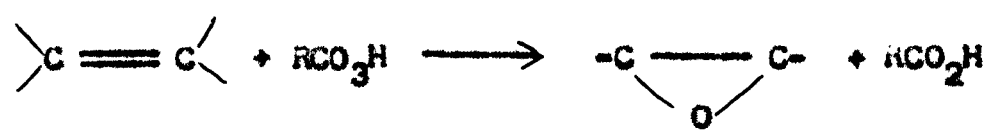


**CHAPTER - I**  
**GENERAL INTRODUCTION**

Epoxidation is the reaction in which ethylenic unsaturation is converted directly to oxirane by reaction with peroxy acid, either preformed or generated in situ:



This reaction was discovered about 1908 by the Russian Chemist, Prileschajew.<sup>1-3</sup> "Oxirane group" is the official "Chemical Abstracts" name for the three membered heterocyclic ring shown above. This group, however, is frequently called the epoxide group (more precisely 1,2 epoxide or  $\alpha$ -epoxide); thus prompting Swern, in whose laboratory considerable fundamental work on this reaction was conducted during forties<sup>4-7</sup> to coin the universally accepted word "epoxidation" for the process. (The term "Oxide group" is frequently found in the older literature).

The importance of epoxides as industrial chemical intermediates is attested by the 1966 worldwide production capacity which was in excess of 5 billion lb/year.<sup>8,9</sup> The major uses of epoxidized oils and esters are as plasticizers-stabilizers for polyvinyl chloride resins.<sup>10-14</sup> Epoxidized oils and esters are incorporated into polyvinyl chloride systems to improve flexibility, elasticity, toughness, and

impart stability to the mixture towards heat and light. Monomeric epoxy esters are efficient plasticizers and impart low temperature flexibility to polyvinyl chloride.

The most striking attribute of all epoxyesters, and the main reason for their wide industrial acceptance, is the marked improvement they impart to the light stability of plasticized polyvinyl chloride. New uses for epoxidized plasticizers-stabilizers and other epoxidized substances are expected to increase the demand for these substances sharply. Promising applications in the polymer field (alkyds, polyesters, and epoxy resins) are among the more important developments. Considerable activity in these fields occurred between 1950 and 1960. Emulsions of polyepoxides are reported to be of value as surface coatings and as additives for fabrics, papers, and leather to improve the shrink resistance, crease resistance, abrasion resistance, and wet strength.<sup>15,16</sup>

Epoxides are intermediates in the metabolism of aromatic hydrocarbons<sup>17-23</sup> and accordingly may also be responsible for the carcinogenic effects of certain aromatic hydrocarbons.<sup>24-27</sup> The epoxy dicarboxylic acid should be of potential commercial interest because it is derived from

benzene via low cost maleic anhydride<sup>28</sup> and because it can be converted into dialkyl tin epoxy succinates which are plasticizer-stabilizers for polyvinyl chloride,<sup>29</sup> as well as into cross-linkable epoxy containing film forming polyamides.<sup>30</sup>

Organic as well as inorganic peracids are among the important epoxidizing agents. A reagentwise review is presented below.

(1) PEROXYBENZOIC ACID:- Peroxybenzoic acid is important for preparing oxiranes not only historical reasons but also because of its ready availability and efficiency. In several cases quantitative yields of oxiranes are obtained and frequently it is well over 75%. The reaction can be conducted in a wide variety of inert organic solvents, most commonly benzene, chloroform, methylene chloride, ether, dioxane, acetone and ethyl acetate. Reaction time is frequently short, but it may vary considerably, depending on the number and nature of groups attached to the unsaturated linkage. Reaction temperature varies from 0° to room temperature usually. The reagent is especially useful for the laboratory epoxidation of non-volatile, water insoluble unsaturated compounds that can not be satisfactorily

converted to the oxirane by way of the chlorhydrin or by antoxidation. Swern<sup>4-7</sup> tabulated the compounds epoxidized by peroxybenzoic acid.

(11) MONOPEROXYPHTHALIC ACID :- Böhme<sup>31,32</sup> was apparently the first to show that monoperoxyphthalic acid (MPA) is consumed by the ethylenic linkage, but Chakravarty and Levin<sup>33</sup> in 1942 were the first to isolate the oxiranes. Since then MPA has had wide use in the epoxidation of unsaturated compounds, notably sterols and other polycyclic compounds, polyenes, and many natural products. Epoxidation with MPA is conducted under the same general conditions and in the same solvents as with peroxybenzoic acid; Excellent yields of oxiranes are usually obtained.

Monoperoxyphthalic acid has two advantages over peroxybenzoic acid. First, when epoxidation requires a long reaction time, its greater stability<sup>33,34</sup> is an asset. Second, since epoxidation with MPA are often conducted in chloroform, in which phthalic acid (the reduction product of MPA) is insoluble, phthalic acid precipitates out and is thus unable to cause the unwanted ring opening reactions.

The epoxidation of unsaturated compounds with phthalic anhydride and hydrogen peroxide in benzene at

moderate temperatures (25-50°) (in situ generation and consumption of MPA) has been patented.<sup>35</sup> The same patent also describes the use of succinic anhydride, 1,2-cyclohexanedicarboxylic acid anhydride, and  $\alpha, \alpha$ -dimethyl benzyl succinic anhydride for in situ epoxidation.

(iii) PEROXYACETIC ACID:- Peroxyacetic acid has become the most important epoxidation reagent during the last 20 years for two main reasons: first, its commercial availability, low price, and ease of preparation; second, the development of mild, high speed reaction conditions for the preparation of a wide variety of oxiranes in high yield. Peroxyacetic acid has the added advantages that it can be used in both aqueous and nonaqueous solvents, and in homogeneous and heterogeneous media. The organic solvents that are employed in epoxidations with peroxybenzoic acid are the common ones. The solvents should however be inert under the reaction conditions and should be easy to dispose off.

Peroxyacetic acid in acetic acid solution was then successfully applied<sup>36</sup> to the epoxidation of a wide variety of long-chain unsaturated compounds (acids, monoesters, triglycerides, alcohols). Swern, Billen, and Scanlan<sup>37</sup>

converted a series of 1-olefins to the corresponding oxiranes in fair yields with dilute (about 1M) peroxyacetic acid in acetic acid solution. The terminally unsaturated compounds have about 24 hrs. reaction time, whereas non-terminal, isolated double bonds need only 2-4 hrs.

(iv) PEROXYFORMIC ACID :- Peroxyformic acid is unstable even at low temperatures and in concentrated form it is a hazardous compound. For this reason it is rarely isolated and its use as an epoxidizing reagent has been exclusively in situ.

The in situ-generation of formic acid, a rapid process requiring no added acid catalysts; attains equilibrium in less than 1 hr. even with relatively dilute (30%) hydrogen peroxide. In situ oxidation with peroxyformic acid is, therefore, an attractive procedure both for laboratory and for large scale work since the active oxygen of hydrogen peroxide can be rapidly transferred to oxidizable substrates.

Formic acid, however, is a considerably stronger acid than acetic acid and causes opening of the oxirane ring at a much faster rate (This facile ring opening reaction can be used to advantage in the preparation of 1,2-glycols in excellent yields from olefins). Therefore, reaction conditions

for in situ epoxidation with peroxyformic acid must be designed to reduce the ring opening while taking into account the fact that oxiranes may form more rapidly, with evolution of more heat in a shorter time.

The first successful epoxidation with peroxyformic acid was reported by Byers and Hickinbottom<sup>30</sup> who isolated an oxirane in low yield from diisobutylene (2,4,4-trimethyl-1-pentene). Diisobutylene was an unfortunate choice as it was not known to the original investigators, that diisobutylene reaction is an abnormal and a whole range of products is obtained, of which the oxirane is a minor one. Also, rather large volumes of formic acid were employed, a condition that is not conducive to high-yield preparation of oxiranes. With peroxybenzoic acid, on the other<sup>hand, a yield</sup> <sup>upto</sup> 40% of the anticipated oxirane was obtained.

The practicability of in situ epoxidation with peroxyformic acid was first demonstrated by Niederhauser and Koroly<sup>39</sup> who used limited amounts of formic acid as the oxygen carrier and, in some cases, organic solvents as well to reduce ring opening. These investigators epoxidized methyl oleate, octyl oleate, propylene glycol dioleate, and soyabean oil, and obtained fair yields of oxiranes.



(v) PEROXYTRIFLUOROACETIC ACID :- The introduction of an electron-withdrawing group into the  $\alpha$ -position of an aliphatic peroxyacid or into the ring of an aromatic one not only enhances the electrophilic character of the peroxyacid but also provides a better leaving molecule in the collapse of the transition state. The result is an enhanced rate of epoxidation.

An excellent illustration of the effect of such substitution on the rate of epoxidation is given by peroxytrifluoroacetic acid, first described by Emmons and Ferris in 1953.<sup>40</sup> Peroxytrifluoroacetic acid is an extremely high speed oxidant and therefore has found most widespread use<sup>41-43</sup> with negative substituted<sup>unsaturated</sup> compounds that undergo unusually slow epoxidation with the usual peroxyacids (peroxybenzoic, peroxyacetic, and peroxyphthalic acids).

Epoxidation with peroxytrifluoroacetic acid must be conducted with particular care because trifluoroacetic acid, the reduction product, is a stronger acid and readily reacts with the oxirane group. Therefore, it is not necessary to use a buffer but the particular one chosen is important and plays a dominant role in certain cases in determining the yield of oxirane.<sup>42</sup> Sodium carbonate and sodium bicarbonate, and disodium hydrogen phosphate have been employed. Sodium

carbonate and bicarbonate are satisfactory buffers in epoxidations where a weak peroxyacid reacts more rapidly with the unsaturated compounds than with the buffer. Disodium hydrogen phthalate is preferred for the unsaturated compounds that epoxidize slowly because this buffer is able to neutralize the trifluoroacetic acid as rapidly as it is formed without making the reaction mixture so basic that the peroxyacid is destroyed before it is consumed. Under appropriate conditions, excellent yield (>90%) of oxiranes can often be obtained with terminal and non terminal olefins and with those containing electron-withdrawing substituents attached to the double bond.

(vi) m-Chloroperoxybenzoic Acid:- m-chloroperoxybenzoic acid, first prepared and characterized by Lynch and Rausacker<sup>44</sup> in 1955, became commercially available in 1962.<sup>45,46</sup> The commercial product is about 85% pure; the parent carboxylic acid, m-chlorobenzoic acid, is the main impurity. A 99% + pure peroxyacid can be readily obtained by washing the commercial grade with aqueous phosphate buffer.<sup>47</sup> Technical data (physical and chemical properties, stability) and epoxidation procedures are presented in a bulletin.<sup>46</sup>

m-chloroperoxybenzoic acid is a stable peroxyacid, soluble in a variety of common organic solvents. The rate of

epoxidation of unsaturated compounds with this peroxyacid is several times that of peroxybenzoic acid<sup>42,46</sup> and is of great advantage in some cases, especially where isomerizations must be avoided (for example, epoxidation of "Dewar" benzene<sup>47</sup>). Although m-chloroperoxybenzoic acid has not received much attention yet as an oxidizing agent, the higher rate of epoxidation, commercial availability, and good stability suggest more widespread use of this peroxyacid for epoxidation and other oxidation reactions.

m-Chloroperoxybenzoic acid was first used by Lynch and Pausecker<sup>44</sup> for the epoxidation of trans-stilbene. Since their interest was primarily in the kinetics and thermodynamic parameters of epoxidation, they did not isolate the oxirane (a known compound). Similarly Schwartz and Blumberg<sup>46</sup> showed that solvents they do not show hydrogen bonding with the peroxyacid give the highest epoxidation rates. Chlorinated solvents-notably chloroform, methylene chloride, 1,2-dichloroethane, and chlorinated benzenes-are best. A large reduction in rate (hundred fold) is experienced when t-butyl alcohol is the solvent.

(vii) p-Nitroperoxybenzoic Acid: p-nitroperoxybenzoic acid, first reported by Medvedev and Blokh<sup>48</sup> in 1933 but characterized some 20 years later by Overberger and Cummins,<sup>49</sup> is another

rapid epoxidation reagent. The nitro group is strongly electron-withdrawing group, and its substitution into the ring of an aromatic peroxyacid substantially enhances the electrophilic character of the peroxyacid.<sup>44,50</sup> The p-nitro group is more effective than chlorine; p-nitroperoxybenzoic acid is 5 to 20 times more reactive than peroxybenzoic acid,<sup>44,46-50</sup> whereas m-chloroperoxybenzoic acid is only slightly more reactive.<sup>44,46</sup> This greatly enhanced reactivity, coupled with outstanding stability,<sup>50,51</sup> often makes p-nitroperoxybenzoic acid the reagent of choice for olefins that epoxidize slowly. Furthermore, the low solubility of p-nitrobenzoic acid, the reduction product, effectively removes it from the reaction medium, thus minimizing oxirane ring opening. The high reactivity and low solubility of p-nitroperoxybenzoic acid, however, limit the choice of solvent that can be used for oxidations. The solvents of choice are chloroform, ether, ether-chloroform, and tetrahydrofuran. Aromatic solvents should generally be avoided, especially those containing electron-donating groups, as they undergo facile ring attack.<sup>52</sup>

Lynsh and Pausacker<sup>44</sup> were the first to use p-nitroperoxybenzoic acid in epoxidation studies (kinetics), but they did not isolate the oxiranes. Vilkas<sup>50</sup> not only compared

the rates of epoxidation of unsaturated compounds with p-nitroperoxybenzoic and peroxybenzoic acids but he was also the first to isolate the oxiranes in several cases.

With organic peracids,  $\alpha$ ,  $\beta$ -unsaturated aldehydes, ketones, acids, and esters react extremely slowly as expected.<sup>53</sup> For these substrates hydrogen peroxide is a better choice. Some of the advantages of hydrogen peroxide in commercial epoxidation are the followings:

- (a) High reaction efficiency
- (b) High yields.
- (c) High reaction specificity.
- (d) Easy product isolation
- (e) Minimum by-products.
- (f) Stoichiometric use of peroxide.
- (g) Absence of metallic or inorganic contamination
- (h) Application to aqueous and non aqueous systems.
- (i) Application to homogeneous and heterogeneous systems.
- (j) Recovery of organic acids for reuse if desired.

#### HYDROGEN PEROXIDE AS AN OXIDANT

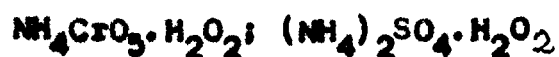
Hydrogen peroxide may act either as an oxidizing agent or as a reducing agent. In both acid and basic solutions it

is a powerful oxidizing agent (better than iodate, hypobromite, or lead dioxide). Its reducing action is generally confined to acid solution in which it is a slightly better reducer than iron(II) but not quite so good as iodide. The oxygen-oxygen single bond is one of the weakest covalent bonds known, it is easily broken or alternatively converted into the more stable oxygen molecule (whose bond is suitably described as a "one-and-two halves" bond).

The oxidation and reduction potentials of hydrogen peroxide are such that it should be able to oxidize itself, that is, it is "thermodynamically unstable" (However, oxidation potentials tell us nothing about the speed of reactions, and unstable situations can survive for years if the systems are not tempered with). The process of self oxidation (some times called disproportionation or dismutation) is common in inorganic chemistry, especially among the less usual transition elements; it is notable in the case of hydrogen peroxide because of the longevity of the unstable species. Hydrogen peroxide reduces substances which readily give up oxygen, such as potassium permanganate and bleaching powder. Compounds of noble metals are also reduced by hydrogen peroxide, thus it deposits gold from gold salt solutions, reduces silver oxide to silver, and mercury oxide to mercury.

The chemical reactions with hydrogen peroxide fall into five types:

1. The hydrogen peroxide is decomposed and the second compound is reduced, for example, with permanganate both substances are simultaneously reduced, and the resulting oxygen comes from both the permanganate and the peroxide.
2. The hydrogen peroxide is decomposed and the second compound is oxidized by the oxygen derived from the peroxide, as was the case with ozone. Sulphur dioxide, for instance, change into sulphuric acid etc.
3. Certain acids form special addition products with the hydrogen peroxide, thus sulphuric acid gives per-sulphuric acid, molybdic acid per molybdic acid, and chromic acid perchromic acid etc.
4. Certain bases may react by double decomposition whereby the one part of the hydrogen of the peroxide is replaced by a metal. In this case the hydrogen peroxide has the character of an acid.
5. Hydrogen peroxide unites with many organic and inorganic salts such in the way of water of crystallization, and it is then called hydrogen peroxide of crystallization, e.g.,



Solutions of hydrogen peroxide are not very stable and readily decompose into oxygen and water;

$$\text{H}_2\text{O}_2 = \text{H}_2\text{O} + \frac{1}{2} \text{O}_2 + 23.47 \text{ Kcals.}$$

Similar is the case with anhydrous peroxide. Substances derived from living organism, and characterized by a specific action in decomposing of hydrogen peroxide are called catalases. Such catalases are found, for example, in blood and in mucous membrane. The catalases belong to a class of so-called ferments or enzymes. There are rather unstable compounds, occurring only in minimal concentration, play in organisms a role similar to that of catalysts in the rest of chemistry. In addition to catalase there is another ferments peroxidase, which acts specifically with hydrogen peroxide. This has the property of activating of hydrogen peroxide, so that in the presence of oxidizable materials it gives up one oxygen atom to the later. In the absence of such oxidizable substances hydrogen peroxide is not decomposed by peroxidase.

Dakin<sup>54</sup> studied the oxidation of the ammonium salts of saturated fatty acids with hydrogen peroxide. The scheme of oxidation is:



$\text{CH}_3\text{COOH} \longrightarrow \text{HCOOH} \longrightarrow \text{CO}_2 + \text{H}_2\text{O}.$  Lower acids are more readily oxidized, because fatty acids and aldehydes are formed



simultaneously in lower acids. Rupp et al.<sup>55</sup> reported that in the presence of small quantities of an Fe salt  $\text{NaHCO}_3$  reacts with hydrogen peroxide to form formic acid and HCHO with evolution of gas. Reiner<sup>56</sup> investigated the kinetics of the reaction  $\text{CH}_3\text{CHO} + \text{H}_2\text{O}_2 \longrightarrow \text{CH}_3\text{COOH} + \text{H}_2\text{O}$ .

Baner et al.<sup>56</sup> carried out the oxidation of unsaturated fatty acids with hydrogen peroxide and with peroxybenzoic acid. Linolenic acid with hydrogen peroxide yields products closely resembling those obtained by air oxidation, but with peroxybenzoic acid it reacts with hydrogen peroxide with a disappearance of all double bonds and a decrease in its I.NO. The ethyl ester of linolenic acid reacts with hydrogen peroxide only in the presence of perbenzoic acid. A study of the oxidation of some dicarboxylic acids by hydrogen peroxide in the presence of certain catalysts was carried out by Walton et al.<sup>57</sup> Hatcher et al.<sup>58</sup> studied oxidation of some dibasic acids, malonic, tartaric, succinic and malic acids with hydrogen peroxide. The rates of reaction indicate the comparability of saturated acids having the same number of carbon atoms, the constancy of mono-hydroxylation in its velocity influence and the diverse effects of  $\text{H}^+$ . The mode of oxidation suggests in each case

a complex through which decomposition occurs. The effects of geometrical isomerism and ethylenic linkage are well marked. It is concluded that oxidizability is due to two or more of the following three factors:

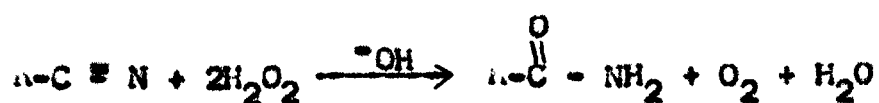
Susceptibility to oxidation of the organic compound, reactivity of hydrogen peroxide to the kind of structure presented to it and ionic condition of the medium.

(viii) Alkaline Hydrogen Peroxide-Nitriles (Peroxy-carboximidic

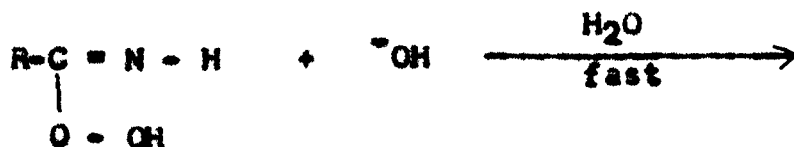
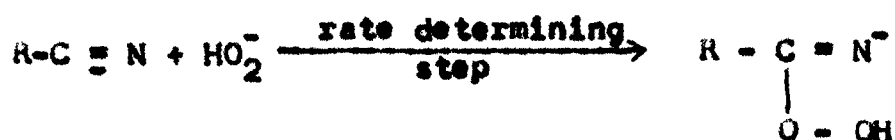
Acids):- The reaction of nitriles with alkaline hydrogen peroxide is an efficient, high speed reaction for preparing the corresponding amides in excellent yields. This reaction was discovered in about 1884 and is sometimes referred to as the Madziszewski reaction.<sup>59</sup>

Although the reaction has been widely used, its mechanism and stoichiometry were not known until 1953, when Wiberg<sup>60</sup> demonstrated that the rate of the reaction of benzonitrile with alkaline hydrogen peroxide showed a first order dependence on the concentration of nitrile, hydrogen peroxide, and the hydroxy ion. Further benzonitrile oxide was shown not to be an intermediate, and from oxygen-18 studies it was demonstrated that the oxygen introduced into the nitrile came from the hydrogen peroxide and not from water

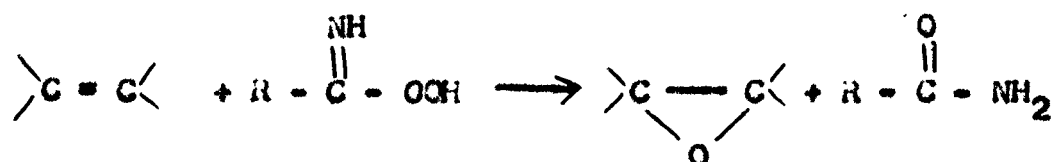
or the hydroxy ion. Electron-withdrawing groups in the aromatic ring caused a marked rate enhancement, a result observed in other nucleophilic reactions on the carbon atom of the nitrile group. The stoichiometry of the reaction was shown to be as follows:



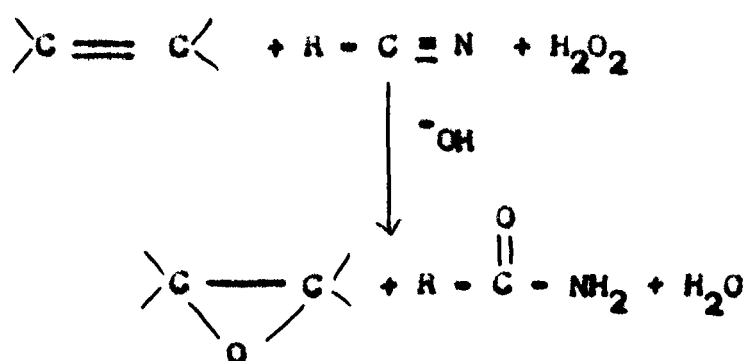
From these results Wiberg concluded that the first step in the reaction is addition of the hydroperoxide anion ( $HO_2^-$ ) to the nitrile group, followed by a fast reaction of the addition product, the highly reactive peroxy-carboximidic acid, with a second molecule of hydrogen peroxide, thus accounting for the products and stoichiometry as follows:



Peroxy-carboximidic acids have not been isolated; they are unstable, highly reactive intermediates and, as already shown, oxidize hydrogen peroxide. Payne, Deming and Williams<sup>61,62</sup> have shown, however, that if a more effective reducing agent, such as an olefin, is presented in the system, reaction of peroxy-carboximidic acids with hydrogen peroxide is largely eliminated (little or no oxygen is evolved) and the olefin is epoxidized instead:



By operating in this way only one mole of hydrogen peroxide is consumed per mole of the olefinic compound and the overall stoichiometry becomes as follows:

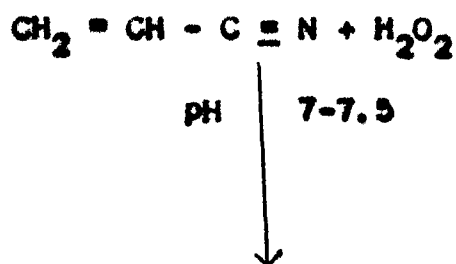


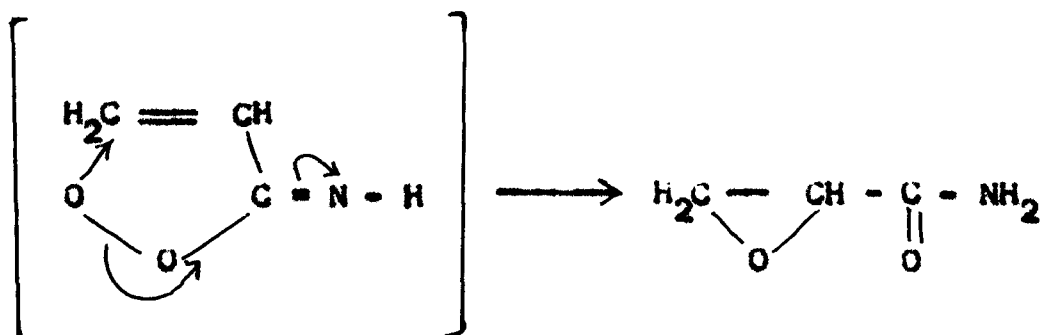
Since the rate determining step in this reaction is the addition of the hydroperoxide anion to the nitrile,

differently substituted olefins, such as 1-hexene and 2-methyl-2-butene, epoxidize at the same rate. This is in contrast to the rates of the reaction of ethylenic compounds with peroxyacids, which is highly dependent on the degree of substitution at the double bond.

$\alpha$ ,  $\beta$ -unsaturated nitriles are not epoxidized by organic peroxyacids owing to the rate-diminishing effect of the electron-withdrawing nitrile group. The alkaline hydrogen peroxide system just described, however, is well suited to the epoxidation of these nitriles, as the nitrile group in the molecule to be oxidized serves as the oxygen carrier without requiring additional nitrile to be added. The epoxidation is intramolecular; the double is converted to the oxirane and the nitrile group to the amide.<sup>63,64</sup>

Perhaps the most striking example of an intramolecular epoxidation of an  $\alpha$ ,  $\beta$ -unsaturated nitrile is the preparation of glycidamide, a novel epoxyamide, in 65-70% yield from acrylonitrile with an equimolar quantity of hydrogen peroxide.<sup>63</sup> The reaction proceeds via the intramolecular rearrangement of the nonisolable peroxyacrylimidic acid, as follows:





The double bond in peroxyacrylimidic acid, no longer strongly polarized by the electron-withdrawing nitrile group, would be expected to be more receptive to electrophilic attack than the double bond of acrylonitrile, especially if the attack were intramolecular.