I Introduction

Understanding organic chemistry reactions is hard. There are a large number of reactions to remember (over 50). Many molecules and reactions are different only in a single atom or bond. There are many different ways to write chemical compounds and reactions (molecular names, formula's, line structures, condensed structures, full structures). All of the above make understanding, writing, and completing chemical reactions difficult.

Critical thinking is the key to understanding chemical reactions. You will need to be flexible, to organize the concepts in your head by noting similarities and differences, and to practice. Learn a general method, not a specific example. Simply trying to memorize all of the reactions is possible but very difficult.

This guide is divided into a number of different sections which will hopefully aid you in your quest to master organic chemical reactions.

- Drawing and Naming organic compounds: This is a separate handout you should have already received, you must master it before you can successfully understand chemical reactions.
- Functional Groups: Table 19.1 p 470, you can't understand chemical reactions unless you know the different classes of molecules.
- Categorize Reactions: There are several ways to classify reactions, if you can remember the category of reaction then it easier to understand the specific reaction. There are several ways to classify reactions:
  - Addition, Substitution, and Elimination reactions.
  - Oxidation and Reduction reactions.
  - Hydration, and Dehydration reactions.
- Reaction Conditions: Another way to recognize reactions is by recognizing specific conditions that cause a reaction to occur.
- Reaction Mechanisms: This is the actual physical/chemical process that occurs during a reaction. Understanding the basic mechanisms can lead to a deeper understanding of the chemical reactions. Sometimes a common reaction mechanism is used in a variety of similar reactions.
- Similarities and Differences: Group things that are similar to decrease the number of reactions you must memorize.
- List of Common Reactions: The last part of this guide is a listing of the reactions you will need to know and understand for this class broken down by class of compound.

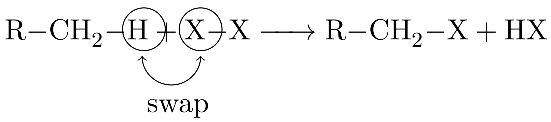
As a general note, this guide is written specifically for CHE 102 Organic and Biochemistry in a single semester meaning that that organic chemistry is covered in 8 weeks! It is not possible to cover the organic chemistry to the level of depth and detail as would be covered in 200 level or year long sequence. Simplifications, omissions and perhaps a few lies are taught in order to simplify the organic chemistry to the level required in this specific course.

II Organizing Reactions

There are many ways to organize and classify reactions. Many reactions can actually be classified in several different ways. I will try to show several themes here. A complete list of reactions can be found in the study guides also.

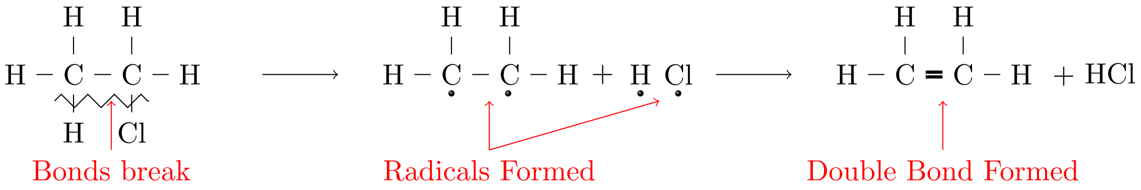
The first classification system for reactions is a simple description of what atoms are changed in the reaction.

- Substitution: Two molecules exchange or swap atoms/functional groups. A more detailed description of the reaction and mechanism (Free Radical) is found in your book on p. 484-490. If you ever take a higher level organic chemistry class you will learn these reactions as SN1 and SN2.

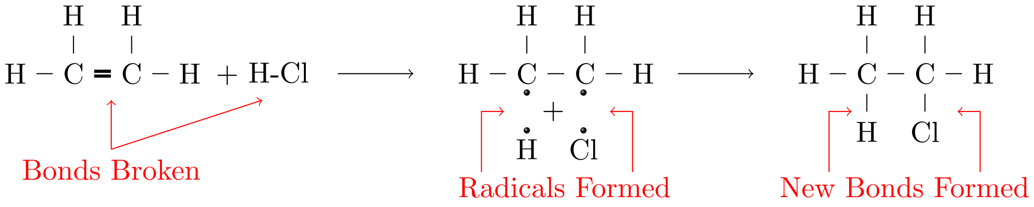


$$R{-}CH_2{-}\bigcirc\!\!\!\!\!H + \bigcirc\!\!\!\!\!X{-}X \longrightarrow R{-}CH_2{-}X + HX$$

- Elimination: The reactant is split into two products. The reaction generally eliminates a small molecule (often referred to as a "leaving group" from a larger molecule, and generally results in the formation of double and triple bonds. If you ever take a higher level organic chemistry class you will learn these reactions as E1 and E2 (we just learn E2).

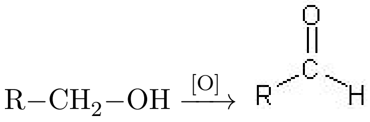


- Addition: Two reactants are added together to make a single product. Generally involves addition of small molecules across double bonds.



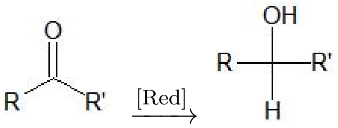
Another common way to organize some reactions is labelling them as oxidation or reduction reactions. These reactions are commonly referred to as oxid/red or redox reactions. The reactions are always paired, meaning if an oxidation occurs a reduction must also occur. However, since the reaction mechanisms for redox reactions are complicated we generally only focus on the oxidation or the reduction of the main molecule and ignore the second part of the reaction. Redox reactions are especially important in biochemistry and metabolism (Ch. 31-35).

- Oxidation: Oxidation reactions result in the molecule of interest losing an electron in a reaction. This is generally accomplished by gaining bonds to Oxygen and/or the loss of a bond to Hydrogen. From a biochemistry viewpoint the important feature of the reaction is that the molecule loses/releases energy (and the body gains energy).



Note that the carbon atom in the reaction gains 2 bonds to oxygen and losses one bond to hydrogen, thus clearly identifying it as an oxidation reaction.

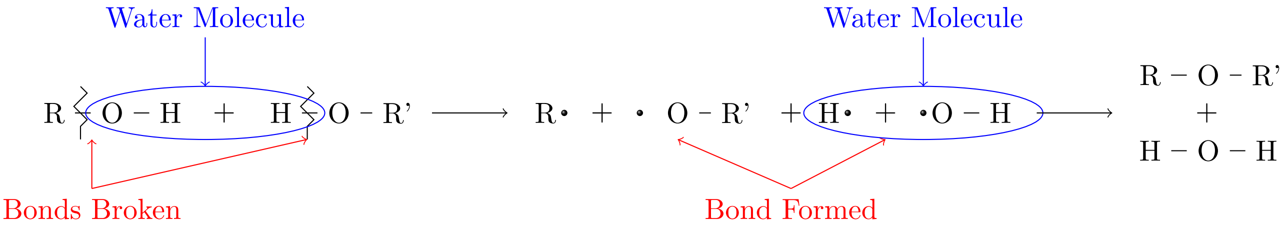
- Reduction: Reduction reactions result in the molecule of interest gaining an electron in the reaction. This is generally accomplished by gaining bonds to Hydrogen and/or the loss of a bond to Oxygen. From a biochemistry viewpoint the important feature of the reaction is that the molecule gains/stores energy (and the body loses energy).



Note that the central carbon atom in the ketone has two bonds to oxygen and zero bonds to hydrogen, but after the reduction reaction it only has one bond to oxygen (lose bonds to oxygen) and has gained a bond to hydrogen.

Another set of common paired reactions are hydration and dehydration reactions. These reactions are considered paired because a dehydration reaction going in the forward direction, is a dehydration reaction going in the reverse direction.

- Dehydration: Results in the loss of water from a molecule or molecules, generally resulting in the formation of a C=C or a new bond combining two or more molecules together.



In the reaction above two primary alcohols have a water molecule removed and form an ether.

- Hydration: The addition of water to a molecule generally breaks a C=C or results in the cleaving of a bond resulting in the formation of two molecules from a single molecule. The previous reaction in the reverse direction is a hydration reaction.

III Reaction Conditions

Another important clue to recognizing the type of reaction that occurs is the conditions under which it happens. This information can include recognizing specific reactants listed either above/below the reaction arrow or sometimes listed as reactants. There are several categories of common reaction conditions one should be able to recognize.

Oxidation Reactions: Generically we can write an oxidation reaction with: $\xrightarrow{[O]}$ There are several common oxidizing agents (compounds that will oxidize organic molecules). These include:

1. Potassium Permanganate: $\xrightarrow[\Delta]{KMnO_4/H_2O}$
2. Chromic Acid: $\xrightarrow[\Delta]{K_2Cr_2O_7/H_2SO_4}$
3. Tollens reagent: $2Ag^+ \xrightarrow[H_2O]{NH_3}$
4. Fehling/Benedicts reagent: $2Cu^{2+} \xrightarrow[H_2O]{NaOH}$

Oxidation reactions generally result in the gain of a bond to Oxygen and the loss of a bond to Hydrogen. They are always paired with a reduction reaction, however, we generally ignore that part as we are interested in only the organic products.

Reduction Reactions: Generically we can write a reduction reaction with: $\xrightarrow{[\text{Red}]}$. Another common way to indicate reductions is with: $\xrightarrow[\Delta]{H_2/\text{Ni}}$

Reduction reactions generally result in the loss of a bond to Oxygen and the gain of a bond to Hydrogen. They are always paired with an oxidation reaction, however, we generally ignore that part as we are interested in only the organic products.

Other Reaction Conditions:

Certain functional groups tend to react the same way or are the site of many types of reactions. Several examples are:

- Alkanes C−C generally react by substitution. Alkenes C=C and Alkynes C≡C generally react by addition, with the reactant being added across the C=C or C≡C. Typical reactants added are: (HX, H_2, H_2O (H−OH), and HNO_3 (HO−NO_2)).
- Hydration: Water is a reactant and added to the molecule (addition reaction). Often shown as $\xrightarrow{[^{+}H_2O]}$.
- Dehydration: Water is a product and removed from the molecule (elimination reaction). Often shown as $\xrightarrow{[-H_2O]}$.
- Other groups typically involved in a series of reactions are alcohols (R-OH), carbonyl groups (C=O), and carboxylic acid groups (R−COOH).

Exceptions:

Just like anything in life, there are always exceptions to every rule. Organic chemistry is very complex, and we are taking only a very quick look at it. Several reactions we see are difficult to categorize and will be listed below.

IV Four Basic Steps

There are a number of different ways to learn and understand chemical reactions. Everyone learns differently and depending on your learning style, your ability to recognize and organize information, and depth of understanding. I find the simplest (yet requires the most memorization) method to be the following:

- Memorize the ”word” reactions.
- Translate the words to generic chemical structures.
- Understand the reaction mechanism
- Use the actual chemical structures.

Word Reactions:

I like to begin studying for reactions by writing them out in words organized by the functional groups (Table 19.1, p.489). This gives a basic framework to begin understanding what occurs in a reaction. For example:

Alkane + Halogen ⟶ Alkyl Halide + Acid (HX)

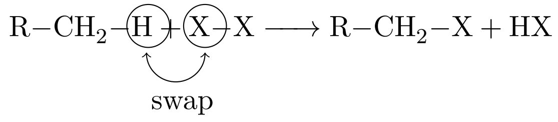
Generic Formula Reactions:

After remembering the basic word reactions it is important to understand what exact part of each molecule changes. To do this it is necessary to associate the given word reaction with a general or generic structure for each reactant and product. This is why Table 19.1 (p. 489) is so important, it allows us to write simple to remember reactions. Using our examples from above we can write:

$$\mathrm{R{-}CH_3 + X_2 \longrightarrow R{-}CH_2X + HX} \qquad \text{where X is any halogen (F, Cl, Br, I)}$$

Reaction Mechanisms:

Examining the reaction we can identify it as a substitution reaction, where we exchange or swap a hydrogen atom on the alkane with a halogen atom from the diatomic halogen atom. Note that we emphasize some bonds in the reaction by drawing them out instead of using the simpler shorthand notations. One could show the mechanism as follows:



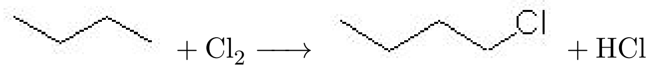
$$\mathrm{R{-}CH_2{-}\underbrace{H + X}_{\text{swap}}{-}X \longrightarrow R{-}CH_2{-}X + HX}$$

Specific Reactions:

The last step is the ability to apply the information in the first 3 steps to a specific molecule or chemical reaction. This is probably the hardest step. Completing our examples from above we show an example of the reaction for a butane molecule:

$$\mathrm{CH_3CH_2CH_2CH_3 + Cl_2 \longrightarrow CH_3CH_2CH_2CH_2{-}Cl + HCl}$$

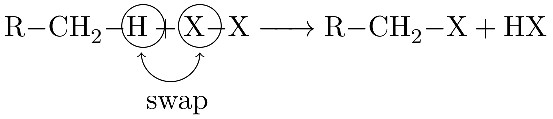
or using line drawings:



Combining the four previous steps above provides a good summary of the entire reaction which you must master.

Word Reaction: Alkane + $X_2 \longrightarrow$ Alkyl Halide + HX (X = halogen)
Generic Reaction: $R-CH_3 + X_2 \longrightarrow R-CH_2-X + HX$

Reaction Mechanism:



$R-CH_2-\textcircled{H}+\textcircled{X}-X \longrightarrow R-CH_2-X + HX$

Specific Reaction: $CH_3CH_2CH_2CH_3 + Cl_2 \longrightarrow CH_3CH_2CH_2CH_2-Cl + HCl$

Completing a reaction - Example 1

I use the following general steps when trying to complete a reaction.

1. Write the class of compound below each reactant and product.
2. Examine the reaction conditions and decide if it is an oxidation, reduction, hydrolysis, dehydration, or other class of reaction.
3. Once the class of reaction is determined complete the reaction using words, then draw missing reactant/product.

The following is an example using the three steps outlined above.

Initial Problem: $CH_3CH_3 + Cl_2 \longrightarrow$

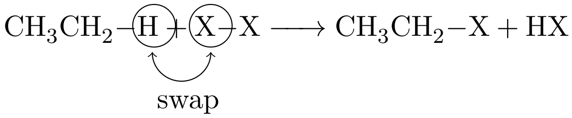
The first step is to identify the class of compound for each reactant.

Identify Reactants: $\underset{\text{Alkane}}{CH_3CH_3} + \underset{\text{Halogen}}{CH_3CH_3} \longrightarrow$

The next step is to identify the expected products. Using the information from the previous example above we see that the products are an Alkyl Halide + HX.

Add Products: $\underset{\text{Alkane}}{CH_3CH_3} + \underset{\text{Halogen}}{CH_3CH_3} \longrightarrow \underset{\text{Alkyl Halide}}{} + \underset{\text{Acid}}{}$

We should also recognize this reaction as a simple substitution reaction which means that we exchange or swap a hydrogen atom from the alkane with one of the halogen atoms. Again, we draw the molecules to emphasize the atoms where bonds are broken. We can show this using the original problem as follows:



$CH_3CH_2-\textcircled{H}+\textcircled{X}-X \longrightarrow CH_3CH_2-X + HX$

Finally we can write the completed reaction. The intermediate steps can be shown, or for simple reactions, one can simply write down the last step.

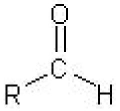
$CH_3CH_2-H + Cl-Cl \longrightarrow CH_3CH_2-Cl + H-Cl$

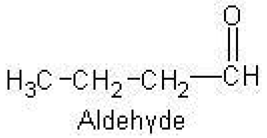
Completing a reaction - Example 2

Another example would be the oxidation of a primary alcohol. We should first identify the reactant as an alcohol. Specifically it is a primary alcohol. Examining the reaction conditions shows us that it is an oxidation reaction. We know (from memorizing) that primary alcohols are oxidized to aldehydes. Furthermore from the generic reactions (also memorized) that the only thing that is changed in the reaction is that the -OH group is changed to an aldehyde group (CH=O).

Initial Problem: $\underset{\text{Primary Alcohol}}{CH_3{-}CH_2{-}CH_2{-}CH_2{-}OH} \longrightarrow \xrightarrow{[O]}$

Word Problem: Primary Alcohol $\xrightarrow{[O]}$ Aldehyde

Generic Reaction: $R{-}CH_2{-}OH \xrightarrow{[O]}$ 

Final Solution: $\underset{\text{Primary Alcohol}}{CH_3{-}CH_2{-}CH_2{-}CH_2{-}OH} \longrightarrow \xrightarrow{[O]}$ 

V Molecular Weak Points

The ability to identify where a reaction takes place is one way to tell what type of reaction is likely to occur. In any molecule there are strong and weak bonds. Reactions generally occur at the weak bond. The alkane (CH) backbone is the least reactive part of an organic molecule, thus most reactions take place at or near the functional groups discussed in class.

- Alkanes and Aromatics: Reactions occur between C-H bonds and are normally substitutions.
- Alkenes C=C and Alkynes C≡C: Reactions typically occur at the double or triple bonds via addition.
- Alcohols reaction by breaking the R-OH bond generally by dehydrations.
- Aldehydes and Ketones possess a C=O and react via addition (similiar to alkenes and alkynes). A secondary weak point is between the C-H bond on the α carbon as shown in the Aldol reactions.
- Carboxylic acids generally react at the alcohol functional group.
- Esters generally break apart between alcohol functional group and the carbonyl carbon.

Alkanes (Ch 19):

Alkanes react via **substitution** much like Double Displacement (DD) reactions from first semester. When you think substitution think "SWAP". One half of the added molecule generally displaces a hydrogen atom (located anywhere on the alkane chain) and the resulting hydrogen radical (from the alkane) reacts immediately with the remaining half of the molecule. More than one product can be produced in substitution reactions, as a general rule in class only give the **monosubstituted** products. One product is generally more stable than the others depending on the stability of the free radical produced. The **order of stability** for free radicals is $3^\circ > 2^\circ > 1^\circ >$. A more detailed discussion of free radicals is given on p. 490. Another way to think of this is that the swapped atom always goes on the carbon with the least number of hydrogen.

- Alkane + HX $\longrightarrow$ Alkyl Halide + H_2
- Alkane + (H−OH) $\longrightarrow$ Alcohol + H_2
- Alkane + X_2 $\longrightarrow$ Alkyl Halide + HX (one X atom added)

Note:
Alkane + $H_2 \longrightarrow$ NR

Alkanes also react via **elimination** which involves the loss of a small molecule or Leaving Group (LG) from the main hydrocarbon. The LG + an adjacent hydrogen are eliminated from the molecule resulting in the formation of a carbon-carbon double bond.(C=C).The first reaction is often called a dehydrogenation since it involves the loss of hydrogen from the molecule. It is also possible to lose an acid molecule as shown in the second reaction, which is the reverse of the halogenation (third reaction shown above). Both reactions can result in multiple products, with the preferred product being given by **Saytzeff's rule**, which states that the more stable product is the more highly substituted alkene. Another way to phrase this is to take the hydrogen from the carbon with the least hydrogen. (Saytzeff's rule is mistakenly located in Ch. 22 on p.577 if you desire to read more about it)

- Alkane $\xrightarrow[\Delta]{500K}$ Alkene + $H_2(g)$
- Alkyl Halide $\xrightarrow[\Delta]{500K}$ Alkene + Acid
- Alcohol $\xrightarrow[\Delta]{500K}$ Alkene + H_2O

A last class of reactions for alkanes (and any organic molecule made up of only C,H,O) are combustion reactions. The easiest way to identify a combustion reaction is that oxygen (O_2) is a reactant. The general, unbalanced, reaction is given below, remember to balance it on exams.

- Any Organic Molecule (C,H,O) + $O_2(g) \longrightarrow CO_2(g) + H_2O(g)$ + heat (Balance the reaction)

Alkenes (Ch 20):

Alkenes react via **addition** across the double bond. Thus both halves of the molecule are added to the alkene. Remember to use **Markovnikov's rule - the hydrogen goes to the carbon atom that has the greater number of hydrogen atoms already** when deciding where to add the H part of unsymmetrical molecules.

- Alkene + HX $\longrightarrow$ Alkyl Halide

- Alkene + (H−OH) $\longrightarrow$ Alcohol

- Alkene + X_2 $\longrightarrow$ Alkyl Halide (both X atoms added)

- Alkene + $H_2(g)$ $\longrightarrow$ Alkane

Alkenes can also be **oxidized** to alcohols, most commonly by Potassium Permanganate ($KMnO_4$). This test is commonly called the Baeyer Test (as done in Experiment 21) and is used as a way to differentiate alkenes (react quickly) and alkanes (react slowly). The reaction mixture changes from purple to a green/brown color when reacting with alkenes and does not change color for alkanes.

- Alkene/Alkyne $\xrightarrow{[O]}$ Alcohol (actually a -diol since both sides of the C=C double bond get an OH group added)
- Baeyer Test: $\underset{\text{Colorless}}{\text{Alkene/Alkyne}} + \underset{\text{Purple}}{KMnO_4} \longrightarrow \text{Diol} + KOH + \underset{\text{Coloredppt}}{MnO_2(s)}$ (Color Change: Purple $\longrightarrow$ Colored ppt)

Aromatics (Ch 20):

Aromatics generally react more like alkanes then alkenes because of the stability of the benzene ring. Thus most reactions are **substitution** reactions (only one half of a molecule is added). Typical things to substitute include halogens (X_2), Acids (HX), water (H_2O) and nitric acid (HNO_3) as shown below.

- Benzene-H + $X_2 or HX or H_2O$ $\longrightarrow$ Benzene-X + HX
- Benzene-H + $HO-NO_2$ $\longrightarrow$ Benzene-NO_2 + H_2O

Two unique reactions though should be noted:

- Alkylation: Benzene-H + RX $\xrightarrow{[AlCl_3]}$ Benzene-R + HX

The reaction is commonly called a Friedel-Craft reaction and is most easily recognized by the use of $AlCl_3$ as a reactant. It is a simple **substitution** reaction and the only change in the molecule is H-R swap places.

The other unique reaction is side chain **oxidation**. It is easily recognizable by the use of Potassium Permanganate or Chromic Acid, and results in the substitution of a R group attached to the benzene ring being oxidized to a carboxylic acid group.

- Side Chain Oxidation: Benzene-R $\xrightarrow{[O]}$ Benzene-COOH + $R_{-1}COOH$

Alcohols (Ch 22):

Oxidation: Easily recognized by the reactants. Generally $\xrightarrow{[O]}$ though any of the common oxidizing agents can be used. The reaction results in the replacement of the -OH group by either an Aldehyde, Ketone, or Carboxylic Acid functional group.

- Primary Alcohol $\xrightarrow{[O]}$ Aldehyde + H_2O $\xrightarrow{[O]}$ Carboxylic Acid
- Secondary Alcohol $\xrightarrow{[O]}$ Ketone + H_2O $\xrightarrow{[O]}$ NR
- Tertiary Alcohol $\xrightarrow{[O]}$ NR

Dehydration: (loss of water): Generally $\xrightarrow[\Delta]{[H_2SO_4]}$, or $\xrightarrow{[-H_2O]}$. All of these reactions result in the loss of the -OH from an alcohol and -H from either another alcohol or an adjacent carbon. Remember to use **Saytzeff's rule** when appropriate.

- Primary Alcohol + Primary Alcohol $\xrightarrow{[-H_2O]}$ Ether + H_2O (Multiple products are possible if the alcohols are different)
- Secondary Alcohol $\xrightarrow{[-H_2O]}$ Alkene + H_2O **(Saytzeff's rule)**
- Tertiary Alcohol $\xrightarrow{[-H_2O]}$ Alkene + H_2O **(Saytzeff's rule)**

Esterfication: Is a special dehydration reaction that typically is an equilibrium between the two sides and is represented by:

- Primary Alcohol + Carboxylic Acid $\xrightleftharpoons{[H^+]}$ Ester + H_2O

Alkaline Hydrolysis: Alcohols can be produced by a substitution reaction of an Alkyl Halide with a strong base.

- Alkyl Halide + Strong Base $\longrightarrow$ Alcohol + Salt

Lucas Test An important reaction for determining if an alcohol is a primary (1°), secondary (2°), or tertiary alcohol (3°) is how quickly the alcohol reacts with $HCl/ZnCl_2$ to form a precipitate. The Lucas test can also be considered a substitution reaction.

- Tertiary Alcohol + HCl $\xrightarrow{[ZnCl_2]}$ Alkyl Chloride (s) + H_2O (Fast < 1 min)
- Secondary Alcohol + HCl $\xrightarrow{[ZnCl_2]}$ Alkyl Chloride (s) + H_2O (Slow 5-15 minutes)
- Primary Alcohol + HCl $\xrightarrow{[ZnCl_2]}$ Alkyl Chloride (s) + H_2O (No Reaction or > 30 minutes)

Chromic Acid Test Another important reaction for determining if an alcohol is a primary (1°), secondary (2°), or tertiary alcohol (3°) is how it reacts with chromic acid (a mixture of potassium dichromate and sulfuric acid) solution. The reaction is an oxidation reaction as discussed above with a very visible color change from orange to green/blue-green color within 5 seconds.

- Primary Alcohol $\xrightarrow[\Delta]{[K_2Cr_2O_7/H_2SO_4]}$ Aldehyde + H_2O (Visible Change: orange/red $\longrightarrow$ blue/green)
- Secondary Alcohol $\xrightarrow[\Delta]{[K_2Cr_2O_7/H_2SO_4]}$ Ketone + H_2O (Visible Change: orange/red $\longrightarrow$ blue/green)
- Tertiary Alcohol $\xrightarrow[\Delta]{[K_2Cr_2O_7/H_2SO_4]}$ NR

Aldehydes and Ketones (Ch 23):

Oxidation: You have already seen the typical oxidation reactions for aldehydes covered in the previous section on alcohols. Two special should be noted here though as they are standard tests used to differentiate between aldehydes and ketones. Both reactions are readily recognizable by the use of specific reaction conditions.

- Tollens Reaction: Aldehyde + $2Ag^+ + NH_3 \xrightarrow{[O]}$ Carboxylic Acid Salt + 2 Ag (s)
  (Visible Change: clear $\longrightarrow$ "Silver Mirror")
- Fehlings/Benidicts: Aldehyde + $2Cu^{2+} + NaOH \xrightarrow{[O]}$ Carboxylic Acid Salt + $Cu_2O(s)^+H_2O$
  (Visible Change: clear blue $\longrightarrow$ brick-red ppt)

Reduction: Reaction conditions are the reverse of the oxidation reactions discussed above. These reactions can also be classified as **addition** or hydrogenation reactions as we are adding $H_2(g)$ across the carobonyl group (C=O). They are most often recognized by the use of $\xrightarrow[\Delta]{H_2/Ni}$.

- Aldehyde $\xrightarrow[\Delta]{H_2/Ni}$ Primary Alcohol
- Ketone $\xrightarrow[\Delta]{H_2/Ni}$ Secondary Alcohol

Addition: These are a special series of reactions that can be broken up into 3 schemes. Pay careful attention to the reactants, as they will tell you which reaction it is. Note the first series use Aldehyde/Ketone + Alcohol, the second set Aldehyde/Ketone + HCN, and the third set Aldehyde/Ketone + Aldehyde/Ketone.

Cyanohydrins: This class of reaction is easily recognizable by the use of HCN as a reactant. These reactions can also be classified as **addition** reactions as we are adding HCN across the carobonyl group (C=O).

- Aldehyde/Ketone + HCN $\xrightarrow{[OH^-]}$ Cyanohydrin

Acetals/Ketals: These reactions are most easily recognized by the use of aldehyde/ketone + alcohol or a hemiacetal/ketal + alcohol in the second step along with the use of trace amounts of acid or dry HCL. This series of reactions differs from an Esterfication because a carboxylic acid is not involved. Recognize these reactions by the reactants.

The first step reaction is an addition reaction:

- Aldehyde + Alcohol $\xrightleftharpoons{[H^+]}$ Hemiacetal
- Ketone + Alcohol $\xrightleftharpoons{[H^+]}$ Hemiketal

The second step adds a second alcohol by a **dehydration** reaction (similar to the reaction whereby a primary alcohol reacts with a primary alcohol to give an ether):

- Hemiacetal + Alcohol $\xrightleftharpoons{[dryHCl]}$ Acetal + H_2O
- Hemiketal + Alcohol $\xrightleftharpoons{[dryHCl]}$ Ketal + H_2O

Aldol Condensations (Self-addition): The Aldol condensations are most easily recognized by the reactants being two aldehydes or two ketones or one of each. The resulting product is generically termed an Aldol, or more specifically a β-hydroxy aldehyde or ketone. The resulting products can also be quite complicated if two different aldehydes/ketones are used as it can lead to up to 4 different products, for instance A + B $\xrightarrow{[\text{dilute NaOH}]}$ AA + AB + BA + BB. Suffice it to say I will only give very easy examples of Aldol reactions where both reactants are the same leading to only one product.

- Aldehyde + Aldehyde $\xrightarrow{[\text{dilute NaOH}]}$ Aldol
- Aldehyde + Ketone $\xrightarrow{[\text{dilute NaOH}]}$ Aldol
- Ketone + Ketone $\xrightarrow{[\text{dilute NaOH}]}$ Aldol

Carboxylic Acids (Ch 24):

Oxidation: There are two routes for making carboxylic acids so these reactions are sometimes called **formation reactions**. You already learned the first route in Chapter 20 and 22, the oxidation of benzene rings to benzoic acid and alcohols to aldehydes to carboxylic acids.

- Oxidation: Primary Alcohol $\xrightarrow{[O]}$ Aldehyde + H_2O $\xrightarrow{[O]}$ Carboxylic Acid
- Side Chain Oxidation: Benzene-R $\xrightarrow[NaOH+\Delta]{NaMnO_4}$ Benzoic Acid + Carboxylic Acid

Hydrolysis: The other method for making carboxylic acids is the hydrolysis of nitriles, by addition of two water molecules across the C≡N triple bond. This can be done in either Acid or Basic conditions. Note that the example in the book shows the formation of an ammonium cation (NH_4^+ instead of the salt, in class we will assume a specific acid is used and show the formation of the ammonium salt, NH_4Cl.

- Acid Hydrolysis: Nitrile + 2 $H_2O + HCl \longrightarrow$ Carboxylic Acid + Ammonium Chloride (NH_4Cl)
- Base Hydrolysis (Two step reaction):
  - Step 1: Nitrile + $H_2O + NaOH \longrightarrow$ Carboxylic Acid Salt + Ammonia (NH_3)
  - Step 2: Carboxylic Acid Salt + Acid (HCl) $\longrightarrow$ Carboxylic Acid + Ionic Salt (NaCl)

Other Reactions: The other reactions for carboxylic acids are shown below. For the Dehydration reaction, there are multiple products possible if the two carboxylic acids are different.

- Substitution: Carboxylic Acid + Thionyl Chloride ($SOCl_2$) $\longrightarrow$ Acid Halide + HCl + $SO_2(g)$
- Dehydration: Carboxylic Acid + Carboxylic Acid $\xrightarrow{[-H_2O]}$ Acid Anhydride + H_2O (mult. products possible)
- Esterfication/Dehydration: Carboxylic Acid + Alcohol $\xrightarrow{[-H_2O]}$ Ester + H_2O

Esters (Ch 24):

Hydrolysis: Only two major reactions will be discussed for esters. The first reaction is already known and is the reverse of the Esterfication/Dehydration reaction discussed under alcohols and carboxylic acids and is thus a Hydrolysis reaction. The other reaction of importance is Saponification which is the reaction of an ester with a base which is essentially a hydrolysis reaction. Both reactions may also be classified as **substitution** reactions.

- Hydrolysis: Ester + H_2O $\xrightarrow{[H^+]}$ Carboxylic Acid + Alcohol.
- Saponification: Ester + Strong Base $\longrightarrow$ Carboxylic Acid Salt + Alcohol

Amines (Ch 25):

Formation: Amines are formed most often by the reaction of an Alkyl Halide (R-X) with either ammonia or any amine. The first three reactions are simple Substitution reactions swapping the R group from the Alkyl Halide with the H on the Amine group. The last step is an Addition reaction.

- Ammonia + Alkyl Halide (RX) $\longrightarrow$ 1^o Amine + HX	Substitution
- 1^o Amine + Alkyl Halide (RX) $\longrightarrow$ 2^o Amine + HX	Substitution
- 2^o Amine + Alkyl Halide (RX) $\longrightarrow$ 3^o Amine + HX	Substitution
- 3^o Amine + Alkyl Halide (RX) $\longrightarrow$ Quaternary Ammonium Salt	Addition

Reduction/Addition: Amides and Nitriles are both reduced to amines. The reducing agent is one way to recognize this type of reaction as there are two commonly used ones: $\xrightarrow{\text{LiAlH}_4}$ and $\xrightarrow{\text{NaBH}_3}$. Recall that reduction reactions decrease the number of bonds to oxygen (or in this case removing the oxygen entirely). A less important reaction is the reduction of nitriles which does not decrease any bonds to oxygen, but does increase the number of bonds to hydrogen. The reaction mechanism in either case is essentially the same with the Addition of H_2 across the carbonyl bond C=O.

- Amide $\xrightarrow[\Delta]{H_2/Ni}$ Amine + H_2O
- Nitrile $\xrightarrow[\Delta]{H_2/Ni}$ 1^o Amine

Base Characteristics: Amines behave much like ammonia (NH_3) in their reactions, and like ammonia, act as bases and produce OH^- ions in water. Amines can also react like bases to neutralize an acid by forming an Ammonium Salt. Note that unlike a what we consider a normal acid/base reaction, no water is produced.

- Base Formation: Amine + H_2O $\rightleftharpoons$ Ammonium ion (${RNH_3}^+$) + OH^-
- Acid Neutralization: Amine + Strong Acid (HX) $\longrightarrow$ Ammonium Salt (${RNH_3}^+X^-$)

Amide formation: Amines are a principle starting material in the formation of amides. The formation reaction is a substitution reaction. This reaction is important biologically because it takes two small molecules and makes a larger molecule. It is also important in making an amide bond which is used in protein synthesis. The reaction can be thought of in terms of one or two steps. Multiple products are possible (but Jay is nice and will only make it the same amine).

- One Step: 2 $1^o/2^o$ Amines + Acid Halide (Cl, F, Br, I) $\longrightarrow$ Amide + Ammonium Salt (${RNH_3}^+X^-$)
- Two Steps:
  - Step 1: Amine + Acid Halide $\longrightarrow$ Amide + HCl
  - Step 2: Amine + HCl $\longrightarrow$ Ammonium Salt

Amides (Ch 25):

Formation/Dehydration: The two formation reactions for making amides are both essentially dehydration reactions.

- Carboxylic Acid + Amine $\xrightarrow{[-H_2O]}$ Amide + H_2O

Hydrolysis: Amides, like esters undergo a number of hydrolysis reactions where water is added back to the molecule. These are essentially addition reactions. The reaction can either be carried out in basic $\xrightarrow{\text{Base}}$ or acidic $\xrightarrow[H_2O]{\text{Acid}}$ conditions. In acidic reactions, an amine salt is formed as an intermediate product which then reacts to give an amine. The net result is the addition of a water molecule across the C−N bond. In basic reactions, the base is simply added across the C−N bond. For both reactions, primary amides react to produce an ammonium salt or ammonia gas, while secondary and tertiary amides result in the formation of amines. Sometimes the acid/base is written over the reaction arrow, and sometimes it is listed as a reactant, be able to recognize it both ways.

- Acid: Amide + Acid (HX) + H_2O $\longrightarrow$ Carboxylic Acid + Ammonium Salt/Ammonium Ion
- Base: Amide + Base $\xrightarrow[\Delta]{}$ Carboxylic Acid Salt + Amine/Ammonia gas (NH_3)