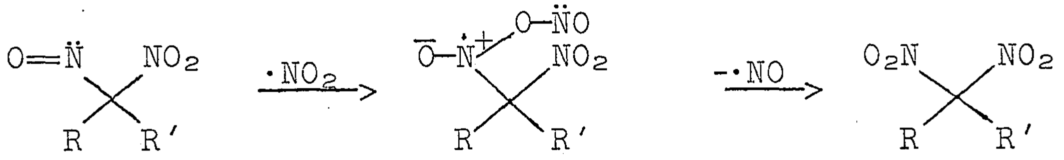


Figure 33. Possible mechanisms for the nitric acid oxidation of aryl ketoximes.

evidence and represents only speculation at this time.

Reactions of $\cdot NO_2$ with an iminoxyl radical could occur in two ways. Figure 33, pathway *1*, shows the reaction of $\cdot NO_2$ (as $\dot{O}-\ddot{N}=O$) with LXXXVIII to give an *aci*-nitro structure CXCII. Rearrangement of CXCII could give a *geminal*-dinitro compound by way of a *geminal*-nitronitroso intermediate (CXCIII). Intermediate CXCIII could be converted to a *gem*-dinitro compound through an intermediate such as CXCIV (Figure 33), or through an intermediate such as CXCV (as shown below).



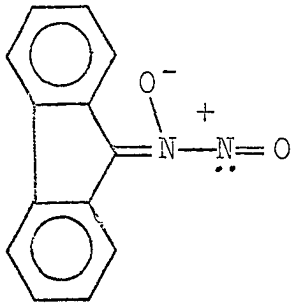
CXCIII CXCV

Intermediate CXCIV could also arise by reaction of an iminoxyl radical with $^+NO_2$ (Figure 33, pathway *2*), which may be generated by the reaction $HNO_3 + H^+ \rightleftarrows NO_2^+ + H_2O$.

Figure 33, pathway *4*, summarizes a second means by which $\cdot NO_2$ could react with an iminoxyl radical. An intermediate CXCVI would be formed, which could result in the formation of a ketone and two molecules of $\cdot NO$ (*via* an intermediate CXCVII). The probability that some ketone is formed by an acid-catalyzed hydrolysis of an oxime has been mentioned. Nitrous acid might react with an oxime (or an iminoxyl radical) to give a *geminal*-dinitro compound. Intermediates similar to those shown in pathway *1* (Figure 33) could be involved in such a reaction.

Reaction of an iminoxyl radical with nitric oxide (Figure 33, pathway 3) could give an intermediate XC, as previously proposed to account for the conversion of aryl diazo compounds by ·NO to nitrimines and ketones (69, 70, 71) (see Figure 1, page 47). Rearrangement of XC would give a ketone, or XC could be converted to a geminal-dinitro compound by reaction with any of several nitrogen oxides and acids present in the solution. Heckert (68) observed that benzophenone oxime was converted to nitriminodiphenylmethane (LXXXVI) and benzophenone by irradiation in the presence of ·NO, but was converted to dinitrodiphenylmethane (LXIX) and benzophenone by reaction with ·NO in the dark (see page 91). The results suggest that either a different intermediate is involved in the reaction of LXXVII with ·NO in the dark than is involved in the photochemical reaction, or the same intermediate (XC?) is involved in both reactions and reacts in different ways depending on the reaction conditions. Irradiation of 9-fluorenone oxime (CLVI) in the presence of nitric oxide gives 9,9-dinitrofluorene (LXII) and 9-fluorenone (68). Oxime CLVI is known to give the geminal-dinitro compound LXII in a variety of reactions in which other ketoximes give nitrimines (see Historical, pages 45--48). The inability of an intermediate CXCVIII (derived from oxime CLVI by reaction with ·NO) to undergo a rearrangement to a nitrimine (the failure to do may be associated with the planar structure of CXCVIII) may permit other reactions of

CXCVIII with ·NO to occur to give LXII. The fact that LXII and dinitrodiphenylmethane (LXIX) are formed when the respective oximes are reacted with both nitric acid and nitric oxide

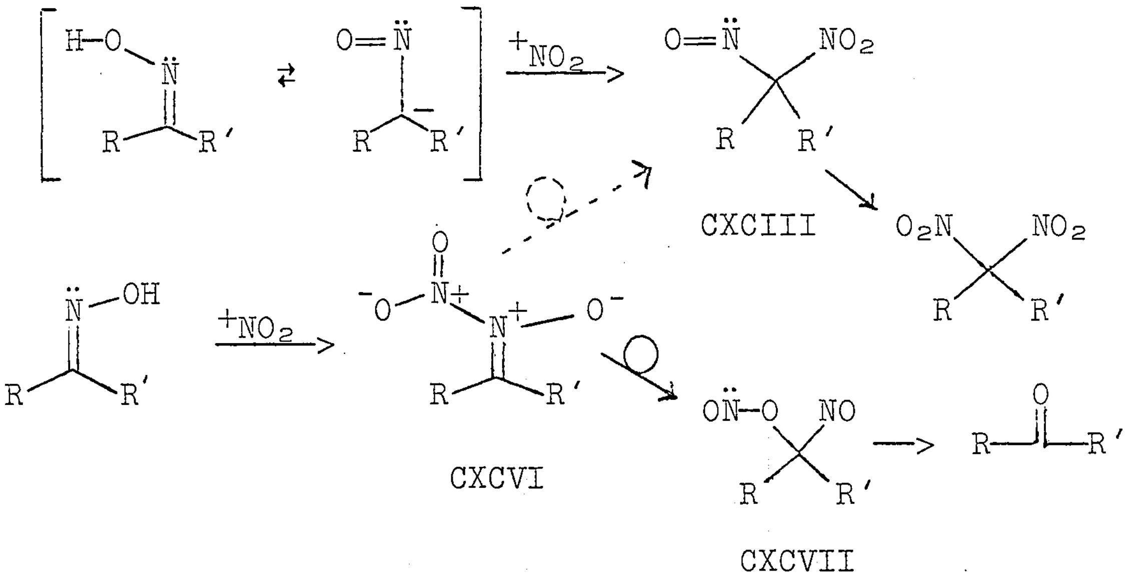


CXCVIII

suggests that ·NO is involved in the oxidation of aryl ketoximes by nitric acid.

Iminoxyl radicals are not required to be involved in the nitric acid oxidation of aryl ketoximes. The reaction of an iminoxyl radical with a nitrosyl ion ($+NO_2$) (Figure 33, pathway 2) can be written as a reaction of an oxime molecule with $+NO_2$. Similarly, the reaction of an iminoxyl radical with $\cdot NO_2$ (Figure 33, pathway 4) can be written as a reaction between an oxime molecule and $+NO_2$ (below). The similarity between CXCVI (below) and the general intermediate XC (Figure 33, pathway 3) should be noted. Rearrangement of CXCVI to intermediate CXCIII provides a possible route for the formation of gem-dinitro compounds.

The oxidation of 9-fluorenone oxime (CLVI) by nitric acid provides a convenient method for the preparation of 9,9-dinitrofluorene (LXII) in good yield. It is possible that the yields of geminal-dinitro compounds from other ketoximes will be improved once optimum ratios of nitric acid to oxime have been determined, and conditions are found where the oxidation reaction can compete with acid hydrolysis of the oximes. Solvents other than methanol may be found which facilitate formation of gem-dinitro compounds. At the present time, the reaction appears to be useful only for the preparation of 9,9-dinitrofluorene, as other ketoximes give lower yields of dinitro compounds when oxidized by nitric acid (Table 14) than when oxidized by CAN in acetone (Table 7).



Mechanistic speculations

The mechanisms of many organic oxidation and reduction reactions are described in terms of the formation and reaction of free radicals with metal complexes. The oxidation and reduction of free radicals with metal complexes follow two general mechanisms, electron transfer and ligand transfer (122). The available evidence concerning the ceric ammonium nitrate oxidation of aryl ketoximes suggests that the reaction is both an electron transfer oxidation and a ligand transfer oxidation.

Factors which influence the formation of geminal-dinitro compounds and other materials in the oxidation of aryl ketoximes by ceric ammonium nitrate (CAN) have been determined mainly by product analysis, which is at best an insensitive tool for mechanistic studies. The mode of formation of geminal-dinitro compounds has been determined by ^{15}N-isotope labeling experiments, which have demonstrated that the origin of a nitro group in the dinitro compounds is the nitrate ion initially complexed with cerium(IV). Indirect evidence suggests that iminoxyl radicals may be the reactive intermediates initially generated by a one-electron oxidation of an oxime molecule by cerium(IV). In a strict sense, the oxidation of aryl ketoximes by cerium(IV) resembles the oxidation of alkyl radicals by copper(II) salts and lead(IV) salts in that electron transfer and ligand transfer oxidation may both occur depending on the ligand associated with the metal ion.

The oxidation of free radicals by metals salts such as cupric sulfate, perchlorate, or carboxylates, in general results in the formation of elimination products (alkenes), and the reactions have been described as electron transfer reactions (123). As one goes from primary to secondary to tertiary alkyl radicals, the alkenes are in part replaced by increasing amounts of substitution products (124). The amount of substitution product relative to the alkene depends on the radical and, to a lesser extent, the solvent. Formation of substitution products is enhanced by protic solvents, with the yields of the products qualitatively paralleling the stability of the corresponding carbonium ion.

The reactivities of free radicals with cupric salts indicate that a sizable amount of positive charge is incorporated into the organic residue in the transition state, regardless of the mechanism through which a particular reaction proceeds (122). The determining factor in an electron transfer oxidation of a free radical by copper(II) appears to be the ease by which the system can achieve cationic character in the transition state.

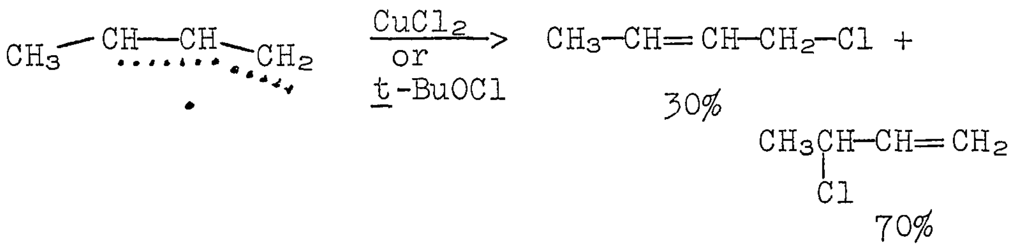
Alkyl radicals which give products of rearrangement on electron transfer oxidation with other copper(II) salts show very little tendency to undergo electron transfer reactions with cupric chloride, and only alkyl halides are formed (122). Carbonium ion character predominates in electron transfer oxidations, resulting in the formation of alkenes from alkyl radicals, in the formation of substitution products from allylic ($CH_2{-}CH{=}CH{-}R$) and benzylic radicals, and in the rearrangement of neopentyl and homoallylic ($\dot{C}H_2{-}CH_2{-}CH{=}CH_2$) radicals. Ligand transfer oxidation gives the same class of products regardless of the nature of the free radical. An overall one-electron change results from the transfer of a ligand, as an atom or free radical, from the metal complex to the free radical being oxidized. Transition states for the two modes of oxidation differ in the respect that the transition state for ligand transfer involves significantly less carbonium ion character than the transition state for electron transfer. General transition states for the two processes are shown in Equations 37 and 38 (122). The ambident butenyl radical gives the same ratio of chlorides when reacted with cupric chloride as it gives in a reaction with t-butyl hypochlorite (Equation 39) (125), indicating that when chlorine is the ligand which is transferred, the transition state is apparently similar to that of an atom transfer in a classical free radical reaction.

Electron transfer:

$$R\cdot + Cu(II)Y \longrightarrow [R\cdot YCu(II) \rightleftarrows R^{+}Y\text{—}Cu(I)] \longrightarrow \text{products} \qquad \underline{37}$$

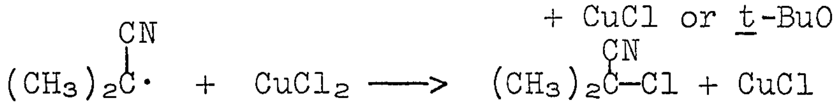
Ligand transfer:

$$R\cdot + Cu(II)\text{—}X \longrightarrow [R\cdot X\text{—}Cu(II) \rightleftarrows R\text{—}XCu(I)] \longrightarrow \text{products} \qquad \underline{38}$$



+ CuCl or t-BuO·

39



$$(CH_3)_2\overset{CN}{\overset{|}{C}}\cdot + CuCl_2 \longrightarrow (CH_3)_2\overset{CN}{\overset{|}{C}}\text{—}Cl + CuCl \qquad \underline{40}$$

The oxidation of α-cyanoisopropyl radicals with cupric chloride gives α-chloroisobutyronitrile in a typical ligand transfer reaction (Equation 40), whereas cupric acetate under the same conditions does not oxidize the radicals (126). Alkyl radicals with other electron-withdrawing *alpha*-substituents (such as carboxy, acetyl, chloro, and nitro) are readily oxidized by cupric chloride to chloro compounds, but are not oxidized by cupric acetate. The fact that negatively substituted alkyl radicals display a marked discrimination toward electron transfer and ligand transfer oxidants supports the formulation of the cationic transition state shown in Equation 37 for electron transfer reactions, and the formulation of the transition state for ligand transfer reactions (Equation 38) where the direct transfer of an atom or radical from the oxidant to the organic radical effectively moderates charge development in the transition state.

The oxidation of aryl ketoximes by ceric ammonium nitrate (CAN) and ceric potassium nitrate (CPN) generally gives *geminal*-dinitro compounds and ketones. Other products, such as azine monoxides and *p*-nitrated ketones, are formed in some CAN oxidations. When 9-fluorenone oxime was oxidized by ceric ammonium sulfate (CAS) or ceric sulfate (CHS), only 9-fluorenone and 9-fluorenone azine monoxide were formed. The dinitro compound, 9,9-dinitrofluorene, was not formed in the CAS and CHS reactions, which qualitatively demonstrates the dependency of product formation in the cerium(IV) oxidation of ketoximes on the ligand associated with the metal ion. The results of the CAS (and CHS) oxidation of 9-fluorenone oxime when compared to the results of the CAN oxidation also suggest that ketone and azine monoxide formation in the CAN reaction does not take place by ligand transfer of nitrate from cerium(IV). The available evidence, however, does not discount the possibility that ligand transfer is involved in the formation of ketones and azine monoxides.

Attempts to obtain kinetic evidence for initial complex formation between oxime and cerium(IV) in the CAN oxidation of aryl ketoximes by spectrophotometric techniques (UV) were unsuccessful. The oxidation was a fast reaction, and any complex formed between cerium(IV) and an oxime was apparently destroyed before detection could be made. Evidence for oxime-cerium(IV) complex formation in the CAN oxidation reactions comes from product studies. Oxidation of 9-fluorenone oxime and benzophenone oxime by CAN in 80% methanol-20% water resulted in a greater recovery of unreacted oxime and in lower yields of gem-dinitro compounds than were obtained in the oxidations in anhydrous methanol (compare Table 8, page 109, with Table 6, page 103). Azine monoxide yields were also higher in the aqueous methanol than in anhydrous methanol. Similar, but not as marked, effects were noted when 9-fluorenone oxime was oxidized in 90% acetone-10% water and anhydrous acetone (compare Table 10, line 4, page 117 with Table 7, line 1, page 104).

The presence of nitric acid in the methanol in which 9-fluorenone oxime and benzophenone oxime were oxidized also resulted in lower yields of the respective gem-dinitro compounds and in higher yields of the respective azine monoxides (compare Table 10 with Table 6, page 103). Considerable unreacted oxime was recovered from the CAN oxidation of 9-fluorenone oxime in methanol containing nitric acid (Table 10).

Evidence for the intermediacy of oxime-cerium(IV) complexes in the CAN oxidation of aryl ketoximes also comes from the results of the oxidation of 9-fluorenone oxime (CLVI) in methanol containing two equivalents of ammonium hydroxide. The products were 9-fluorenone (LXIII) and 9-fluorenone azine monoxide (CLXII) in yields of 52% and 5%, respectively, while a 59% recovery of unreacted oxime was obtained (Table 10, page 117). The dinitro compound, 9,9-dinitrofluorene (LXII), was not formed. Product yields were insensitive to variations in reaction times. Strongly complexing ligands are known to stabilize the higher valence state of a metal ion relative to the lower valence state (115). Hydroxide ion was probably serving in that capacity when CLVI was reacted with CAN in the presence of NH_4OH. Part of the cerium(IV) was apparently rendered inactive by formation of insoluble cerium(IV) oxides and alkoxides, since LXIII and CLXII were formed in about the same amounts regardless of the reaction time used. The lack of formation of 9,9-dinitrofluorene (LXII) suggests the inability of oxime CLVI, or some intermediate derived from the oxime, to compete with hydroxide ion for coordination sites on the cerium(IV) which was not removed from solution by precipitation.

Methanol should be capable of competing with oxime molecules for coordination sites on cerium(IV) in a manner similar to that observed for water and base. A comparison of the results for the CAN oxidation of aryl ketoximes in the three solvents, acetone, methanol, and 80% methanol-20% water, does suggest that the alcohol functions in such a capacity. Acetone is non-hydroxylic in nature (with the exception of a small amount of the enol present), and would be expected to be the least effective in complexing with cerium(IV). One might expect oxime-cerium(IV) complexes to be more stable in anhydrous acetone than in either methanol or the aqueous solvents. The amount of ligand transfer product (dinitro compound) formed on oxidation of an oxime in a given solvent may reflect in part the stability of an oxime-cerium(IV) complex in that solvent. Geminal-dinitro compounds are formed in greater amounts in the CAN oxidation of oximes in acetone than are formed in methanol, and in greater amounts in methanol than in 80% methanol-20% water.

Electron spin resonance (esr) studies on the CAN oxidation of aryl ketoximes suggest that iminoxyl radicals are the reactive intermediates formed by a one-electron cerium(IV) oxidation of the oximes. The results concerning the lifetimes of the radicals 9-fluorenone iminoxyl (CXC) and benzophenone iminoxyl (CXCI) (see Table 27, page 475) at least qualitatively parallel the product isolation results obtained when the respective oximes were oxidized by CAN in methanol and 80% methanol-20% water. The lifetimes of the iminoxyl radicals were somewhat longer under conditions where _gem_-dinitro compounds were formed in only trace amounts and yields of azine monoxides were increased. The only conclusion which may be drawn from the evidence is that iminoxyl radicals could be primary intermediates in the cerium(IV) oxidation of aryl ketoximes. Evidence directly relating iminoxyl radical formation and destruction to product formation has not been obtained.

The high percent incorporation of one ^{15}N atom per molecule of 9,9-dinitrofluorene (LXII) (94-95%) and per molecule of 1,1-dinitroindane (CLXIII) (97-100%) indicated that only one nitrate-nitrogen was being incorporated into each molecule of a dinitro compound. The origin of the nitrogen atom in the remaining nitro group of the dinitro compounds was apparently the nitrogen atom originally present in the oxime undergoing oxidation.

Possible modes of formation of _geminal_-dinitro compounds in the CAN oxidation of aryl ketoximes are summarized in Figure 34. The involvement of an oxime-cerium(IV) complex in the overall reaction is indicated in Figure 34, but the exact nature of the complex has not been specified. More than one oxime molecule could be present in the complex with cerium(IV). It is also possible that aggregates containing more than one oxime molecule and more than one ceric ion could be formed when solutions of oxime and ceric ion are mixed.

Transfer of nitrate ion from cerium(IV) to a discrete iminoxyl radical could occur within a complex such as CXCIX (Figure 34). The intermediate CC could then rearrange to a dinitro compound as shown. The mechanism suggests than an iminoxyl radical is formed in the initial oxime oxidation step. Nitrate could also be transferred to the oxime without involving a discrete iminoxyl radical (Figure 34, dotted arrows). This mechanism is in essence the same as that involving an iminoxyl radical, since the same intermediate (CCI) may be achieved by a slightly different rearrangement of electrons in the complex CXCIX. Whether or not the initial transfer of nitrate is an oxidative transfer cannot be determined, and such representations are only speculative.

An interesting alternative which involves an initial non-oxidative transfer of nitrate from cerium(IV) to an oxime molecule is suggested by the intermediate CCI shown in Figure 34. The conversion of the salts of primary and secondary nitro compounds to gem-dinitro compounds which occurs on treatment of the salts with inorganic nitrites in the presence of silver (I) (or mercury(II)) ions (51, 52) is illustrated by Equation 23. An intermediate complex (CCII) similar to LXV (shown in

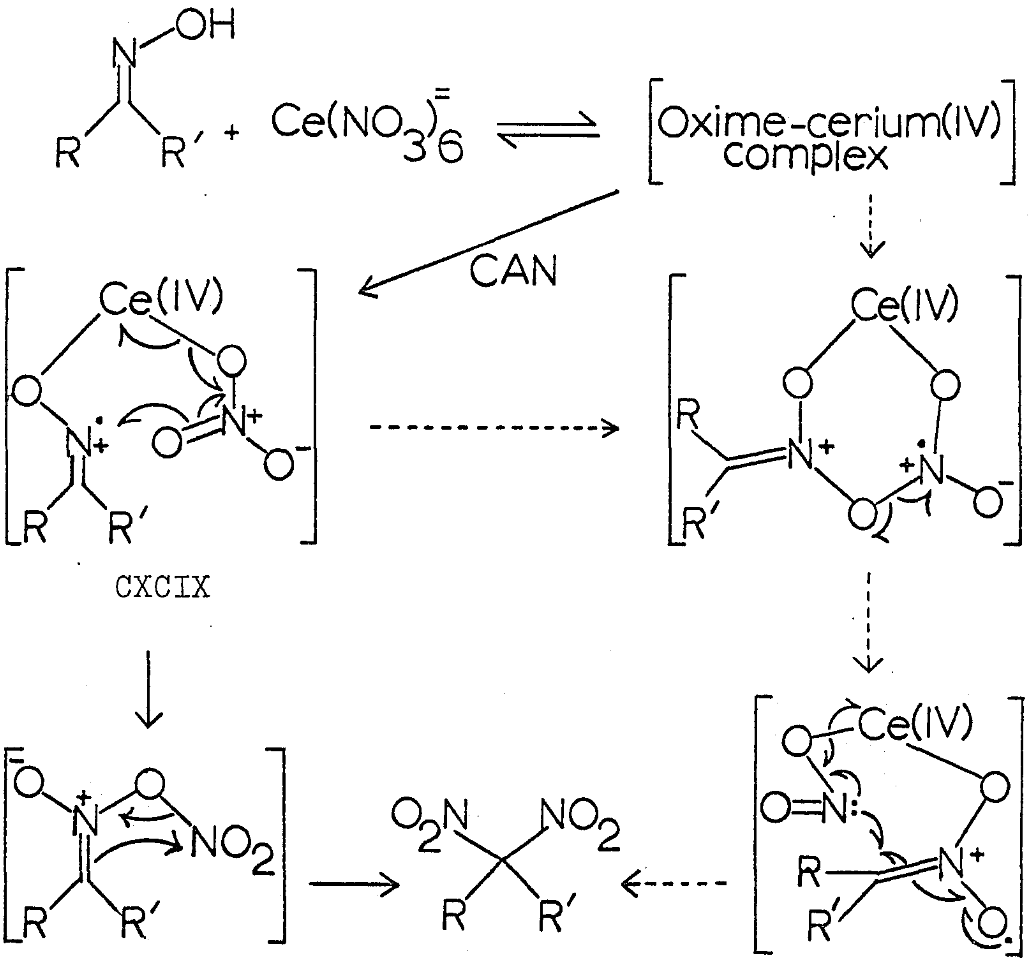
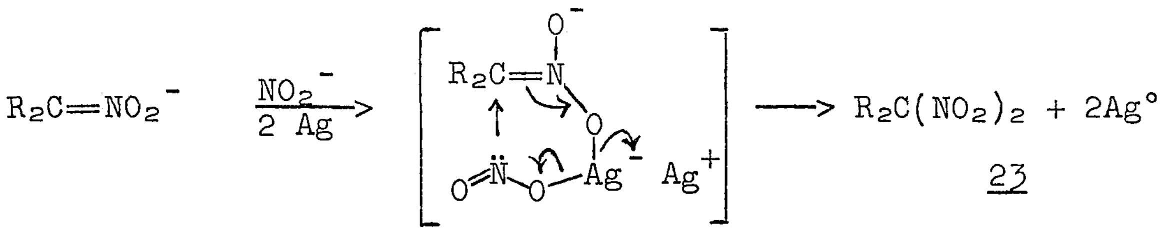
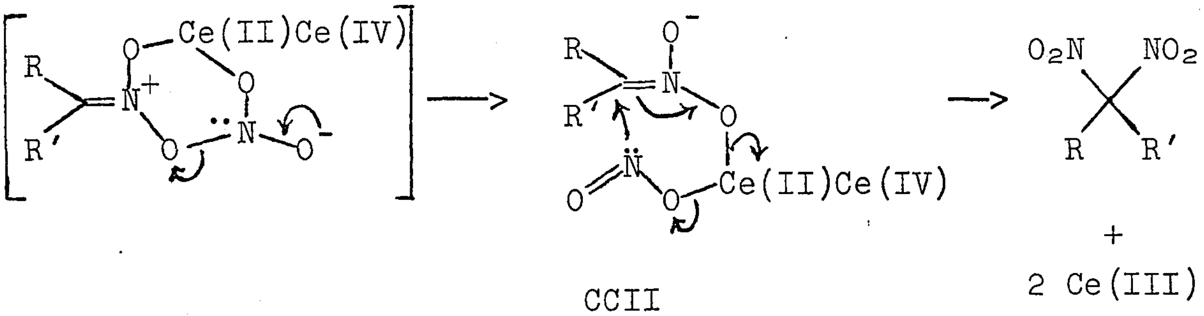


Figure 34. Formation of geminal-dinitro compounds in the CAN oxidation of aryl ketoximes.

Equation 23) could arise through a non-oxidative transfer of nitrate from cerium(IV) to an oxime molecule (see next page). The complex CCII differs from complex CCI (Figure 34) mainly in the stage to which oxidation by cerium(IV) has progressed. The possibility that the oxidation of an oxime to a gem-dinitro compound occurs by one two-electron oxidation involving the transient existence of cerium(II) is suggested by



LXV



CCII

the mechanism passing through complex CCII. A rapid electron transfer between cerium(II) and cerium(IV) to give two cerium(III) ions may be the fate of any cerium(II) formed in the reaction.

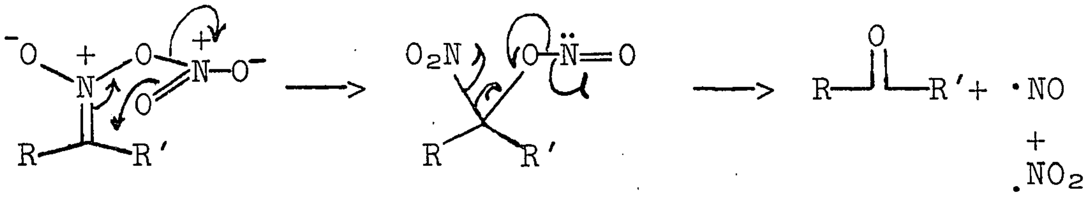
The elements of the nitrate ion being transferred from ceric ion to an oxime molecule apparently never become detached from the complex in which the transfer is taking place. An additional scrambling of the ^{15}N-label in a gem-dinitro compound over that required by the statistical distribution of ^{15}N in the nitrate ion would have been observed if the $-NO_2$ residue became detached from either nitrate ion or a complex. Other mechanisms for the formation of gem-dinitro compounds in the CAN oxidation of aryl ketoximes may be written which are consistent with the results of the ^{15}N-isotope labeling experiments, but which are only variations of the scheme shown in Figure 34. The nitrogen atom of an oxime molecule is not required to be the site of the initial transfer of nitrate from cerium(IV). Direct transfer of nitrate to the carbon atom of the C-N double bond could be occurring. It is possible that the oxygen atom found in the nitro group which originated from the oxime nitrogen did not come from the same nitrate ion as the incorporated nitro group.

The involvement of nitrite ion in the production of gem-dinitro compounds by its formation from nitrate and transfer to an organic residue from cerium(IV) (complex CCI, Figure 34, and complex CCII) has some appeal in another respect. Nitrogen dioxide was detectable in flasks containing solutions of ketoximes and CAN both by odor and by visual observation (brown gas). Nitrite ion rapidly reacts with cerium(IV) to give $\cdot NO_2$ and cerium(III) when solutions of the materials are mixed. A reaction between cerium(IV) and complexed nitrite ion could give nitrogen dioxide before transfer of the nitrite ion to an organic residue can occur. Several other mechanisms for the formation of $\cdot NO_2$ from nitrate may be written, however, and the fact that $\cdot NO_2$ is readily formed only suggests that nitrite ion is involved in some manner in the CAN oxidation reactions.

A scheme summarizing possible mechanisms for the oxidation of aryl ketoximes by cerium(IV) salts is shown in Figure 35, page 270 . Figure 35 summarizes some features of a mechanism for the formation of gem-dinitro compounds in the CAN oxidation of aryl ketoximes which have been discussed, and provides a basis for a discussion of means by which ketones, azine monoxides, and para-nitrated ketones may be formed in the oxidation of ketoximes by CAN and other cerium(IV) salts.

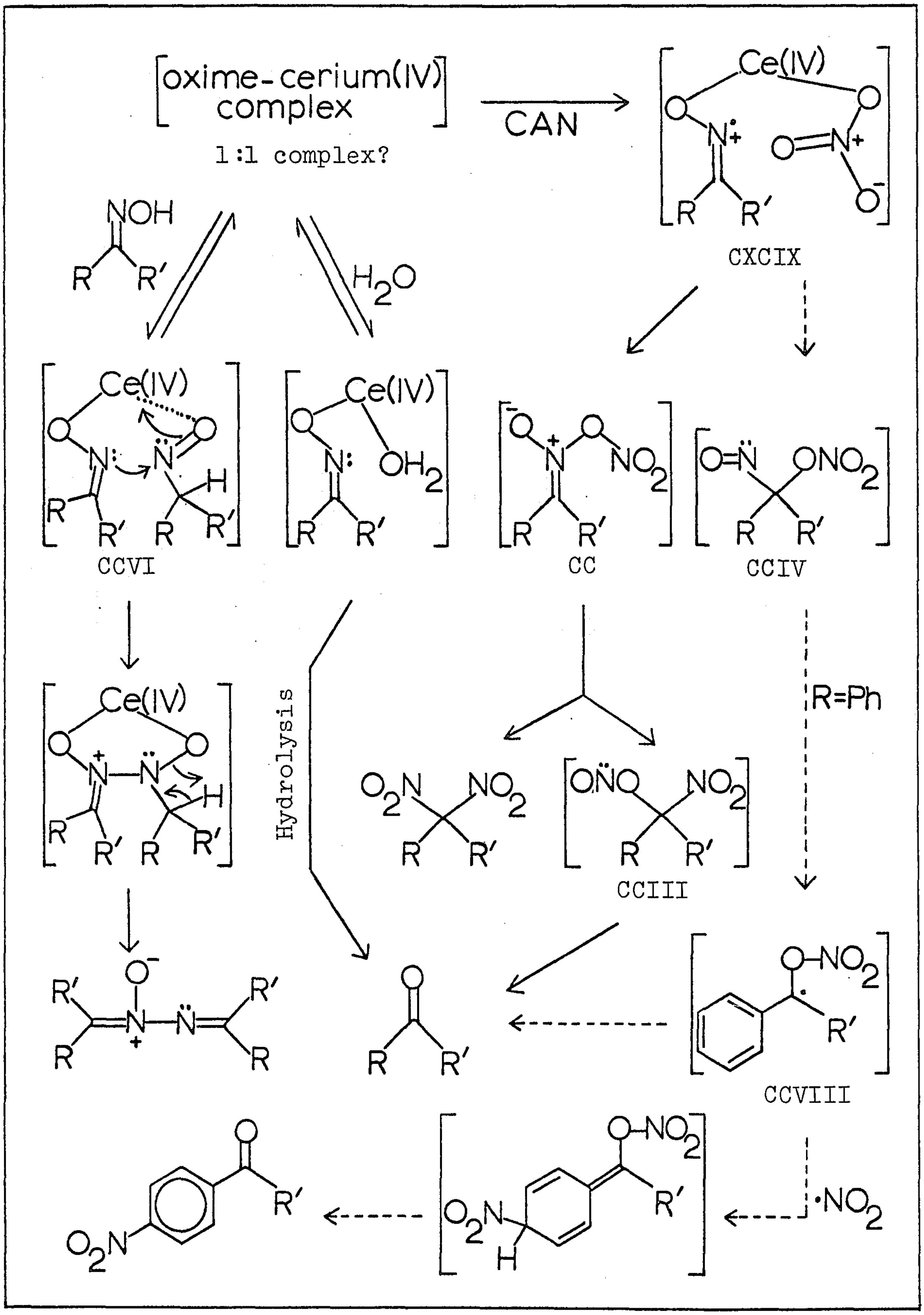
Ammonium ion had little or no role in product formation in the CAN oxidation of aryl ketoximes, as indicated by the fact that the oxidation of 9-fluorenone oxime (CLVI) by ceric potassium nitrate in methanol gave the same products in nearly the same yields as did the CAN oxidation of CLVI (see Table 6, page 103). The fact that 9-fluorenone and 9-fluorenone azine monoxide were formed when CLVI was oxidized by ceric ammonium sulfate and ceric sulfate, as well as by CAN, suggested that the formation of ketones and azine monoxides in the CAN reactions was occurring by mechanisms in which nitrate was not involved.

Ligand transfer of nitrate from cerium(IV) to an iminoxyl radical was suggested previously to give a precursor (CC) in the formation of a gem-dinitro compound (Figure 34). The species CC might also lead to ketone formation by rearrangement in the manner shown below. Decomposition of a species

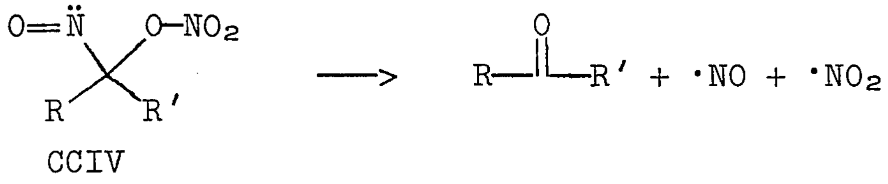


CC CCIII

Figure 35. Possible mechanisms for product formation in the oxidation of aryl ketoximes by CAN and other cerium(IV) salts.

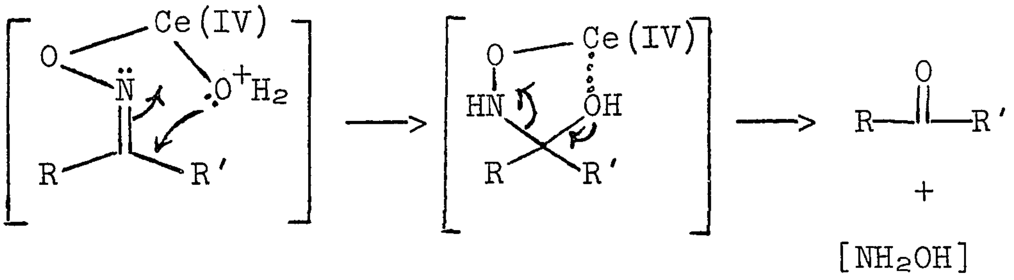

oxime-cerium(IV) complex
1:1 complex?
CAN
H2O
CXCIX
CCVI
CC
CCIV
R=Ph
Hydrolysis
CCIII
CCVIII
·NO2

such as CCIII would give ketone, nitric oxide, and nitrogen dioxide. Ketone precursors such as CCIV might be formed by a direct transfer of nitrate from cerium(IV) to the carbon atom of an oxime molecule or an iminoxyl radical, the decomposition of which would also give $\cdot NO$ and $\cdot NO_2$ as by-products. Intermediates such as CCIII and CCIV may be involved in ketone



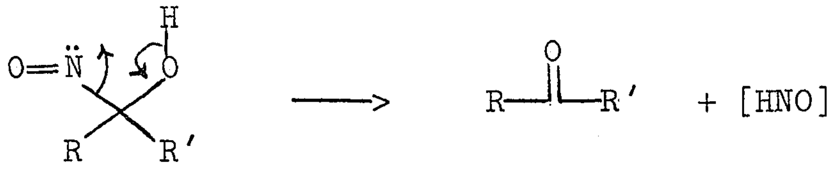
formation when nitrate is the ligand accompanying cerium(IV), but it is not possible to determine at this time whether such mechanisms are of any importance in rationalizing ketone formation.

Water could be involved in ketone formation in the cerium(IV) oxidation of ketoximes, and the ligand associated with the cerium(IV) (nitrate or sulfate) may be of no importance at all. The effect of water on product formation in the CAN oxidation reactions could be one where hydrolysis of nitratocerium(IV) complexes was occurring, with water becoming the ligand available for transfer in some manner rather than nitrate. Ketone formation could occur simply by a cerium(IV)-catalyzed hydrolysis of an oxime molecule (see below). The hydroxylamine formed would probably be rapidly oxidized by cerium(IV), however, and it would be difficult to distinguish a simple hydrolysis mechanism for ketone formation from one involving an oxidative transfer of water from cerium(IV) to an oxime.



A comparison of the results for the CAN oxidation of 9-fluorenone oxime in aqueous methanol (Table 8) with the results of the oxidation in anhydrous methanol (Table 6) shows that yields of 9-fluorenone were not affected much by the presence of water in the solvent. Significantly higher yields of 9-fluorenone azine monoxide were obtained in aqueous methanol than in anhydrous methanol, however. In the CAN oxidation of benzophenone oxime, the yield of benzophenone was increased in aqueous methanol over that observed in anhydrous methanol, accompanied by a smaller but finite increase in the yield of benzophenone azine monoxide. In addition to providing some evidence to support the suggestion that water is involved in ketone formation, the results also suggest that the same intermediate (or intermediates) which is involved in ketone formation is involved in azine monoxide formation.

Intermediates such as CCV could be formed in an oxidative transfer of the elements of water from cerium(IV) to an oxime molecule (or some intermediate derived from an oxime). Decomposition of CCV by loss of HNO would lead to ketone

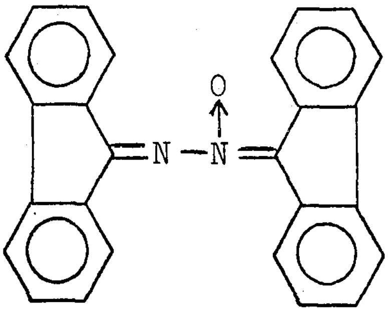


CCV

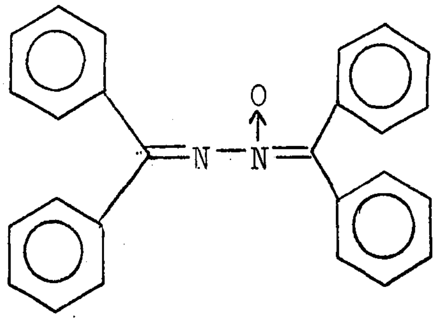
formation. Whether or not a species such as HNO is formed in the cerium(IV) oxidation reactions is unknown. The involvement of intermediates such as CCV in ketone formation cannot be discounted.

Azine monoxide formation was observed in the CAN oxidation of aryl ketoximes in only three instances. The fact that azine monoxides were not isolated in other ketoxime oxidations does not mean that azine monoxide formation did not occur in those reactions. Benzophenone azine monoxide (LXXVIII) and *p*-nitroacetophenone azine monoxide (CLXXV) are thermally unstable. Formation and decomposition of the azine monoxides may have been occurring in some reactions before isolation could be made. It has been determined that cerium(IV) oxidizes 9-fluorenone azine monoxide (CLXII) to give 9-fluorenone. Consequently, it is possible that azine monoxide formation, followed by a rapid oxidation of the azine monoxide by cerium(IV) to give ketone, was occurring in some cases.

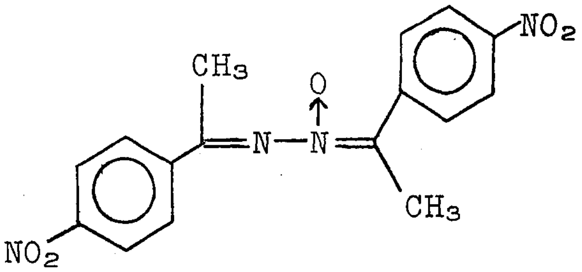
An azine monoxide is formally the product of a dehydration reaction between two molecules of unoxidized oxime. The interesting possibility exists that azine monoxide formation



CLXII

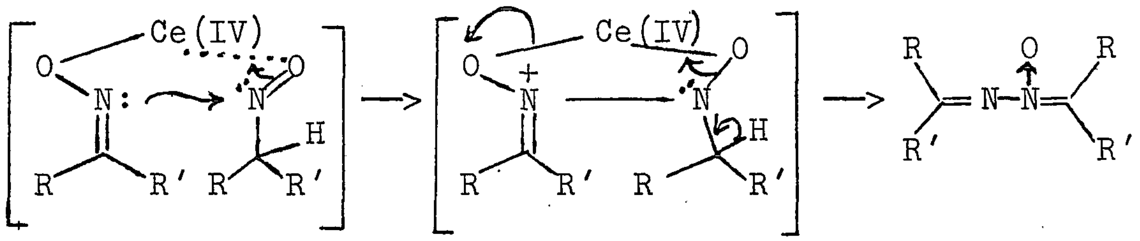


LXXVIII



CLXXV

does occur by a cerium(IV)-catalyzed dehydration reaction (see below). A condensation between an oxime molecule and its tautomeric form (complex CCVI) is not unreasonable, since a small amount of the tautomeric form of the oxime could be present in the reaction mixture. A net two-electron oxidation of an oxime molecule has taken place, with oxygen the electron acceptor rather than cerium(IV). Two features of a mechanism for



CCVI

+ Ce(IV) + H_2O

azine monoxide formation similar to that shown above are to be noted. Cerium(IV) is not involved in the reaction in any capacity other than as a catalyst for a condensation, and is available for other reactions which are promoted by cerium(IV) oxidation. The mechanism also suggests that water is a by-product in the formation of an azine monoxide. Water was formed in detectable amounts in the CAN oxidation of 9-fluorenone oxime, where significant amounts of azine monoxide were formed. Water formation could occur in the CAN oxidation of aryl ketoximes in other ways, however, and the fact that water was formed is not definitive evidence for the production of azine monoxides by a dehydration mechanism.

The dehydration mechanism for azine monoxide formation has been included in the mechanistic scheme shown in Figure 35 for the oxidation of aryl ketoximes by cerium(IV) salts. One approach to the formation of azine monoxides by cerium(IV) oxidation of an oxime was through the corresponding azine-bis-oxides (XCI).[1] The azine-bis-oxides may be generated in situ by the dimerization of two iminoxyl radicals (LXXXVIII) initially formed by the ceric ion oxidation of two oxime molecules. Difficulties with a mechanism involving azine-bis-oxides (XCI) in the formation of azine monoxides immediately became apparent

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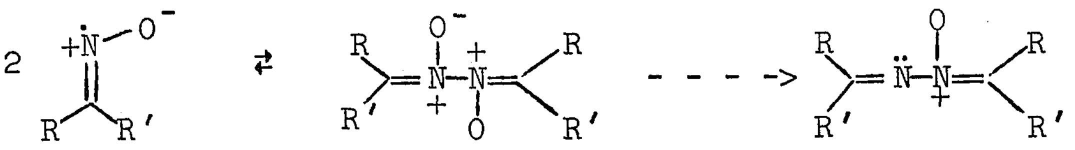
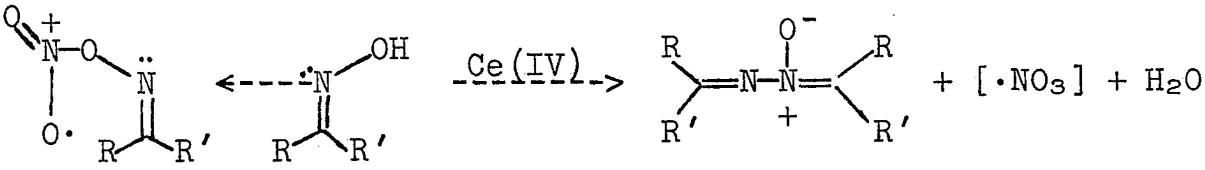
[1] Ketazine-bis-oxides (XCI, R and R′ = aryl or alkyl) are unknown compounds. Aldazine-bis-oxides (XCI, R or R′ = hydrogen) are sufficiently stable to allow isolation and have been characterized by several groups (see Historical).



LXXXVIII XCI

when one attempts to rationalize the loss of one of the oxygen atoms in a manner which results in the proper electronic configuration for an azine monoxide. It is sufficient to note in passing that mechanisms for azine monoxide formation are possible which involve a condensation of intermediates such as CCVII (formed by a transfer of nitrate from cerium(IV) to an iminoxyl radical) with oxime molecules. Evidence for the involvement of ligand transfer in azine monoxide formation has

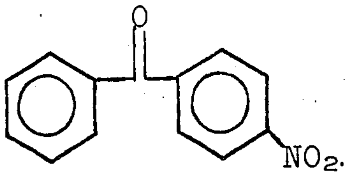


CCVII

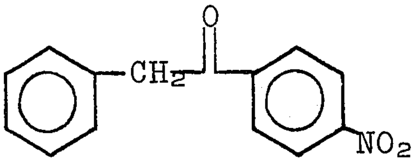
not been obtained. In addition, the very complexity of the electronic changes required in order to convert intermediates such as CCVII to azine monoxides suggest that such mechanisms are of no significance beyond being theoretical possibilities.

The CAN oxidation of benzophenone oxime, α-phenylacetophenone oxime, and acetophenone oxime gave small amounts of p-nitrobenzophenone (CLXX), α-phenyl-p-nitroacetophenone (CLXXVIII), and p-nitroacetophenone (CLXXIV), respectively.

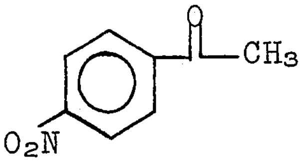
Solvent appeared to have some influence on the yields of the



CLXX



CLXXVIII



CLXXIV

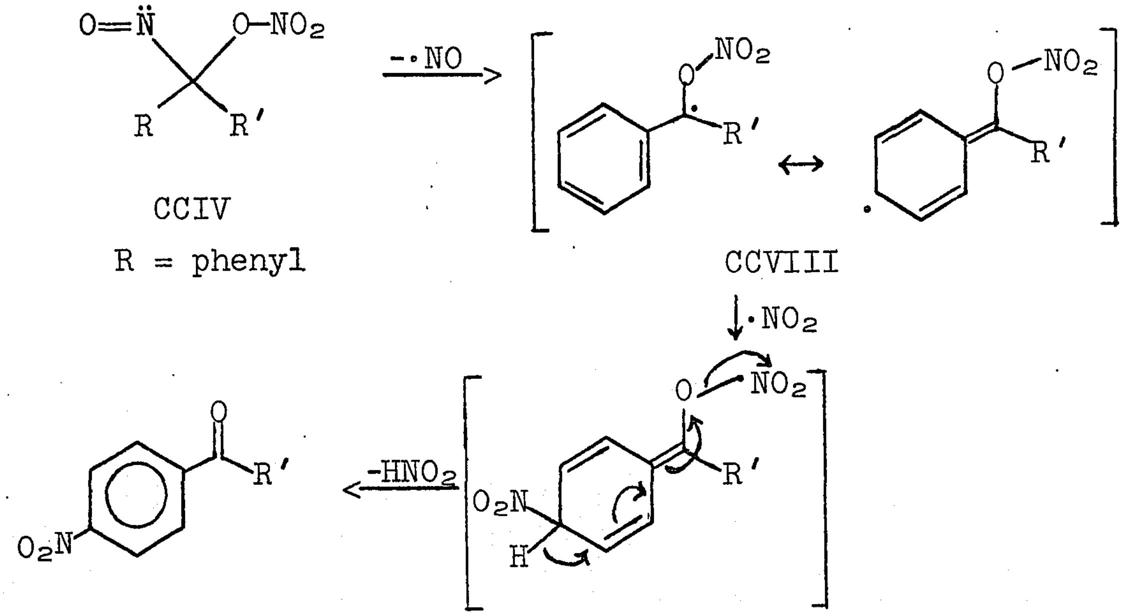
nitrated ketones, since the yields were generally higher in acetone than in methanol (ketone CLXX was not formed in the CAN oxidation of benzophenone oxime in methanol). However, the amounts of the compounds formed in any reaction were too small to permit an accurate determination of factors governing their formation.

The absence of *ortho*-nitrated ketones from product mixtures suggested that the *para*-nitrated ketones were being formed in a complex with cerium(IV), where a direct transfer of the elements of a nitro group from cerium(IV) to the *para*-position of an aromatic ring in some intermediate could occur. Alternatively, attack by a free molecule of $\cdot NO_2$ at the *para* position of an aromatic ring in some intermediate derived from an oxime could occur, where the *ortho* positions on the aromatic ring were effectively shielded to attack by ligands present on cerium(IV). In either mechanism, the origin of the nitro group found in the *p*-nitroketones would be nitrate ion.

Isotope labeling experiments using ^{15}N-labeled ceric ammonium nitrate for the oxidation of a ketoxime which gives a p-nitroketone are necessary before a choice can be made between a mechanism involving direct transfer of the elements of nitrate and a mechanism involving attack by free $\cdot NO_2$. A high percent incorporation of ^{15}N into a p-nitroketone should occur if a direct transfer mechanism is operative, whereas additional scrambling of ^{15}N-label should occur if the nitro group originates from $\cdot NO_2$ which is free in solution.

Insufficient information is available concerning the geometry of cerium(IV) complexes in solution to allow a description to be made of how a direct transfer of nitrate ion to some intermediate might lead to p-nitroketone formation. Some consideration can be given to possible intermediates from which p-nitroketones might be formed, however. The possibility has been presented (page 271) that unsubstituted ketones could be formed by the decomposition of intermediates such as CCIV. A radical CCVIII could be formed from CCIV (R = phenyl) by loss of $\cdot NO$, followed by delocalization of the odd electron in the aromatic π-system. Attack by $\cdot NO_2$ at the para-position of the aromatic ring, followed by loss of HNO_2, would give a p-nitroketone (Figure 35). The severest criticism for such a sequence is that, unless the conversion occurs entirely within a complex with cerium(IV) where the ortho-positions of the ring in CCVIII might be blocked by ligands, some o-nitroketone should be formed also.

Some evidence was obtained for the formation of nitroölefins in the CAN oxidation of some arylalkyl ketoximes in methanol and acetone. The olefinic materials were not isolated in pure form due to the fact that they were formed in small amounts and were usually present in mixtures with other


CCIV
R = phenyl
CCVIII

reaction products. The geminal-dinitro compounds which were formed in the ketoxime oxidations were stable to all phases of the work-ups of the reactions, eliminating the possibility that olefinic materials were formed by an induced decomposition of the respective dinitro compounds. The obvious factor governing the formation of olefinic compounds in the CAN oxidation of arylalkyl ketoximes was the presence of hydrogens alpha to the oxime group undergoing oxidation. However, the fact that the olefinic materials were only tentatively characterized as nitroölefins is not sufficient grounds to warrant a discussion of possible mechanisms for the formation of those compounds.

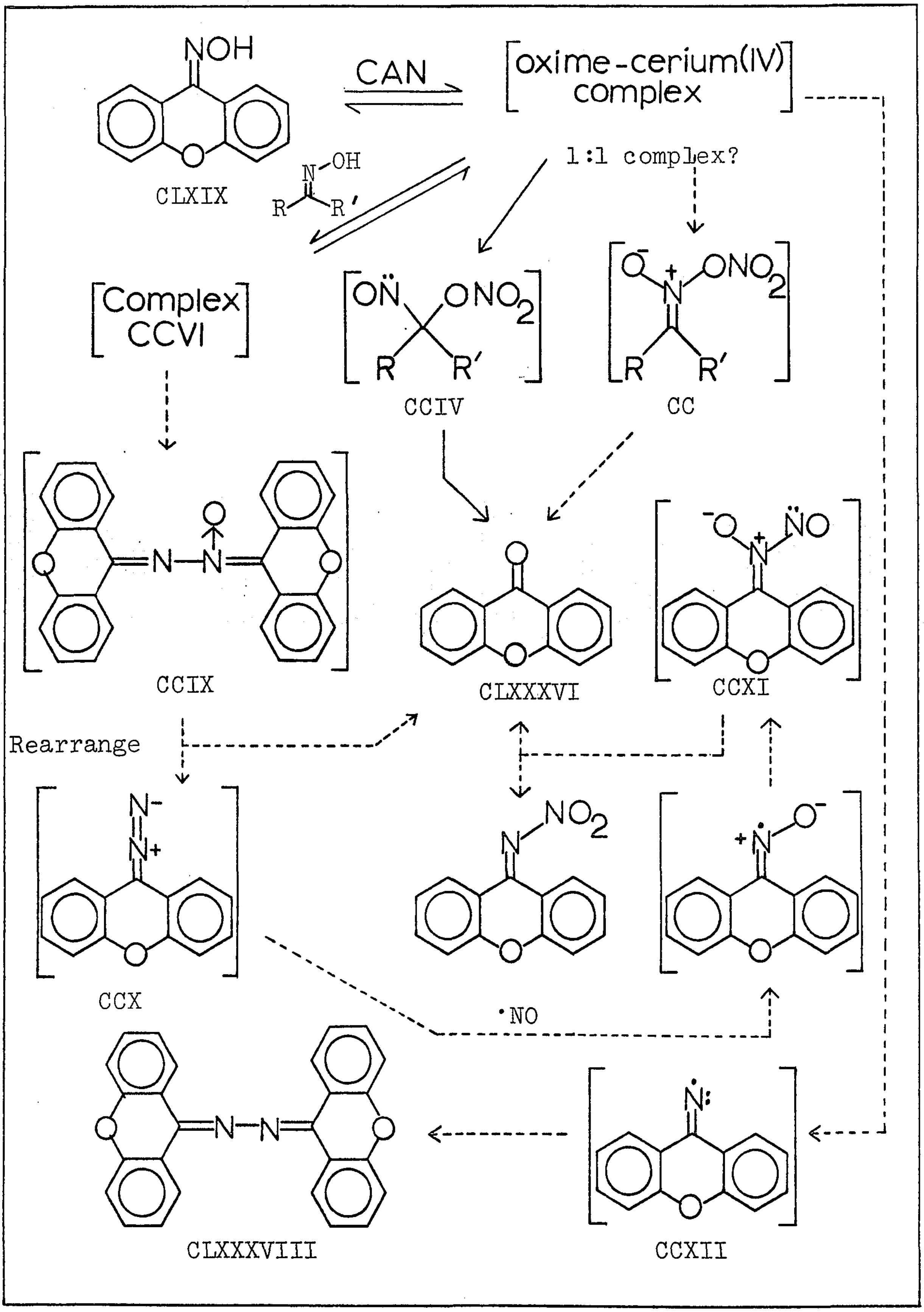
The general mechanistic scheme shown in Figure 35 summarizes some aspects of the reactions of aryl ketoximes with CAN and other cerium(IV) salts, and is at best a simplified picture for very complex reactions. The major concern in the previous discussion was to provide some rationale for the results of the CAN oxidation of those aryl ketoximes which gave geminal-dinitro compounds. It should be recalled that the CAN oxidation of anthraquinone monoxime (CLIII) gave only anthraquinone. It is probable that conversion of CLIII to anthraquinone took place by the same mechanism as did the conversion of other ketoximes to ketones. The mechanisms shown in Figure 35 for the conversion of ketoximes to ketones by CAN are as reasonable as any other for the conversion of CLIII to anthraquinone at this time. The CAN oxidation of 9-xanthenone oxime (CLXIX) gave 9-xanthenone (CLXXXVII) and small amounts of 9-nitriminoxanthene (CLXXXVI) and 9-xanthenone azine (CLXXXVIII). Oxime CLXIX was the only oxime investigated which gave a nitrimine and an azine on oxidation by CAN. It is apparent then that some aspects of a mechanism for the CAN oxidation of CLXIX must be different from a mechanism for the CAN oxidation of other aryl ketoximes.

A possible mechanism for the CAN oxidation of 9-xanthenone oxime (CLXIX) is summarized in Figure 36, page 283. The scheme shown in Figure 36 forms the basis for the following discussion. Formation of 9-xanthenone (CLXXXVII) probably occurs in part by a mechanism similar to that described for the conversion of other ketoximes to ketones (Figure 35). Means by which CLXXXVII may be formed in the CAN oxidation of CLXIX are included in Figure 36. The possibility does exist that some of the ketone is formed in different ways than were discussed previously.

One means by which 9-nitriminoxanthene (CLXXXVI) might be formed in the CAN oxidation of oxime CLXIX is shown in Figure 36. It is possible that 9-xanthenone azine monoxide (CCIX) was formed in the oxidation of CLXIX and decomposed (by rearrangement) to 9-xanthenone (CLXXXVII) and 9-diazoxanthene (CCX). Reaction of diazo compound CCX with nitric oxide (·NO) may then give nitrimine CLXXXVI and ketone CLXXXVII, by way of an intermediate CCXI. The reaction of aryl diazo compounds with ·NO has been shown to result in the formation of nitrimines and ketones (69-71) (see Figure 1, page 47, and surrounding text). Iminoxyl radicals were characterized as the reactive intermediates in the formation of nitrimines and ketones from diazo compounds by reaction with ·NO (71). Reaction between an iminoxyl radical derived from CLXIX by cerium(IV) oxidation and ·NO could also occur to give nitrimine CLXXXVI without involving the formation of azine monoxide CCIX and rearrangement of CCIX to diazo compound CCX.

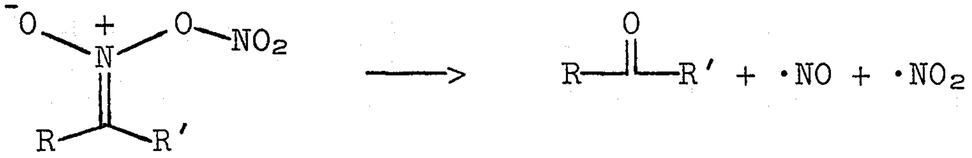
Any role that azine monoxide CCIX may have in the formation of nitrimine CLXXXVI may be determined once the azine monoxide has been prepared and its properties become known. It also remains to be shown whether or not 9-diazoxanthene

Figure 36. Possible mechanism for product formation in the CAN oxidation of 9-xanthenone oxime (CLXIX).


NOH
CAN
oxime-cerium(IV) complex
1:1 complex?
CLXIX
N-OH
R
R'
Complex CCVI
ON
ONO2
R
R'
CCIV
O
N
ONO2
R
R'
CC
CCIX
CLXXXVI
NO
CCXI
Rearrange
N-
N+
NO2
N
CCX
·NO
CLXXXVIII
CCXII

(CCX) is converted to nitrimine CLXXXVI and ketone CLXXXVII by ·NO. Evidence of the generation of ·NO in the CAN oxidation of oxime CLXIX has not been obtained, but it is reasonable to expect that some ·NO was formed. Nitrogen dioxide (·NO_2) has been detected in reaction mixtures, which could give ·NO by equilibration with O_2.

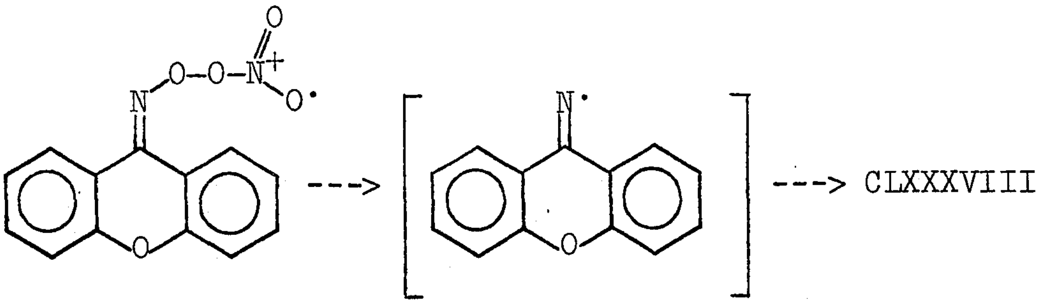
Formation of intermediate CC by transfer of nitrate from cerium(IV) to an iminoxyl radical was suggested as one way in which gem-dinitro compounds might be formed in the CAN oxidation of ketoximes. If intermediates such as CC were formed



CC

from anthraquinone monoxime and 9-xanthenone oxime, rearrangement to gem-dinitro compounds apparently did not occur. It is possible, though, that the dinitro compounds in these instances were unstable and decomposed on attempted isolation. Rearrangement of CC to the respective ketones might still occur, however, which would provide a source of ·NO for nitrimine formation (Figure 36).

One approach to the formation of 9-xanthenone azine (CLXXXVIII) in the CAN oxidation of oxime CLXIX is through the formation and dimerization of an iminium radical (CCXII). The transient existence of a species such as CCXII in a complex with cerium(IV) may be possible. The means by which CCXII might be formed from CLXIX is an open question. Precursors of radical CCXII might be formed by the oxidative transfer of a ligand such as nitrate from ceric ion to the oxygen atom of an iminoxyl radical (see CCXIII below). However, intermediates



CCXIII CCXII

in azine formation similar to CCXIII can be seriously questioned on the basis of the fact that they could be formed in reactions of other ketoximes with CAN and would be expected to lead to azine formation in those instances also. Azines were not formed in other ketoxime oxidations. The formation of azine CLXXXVIII by the generation and dimerization of radical CCXII (Figure 36) can only be suggested at this time.

The effects that solvent and the ligand accompanying cerium(IV) have on the oxidation of aryl ketoximes by cerium(IV) salts indicate that oxime-cerium(IV) complexes are involved in the ketoxime oxidations. The evidence is based on product analysis, however, and although it is probable that complexes are involved, the nature of those complexes cannot be determined. The assumption has been made in Figure 35 and in Figure 36 that a 1:1 oxime-cerium(IV) complex is initially formed in the reactions. A cerium(IV)-catalyzed dehydration mechanism for azine monoxide formation would involve a 2:1 oxime-cerium(IV) complex (Figure 35). It has also been suggested that more than one ceric ion could be present in a complex with an oxime molecule (page 266). The use of low temperatures may be necessary in order to obtain kinetic evidence for the intermediacy of complexes in the CAN reactions, since the reactions are too rapid at ambient temperatures to permit kinetic studies to be made.

A second aromatic ring in conjugation with the oxime function may be the reason for the higher yields of gem-dinitro compounds in the oxidation of diaryl ketoximes than in the oxidation of arylalkyl ketoximes. The presence of oxidizable hydrogens alpha to the oxime function in arylalkyl ketoximes could also explain why those ketoximes gave lower yields of dinitro compounds than did diaryl ketoximes. A significant portion of an arylalkyl ketoxime might be consumed by secondary oxidation at the alpha-carbon before dinitro compound could be formed.

Some evidence is available which suggests that the electronic nature of a ketoxime does influence the course of the CAN oxidation of that ketoxime. The structural feature common to anthraquinone monoxime (CLIII), 9-xanthenone oxime (CLXIX), and p-nitroacetophenone oxime (CLXIV) is an electron-withdrawing group para to the oxime function. In CLIII, the carbonyl group is held in a plane with the oxime function so that maximum interaction by resonance could occur, while in CLXIX, the oxygen atom is held in a plane with the oxime function so that maximum interaction by an inductive effect could occur. In CLXIV, the aromatic ring is not restricted to a plane with the oxime function, but resonance interaction between the p-nitro group and the oxime function is still possible. Oximes CLIII and CLXIX gave no gem-dinitro compounds when oxidized by CAN. Oxime CLXIV gave a lower yield of a gem-dinitro compound in methanol and acetone than was given by the oxidation of any ketoxime from which a gem-dinitro compound was formed. High yields of the respective ketones were formed in the oxidations of CLIII, CLXIX, and CLXIV.

It remains to be determined whether or not strongly electron-donating substituents have a significant effect on the yields of gem-dinitro compounds and ketones. If the electron-withdrawing nature of groups in the para-positions in oximes CLIII, CLXIV, and CLXIX is an accurate explanation for the results of the CAN oxidation of those ketoximes, it is reasonable to expect that electron-donating groups would facilitate the formation of gem-dinitro compounds and inhibit the formation of ketones. The oxidation of a series of substituted benzophenone oximes or substituted acetophenone oximes should provide additional information concerning electronic effects in the formation of geminal-dinitro compounds. The oxidation of a series of substituted 9-fluorenone oximes, where electronic interactions between the oxime function and substituents would be at a maximum due to the planar fluorene nucleus, should allow the determination of any electronic effects in the formation of substituted 9,9-dinitrofluorenes.

The scope of the oxidation of oximes by ceric ammonium nitrate (and ceric potassium nitrate) to form *geminal*-dinitro compounds remains to be determined. It may be found that dialkyl ketoximes give reactions with CAN which are too complex to be of any use in the preparation of *gem*-dinitro compounds. The CAN oxidation of aryl ketoximes does provide a convenient method for the preparation of a relatively unknown class of compounds. The method of preparation of the dinitro compounds may be improved once the factors influencing the formation of the compounds become better understood. The formation of ketones as major reaction products does not prohibit the use of the reaction as a synthetic tool. The ketones can again be converted to oximes and the oximes oxidized by CAN, giving a higher conversion of a ketoxime to a dinitro compound than could be obtained from one oxidation reaction.

Mass spectra of geminal-dinitro compounds

A discussion of the mass spectra of *geminal*-dinitro compounds has been deferred to this point so that the mass spectral fragmentations observed for individual *gem*-dinitro compounds could be viewed within the context of general fragmentation pathways found to be characteristic of the compounds. The mass spectra of the diaryldinitromethanes, 9,9-dinitrofluorene (LXII) and dinitrodiphenylmethane (LXIX) have been summarized in Table 15, page 291. The mass spectrum of 9-nitriminoxanthene (CLXXXVI) is also summarized in Table 15. The mass spectrum of 1,1-dinitroindane (CLXXI), and the mass spectra of the dinitroethanes, 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII) and 1,1-dinitro-1,2-diphenylethane (CLXXVI), have been summarized in Table 16, page 292. Data concerning the mass spectra of the dinitroethanes, 1,1-dinitro-1-phenylethane (LXXII), 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI), and 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) is shown in Table 17, page 293. Metastable ions which were observed in the spectra of dinitro compounds LXII, CLXXI, LXXII, and CLXXXI, and in the spectrum of nitrimine CLXXXVI, are given in Table 18, page 294 The fragmentation processes to which the metastable ions were related are given in Table 18. Only the dinitro compounds shown in Table 18 gave observable metastable ions at 70 ev. All mass spectra were recorded at 70 ev.

Fragment ions of mass lower than m/e 74 have not been included in Tables 15, 16, or 17. Ions of intensity relative to the base peak of less than 5% are not included in the Tables unless the ion is either a molecule ion, or some ion resulting from a general fragmentation mode.

The general fragmentation patterns for geminal-dinitro compounds are summarized in Figure 37. In all but one case, electron impact resulted in an observable loss of $\cdot NO_2$ from the molecule ion to give an ion $[M-46]^+$. The one exception was 1,1-dinitro-1-phenylethane (LXXII), which gave neither a molecule ion nor an ion $[M-46]^+$, although ions derived from the M-46 ion were observed. An ion of appreciable intensity at m/e 46 (NO_2^+) was observed in the mass spectra of the dinitro compounds.

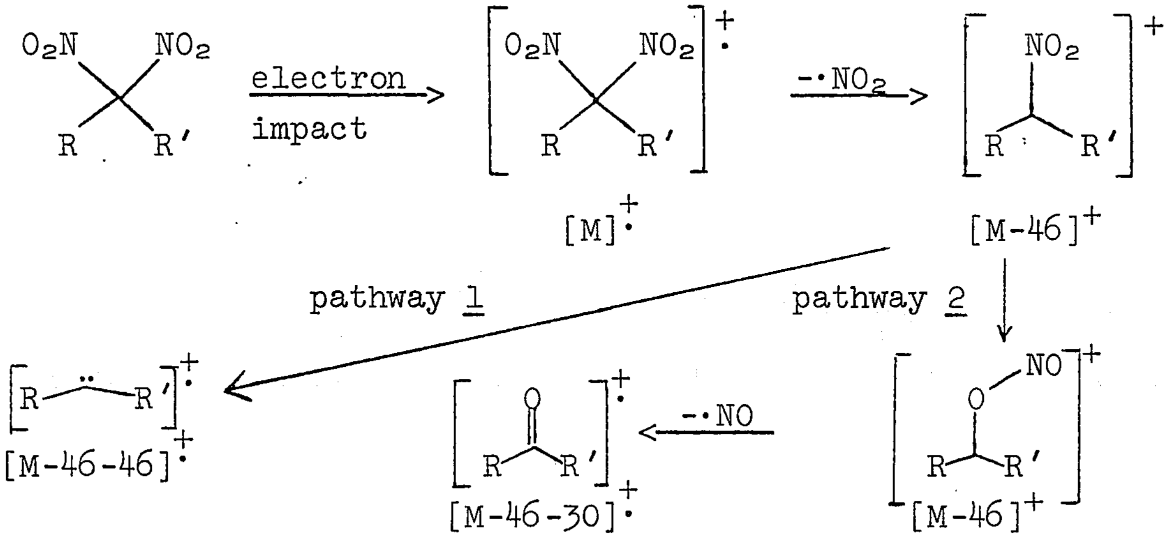


Figure 37. General mass spectral fragmentation of _geminal_-dinitro compounds.

Fragmentation of an ion $[M-46]^+$ was observed to take place in two ways. One way was through a loss of another molecule of $\cdot NO_2$ to give an ion corresponding to a carbenoid species $[M-46-46]^{+\cdot}$ (Figure 37, pathway _1_). The other way was through a nitro → nitrite rearrangement followed by loss of $\cdot NO$ to give a ketone ion $[M-46-30]^{+\cdot}$ (Figure 37, pathway _2_). Whether the ion $[M-46]^+$ fragmented by pathway _1_ or by pathway _2_ appeared to depend somewhat on the structure of the original

Table 15. Mass spectra of 9,9-dinitrofluorene (LXII), dinitrodiphenylmethane (LXIX), and 9-nitriminoxanthene (CLXXXVI)

m/e[b]	Intensity[a] LXII	 LXIX	 CLXXXVI	m/e[b]	Intensity[a] LXII	 LXIX	 CLXXXVI
259		0.04		164	15.7	8.5	
258		0.4*		163	24.9	8.7	
257	2.3	0.4		162	4.6		
256	14.2*			156		10.2	
241			3.3	154		14.9	
240			21.3*	153	3.0	9.5	
213		10.0		152	18.8	7.0	
212		66.4		151	7.1		
211	5.6			150	3.6		
210	33.5			144		11.4	
196			11.7	140			8.5
195			19.0	139		9.8	9.3
194			100.0	115		6.4	
193			8.5	106		7.9	
184		16.4		105		100.0	
182		19.1		83		19.7	
181	14.7	10.3		82.5		22.8	
180	100.0	4.1	2.4	82		31.1	
168			4.5	81.5		8.3	
167		5.6	4.2	81		11.2	
166		16.6	16.8	77		37.5	
165	4.1	74.9	1.5	76		8.1	3.2

[a] Intensity recorded as percent of the base peak (base peak = 100%). An asterisk (*) denotes the molecule ion.

[b] Spectra were recorded at 70 ev.

Table 16. Mass spectra of 1,1-dinitroindane (CLXXI), 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII), and 1,1-dinitro-1,2-diphenylethane (CLXXVI)

		Intensity[a]				Intensity[a]	
m/e[b]	CLXXI	CLXXIII	CLXXVI	m/e[b]	CLXXI	CLXXIII	CLXXVI
273			2.0	148		7.0	
272			11.1*	133	10.1		
227			8.1	132	100.0		
226			49.5	131	16.3		
209	0.04			121		18.0	
208	0.4*			120		27.9	
207	0.2			116	20.2		
196		9.9	2.6	115	59.0		
195		100.0	2.3	106			8.1
181			23.5	105	6.0		100.0
180			85.5	104	61.9		
179			64.9	103	14.1		6.0
178			61.5	102	2.6	34.9	9.7
177			22.2	93		10.4	
176			9.4	92		12.8	6.0
168			8.5	91		30.2	67.5
167		5.8	48.7	90	1.9	12.8	3.8
166			4.8	89	11.9	9.3	13.7
165		1.2	23.9	83		30.2	
163	6.4			78	11.2	8.1	
162	61.9			77	7.1	84.9	41.0
152			13.7	76	3.7	31.4	13.7
151		2.0	6.8	75	3.1	19.8	
150		19.8		74	1.9	9.9	

[a] Intensity recorded as percent of the base peak (base peak = 100%). An asterisk (*) denotes the molecule ion.

[b] Spectra were recorded at 70 ev.

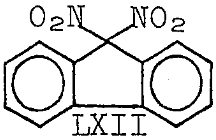
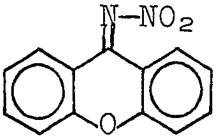
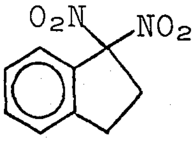
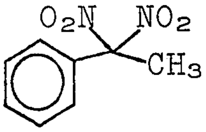
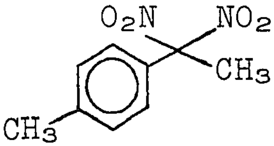
Table 17. Mass spectra of 1,1-dinitro-1-phenylethane (LXXII), 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI), and 1,1-dinitro-1-(2,4-dimethylphenyl)ethane (CLXXXIII)

		Intensity[a]				Intensity[a]	
m/e[b]	LXXII	CLXXI	CLXXXIII	m/e[b]	LXXII	CLXXXI	CLXXXIII
225			2.3	118	2.3	8.4	7.8
224			13.9*	117		36.0	37.0
210		0.8*		116		9.0	20.0
207			6.6	115		25.3	40.0
179			12.7	109			41.3
178			100.0	108		9.0	16.2
165		9.6		107		6.5	18.4
164		81.5		106			8.5
150			31.2	105	83.9		
149	0.1			104	100.0		
148	0.3			103	67.8	7.3	13.1
136		6.8		102		5.1	
134	0.8	1.1	10.8	95		68.5	17.3
133	0.8	2.2	85.4	93	4.2		23.1
132		3.0	9.2	92	2.3		
131			17.4	91	4.6	87.1	48.5
129			7.7	82		9.6	
128			9.6	81			24.6
127			5.1	79		15.2	23.9
122			10.8	78	18.3	7.9	12.3
121	3.4		42.3	77	88.5	24.2	46.2
120	40.2	9.5	4.2	76	27.6		
119	60.8	100.0	8.5				

[a] Intensity recorded as percent of the base peak (base peak = 100%). An asterisk (*) denotes the molecule ion.

[b] Spectra were recorded at 70 ev.

Table 18. Metastable ions in the mass spectra of geminal-dinitro compounds and nitrimines

Compound	Table	Fragmentation Process[a]	Metastable Ion (m/e)	Intensity[b]
 LXII	15	210 → 180 180 → 152	154.3 128.3	s m
 CLXXXVI	15	240 → 194 196 → 168 168 → 140	156.7 144.0 116.6	s s (broad) m
 CLXXI	16	162 → 132 132 → 104 115 → 89 104 → 78	107.5 82.0 68.8 58.5	vs vs s s
 LXXII	17	119 → 104 104 → 77	90.9 57.0	s vs
 CLXXXI	17	119 → 91	69.6	w

[a] The fragmentation process to which the metastable ion corresponds. Data taken from mass spectra recorded at 70 ev.

[b] Intensity expressed on an arbitrary scale: vs = very strong; s = strong; m = medium; and w = weak.

gem-dinitro compound, although fragmentation occurred by both pathways in every instance.

The mass spectra of the diaryldinitromethanes, LXII and LXIX, illustrate in part the general fragmentation summarized in Figure 37. The mass spectrum of LXII showed a molecule ion at m/e 256 (relative intensity 14.2% of the base peak), from which a loss of $\cdot NO_2$ occurred to give the ion m/e 210 (Table 15, Figure 38). The base peak was observed at m/e 180, corresponding to 9-fluorenone ion. Destruction of m/e 210 occurred in two ways. That the ion m/e 180 originated from m/e 210 by a nitro → nitrite rearrangement and loss of $\cdot NO$ (Figure 38, pathway 2) was supported by the occurrence of a strong metastable ion at m/e 154.3 (Table 18). Loss of $\cdot NO_2$ from m/e 210 also occurred (pathway 1) to give an ion m/e 164, but was less important (ion intensities are given in parentheses in Figure 38). The correspondence of m/e 180 to a ketone ion was supported by a peak at m/e 152, arising by loss of CO from m/e 180 as evidenced by a metastable ion at m/e 128.3.

The mass spectrum of dinitrodiphenylmethane (LXIX) was somewhat more complex than the mass spectrum of LXII. A molecule ion was observed at m/e 258, accompanied by an ion at m/e 257 (corresponding to a loss of hydrogen from m/e 258) (Table 15, Figure 39). Loss of $\cdot NO_2$ from m/e 258 gave an ion at m/e 212 (ion intensities shown in parentheses in Figure 39). Rearrangement of m/e 212 and loss of $\cdot NO$ (pathway 2) gave an ion

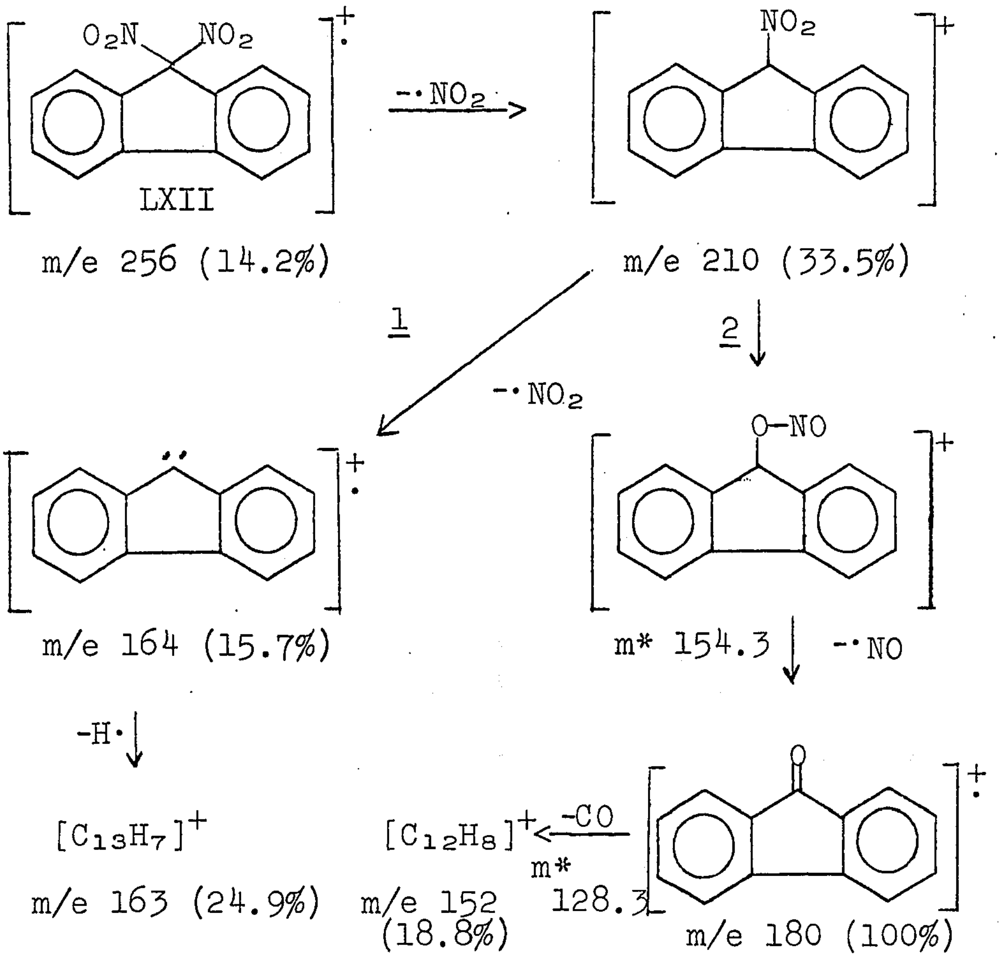


Figure 38. Mass spectral fragmentation of 9,9-dinitrofluorene (LXII).

at m/e 182, corresponding to benzophenone ion. Some loss of CO from m/e 182 apparently occurred to give m/e 154 (biphenyl radical cation). The base peak of the spectrum appeared at m/e 105, corresponding to $[C_6H_5CO]^+$.

Fragmentation of m/e 212 to give m/e 166 also occurred (Figure 39, pathway 1). An ion at m/e 165 probably arose by loss of H· from m/e 166. The origins of ions at m/e 144,

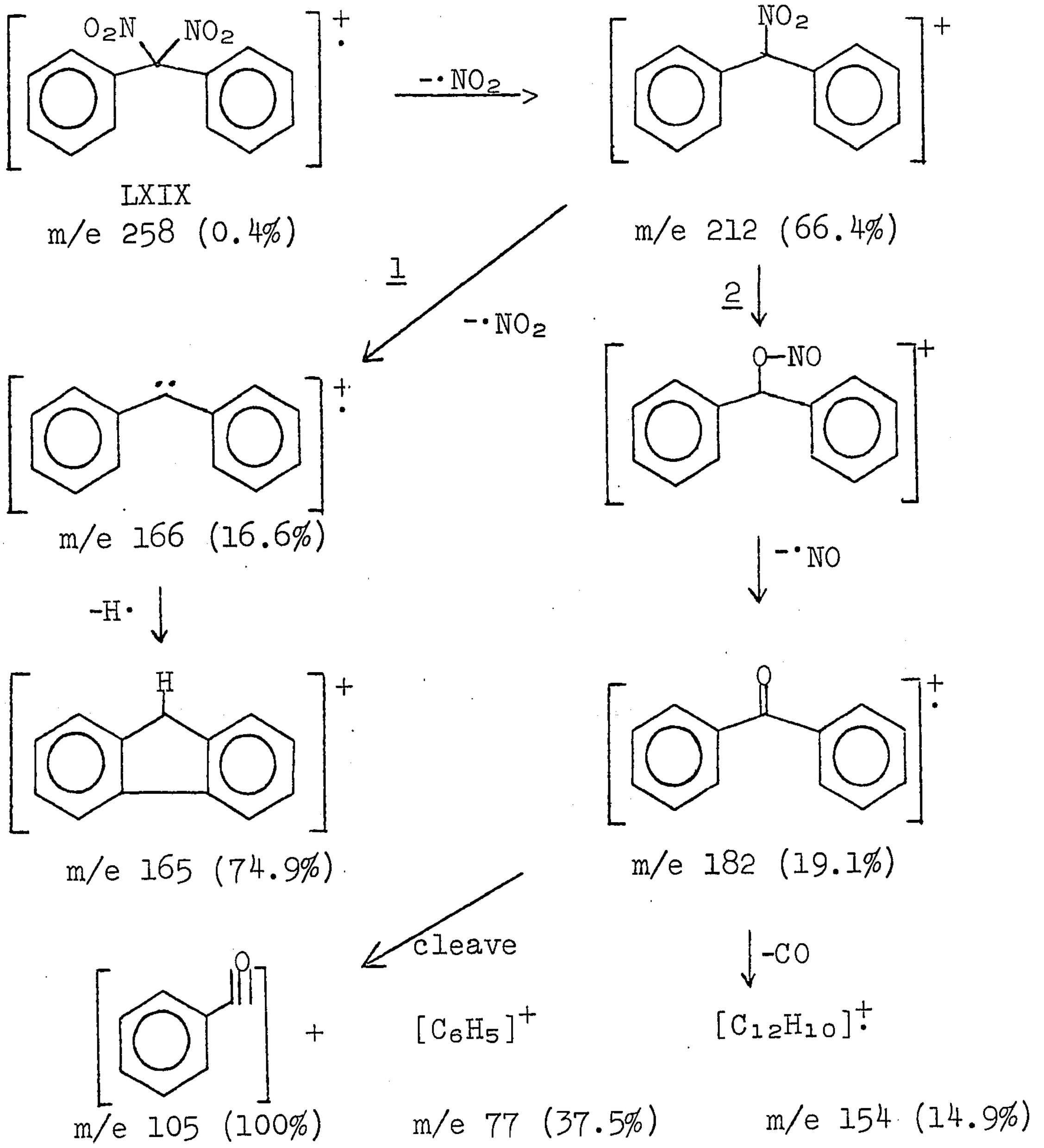


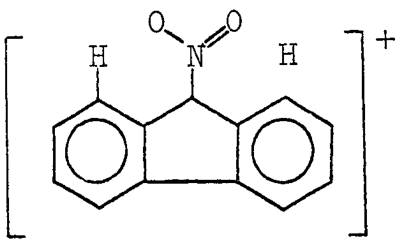
Figure 39. Mass spectral fragmentation of dinitrodiphenylmethane (LXIX).

m/e 139, and m/e 115 were not obvious, although these ions are commonly found in the mass spectra of polycyclic aromatic compounds. An ion at m/e 69.5 was observed which is also a common phenonemon, arising from m/e 139.

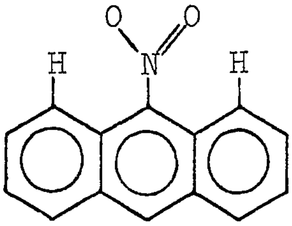
A comparison of the data summarized in Table 15 for LXII and LXIX suggests an interesting possibility concerning an effect that the structure of a gem-dinitro compound may have on its mass spectral behavior. A comparison of the sums of the relative intensities of ions arising from $[M-46]^+$ by either pathway 1 or 2 may provide at least a rough measure of the relative importance of one fragmentation pathway over the other. Only ions of m/e greater than 77 can be included in the summation, since the pathways meet at that point. The possibility that both nitro groups are lost on initial electron impact to give a carbenoid species without involving a mononitro species cannot be disregarded, however.

For 9,9-dinitrofluorene (LXII), a comparison of the sum of ion intensities for pathway 1 (49%) with the sum of ion intensities for pathway 2 (147%) suggests that pathway 2 is favored over pathway 1. For dinitrodiphenylmethane (LXIX), a similar summation indicates that fragmentations by pathway 1 (212%) and by pathway 2 (199%) occur to about the same extent (ion intensities for m/e 81 and 144 are not included in either sum; the intensities of m/e 115 and 139 are included in the sum for pathway 1). It should be noted that intensity comparisons of this type are somewhat risky and should be substantiated by studies at lower electron energies. Nevertheless, the following conclusions can at least tentatively be presented.

One feature of an ion m/e 210 (derived from 9,9-dinitrofluorene) is that the two peri-hydrogens of the fluorene nucleus may be required to be coplanar with the remaining nitro group. An interaction between the peri-hydrogens and the nitro groups could keep the plane of the nitro group out of the plane of the fluorene nucleus. Overlap between a half-vacant orbital on the carbon bearing the nitro group with an orbital on one of the oxygen atoms of the nitro group might occur as a result of the out-of-plane twisting of the nitro group. Fragmentation of m/e 210 by a nitro → nitrite rearrangement might then be favored over fragmentation by loss of $\cdot NO_2$. A similar nitro → nitrite rearrangement has been invoked to explain the mass spectral fragmentation of 9-nitroanthracene (CLII). It was proposed that the peri-hydrogens of



m/e 210



CLII

the anthracene nucleus in CLII served to keep the plane of the nitro group at almost right angles to the plane of the anthracene ring, allowing overlap of a half-vacant orbital on oxygen with an orbital on the adjacent aromatic ring (114). However, mass spectral fragmentation by a nitro → nitrite rearrangement and loss of ·NO has been found to be generally characteristic of aromatic nitro compounds (127), and does not depend solely on some structural feature as a driving force for the rearrangement. Furthermore, the mononitro species derived from a gem-dinitro compound is not an aromatic nitro compound. It differs from an ion $[M]^{+\cdot}$ derived from an aromatic nitro compound in that there is one less electron associated with it (i.e., an even-electron fragment), and fragmentation of $[M-46]^+$ by a nitro → nitrite rearrangement would not be entirely the same as the fragmentation of an aromatic nitro compound.

The mass spectrum of 9-nitriminoxanthene (CLXXXVI) is summarized in Table 15. The spectrum of CLXXXVI showed a molecule ion at m/e 240 (Table 15, Figure 40). The compound apparently fragmented in two ways. One mode of fragmentation was a loss of $\cdot NO_2$ to give an ion at m/e 194 (the base peak; Figure 40, pathway 1). Loss of $\cdot NO_2$ was supported by a strong metastable ion at m/e 156.7 (Table 18). The second mode of fragmentation for CLXXXVI (Figure 40, pathway 2) was suggested by an ion at m/e 196, corresponding to 9-xanthenone ion. The ketone ion could be formed by a rearrangement analogous to a nitro → nitrite rearrangement, where N_2O would be formed rather than ·NO. An ion at m/e 195 probably arose in part by loss of hydrogen from m/e 196. Loss of ·CN (or HCN) from m/e 194 gave m/e 168 (in part?) (or m/e 167) (Figure 40). A strong, broad metastable ion at m/e 144 suggested that the conversion m/e 196 → m/e 168 was important. Loss of CO from m/e 168 to give m/e 140 was supported by a metastable ion at m/e 116.6. Doubly-charged ions appeared at m/e 69.5, m/e 82.5, and m/e 97.5, corresponding to ions at m/e 139, m/e 165, and m/e 195, respectively.

The prominent mode of fragmentation for nitrimine CLXXXVI at 70 ev. was an initial loss of $\cdot NO_2$ (Figure 40). The interesting fragmentation mode was pathway 2, involving the apparent rearrangement $>C=N-NO_2 \rightarrow >=O + N_2O$, even though this mode was unimportant compared to the loss of $\cdot NO_2$. The lowest energy ionization of CLXXXVI would presumably involve the removal of an electron from either a non-bonding orbital on the nitro group or the nonbonding orbital (containing the unshared electron pair) on the imine nitrogen. It is assumed for the moment that removal of an electron from a nonbonding orbital on the nitro group is the lowest energy ionization. The nonbonding orbital is crudely represented as a p-atomic orbital on oxygen in the following discussion.

Some overlap of the half-vacant nonbonding orbital in m/e 240 with the adjacent C-N π-bond might occur, which could result in the formation of a species CCXIV. Collapse of CCXIV would give ketone and N_2O^+ (an ion of appreciable intensity was observed at m/e 44 in the spectrum of CLXXXVI, but does not provide definitive evidence for the rearrangement, since

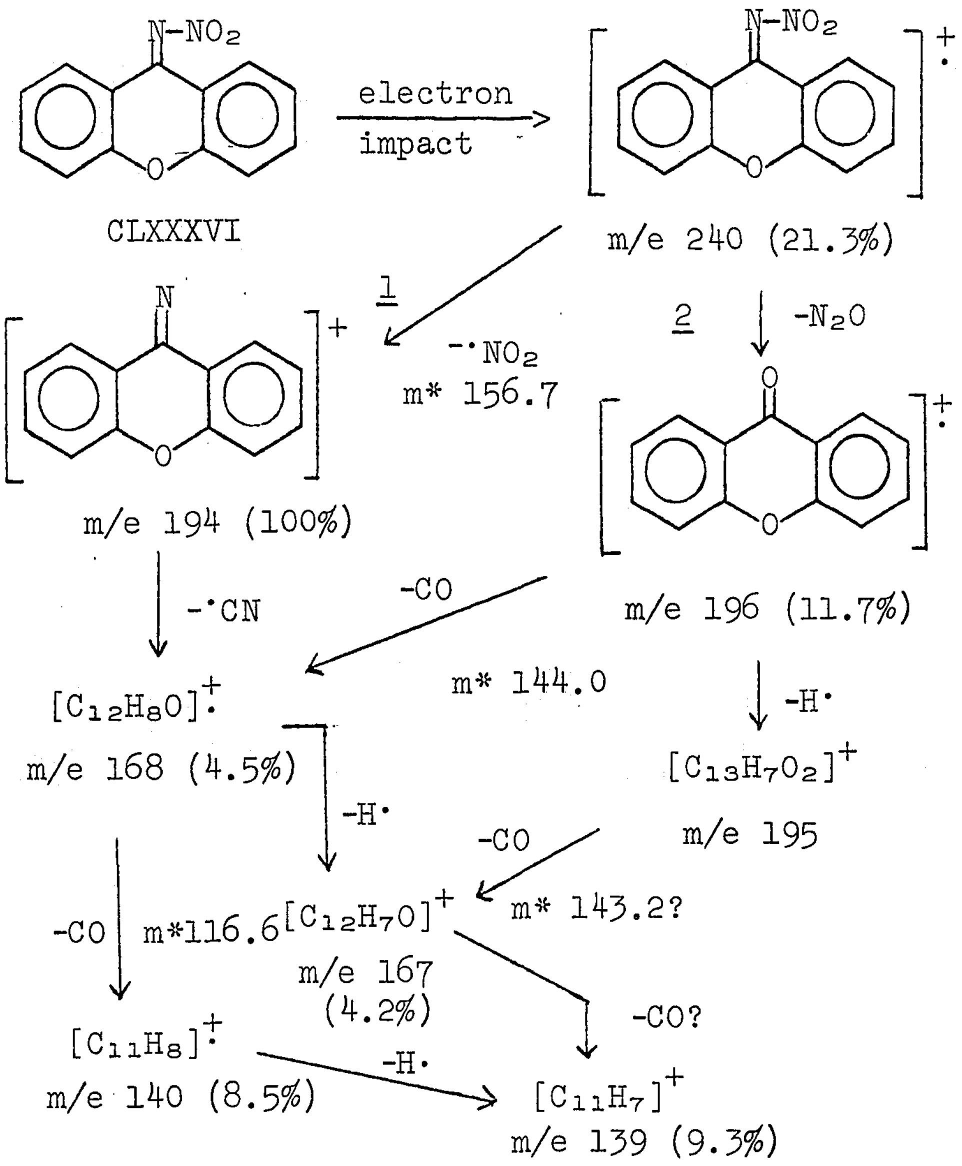
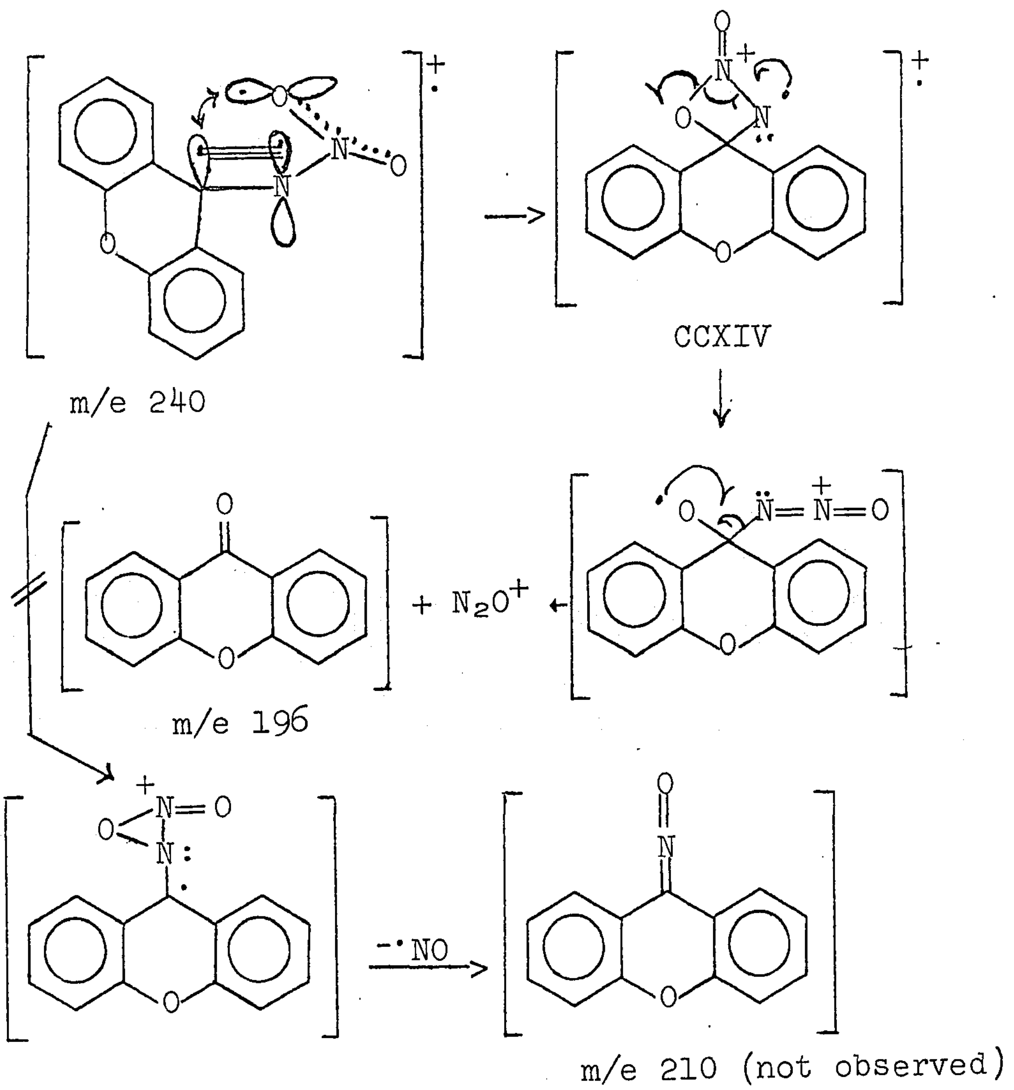


Figure 40. Mass spectral fragmentation of 9-nitrimino-xanthene (CLXXXVI).

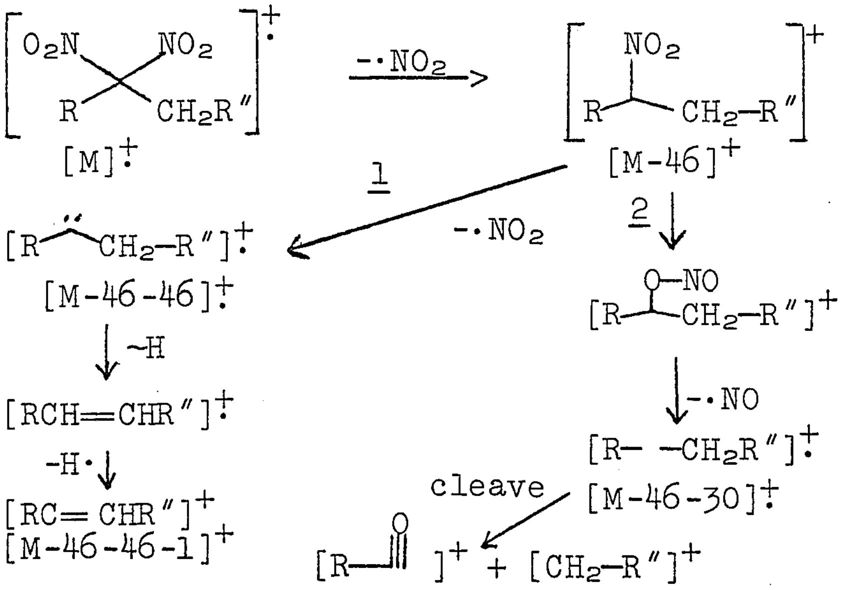
it could arise from other sources). A nitro → nitrite rearrangement, where the oxygen atom becomes bound to the imine nitrogen to form an intermediate analogous to an oxaziridine, apparently did not occur, since an ion at m/e 210 was not observed. Little is known concerning the mass spectral



fragmentation of nitrimines, and the generality of the rearrangement remains to be determined. In fact, the fragmentation scheme shown in Figure 40 should be further substantiated by low energy electron impact studies before any conclusions are drawn.

The remaining <u>geminal</u>-dinitro compounds have the feature in common of an alkyl group attached to the carbon bearing the nitro groups. The fragmentation pathways for the dinitro compounds LXII and LXIX remain important to considerations of the mass spectra of the arylalkyldinitromethanes. However, some variations in pathway 1 (loss of $\cdot NO_2$ to give a carbenoid species) and pathway 2 (nitro → nitrite rearrangement and loss of $\cdot NO$ to give a ketone ion) are necessary. The mass spectra of gem-dinitro compounds with hydrogens alpha to the carbon bearing the nitro groups were generally more complex than the spectra of the diaryldinitromethanes. A scheme similar to that shown in Figure 37 is shown on the following page. The group R′ has been replaced by the group $-CH_2-R''$ to illustrate the role of the alpha hydrogens in the fragmentation of the compounds.

The mass spectral fragmentation of 1,1-dinitroindane (CLXXI) is shown in Figure 41 to illustrate the following scheme. The spectrum of CLXXI showed a weak molecule ion at



m/e 208 (ion intensities are given in parentheses in Figure 41). Loss of $\cdot NO_2$ gave an ion at m/e 162. Degradation of m/e 162 by pathway 2 gave an ion at m/e 132 (the base peak), corresponding to the ketone ion. The conversion m/e 162 → m/e 132 was supported by a strong metastable ion at m/e 107.5 (Table 18). Loss of CO from m/e 132 to give m/e 104 was supported by a metastable ion at m/e 82.0. Loss of acetylene from m/e 104 to give m/e 78 was supported by a metastable ion at m/e 58.5. Loss of $\cdot NO_2$ from m/e 162 (Figure 41, pathway 1) gave an ion at m/e 116. Rearrangement of m/e 116 to an olefin and loss of H· gave an ion at m/e 115. Loss of acetylene from m/e 115 accounted for an ion at m/e 89.

The mass spectrum of 1,1-dinitro-1,2-diphenylethane (CLXXVI) (Table 16) showed a molecule ion at m/e 272 (11.1%). Loss of $\cdot NO_2$ from m/e 272 gave m/e 226 (49.5%). The ion m/e 226 was degraded roughly to the same extent by pathways 1 and 2. Loss of $\cdot NO_2$ from m/e 226 gave m/e 180 (85.5%), which was presumably the origin of ions at m/e 179, m/e 178, m/e 177, and m/e 176, through losses of hydrogen. Other features of the fragmentation of m/e 226 by pathway 1 are shown in Figure 42 (ion intensities are given in parentheses).

Rearrangement of m/e 226 followed by loss of ·NO gave the ketone ion m/e 196 (Figure 42, pathway 2). Cleavage of m/e 196 gave m/e 105 (the base peak) and m/e 91. The fragmentation of m/e 226 which could be assigned to pathway 2 was essentially the same as that observed in the spectrum of authentic

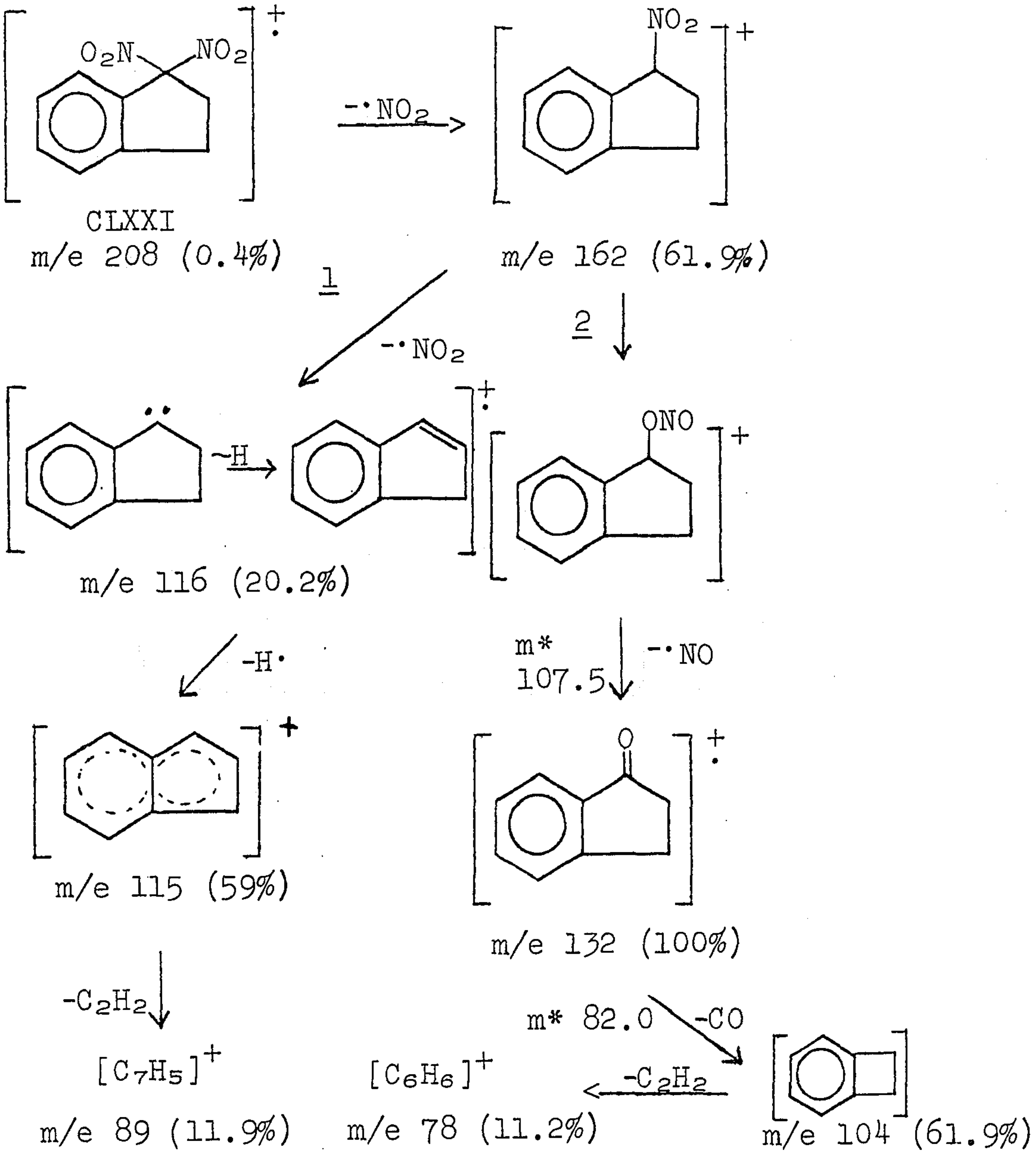


Figure 41. Mass spectral fragmentation of 1,1-dinitroindane (CLXXI).

α-phenylacetophenone, and does not require further discussion (see Figure 42).

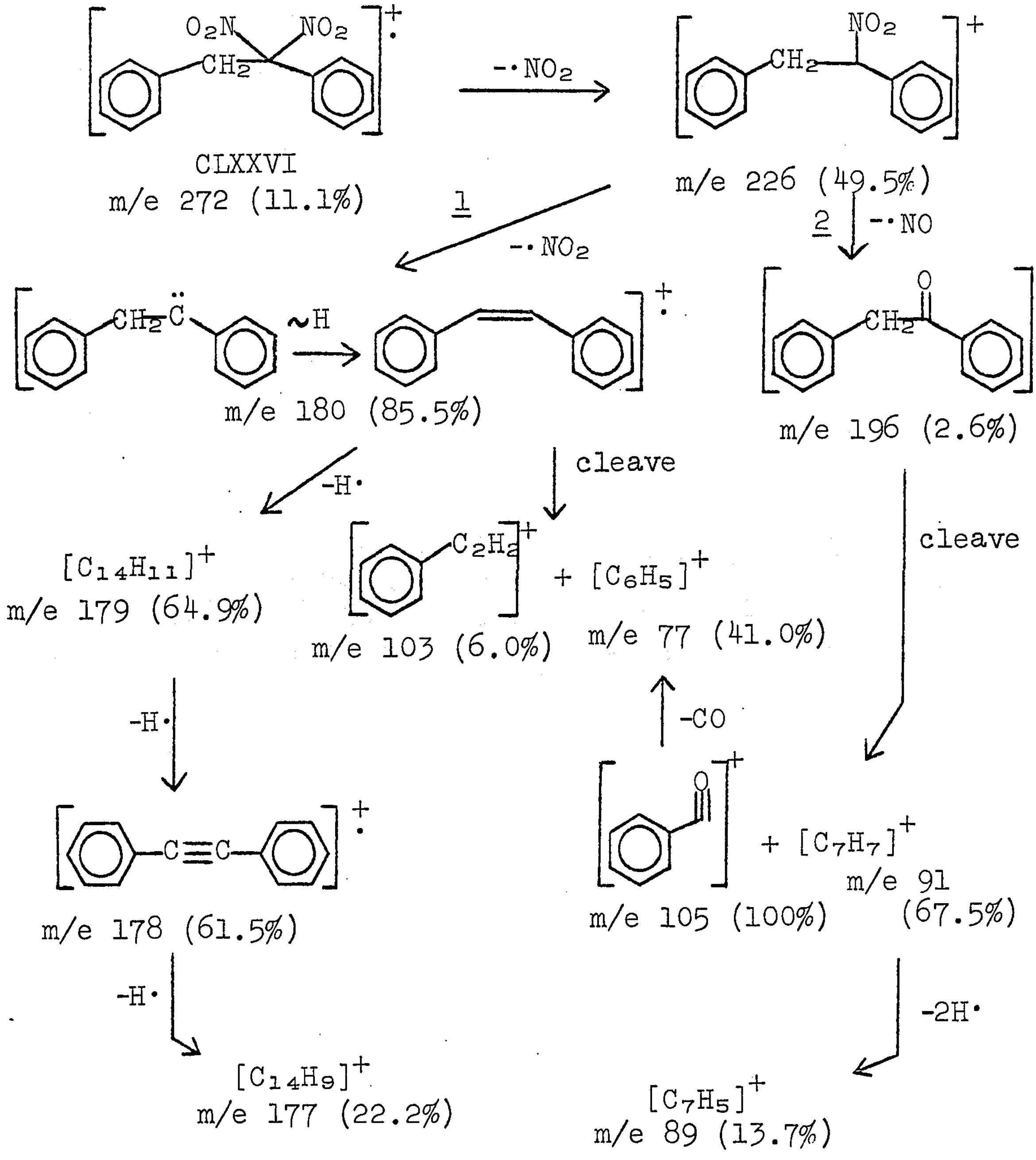


Figure 42. Mass spectral fragmentation of 1,1-dinitro-1,2-diphenylethane (CLXXVI).

A comparison of the sums of the relative intensities of ions involved in pathways 1 and 2 for 1,1-dinitroindane (CLXXI) with the sums of ion intensities for the pathways for 1,1-dinitro-1,2-diphenylethane (CLXXVI) again suggests that the structure of the *gem*-dinitro compound has an important effect on the fragmentation pathways. Fragmentation of m/e 162 (from CLXXI) by pathway 2 (total, 222%) appears to be favored over pathway 1 (93%). For m/e 226 (from CLXXVI), fragmentation by pathway 1 (total, 316%) appears to be favored somewhat over pathway 2 (total, 272%). The *peri*-hydrogen on the indane nucleus in m/e 162 could force the remaining nitro group out of a plane with the remainder of the structure and promote overlap of a half-vacant orbital on the nitro group with a half-vacant orbital on carbon. Rearrangement of m/e 162 might then be favored over loss of $\cdot NO_2$. As before, however, this explanation for the predominance of pathway 2 over pathway 1 in the fragmentation of $[M-46]^+$ in some instances can only be suggested at this time.

The mass spectra of 1,1-dinitro-1-(*p*-nitrophenyl)-ethane (CLXXIII) (Table 16) and 1,1-dinitro-1-phenylethane (LXXII) (Table 17) failed to show molecule ions even at low electron energies. However, the fragmentation patterns observed for CLXXIII and LXXII were consistent with the general pathways described previously. It is sufficient to simply point out the prominent features of the spectra of these compounds without including detailed schemes.

The base peak of the spectrum of CLXXIII was observed at m/e 195, which corresponds to the species $[M-46]^+$. An ion at m/e 165 (1.2%) arose by rearrangement of m/e 195 and loss of $\cdot NO$, and corresponds to the ketone ion (pathway 2). Loss of $\cdot CH_3$ from m/e 165 gave m/e 150 (19.8%) (a benzoyl ion). Loss of $\cdot NO$ from m/e 150 via another nitro → nitrite rearrangement gave m/e 120 (27.9%). Degradation of m/e 195 by loss of $\cdot NO_2$ to give m/e 149 apparently occurred, although the intensity of m/e 149 was very low. Loss of hydrogen from m/e 149 gave m/e 148 (7.0%). Loss of C_2H_3 from m/e 148 gave m/e 121 (18.0%). Loss of $\cdot NO_2$ from m/e 148 provides a means by which m/e 102 (34.9%) could be formed. Rearrangement of m/e 121 and loss of $\cdot NO$ gave (in part) m/e 91 (30.2%).

In addition to not showing a molecule ion, the spectrum of LXXII did not show an ion arising by loss of $\cdot NO_2$ from the molecule ion. Weak ions at m/e 149 (0.1%) and m/e 148 (0.3%) were observed, however. Aliphatic nitro compounds tend to lose HNO_2 in the mass spectrometer (128), which may have been occurring to some extent in the fragmentation of LXXII. An ion at m/e 120 (60.8%) indicated that formation of $[M-46]^+$ (m/e 150, not observed) and rearrangement followed by loss of $\cdot NO$ was occurring. An ion at m/e 119 (40.2%) would arise by loss of $\cdot NO$ from m/e 149. Loss of $\cdot CH_3$ from m/e 120 gave m/e 105 (in part, 83.9%). Loss of $\cdot NO_2$ from m/e 150 gave m/e 104 (the base peak), which indicated that fragmentation by pathway 1 was occurring. Loss of $\cdot C_2H_3$ from m/e 104 to give m/e

77 (88.5%) was supported by a metastable ion at m/e 57.0 (Table 18).

A unique feature of the mass spectrum of CLXXIII was that the $[M-46]^+$ ion was the base peak. The apparent stability of $[M-46]^+$ derived from CLXXIII at 70 ev. may be related to the presence of the nitro group on the aromatic ring, which could stabilize the ion by delocalization of the electron remaining on the α-carbon. However, the base peak of the spectrum of 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) was also observed to correspond to $[M-46]^+$ at 70 ev. Substituent effects by electronic interaction with the α-carbon were not the only factors affecting the degradation of $[M-46]^+$.

The mass spectra of 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI) and 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) are summarized in Table 17. Fragmentation of CLXXXI follows the general pathways with little variation. Fragmentation of CLXXXIII is also consistent with the general pattern. However, the spectra of CLXXXI and CLXXXIII are complicated by the presence of the methyl groups on the aromatic rings, which introduce the possibility for tropylium ion intervention in the general fragmentation schemes, and which could have assorted other effects on the fragmentation of the compounds. Several ions do in fact appear in the spectrum of CLXXXIII, which do not fit into the general scheme described for the fragmentation of arylalkyldinitromethanes (page 304). A comparison of the data in Table 17 with the scheme on page 304 should show that, for the most part, CLXXXI and CLXXXIII do fragment according to the general pattern.

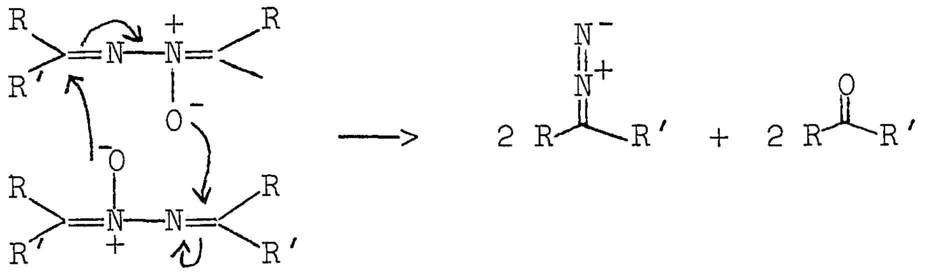
Structural factors may be responsible for the enhancement of the fragmentation of a species $[M-46]^+$ derived from some dinitro compounds by a nitro → nitrite rearrangement and loss of ·NO to give a ketone ion (pathway 2), at the expense of a second loss of $\cdot NO_2$ (pathway 1). It is apparent that if structure does influence the fragmentation, the effect is only one way of making an important mode become more important. Complete studies of the mass spectral fragmentation of gem-dinitro compounds have not been made. The data described here was obtained in studies aimed at the determination of the gross structures of the compounds, and represents only preliminary observations in this area.

Mass spectra of azine monoxides

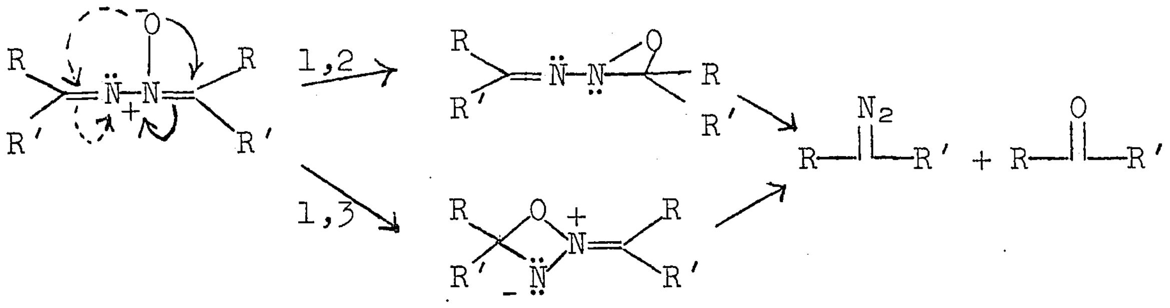
Only a limited investigation of the mass spectral behavior of azine monoxides was conducted. Those studies were oriented toward determination of the gross structural features of the compounds isolated from oxidation reactions of oximes with ceric ammonium nitrate. The mass spectra of 9-fluorenone azine monoxide (CLXII), benzophenone azine monoxide (LXXVIII), and p-nitroacetophenone azine monoxide (CLXXV) are summarized in Table 19, page 315. The mass spectra were measured at 70 ev.

It has been proposed that the chemical behavior of azine monoxides is determined by an intermolecular oxygen shift between two molecules of azine monoxide, forming two molecules of diazo compound and two molecules of ketone (116). The compounds are unstable thermally (with the exception of 9-fluorenone azine monoxide) and decompose on heating to form diazo compounds and ketones. Limited photochemical studies have been performed on azine monoxides. The only product reported from the photolysis of benzophenone azine monoxide (LXXVIII) in benzene was the ketone, benzophenone (116).

The question of the manner in which azine monoxides rearrange to carbonyl compounds and diazo compounds remains open. Three possible rearrangements may occur. An intermolecular shift of an oxygen atom between two molecules of azine monoxide is the first possibility (116). Rearrangement of the compounds in this manner (below) could occur both photochemically and thermally. The remaining possibilities are intramolecular



oxygen shifts, where the oxygen atom of an azine monoxide remains attached to a portion of the molecule at all times during the rearrangement. An intramolecular oxygen shift may occur either as a 1,3-shift (dotted arrow, next page) or as a 1,2-shift (solid arrow, next page). A 1,2-shift involves a



three-member ring intermediate, while a 1,3-shift involves a four-member ring intermediate. Ketone and diazo compound would be formed in either case. The mass spectra of azine monoxides are of interest in connection with the rearrangements described above.

A general fragmentation observed in the mass spectra of azine monoxides CLXII, LXXVIII, and CLXXV is summarized in Figure 43, page 314. Rearrangement of azine monoxide molecular ions to ketone ions and charged diazo compounds is an important process by which these compounds decompose in the mass spectrometer (Figure 43). At the low pressures used in mass spectrometry it is probable that the rearrangement does not involve an intermolecular oxygen shift between two molecules of azine monoxide. The likely mechanism for the rearrangement is an intramolecular oxygen shift. Whether the oxygen shift is 1,2 or 1,3 cannot be determined at this time.

Electron impact gives a molecule ion which undergoes rearrangement to a diazo ion ($[M\text{-}K]^{+\cdot}$) and a ketone ion ($[M\text{-}D]^{+\cdot}$) (Figure 43). The lower line of the general scheme in Figure

43 summarizes the fragmentation of $[M-K]^{+\cdot}$ and $[M-D]^{+\cdot}$ which characterized the ions.

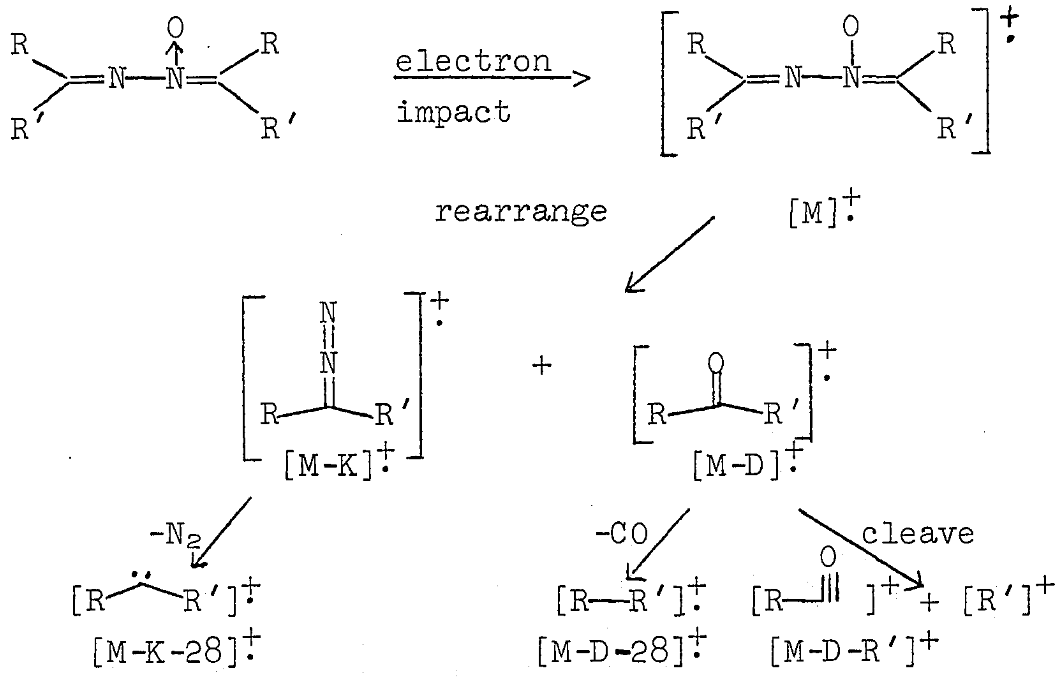


Figure 43. General mass spectral fragmentation of azine monoxides.

The mass spectrum of 9-fluorenone azine monoxide (CLXII) (Table 19 and Figure 44) showed a molecule ion at m/e 372 (ion intensities shown in parentheses in Figure 44). The base peak was observed at m/e 180, corresponding to fluorenone ion, which indicated that rearrangement had taken place. An ion at m/e 192 was also present in the spectrum, corresponding to diazofluorene ion. Loss of N_2 from m/e 192 gave m/e 164. Loss of CO from m/e 180 gave m/e 152, as evidenced by a metastable ion at m/e 128.3. A significant amount of CLXII was degraded by loss of oxygen (0), as evidenced by an ion at m/e

Table 19. Mass spectra of azine monoxides

		Intensity[a]				Intensity[a]	
m/e[b]	CLXII[c]	LXXVIII[d]	CLXXV[e]	m/e[b]	CLXXII[c]	LXXVIII[d]	CLXXV[e]
376		1.0*		164	50.2	7.3	59.1
372	12.6*			163	13.8	5.9	25.3
361		0.5		153	5.5	1.8	
360		1.6		152	31.8	3.9	
357	6.0			151	25.9	1.8	9.1
356	17.5			150	14.5	1.9	100.0
355	12.8			149			57.1
342	2.0		1.2*	133			4.6
341	3.6			126	6.4		
326	6.0		1.6	120			7.1
325	8.0			119			12.0
324	6.2			118			6.5
284		0.4		117			24.0
283		1.8		106		8.4	
257		0.5		105		100.0	
194		7.8		104			32.4
192	2.9						
183		7.8		103			48.1
182		51.2		102			12.3
181	14.2	10.0	3.0	92			12.3
180	100.0		27.6	91			18.8
179	61.6		3.0	90	4.2		5.8
178	16.6	1.7		89	3.6		7.1
177	11.9		9.1	77	3.1	53.7	48.1
166	5.2	38.0	3.9	76	29.6		46.1
165	8.8	54.6	39.2	75	10.2		20.8

[a] Intensity recorded as percent of the base peak (base peak = 100%). An asterisk (*) denotes the molecule ion. [b] Spectra were recorded at 70 ev. [c] CLXII = 9-fluorenone azine monoxide. [d] LXXVIII = benzophenone azine monoxide. [e] CLXXV = p-nitroacetophenone azine monoxide.

356. Loss of ·OH from m/e 372 and/or loss of H· from m/e 356 yielded the ion m/e 355. The ion m/e 356 corresponds to 9-fluorenone azine, which cleaves to give an ion m/e 178.

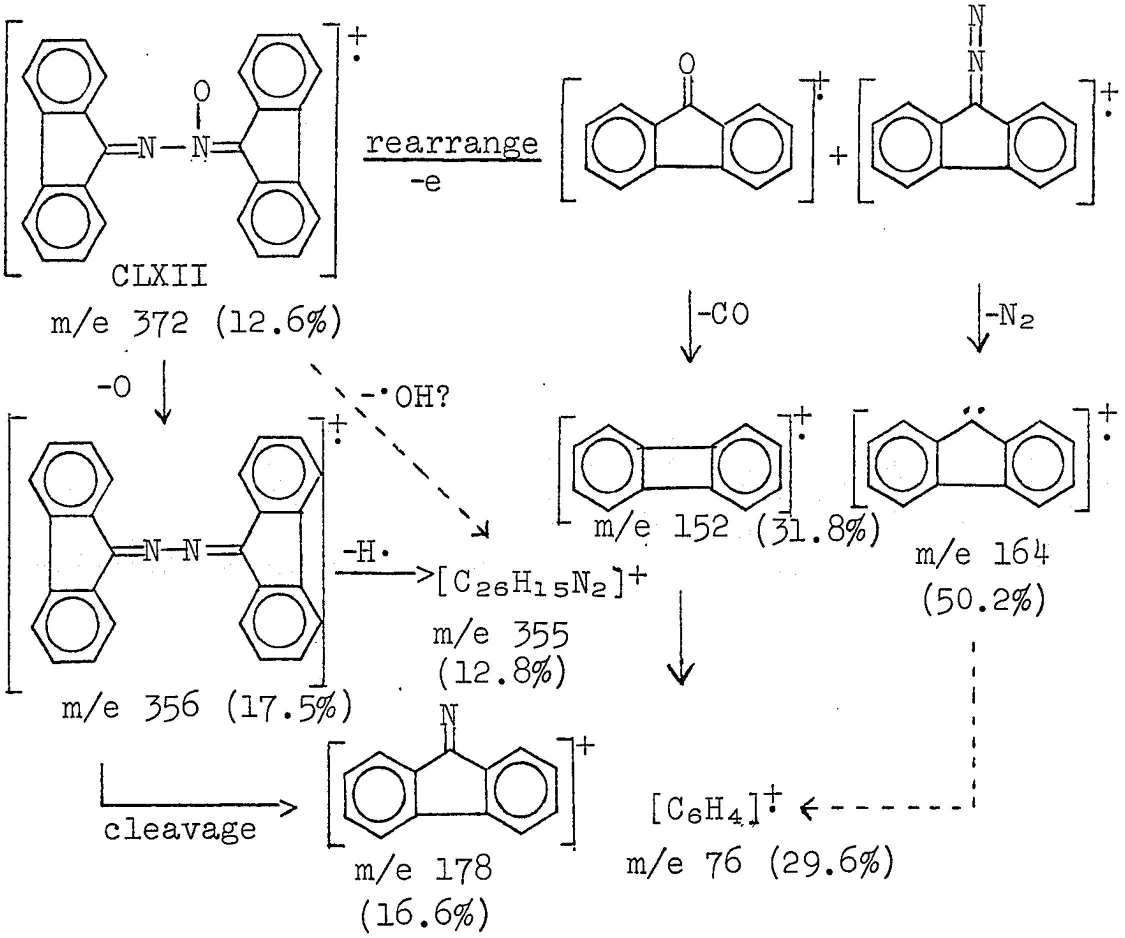


Figure 44. Mass spectral fragmentation of 9-fluorenone azine monoxide (CLXII).

The mass spectrum of benzophenone azine monoxide (LXXVIII) indicated that the molecule ion (m/e 376) fragmented almost entirely by rearrangement to m/e 182 (benzophenone ion) and m/e 194 (diazodiphenylmethane ion) (Figure 45). Loss of N_2 from m/e 194 gave an ion at m/e 166, from which would be derived the ion m/e 165 by loss of hydrogen. Loss of CO from m/e 182 would give an ion at m/e 154 (very weak). Cleavage of m/e 182 would give m/e 105 (the base peak of the spectrum) and m/e 77. Loss of CO from m/e 105 would also give m/e 77. A small amount of LXXVIII was degraded by loss of oxygen (O) to give an ion at m/e 360 (Figure 45), corresponding to benzophenone azine ion. Loss of C_6H_5 from m/e 360 would give m/e 283. Loss of ·CN from m/e 283 would give m/e 257. Loss of N_2 from m/e 360 would account for an ion at m/e 332 (not included in Table 19; see Figure 45), which would correspond to tetraphenylethylene. The assignment of m/e 360 to benzophenone azine ion was supported by the mass spectrum of the authentic azine, which showed exactly the same mass spectral ions.

The mass spectrum of p-nitroacetophenone azine monoxide (CLXXV) showed a molecule ion at m/e 342 (1.2%). Again the major fragmentation observed was the rearrangement of m/e 342 to give ketone ion (m/e 165, 39.2%) and charged diazo compound (m/e 177, 9.1%). Loss of $\cdot CH_3$ from m/e 165 gave a benzoyl ion at m/e 150, which was the base peak of the spectrum. A nitro → nitrite rearrangement and loss of ·NO from m/e 150 gave m/e 120 (7.1%). Loss of $\cdot NO_2$ from m/e 165 could give m/e 119 (12% of

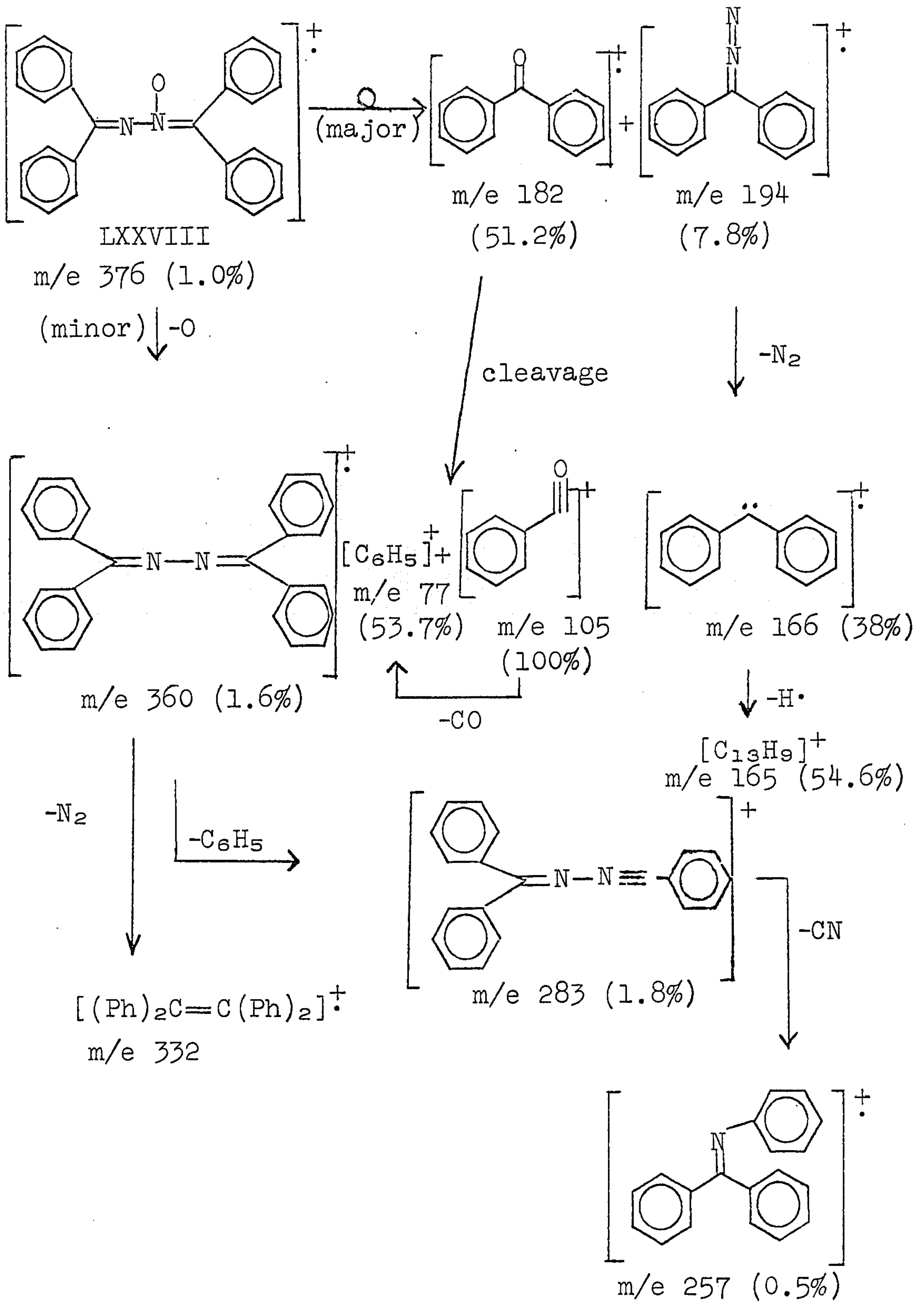


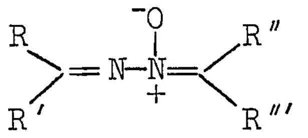
Figure 45. Mass spectral fragmentation of benzophenone azine monoxide (LXXVIII).

the base peak). Loss of $\cdot CH_3$ from m/e 119 gave an ion at m/e 104 (32.4%). Loss of CO from m/e 120 gave m/e 92 (12.3%). Fragmentation of the diazo species m/e 177 by loss of N_2 would give m/e 149 (57.1%), which could rearrange to a vinylnitrobenzene. Loss of ·NO (via a nitro → nitrite rearrangement) from m/e 149 could give a new ion m/e 119 (not the same as m/e 119 generated by degradation of m/e 165). Loss of $\cdot NO_2$ from m/e 149 would give m/e 103 (48.1%).

Fragmentation of CLXXV by cleavage of the N-N bond could be the source of ions at m/e 163 (25.3%) and m/e 164 (59.1%), although those ions could arise from m/e 165 by losses of hydrogen (Table 19). An ion at m/e 179 (3.0%) also suggested that cleavage of the N-N bond was occurring. The spectrum of CLXXV was further complicated by a small but finite loss of oxygen (O) from m/e 342 to give m/e 326 (1.6%) (p-nitroacetophenone azine ion).

The generality of the rearrangement of azine monoxide molecule ions to ketone ions and charged diazo compounds has been established to some extent by the data. Whether or not the mass spectral rearrangement is characteristic of all azine monoxides remains to be determined. Fragmentation by initial loss of oxygen (O) from the molecule ion has also been observed, although this mode is unimportant by comparison to the rearrangement process. Mass spectral fragmentation of azine monoxides by loss of oxygen (O) (and OH) is not unreasonable. Nitrones have been observed to lose oxygen (and OH) following electron impact ionization,[1] and nitrones are at least structurally similar to azine monoxides (i.e., the group RR′NO is present in both). A mass spectral loss of oxygen (and OH) has also been observed with sulfoxides, aromatic amine oxides, and azoxy compounds (129). Some cleavage of the N-N bond in azine monoxides is suggested by the data, but the evidence is not definitive.

The information which might be gained through observation of the mass spectra of azine monoxides where the groups R, R′, R″, and R‴ are different may make it possible to determine whether azine monoxide molecular ions are converted to ketone ions and charged diazo compound by an intramolecular oxygen shift involving a three-membered transition state or a four-membered transition state. Similarly, it may be possible to determine the nature of the photochemical and thermal rearrangements of azine monoxides (whether intermolecular or intramolecular) through studies on compounds containing four different R groups.



$R \neq R' \neq R'' \neq R'''$

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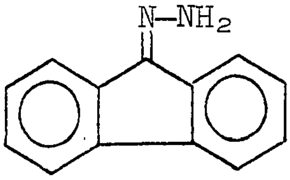
[1] T. H. Kinstle and J. Stam. Department of Chemistry, Iowa State University of Science and Technology, Ames, Iowa. Mass spectra of nitrones. Unpublished observations. 1967.

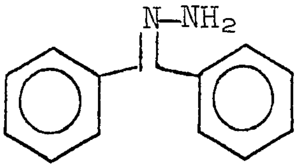
Oxidation of Hydrazones by Ceric Ammonium Nitrate

Preliminary studies on the oxidation of hydrazones by ceric ammonium nitrate (CAN) have been performed. The oxidation of 9-fluorenone hydrazone (CXVII) and benzophenone hydrazone (CXIX) by CAN in ethanol were performed at room temperature (24-26°C). The respective azines, 9-fluorenone azine (CXVIII) and benzophenone azine (CXX), were the major reaction products. Product mixtures were generally separated by column chromatography on silica gel. The procedure used for the chromatographic separations was essentially the same as that employed for the separation of product mixtures in the oxidation of aryl ketoximes by ceric ammonium nitrate.

Ethanol was employed as the solvent for the oxidation reactions since the hydrazones CXVII and CXIX exhibited somewhat greater solubility in ethanol than in methanol. Ceric ammonium nitrate was not as soluble in ethanol as it was in methanol but the lower solubility of the salt in ethanol presented no great difficulty. Solutions of CAN in ethanol were prepared immediately before using in order to minimize loss of cerium(IV) by reaction with the solvent. Hydrazones CXVII and CXIX were prepared by standard methods from the respective



CXVII



CXIX

ketones and hydrazine hydrate ($NH_2NH_2 \cdot H_2O$), and had satisfactory melting points and spectroscopic properties. The ceric ammonium nitrate employed as the oxidant was Fischer Scientific Reagent grade (99.7% minimum CAN).

Reactions and products

The results of the oxidation of 9-fluorenone hydrazone (CXVII) and benzophenone hydrazone (CXIX) by ceric ammonium nitrate are summarized in Table 20, page 323. Products of the oxidation reactions were generally azines and ketones. All reactions were conducted by treating a solution of the hydrazone in ethanol with a solution of CAN in ethanol with rapid stirring. The only major variation in the conditions used for the reactions was made in the rate of addition of the CAN solution to the hydrazone solution. The addition rate employed for a given reaction is shown in Table 20 also. The effects of temperature, water, and other agents on the reactions remain to be investigated. One equivalent of CAN per equivalent of hydrazone to be oxidized was used in all instances. The stoichiometry of the reaction was not determined.

Oxidation of 9-fluorenone hydrazone (CXVII) with one equivalent of ceric ammonium nitrate in absolute ethanol employing a dropwise addition (over 10 minutes) of the CAN reagent gave 9-fluorenone azine (CXVIII), 9-fluorenone (LXIII), and 9,9′-bifluorene (CCXV) in yields of 60.7%, 18.8%, and 3.9%, respectively (Table 20). Some gas evolution was noted

Table 20. Oxidation of hydrazones by ceric ammonium nitrate in ethanol

Hydrazone	Addition Rate[b]	YIELDS (%)[a] Azine[c]	Ketone[d]	Other
9-Fluorenone (CXVII)	10 min.	60.7	18.8	3.9[e]
	rapid	70.1	12.0	4.0[e]
Benzophenone (CXIX)	rapid	56.8	6.7	
	rapid	59.3	26[f]	

[a] Yields based on recovered starting material.

[b] Rate of addition of CAN solution to the hydrazone solution.

[c] Yield of the symmetrical azine, based on one-half of the hydrazone which reacted.

[d] Ketone = 9-fluorenone or benzophenone.

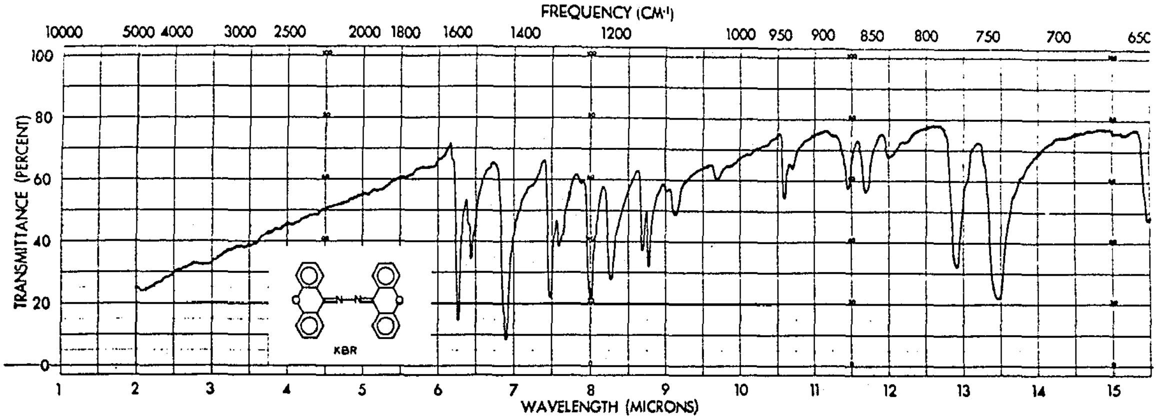
[e] Yield of 9,9′-bifluorene (CCXV).

[f] Based on an oil with satisfactory spectral properties.

as each drop of CAN reagent was added to the hydrazone solution. Shortly after the addition of CAN was begun, a red-orange precipitate began to form which became heavier as the reagent was added. Filtration of the red-orange slurry after 15 hours stirring gave 9-fluorenone azine (CXVIII). Nearly all of the azine isolated from the product mixture was obtained in the initial filtration step, with very little of the compound remaining in the solution. Oxidation of CXVII by CAN in absolute ethanol employing a rapid addition (one portion) of the CAN reagent gave azine CXVIII, ketone LXIII, and dimer CCXV in yields of 70.1%, 12%, and 4%, respectively (Table 20). The addition of the CAN reagent was made with rapid stirring. Vigorous gas evolution commenced immediately. In about 30 seconds, a red precipitate began to form from the red-orange solution. Filtration of the solution after 15 hours again gave nearly all of the azine CXVIII which was obtained from the reaction. None of the hydrazone CXVII was recovered from the oxidations.

Oxidation of benzophenone hydrazone (CXIX) by one equivalent of CAN in ethanol employing a rapid addition of the CAN solution gave benzophenone azine (CXX) and benzophenone (CLIX) in yields of 56.8% and 6.7%, respectively (Table 20). The reaction mixture was rapidly stirred during the addition of the reagent. Vigorous gas evolution was observed immediately upon mixing solutions of the reagents. A green color was noted in the solution at the point where the CAN solution initially contacted the hydrazone solution. The azine CXX did not precipitate from the solution on formation. The oxidation of CXIX was repeated using twice the scale of reagents that was used in the above reaction. The CAN solution was again added in one portion to the hydrazone solution. Azine CXX and ketone CLIX were obtained from the product mixture, in yields of 59.3% and 26% (crude), respectively (Table 20). In addition, a small amount of a solid was isolated from some later chromatography fractions which was only partially characterized. None of the hydrazone CXIX was recovered from the oxidations.

Figure 46. Infrared spectra.
Top: 9-Xanthenone azine (CLXXXVIII).
Middle: 9-Fluorenone azine (XCVIII).
Bottom: Benzophenone azine (CXX).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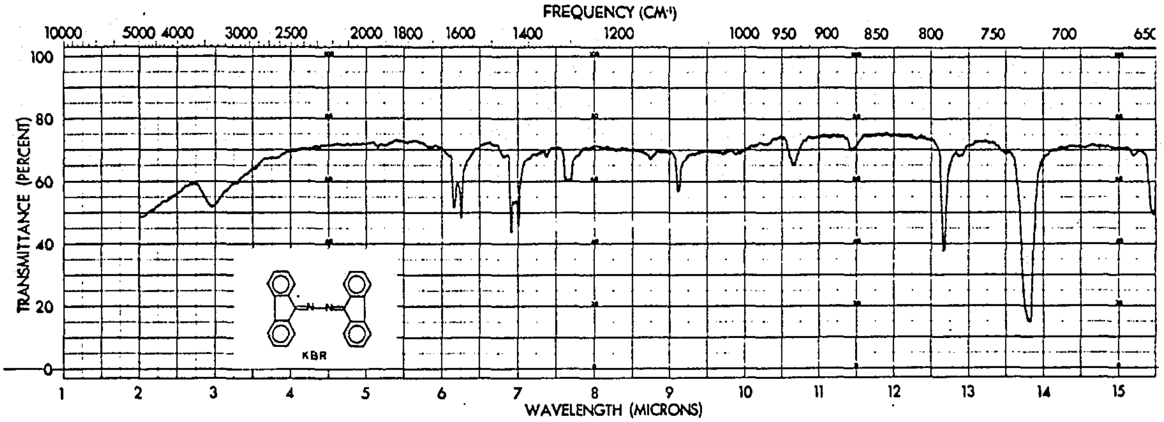
KBR
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)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KBR
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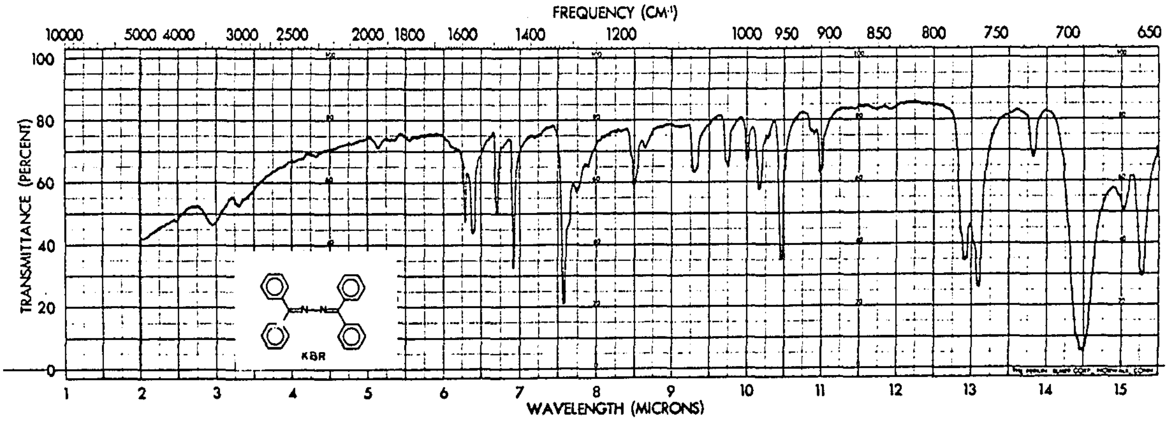
WAVELENGTH (MICRONS)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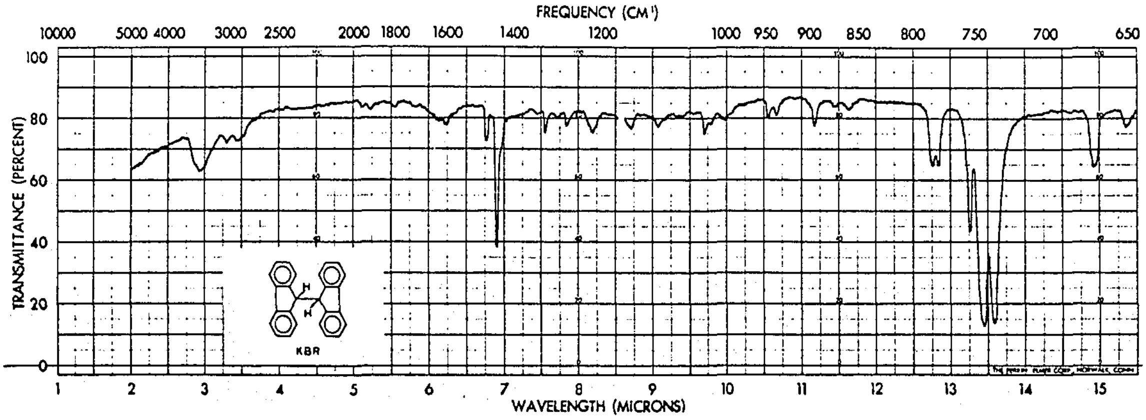
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
KBR
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)

Figure 47. Infrared spectra.
Top: 9,9′-Bifluorene (CCXV).
Bottom: Unknown F.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3000
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2000
1800
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
H
H
KBR
1
2
3
4
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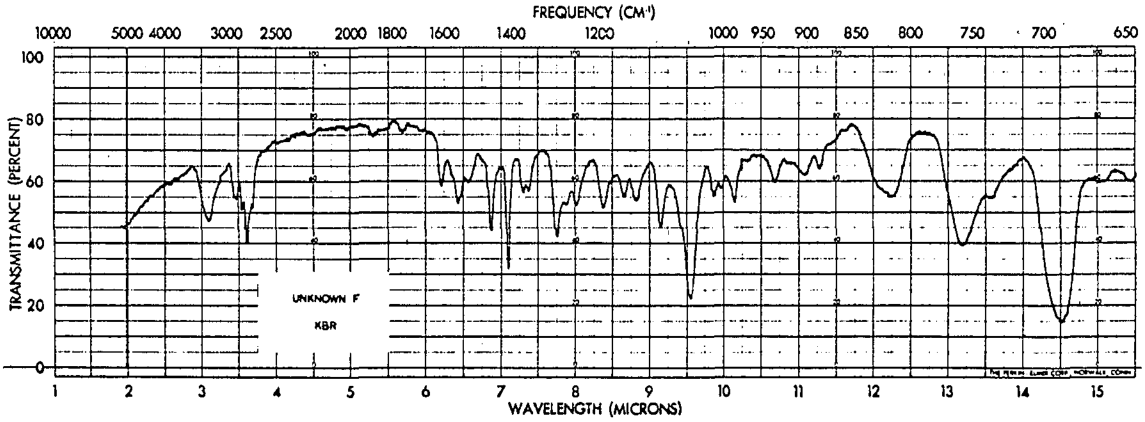
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)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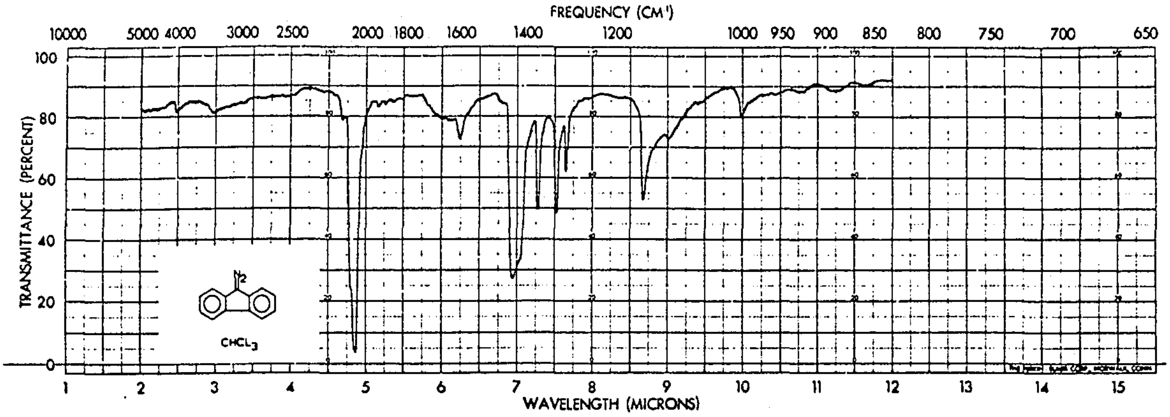
2000
1800
1600
1400
1200
1000
950
900
850
800
750
700
650
TRANSMITTANCE (PERCENT)
100
80
60
40
20
0
UNKNOWN F
KBR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH (MICRONS)

Figure 48. Infrared spectra.
Top: 9-Diazofluorene (LXXXVII).
Middle: Chromatography fraction 1.
Bottom: Unknown G.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TRANSMITTANCE (PERCENT)
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N2
CHCL3
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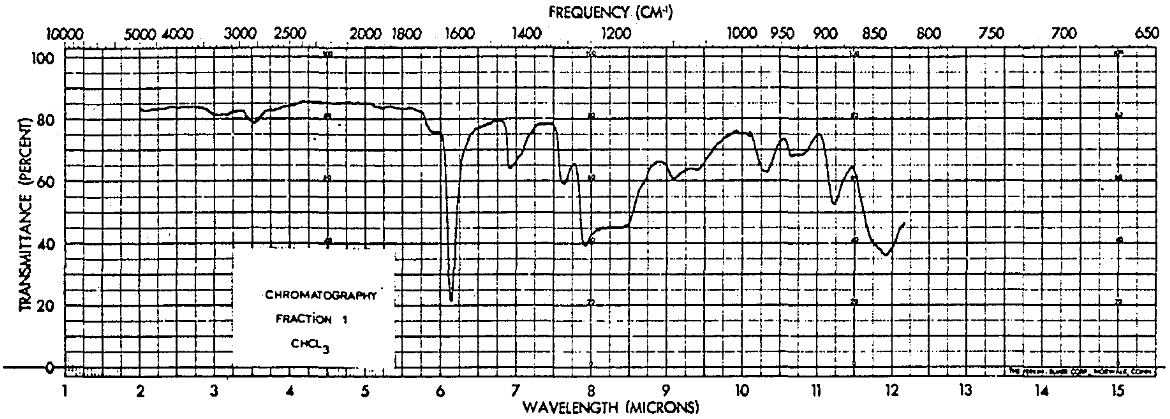
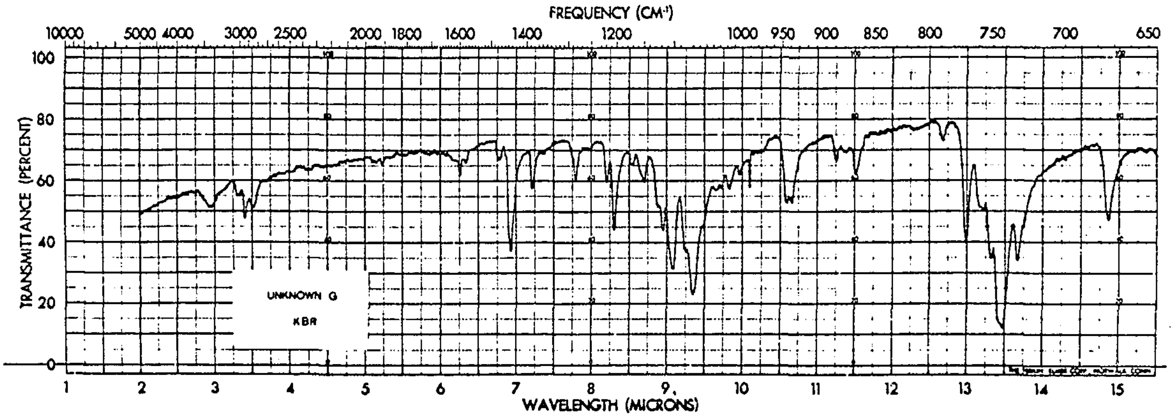
WAVELENGTH (MICRONS)


FREQUENCY (CM⁻¹)
10000 5000 4000 3000 2500 2000 1800 1600 1400 1200 1000 950 900 850 800 750 700 650
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
CHROMATOGRAPHY
FRACTION 1
CHCL3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)


FREQUENCY (CM⁻¹)
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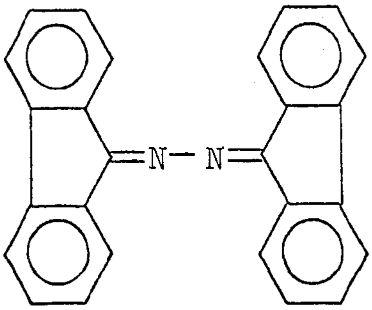
TRANSMITTANCE (PERCENT)
100 80 60 40 20 0
UNKNOWN G
KBR
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
WAVELENGTH (MICRONS)

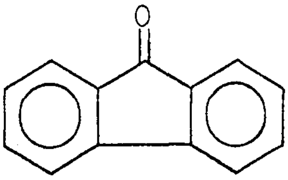
It is probable that the length of time (12-15 hours) that reaction mixtures were allowed to stir was of no importance. The cerium(IV) was rapidly decomposed in all cases. The formation of a precipitate of azine CXVIII in the solution in which hydrazone CXVII was oxidized was observed almost immediately upon mixing solutions of the reagents, which indicated that the reactions were rapid reactions. The extended reaction times were employed so that investigations in other areas could be carried out simultaneously with the oxidation of the hydrazones without resulting in conflicts in space. Shorter reaction times probably will give essentially the same results as were obtained using the longer reaction times.

The azine, 9-fluorenone azine (CXVIII), was obtained as a red-brown powder, m.p. 263-6°, directly from reaction mixtures. The compound was purified by recrystallization from either ethanol or ethyl acetate to give deep red needles, m.p. 267.5-9°. Azine CXVIII gave an i r spectrum (KBr, Figure 46, page 326) which was identical to the i r spectrum (KBr) given by authentic 9-fluorenone azine. A mixed melting point of CXVIII with the authentic azine, m.p. 268-70°, gave no depression (m.m.p. 267-9°). The mass spectrum of CXVIII (Table 21, page 350) showed a molecule ion at m/e 356. The mass spectrum of CXVIII is discussed in a later section.

The ketone, 9-fluorenone (LXIII), was isolated as a solid which exhibited a satisfactory melting point. The i r spectrum of LXIII was identical to that given by authentic 9-fluorenone.

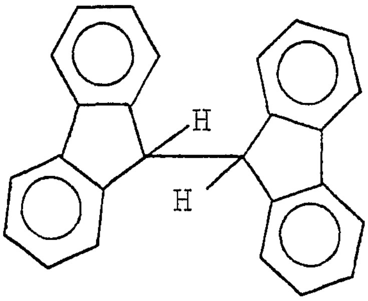


CXVIII



LXIII

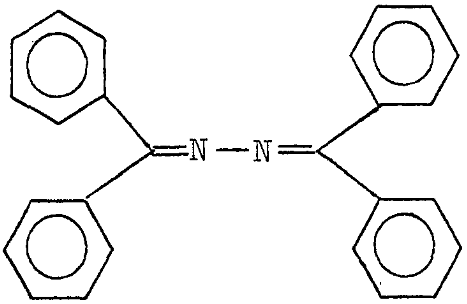
The third product of the oxidation of hydrazone CXVII, 9,9′-bifluorene (CCXV), was purified by recrystallization from ethanol to give finely-divided, light yellow needles, m.p. 239.5-41°. The i r spectrum of CCXV (KBr) is shown in Figure 47, page 328. The simplicity of the i r spectrum indicated the symmetrical nature of the compound. The mass spectrum of CCXV showed a molecule ion at m/e 330, a peak at m/e 165 (the base peak of the spectrum), and practically no other peaks. The nmr spectrum ($CDCl_3$, Figure 31, page 191) of CCXV showed



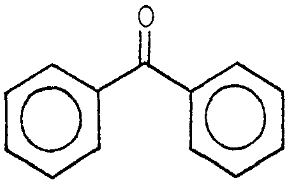
CCXV

aromatic protons (in two sets) between 2.4-2.9τ, and a singlet at 5.18τ, due to the methine protons, in the ratio 8:1, respectively. The nmr spectrum was in good agreement with the published spectrum of CCXV (130 , methine protons at 5.29τ ($CDCl_3$)).

Benzophenone azine (CXX) was obtained in part as a mixture with benzophenone (CLIX) from chromatography columns. Azine CXX was purified by recrystallization from ethanol to give nearly colorless needles, m.p. 160.5-61.5°. The i r spectrum (KBr) of CXX is shown in Figure 46, page 326. The physical and spectroscopic properties of CXX were identical to those of authentic benzophenone azine. The mass spectrum of CXX (Table 21, page 350) gave a molecule ion at m/e 360, and fragmentation which was strangely consistent with CXX. The mass spectrum of CXX is discussed in a later section.



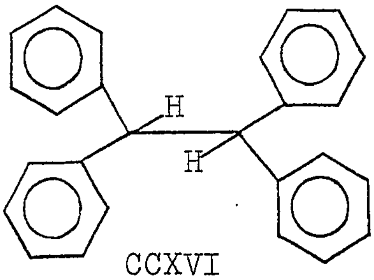
CXX



CLIX

Ketone CLIX was obtained as a crystalline material in one oxidation of hydrazone CXIX (Table 20, line 3, 6.7% yield). In the other reaction, CLIX was obtained in considerably greater quantity (Table 20, line 4, 26%) but could not be induced to crystallize. In both instances, the i r spectrum ($CHCl_3$) of CLIX was identical to that given by authentic benzophenone. In the larger scale reaction, a small amount (0.015 g.) of orange needles, m.p. 93-8°, was obtained from later chromatography fractions by recrystallization from ethanol. The i r spectrum of the material (KBr) is shown in Figure 47, page 328, title Unknown F. The i r spectrum of Unknown F was similar, but not identical, to that given by authentic hydrazone CXIX. The mass spectrum of Unknown F (70 ev.) suggested that the material was a mixture. Peaks above m/e 300 slowly disappeared over several scans of the spectrum, with the exception of a peak at m/e 356, which was observed to slowly increase in intensity. The material was not characterized further.

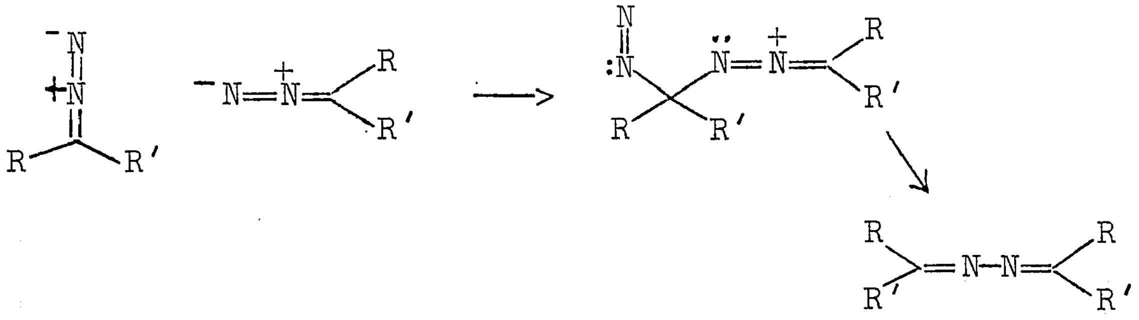
Formation of tetraphenylethane (CCXVI) may have taken place in the oxidation of CXIX, but the compound was not isolated, nor was it detected at any point in the work-up of reactions. Considerable amounts of gum accompanied the oxidation of the hydrazones, particularly hydrazone CXIX, and it is probable that other materials will be isolated and characterized eventually.



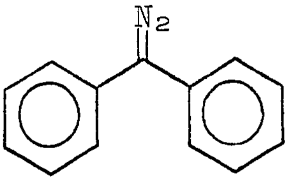
CCXVI

Mechanistic speculations

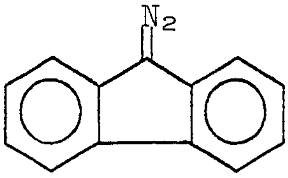
An obvious approach to the formation of azines by oxidation of hydrazones with cerium(IV) (as CAN) was through the respective diazo compounds. Generation of diazo compounds by oxidative dehydrogenation of the hydrazones, followed by a condensation of two molecules of the diazo compound, would give an azine. Difficulties with this mechanism for azine formation are numerous. Primarily, the diazo compounds, 9-diazofluorene and diazodiphenylmethane, exhibit considerable thermal stability and undergo azine formation by condensation only under forcing conditions. The conditions used for the oxidation of the hydrazones CXVII and CXIX were much too mild to be termed "forcing conditions" (i.e., room temperature). It is unlikely that diazo compounds are involved in azine formation in the reactions. Evidence for the lack of generation of diazodiphenylmethane (LXXXV) in the oxidation of CXIX by cerium(IV) comes also from the fact that the deep purple color of LXXXV was observed at no time during the reaction. A green color was observed, which might be due to a nitroso species of some type.



By analogy then, it is also doubtful that 9-diazofluorene (LXXXVII) is involved in the oxidation of CXVII to form azine CXVIII, although the deep red color of LXXXVII could not have been observed in the oxidation mixtures due to the formation



LXXXV



LXXXVII

of the deep red azine precipitate.

The possibility that azine formation might occur from diazo compounds held within a complex with cerium(IV) (or cerium(III)) was investigated. Diazo compound LXXXVII was treated with ceric ammonium nitrate in ethanol. Azine CXVIII was not isolated, nor was it detected in the product mixture. The ketone, 9-fluorenone (LXIII), was isolated in about 35% yield. The major component of the product mixture was isolated in the first chromatography fraction of the work-up. The i r spectrum ($CHCl_3$) of the crude fraction is shown in Figure 48, page 330. The prominent 6.14μ band in the i r spectrum was also present in the i r spectrum ($CHCl_3$) of the crude product mixture, indicating that the material responsible for the i r shown in Figure 48 was a legitimate product of some reaction of LXXXVII with cerium(IV). An nmr spectrum (CCl_4) of the crude fraction showed aromatic protons, a broad singlet at 3.24τ, and a broad absorption at 4.49τ, in the ratio 22.4:1.5:1, respectively. The nature of the material (or materials) responsible for the i r and nmr absorptions remains to be determined. The important fact at the moment is that azine CXVIII was not formed.

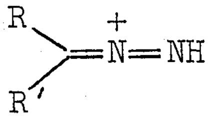
A small amount of white prisms (0.009 g.), m.p. 193-6°, was isolated from the fraction containing ketone LXIII in the oxidation of LXXXVII by CAN. The i r spectrum (KBr) of the solid is shown in Figure 48, page 330, titled Unknown G. The mass spectrum (70 ev.) of Unknown G showed an apparent molecule ion at m/e 412, with a prominent fragment ion appearing at m/e 206. At 18 ev., the peaks at m/e 412 and m/e 206 increased in intensity relative to other ions in the mass spectrum. The material was not characterized further due to the small quantity initially isolated.

The observation of vigorous evolution of a colorless, odorless gas (nitrogen ?) when hydrazones were treated with ceric ammonium nitrate, coupled with the fact that discrete diazo compounds are probably not involved in azine formation, suggests that azine formation results by a reaction of some species derived from hydrazones by cerium(IV) oxidation which is intermediate in its oxidation state between a hydrazone and its corresponding diazo compound. The mechanism by which azine formation occurs in the oxidation of hydrazones is probably very similar to the mechanisms of the oxidation of hydrazones by N-bromosuccinimide and manganese dioxide to give azines (the gross features of the NBS and MnO_2 reactions have been reviewed in the Historical Section, pages 68-70). The possible involvement of tetrazene CXXIII in the oxidation of benzophenone hydrazone by tetrahalo-o-benzoquinones (102) to give benzophenone azine has been noted (see Historical , page 71). Intermediates such as CXXV have been postulated to

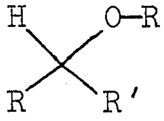
$$Ph_2C{=}N{-}N{=}N{-}N{=}CPh_2$$

CXXIII

account for the conversion of hydrazones to ketones and ethers of the type CXVI by oxidation with peracetic acid (see Figure 4, page 76). The oxidation of substituted hydrazones by manganese



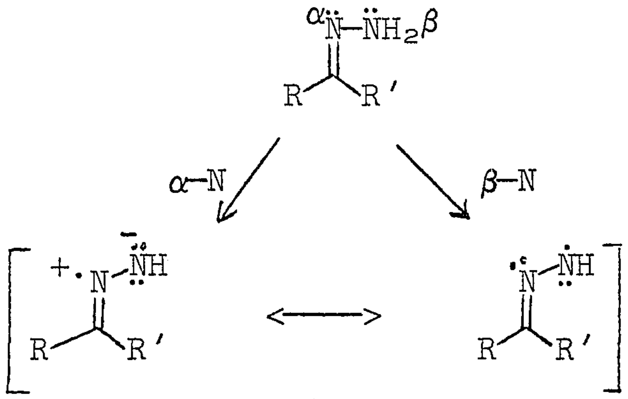
CXXXV



CXXVI

dioxide has been described (113), and intermediates similar to those proposed to account for the observed products (see Historical, pages 85-88) could be written to account for azine and ketone formation in the oxidation of hydrazones by ceric ammonium nitrate.

Initial hydrazone oxidation by cerium(IV) may take place either at the α-nitrogen or at the β-nitrogen. Whether oxidation occurs at the α- or β-nitrogen is unimportant, however, since the radical produced by oxidation at the β-nitrogen is one resonance form of a radical produced by oxidation at the α-nitrogen. The radical CCXVII is a nitrogen analog of an

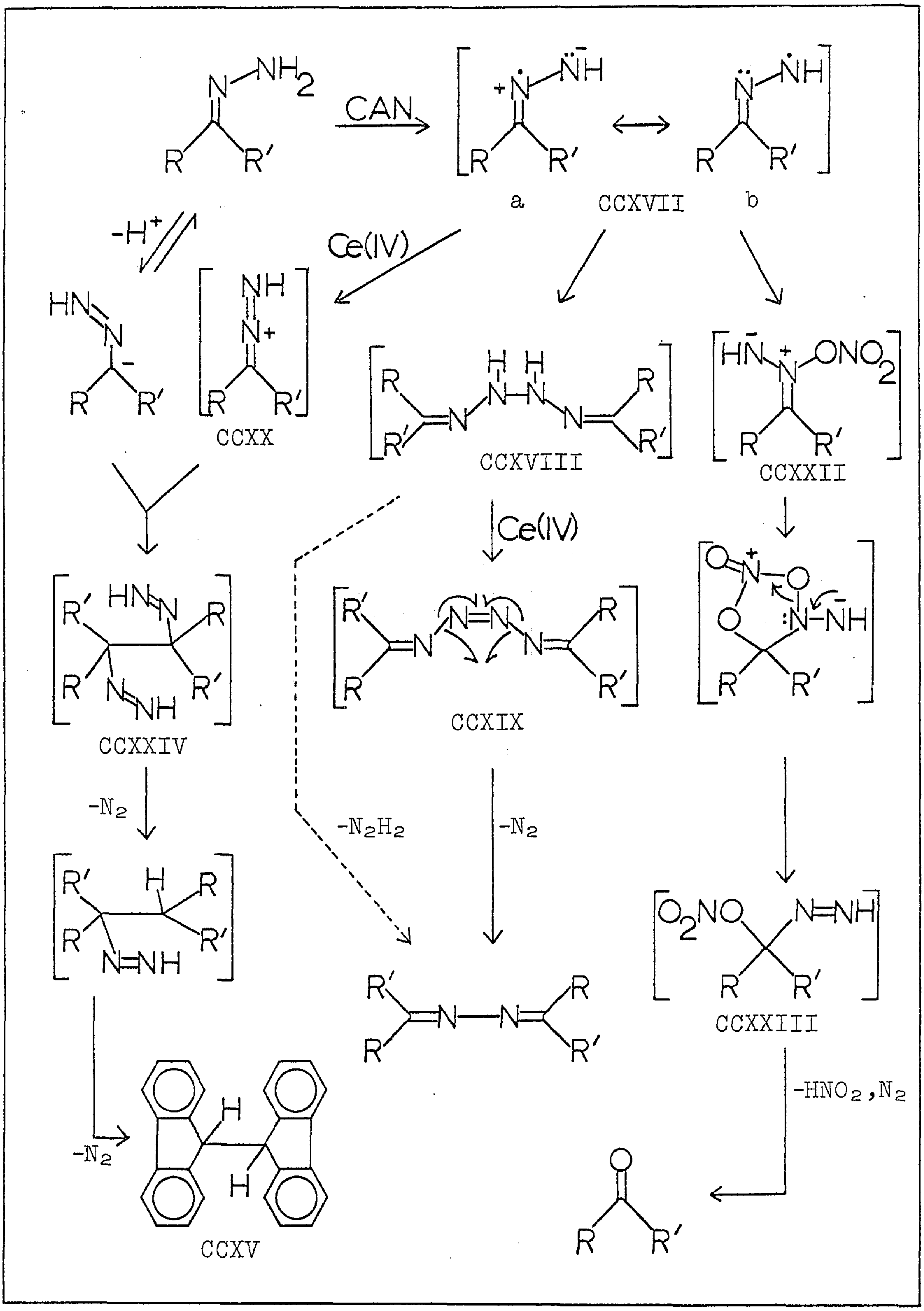


CCXVII

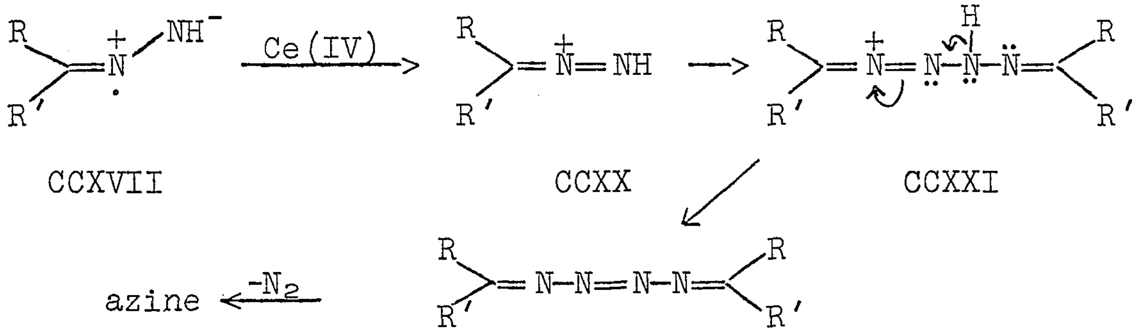
iminoxyl radical. It is possible that CCXVII could be an intermediate in product formation in the cerium(IV) oxidation of hydrazones, just as an iminoxyl radical could be an intermediate in product formation in the oxidation of aryl ketoximes by cerium(IV). A mechanistic scheme is shown in Figure 49, which illustrates this possibility, and which forms the basis for the following discussion. It is emphasized that the mechanisms for formation of ketones and azines shown in Figure 49 are not the only ways in which the compounds could be formed.

Dimerization of the radical CCXVII could occur to give a dihydrotetrazene derivative, CCXVIII (Figure 49). Oxidation of CCXVIII by cerium(IV) to tetrazene CCXIX may occur, which through loss of nitrogen would give azine. Loss of diimide (N_2H_2) from CCXVIII could result in an azine without involving tetrazene CCXIX (Figure 49, dotted arrow). A rapid second oxidation of CCXVII could occur to give an intermediate CCXX (below). Dimerization of CCXX to give an intermediate CCXXI, followed by loss of hydrogen ion, would give tetrazene CCXIX.

Figure 49. Possible mechanisms for product formation in the CAN oxidation of aryl hydrazones.


CAN
a
CCXVII
b
$-H^+$
Ce(IV)
CCXX
CCXVIII
CCXXII
Ce(IV)
CCXXIV
CCXIX
$-N_2$
$-N_2H_2$
$-N_2$
CCXXIII
$-HNO_2,N_2$
$-N_2$
CCXV

Loss of N_2 from CCXIX would give azine.



CCXVII CCXX CCXXI

CCXIX

Transfer of nitrate from cerium(IV) to the α-nitrogen of CCXVII would give intermediate CCXXII, which by rearrangement to CCXXIII and loss of N_2 and HNO_2 could give ketone (Figure 49). Similar mechanisms involving transfer of nitrate to the β-nitrogen of CCXVII can be written. The present difficulty with mechanisms for ketone formation by transfer of nitrate from cerium(IV) is that there is no evidence for the occurence of ligand transfer in the reaction. A cerium(IV)-catalyzed hydrolysis of a hydrazone could also account for ketone formation.

The dimeric compound, 9,9′-bifluorene (CCXV), was also formed in the oxidation of 9-fluorenone hydrazone. One means by which CCXV could be formed in the oxidation of hydrazone CXVII is shown in Figure 49. Reaction of an ionized, but unoxidized, molecule of hydrazone with an intermediate CCXX may result in CCXXIV. Loss of two molecules of nitrogen and capture of hydrogen ion would give CCXV. The mechanism has been written in terms of general structures since the formation of dimeric species similar to CCXV in the oxidation of other hydrazones has not been discounted.

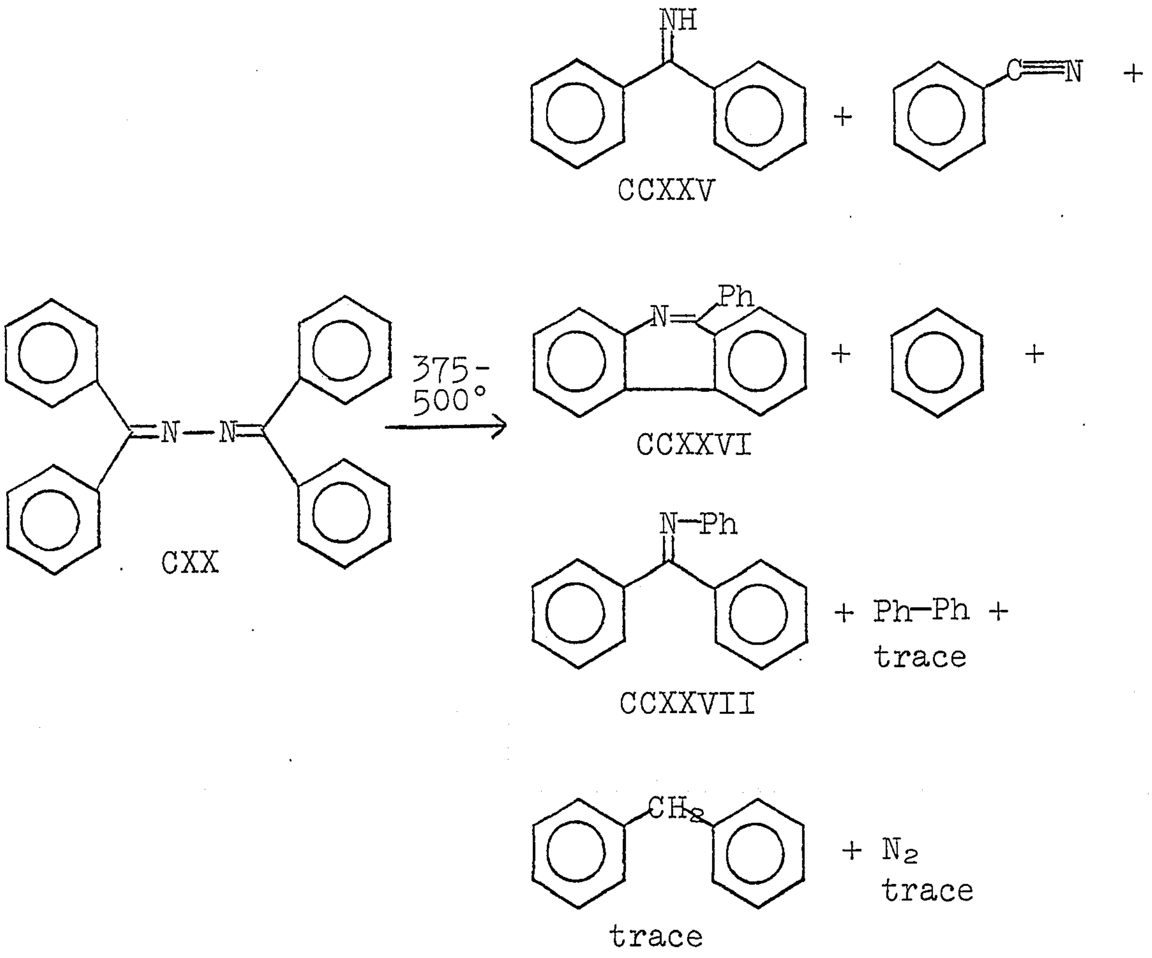
Initial hydrazone-cerium(IV) complex formation is probably involved in the oxidation of hydrazones by CAN, by analogy to the oxidation of aryl ketoximes by cerium(IV) salts. Hydrazones might form complexes with cerium(IV) which are more stable than oxime-cerium(IV) complexes, since hydrazones are stronger bases than are oximes. Water could have little or no effect on the results of the oxidation of hydrazones if in fact they are bound more tightly to cerium(IV) than oximes.

Very little evidence concerning the mechanism of the cerium(IV) oxidation of hydrazones has been obtained to date. Dimerization mechanisms for the formation of azines are given some support by the results summarized in Table 20, page 323, for the oxidation of 9-fluorenone hydrazone (CXVII). A 10% increase in the yield of azine CXVIII was noted when a rapid addition of CAN reagent was used for the oxidation, over that observed for a dropwise addition of CAN reagent. The yield of ketone LXIII was lower by about 7% in the fast addition reaction than it was in the dropwise addition reaction. At high concentrations of a species such as CCXVII (i.e., fast addition reaction), dimerization to form an azine precursor might be favored over the transfer of nitrate to CCXVII to give a ketone precursor. The magnitude of such an effect is not great, however, and additional data is necessary before it can be determined whether or not the effect is real.

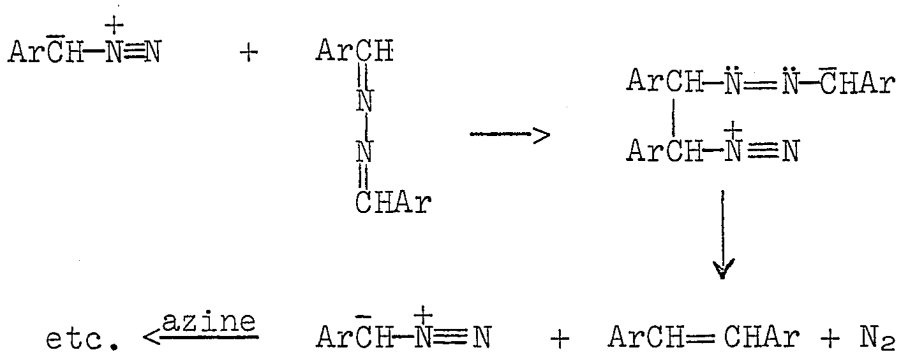
Mass spectra of azines

The mass spectra of benzophenone azine (CXX, from the ceric ion oxidation of benzophenone hydrazone), 9-fluorenone azine (CXVIII, from the ceric ion oxidation of fluorenone hydrazone), and 9-xanthenone azine (CLXXXVIII, from the ceric ion oxidation of 9-xanthenone oxime) are described here. The mass spectral data for the azines is summarized in Table 21, page 350. The data was taken from spectra recorded at 70 ev. Some similarities between the electron impact-induced fragmentation of benzophenone azine (CXX) and the pyrolytic decomposition of CXX are apparent from a comparison of the mass spectral results with the results recently made available concerning the pyrolysis of CXX (131).

The pyrolysis of benzophenone azine (CXX) over the temperature range 375-500°C gives benzhydrylidenimine (CCXXV), benzonitrile, and 6-phenylphenanthridine (CCXXVI), together with lesser amounts of benzene, benzhydrylideneaniline (CCXXVII), biphenyl, diphenylmethane, and nitrogen (131). The pyrolysis of aromatic aldazines has been shown to give predominantly diarylethylenes (stilbenes) and N_2 (132). Aldazines decompose thermally by a mechanism which involves participation of an aryldiazomethane (see below). Benzophenone azine did not undergo pyrolysis by a scheme similar to that shown for aldazine pyrolysis, as was apparent from the facts that no tetraphenylethylene was formed and only a trace of N_2 was formed (131).



The results of the pyrolysis of CXX were rationalized in terms of a free radical mechanism (131), as opposed to the molecular mechanism (below) for the pyrolysis of aldazines (132). A mechanism for the pyrolysis of CXX is shown in Figure 50 (131). Those benzhydrylidenimino radicals which do not abstract hydrogen (to give CCXXV) would serve as a source of benzonitrile and phenyl radicals, which could initiate the formation of 6-phenylphenanthridine (CCXXVI).



The possibility that phenanthridine CCXXVI arose by reaction between a phenyl radical and benzhydrylidenimine (CCXXV) was deemed unlikely (131). The anil (CCXXVII) was stable to the conditions required for the pyrolysis of CXX. The minor products, CCXXVII, benzene, and biphenyl, were accounted for by standard reactions of phenyl radicals and benzhydrylidenimino radicals.

The different principal courses of pyrolysis of the aldazines and ketazine CXX led to an investigation of the pyrolytic decomposition of benzhydrylidene-benzylidene azine (CCXXVIII) (131). Both the molecular mechanism and the free radical mechanism (Figure 50) (131) were found to participate to a major extent. Benzonitrile, benzhydrylidenimine, phenanthridine, and 6-phenylphenanthridine (benzene and biphenyl also) were found in the mixture from pyrolysis of CCXXVIII at 495° (131), and were accounted by a scheme similar to Figure 50. The formation of both phenanthridine and 6-phenylphenanthridine was consistent with a lack of discrimination between nitrogen atoms in the attack of a phenyl radical. Formation

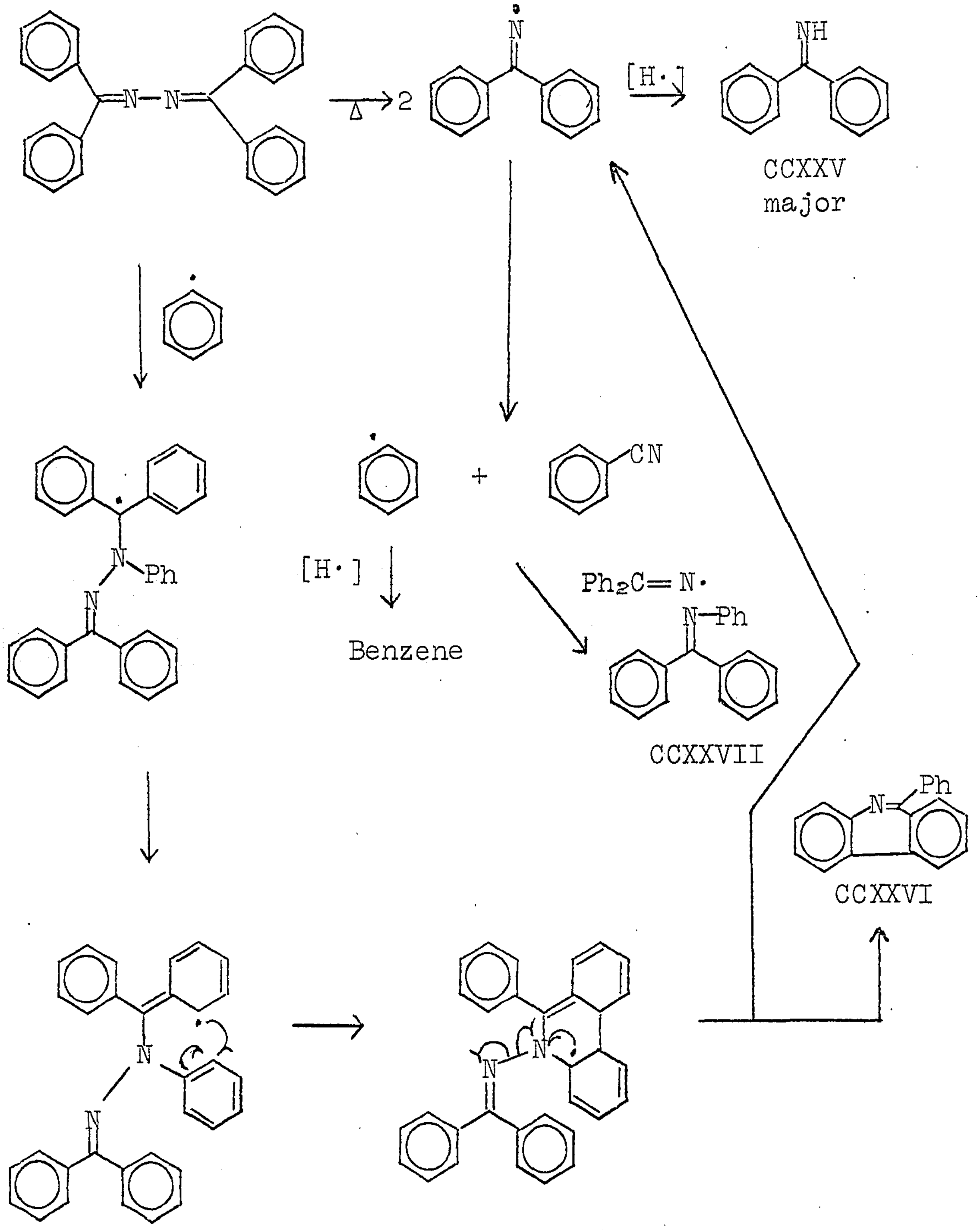
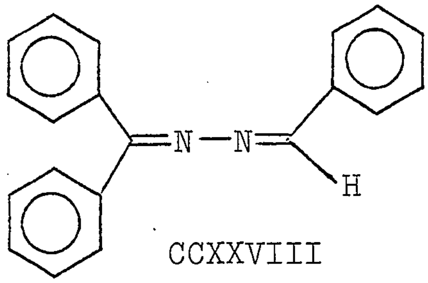


Figure 50. Pyrolysis of benzophenone azine (CXX).



CCXXVIII

of triphenylethylene and nitrogen was accounted for by the molecular mechanism involving an aryldiazomethane. Diazodiphenylmethane, and not diazophenylmethane, was involved in the reaction (131). Traces of diphenylmethane and fluorene were present in the pyrolysate, arising by decomposition of diazodiphenylmethane to a divalent carbon species followed by H abstraction to give diphenylmethane, or ring closure and H abstraction to give fluorene.

A molecular mechanism such as that described to account for the results of the pyrolysis of aldazines (132) would be unimportant in the mass spectral fragmentation of CXX due to the high vacuum conditions. The formation of substituted olefins from azines would occur by an intramolecular rearrangement and loss of nitrogen, rather than by reaction between a diazomethane molecule and an azine molecule. The mass spectral fragmentation of CXX parallels the free radical mechanism (Figure 50) for the pyrolytic fragmentation.

The observation of a prominent peak at m/e 359 in the spectrum of CXX (31% relative intensity) indicated that an aromatic hydrogen could be lost from the molecule ion (m/e 360). Hirsch (131) proposed that the hydrogen atom found on nitrogen of benzhydrylidenimine from the pyrolysis of CXX originated from one of the aromatic rings. The only source of hydrogen for abstraction by a benzhydrylidenimino radical was the aromatic hydrogens of CXX.

A prominent peak was observed at m/e 283 in the spectrum of CXX, which corresponded to a loss of C_6H_5 from m/e 360 (Figure 51). The process m/e 360 → m/e 283 was supported by a strong metastable ion at m/e 222.4. Cleavage of the N-N bond in m/e 360 to form benzhydrylidenimino ion (m/e 180) was also noted. The ion m/e 283 decomposed in two ways. Loss of ·CN by rearrangement gave m/e 257, which corresponds to benzhydrylideneanilino ion. Loss of HCN from m/e 283 and/or loss of H from m/e 257 accounts for the ion m/e 256. The other mode of fragmentation for m/e 283 was suggested by the ion m/e 205, which would arise by loss of C_6H_5 from m/e 283. Loss of ·CN from m/e 205 gave m/e 180 (in part). Loss of C_6H_5 from m/e 257 would provide another source of m/e 180. The possibility that m/e 180 could arise through fragmentation other than a cleavage of the N-N bond in CXX suggests that direct cleavage to form m/e 180 was not as important as the loss of C_6H_5 to give m/e 283. Fragmentation of m/e 180 by loss of HCN was suggested by the ion m/e 153 (Figure 51).

Table 21. Mass spectra of aromatic azines

m/e[b]	Intensity[a]			m/e[b]	Intensity[a]		
	CXX[c]	CXVIII[d]	CLXXXVIII[e]		CXX[c]	CXVIII[d]	CLXXXVIII[e]
389			27.1	254		2.3	
388			100.0*	221			1.5
387			63.2	220			8.4
372			2.2	219			2.5
371			6.6	205	5.0		
361	28.6			196			4.4
360	100.0*		5.2	194			13.0
359	31.0		8.3	182	13.5		
358			8.5	181	12.3		2.6
357		26.1	2.9	180	41.3	4.8	10.5
356		100.0*	2.8	179	7.1		4.2
355		75.5		178		22.8	
329		3.4		177		13.7	
328		10.2		168			1.7
327		22.0		167	5.6		
326		17.8		166	8.1	1.7	
325		4.0		165	30.2	5.1	
324		2.9		164	3.7	5.6	
295			0.6	163		7.8	
284	19.0			153	3.2	0.7	1.3
283	83.3			152	4.4	3.6	8.5
279		0.4		151	3.6	7.5	3.7
258	3.2			150		3.3	2.2
257	14.3			105	33.3		
256	11.1			77	49.2		

[a] Intensity expressed as percent of the base peak (base peak = 100%). An asterisk (*) denotes the molecule ion.

[b] Spectra were recorded at 70 ev. [c] CXX = benzophenone azine. [d] CXVIII = 9-fluorenone azine.

[e] CLXXXVIII = 9-xanthenone azine.

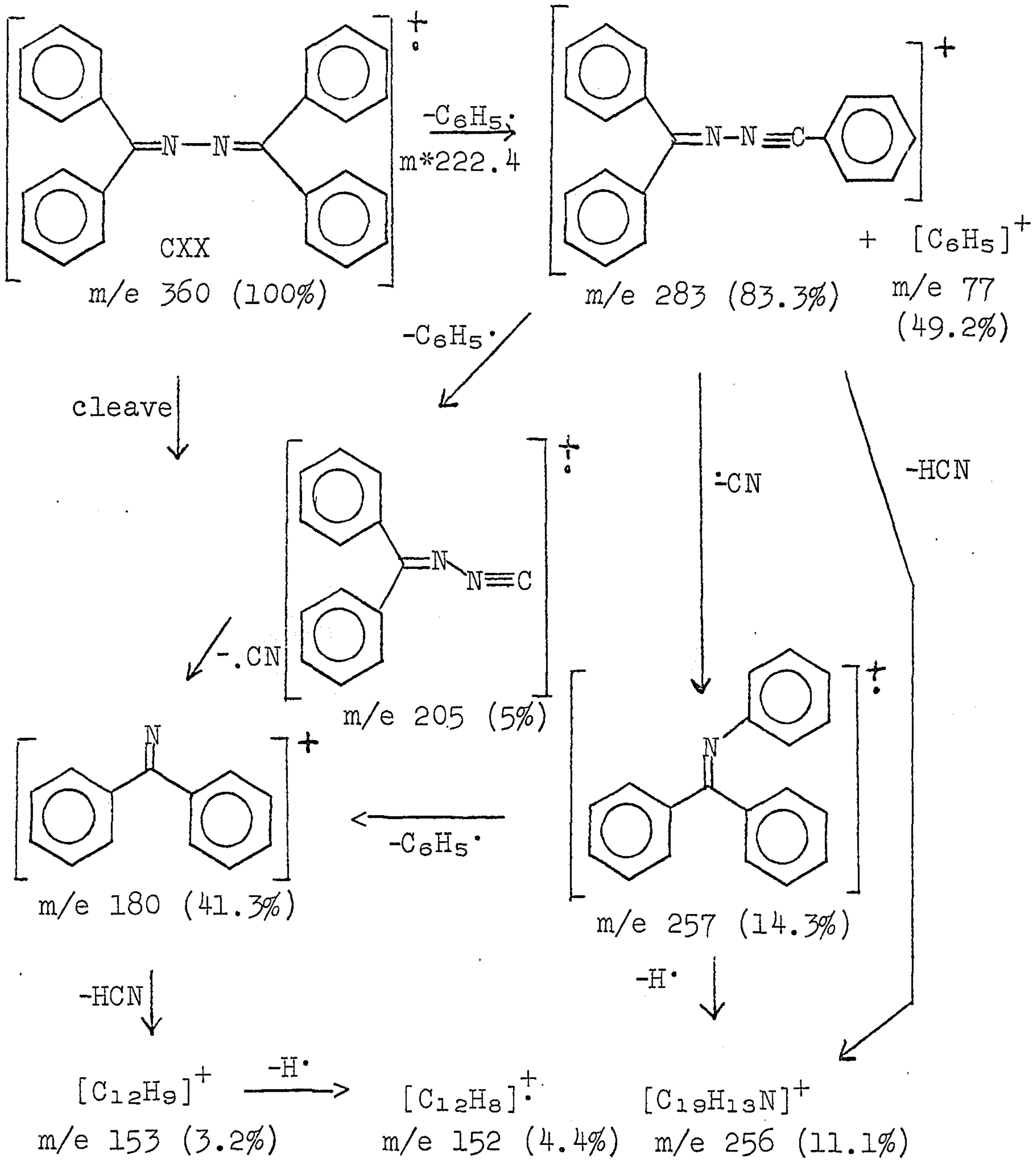
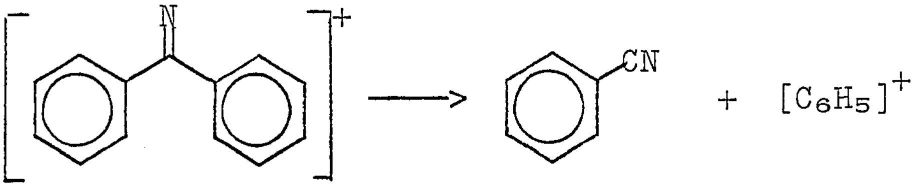


Figure 51. Mass spectral fragmentation of benzophenone azine (CXX).

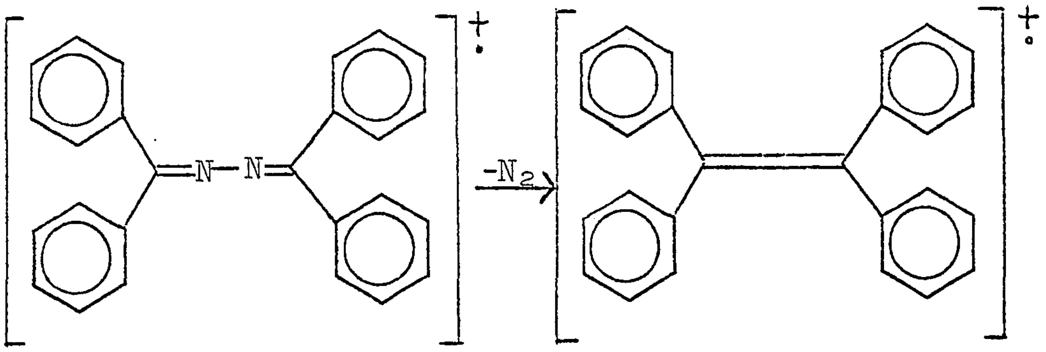
Cleavage of m/e 180 to give benzyl cyanide ion (m/e 103) and $C_6H_5\cdot$ apparently did not occur, as an ion m/e 103 was not observed in the spectrum of CXX. However, formation of a neutral species of m.w. 103 and m/e 77 (below) cannot be discounted.



m/e 180 neutral m/e 77

A weak ion at m/e 332 indicated that some rearrangement of m/e 360 and loss of N_2 was occurring. However, the relative intensity of the ion m/e 332 was less than 1% of the base peak. A similar loss of N_2 from 9-fluorenone azine (CXVIII) and 9-xanthenone azine (CLXXXVIII) to give the corresponding olefins was more prominent in the spectra of those azines (70 ev.), probably as a result of the fact that loss of an aromatic residue from CXVIII and CLXXXVIII was less favorable than from CXX due to the additional stability of the fluorene and xanthene nuclei.

Loss of N_2 from CXVIII (m/e 356, the base peak) gave an ion m/e 328 (Figure 52). The process m/e 356 → m/e 328 was supported by a strong metastable ion at m/e 302.2. Loss of hydrogen from m/e 328 and/or loss of N_2 from m/e 355 accounts for an ion m/e 327.



CXX
m/e 360

m/e 332

Loss of hydrogen from m/e 356 gave m/e 355. Loss of N_2 from 9-xanthenone azine molecular ion (m/e 388, the base peak) gave m/e 360 (Figure 53). An ion at m/e 359 arose either by loss of N_2 from m/e 387, or by loss of H from m/e 360 (or both). The ion m/e 387 arose by loss of H from m/e 388. A broad, strong metastable ion between m/e 333-334 in the spectrum suggested that both of the processes, m/e 388 → m/e 360 and m/e 387 → m/e 359, were important.

Cleavage of the N-N bond in CXVIII to give m/e 178 (9-fluorenone imino ion) was important (Figure 52). A weak metastable ion at m/e 128.1 supported a loss of HCN from m/e 178 to give m/e 151.

An interesting feature of the mass spectrum of CXVIII was a weak ion at m/e 279, which could arise by loss of the equivalent of C_6H_5 from m/e 356 (Figure 52). A weak ion was also apparent at m/e 280. Loss of ·CN from m/e 280 (and m/e 279) was suggested by an ion m/e 254 (and m/e 253). The ion m/e 280 would correspond to a species similar to m/e 283 (Figure 51) formed in the degradation of benzophenone azine. Loss of C_6H_4 from m/e 254 would give m/e 178 in a process analogous to that described for the conversion m/e 257 → m/e 180 in the spectrum of CXX.

An ion m/e 194 in the spectrum of CLXXXVIII indicated that cleavage of the N-N bond of m/e 388 was taking place (Figure 53). Cleavage of m/e 360 (9,9′-bixanthene ion) would be the likely source for m/e 180. Loss of CO from m/e 180 to give m/e 152 was supported by a weak metastable ion at m/e 128.3.

A third means of fragmentation for CLXXXVIII was suggested by ions at m/e 372 and m/e 371. A conversion m/e 388 → m/e 371 was supported by a metastable ion at m/e 354.7 (medium). Loss of an oxygen atom from the bridge linking the aromatic rings in an xanthene nucleus, and one of the aromatic hydrogens (Figure 53), could account for an ion m/e 371 (loss of O gives m/e 372).

Loss of a hydrogen atom from the molecule ion on electron impact was important in the spectrum of each of the azines (Table 21). A rough measure of the appearance potential for loss of a hydrogen from 9-fluorenone azine was obtained. At 29 ev., the relative intensity of m/e 359 was 62% of m/e 360 (the base peak), compared to 75.5% at 70 ev. At 25 ev. and 22 ev., the intensities were 38% and 17%, respectively. The only ions noted at 22 ev. and 25 ev. were m/e 359, m/e 360, and m/e 361, and were very weak. The results indicate that a

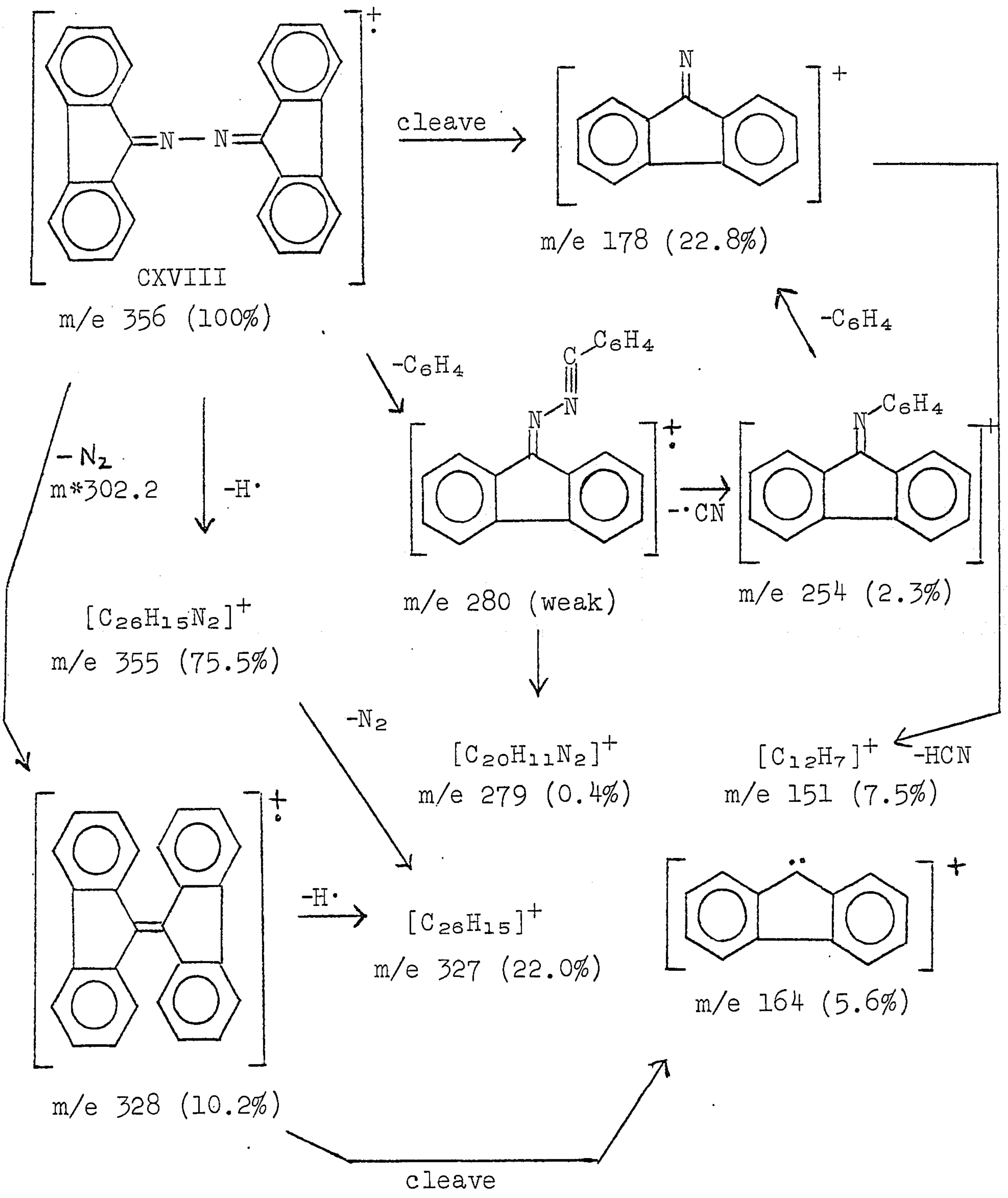


Figure 52. Mass spectral fragmentation of 9-fluorenone azine (CXVIII).

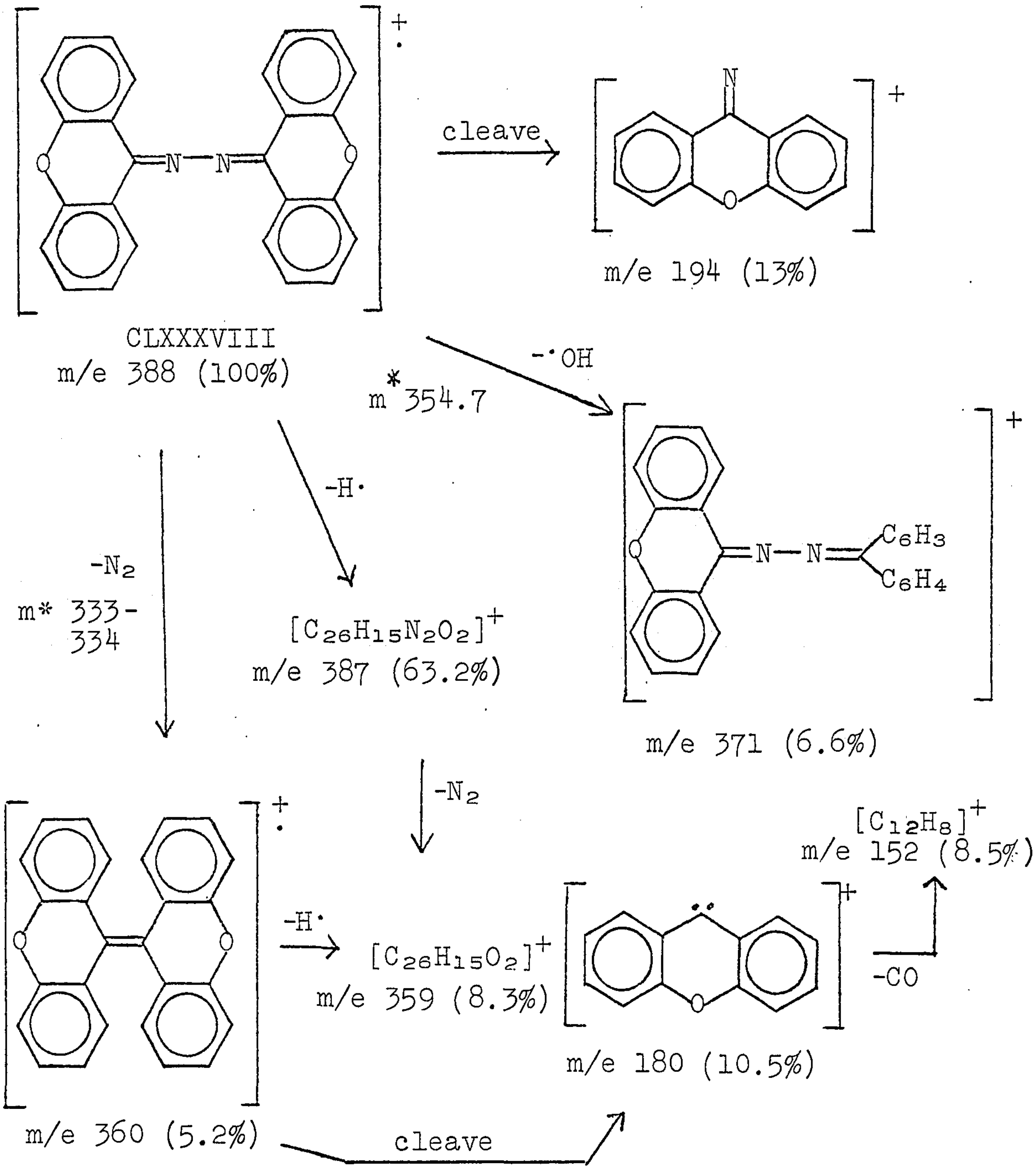


Figure 53. Mass spectral fragmentation of 9-xanthenone azine (CLXXXVIII).

loss of hydrogen from CXVIII was the lowest energy fragmentation process. It is reasonable to expect that losses of hydrogen from CXX and CLXXXVIII are also low energy processes.

Fragmentation of the azines by cleavage of the N-N bond was expected, as was a loss of N_2 to give olefin ions. Fragmentation of CXVIII by loss of an aromatic residue was unexpected, although the mode was unimportant by comparison to other fragmentations for CXVIII. Fragmentation of CLXXXVIII by loss of an aromatic residue was not observed. An initial loss of hydroxyl to give an ion containing a diphenylmethyl residue apparently occurred before loss of an aromatic ring could take place. Degradation of m/e 371 in the manner observed for benzophenone azine was suggested by several ions of low intensity, but additional data is required before any conclusions can be drawn concerning this mode of fragmentation for CLXXXVIII.

The similarity between the pyrolytic fragmentation of CXX (Figure 50) and the mass spectral fragmentation of the azine (Figure 51) suggests that CXVIII and CLXXXVIII would pyrolyze in a manner analogous to CXX. The photochemical behavior of the azines may be of interest. Benzophenone azine (CXX) is sensitive to light, and turns green on standing for prolonged periods in the room light. The photolysis of CXX may show that degradation of the azine nucleus by loss of an aromatic ring can be induced by light as well as by heat and by electron impact.

EXPERIMENTAL

> "Prevent the passage of such molecules as you
> may discover attempting to make good their
> departure at the mouth of the flask."
>
> -----adapted from Anonymous

Instruments and Methods

The nuclear magnetic resonance spectra (nmr) were run in deuteriochloroform or carbon tetrachloride. Spectra were measured on a Varian Associates Model A-60 spectrophotometer operating at 60 mc. Chemical shifts are reported as parts per million (ppm) on the *tau*-scale (133) relative to tetramethylsilane (TMS).

The infrared spectra (i r) were recorded on a Perkin-Elmer Model 21 spectrophotometer.

The mass spectra were measured using an Atlas CH-4 spectrometer made available by a National Science Foundation Research Instruments Grant.

The electron spin resonance spectra (esr) were obtained through the use of a Varian Associates V4500-10A spectrometer. Hyperfine splitting constants were measured with a Varian "Fieldial" attachment.

Analyses were performed by Spang Microanalytical Laboratory, Ann Arbor, Michigan.

All melting points and boiling points are uncorrected. Melting points were obtained using a Thomas-Hoover capillary melting point apparatus.

Materials

The oximes and hydrazones used in this study were prepared by standard techniques (134, 135) with the exceptions of 9-xanthenone oxime and anthraquinone monoxime. The preparation of 9-xanthenone oxime was accomplished by the method of Campbell and coworkers (136). Anthraquinone monoxime was prepared by the method of Meisenheimer (137). All compounds had satisfactory melting points and spectroscopic properties.

Fischer Reagent ceric ammonium nitrate (99.7% purity) was used in all oxidations involving that salt. Ceric potassium nitrate (G. Fredrick Smith Reagent) required some purification before use, as is described in a later section. All other cerium(IV) salts were used as obtained from the G. Fredrick Smith Chemical Company.

The methanol and acetone utilized as solvents were reagent-grade and were used without further purification or drying.

Experimental for the Oxidation of Oximes by Cerium(IV) Salts

All reactions of oximes with cerium(IV) salts were conducted at room temperature (22-27°C) unless otherwise noted. Product mixtures were separated by a chromatographic procedure. Yields are reported as percent pure product with satisfactory melting point and spectroscopic properties. Yields are based on recovered starting material in all cases. For "dimeric" species, such as azines and azine monoxides, yields are based on one-half of the starting material which reacted. Whenever necessary, products were further identified by direct comparison with authentic samples either commercially available or synthesized by unambiguous methods.

Chromatographic procedure

Silica gel (180-200 g. per 1 g. of material to be chromatographed) was slurried with petroleum ether "B" (Skelly B), b.p. 60-70°, and was introduced to a column containing petroleum ether "B". The material to be chromatographed was taken up in the minimum amount of hot benzene, or a petroleum ether-benzene mixture, and was placed on the column. Elution with petroleum ether "B"-benzene mixtures (4:1 petroleum ether-benzene to 1:1 petroleum ether-benzene) gave *geminal*-dinitro compound and/or nitrimine and azine. Elution with 1:1 petroleum ether-benzene through benzene gave ketone.

Elution with benzene, benzene-chloroform mixtures, chloroform, and chloroform-methanol mixtures gave azine monoxide and other products of the oxidation. Finally, the column was stripped with methanol.

Experimental for the Oxidation of 9-Fluorenone Oxime (CLVI) by Ceric Ammonium Nitrate

Oxidation of 9-fluorenone oxime (CLVI) in methanol

A. A solution of 1.00 g. (0.005 mole) of 9-fluorenone oxime (CLVI) in 40 ml. of absolute methanol (0.125 moles) was prepared. A freshly prepared solution of 2.75 g. (0.005 mole) of ceric ammonium nitrate (CAN[1]) in 5 ml. of absolute methanol was added to the oxime solution in one portion through a funnel. The time required to introduce the cerium(IV) solution into the reaction vessel was approximately 5 seconds. Rapid stirring of the reaction mixture was maintained during the addition and throughout the course of the reaction. A rapid discharge of the blood red color of the cerium(IV) was observed, simultaneous with the formation of a dark orange precipitate.

The orange slurry was allowed to stir for 15 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The residual red-orange solids were extracted with three 50-100 ml. portions of benzene. The insoluble materials were dissolved in 20-50 ml. of water, and the water solution was extracted with two 50 ml. portions of benzene, followed by 50 ml. of chloroform. The combined extracts were dried (anhydrous magnesium sulfate) and the solvents were removed at reduced pressure. The red-orange residue was chromatographed on silica gel.

Fraction 1 of the chromatography (1:1 petroleum ether-benzene) contained a light yellow solid which was recrystallized from hexane to give 0.499 g. (38%) of 9,9-dinitrofluorene

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[1] This abbreviation for ceric ammonium nitrate will be used throughout the Experimental Section.

(LXII), m.p. 135-7° (dec.). Successive recrystallizations from hexane raised the melting point of LXII to 139-40° (dec.) (light yellow needles) lit. (52), m.p. 130-1.5°. The infrared spectrum (i r) showed 6.41μ and 7.40μ absorptions (nitro group), and bonds characteristic of the aromatic nucleus (KBr, Figure 16, page 145). The nuclear magnetic resonance (nmr) spectrum ($CDCl_3$) showed only aromatic protons. The mass spectrum gave a molecule ion at m/e 256 (Table 15, page 291).

Anal. Calcd. for $C_{13}H_8N_2O_4$: C, 60.94; H, 3.15; N, 10.93. Found: C, 60.96; H, 3.18; N, 10.91.

Fraction 2 (3:2 benzene-petroleum ether through benzene) contained 9-fluorenone (LXIII , 0.375 g., 40.6%, m.p. 81-3° (ethanol-benzene)). The infrared spectrum of LXIII was identical to that of the authentic ketone. A mixed melting point of LXIII with the authentic ketone, m.p. 82-3°, gave no depression (m.m.p. 81-3°).

Elution with benzene-chloroform mixtures through chloroform gave 9-fluorenone azine monoxide (CLXII) as a red gum. Recrystallization of the gum from ethanol yielded 0.055 g. (5.8%) of red solid, m.p. 173-4°. The i r spectrum (KBr, Figure 20, page 153) was superimposable with that given by the authentic azine monoxide (prepared by peracetic acid oxidation of fluorenone azine). A mixed melting point of CLXII with the authentic material, m.p. 174-5°, gave no depression (m.m.p. 173-5°). The nmr spectrum ($CDCl_3$) showed only aromatic protons. The molecular weight was found to be 372 (mass spec.,

Table 19, page 315). Recrystallization of CLXII for analytical purposes gave finely-divided red-orange needles, m.p. 174-5°.

Anal. Calcd. for $C_{26}H_{16}N_2O$: C, 83.85; H, 4.33; N, 7.52. Found: C, 83.90; H, 4.45; N, 7.53.

The chromatography column was stripped with methanol to give 0.118 g. of dark brown gum from which nothing could be isolated. None of the oxime CLVI was recovered.

The yields given in the above procedure are those observed in the reaction in which the highest yield of the dinitro compound LXII was obtained. The average yields for several runs were as follows: LXII, 33%; fluorenone (LXIII), 40%; and azine monoxide CLXII, 10%.

B. A solution of 2.75 g. (0.005 mole) of CAN in 5 ml. of absolute methanol was prepared in an addition funnel equipped with a Teflon-tipped probe.[1] The solution was added dropwise over one minute to a solution of 1.00 g. (0.005 mole) of 9-fluorenone oxime (CLVI) in 40 ml. of absolute methanol. Rapid stirring of the reaction mixture was maintained as before. After all of the CAN solution had been added, the orange slurry was allowed to stir for 15 minutes. The solvent was removed on a rotary evaporator at 60°. Subsequent work-up

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[1] The funnel was manufactured by the Kontes Glass Company, Vineland, New Jersey. It is constructed so that addition rates may be exactly reproduced by setting the Teflon probe to the same calibration mark on the dropping tip. See Figure 54, page 372.

of the residue was carried out as described in part A. The results of the chromatography were as follows: 9,9-dinitrofluorene (LXII), 28.3% (0.372 g., m.p. 134-5° (dec.)); 9-fluorenone (LXIII), 28.3% (0.263 g., m.p. 80-81°); and 9-fluorenone azine monoxide (CLXII), 21.3% (0.203 g., m.p. 171-3°). None of the oxime CLVI was recovered.

C. Experiments were conducted by a procedure similar to that just described, in which a solution of 2.75 g. of CAN in 20 ml.[1] of absolute methanol was added dropwise to a solution of 1 g. of CLVI in 40 ml. of absolute methanol over a period of one hour. Rapid stirring of the reaction mixture was maintained during the addition as before. After the addition was completed, the slurry was stirred for 15 minutes. The solvent was stripped on a rotary evaporator, and the work-up was carried out as previously described.

The average yields of two reactions were as follows: 9,9-dinitrofluorene (LXII), 26.2%; 9-fluorenone (LXIII), 47.2%; and 9-fluorenone azine monoxide (CLXII), 19.1%. None of the oxime CLVI was recovered in either run.

D. A solution of CLVI (1.00 g., 0.005 mole) in absolute methanol (40 ml.) was allowed to react with a solution of CAN (5.50 g., 0.01 mole) in absolute methanol (10 ml.) containing

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[1] A rapid addition of the more dilute solution of CAN (2.75 g. in 20 ml. of methanol) gave results which were the same as those obtained using a more concentrated CAN solution (2.75 g. in 5 ml. of methanol).

two equivalents of cerium(IV) per equivalent of oxime to be oxidized. The CAN solution was added in one portion (10 seconds) with rapid stirring of the reaction mixture. The red color of the cerium(IV) was discharged immediately to give a bright yellow slurry. After stirring for 30 minutes, the solvent was removed on a rotary evaporator at 60°. The light yellow-orange residue was extracted with four 50 ml. portions of benzene. The insoluble materials were dissolved in 50 ml. of water, and the water solution was extracted with two 50 ml. portions of benzene and two 50 ml. portions of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), and the solvents were removed at reduced pressure. Chromatography of the yellow-orange residue gave the results which follow.

Fraction 1 (3:2 petroleum ether-benzene) yielded, after recrystallization (hexane), 0.365 g. (27.8%) of the dinitro compound LXII, m.p. 136-8° (dec.). Fraction 2 (3:2 petroleum ether-benzene) contained a mixture of materials and was discarded. Elution with benzene gave a third fraction, which contained 9-fluorenone in 66.1% yield (0.610 g., m.p. 81-3° from the column), and fraction 4 as a red gum (0.018 g.) which was discarded. Fraction 5 (benzene and 1:1 benzene-chloroform) was recrystallized from ethanol to give 0.029 g. (3%) of the azine monoxide CLXII, m.p. 172-4°. Elution with chloroform and methanol gave only small amounts of brown gum which were not identified further. None of the oxime CLVI was recovered.

Oxidation of 9-fluorenone oxime (CLVI) in methanol at 0°C

A solution of 1.008 g. (0.005 mole) of 9-fluorenone oxime (CLVI) in 80 ml.[1] of absolute methanol (0.0625 molar) was prepared and was cooled to 0° in an ice-salt bath. A solution of 2.76 g. (0.005 mole) of ceric ammonium nitrate in 20 ml. of absolute methanol was prepared. After the CAN solution was cooled to 0°, it was added to the oxime solution in one portion (10 seconds) through a funnel. Rapid stirring of the reaction mixture was maintained during the addition. The red color of the ceric ion was discharged rapidly, simultaneous with the formation of a yellow precipitate. The reaction mixture was allowed to stir for 70 minutes in the ice bath. After this time, the flask was removed from the bath, and the contents we were allowed to warm to room temperature. The solvent was removed on a rotary evaporator at 60°.

The yellow-orange residue was extracted as described previously. Chromatography of the extraction residue (orange solid) gave the following results: 9,9-dinitrofluorene (LXII), 38.5% (0.506 g., m.p. 137-9° (dec.)); 9-fluorenone (LXIII), 35.1% (0.324 g., m.p. 76-9°); and 9-fluorenone azine monoxide (CLXII), 13.9% (0.132 g., m.p. 171-4°). None of the oxime was recovered.

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[1] The larger volume of methanol was used in order to keep the oxime in solution at the lower temperature. At room temperature, the oxidation of an 0.0625 molar solution of the oxime gave the same results as those obtained for the oxidation as previously described for a 0.125 molar solution.

Oxidation of 9-fluorenone oxime (CLVI) in deoxygenated methanol

A. A solution of 1.00 g. of 9-fluorenone oxime in 40 ml. of absolute methanol was prepared in a 150 ml. two-necked flask. A sintered glass gas bubbler was inserted through one neck of the flask such that the end was completely immersed in the solution. The rapidly stirred solution was degassed for 45 minutes with prepurified nitrogen. An addition funnel containing a solution of 2.75 g. of CAN in 5 ml. of absolute methanol was placed on the other neck of the flask. The solution was degassed for 15 minutes with prepurified nitrogen by means of a long needle inserted below the level of the liquid. The CAN solution was added to the oxime solution in one portion (10 seconds) with rapid stirring. Nitrogen was continuously bubbled through the reaction mixture during the addition and throughout the course of the reaction. Immediate discharge of the color of the cerium(IV) and formation of an orange precipitate were noted as before.

The orange slurry was allowed to stir for 50 minutes. The solvent was then removed at reduced pressure. The work-up of the red-orange residue was carried out as described previously. The extraction residue (red-orange oil) was chromatographed.

Fraction 1 (1:1 petroleum ether-benzene) yielded 0.344 g. (26.2%) of 9,9-dinitrofluorene (LXII), m.p. 136-8° (dec.), after recrystallization from hexane. Fraction 2 (1:1 petroleum ether-benzene) contained nothing. Fraction 3 (benzene) contained 9-fluorenone (LXIII, 0.34 g., 37.5%, m.p. 78-80° (minimum ethanol-benzene)). A small amount of unreacted oxime CLVI was detected in fraction 4 (benzene and 1:1 benzene-chloroform), but was not isolated due to contamination by ketone LXIII and azine monoxide CLXII. Fraction 5 (1:1 benzene-chloroform and chloroform) and fraction 6 (9:1 chloroform-methanol) were combined and the residue was recrystallized from ethanol to give 0.224 g. (23.6%) of 9-fluorenone azine monoxide (CLXII), m.p. 172-4°. Stripping the column with methanol gave only a trace of a brown semisolid which was discarded.

A reaction was conducted, in the manner just described, in which the oxime solution was degassed for 30 minutes and the CAN solution was degassed for 10 minutes. Nitrogen was again allowed to pass through the solution during the addition and the subsequent stirring period. After 15 minutes, the solvent was removed, and the residue was given the same work-up as before. The chromatographic results were as follows: 9,9-dinitrofluorene, 34.8%; 9-fluorenone, 36.8%; and 9-fluorenone azine monoxide, 15.9%. Again, some (<1%) of the oxime was detected in fraction 4 of the chromatography, but was not isolated due to difficulty in separating it from the ketone and azine monoxide present in the fraction.

B. Oxidation of 9-fluorenone oxime in methanol with ceric ammonium nitrate was conducted in a helium atmosphere. The apparatus utilized in this reaction is shown in Figure 54, page 372.

A solution of 1.00 g. of 9-fluorenone oxime in 80 ml. of absolute methanol was prepared in a tubular reaction vessel equipped with a gas bubbler inserted through the vessel wall, a gas exit sidearm, and a ground glass point at the top. The volume of methanol used to dissolve the oxime was sufficient to insure that the gas bubbler was totally immersed in the solution. An addition funnel containing 2.75 g. of CAN in 20 ml. of absolute methanol was placed in the neck at the top of the vessel. A long needle was inserted below the level of the solution in the funnel. The two solutions were then degassed with dry helium for 45 minutes. The gas exit sidearm was kept closed during the degassing period, forcing the exit gas to pass through an equilibration sidearm and out the mouth of the funnel. Rapid stirring of the oxime solution was maintained throughout the degassing period.

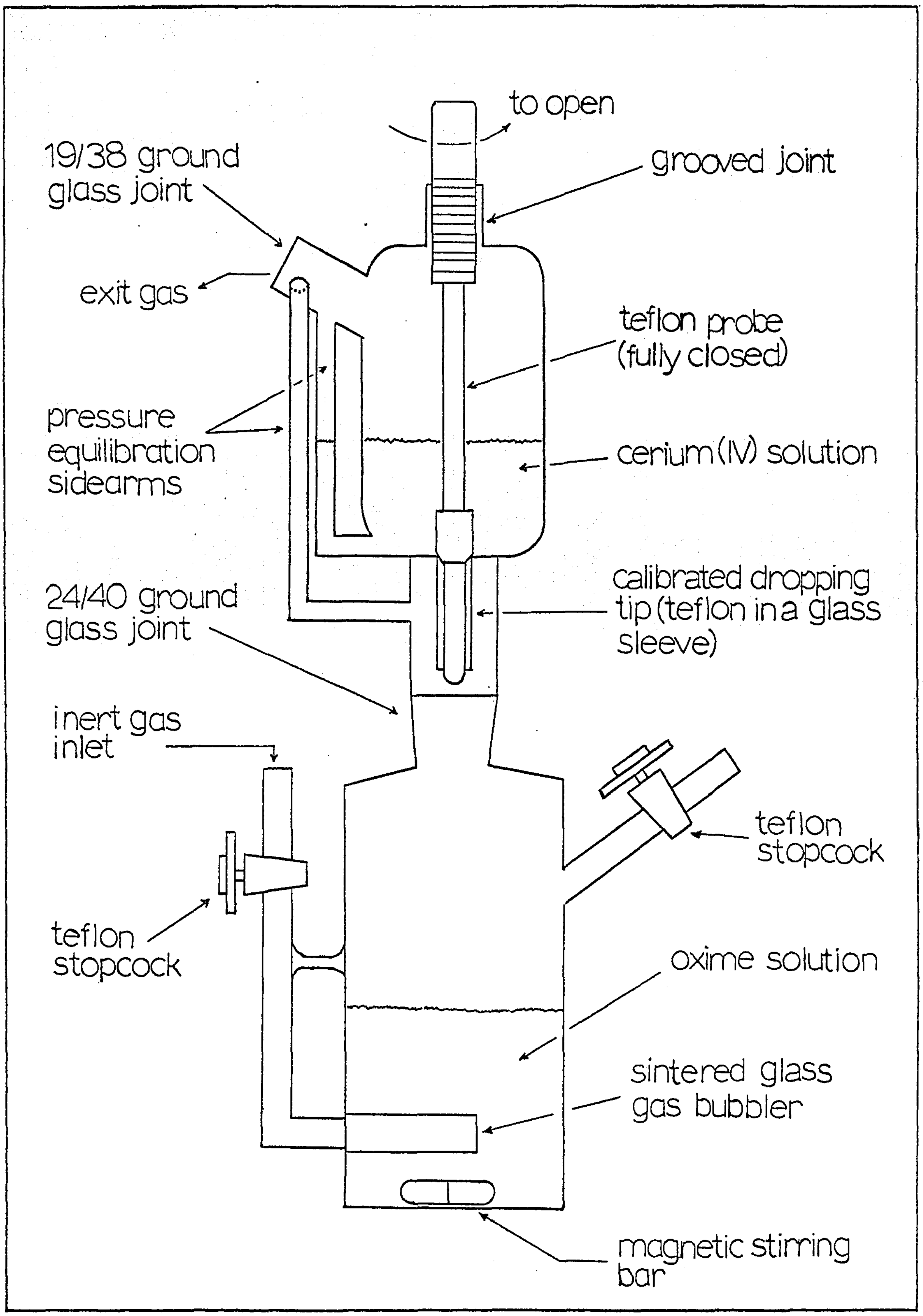
After 45 minutes, the helium flow through the apparatus was stopped, and the system was sealed from the outside air by immediately placing a stopper in the mouth of the addition funnel. The CAN solution was then added to the oxime solution in one portion (10 seconds) with rapid stirring. The red color of the ceric ion was again rapidly discharged. After ca. 20 seconds, a precipitate began to form. The orange slurry was allowed to stir for 30 minutes, after which the system was opened to the air, and the reaction mixture was transferred to another flask. The solvent was removed on a rotary evaporator at 60°. Subsequent work-up of the residue was carried out as previously described.

The chromatography of the extraction residue gave the following results: 9,9-dinitrofluorene, 0.441 g., m.p. 135-7° (dec.) (33.6%); 9-fluorenone, 0.310 g., m.p. 78-80° (from the column) (33.6%); and 9-fluorenone azine monoxide, 0.220 g., m.p. 173-5° (23.1%). None of the oxime was detected in the chromatography fractions.

Oxidation of 9-fluorenone oxime (CLVI) in aqueous methanol

9-Fluorenone oxime (1.00 g., 0.005 mole) was dissolved in 100 ml. of 80% methanol-20% water. A solution of ceric ammonium nitrate (2.75 g., 0.005 mole) in 20 ml. of 80% methanol-20% water was added to the oxime solution in one portion (10 seconds) from an addition funnel. The reaction mixture was rapidly stirred during the addition. A yellow precipitate formed which turned orange in ca. 30 seconds. The orange slurry was stirred for 30 minutes, after which time most of the methanol was removed on a rotary evaporator at 60°. The residual red-orange slurry was extracted with two 100 ml. portions of benzene. The red-orange water solution remaining was then extracted with two 50 ml. portions of chloroform and 50 ml. of benzene in a separatory funnel. The combined extracts were dried (anhydrous magnesium sulfate), concentrated on a rotary evaporator, and the red-orange residue was chromatographed. The results of the chromatography were as follows.

Figure 54. Apparatus for deoxygenation experiments.


to open
19/38 ground glass joint
grooved joint
exit gas
teflon probe (fully closed)
pressure equilibration sidearms
cerium(IV) solution
24/40 ground glass joint
calibrated dropping tip (teflon in a glass sleeve)
inert gas inlet
teflon stopcock
teflon stopcock
oxime solution
sintered glass gas bubbler
magnetic stirring bar

Fraction 1 (1:1 petroleum ether-benzene) gave 0.037 g. (4%) of LXII, m.p. 135-8° (dec.), after recrystallization from hexane. Fluorenone (LXIII, 0.350 g., 53.9%, m.p. 79-82° (benzene)) was eluted from the column immediately following the dinitro compound.

Only partial separation of azine monoxide CLXII and unreacted oxime CLVI was obtained. Fraction 4 (benzene) yielded, after recrystallization from methanol, 0.172 g. of 9-fluorenone oxime (CLVI), m.p. 190-92.5°. Fraction 5 (benzene) contained a red glass. Recrystallization of the glass from ethanol gave 0.185 g. of 9-fluorenone azine monoxide (CLXII), m.p. 171-4°. After removal of CLXII, the residue was recrystallized from chloroform to give 0.10 g. of the oxime, m.p. 189-92°. Trituration of the remaining gum with ethanol gave an additional 0.019 g. of CLXII, m.p. 167-70° (total azine monoxide, 0.204 g., 60.9%). Finally, an additional 0.023 g. of the oxime crystallized from a chloroform solution of the residue (total recovery of oxime, 0.298 g., 29.8%).

Elution with benzene-chloroform mixtures, chloroform, and chloroform-methanol mixtures, gave only a trace of a brown gum which was discarded. Stripping of the column with methanol gave a trace of red material which was discarded.

Oxidation of 9-fluorenone oxime (CLVI) in methanol containing nitric acid

Ceric ammonium nitrate (2.76 g., 0.005 mole) was dissolved in 20 ml. of anhydrous methanol in an addition funnel.

A solution of 1.006 g. (0.005 mole) of 9-fluorenone oxime in 50 ml. of anhydrous methanol was prepared. To this solution was added 1.3 ml. of 70% nitric acid (sp. gr. 1.42, 4 molar excess) with rapid stirring. The nitric acid was added dropwise to minimize heat generation. Two minutes after the nitric acid had been added to the oxime solution, the CAN solution was added in one portion (10 seconds) with rapid stirring. A yellow precipitate formed immediately, which slowly turned orange over *ca*. 15 seconds. The orange slurry was stirred for 40 minutes. The methanol was then removed on a rotary evaporator at 60°. Water (100 ml.) was poured into the residual red-orange slurry. The insoluble solids were removed by filtration and washed with 100 ml. of water. The combined filtrate and washings were extracted with two 100 ml. portions of benzene and two 100 ml. portions of chloroform. After combining the red-orange solids removed previously with the extracts, the solution was dried (anhydrous magnesium sulfate), concentrated, and the residue was chromatographed.

Elution with 1:1 petroleum ether-benzene gave five fractions. Fraction 1 yielded 0.055 g. (7.7%) of 9,9-dinitrofluorene, m.p. 134-6° (dec.) (hexane). Fraction 2 contained 0.273 g. (54.2%) of 9-fluorenone, m.p. 80-82° (from the column). Nothing was found in fraction 3. Fractions 4 and 5 were combined and recrystallized from methanol to give 0.460 g. (46% recovery) of 9-fluorenone oxime, m.p. 190-92°.

Elution with benzene gave fraction 6. The red gum was recrystallized from ethanol to give 0.061 g. (23.5%) of 9-fluorenone azine monoxide, m.p. 169-72° The later fractions (chloroform and methanol) contained only traces of materials and were discarded.

Reaction of 9,9-dinitrofluorene (LXII) with nitric acid in methanol

A solution of 0.202 g (0.0008 mole) of LXII in 40 ml. of methanol was prepared. Nitric acid (4 ml., 70%, sp. gr. 1.42) was added dropwise to the solution with rapid stirring. After stirring for 3 hours, the solvent was removed on a rotary evaporator at 60°. Water (40 ml.) was poured into the residue, and the resulting slurry was filtered to give 0.189 g. (93.5% recovery) of LXII, m.p. 135-7° (dec.). The filtrate was extracted with two 50 ml. portions of benzene. The extracts were dried (anhydrous magnesium sulfate) and were evaporated to give 0.007 g. of a yellow solid. An i r spectrum ($CHCl_3$) showed the solid to be predominantly unreacted LXII, but a weak 5.85μ absorption (due to 9-fluorenone) was noted.

The above reaction was repeated using 0.200 g. of LXII. After the nitric acid had been added, the mixture was stirred for 9 hours. After this time, work-up of the reaction was conducted exactly as before. Unreacted LXII (0.191 g., 95.6% recovery, m.p. 136-8° (dec.)) was isolated in the filtration. Extraction of the filtrate as before gave 0.006 g. of yellow gum. An i r spectrum showed the gum to contain LXII, contaminated by a trace of fluorenone.

Oxidation of 9-fluorenone oxime (CLVI) in methanol containing ammonium hydroxide

9-Fluorenone oxime (1.00 g.) was dissolved in 40 ml. of methanol. To this solution was added 0.7 ml. of 58% ammonium hydroxide (2 equivalents) dropwise with rapid stirring. A freshly prepared solution of 2.75 g. of ceric ammonium nitrate in 5 ml. of methanol was then added to the basic oxime solution in one portion (5 seconds) with rapid stirring. A red-brown precipitate immediately formed from the very dark brown solution. The mixture was allowed to stir for 23 hours. The solvent was then removed on a rotary evaporator at 60°. Water (100 ml.) was added to the red-brown residue. The insoluble materials were removed by filtration, and were washed with 100 ml. of water. The filtrate was extracted with two 50 ml. portions of benzene and 50 ml. of chloroform, and the extracts were combined with the solids previously filtered off. After drying (anhydrous magnesium sulfate), the extracts were concentrated, and the residue was chromatographed as before.

The results of the chromatography were as follows: 9-fluorenone (LXIII), 52%; unreacted oxime CLVI, 59% recovery; and 9-fluorenone azine monoxide (CLXII), 5%. None of the dinitro compound LXII was isolated. The yields of LXIII and CLXII were based on unreacted oxime as before.

Reactions were conducted in an analogous manner using stirring times of 20 minutes and 4 hours. Results virtually identical to those described above were obtained regardless of the length of time the reaction mixture was allowed to stir. In one instance, a fraction initially containing a small amount of a mixture of CLVI and azine monoxide CLXII (as shown by i r) was found, after standing for several weeks on the desk top, to contain dinitro compound LXII and ketone LXIII. Little or no oxime remained, as evidenced by an i r spectrum. Investigation of this phenomenon is described in a later section.

Reaction of 9-fluorenone oxime (CLVI) with ammonium hydroxide in methanol

A solution of 0.200 g. of CLVI and 0.15 mole of 58% ammonium hydroxide in 8 ml. of methanol was prepared and was allowed to stir for 22 hours. Removal of the solvent on a rotary evaporator at 60° and addition of 10 ml. of water to the residue gave, after filtration, 0.194 g. (97%) of the unreacted oxime, m.p. 188-91°. The solid was then passed through a column containing 40 g. of silica gel using benzene as eluent. Only unreacted oxime (0.187 g., 93.5% recovery, m.p. 193-4.5°) could be eluted from the column.

Reaction of 9,9-dinitrofluorene (LXII) with ceric ammonium nitrate in methanol

A slurry[1] of 0.201 g. of LXII in 30 ml. of methanol was treated with a solution of 1.38 g. of ceric ammonium nitrate in 3 ml. of methanol. The mixture was rapidly stirred for 15

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(1) A slurry of LXII in methanol was used in the reaction since in the oxidation of fluorenone oxime in methanol the nitro compound partially precipitated as formed to give a similar situation.

minutes, after which time the solvent was removed on a rotary evaporator at 60°. The red-orange residue was extracted with 80 ml. of benzene and 80 ml. of chloroform. The solvents were removed, and the residual light brown solid was recrystallized from hexane to give 0.190 g. (94.5% recovery) of the dinitro compound LXII, m.p. 136-8° (dec.). The orange solid remaining (0.015 g., m.p. 110-116° (dec.)) after evaporation of the filtrate was shown to be LXII by i r.

Oxidation of 9-fluorenone oxime (CLVI) in acetone

A solution of 1.004 g. (0.005 mole) of 9-fluorenone oxime in 25 ml. of anhydrous acetone (AR) was prepared. Ceric ammonium nitrate (2.75 g., 0.005 mole) was dissolved in 40 ml. of anhydrous acetone (AR) in an addition funnel. The CAN solution was added to the oxime solution in one portion (10 seconds) with rapid stirring. The orange color of the ceric ion in acetone was slowly discharged over a period of approximately one minute to give a yellow solution.[1] A white solid was observed to precipitate from the solution.

The reaction mixture was allowed to stir for 30 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The dark yellow residue was extracted with two 50 ml. portions of benzene and two 50 ml. portions of chloroform. The insoluble materials were dissolved in 40 ml. of water, and the water solution was extracted with two 50 ml.

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[1] The odor of nitrogen(IV) oxide became very noticeable over the solution as the color of the ceric ion disappeared.

portions of benzene. The combined extracts were dried (anhydrous magnesium sulfate), concentrated, and the residue was chromatographed on silica gel.

The results of the chromatography were as follows. Recrystallization of fraction 1 (1:1 petroleum ether-benzene) from hexane gave 0.742 g. (56.5%) of 9,9-dinitrofluorene, m.p. 136-8° (dec.), identical in every respect to the compound isolated and characterized from the oxidation of 9-fluorenone oxime in methanol. Fraction 2 contained a trace of impure _geminal_-dinitro compound and was discarded. Fluorenone (0.367 g., 39.8%, m.p. 78-81° (ethanol-benzene)) was isolated in fraction 3 (4:1 benzene-petroleum ether and benzene). Elution with benzene-chloroform mixtures, chloroform, chloroform-methanol mixtures, and methanol gave a small amount of a red semisolid from which none of the azine monoxide could be isolated. None of the starting oxime was recovered.

The average yields for several reactions were as follows: 9,9-dinitrofluorene, 55.5%; and 9-fluorenone, 34.3%. In one instance, some of the azine monoxide was isolated from the later chromatography fractions. However, the yield was considerably less than 1%.

Oxidation of 9-fluorenone oxime (CLVI) in deoxygenated acetone

Oxidation of CLVI with ceric ammonium nitrate in deoxygenated acetone was carried out in the apparatus shown in Figure 54, page 372. The procedure used for degassing solutions of the reactants was the same as that previously described for the oxidation of CLVI in methanol under helium.

A rapidly stirred solution of CLVI (1.00 g., 0.005 mole) in anhydrous acetone (80 ml., AR) was degassed for 45 minutes with dry helium. A solution of ceric ammonium nitrate (2.77 g., 0.005 mole) in anhydrous acetone (25 ml., AR) was degassed (simultaneously with the oxime solution) for 45 minutes with dry helium in an addition funnel. The helium flow through the solutions was stopped and the system was sealed as before. The CAN solution was added to the oxime solution in one portion (10 seconds) with rapid stirring. The color of the cerium(IV) was not rapidly discharged but slowly faded over several minutes to a light orange. The reaction mixture was allowed to stir for 1 hour, after which time the solution was transferred to a flask, and the solvent was removed on a rotary evaporator at 60°.

The crude reaction mixture was extracted by the procedure described for the oxidation in nondegassed solution, and the extraction residue was chromatographed to give the results which follow. Elution with 1:1 petroleum ether-benzene gave two fractions. The first fraction was recrystallized from hexane yielding 0.664 g. (52.4%) of dinitro compound LXII, m.p. 135-7° (dec.). The second fraction contained LXIII, m.p. 63-75° from the column. A chloroform solution of the fraction was treated twice with charcoal, the residue (after removal of solvent) was dissolved in hot hexane and was decanted from an insoluble red gum. The solvent was evacuated to give 0.325 g.

(36.5%) of LXIII, m.p. 76-9°. Elution with benzene gave a third fraction which contained nothing. Fraction 4 (chloroform) was recrystallized from chloroform to give 0.035 g. (3.5% recovery) of unreacted CLVI, m.p. 191-3°. The residue remaining after removal of CLVI yielded 0.02 g. of impure azine monoxide CLXII on recrystallization from ethanol. A second recrystallization (ethanol) of CLXII gave 0.014 g (1.5%), m.p. 173-5°. Red-brown gum (0.02 g.) was isolated on stripping the column with methanol, which was discarded without further characterization.

Reaction of 9-fluorenone azine monoxide (CLXII) with ceric ammonium nitrate in acetone

Azine monoxide CLXII (0.408 g., 0.00109 mole, m.p. 173-5°) was covered with anhydrous acetone (25 ml.) resulting in the formation of a red slurry. A solution of ceric ammonium nitrate (0.601 g., 0.00109 mole) in anhydrous acetone (10 ml.) was added to the slurry in one portion with rapid stirring. The remainder of the azine monoxide immediately dissolved to give a dark red solution. The solution was allowed to stir for 70 minutes, over which time the red color was observed to slowly lighten. The solvent was removed from the red-orange solution on a rotary evaporator at 60°. The residue was extracted with three 50 ml. portions of benzene. Water (50 ml.) was mixed with the residue and the solution was extracted with three 50 ml. portions of benzene (the remaining water layer was colorless). The benzene extracts were combined, dried (anhydrous magnesium sulfate), and the solvent was removed at reduced pressure. The residue was chromatographed on silica gel (60 g.).

Elution with 1:1 petroleum ether-benzene gave three fractions. The first fraction taken contained nothing. Fraction 2 contained 0.055 g. of red-orange solid. An i r spectrum ($CHCl_3$) indicated the solid to be predominantly 9-fluorenone (LXIII), with only a trace of 9,9-dinitrofluorene (LXII) present. A benzene solution of the solid was treated with charcoal, filtered, and the filtrate was evacuated thoroughly. Isolated of the orange solid gave 0.047 g., m.p. 69-75° (at 120-25° the remaining red oil bubbled vigorously, giving off NO_2). Recrystallization of the solid (ethanol) gave 0.039 g., m.p. 76-79°. Fraction 3 yielded 0.131 g. of LXIII, m.p. 78-81°, after treatment with charcoal, filtration, and thorough evacuation. The overall yield of LXIII was 71.1% (0.170 g.). The dinitro compound LXII could not be isolated in pure form, but the available evidence indicated that a small amount of it was present in the product mixture.

Elution with benzene gave three additional fractions. Fraction 4 contained a trace of gum which was discarded. Fraction 5 was recrystallized from ethanol to give 0.161 g. (39.4% recovery) of CLXII, m.p. 173.5-5°. Fraction 6 contained 0.008 g. of red-brown gum which was discarded. Fraction 7 (chloroform and methanol) held 0.015 g. of red-brown gum which showed an ill-defined i r spectrum. Further identification of the gum was not made.

Oxidation of 9-fluorenone oxime (CLVI) in aqueous acetone

9-Fluorenone oxime (1.00 g., 0.005 mole) was dissolved in 90% acetone-10% water (25 ml.). Ceric ammonium nitrate (2.75 g., 0.005 mole) was dissolved in 90% acetone-10% water (40 ml.) in an addition funnel. The CAN solution was added to the oxime solution in one portion (15 seconds) with rapid stirring. The orange color of the ceric ion faded slowly over one minute, then appeared to deepen again. After a short time the odor of nitrogen dioxide was noticeable over the solution. After the solution was stirred for 1.5 hours, the acetone was removed on a rotary evaporator at 60°. Water (20 ml.) was poured into the dark orange slurry, and the mixture was extracted with four 50 ml. portions of benzene and two 50 ml. portions of chloroform. The extracts were dried (magnesium sulfate), concentrated at reduced pressure, and the residue was chromatographed to give the following results.

Fraction 1 (1:1 petroleum ether-benzene) was recrystallized from hexane to yield 0.612 g. (46.6%) of 9,9-dinitrofluorene, m.p. 136-8° (dec.). 9-Fluorenone was isolated from fraction 3 (1:1 petroleum ether-benzene and benzene) without further purification in 35.9% yield (0.331 g., m.p. 80-82°). Fraction 5 (chloroform) contained 9-fluorenone azine monoxide as a red gum, which was recrystallized from ethanol to give 0.078 g. (8.2%) of red needles, m.p. 171-3°. None of the oxime CLVI was recovered.

Oxidation of 9-fluorenone oxime (CLVI) in aqueous acetone containing ammonium nitrate

Fluorenone oxime (CLVI, 1.00 g., 0.005 mole) and ammonium nitrate (0.409 g., 0.005 mole) were dissolved in 90% acetone-10% water (45 ml.). To this solution was added ceric ammonium nitrate (2.76 g., 0.005 mole) in 90% acetone-10% water (40 ml.). The CAN solution was added from an addition funnel in one portion with rapid stirring as before. The orange solution was stirred for 4 hours. The acetone was then removed at reduced pressure. Water (20 ml.) was added to the residue, and the resulting slurry was extracted with four 50 ml. portions of benzene and two 50 ml. portions of chloroform. The extracts were dried (anhydrous magnesium sulfate), concentrated, and the residue was chromatographed as before.

The following chromatographic results were obtained: LXII, 0.582 g. (44.3%, m.p. 134-6° (dec.) (hexane)); LXIII, 0.350 g. (37.9%, m.p. 79-82° (ethanol-benzene)); and CLXII, 0.085 g. (8.9%, m.p. 168-71° (ethanol)). None of the oxime was recovered.

Titration of CLVI in methanol

A standard solution of ceric ammonium nitrate in absolute methanol was prepared and was added dropwise from a buret to a solution of 9-fluorenone oxime (CLVI) in absolute methanol. Addition of the CAN solution was made until the red color of the cerium(IV) was no longer discharged.

A sample of 0.0510 g. (0.00026 mole) of CLVI in 5 ml. of absolute methanol was titrated in the above manner. The standard solution was prepared to contain 0.000404 mole of cerium(IV) per milliliter of solution. A volume of 1.30 ml. of standard was required to reach a point where no further color change was apparent. The stoichiometry of the reaction was found to be two moles of cerium(IV) per mole of oxime ($(0.000404)(1.30)/0.00026 \cong 2.0$). Due to the formation of the red-orange azine monoxide CLXII in the reaction, difficulty was experienced in observing an endpoint. Titration of other samples of CLVI in the above manner gave molar ratios in the range 1.9-2.2 moles of cerium(IV) per mole of oxime.

A standard oxime solution was prepared by dissolving 1.0010 g. of CLVI in 40.0 ml. of absolute methanol (0.000125 mole/ml.). A sample of 1.1122 g. (0.00203 mole) of ceric ammonium nitrate was dissolved in 4 ml. of absolute methanol. The standard oxime solution was added dropwise to the cerium-(IV) with swirling until no further change in the orange color of the solution could be detected. This point was reached in the range of 7.0 to 7.6 ml. of standard solution. The stoichiometry of the reaction was found to be in the range 2.1-2.3 moles of cerium(IV) per mole of oxime. Titration of other samples of CAN in the above manner gave values in the range of 2.1-2.4 moles of cerium(IV) per mole of CLVI.

Preparation of 9-fluorenone azine monoxide (CLXII)

Authentic 9-fluorenone azine monoxide (CLXII) was prepared by the procedure (116) which follows. Peracetic acid reagent was prepared by dissolving 2 ml. of 40% peracetic acid in 8 ml. of chloroform and drying the solution over magnesium sulfate (anhydrous). The reagent was cooled to 0° in an ice bath. Four ml. of the peracetic acid-chloroform solution were then added dropwise with stirring over a 15 minute period to a solution of 0.5 g. (0.0014 mole) of 9-fluorenone azine in 10 ml. of chloroform which had previously been cooled to 0° (ice bath). The solution was stirred for 25 hours, after which time it was extracted with two 25 ml. portions of saturated sodium carbonate and two 25 ml. portions of water. The chloroform layer was dried, and the solvent was removed. The residual red solid was recrystallized from ethanol to give 0.412 g. (79.1%) of CLXII, m.p. 174-6° (red-orange needles).

Preparation of 9-fluorenone azine (CXVIII)

Fluorenone (1.21 g., 0.0067 mole) was dissolved in xylene (20 ml., b.p. 129-30°). Hydrazine hydrate (*ca*. 0.22 g.) was added to the solution, followed by barium oxide (3.0 g.). The mixture was refluxed for 70 hours (hot plate). After this time, the insoluble solids were removed by filtration of the hot solution. Approximately 10 ml. of xylene was distilled away, and the remaining solution was cooled to give red needles. The yield was 0.844 g. (70.5%) of 9-fluorenone azine, m.p. 268-70° (lit. (138), m.p. 265-9°).

Experimental for the Oxidation of 9-Fluorenone Oxime (CLVI) by Ceric Potassium Nitrate

Purification of ceric potassium nitrate

The ceric potassium nitrate (G. Fredrick Smith Chemical Co.) was purified before use as follows. Weighed samples of the crude salt were washed with small portions of methanol until the red color of the cerium(IV) was no longer evident in the washings. The insoluble white powder was then weighed. The reagent was found to be about 70% ceric potassium nitrate by this method. An infrared spectrum (KBr) of the methanol-insoluble solid indicated it to be an inorganic nitrate, presumably potassium nitrate.

Oxidation of 9-fluorenone oxime (CLVI) in methanol

A sample of 3.497 g. of crude ceric potassium nitrate (CPN) was washed with successive 5 ml. portions of absolute methanol until the red color was no longer evident in the solution. The washings (total volume, 50 ml.) were combined and were placed in an addition funnel. The solution contained 2.42 g. (0.004 mole) of ceric potassium nitrate. The insoluble white powder (1.075 g., 30.7% of the original sample) was discarded.

A solution of 0.946 g. (0.004 mole) of 9-fluorenone oxime (CLVI) in 40 ml. of absolute methanol was prepared. The CPN solution was then added to the oxime solution in one portion (10 seconds) with rapid stirring from the addition funnel.

After *ca*. 20 seconds, the red color of the cerium(IV) was completely discharged to give an orange solution and precipitate. The reaction mixture was allowed to stir for 2 hours. After this time, the solvent was removed on a rotary evaporator at 60°. The dark red-orange residue was extracted with two 50 ml. portions of benzene, two 50 ml. portions of chloroform, and two 50 ml. portions of ether. The insoluble residue was dissolved in 50 ml. of water, and the solution was extracted with 50 ml. of benzene and 50 ml. of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), concentrated at reduced pressure, and the red-orange residue was chromatographed on silica gel.

The results of the chromatography were as follows. Fraction 1 (1:1 petroleum ether-benzene) was recrystallized from hexane to give 0.370 g. (29%) of 9,9-dinitrofluorene (LXII), m.p. 134-6° (dec.). Fraction 4 (4:1 benzene-petroleum ether and benzene) contained 9-fluorenone (LXIII). Recrystallization of LXIII from ethanol-benzene gave 0.409 g. (46.8%) of orange powder, m.p. 80-82°. Fractions 6 and 7 (benzene, benzene-chloroform mixtures, and chloroform) yielded 0.124 g. (13.7%) of 9-fluorenone azine monoxide (CLXII), m.p. 172-4°, after recrystallization from ethanol. Fraction 8 (9:1 chloroform-methanol and methanol) contained 0.044 g. of an intractable red-brown gum which was discarded. None of the starting oxime was recovered.

Experimental for the Oxidation of 9-Fluorenone Oxime (CLVI) by Ceric Ammonium Sulfate

Oxidation of 9-fluorenone oxime (CLVI) in aqueous methanol

A. To a solution of 1.00 g. (0.005 mole) of 9-fluorenone oxime (CLVI) in 50 ml. of methanol was added a slurry of 3.16 g. (0.005 mole) of ceric ammonium sulfate in 100 ml. of 60% methanol-40% water. The light yellow slurry was stirred for 4 days. The red slurry present at the end of this time was filtered to remove insoluble materials. The filtrate was concentrated on a rotary evaporator at 60°. After combining the solids previously removed with the residual orange slurry, 100 ml. of water was added to the mixture, and the solution was extracted with two 100 ml. portions of benzene. The water layer was then acidified with sulfuric acid to dissolve all insoluble salts. The acid solution was extracted with two 100 ml. portions of benzene and 100 ml. of chloroform. All extracts were combined and dried with anhydrous magnesium sulfate. The solvents were removed at reduced pressure, and the residue was chromatographed.

Elution with 1:1 petroleum ether-benzene gave a small amount of a yellow solid, m.p. 221-5°, which was not characterized further. None of the gem-dinitro compound LXII was detected in fraction 1. Continued elution with 1:1 petroleum ether-benzene and 3:2 benzene-petroleum ether gave fraction 2 as a light orange solid. Isolation and thorough drying of this material gave 0.164 g. (46.7%) of 9-fluorenone (LXIII), m.p. 78-80° (from the column). Fraction 3 (3:2 and 4:1 benzene-petroleum ether) contained only a trace of impure LXIII. Several recrystallizations of fractions 4 and 5 (4:1 benzene-petroleum ether and benzene) from chloroform gave 0.62 g. (62% recovery) of the unreacted oxime, m.p. 190-4° (orange needles). After removal of the oxime, the residue was recrystallized from ethanol to give 0.044 g. of impure azine monoxide. Fraction 6 (chloroform) yielded 0.052 g. of impure azine monoxide on recrystallization from ethanol. The red solids from fractions 4-6 were combined and were recrystallized again from ethanol, yielding 0.083 g. (45.8%) of CLXII, m.p. 173-5°. The column was stripped with methanol to give 0.026 g. of a red-brown gum which was discarded.

B. A solution of 1.00 g. of CLVI in 50 ml. of methanol was prepared as before. A slurry of 3.16 g. of ceric ammonium sulfate in 100 ml. of 60% methanol-40% water was added, and the light yellow slurry was allowed to stir for 4 days. After this time, the reaction mixture (red slurry) was filtered, and the filtrate was concentrated at reduced pressure. After combining the solids removed previously with the residual orange slurry, 100 ml. of water was added to the mixture. Subsequent work-up was carried out exactly as described in part A. An infrared spectrum ($CHCl_3$) of the red-orange extraction residue showed only absorptions due to LXIII, CLXII, and unreacted oxime. Addition of ca. 50 ml. of benzene to the residue resulted in the formation of a thick red slurry (due to the low solubility of the oxime in benzene). The slurry was allowed to stand on the desk top for 6 weeks at room temperature. The oxime was observed to slowly dissolve during this time, accompanied by a disappearance of the bright red color of the azine monoxide from the solution. A faint odor of nitric oxide or nitrogen dioxide could be detected over the solution after several weeks. After 6 weeks, the light orange solution was warmed to dissolve the small amount of solid remaining, and the mixture was chromatographed on silica gel as before.

The results of the chromatography were as follows. Fraction 1 (1:1 petroleum ether-benzene) yielded 0.416 g. (31.7%) of 9,9-dinitrofluorene (LXII), m.p. 134-6° (dec.), after recrystallization from hexane. Fraction 2 (1:1 petroleum ether-benzene) contained impure LXIII and was discarded. The ketone LXIII was isolated from fraction 3 (1:1 and 3:2 benzene-petroleum ether) without further purification, giving 0.537 g. (58.2%), m.p. 78-80°. A small amount of a tan solid, m.p. 205-10°, was obtained from fraction 4 (3:2 benzene-petroleum ether and benzene) which was not characterized further. Fractions 5 and 6 (benzene and chloroform, respectively) were combined and were recrystallized from ethanol to give 0.018 g. (<u>ca</u>. 1%) of impure azine monoxide CLXII, m.p. 159-65°. Only a trace of red gum was found in fraction 7 (methanol). None of the oxime CLVI was recovered, nor was it detected in the chromatography fractions.

Reaction of 9-fluorenone oxime (CLVI) with 9-fluorenone azine monoxide (CLXII) in benzene

A mixture of 0.105 g. (0.00028 mole) of azine monoxide CLXII and 0.076 g. (0.00039 mole) of oxime CLVI was dissolved in 10 ml. of benzene. The resulting red slurry was allowed to stand at room temperature on the desk top for 35 days. After this time, additional benzene was added, and the solution was warmed to dissolve the solids present. The hot solution was poured on to a column of silica gel (30 g.) and subsequently chromatographed.

Elution with 1:1 petroleum ether-benzene gave two fractions. An i r spectrum ($CHCl_3$) of fraction 1 (0.010 g.) showed absorptions at 4.86μ and 5.85μ, suggesting a mixture of 9-diazofluorene and 9-fluorenone. The dinitro compound LXII was not detected in the red semisolid. Fraction 2 (0.008 g.) gave an i r spectrum ($CHCl_3$) which was superimposable with that given by an authentic sample of 9-fluorenone (LXIII). The contents of these fractions were not characterized further.

Elution with benzene resulted in the isolation of a mixture of CLXII (predominant) and CLVI (fraction 3). Recrystallization of the red-orange solid from ethanol gave 0.093 g. (88.6% recovery) of CLXII, m.p. 172-4°. The residue after CLXII had been removed was recrystallized from chloroform to give 0.016 g. of CLVI, m.p. 190-2°. A mixture (0.019 g.) of about equal quantities of CLXII and CLVI remained in the fraction. Further separation was not attempted. Continued elution with benzene gave fraction 4. The yellow solid was recrystallized from chloroform to give 0.050 g. of CLVI, m.p. 192-4°. The total recovery of CLVI was 86.8% (0.066 g.). Elution with methanol yielded 0.006 g. of brown gum which was not identified further.

Experimental for the Oxidation of 9-Fluorenone Oxime (CLVI) by Ceric Sulfate

Oxidation of 9-fluorenone oxime (CLVI) in aqueous methanol

To a solution of 1.00 g. (0.005 mole) of CLVI in 150 ml. of methanol was added a solution of 2.65 g. (0.005 mole) of ceric sulfate (as $Ce(HSO_4)_4$) in 100 ml. of water. The resulting orange slurry[1] was stirred for 7 days. After this time, the solution was filtered to remove the orange and white solids present. The filtrate was concentrated at reduced pressure to remove the methanol, and the remaining orange water slurry was filtered. The aqueous filtrate was extracted with two 100 ml. portions of benzene to give red-orange extracts. All solids removed by filtration were combined and were digested with two 100 ml. portions of hot benzene. The insoluble salts were discarded. The benzene extracts were combined and were dried over anhydrous magnesium sulfate. Removal of the solvent at reduced

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[1] Ceric sulfate is only slightly soluble in methanol. Mixing of the two solutions resulted in the partial precipitation of both the oxime and the cerium(IV) salt.

pressure and chromatography of the red-orange residue gave the following results.

Elution with 1:1-petroleum ether-benzene gave 2 fractions. Fraction 1 contained only a trace of a yellow solid, m.p. >250°, which was not identified further. Fraction 2 gave, after thorough drying, 0.236 g. (68%) of 9-fluorenone, m.p. 80-82° (from the column). Unreacted oxime (0.614 g., 61.4% recovery, m.p. 191-3° (methanol)) eluted in 3:2 benzene-petroleum ether. Fraction 4 (benzene) was recrystallized from ethanol to give 0.044 g. (24.6%) of CLXII, m.p. 168-71°. The residue of fraction 4 yielded 0.013 g. (<u>ca</u>. 1% recovery) of impure oxime (m.p. 180-3°) on recrystallization from chloroform. Elution with chloroform, chloroform-methanol mixtures, and methanol gave only traces of red gum which were discarded.

<u>Oxidation of 9-fluorenone oxime (CLVI) in methanol containing sulfuric acid</u>

To a solution 1.00 g. of CLVI in 90 ml. of methanol was added 10 ml. of 97% sulfuric acid. The addition was made dropwise to minimize heat generation. After 5 minutes, a slurry of 2.66 g. of ceric sulfate in 20 ml. of methanol-10 ml. of 97% sulfuric acid was added in small portions to the oxime solution (to minimize heat generation). Sufficient methanol was used in the transfer of the cerium(IV) slurry to the reaction flask to bring the volume of solution in the flask to 150 ml. The yellow-orange slurry was allowed to stir for 14 hours.

The reaction mixture was then filtered, and the yellow filtrate was concentrated at reduced pressure. The residual orange oil was poured into 200 ml. of water. An additional 100 ml. of water was added, and the slurry was filtered. The filtrate was extracted with two 100 ml. portions of benzene and two 100 ml. portions of chloroform. The yellow solid which had been isolated in the filtration was combined with the extracts, and the solution was dried (anhydrous magnesium sulfate). The solvents were removed and the residue was chromatographed as before.

Elution with 1:1 petroleum ether-benzene gave LXIII (0.290 g., 90.9%, m.p. 80-82° (from the column)). Unreacted oxime (0.657 g., 65.7% recovery, m.p. 190-2° (methanol)) eluted in 1:1 petroleum ether-benzene through benzene. Azine monoxide (CLXII) was not detected in the later chromatography fractions. This fact, coupled with the observed high yield of LXIII, suggested that the reaction was one of hydrolysis of the oxime rather than an oxidation by ceric sulfate.

Experimental for the oxidation of Benzophenone Oxime (LXXVII) by Ceric Ammonium Nitrate

Oxidation of benzophenone oxime (LXXVII) in methanol

To a solution of 1.00 g. (0.005 mole) of benzophenone oxime (LXXVII) in 40 ml. of absolute methanol was added a solution of 2.76 g. (0.005 mole) of ceric ammonium nitrate in 10 ml. of absolute methanol. The addition was made in one portion (10 seconds) from an addition funnel with rapid stirring of the reaction mixture. The red color of the cerium(IV) was immediately discharged to give a bright blue-green solution. The blue-green faded to a green color in 5-10 seconds. The odor of nitrogen(II) or nitrogen(IV) oxide became very distinct over the solution after several minutes. The reaction mixture was allowed to stir for 15 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with three 50 ml. portions of benzene, 50 ml. of chloroform, and 50 ml. of ether. The insoluble solids were dissolved in 50 ml. of water and the water solution was extracted with 50 ml. of benzene and 50 ml. of chloroform. After the combined extracts were dried (anhydrous magnesium sulfate), the solvents were removed at reduced pressure. The yellow oil remaining was chromatographed on silica gel to give the results which follow.

Fraction 1 (1:1 petroleum ether-benzene) contained a yellow oil which partially crystallized on standing. Recrystallization of the material from hexane gave 0.285 g. (21.8%) of a tan solid, m.p. 74-6°. The infrared spectrum (CCl_4) of dinitrodiphenylmethane (LXIX) is shown in Figure 16, page 145. The absorptions at 6.35 (broad) and 7.44μ indicated the presence of the nitro groups in the molecule. The mass spectrum gave a molecule ion at m/e 258 (Table 15, page 291). The nmr spectrum (CCl_4) showed only aromatic protons. A second crystallization of LXIX from hexane gave a white powder, m.p. 75-6° (lit. (55), m.p. 79°).

Anal. Calcd. for $C_{13}H_{10}N_2O_4$: C, 60.46; H, 3.90; N, 10.85. Found: C, 60.39; H, 3.90; N, 10.75.

Fraction 2 (3:2 benzene-petroleum ether) was found to contain a small amount of a mixture of benzophenone and the geminal-dinitro compound LXIX, and the fraction was discarded. Elution with 4:1 benzene-petroleum ether gave fraction 3 as a brown oil. A chloroform solution of the oil was treated with decolorizing charcoal. The solvent was removed, and the residue was evacuated thoroughly at reduced pressure. On cooling, the oil crystallized to give 0.431 g. (46.7%) of benzophenone (CLIX), m.p. 45-7°. An infrared spectrum (CCl_4) of the material was identical to that given by an authentic sample of benzophenone.

Fraction 4 (benzene) and fraction 5 (9:1) benzene-chloroform) contained only traces of material and were discarded. The infrared spectra ($CHCl_3$) of fractions 6 and 7 (1:1 benzene-chloroform) showed a 6.06μ absorption. Nothing could be isolated from the small amount of yellow gum present in these fractions.

Fraction 8 (chloroform) contained 0.182 g. of a red-brown semisolid. Trituration of the gum with carbon tetrachloride gave 0.052 g. of a yellow solid, m.p. 149-53° (dec.). Recrystallization of the solid from ethanol gave 0.030 g. (3.1%) of benzophenone azine monoxide (LXXVIII), m.p. 158-60° (dec.) (lit. (65), m.p. 156-9°). An infrared spectrum (KBr, Figure 20, page 153) of LXXVIII was identical to that given by an authentic sample of benzophenone azine monoxide (prepared by the peracetic acid oxidation of benzophenone azine). The molecular weight was found to be 376 (mass spec., Table 19, page 315). The nmr spectrum ($CDCl_3$) showed only aromatic protons.

Anal. Calcd. for $C_{26}H_{20}N_2O$: C, 82.95; H, 5.36; N, 7.44. Found: C, 82.91, H, 5.42; N, 7.32.

Attempts at crystallization of additional LXXVIII from fraction 8 were unsuccessful. The infrared spectrum ($CHCl_3$) of the remaining red gum showed absorptions at 4.90μ (strong) and 6.05μ (strong), which suggested the presence of diazodiphenylmethane and benzophenone, respectively, in the mixture. The red color of the gum slowly deepened when the mixture was heated. The column was stripped with methanol to give a trace of red-brown gum which was discarded. None of the starting oxime was recovered.

Oxidation of benzophenone oxime (LXXVII) in deoxygenated methanol

A solution of 2.00 g. (0.01 mole) of benzophenone oxime (LXXVII) in 80 ml. of absolute methanol was prepared in a two-neck 250 ml. flask. The solution was degassed for one hour with dry helium by means of a sintered-glass gas bubbler inserted through one neck of the flask below the level of the liquid. A solution of 5.54 g. (0.01 mole) of ceric ammonium nitrate in 20 ml. of absolute methanol was degassed for 20 minutes with dry helium in an addition funnel by means of a long needle inserted below the level of the liquid.

The CAN solution was added in one portion (20 seconds) to the oxime solution with rapid stirring. Helium was allowed to flow through the apparatus during the addition and throughout the entire reaction time. A bright green solution formed immediately, which faded to pale yellow-green in about 15 seconds. The reaction mixture was allowed to stir for 30 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with two 100 ml. portions of benzene, 100 ml. of chloroform, and two 100 ml. portions of ether. The insoluble solids were dissolved in 80 ml. of water, and the water solution was extracted with 100 ml. of benzene and 50 ml. of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), were concentrated at reduced pressure, and the yellow residue was chromatographed.

Fraction 1 (1:1 petroleum ether-benzene) yielded 0.653 g. (24.9%) of dinitrodiphenylmethane (LXIX), m.p. 73-6°, after recrystallization from hexane. Fractions 2 and 3 (1:1 petroleum ether-benzene) contained 0.06 g. of a mixture of LXIX and benzophenone (CLIX) and were discarded. Fractions 4 and 5 (benzene) were found by i r to contain benzophenone. The yellow oil was treated with charcoal, and, after thorough evacuation, crystallized to give 1.083 g. (58.6%) of CLIX, m.p. 46-8°. Fraction 6 (benzene) held only a trace of CLIX and was discarded.

Elution with benzene-chloroform mixtures gave fractions 7, 8, and 9. The i r spectra ($CHCl_3$) of these fractions were very similar. Absorptions at 2.80μ (sharp, weak) and 9.94μ (strong) suggested the presence of unreacted oxime in the fractions, but none of the oxime could be isolated. The combined fractions contained 0.185 g. of yellow gum. After several unsuccessful attempts to simplify the mixture were made, an i r spectrum ($CHCl_3$) was recorded which revealed a sharp increase in the intensity of a 6.05 μ absorption (due to benzophenone) and a complete loss of absorption due to a hydroxyl group in the 2.8-3.2μ range. When a sample of authentic LXXVII was allowed to stand on the desk top in the room light for several days, decomposition and formation of a brown oil were observed. The i r spectrum ($CHCl_3$) of the oil showed it to be predominantly benzophenone. Further characterization of fractions 7-9 was not carried out.

Fraction 10 (chloroform) contained a trace of material which was discarded. A red gum (0.025 g.) was isolated in fraction 11 (9:1 chloroform-methanol). An i r spectrum suggested the presence of azine monoxide LXXVIII in the fraction, but none could be isolated. A trace of red gum isolated on stripping the column with methanol was discarded without further identification.

Oxidation of benzophenone oxime (LXXVII) in aqueous methanol

Benzophenone oxime (LXXVII, 1.00 g., 0.005 mole) was dissolved in 80% methanol-20% water (100 ml.). A solution of ceric ammonium nitrate (2.77 g., 0.005 mole) in 80% methanol-20% water (20 ml.) was added from an addition funnel in one portion (10 seconds) with rapid stirring. The solution immediately turned blue-green as observed before. The reaction mixture was allowed to stir for 1 hour. The methanol was removed on a rotary evaporator at 60°. The remaining green water slurry was extracted with two 100 ml. portions of benzene and two 100 ml. portions of chloroform. The extracts were dried, concentrated at reduced pressure, and the residue was chromatographed to give the following results.

Fraction 1 (1:1 petroleum ether-benzene) yielded 0.016 g. (1.2%) of dinitrodiphenylmethane (LXIX), m.p. 73-5° (hexane). A mixture of LXIX and benzophenone was found in fraction 2 (1:1 petroleum ether-benzene, 0.02 g.) and was discarded. Benzophenone (CLIX, 0.735 g., 79.6%, m.p. 45-7°) was isolated from fraction 3 (1:1 petroleum ether-benzene) after the crude fraction had been treated as previously described.

The i r spectra ($CHCl_3$) of fractions 4 and 5 (benzene and 1:1 benzene-chloroform; total, 0.088 g. of yellow gum) showed 6.06μ absorptions and weak bands due to a nitro group (aromatic) at 6.58μ, in addition to other bands indicative of a mixture of materials. Attempts to isolate the material, or materials, responsible for the i r bands were unsuccessful.

Fraction 6 (chloroform) partially crystallized after thorough evacuation of the solvent. Recrystallization of the yellow-orange semisolid from ethanol gave 0.077 g. (8%) of benzophenone azine monoxide (LXXVIII), m.p. 155-8° (dec.). Elution with methanol gave a trace of material which was discarded. Evidence for the presence of unreacted oxime LXXVII in the chromatography fractions was not obtained.

Oxidation of benzophenone oxime (LXXVII) in methanol containing nitric acid

A solution of 2.77 g. (0.005 mole) of ceric ammonium nitrate in 20 ml. of methanol was prepared in an addition funnel. A solution containing 1.00 g. (0.005 mole) of benzophenone oxime (LXXVII) and 1.3 ml. of 70% nitric acid (sp. gr. 1.42, 4 molar excess) in 50 ml. of methanol was prepared. The CAN solution was added to the oxime solution in one portion (10 seconds) with rapid stirring. The green color which immediately formed in the solution slowly faded to yellow over 1 minute. The solution was stirred for 40 minutes, after which time the solvent was removed on a rotary evaporator at 60°. Water (50 ml.) was poured into the residual oil, and the water solution was extracted with four 100 ml. portions of benzene and 100 ml. of chloroform. The extracts were dried, concentrated at reduced pressure, and the residue was chromatographed as before.

Elution with 3:2 petroleum ether-benzene gave 2 fractions. Fraction 1 was recrystallized from hexane to give 0.015 g. (1.1%) of dinitrodiphenylmethane, m.p. 72-4°. Fraction 2 was a mixture of materials (0.03 g.) and was discarded. Fraction

3 (1:1 petroleum ether-benzene), after treatment with charcoal and thorough evacuation, yielded 0.697 g. (76.3%) of CLIX, m.p. 46-8°. Fractions 4 and 5 (3:2 benzene-petroleum ether and benzene) were combined, and the brown semisolid (0.06 g.) was recrystallized from methanol to give 0.012 g. (ca. 1% recovery) of unreacted oxime LXXVII, m.p. 134-7°. An intractable gum (0.02 g.) was isolated in fraction 6 (1:1 benzene-chloroform and chloroform) and was discarded. Continued elution with chloroform gave 0.056 g. of yellow gum which was recrystallized from ethanol to give 0.009 g. (2%) of azine monoxide LXXVIII, m.p. 153-6° (dec.). Additional LXXVIII could not be obtained from the residual red-orange gum. A trace of a gum was eluted with methanol, and was discarded.

Oxidation of benzophenone oxime (LXXVII) in acetone

A solution of benzophenone oxime (LXXVII, 2.00 g., 0.01 mole) in anhydrous acetone (AR, 80 ml.) was prepared. A solution of ceric ammonium nitrate (5.54 g., 0.01 mole) in anhydrous acetone (AR, 50 ml.) was added from an addition funnel in one portion (15 seconds) with rapid stirring. After a short (2-3 second) induction period, the red-orange color of the cerium(IV) began to disappear. A yellow solution and precipitate were noted after 2 minutes. The odor of nitric oxide or nitrogen dioxide was very heavy over the solution. The reaction mixture was allowed to stir for 30 minutes. The solvent was removed on a rotary evaporator at 60° to give a red-brown oil. The residue was extracted with two 100 ml. portions of benzene, two 100 ml. portions of ether, and 100 ml. of chloroform. The insoluble solids were dissolved in water (80 ml.), and the water solution was extracted with two 50 ml. portions of benzene and 50 ml. of chloroform. After drying the combined extracts (magnesium sulfate), the solvents were removed, and the residue (red-brown) was chromatographed.

Fraction 1 of the chromatography (1:1 petroleum ether-benzene) was recrystallized as before to give 1.157 g. (44.2%) of dinitrodiphenylmethane (LXIX), m.p. 76-8°. Fraction 2 (benzene) contained 0.013 g. of a red semisolid which was discarded. Benzophenone (CLIX, 0.845 g., 45.7%, m.p. 46-8°) was isolated from fractions 3 and 4 (benzene) by the procedure described previously.

Fractions 5, 6, and 7 (1:1 benzene-chloroform) were combined and were recrystallized from ethanol to give 0.026 (2.3%) of p-nitrobenzophenone (CLXX), m.p. 131-3°. Two recrystallizations of the solid (ethanol) raised the melting point to 136-7° (lit. (139), m.p. 138°). The i r spectrum (KBr) of CLXX showed absorptions at 6.07μ (carbonyl), 6.60μ (nitro group), and 7.37μ (nitro group) (Figure 27, page 183). The mass spectrum gave a molecule ion at m/e 227, consistent with CLXX. An nmr spectrum ($CDCl_3$, Figure 29) revealed an A_2B_2 pattern centered at about 1.87τ (J_{AB} = ca. 9 c.p.s.), the high-field portion of which was partially obscured by a complex absorption due to protons on the other aromatic ring of CLXX.

Anal. Calcd. for $C_{13}H_9NO_3$: C, 68.72; H, 3.99; N, 6.16. Found: C, 68.77; H, 4.02; N, 5.99.

Fraction 8 (chloroform) contained 0.02 g. of gum, which was found to be a mixture of materials (by i r) and was not characterized further. Elution with 19:1 chloroform methanol, 9:1 chloroform-methanol, and 1:1 chloroform-methanol gave fractions 9 and 10 as a brown gum (total, 0.15 g.). The infrared spectrum ($CHCl_3$) of the combined fractions suggested the presence of an acidic material of some type in the gum, but all attempts to isolate and characterize anything were futile. An additional 0.012 g. of brown gum was obtained on stripping the column with methanol. This was discarded without further identification. Azine monoxide was not detected in the chromatography fractions. No oxime (LXXVII) was recovered.

Oxidation of benzophenone oxime (LXXVII) in deoxygenated acetone

Oxidation of benzophenone oxime (LXXVII) with ceric ammonium nitrate in deoxygenated acetone was carried out in the apparatus shown in Figure 54, page 372. The procedure used for degassing the solution was the same as that previously described for the oxidation of 9-fluorenone oxime (CLVI) in methanol under helium.

A rapidly stirred solution of 1.00 g. (0.005 mole) of benzophenone oxime in 80 ml. of anhydrous acetone (AR) was degassed for 45 minutes with dry helium. A solution of 2.76 g. (0.005 mole) of ceric ammonium nitrate in 25 ml. of anhydrous acetone

(AR) was degassed for 45 minutes with dry helium in an addition funnel. The helium flow through the solutions was stopped and the system was sealed. The CAN solution was added to the oxime solution in one portion (15 seconds) with rapid stirring. The red color of the cerium(IV) was rapidly discharged to give a dark green solution. A precipitate formed as the dark green color slowly faded to light yellow (ca. 1 minute). The reaction mixture was stirred for 30 minutes, after which time the solution was transferred to a flask, and the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with two 50 ml. portions of ether, two 50 ml. portions of benzene, and 50 ml. of chloroform. The insoluble salts were dissolved in 40 ml. of water, and the water solution was extracted with two 50 ml. portions of benzene and 50 ml. of chloroform. After drying the combined extracts (magnesium sulfate), the solvents were removed at reduced pressure and the residue was chromatographed to give the following results.

Dinitrodiphenylmethane (LXIX, 0.593 g., 45.3%, m.p. 75-7° (hexane)) was again isolated in fraction 1 (1:1-petroleum-benzene). The brown oil which composed fraction 3 (benzene) was purified and crystallized as described previously to give 0.419 g. (45.4%) of benzophenone (CLIX), m.p. 46-8°. Fraction 5 (1:1 benzene-chloroform) contained 0.068 g. of yellow gum which was recrystallized from ethanol to give 0.008 g. of impure p-nitrobenzophenone (CLXX), m.p. 128-31°. Additional material could not be isolated from fraction 5. Fractions 6 and 7 (chloroform and methanol) were combined to give 0.116 g. of an intractable brown gum from which nothing was isolable. Fractions 2 and 4 of the chromatography contained nothing. None of the starting oxime was recovered.

Preparation of benzophenone azine monoxide (LXXVIII)

Azine monoxide LXXVIII was prepared by the procedure of Horner, *et al* (116). Authentic benzophenone azine (CXX, 0.6 g.) was dissolved in chloroform (15 ml.) and the solution was cooled to 0° in an ice bath. A solution of peracetic acid in chloroform was prepared as follows. Three ml. of 40% peracetic acid was dissolved in 10 ml. of chloroform. After drying (anhydrous magnesium sulfate) and filtration, the solution was cooled to 0° (total volume of reagent, 15 ml.). A portion of the reagent (3.5 ml.) was then added to the azine solution dropwise over a 20 minute period with stirring. The temperature was maintained at 0° during the addition.

The reaction mixture was allowed to stir for 18 hours, over which time the solution was allowed to warm to room temperature. After this time, the reaction mixture was extracted with three 30 ml. portions of saturated sodium carbonate solution, and washed with two 30 ml. portions of water. The chloroform layer was dried (anhydrous magnesium sulfate), and the solvent was removed on a rotary evaporator. The crude brown oil remaining was passed through a column containing 40 g. of silica gel. Elution with benzene gave benzophenone, which was discarded. Azine monoxide LXXVIII eluted from the column in chloroform. The yellow-brown semisolid was triturated with carbon tetrachloride and the resulting yellow slurry was cooled to -10°. Filtration of the slurry gave 0.357 g. (57%) of benzophenone azine monoxide (LXXVIII), m.p. 158-60° (dec.), identical in every respect to LXXVIII isolated from the oxidation of benzophenone oxime with ceric ammonium nitrate.

Reaction of dinitrodiphenylmethane (LXIX) with nitric acid in methanol

Dinitrodiphenylmethane (0.225 g., m.p. 76-8°) was dissolved in methanol (40 ml.). Nitric acid (4 ml., 70%, sp. gr. 1.42) was added dropwise to minimize heat generation. The solution was then allowed to stir for 8 hours. After the solvent was removed (rotary evaporator), 50 ml. of water was added to the residue. The resulting slurry was extracted with four 50 ml. portions of benzene and 50 ml. of chloroform. Drying of the extracts with anhydrous $MgSO_4$ and removal of the solvents at reduced pressure gave 0.227 g. of a yellow oil. An infrared spectrum (CCl_4) of the oil was practically identical to that given by LXIX. A small absorption at 6.01μ was noted which was not present in the spectrum of LXIX. Chromatography on silica gel gave results which confirmed the i r analysis. Elution with 1:1 petroleum ether-benzene gave 2 fractions. Fraction 1 yielded 0.213 g. (95% recovery) of unreacted LXIX, m.p. 75-7° (hexane). Fraction 2 contained 0.010 g. of a light brown semisolid which would not crystallize. The i r spectrum (CCl_4) indicated the material to be impure benzophenone.

Experimental for the Oxidation of 1-Indanone Oxime (CLXIII) by Ceric Ammonium Nitrate

Oxidation of 1-indanone oxime (CLXIII) in methanol

To a solution of 1.00 g. (0.0068 mole) of 1-indanone oxime in 40 ml. of absolute methanol was added a solution of 3.74 g. (0.0068 mole) of ceric ammonium nitrate in 10 ml. of absolute methanol. The CAN solution was added in one portion (5 seconds) through a funnel with rapid stirring of the reaction mixture. The red color of the cerium(IV) was immediately discharged to give a light blue solution, which faded to yellow after 1 minute. The reaction mixture was allowed to stir for 20 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The dark yellow residue was extracted with 50 ml. of ether, three 50 ml. portions of benzene, and three 50 ml. portions of chloroform. The insoluble solids were mixed with 50 ml. of water, and the water solution was extracted with 50 ml. of benzene and 50 ml. of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), and the solvents were removed at reduced pressure. The residual dark red oil was chromatographed on silica gel to give the results which follow.

A yellow oil was isolated in fraction 1 (1:1 petroleum ether-benzene). Treatment of the oil with charcoal and recrystallization from hexane gave 0.379 g. (26.8%) of 1,1-dinitroindane (CLXXI), m.p. 40-42°. A second recrystallization from hexane raised the melting point to 42-3°. The i r spectrum (KBr) of CLXXI is shown in Figure 16, page 145. The mass spectrum gave a weak molecule ion at m/e 208 (Table 16, page 292). The nmr spectrum (CCl_4) revealed aromatic protons at 2.2-2.8τ (4H), and a singlet at 6.79τ (4H)(Figure 21, page 155). The "singlet" at 6.79τ (CCl_4) was observed to break up into a complex A_2B_2 pattern, centered at 7.52τ, when the nmr was recorded in benzene (Figure 21). This observation confirmed the fact that the nitro groups were on the 1 position of the indane nucleus, rather than the 2 position.

Anal. Calcd. for $C_9H_8N_2O_4$: C, 51.92; H, 3.87; N, 13.46. Found: C, 52.05; H, 3.81; N, 13.30.

Fractions 2 and 3 (benzene) contained 1-indanone (CLXXII) as a brown oil. A chloroform solution of the oil was treated with charcoal. After thorough evacuation and cooling, the oil crystallized to give 0.222 g. (24.7%) of CLXXII, m.p. 39-41° (lit. (140), m.p. 42°). The i r spectrum (KBr) of CLXXI was identical to that given by the authentic ketone.

Elution with 1:1 benzene-chloroform, chloroform, 4:1 chloroform-methanol, and methanol, gave fractions 4 through 7, respectively. Fraction 4 contained 0.045 g. of a yellow gum from which nothing could be isolated. Fractions 5 through 7 were combined to give 0.2 g. of brown semisolid. Trituration of the semisolid with ether gave 0.017 g. of a yellow solid, m.p. >300°, the i r spectrum of which was ill-defined in natre. Further identification was not carried out. The oxime CLXIII was not detected in the later chromatography fractions.

Oxidation of 1-indanone oxime (CLXIII) in acetone

A solution of 7.51 g. (0.013 mole) of ceric ammonium nitrate in 80 ml. of anhydrous acetone (AR) was added to a solution of 2.00 g. (0.013 mole) of 1-indanone oxime (CLXIII) in 50 ml. of anhydrous acetone (AR). The CAN solution was added in one portion (15 seconds) through a funnel with rapid stirring of the reaction mixture. The solution immediately became blue-green, followed by the formation of a precipitate. The color slowly faded to yellow-orange over a few minutes. The reaction mixture was stirred for 2 hours. The solvent was then removed from the orange-red solution on a rotary evaporator at 60°. Addition of 50 ml. of ether to the residue gave a blood red oil which was insoluble in the ether. The oil was extracted with five 100 ml. portions of benzene (100 ml. hot) and five 100 ml. portions of chloroform (100 ml. hot). Water (50 ml.) was poured into the residual solid, and the solution was extracted with 50 ml. of benzene and 50 ml. of chloroform. The combined extracts were dried ($MgSO_4$), and the solvents were removed at reduced pressure. The dark red oil was chromatographed as before.

Fraction 1 (1:1 petroleum ether-benzene) contained 1,1-dinitroindane (CLXXI) as a yellow semisolid, which was recrystallized from hexane to give 1.069 g. (37.8%) of light yellow solid, m.p. 38-40°. Fraction 2 (benzene) contained a trace of a mixture of CLXXI and 1-indanone. Fractions 3 and 4 (benzene and 9:1 benzene-chloroform) were combined. The brown oil was crystallized in the manner described previously to give 0.659 g. (36.6%) of 1-indanone (CLXXII), m.p. 38-40°.

The later fractions of the chromatography (fractions 5 through 11, 9:1 benzene-chloroform through methanol) were combined after attempts to identify the contents of the individual fractions proved to be futile. Varying amounts of red-brown gum were found in these fractions. The contents of the fractions totaled 0.49 g. after combination, which accounted for about 15% (by weight) of the crude residue before chromatography. Again, none of the oxime CLXIII was recovered.

Oxidation of 1-indanone oxime (CLXIII) in deoxygenated acetone

The oxidation of CLXIII with ceric ammonium nitrate in deoxygenated acetone was conducted in the apparatus shown in Figure 54, page 372. The degassing procedure was the same as that previously described for the oxidations of 9-fluorenone oxime and benzophenone oxime.

Solutions of 1.00 g. (0.0068 mole) of CLXIII in 80 ml. of anhydrous acetone (AR) and 3.74 g. (0.0068 mole) of CAN in 40 ml. of anhydrous acetone (AR) were degassed for 45 minutes with dry helium. After the helium flow was stopped and the system sealed, the CAN solution was added to the oxime solution in one portion (20 seconds) with rapid stirring. The immediate formation of a blue-green color in the solution was observed as before. A precipitate formed as the color faded to yellow-orange. The solution was stirred for 30 minutes. The reaction mixture was transferred to a flask, and the solvent was removed at reduced pressure (60°). The red-brown residue was extracted with two 50 ml. portions of benzene, two 50 ml. portions of ether, and 50 ml. chloroform. Water (50 ml.) was poured into the extraction residue, and the solution was extracted with two 50 ml. portions of benzene, two 50 ml. portions of ether, and 50 ml. of chloroform. The combined extracts were dried ($MgSO_4$), and were concentrated at reduced pressure. The red residue was chromatographed.

The results of the chromatography were as follows: 1,1-dinitroindane (CLXXI), 36.2% (0.512 g., m.p. 41-3° (pentane-hexane)); 1-indanone (CLXXII), 37.2% (0.334 g., m.p. 38-40°); and red-brown gum, 0.249 g. (about 16% by weight of the crude extraction residue).

In a similar experiment, a solution of 2.00 g. of CLXIII in 80 ml. of anhydrous acetone (AR) was prepared and was degassed with dry helium for 1.5 hours by means of a sintered glass gas bubbler inserted through one neck of a flask. A solution of 7.48 g. of CAN in 80 ml. of anhydrous acetone (AR) was degassed for 1 hour in an addition funnel. The CAN solution was added dropwise over a 20 minute period to the oxime solution with rapid stirring of the reaction mixture. Helium was allowed to flow through the apparatus during the entire reaction.

After all of the cerium(IV) solution had been added, the reaction mixture was allowed to stir for 50 minutes. The solvent was removed, and the residue was worked up in the normal manner. The results of the chromatography are summarized as follows: 1,1-dinitroindane (CLXXI), 27.7% (0.785 g., m.p. 42-3°(pentane-hexane)); 1-indanone (CLXXII), 35.6% (0.630 g., m.p. 37-9°); and red-brown gum, 0.23 g. (ca. 10% by weight of the crude reaction mixture).

Titration of 1-indanone oxime (CLXIII)

A. Acetone A standard solution of ceric ammonium nitrate in anhydrous acetone (AR) was prepared which contained 0.000144 mole of cerium(IV) per milliliter of solution. Samples of CLXIII were weighed out and dissolved in anhydrous acetone (AR). Titration of each sample was carried out by the dropwise addition of CAN solution from a buret until no further disappearance of the red-orange color of the cerium(IV) could be detected after a 15 minute waiting period. The data which was recorded is summarized in Table 22. The stoichiometry of the reaction was found to be about 2 moles of cerium(IV) per mole of CLXIII. The numbers in parentheses in the last three columns of Table 22 are shown to illustrate the following observation. The initial dropwise addition of CAN solution was followed by a rapid discharge of the red color of the cerium-(IV) to give a blue-green solution. The blue-green color then faded, leaving a colorless solution. In each instance, a point was reached where the solution began to turn yellow after each

Table 22. Titration of 1-indanone oxime (CLXIII) in acetone

Sample No.	Weight Oxime (g.)	Moles Oxime[a]	Volume CAN[b]	Moles CAN[a]	(Moles CAN) / (Moles Oxime)
1	0.0357	2.4	3.41 (1.17)	4.9 (1.7	2.02 (0.70)
2	0.0385	2.6	3.72 (1.31)	5.3 (1.9)	2.03 (0.71)
3	0.0294	2.0	2.87 (0.98)	4.1 (1.4)	2.05 (0.70)

[a] Moles of oxime or CAN x 10^{-4}.

[b] Volume of ceric ammonium nitrate solution in milliliters.

drop of CAN had been added and had reacted. The yellow color deepened rapidly on further titration even though the cerium(IV) was still reacting immediately. As can be seen from the data, 0.7 mole of CAN was required to reach this point.

After the last sample had been titrated to a satisfactory endpoint, the three reaction mixtures were combined. The solvent was removed on a rotary evaporator at 60° to give a red-orange residue, which was extracted with 50 ml. portions of ether, benzene, and chloroform, respectively. The insoluble solids were dissolved in 15 ml. of water, and the water solution was extracted with 25 ml. each of benzene and chloroform. The combined extracts were dried ($MgSO_4$), and the solvents were removed to give 0.167 g. of red-brown residue. The residue was chromatographed on silica gel to give the results which follow.

Fraction 1 (1:1 petroleum ether-benzene) was recrystallized from hexane to give 0.043 g. (20%) of 1,1-dinitroindane (CLXXI), m.p. 40-42°. Fraction 2 (benzene) contained only a trace of material which was discarded. Fractions 3 and 4 (benzene-chloroform mixtures) showed i r spectra ($CHCl_3$) which were identical to that of authentic 1-indanone. The brown oil (0.075 g. crude) was dissolved in ethanol and a 2,4-dinitrophenylhydrazone derivative was prepared by a standard method (134). The red solid was filtered and was recrystallized (ethyl acetate-ethanol) to give 0.126 g. of the derivative, m.p. 255-7° (lit. (141), m.p. 257-8°). A mixed melting point with authentic 1-indanone-2,4-dinitrophenyl hydrazone, m.p. 256-8°, gave no depression (m.m.p. 256-8°). The yield of CLXXII was 57.5% based on the derivative. Elution with chloroform and methanol gave 0.026 g. of red gum which was not characterized further.

B. <u>Methanol</u> A standard solution of ceric ammonium nitrate in methanol containing 0.000146 mole of CAN per milliliter of solution was prepared and placed in a buret. Samples of CLXIII were dissolved in absolute methanol and were titrated in the manner described for the titration in acetone solution. The data which was recorded is shown in Table 23. The stoichiometry of the reaction was found to be about 3 moles of CAN per mole of CLXIII. The numbers in parentheses in the last three columns of Table 23 again indicate a point in the titrations where the blue-green color initially formed no longer faded to give a colorless solution. After about 1 mole of CAN had been added, each additional drop imparted a rapidly deepening yellow color to the solution regardless of the fact that the cerium(IV) still reacted immediately. The rate of disappearance of the cerium(IV) color decreased noticeably after about two moles of CAN had been added, even though reaction was still occurring. A good estimate of the quantity of cerium(IV) required to reach this point could not be made due to color difficulties.

Table 23. Titration of 1-indanone oxime (CLXIII) in methanol

Sample No.	Weight Oxime (g.)	Moles Oxime[a]	Volume CAN[b]	Moles CAN[a]	(Moles CAN)/(Moles Oxime)
1	0.0338	2.3	4.67	6.8	2.97
2	0.0517	3.5	7.21 (2.50)	10.5 (3.7)	3.00 (1.04)
3	0.0589	4.0	8.73 (2.75)	12.7 (4.0)	3.17 (1.00)

[a] Moles of oxime or CAN x 10^{-4}.

[b] Volume of ceric ammonium nitrate solution in milliliters.

Reaction of 1,1-dinitroindane (CLXXI) with ceric ammonium nitrate

The dinitro compound CLXXI (0.392 g., 0.0019 mole) in anhydrous acetone (20 ml.) was treated with a solution of ceric ammonium nitrate (1.04 g., 0.0019 mole) in anhydrous acetone (20 ml.). The red-orange solution was stirred for 30 minutes. No change in the color of the solution could be detected at the end of this time. The solvent was removed on a rotary evaporator at 60°. The red-orange residue was extracted with two 50 ml. portions of ether and 50 ml. of benzene. The insoluble orange solids were dissolved in 30 ml. of water, and the water solution was extracted with 50 ml. of ether. The combined extracts were dried (anhydrous $MgSO_4$), and the solvents were removed at reduced pressure. An i r spectrum (CCl_4) of the residual brown oil showed it to be unreacted CLXXI. Recrystallization of the oil from pentane-hexane gave 0.236 g. (60.2% recovery) of CLXXI, m.p. 40-42.5°. Only 0.029 g. of impure CLXXI remained in the mother liquor (as shown by i r) from the recrystallization (total recovery of CLXXI, about 67%).

Experimental for the Oxidation of p-Nitroacetophenone Oxime (CLXIV) by Ceric Ammonium Nitrate

Oxidation of p-nitroacetophenone oxime (CLXIV) in methanol

Ceric ammonium nitrate (3.018 g., 0.0055 mole) was dissolved in absolute methanol (20 ml.) in an addition funnel. A solution of p-nitroacetophenone oxime (CLXIV, 1.003 g., 0.0055 mole) in absolute methanol (50 ml.) was prepared. The CAN solution was added to the oxime solution in one portion (10 seconds) with rapid stirring of the reaction mixture. The red color of the cerium(IV) was immediately discharged to give a dark green solution, which faded to yellow in about 20 seconds. After 2 minutes, the odor of nitrogen(II) or nitrogen(IV) oxide became noticeable over the light yellow solution.

The reaction mixture was stirred for 40 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The light yellow residue was extracted with 100 ml. of ether, and four 100 ml. portions of benzene. The insoluble solids were dissolved in water (50 ml.), and the water solution was extracted with four 50 ml. portions of benzene. The combined extracts were dried (anhydrous $MgSO_4$), and the solvents were removed at reduced pressure. The residue was then chromatographed as before.

Elution with 1:1 petroleum ether-benzene gave only a trace of material which was discarded. Fraction 2 (3:2 through 4:1 benzene-petroleum ether) contained a yellow oil. An infrared spectrum (CCl_4) showed (in addition to considerable residual hydrocarbon solvent) broad absorptions at 6.37-6.54μ (medium), and 7.44μ (strong) which were consistent with a compound containing both aliphatic and aromatic nitro groups. A band at 6.09μ (medium) was also present in the spectrum which suggested an olefinic material. A chloroform solution of the oil was treated with charcoal, and, after thorough evacuation, the residue was recrystallized from pentane. Colorless needles (0.017 g., 1.4%), m.p. 39-41°, were obtained. The infrared spectrum (KBr, Figure 17, page 147) was consistent with 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII) (6.37, 6.53μ-aliphatic and aromatic nitro groups; also broad 7.42μ-both types of nitro groups). The mass spectrum gave no molecule ion (Table 16, page 292). The olefinic material suggested by the i r spectrum of the crude fraction could not be isolated and characterized.

Fraction 3 (benzene) showed a weak 5.80μ absorption in the i r ($CHCl_3$), in addition to absorptions due to a small amount of p-nitroacetophenone (CLXXIV). Nothing could be crystallized from the 0.03 g. of yellow gum and no further characterization was made. Fraction 4 (benzene, benzene-chloroform mixtures, and chloroform) was recrystallized from ethanol to give 0.601 g. (75.5%) of p-nitroacetophenone (CLXXIV), m.p. 75-8°. Recrystallization of a small portion of the solid gave finely divided yellow needles, m.p. 81-2° (lit. (142), m.p. 77-8°). A mixed melting point of CLXXIV with authentic p-nitroacetophenone, m.p. 82-3°, gave no depression (m.m.p. 81.5-83°). The i r spectrum ($CHCl_3$) of CLXXIV was identical to that given by the authentic ketone.

Fraction 5 (chloroform) contained 0.266 g. of a yellow solid. An i r spectrum ($CHCl_3$) indicated the material to be mostly unreacted oxime CLXIV. Recrystallization of the solid from ethanol gave, instead of oxime, 0.039 g. of p-nitroacetophenone azine monoxide (CLXXV), m.p. 138-142° (dec.). The residue remaining after removal of CLXXV was recrystallized from chloroform to give 0.151 g. of impure oxime CLXIV, m.p. 168-71°. A second recrystallization of CLXIV (chloroform) gave 0.135 g. (13.5% recovery), m.p. 173-5°. The i r spectrum (KBr) of CLXIV was superimposable with that given by the authentic oxime. The yellow gum (0.05 g.) remaining after CLXIV and

CLXXV had been removed from the fraction was discarded due to its intractable nature.

The crude azine monoxide isolated from fraction 5 was recrystallized from ethanol to give 0.027 g. (3.3%) of yellow solid, m.p. 140-42° (dec.). The molecular weight of the compound was shown by a mass spectrum to be 342 (Table 19, page 315). The i r spectrum (KBr) of CLXXV is shown in Figure 20, page 153. A satisfactory combustion analysis was not obtained for CLXXV due to partial decomposition during recrystallization. Several attempts at recrystallization resulted in the isolation of solid with a melting point lower than that of the material before recrystallization. An nmr spectrum ($CDCl_3$) of CLXXV contaminated with p-nitroacetophenone oxime (CLXIV) is shown in Figure 26, page 165. The nmr spectrum ($CDCl_3$, saturated solution) of CLXIV is shown in Figure 26 for purposes of comparison. The assignments of the absorptions in the spectrum of the mixture were as follows: An A_2B_2 pattern due to the para-disubstituted aromatic rings of CLXXV centered at 1.91τ (J_{AB} = ca. 9 c.p.s.), superimposed on an A_2B_2 from CLXIV centered at 1.98τ (J_{AB} = 9.2 c.p.s.); oxime hydroxyl proton at 7.32τ (disappeared on addition of D_2O to sample); methyl groups of CLXXV, singlet at 7.56τ. The composition of the mixture was about 72% CLXXV and 28% CLXIV (by nmr integration). The peak at 8.74τ was due to additional impurity in the sample.

Fraction 6 (methanol) contained 0.017 g. of a brown gum which gave an i r spectrum ($CHCl_3$) suggestive of an acidic material. Nothing was isolable from the crude fraction. No further identification was made.

Oxidation of p-nitroacetophenone oxime (CLXIV) in aqueous methanol

p-Nitroacetophenone oxime (1.00 g., 0.0055 mole) was dissolved in 80% methanol-20% water (100 ml.). Ceric ammonium nitrate (3.02 g., 0.0055 mole) dissolved in 80% methanol-20% water (25 ml.) was added to the oxime solution in one portion (10 seconds) from an addition funnel with rapid stirring. The solution turned green immediately, accompanied by the formation of a white precipitate. The green color faded rapidly to a light yellow (10 seconds). Ten minutes after the CAN solution had been added, it was noted that the precipitate had completely redissolved. The reaction mixture was allowed to stir for 1 hour, after which time most of the methanol was removed on a rotary evaporator at 60°. Water (50 ml.) was mixed with the residue, and the yellow slurry was extracted with four 100 ml. portions of benzene and 100 ml. of chloroform. The extracts were dried (anhydrous $MgSO_4$), and the solution was evaporated at reduced pressure. The chromatography of the residue gave the results which follow.

Fraction 1 (7:3, 3:2, and 1:1 petroleum ether-benzene) contained 0.027 g. of brown oil. The i r spectrum ($CHCl_3$) gave no evidence for the presence of an olefinic material. The oil was recrystallized (pentane) to give 0.009 g. (<1%)

of 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII), m.p. 39-41°.

Continued elution with 1:1 petroleum ether-benzene gave fraction 2 (tan semisolid, 0.067 g.). Recrystallization of the fraction from ethanol afforded 0.009 g. of yellow-orange needles, m.p. 162-3° (dec.). An i r spectrum (KBr, Figure 19, page 151, Unknown A) of the compound was similar to that given by oxime CLXIV, but showed no absorption characteristic of the hydroxyl group of CLXIV. Differences in the 11.7-15.0μ region of the spectrum indicated that some change in the nature of a substituent on the aromatic nucleus of CLXIV had taken place. A weak absorption at 6.12μ (nearly nonexistent in the i r of CLXIV) was noted. The mass spectrum of the solid gave a weak molecule ion at m/e 327 (70 ev.). The base peak of the spectrum was observed at m/e 180. At an ionization energy of 18 ev., the peak at m/e 327 became one of the most intense peaks in the spectrum.

The brown gum remaining in the fraction yielded a trace of orange solid, m.p. range 125-185° (dec.), on a second recrystallization from ethanol. An i r spectrum ($CHCl_3$) of the remaining gum indicated it to be predominantly p-nitroacetophenone (CLXXIV).

Fraction 3 (1:1 and 7:3 benzene-petroleum ether) was recrystallized from ethanol to give 0.391 g. (56.1%) of p-nitroacetophenone (CLXXIV), m.p. 78-80°. Fraction 4 (4:1 benzene-petroleum ether and benzene) yielded 0.050 g. of a tan solid, m.p. 92-6° (Unknown B) on recrystallization from ethanol. The i r spectrum (KBr, Figure 19, page 151, Unknown B) showed no absorption due to a carbonyl group. Absorptions at 6.59μ and 7.43μ indicated the presence of an aromatic nitro group in the molecule. An nmr spectrum (CCl_4, Figure 31, page 191) revealed superimposed AB (or A_2B_2) (to a first approximation) patterns in the 1.67-2.50τ region, and six singlets, at 6.80, 6.90, 7.60, 7.79, 8.22, and 8.37τ, respectively. The ratio of aromatic protons to aliphatic protons was 1:1.04. The smaller singlets (6.90, 7.79, and 8.37τ) integrated in the ratio of 1:5 with the larger peaks (6.80, 7.60, and 8.22τ), and the absorptions in each set integrated in the ratio of 1:1 with each other.

Recrystallization of Unknown B (m.p. 92-6°) from hexane gave white clumps (0.035 g.), m.p. 105-8° (Unknown C). An nmr spectrum (CCl_4) of Unknown C was identical in every respect to the spectrum given by Unknown B. An i r spectrum (CCl_4) was also identical to the one given by Unknown B. The mass spectra of Unknown B and Unknown C are summarized in Table 24. The spectra were recorded at 70 ev. Intensities are expressed as percent of the base peak. Metastable ions which were observed in the spectra are also given. At an ionization energy of 18 ev., only ions at m/e 150, 165, 179, 180, and 181 were observed in the mass spectrum of Unknown C. At ionization energies of 13 and 14 ev., only ions at m/e 179, 180, and 181 remained in the spectrum of C. Further characterization of the materials was not carried out due to the small quantity remaining.

Table 24. Mass spectra of Unknown B and Unknown C at 70 ev.

	Intensity[a]			Intensity[a]	
m/e	B	C	m/e	B	C
43	7.0	24.1	124		2.1
44	1.0	53.3	125		4.1
50	2.1	3.8	126		4.6
51	1.4	3.6			
57	1.4	18.9			
63	1.0	7.2	134	12.8	
65	1.8		135	1.5	6.2
75	1.6	7.9	137		4.4
76	4.1	18.2	149	1.0	25.5
77	4.1		150	3.1	25.5
91	10.9	3.4	151	0.4	17.6
92	1.9	2.7	152		22.2
103	1.9		163	4.5	2.3
104	1.8	3.6	164	1.7	2.2
105		3.7	165	0.7	10.8
117	4.1		166		5.1
			179	2.0	43.7
			180	100.0	100.0
			181	11.0	15.3
123		3.3			

Metastable ions in the mass spectra of Unknowns B and C

PROCESS		
B	C	m/e (Intensity[b])
180 → 163		147.6 (vw)
	180 → 152	128.4 (s)
180 → 150		125.0 (m)
150 → 134		119.7 (w)
180 → 134		99.7 (m)
150 → 120		96.0 (w)
163 → 117		83.9 (w)

[a] Intensity expressed as percent of the base peak (100%).

[b] vw = very weak; w = weak; m = medium; and s = strong.

A mixture of compounds eluted from the column in benzene (fraction 5). Fractional recrystallization of the mixture from chloroform gave 0.239 g. (23.9%) of unreacted CLXIV. After removal of CLXIV, the residue was recrystallized from ethanol to give 0.039 g. (5%) of p-nitroacetophenone azine monoxide (CLXXV), m.p. 139-5-41° (dec.). Elution with chloroform and methanol resulted in the isolation of a brown gum (0.05 g.) which was not characterized further.

Oxidation of p-nitroacetophenone oxime (CLXIV) in acetone

A solution of 1.00 g. (0.0055 mole) of p-nitroacetophenone oxime (CLXIV) in 50 ml. of anhydrous acetone (AR) was prepared. A solution of 3.02 g. (0.0055 mole) of ceric ammonium nitrate in 50 ml. of anhydrous acetone was prepared in an addition funnel. The CAN solution was then added to the oxime solution in one portion (10 seconds) with rapid stirring. The orange color of the cerium(IV) was observed to disappear very slowly. A precipitate cerium(III) salts) began to form after 1 minute. No blue or green color was observed to form upon addition of the cerium(IV) solution. After 4 minutes, the color of the solution had faded to light yellow. The solution was allowed to stir for 40 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with 100 ml. of ether, and four 100 ml. portions of benzene. The insoluble residue was dissolved in water (50 ml.), and the water solution was extracted with four 50 ml. portions of benzene. The combined extracts were dried ($MgSO_4$) and the solvents were removed at reduced pressure. The residue was chromatographed as before.

Elution with 4:1 petroleum ether-benzene gave fraction 1 which contained nothing. The i r spectrum ($CHCl_3$) of fraction 2 (4:1 and 7:3 petroleum ether-benzene) showed an absorption at 6.14μ (C=C), and absorptions at 6.45-6.60μ (broad) and 7.45μ (olefinic and/or aromatic nitro groups). Only 0.018 g. of yellow oil was isolated in the fraction, a good portion of which was residual high-boiling hydrocarbon solvent. In this light, further characterization was not attempted.

Elution with 3:2 and 1:1 petroleum ether-benzene gave fraction 3 as a light yellow oil (0.333 g.). Recrystallization of the oil (hexane) yielded 0.272 g. (18.6%) of 1,1-dinitro-1-(p-nitrophenyl)-ethane (CLXXIII), m.p. 41-3°. The i r spectrum (KBr) was identical to that given by CLXXIII isolated from the oxidation of p-nitroacetophenone oxime in methanol (Figure 17, page 147). Two recrystallizations of CLXXIII from pentane gave white needles, m.p. 41.5-42.5°. No molecule ion was observed in the mass spectrum of CLXXIII (Table 16, page 292) even at low electron energies. The nmr spectrum ($CDCl_3$, Figure 22, page 157) showed a singlet at 7.33τ (3H) and a complex A_2B_2 pattern centered at 1.94τ (4H).

Anal. Calcd. for $C_8H_7N_3O_6$: C, 39.84; H, 2.93; N, 17.42. Found: C, 40.06; H, 3.19; N, 17.41.

Fraction 4 (1:1 petroleum ether-benzene through benzene) was recrystallized from ethanol to give 0.653 g. (71.3%) of p-nitroacetophenone (CLXXIV), m.p. 77-9°.

Fraction 5 (benzene through 1:1 benzene-chloroform) was found to contain predominantly high boiling hydrocarbons (by i r). Attempts to obtain crystalline material from the 0.14 g. of brown oil were unsuccessful. Fraction 6 (0.057 g. of yellow gum, 1:1 benzene-chloroform through chloroform) gave an i r spectrum which indicated the presence of compounds containing an aromatic nitro group. Nothing was isolable from the mixture. Fraction 7 (9:1 chloroform-methanol) contained 0.095 g. of brown gum. An i r spectrum of a saturated chloroform solution of the gum gave broad absorptions reminescent of polymeric materials. Attempts to crystallize the gum were unsuccessful. Further characterization was not made. None of the azine monoxide CLXXV or unreacted oxime CLXIV was detected in fractions 5-7.

Experimental for the Oxidation of α-Phenylacetophenone Oxime (CLXV) by Ceric Ammonium Nitrate

Oxidation of α-phenylacetophenone oxime (CLXV) in methanol

A solution of 2.58 g. (0.0047 mole) of ceric ammonium nitrate in 10 ml. of absolute methanol was added in one portion (10 seconds) to a solution of 1.00 g. (0.0047 mole) of α-phenylacetophenone oxime (CLXV) in 40 ml. of absolute methanol. The CAN solution was added from an addition funnel with rapid stirring of the reaction mixture. The solution became blue-green immediately, the color of which slowly faded to yellow over a few minutes. The odor of a nitrogen oxide became very noticeable over the solution. The reaction mixture was stirred for 1 hour, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with 50 ml. of ether, four 50 ml. portions of benzene, and two 50 ml. portions of chloroform. The insoluble material was dissolved in water (50 ml.), and the water solution was extracted with two 50 ml. portions each of benzene and chloroform. The combined extracts were dried (anhydrous magnesium sulfate), and the solvents were removed at reduced pressure. The residual yellow oil was chromatographed on silica gel to give the following results.

Fraction 1 (1:1 petroleum ether-benzene) contained 0.38 g. of yellow oil which was found (by i r) to contain a nitro compound contaminated by a ketone. The oil was then rechromatographed on a long, narrow column of silica gel (50 g.). Elution with 1:1 petroleum ether-benzene and benzene gave two new fractions. Fraction 1 was recrystallized from pentane to give 0.167 g. (13%) of 1,1-dinitro-1,2-diphenylethane (CLXXVI) as light yellow-needles, m.p. 70-71°. The nitro compound CLXXVI was recrystallized again giving white needles, m.p. 71-2° (pentane). The i r spectrum (KBr) of 1,1-dinitro-1,2-diphenylethane (CLXXVI) is shown in Figure 17. The nmr spectrum of CLXXVI (CCl_4, Figure 23) gave a singlet at 5.83τ (methylene) and aromatic hash at 2.50-3.17τ, in the ratio 1:5, respectively. The molecular weight was found to be 272 (mass spec.,

Table 16, page 292).

Anal. Calcd. for $C_{14}H_{12}N_2O_4$: C, 61.76; H, 4.44; N, 10.29. Found: C, 61.73; H, 4.51; N, 10.17.

The i r spectrum (CCl_4) of the original fraction before the second silica gel separation was carried out had indicated the presence of a small amount of an olefinic material (6.10μ absorption) in the oil. The absorption at 6.10μ was also noted in the i r spectrum (CCl_4) of the first fraction of the second chromatography.. Attempts at isolation and characterization of the compound responsible for the i r band were unsuccessful.

The second fraction (1:1 petroleum ether-benzene and benzene) collected in the rechromatography of fraction 1 contained 0.108 g. of a yellow gum, which yielded 0.073 g (7.8%) of α-phenylacetophenone (CLXXVII), m.p. 53-5°, on recrystallization from ethanol.

Fractions 2, 3, and 4 (1:1 petroleum ether-benzene) of the first chromatography were combined on the basis of i r spectra (CCl_4). The yellow solid was recrystallized from ethanol to give 0.525 g. (56.5%) of α-phenylacetophenone (CLXXVII), m.p. 54-6° (lit. (143), m.p. 55-6°), identical in every respect to the authentic ketone. The overall yield of CLXXVII was 64.3% (0.598 g.).

Fraction 5 (benzene) contained 0.035 g. of a brown solid, which was recrystallized from ethanol to give 0.014 g. (1.2%) of tan needles, m.p. 147-50°. The mass spectrum of the solid gave a molecule ion at m/e 241. The nmr spectrum of α-phenyl-p-nitroacetophenone (CLXXVIII) ($CDCl_3$, Figure 29) showed an A_2B_2 pattern centered at 1.82τ (4H, J_{AB} = ca. 9 c.p.s., δ_A = ca. 1.75τ, δ_B = ca. 1.90τ), and singlets at 2.73τ (5H) and 5.71τ (2H). The observation of the A_2B_2 pattern indicated that the position of the nitro group in CLXXVIII was para to the carbonyl moiety. The i r spectrum (KBr) of CLXXVIII is shown in Figure 27. Recrystallization of CLXXVIII for analytical purposes gave light yellow needles, m.p. 155-7° (lit. (144), m.p. 156-7.5°).

Anal. Calcd. for $C_{14}H_{11}NO_3$: C, 69.70; H, 4.60; N, 5.81. Found: C, 69.72; H, 4.62; N, 5.79.

Fraction 6 (chloroform) held a light yellow semisolid, the i r spectrum ($CHCl_3$) of which showed a 5.75μ absorption and no bands characteristic of a nitro group. The semisolid was recrystallized from hexane to give 0.040 g. of a tan solid, m.p. 79-82°. A second recrystallization raised the melting point to 83-4°. An nmr spectrum (CCl_4, Figure 30, page 189) of the material (Unknown D) showed complex absorptions at 1.92-2.35τ and 2.45-2.90τ (with a superimposed singlet at 2.83τ) characteristic of an ortho-disubstituted aromatic compound, and a singlet at 5.73τ, in the ratio 2:5.5:1, respectively. Addition of D_2O to the sample gave no change in the ratio of the absorptions. The i r spectrum (KBr) is shown in Figure 28, labeled Unknown D. The results of a combusion analysis of the material suggested an empirical formula of $C_{20}H_{17}NO_2$

(calculated $C_{19.9}H_{16.8}NO_2$), which required a molecular weight of 303. The mass spectrum gave an apparent molecule ion at m/e 224. The base peak of the spectrum was observed at m/e 105, accompanied by less intense ions at m/e 91 and 77. Furthur characterization of the material was not made.

Anal. Found: C, 79.13; H, 5.56; N, 4.64.

Fraction 7 (9:1 chloroform-methanol) contained 0.061 g. of brown gum. An i r spectrum of the gum showed a broad absorption at 2.8-3.4μ which suggested that some unreacted oxime was present in the mixture. Attempts to obtain crystalline material from the fraction were unsuccessful. Stripping the column with methanol gave a trace of a white solid which was not characterized further.

Oxidation of α-phenylacetophenone oxime (CLXV) in acetone

A solution of 1.00 g. (0.0047 mole) of α-phenylacetophenone oxime (CLXV) in 40 ml. of anhydrous acetone (AR) was prepared. A solution of 2.58 g. (0.0047 mole) of ceric ammonium nitrate in 50 ml. of anhydrous acetone (AR) was prepared in an addition funnel and was added to the oxime solution in one portion (10 seconds) with rapid stirring. The orange color of the cerium(IV) slowly faded to give a green solution. The green color then faded leaving a yellow solution. The odor of a nitrogen oxide was noticeable in the reaction vessel. The reaction mixture was stirred for 30 minutes, and the solvent was removed on a rotovac at 60°. The residue was extracted by the procedure given under the oxidation of CLXV in methanol. After drying the extracts (anhydrous $MgSO_4$), the solvents were removed, and the residue was chromatographed as before.

Elution with 4:1 petroleum ether-benzene gave fraction 1 as a yellow oil. The oil was recrystallized from pentane yielding 0.266 g. (20.6%) of 1,1-dinitro-1,2-diphenylethane (CLXXVI) m.p. 70-71°. The material was identical in every respect to CLXXVI characterized in the oxidation of oxime CLXV in methanol.

Fraction 2 (7:3 petroleum ether-benzene) contained 0.047 g. of a yellow semisolid. An i r spectrum (CCl_4, Figure 17, page 147) showed a 6.10μ absorption, in addition to 5.82μ and 5.95μ carbonyl bands, due to an unknown material and a small amount of CLXXVII, respectively. A broad band at 6.37μ, with a 6.55μ shoulder, and a band at 7.42μ, suggested the presence of compounds containing aliphatic and olefinic (or aromatic) nitro groups. The nmr spectrum (CCl_4, Figure 23) of the crude fraction showed absorptions at 1.77τ and 1.92τ, perhaps due to the presence of <u>trans</u>- and <u>cis</u>-α-nitrostilbene (CLXXIX),[1] respectively in the mixture. The lack of an absorption at 5.71τ (corresponding to the CH_2 group of α-phenyl-<u>p</u>-nitroacetophenone (CLXXVIII)) indicated that the low field absorptions were not a part of the A_2B_2 pattern observed in the spectrum of CLXXVIII (Figure 29). The broad singlet at 5.82τ was assigned to the

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[1] See Results and Discussion Section, page 196 .

methylene protons of CLXXVI and the ketone CLXXVII.[1] The singlet at 4.72τ was unassigned, although it may have been due to the compound which had contributed the 5.82μ carbonyl band to the i r spectrum of the mixture. Attempts to characterize the mixture further were unsuccessful.

Fraction 3 (1:1 petroleum ether-benzene) was recrystallized from ethanol to give 0.490 g. (52.7%) of α-phenylacetophenone (CLXXVII), m.p. 54-6°, identical in every respect to the authentic ketone. Fraction 4 (4:1 petroleum ether-benzene and benzene) contained impure α-phenyl-p-nitroacetophenone. Recrystallization of the fraction from ethanol gave 0.026 g. (2.3%) of tan needles, m.p. 149-51°, which were identical in every respect to CLXXVIII characterized previously. Fraction 5 (benzene) was discarded as it was found to contain a mixture of materials (0.016 g.).

Fraction 6 (1:1 benzene-chloroform and chloroform) gave an i r spectrum ($CHCl_3$) which was identical to that given by Unknown D from the oxidation in methanol. The gum was recrystallized from hexane to give 0.039 g. of tan solid, m.p. 78-81°. A second recrystallization (hexane) raised the melting point of the solid to 82-4°. A mixed melting point with Unknown D isolated previously, m.p. 83-4°, showed no depression (m.m.p. 82-4°). The spectral properties of the compound were noted previously.

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[1] The methylene protons of CLXXVI were observed at 5.83τ (Figure 23), while those of CLXXVI were observed at 5.92τ in the spectrum (CCl_4) of an authentic sample (Figure 30).

Elution with chloroform, 9:1 chloroform-methanol, and methanol, gave fractions 7, 8, and 9, respectively. Fraction 7 contained 0.03 g. of gum which was found to be a mixture of materials (by i r). Further characterization of the fraction was not carried out. Fractions 8 and 9 (0.097 combined) gave i r spectra ($CHCl_3$) which suggested the presence of a carboxylic acid in the gum (broad 2.85-4.5μ, OH; broad 5.82μ, C=O). Numerous attempts at isolation of a compound (or compounds) responsible for the observed i r were unsuccessful. None of the oxime CLXV was recovered.

Experimental for the Oxidation of Acetophenone Oxime (CLXVI) by Ceric Ammonium Nitrate

Oxidation of acetophenone oxime (CLXVI) in methanol

A solution of 1.00 g. (0.0074 mole) of acetophenone oxime (CLXVI) in 50 ml. of absolute methanol was reacted with a solution of 4.06 g. (0.0074 mole) of ceric ammonium nitrate in 20 ml. of absolute methanol as follows. Addition of the CAN solution to the oxime solution was made from an addition funnel in one portion (10 seconds) with rapid stirring. The reaction mixture became a brilliant blue immediately. After 7 minutes, the blue color was observed to have faded to a light blue-green. The solution was stirred for 35 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with four 50 ml. portions of ether, two 50 ml. portions of benzene, and 50 ml. of chloroform.

Solids insoluble in the organic solvents were dissolved in water (50 ml.), and the water solution was extracted with two 50 ml. portions of ether and 50 ml. of benzene. The combined extracts were dried ($MgSO_4$), and the solvents were removed at reduced pressure. The residual yellow oil was chromatographed on silica gel.

Elution with 1:1 petroleum ether-benzene gave fraction 1 as a yellow oil (crude 0.45 g.). A chloroform solution of the oil was dried (anhydrous magnesium sulfate), followed by treatment of the solution with charcoal. After filtration and thorough evacuation of the filtrate, 0.395 g. (27%) of a viscous oil (LXXII) was obtained. A small amount of the oil was distilled (molecular still), to give a nearly colorless liquid, b.p. 85-7°/0.13 mm. (lit. (56), m.p. 6°). The i r spectrum (neat) of 1,1-dinitro-1-phenylethane (LXXII) is shown in Figure 18, page 149. The nmr spectrum (CCl_4 , Figure 24, page 161) showed singlets at 2.58τ and 7.51τ, in the ratio 5:3, respectively. The mass spectrum of LXXII (Table 17, page 293) gave no molecule ion even at low ionization energies.

<u>Anal</u>. Calcd. for $C_8H_8N_2O_4$: C, 48.98; H, 4.11; N, 14.28. Found: C, 49.01; H, 4.12; N, 14.14.

Fraction 2 (1:1 petroleum ether-benzene and benzene) contained 0.017 g. of brown oil. An absorption at 6.10μ (strong) in the i r spectrum (CCl_4) of the fraction indicated the presence of an olefinic material. Bands at 6.40μ (broad, medium) provided evidence for the presence of a compound (or compounds) bearing a nitro group. Further characterization of the contents of the fraction was not made. Fraction 3 (benzene) contained only a trace of gum and was discarded.

Fraction 4 (benzene and 1:1 benzene-chloroform) gave an i r spectrum (neat) which was practically superimposable with a spectrum of acetophenone. The 2,4-dinitrophenylhydrazone derivative of ketone CLXXX was prepared in the standard fashion (133) to give 0.880 g. of orange solid, m.p. 245-7° (ethanol-ethyl acetate) (lit. (145), m.p. 247-8°). A mixed melting point of the DNP with authentic acetophenone-2,4-dinitrophenylhydrazone prepared by the same technique, m.p. 246-8°, gave no depression (m.m.p. 245.5-8°). The yield of CLXXX was 39.6% based on the DNP derivative.

Elution with chloroform gave fraction 5 as a white gum (0.014 g.). The i r spectrum ($CHCl_3$, Figure 27, page 183) of this semisolid was identical to that given by an authentic sample of p-nitroacetophenone (CLXXIV). Recrystallization from ethanol proved to be unsatisfactory as a means of purifying the small quantity of CLXXIV present. Attempts to obtain crystalline CLXXIV through the use of other solvents were also unsuccessful. Further characterization was not carried out. The yield of CLXXIV based on the crude chromatography fraction was about 1%.

Fractions 6 (chloroform) and 7 (methanol) were combined and were found to contain 0.06 g. of brown gum. Infrared analysis ($CHCl_3$) of the gum revealed broad, diffuse absorptions characteristic of polymeric materials. Nothing was isolable by recrystallization. Absorptions at 6.45 and 7.44μ in the i r spectrum suggested the presence of material containing a nitro group. None of the oxime CLXVI was recovered.

Oxidation of acetophenone oxime (CLXVI) in acetone

Acetophenone oxime (CLXVI, 1.00 g., 0.0074 mole) was dissolved in anhydrous acetone (50 ml., AR). Ceric ammonium nitrate (4.06 g., 0.0074 mole) in anhydrous acetone (50 ml., AR) was added to the oxime solution from an addition funnel in one portion (15 seconds). The reaction mixture was rapidly stirred during the addition as before. The color of the solution became green immediately. The odor of a nitrogen oxide became very noticeable over the solution as the green color faded to yellow (over 15 minutes). The reaction mixture was stirred for 40 minutes, after which time the solvent was removed at reduced pressure (60°). Extraction of the yellow residue was conducted as previously described for the reaction of CLXVI in methanol. After drying the extracts ($MgSO_4$), the solvents were removed at reduced pressure, and the residue was chromatographed as before to give the results which follow.

Elution with 4:1 petroleum ether-benzene gave fraction 1 as a yellow oil. The oil was purified as described previously. After thorough evacuation, 0.366 g. (25.2%) of 1,1-dinitro-1-phenylethane (LXXII) remained, as a viscous oil. The spectral properties of the compound were identical in every respect to LXII isolated previously. Fractions 2 and 3 (4:1 and 1:1

petroleum-benzene) contained 0.019 g. of a brown gum. The i r spectrum ($CHCl_3$) of these fractions indicated the absence of any olefinic or nitro compounds. The gum was discarded.

Continued elution with 1:1 petroleum ether-benzene yielded acetophenone (CLXXX) as a yellow oil. Preparation of the 2,4-dinitrophenylhydrazone derivative was carried out as before to give 0.927 g. of orange solid, m.p. 245-7°. The yield of ketone CLXXX was 41.8% based on the DNP derivative. Fraction 5 (benzene and chloroform) contained 0.056 g. of a light yellow gum, which was demonstrated by the i r spectrum ($CHCl_3$) to be impure p-nitroacetophenone (CLXXIV). Again, attempts to crystallize CLXXIV from the crude fraction were unsuccessful due to the gum-like substances present. It was estimated from the i r that about 60% of the mixture was CLXXIV, equivalent to a yield of ca. 2-3%.

Characterizable materials were not isolated from fractions 6 and 7 (chloroform, chloroform-methanol mixtures, and methanol). An i r spectrum of the 0.13 g. of gum present in the fractions suggested that some unreacted oxime CLXVI was present (2.9-3.1μ, OH), but the remainder of the spectrum revealed nothing more than the fact that the gum was at best a complex mixture.

Experimental for the Oxidation of p-Methylacetophenone Oxime (CLXVII) by Ceric Ammonium Nitrate

Oxidation of p-methylacetophenone oxime (CLXVII) in methanol

A solution of 1.00 g. (0.0067 mole) of p-methylacetophenone oxime (CLXVII) in 50 ml. of absolute methanol was prepared. To the rapid stirred oxime solution was added a solution of 3.67 g. (0.0067 mole) of ceric ammonium nitrate in 20 ml. of absolute methanol. The addition was made in one portion (10 seconds) from an addition funnel. Rapid discharge of the red color of the cerium(IV) to give a light blue solution was observed. The reaction mixture was allowed to stir for 35 minutes, after which time the solvent was removed from the colorless solution on a rotary evaporator at 60°. The residue was extracted with four 50 ml. portions of ether, two 50 ml. portions of benzene, and 50 ml. of chloroform. Water (50 ml.) was mixed with the remaining solids, and the water solution was extracted with two 50 ml. portions of ether and 50 ml. of benzene. After drying the combined extracts (anhydrous magnesium sulfate), the solvents were removed at reduced pressure. The yellow residue was chromatographed on silica gel as before.

Fraction 1 (4:1 petroleum ether-benzene) was found to contain 0.55 g. of a mixture of a nitro compound and a ketone (by i r). The mixture was rechromatographed on 80 g. of silica gel. Careful elution with 4:1 petroleum ether-benzene gave two new fractions. A benzene solution of the first fraction was dried (anhydrous magnesium sulfate) and was treated with charcoal. After filtration and thorough evacuation of the filtrate, 0.384 g. (27%) of 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI) was obtained as a viscous oil. Distillation of a portion of the oil (molecular still) gave a light yellow liquid, b.p. 92-4° /0.07 mm. The nmr spectrum (CCl_4, Figure 24, page 161) revealed a complex A_2B_2 pattern centered at about 2.75τ, and singlets at 7.53τ and 7.62τ, in the ratio 4:3:3, respectively. The i r spectrum (neat) of CLXXXI is shown in Figure 18, page 149. A weak molecule ion at m/e 210 in the mass spectrum (Table 17, page 147) was consistent with CLXXXI ($C_9H_{10}N_2O_4$).

The second fraction collected on rechromatographing fraction 1 contained 0.124 g. of crude p-methylacetophenone (CLXXXII), as shown by i r. This was combined with CLXXXII which was isolated in fraction 3 of the original chromatography.

Fraction 2 (4:1 petroleum ether-benzene) of the first chromatography contained only a trace of material and was discarded. Fraction 3 (4:1 and 1:1 petroleum ether-benzene) contained p-methylacetophenone (CLXXXII). An i r spectrum (neat) of the oil was identical to that given by the authentic ketone. After combining the 0.124 g. of CLXXXII (above) with fraction 3, the p-nitrophenylhydrazone derivative was prepared by a standard method (134). The derivative was recrystallized from ethanol to give 0.914 g. of red-brown solid, m.p. 196-8° (lit. (135), m.p. 198°). A mixed melting point with authentic p-methylacetophenone p-nitrophenylhydrazone prepared by the same procedure, m.p. 197-8°, gave no depression (m.m.p. 196-8°). The yield of CLXXXII was 50.8% based on the derivative.

Fractions 4 (benzene), 5 (chloroform), and 6 (chloroform) contained a total of 0.05 g. of brown oil. The i r spectra

($CHCl_3$) indicated that the fractions were mixtures of compounds. Nothing could be isolated from the combined fractions. Fraction 7 (1:1 chloroform-methanol and methanol) gave an i r spectrum ($CHCl_3$) which strongly suggested a carboxylic acid. Nothing was isolable from the 0.013 g. of brown gum. None of the oxime (CLXVII was recovered.

Oxidation of p-methylacetophenone oxime (CLXVII) in acetone

p-Methylacetophenone oxime (CLXVII, 1.00 g., 0.0067 mole) was dissolved in anhydrous acetone (50 ml., AR). A solution of ceric ammonium nitrate (3.67 g., 0.0067 mole) in anhydrous acetone (50 ml., AR) was prepared in an addition funnel and was added to the oxime solution in one portion (10 seconds) with rapid stirring. The bright green color which formed immediately slowly faded over 20 minutes to a yellow. The odor of a nitrogen oxide was noticeable in the reaction vessel. The reaction mixture was allowed to stir for 40 minutes, after which time the solvent was removed on a rotary evaporator at 60°. Extraction of the yellow residue was conducted as previously described in the work-up of the oxidation reaction in methanol as solvent. After drying the extracts and removal of the solvents, the residual oil was chromatographed.

Elution with 4:1 petroleum ether-benzene gave fraction 1 as a trace of brown gum which was discarded. The oil obtained in fraction 2 (7:3 and 1:1 petroleum ether-benzene) was purified as before to give 0.483 g. (34.3%) of 1,1-dinitro-1-(p-tolyl)-ethane (CLXXXI), identical in every respect to CLXXXI characterized in the oxidation of CLXVII in methanol. Fraction 3 (1:1 petroleum ether-benzene) held 0.028 g. of a mixture of CLXXXI and an olefinic material (i r (neat)-6.11μ) which was not characterized further. Nothing was isolated on elution with 4:1 benzene-petroleum ether.

Fraction 5 (benzene and 1:1 benzene-chloroform) contained p-methylacetophenone (CLXXXII). Preparation of the p-nitrophenylhydrazone of CLXXXII as before gave 0.880 g. of red-brown solid, m.p. 195-7°. The yield of CLXXXII was 48.9% based on the derivative.

Fraction 6 (chloroform) contained 0.017 g. of gum which showed a 5.80μ absorption in the i r ($CHCl_3$), in addition to other absorptions. Attempts to isolate the compound responsible for the 5.80μ band were unsuccessful. A brown gum (0.134 g.) was isolated on stripping the column with methanol, which gave an i r reminescent of a carboxylic acid (2.8-4.0, broad; 5.90, broad). All attempts to characterize the contents of the gum were unsuccessful. Oxime CLXVII was not recovered. Products arising from nitration of the aromatic ring in CLXVII were not detected in the chromatography fractions.

Experimental for the Oxidation of 2,4-Dimethylacetophenone Oxime (CLXVIII) with Ceric Ammonium Nitrate

Oxidation of 2,4-dimethylacetophenone oxime (CLXVIII) in methanol

A solution of 1.00 g. (0.0061 mole) of 2,4-dimethylacetophenone oxime (CLXVIII) in 50 ml. of absolute methanol was prepared. A solution of 3.37 g. (0.0061 mole) of ceric ammonium nitrate in 20 ml. of absolute methanol was added to the oxime solution from an addition funnel in one portion (10 seconds). The reaction mixture was rapidly stirred during the addition. The solution immediately became a bright blue-green. After stirring for 35 minutes, the solvent was removed from the light yellow solution on a rotary evaporator at 60°. The residue was extracted with 100 ml. of ether, four 50 ml. portions of benzene, and 50 ml. of chloroform. Water (40 ml.) was mixed with the insoluble solids, and the solution was extracted with two 50 ml. portions of benzene, and 50 ml. of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), and the solvents were removed at reduced pressure. The brown oil was chromatographed to give the results which follow.

Elution with 4:1 petroleum ether-benzene gave nothing. Fraction 2 (7:3 petroleum ether-benzene) contained 0.3 g. of a viscous yellow oil. After drying (anhydrous magnesium sulfate) and treatment of a chloroform solution of the oil with charcoal, followed by thorough evacuation, 0.280 g. (20%) of 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) remained as a light brown oil. Analysis of the oil by nmr (CCl_4, Figure 25, page 163) showed aromatic protons at 2.9-3.0τ, and singlets at 7.51τ, 7.68τ, and 7.80τ, in the ratio 1:1:1:1, respectively. Distillation of a portion of the oil (molecular still) gave a yellow liquid, b.p. 110-113°/0.25 mm, which crystallized at Dry Ice-acetone temperature. The i r spectrum (neat) of CLXXXIII is shown in Figure 18, page 149. The mass spectrum (Table 17, page 293) gave a molecule ion at m/e 224 and fragmentation which was consistent with CLXXXIII ($C_{10}H_{12}N_2O_4$).

The yellow oil isolated in fraction 3 (7:3 petroleum ether-benzene, 0.08 g.) gave an i r spectrum which suggested a mixture of CLXXXIII and an olefinic compound (Figure 19, page 151). The 6.20μ absorption was intensified and broadened relative to the 6.36μ peak (compared to the spectrum of CLXXXIII), and absorption maxima due to a nitro group appeared at 6.40μ and 7.57μ (compared to 6.36μ and 7.41μ for CLXXXIII). An nmr spectrum (CCl_4, Figure 25, page 163) indicated that some change in the aliphatic C-H portion of the starting material (CLXVIII) had occurred. An expansion of the 7.4-8.0τ portion of the spectrum revealed an AB pattern (to a first approximation; J_{AB} = ca. 7 c.p.s.) partially obscured by absorptions due to the aromatic methyl groups of both CLXXXIII and the unknown material. The 2.3-3.1τ region of the spectrum showed an AB pattern (partially obscured, J_{AB} = ca. 8 c.p.s.), indicating that a significant change in the nature of one of two para substituents on the aromatic nucleus of CLXVIII had occurred. The spectrum was consistent with a substituted vinyl benzene, such as α-nitro-2,4-dimethylstyrene. Further characterization of the mixture was not carried out, as the components could not be separated.

Fraction 4 (1:1 petroleum ether-benzene, benzene, and 1:1 benzene-chloroform) contained 2,4-dimethylacetophenone (CLXXXIV), as shown by an i r spectrum (neat). The p-nitrophenylhydrazone derivative was prepared by a standard method (134) to give 0.888 g. of yellow-brown solid, m.p. 144-6° (ethanol) (lit. (146), m.p. 153-4°). A mixed melting point with authentic 2,4-dimethylacetophenone-p-nitrophenylhydrazone prepared by the same technique, m.p. 145-6.5°, gave no depression (m.m.p. 144-6°). Fraction 5 (chloroform) contained only a trace of material which was discarded. The yield of CLXXXIV was 51.1% based on the derivative.

Stripping the column with methanol gave 0.062 g. of gum which gave an i r spectrum ($CHCl_3$) suggestive of a carboxylic acid (2.9-4.0μ, OH; 5.95μ, broad C=O). Several attempts to crystallize the compound or compounds responsible for the i r absorptions were unsuccessful. None of the oxime CLXVIII was recovered.

Oxidation of 2,4-dimethylacetophenone oxime (CLXVIII) in acetone

Oxime CLXVIII (1.00 g., 0.0061 mole) was dissolved in anhydrous acetone (50 ml., AR). Ceric ammonium nitrate (3.37 g., 0.0061 mole) in anhydrous acetone (50 ml., AR) was added to the oxime solution from an addition funnel in one portion (10 seconds). The solution was rapidly stirred during the addition. The red color of the cerium(IV) was discharged slowly over 20 seconds to give a light green solution. After 12 minutes, the solution had turned yellow. The reaction mixture was stirred for 35 minutes, after which time the solvent was removed on a rotary evaporator at 60°. Subsequent work-up of the reaction mixture was conducted as described previously for the oxidation of CLXVIII in methanol. The extraction residue was chromatographed to give the results which follow.

Elution with 4:1 petroleum ether-benzene gave three fractions. Fraction 1 contained nothing. Fraction 2 yielded 0.431 g., (31.4%) of 1,1-dinitro-1-(2,4-dimethylphenyl)-ethane (CLXXXIII) after drying and thorough evacuation. The light yellow oil was identical in every respect to CLXXXIII isolated previously. Fraction 3 yielded a trace of gum which was discarded.

Ketone CLXXXIV was eluted from the column with 1:1 and 4:1 benzene-petroleum ether (fraction 4). The p-nitrophenylhydrazone derivative was prepared as before to give 0.685 g. of yellow-brown solid, m.p. 146-8°, identical in every respect to the authentic p-nitrophenylhydrazone of CLXXXIV. The yield of CLXXXIV was 39.4% based on the derivative.

Fraction 5 (benzene and 1:1 benzene-chloroform, 0.07 g.), fraction 6 chloroform, 0.12 g.), and fraction 7 (methanol, 0.04 g.) gave i r spectra $CHCl_3$) which indicated the presence of acidic materials in the various gums. Nothing was isolable from the individual fractions by recrystallization or by extraction with base. The olefinic material which was isolated and partially characterized in the oxidation in methanol was not detected in the chromatography fractions. None of the oxime was recovered.

Experimental for the Oxidation of Anthraquinone Monoxime (CLIII) by Ceric Ammonium Nitrate

Oxidation of anthraquinone monoxime (CLIII) in methanol-benzene

A solution of 1.00 g. (0.0044 mole) of anthraquinone monoxime (CLIII) in 140 ml. of absolute methanol and 20 ml. of benzene[1] was prepared. A solution of 2.45 g. (0.0044 mole) of ceric ammonium nitrate in 5 ml. of methanol was added to the oxime solution in one portion (5 seconds) with rapid stirring. After about 25 seconds, the red color of the cerium(IV) began to fade to orange, accompanied by the formation of a precipitate. The solution was stirred for 30 minutes, after which time the solvents were removed on a rotary evaporator at 60°. The light red residue was extracted with two 50 ml. portions of benzene, followed by two 50 ml. portions of chloroform. The combined extracts were dried (anhydrous magnesium sulfate), concentrated to one-half the original volumne, and were chromatographed on silica gel.

Elution with 1:1 petroleum ether-benzene, benzene, and 1:1 benzene-chloroform gave several fractions which contained varying amounts of a yellow solid, identified as anthraquinone (CLIV). The combined fractions yielded 0.784 g. (84.2%) of

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[1] Benzene was added to the solution to improve the solubility of the monoxime.

CLIV, m.p. 277-9° (subl.), identical in all respects to authentic anthraquinone.

Continued elution with 1:1 benzene-chloroform gave a fraction which contained nothing. Elution with chloroform gave 0.1 g. of a light red solid, the i r ($CHCl_3$) of which was very similar to that of CLIV. Trituration of the solid with hot hexane and filtration yielded 0.04 g. of an insoluble red solid, which showed two "melting" points: Rearrangement of crystalline form and disappearance of all red color were observed at 144-8°, leaving light yellow crystals which melted at 270-75° (subl.). The mass spectrum of the material gave an apparent molecule ion at m/e 208 (70 ev.) and fragmentations which were consistent with anthraquinone (CLIV). Peaks at m/e greater than 208 were not observed even at low ionization energies (18 and 22 ev.). Attempts to isolate the material responsible for the red color of the solid resulted in a loss of color and in isolation of only anthraquinone (CLIV).

Oxidation of anthraquinone monoxime (CLIII) in acetone

Anthraquinone monoxime (0.2 g., 0.0009 mole) was dissolved in anhydrous acetone (40 ml., AR), and the solution was deoxygenated for 10 minutes with prepurified nitrogen. A solution of ceric ammonium nitrate (0.49 g., 0.0009 mole) in anhydrous acetone (50 ml., AR) was deoxygenated for 10 minutes with prepurified nitrogen in an addition funnel. The CAN solution was then added to the oxime solution in one portion (15 seconds) with rapid stirring. A nitrogen atmosphere was maintained in the reaction vessel during the addition and throughout the course of the reaction. The initial red-orange color of the reaction mixture slowly faded to yellow-orange over a period of 1.5 hours. After this time, most of the solvent was removed at reduced pressure (rotary evaporator). The remainder of the acetone was evaporated by means of a stream of nitrogen. Decomposition of the residue was not observed. The residual solids were extracted with two 40 ml. portions of chloroform. The extracts were dried (anhydrous $MgSO_4$), and the solvent was removed at reduced pressure to give a yellow solid. An i r spectrum ($CHCl_3$) indicated the residue to be impure anthraquinone (CLIV). Chromatography of the residue on silica gel gave the results which follow.

Anthraquinone (0.165 g., m.p. 275-8° (subl.), 89%) was eluted from the column with benzene-petroleum ether mixtures, benzene, and 1:1 benzene-chloroform. Continued elution with 1:1 benzene-chloroform gave 0.024 g. of a red-brown solid, m.p. 142-62°, the i r spectrum ($CHCl_3$) of which was very similar to that of anthraquinone. The mixture was not characterized further. Oxime CLIII was not recovered.

In another experiment, CLIII (0.056 g., 0.0002 mole) was reacted with ceric ammonium nitrate (0.134 g., 0.0002 mole) in anhydrous acetone solution without prior deoxygenation of the two solutions. After the reaction mixture was stirred for 80 minutes, most of the solvent was removed from the light yellow solution at reduced pressure. The remainder of the solvent was then evaporated using a nitrogen stream as before. Mild decomposition (exothermic) of the light yellow residue was observed, accompanied by the formation of a brown gas ($\cdot NO_2$). The residue remaining after decomposition was triturated with 20 ml. of chloroform, and the insoluble white solids were removed by filtration. An i r spectrum of the extracts showed absorptions due to anthraquinone (CLIV). Removal of the solvent at reduced pressure gave 0.063 g. of yellow solid, m.p. 269-75° (subl.), which was recrystallized from ethanol to give 0.049 g. (94%) of CLIV, m.p. 276-9° (subl.).

Experimental for the Oxidation of 9-Xanthenone Oxime (CLXIX) by Ceric Ammonium Nitrate

Oxidation of 9-xanthenone oxime (CLXIX) in methanol

A. A solution of 1.00 g. (0.0047 mole) of 9-xanthenone oxime (CLXIX) in 40 ml. of absolute methanol was prepared. A solution of 2.60 g. (0.0047 mole) of ceric ammonium nitrate in 10 ml. of absolute methanol was prepared in an addition funnel and was added to the oxime solution in one portion (10 seconds) with rapid stirring. The red color of the cerium(IV) was discharged rapidly to give a yellow-orange solution. The reaction mixture was stirred for 20 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The yellow residue was extracted with two 50 ml. portions of benzene, two 50 ml. portions of chloroform, and 50 ml. of ether. Insoluble solids were mixed with 50 ml. of water, and the water solution was extracted with 50 ml. each of benzene and chloroform. The combined extracts were dried (anhydrous magnesium sulfate) and the solvents were evaporated at reduced pressure. The residue was chromatographed on silica gel to give the results which follow.

Elution with 1:1 petroleum ether-benzene gave two fractions. Fraction 1 contained only a trace of a yellow solid which was discarded. Fraction 2 yielded 0.035 g. (3.1%) of yellow needles, m.p. 144-6°, on recrystallization from hexane. The infrared spectrum (KBr) of 9-nitriminoxanthene (CLXXXVI) is shown in Figure 28, page 185. The mass spectrum (Table 15) gave a molecule ion at m/e 240 and fragmentation consistent with CLXXXVI. An nmr spectrum ($CDCl_3$) of CLXXXVI showed only aromatic protons. A second recrystallization from hexane gave CLXXXVI as pale yellow needles, m.p. 145-6°.

<u>Anal</u>. Calcd. for $C_{13}H_8N_2O_3$: C, 65.00; H, 3.36; N, 11.66. Found: C, 65.09; H, 3.42; N, 11.71.

Fraction 3 (0.01 g., benzene and benzene-chloroform mixtures) was found to consist of a mixture of compounds, and the fraction was discarded. A white solid, m.p. 172-4°, was isolated in fraction 4 (1:1, 7:3, and 4:1 chloroform-benzene). Recrystallization from ethanol gave 0.839 g. (90.4%) of 9-xanthenone (CLXXXVII), m.p. 173-4°. A mixed melting point with authentic 9-xanthenone, m.p. 173-4°, gave no depression (m.m.p. 173-4°). The i r spectrum (KBr) of CLXXXVII was identical to that given by the authentic ketone.

Fraction 5 (4:1 chloroform-benzene) contained 0.028 g. of a mixture of CLXXXVII and other materials which were not identified further. An intractable brown gum (0.02 g.) isolated in fraction 6 (chloroform and 9:1 chloroform-methanol) was discarded without further identification. Fraction 7 (1:1 chloroform-methanol and methanol) was only partially soluble in chloroform. Filtration of the chloroform solution gave 0.011 g. of a light yellow solid, m.p. 227-37° (subl.), which was not characterized further. Oxime CLXIX was not recovered in the chromatography.

B. A solution of 2.60 g. (0.0047 mole) of ceric ammonium nitrate in 10 ml. of absolute methanol was added dropwise from an addition funnel to a solution of 1.00 g. (0.0047 mole) of CLXIX in 40 ml. of absolute methanol. The dropwise addition was made over a period of 30 minutes with continuous rapid stirring of the reaction mixture. After the addition was completed, the orange-brown slurry was allowed to stir for 1 hour. The solvent was then removed on a rotary evaporator at 60°. The yellow-brown residue was extracted as described previously, and the extraction residue was chromatographed to give the results summarized below.

An orange solid (0.113 g.) eluted from the column in 1:1 petroleum ether-benzene which was found to be a mixture of two compounds. Fractional recrystallization of the mixture from ethyl acetate gave 0.039 g. (4.2%) of 9-xanthenone azine (CLXXXVIII), m.p. 287-9°. The i r spectrum (KBr) of CLXXXVIII is shown in Figure 46. The molecular weight was found to be 388 (mass spec., Table 21). An nmr spectrum ($CDCl_3$) of CLXXXVIII showed only aromatic protons. Recrystallization of CLXXXVIII (ethanol-ethyl acetate) yielded finely divided orange needles, m.p. 287.5-9° (lit. (147), m.p. 285°).

Anal. Calcd. for $C_{26}H_{16}N_2O_2$: C, 80.40; H, 4.15; N, 7.21. Found: C, 80.40; H, 4.24; N. 7.16.

The yellow-orange solid remaining in fraction 1 (after CLXXXVIII had been removed) was dissolved in excess hot hexane, and the solution was decanted from a small amount of insoluble gum. After concentration and cooling, 0.015 g. (1.3%) of 9-nitriminoxanthene (CLXXXVI), m.p. 139-42°, crystallized from the hexane solution. The compound was identical in every respect to nitrimine CLXXXVI previously characterized.

Fraction 2 (benzene) was recrystallized from ethanol to give 0.820 g. (88.4%) of 9-xanthenone (CLXXXVII), m.p. 172.5-74°, identical in every respect to the authentic ketone. Elution with 1:1 benzene-chloroform and chloroform gave fraction 3 as only a trace of material which was discarded. An orange solid was eluted with 1:1 chloroform-methanol and methanol. Recrystallization of the solid from ethyl acetate gave 0.011 g. of tan needles, m.p. 232-4° (subl.). An i r spectrum (KBr) of the material is shown in Figure 28, labeled Unknown E. The mass spectrum gave a molecule ion at m/e 356.

The substance was not characterized further due to the small quantity isolated.

Oxidation of 9-xanthenone oxime (CLXIX) in aqueous methanol

A solution of CLXIX (1.00 g., 0.0047 mole) in 100 ml. of 80% methanol-20% water was prepared. Ceric ammonium nitrate (2.60 g., 0.0047 mole) in 20 ml. of 80% methanol-20% water was added to the oxime solution from an addition funnel in one portion (10 seconds). The reaction mixture was rapidly stirred during the addition. The red color of the cerium(IV) was discharged rapidly to give a yellow-orange solution. After 5 minutes, the solution had become light yellow. The reaction mixture was stirred for 1 hour, after which time the methanol was removed at reduced pressure (60°). Water (50 ml.) was poured into the residue, and the light yellow slurry was extracted with four 100 ml. portions of benzene and 100 ml. of chloroform. The extracts were dried ($MgSO_4$), evaporated, and the residue was chromatographed as before.

Fraction 1 (3:2 petroleum ether-benzene) was predominantly the nitrimine CLXXXVI, and was recrystallized from hexane to give 0.012 g. (1%) of CLXXXVI, m.p. 143.5-5°. Fraction 2 (3:2 and 1:1 petroleum ether-benzene) contained the azine CLXXXVIII contaminated with a trace of CLXXXVI. The orange solid was recrystallized from ethyl acetate giving 0.011 g. (1.2%) of 9-xanthenone azine (CLXXXVIII), m.p. 285-8°, identical in all respects to CLXXXVIII isolated previously. Fraction 3 (benzene) contained the ketone CLXXXVII, which was recrystallized (ethanol) to give 0.804 g. (86.7%) of white needles, m.p. 173-4°. Elution with chloroform and 1:1 chloroform-methanol resulted in the isolation of a trace of gum which was discarded. A yellow solid (0.006 g., m.p. 248-52° (dec., subl.)) was isolated from fraction 5 (1:1 chloroform-methanol and methanol) after trituration with ethyl acetate and filtration. This material was not identified further. Oxime CLXIX was not recovered.

Oxidation of 9-xanthenone oxime (CLXIX) in acetone

Xanthenone oxime (CLXIX, 1.00 g., 0.0047 mole) was dissolved in anhydrous acetone (40 ml., AR). A solution of ceric ammonium nitrate (2.60 g., 0.0047 mole) in anhydrous acetone (25 ml., AR) was added to the oxime solution from an addition funnel in one portion (10 seconds). The reaction mixture was rapidly stirred during the addition as before. The solution immediately became deep red. After 5 minutes, the red color had faded, leaving a light yellow solution. After stirring the solution for 30 minutes, the solvent was removed on a rotary evaporator at 60°. Extraction of the residue was carried out as previously described. The yellow solids isolated from the extracts were chromatographed on silica gel to give the results which follow.

Fraction 1 (1:1 petroleum ether-benzene) was recrystallized from hexane giving 0.019 g. (1.7%) of 9-nitriminoxanthene (CLXXXVI), m.p. 145-6°. The ketone CLXXXVII eluted in benzene and 1:1 benzene-chloroform. Recrystallization from ethanol yielded 0.823 g. (88.7%) of CLXXXVII, m.p. 173-4°. Elution with 7:3 chloroform-benzene and chloroform gave 0.049 g. of a red gum which was not characterized further. Finally, 0.049 g. of a brown semisolid was isolated on stripping the column with methanol. Attempts at crystallization of any characterizable substances from the semisolid were unsuccessful. Further identification was not carried out. Oxime CLXIX was not recovered.

Experimental for the Oxidation of Oximes by Nitrate-^{15}N labeled Ceric Ammonium Nitrate

Preparation of nitrate-^{15}N labeled ceric ammonium nitrate

Nitrate-^{15}N labeled ceric ammonium nitrate was prepared as follows. Reagent grade ceric ammonium nitrate (Fischer reagent) was accurately weighed out and was dissolved in absolute methanol. An accurately weighed portion of nitrate-^{15}N labeled ammonium nitrate (Bio-Rad Laboratories, 95.7% ^{15}N-nitrate) was then added to the CAN-methanol solution. After all of the labeled ammonium nitrate had dissolved, the solution was allowed to stand for a period of time sufficient to insure equilibration of the ^{15}N-labeled nitrate with the unlabeled nitrate present in the complex salt. Without further treatment, the CAN-nitrate-^{15}N solution was added to a solution containing one equivalent of the oxime to be oxidized per equivalent of cerium(IV) present in the reagent.

Oxidation of 9-fluorenone oxime (CLVI) in methanol

A solution of 0.2150 g. (0.0011 mole) of CLVI in 10 ml.

of absolute methanol was prepared. A solution of 0.6028 g. (0.0011 mole) of ceric ammonium nitrate and 0.1100 g. (0.0013 mole) of ammonium nitrate-^{15}N (95.7% ^{15}N labeled) was prepared as described above. The CAN-nitrate-^{15}N solution was added in one portion (10 seconds) to the oxime solution through a funnel with rapid stirring. The funnel and beaker from which the CAN solution was transferred were rinsed into the reaction vessel with a small amount of absolute methanol to insure complete transfer of the labeled salt. The solution was allowed to stir for 15 minutes, after which time the solvent was removed on a rotary evaporator at 60°. The residue was extracted with 50 ml. of ether, and two 50 ml. portions of benzene. Insoluble materials were dissolved in 25 ml. of water, and the water solution was extracted with two 25 ml. portions of benzene. The combined extracts were dried as before, the solvents were removed at reduced pressure, and the residue was chromatographed on silica gel (30 g.). The following results were obtained from the chromatography: 9,9-dinitrofluorene (LXII), 0.076 g., 26.9%, m.p. 137-8° (dec.) (hexane); 9-fluorenone (LXIII), 0.089 g., 45%, m.p. 81-3° (ethanol); and 9-fluorenone azine monoxide (CLXII), 0.016 g., 15.7%, m.p. 173-6° (ethanol). Oxime CLVI was not recovered.

The extent of incorporation of ^{15}N from the labeled nitrate into the dinitro compound LXII was determined by mass spectroscopy. A mass spectrum of LXII (obtained from a similar reaction in the absence of labeled nitrate) was used as a control by measuring the intensities of the M, M + 1, and M + 2 peaks, and calculating the ratios (M + 1)/M and (M + 2)/M. The (M + 1)/M and (M + 2)/M ratios were then calculated for LXII from the mass spectrum of the compound obtained in the oxidation in the presence of ^{15}N-labeled nitrate. The percent incorporation of ^{15}N into LXII was given by dividing the observed increases in the (M + 1)/M and (M + 2)M ratios by the theoretical maximum increase possible as determined by the percent of ^{15}N-nitrate present in the original CAN solution. A similar procedure based on the (M - 46 + 1)/(M - 46) ratios was also employed to find the percent of ^{15}N incorporation. All mass spectral measurements were made at an ionization energy of 20 ev. The results of the mass spectral analyses of unlabeled and labeled LXII are summarized in Table 25. Peak intensities are given in Table 25 in units of millimeters multiplied x 10. Ratios are recorded as percentages The percent of ^{15}n-labeled nitrate in the total nitrate ion in the CAN-NH_4NO_3 reagent was [(0.001358)(0.957)/0.007970](100) = 16.30% $^{15}N\ O_3^-$.

The increase in (M + 1)/M was 30.58-15.22 = 15.36%, which was equivalent to (15.36/16.30)(100) = 94.2% incorporation of one ^{15}N atom per molecule of LXII. The theoretical value of (M + 1)/M for a compound of empirical formula $C_{13}H_8N_2O_4$ was calculated to be 15.09% (120), which was in good agreement with that observed. Assuming equal probability for the loss of either of the two nitro groups from LXII in the mass

Table 25. Mass spectrum of ^{15}N-labeled 9,9-dinitrofluorene (LXII)

Unlabeled LXII[a]					Labeled LXII[b]				
M^c	$M+1^c$	$M+2^c$	$\frac{(M+1)^d}{M}$	$\frac{(M+2)^d}{M}$	M^c	$M+1^c$	$M+2^c$	$\frac{(M+1)^d}{M}$	$\frac{(M+2)^d}{M}$
1240	190	21	15.32	1.69	590	179	26	30.34	4.41
1272	195	27	15.33	2.12	620	187	27	30.16	4.35
1325	200	28	15.09	2.11	637	197	30	30.93	4.71
1242	188	24	15.13	1.93	647	200	29	30.91	4.48
		avg.	15.22	1.96				30.58	4.49

$(M-46)^c$	$(M-46+1)^c$	$\frac{(M-46+1)^d}{(M-46)}$	$(M-46)^c$	$(M-46+1)^c$	$\frac{(M-46+1)^d}{(M-46)}$
784	118	15.05	990	226	22.82
784	118	15.05	1070	243	22.71
785	119	15.15	1092	250	22.89
	avg.	15.08			22.80

[a] Data taken from a control mass spectrum of LXII.

[b] Data taken from the mass spectrum of LXII from the oxidation of CLVI by nitrate-^{15}N labeled ceric ammonium nitrate.

[c] M = molecule ion (m/e 256); M + 1 = m/e 257; M + 2 = m/e 258; M - 46 = 256 - 46 = m/e 210; M - 46 + 1 = m/e 211. Numbers in the columns headed M, M + 1, M + 2, M - 46, and M - 46 + 1 are the intensity of the respective peak in millimeters x 10.

[d] Ratios recorded as percentages (ratio x 100).

spectrometer, and hence a loss of one-half of the ^{15}N label in the molecule, the percent of ^{15}N incorporation in LXII based on (M - 46 + 1)/(M - 46) was found to be [(22.80 - 15.08) (2) (100)]/(16.30) = (15.44/16.30)(100) = 94.7% of one ^{15}N atom per molecule of LXII. The (M + 1)/M ratio given by Beynon

(120) for a species $C_{13}H_8NO_2$ (equivalent to a loss of NO_2 from $C_{13}H_8N_2O_4$) was 14.63%, which gave a percent incorporation of 100% of one ^{15}N atom per molecule of LXII.

Although a 24% incorporation of two ^{15}N atoms per molecule of LXII was calculated from the data given in Table 25 for the (M + 2)/M ratios, no significance could be attached to the number due to the large error involved in measuring the small M + 2 peaks in the control spectrum and the spectrum of the labeled material. Further, the high incorporation of one ^{15}N atoms was negligible. The procedure used to analyze the (M + 2)/M data is as follows. An (M + 2)/(M + 1) ratio was calculated from the control data for LXII to be 0.1287. An increase in the M + 2 peak intensity equal to 12.87% of the absolute value of the increase in the M + 1 peak must occur solely on the basis of natural isotopic abundances of the elements in LXII. This contribution to M + 2 was found to be (15.36/30.58)(190)(0.1287) = 12 units, or 42.8% of the intensity of M + 2 as measured from the spectrum of labeled LXII. The contribution of the "normal" M + 2 peak to the intensity of the M + 2 peak in the spectrum of the labeled material was (1.96/4.49)(100) = 43.7%, or about 12 units, of the observed intensity. An increase in the ratio (M + 2)/M of (0.163)(0.163)(100) = 2.66% would be expected if 100% incorporation of two ^{15}N atoms per molecule of LXII had occurred. The remaining 4 units of the observed intensity of M + 2 in the mass spectrum of labeled LXII accounted for an increase in (M + 2)M of (4/623)(100) = 0.6%, or a (0.6/2.66)(100) = 24% incorporation of two ^{15}N atoms. The reader is reminded that 4 units on the scale of the numbers shown in Table 25 for peak intensities is equivalent to 0.4 mm., which is far too small to be of any significance, since the limit of accuracy in the measurement of any given peak was about ± 1 mm.

Oxidation of 1-indanone oxime (CLXIII) in methanol

A solution of 1.4980 g. (0.0027 mole) of ceric ammonium nitrate and 0.2548 g. (0.0031 mole) of ammonium nitrate-^{15}N (95.7% ^{15}N-labeled) in 10 ml. of absolute methanol was prepared and was allowed to stand for a short time to insure equilibration of the labeled nitrate with that present in the complex salt. The solution was then added in one portion (10 seconds) to a rapidly stirred solution of 0.4062 g. (0.0027 mole) of 1-indanone oxime (CLXIII) in 16 ml. of absolute methanol. The beaker and funnel used to transfer the CAN-$NH_4{}^{15}NO_3$ solution to the reaction flask were rinsed with a small amount of methanol to insure complete transfer of the labeled material. The solution was allowed to stir for 20 minutes, after which time the solvent was removed on a rotary evaporator. The residue was extracted with 25 ml. of ether, two 50 ml. portions of benzene, and 50 ml. of chloroform. Water (25 ml.) was mixed with the insoluble materials, and the water solution was extracted with 25 ml. each of benzene and chloroform. The combined extracts were dried (anhydrous magnesium sulfate), the solvents were removed at reduced pressure, and the residue was chromatographed on silica gel (80 g.). The results of the chromatography were as follows: 1,1-dinitroindane (CLXXI), 0.145 g., 25.3%, m.p. 40-42° (pentane-ether); and 1-indanone (CLXXII), 59% (based on the 2,4-DNP derivative prepared by a standard procedure (134), m.p. 257-8°). Oxime CLXIII was not recovered.

The extent of incorporation of ^{15}N from the labeled nitrate into the dinitro compound CLXXI was determined by mass spectroscopy in the same manner as for 9,9-dinitrofluorene. A control spectrum of CLXXI was obtained, from which the ratio (M + 1)/M was calculated for the unlabeled compound. The molecule ion and M + 1 were very weak for CLXXI, and the M + 2 peak could not be measured with any accuracy. Considerable difficulty was experienced in attempting to eliminate an M - 1 peak even at low electron energies. Consequently, the percent of ^{15}N incorporation in CLXXI based on measurements of the (M - 46 + 1)/(M - 46) ratios was considered to be a more accurate number than that obtained from the (M + 1)/M ratios. The data obtained from the mass spectra of labeled and unlabeled CLXXI is shown in Table 26. Mass spectral measurements of M and M + 1 for unlabeled CLXXI were obtained at ionization energies of 17, 19, 20, and 25 ev., while those for labeled CLXXI were obtained at 19 ev. Only those measurements of recordings where the M - 1 peak was very small or nonexistent are given. Measurements of M - 46 and M - 46 + 1 were obtained at an ionization energy of 17 ev. for both the labeled and unlabeled compounds. Peak intensities are given in units of millimeters x 10 as before. Ratios are recorded as percentages. The percent of ^{15}N-nitrate in the total nitrate ion present in the CAN-NH_4NO_3 reagent was

$[(0.003146)(0.957)/(0.019544)](100) = 15.41\%\ ^{15}NO_3^-$.

The percent incorporation of ^{15}N into CLXXI based on (M + 1)/M ratios was found to be $[(27.06-11.13)/15.41](100) =$ >100% of one ^{15}N atom per molecule of CLXXI. Beynon (120) gives a value of 10.77% as the theoretical (M + 1)/M ratio for a compound $C_9H_8N_2O_4$, which was in reasonable agreement with the observed value. From the data for the (M - 46 + 1)/(M - 46) ratios, the percent of ^{15}N incorporation was found by the method previously described to be $[(17.95-10.46)(2)/15.41](100) = (14.98/15.41)(100) = 97.2\%$ of one ^{15}N atom per molecule of CLXXI. The theoretical value of (M + 1)/M for a compound of the formula $C_9H_8NO_2$ (equivalent to a loss of NO_2 from $C_9H_8N_2O_4$) is given by Beynon (120) as 10.31%, in good agreement with the value obtained from the control spectrum of CLXXI.

Reaction of 9-fluorenone oxime (CLVI) with ammonium nitrate in methanol

Ammonium nitrate (6.24 g., 0.0775 mole) was dissolved in methanol (100 ml.) with stirring. The oxime CLVI (0.504 g., 0.0026 mole) was then added to the solution, and the mixture was allowed to stir for 67 hours. After this time, the solvent was removed on a rotary evaporator at 60°. Water (200 ml.) was mixed with the residue, and the resulting light yellow

Table 26. Mass spectrum of ^{15}N-labeled 1,1-dinitroindane (CLXXI)

Unlabeled CLXXI[a]			Labeled CLXXI[b]		
M[c]	(M + 1)[c]	$\frac{(M + 1)}{M}$[d]	M[c]	(M + 1)[c]	$\frac{(M + 1)}{M}$[d]
180	20	11.11	964	260	26.97
275	30	10.91	1050	290	27.62
330	37	11.21	1145	312	27.24
330	39	11.82	1155	305	26.40
329	35	10.64			
		avg. 11.13			27.06

(M-46)[c]	(M-46+1)[c]	$\frac{(M-46+1)}{(M-46)}$[d]	(M-46)[c]	(M-46+1)[c]	$\frac{(M-46+1)}{(M-46)}$[d]
1410	148	10.49	1178	211	17.91
1487	155	10.42	1217	218	17.99
1555	163	10.48			
		avg. 10.46			17.95

[a] Data taken from a control mass spectrum of CLXXI.

[b] Data taken from the mass spectrum of CLXXI from the oxidation of CLXIII by nitrate-^{15}N labeled ceric ammonium nitrate.

[c] M = molecule ion (m/e 208); M + 1 = m/e 209; M - 46 = 208-46 = m/e 162; M - 46 + 1 = m/e 163. Intensities of M, M + 1, M - 46, and M - 46 + 1 in millimeters x 10.

[d] Ratios given as percentages (ratio x 100).

slurry was filtered to give 0.499 g. of yellow solid, m.p. 188-90°. Recrystallization from methanol gave 0.485 g. (96.2% recovery) of CLVI, m.p. 192-4.5°, which was identical in every respect to the authentic oxime.

Reaction of 1-indanone oxime (CLXIII) with ammonium nitrate in methanol

A solution of CLXIII (0.504 g., 0.0034 mole) and ammonium nitrate (0.318 g., 0.0039 mole) in 30 ml. of methanol was prepared and was stirred for 45 minutes. The solvent was removed on a rotary evaporator at 60°, and the residue was extracted with 150 ml. benzene. The benzene-insoluble materials were removed by filtration. The benzene was evaporated, and the residue was recrystallized from methanol to give 0.489 g. (97% recovery) of CLXIII, m.p. 144-6°, identical in every respect to the authentic oxime.

Experimental for Electron Spin Resonance Studies

Apparatus

A Varian V4500-10A electron spin resonance (esr) spectrometer was used. Hyperfine splitting constants were measured with a Varian "Fieldial" attachment. Experiments in a static system were performed using an inverted U-tube[1] and a quartz esr cell.[2] Solutions of reactants contained in separate arms of a U-tube were deoxygenated by bubbling either prepurified nitrogen or helium through them before mixing. Electron spin resonance (esr) spectra were recorded at room temperature in an inert gas atmosphere shortly after mixing of the solutions

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[1] The design and use of the U-tube for esr studies have been described by Janzen.

[2] Varian V-4548 aqueous solution flat-fused silica cells were used in all experiments.

by inversion of the apparatus and transfer of the cell to the cavity of the spectrometer.

A fast flow system was used in some esr experiments. The flow system employed was a modification of the apparatus previously described by Janzen.[3] Modifications in the apparatus employed by Janzen were made, which were not necessarily improvements in design. The system which was used in the studies reported here is shown in Figure 55. Solutions of reactants were placed in the 125 ml. bulbs and were degassed with helium prior to mixing. The tops of the reservoirs were closed by means of ground glass stoppers connected by rubber tubing to a three-way stopcock through which the exit gas passed. The three-way stopcock interconnecting the reservoirs with the esr cell was closed to prevent premature mixing of the solutions. The reservoir system was joined to the quartz esr cell by means of a ground glass joint. The use of ball joints to connect the reservoirs to the remainder of the apparatus was suggested by Janzen to allow greater flexibility in the apparatus upon manipulation of stopcocks, and thus prevent breakage of the arms by sudden movement of the reservoirs in an undesired manner. The quartz esr cell was the same as that used for studies in a static system. The liquid exit consisted of

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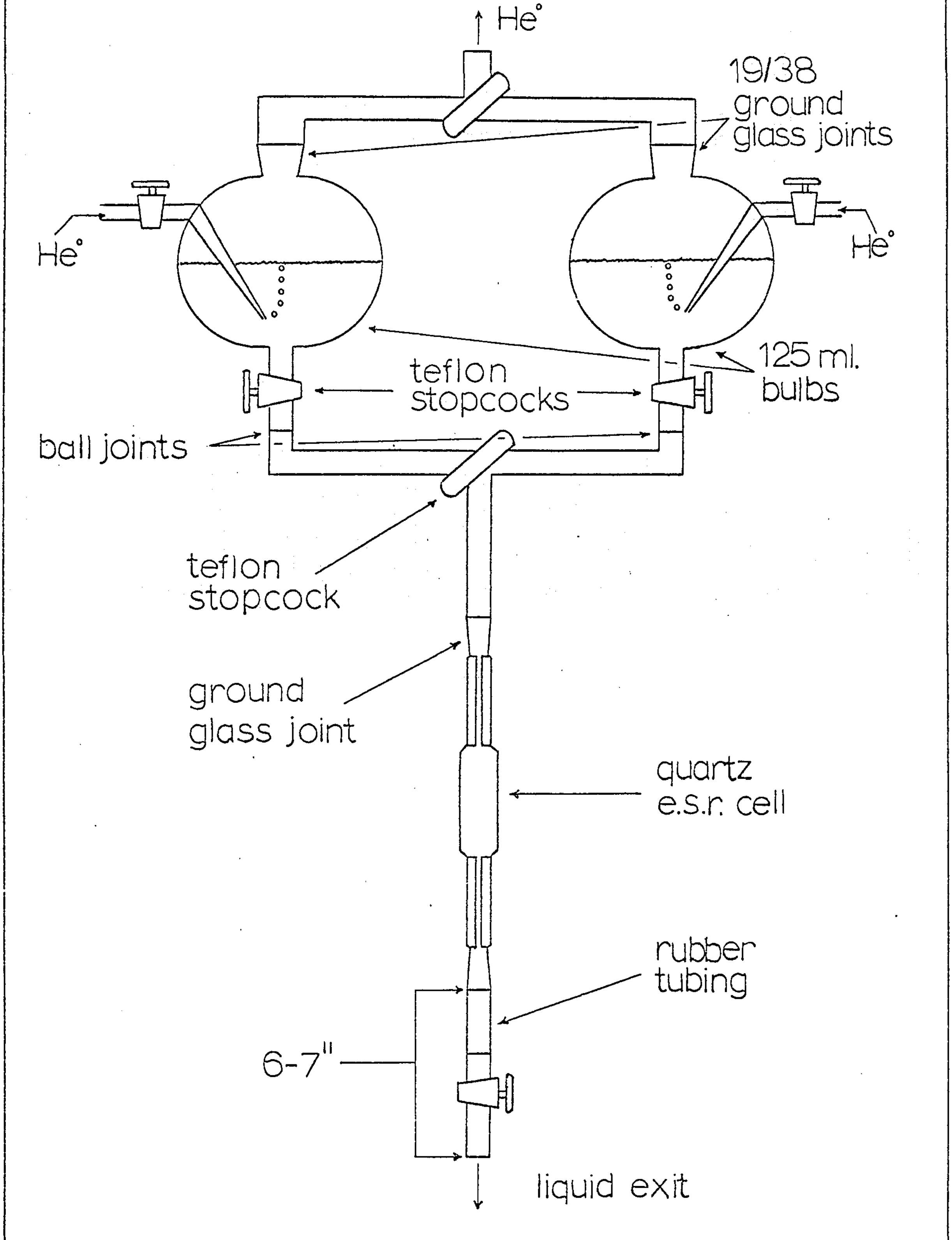
[3] Janzen (121a, p. 320).

Figure 55. Stop-flow system for electron spin resonance studies.


He°
19/38
ground
glass joints
He°
He°
125 ml.
bulbs
teflon
stopcocks
ball joints
teflon
stopcock
ground
glass joint
quartz
e.s.r. cell
rubber
tubing
6-7"
liquid exit

piece of rubber tubing placed over the lower end of the esr cell, which was connected to a two-way stopcock used to control the flow of solution from the cell. The lack of a third reservoir containing rinse solvent as described by Janzen made cleaning of the apparatus in the cavity difficult. Consequently, the apparatus was removed from the cavity of the spectrometer and cleaned after each experiment.

Air bubbles were removed from the cell by removing the reservoirs and filling the cell with the solvent to be used in the experiment to just below the ball joints, followed by degassing of the solvent in the cell by means of a needle inserted in the rubber tubing at the bottom of the apparatus. The solvent level was then lowered to the level of the three-way stopcock, the stopcock was closed, and the reservoirs were replaced. Solutions of the reactants were placed in the reservoirs at that point, taking care not to trap any bubbles in the arms.

Solutions of reactants were degassed with helium for 15-20 minutes prior to mixing. A slow stream of helium was allowed to flow through the solutions as the experiments were conducted. Solutions were mixed by opening the three-way stopcock to both reservoirs and the cell simultaneous with the opening of the liquid exit stopcock. The flow of liquid through the cell was maintained for 10-15 seconds before stopping by simultaneously closing the three-way stopcock and the liquid exit stopcock. The time required for the passage of a measured volume of pure solvent through the cell in a measured period of time indicated that the time which elapsed from the initial mixing of the reactant solutions to the passage of the solution through the cell was 4-5 seconds. The esr spectrum was recorded within 3-5 seconds after the flow had been stopped.

Results

The esr experiments in static systems were conducted using solutions of oxime and ceric ammonium nitrate which were 2.5 x 10^{-2} M and 1.25 x 10^{-2} M, respectively. The oximes which were investigated in static systems were anthraquinone monoxime (CLIII), 9-fluorenone oxime (CLVI), benzophenone oxime (LXXVII), 1-indanone oxime (CLXIII), *p*-nitroacetophenone oxime (CLXIV, α-phenylacetophenone oxime (CLXV), and acetophenone oxime (CLXVI). The solvents employed for the major portion of the studies were methanol and acetone.

Solutions of the oxime under investigation (2.5 x 10^{-2} M) and ceric ammonium nitrate (1.25 x 10^{-2} M) were placed in separate arms of a U-tube apparatus and were deoxygenated by bubbling either prepurified nitrogen or helium through them by means of long needles inserted through the rubber septems used to seal the arms of the tube. After solutions of the reactants had been degassed for 10-15 minutes, the needles were removed from the arms of the U-tube and the apparatus was sealed by placing a stopper in the open end of the attached quartz esr cell. The esr cell was then placed in the cavity of the spectrometer as quickly as possible. The time usually required for the transfer of the apparatus to the cavity of the spectrometer and the initial observation of the esr spectrum was in the range of 4-7 minutes.

Of the oximes listed previously, only anthraquinone monoxime (CLIII) gave an observable esr spectrum when oxidized by ceric ammonium nitrate in methanol in the static system. The first derivative esr given by the solution of CLIII and CAN in methanol corresponded to the iminoxyl radical CLXXXIX, and contained 6 lines (three sets of 1:1 doublets) with nitrogen (a_N) and hydrogen (a_H) hyperfine splitting constants of 30.3 gauss and 3.4 gauss, respectively, in reasonable agreement with literature values (79, a_N = 29.8 gauss, a_H = 2.5 gauss). The data obtained from the esr spectrum of CLXXXIX is included in Table 27 with the data obtained from the spectra of other iminoxyl radicals. When higher concentrations of CAN solution (i.e., 2.5 x 10^{-2} M) were used, the decay of the signal due to CLXXXIX was much more rapid than that observed using the lower concentration of CAN (1.25 x 10^{-2} M). Regardless of the initial concentration of the CAN solution, the buildup and decay of signal due to CLXXXIX was rapid, with no signal remaining in the esr spectrum after 8-10 minutes from the time the solutions of CLIII and CAN were mixed. In every instance where the esr spectrum of CLXXXIX was observed, the signal was in the last stages of decay, and the lifetime of the radical could not be determined.

Observation of the esr spectrum of CLXXXIX generated by the oxidation of CLIII by CAN in acetone was complicated by the fact that gas formation occurred on mixing the reactant solutions causing a buildup of pressure in the apparatus. None of the other oximes listed previously gave an esr signal when oxidized by CAN in acetone in the static system. Some pressure buildup in the apparatus was noted when 1-indanone and acetophenone oxime were oxidized in acetone, but observation of the esr spectra was possible. No signal was obtained in either case.

The esr spectra of solutions of 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII) when reacted with CAN in 80% methanol-20% water were observed in a static system. Solutions of the reactants were prepared and degassed as before. A weak signal was obtained in the experiment with 9-fluorenone oxime and CAN. The signal was gone, however, a short time after the initial observation was made. An approximate nitrogen hyperfine splitting constant (a_N) was estimated from the spacing of the three broad lines in the spectrum to be 29-32 gauss, which was at least in the right range expected for an iminoxyl radical (CXC) derived from 9-fluorenone oxime, but resolution was too poor to allow estimation of a value for a_H. No signal was observed when the esr spectrum of a solution of benzophenone oxime and CAN in 80% methanol-20% water was recorded.

The elapsed time of 4-7 minutes between the transfer of the apparatus used in the experiments in a static system to the instrument cavity and the initial observation of the esr spectrum of the reaction mixture in question was more than ample time for the concentration of a short-lived radical to build up and decay before observation of an esr spectrum could be made. The flow system shown in Figure 55 was constructed and was employed in the remaining esr experiments to avoid this time problem.

The esr experiments using the fast flow system were conducted using solutions of oxime and ceric ammonium nitrate which were 2.5×10^{-2} $\underline{M}$ in the respective reactant. The oximes investigated were 9-fluorenone oxime (CLVI) and benzophenone oxime (LXXVII). The solvents employed for the studies were methanol and 80% methanol-20% water. A solution of either CLVI or LXXVII in either methanol or 80% methanol-20% water (50-75 ml.) was placed in one of the reservoirs shown in Figure 55. A solution containing ceric ammonium nitrate in the same solvent as that in which the oxime was dissolved was placed in the other reservoir. The solutions were degassed for 15-20 minutes with helium using the tubes inserted in the reservoir walls (see Figure 55). The respective experiments were then conducted as described previously. The results of the oxidation of CLVI and LXXVII by CAN in methanol and 80% methanol-20% water in the fast flow system are summarized in Table 27 accompanying the results obtained from the oxidation of anthraquinone monoxime (CLIII) by CAN in a static system. A six-line first derivative esr spectrum (three 1:1 doublets) corresponding to iminoxyl radical CXC was observed when 9-fluorenone oxime (CLVI) was oxidized by CAN in both methanol and 80%

Table 27. Electron spin resonance spectra of iminoxyl radicals

Oxime[a]	Solvent	a_N[b]	a_H[b]	No. of Protons[c]	Half-life (t 1/2 min.)[d]
Anthraquinone monoxime	CH_3OH	30.3	3.4	1	---[e]
9-Fluorenone	CH_3OH	30.9	3.0	1	2
	80%CH_3OH- 20%H_2O	30.8	3.0	1	3.5
Benzophenone	CH_3OH	31.6	1.6	2	1
	80%CH_3OH- 20%H_2O	31.6	1.6	2	1.5

[a] The oxime oxidized by CAN to give the iminoxyl radical.

[b] Values of nitrogen (a_N) and hydrogen (a_H) splitting constants in gauss.

[c] Number of protons (equivalent) interacting with the odd electron.

[d] Half-lives (t 1/2) are only approximate values; see text.

[e] Spectrum obtained using a static system. The half-life was not measured.

methanol-20% water. The values of a_N and a_H for CXC in Table 27 were in good agreement with literature values (79, a_N = 30.8 gauss, a_H = 2.7 gauss). A nine-line first derivative esr spectrum (three 1:2:1 triplets) corresponding to the iminoxyl radical CXCI was observed when benzophenone oxime (LXXVII) was oxidized by CAN in methanol and 80% methanol-20% water. The values of a_N and a_H in Table 27 for CXCI were also in good agreement with literature values (70, a_N = 31.4 gauss, a_H = 1.4 gauss).

Approximate half-lives (t 1/2) for the iminoxyl radicals CXC and CXCI were measured in methanol and 80% methanol-20% water, based on the decay of the radicals. The values for the half-lives of CXC and CXCI are shown in Table 27. Two methods were available for use in the measurements of half-lives. The decay in radical concentration could be followed on the instrument recorder by scanning a given peak upfield and downfield, or by stopping the scan at the top of a given peak and recording the decrease in intensity with time. Both methods were used and were found to give essentially the same values for the half-lives. The peak used in the measurements was the center peak of the three basic peaks observed in each of the esr spectra.

Experimental for the Oxidation of Oximes by Nitric Acid

Procedure

Solutions of oximes in methanol were treated with 70% nitric acid (30 molar excess) and were stirred for periods of 14-15 hours at room temperature. Work-up of the reactions was carried out by procedures similar to those used for the oxidations of the respective oximes with cerium(IV) salts. Extraction residues were chromatographed on columns containing silica gel in a ratio of 180-200 g. per 1 g. of material to be chromatographed.

Oxidation of 9-fluorenone oxime (CLVI)

Nitric acid (70%, sp. gr. 1.42, 5.2 ml.) was added dropwise to a solution of CLVI (0.503 g., 0.0026 mole) in 40 ml. of methanol with rapid stirring. The bright yellow solution was then allowed to stir for 15 hours at room temperature. A white precipitate had formed after 9 hours stirring. At the end of 15 hours, the solution was filtered to give 0.253 g. of 9,9-dinitrofluorene (LXII), m.p. 136-8° (dec.). The filtrate was concentrated at reduced pressure, and water (100 ml.) was poured into the residual slurry. The water slurry was filtered to give 0.353 g. of a yellow solid, m.p. 117-23° (dec.). The aqueous filtrate was extracted with two 50 ml. portions of benzene, the extracts were dried (anhydrous magnesium sulfate), and the solvent was stripped. The residual yellow gum was combined with the 0.353 g. of crude LXII isolated above, and the mixture was chromatographed.

Two fractions were collected on elution with 1:1 petroleum ether-benzene. Fraction 1 contained 0.241 g. of 9,9-dinitrofluorene (LXII), m.p. 136-8° (dec.)(hexane). The yield of LXII was 0.494 g. (75.2%), which was identical in all respects to the compound characterized previously. Fraction 2 yielded 0.078 g. (16.8%) of 9-fluorenone (LXIII), m.p. 76-8°, on recrystallization from benzene. Elution with other solvents gave nothing. Oxime CLVI was not recovered.

Oxidation of benzophenone oxime (LXXVII)

Benzophenone oxime (LXXVII, 0.355 g., 0.0018 mole) was dissolved in methanol (26 ml.). Nitric acid (3.3 ml., 70%) was added dropwise to the oxime solution with stirring. The reaction vessel was then covered to exclude all light.[1] The solution was stirred for 15 hours (after 9 hours, the odor of NO or NO_2 was detectable in the flask). The solvent was removed on rotary evaporator, and water (70 ml.) was mixed with the residual yellow oil. The aqueous dispersion was extracted with four 50 ml. portions of benzene, followed by two 50 ml. portions of chloroform. The extracts were dried (anhydrous magnesium sulfate), the solvents were stripped, and the residue was chromatographed.

Dinitrodiphenylmethane (LXIX, 0.135 g., 29%, m.p. 74-6° (hexane)) was eluted with 1:1 petroleum ether-benzene, followed closely by benzophenone (CLIX). Elution with benzene and 1:1 benzene-chloroform yielded additional CLIX. A total of 0.220 g. (67.1%) of CLIX, m.p. 45-7°, was isolated. Oxime was not recovered.

Oxidation of 1-indanone oxime (CLXIII)

Nitric acid (6.5 ml., 70%) was added dropwise with stirring to a solution of CLXIII (0.503 g., 0.0034 mole) in methanol (50 ml.). The resulting solution was allowed to stir for 15 hours, after which time the solvent was removed from the colorless solution on a rotary evaporator. Water (50 ml.) was mixed with the residual oil, and the dispersion was extracted with five 100 ml. portions of benzene. The

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[1] Benzophenone oxime is decomposed by light in air to give benzophenone and NO. D. C. Heckert. Unpublished observations. Iowa State University of Science and Technology, Ames, Iowa. 1965.

extracts were dried as before, the solvent was stripped, and the residue was chromatographed.

Elution with 1:1 petroleum ether-benzene gave 1,1-dinitroindane (CLXXI). The yellow oil was recrystallized from hexane-pentane to give 0.122 g. (17.3%) of CLXXI, m.p. 42-3°. The ketone CLXXII eluted from the column in benzene. The brown oil crystallized after thorough evacuation yielding 0.220 g. (49%) of CLXXII, m.p. 38-40°. A total of 0.095 g. of brown gum was collected in the later chromatography fractions. Attempts at characterization of the gum were unsuccessful. Oxime CLXIII was not recovered.

Oxidation of acetophenone oxime (CLXVI)

Acetophenone oxime (CLXVI, 0.505 g., 0.0037 mole) was dissolved in methanol (56 ml.). Nitric acid (7.1 ml., 70%) was added to the oxime solution dropwise with stirring. The reaction mixture was stirred for 15 hours, after which time the solvent was removed at reduced pressure. Water (50 ml.) was mixed with the residual oil, and the dispersion was extracted with five 100 ml. portions of benzene. The extracts were dried as before, the solvent was stripped, and the residue was chromatographed. Only a small amount (0.02 g., 2.7%) of 1,1-dinitro-1-phenylethane (LXXII) was isolated on elution with 4:1 petroleum ether-benzene. Acetophenone (CLXXX) eluted from the column with 1:1 petroleum ether-benzene. A 2,4-dinitrophenylhydrazone derivative was prepared as before to give 0.683 g. of red-orange solid, m.p. 242-5°. The yield of CLXXX was 61% based on the DNP. Only traces of materials were isolated in the later chromatography fractions. Oxime CLXVI was not recovered.

Oxidation of 9-xanthenone oxime (CLXIX)

A solution of 9-xanthenone oxime (CLXIX, 0.501 g., 0.0024 mole) in methanol (40 ml.) was treated with nitric acid (5.2 ml., 70%) and the acid solution was allowed to stir for 14 hours. The solvent was then removed on a rotary evaporator. Water (50 ml.) was mixed with the residual white slurry, and the aqueous solution was filtered to give 0.443 g. of 9-xanthenone (CLXXXVII), m.p. 172-3°. The aqueous filtrate was extracted with two 50 ml. portions of benzene, followed by two 50 ml. portions of chloroform. The extracts were dried as before, and the solvents were removed to give 0.021 g. of light yellow solid. This was combined with the 0.443 g. of material removed by filtration previously, and everything was recrystallized from ethanol to give 0.454 g. (97.6%) of CLXXXVII, m.p. 173-4°. Only CLXXXVII remained in the filtrate from the recrystallization. Oxime was not recovered.

Experimental for the Oxidation of Hydrazones by Ceric Ammonium Nitrate

Reactions of hydrazones with ceric ammonium nitrate were conducted at room temperature (24-26°C.). All product mixtures were separated by chromatography on silica gel. Yields are reported as percent pure product with satisfactory melting point and spectroscopic properties, and are based on recovered starting material. For "dimeric" species, yields are based on one-half of the starting material which reacted.

Chromatographic procedure

The same chromatographic procedure was used in the oxidation of hydrazones as was previously described for oxidation of oximes with cerium(IV) salts. Minor variations will be pointed out as needed in the experimental details of each reaction.

Experimental for the Oxidation of 9-Fluorenone Hydrazone (CXVII) by Ceric Ammonium Nitrate

Oxidation of 9-fluorenone hydrazone (CXVII) in ethanol

A. A solution of 1.00 g. (0.005 mole) of 9-fluorenone hydrazone (CXVII) in 100 ml. of absolute ethanol was prepared. A solution of 2.76 g. (0.005 mole) of ceric ammonium nitrate in 30 ml. of absolute ethanol was prepared in an addition funnel, and was added dropwise over ten minutes to the hydrazone solution. Rapid stirring of the reaction mixture was maintained during the addition and throughout the course of the reaction. Some gas evolution was observed as the CAN was added. A red-orange precipitate began to form after about 1 ml. of the reagent had been added, which became heavier as the addition was continued. The red-orange slurry was allowed to stir for 15 hours, after which time the solution was filtered to give 0.533 g. of a red-brown solid, m.p. 263-5°. The filtrate was concentrated on a rotary evaporator at 60°. Water (100 ml.) was poured into the yellow-orange residue, and the slurry was extracted with four 100 ml. portions of benzene. The extracts were dried (anhydrous magnesium sulfate), the solvent was removed at reduced pressure, and the residue was chromatographed on silica gel (100 g.).

The red-brown solid filtered from the reaction mixture was recrystallized from ethanol to give 0.511 g. (55.6%) of red-orange needles, m.p. 266-8° (lit. (138), m.p. 265-9°). The infrared spectrum (KBr) of 9-fluorenone azine (CXVIII) is shown in Figure 46. The molecular weight was found to be 356 (mass spec., Table 21). A mixed melting point of CXVIII with authentic 9-fluorenone azine, m.p. 268-70°, gave no depression (m.m.p. 267-9°). Recrystallization of CXVIII from ethyl acetate gave deep red needles, m.p. 267.5-9°.

Anal. Calcd. for $C_{26}H_{16}N_2$: C, 87.61; H, 4.53; N, 7.86. Found: C, 87.45; H, 4.56; N, 7.88.

Chromatography of the extraction residue gave the results which follow. Fraction 1 (1:1 petroleum ether-benzene) was digested with hot ethanol. After cooling to room temperature, the solution was filtered to give 0.043 g. of azine CXVIII, m.p. 263-5°. Fraction 2 (1:1 petroleum ether-benzene) yielded 0.004 g. of CXVIII, m.p. 262-5°, upon digestion with ethanol. The total amount of CXVIII isolated in the work-up of the reaction was 0.558 g. (60.7%). The residue remaining in fraction 2 after removal of the azine was combined with fraction 3 (1:1 petroleum ether-benzene). A benzene solution of the combined material was treated with charcoal, filtered and evacuated thoroughly. On cooling, the oil crystallized to give 0.122 g. (13.2%) of 9-fluorenone (LXIII), m.p. 75-8°.

An orange solid remained in fraction 1 after removal of azine CXVIII. Two recrystallizations of the solid from ethanol yielded 0.014 g. of 9,9′-bifluorene (CCXV), m.p. 238-40° (lit. (148), m.p. 244-5°). The i r spectrum of CCXV (KBr, Figure 47) showed only C-H and aromatic nuclear absorptions. A molecule ion was observed at m/e 330 in the mass spectrum of CCXV. An nmr spectrum ($CDCl_3$, Figure 31) showed a singlet at 5.18τ, due to the methine protons, and aromatic protons in the ratio 1:8, respectively (130), methine protons, 5.29τ ($CDCl_3$). Recrystallization of CCXV (ethanol) for analytical purposes gave finely-divided light yellow needles, m.p. 239.5-41°.

<u>Anal</u>. Calcd. for $C_{26}H_{18}$: C, 94.50; H, 5.50. Found: C, 94.38; H, 5.57.

The i r spectra ($CHCl_3$) of the residue in fraction 1 (after CXVIII and CCXV had been removed) and fraction 4 (benzene and chloroform) indicated the same mixture of materials. These were combined for purposes of a second chromatography on silica gel. Fraction 5 (chloroform-methanol mixtures) contained 0.02 g. of a red gum which was not characterized further.

The residue remaining in fraction 1 and the contents of fraction 4 were combined and rechromatographed to give four new fractions. Fraction 1 (petroleum ether and 4:1 petroleum ether-benzene) contained only a trace of material which was discarded. Fraction 2 (1:1 petroleum ether-benzene) was recrystallized from ethanol to give 0.019 g. of 9,9′-bifluorene (CCXV), m.p. 233-6°. The overall yield of CCXV, including the 0.014 g. isolated previously, was 0.033 g. (3.9%). Fraction 3 (benzene) yielded an additional 0.052 g. (5.6%) of 9-fluorenone (LXIII). The yield of LXIII for the reaction was 0.174 g. (18.8%). Fraction 4 (chloroform) contained a gum (0.046 g.) which was not identified further. None of the hydrazone CXVII was recovered in the two chromatograms.

B. The hydrazone CXVII (1.00 g.) was dissolved in absolute ethanol (100 ml.) as before. Ceric ammonium nitrate (2.76 g.) was dissolved in absolute ethanol (30 ml.) in an addition funnel, and the solution was added to the hydrazone solution in one portion (10 seconds) with rapid stirring. Vigorous gas evolution commenced immediately. After about 30 seconds, a red precipitate began to form from the red-orange solution. The slurry was allowed to stir for 15 hours. The mixture was then filtered to give 0.605 g. (65.9%) of azine CXVIII, m.p. 263-5°. The filtrate was concentrated on a rotary evaporator, and the orange residue was extracted in the manner described previously. The extraction residue was chromatographed on silica gel (80 g.).

Elution with 4:1 petroleum ether-benzene gave two fractions. Fraction 1 contained 0.17 g. of a mixture of ketone LXIII and 9,9′-bifluorene (CCXV), which was set aside to be rechromatographed. Fraction 2 yielded 0.039 g. (4.2%) of deep red needles, m.p. 266-8°, from ethanol, which were identical to azine CXVIII in every respect. The overall yield of azine CXVIII was 70.1% .

Elution with 1:1 petroleum ether-benzene gave 9-fluorenone (0.048 g., 5%), m.p. 74-8° (from the column). Fraction 4 (chloroform) and fraction 5 (methanol) contained a total of 0.04 g. of red gum from which nothing could be isolated and characterized.

Fraction 1 (0.17 g. crude) was rechromatographed on silica gel (25 g.) to give the results which follow. Elution with 4:1 petroleum ether-benzene gave two fractions. Fraction 1 was recrystallized from ethanol to give 0.035 g. (4%) of 9,9′-bifluorene, m.p. 228-33°. The second fraction contained ketone LXIII, and was recrystallized from ethanol (minimum) to give 0.065 g. (7%) of light orange powder, m.p. 78-81°. The overall yield of LXIII, including fraction 3 of the first chromatography, was 12%. Elution with benzene and chloroform gave a small amount of red-brown gum which was discarded. None of the hydrazone CXVII was recovered in the chromatograms.

Preparation of 9-diazofluorene (LXXXVII)

Diazofluorene (LXXXVII) was prepared by the method of Schönberg (104). A mixture of 1.308 g. of 9-fluorenone hydrazone (CXVII), 2.21 g. of mercuric oxide (yellow), and 0.63 g. of anhydrous sodium sulfate was prepared by grinding the three materials together in a mortar. The mixture was placed in a 125 ml. Erlenmeyer flask and was covered with 30 ml. of ether. Twenty drops of a freshly prepared potassium hydroxide-ethanol solution (concentrated) were added. The solution was allowed to stand with occasional swirling for 1 hour, after which time the inorganic salts were removed by filtration. The solids were washed with excess ether and the washings were combined with the original filtrate. The solvent was removed at reduced pressure to give 1.293 g. of 9-diazofluorene (LXXXVII), m.p. 95-6° (finely divided red-orange needles). The compound was used without further purification. An i r spectrum ($CHCl_3$) of LXXXVII is shown in Figure 48.

Oxidation of 9-diazofluorene (LXXXVII) by ceric ammonium nitrate in ethanol

A solution of 0.117 g. (0.0006 mole) of LXXXVII in 15 ml. of absolute ethanol was prepared. A solution of 0.176 g. (0.00032 mole) of ceric ammonium nitrate in 5 ml. of absolute ethanol was added to the solution of LXXXVII in one portion through a funnel. Rapid stirring of the reaction mixture was maintained during the addition. The red color of the solution slowly faded to orange. After 15 minutes stirring, the solvent was removed on a rotary evaporator at 60°. Water (15 ml.) was mixed with the residue, and the slurry was extracted with benzene (5 x 20 ml. portions). The extracts were dried (anhydrous magnesium sulfate), and were evaporated to give 0.13 g. (crude) of red-orange gum. An i r spectrum ($CHCl_3$) of the crude reaction mixture contained no 4.86μ absorption due to unreacted LXXXVII. The prominent features of the spectrum were a 5.85μ carbonyl band, and an intense band at 6.14μ. The residue was then chromatographed on silica gel (30 g.).

Fraction 1 (4:1 petroleum ether-benzene) contained 0.05 g.

of a yellow semisolid which partially crystallized on standing. Attempts to obtain crystalline material through the use of various solvents were unsuccessful. The i r spectrum ($CHCl_3$) of the fraction is shown in Figure 48. An nmr spectrum (CCl_4) of the crude fraction showed, in addition to aromatic protons, a broad singlet at 3.24τ and a broad absorption at 4.49τ, in the ratio 22.4:1.5:1, respectively. Other absorptions at higher field than 4.49τ indicated that the fraction was indeed crude. None of the azine CXVIII was isolated from or detected in the fraction. Further characterization of the mixture was not carried out.

Fraction 2 (4:1 petroleum ether-benzene) contained 0.05 g. of a yellow semisolid, which an i r spectrum indicated to be impure fluorenone (LXIII). Trituration of the semisolid with ethanol yielded 0.009 g. of white prisms, m.p. 193-6°. The molecular weight of the solid was found to be 412 (mass spec.), with prominent fragment ions appearing at m/e 206, 179, 151, 150, and 148 in the mass spectrum. At an ionization energy of 18 ev., the peaks at m/e 206 and 412 increased in intensity, while all others decreased in intensity. The i r spectrum (KBr) of the material (Unknown G) is shown in Figure 48. Fluorenone (LXIII) remained in fraction 2 after the solid had been removed. The yield of LXIII was about 35% (ca. 0.038 g.) based on the crude material.

Elution with benzene, chloroform, and methanol gave a total of 0.03 g. of brown gum which exhibited an ill-defined i r spectrum. Attempts at identification of the gum were unsuccessful, and the material was discarded.

Experimental for the Oxidation of Benzophenone Hydrazone (CXIX) by Ceric Ammonium Nitrate

Oxidation of benzophenone hydrazone (CXIX) in ethanol

A solution of 1.00 g. (0.005 mole) of benzophenone hydrazone in 70 ml. of absolute ethanol was prepared. A solution of 2.76 g. (0.005 mole) of ceric ammonium nitrate in 30 ml. of absolute ethanol was prepared in an addition funnel and was added to the hydrazone solution in one portion (15 seconds) with rapid stirring. A green color was noted at the point where the CAN solution initially contacted the hydrazone solution. Vigorous gas evolution occurred immediately. The light orange solution was allowed to stir for 12 hours, after which time the solvent was removed on a rotary evaporator. Water (100 ml.) was mixed with the residue, and the resulting red-orange slurry was extracted with four 100 ml. portions of benzene. The extracts were dried (anhydrous magnesium sulfate), the solvent was removed at reduced pressure, and the residue was chromatographed.

Elution with 1:1 and 7:3 benzene-petroleum ether gave only a trace of material which was discarded. Fraction 2 (4:1 benzene-petroleum ether) contained 0.015 g. of benzophenone (CLIX). Fraction 3 (benzene) contained a yellow solid which was recrystallized from ethanol yielding 0.521 g. (56.8%) of benzophenone azine (CXX), m.p. 158-60° (lit. (65), m.p.

161.5-62°). The i r spectrum (KBr) of CXX is shown in Figure 46. The mass spectrum of CXX gave a molecule ion at m/e 360 (Table 21). A second recrystallization from ethanol gave nearly colorless needles, m.p. 160.5-161.5°.

Anal. Calcd. for $C_{26}H_{20}N_2$: C, 86.63; H, 5.59; N, 7.77. Found: C, 86.56; H, 5.58; N, 7.74.

Fraction 2 and the residue (brown oil) remaining after removal of CXX from fraction 3 were combined. A chloroform solution of the oil was dried (anhydrous $MgSO_4$), treated with charcoal, and the solvent was removed to give a yellow semisolid. After thorough evacuation and cooling, the residue crystallized yielding 0.062 g. (6.7%) of benzophenone, m.p. 42-5°.

Fractions 4 (benzene and 4:1 benzene-chloroform) and 5 (1:1 benzene-chloroform and chloroform) contained a total of 0.11 g. of brown gum, the i r spectrum ($CHCl_3$) of which indicated the gum to be a mixture of compounds. Attempts to simplify the mixture by chromatography and recrystallization were unsuccessful. Fraction 6 (9:1 chloroform-methanol) contained 0.09 g. of a red semisolid which gave an ill-defined i r spectrum ($CHCl_3$). Further characterization was not carried out. None of the hydrazone CXIX was recovered.

In another experiment, 2.00 g. (0.01 mole) of the hydrazone CXIX in 140 ml. of absolute ethanol was allowed to react with 5.52 g. (0.01 mole) of ceric ammonium nitrate in 60 ml. of absolute ethanol. The CAN solution was added to the hydrazone solution in one portion (40 seconds) with rapid stirring as before. After 9 hours, the solvent was removed on a rotary evaporator. Subsequent work-up of the crude reaction mixture was carried out as described previously. Chloroform (two 100 ml. portions) was used in the extraction in addition to benzene. The extraction residue was chromatographed as before.

Elution with 1:1 petroleum ether-benzene gave five fractions, which contained varying amounts of the ketone CLIX and the azine CXX. The fractions were combined and were recrystallized from ethanol to give 1.090 g. (59.3%) of CXX, m.p. 158-60°. The residual brown oil (0.527 g.) would not crystallize after treatment as described previously for CLIX, and was rechromatographed on silica gel (50 g.) to give three new fractions. The first fraction (4:1 petroleum ether-benzene) contained 0.50 g. of nearly pure ketone CLIX as shown by an i r spectrum. The second and third fractions (4:1 petroleum ether-benzene and benzene and chloroform, respectively) contained 0.01 g. of brown gum which was discarded. The yield of CLIX was about 26% based on the crude fraction.

Fraction 6 of the first chromatography (4:1 benzene-petroleum ether, benzene, and chloroform) contained 0.14 g. of a red-orange gum. Recrystallization of the gum from ethanol resulted in the isolation of 0.015 g. of orange needles, m.p. 93-8° (Unknown F). A comparison of the i r spectrum (KBr) of the solid (Figure 47) with that given by authentic hydrazone

CXIX showed that the material was not unreacted hydrazone. The mass spectrum of Unknown F suggested that it was a mixture of materials. Peaks above m/e 300 slowly disappeared over several scans of the spectrum, with the exception of a peak at m/e 356, which was observed to slowly increase in intensity. Further characterization of the solid was not made. Nothing was isolable from the gum remaining in fraction 6.

Fraction 7 (chloroform) contained 0.1 g. of a red gum which yielded a trace of dark brown solid (0.002 g., m.p. 84-90°) on recrystallization from ethanol. Further attempts at characterization of the remaining gum were unsuccessful. The column was stripped with methanol to give a trace of gum which was discarded.

SUMMARY

Several diaryl and arylalkyl ketoximes are rapidly converted to *geminal*-dinitro compounds by ceric ammonium nitrate at room temperature in anhydrous methanol in yields ranging from 1% to 38%, and in anhydrous acetone in yields ranging from 18% to 55%. Ketones are the major oxidation products in most instances. Azine monoxides and *p*-nitroketones are formed in low yields in some reactions. Ceric potassium nitrate converts 9-fluorenone oxime to 9,9-dinitrofluorene, 9-fluorenone, and 9-fluorenone azine monoxide in methanol in the same yields as does ceric ammonium nitrate. Oxidation of aryl and diaryl ketoximes by ceric ammonium nitrate provides a convenient method for the preparation of aryl- and diaryl-substituted dinitromethanes, one which may be carried out under extremely mild conditions to give products which are readily separable by column chromatography.

Of the aryl ketoximes studied, only 9-xanthenone oxime and anthraquinone monoxime did not yield *gem*-dinitro derivatives when oxidized by ceric ammonium nitrate. Oxidation of 9-xanthenone oxime in anhydrous methanol and aqueous methanol gives 9-xanthenone (major), 9-nitriminoxanthene, and 9-xanthenone azone. The azine is not formed in acetone solution. Anthraquinone monoxime gives only anthraquinone when oxidized by the reagent.

Factors influencing product formation in the ceric ammonium nitrate oxidation of aryl ketoximes are discussed.

Oxidation of 9-fluorenone oxime by ceric ammonium sulfate or ceric sulfate in aqueous methanol gives 9-fluorenone and 9-fluorenone azine monoxide, but gives no 9,9-dinitrofluorene. Nitrogen-15 isotope labeling experiments indicate that the origin of one of the nitro groups in geminal-dinitro compounds is the nitrate ion initially complexed with cerium(IV) in the ceric ammonium nitrate reagent. Indirect evidence (from electron spin resonance studies) suggests that iminoxyl radicals are the reactive intermediates to which ligand transfer from cerium(IV) takes place. Data directly relating iminoxyl radical formation and decay to product formation has not been obtained, however. The experimental evidence suggests that the cerium(IV) oxidation of oximes occurs *via* initial formation of an oxime-cerium(IV) complex, but the nature of the complex cannot be determined from the data.

Nitric acid in methanol converts some aryl ketoximes to geminal-dinitro compounds and ketones at room temperature. Ketones predominate, except in the oxidation of 9-fluorenone oxime, where 9,9-dinitrofluorene is formed in 75% yield.

Symmetrical ketazines are the major products of the ceric ammonium nitrate oxidation of 9-fluorenone hydrazone and benzophenone hydrazone. The respective ketones are also formed in low yields. Small quantities of 9,9′-bifluorene are formed in the oxidation of 9-fluorenone hydrazone. Tetrazenes have been proposed as intermediates in the formation of azines in the reaction.

The mass spectra of _geminal_-dinitro compounds are discussed in relation to general fragmentation modes found to be characteristic of the compounds. Azine monoxides undergo rearrangement to carbonyl compounds and diazo compounds in the mass spectrometer. The mass spectra of the azine monoxides characterized in the cerium(IV) oxidation studies are described to illustrate this novel rearrangement. The mass spectra of some ketazines are also discussed.

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