Experiment 1
Chemical Reactions and Net Ionic Equations

I. Objective:

To predict the products of some displacement reactions and write net ionic equations.

II. Chemical Principles:

A. Reaction Types.

Chemical reactions can be classified into several different categories. The common classifications are as follows:

Note: For ease of production in this syllabus (aq) has been eliminated from all equations while (s), (l) and (g) have been used to represent phases. ***When you write chemical reactions in your lab reports you must show all phases including (aq).***

1. Combination. This reaction type involves the combining of elements and/or compounds to form a new compound.

element + element $\rightarrow$ compound
$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$

element + compound $\rightarrow$ compound
$O_2(g) + 2\ NO(g) \rightarrow 2\ NO_2(g)$

compound + compound $\rightarrow$ compound
$NH_3(g) + HBr(g) \rightarrow NH_4Br(s)$

2. Decomposition. This reaction type involves the splitting apart of a single compound to form new compounds or elements.

compound $\rightarrow$ new compound and/or elements
$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

3. Single Replacement. This reaction type involves an element displacing another element or ion in a compound, or a chemical compound displacing an element or ion from another compound.

$\text{element}_a + \text{compound}_a \rightarrow \text{element}_b + \text{compound}_b$
$Zn(s) + 2\ HCl \rightarrow H_2(g) + ZnCl_2(s)$

$Cl_2(g) \quad + \quad 2\ NaI \quad \rightarrow \quad I_2 \quad + \quad 2\ NaCl$

4. <u>Double Displacement (Metathesis).</u> This reaction type involves the exchange of elements or ions in two compounds.

$$\text{compound}_a + \text{compound}_b \rightarrow \text{compound}_c + \text{compound}_d$$

a. precipitation:

$AgNO_3 + NaBr \rightarrow AgBr(s) + NaNO_3$

b. dissolution

$CuO(s) + 2\ HCl \rightarrow H_2O(l) + CuCl_2$

c. neutralization

$HNO_3 + NH_3 \rightarrow NH_4NO_3$

5. <u>Acid-Base Reactions.</u> These reactions are commonly displacement reactions. To be able to predict such a reaction, you must know the identity and properties of a few specific acids and bases.

<u>Acids</u>

1. <u>*Strong Acids.*</u> All strong acids completely dissociate in water, for example: $HClO_4$, HCl, HBr, HI, HNO_3, H_2SO_4

a. nitric acid: $HNO_3 + H_2O(l) \rightarrow H_3O^+ + NO_3^-$

b. sulfuric acid: $H_2SO_4 + H_2O(l) \rightarrow H_3O^+ + HSO_4^-$

$HSO_4^- + H_2O(l) \ \square\ H_3O^+ + SO_4^{2-}$

The first ionization step for sulfuric acid is 100%, however the second step is an equilibrium situation and ionization is only partial.

Note: Molecules of strong acids such as $HClO_4$ and H_2SO_4 do not exist in solution because we treat them as ionizing 100 %, that is as strong electrolytes. $H^+(aq)$ can be written in place of H_3O^+, the hydronium ion.

2. *Weak Acids.* These acids react only slightly with water to produce the hydronium ion. They, however, will react completely with a strong base.

Acid	Reaction	Extent of Reaction
acetic acid	$HC_2H_3O_2 + H_2O(l) \rightleftharpoons H_3O^+ + C_2H_3O_2^-$	0.42%
carbonic acid	$H_2CO_3 + H_2O(l) \rightleftharpoons H_3O^+ + HCO_3^-$ $HCO_3^- + H_2O(l) \rightleftharpoons H_3O^+ + CO_3^{2-}$	0.065%
ammonium ion	$NH_4^+ + H_2O(l) \rightleftharpoons H_3O^+ + NH_3$	0.0024%

Bases

1. *Strong bases:* dissociate completely in water.
   a. Soluble metal hydroxides. $MOH \rightarrow M^+ + OH^-$
   b. Insoluble metal hydroxides. All insoluble metal hydroxide dissolve to a very limited extent to form metal ions and hydroxide ions. Because the dissolved form of the insoluble metal hydroxide dissociates completely it is considered a strong electrolyte and thus it is a strong base. The OH^- ion is the strongest base that exists in water. For example, calcium hydroxide is said to be insoluble, but the reality is that some calcium and hydroxide ions exist in solution and therefore the solution is basic. $Ca(OH)_2(s) \rightleftharpoons Ca^{2+} + 2\,OH^-$
   Moderately soluble bases are strong bases because what does dissolve, dissociates 100%.
2. *Weak bases:* These substances react slightly with water to produce OH^- and are weak electrolytes.

Base	Reaction	Extent of reaction*
ammonia	$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$	1.3%
acetate ion	$C_2H_3O_2^- + H_2O \rightleftharpoons HC_2H_3O_2 + OH^-$	0.42%
carbonate ion	$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$	0.0024%
fluoride ion	$F^- + H_2O \rightleftharpoons HF + OH^-$	0.00039%

* 1.0 M solution

Salts:

Salts contain a metal ion and a nonmetal or polyatomic anion. Salts can be formed by a neutralization reaction: a reaction between an acid and a base producing a salt and water. For example:

$NaOH + HF \rightarrow NaF + H_2O(l)$
$Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4(s) + 2H_2O(l)$

Some salts, such as sodium fluoride, are very soluble in water, therefore a change is not observed upon reaction. However, some salts such as barium sulfate are quite insoluble in water and a precipitate will be observed when formed as a product in a reaction.

B. Predicting Products of Displacement Reactions and Writing Net Ionic Equations.

To predict if a displacement reaction will occur, you must become familiar with the conditions required before a reaction takes place. Rules have been developed to assist you with predicting the products of displacement reactions and for writing the net ionic equations associated with these reactions.

You first determine if a displacement reaction can occur when you have two salts or an acid and base or a salt and acid/base reacting. Assume that a single or double displacement is responsible for causing a reaction. Carry out the single or double displacement reaction and focus on the predicted products. A product of a reaction having one of the characteristics in Table I supports the occurrence of a displacement reaction.

Table I. Observations of a Chemical Reaction

1.A A solid (precipitate) forms. This requires that you know the solubility rules.
2.A A new weak electrolyte or a compound with a new covalent bond forms. For example; formation of water, acetic acid, or carbon dioxide.
3.A A new gas forms. For example; the formation of gaseous water, carbon dioxide, hydrogen sulfide, hydrogen, or ammonia.
4.A A new element forms. Zn, Pb, H_2, O_2 etc.
5.A A precipitate dissolves. A colored, or clear, solution may result.

Unless a precipitate forms, a gas evolves, or a colored ion forms, it may be difficult to determine with your senses if a displacement reaction has taken place. Examples of physical evidence that sometime accompany a displacement reaction and which may indicate their occurrences are:

- change in acidity or basicity of the product compared to the reactants.
- evolution or absorption of heat, other than heat of solution.
- solid reactant disappears.

- change in the color of the solution.
- precipitate forms in a solution.

To apply these rules (1A -5A) you need to know which substances are strong and weak electrolytes and which substances are soluble and insoluble and what is the limit of solubility of a compound in aqueous solution. Some rules are given in the following Tables.

Table II. Strong and Weak Electrolytes

1.B *Strong electrolytes* include all ionic substances except the halides and cyanides of Hg_2^{2+}, Cd^{2+}, Zn^{2+}, and Ag^+. Strong acids, strong bases and many salts are strong electrolytes.*
2.B *Weak electrolytes* include weak acids, weak bases and many organic compounds. Only a few ions will be produced in aqueous solution.
3.B *Nonelectrolytes* include pure water and many organic compounds, including sugar, for example. These are normally molecular compounds.

* Many salts are insoluble in water, however, what limited quantity that does dissolve in water, dissociates 100%. Salts, soluble or insoluble (except for those identified in 1B) will be treated as strong electrolytes. The terms strong electrolyte and solubility are not equivalent.

Table III. Solubility Rules for Salts.

1.C All alkali metal and ammonium compounds are soluble. $KClO_4$ is slightly soluble.
2.C All nitrates are soluble.
3.C All acetate salts are soluble. $AgC_2H_3O_2$ is slightly soluble.
4.C All sulfate salts are soluble except $BaSO_4$, $PbSO_4$, and Hg_2SO_4. Slightly soluble salts include $CaSO_4$, and $SrSO_4$.
5.C All salts of chloride, bromide, and iodide are soluble except those of Ag^+, Pb^{2+}, and Hg_2^{2+}.
6. C All hydroxides, phosphates, carbonates, chromates, oxalates and sulfides are insoluble except those of the alkali metals and ammonium ion. $Ba(OH)_2$, $Ca(OH)_2$, and $Sr(OH)_2$ are moderately soluble.
7.C All oxides are quite insoluble.
Note: If a compound is slightly soluble, usually it can be considered insoluble.
It is necessary to know the <u>*solubility limit*</u> of a particular compound.

Solubility is defined as the maximum amount of substance that dissolves in a given amount of solvent at a given temperature . The solubility limit of many compounds can be found in the <u>Handbook. of Chemistry and Physics.</u>

C. Rules for Writing Net Ionic Equations

1. Write the overall balanced "molecular" equation.

2. Rewrite the molecular equation so that only soluble, strong electrolytes are separated into their ions.

3. Eliminate all species common to the reactants and products (spectator ions).

4. The resultant equation is the net ionic equation.

5. There is no net ionic equation if there is no reaction.

D. Application of Net Ionic Equation Rules.

Example 1: (Production of a **solid**)
Predict the outcome of the following reaction and write the net ionic equation,

$MgCl_2 + \quad K_2CO_3 \quad \rightarrow \quad ?$

a. Complete the equation by carrying out a double replacement reaction (exchange partners)

$MgCl_2 \quad + \quad K_2CO_3 \quad \rightarrow \quad 2\,KCl \quad + \quad MgCO_3$

b. Use rules 1.A - 6.A, 1.B - 3.B, and 1.C - 7.C to determine if a reaction occurred. According to 6.C, $MgCO_3$ is insoluble and will precipitate. According to 1.A, a reaction occurs.

c. Write the molecular equation and then apply rules given above to separate strong electrolytes into their ion forms and identify magnesium carbonate as an insoluble substance.

$MgCl_2 \quad + \quad K_2CO_3 \quad \rightarrow \quad 2\,KCl \quad + \quad MgCO_3(s)$

$Mg^{2+} + 2Cl^{-} + 2K^{+} + CO_3^{2-} \rightarrow 2K^{+} + 2Cl^{-} + MgCO_3(s)$

d. Eliminate ions common to reactants and products and the result is the net ionic equation:

$Mg^{2+} \quad + \quad CO_3^{2-} \quad \rightarrow \quad MgCO_3(s)$

Example 2: (Production of a **Gas)**
Predict the outcome of the reaction of hydrochloric acid with $MgCO_3(s)$.

a. Complete the double displacement reaction.

$$MgCO_3(s) + 2HCl \rightarrow MgCl_2 + H_2CO_3 \xrightarrow{Heat} MgCl_2 + H_2O(l) + CO_2(g)$$

Note: H_2CO_3 is a weak acid that in the presence of heat decomposes to $H_2O(l)$ and $CO_2(g)$, We normally show carbonic acid in the decomposed form.

b. Use the rules to determine if a reaction has occurred. A reaction occurs because carbonic acid forms and it is a weak acid and weak electrolyte.

c. Separate the soluble and strong electrolytes into ions.

$$MgCO_3(s) + 2H^+ + 2Cl^- \rightarrow Mg^{2+} + 2Cl^- + H_2O(l) + CO_2(g)$$

d. Eliminate the common ions and the result is the net ionic equation.

$$MgCO_3(s) + 2H^+ \rightarrow Mg^{2+} + H_2O(l) + CO_2(g)$$

Example 3: (No observed reaction)
Predict the result of the following reaction and write the net ionic equation.

$$NaCl + Cu(NO_3)_2 \rightarrow ?$$

a. Complete the equation by carrying out a double displacement reaction.

$$2\,NaCl + Cu(NO_3)_2 \rightarrow CuCl_2 + 2\,NaNO_3$$

b. Use the rules to determine if a reaction has occurred.
Both $CuCl_2$ (5.C) and $NaNO_3$ (2.C) are soluble and strong electrolytes. Thus no reaction can occur as the requirements of Rules 1.A - 5.A are not met.

c. $2Na^+ + 2Cl^- + Cu^{2+} + 2NO_3^- \rightarrow Cu^{2+} + 2Cl^- + 2Na^+ + 2NO_3^-$

d. All the ions cancel and thus there is no net ionic equation.

Example 4: (Acid - base reaction)
Predict the outcome of the following reaction and write the net ionic equation.

$$HC_2H_3O_2 + NaOH \rightarrow$$

a. Complete the balanced equation by carrying out a double displacement reaction.

$$HC_2H_3O_2 + NaOH \rightarrow H_2O(l) + NaC_2H_3O_2$$

b. Has a reaction occurred?
Water is a new covalent substance (2.A), so a reaction has occurred.

c. Separate all strong electrolytes into ions.

$HC_2H_3O_2(aq) + Na^+ + OH^- \rightarrow H_2O(l) + Na^+ + C_2H_3O_2^-$

Note: $HC_2H_3O_2$ is a weak electrolyte and therefore it written as a molecule.

d. Eliminate the spectator ion and the result is the net ionic equation.

$HC_2H_3O_2 + OH^- \rightarrow H_2O(l) + C_2H_3O_2^-$

Example 5 (Acid-base reaction):
Predict the outcome of the following reaction and write the net ionic equation.

$HCl + NH_3 \rightarrow$

a. Complete the equation by carrying out a single displacement reaction.

$HCl + NH_3 \rightarrow NH_4Cl$

b. This is a strong acid reacting with a weak base. A weaker acid (a new covalent substance), H_2O, is produced therefore a reaction occurs.

c. $H^+ + Cl^- + NH_3 \rightarrow NH_4^+ + Cl^-$

d. Eliminating chloride ion, the spectator ion, gives the net ionic equation.

$H^+ + NH_3 \rightarrow NH_4^+$

B. Procedues: Solubilities and Primary Species of Substances in Water and Acid.

Experimental Procedures for Table II:

Slowly add, with a spatula, a very *tiny* amount (big enough to see how it will behave in water, but not so much to exceed the capacity of your solvent) of each compound to about 1 mL (approximately 20 drops) of water in a test tube. Note any change in the solubility. Do not add too much compound to the water as the volume is small and only a small amount of compound is required. Add extra water if needed.

Waste Disposal for Table II:

Your laboratory instructor has already shown you where the waste disposal bottles are in the back fume hood. The following compounds need to be placed in the correct waste bottle for safety reasons as well to reduce fees incurred by cross contamination.
The following compounds need to be disposed of in the Metal Salts container:

- $BaSO_4$, $Ca(NO_3)_2$, $Ca_3(PO_4)_2$, $(NH_4)_2SO_4$, $PbCO_3$, $AgC_2H_3O_2$, Hg_2Cl_2,
- Cu_2O, $NaHSO_4$, KI, BaCl.

Use the Organic Waste container for the following compounds:

- $C_6H_{12}O_6$
- benzoic acid, C_6H_5COOH

Table II Solubility of Compounds in Water

	Solid compound	Name of compound	Strong, Weak, Nonelectrolyte	Primary species in H_2O	Predicted Solubility in H_2O	Solubility in 100mL H_2O (Handbook)	Predicted Solubility in HNO_3	Laboratory Observations
1a	$BaSO_4$	Barium sulphate	Strong	$BaSO_4$	insoluble	0.2 mg		
1b	$BaSO_4$							
2a	$Ca_3(PO_4)_2$							
2b	$Ca_3(PO_4)_2$							
3	$(NH_4)_2SO_4$							
4a	$PbCO_3$							
4b	$PbCO_3$							
5a	$AgC_2H_3O_2$							
5b	$AgC_2H_3O_2$							
6	Hg_2Cl_2	Mercury(I) chloride	Strong	$Hg_2Cl_2(s)$	Insoluble	0.2 mg		
7a	Cu_2O							
7b	Cu_2O							
8	Glucose $C_6H_{12}O_6$							
9	$NaHSO_4$							
10	KI							
11	benzoic acid, C_6H_5COOH							
12	BaCl	Barium chloride	Strong	Ba^{2+} and Cl^{-} ions	soluble	37.5 g		

Note: Shaded boxes indicate that no data will be collected. Don't fill in the shaded boxes. You will test the solubility of compounds 1b, 2b, 4b, 5b, and 7b in HNO_3 only. You will have the solubility of those same compounds in water just above the "b" series.
Write Net Ionic Equations for the "b" series compounds with HNO_3 below or on a clearly labeled separate sheet of paper.

Table III: Electrolytes

Compound	Primary Species in H_2O	Acid, Base, Salt, Organic	Strong, Weak, Nonelectrolyte	Observation in the laboratory
HNO_3				
$HC_2H_3O_2$	$HC_2H_3O_2$	Weak acid	Weak electrolyte	
NH_3				
NaOH				
$Ca(OH)_2$				
$PbCO_3$				
K_2CO_3	$2K^+$, CO_3^{2-}	salt and weak base (CO_3^{2-})	strong electrolyte	
$PbCl_2$				
$NiCl_2$				
$MgCl_2$				
$Zn(NO_3)_2$				
$Cu(NO_3)_2$				
C_2H_5OH (ethanol)				
$C_6H_{12}O_6$ (sugar)				

Experimental Procedures: Place each compound in the first column in a well of a spot plate. If a compound is a solid and not a liquid, add a small amount of water to it and stir. Use a conductivity device to determine if the substance is conducting or not. Record the relative brightness of the light or absence of light. A bright light only indicates more ions are in solution compared to a dim light, not whether it is a strong or weak electrolyte. The concentration of ions must be known to make a more definitive conclusion. The absence of a light indicates that ions are not present. Only the ends of the two copper probes of the device should be in the solution. Your instructor will demonstrate the use of the conductivity device.

Table IV. Net Ionic Reactions

	Reactants (A)	Net Ionic Equations (B)	Predicted Observation (C)	Experimental Observations (D)
1a	$Ba(NO_3)_2$ + K_2SO_4			
1b	$BaSO_{4(s)}$+ HCl(12M)			
2a	$NiCl_2$ + Na_2CO_3			
2b	$NiCO_{3(s)}$+HCl (12M)			
3a	$CoCl_2$ + KOH (6M)			
3b	$Co(OH)_{2(s)}$ +HCl(12M)			
4a	Na_3PO_4 + $ZnSO_4$			
4b	$Zn_3(PO_4)_{2(s)}$+HCl(12M)			
5	KCl + $Cu(NO_3)_2$			
6a	Na_2S + $Cu(NO_3)_2$			
6b	$CuS_{(s)}$ + HCl (12M)			
7	Na_2CO_3(sat'd) + HCl (12 M)			
8	$(NH_4)_2SO_4$(sat'd) + NaOH (6M)			
9	$Cu(NO_3)_2$ + NH_3 (12M)			
10a	$AgNO_3$ + NaCl			
10b	$AgCl_{(s)}$ + NH_3 (12M)			
11	$CaCl_2$ + NH_3(aq)			
12	$CaCl_2$ + NaOH			
13	$Ca(OH)_2$(aq)(sat'd) + NH_4Cl			
14	NH_4Cl + NaOH			

Experimental Procedure: Add approximately 2 drops of each pair of reactants in the first column to a test tube or the well of a spot plate. Use 0.1 M solutions for all reactants except when noted differently. Record your observations in column D. Be sure to note the formation of a precipitate, any color change, color of precipitate, evolution of a gas, etc. **For a "b" reaction**, remove the excess solution from the product of the "a" reaction by gently drawing the solution off the top with a Pasteur pipet. Add 6 drops of the indicated reagent to the precipitate that is left in the well plate to determine if it dissolves in the reagent. Record your observations in column D.

Waste Disposal:

Place all waste in the Metal Salts container.

D. Prelaboratory Assignment: You will not be allowed to perform the experiment if the prelaboratory assignment is not completed when you come to lab.

Day 1: (continues on next page)

- If you do not have the lab manual, print out entire experiment.
- Read pages 14-23.
- Using WORD, construct and Print out tables (Prelab Table I-Table III). For future experiments, you will be required to construct tables in your notebook.
- **Prelab Table I**: Using the solubility rules on page 18 or your text book, fill in the predicted results for each pair of ions. Write the formula of the compound that would result for each pair and indicate an I for insoluble, or S for soluble. Two examples have been done for you. You should print this table (and all other tables) on separate pages and make them larger at your convenience.

Table I : Prediction of Solubility of Salts in water.

	Cl^-	Br^-	I^-	SO_4^{2-}	PO_4^{3-}	OH^-	CO_3^{2-}	$C_2H_3O_2^-$	S^{2-}	CrO_4^{2-}
Na^+	$NaCl$ S									
K^+										
NH_4^+										
Ca^{2+}										
Mg^{2+}										
Ba^{2+}										
Cr^{3+}										
Fe^{2+}										
Co^{2+}										
Ni^{2+}							$NiCO_3$ I			
Cu^{2+}										
Ag^+										
Pb^{2+}										

Day 1 Continued:

- **Table II**: Once prepared in WORD, fill in all columns (typed) EXCEPT the one labeled Laboratory Observations. Laboratory Observations column will be done in lab. Write net ionic equations for the "b" series compounds from that table.
- In the column labeled "**primary species in water**" you are to type the primary form of each substance when it is present in water. If it is insoluble or a weak electrolyte, you are to type it in a "molecular" form with its phase. If it is soluble and a strong electrolyte, you type it in the ion form. In the column labeled "**solubility in 100 mL of water"**, look up the solubility of each compound in 100 mL of water in the <u>Handbook of Chemistry and Physics</u> or find it in a reliable source from the internet. A copy of <u>Handbook of Chemistry and Physics</u> is in Sequoia 502. Organic compounds may not have solubility data. Two examples are shown.

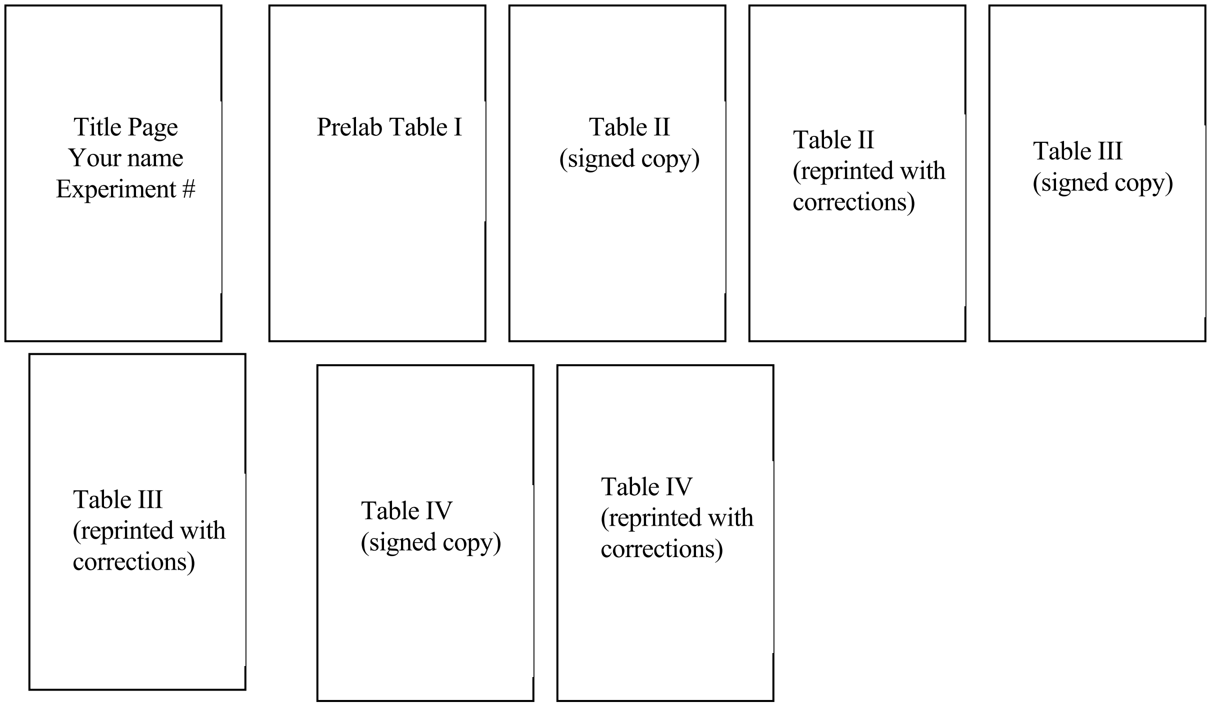
- **Table III**: Print out Table III. Fill in all columns (typed) EXCEPT the one labeled Laboratory Observations. Just like for Table II, you will fill in that column during lab.

Day 2 Prelab:

- Print out **Table IV** as shown on page 24. Print in "landscape mode. Type in all columns EXCEPT column D. You will record your observations in column D during lab.
- Column C: Type in whether you think a soluble or insoluble product will form.

E. Laboratory Report:

1. Printed Title page
2. Laboratory data pages containing your instructor's signature. These are the same tables that you printed out for your prelab assignment. If your instructor has indicated errors on these pages, correct those on a separate sheet of paper and attached it after the table.
3. Table IV: Since you have already typed this table, print out a new copy of it containing your typed corrections where needed.
4. Once your report has been assembled, write the page number in the upper right corner for each page. An example layout is shown below.


Title Page
Your name
Experiment #
Prelab Table I
Table II
(signed copy)
Table II
(reprinted with
corrections)
Table III
(signed copy)
Table III
(reprinted with
corrections)
Table IV
(signed copy)
Table IV
(reprinted with
corrections)