CHAPTER I

INTRODUCTION

ELIMINATION REACTIONS

Olefin-forming eliminations encompass a wide variety of mechanistic types occurring under conditions ranging from strongly basic solution to gas-phase high temperature reaction \(^1\)-\(^8\). The expression “Polar elimination” is generally used in organic chemistry to designate reactions in which an electrophilic and nucleophilic leaving group depart from the same molecule. If they are on the adjacent atoms, usually but not necessarily carbon, an olefinic double bond results (1,2-or \(\beta\)-elimination): if the leaving groups are further removed, a cyclic product is formed (\(\gamma\) and \(\delta\)-eliminations). Alkene-forming elimination reactions are frequently assisted by base, since electrophilic leaving group is usually a proton. Compounds which undergo eliminations, for example, alkyl halides and sulfonates, and the conditions also are those which are conducive to nucleophilic substitutions. Consequently elimination and substitution pathways frequently occur together, leading to mixtures of product

Mechanistic Classification

The **E1 Mechanism** (Unimolecular Elimination)

It is a two-step process in which the rate-determining step is ionisation of the substrate to give a carbocation which rapidly loses a \(\beta\)-proton to a base, usually the solvent.
The E1 mechanism normally operates without an added base. It has been shown that E1 reactions can involve ion pairs. If a solvated planar carbocation is formed, then the β-proton lost to solvent in the second step should come with equal probability from either the same or opposite side of the plane of the original leaving group. If, however, the elimination ends before the dissociated group X gets far enough away, a trans-elimination will predominate. On the other hand if the nucleophilic group is so positioned that it can stabilise the configuration of the carbocation until the elimination is over, then cis-elimination will predominate. When more than one β-positions are available the E1 reactions are found to obey the Saytzev rule, the olefin having most alkyl substituents about the double bond is the favoured product. Saytzev rule, however, is not necessarily obeyed when intimate ion pairs are involved in the reaction.

**The E2 Mechanism (Bimolecular Elimination)**

This, the bimolecular mechanism, is the most widespread of all elimination processes and is formulated:
The reagent B is basic and removes a proton from the β-carbon atom of the substrate. The electron attracting group X synchronously* splits off, and the electron transfer as shown by curved arrows in order to maintain the atomic octets. The reaction is second order: first order in each component.

Base initiated reactions with many secondary systems, \( R'\text{CH}_2\text{CH}(R)\text{X} \), proceed by concerted mechanism, although here the mechanism can merge imperceptibly into cation mechanism (E1) as the ionisation of the C—X bond is made easier as the base is made weaker. In most cases it has been found that the E2 reaction is stereospecific, that is five atoms involved (including the base) must be in one plane, and that H and X must be trans. This conformation, H and X is called anti-periplanar. The dihedral angle between H and X is 180°. The leaving group may be positive or neutral, and the base may be negatively charged or neutral. Although the universality of the one-stage mechanism has been accepted generally, it has become apparent that degree of H—C and C—X bond breaking in the transition state for most concerted E2 eliminations cannot be equal and should account for structure-reactivity variations ranging from carbanion like

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* A synchronous or concerted mechanism involves no intermediates and so possesses only one transition state between the reactants and products.
to carbocation like transition states\textsuperscript{12,13}. In E2 elimination reactions a
distinction may be made according to whether the base co-ordinate solely to
proton (E2H) or initially to the α-carbon (E2C).

**The E1cB Mechanism** (Elimination Unimolecular from the conjugate Base)

Another mechanism that is consistent with second order
kinetics is a two step process in which proton abstraction is followed by a
unimolecular ejection of X from the conjugate base of the substrate: hence
the designation E1cB.

\[
\begin{align*}
\text{B:} & \quad + \quad \begin{array}{c}
\text{C}\,\text{C}\,
\end{array}
\quad \begin{array}{c}
X
\end{array}
\quad \leftrightarrow \quad \begin{array}{c}
\text{C}\,\text{C}\,
\end{array}
\quad \begin{array}{c}
X
\end{array}
+ \quad \begin{array}{c}
\text{B}^+\text{H}
\end{array}

\text{fast} \\
\begin{array}{c}
\text{C}\,\text{C}\,
\end{array}
\quad \begin{array}{c}
X
\end{array}
\quad \rightarrow \quad \begin{array}{c}
\text{C}=\text{C}
\end{array}
\quad + \quad \begin{array}{c}
\text{X}^-
\end{array}
\end{align*}
\]

A second order rate law is obeyed. The existence of this
mechanism is much less firmly established than that of E1 or E2 mechanisms.
However, studies of the reaction of four isomers of butyl iodide with strong
organic bases, tetrakis(dimethylamine), using crossed supersonic nozzle beam
technique, revealed the formation of carbanion as the reaction intermediate\textsuperscript{14}.
It may be pointed out that in many cases the above mentioned categories of mechanism are not clearly distinct and there can be a merging of mechanism so that E2 reaction may be designated 'E_{1cB}-like' (or *paene-carbanion*) or 'E_{1}-like' (*paene-carbocation*) according to whether C—H bond fission has progressed ahead of or lags behind C—X bond fission at the transition state.

**SUBSTITUTION REACTIONS**

Nucleophilic substitution reactions are generally referred to the replacement of an atom or group, along with its bonding electron pair, by another atom or group which provides the electron pair for the formation of the new bond. The reaction involves the attack of a nucleophilic reagent \( Y \), on the carbon atom of a substrate \( R-X \), with displacement of the group or atom \( :X \), with its bonding electron pair. The group \( :X \) is called the leaving group. The reaction can be formulated in the following general way:

\[
Y: + R : X \xrightarrow{[\text{Transition state}]} Y : R + : X (S_N)
\]

(nucleophile) (substrate)

Since there is an electron transfer from the substituting agent \( Y \) to the centre of substitution in \( R \), and from this centre to the expelled group \( X \), \( Y \) becomes formally one electronic unit more positive and \( X \) one more negative. Subject to this no other restriction on the states of electrification of the species involved need be placed. For convenience this
type of reaction is symbolised $S_N$. Examples are Finkelstein reaction, the Menschutkin reaction, the Hofmann degradation, the acid, alkaline and neutral hydrolysis and alcoholysis of alkyl halides and sulfonates.

**The Hughes-Ingold Theory of Nucleophilic Aliphatic Substitution**

Based on the idea that the introduction of the replacing group and the expulsion of the replaced group are interdependent features of a single synchronous process and the prior dissociation of compound substituted to give a carbocation which would later combine with the substituting agent, Hughes and Ingold developed a comprehensive theory of nucleophilic aliphatic substitution. This theory was remarkably successful in correlating and explaining the large amount of data dealing with reactions of this type. The theory postulates that a nucleophilic substitution in solution being a heterolytic reaction, has two available reaction mechanisms, namely the ionisation mechanism ($S_{N1}$ - Substitution Nucleophilic Unimolecular) and direct displacement mechanism ($S_{N2}$ - Substitution Nucleophilic Bimolecular)

The $S_{N1}$ mechanism is formulated as

$$\begin{align*}
R-X & \xleftarrow{\text{slow}} R^+ + X^- \\
R^+ + Y^- & \xrightarrow{\text{fast}} R-Y
\end{align*}$$
This mechanism proceeds by rate-determining heterolytic dissociation of the substrate to a tri co-ordinate carbocation (also referred to as carbenium ion \(^{15}\)) and the leaving group. This dissociation is followed by rapid reaction between the carbocation and the nucleophile. The consequences of this mechanism are that the reaction will exhibit first order kinetics overall, with the rate of decomposition of the substrate being independent of the concentration or nature of the nucleophile. The observed decrease in the overall reaction rate by the addition of \(X^-\) ion from outside known as common-ion effect or the mass-law effect\(^1\) and increase of rate by increasing the ionic strength of the solution known as salt effect\(^{16}\) provide kinetic evidence for the mechanism of heterolytic fission.

The \(S_N2\) mechanism is formulated as

\[
Y^- + \mathrm{C}--X \rightarrow \left[ \delta- \mathrm{C}--\delta- \right] \rightarrow \mathrm{Y}--\mathrm{C} + X^-
\]

In this mechanism the nucleophile approaches the substrate from a position 180° away from the leaving group, bond making to the nucleophile increasing along the reaction co-ordinate simultaneously with bond breaking between carbon atom and leaving group. The reaction is a one step process. The \(\mathrm{C}--\mathrm{Y}\) bond is formed as the \(\mathrm{C}--\mathrm{X}\) bond is broken. The kinetics of this process is consistent with a second order rate expression, first order in substrate and first order in nucleophile. Since the attacking species is
involved intimately in the rate-determining step, not only will the rate depend on its concentration, but also the chemical nature of the nucleophile.

There are many examples of nucleophilic substitution reactions in which the kinetic data do not allow assignment of $S_N1$ or $S_N2$ mechanisms. Such behaviour has been described as 'borderline'\(^\text{17}\). The cause of borderline behaviour is a matter of controversy and different viewpoints have been expressed by various workers\(^\text{1,17-19}\). Detailed kinetic investigations\(^\text{20-22}\), primarily concerned with salt effects on solvolytic reactions, revealed inadequacies in each of the proposed mechanism and led to the suggestion of dual ion-pair scheme by Winstein and his co-workers\(^\text{23}\).

Winstein and his co-workers\(^\text{23}\) suggested that in addition to the dissociated carbocation and counter ion of the leaving group, two ion pair intermediates were required to reconcile the available data on kinetics, salt effects and stereochemistry of solvolytic reactions. The process of ionisation generates a carbocation and a counter ion in proximity to each other. This species is called the intimate or tight ion pair. One process available to the intimate ion pair is conversion to a solvent-separated ion pair, in which one or more solvent molecules have inserted between the carbocation and the leaving group. Conversion of solvent-separated ion pair to 'free ions' occurs by diffusion of the solvated cation and counter ion away from each other, and is referred to as dissociation.
According to this scheme, attack by a nucleophile or solvent can occur on the covalent substrate, the intimate ion pair, the solvent-separated ion pair, or on the dissociated carbocation. Several lines of evidence supported the essential correctness of this scheme, especially the involvement of more than one ion pair intermediate. The effect of added lithium perchlorate on the rate of solvolysis is anomalous towards certain substrates in producing an initial sharp increase in the solvolysis rate, followed by the expected linear increase at higher concentrations of lithium perchlorate (special salt effect\textsuperscript{24}). Winstein\textsuperscript{25} ascribed this to interaction of lithium perchlorate with solvent-separated ion pair to form a solvent-separated carbocation perchlorate ion pair that does not undergo return to the intimate ion pair or covalent substrate. This new ion pair can go only to product and its formation leads to an increase in solvolysis rate more pronounced than for a simple medium effect.

Sneen and his co-workers\textsuperscript{26-30} have undertaken an extensive investigation of the mechanism of nucleophilic substitution reaction at a saturated carbon atom and suggested that the penta co-ordinate transition state of the traditional $S_N2$ displacement is without experimental proof. Ion pair intermediates, on other hand, are amply supported as having finite existence. Sneen and Larsen\textsuperscript{30} extended their interpretation by suggesting that “all reactions of nucleophilic substitution at a saturated carbon atom proceed
via an ion pair mechanism. The Sneen mechanism adopts most elements of the Weinstein ion pair scheme. Sneen proposes the following scheme.

\[ RX \xrightleftharpoons{\text{SOR}} R^+X^- \xrightleftharpoons{\text{NR}} R^+\xrightleftharpoons{\text{ROS}} X^- \xrightleftharpoons{\text{RN}} R^+ + X^- \]

where the solvent is SOH and N\(^-\) is a nucleophilic anion.

Attack by solvent can occur with inversion of configuration at the intimate ion pair stage, with retention of configuration at the solvent-separated ion pair stage, or with racemization at the dissociated ion stage. Attack by an external nucleophile can occur with inversion at the intimate ion pair stage or with racemization at the dissociated ion stage. It is considered that while normal retention of configuration would occur on attack by nucleophile at the solvent-separated ion pair stage, such a process would be competitive with solvent collapse. In most secondary systems, including those described as borderline, attack by nucleophile would occur at the intimate ion pair stage. The "Sneen mechanism" was the subject of great deal of debate and critical summaries have been published\(^{31-33}\).

Schleyer and Bentley\(^{33-35}\) proposed an alternative ion pair mechanism for the solvolytic reactions which resembles classical \(S_N2\) mechanism more closely. In their scheme which has been termed \(S_N2\) (intermediate), the first step is the rate-determining, resulting in the formation of nucleophilically solvated ion pair. The ion pair intermediate then reacts
with solvent in a rapid product-determining step. Schleyer and Bentley suggested that borderline behaviour fits readily in to this scheme. At the \( \text{S}_{\text{N}2} \) end of the spectrum the reaction proceeds through either a classical one-step pathway with strong nucleophiles or through nucleophilically solvated ion pair for weak nucleophiles. At the \( \text{S}_{\text{N}1} \) end of the spectrum, ion pair formation is nucleophilically unassisted. "Borderline" behaviour is consistent with partial nucleophilic assistance in the formation of the ion pair. Thus according to Schleyer and Bentley the major difference between the \( \text{S}_{\text{N}1} \) and \( \text{S}_{\text{N}2} \) solvolytic pathways may be attributed to the degree of nucleophilic assistance to the transition state. Recently a single electron transfer (SET) mechanism has been proposed for certain nucleophilic substitution reactions where there is evidence that radicals and/or radical ions are actually involved\(^{36-38}\).

**COMPETITION BETWEEN ELIMINATION AND SUBSTITUTION**

As mentioned earlier Elimination and Substitution reactions usually occur concurrently, the \( \text{E}1 \) and \( \text{S}_{\text{N}1} \) pathways being coupled and the \( \text{E}2 \) with \( \text{S}_{\text{N}2} \). In each case, product determination depends upon relative rate of attack of nucleophile at \( \alpha\)-C or \( \beta\)-H. In the progression from primary \( \rightarrow \) secondary \( \rightarrow \) tertiary substrates the amount of olefin generally increases since the \( \text{S}_{\text{N}2} \) reaction becomes subject to severe steric hindrance, while the \( \text{E}2 \) reaction is much less so since the peripheral hydrogens are exposed to attack. Alkyl substituents which stabilise the alkene product will also facilitate reaction. The same combination of steric and electronic factors guides the selectivity of the attack in the carbocation intermediate of \( \text{E}1/\text{S}_{\text{N}1} \) reactions in tertiary substrates.
A β-aryl group greatly promotes elimination over substitution due to the conjugation developed. Branching at the α-carbon has a similar effect though less pronounced. Higher temperatures may favour elimination, which is usually has a higher activation energy than substitution.

**E2** reactions lead to more alkene product than **E1** reactions of the same substrates. It is often possible to manipulate the preferred route in tertiary systems by means of solvent variation: in methanol, the **E1** route is favoured but in the less polar tert-butanol, the **E2** route predominates. The nature of leaving group is important; treatment of octadecyl bromide with butoxide yields 85% elimination; with corresponding tosylate, 99% substitution is obtained. The factors which determine the E/S ratio are complex. Conjugation and hyperconjugation can be discerned as favouring elimination, implying that the transition state resembles products. Steric interactions will have a similar result by disfavouring substitution.

**Review of the present work**

The work reported in this thesis consists of three parts. **Part 1.** deals with the kinetics of elimination reaction (β-elimination) of 1-p-anisyl-2-phenylethyl chloride in acetonitrile and dimethyl sulfoxide. The kinetic studies were carried out by both titrimetric and spectrophotometric methods. The effects of salts such as LiClO₄ and tetramethylammonium

* Two papers based on the work have been submitted for publication.
chloride (TMAC) on the rate of elimination reaction have been investigated. The effects of bases like pyridine and piperidine have also been studied. The main findings are

(i). The elimination of hydrogen chloride (β-elimination) from 1-p-anisyl-2-phenylethyl chloride was found to be quantitative in solvent acetonitrile and dimethyl sulfoxide. A unimolecular mechanism (E1) is operating for the elimination reaction. Support for this is obtained from the observation that a special salt effect as well as a mass-law effect is present for the elimination reaction of 1-p-anisyl-2-phenylethyl chloride in acetonitrile; the rate of elimination reaction is also higher in dimethyl sulfoxide than in acetonitrile.

(ii). Pyridine (weak base) has no effect on the rate of elimination reaction in acetonitrile whereas in presence of piperidine (a stronger base) there is the operation of a bimolecular mechanism also. A mixed mechanism (E1 + E2) is operating for the elimination reaction in acetonitrile in presence of piperidine. The activation parameters for the elimination reaction in the absence and presence of added base have been determined and discussed.

Part. 2. :- deals with kinetics of elimination reaction (β-elimination) of 1,2-diphenylethyl methanesulfonate and its 1-para substituted derivatives (1-p-methyl and 1-p-chloro) in acetonitrile, dimethyl sulfoxide and methanol. The effect of bases like pyridine, piperidine and sodium methoxide on the rate of elimination reaction has also been studied. The mechanisms of elimination of these substrates in the absence and presence of bases have been found to be similar to that of 1-p-anisyl-2-phenylethyl chloride. It was found that in the absence of added base the effect of 1-para substituted groups is similar to that
of an SN1 reaction, supporting the suggestion of E1 mechanism for the elimination reaction for the substrate in acetonitrile. The activation parameters for the elimination reaction in the absence and presence of bases have been determined and discussed.

**Part. 3.** deals with the effect of solvent on the rate of solvolysis of 1,2-diphenylethyl methanesulfonate. The solvents used were aqueous acetone, aqueous dioxane, and aqueous acetonitrile. Our data support the observation that the major cause of the 'dispersion' in the Grunwald-Winstein plot is due to the differences exist between the solvation of aryl and alkyl groups.