Experiment 5: Chemical Reactions

Part A: Precipitation and acid-base reactions

(This part of the experiment was adapted from CC-BY Torres & González-Urbina Experiment: Precipitation and Acid-Base Reactions)

Purpose

The goal of this experiment is to carry a set of simple acid-base and precipitation reactions in aqueous solutions. For the precipitation reactions you will use the solubility rules to identify the solid and aqueous products of the reaction. For the acid-base reactions, you will identify the acidic/basic character of each reactant chemical and observe whether there is heat involved in the acid-base reaction.

Chemicals

Type A Solutions of	NaCl	NaBr	Na_2SO_4	KCl
Type B Solutions of	$Ba(NO_3)_2$,	$AgNO_3$		
Type C Solutions of	HCl	CH_3COOH		
Type D Solutions of	NaOH	Na_2CO_3		

Equipment

Red and blue litmus paper

4 small test tubes

Background

Many chemical reactions take place in aqueous solution, and most of these reactions involve ions. Let's consider as an example what happens when mixing a colorless solution of silver nitrate ($AgNO_3$) with a colorless solution of sodium chloride (NaCl). The solution of silver nitrate contains Ag^+ cations and NO_3^{1-} anions, whereas the solution of sodium chloride contains Na^+ cations and Cl^- anions. When we mix these two aqueous solutions, a white precipitate (AgCl) forms immediately due to the ion exchange process.

$$AgNO_3(aq) + NaCl\ (aq) \rightarrow AgCl\ (s) + NaNO_3(aq)$$

Acid-base reactions are aqueous reaction also. Acids and bases react by means of a neutralization reaction. An example would be:

$$HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O(l)$$

This experiment addresses these two important types of chemical reactions, studying several classic precipitation and acid-base reactions.

Precipitation reactions

Some ionic compounds are soluble in water whereas others are not. In a precipitation reaction, two strong-electrolyte solutions are mixed to produce an insoluble solid called precipitate.

Ions that form soluble compounds	**... except when combined with**
Group I ions (Na^+, Li^+, K^+, etc)	no exceptions
Ammonium (NH_4^+)	no exceptions
Nitrate (NO_3^-)	no exceptions
Acetate (CH_3COO^-)	no exceptions
Hydrogen carbonate (HCO_3^-)	no exceptions
Chlorate (ClO_3^-)	no exceptions
Halides (F^- , Cl^- , Br^-)	Pb^{2+}, Ag^+ and Hg_2^{2+}
Sulfate (SO_4^{2-})	Ag^+,Ca^{2+}, Sr^{2+},Ba^{2+}, Hg_2^{2+} and Pb^{2+}

Ions that form insoluble compounds...……...	**except when combined with**
Carbonate (CO_3^{2-})	group I ions (Na^+, Li^+, K^+, etc) or ammonium (NH_{4+})
Chromate (CrO_4^{2-})	group I ions (Na^+, Li^+, K^+, etc) or Ca^{2+}, Mg^{2+} or ammonium (NH_{4+})
Phosphate (PO_4^{3-})	group I ions (Na^+, Li^+, K^+, etc) or ammonium (NH_{4+})
Sulfide (S^{2-})	group I ions (Na^+, Li^+, K^+, etc) or ammonium (NH_{4+})
Hydroxide (OH^-)	group I ions (Na^+, Li^+, K^+, etc) or Ca^{2+}, Mg^{2+}, Sr^{2+} or ammonium (NH_{4+})

Acids and Bases

Acids are chemicals that produce hydrogen ions (H^+) in water. Bases produce hydroxide ions (OH^-) that accept hydrogen ions. H^+ and OH^- combine to form water. Acids and bases change the color of certain chemicals called indicators, and litmus is a well-known acid-base indicator. Acids and bases can be classified as strong or weak according to the extent to which they ionize/dissociate in solution. A strong acid is completely ionized in solution, whereas a weak acid is only slightly ionized. The same can be applied to bases.

Strong Acids	**Strong Bases**
HCl, HBr, HI	NaOH, KOH
$HClO_4$, $HClO_3$	$Sr(OH)_2$, $Ba(OH)_2$
H_2SO_4	Na_2O, BaO
Weak Acids	**Weak Bases**
HF, CH_3COOH, H_2SO_3	NH_3

Acid-Base Neutralization Reactions
A neutralization reaction between a strong acid and a strong base yields a salt and water:

Acid (aq) + Base (aq) $\rightarrow$ Salt (aq) + H_2O(l)

Litmus paper
Litmus paper is a quick test to identify whether a solution is acidic or basic. There are two variants for litmus paper. You can find red litmus paper and blue litmus paper. Blue litmus paper turns pink under acidic conditions whereas red litmus paper turns blue under basic conditions. Regardless of which litmus you start with, remember that ***bases turn litmus blue***.

	Red litmus paper	Blue litmus paper
Acidic solution	Red	Red
Basic solution	Blue	Blue

Figure 12: (Left panel) A precipitate of PbI_2; (Right panel) The result of an acid-base neutralization.

Ionic and Net ionic equations
The ionic equation for a precipitation reaction or acid base reaction shows all the species as they actually exist in solution. Because dissolved ionic compounds exist as separate aqueous ions, in an ionic equation the ions should be shown separately. Some of these ions appear the same as both reactants and products. This means that they play no role in the reaction: they are spectator ions. In the ionic equation, you can simplify the chemical equation by canceling the spectators out on each side of the arrow; this produces the net ionic equation.

The ionic and net ionic equations for the reaction between aqueous solutions of silver nitrate ($AgNO_3$) and potassium chromate (K_2CrO_4) to give a precipitate of silver chromate (Ag_2CrO_4) and a solution of potassium nitrate (KNO_3) are:

$Ag^{1+}_{(aq)} + NO_3^{1-}{}_{(aq)} + 2K^{1+}_{(aq)} + CrO_4^{2-}{}_{(aq)} \rightarrow Ag_2CrO_{4(s)} + K^{1+}_{(aq)} + NO_3^{1-}{}_{(aq)}$

$Ag^{1+}_{(aq)} + CrO_4^{2-}{}_{(aq)} \rightarrow Ag_2CrO_{4(s)}$ *(no spectator ions shown)*

Procedure
Precipitation reactions

1) Arrange in the following order the set of reactants Type A:
   NaCl (aq) NaBr (aq) Na_2SO_4(aq) KCl (aq)

2) Arrange in the following order the set of reactants Type B:
   $Ba(NO_3)_2$(aq) $AgNO_3$(aq)

3) Use reactant Type A NaCl (aq) and add 20 drops to a set of two test tubes. Each tube should have now 20 drops of NaCl.

4) Use reactant Type B $Ba(NO_3)_2$(aq). Add 20 drops to the first test tube containing the NaCl. Write down your observation:
   Indicate soluble as (aq) for aqueous or insoluble as (s) for solid.

5) Use reactant Type B $AgNO_3$(aq). Add 20 drops to the second test tube containing the NaCl. Write down your observation:
   Indicate soluble as (aq) for aqueous or insoluble as (s) for solid.

6) Repeat steps 3 – 5 for each of the other Type A reactants, in the following order:
   NaBr Na_2SO_4 KCl

(Record all observations in your notebook, in the order indicated above.)

Acid Base Neutralization Reactions

7) Arrange in the following order the set of reactants Type C: NaOH (aq) Na_2CO_3(aq)

8) Arrange in the following order the set of reactants Type D: HCl (aq) CH_3COOH (aq)

9) For each chemical in Type C and Type D, put one drop of solution on a piece of red litmus paper. Then put one drop of each solution on a piece of blue litmus paper. Record all of your observations and identify each chemical as an acid or base.

10) Use reactant Type C NaOH (aq) and add 20 drops to a set of two test tubes. Each tube will have now 20 drops of a NaOH.

11) Use reactant Type D HCl. Add 20 drops to the first test tube containing the NaOH. Observe if you feel any heat generated.

12) Use litmus paper to test the acidity of the resulting solution. Write down the result as: acidic or basic.

13) Repeat steps 10 – 12 for each of the remaining combinations:

NaOH with CH_3COOH Na_2CO_3 with HCl Na_2CO_3 with CH_3COOH

References
(1) Fetzer-Gislason, P. R.D.W. S., Lab Experiments in Introductory Chemistry; Freeman: 2003.
(2) Murov, S., Experiments in General Chemistry; Cengage: 2013.
(3) Ebbing, R. W.D. D., Experiments in General Chemistry; Houghton Mifflin Harcourt Publishing Company: 2004.

Postlab Questions for Part A
(Do these in your notebook, in the Calculation/Results section.)
1. Indicate whether each of the following compounds will be soluble (aq) or insoluble (s) when put into water:

$NaNO_3$ NH_4Br
BaS $Ni(OH)_2$

2. Write the balanced **ionic equation** for each of the chemical combinations you did in Part A. If a precipitate did not form, then write 'no rxn' on the product side of the reaction arrow. Write your equations in the order shown below:

1. NaCl, $Ba(NO_3)_2$	7. KCl, $Ba(NO_3)_2$
2. NaCl, $AgNO_3$	8. KCl, $AgNO_3$
3. NaBr, $Ba(NO_3)_2$	9. NaOH, HCl
4. NaBr, $AgNO_3$	10. NaOH, CH_3COOH
5. Na_2SO_4, $Ba(NO_3)_2$	11. Na_2CO_3, HCl
6. Na_2SO_4, $AgNO_3$	12. Na_2CO_3, CH_3COOH

Part B: The Scientific Method

This experiment was adapted from Torres & González-Urbina, CUNY, The Scientific Method.

Purpose

The goal of this experiment is to understand how the scientific method works. In order to do this, you will make observations, look for patterns and come up with a hypothesis in order to identify an unknown compound. You will do this by comparing the reaction of the unknown compound with a set of known compounds. Observe changes that indicate a chemical reaction has occurred, such as gas evolution, the formation of a precipitate, a change of color, or the generation of heat.

Chemicals

Known compounds: $NaCl_{(s)}$ $NaI_{(s)}$ $Na_2CO_{3(s)}$ $Na_2HPO_{4(s)}$ $Na_2SO_{4(s)}$,

Reagents: $HNO_{3(aq)}$ $NH_{3(aq)}$ $Ba(NO_3)_{2(aq)}$ $AgNO_{3(aq)}$ thymol blue

Unknown compound

Caution: Solutions of HNO_3 and NH_3 can cause chemical burns. Solutions of barium are toxic.

Equipment

Six test tubes (you will clean reuse these test tubes during this experiment)

Background The scientific method is a sequence of logical steps.
The first step is to collect data by making observations and/or measurements of a sample. The next step consists of looking for patterns and trends in the data. When a pattern is observed, scientists develop a hypothesis, that is, a feasible explanation of the observations. After formulating a hypothesis, scientists think of experiments to test the hypothesis. If the results of repeated experiments support the hypothesis, scientists formulate a theory that explains the observations.
This experiment was adapted from the literature [1, 2].

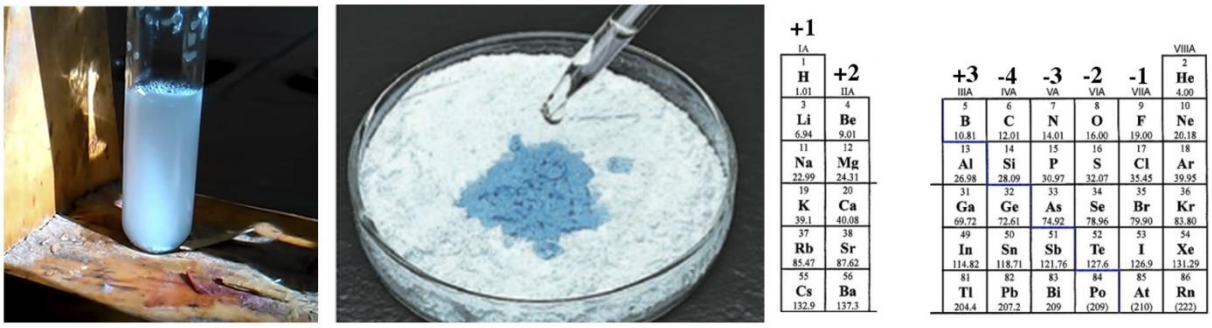

Figure 1: (Left panel) Gas evolution in a chemical reaction. (Center panel) Color change due to a chemical reaction. (Right panel) The valences on the periodic table.

Procedure

1) Obtain the unknown compound, the known compounds, and the reagents.

2) Visually compare the unknown with the known compounds and guess the identity of the unknown. That is your hypothesis. Write down your guess in your notebook.

3) Place a pea-size portion of the unknown in a 250 mL beaker, and add 150 mL of water using a 100 mL graduated cylinder to measure it. Swirl until all the solid has dissolved.

4) Set aside the remaining portion of your solid unknown.

Testing for gas products

5) Obtain six test tubes. To each test tube you will add a pea-size sample of a different known compound and the unknown.
Use a clean spatula to place pea-size solid samples in the test tubes in this order:

Test tube	1	2	3	4	5	6
Chemical	NaCl	NaI	Na_2CO_3	Na_2HPO_4	Na_2SO_4	Unknown

Label your test tubes. (Keep this order throughout this experiment.)

6) Add five drops of HNO_3 to each test tube and record your observations: gas or no-gas evolution.

7) Discard the solutions from the test tubes into the waste container. Wash the test tubes, and rinse them with distilled water. You will reuse these test tubes for the following steps.

Use the solutions of NaCl, NaI, Na_2CO_3, Na_2HPO_4 and Na_2SO_4 that you will find in the laboratory, and the solution of your unknown, prepared in step 3, for the remaining tests in this experiment.

Testing for a barium precipitate *(The following test will use only liquid samples.)*

8) Using the cleaned 6 test tubes, add 20 drops of solution to each test tube. Each test tube should have a different known compound solution, and the last test tube has the unknown solution.

Add 3 drops of ammonia (NH_3) solution to each test tube and mix.

9) Add five drops of the $Ba(NO_3)_2$ solution to each of the test tubes. Shake gently to obtain homogeneity. Examine each test tube carefully and look at the results. Record your observations: precipitate or no precipitate.

10) Discard the solutions from the test tubes into the waste container. Wash the test tubes, and rinse them with distilled water. You will reuse these test tubes for the following steps.

Testing for a silver precipitate *(The following test will use only liquid samples.)*

11) Using the cleaned 6 test tubes, add 20 drops of solution to each test tube. Each test tube should have a different known compound solution, and the last test tube has the unknown solution.

12) Add five drops of the silver nitrate $AgNO_3$ solution to each test tube. Record your observations: precipitate or no precipitate.

13) Discard the solutions from the test tubes into the waste container. Wash the test tubes, and rinse them with distilled water. You will reuse these test tubes for the following steps.

Testing with thymol blue

14) Using the cleaned 6 test tubes, add 20 drops of a different known solution and the unknown solution to each test tube.

15) Add five drops of the thymol blue solution to each test tube. Shake each test tube gently before recording your observations: write down the colors of the resulting solutions.

16) Discard the solutions from the test tubes into the right waste container. Wash the test tubes, and dispose of them in the broken glass container.

Identifying the unknown compound

17) The unknown is one of these compounds:

$NaCl$, NaI, Na_2CO_3, Na_2HPO_4, Na_2SO_4.

You should be able to identify your unknown compound by matching its chemical reactions with those of one of the known compounds. Explain your logic when you identify your unknown.

References
(1) Ebbing, R. W.D. D., Experiments in General Chemistry; Houghton Mifflin Harcourt Publishing Company: 2004.
(2) Beran, J. A., Laboratory manual for principles of general chemistry; John Wiley and Sons: 2010.

Postlab Questions for Part B
(Do these in your notebook, in the Calculation/Results section.)

1. Give the chemical formulas for the following compounds:

Sodium iodide	Sodium carbonate
Lithium fluoride	Sodium oxide

2. Give the balanced ionic equation for each combination of chemicals in Part B for the known compounds. If a chemical reaction was not observed, write 'no rxn' on the product side of the reaction arrow. Put your chemical equations in the following categories, in the same order as the test tubes:

Reactions that produced a gas
Reactions that produced a barium precipitate
Reactions that produced a silver precipitate