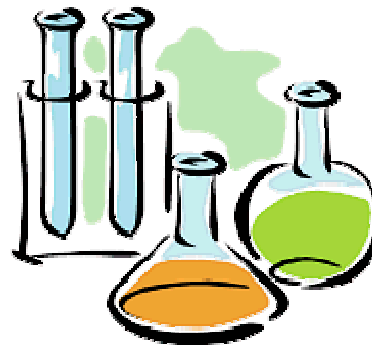


*Descriptive
Chemistry*



INTRODUCTION

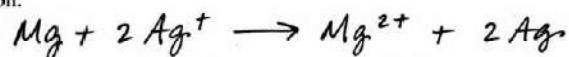
A major section of the Advanced Placement Chemistry exam is the reaction section of the Free-Response session – the notorious Question 4. Provided three descriptions of chemical reactions, Question 4 asks you to write chemical formulas for the given reactants and the products of the reaction. In addition, a follow-up question is asked that requires fundamental knowledge of chemical processes. The instructions are provided here (College Board, *Chemistry Course Description*):

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:



(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

The follow-up question surrounds applications of the reaction, the chemistry of the reaction or myriad other topics related to the chemical reaction. Points will be awarded for the correct formulas of the reactants, correct formulas for products, and correct answers to the follow-up question. **Note that you can earn points for any one part of the item without earning points (or even answering) other parts of the item.** For example, you might know that the products of a hydrocarbon combustion are water and carbon dioxide, but you may not know the formula for the reactant 2,4-dimethyl hexane.

The reaction limits for Question 4 are those commonly discussed in a first-year college course laboratory or in the context of the curriculum – as in oxidation reduction reactions, simple organic reactions, single- and double-replacement reactions, acid-base reactions (including hydrolysis), synthesis reactions and decomposition reactions. Notable inclusions are those reactions of copper with the oxidizing acid nitric acid, and the reactions that result in decomposing products like carbonic acid, sulfurous acid and ammonium hydroxide. You will not be expected to know more than cursory organic chemistry reactions, and you will not typically be required to know complex ion formation.

- Reactions must be written in net-ionic form
- Reactions must be balanced as to mass and charge
- Reactions do not have to be represented with phase symbols
- Reactions always occur – there are no ‘no reaction’ options

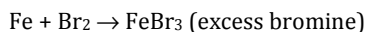
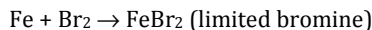
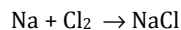
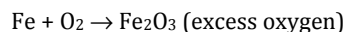
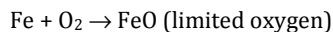
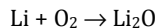
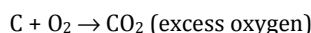
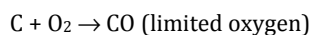
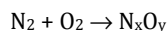
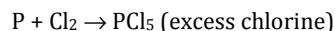
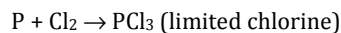
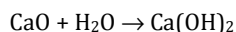
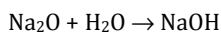
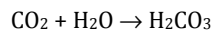
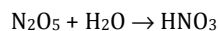
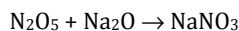
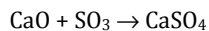
You will have a table of reduction potentials available to you on the exam.

For clarity, the reactions on the following pages are not balanced, and the phases of the species are not shown unless it is germane to the reaction. Moreover, the net ionic equations are not shown so as to present a more complete picture from which you can learn.

SYNTHESIS REACTIONS

Inorganic reactions classified as synthesis reactions are those that produce a single product from two or more reactants.

Reactions of
Elements
and
Reactions
of Oxides
[including water]

Metals and non-oxygen nonmetals form salts:**Metals and oxygen form metal oxides:****Nonmetals and oxygen form nonmetal oxides:****Nonmetals form molecular compounds:****Soluble metal oxides and water form hydroxides:****Nonmetal oxides and water form ternary acids:****Nonmetal oxides and metal oxides form salts:**

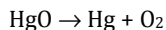
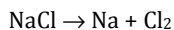
- Use the common oxidation numbers of 1+ for Group 1 metals and silver
- Use the common oxidation numbers of 2+ for Group 2 metals and zinc
- Use the common oxidation number of 3+ for aluminum
- Increase the oxidation number of a transition metal if the nonmetal is present in excess
- Increase the oxidation number of a less electronegative nonmetal (if possible) with halogens or oxygen if the halogen or oxygen is present in excess
- Other reactions with water are shown under the hydrolysis of salts section
- Note that reactions *of* water are not the same as reactions *in* water
- Most products formed here are soluble and should be written dissociated
- The oxidation states of the elements do not change in the formation of acids or salts

DECOMPOSITION REACTIONS

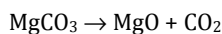
Decomposition reactions are suggested by the presence of a single reactant, which will decompose into elements or compounds.

**General
Decomposition
Reactions**

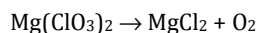
Binary compounds decompose into their elements:



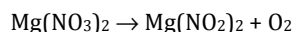
Carbonates decompose into metal oxides and carbon dioxide:



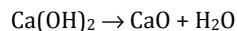
Chlorates decompose into metal chlorides and oxygen gas:



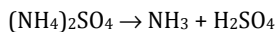
Alkali and alkaline nitrates decompose into nitrites and oxygen gas:



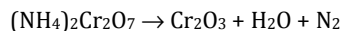
Metal hydroxides may decompose into metal oxides and water:



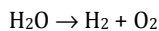
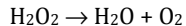
Some ammonium salts decompose to lose ammonia:



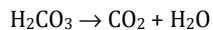
Ammonium salts containing nitrate, nitrite or dichromate decompose to produce a metal oxide, water and nitrogen gas – the metal undergoes reduction:



Water and hydrogen peroxide decompose as shown:



Ternary acids decompose into nonmetal oxides and water:



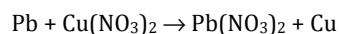
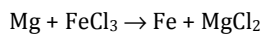
- Group 1 carbonates do not decompose into metal oxides and carbon dioxide
- All hydroxides here are solid – aqueous hydroxides (i.e., strong bases) – dissociate rather than decompose
- Ammonium salts may also follow various other schemes – these will be addressed individually
- Most decomposition reactions require heat or light
- Electrolysis can be used to decompose molten salts (i.e., melted), but electrolysis in aqueous solution follows other patterns of reactivity, which are discussed on Page 276.

SINGLE-REPLACEMENT REACTIONS

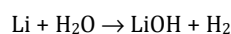
Single-replacement reactions are a form of redox reactions in which a more active metal replaces a less active metal or hydrogen or a more active nonmetal replaces a less active nonmetal.

**General Single-
Replacement
Reactions**

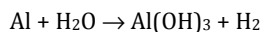
More-active metals replace less-active metals in aqueous solution:



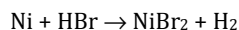
The active metals Li, K, Na and Ca replace hydrogen from cold water, steam and non-oxidizing acids and release hydrogen gas:



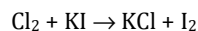
The active metals Mg, Al, Mn, Zn, Cr and Fe replace hydrogen from steam and non-oxidizing acids and release hydrogen gas:



The active metals Cd, Co, Ni, Sn and Pb replace hydrogen from non-oxidizing acids and release hydrogen gas:



Active nonmetals replace less-active nonmetals from their compounds in aqueous solution:



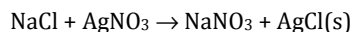
- At the Advanced Placement level, one should use reduction potentials to determine the occurrence of single-replacement reactions, but do not lose sight of periodic table location to determine activity
- For transition metals, select a common oxidation state when forming the new compound
- The common oxidizing acid is HNO_3 , which does not participate as shown

DOUBLE-REPLACEMENT (METATHESIS) REACTIONS

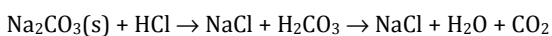
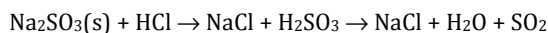
Metathesis reactions occur owing to the removal of ions from solution. Metathesis reactions are never redox reactions. (See outline on Page 274.)

**Precipitation and
Gas-forming
Reactions**

Two soluble salts' aqueous solutions may produce an insoluble compound (a precipitate):



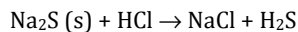
A solid sulfite or carbonate react with non-oxidizing acids to produce a decomposing compound that results in the formation of a molecular oxide, water and a salt:



Ammonium salts react with soluble hydroxides to form ammonia, water and a salt:



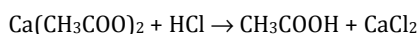
Sulfides react with non-oxidizing acids to form hydrogen sulfide gas and a salt:



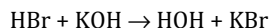
- It will be especially important to learn the common exceptions to solubility to correctly identify the precipitate. Look for silver, barium, lead cations, and look for phosphate, carbonate and hydroxide anions
- You must learn the three decomposing compounds – H_2SO_3 , H_2CO_3 and NH_4OH – and the direct formation of H_2S [See the note about these compounds under *Hydrolysis Reactions* on Page 273]

**Molecular
Compound-
formation
Reactions**

Salts that contain the conjugate of a weak acid will react with acids to form the weak acid:



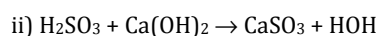
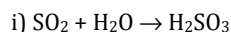
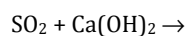
Acids and bases form a salt and water [see also below]:



- The common molecular compounds that form in these reactions are water and the weak acids
- Watch for quantities to be given in acid base reactions with polyprotic acids – react only the correct number of hydrogen ions

**Acid-Base
Neutralization
Reactions**

Anhydrides of acid and bases first react with water to form their respective acid or base, and then the acid or base reacts:

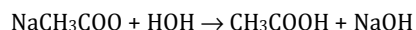


- Acid anhydrides are the nonmetal oxides that form acids upon reaction with water, and the basic anhydrides are the metal oxides that form bases upon reaction with water [See *Reactions of Oxides* on Page 269]

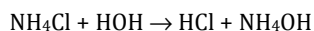
HYDROLYSIS REACTIONS

Hydrolysis

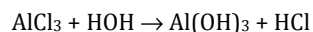
Conjugate bases of weak acids react with water to form the weak acid – they hydrolyze:



Ammonium ions will undergo hydrolysis to form ammonium hydroxide:

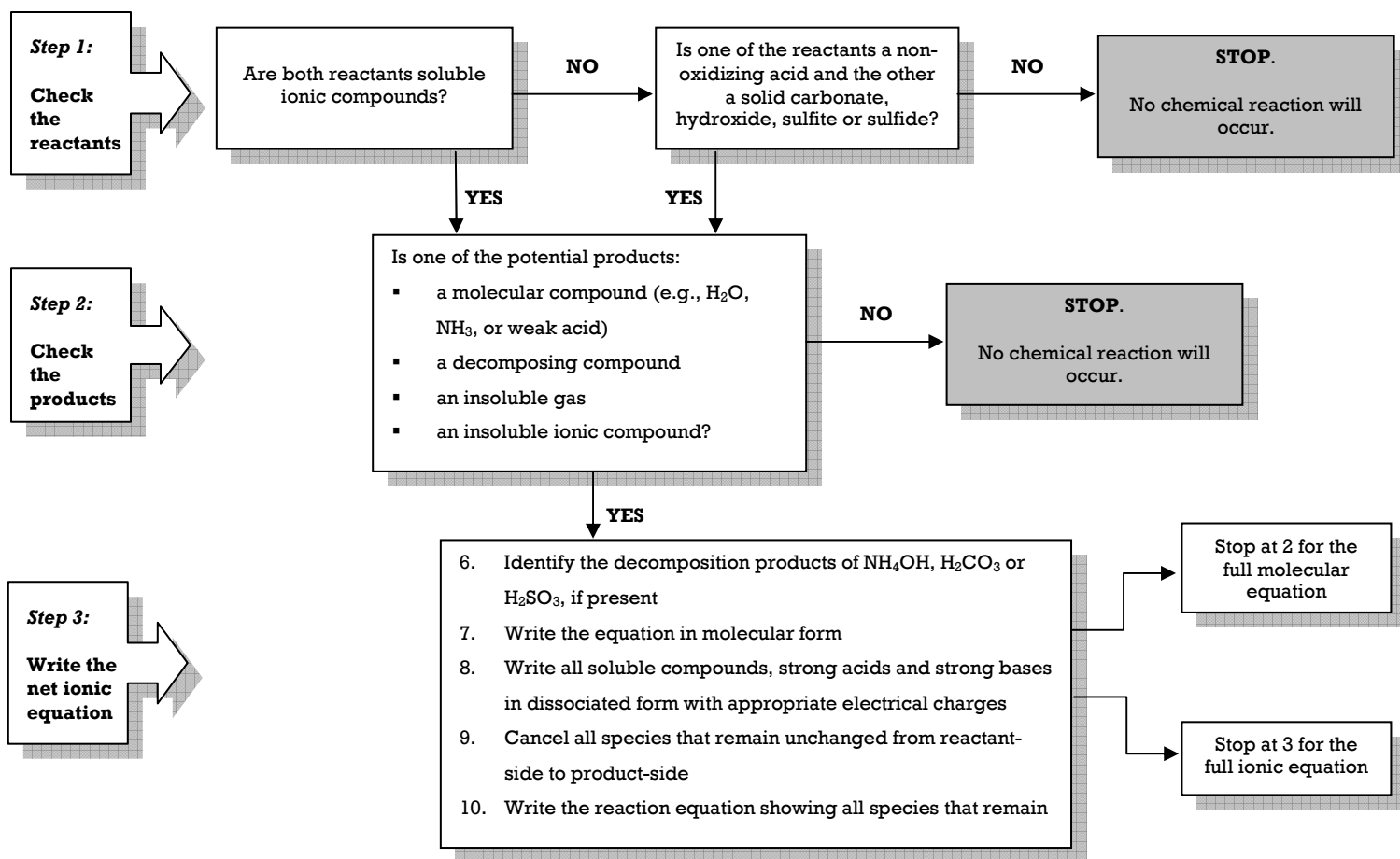


Many metal cations act as Lewis acids in water to form metal hydroxides and a strong acid:



- The decomposition reactions of H_2SO_3 , H_2CO_3 and NH_4OH we saw upon their formation in precipitation reactions does NOT occur during hydrolysis owing to their very low concentrations
- The metal ions of strong bases do not act as Lewis acids
- Do not hydrolyze the strong acids' conjugates

OUTLINE OF AQUEOUS METATHESIS REACTIONS



REDOX REACTIONS

Many of the above reactions are redox reactions, but there are also additional reactions that are arbitrarily classified here for convenience. A table of common reducing agents and oxidizing agents is given on Page 275.

| | | |
|----------------------------------|---|---|
| Oxyanion Reactions | <p>MnO₄⁻ undergoes reduction: $\text{MnO}_4^- \rightarrow \text{Mn}^{2+} \text{ [acid solution]}$ $\text{MnO}_4^- \rightarrow \text{MnO}_2 \text{ [base or neutral solution]}$</p> <p>Cr₂O₇²⁻ undergoes reduction in acid solution: $\text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Cr}^{3+}$</p> <p>IO₃⁻ undergoes reduction in acid solution: $\text{IO}_3^- \rightarrow \text{I}_2$</p> <p>C₂O₄²⁻ undergoes oxidation to carbon dioxide: $\text{C}_2\text{O}_4^{2-} \rightarrow \text{CO}_2 \text{ [[via CO}_3^{2-}\text{]]}$</p> | <ul style="list-style-type: none"> ▪ This is not an exhaustive representation – these are simply some of the more common oxyanions that you will encounter ▪ Remember – one species undergoes reduction and one species undergoes oxidation; look at the other species in the reaction (often a metal) and try to deduce the chemistry in terms of that species |
| Atypical Copper Reactions | <p>Copper with concentrated sulfuric acid: $\text{Cu} + \text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{SO}_2 + \text{H}_2\text{O}$</p> <p>Copper with nitric acid: $\text{Cu} + \text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + \text{NO} + \text{H}_2\text{O} \text{ [dilute acid]}$ $\text{Cu} + \text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + \text{NO}_2 + \text{H}_2\text{O} \text{ [conc acid]}$</p> | <ul style="list-style-type: none"> ▪ Note atypical reactions of copper: these are not ordinary single-replacement, as the products are not the salt and hydrogen gas as in those on Page 271. |
| Other Considerations | <p>See the table on Page 276 for more information on the reduction or oxidation of individual species</p> | <ul style="list-style-type: none"> ▪ Practicing these and understanding the concept of electron transfer will cause this list to become engrained in your brain! |

COMMON OXIDIZING AND REDUCING AGENTS

- **Common oxidizing agents – these species will cause a loss of electrons in another species, and they will themselves gain electrons. Oxidizing agents undergo reduction.**

| | | |
|---|---|--|
| MnO_4^- in acid solution | → | Mn^{2+} |
| MnO_2 in acid solution | → | Mn^{2+} |
| MnO_4^- in neutral or base solution | → | $\text{MnO}_2(\text{s})$ |
| $\text{Cr}_2\text{O}_7^{2-}$ in acidic solution | → | Cr^{3+} |
| HNO_3 (conc) | → | NO_2 |
| HNO_3 (dilute) | → | NO |
| H_2SO_4 (hot, conc) | → | SO_2 |
| metallic ions | → | metallous ions (lower oxidation state) |
| free halogens | → | halide ions |
| Na_2O_2 | → | NaOH |
| HClO_4 | → | Cl^- |
| H_2O_2 | → | H_2O |
| $\text{S}_2\text{O}_8^{2-}$ | → | SO_4^{2-} |
| CrO_4^{2-} | → | Cr^{3+} |

- **Common reducing agents – these species will cause a gain of electrons in another species, and they will themselves lose electrons. Additional reducing agents will be added. Reducing agents undergo oxidation.**

| | | |
|--------------------------------------|---|--|
| halide ions | → | free halogens |
| free metals | → | metal ions |
| sulfite ions or SO_2 | → | sulfate ions |
| nitrite ions | → | nitrate ions |
| free halogens, dilute basic solution | → | hypohalite ions |
| free halogens, conc basic solution | → | halate ions |
| metallous ions | → | metallic ions (higher oxidation state) |
| $\text{C}_2\text{O}_4^{2-}$ | → | CO_2 |
| MnO_2 in base solution | → | MnO_4^- |

We will add species to this list throughout the course.

ELECTROLYSIS

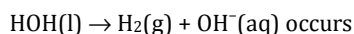
Electrolysis involves the passage of an electrical current into a molten salt (which is a simple decomposition), or the passage of electrical current into an aqueous solution of a salt (which is *not* simple decomposition).

Electrolysis Reactions**Cathode reactions (reduction):**

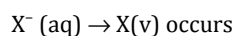
- For metals that are easily reduced (i.e., less-active metals):



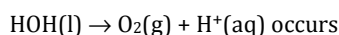
- For metals that are not easily reduced (i.e., more-active metals)

**Anode reactions (oxidation):**

- For nonmetals that are easily oxidized (i.e., less-active nonmetals)



- For nonmetals that are not easily oxidized (i.e., more-active nonmetals)



- These are among the most difficult reactions to address
- The result of an electrolysis of an aqueous salt solution is either the reduction of water at the cathode or the oxidation of water at the anode – or – the reduction of a metal at the cathode or the oxidation of a nonmetal at the anode: the occurrence is based upon the battle for reduction at the cathode between the metal ion and water and the battle at the anode for the oxidation of the anion or water
- The symbol (v) indicates variable phase for the oxidized nonmetal

NAMING COMMON COMPLEXES

Complex ions are named using the general format here. If no cation or anion is present (that is, only the complex ion is named, then drop 'cation +' or '+ anion,' as appropriate, below)

cation + prefix for number of ligands + name of the ligand + name of the metal in complex ion (-ate ending)(Roman numeral)

or

prefix for number of ligands + name of the ligand + name of the metal in complex ion(Roman numeral) + anion

Examples –

$[Cu(OH)_4]^{2-}$ is *dihydroxocuprate(II)*

$Na_2[Fe(CN)_4]$ is *sodium tetracyanoferrate (II)*

$[Zn(NH_3)_4](NO_3)_2$ is *tetramminezinc nitrate*

Latin names for complex anions:

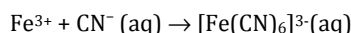
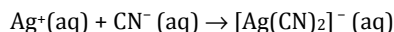
copper (cuprate), gold (aurate), silver (argentate), tin (stannate), iron (ferrate), lead (plumbate) – others use element name with -ate suffix

COORDINATION CHEMISTRY

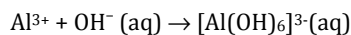
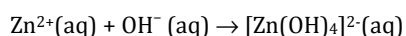
Complex ions – although more rare on the exam than other reactions – can be readily determined using a few simple rules. They are important in the qualitative analysis of ion solutions (i.e., determining the presence of ions), so we shall review them as part of descriptive chemistry.

Complex Ion
Formation and
Dissolution

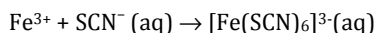
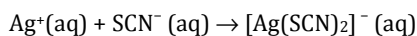
Lewis acids react with excess cyanide ion to form cyano complexes:



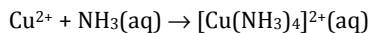
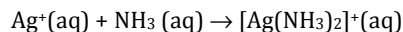
Lewis acids react with excess hydroxide ion to form hydroxo complexes:



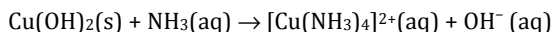
Lewis acids react with excess thiocyanate ion to form thiocyanato complexes:



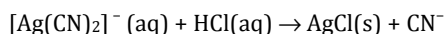
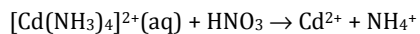
Lewis acids react with excess ammonia ion to form ammine complexes:



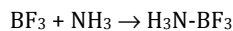
Solid metal hydroxides of Lewis acids react with ammonia to produce ammine complexes and hydroxide ion:



Addition of dilute acid to a complex typically releases the ligand as its ion and releases the metal as its ion or a precipitate if the acid contains an anion with which the metal ion is insoluble:



Lewis acids and Lewis bases react to form a coordinate covalent compound:



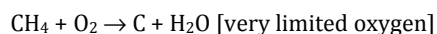
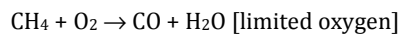
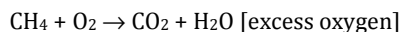
- The common metals ions that form complex ions or coordination complexes are the Lewis acids iron ion, cobalt ion, nickel ion, chromium ion, copper ion, zinc ion, silver ion and aluminum ion
- The most common ligands are ammonia, NH_3 , (*ammine* complexes), cyanide ion, CN^{-} , (*cyano* complexes), hydroxide ion, OH^{-} , (*hydroxo* complexes), thiocyanate ion, SCN^{-} , (*thiocyanato* complexes)
- The number of ligands is best predicted as two times the charge on the metal ion (called the coordination number)
- Treatment of a complex ion with acid often results in its dissolution of the complex
- The reactions shown at left are those that should cover about 90% of the complexes presented on the AP Exam. However, additional complexes may form with:
 - halo- ligands F^{-} , Br^{-} , Cl^{-} , I^{-}
 - carbonato ligand CO_3^{2-}
 - hydrido ligand H^{-}
 - nitrate/nitrite ligands NO_3^{-} , NO_2^{-}
 - oxalato ligand $[\text{ox}] \text{C}_2\text{O}_4^{2-}$
 - oxo ligand O^{2-}
 - sulfato SO_4^{2-}
 - thiosulfato $\text{S}_2\text{O}_3^{2-}$
 - ethylenediamine $(\text{CH}_2)_2(\text{NH}_2)_2$
 - methylamine CH_3NH_2
 - dimethylamine $(\text{CH}_3)_2\text{NH}_2$
 - aquo H_2O

ORGANIC REACTIONS

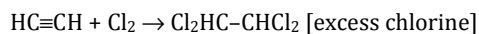
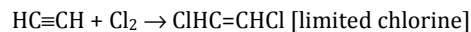
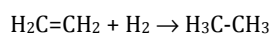
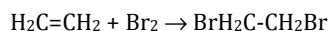
Simple organic reactions are common on the AP Chemistry exam.

**General Organic
Reactions**

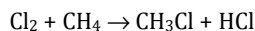
Combustion produces carbon dioxide and water, carbon monoxide and water, or carbon and water:



Halogenation or hydrogenation occurs in alkenes and alkynes:

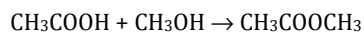


Substitution reactions result in no change in bonding, only replacement of an atom to which carbon is bonded; an inorganic acid forms:



[excess halogen results in di-, tri- or tetra-substitution]

Esterification results when an organic acid and an alcohol react – the acid loses its –OH group and the alcohol loses the alcohol group's hydrogen; water forms:



- Practice will be essential for the organic reactions
- Note the use of limited or excess reactants – the presence of a catalyst is almost always required
- Additional notes will be made as needed for organic reactions

ORGANIC NAMING

There are essentially nine organic classes with which you should be familiar. Organic compounds are those compounds of carbon (except the carbonates and carbon dioxide, which are inorganic compounds).

- The basic hydrocarbons: alkanes, alkenes and alkynes
 - Contain only carbon and hydrogen
 - React with oxygen to produce typical combustion products
 - Are identified by their *-ane* (saturated hydrocarbons – all single bonds), *-ene* (double bonds between carbons), or *-yne* (triple bonds between carbons) endings

- The alcohols
 - Contain the *-OH* function
 - React with oxygen to produce typical combustion products
 - Are identified by their *-ol* ending
 - React with carboxylic acids to form esters

- The ethers
 - Contain the *-O-* function
 - Are identified by their *-oxy* component

- The carboxylic acids
 - Contain the *-COOH* function
 - Are identified by their *-oic* ending
 - React with alcohols to form esters

- The esters
 - Contain carbon, hydrogen and the *-CO-O* function
 - Are identified by their *-oate* ending
 - Form when alcohols and carboxylic acids react in a condensation reaction

- The aldehydes and ketones
 - Contain the *-CO* function in a middle (ketone) or end (aldehyde) position
 - Are identified by their *-one* or *-al* ending

- The amines and amides
 - Amines: R – NH₂ (ammonia derivatives)
 - Amides: R – CO – NH₂ (carboxylic-amine derivatives)
 - Are identified by their *amine* or *amide* ending

- Common groups appended to stems: –CH₃ (methyl), –CH₂CH₃ (ethyl), –CH₂CH₂CH₃ (propyl), –CH₂CH₂CH₂CH₃ (butyl)
- Halogens are often added before the stem as chloro-, bromo-, fluoro- and iodo-.

Naming organic compounds begins with naming the basic alkanes, alkenes and alkynes. Please use the notes sections to add additional considerations as we progress. We will consider naming of alkanes, alkenes, alkynes, alcohols, carboxylic acids, esters, aldehydes and ketones. We will reserve the naming of ethers, amines and amides for later.

- Naming Alkanes

- ✓ Identify the longest chain of carbon atoms
- ✓ Name the alkane:

$n = 1 \rightarrow$ methane

$n = 6 \rightarrow$ hexane

$n = 2 \rightarrow$ ethane

$n = 7 \rightarrow$ heptane

$n = 3 \rightarrow$ propane

$n = 8 \rightarrow$ octane

$n = 4 \rightarrow$ butane

$n = 9 \rightarrow$ nonane

$n = 5 \rightarrow$ pentane

$n = 10 \rightarrow$ decane

- ✓ If there are substituents (appended organic groups of carbon and hydrogen), then:
 - name the longest chain and give it the name of the basic alkane
 - name the substituents using the group names on the bottom of Page 279
 - indicate the position of the substituents by numbering the carbons to give the substituents the lowest possible numbers
 - indicate the presence of more than one substituent of the same kind using a Greek prefix and separating the positions with commas
 - where more than one substituent type is present, name the substituents as above and place them in alphabetical order; use hyphens to separate the "pieces"

- Naming Alkenes (double bond present)

- ✓ Identify the longest chain of carbon atoms that contains a double bond, and name this using the alkane stem; give the double bond(s) the lowest numbers, and change the ending to *-ene*
- ✓ If there are substituents, name these as in alkanes while still giving the alkene position(s) the lowest number(s)

- Naming Alkynes (triple bond present)

- ✓ Identify the longest chain of carbon atoms and name this using the alkane stem; give the triple bond(s) the lowest numbers, and change the ending to *-yne*
- ✓ If there are substituents, name these as in alkanes while still giving the alkyne position(s) the lowest number(s)

- Naming Alcohols

- ✓ Identify the longest chain of carbon atoms containing the function, and give the carbon with the alcohol function the lowest number, and then change the stem of the corresponding alkane by dropping the *-e* and adding *-ol*
- ✓ If there are substituents, name these as before while always giving the alcohol position(s) the lowest numbers

- Naming Carboxylic Acids

- ✓ Drop the *-e* from the name of the corresponding alkane and append the name with *-oic acid*

- Naming Esters

- ✓ Name the alcohol part of the compound with an *-yl* ending, and then name the acid part of the compound including the $-\text{COO}$ carbon with an *-oate* ending.

- Naming Aldehydes and Ketones

- ✓ Name the longest string of carbon atoms that contains the function, and append *-one* or *-al* to the name.