Organic Chemistry I: Reactions and Overview

Andrew Rosen

Editor: Raghav Malik

January 13, 2013

Contents

I Library of Synthetic Reactions 3

II Organic Trends and Essentials 4

1 The Basics: Bonding and Molecular Structure 4
- 1.1 Resonance Stability . . . 4

2 Families of Carbon Compounds 4
- 2.1 Strength of London Dispersion Forces (Polarizability) . . . 4
- 2.2 Degree of Unsaturation . . . 4

3 An Introduction to Organic Reactions and Their Mechanisms 4
- 3.1 Comparing Acid Strengths . . . 4

4 Nomenclature and Conformations of Alkanes and Cycloalkanes 5
- 4.1 Ring Flipping . . . 5

5 Stereochemistry 5
- 5.1 Naming Enantiomers via the -R and -S System . . . 5
- 5.2 Stereochemistry Examples . . . 6

6 Ionic Reactions - Overview 6
- 6.1 General Nucleophilic Substitution Reactions . . . 6
- 6.2 Carbocation Stability . . . 6
- 6.3 Factors Affecting the Rates of S_N1 and S_N2 Reactions . . . 6
- 6.4 Elimination Reactions . . . 7
- 6.5 Summary . . . 7

7 Alkenes and Alkynes I - Overview 8
- 7.1 The E-Z System . . . 8
- 7.2 Relative Stabilities of Alkenes . . . 8
- 7.3 Factors Affecting Elimination Reactions . . . 8
- 7.4 Acid-Catalyzed Dehydration of Alcohols . . . 8

III Reaction Mechanisms **9**

8 Ionic Reactions - Mechanisms **9**
- 8.1 The S_N2 Reaction 9
- 8.2 The S_N1 Reaction 10
- 8.3 The E2 Reaction 10
- 8.4 The E1 Reaction 11

9 Alkenes and Alkynes I - Mechanisms **11**
- 9.1 Acid-Catalyzed Dehydration of Secondary or Tertiary Alcohols: An E1 Reaction 11
- 9.2 Acid-Catalyzed Dehydration of Primary Alcohols: An E2 Reaction 12
- 9.3 Synthesis of Alkynes from Vic-Dihalides 12
- 9.4 Substitution of the Acetylenic Hydrogen Atom of a Terminal Alkyne 12
- 9.5 Deprotonation Reagents 12
- 9.6 Hydrogenation 13

10 Alkenes and Alkynes II - Mechanisms **13**
- 10.1 Addition of H−X to an Alkene 13
- 10.2 Acid-Catalyzed Hydration of an Alkene 13
- 10.3 Mercuration-Demercuration and Hydroboration-Oxidation 13
- 10.4 Summary of H−X and H−OH Additions 14
- 10.5 Electrophilic Addition of Bromine and Chlorine to Alkenes 14
- 10.6 Halohydrin Formation from an Alkene 15
- 10.7 Oxidative Cleavage of Alkenes 15
- 10.8 OsO_4 Reaction 15
- 10.9 Summary for Dihalide, Dihydroxy, and Carbene Additions 16
- 10.10 Electrophilic Addition of Bromine and Chlorine to Alkynes 16
- 10.11 Addition of Hydrogen Halides to Alkynes 16
- 10.12 Oxidative Cleavage of Alkynes 16

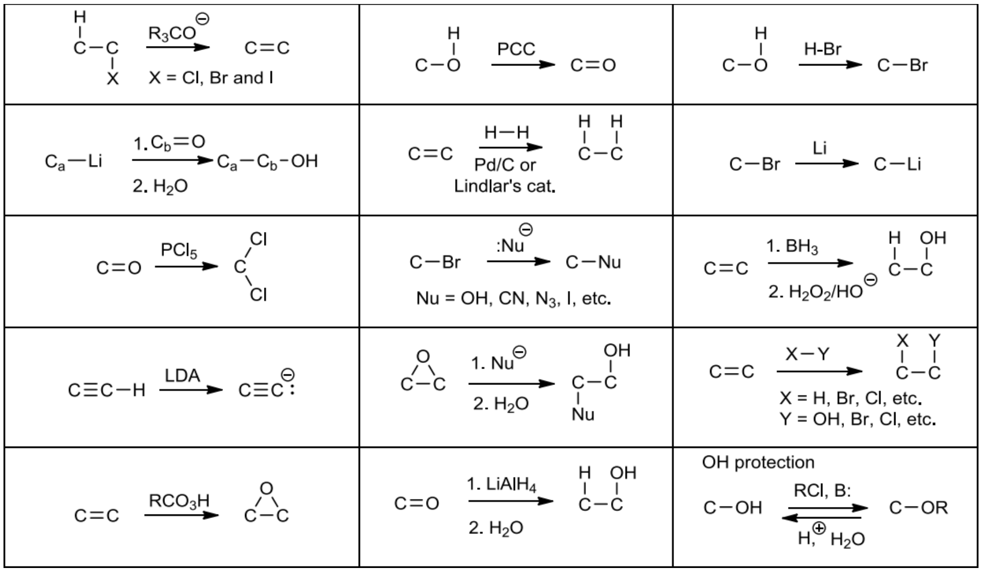
11 Alcohols and Ethers - Mechanisms **16**
- 11.1 Alcohols with H−X 16
- 11.2 Alcohols with PBr_3 or $SOCl_2$ 17
- 11.3 Leaving Group Derivatives of Alcohols 17
- 11.4 Converting OH to LG Summary 17
- 11.5 Synthesis of Ethers 17
- 11.6 Protecting Groups 18
- 11.7 Ether Reactions Summary 18
- 11.8 Epoxides 18
- 11.9 Epoxide Reaction Summary with Example 19

12 Alcohols from Carbonyl Compounds - Mechanisms **19**
- 12.1 Alcohols by Reduction of Carbonyl Compounds 19
- 12.2 Oxidation of Alcohols 19
- 12.3 Alcohols from Grignard Reagents 19

13 Radical Reactions - Mechanisms **20**
- 13.1 Bromination 20
- 13.2 Chlorination 20

Part I

Library of Synthetic Reactions [1]



- Note that this is a partial list of reactions

---

[1] Graphics are obtained mostly from Stony Brook University CHE 327 PowerPoint slides and "Organic Chemistry", 10th Edition by Solomons and Fryhle.

Part II

Organic Trends and Essentials

1 The Basics: Bonding and Molecular Structure

1.1 Resonance Stability

1. The more covalent bonds a structure has, the more stable it is
2. Charge separation (formal charges) decreases stability
3. Negative charges on the more electronegative elements and positive charges on the more electropositive elements are more favorable[2]

2 Families of Carbon Compounds

2.1 Strength of London Dispersion Forces (Polarizability)

1. Large atoms are easily polarizable and small atoms are not
2. Atoms with unshared electron pairs are more polarizable than atoms with only bonding pairs
3. Molecules that are longer and flatter ("long chains") have more surface area and thus have larger dispersion forces when other factors are similar

2.2 Degree of Unsaturation

- A degree of unsaturation is either a π bond or a ring structure
- Formula: $\frac{2C+2+N-H-X}{2}$ where the variables are the number of carbons (C), nitrogens (N), hydrogens (H), and halogens (X)

3 An Introduction to Organic Reactions and Their Mechanisms

3.1 Comparing Acid Strengths

Factors Affecting Acidity (in decreasing significance)[3]: ARIO

1. Atom
2. Resonance Stabilization
3. Induction Effect
4. Orbital (s character)

---

[2] For the purposes of drawing all resonance structures, it is not considered a violation of the octet rule if a second-row element, like carbon, has fewer than an octet. It is less likely but still imperative to draw.

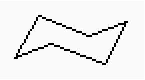
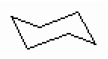
[3] This general trend is not always perfectly applicable. However, it is usually a fairly good indicator.

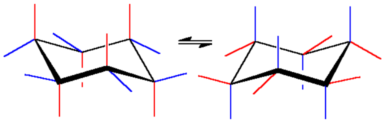
"ARIO" Explained:

- Atom: Look at what atom the charge is on for the conjugate base.
    - For atoms in the same row, we consider electronegativity. The further to the right on the periodic table an atom is, the more electronegative it is. If a conjugate base's negative charge is on a more electronegative atom, it is more stable, and thus the parent acid is stronger.
    - For atoms in the same column, we consider an atom's ability to stabilize a charge. The further down on the periodic table an atom is, the better it is at stabilizing a charge. If a conjugate base's negative charge is more stabilized on an atom further down a group, it is a more stable molecule, and thus the parent acid is stronger.
- Resonance Stabilization: Look at resonance structures. The more distributed the charge of the conjugate base is, the stronger the parent acid is.
- Inductive Effect: Look for inductive effect. If there are many electronegative atoms near the conjugate base's negative charge, electron density is pulled toward these atoms. This creates more stable anions and thus more acidic parent molecules. However, if there are many alkyl groups, this is a process called hyperconjugation, and the parent acid is actually less stable.
- Orbital: Look at the orbital where the negative charge for the conjugate base is. More *s* character of a bond with hydrogen makes it more acidic.

4 Nomenclature and Conformations of Alkanes and Cycloalkanes

4.1 Ring Flipping

- The axial groups become equatorial and vice versa
    - When doing a ring flip, whether a group is up or down does not change
- Chair Conformation 1:  Chair Conformation 2 (after ring flip): 
- When performing a chair flip, each atom is rotated one spot in the clockwise direction
- A molecule is more stable when steric hindrance is minimized and bulky substituents are equatorial as opposed to axial

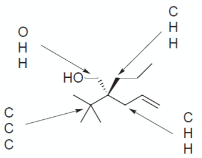


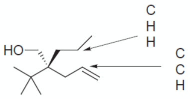
Ring-Flip

5 Stereochemistry

5.1 Naming Enantiomers via the -R and -S System

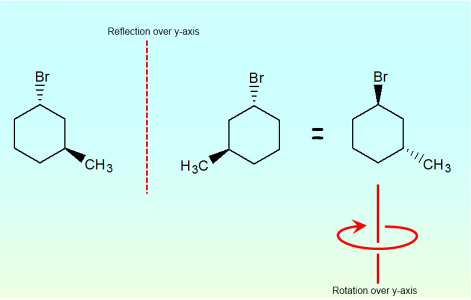
1. Each of the four groups attached to the chirality center is assigned a priority of 1, 2, 3, or 4. Priority is assigned on the basis of the atomic number of the atom that is directly attached to the chirality center. The group with the highest atomic number gets the highest priority and vice versa.
2. When a priority cannot be assigned on the basis of atomic number of the atoms, then the next set of atoms in the unassigned groups is examined. This process is continued until a decision can be made at the first point of difference.

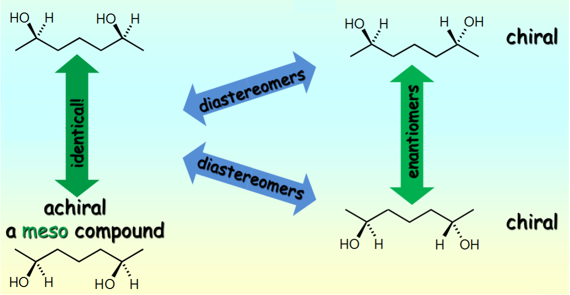
(a) Step 1: 

Step 2: 

3. If the 4th atom is a dashed wedge (downward): Analyze if the numbers (1 → 2 → 3 → 4) go clockwise or counterclockwise. Clockwise indicates that the molecule is “R,” while counterclockwise indicates the molecule is “S.”
4. If the 4th atom is a solid wedge (upward): Analyze this “intermediate” molecule to see if the numbers go clockwise or counterclockwise. Clockwise indicates that the original molecule is “S,” while counterclockwise indicates the molecule is “R.”

5.2 Stereochemistry Examples



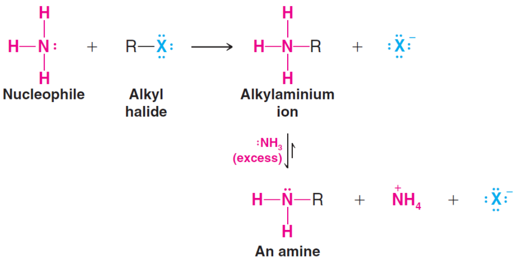


6 Ionic Reactions - Overview

6.1 General Nucleophilic Substitution Reactions

- A deprotonation step is required to complete the reaction when the nucelophile was a neutral atom that bore a proton

Example showing deprotonation[4]:



6.2 Carbocation Stability

- Order of Carbocation Stability: 3° > 2° > 1° > Methyl

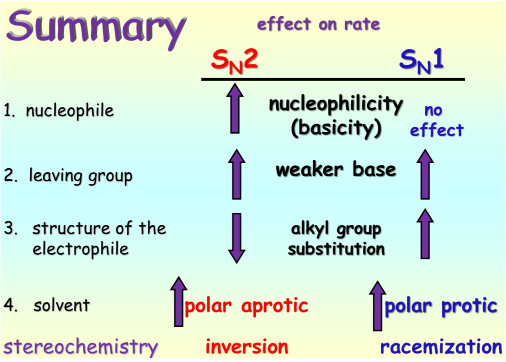
6.3 Factors Affecting the Rates of S_N1 and S_N2 Reactions

- Simple *alkyl halides* show the following trend for order of reactivity in S_N2 reactions:
  - Methyl > primary > secondary ≫ (tertiary-unreactive)

---

[4] Deprotonation is normally seen as H_3O^+ in water, but when there is a different solvent in excess it will be different

- The rates of S_N2 reactions (not S_N1) depend on both the concentration and identity of the attacking nucleophile
- In a selection of nucleophiles in which the nucleophilic atom is the same, nucleophilicities parallel basicities:
    - $RO^- > HO^- \gg RCO_2^- > ROH > H_2O$
- Nucleophiles parallel basicity when comparing atoms in the same period
- Nucleophiles do not parallel basicity and, instead, parallel size when comparing atoms of the same group
- The best leaving groups are weak bases after they depart
- Polar aprotic solvents favor S_N2 and polar protic solvents favor S_N1
    - Most of the solvents with abbreviated names are polar aprotic



Summary effect on rate

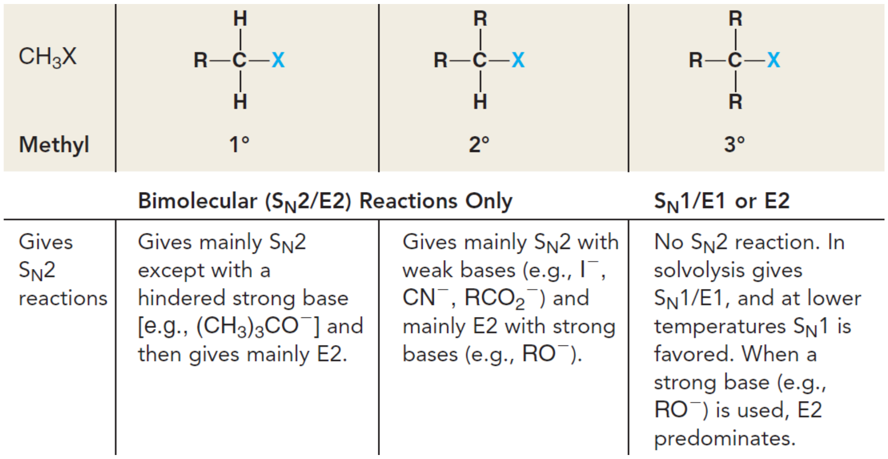
	S_N2		S_N1
1. nucleophile	↑	nucleophilicity (basicity)	no effect
2. leaving group	↑	weaker base	↑
3. structure of the electrophile	↓	alkyl group substitution	↑
4. solvent	↑ polar aprotic		↑ polar protic
stereochemistry	inversion		racemization

6.4 Elimination Reactions

- Higher temperatures increase the rates of elimination reactions
- A product with a more substituted double bond is more stable and thus more favorable
- If *tert*-butoxide is used, sterics must be considered to find out which hydrogen it takes through the $E2$ reaction

6.5 Summary

- Note: It is debatable, but secondary molecules can have S_N1 or $E1$ in polar protic solvents



CH_3X Methyl	$\mathrm{R{-}\overset{H}{\underset{H}{C}}{-}X}$ 1°	$\mathrm{R{-}\overset{R}{\underset{H}{C}}{-}X}$ 2°	$\mathrm{R{-}\overset{R}{\underset{R}{C}}{-}X}$ 3°
	Bimolecular (S_N2/E2) Reactions Only		S_N1/E1 or E2
Gives S_N2 reactions	Gives mainly S_N2 except with a hindered strong base [e.g., $(CH_3)_3CO^-$] and then gives mainly E2.	Gives mainly S_N2 with weak bases (e.g., I^-, CN^-, RCO_2^-) and mainly E2 with strong bases (e.g., RO^-).	No S_N2 reaction. In solvolysis gives S_N1/E1, and at lower temperatures S_N1 is favored. When a strong base (e.g., RO^-) is used, E2 predominates.

7 Alkenes and Alkynes I - Overview

7.1 The E-Z System

- To determine *E* or *Z*, look at the two groups attached to one carbon atom of the double bond. Decide which has higher priority. Then, repeat this at the other carbon atom.
  - If the two groups of higher priority are on the same side of the double bond, the alkene is designated *Z*.
  - If the two groups of higher priority are on opposite sides of the double bond, the alkene is designated *E*.

7.2 Relative Stabilities of Alkenes

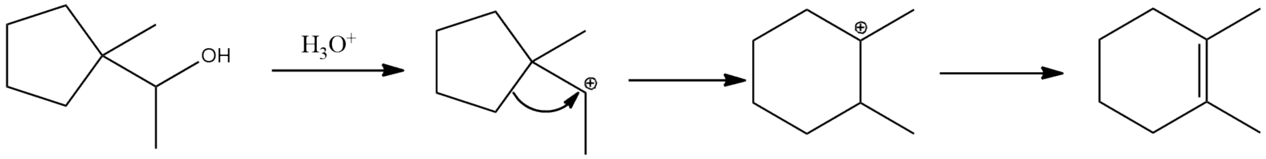
- The trans isomer is generally more stable than the cis isomer
- The greater number of attached alkyl groups, the greater the stability of an alkene

7.3 Factors Affecting Elimination Reactions

- A non-bulky base favors the more substituted double bond while a bulky base favors in making the less substituted double bond

7.4 Acid-Catalyzed Dehydration of Alcohols

- Rearrangements, also known as 1,2 shifts, can occur in primary and secondary alcohol dehydration
  - The more favored product is dictated by the stability of the alkene being formed
- For dehydration of secondary alcohols, the positive charge is shifted through a hydride shift or alkyl shift
- For the dehydration of primary alcohols, a carbocation is not formed as an intermediate. However, rearrangements can still occur after dehydration. The resulting alkene's π bond is broken when a hydrogen atom from the acid bonds to the carbon to form a carbocation. Rearrangement then occurs as usual.
- A ring can change in size due to a methyl shift, especially to reduce ring strain. An example is shown below:



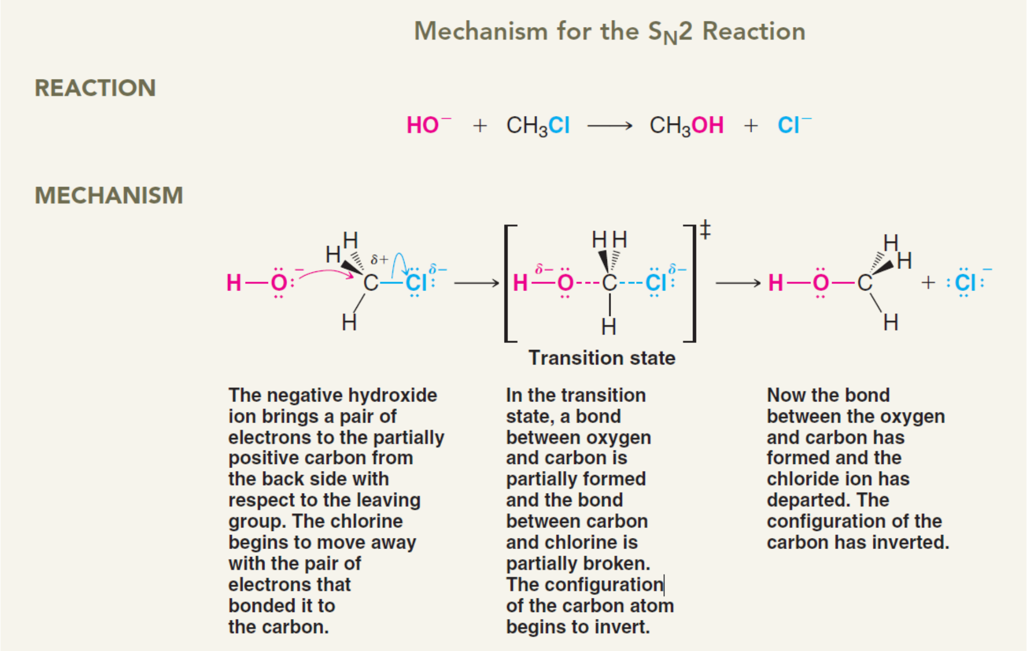
- Note: Never do two migrations

Part III

Reaction Mechanisms

8 Ionic Reactions - Mechanisms

8.1 The S_N2 Reaction



Mechanism for the S_N2 Reaction

REACTION

$HO^- + CH_3Cl \longrightarrow CH_3OH + Cl^-$

MECHANISM

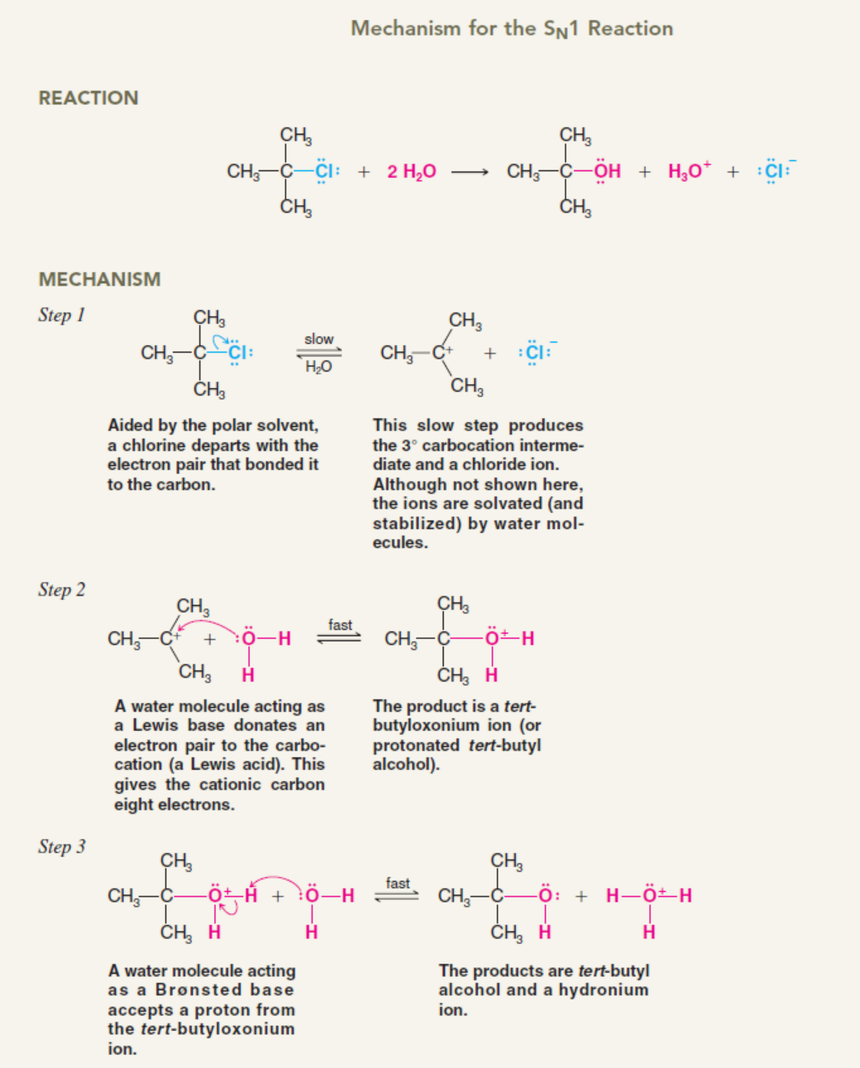
The negative hydroxide ion brings a pair of electrons to the partially positive carbon from the back side with respect to the leaving group. The chlorine begins to move away with the pair of electrons that bonded it to the carbon.

In the transition state, a bond between oxygen and carbon is partially formed and the bond between carbon and chlorine is partially broken. The configuration of the carbon atom begins to invert.

Now the bond between the oxygen and carbon has formed and the chloride ion has departed. The configuration of the carbon has inverted.

- Occurs with inversion of configuration
- If the bond to a chirality center is broken, there is an inversion of stereochemistry

8.2 The S_N1 Reaction



Aided by the polar solvent, a chlorine departs with the electron pair that bonded it to the carbon.

This slow step produces the 3° carbocation intermediate and a chloride ion. Although not shown here, the ions are solvated (and stabilized) by water molecules.

A water molecule acting as a Lewis base donates an electron pair to the carbocation (a Lewis acid). This gives the cationic carbon eight electrons.

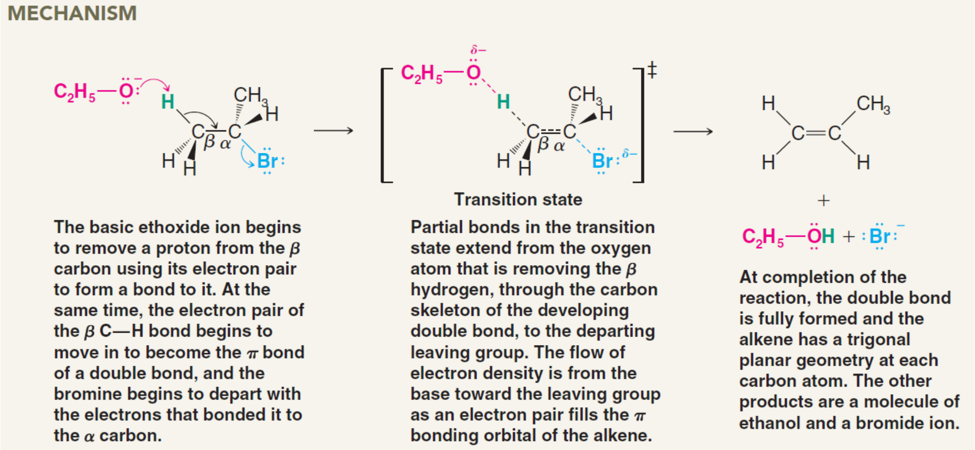
The product is a *tert*-butyloxonium ion (or protonated *tert*-butyl alcohol).

A water molecule acting as a Brønsted base accepts a proton from the *tert*-butyloxonium ion.

The products are *tert*-butyl alcohol and a hydronium ion.

- An S_N1 reaction will cause racemization if enantiomers are possible products

8.3 The E2 Reaction



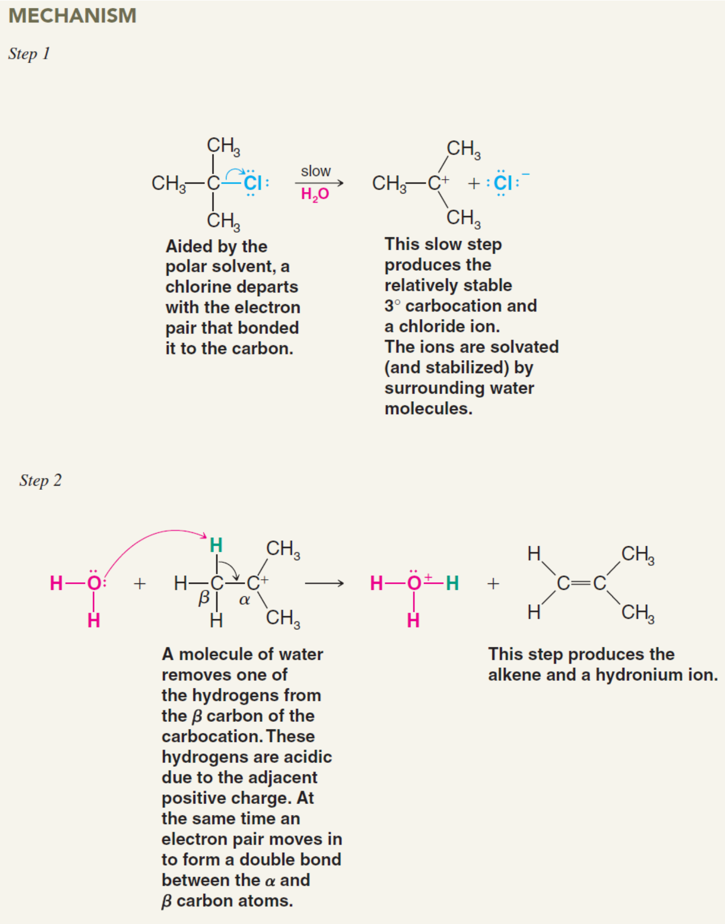
The basic ethoxide ion begins to remove a proton from the β carbon using its electron pair to form a bond to it. At the same time, the electron pair of the β C—H bond begins to move in to become the π bond of a double bond, and the bromine begins to depart with the electrons that bonded it to the α carbon.

Partial bonds in the transition state extend from the oxygen atom that is removing the β hydrogen, through the carbon skeleton of the developing double bond, to the departing leaving group. The flow of electron density is from the base toward the leaving group as an electron pair fills the π bonding orbital of the alkene.

At completion of the reaction, the double bond is fully formed and the alkene has a trigonal planar geometry at each carbon atom. The other products are a molecule of ethanol and a bromide ion.

- There must be an anti-coplanar nature

8.4 The E1 Reaction



Aided by the polar solvent, a chlorine departs with the electron pair that bonded it to the carbon.

This slow step produces the relatively stable 3° carbocation and a chloride ion. The ions are solvated (and stabilized) by surrounding water molecules.

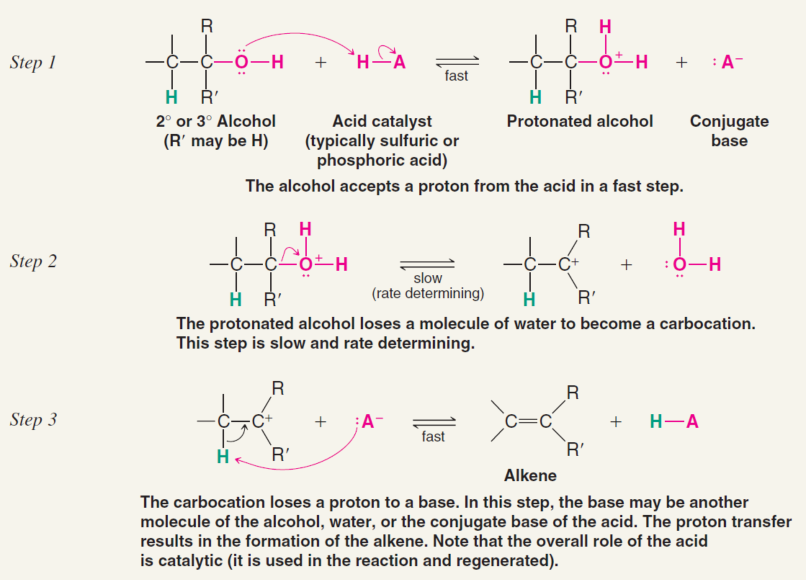
A molecule of water removes one of the hydrogens from the β carbon of the carbocation. These hydrogens are acidic due to the adjacent positive charge. At the same time an electron pair moves in to form a double bond between the α and β carbon atoms.

This step produces the alkene and a hydronium ion.

- E1 reactions almost always accompany S_N1 reactions to some extent

9 Alkenes and Alkynes I - Mechanisms

9.1 Acid-Catalyzed Dehydration of Secondary or Tertiary Alcohols: An E1 Reaction

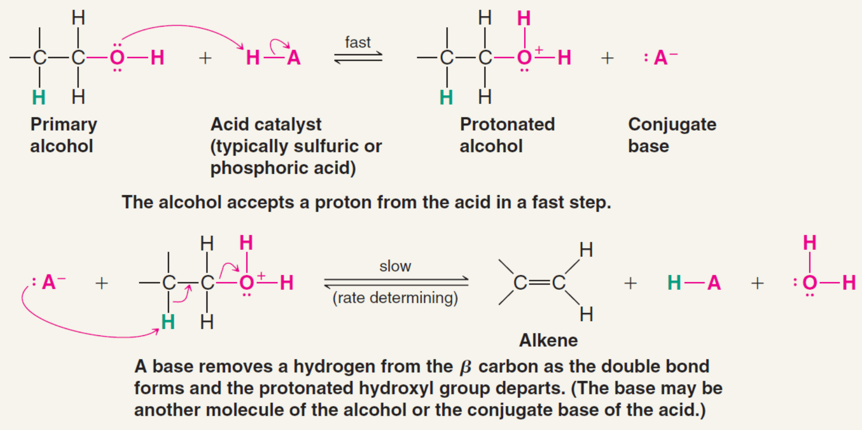


The alcohol accepts a proton from the acid in a fast step.

The protonated alcohol loses a molecule of water to become a carbocation. This step is slow and rate determining.

The carbocation loses a proton to a base. In this step, the base may be another molecule of the alcohol, water, or the conjugate base of the acid. The proton transfer results in the formation of the alkene. Note that the overall role of the acid is catalytic (it is used in the reaction and regenerated).

9.2 Acid-Catalyzed Dehydration of Primary Alcohols: An E2 Reaction

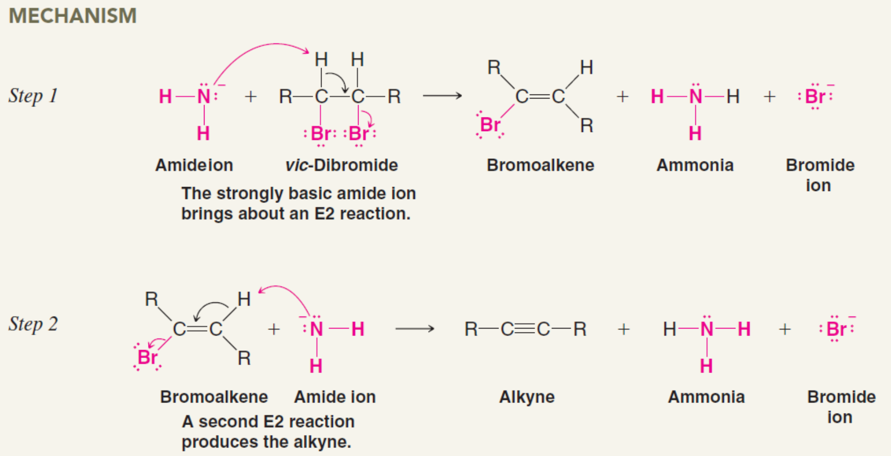


The alcohol accepts a proton from the acid in a fast step.

A base removes a hydrogen from the β carbon as the double bond forms and the protonated hydroxyl group departs. (The base may be another molecule of the alcohol or the conjugate base of the acid.)

9.3 Synthesis of Alkynes from Vic-Dihalides

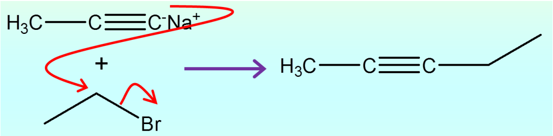
- Alkynes can be synthesized from alkanes via compounds called vicinal dihalides, which are compounds bearing the halogens on adjacent carbons
  - It requires the use of NH_2^-, which can frequently be found as $NaNH_2$ with NH_4Cl



The strongly basic amide ion brings about an E2 reaction.

A second E2 reaction produces the alkyne.

9.4 Substitution of the Acetylenic Hydrogen Atom of a Terminal Alkyne



- A primary halide and a strong base must be used

9.5 Deprotonation Reagents

There are two good reactant choices:

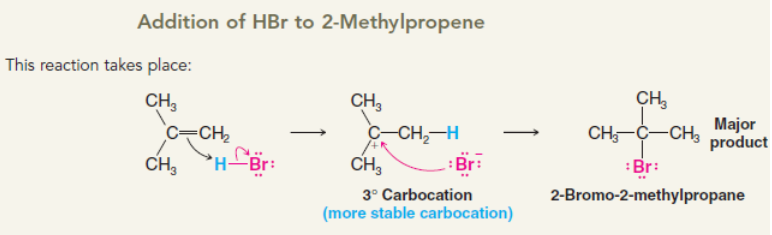
1. $NaNH_2$ and liquid NH_3
2. LDA

9.6 Hydrogenation

- Metal catalyzed H_2 addition to an alkyne (eg: H_2/Pd-C) produces an alkane
- Controlled metal catalyzed H_2 addition to an alkyne (eg: H_2 and Lindlar's Catalyst[5]) produces an alkene with syn-addition (cis). This is also for $H_2/Ni_2B(P-2)$
- Chemical reduction of an alkyne produces an alkene with anti-addition (trans). Sodium metal and liquid NH_3 is one example. Another is Li, C_2H_5 with NH_4Cl

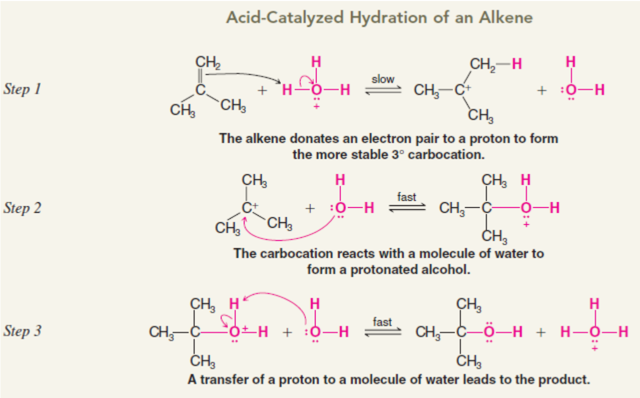
10 Alkenes and Alkynes II - Mechanisms

10.1 Addition of H−X to an Alkene



- Markovnikov, not stereospecific, and rearrangements are possible

10.2 Acid-Catalyzed Hydration of an Alkene



- Markovnikov, not stereospecific, and rearrangements are possible

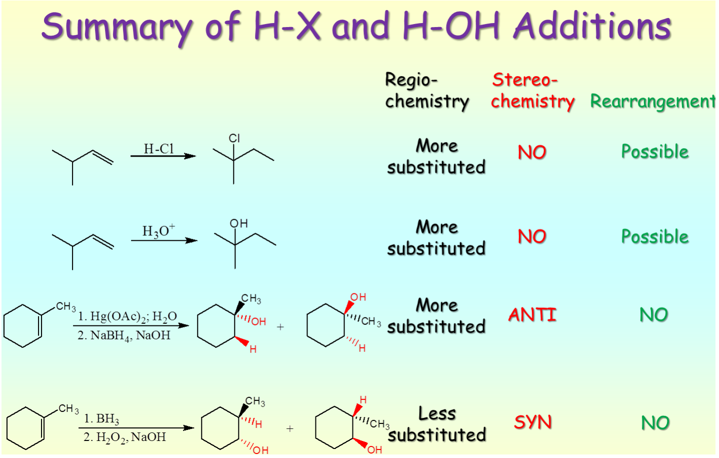
10.3 Mercuration-Demercuration and Hydroboration-Oxidation

- Mercuration-Demercuration: Markovnikov addition, anti stereochemistry, and no rearrangements
  - Uses $Hg(OAc)_2, H_2O$ and then $NaBH_4, NaOH$
- Hydroboration-Oxidation: Anti-Markovnikov addition, syn stereochemistry, and no rearrangements
  - Uses BH_3 and then $H_2O_2, NaOH$

---

[5] Lindlar's Catalyst is $Pd/CaCO_3/Pb$

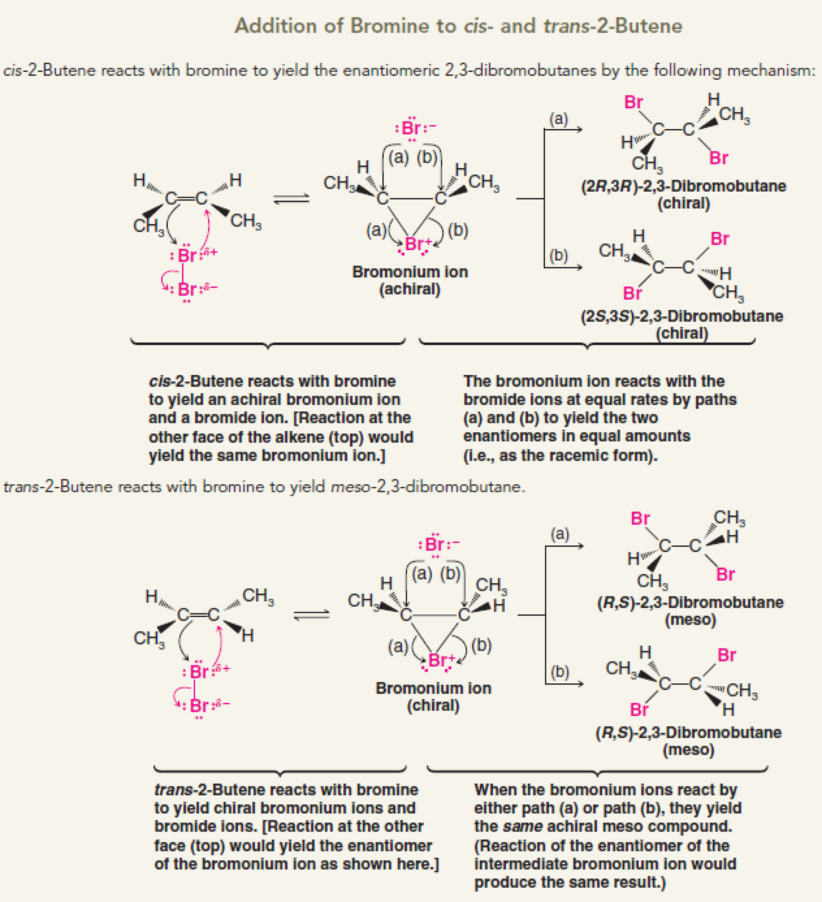
10.4 Summary of H−X and H−OH Additions



Summary of H-X and H-OH Additions

Reaction	Regio-chemistry	Stereo-chemistry	Rearrangement
H-Cl	More substituted	NO	Possible
H_3O^+	More substituted	NO	Possible
1. $Hg(OAc)_2$; H_2O 2. $NaBH_4$, NaOH	More substituted	ANTI	NO
1. BH_3 2. H_2O_2, NaOH	Less substituted	SYN	NO

10.5 Electrophilic Addition of Bromine and Chlorine to Alkenes



Addition of Bromine to *cis*- and *trans*-2-Butene

cis-2-Butene reacts with bromine to yield the enantiomeric 2,3-dibromobutanes by the following mechanism:

***cis*-2-Butene reacts with bromine to yield an achiral bromonium ion and a bromide ion. [Reaction at the other face of the alkene (top) would yield the same bromonium ion.]**

The bromonium ion reacts with the bromide ions at equal rates by paths (a) and (b) to yield the two enantiomers in equal amounts (i.e., as the racemic form).

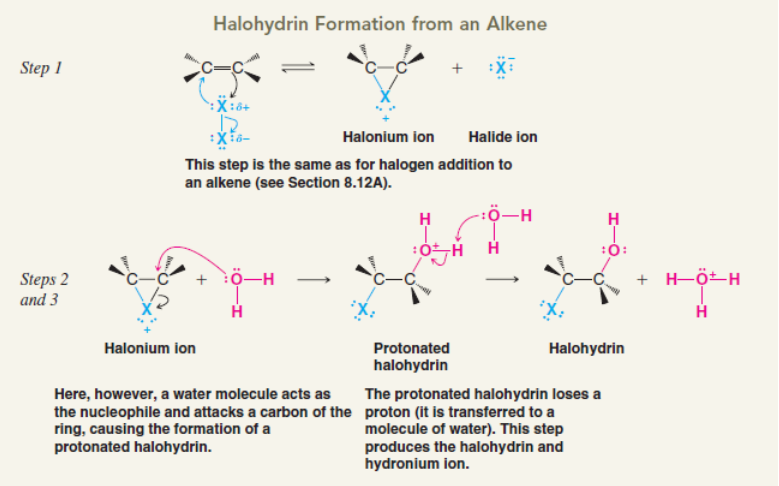
trans-2-Butene reacts with bromine to yield *meso*-2,3-dibromobutane.

***trans*-2-Butene reacts with bromine to yield chiral bromonium ions and bromide ions. [Reaction at the other face (top) would yield the enantiomer of the bromonium ion as shown here.]**

When the bromonium ions react by either path (a) or path (b), they yield the *same* achiral meso compound. (Reaction of the enantiomer of the intermediate bromonium ion would produce the same result.)

10.6 Halohydrin Formation from an Alkene

- A halohydrin is produced when the halogenation of an alkene is carried out in an aqueous solution as opposed to a non-nucleophilic solvent
- If the alkene is unsymmetrical, there is anti-Markovnikov addition



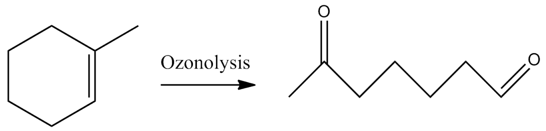
This step is the same as for halogen addition to an alkene (see Section 8.12A).

Here, however, a water molecule acts as the nucleophile and attacks a carbon of the ring, causing the formation of a protonated halohydrin.

The protonated halohydrin loses a proton (it is transferred to a molecule of water). This step produces the halohydrin and hydronium ion.

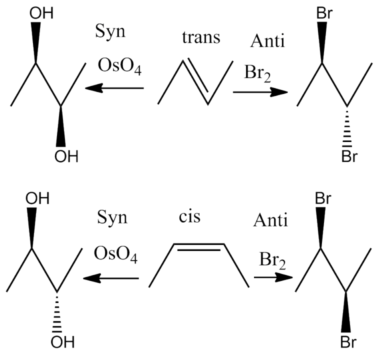
10.7 Oxidative Cleavage of Alkenes

- O_3 or $KMnO_4$ can perform oxidative cleavage of alkenes with syn additions (useful for adding multiple hydroxyl groups)
- Hot, basic $KMnO_4$ cleaves the double bond of an alkene. Disubstituted alkene carbons are oxidatively cleaved to ketones, monosubstituted alkene carbons are cleaved to carboxylic acids, and unsubstituted alkene carbons are oxidized to carbon dioxide.
- Using ozone - ozonolysis - is the best method to cleave alkenes and can open up cycloalkenes, as in the following example. The reagents are O_3, CH_2Cl_2 and then Me_2S

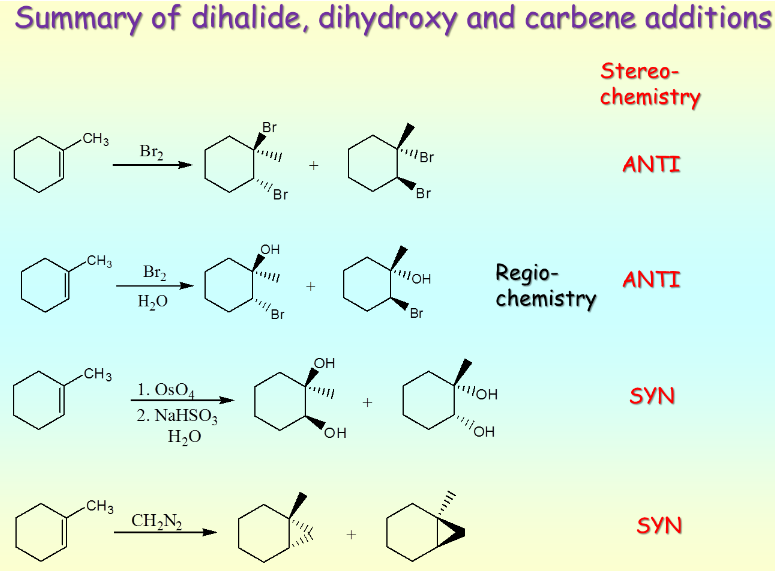


10.8 OsO_4 Reaction

- For details of this reaction, see the table below
- It is important to keep the backbone the same to ensure proper stereochemistry. An example is shown below:



10.9 Summary for Dihalide, Dihydroxy, and Carbene Additions

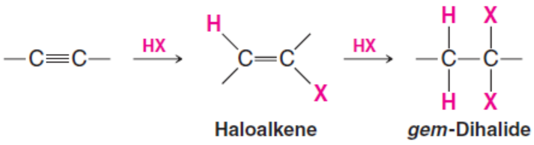


10.10 Electrophilic Addition of Bromine and Chlorine to Alkynes

- Alkynes show the same kind of halo-addition as alkenes (anti-addition)
- Addition may occur once or twice depending upon the molar equivalents of the halogen reagent

10.11 Addition of Hydrogen Halides to Alkynes

- Alkynes react with one molar equivalent of HX to form haloalkenes and with two molar equivalents to form geminal dihalides via Markovnikov's Rule



- Anti-Markovnikov addition occurs when peroxides are present

10.12 Oxidative Cleavage of Alkynes

- Oxidative cleavage of alkynes with ozone will yield two carboxylic acids

11 Alcohols and Ethers - Mechanisms

11.1 Alcohols with H$-$X

- Racemic mixtures are produced if enantiomers are possible
- Rearrangements are present
- Methanol and 1° alcohols go through an S_N2 mechanism. 2° and 3° alcohols go through an S_N1 mechanism

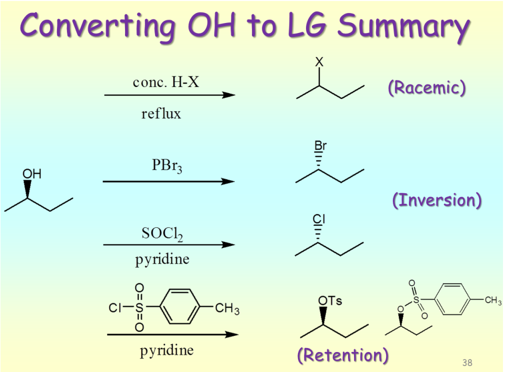
11.2 Alcohols with PBr_3 or $SOCl_2$

- Converts a 1° or 2° alcohol to a leaving group without rearrangements
- Inversion of configuration occurs since the reaction is S_N2

11.3 Leaving Group Derivatives of Alcohols

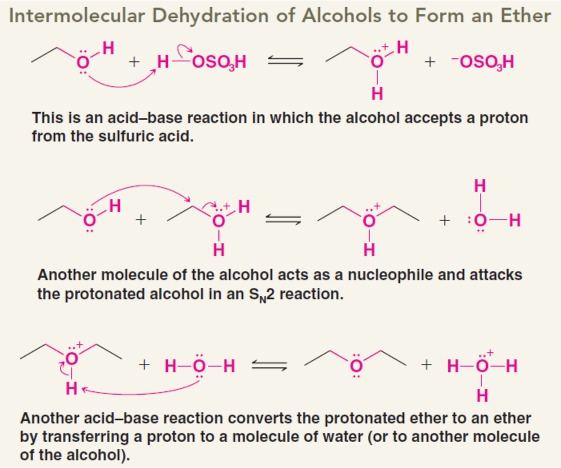
- Using either pyridine or DMAP, sulfonate esters can be prepared from combining an alcohol with a chlorinated sulfonate derivative
- There is retention of configuration with this reaction

11.4 Converting OH to LG Summary


Converting OH to LG Summary

11.5 Synthesis of Ethers

- Alcohols can dehydrate to form alkenes, as mentioned in **Section 7**. Also, 1° alcohols can dehydrate to form ethers by the following mechanism:

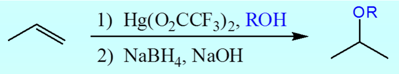

Intermolecular Dehydration of Alcohols to Form an Ether

This is an acid–base reaction in which the alcohol accepts a proton from the sulfuric acid.

Another molecule of the alcohol acts as a nucleophile and attacks the protonated alcohol in an S_N2 reaction.

Another acid–base reaction converts the protonated ether to an ether by transferring a proton to a molecule of water (or to another molecule of the alcohol).

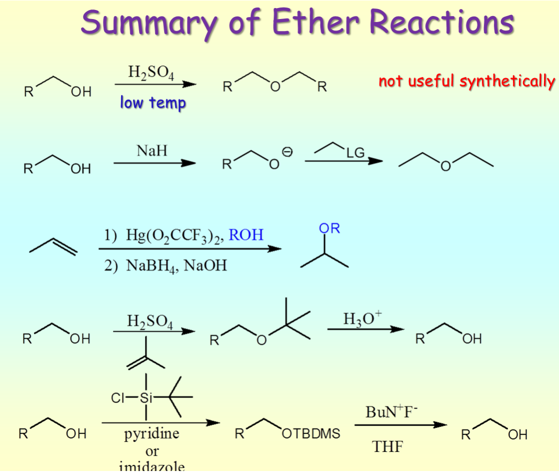
- Acid-catalyzed dehydration is not useful for preparing unsymmetrical ethers from different 1° alcohols because the reaction leads to a mixture of products (ROR, ROR′, and R′OR′)
- Alkoxymercuration-demercuration is a method for synthesizing ethers directly from alkenes, like in the example below, and parallels oxymercuration-demercuration



11.6 Protecting Groups

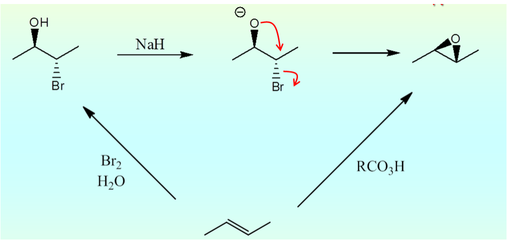
- To add a protecting group to an alcohol, use TBDMS in pyridine
- To remove a protecting group, a fluorine anion can be used

11.7 Ether Reactions Summary

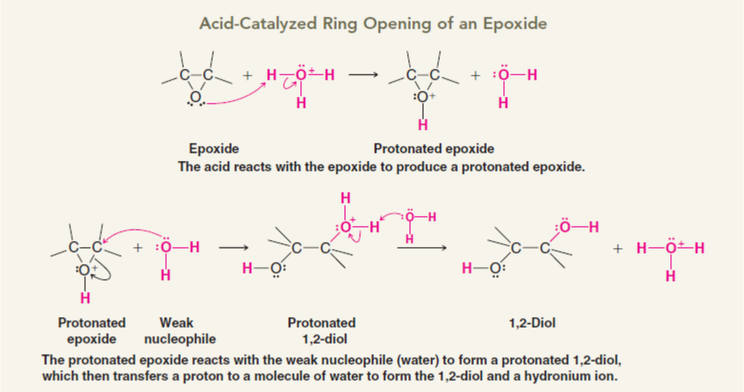


11.8 Epoxides

- Epoxidation is a syn addition that is stereospecific
- RCO_3H can be used to make an epoxide from an alkene:

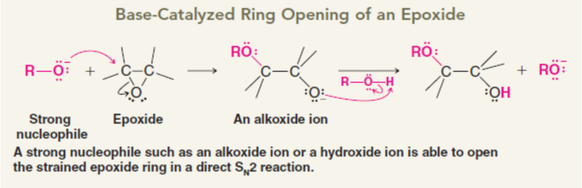


- There are two types of reactions that epoxides go through: Acid-Catalyzed and Base-Catalyzed (both ring-opening and anti-configuration)
  - Use the acronym "BLAM"
    - Basic = Less Substituted   Acidic = More Substituted



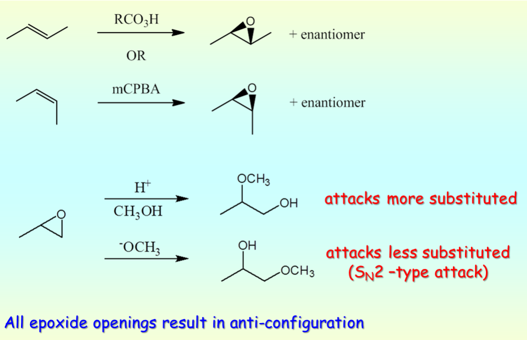
The acid reacts with the epoxide to produce a protonated epoxide.

The protonated epoxide reacts with the weak nucleophile (water) to form a protonated 1,2-diol, which then transfers a proton to a molecule of water to form the 1,2-diol and a hydronium ion.

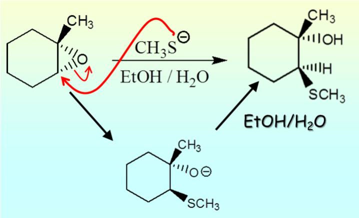


A strong nucleophile such as an alkoxide ion or a hydroxide ion is able to open the strained epoxide ring in a direct S_N2 reaction.

11.9 Epoxide Reaction Summary with Example



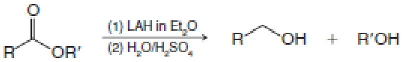
Example of “BLAM”:



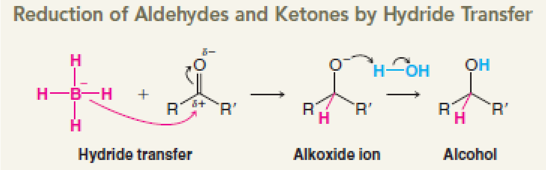
12 Alcohols from Carbonyl Compounds - Mechanisms

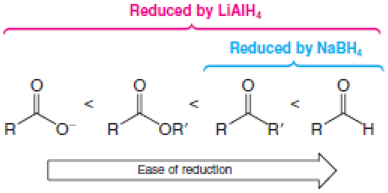
12.1 Alcohols by Reduction of Carbonyl Compounds

- Reduction converts a carboxylic acid to a primary alcohol by taking off an oxygen from C=O
- Reduction converts an ester into two 1° alcohols, one derived from the carbonyl part of the ester group and the other from the alkoxyl part of the ester
- Reduction converts a ketone to a 2° alcohol and an aldehyde to a 1° alcohol



- Aldehydes and ketones are easily reduced by $NaBH_4$. LAH is another reducing agent:





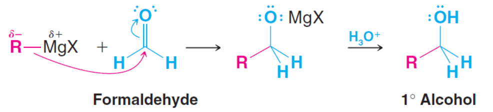
12.2 Oxidation of Alcohols

- PCC will convert a 1° alcohol to an aldehyde and oxidize a 2° alcohol to a ketone (not useful for 3°)
- $KMnO_4$ or H_2CrO_4 (Jones Reagent) can oxidize a 1° alcohol to a carboxylic acid
- H_2CrO_4 can oxidize a 2° alcohol to a ketone

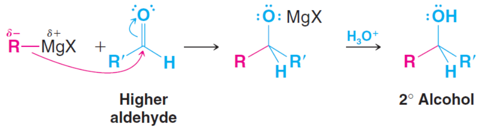
12.3 Alcohols from Grignard Reagents

- Grignard Reagents react with any compound that has a hydrogen attached to an atom of high electronegativity (eg: oxygen, nitrogen, sulfur, etc.) and react well with compounds that have carbonyl groups

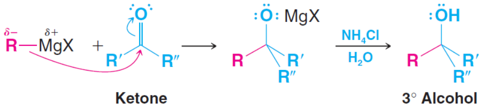
1. **Grignard Reagents React with Formaldehyde to Give a Primary Alcohol**



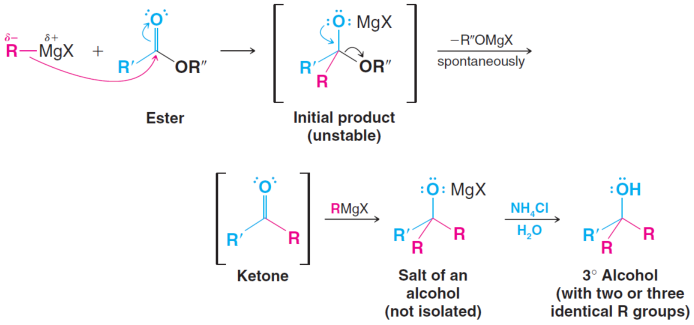
2. **Grignard Reagents React with All Other Aldehydes to Give Secondary Alcohols**



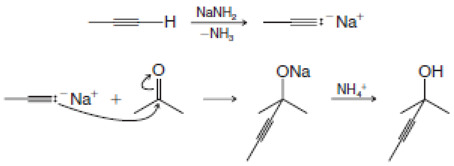
3. **Grignard Reagents React with Ketones to Give Tertiary Alcohols**



4. **Esters React with Two Molar Equivalents of a Grignard Reagent to Form Tertiary Alcohols**



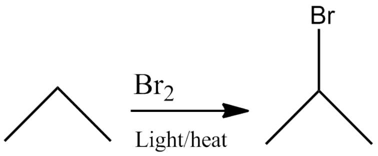
- Sodium alkynides react with aldehydes and ketones to yield alcohols:



13 Radical Reactions - Mechanisms

13.1 Bromination

- Br_2 and heat/light can perform the following halogen addition to the more substituted carbon of an alkane:



- HBr with a peroxide (ROOR) will have the bromine added to the least substituted carbon of an alkene

13.2 Chlorination

- Cl_2 and heat/light adds a chlorine atom to an alkane; however, it is only useful synthetically when all possible replacements yield the same compound (e.g. neopentane and Cl_2)