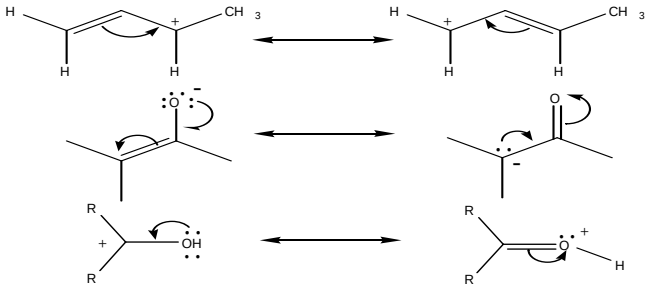
MCAT Organic Equation Sheet

MOLECULAR STRUCTURE

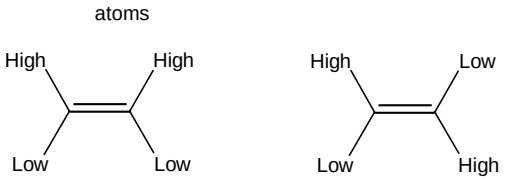
Hybridization:
an atom is **SP^3** hybridized if it contains only single bonds (tetrahedral geometry) 109.5^o
an atom is **SP^2** hybridized if it contains 1 double bond (trigonal geometry) 120^o
an atom is **SP** hybridized if it contains 2 double bonds or 1 triple bond (linear, 180^o)
NOTE this only works for neutral atoms a carbocation is sp^2 hybridized

Determining formal charge: # of electrons an atom wants (4 for C, 5 or N, 6 for O) – (# of bonds and each electron in a lone pair)
a single bond has 1 σ bond
a double bond has 1 σ bond and 1 π bond
a triple bond has 1 σ bond and 2 π bonds

Resonance:
- occurs when there's α,β-unsaturation next to an atom with a charge or an atom with a lone pair next to a carbocation
- to draw the resonance contributor always move electrons (ie. Either the double bond in the case of a cation and lone pair of electrons in the case of a negative charge)



Naming alkenes: E or Z
When an alkene is tri- or tetra- substituted, E/Z nomenclature is used. To do this, each substituent across the double bond is assigned a priority according to the Cahn-Ingold-Prelog rules:
(i) Rank according to atomic number of attached atom (Br>Cl>O>N>C>H)
(ii) If the above rule does not solve the ranking, look at 2^{nd}, 3^{rd}, 4^{th}, atoms away to try and find a difference in atomic number
(iii) Multiple-bonded atoms are equivalent to the same number of single-bonded



Z- on the same side E- on opposite sides

Assigning stereochemistry to chiral centers:
→ substituents are ranked according to the Cahn-Ingold-Prelog rules (E/Z alkenes)
Once substituents have been ranked, the lowest ranked is aimed away from the viewer (i.e. into the page).
- If the remaining 1^{st}, 2^{nd} and 3^{rd} ranked substituents are arranged:
  (i) Clockwise: **R Stereochemistry**
  (ii) Counter-clockwise **S Stereochemistry**

Racemic mixtures**:** **equal (50:50) mixtures of two enantiomers; often denoted by** (+/-)
Enantiomers have identical physical properties but diastereomers do not.

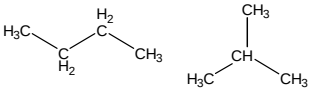
Meso compounds- molecules that have at least 2 stereocentres BUT are achiral
because they have a plane of symmetry.

Fischer Projections:

- most highly oxidized group at the top (position A)
- longest carbon chain is vertical (A to C)
- Can rotate 180° but not 90 or 270°
- Can hold one substituent in place then rotate others either clockwise or counter-c.w.

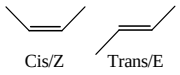
isomers
(have the same molecular formula)

structural isomers
(also known as constitutional isomers)
- have a different bonding arrangement of atoms
ex.

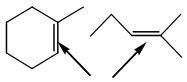


sterioisomers
(have the same bonding arrangement of atoms but a different 3-D arrangement of atoms)

geometric
(also know as cis/trans) or Z / E



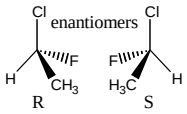
- double bonds in a ring can't have cis/trans isomers
- double bonds with 2 of the same substituents on the same carbon can't have cis/trans isomers
ex.



can't have cis/trans isomers

- C=O's don't have cis/trans isomers

chiral centers
(also known as steriocenters or stereogenic centers)
- occurs at an sp3 hybridized carbon with 4 different substituents



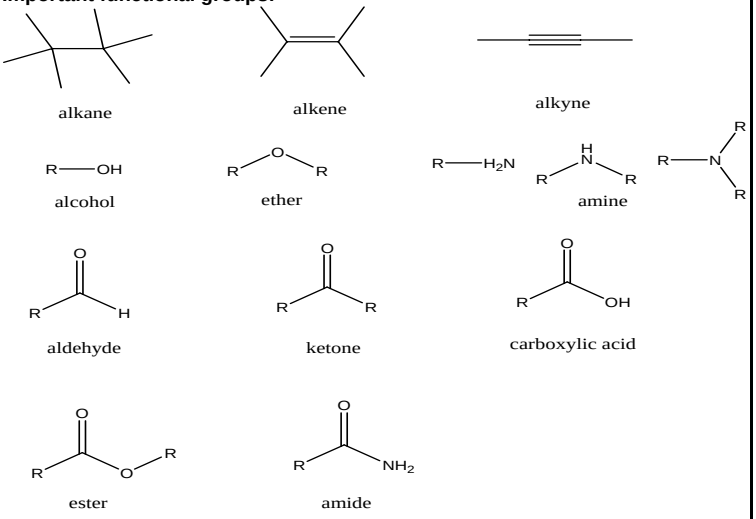
definitions:
- enantiomers are sterioisomers which are mirror images
- diasteriomers are sterioisomers which aren't mirror images
- meso compounds have 2 or more chiral centers and a plane of symmetry making them achiral

ex. if you have a molecule with 2 chiral centers which are R,R
- it's enantiomer would be S,S
- it's diasteriomers would be R,S or S,R

NOTE a conformation is a rotation of a bond or a flip of the chair in cyclohexane

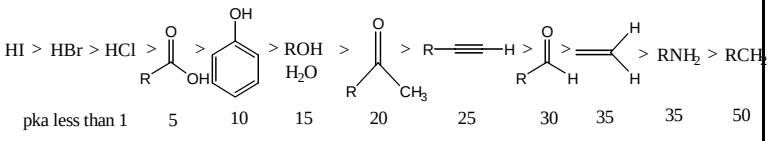
total stereoisomers = 2^n (where n equals the number of chiral centers and double bonds which can have cis/trans isomers)

Important functional groups:



Acidity Summary:

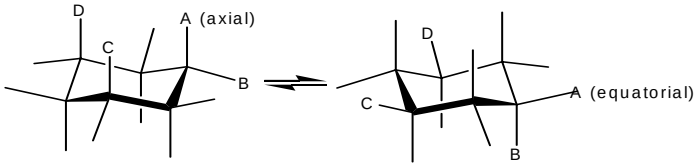
Strongest acids ⟷ Weakest acids
Better leaving groups ⟷ Poorer leaving groups
Weakest conjugate bases ⟷ Strongest conjugate bases



HYDROCARBONS, ALCOHOLS, AND SUBSTITUTIONS\ELIMINATIONS

Cyclohexane:

Ring-flip in cyclohexane



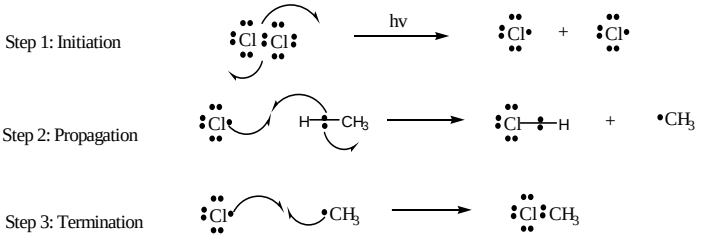
1,3-Diaxial interactions (occur between A-C, C-D and A-D, on the left above)

- Result from steric strain between axial substituents 3 carbons apart on a ring
- Equatorial position generally preferred to avoid 1,3-diaxial interactions

Radical Reactions:

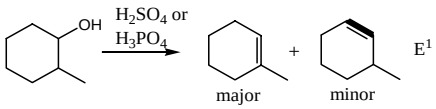
→ Homolytic bond breaking

An example of a radical reaction mechanism



Alkenes

Alkenes may be synthesized via alcohol dehydration

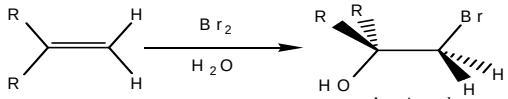


Zaitsev's Rule:
form most substituted double bond

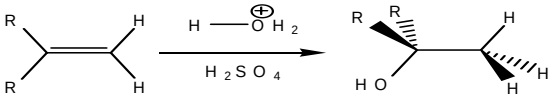
or dehydrohalogenation (similar mechanism).

Addition reactions:

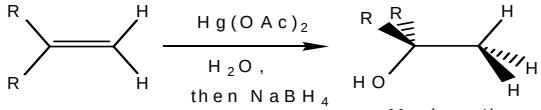
Halohydrin



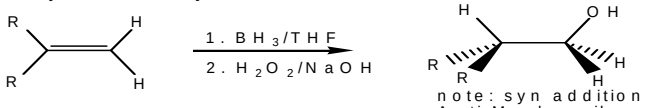
Hydration: Industrial



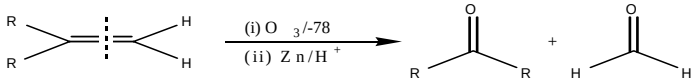
Hydration: Oxymercuration



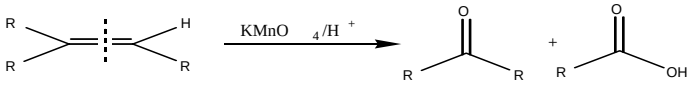
Hydration: Hydroboration



Ozonolysis



Permanganate Cleavage



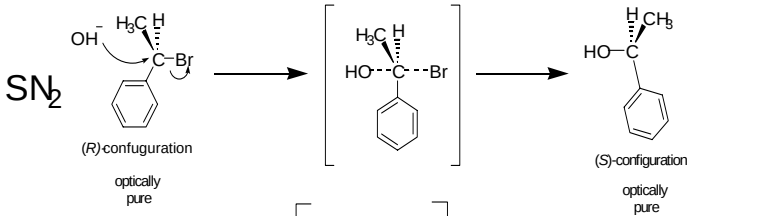
Substitution/Elimination Summary:

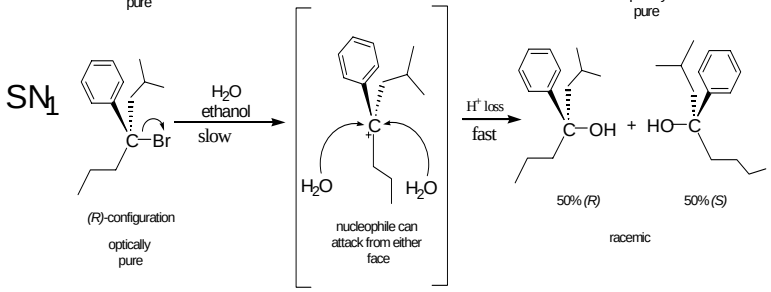
SN^2 1^o > benzylic/allylic > 2^o > (3^o does not work)
Needs a stong nucleophile

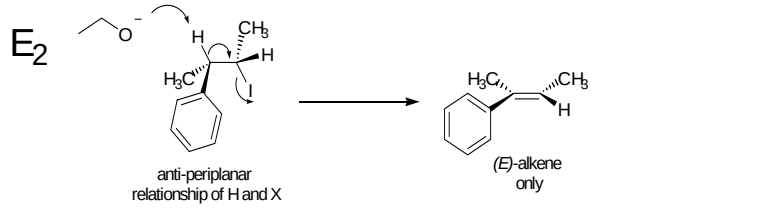
SN^1 3^o > benzylic/allylic > 2^o > (1^o does not work)
Weak nucleophiles will do since any nucleophile will attack a carbocation

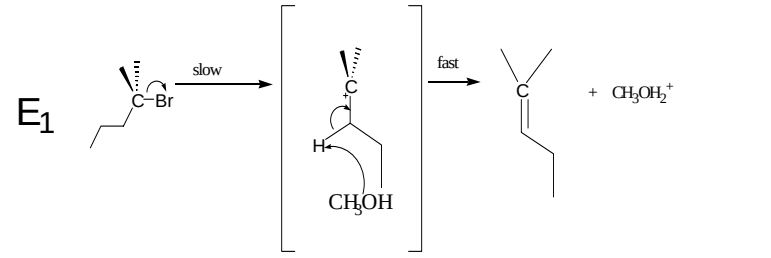
E^2 Doesn't matter what the carbon with the nucleophile is since you're pulling an H
Need a strong base

E^1 3^o > benzylic/allylic > 2^o > (1^o does not work)
Weak bases will do since any base will attack a carbocation

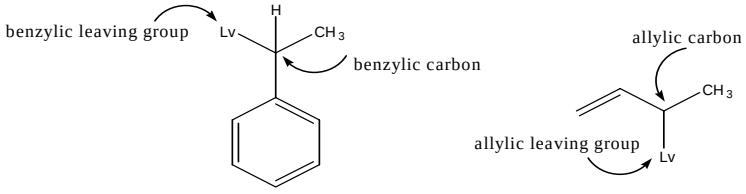








Carbocation Stability: 3^o > benzylic/allylic > 2^o > 1^o > methyl

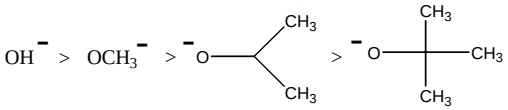


When the atom with the lone pair can act as a base or nucleophile:
SN^2 and E^2 will compete and SN^1 and E^1 will compete.

To determine the mechanism:

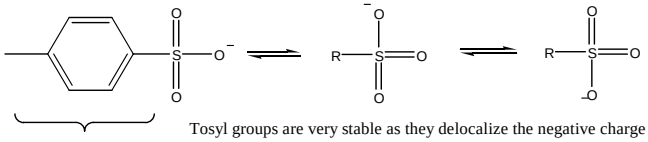
- Look at degree of substitution of the halide, the more substituted, the greater the chance
that it will undergo an S_N1 or an E1
- Look at what the halide is reacting with:
  - a Nucleophile (S_N2 or S_N1)
  - a Base (E2 or E1)
- If you have a molecule which can act as a base or a nucleophile look at the double bond
that would be formed in the elimination mechanism. If it is conjugated or highly
substituted elimination will be favoured over substitution.

- **Nucleophiles:** are atoms with a lone pair of electrons. In nucleophilic substitution they donate the pair of electrons to form a new covalent bond.
(factors listed from most important to least important)
$I^->Br^->Cl^->F^-$
$CN^->OH^->F^-$
$H_2S>H_2O$
  - the best nucleophiles are **negative**ly charged (ie. $OH^- > H_2O$)
  - the **larger the atom** the better the nucleophile (ie. $I^- > Br^- > Cl^- > F^-$)
  - **smaller molecules** are better nucleophiles than larger ones



  - the lower electronegativity of the atom with the lone pair, the stronger the Nu (ie. $CN^->OH^->F$)

- **Leaving Groups:** groups that best stabilize a negative charge (tosylate, iodide, bromide, chloride, acetate)
(factors listed from most important to least important)
  - good leaving groups leave **neutral**
  - good leaving groups are **stable anions** (resonance stablilized)
  - **larger** the atom bearing the negative charge the better the Lv group ($I^- > Br^- > Cl^- > F^-$)
  - more **electronegative** the atom bearing the negative charge the better the leaving group ($F^- > O^- > N^- > C^-$)



Tosyl groups are very stable as they delocalize the negative charge over 3 different oxygens

Note: halogens are good leaving groups too as they are very electronegative, but they don't have resonance stabilization like tosyl groups

- **Bases:** Are atoms with a lone pair of electrons. An atom with a lone pair of electons can be a base or a nucleophile. By definition if an atom with a lone pair attacks at the carbon it is a nucleophile. If it pulls a proton it is a base.
  - good bases are **negative**ly charged
  - the **bigger** the molecule with the lone pair the better the base and poorer the Nu

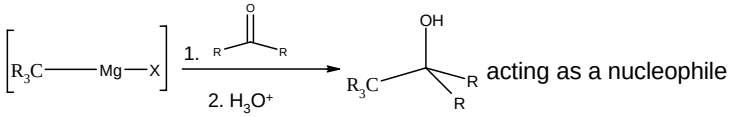
Nucleophile

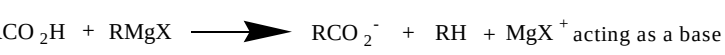
small → Nu
large → base
negative → strong
neutral → weak

Grignards:

$RX + Mg \longrightarrow RMgBr = R^-$

A Grignard will act as a base 1st if there's an acidic proton around (ROH, SH, RCO_2H) otherwise it acts as a Nucleophile.





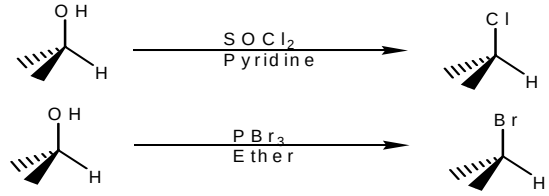
Is it an Oxidation or Reduction?
- oxidation is a gain of oxygen or loss of hydrogen
- reduction is gain of hydrogen or loss of oxygen

NOTE treat S, I, Br, Cl and OH groups as oxygen
NOTE addition of HI, HBr, HCl or H-OH **is not** an oxidation or reduction since

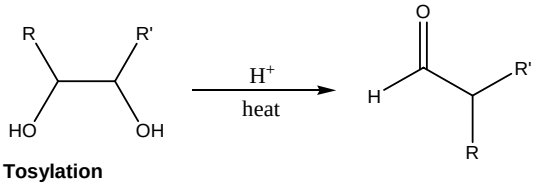
you're adding an O and an H

Alcohols

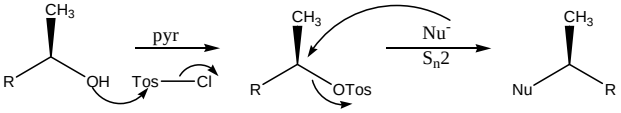
Alkyl Halides from Alcohols



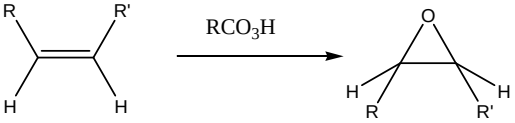
Pinacol rearrangement



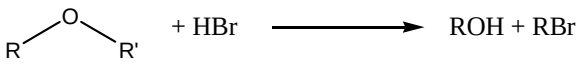
Tosylation



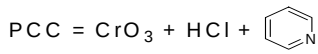
Epoxide Formation



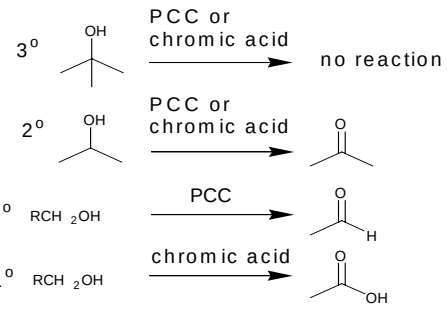
Alkyl halide formation from ether



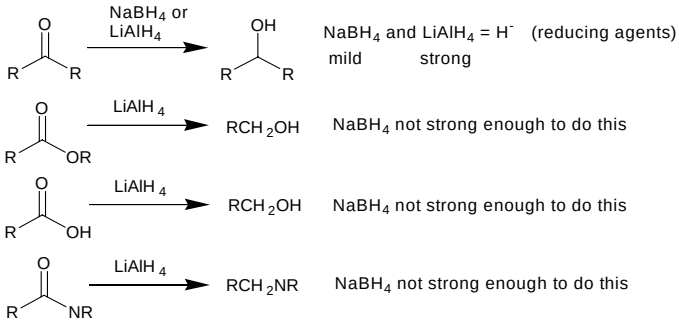
Oxidations:



Chromic Acid = H_2CrO_4/acetone
or $K_2Cr_2O_7/H_2SO_4$/acetone (strong oxidizers)
or CrO_3/H_2SO_4/acetone



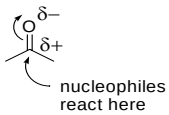
Reductions:



CARBONYLS AND AMINES

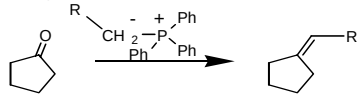
Carbonyl reactions:

Nucleophilic addition reactions

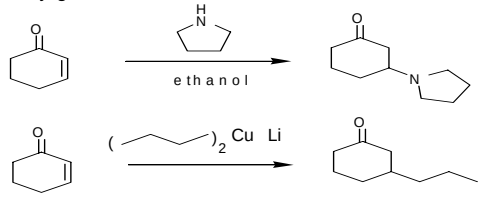


These reactions produce an alcohol. Nucleophiles include H_2O, CN^- or RMgX

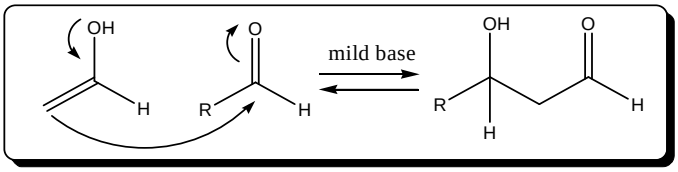
Wittig Reaction

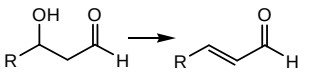


Conjugate addition

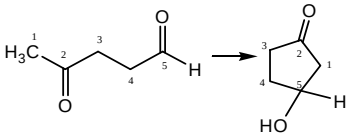


The aldol condensation between two aldehydes to give a β-hydoxy aldehyde



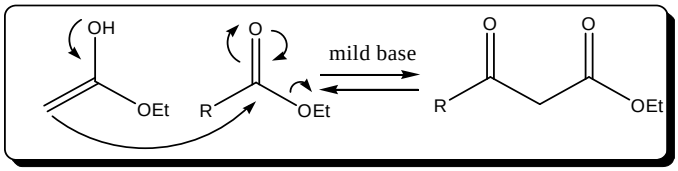


aldol products can dehydrate under acidic or basic conditions to give the conjugated product

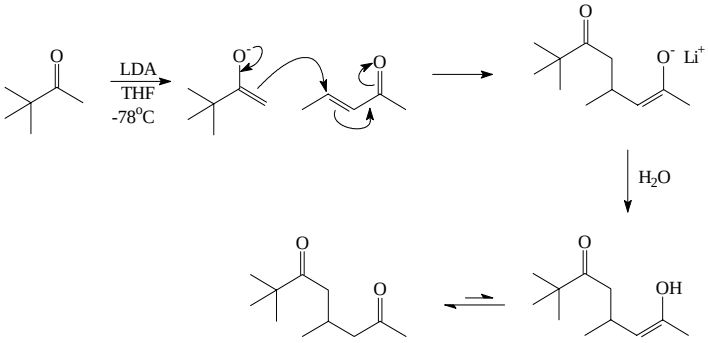


aldol reactions can occur intramoleuclarly to give cyclic products (favouring 5 or 6 membered rings)

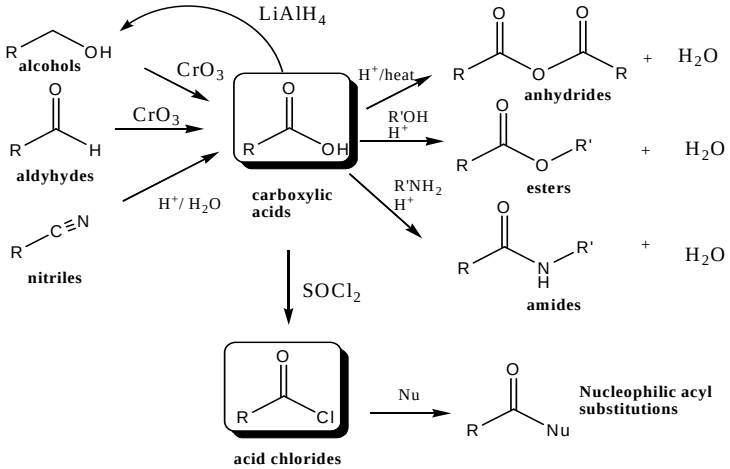
Claisen condensation is similar to the aldol reaction, with esters as the starting material



Michael Addition



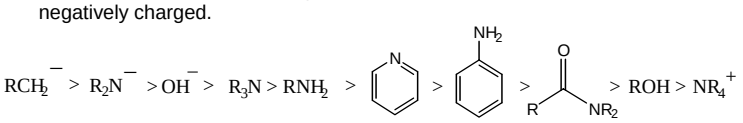
Carboxylic Acid



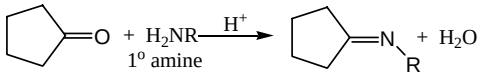
Amines

Basicity Review

A base is an atom with a lone pair of electrons. The best bases are negatively charged.

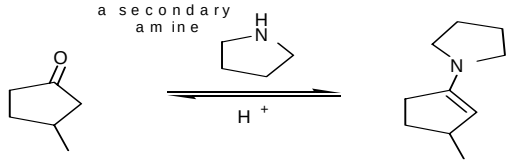


Reductive Aminolysis



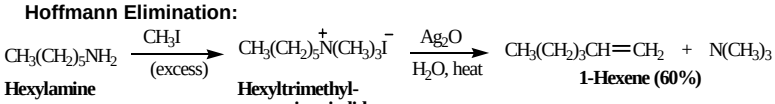
(know this forward and backwards)

an imine or Schiff base



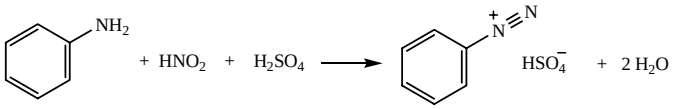
an enamine

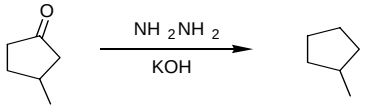
Hoffmann Elimination:



Hexylamine — **Hexyltrimethyl-ammonium iodide** — **1-Hexene (60%)**

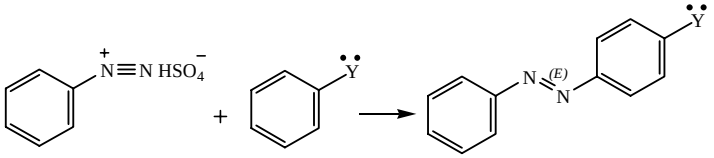
Diazotization Reaction:





Wolff-Kischner reduction

Diazonium Coupling Reaction:

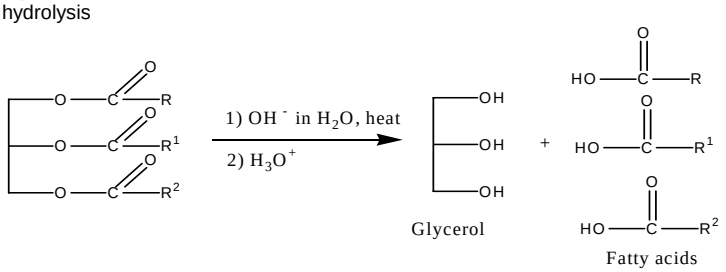


where Y = − OH or $-NR_2$

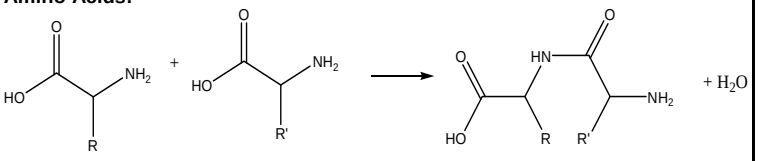
An azo compound

BIOCHEMISTRY AND LAB TECHNIQUES

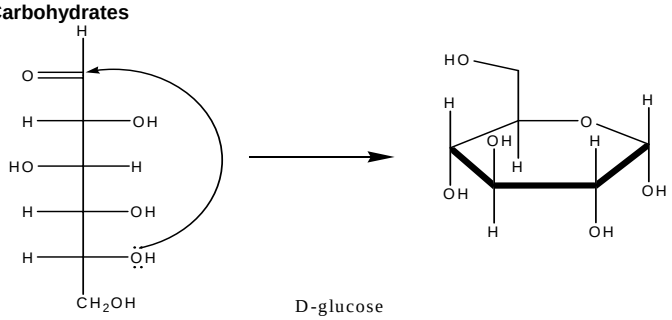
Lipids:
hydrolysis



Amino Acids:



Carbohydrates



The human body can assimilate only D-fructose and D-glucose and cannot assimilate L-fructose and L-glucose.

An Approach To Structure Determination:

1. Determine the units of unsaturation
2. Gather information from the IR spectrum
   From an IR spectrum you should be able to tell if there is a C=O, O-H, CO_2H, N-H, nitrile, C=C or alkyne
   - an IR is good for determining functional groups present when there are heteroatoms in the molecular formula
   - ex. If there is an O in the molecular formula the IR can tell you if it is a ketone or aldehyde, carboxylic acid or alcohol. If none of these peaks are observed then it is probably an ether
     ex. If there is an N in the molecular formula the IR can tell you if it is an N-H or nitrile. If neither of these peaks are observed the N may be a tertiary amine or amide. If it was an amide you would observe a C=O peak in the IR.
3. Gather information from the NMR spectrum
   - Easy things to spot in the NMR are aromatic ring, aldehyde, carboxylic acid and alkene.
   - If there is 4 or more units of unsaturation immediately look to see if there is an aromatic ring in the structure (peak in the NMR spectrum between 6.8-8 ppm)
   - Then look for the number of CH_3 peaks there are (integrate for 3 protons)
   - Then use all the data you've learned from the molecular formula, IR and NMR to draw possible structures. Then look at each structure and compare them to the number of chemical shifts in the NMR and the splitting and integration observed in the NMR. The structure should match the observed NMR data perfectly. If it doesn't it is not the correct structure. Eliminate it and look at the next possible structure.