Experiment 5: DOUBLE DISPLACEMENT REACTIONS

Purpose: To observe and record the results when two ionic solutions are mixed.

To practice writing molecular, total ionic, and net ionic reactions.

Background Information:

A **double displacement,** or **metathesis,** reaction occurs when an insoluble **precipitate** is formed, a gas is formed, or when an acid neutralizes a base to produce the **weak electrolyte**, water. During the reaction, the cation of the first substance exchanges an anion with the cation of the second substance and vice versa, creating two new substances. The general form of the equation is:

$AX + BY \rightarrow AY + BX$ where: A is cation one
X is anion one
B is cation two
Y is anion two

A specific example of such a reaction is:

$Mg(NO_3)_2\,(aq) + K_2CO_3\,(aq) \rightarrow MgCO_3\,(s) + 2\,KNO_3\,(aq)$ where: Mg^{+2} is A
NO_3^- is X
K^+ is B
CO_3^{-2} is Y

Note how Mg^{+2} exchanges its original anion, NO_3^-, with K^+ and K^+ exchanges its original anion, CO_3^{-2}, with Mg^{+2}. This double exchange is why this type of reaction is called a double displacement.

There are 3 different ways that we can write double displacement reactions. The first way is called a **molecular equation**. In a molecular equation, all species are written in their **undissociated** or **molecular** forms. The equation above is a molecular equation.

The second way is called the **complete ionic equation**. In this type of equation, all species are written as they predominately exist in solution. Thus, insoluble compounds and weak electrolytes like water, are written in their undissociated forms (just as they are in a molecular equation), but soluble compounds and **strong electrolytes** are written in their **dissociated** or **ionic** forms. The above reaction written as a complete ionic equation looks like this:

$$Mg^{+2}\,(aq) + 2\,NO_3^-\,(aq) + 2\,K^+\,(aq) + CO_3^{-2}\,(aq) \rightarrow MgCO_3\,(s) + 2\,NO_3^-\,(aq) + 2\,K^+\,(aq)$$

Remember that strong acids and bases are considered to be strong electrolytes (and thus should be written in ionic form) and that weak acids and bases are considered to be weak electrolytes (and thus should be written in molecular form). Any gases that are produced are always written in their molecular forms.

The third way to write a double displacement reaction is called the **net ionic equation.** In this form, only reacting ions and their product(s) are written, any **spectator ions** are omitted. In the above equation, the potassium and nitrate ions are considered to be spectator ions because they do not combine to form an undissociated product. Therefore, the net ionic reaction for the above example would be:

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

When two ionic solutions are mixed, a reaction does not always take place. Only when one of the products is an insoluble precipitate, water, an undissociated product (like a weak acid or weak base), or a gas such as CO_2, SO_2 or H_2S does a reaction go to completion. In this experiment, you will observe all 3 of these types of metatheses reactions. A precipitate appears as a cloudy solid in the test tube; the formation of water gives off heat (more specifically called an **exothermic process**); and the formation of a gas produces small bubbles that can be observed floating through the solution.

The reaction highlighted above is an example of a precipitation reaction, because one of the products is an insoluble precipitate. Magnesium carbonate is a white insoluble solid and would appear as a white cloud in the reacting test tube. The remaining liquid is called the **supernatant**. (A **clear** solution is one that does not contain a precipitate. A clear solution is not the same as a **colorless** solution. A colorless solution is one that has no color)

At the end of this background information, there is a solubility table which you may use to help you determine which products of a double displacement reaction, if any, will form a precipitate. When a precipitate is observed to form, you should always note its color, as this will help you to determine its chemical formula.

The molecular, complete ionic and net ionic equations for an acid-base reaction that produces water follows:

Molecular eqn: $HNO_2\,(aq) + NaOH\,(aq) \rightarrow H_2O\,(l) + NaNO_2\,(aq)$

Total ionic eqn: $HNO_2\,(aq) + Na^+\,(aq) + OH^-\,(aq) \rightarrow H_2O\,(l) + Na^+\,(aq) + NO_2^-\,(aq)$

Net ionic eqn: $HNO_2\,(aq) + OH^-\,(aq) \rightarrow H_2O\,(l) + NO_2^-\,(aq)$

Note that nitrous acid is a weak acid and thus is written as a molecular species in the total ionic equation, while sodium hydroxide is a strong base and thus is written in ionic form. (Your textbook has a list of the most common strong acids and bases.) A reaction that forms water does not produce any visible changes in the test tube, but always produces heat. The heat generated by your reaction may not be sufficient to raise the temperature of the solution by a noticeable amount. Your laboratory thermometer is much more sensitive to temperature changes than your fingers, so you should note the temperature of all the reactant solutions before you mix them. After mixing them, if it appears that nothing has happened, be sure to take the temperature of the final solution. If an acid-based neutralization has occurred, your final solution should have a higher temperature than either of the two initial solutions.

The molecular, complete ionic and net ionic equations for a double displacement reaction that produces a gas follows:

Molecular eqn: $BaCO_3 (s) + 2 HNO_3 (aq) \rightarrow CO_2 (g) + H_2O (l) + Ba(NO_3)_2 (aq)$
Total ionic eqn: $BaCO_3 (s) + 2 H^+ (aq) + 2NO_3^- (aq) \rightarrow$
$CO_2(g) + H_2O (l) + Ba^{2+} (aq) + 2NO_3^- (aq)$
Net ionic eqn: $BaCO_3 (s) + 2 H^+ (aq) \rightarrow CO_2(g) + H_2O (l) + Ba^{2+} (aq)$

Again note that insoluble barium carbonate is written in the molecular from in total ionic reaction, while the strong acid nitric acid is written in the ionic form. The gas carbon dioxide is always written in the molecular form. It is also acceptable to combine the carbon dioxide and water into carbonic acid and write the above equations like this:

Molecular eqn: $BaCO_3 (s) + 2 HNO_3 (aq) \rightarrow H_2CO_3 (aq) + Ba(NO_3)_2 (aq)$
Total ionic eqn: $BaCO_3 (s) + 2 H^+ (aq) + 2 NO_3^- (aq) \rightarrow H_2CO_3 (aq) + Ba^{2+} (aq) +$
$2 NO_3^- (aq)$
Net ionic eqn: $BaCO_3 (s) + 2 H^+ (aq) \rightarrow H_2CO_3 (aq) + Ba^{2+} (aq)$

After mixing the two reactant solutions, if a gas is formed, there will be small bubbles present in the final solution. You might have to look very closely to see them. The most common gases produced are CO_2, SO_2, and H_2S.

Not all mixtures result in a reaction. For example, when iron (II) sulfate and magnesium chloride are mixed, neither of the two possible products, iron (II) chloride or magnesium sulfate form precipitates. In addition, no gases or water are made. Therefore, no double displacement occurs. We indicate this by writing the following equation:

$$FeSO_4 (aq) + MgCl_2 (aq) \rightarrow NR$$

where NR stands for no reaction. A few of the mixtures you will observe in this lab will have no reaction, but not many. **Be sure to check for a change in temperature or for bubbles before you come to the conclusion that no reaction has occurred.**

Procedure:

1) You will be mixing 10 different pairs of solutions. These solutions are listed on the page that follows the solubility chart. For each pair of solutions, use the droppers provided on each reagent bottle and put about 3 mLs of solution #1 into a clean test tube. You do not have to use exactly 3 mLs.
2) Put about 3 mLs of solution #2 in another clean test tube.
3) Note the initial temperatures of both solutions with your thermometer. Either use two different thermometers for each solution or make sure you wash your thermometer between readings. Do not put the thermometer into solution #2 directly from solution #1; you will contaminate solution #2 with solution #1 before you are ready to observe the results.

4) When you are ready, quickly add solution #2 to solution #1. Note any formation of precipitate, evolution of gas, or color change in your notebook or on your report sheet. Be sure to note the color of any precipitate that forms. Take the temperature of the final reaction mixture.
5) Discard the mixture in the waste container provided and wash out your test tubes, first with tap water and then with distilled water.
6) Proceed to the next pair of solutions and repeat steps 1-5.

Reaction Mixture	Solution #1	Solution #2
1	0.3 M sodium carbonate	0.5 M hydrochloric acid
2	0.3 M potassium hydroxide	0.5 M hydrochloric acid
3	0.1 M sodium chloride	0.3 M sodium carbonate
4	0.1 M lead (II) nitrate	0.1 M sodium iodide
5	0.1 M sodium sulfate	0.1 M barium chloride
6	0.3 M sodium carbonate	0.1 M calcium chloride
7	0.3 M potassium hydroxide	0.3 M magnesium nitrate
8	0.1 M sodium sulfate	0.1 M copper (II) nitrate
9	0.5 M hydrochloric acid	0.3 M potassium bicarbonate
10	0.3 M strontium nitrate	0.3 M potassium iodate

Report Sheet:

In your laboratory notebook, complete the following for each of the 10 Reaction Mixtures:

Reaction number ___________________

Name of solution #1, its initial color, and its initial temperature:
______________________ _________________ _______ ^{o}C
Name of solution #2, its initial color, and its initial temperature:
______________________ _________________ _______ ^{o}C

Observations after mixing:
This part should state if you saw a precipitate (also note its color) or gas being formed.
Color of supernatant or final reaction mixture and its temperature:
______________________ ________ ^{o}C
Did a reaction occur? _______
If a reaction occurs, what type was it? (precipitation, acid-based, or gas evolution)
If a reaction occurs, write the molecular, total ionic, and net ionic equations.

Organize your data for the 10 Reaction Mixtures into a table.

Solubility Table

	$C_2H_3O_2^-$	AsO_4^{3-}	Br^-	CO_3^{2-}	$C1^-$	CrO_4^{2-}	OH^-	I^-	NO_3^-	$C_2O_4^{2-}$	O^2	PO_4^{3-}	SO_4^{2-}	S^{2-}	SO_3^{2-}
$A1^{3-}$	S	I	S	-	S	-	I	s	s	-	I	I	S	d	-
NH_4^-	S	S	S	S	S	S	S	S	S	S	-	S	S	S	S
Ba^{2-}	S	I	S	I	S	I	*s*	S	S	I	*s*	I	I	d	I
$B1^{3-}$	-	***s***	d	I	d	-	I	I	d	I	I	S	d	I	-
Ca^{2-}	S	I	S	I	S	S	I	S	S	I	I	I	I	d	I
Co^{2-}	S	I	S	I	S	I	I	S	S	I	I	I	S	I	I
Ca^{2-}	S	I	S	I	S	I	I	-	S	I	I	I	S	I	-
Fe^{2-}	S	I	S	*s*	S	-	I	S	S	I	I	I	S	I	S
Fe^{3-}	I	I	S	I	S	-	I	-	S	S	I	I	S	I	-
Pb^{2-}	S	I	I	I	I	I	I	I	S	I	I	I	I	I	I
Mg^{2-}	S	d	S	I	S	S	I	S	S	I	I	I	S	d	S
Hg^{2-}	S	I	I	I	S	*s*	I	I	S	I	I	I	d	I	-
K^-	S	S	*s*	S	S	S	S	S	S	S	S	S	S	S	S
Ag^-	S	I	I	I	I	I	-	I	S	I	I	I	I	I	I
Na^-	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Zn^{2-}	S	I	S	I	S	I	I	S	S	I	I	I	S	I	I

KEY: S= soluble in water
s= slightly soluble in water

I= Insoluble in water (less than 1 g/100 g H_20)
d= Decomposed in water

Name ______________________________

Postlaboratory Assignment – Experiment 5

1. Scientists often use their knowledge of precipitation reactions to help them identify unknown liquids. Given each of the following pairs of liquids, which single solution could you use to distinguish them from each other? In each case, describe the observations you would make and write molecular, complete and net ionic equations for any reaction that occurs. Use the 10 reaction mixtures you studied in this experiment for guidance.

   a) potassium nitrate and barium nitrate (add one substance to each of these solutions so that 2 different reactions occur.)

   b) sodium chloride and hydrochloric acid

2. A student was given five known solutions and asked to observe their interactions. She mixed them in pairs and recorded her observations on a grid like the one below. Based on your experiments and the solubility chart, fill in what she saw. Use "NR" to indicate no reaction, "ppt" for precipitate, and "gas" for any bubbles observed. Note that the table is symmetrical, so the reaction between HCl and NaCl is the same as NaCl and HCl.

	NaCl	HCl	Na_2CO_3	Na_2SO_4	$Ba(NO_3)_2$
$Ba(NO_3)_2$					----------
Na_2SO_4				-----------	
Na_2CO_3			-----------		
HCl		-----------			
NaCl	-----------				

The student was then given the same set of five solutions, but this time in test tubes labeled A, B, C, D and E. When these solutions were mixed, the student recorded the following observations.

	A	B	C	D	E
E	NR	NR	white ppt	gas	--------
D	NR	NR	NR	--------	gas
C	white ppt	NR	--------	NR	white ppt
B	NR	--------	NR	NR	NR
A	---------	NR	white ppt	NR	NR

Identify the solution in each test tube.

Test tube A ____________________________

Test tube B ____________________________

Test tube C ____________________________

Test tube D ____________________________

Test tube E ____________________________

Write a total ionic equation for each pair of solutions that resulted in a successful double displacement reaction.

Name ___________________________

Prelaboratory Assignment – Experiment 5

1. Classify the following solutions as a clear solution, a colorless solution, both, or neither:

   a) The supernatant of a reaction mixture has no color and contains a blue precipitate.

      ____

   b) The supernatant of a reaction mixture is orange and contains a white precipitate.

      ____

   c) The supernatant of a reaction mixture has no color and contains no precipitate.

      ____

   d) The supernatant of a reaction mixture is blue and contains no precipitate.

      ____

2. When a blue copper (II) nitrate solution is mixed with a colorless sodium sulfide solution, a black precipitate is formed.

   a) Use the solubility table to determine the identity of the black precipitate.

   b) Write the molecular equation for this reaction.

   c) Write the total ionic equation for this reaction.

   d) Write the net ionic reaction for this reaction.

3. Will a double displacement reaction occur if a potassium hydroxide solution is mixed with lead (II) nitrate solution? Why or why not? If a reaction does occur, write the net ionic equation for the reaction.

Name ___________________________

Double Replacement Reactions

1. Complete each molecular equation (even if no reaction occurs) with correct formula and phase for each product.

2. Write a total ionic equation for each reaction.

3. Write a net ionic equation for each reaction-if no reaction occurs write "no net reaction" in place of the net ionic reaction.

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Example: $NaBr$ (aq) + $Ca(NO_3)_2$ (aq) $\rightarrow$

1. 2 $NaBr$ (aq) + $Ca(NO_3)_2$ (aq) $\rightarrow$ $CaBr_2$ (aq) + $NaNO_3$ (aq)
2. 2 Na^+ (aq) + 2 Br^- (aq) + Ca^{2+} (aq) + 2 NO_3^- (aq) $\rightarrow$ 2 Ca^{2+} (aq) + 2 Br^- (aq) + 2 Na^+ (aq) + 2 NO_3^- (aq)
3. No net reaction

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1. $AlC1_3$ (aq) + NH_4OH (aq) $\rightarrow$

2. $Ca(HCO_3)_2$ (aq) + HI (aq) $\rightarrow$

3. Na_2CO_3 (aq) + $CuSO_4$ (aq) $\rightarrow$

4. $CaCO_3$ (s) + HCl (aq) $\rightarrow$

5. K_3PO_4 (aq) + $AgNO_3$ (aq) $\rightarrow$

6. HNO_3 (aq) + $Ba(OH)_2$ (aq) $\rightarrow$

7. $NaOH$ (aq) + NH_4C1 (aq) $\rightarrow$

8. $MgSO_3$ (aq) + $HC1$ (aq) →

9. $BaC1_2$ (aq) + Na_3PO_4 (aq) →

10. $Fe_2(SO_4)_3$ (aq) + $NaOH$ (aq) →

11. $MgSO_4$ (aq) + $Cu(NO_3)_2$ (aq) →

12. Na_3AsO_4 (aq) + $FeCl_3$ (aq) →

13. $NaNO_3$ (aq) + $FeC1_3$ (aq) →

14. $HC1$ (aq) + $KC_2H_3O_2$ (aq) →

15. $Mg(OH)_2$ (s) + H_2SO_4 (aq) →