Teacher Version: Qualitative Classifications of Metals Ions

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Background:

From a previous investigation, "Comparison of Metallic Elements and Metal Compounds," students are aware that metals can be found in the environment as both metallic elements (metals) and metallic compounds composed of metallic cations and nonmetallic anions.

Calcium's property of crosslinking with a polymer relates to its role in bone. Bone is primarily composed of a matrix having inorganic and organic components. The inorganic component is calcium hydroxyapatite plus other inorganic calcium compounds. The organic component of the matrix is the protein collagen. Collagen is rich in several specific amino acids including glycine (which has a hydrophobic amino acid side chain) and hydroxyproline (which has a hydrophilic amino acid side chain). Hydroxyproline has an O-H group similar to water and is capable of hydrogen bonding to the inorganic hydroxyapatite. The combination of the hydrophobic and hydrophilic side chains allow the collagen protein to assemble into strong helices as well as complex to the inorganic hydroxyapatite.

In chemistry, qualitative tests of metal cations with specific anions and chemicals called complexing agents allow the metals to be identified on the basis of their color, solubility and reactions. This identification process teaches many fundamental properties and reactions. Unfortunately, these tests often use solutions of lead, mercury and silver ions, substances which are toxic and to which many teachers and schools do not want students exposed. Fortunately, other reactions exist which help students to understand the chemistry behind identification of some different metal cations, as in the following series of activities. In developing an environmentally and student friendly method for distinguishing between some metal cations, we proposed testing metal ions with alginate, a potential complexing agent of biological origin. Alginate originates in the cell walls of seaweed and is an approved food additive used to increase viscosity and as an emulsifier.

Alginate is a polymer composed of the subunits D-mannuronic acid and L-guluronic acid, which are both carbohydrates. Thus, alginate can be thought of a polymer of carbohydrates where each carbohydrate unit contains a water-loving carboxylic acid functional group (notice each of the compounds in the polymer have names ending in "–ic acid.") The carboxylic acid functional group can be crosslinked by some 2+ metallic ions producing an interesting physical change in the alginate. Since students can observe this physical change, reactions with alginate can be used to distinguish between 1+ and 2+ metal cations.

This lesson consists of three parts. Part One is an exploratory activity that introduces students to using the physical change in alginate to distinguish between 1+ and 2+ metal cations. In Part Two, further investigation allows students to begin to understand the reaction in a more quantitative manner. In Part Three students apply this knowledge to test for calcium (a 2+ metal cation) in fortified foods.

Concept checklist

To help you plan for using this lesson in your classroom and potentially modify it to meet your needs, consider the following list of targeted concepts and note whether your students will be introduced to them for the first time or will be revisiting concepts they have been exposed to previously.

Targeted concept	Introducing	Revisiting
metal		
metallic cation		
anion		
ionic compound		
divalent cation		
monovalent cation		

Part 1:

Note: Students begin this investigation using nontoxic calcium chloride. Depending upon classroom circumstances, you may have them investigate other metals such as copper ion. Lead or mercury ions are NOT recommended.

Part 1 Materials:

- food grade sodium alginate (Available from www.modernistpantry.com and other online sources.)
- deionized or distilled water
- calcium chloride (available as an ice melt product or as a home brewing aid)
- potassium chloride (Original No Salt)
- Beral pipets
- small cups or beakers
- plastic spoons
- (optional) food color

Part 1 Getting Ready:

1. Prepare a sodium alginate stock solution. Slurry or shake 1 gram of food grade sodium alginate with 100 mL of deionized or distilled water. The sodium alginate is initially very slow to be wet by water and will clump similarly to flour in warm water. Vigorous stirring or shaking will help it go into solution. Preparing the solution one or more days before it is needed is also helpful. (Note: Although some references suggest dissolving 2 grams of alginic acid sodium salt (another name for sodium alginate) in 100 mL deionized water, our experience indicates that 2 grams of the food grade sodium alginate is too thick if dissolved in 100 mL water.)

2. Prepare a calcium chloride stock solution by dissolving 1 gram of calcium chloride in 100 mL water. If the calcium chloride is from either an ice melt product or a food source, the degree of hydration may not be known but can be estimated to be rather high. If the calcium chloride is assumed to be a mixture of tetrahydrated (183 grams/mole) and hexahydrated (219 grams/ mole), the formula weight could be estimated to be 200 grams/mol. The weight of calcium in one gram of calcium chloride is then approximately 0.2 grams. This gives a calcium ion concentration of approximately 0.2 grams Ca^{2+} per 100 grams of water, which is approximately 2 parts Ca^{2+} per 1000 parts, or 2,000/1,000,000 (2,000 ppm).
3. Prepare a potassium chloride stock solution by dissolving 1 gram of potassium chloride (Original No Salt) in 100 mL water. This is 5,200 per 1,000,000 parts K^{+} or 5,200 ppm.
4. Prepare a copper sulfate solution by dissolving 1 gram copper sulfate pentahydrate in 100 mL water. This is 2,500 per 1,000,000 parts Cu^{2+}or 2,500 ppm.
5. Prepare a cobalt chloride solution by dissolving 1 gram cobalt chloride hexahydrate in 100 mL water. This is 2,500 per 1,000,000 parts Co^{2+}or 2,500 ppm.
6. (Optional) Prepare stock solutions of other ionic compounds, such as saturated sodium chloride (NaCl), saturated potassium chloride (KCl), or saturated magnesium chloride or sulfate (Epsom salts).
7. (Optional) If you are extremely pressed for time, you may add food color to the alginate solution to make the gellation immediately visible.

Part 1 Procedure:

The procedure outlined below is written to the teacher. In cases where teachers have students propose and design their own investigations, this procedure serves as an example for the teacher of a tested procedure that produces observable outcomes. While finding no observable outcome is a viable result in itself, and certainly may happen in student-directed investigations, having a tested procedure as a reference point can help teachers facilitate discussions with students as they propose their own procedures. In cases where teachers supply students with a procedure for the investigation, the written procedure can be quickly adapted for students to read directly.

Note: *This procedure suggests that teachers direct students in the initial reaction using two test solutions. From these two test solutions students should discuss what they think is occurring and possible other compounds to test to help them further understand the reaction.*

Safety Note: *For safety reasons, students are usually not allowed to touch chemicals or chemical reaction products. Since the reactants of calcium chloride solution or potassium chloride solution with sodium alginate solution are all GRAS (generally recognized as safe) chemicals that have applications in the food industry, students might be permitted to touch a positive reaction. Later, if students investigate reactions of the sodium alginate with other divalent ions such as magnesium, copper, and cobalt, students should not touch the products of these reactions.*

Suggest to students that they pour a small amount of potassium chloride solution into a small cup or beaker, add several drops of sodium alginate to the calcium chloride solution, and observe. Also suggest to students that they pour a small amount of potassium chloride solution into a small cup or beaker, add several drops of sodium alginate to the calcium chloride solution, and observe.

Students may want to use a spoon to look for any sign of a reaction and help them make further observations. Students should discuss their observations and propose additional ionic compounds to test with sodium alginate. Students can record their data in a table similar to one below:

Initial Reaction of Sodium Alginate Solution and Metallic Ion Solutions

Metal Ion Solution	Description of Results of added Sodium Alginate	Positive or negative Test	Number of negative charged ions in the ionic compound (number of chloride ions in the ionic compound)	Charge on the metallic ion
Potassium Chloride				
Calcium Chloride				

Depending upon student questions and further investigations, they may want to add to a data table such as the one below:

Further Reactions of Sodium Alginate Solution and Metallic Ion Solutions

Metal Ion Solution	Description of Results of added Sodium Alginate	Positive or negative Test	Number of negative charged ions in the ionic compound (number of chloride ions in the ionic compound)	Charge on the metallic ion
Potassium Chloride				
Calcium Chloride				
Cobalt Chloride				
Copper Sulfate				
Calcium Lactate				
Sodium Chloride				
Magnesium Sulfate				

Part 1 Post-Activity Discussion

The post-activity discussion is designed to help the teacher facilitate student learning as students summarize their observations and make claims about the outcome of the investigation using their data as evidence. Whether students use a provided procedure or have designed one of their own, this discussion incorporates key components of inquiry-based learning into the lesson.

Observations/Data

- How can a positive test between a metallic ion and sodium alginate be described? *The alginate gels and becomes thick and rubbery.*

Claims/Evidence

- How can a positive test between a metallic ion and sodium alginate be described? *The alginate gels and becomes thick and rubbery.*
- What do you think is required for a positive test reaction with sodium alginate? Since calcium, cobalt, and copper gel, and potassium, sodium, and magnesium do not gel, a 2+ ion appears to be necessary.
- What additional compounds or metallic ions of the periodic table would you test to establish your claim about what is required for a positive test with sodium alginate? *Other 2+ ions to test would include barium, lead, and tin*.
- How does your reaction evidence support your claim? Students should notice that calcium 2+ ions are formed from both calcium chloride and calcium lactate as well as notice that calcium chloride, copper sulfate, and cobalt chloride also generate 2+ metal ions. In contrast, potassium chloride generates potassium 1+ ions which do not react with the alginate.

Reflection

- What other evidence or questions do you have the about the reaction of metallic ions and sodium alginate? *Student responses will vary.*
- What tests could you propose to answer your questions? *Student responses will vary.*
- Since alginate has a biological origin (is a compound derived from seaweed), do you think the effect of metal ions on alginate could be used as a model for how toxic metals in the environment such as lead or mercury 2+ ions become attached to specific biological tissues such as the brain and impair normal cell functions? Why or why not? *Student responses will vary.*
- High school students might compare how their reaction table of metal ions and sodium alginate compares to the solubility rules and/or tables found in their textbook or other classroom resources.

Part 2: Quantitative Limits of the Gelation of Sodium Alginate with Calcium Chloride Solution

The reactions students observed in Part One result from the divalent metal ions calcium and copper (and by extension, lead and mercury) reacting with two negatively charged ions. If the two negatively charged ions are attached to one molecule, the divalent metallic ion can be considered to cross link two parts of one molecule. In the case of the polymeric alginate molecule, crosslinking results in a dramatic change in viscosity called gelation. The following investigation extends Part One by looking at what effect the concentration of divalent metal ions has on the crosslinking of alginate. This question is important to Part Three of this lesson since the answer relates to the level of calcium in supplemented foods that students could detect using the addition of sodium alginate. This investigation also allows students to design a dilution scheme.

Part 2 Materials:

- 6-8 small beakers or cups
- Small volumetric lab ware (10 mL graduated cylinder, or pipets, or syringes)
- Beral (disposable) pipets

- 2,000 ppm calcium chloride solution from Part 1
- Sodium alginate solution from Part 1

Part 2 Pre-Activity Discussion

The pre-activity brainstorming discussion outlined below is designed for instructors to engage students in understanding the goals of the investigation and possible approaches to doing the investigation. In cases where teachers use inquiry and facilitate student proposed and designed investigations, this discussion provides a starting point for that process. In cases where teachers supply students with a procedure for the investigation, this discussion incorporates some elements of student inquiry into the activity.

Direct students in drawing a model of calcium ions crosslinking alginate carboxylate groups. Alternatively have student dramatize the crosslinking of alginate carboxylate groups similar to the gelation of polyvinyl alcohol or gluep. Ask students "What is the effect of the change in viscosity of the polymers if the number of crosslinkers is reduced?" Ask students how they could find out how many calcium ions are required in the solution to observe the crosslinking effect? Students might suggest making less concentrated dilutions of the 2,000 ppm calcium ion solution, adding drops of sodium alginate, and observing any gelation.

Part 2 Procedure:

The procedure outlined below is written to the teacher. In cases where teachers have students propose and design their own investigations, this procedure serves as an example for the teacher of a tested procedure that produces observable outcomes. While finding no observable outcome is a viable result in itself, and certainly may happen in student-directed investigations, having a tested procedure as a reference point can help teachers facilitate discussions with students as they propose their own procedures. In cases where teachers supply students with a procedure for the investigation, a written procedure can be adapted for students to read directly.

Depending on student grade levels and experience, having the students develop the dilution scheme is ideal. Students should be told the volume of the solutions to prepare is 10-20 mL, depending upon the volumetric lab ware available. To help students get started, an opening question could be "What is the resulting concentration of calcium ions when equal volumes of water and the stock solution (2,000 ppm) are mixed?" Ask students to think about what other concentrations they would like to test.

You might ask students to work independently to determine the volume of water and the corresponding volume of stock calcium ion solution for the concentrations they want to test. Then, they could meet in small groups to review their calculations and decide which dilutions to test as a group. A table similar to the one below (without any values in it) will help them organize this process. How dilute the group plans to make the solutions can be determined either by the results or the group questions and discussion.

Reactions of Diluted Calcium Ion Solutions with Sodium Alginate Solution

Solution Concentration	Water Number of milliliters	2,000 ppm Number of milliliters	Results with added drops of sodium alginate	Positive or Negative Reaction

2,000 ppm	0	20		
1,000 ppm	10	10		
500 ppm	5	15		
200 ppm	2	18		
100 ppm	1	19		
50 ppm	0.5	19.5		

Part 2 Post Activity Discussion:

The post-activity discussion is designed to help the teacher facilitate student learning as students summarize their observations and make claims about the outcome of the investigation using their data as evidence. Whether students use a provided procedure or have designed one of their own, this discussion incorporates key components of inquiry-based learning into the lesson.

Observations/Data

- Did diluting the calcium ion solution have an effect on the gelling of the alginate? If so, describe it.

Claims/Evidence

- What claim can you make about the relationship of calcium ion concentration and gelling of alginate? What is your evidence? *The gel is softer with lower concentrations of calcium.*
- What is the limiting concentration for a positive test reaction with sodium alginate solution being used to detect calcium ions? *Student results will vary.*
- What evidence did you use to find the detection limit of sodium alginate for calcium ion? *Student results will vary. They may notice that the higher concentrations create a firm, tough gel, and lower concentrations produce a softer and softer gel as the amount of calcium ion decreases. Depending on what concentrations they test, they may continue to see some effect in all.*

Reflection

- High school chemistry students may want to consider how many calcium ions are present in even a very low concentration of calcium ions, possibly 50 ppm. For example, if one has a solution of 20 mL of 50 ppm calcium ion, approximately how many million water molecules are in that volume? Considering your answer to how many million water molecules are present, about how many calcium ions are present? The answers to these questions aren't just academic exercises, since some metals fit into specific active sites of biological molecules for example iron in hemoglobin, a small number of metal ions may cause specific biological effects.

<u>Part 3: Can Sodium Alginate Solution Detect Calcium Ions in Food?</u>

For Part 3, have students design experiments based upon the results of Part 2 to test naturally calcium-rich foods or calcium-supplemented foods for the presence of calcium ions. You might provide specific foods or bring in foods based on student suggestions.

Materials:
- Small cups or beakers
- Samples of calcium rich or fortified foods
- Vinegar
- Beral (disposable) pipets
- Sodium alginate solution from Part 1

Procedure

Have students work in small groups to write a procedure for how they plan to test specific foods for calcium ions. Upon your approval, have students perform their experiments and report results. Remind students to collect their data in an appropriate data table.

Part 3 Post Activity Discussion:

The post-activity discussion is designed to help the teacher facilitate student learning as students summarize their observations and make claims about the outcome of the investigation using their data as evidence. Whether students use a provided procedure or have designed one of their own, this discussion incorporates key components of inquiry-based learning into the lesson.

Observations/Data
- What are the results of your food testing?

Claims/Evidence
- Are the results what you would have predicted? Why or why not?

Reflection
- Try to reconcile information either known about a food sample or provided on the food sample package with your results. Is it possible that some calcium ions in specific foods may not be freely accessible to the sodium alginate solution for detection? For example is the natural calcium tied up with an enzyme of other biochemical structure? Is the calcium supplementation in an insoluble form? *Note: In some cases, calcium ions in foods are not available to the alginate. Mixing these foods with vinegar prior to testing may make the calcium ions available. You may want to have students retest some of their foods in this way if they did not see any gelling of the alginate even though the food label indicated a high calcium content. For the process of a student led investigation, it is important not to bring this up before they begin, but as they work, you could engage them in a discussion that could lead to this additional testing.*

  - Read about chemicals called chelators and chelation therapy for lead exposure, and describe how this activity relates to chelation.

  Medical treatment with chemicals called chelators is used for severe cases of lead poisoning. Chelators grab onto the metals so they no longer react with body systems and allow the body to remove them as waste. Treatment with chelators can be dangerous, because any metal in the body can be grabbed up, including those essential for health, such as calcium. Sodium alginate is a chelator. In this activity, it attaches to calcium ions.

Extension

A food-related extension of this activity is applying the principles demonstrated in this activity to making "fruit caviar." Using all food grade ingredients and food safe utensils, students can mix sodium alginate into fruit juice and then drop it into a calcium chloride solution to create fruity, edible spheres. An online search for fruit caviar will yield a variety of recipes. Here's one: http://mylastbite.wordpress.com/2008/12/31/adventures-in-molecular-cooking-3/