9 Elimination Reactions
Assigned Problems 9.1-20, 22-28

9.1 General reaction
An elimination reaction occurs when a proton and leaving group are lost from adjacent carbons, as discussed above in 8.14. The reaction is termed a 1,2-elimination. If we number the carbon attached to the leaving group 1 the proton is lost from carbon 2.

9.2 Bimolecular Reaction
The reaction of ethoxide ion with tert-butyl bromide in ethanol yields the elimination product 2-methylpropene. This reaction follows a second order rate law:

\[ \text{Rate} = k[\text{EtO}^-][\text{t-BuBr}] \]

The rate law is consistent with a one-step or concerted mechanism and is typically referred to as a bimolecular elimination of E2 reaction. The E2 reaction often competes with the S_N2 reaction. The mechanism of the E2 reaction involves simultaneous breakage of the C-H and C-Br bonds and formation of the C=C and O-H bonds. Example

Carbon-Deuterium bonds are stronger than C-H bonds. When the cleavage of a C-H(D) bond occurs during the rate limiting step of a reaction the reaction is slower for D than H. This is called a kinetic isotope effect. The presence of a kinetic isotope effect in E2 reactions supports concerted C-H and C-Br cleavages.
9.3  **Stereochemistry of the E2 Reaction**
Reactions that have several bonds are made a broken simultaneously usually have strict stereoelectronic requirements. This is due to the need for appropriate orbital overlap throughout the reaction. In the E2 reaction the sp³ orbitals of the C-H and C-LG sigma bonds begin to form a \( \pi \)-bond and thus must be coplanar. There are two possible orientations for coplanarity – syn-periplanar and anti-periplanar. Figure 9.1

The syn-periplanar conformation has all of the bonds eclipsed while the anti-periplanar conformation has all of the bonds staggered, and is thus more stable. The preference for the anti-periplanar conformation provides different stereoisomeric products from different stereoisomeric starting materials. Figure 9.2

For anti elimination to occur in a cyclohexane ring, the leaving group and the hydrogen must have a trans-diaxial arrangement. This requirement makes the analysis of the elimination products from cyclohexane derivatives difficult. Figure 9.4 and 9.5

9.4  **Direction of Elimination**
Elimination reactions frequently have two or more different structural isomers as possible products. These differences in reactivity are refereed to as regiochemistry. Most E2 reactions follow Zaitsev’s rule

The major alkene product is the one with more alkyl groups on the carbons of the double bond (the more highly substituted product). The elimination reaction of 2-bromobutane provides an example.

While Zaitsevs’ rule was empirically derived, it can be explained by the order of stability of substituted alkenes: tetra > tri > di > mono
The formation of the more highly substituted product which is more stable is termed product development control. The transition states are stabilized by the same factors that stabilize the products. Figure 9.6

While many E2 reactions follow Zaitsev’s rule, one major exception is the Hofmann Elimination. Hofmann Elimination reactions use either a very bulky quaternary nitrogen atom as the leaving group or very hindered bases. Hofmann’s Rule states: The major alkene product has fewer alkyl groups bonded to the carbons of the double bond (the less highly substituted alkene). Steric effects are one important component of Hofmann’s rule. Examples

The primary product for an elimination reaction (more substituted vs less substituted) can be controlled by the choice of base. Example

If a new double bond can be formed with conjugation to another double bond or benzene ring, it is preferred. The conjugated system is more stable. Example
9.5 Unimolecular Elimination
The reaction of tert-butyl bromide with ethanol yields a mixture of the substitution and elimination products. The mixture of products is due to two competing mechanisms: S_N1 and the unimolecular elimination or E1 reaction. The appearance of both products follows a first order rate law:

\[
\text{Rate} = k[t-\text{BuBr}]
\]

The E1 and S_N1 reactions follow the same rate law and have the same rate-determining step, unimolecular dissociation to form a carbocation. If elimination is possible (β-hydrogen) some E1 product will always be observed along with the S_N1 product. This, and carbocationic rearrangements, limit the usefulness of these reactions.

9.6 Regiochemistry and Stereochemistry of the E1 Reaction
E1 reactions follow Zaitsev’s rule, and form prefer to form the more substituted alkene. The relative yields of the elimination products follow product development control. Since the E1 reaction has a carbocationic intermediate, the stereochemistry of the leaving group and hydrogen is not important. Thus, trans-diaxial elimination is not required and different product distributions will be observed compared to the E2 reaction. Menthyl Example

The E1cb Mechanism
In elimination reactions there are three possible reaction mechanisms:
1. The leaving group-C bond breaks first – E1
2. The leaving group-C and the H-C bonds break simultaneously – E2
3. The H-C bond breaks first – E1cb
In the E1cb reaction a stable conjugate base of the initial reactant is formed. This species is an intermediate and usually follows second order kinetics but does not have strict stereochemical requirements. Example

9.7 Competition Between Elimination and Substitution
A competition between four different mechanisms (SN1, SN2, E1 and E2) occurs in substitution and elimination reactions. We typically try to carry out the reactions under condition which favor one mechanism. The following generalizations provide a summary of the factors that control the competition.

**SN2 vs E2**
Good nucleophiles or bases tend to react via SN2 or E2 mechanisms. Steric hinderance plays an important role since substitution is more strongly effected by sterics. Example

Stronger bases tend to give higher concentrations of elimination products, while weaker bases give more substitution. Examples

**SN1 vs E1**
These reactions have the same rate-determining step (carbocation formation). Since the product determining step comes after the RDS it is difficult to influence the ratio of substitution to elimination, but there is typically always a mixture.

**Methyl Substrates:** CH₃L
Excellent SN2 substrates, there is no β-hydrogen so elimination is not possible.

**Primary Substrates:** RCH₂L
Usually good SN2 substrates but can be forced to undergo E2 reactions with strong non-nucleophilic bases such as t-BuOK.

**Secondary Substrates:** R₂CHL
Most difficult to predict, good non-basic nucleophiles (RCO₂⁻, CN⁻, RS⁻) provide SN2 products, Strong bases (OH⁻ or RO⁻) give E2 products and reactions in polar protic solvent (and nucleophile) a solvolysis reaction, gives SN1 products (with some E1 side product).

**Tertiary Substrates:** R₃CL
$S_{N2}$ reactions do not occur due to steric hinderance, but $S_{N1}$ reactions are favorable as long as the nucleophile is not a good base. However, some E1 product will typically be observed. E2 reactions can be carried out when a strong base is used.