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Survey in Substitution Reactions and Elimination Reactions

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Abstract
The reactions of alkyl halides typically involve either substitution or elimination pathways. Depending on a variety of factors, the reaction mechanism can be either S_N1, S_N2, E1, E2, or some combination of these. By understanding the influences different factors have on each of these mechanisms, it is usually possible to predict which mechanism will predominate.
Keywords: S_N1, S_N2, E1, E2 ,elimination , substitution ,conditions.

Introduction

1. The S_N2 Mechanism

As described in the previous section, a majority of the reactions thus far described appear to proceed by a common single-step mechanism. This mechanism is referred to as the **S_N2** mechanism, where **S** stands for **S**ubstitution, **N** stands for **N**ucleophilic and **2** stands for **bi**molecular. Other features of the S_N2 mechanism are inversion at the alpha-carbon, increased reactivity with increasing nucleophilicity of the nucleophilic reagent and steric hindrance to rear-side bonding, especially in tertiary and neopentyl halides. Although reaction **3** exhibits second order kinetics, it is an elimination reaction and must therefore proceed by a very different mechanism, which will be described later.

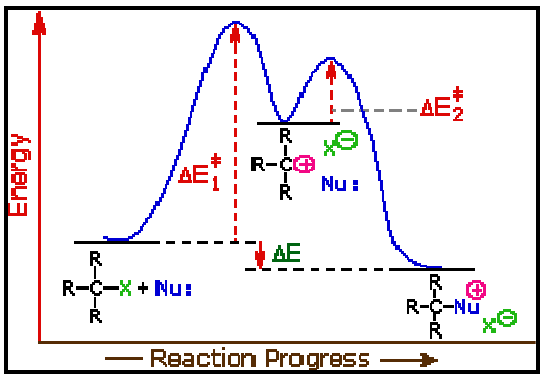
2. The S_N1 Mechanism

Reaction , shown at the end of the previous section, is clearly different from the other cases we have examined. It not only shows first order kinetics, but the chiral 3º-alkyl bromide reactant undergoes substitution by the modest nucleophile water with extensive racemization. In all of these features this reaction fails to meet the characteristics of the S_N2 mechanism. A similar example is found in the hydrolysis of tert-butyl chloride, shown below. Note that the initial substitution product in this reaction is actually a hydronium ion, which rapidly transfers a proton to the chloride anion. This second acid-base proton transfer is often omitted in writing the overall equation, as in the case of reaction **7** above.

$(CH_3)_3C\text{-}Cl + H_2O \longrightarrow (CH_3)_3C\text{-}OH_2^{(+)} + Cl^{(-)} \longrightarrow (CH_3)_3C\text{-}OH + HCl$

Although the hydrolysis of tert-butyl chloride, as shown above, might be interpreted as an S_N2 reaction in which the high and constant concentration of solvent water does not show up in the rate equation, there is good evidence this is not the case. First, the equivalent hydrolysis of ethyl bromide is over a thousand times slower, whereas authentic S_N2 reactions clearly show a large rate increase for 1º-alkyl halides. Second, a modest increase of hydroxide anion concentration has no effect on the rate of hydrolysis of tert-butyl chloride, despite the much greater nucleophilicity of hydroxide anion compared with water.

The first order kinetics of these reactions suggests a two-step mechanism in which the rate-determining step consists of the ionization of the alkyl halide, as shown in the diagram on the right. In this mechanism, a carbocation is formed as a high-energy intermediate, and this species bonds immediately to nearby nucleophiles. If the nucleophile is a neutral molecule, the initial product is an "onium" cation, as drawn above for t-butyl chloride, and presumed in the energy diagram. In evaluating this mechanism, we may infer several outcomes from its function.



First, the only reactant that is undergoing change in the first (rate-determining) step is the alkyl halide, so we expect such reactions would be unimolecular and follow a first-order rate equation. Hence the name **S_N1** is

applied to this mechanism.

Second, since nucleophiles only participate in the fast second step, their relative molar concentrations rather than their nucleophilicities should be the primary product-determining factor. If a nucleophilic solvent such as water is used, its high concentration will assure that alcohols are the major product. Recombination of the halide anion with the carbocation intermediate simply reforms the starting compound. Note that S_N1 reactions in which the nucleophile is also the solvent are commonly called **solvolysis** reactions. The hydrolysis of t-butyl chloride is an example.

Third, the Hammond postulate suggests that the activation energy of the rate-determining first step will be inversely proportional to the stability of the carbocation intermediate. The stability of carbocations was discussed earlier, and a qualitative relationship is given below.

Carbocation Stability	$CH_3^{(+)}$	<	$CH_3CH_2^{(+)}$	<	$(CH_3)_2CH^{(+)}$	≈	CH_2=CH-$CH_2^{(+)}$	<	$C_6H_5CH_2^{(+)}$	≈	$(CH_3)_3C^{(+)}$

Consequently, we expect that 3º-alkyl halides will be more reactive than their 2º and 1º-counterparts in reactions that follow an S_N1 mechanism. This is opposite to the reactivity order observed for the S_N2 mechanism. Allylic and benzylic halides are exceptionally reactive by either mechanism.

Fourth, in order to facilitate the charge separation of an ionization reaction, as required by the first step, a good ionizing solvent will be needed. Two solvent characteristics will be particularly important in this respect. The first is the ability of solvent molecules to orient themselves between ions so as to attenuate the electrostatic force one ion exerts on the other. This characteristic is related to the **dielectric constant, ε,** of the solvent. Solvents having high dielectric constants, such as water (ε=81), formic acid (ε=58), dimethyl sulfoxide (ε=45) & acetonitrile (ε=39) are generally considered better ionizing solvents than are some common organic solvents such as ethanol (ε=25), acetone (ε=21), methylene chloride (ε=9) & ether (ε=4). The second factor is **solvation**, which refers to the solvent's ability to stabilize ions by encasing them in a sheath of weakly bonded solvent molecules. Anions are solvated by hydrogen-bonding solvents, as noted earlier. Cations are often best solvated by nucleophilic sites on a solvent molecule (e.g. oxygen & nitrogen atoms), but in the case of carbocations these nucleophiles may form strong covalent bonds to carbon, thus converting the intermediate to a substitution product. This is what happens in the hydrolysis reactions described above.

Fifth, the stereospecificity of these reactions may vary. The positively-charged carbon atom of a carbocation has a trigonal (flat) configuration (it prefers to be sp^2 hybridized), and can bond to a nucleophile equally well from either face. If the intermediate from a chiral alkyl halide survives long enough to encounter a random environment, the products are expected to be racemic (a 50:50 mixture of enantiomers). On the other hand, if the departing halide anion temporarily blocks the front side, or if a nucleophile is oriented selectively at one or the other face, then the substitution might occur with predominant inversion or even retention of configuration.

To see an animated model of the S_N1 ionization step in which a chiral alkyl halide generates a trigonal carbocation

3. Activation by Electrophilic Cations

Heterolytic cleavage of the carbon-halogen bond of alkyl halides may be facilitated by the presence of certain metal cations. In the extreme, carbocations may be generated as shown in the following equation, where R is alkyl or hydrogen, and M = Al (n=3) or Fe (n=3) or Sn (n=4) or Zn (n=2).

$R_3C\text{-}X + MX_n$ (reactivity = Al > Fe > Sn > Zn) ——> $R_3C(+) + MX_n\text{-}X^{(-)}$

Although this technique is useful for generating carbocation intermediates in hydrocarbon solvents, the metal halide reactants are deactivated in protic solvents such as water and alcohol, rendering these reactants relatively useless for inducing S_N1 reactions. There is, however, a related halophilic reactant that accomplishes this. This compound is silver nitrate, and in aqueous or alcoholic solution it promotes ionization of the alkyl halide and the formation of S_N1 products. When silver nitrate is used with 1º or 2º-alkyl halides, rearrangement may occur before the product formation stage. For example:

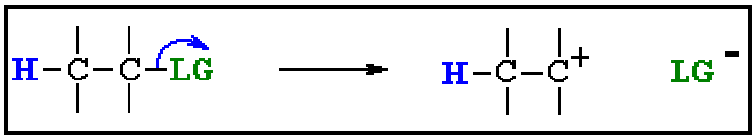
$(CH_3)_3CCH_2\text{-}Br + H_2O + AgNO_3$ ——> $(CH_3)_2C(OH)CH_2CH_3 + AgBr + HNO_3$

E1 mechanism

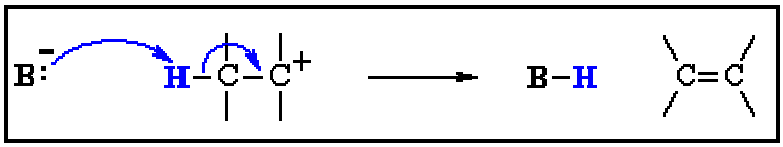
E1 indicates a ***elimination***, ***unimolecular*** reaction, where rate = k [**R-LG**].

This implies that the rate determining step of the mechanism depends on the decomposition of a single molecular species.

Overall, this pathway is a multi-step process with the following two critical steps:



loss of the leaving group, LG, to generate a carbocation intermediate, then



loss of a proton, H^+, from the carbocation to form the π-bond

Let's look at how the various components of the reaction influence the reaction pathway:

R-

Reactivity order : $(CH_3)_3C-$ > $(CH_3)_2CH-$ > CH_3CH_2- > CH_3-

In an E1 reaction, the rate determining step is the loss of the leaving group to form the intermediate carbocation. The more stable the carbocation is, the easier it is to form, and the faster the E1 reaction will be. Some students fall into the trap of thinking that the system with the less stable carbocation will react fastest, but they are forgetting that it is the generation of the carbocation that is rate determining. Since carbocation intermediates are formed during an E1, there is always the possibility of rearrangements (*e.g.* 1,2-hydride or 1,2-alkyl shifts) to generate a more stable carbocation. This is usually indicated by a change in the position of the alkene or a change in the carbon skeleton of the product when compared to the starting material.

-LG

The only event in the rate determining step of the E1 is breaking the **C-LG** bond. Therefore, there is a very strong dependence on the nature of the leaving group, the better the leaving group, the faster the E1 reaction will be. In the acid catalysed reactions of alcohols, the -OH is protonated first to give an oxonium ion, providing the much better leaving group, a water molecule (see scheme below).

B

Since the base is not involved in the rate determining step, the nature of the base is unimportant in an E1 reaction. However, the more reactive the base, the more likely an E2 reaction becomes.

Selectivity

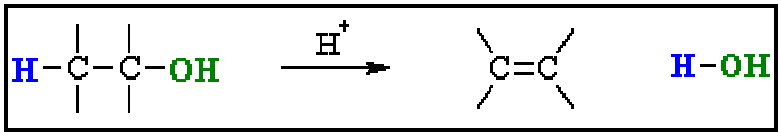
E1 reactions usually favour the more stable alkene as the major product *: i.e.* more highly alkyl substituted and trans- > cis-

This E1 mechanistic pathway is most common with:

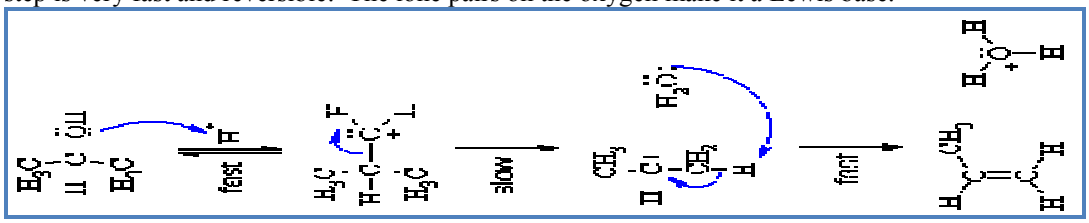
- good leaving groups
- stable carbocations
- weak bases.

A typical example is the acid catalysed dehydration of 2^o or 3^o alcohols.

E1 MECHANISM FOR ALCOHOLS



Step 1: An acid/base reaction. Protonation of the alcoholic oxygen to make a better leaving group. This step is very fast and reversible. The lone pairs on the oxygen make it a Lewis base.



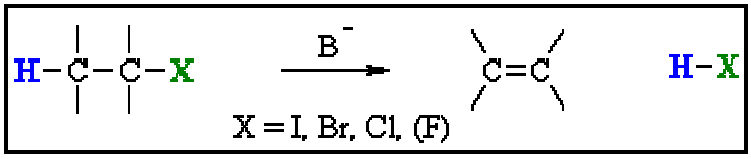
Step 2:

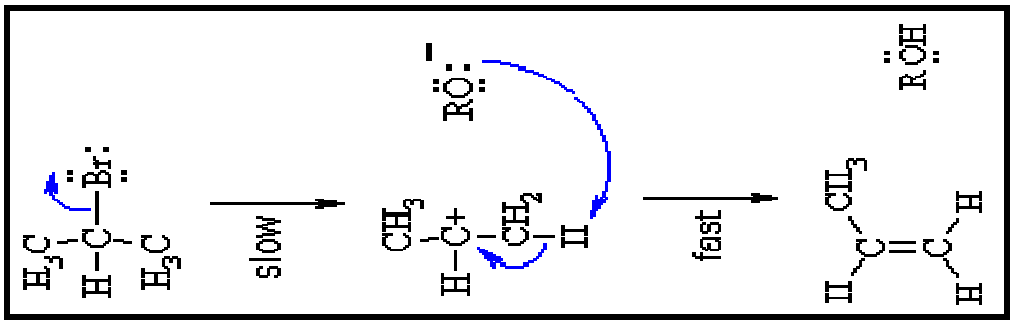
Cleavage of the **C-O** bond allows the loss of the good *leaving group*, a neutral water molecule, to give a carbocation intermediate. This is the rate determining step (bond breaking is endothermic)

Step 3:

An acid/base reaction. Deprotonation by a base (a water molecule) from a **C** atom adjacent to the carbocation center leads to the creation of the **C=C**

E1 MECHANISM FOR ALKYL HALIDES

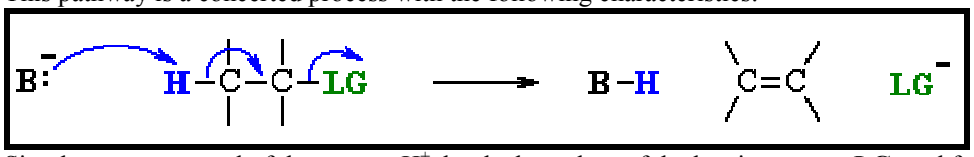




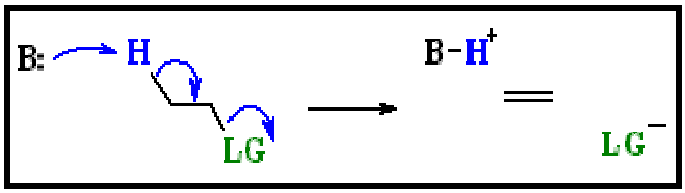
Step 1:
Cleavage of the polarised **C-X** bond allows the loss of the good *leaving group*, a halide ion, to give a carbocation intermediate. This is the rate determining step (bond breaking is endothermic)

Step 2:
An acid/base reaction. Deprotonation by a base (here an alkoxide ion) from a **C** atom adjacent to the carbocation center leads to the creation of the **C=C**

E2 mechanism
E2 indicates an ***elimination***, ***bimolecular*** reaction, where rate = k [**B**][**R-LG**].
This implies that the rate determining step involves an interaction between these two species, the base **B**, and the organic substrate, **R-LG**
This pathway is a concerted process with the following characteristics:



Simultaneous removal of the proton, H^+, by the base, loss of the leaving group, **LG**, and formation of the π-bond
Let's look at how the various components of the reaction influence the reaction pathway:
Effects of R-
Reactivity order : $(CH_3)_3C-$ > $(CH_3)_2CH-$ > CH_3CH_2- > CH_3-
In an E2 reaction, the reaction transforms 2 sp^3 C atoms into sp^2 C atoms. This moves the substituents further apart decreasing any steric interactions. So more highly substituted systems undergo E2 eliminations more rapidly. This is the *same* reactivity trend as seen in E1 reactions.
-LG
The **C-LG** bond is broken during the rate determining step, so the rate does depend on the nature of the leaving group.
However, if a leaving group is too good, then an E1 reaction may result.
B
Since the base is involved in the rate determining step, the nature of the base is very important in an E2 reaction. More reactive bases will favour an E2 reaction.
Stereochemistry
E2 reactions occur most rapidly when the **H-C** bond and **C-LG** bonds involved are co-planar, most often at 180° or antiperiplanar. This sets up the s bonds that are broken in the correct alignment to become the p bond. More details ?



Selectivity

The outcome of E2 reactions is controlled by the stereochemical requirements described above. Where there is a choice, the more stable alkene will be the major product.

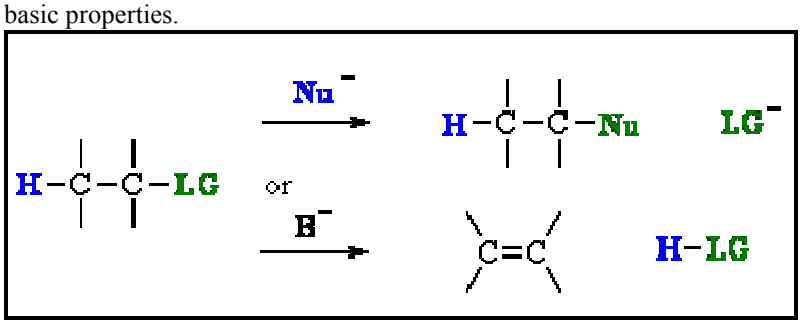
The E2 pathway is most common with:

- high concentration of a strong base
- poorer leaving groups
- **R-LG** that would not lead to stable carbocations (when the E1 mechanism will occur).

A typical example is the dehydrohalogenation of alkyl halides using KOtBu / tBuOH

Substitution versus Elimination:

Substitution and elimination reactions often compete with each other because it's a question of nucleophilic or basic properties.



Substitution and elimination reactions are strongly influenced by many experimental factors. Some of more important factors are outlined in the following table.

In the table, the significance of the effect is stated first, and then the "system" that will favour the reaction is stated.

This should help you deal with the questions....

1. When does an anion function as a **Nu** and when does it function as a **B** ?, and therefore,
2. When to I get substitution and when do I get elimination ?

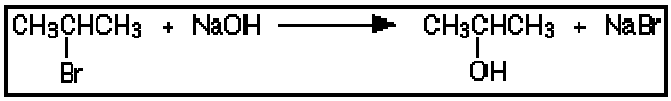
Reaction	Solvent	Nu or Base	Leaving Group	Substrate	Example conditions
S_N1	**Very Strong** Polar solvents	**Weak** Good Nu and weak base	**Strong** Good LG	**Strong** 3° or resonance stabilised	alkyl halide / $AgNO_3$ / aq. EtOH alcohol / HX
S_N2	**Strong** Polar aprotic solvents	**Strong** Good Nu and weak base	**Strong** Good LG	**Strong** methyl or 1°	alkyl halide / NaI / acetone alcohol / $SOCl_2$ or PX_3
E1	**Very Strong** Polar solvents	**Weak** Weak base	**Strong** Good LG	**Strong** 3° or resonance stabilised	alkyl halide / H_2O alcohol / H_2SO_4 / heat
E2	**Strong** Polar aprotic solvents	**Strong** Poor Nu and strong base	**Strong** Good LG	**Strong** 3°	alkyl halide / KOH / heat

The reactions :

Both reactions involve heating the halogenoalkane under reflux with sodium or potassium hydroxide solution.

Nucleophilic substitution:

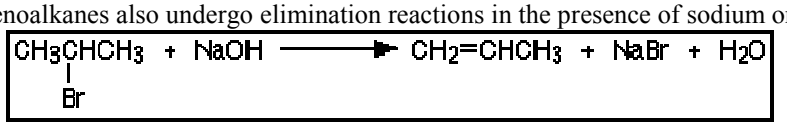
The hydroxide ions present are good nucleophiles, and one possibility is a replacement of the halogen atom by an -OH group to give an alcohol via a nucleophilic substitution reaction.



In the example, 2-bromopropane is converted into propan-2-ol.

Elimination

Halogenoalkanes also undergo elimination reactions in the presence of sodium or potassium hydroxide.



The 2-bromopropane has reacted to give an alkene - propene.

Notice that a hydrogen atom has been removed from one of the end carbon atoms together with the bromine from the center one. In all simple elimination reactions the things being removed are on adjacent carbon atoms, and a double bond is set up between those carbons.

What decides whether you get substitution or elimination?

The reagents you are using are the same for both substitution or elimination - the halogenoalkane and either sodium or potassium hydroxide solution. In all cases, you will get a mixture of both reactions happening - some substitution and some elimination. What you get most of depends on a number of factors.

The type of halogenoalkane :

This is the most important factor.

type of halogenoalkane	substitution or elimination?
primary	mainly substitution
secondary	both substitution and elimination
tertiary	mainly elimination

For example, whatever you do with tertiary halogenoalkanes, you will tend to get mainly the elimination reaction, whereas with primary ones you will tend to get mainly substitution. However, you can influence things to some extent by changing the conditions.

1-The solvent

The proportion of water to ethanol in the solvent matters.

- Water encourages substitution.
- Ethanol encourages elimination.

2-The temperature

Higher temperatures encourage elimination.

3-Concentration of the sodium or potassium hydroxide solution

Higher concentrations favour elimination.

In summary

For a given halogenoalkane, to favour elimination rather than substitution, use:

- heat
- a concentrated solution of sodium or potassium hydroxide
- pure ethanol as the solvent

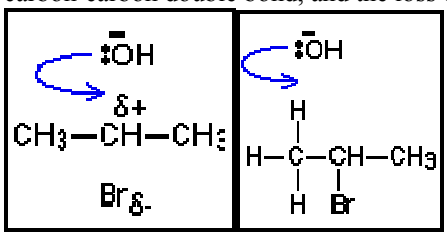
The role of the hydroxide ions

The role of the hydroxide ion in a substitution reaction

In the substitution reaction between a halogenoalkane and OH^- ions, the hydroxide ions are acting as nucleophiles. For example, one of the lone pairs on the oxygen can attack the slightly positive carbon. This leads on to the loss of the bromine as a bromide ion, and the -OH group becoming attached in its place.

The role of the hydroxide ion in an elimination reaction

Hydroxide ions have a very strong tendency to combine with hydrogen ions to make water - in other words, the OH^- ion is a very strong base. In an elimination reaction, the hydroxide ion hits one of the hydrogen atoms in the CH_3 group and pulls it off. This leads to a cascade of electron pair movements resulting in the formation of a carbon-carbon double bond, and the loss of the bromine as Br^-.



The reactions of alkyl halides typically involve either substitution or elimination pathways. Depending on a variety of factors, the reaction mechanism can be either S_N1, S_N2, E1, E2, or some combination of these. By understanding the influences different factors have on each of these mechanisms, it is usually possible to predict which mechanism will predominate.

S_N2 Reaction :

The key feature of these reactions is a "five-coordinate" transition state. This requires that the central carbon atom is NOT crowded. In practice, S_N2 reactions are limited to primary and secondary alkyl halides. The nature of the attacking nucleophile is an important factor determining the rate of these reactions. Polar, aprotic solvents are best.

S_N1 Reaction :

In this mechanism, the leaving group is "lost" (or at least partially dissociated) in the rate-determining step, so the nature of the attacking nucleophile is not an important factor. Since tertiary carbon centers give the most stable carbocations, these are by far the most reactive alkyl halides via this mechanism. Protic solvents (H_2O, ROH, RNH_2, etc.) are best due to the fact that they help remove/stabilize the leaving group.

E2 Reaction :

Elimination reactions following E2 mechanism are preferred for all secondary and tertiary alkyl halides when a strong base (OH^-, RO^-, R-C^{o}C:$^-$, NH_2^-) is used. For primary alkyl halides, the E2 pathway is preferred if a bulky base (such as $(CH_3)_3CO^-$) is used.

E1 Reaction :

The initial, rate-determining step for this mechanism is the same as for the S_N1 mechanism. The best conditions for E1 reactions involve using a weakly basic nucleophile (strong bases react via E2), protic solvents, and high temperatures. This is not a generally useful synthetic route.

Summary

	1° alkyl halide	2° alkyl halide	3° alkyl halide
Strong, hindered base	E2	E2	E2
Strong base	S_N2	E2	E2
Good nucleophile (only weakly basic)	S_N2	S_N2	S_N1
Poor nucleophile, protic solvent	NR	S_N1 or NR	S_N1 & E1
Poor nucleophile, aprotic solvent	NR	S_N2 or NR	NR

Summary of Substitution and Elimination Reactions of Alkyl Halides

I)- First, you have to know which products to expect from each mechanism, then figure out which mechanism should occur.

1) 1° halides give pure SN2 unless they are very hindered on the back side or the base is very hindered (a poor nucleophile). With tert-butoxide you get a lot of E2 products.

2) 3° halides give pure E2.

3) 2° halides give a mixture of SN2 and E2 products; E2 predominates in most solvents, SN2 predominates in polar aprotics solvents such as DMSO and DMF. With hindered strong base you get only E2.

II) If there is no strong base, is there a weak base which is a good nucleophile?

A) 1° and 2° alkyl halides will give SN2. This works especially well when NaI in acetone is used (the precipitation of NaBr drives the equilibrium to products).

B) 3° halides will give mostly SN1/E1.

III) If there is no good nucleophile and no strong base:

A) 1° halides give SN2. This SN2 is very slow with H2O or ROH as the only nucleophile (solvolysis).

B) 2° and 3° halides give SN1/E1.

Nucleophilic Substitution

- R-X + Nu:- ----> R-Nu + X:-
- replacement of X- (a leaving group)
- X- often halide
- wide variety of nucleophiles
- very versatile synthetic reaction

Recognizing Nucleophiles

- must have a pair of electrons

- often have a negative charge
- are also basic
    - nucleophiles bond to positive carbon
    - bases bond to positive hydrogen

Solvents

- Protic solvent: a solvent that is a hydrogen bond donor the most common protic solvents contain -OH groups
- Aprotic solvent: a solvent that cannot serve as a hydrogen bond donor nowhere in the molecule is there a hydrogen bonded to an atom of high electronegativity
- Solvents are classified as polar and nonpolar the most common measure of solvent polarity is dielectric constant
- Dielectric constant: a measure of the ability of a solvent to insulate opposite charges from one another
- The greater the value of the dielectric constant of a solvent, the smaller the interaction between ions of opposite charge dissolved in that solvent
- Polar protic solvents: water, alcohols, carboxylic acids
- Polar aprotic solvents: DMSO, DMF, acetonitrile, acetone
- Nonpolar solvents: alkanes, cycloalkanes, ethers

The SN2 Mechanism

- concerted (single step)
- involves backside attack
  (simultaneous bond-making and bond-breaking)

SN2 Mechanism - Evidence

- reaction rate proportional to concentration of both reactants
  Rate = k [RX] [Nu]
- kinetics are second-order
- mechanism is bimolecular

SN2 Mechanism - Evidence

- stereochemistry is inverted
- indicates backside attack

SN2 Mechanism - R Groups

- bulky R groups react much slower
- reactivity order in SN2:
  CH3 > 1° > 2° > 3°
- steric hindrance to attack by the nucleophile slows the rate
  n-Bu > i-Bu > s-Bu > t-Bu

SN2 Mechanism - X Groups

- larger leaving groups react faster
  I- > Br- > Cl- >> F-
- poor leaving groups
  (unstable anions, strong bases)
  OH- , RO- , NH2-

SN2 Mechanism - Nucleophiles

- Nucleophilicity: a kinetic property measured by the rate at which a Nu attacks a reference compound under a standard set of experimental conditions
- Basicity: a equilibrium property measured by the position of equilibrium in an acid-base reaction
- Because all nucleophiles are also bases, we study correlations between nucleophilicity and basicity
- Within a period, nucleophilicity parallels basicity
  CH3- > NH2- > OH- > F-
- Within a family, larger atoms are better nucleophiles (polarizability)
  I- > Br- > Cl- >F- or R2Se > R2S > R2O or R3P > R3N
- With the same nucleophilic atom but different charge type, nucleophilicity parallels basicity
  OH- > H2O or SH- > H2S
- With the same nucleophilic atom, same charge type, nucleophilicity parallels basicity
  OH- > CH3COO-

Solvent Effects on Nucleophilicity:

- Relative nucleophilicities of halide ions in polar aprotic solvents are quite different from those in polar protic solvents

- A guiding principle: the freer the nucleophile, the greater its nucleophilicity
- Polar aprotic solvents (e.g., DMSO, acetone, acetonitrile, DMF) are very effective in solvating cations, but not nearly so effective in solvating anions.
- Because anions are only poorly solvated, they participate readily in SN reactions, andnucleophilicity parallels basicity: F- > Cl- > Br- > I-
- Polar protic solvents (e.g., water, methanol) anions are highly solvated by hydrogen bonding with the solventthe more concentrated the negative charge of the anion, the more tightly it is held in a solvent shell the nucleophile must be at least partially removed from its solvent shell to participate in SN reactions because F- is most tightly solvated and I- the least, nucleophilicity is I- > Br- > Cl- > F-

SN1 Mechanism:

- two-step mechanism
  first X- leaves, then Nu- bonds
- carbocation intermediate
  R-X ----> R+ + X-
  R+ + Nu- ----> R-Nu

SN1 Mechanism – Evidence:

- reaction rate proportional to concentration of RX reactant,
  but independent of concentration of Nu
  Rate = k [RX]
- kinetics are first-order
- mechanism is unimolecular

SN1 Mechanism – Evidence:

- stereochemistry is scrambled
- chiral reactant gives racemic product
- carbocation intermediate is achiral

SN1 Mechanism - R Groups:

- R groups that make more stable carbocations react faster
  3° > 2° > 1° > CH3
- tertiary RX react by SN1
- CH3 and primary RX react by SN2
- secondary RX react either way

SN1 Mechanism - X Groups:

- same effects as for SN2
  I- > Br- > Cl- >> F-

E2 Elimination Mechanism

- concerted (single-step)
- the H and X eliminated must be aligned anti to one another
- the breaking sigma bonds merge into overlapping p orbitals for the pi bond

E2 Stereochemistry

- anti periplanar arrangement of H and X may lead to specific products

E1 Elimination Mechanism

- two-step mechanism
  first X- leaves, then H+ leaves
- carbocation intermediate
- same first step as SN1

Substitution or Elimination ?

- substitution: nucleophile attacks C
  either attacks RX [SN2] or R+ [SN1]
- elimination: base attacks H
  either attacks RX [E2] or R+ [E1]

Reactivity Patterns

- CH3X - can only do SN2
- primary (1°) RCH2X :
  SN2 works well, E2 with KOtBu
  SN1 and E1 don't work
- secondary (2°) R2CHX :

SN2 works with a good nucleophile
E2 works with KOtBu
SN1 and E1 occur without strong base or nucleophile

- tertiary (3°) R3CX :
  SN1 works well with a good nucleophile
  E1 often competes with SN1
  E2 works well with KOtBu

Nucleophilic Substitution Mechanisms
What's the difference between SN1 and SN2 ?

	SN2	SN1
Reaction	RX + Nu --> RNu + X	same
Mechanism	concerted	two steps
Intermediate	none	carbocation
Kinetics	second-order	first order
Stereochemistry	complete inversion	nonspecific
Nucleophile	important	unimportant
Leaving Group	important	important
Alkyl Group	CH3 > 1° > 2° > 3° (steric hindrance)	3° > 2° > 1° > CH3 (carbocation stability)
Occurrence	CH3 , 1° , some 2°	3° , some 2°
Solvent Effects	variable	polar, protic

Elimination Mechanisms
What's the difference between E1 and E2 ?

	E2	E1
Reaction	RX + base --> C=C	same
Mechanism	concerted	two steps
Intermediate	none	carbocation
Kinetics	second-order	first order
Stereochemistry	anti periplanar	nonspecific
Base	important	unimportant
Leaving Group	important	important
Alkene Produced	Zaitsev Rule	same

Substitution vs. Elimination

How can you make ... react in an ... mechanism ?

	SN1	SN2	E1	E2
CH3X	No	good nucl.	No	No
1° (RCH2X)	No	good nucl., weak base	No	strong base, weak nucl.
2° (R2CHX)	No	good nucl., weak base	No	strong base
3° (R3CX)	good nucl., weak base	No	polar solvent, no base or nucl.	strong base

What's most likely to happen when ... reacts with ... ?

	Good nucl., strong base, e.g., OH-	Good nucl., weak base, e.g., I-	Poor nucl., strong base, e.g., tBuO-	Poor nucl., weak base, e.g., H2O
CH3X	SN2	SN2	SN2	No reaction
1° (RCH2X)	SN2	SN2	E2	No reaction
2° (R2CHX)	E2	SN2	E2	No reaction
3° (R3CX)	E2	SN1	E2	SN1

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