Chemical Solutions Incorporated (CSI) has earned a contract from the City of Augusta, which is trying to identify the source of metal contamination detected in the Kennebec River. Excessively high levels of the heavy metal cations Ag⁺, Cu²⁺, Fe³⁺, Cr³⁺, Zn²⁺, and Ba²⁺ have been detected in the region of the Augusta State House, which has concerned legislators thinking about the possible impact of the contamination on tourism in the area, especially the Great Whatever Race. The businesses that are likely suspects for contributing one or more heavy metal cations to the river water (Figure 1) are: Smiley’s Photo Studio (1), Callie’s Computer Chips (2), Central Maine Medical Testing (3), Peaceful Valley Funeral Home (4), Axel’s Auto Body & Repair (5), Evergreen Paper Mill (6), Monet’s Art Restoration (7), Stay Dry Cleaners (8), and Call of the Wild Taxidermy (9).

CSI’s research team has compiled a useful summary below on inorganic qualitative analysis, which can be used to detect ions present in a water sample. We will use these methods to separate and identify the presence (or absence) of the relevant cations in river water samples collected near each of the suspect facilities that have been provided by the City of Augusta. Additionally, the City would like an easy to follow, effective qualitative analysis scheme that they can use to monitor the river water for these cations from now on.

Therefore, every CSI investigator will develop a qualitative analysis scheme to separate each cation and confirm its identity. This scheme will be used to test water samples taken from two of the nine possible pollution sites. For the separation and detection of the cations in question, you will use reactions that involve different tendencies of these ions to precipitate, form complex ions, or display amphoteric behavior. To familiarize yourself with these different chemical properties, you will first do standard tests to observe the characteristic behavior of each cation before testing the river samples.

Qualitative Analysis Summary

I. Sparingly Soluble Salts

Some cations form relatively insoluble salts that precipitate out of aqueous solution. For example, chloride salts are generally soluble with the notable exceptions of the salts containing Ag⁺, Pb²⁺, and Hg₂⁺. Similarly, most sulfate salts are soluble except BaSO₄, PbSO₄, Hg₂SO₄, and CaSO₄. The formation of a precipitate upon introduction of chloride or sulfate ions into solution would therefore be a positive test for Ag⁺ or Ba²⁺, respectively.

Most hydroxide salts are insoluble. For example, the solubility of Fe³⁺ in basic solution is governed by the reaction shown in eq 1, from which the corresponding equilibrium constant expression can be derived (eq 2). The equilibrium constant for the reaction $K_{sp}$ is $6.3 \times 10^{-38}$, which says that Fe(OH)₃ is sparingly soluble under
most conditions. Equation 2 can be solved for the solubility of Fe\(^{3+}\) in solution (eq 3). Equation 3 says that the solubility of Fe\(^{3+}\) rapidly decreases as the solution becomes more basic ([OH\(^-\)] increases). Indeed, for hydroxide concentrations greater than 10\(^{-11}\) M (pH > 3), Fe\(^{3+}\) is relatively insoluble. Therefore, in a qualitative analysis scheme (or “qualitative analysis scheme”) Fe\(^{3+}\) may be removed from solution by making the solution basic, thereby precipitating Fe(OH)\(_3\). This precipitate can be removed from solution by centrifugation.

\[
\text{Fe(OH)}_3 (s) \rightleftharpoons \text{Fe}^{3+} (aq) + 3 \text{OH}^- (aq) \quad (1)
\]

\[
K_{sp} = [\text{Fe}^{3+}][\text{OH}^-]^3 \quad (2)
\]

\[
\text{solubility} = [\text{Fe}^{3+}] = \frac{K_{sp}}{[\text{OH}^-]^3} \quad (3)
\]

However, other cations for which you are testing also form insoluble hydroxides. Therefore, the addition of base to a mixture of cations may precipitate other metal hydroxides in addition to Fe(OH)_3. For example, if Zn\(^{2+}\) is also present, the analogous reaction and relationships hold (eqs 4-6)

\[
\text{Zn(OH)}_2 (s) \rightleftharpoons \text{Zn}^{2+} (aq) + 2 \text{OH}^- (aq) \quad (4)
\]

\[
K_{sp} = [\text{Zn}^{2+}][\text{OH}^-]^2 = 4.5 \times 10^{-17} \quad (5)
\]

\[
\text{solubility} = [\text{Zn}^{2+}] = \frac{K_{sp}}{[\text{OH}^-]^2} \quad (6)
\]

At hydroxide concentrations greater than 10\(^{-6}\) M (pH > 8), both Fe\(^{3+}\) and Zn\(^{2+}\) are insoluble and would coprecipitate as their hydroxides. In theory, one might be able to adjust the pH to the range where Fe\(^{3+}\) will precipitate but Zn\(^{2+}\) will not, but in practice this approach works poorly. Alternative approaches to separating Fe\(^{3+}\) and Zn\(^{2+}\) are either to use the amphoteric nature of Zn(OH)_2 or the ability of Zn\(^{2+}\) to form complex ions as described below.

**II. Amphoteric Hydroxides**

Some metal-hydroxide precipitates dissolve in excess hydroxide solutions because of the formation of soluble hydroxide complex ions, as seen for Zn\(^{2+}\) in eq 7. Such hydroxides are called amphoteric hydroxides because they will react with and dissolve in both acid and base. The equilibrium constant for this reaction is very product-favored (K = 2 \times 10^{20}). Therefore, Zn(OH)_2 solids will form when small amounts of a strong base are added to a Zn\(^{2+}\)-containing solution, but the continued addition of strong base will dissolve that precipitate as [Zn(OH)_4]\(^2-\) is formed. This amphoteric behavior is useful in qualitative analysis. Thus, if excess base is added to a mixture of Fe\(^{3+}\) and Zn\(^{2+}\) ions, Fe(OH)_3 will precipitate but the soluble [Zn(OH)_4]\(^2-\) will remain in solution to separate Fe\(^{3+}\) and Zn\(^{2+}\). Note that Cr\(^{3+}\) forms a similar soluble species [Cr(OH)_4]\(^-\) in the presence of excess base.

\[
\text{Zn(OH)}_2 (s) + 2 \text{OH}^- (aq) \rightleftharpoons [\text{Zn(OH)}_4]^{2-} (aq) \quad (7)
\]
III. Complex Ion Formation

The formation of other complexes ions can also be useful. For example, Cu$^{2+}$ and ammonia react to form the complex ion $[\text{Cu(NH}_3)_4]^{2+}$ (eq 8) with a large equilibrium constant ($K = 4.8 \times 10^{12}$), showing that the formation of $[\text{Cu(NH}_3)_4]^{2+}$ is very favorable. The utility of ammonia in qualitative analysis schemes can be shown by the behavior of a mixture of Fe$^{3+}$ and Cu$^{2+}$ ions. If concentrated ammonia (a basic solution because ammonia is a weak base, eq 9) is added to a solution containing Fe$^{3+}$ and Cu$^{2+}$ ions, Fe(OH)$_3$ will precipitate in the presence of base (eq 1) and the soluble complex ion $[\text{Cu(NH}_3)_4]^{2+}$ will remain in solution, separating the Fe$^{3+}$ and Cu$^{2+}$ ions.

$$ \text{Cu}^{2+} (\text{aq}) + 4 \text{NH}_3 (\text{aq}) \rightleftharpoons [\text{Cu(NH}_3)_4]^{2+} (\text{aq}) \quad (8) $$

$$ \text{NH}_3 (\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ (\text{aq}) + \text{OH}^- (\text{aq}) \quad (9) $$

IV. Oxidation-Reduction Reactions

Oxidation reactions can also play a role in qualitative analysis. All of the ions for which you are testing are in their maximum aqueous oxidation state except Cr$^{3+}$. Therefore, we can use a basic solution containing hydrogen peroxide to generate a good oxidizing agent, OOH$^-$, (eq 10) which can oxidize Cr$^{3+}$ to soluble chromate ion (CrO$_4^{2-}$). Chromate ion is brightly colored and therefore the oxidation of Cr$^{3+}$ is a good visual test for chromium.

$$ \text{H}_2\text{O}_2 + \text{OH}^- (\text{aq}) \rightleftharpoons \text{OOH}^- (\text{aq}) + \text{H}_2\text{O} \quad (10) $$

V. The Presence of Colored Ions

A preliminary examination of an unknown that may contain a colored cation can yield valuable information. Three of the cations for which you are testing are colored: Fe$^{3+}$ (rust or yellow), Cr$^{3+}$ (blue-green), and Cu$^{2+}$ (aqua). If the solution is colorless, you know immediately that these three ions are either absent or present in extremely low concentrations. However, in your role as a highly paid consultant, be aware that clues can sometimes be misleading. For example, if Fe$^{3+}$ and Cu$^{2+}$ are both present, what color would you observe? Undoubtedly, the color depends on the proportions of each cation present.

Pre-Laboratory Assignments

Besides the usual outline of the experiment in your lab notebook for week one, please do the following.

Week 1 Due March 30th, Friday, before 9 AM. For each reaction given in Appendix 1, write the appropriate balanced chemical equation. Remember a balanced chemical equation has both moles and charges balanced. Print Appendix 1 and write the appropriate coefficients directly on the sheet, attaching any work you did to balance the reactions. Must show work for full credit.

Week 2 Due at the beginning of your lab period April 9th-13th instead of a procedure (written directly in your lab notebook). Use your observations and the provided reference sheet from Week 1 to devise a qualitative analysis scheme that will both separate and uniquely identify the six cations individually.

1. This scheme should take advantage of the solubility differences among the salts, hydroxides, and complexes, the redox properties of the metal cations, and include all the confirmatory tests.
2. Your task is to design a qualitative analysis scheme of separation and identification that is effective, that entails the fewest steps, and that achieves the cleanest separations.
3. Your qualitative analysis scheme should be presented as a top down design (as shown in the example below).

4. A confirmation test can only be used to confirm a cation is present/absent. It cannot be used to separate a cation from the other cations.

5. This flow diagram should reference the appropriate balanced chemical reactions that you prepared for Week 1.

An example qualitative analysis scheme for a different set of cations and test reagents than the ones you’ll use is shown in Figure 2 (without the balanced equations, to save room). The better prepared you are before lab the more success you will have when using your scheme on the two river water samples! An incomplete scheme will eat up your valuable time and lead you to incorrect or unsubstantiated conclusions. To be fair to all investigators no one will be allowed to work past the end of the lab period. Thus, all of your lab work must be completed during your lab period and results turned in before 4 PM for afternoon lab, by 11AM for morning lab.

![Sample separation scheme](image)

**Experimental Procedure**

**I. Techniques**

- **Addition of Reagents.** Always use a dropper or capillary pipette when adding a small quantity of a liquid to a test tube or other vessel. One mL is about 20 drops. If a reagent bottle has a dropper, replace it promptly after use. Do not allow the dropper to touch the container or solution to which you are adding the dropper’s
contents. Do not set the dropper down on the bench top or another surface, and be sure to return it to the right bottle. Always mix thoroughly after adding reagent.

- **Precipitation** To detect the formation of a precipitate on mixing two solutions, it is essential that both solutions be initially clear; if necessary, centrifuge to clarify. A “clear” solution is transparent but not necessarily colorless.

  After adding a reagent to bring about precipitation, **always** test for complete precipitation if the purpose is to separate one substance from another. Suppose, for example, that a solution contains 0.10 millimole of Ba\(^{2+}\). We add to this solution a few drops of dilute H\(_2\)SO\(_4\), and the amount happens to contain 0.08 millimole of SO\(_4^{2-}\). We have thus produced 0.08 millimole of solid BaSO\(_4\), but 0.02 millimole of Ba\(^{2+}\) remains in the supernatant liquid, because we did not add enough H\(_2\)SO\(_4\) to precipitate all the Ba\(^{2+}\) as BaSO\(_4\).

  This fact can be discovered by centrifuging and adding another drop of reagent (dilute H\(_2\)SO\(_4\) in this case) to the clear supernatant. If precipitation is complete, no additional precipitate will form. However, if insufficient reagent was added the first time, the additional drop will cause formation of more precipitate. If more precipitate is observed, add several more drops of reagent, centrifuge, and again test for completeness of precipitation. Repeat until no precipitate is formed on adding reagent.

  After the precipitate and supernatant are separated, the precipitate is washed by adding a few drops of the washing reagent (usually water), mixing thoroughly with a stirring rod, centrifuging, and removing the washings with a capillary pipette. Two or more washings are generally necessary to prevent contamination of the precipitate. **Failure to wash precipitates is one of the most common sources of error in qualitative analysis.**

- **Transfer of Precipitates** The easiest way to transfer a residue from one container to another is to mix the residue with small amounts of washing liquid and pour the suspension quickly into the new container. Repeat this two or three times to get complete transfer. For small volumes, draw the suspension into a pipette for transfer.

- **Heating of Solutions** To avoid excessive evaporation use a water bath. Always stir when heating test tubes. A water bath with an aluminum test tube holder will be set up for you in your fume hood. Place your test tubes into the pre-labeled positions and heat the water to a gentle boil.

- **Adjusting Acidity** Always stir well when adding acid or base. To test the pH of the solution, apply a drop onto litmus paper. *Never dip the paper into the solution.*

### II. Available Equipment

- **Centrifuge** The centrifuge is used to speed up the separation of a precipitate from a liquid. When a mixture of solid and liquid is placed in a tube and rotated at high speed in a centrifuge, the more dense precipitate is forced to the bottom of the tube by a centrifugal force that is many times greater than the force of gravity. After centrifuging, the *supernatant*, or clear liquid above the precipitate, can easily be poured off or withdrawn with a capillary (Pasteur) pipette. The centrifuge may be damaged if allowed to run unbalanced. Insert your test tubes in opposite positions in the centrifuge, noting their locations by number. Set the machine in motion for one minute, which should be sufficient to achieve effective separation of the solid from the liquid. Allow the centrifuge to stop spinning before trying to remove your test tubes.

- **Vortex Mixer** This motorized mixer can be used to ensure complete homogeneity after reagent addition. Simply place your test tube in the cup at the top and gently but firmly press down to achieve mixing.
III. Available Chemicals

<table>
<thead>
<tr>
<th>Standards</th>
<th>Test Reagents</th>
<th>For Confirmatory Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 M AgNO₃</td>
<td>3 M HCl</td>
<td>6 M acetic acid</td>
</tr>
<tr>
<td>0.2 M Cu(NO₃)₂</td>
<td>6 M NH₃</td>
<td>0.2 M K₄Fe(CN)₆</td>
</tr>
<tr>
<td>0.2 M Fe(NO₃)₃</td>
<td>6 M NaOH</td>
<td>0.2 M KNCS</td>
</tr>
<tr>
<td>0.2 M Cr(NO₃)₃</td>
<td>3 M H₂SO₄</td>
<td></td>
</tr>
<tr>
<td>0.2 M Zn(NO₃)₂</td>
<td>3% H₂O₂</td>
<td></td>
</tr>
<tr>
<td>0.1 M Ba(NO₃)₂</td>
<td>15 M NH₃ (to be used in front fume hood only)</td>
<td></td>
</tr>
</tbody>
</table>

IV. Development of Scheme-Week 1, April 2nd to April 6th

Before you receive the river water sample, you will study the properties of the individual cations Ag⁺, Cu²⁺, Fe³⁺, Cr³⁺, Zn²⁺, and Ba²⁺ in order to develop a qualitative analysis scheme. You will use the provided individual solutions of known cations and complete the tests outlined below to see how each cation behaves. Carefully and completely record all of your observations (precipitates, dissolving of precipitates, colors, etc.) in your notebook so that you are able to use this information to identify the cations present in your sample of river water next week!

SEPARATION TESTS:

1. Before doing any tests, record the color of each cation solution.

2. Precipitation of Chlorides with Dilute HCl. In a spot plate add 10 drops of each cation solution to a different well. To each cation add a few drops of 3 M HCl and record observations. **Caution:** Never treat chlorides with strong oxidizing agents. Chlorine gas may be produced.

3. Precipitation of Hydroxides. You will produce hydroxide precipitates of some of the cations; save these precipitates for later tests.
   
   A) In a set of 6 test tubes, each containing 10 drops of one of the cations, add 15 drops of water and 1 drop of 6 M NaOH solution. Mix. If no precipitate forms, test the solution with litmus paper. If the solution is still acidic, add 6 M NaOH until the solution is just basic. (Addition of too much NaOH may cause the amphoteric hydroxides to redissolve.) Observe each solution carefully and record what each looks like, before versus after. Take the test tubes with precipitates, centrifuge, and discard the supernatant from each. Keep the remaining precipitate of each for the “…Excess NaOH” test 4 below. All other test tubes can be cleaned for re-use.

   B) In a set of six clean test tubes, each containing 10 drops of one of the cations, add 15 drops of water and 1 drop of 6 M NH₃ solution. Mix. If no precipitate forms, test the solution with litmus paper. If the solution is still acidic, add more 6 M NH₃ until the solution is just basic, then add two more drops. (Addition of too much NH₃ may cause the cations that form NH₃ complexes to redissolve.) Observe each solution carefully and record what each looks like, before versus after. Take just the test tube of iron, centrifuge, and discard the supernatant. Keep the iron precipitate for the “Confirmatory Test for Iron” (test 11). All other test tubes can be cleaned for reuse.

4. Amphoteric Nature of the Hydroxides: Excess NaOH. Amphoteric hydroxides will dissolve in excess base. To the hydroxide precipitates from test 3A, add 6 drops of 6 M NaOH solution. Vortex well to mix. Observe to see which, if any, of the precipitates dissolve and record observations for all test tubes.
5. **Ability to Form Coordination Complexes with NH₃: Excess NH₃.** In six clean test tubes, each containing 10 drops of one of the cations dip a glass rod to test the pH on litmus paper. If any solution is acidic, add 1 drop 6 M NH₃ to that test tube to make the solution just basic (add more if necessary). Then go to the large fume hood (up front) to add 20 drops (1mL) of 15 M NH₃ and mix. Make a note of which cations do and do not change. The contents of these test tubes will not be used again later, so empty them into the labeled container, then clean and re-use the test tubes.

6. **Precipitation of Sulfates with Dilute Sulfuric Acid.** In a spot plate test each cation by adding a few drops of 3 M H₂SO₄ to 10 drops of a cation solution in a different well. Do not let the H₂SO₄ dropper touch the cation solutions! Mix with a stir rod and then record observations for all six cations. Clean the spot plate.

7. **Oxidation with Alkaline Hydrogen Peroxide.** To six clean test tubes, add 10 drops of each cation solution, then 6 M NaOH drop by drop until the solution is just basic. Add another 6 drops of 6 M NaOH, then 10 drops of 3% H₂O₂. Mix. Record what each looks like. Heat for 3 minutes in a boiling water bath. Mix. Record what each one looks like. Note the results that differ from tests 2 and 3A. (In this step some of the precipitates change color but do not dissolve. This color change is probably due to the thermal decomposition of the hydroxide to an oxide.) Save the chromium test tube for the ‘Confirmatory Test for Chromium” (test 8 below), all other test tubes can be cleaned for re-use.

**CONFIRMATION TESTS:**

8. **Confirmatory Test for Chromium.** After separation test 7 above, which oxidized Cr³⁺ to chromate and formed a yellow solution, add 6 M acetic acid until the solution is barely acidic. Then add 10 drops of the Ba(NO₃)₂ ion solution. Mix. The precipitate should be yellow if CrO₄²⁻ is present. Record your observation. If you are doing this test on a mixture of cations and you added excess sulfate earlier, some BaSO₄ (a white precipitate) will also form. To avoid this problem, if you do not have Ba²⁺ in your unknown, it is not necessary to perform the separation step using sulfuric acid prior to this test. This test can also be used in your qualitative analysis scheme if you need to precipitate CrO₄²⁻ from solution. Just remember that this test doesn’t work with Cr³⁺; you must oxidize Cr³⁺ to CrO₄²⁻ first.

9. **Confirmatory Test for Zinc.** When added to a slightly acidic solution containing zinc ions, ferrocyanide [Fe(CN)₆⁴⁻], properly called hexacyanoferrate(II)] produces a whitish precipitate that is quite satisfactory as a test for zinc. To observe this reaction, put 10 drops of zinc solution into a test tube. Test the pH with litmus paper to make sure it is acidic. If it is not, add 6 M acetic acid drop wise until it is barely acidic. Add 5 drops of 0.2 M potassium ferrocyanide solution [K₄Fe(CN)₆] and mix. A white or off-white precipitate confirms the presence of zinc. Record your observation.

10. **Confirmatory Test for Copper.** Copper ions can be detected in very dilute solutions by forming the brick-red species Cu₂Fe(CN)₆. To observe this reaction, put 10 drops of copper solution into a test tube. Test the pH with litmus paper to ensure that it’s acidic. If necessary, add 6 M acetic acid, a few drops at a time, testing with litmus, until the solution is just acidic. Then add 2 drops of 0.2 M potassium ferrocyanide solution [K₄Fe(CN)₆] and mix well. A brick red precipitate confirms the presence of copper. Record your observation.

**Important Note:** Try this test with Fe³⁺. Simply add about 10 drops each of the Fe(NO₃)₃ solution and the potassium ferrocyanide solution to a test tube. Observe and record. What does this tell you about the importance of separating ions prior to this test? Because multiple metal ions react with potassium
ferrocyanide to produce a precipitate, these ions must be separated in your scheme prior to using this test. If two or more are present in the solution of unknowns, then any dark precipitate will undoubtedly mask any lighter colored precipitates formed by other ions.

11. **Confirmatory Test for Iron.** After separation test 3B, add 1 mL (~20 drops) of 3 M H\(_2\)SO\(_4\) solution to the Fe(OH)\(_3\) precipitate. If the precipitate does not dissolve at once, heat it in the water bath until it does. Cool and add 4 drops of 0.2 M potassium thiocyanate (K\(_2\)SCN) solution. Record your observation. Remember the theater client? The deep red confirms the presence of iron(III). A pink color is not significant, since there is usually a trace of iron in the reagents used that is sufficient to produce a pink color.

Place your twelve cleaned test tubes in your lab drawer for re-use next week. Leave the spot plate and test tube rack on the lab bench.

Your goal for next week is to use your recorded observations to develop your own qualitative analysis scheme. This scheme should outline the procedure that you will follow to separate the six cations from one another and confirm or deny the presence of each. Note that the relevant reactions are provided in Appendix 1. **As you develop your scheme, you must pay careful attention to the sequence of reactions you perform.** For example, if you have already formed the soluble Cu(NH\(_3\))\(_4\)\(^{2+}\) species, then you cannot add NaOH to precipitate Cu\(^{2+}\) as Cu(OH)\(_2\). Make sure that you also include confirmatory tests in your scheme.

### V. Identification of Unknown Samples - Week 2 April 9\(^{th}\) - April 13\(^{th}\)

**A. Testing Your Scheme**

Prior to initiating work on the river water sample, you should test your scheme on known mixtures of the cations to make sure it works. Make up a solution containing some of the standard cation solutions and then run through your proposed scheme to see if it successfully detects all of the cations present. Try some of the tests on a spot plate instead of in test tubes. Initial testing of your unknown with spot plate tests can quickly rule out some cations, so that the steps that are designed to separate these cations can be eliminated from your procedure for that particular sample. For example, if you add H\(_2\)SO\(_4\) to your mixture in a spot plate and no precipitate appears, then there is no need to add it on a large scale to your unknown. Make sure to revise your separation scheme as necessary. Include approximate amounts and concentrations of test reagents in your final scheme.

**B. Testing the River Water Samples**

Once you have given your qualitative analysis scheme a test-drive, you can begin analysis of your river water samples, each of which will be designated by a number that can be linked to sites 1-9 on the provided map. Each sample is the effluent (comes directly out of the building via a pipe, into the Kennebec River) from one of the nine locations, not a mixture from different businesses. When working with your two river water samples, which we will refer to as “unknowns”, **START WITH 10 DROPS** of each and use about 5-10 drops of most reagents. Be sure that you do not need the supernatant before discarding it. Also, make certain that the total volumes do not exceed about 3 mL. Always test for complete precipitation; this precaution is especially important here, since no one has previously worked on your scheme with this unknown to determine what quantities of reagents are needed. Also test pH as the correct pH is vital for the success of many of these tests. Simplify your scheme as you go along. If you know that a certain cation is absent, either from spot plate tests or early steps in your scheme, then the steps involving that cation can be eliminated from your scheme. For example, if a spot plate test shows that Ag\(^{+}\) is absent, don’t bother to add HCl to your unknown. In your lab notebook, keep track of all your observations, including the amounts and concentrations of the test reagents you used. It is possible that the unknown solutions contain acid. When a basic reagent such as NH\(_3\) or NaOH is
added to an acidic solution, no result is to be expected until enough reagent has been added to neutralize the acid. Test with litmus paper to be sure that you have made the solution basic before you draw any conclusions. All identifications must be completed and turned in by 4 PM (for afternoon lab), by 11 AM (for morning lab).

C. Reporting the Results In-House

To verify your findings the Maine Bureau of Quality Assurance will conduct an ICP analysis of your two samples. ICP is the abbreviation for inductively coupled plasma emission spectroscopy. This instrument is used to analyze any liquid sample for cations. For instance, to get a housing loan through a bank the drinking water may be required to be tested for metals. It isn’t uncommon to be required to report iron, lead, arsenic, sodium, copper, and zinc concentrations and this is the instrument that does all of that in less than two minutes! Once you have identified the presence and absence of the six cations in each water sample, fill out the provided Internal Report Form. Clean up all of your test tubes and bring them to the collection area on the front lab table. Put your two unknown river water samples in the rack on the front table. Exchange your form for your copy of the in-house ICP results. Be sure to tape these results into your lab notebook to document the verification. Remember this is just an in-house confirmation that your qualitative analysis scheme is working. You would want to mention to your client that you have ICP verification.

Client Report

Prepare a ONE-PAGE typed letter summarizing your findings for the City of Augusta. Make sure to tell them the “unknown” numbers you worked on, the identity of each business, which metals the business did and did not come from this business. You should attach to this report the scheme that you used in your analysis so that the City of Augusta will be able to continue to monitor the water quality of the river after they impose a big fine on the offenders. The “source of error” discussion should pertain to the following: a) if any of your cation identifications were incorrect, discuss why that might be and warn your client how to avoid the same error in the future, b) if all of your conclusions were correct, caution the client how to avoid a particular example of possible misidentification. A professional looking qualitative analysis scheme is expected, thus it would include all relevant reactions, clearly indicate when to vortex or centrifuge, and tell the client which cations are present at each juncture (start to finish).
Appendix 1. Relevan Cation Reactions to balance for Pre-lab Assignment (due before 9am, March 30th)

1. $\text{Ag}^+ (\text{aq}) + \text{Cl}^- (\text{aq}) \rightarrow \text{AgCl} (\text{s})$
2. $\text{Ag}^+ (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{AgOH} (\text{s})$
3. $\text{Cu}^{2+} (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{Cu(OH)}_2 (\text{s})$
4. $\text{Fe}^{3+} (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{Fe(OH)}_3 (\text{s})$
5. $\text{Cr}^{3+} (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{Cr(OH)}_3 (\text{s})$
6. $\text{Zn}^{2+} (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{Zn(OH)}_2 (\text{s})$
7. $\text{Cu}^{2+} (\text{aq}) + \text{NH}_3 (\text{aq}) + \text{H}_2\text{O} \rightarrow \text{Cu(OH)}_2 (\text{s}) + \text{NH}_4^+ (\text{aq})$
8. $\text{Fe}^{3+} (\text{aq}) + \text{NH}_3 (\text{aq}) + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 (\text{s}) + \text{NH}_4^+ (\text{aq})$
9. $\text{Cr}^{3+} (\text{aq}) + \text{NH}_3 (\text{aq}) + \text{H}_2\text{O} \rightarrow \text{Cr(OH)}_3 (\text{s}) + \text{NH}_4^+ (\text{aq})$
10. $\text{Zn}^{2+} (\text{aq}) + \text{NH}_3 (\text{aq}) + \text{H}_2\text{O} \rightarrow \text{Zn(OH)}_2 (\text{s}) + \text{NH}_4^+ (\text{aq})$
11. \( \text{Cr}(\text{OH})_3 (s) + \text{OH}^- (\text{aq}) \rightarrow \text{Cr(OH)}_4^- (\text{aq}) \)

12. \( \text{Zn(OH)}_2 (s) + \text{OH}^- (\text{aq}) \rightarrow \text{Zn(OH)}_4^{2-} (\text{aq}) \)

13. \( \text{Cu(OH)}_2 (s) + \text{NH}_3 (\text{aq}) \rightarrow \text{Cu(NH}_3)_4^{2+} (\text{aq}) + \text{OH}^- (\text{aq}) \)

14. \( \text{Zn(OH)}_2 (s) + \text{NH}_3 (\text{aq}) \rightarrow \text{Zn(NH}_3)_4^{2+} (\text{aq}) + \text{OH}^- (\text{aq}) \)

15. \( \text{Ba}^{2+} (\text{aq}) + \text{SO}_4^{2-} (\text{aq}) \rightarrow \text{BaSO}_4 (s) \)

16. \( \text{Cr(OH)}_4^- (\text{aq}) + \text{H}_2\text{O}_2 (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{CrO}_4^{2-} (\text{aq}) + \text{H}_2\text{O} \)

17. \( \text{Zn}^{2+} (\text{aq}) + \text{K}^+ (\text{aq}) + \text{Fe(CN)}_6^{4-} (\text{aq}) \rightarrow \text{Zn}_2\text{K}_2[\text{Fe(CN)}_6]_2 (s) \)

18. \( \text{Cu}^{2+} (\text{aq}) + \text{Fe(CN)}_6^{4-} (\text{aq}) \rightarrow \text{Cu}_2\text{Fe(CN)}_6 (s) \)

19. \( \text{CrO}_4^{2-} (\text{aq}) + \text{Ba}^{2+} (\text{aq}) \rightarrow \text{BaCrO}_4 (s) \)

20. \( \text{Fe}^{3+} (\text{aq}) + \text{NCS}^- (\text{aq}) \rightarrow \text{FeNCS}^{2-} (s) \)