# 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 perform 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 characteristic of each reactant chemical.

### Chemicals

| | | | | |
|---|---|---|---|---|
| Type A Solutions of | NaCl | NaBr | $Na_2SO_4$ | KCl |
| Type B Solutions of | $Ba(NO_3)_2$, | $AgNO_3$ | *(Barium nitrate is toxic!!! Use in the hood.)* | |
| 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 (You will clean and reuse these test tubes during this experiment.)

### 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.

**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.

## Solubility Guidelines:

| **Ions that form soluble compounds (aq)……..….. 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 (s)…….except when combined with….** | |
|---|---|
| Carbonate ($CO_3^{2-}$ ) | group I ions ($Na^+$, $Li^+$, etc) or ($NH_4^+$) |
| Chromate ($CrO_4^{2-}$ ) | group I ions ($Na^+$, $Li^+$, etc) or $Ca^{2+}$, $Mg^{2+}$ or ($NH_4^+$) |
| Phosphate ($PO_4^{3-}$ ) | group I ions ($Na^+$, $Li^+$, etc) or ($NH_4^+$) |
| Sulfide ($S^{2-}$ ) | group I ions ($Na^+$, $Li^+$, etc) or ($NH_4^+$) |
| Hydroxide ($OH^-$) | group I ions ($Na^+$, $Li^+$, etc) or $Ca^{2+}$, $Mg^{2+}$, $Sr^{2+}$ or ($NH_4^+$) |

**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; 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 and acids turn litmus red.***

| | Red litmus paper | Blue litmus paper |
|---|---|---|
| Acidic solution | Red | Red |
| Basic solution | Blue | Blue |

**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, 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)*

**Summary Checklist of Chemical Reactions for Part A, Steps 1-6:**

| | NaCl | NaBr | $Na_2SO_4$ | KCl |
|---|---|---|---|---|
| $Ba(NO_3)_2$ | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt |
| $AgNO_3$ | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt |

****Do not put your observations on this paper. Your observations go in your notebook worksheet.*

**Summary Checklist of Chemical Reactions for Part A, Steps 7-9:**

| | NaOH | $Na_2CO_3$ | HCl | $CH_3COOH$ |
|---|---|---|---|---|
| Red Litmus | color | color | color | color |
| Blue Litmus | color | color | color | color |

****Do not put your observations on this paper. Your observations go in your notebook worksheet.*

**Summary Checklist of Chemical Reactions for Part A, Steps 10-12:**

| | NaOH | $Na_2CO_3$ |
|---|---|---|
| HCl | Heat? | Gas or heat? |
| $CH_3COOH$ | Heat? | Gas or heat? |

****Do not put your observations on this paper. Your observations go in your notebook worksheet. These reactions do take place, even if you don't feel heat or see gas formation.*

## 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 10 drops to a set of two test tubes. Each tube should have now 10 drops of NaCl.

4) Use reactant Type B $Ba(NO_3)_2$(aq). Add 10 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 10 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

### *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 10 drops to a set of two test tubes. Each tube will have now 10 drops of a NaOH.

11) Use reactant Type D HCl. Add 10 drops to the first test tube containing the NaOH. Observe if you feel any heat generated. Sometimes the acid and base concentrations are too low to feel heat. However, a reaction has still taken place.

12) Repeat steps 10 – 11 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.

## 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 chemical reactions 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

***Caution: Solutions of barium are toxic.***

Known compounds: $NaCl_{(aq)}$ $NaI_{(aq)}$ $Na_2CO_{3(aq)}$ $Na_2HPO_{4(aq)}$ $Na_2SO_{4(aq)}$,
Reagents: $Ba(NO_3)_{2(aq)}$ $AgNO_{3(aq)}$ thymol blue
Unknown compound$_{(aq)}$
$NH_{3(aq)}$, which is also written as $NH_4OH_{(aq)}$

### Equipment

Six test tubes (you will clean and 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].

### Summary Checklist of Chemical Reactions for Part B:

| Reagents to add to Test Tubes | Known Chemicals and Unknown in the Test Tubes (6 test tubes) | | | | | |
|---|---|---|---|---|---|---|
| | NaCl | NaI | $Na_2CO_3$ | $Na_2HPO_4$ | $Na_2SO_4$ | Unknown |
| $Ba(NO_3)_2$ | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt |
| $AgNO_3$ | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt | ppt or no ppt |
| thymol blue | color | color | color | color | color | color |

****Do not put your observations on this paper. Your observations go in your notebook worksheet.*

**Procedure**

1) Obtain the unknown compound solution, the known compound solutions, and the reagent solutions.

**Testing for a barium precipitate**

2) Using 6 test tubes, add 10 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 2 drops of ammonia ($NH_3$) solution to each test tube and mix. ($NH_3$ will not be part of the chemical equation.)

3) 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.

4) 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**

5) Using the cleaned 6 test tubes, add 10 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.

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

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.

**Testing with thymol blue**

8) Using the cleaned 6 test tubes, add 10 drops of a different known solution and the unknown solution to each test tube.

9) 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.

10) 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

11) 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.