OBJECTIVES:

1. Predict precipitation reactions based on solubility rules.
2. Write the following forms of a balanced chemical equation for precipitation reactions.
   a. Molecular equation
   b. Ionic equation
   c. Net ionic equation

BACKGROUND:

A **Chemical Equation** is used to describe a chemical reaction. The reactants are shown on the left side of the equation. The products are shown on the right. The reactant side is separated from the product side by the reaction arrow, which indicates the direction of the reaction.

Reactants → Products

A **Balanced Chemical Equation** has the same number of each participating atom shown on both sides of the reaction. **Coefficients** are used to balance the number of atoms on each side of a chemical equation. They are written to the left of the chemical formula and serve to multiply the number of each atom in the formula. Equations cannot be balanced by changing the chemical formula. Coefficients need to be reduced to the lowest whole numbers that balance the equation.

State symbols are written in parenthesis to the right of each formula and used to indicate the physical state of each reactant and product in the equation as follows.

Table 1 – Physical State Symbols

symbol	Meaning
s	solid
l	liquid
g	gas
aq	aqueous (dissolved in water)

EXAMPLE:

$H_2(g) + O_2(g) \rightarrow H_2O(l)$

As written, the oxygen atoms are not balanced. We cannot balance oxygen by changing H_2O to H_2O_2! Instead, we use coefficients as follows.

$\mathbf{2}H_2(g) + O_2(g) \rightarrow \mathbf{2}H_2O(l)$

A chemical equation can be expressed in 3 forms, as follows:

1. A **molecular equation** represents each reactant and product as a molecule, using molecular formulas.

$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow 2KNO_3(aq) + PbI_2(s)$

2. An **ionic equation** represents any aqueous participants as dissociated ions. It represents any solids, liquids or gases as molecules.

$Pb^{2+}(aq) + 2NO_3^{-1}(aq) + 2K^+(aq) + 2I^-(aq) \rightarrow$

$2K^+(aq) + 2NO_3^-(aq) + PbI_2(s)$

3. A **net ionic equation** is similar to an ionic equation, except that it eliminates any **spectator ions**; ions that show up unchanged on both sides of the equation.

$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$

Solubility rules are used to predict weather a given combination of ions will be soluble or insoluble in water. Solubility rules are summarized in Tables 2A and 2B. Since solubility also depends on the concentration of each ion and the temperature of the solution, the rules by themselves are somewhat imprecise. Nevertheless, the rules work well most of the time.

A **precipitation reaction** occurs when ions from soluble reactants interact to form an insoluble product. Many precipitation reactions occur when the cations of two soluble reactants switch partners, and one of the new combinations turns out to be insoluble.

EXAMPLE:

AB(aq) + **C**D(aq) → **C**B(aq) + **A**D(s)

In this example, A and C switch partners, to produce AD, which is insoluble and "precipitates" out of solution as a solid.

Table 2A Ions that form soluble compounds

Ions that form soluble compounds	**Exception when combined with:**
Group I ions Li^+, Na^+, K^+, etc.	
Ammonium NH_4^+	
Nitrate NO_3^-	
Acetate CH_3COO^-	
Bicarbonate HCO_3^-	
Chlorate ClO_3^-	
Halides Cl^-, Br^-, I^-	Ag^+, Pb^{2+}, Hg_2^{2+}
Sulfate SO_4^{2-}	Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}

Table 2B Ions that form insoluble compounds

Ions that form insoluble compounds	Exception when combined with:
Carbonate CO_3^{2-}	Li^+, Na^+, K^+, etc. NH_4^+
Chromate CrO_4^{2-}	Li^+, Na^+, K^+, etc. Ca^{2+}, Mg^{2+} NH_4^+
Phosphate PO_4^{3-}	Li^+, Na^+, K^+, etc. NH_4^+
Sulfide S^{2-}	Li^+, Na^+, K^+, etc. NH_4^+
Hydroxide OH^-	Li^+, Na^+, K^+, etc. Ca^{2+}, Ba^{2+}, Sr^{2+} NH_4^+

PROCEDURE

1. Set up a 6x6 test tube rack with 21 small (13x100mm) disposable test tubes and label the tubes as shown in Table 3.

Table 3 – Solution Combinations

1,2	1,3	1,4	1,5	1,6	1,7
	2,3	2,4	2,5	2,6	2,7
		3,4	3,5	3,6	3,7
			4,5	4,6	4,7
				5,6	5,7
					6,7

2. Dispense 1mL of each solution in Table 4 into its respective test tubes.

Table 4 – Solutions

1	$BaCl_2$	Barium chloride	0.1M
2	$CuSO_4$	Copper sulfate	0.1M
3	$CaCl_2$	Calcium chloride	0.1M
4	Na_2CO_3	Sodium carbonate	0.1M
5	$NaOH$	Sodium hydroxide	0.5M
6	Na_2S	Sodium sulfide	0.1M
7	NH_4OH	Ammonium hydroxide	1M

3. For each of the 21 combinations of solutions:
   A. Hold the test tube near the top and ***gently*** flick the bottom of the test tube with your finger tip to mix the solutions
   B. Record your visual observations in Table 5
   C. For any combination that ***should*** give a precipitate (based on solubility rules), write the following forms of the balanced chemical equation for the reaction in Table 5:
      i. molecular equation
      ii. ionic equation
      iii. net ionic equation
   D. For any combination that should NOT give a precipitate (based on solubility rules), write NR.

Table 5 – Summary of reactions.

Mixture	Observations or "None"	Chemical Equations or "No Reaction"
example	The starting solutions were both clear and colorless. On mixing, a bright yellow precipitate was formed.	$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow 2KNO_3(aq) + PbI_2(s)$ $Pb^{2+}(aq) + 2NO_3^{-1}(aq) + 2K^{+}(aq) + 2I^{-}(aq) \rightarrow 2K^{+}(aq) + 2NO_3^{-}(aq) + PbI_2(s)$ $Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$
1+2		
1+3		
1+4		
1+5		

1+6		
1+7		
2+3		
2+4		
2+5		
2+6		

2+7		
3+4		
3+5		
3+6		
3+7		
4+5		

4+6		
4+7		
5+6		
5+7		
6+7		