

## Lab #9: Qualitative Analysis of Cations and Anions

### Objectives:

1. To understand the rationale and the procedure behind the separation for various cations and anions.
2. To perform qualitative analysis of two unknown solutions that contain various ions (cations and anions) and positively identify these ions using established schemes.

### Materials:

#### Unknown Cation Solution

(may contain some or all of the following)

- 0.05 M silver nitrate,  $\text{AgNO}_3 (aq)$
- 0.05 M copper (II) nitrate,  $\text{Cu}(\text{NO}_3)_2 (aq)$
- 0.05 M zinc nitrate,  $\text{Zn}(\text{NO}_3)_2 (aq)$
- 0.05 M iron (III) nitrate,  $\text{Fe}(\text{NO}_3)_3 (aq)$

6 M  $\text{HCl} (aq)$

6 M  $\text{HNO}_3 (aq)$

6 M  $\text{NH}_3 (aq)$

6 M  $\text{H}_2\text{SO}_4 (aq)$

6 M  $\text{NaOH} (aq)$

6 M  $\text{CH}_3\text{COOH} (aq)$

0.1 M  $\text{KSCN} (aq)$

0.1 M potassium ferrocyanide solution,  $\text{K}_4\text{Fe}(\text{CN})_6 (aq)$

0.1 M  $\text{AgNO}_3 (aq)$

Saturated  $\text{Ba}(\text{OH})_2 (aq)$

0.1 M  $\text{BaCl}_2 (aq)$

Aluminum granules

#### Unknown Anion Solution

(may contain some or all of the following)

0.05 M sodium chloride,  $\text{NaCl} (aq)$

0.05 M sodium carbonate,  $\text{Na}_2\text{CO}_3 (aq)$

0.05 M sodium sulfate,  $\text{Na}_2\text{SO}_4 (aq)$

0.05 M sodium nitrate,  $\text{NaNO}_3 (aq)$

18 Test Tubes and 4 Test Tube Racks

400 mL Beaker (Waste)

250 mL Beaker

Spatula

6 Beral-type Pipets

Hot Plate

Stirring Rods

6 Small Test Tube Stoppers

Litmus or pH Paper

Watch Glass

Centrifuge

### Background Information:

Qualitative analysis is an analytical procedure in which the question “what is present?” is answered. In a systematic qualitative analysis scheme, each substance present is separated from the other substances. Then a confirmatory test is used to prove that the isolated substance is the expected one.

To begin the lab experiment, a solution containing four cations is analyzed using the techniques for qualitative analysis of cations. A second solution containing four anions is then analyzed using the qualitative scheme for anions. Two solutions, one containing any combination of four different cations, and another containing any combination of four anions will be assigned to each student group. The two “unknown” solutions are then analyzed to determine which ions are present and which are absent. This experiment is carried out on a semi-micro scale. Very small quantities of reagents are used. Cleanliness and a great deal of care are necessary to obtain good results. While going through the steps of the analysis, keep a copy of the appropriate flow chart available for reference. The flow charts appear on a later page are simplified versions of what you have learned from the textbook. They will help to give the “total picture” of where each analysis is and where it is heading. Read the directions carefully, and read the paragraphs that give the notes or chemical theory for each step. Don’t just follow directions “cook book” style, but make an effort to understand the chemical principles behind the procedures.

### Heating Solutions

Frequently it will be necessary to heat a solution to speed up a reaction. Do NOT heat small test tubes over Bunsen burner flames. A sudden steam bubble will cause the solution to shoot out of the test tube. Instead, heat test tubes in a boiling water bath. A good idea is to set up this bath when beginning work in the lab because it may take time to heat the bath to the appropriate temperature.

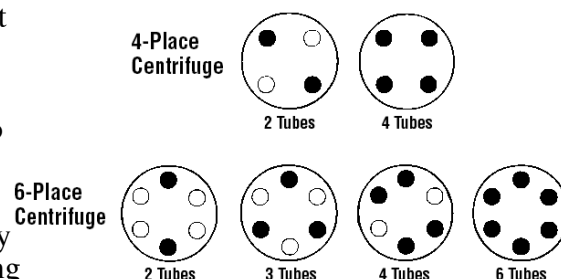
**Stirring Solutions**

Each time a reagent is added to a test tube, the solution needs to be stirred. It is important to mix the solutions at the top and the bottom of the test tube. A stirring rod that is flattened at the bottom can be used as a plunger to effectively mix solutions in narrow test tubes.

**Separating Solids from Solutions**

Centrifuge solutions so that the solid is packed at the bottom of the test tube. Don't forget to counterbalance the test tubes in the centrifuge with similar test tubes holding equivalent volumes of liquid (Figure 1). Let the centrifuge spin for about 30 seconds. Usually the supernatant liquid (the liquid above the precipitate) can be poured off of the precipitate. Sometimes precipitates tend to float on the surface of the solution. If this is the case, use a Beral-type pipet to draw off the supernatant liquid. It is better to leave a little liquid over the precipitate than to transfer some of the precipitate.

- Never fill centrifuge tubes to capacity. Keep liquid levels at least 1 cm from the top.
- Label all centrifuge tubes before inserting to avoid mix-up.
- Place tubes in a symmetrical fashion, the objective being to keep the rotor balanced. Fill all tubes to the same height.
- Follow manufacturer's directions.
- If only one tube needs to be centrifuged, achieve balance by inserting an additional tube (labeled as a "blank") containing the same volume of liquid.



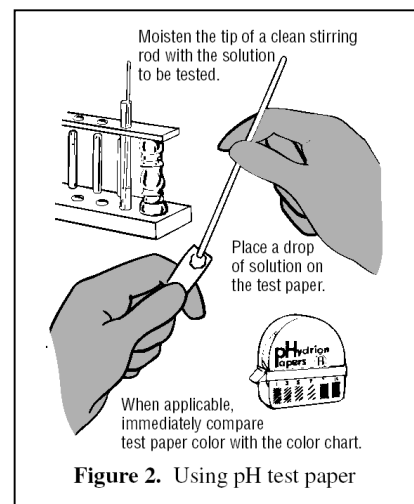
**Figure 1.** How to safely load and use a centrifuge.

**Washing Precipitates**

It is almost always necessary to wash precipitates to free them from ions that might cause confusion in later steps. To do this, add 1 or 2 mL of water to the precipitate, stir, centrifuge, and discard the wash water. Sometimes the directions will require a specific reagent in the wash water.

**Checking the pH**

To check the pH of a solution, put a piece of litmus paper or pH paper on a clean glass plate or watch glass. Dip the stirring rod into the solution in the test tube, and touch the stirring rod to the paper (see Figure 2). Do NOT dip the test paper into the test tube. This may cause some of the indicator dye to dissolve in the solution, and the indicator colour may confuse subsequent tests.

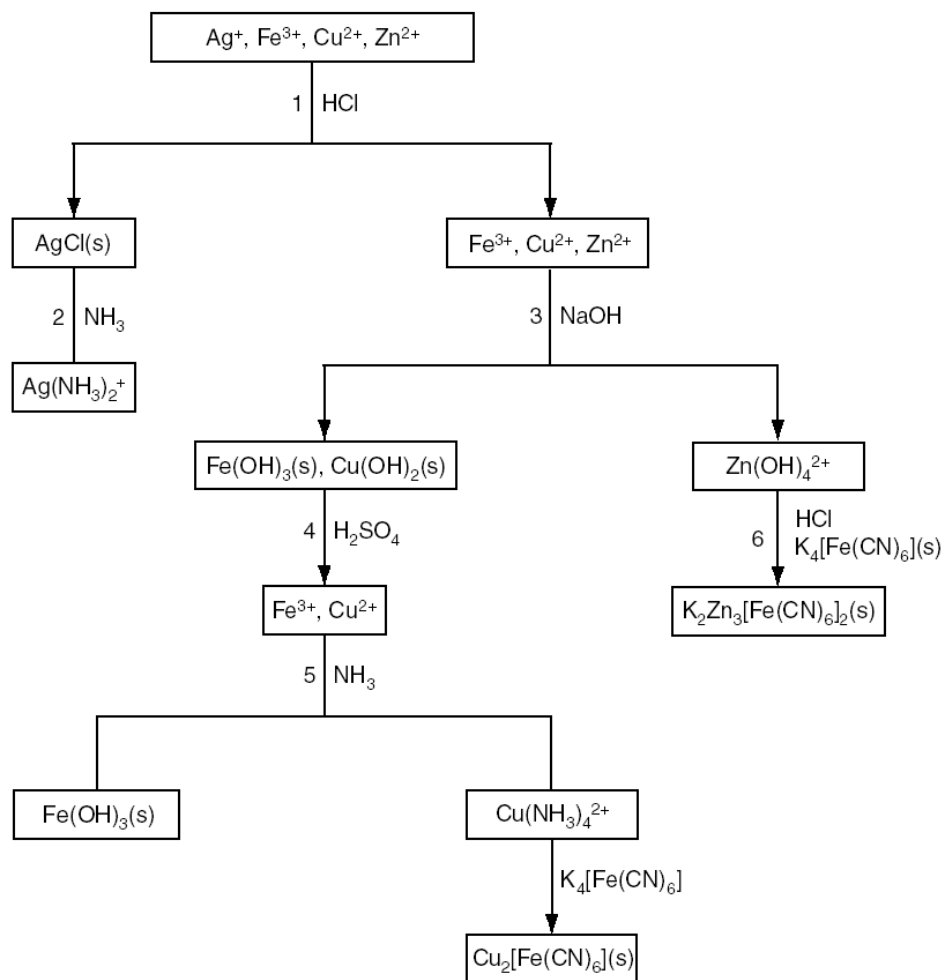


**Figure 2.** Using pH test paper

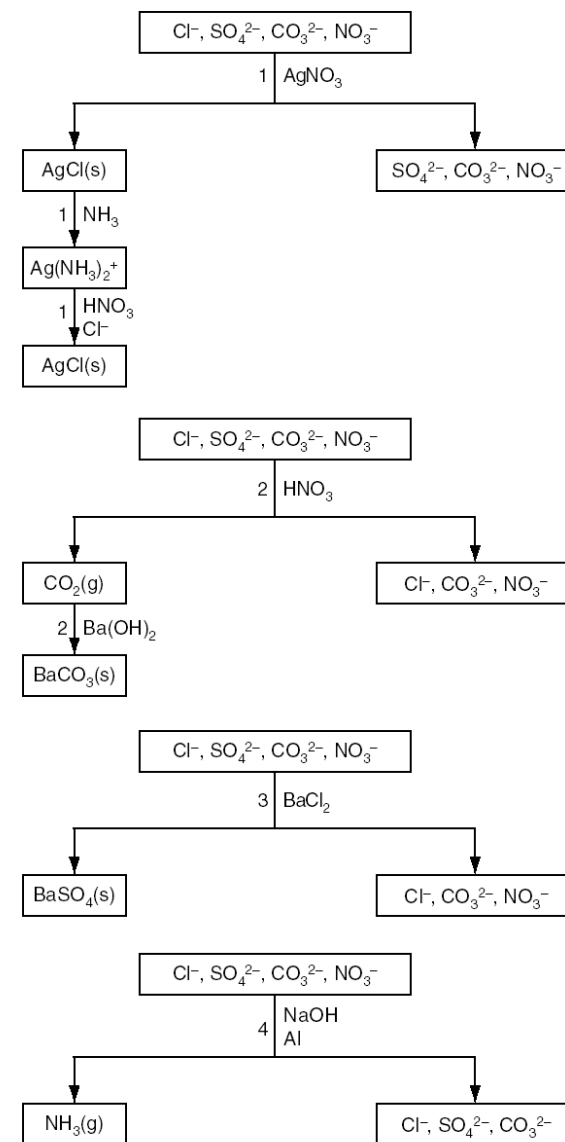
**Safety Precautions**

*Silver nitrate solution is mildly toxic and irritating to body tissue. It also stains skin and clothing. Copper (II) nitrate solution is mildly toxic. Zinc nitrate solution is mildly toxic and is irritating to body tissue. Ferric nitrate solution is irritating to body tissue. Barium hydroxide and barium chloride solutions are toxic by ingestion. Potassium thiocyanate solution is slightly toxic by ingestion. Avoid contact with concentrated acids since toxic hydrogen cyanide gas may be liberated. Concentrated ammonia (ammonium hydroxide) solution and hydrochloric acid solutions are toxic by inhalation, ingestion, and are corrosive to all body tissues. Sulfuric acid solution and sodium hydroxide solution are severely corrosive to eyes, skin, and other tissue. Nitric acid solution is severely corrosive, a strong oxidant, and toxic by ingestion and inhalation. Acetic acid solution is a corrosive liquid. Wear chemical splash goggles, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.*

## Qualitative Analysis of Cations Flow Chart



## Qualitative Analysis of Anions Flow Chart



**Pre-Lab Questions**

Use the flow charts on the previous page to answer the following questions. In each question, a test is carried out to determine the presence or absence of several ions. Only those listed may be present. State if the tests indicate if each ion is present, absent, or undetermined.

1. Test for  $\text{Ag}^+$ ,  $\text{Cu}^{2+}$ ,  $\text{Fe}^{3+}$

Some 6 M HCl is added to a solution that may contain the three ions. A white precipitate forms.

Ions present: \_\_\_\_\_ Ions absent: \_\_\_\_\_ Ions undetermined: \_\_\_\_\_

2. Test for  $\text{Cu}^{2+}$ ,  $\text{Ag}^+$ , and  $\text{Zn}^{2+}$

Some 6 M HCl is added to a solution that may contain the three ions. No precipitate forms. The addition of 6 M NaOH until the solution is basic results in no formation of precipitate.

Ions present: \_\_\_\_\_ Ions absent: \_\_\_\_\_ Ions undetermined: \_\_\_\_\_

3. Test for  $\text{Cu}^{2+}$ ,  $\text{Fe}^{3+}$ , and  $\text{Zn}^{2+}$

6 M NaOH is added to a clear solution that may contain the three ions until the solution is basic. A dark precipitate forms. The precipitate totally dissolves in 6 M  $\text{H}_2\text{SO}_4$ . The addition of 6 M  $\text{NH}_3$  to this acidic solution until it is basic results in a clear solution containing a dark precipitate. The resulting dark precipitate completely dissolves in 6 M  $\text{H}_2\text{SO}_4$ .

Ions present: \_\_\_\_\_ Ions absent: \_\_\_\_\_ Ions undetermined: \_\_\_\_\_

4. Test for  $\text{CO}_3^{2-}$  and  $\text{Cl}^-$

Some 6 M  $\text{HNO}_3$  is added to the solution that may contain the above ions. Formation of bubbles is noted as the solution is heated.

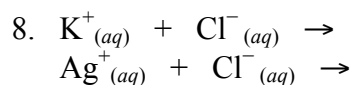
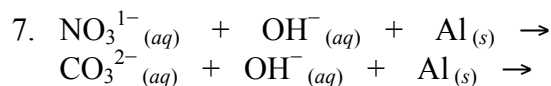
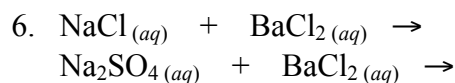
Ions present: \_\_\_\_\_ Ions absent: \_\_\_\_\_ Ions undetermined: \_\_\_\_\_

5. Test for  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{2-}$ , and  $\text{NO}_3^{1-}$

Addition of  $\text{AgNO}_3$  causes no precipitate to form. Addition of  $\text{BaCl}_2$  to fresh solution also causes no precipitate to form.

Ions present: \_\_\_\_\_ Ions absent: \_\_\_\_\_ Ions undetermined: \_\_\_\_\_

Only one of each of the following pairs of reactants undergoes a reaction. Complete and balance the equation for the reaction that occurs.



**Procedure:****Part A: Qualitative Analysis of Cations**

*Note that the following directions are written for a “known” solution that contains all of the cations. An “unknown” solution will probably not form all of the products described in this procedure. Make note of any differences in the “unknown” solution as it is analyzed.*

**1. Separation of the Silver from Iron, Copper, and Zinc Ions.**

- Add 8 drops of 6 M HCl to the solution to be analyzed. Stir. A white precipitate indicates that the  $\text{Ag}^+$  ion is present.
- Centrifuge the solution and test to be sure that precipitation is complete by adding one more drop of 6 M HCl. No additional precipitate should form. If more precipitate does form, continue adding 6 M HCl until precipitation is complete.
- Centrifuge, decant (pour off), and save the clear liquid into a second test tube for procedure #3. Alternatively, use a Beral-type pipet to draw off the supernatant liquid to transfer it to another test tube.
- Wash the precipitate by adding 1 mL distilled water and stirring. Centrifuge and discard the wash water. Save the precipitate for procedure #2.

**2. Confirmation of Silver.**

- To the precipitate from procedure 1d, which is AgCl, add 1 mL 6 M  $\text{NH}_3$ .
- Stir until the precipitate completely dissolves.
- Add 15 drops of 6 M HCl to the solution. The solution will smoke and the reaction between the strong acid and the base will give off heat whether or not silver is present. The test tube may get very warm.
- Stir and test with pH indicator paper or litmus paper to be sure the solution is acidic. If it is not acidic, add more HCl. The reappearance of the white AgCl precipitate in the acidic solution confirms the presence of silver.
- Dispose of the silver compound as directed by the instructor.

**3. Separation of Iron and Copper from Zinc.**

- To the solution saved from procedure 1c, add, with stirring, 6 M sodium hydroxide, NaOH, until the solution is basic and then add 3 more drops.
- Stir and place the test tube in a hot water bath for 3 minutes. The formation of a precipitate indicates the presence of either copper or iron or both.
- Centrifuge the solution, and separate the clear solution from the solid. Save the clear solution, which may contain  $\text{Zn}(\text{OH})_4^{2-}$  ions for procedure #6.
- Wash the precipitate with a mixture of 10 drops of 6 M NaOH and 10 drops of water.
- Centrifuge and discard the wash water. Save the precipitate for procedure #4.

**4. Separation of Iron from Copper; Confirmation of Copper.**

- To the precipitate from procedure 3, add 5 drops of water.
- Add 6 M  $\text{H}_2\text{SO}_4$  dropwise until the solution is acidic when tested with litmus paper (about 6 drops). Stir to dissolve precipitate.
- To the solution, add 6 M aqueous  $\text{NH}_3$  until the solution is basic to litmus, and then add 1 mL extra.
- Centrifuge and separate the supernatant liquid from the precipitate. Save the precipitate for procedure #5. The presence of the blue  $\text{Cu}(\text{NH}_3)_4^{2+}$  ion is the confirmatory test for copper.
- For an additional confirmatory test, to the solution containing the  $\text{Cu}(\text{NH}_3)_4^{2+}$  add 6 M  $\text{CH}_3\text{COOH}$ , acetic acid, until the blue colour fades and the solution becomes acidic. Then add 2 drops of 0.1 M  $\text{K}_4[\text{Fe}(\text{CN})_6]$ . A red-brown precipitate of  $\text{Cu}_2[\text{Fe}(\text{CN})_6]$  reconfirms the presence of copper.
- Dispose of the copper solution as directed by the instructor.

**5. Confirmation of Iron.**

- Wash the precipitate of iron hydroxides from procedure **4d**.
- Add 6 M  $\text{H}_2\text{SO}_4$  dropwise until the precipitate dissolves.
- To the solution add 5 drops of 0.1 M  $\text{KSCN}$  solution. The deep red  $\text{FeSCN}^{2+}$  ion confirms the presence of iron.
- Dispose of the iron solution as directed by the instructor.

**6. Confirmation of Zinc.**

- Make the solution from procedure **3c** slightly acidic by adding 6 M  $\text{HCl}$  dropwise.
- Add 3 drops of 0.1 M  $\text{K}_4[\text{Fe}(\text{CN})_6]$  and stir.
- Centrifuge to see the confirmatory precipitate of  $\text{K}_2\text{Zn}_3[\text{Fe}(\text{CN})_6]_2$  which will be white to light green or blue green in colour.
- Dispose of the zinc precipitate and solution as directed by the instructor.

7. Repeat steps #1 – #6 for the cation unknown sample. Be sure to record the results for each step.

**Part B: Qualitative Analysis of Anions**

Obtain both the anion standards sample and the unknown anions sample. As with the analysis of cations, record the results of each step in the Anion Data Table.

**1. Separation of the Chloride ( $\text{Cl}^-$ ); Confirmation of Chloride.**

- Place 10 drops of the original test solution (or unknown solution) in a test tube. Test to see if the solution is acidic. If it is not, add 6 M acetic acid,  $\text{CH}_3\text{COOH}$ , dropwise with stirring until the solution is acidic.
- Add 10 drops of 0.1 M silver nitrate,  $\text{AgNO}_3$ . A precipitate of  $\text{AgCl}$  will form.
- Centrifuge and pour off the supernatant liquid.
- Wash the solid with 0.5 mL distilled water, centrifuge and discard the wash water.
- Add 0.5 mL 6 M ammonia,  $\text{NH}_3$ , to the precipitate. Stir to dissolve any  $\text{AgCl}$ .
- Centrifuge, and pour the supernatant liquid into another test tube to test for chloride ion.
- Add 1 mL 6 M nitric acid,  $\text{HNO}_3$ , to the solution containing the dissolved silver chloride. The solution will get hot and smoke from the reaction with the excess ammonia whether or not silver chloride is present.
- Test with litmus or pH paper to see if the solution is acidic. If it is not, add more  $\text{HNO}_3$  until the solution is acidic. The appearance of the white precipitate of  $\text{AgCl}$  in the acidic solution confirms the presence of chloride.

**2. Confirmation of Carbonate.**

- Place 2 mL of clear, saturated  $\text{Ba}(\text{OH})_2$  solution in a test tube to be available for the test with carbon dioxide.
- Place 1 mL of the original test solution (or unknown solution) in a different test tube.
- Acidify this solution by adding 0.5 mL of 6 M  $\text{HNO}_3$ .
- Place the tube in a hot water bath and observe to see if any gas bubbles form.
- Take a dry Beral-type pipet and squeeze the bulb closed. Place the tip of the pipet close to (but not touching) the surface of the liquid in the test tube and slowly release the bulb to draw escaping carbon dioxide into the pipet.
- Put the pipet into the barium hydroxide solution, and slowly squeeze the bulb, causing the gas in the pipet to bubble through the barium hydroxide solution. This procedure may be repeated. The formation of a cloudy white precipitate of barium carbonate confirms the presence of carbonate ion in the original solution.

**3. Confirmation of Sulfate.**

- Place 0.5 mL of the original test solution (or unknown solution) in a test tube.
- Add 6 M nitric acid,  $\text{HNO}_3$ , dropwise until the solution is acidic.
- Add 0.5 mL 0.1 M  $\text{BaCl}_2$  solution. The formation of a white precipitate of  $\text{BaSO}_4$  confirms the presence of sulfate.

**4. Confirmation of Nitrate.**

- Place 1 mL of the original test solution (or unknown solution) in a test tube.
- Add 6 M  $\text{NaOH}$  dropwise until the solution is basic, and then add 6 drops in excess.
- Use a Beral-type pipet to transfer the solution to the bottom of a dry test tube without getting the walls of the test tube wet with solution.
- Add the tip of a spatula containing aluminum granules.
- Place a small cotton wad loosely about halfway down the test tube, but not touching the solution. This is to prevent spattering of the solution onto the litmus paper.
- Hang a piece of moist red litmus paper (or pH paper) in the tube so that the bottom of the paper is close to (but not touching) the cotton.
- Warm the solution in a hot water bath until it starts bubbling strongly. Be sure that the solution and the cotton do not touch the litmus paper.
- Allow the solution to cool. A slow colour change (within 3 to 5 minutes) of the litmus from pink to blue, starting at the bottom and spreading to the top, indicates the evolution of ammonia and confirms the presence of nitrate ion in the original solution.

5. Repeat anion procedures #1 – #4 for the anion unknown sample.

**Observations:****Part A: Qualitative Analysis of Cations**

Cations Unknown #: \_\_\_\_\_

Step	Procedure (Be Specific)	Known Solution		Unknown Solution
		Results	Conclusion	Results
1.				
2.				
3.				
4.				
5.				
6.				

**Part B: Qualitative Analysis of Anions**

Anions Unknown #: \_\_\_\_\_

Step	Procedure (Be Specific)	Known Solution		Unknown Solution
		Results	Conclusion	Results
1.				
2.				
3.				
4.				

**Analysis:****Part A: Qualitative Analysis of Cations**

Identify the cations present in the unknown cation solution.

**Part B: Qualitative Analysis of Anions**

Identify the anions present in the unknown anion solution.

**Evaluation:**

- Write out the balanced net ionic equations for all the observations in the analysis of the known cation solution. (There should be a total of 15 equations.) Indicate the colour of the ions and precipitate underneath the chemical species. Consult your textbook, this lab handout, your notes or the Internet.
- Write out the balanced net ionic equations for all the observations in the analysis of the known anion solution. (There should be a total of 7 equations. The last one is a redox reaction and it is written out for you – see #6 below) Indicate the colour of the ions and precipitate underneath the chemical species. Consult your textbook, this lab handout, your notes or the Internet.
- What is the precipitating reagent for silver ( $\text{Ag}^+$ )? Would a solution of NaCl work as well? Why or why not?
- During the analysis of the anions, in step 3,  $\text{Ba}^{2+}$ , is added to the solution containing all six of the anions and precipitates  $\text{BaSO}_4$ , but not  $\text{BaCO}_3$ . However, in step 2, the precipitation of  $\text{BaCO}_3$  is the confirmatory test for carbonate ion. Why doesn't  $\text{BaCO}_3$  precipitate in step 3 but does in step 2?
- In the nitrate test, why must care be taken to keep the moist litmus from coming in contact with the cotton or the solution?
- (Bonus) Write separate oxidation and reduction half-reactions for the procedure used in the test for nitrate ions.  
(The full redox equation is:  $3 \text{NO}_3^{1-}, (aq) + 8 \text{Al} (s) + 5 \text{OH}^- (aq) + 18 \text{H}_2\text{O} (l) \rightarrow 3 \text{NH}_3 (aq) + 8 \text{Al}(\text{OH})_4^{1-}, (aq)$ )

**Conclusion:**

Summarize what you have learned from this lab.