EXPERIMENT 10: Precipitation Reactions

Metathesis Reactions in Aqueous Solutions (Double Displacement Reactions)

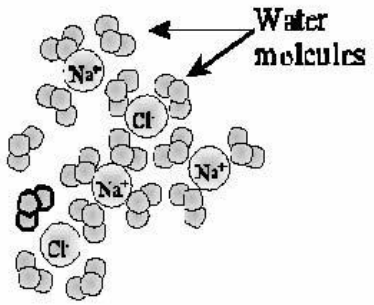
Purpose –

a) Identify the ions present in various aqueous solutions.
b) Systematically combine solutions and identify the reactions that form precipitates and gases.
c) Write a balanced molecular equation , complete ionic equation, and net ionic equation for metathesis reaction.

Apparatus and Chemicals

Aqueous salt solutions (1.0 M) Spot plates (or small test tubes) Stirring rod

Introduction- When one substance dissolves in another substance, a **solution** is formed. A **solution** is a homogeneous mixture in which the components are uniformly mixed. A solution consists of **solute** (the species that is dissolved) and **solvent** (the medium in which the solute has dissolved). The solvent is usually present in larger amount than the solute. When water is the solvent, the solution is called **aqueous solution**.
When an ionic compound dissolves in water, it dissociates into its constituent ions. Such a compound is a strong electrolyte and conducts electricity well in dilute aqueous solutions. For example, when NaCl dissolves in water, it dissociates into separate Na^+ and Cl^- ions.



This process occurs as polar water molecules orient themselves around the sodium and chloride ions and pull them free from the solid crystal. Once removed from the solid crystal, the ions remain separated and surrounded by water molecules. Therefore, the solution now consists of mostly water, and sodium and chloride ions. For all practical purposes, there are no undissociated NaCl units floating around.

Precipitation Reactions: A chemical reaction that involves the formation of an insoluble product (precipitate; solid) is called Precipitation reaction. The reactants are soluble, but the product formed would be insoluble and separates out as a solid.
The chemical equation by which a chemical change is described is adequate for reaction in solutions, but for reactions of ionic compounds in aqueous solution (water), the typical molecular equation has different representations. A molecular equation may indicate formulas of reactants and products that are not present, and eliminate completely the formulas of the ions that are the real reactants and products. If the substance in the molecular equation that are actually present as dissociated ions are written in the form of their ions, the result is an **ionic equation.** The ions which appear on both sides of an ionic equation are present in a chemical reaction and experience no chemical change themselves.

They are called **spectator ions,** or simply **spectators.** Canceling the spectator ions from both sides of an ionic equation remains the **net ionic equation** that includes only the substances and ions that actually remains in the reaction as water, gas, insoluble solid (precipitate), weak electrolyte, and no electrolyte.

Guidelines for Writing Net Ionic Equations

Step I.
Write the molecular equation, including designations of state solutions, for solid (s), for liquid (l), and for dissolved compounds or ions (aq). **Be sure the equation is balanced.**

Step II.
Write the complete ionic equation. Separate soluble substances into ions. Leave insoluble substances alone. **Be sure the equation is still balanced, both in atoms and charges.**

Step III.
Write the net ionic equation by eliminating the spectator ions if necessary, reduced the coefficients to their lowest values (whole number). **Be sure the equation is still balanced, both in atoms and charges.**

The solubility of reactions and products may be determined by referring to a solubility table. The solubility of several compounds is listed by referring to a solubility table. The solubility of several compounds is listed in the following "solubility rules":

Solubility Rules:

One of the factors driving a double-replacement reaction is the formation of a precipitate. A precipitate is an insoluble solid compound formed during a chemical reaction in solution. To predict whether a precipitate will form when you mix together two ionic reactants, you need to know whether any of the possible products are insoluble. Considering the number of ionic compounds, it would be very difficult to memorize the solubilities of so many compounds. Fortunately we can group compounds into solubility categories. This is done with a set of eight rules called **solubility rules**.

Solubility Rules

	Rule Statement	Exceptions
1	**All Group IA and ammonium compounds are soluble.**	--
2	**All Acetates and nitrates are soluble.**	--
3	**Most chlorides, bromides, and iodides are soluble.**	**AgCl, Hg_2Cl_2, $PbCl_2$, AgBr, $HgBr_2$, Hg_2Br_2, $PbBr_2$, AgI, HgI_2,Hg_2I_2, PbI_2**
4	**Most sulfates are soluble.**	**$CaSO_4$, $SrSO_4$, $BaSO_4$, Ag_2SO_4, Hg_2SO_4, $PbSO_4$**
5	**Most carbonates are insoluble.**	**Group IA carbonates, $(NH_4)_2CO_3$**
6	**Most phosphates are insoluble.**	**Group IA phosphates, $(NH_4)_2PO_4$**
7	**Most sulfides are insoluble.**	**Group IA sulfides, $(NH_4)_2S$**
8	**Most hydroxides are insoluble.**	**Group IA hydroxides, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$**

Example (1) - Let us consider the possible reaction of aqueous solution of NaCl with aqueous solution of $AgNO_3$. We would place a few drops of the NaCl solution in the reaction container followed by a few drops of $AgNO_3$ solution and observe an immediate cloudiness (white precipitate) that indicates a solid precipitate has formed. A precipitation chemical reaction has occurred.

In order to determine the possible identity of the solid product that forms, we first identify the ions present in each of the two aqueous solutions we started with: Na^+, Cl^- (from NaCl) and Ag^+, NO_3^- (from $AgNO_3$).

Next we examine the ions for possible new combinations that may lead to a reasonable product formula.
The combination of ions (NaCl, $AgNO_3$) that existed in solution prior to the experiment had been soluble and therefore should remain as such without separating out as solid after the reaction. This allows us to eliminate combinations like NaCl and AgNO3 from the list of possibilities.

This leaves us with only two other possibilities, AgCl and $NaNO_3$. From the knowledge of **Solubility Rules** we can determine which of these two products is insoluble. Solubility Rule indicates that nitrate salts are soluble. Therefore, $NaNO_3$ cannot be the precipitate in this reaction. Also solubility Rule states that most chloride salts are soluble. AgCl is listed as an exception to this rule. In this case, *it is* AgCl which is the precipitate.

Once the chemical identity of the solid product is determined, we can then determine the **balanced formula equation**, the **complete ionic equation** as well as the **net ionic equation**, describing the chemistry that has occurred.

a) The **balanced formula equation** for the reaction of aqueous $AgNO_3$ with NaCl is written as:

$$\mathbf{AgNO_3}\textit{(aq)} + \mathbf{NaCl}\textit{(aq)} \rightarrow \mathbf{AgCl}\textit{(s)} + \mathbf{NaNO_3}\textit{(aq)}$$

Note that in the above equation, the physical state of the AgCl product is denoted by the letter s, to indicate that it is the precipitate. The number of atoms of each element is same before and after the reaction, indicating that the equation is balanced.

b) The **complete ionic equation**, indicates which reactants and products exist as ions and which ones do not:

$$\mathbf{Ag^+}\textit{(aq)} + \mathbf{NO_3^-}\textit{(aq)} + \mathbf{Na^+}\textit{(aq)} + \mathbf{Cl^-}\textit{(aq)} \rightarrow \mathbf{AgCl}\textit{(s)} + \mathbf{Na^+}\textit{(aq)} + \mathbf{NO_3^-}\textit{(aq)}$$

The ions that actually undergo change in the chemical reaction and participate in the formation of the insoluble product are called ***participating ions***. In the above reaction, Ag^+ and Cl^- are the participating ions. Those that do not undergo change are called ***spectator ions***. In the above reaction, Na^+ and NO_3^- are the spectator ions.

c) The **net ionic equation** displays only the participating ions on the reactant side, and the precipitate on the product side. The physical states of the reactants and products are also indicated. The spectator ions are not included.

$$\mathbf{Ag^+}\textit{(aq)} + \mathbf{Cl^-}\textit{(aq)} \rightarrow \mathbf{AgCl}\textit{(s)}$$

Example (2) - Considering the reaction between solutions of barium chloride and sulfuric acid. When the two clear solutions are mixed, the observation is that a white insoluble barium sulfate precipitates.

Molecular equation:

$$BaCl_2\,(aq) + H_2SO_4\,(aq) \rightarrow BaSO_4(s) + 2\,HCl\,(aq)$$

Ionic Equation:

Three of these compounds in the equation are soluble in water and dissociate into ions when dissolved in water. Replacing the compound formulas of dissolved substances in the molecular equation with the ions really present gives the ionic equation;

$$Ba^{2+}\,(aq) + 2Cl^-\,(aq) + 2\,H^+\,(aq) + SO_4^{2-}\,(aq) \rightarrow BaSO_4(s) + 2H^+\,(aq) + 2Cl^-\,(aq)$$

Net- Ionic Equation:

Eliminate the **spectator ions (two hydrogen ions and two chloride ions)** from the ionic equation gives the net ionic equation;

$$Ba^{2+}\,(aq) + SO_4^{2-}\,(aq) \rightarrow BaSO_4(s)$$

The net ionic equation isolates the two reactants that actually change chemical and the single new substance produced. There are three steps in writing net ionic equation in the procedure:

In this experiment, you will be combining different aqueous solutions of ionic compounds in very small amounts (4-5 drops) and then observing them for signs of a **any reaction**. In cases where a reaction occurs, an insoluble solid product (***precipitate***) or gas will be formed. ***In precipitation or gaseous reactions, a color change alone does not indicate a reaction has occurred. A solid or gas must be formed.***

Common Ions

Cations (Positively Charged)

Name	Formula	Charge
aluminum	Al^{3+}	+3
ammonium	NH_4^+	+1
barium	Ba^{2+}	+2
cadmium	Cd^{2+}	+2
calcium	Ca^{2+}	+2
cesium	Cs^+	+1
chromium (II)	Cr^{2+}	+2
chromium (III)	Cr^{3+}	+3
cobalt (II)	Co^{2+}	+2
cobalt (III)	Co^{3+}	+3
cobalt (IV)	Co^{4+}	+4
copper (I)	Cu^+	+1
copper (II)	Cu^{2+}	+2
gold (I)	Au^+	+1
gold (III)	Au^{3+}	+3
hydrogen *{See note}*	H^+	+1
hydronium	H_3O^+	+1

Name	Formula	Charge
iron (II)	Fe^{2+}	+2
iron (III)	Fe^{3+}	+3
lead (II)	Pb^{2+}	+2
lead (IV)	Pb^{4+}	+4
lithium	Li^+	+1
magnesium	Mg^{2+}	+2
manganese (II)	Mn^{2+}	+2
manganese (III)	Mn^{3+}	+3
manganese (VII)	Mn^{7+}	+7
mercury (I) *{See note}*	Hg_2^{2+}	+2
mercury (II)	Hg^{2+}	+2
nickel (II)	Ni^{2+}	+2
nickel (IV)	Ni^{4+}	+4
potassium	K^+	+1
rubidium	Rb^+	+1

Name	Formula	Charge
scandium (III)	Sc^{3+}	+3
silver	Ag^+	+1
sodium	Na^+	+1
tin (II)	Sn^{2+}	+2
tin (IV)	Sn^{4+}	+4
titanium (II)	Ti^{2+}	+2
titanium (III)	Ti^{3+}	+3
titanium (IV)	Ti^{4+}	+4
vanadium (II)	V^{2+}	+2
vanadium (III)	V^{3+}	+3
vanadium (IV)	V^{4+}	+4
zinc	Zn^{2+}	+2

Anions (Negatively Charged)

Name	Formula	Charge
acetate	CH_3COO^-	-1
bicarbonate (hydrogen carbonate)	HCO_3^-	-1
bisulfate (hydrogen sulfate)	HSO_4^-	-1
bromate	BrO_3^-	-1
bromide	Br^-	-1
carbonate	CO_3^{2-}	-2
chlorate	ClO_3^-	-1

Name	Formula	Charge
chloride	Cl^-	-1
chromate	CrO_4^{2-}	-2
cyanate	OCN^-	-1
cyanide	CN^-	-1
dichromate	$Cr_2O_7^{2-}$	-2
dihydrogen phosphate	$H_2PO_4^-$	-1
fluoride	F^-	-1
hydroxide	OH^-	-1
iodate	IO_3^-	-1
iodide	I^-	-1

Name	Formula	Charge
nitrate	NO_3^-	-1
nitride	N^{3-}	-3
oxalate	$C_2O_4^{2-}$	-2
oxide	O^{2-}	-2
permanganate	MnO_4^-	-1
phosphate	PO_4^{3-}	-3
sulfate	SO_4^{2-}	-2
sulfide	S^{2-}	-2
thiocyanate	SCN^-	-1
thiosulfate	$S_2O_3^{2-}$	-2

A note about hydrogen and hydronium: rarely does hydrogen ion exist on its own. When H^+ is written in equations or textbooks, it usually is a simplified way of saying H_3O^+. Water, H_2O, is constantly breaking up to form a dilute solution of hydroxide (OH^-) and hydronium (H_3O^+) ions.

A note about mercury: mercury (I) is diatomic. Hg_2 can generally be treated as a single unit.

Procedure:

Work independently to carry out each of the reactions and note the observations. After completing all the reactions, but before disposing the contents of the test tubes, confer your observations with your lab partner and work together to write the required chemical equations.

Note: Different mixtures have different reactions. Do one reaction at a time and be very careful not to mix up droppers as this would lead to contamination of the dropper bottles. The information 1.0*M* in the second line of the label, refers to the concentration of the solution, where *M* stands for Molarity.

Obtain one clean spot plate (or 10 clean small test tubes in a test tube rack). For each of the reactions indicated in your report sheet, add 4-5 drops of each of the two specified reactants and mix well.

A precipitation reaction is said to have occurred if the solution turns cloudy (that is, a precipitate forms). A gas reaction is said to have occurred if the solution bubbles (that is, a gas forms)

Record your observations on the data sheet. If a reaction occurs, note the color of the solid formed as well as any other observations. Write "no reaction" if no visible reaction is observed.

For each reaction write the balanced molecular equation reactions, complete ionic equation reactions, and net ionic equation reactions that occurred.

EXPERIMENT 10: Precipitation Reactions

REPORT FORM

Name _____

Instructor _____

Date _____

Partner's Name: _____

Part I. Observation

Mix 5-10 drops of the following pairs of solutions in a well plate (spot test plate). Mix well with a Toothpick (or stirring rod) and record any observed change (gas evolved, solid precipitate formed, sharp odor, or no visible observation) in the appropriate box. If no changes occur, simply write "NR".

#1	#2	#3	#4
$AgNO_3$ (aq) + NaCl (aq) ➔	$AgNO_3$ (aq) + HCl (aq) ➔	$AgNO_3$ (aq) + H_2SO_4(aq) ➔	$AgNO_3$ (aq) + Na_2SO_4(aq) ➔
#5	**#6**	**#7**	**#8**
$AgNO_3$ (aq) + Na_2CO_3(aq) ➔	$AgNO_3$(aq) + NH_4Cl (aq) ➔	$AgNO_3$(aq) + KI(aq) ➔	$AgNO_3$(aq) + $BaCl_2$ (aq) ➔
#9	**#10**	**#11**	**#12**
Na_2S(aq) + $Pb(NO_3)_2$(aq) ➔	KOH(aq) + $BaCl_2$ (aq) ➔	KOH(aq) + $CuSO_4$(aq) ➔	KOH(aq) + Na_2CO_3(aq) ➔
#13	**#14**	**#15**	**#16**
$Pb(NO_3)_2$(aq) + NaCl (aq) ➔	$Pb(NO_3)_2$(aq) + KI(aq) ➔	$Pb(NO_3)_2$ (aq) + H_2SO_4(aq) ➔	$Pb(NO_3)_2$(aq) + $BaCl_2$ (aq) ➔
#17	**#18**	**#19**	**#20**
$Pb(NO_3)_2$(aq) + HCl (aq) ➔	$Pb(NO_3)_2$ (aq) + $CuSO_4$(aq) ➔	$BaCl_2$ (aq) + Na_2CO_3(aq) ➔	$BaCl_2$ (aq) + Na_2SO_4(aq) ➔
#21	**#22**	**#23**	**#24**
$BaCl_2$ (aq) + H_2SO_4(aq) ➔	$BaCl_2$ (aq) + $CuSO_4$(aq) ➔	NaCl (aq) + Na_2CO_3(aq) ➔	$Pb(NO_3)_2$(aq) + NH_4Cl (aq) ➔

Part I. Equations

a) Write net ionic equations for each reaction that occurs.
b) List the spectator ions.
Note - If there is no reaction, simply write "NR". Experiment 1 is shown as an example.

1	$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$ $Ag^+(aq) + Cl^-(aq) \rightarrow$ **AgCl (s)** spectator ions are $Na^+(aq) + NO_3^-(aq)$
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EXPERIMENT 10: Precipitation Reactions

Reactions in Aqueous Solutions: Metathesis Reactions and Net Ionic Equations

Pre- laboratory Questions and Exercises

Due before lab begins. Answer on separate sheet of paper.

1. Define the following ;

   a) Metathesis reaction-

   b) Spectator ions-

   c) Aqueous solution-

   d) Standard solution-

2. Write the molecular equations for the dissociation of the following in water.

   a) Na_2S b) HBr c) $AlCl_3$ d) $Pb(NO_3)_2$

   e) $KHSO_3$ f) NH_4OH g) $Pb(C_2H_3O_2)_2$ h) Na_2CO_3

3. Write ionic and net ionic equations for the following reactions.

   a) $2AgNO_3(aq) + Na_2CrO_4(aq) \rightarrow Ag_2CrO_4(s) + 2NaNO_3(aq)$

   b) $H_2SO_4(aq) + MgCO_3(s) \rightarrow MgSO_4(aq) + H_2O(l) + CO_2$

4. Predict whether a precipitation reaction will occur when aqueous solutions of $CdCl_2$ and $(NH_4)_2S$ are mixed. Write the net ionic equation.

5. How might you use a precipitation reaction to prepare a sample of $CuCO_3$? Write the net ionic equation

EXPERIMENT 10: Precipitation Reactions

Reactions in Aqueous Solutions: Metathesis Reactions and Net Ionic Equations

Post- laboratory Questions and Exercises

Due after completing lab. Answer in space provided.

1. Predict the solubility in water of each of the following compounds. (Write S= soluble, INS =insoluble, SS= slightly soluble)

   a) $CaCO_3$ b) $Mg(OH)_2$ c) HgCl d) $Pb(NO_3)_2$

2. Predict whether a precipitation reaction will occur when aqueous solutions of ammonium sulfate and calcium acetate are mixed. Write the net ionic equation.

3. Predict whether a reaction occurs when each of the following pairs of solutions are mixed. If a reaction does occur, write balanced molecular, ionic, and net ionic equations, and identify the spectator ions.
   a) Silver nitrate (aq) and sodium chloride (aq)

   b) Potassium nitrate and ammonium chloride

4. Complete the following reactions and write net ionic equations for each if any.

   a) $Pb(NO_3)_2$ and $Fe_2(SO_4)_3$

   b) $Mg(OH)_2$ and $(NH_4)_2SO_4$

5. Complete the following reactions and write spectators for each if any.

   a) Iron(III) chloride (aq) and cesium phosphate (aq)

   b) Sodium phosphate(aq) and calcium chloride(aq)