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LESSON:

Water Alchemy

Summary: Students read the article "Aquatic Alchemy" and discuss the different possible solutions for purifying water. Then, students conduct an experiment to show how alum and hydrated lime are used in water treatment plants to help purify drinking water. This lesson extends discussion of a topic addressed within the article.

EHP Article: "Aquatic Alchemy," *EHP Student Edition*, May 2005: A110–A114.
http://ehp.niehs.nih.gov/members/2005/113-2/innovations.html

Objectives: By the end of this lesson students should be able to:

1. discuss the physical and chemical principles involved in at least four water treatment processes;
2. calculate the percentage by weight of a solid dissolved in a solution;
3. write and balance simple chemical equations;
4. define colloids and explain how they can be removed from water using chemical reactions;
5. set up and conduct experiments involving weighing solids, measuring liquid volume, and making solutions; and
6. describe common water contaminants and how they could be removed.

Class Time: 2 hours (allow more time if students filter the water)

Grade Level: 10–12

Subjects Addressed: Chemistry, Environmental Science

Prepping the Lesson (30 minutes)

INSTRUCTIONS:

1. Obtain a class set of *EHP Student Edition*, May 2005, or download article at http://ehp.niehs.nih.gov/docs/2005/113-2/inn.html and make copies.
2. Make copies of the student instructions.
3. Review the article "Aquatic Alchemy."
4. Download and review the hazardous substance fact sheets (material safety data sheets) for aluminum sulfate (http://www.state.nj.us/health/eoh/rtkweb/0068.pdf) and calcium hydroxide (http://www.state.nj.us/health/eoh/rtkweb/0322.pdf).
5. Assemble the materials needed for the laboratory activity.
6. Prepare a stock solution of cloudy water (colloidal suspension of topsoil in water) in a 1,000-mL beaker by thoroughly mixing 40 g of topsoil in 800 mL of water. The concentration does not have to be exact; you only want to make some cloudy water. Filter the solution into another 1,000-mL beaker to remove suspended and undissolved dirt. A cone coffee filter works very well for filtering. This quantity is sufficient for at least one class of five groups. The topsoil can be purchased at any gardening store or collected from the outside.
7. Prepare a stock slurry (mixture of water and solids) of calcium hydroxide or hydrated lime in a 500-mL beaker by mixing 1.0 g of calcium hydroxide in 200 mL of water. The calcium hydroxide will not dissolve in the water. This quantity is sufficient for at least one class of five groups. Hydrated lime can be found in the gardening section of hardware and gardening stores or purchased from a chemical supply company. It is used to treat soil to increase its pH. If desired, you could have each group create its own calcium hydroxide slurry.

MATERIALS:

Per Student
- Safety goggles
- Laboratory apron
- 1 copy of *EHP Student Edition*, May 2005, or 1 copy of the article "Aquatic Alchemy"

Per Group
- 1 copy of the student instructions
- 1 gram of aluminum sulfate or alum (alum can be found in the supermarket in the spice section, or purchased from a chemical supply company)
- 1 100-mL graduated cylinder
- 3 test tubes (20 mm x 150 mm) or equivalent per group. The diameter of the test tube is not important, but the test tube length should be at least 150 mm.
- 1 test tube rack
- tape and/or pen to mark test tubes and beakers
- 1 250-mL beaker
- 1 50-mL beaker
- balance capable of weighing to 0.1 g
- 2 stirring rods
- A spatula
- An eye dropper
- pHydrion paper or equivalent
- Water source

Per Class
- stock solution of cloudy water (40 g of top soil in 800 mL of water, then filter out the dirt)
- stock slurry of calcium hydroxide or hydrated lime (1 g of calcium hydroxide or hydrated lime in 200 mL of water)

VOCABULARY:

Acidic
Basic
Coagulation
Colloid
Flocculation
Ion
pH
Solution
Suspension
Turbidity

BACKGROUND INFORMATION:

Water can become polluted with a variety of naturally occurring and human-created contaminants that make it unsuitable for drinking and other purposes such as cooking and bathing. Common contaminants in surface and groundwater include microorganisms, bacteria, viruses, radionuclides, nitrates, nitrites, heavy metals (e.g., arsenic, mercury, and lead), fertilizers, pesticides, and organic chemicals (e.g., gasoline, dry-cleaning fluids, and industrial chemicals). Although the number of contaminants in space is more limited, the problem of recovering and purifying water is especially challenging because of the limited resources available.

Removing contaminants from water involves water treatment processes based on the physical, chemical, and biological properties of the contaminants. Because of the wide range of possible contaminants, multiple treatment processes are usually used. The "Aquatic Alchemy" article touches on a number of the treatment processes currently available. Table 1 summarizes the treatment processes mentioned in the article and the water contaminants they address.

Table 1

Water Treatment Processes Mentioned in "Aquatic Alchemy"

Water Treatment Technology	Description	Treatment Results
Activated carbon	Adsorption of contaminants onto porous surface of carbon	Removes some organic contaminants and heavy metals
Bacteria biofilm oxidation	Enriched bacteria on thin film convert water contaminants to less harmful alternatives	Removes organic and inorganic dissolved contaminants
Catalytic oxidation	Treated surface enhances oxidation	Removes low-molecular-weight organic molecules
Chlorination	Chemical treatment with chlorine	Disinfects
Distillation	Boil water and condense the steam	Removes dissolved solids and disinfects
Evaporation	Allow water to evaporate and condense vapor	Removes dissolved solids and disinfects
Heat	Increase water temperature	Disinfects
Mechanical filtration	Pass water through a porous medium such as a membrane or sand	Removes undissolved solids suspended in water
Ion exchange	High-molecular-weight solid exchanges ions on its surface for similar charged ions in solution	Removes dissolved ionic solids

There are additional water treatment processes not mentioned in the article. Table 2 describes some of the other common options.

Table 2

Additional Water Treatment Processes

Water Treatment Technology	Description	Treatment Results
Aeration	Bring air into contact with the water	Removes volatile organic substances and adds oxygen
Coagulation and flocculation	Chemically treat water, causing colloidal suspension of solids in water to settle to bottom	Removes colloids (tiny solid particles suspended in water) that can not be removed by filtration
Reverse osmosis	Semipermeable membrane allows pressurized water but not contaminants to pass through	Removes most organic and inorganic dissolved contaminants
Sedimentation	Water is allowed to stand, and suspended solids in water settle to bottom	Removes suspended solids

A typical water treatment facility takes the following steps: 1) retrieval of water from groundwater, reservoirs, or other water bodies, such as rivers and lakes; 2) coagulation/flocculation; 3) sedimentation; 4) filtration; 5) disinfection; and 6) storage.

This activity investigates the chemistry involved in the coagulation/flocculation step of most water treatment facilities using the actual chemicals commonly used in the process. Water contaminated with soil and other solid particles in the size range of 0.1 to 0.001 microns in diameter (10^{-6} meters) will not settle out with time and cannot be removed by mechanical filtration. These small particles suspended in water are called colloids. Colloids bridge the gap between solutions and suspensions. Technically they are a "suspension of finely divided particles in a continuous medium from which the particles do not settle out rapidly and are not readily filtered.? Thus, they are homogeneous mixtures of two or more substances which are not solutions.

Colloids cannot be seen by the eye, but cause light to scatter as it passes through the water and give the water a cloudy or murky appearance. The measure of the cloudiness of water is called its turbidity. Common colloids include fog, milk, and paint. The colloid particles are similarly charged and as a result, are repelled by each other. This prevents the charged colloid particles from coming together and coagulating to form larger particles and settle out of solution. Typically, colloids have a negative charge. In coagulation, the colloid is treated with a chemical such as alum that creates ions in solution, which neutralizes the charges on the colloid. A second chemical such as hydrated lime is then added to neutralize the acidic properties of the alum and create a precipitate called floc. The floc adheres to the coagulated particles and settles to the bottom by sedimentation, resulting in clear water.

RESOURCES:

Environmental Health Perspectives, Environews by Topic page. Choose Drinking Water Quality, Innovative Technologies, http://ehp.niehs.nih.gov/topic

United States Environmental Protection Agency, Ground Water and Drinking Water,

http://www.epa.gov/safewater/index.html

Water on Tap, What You Need to Know, http://www.epa.gov/safewater/wot/

Classroom Activities and Experiments, http://www.epa.gov/safewater/kids/index.html

University of Minnesota Extension Service, Safe Drinking Water and Water Treatment Educational Resources,

http://www.extension.umn.edu/water/drinking_water.html

University of Waterloo, Canada, Water Treatment Description, http://www.science.uwaterloo.ca/~cchieh/cact/applychem/watertreatment.html

Implementing the Lesson

INSTRUCTIONS:

1. Have students read the article “Aquatic Alchemy.”
2. Discuss with students the different technologies and the scientific principles used to purify water as described in the article .
3. Tell students that are going to investigate the chemistry of one of the common water treatment process called coagulation/flocculation. Review vocabulary, chemical formulas, unit conversions, and balancing chemical equations as needed.
4. Divide students into groups, and pass out the materials and student instructions for the “Water Alchemy” activity.
5. Explain the hazards and the safety precautions associated with handling the chemicals involved.
6. Once each group has completed the activity, have each group present its findings and conclusions to the class.
7. After all the groups have presented, discuss and summarize the groups’ results.

NOTES & HELPFUL HINTS:

- Because of the different types of laboratory balances available and the different possible procedures for weighing, the student instructions do not include detailed weighing procedures. You must give additional guidance to your class about how you want the aluminum sulfate or alum to be weighed. This might involve using a piece of paper to weigh the aluminum sulfate or weighing directly into the beaker.
- Depending on the level of your students, you may need to provide some assistance in writing some of the chemical equations and explaining the pH results.
- The solutions of cloudy water, cloudy water with alum, and cloudy water with hydrated lime can be disposed of down the sink.
- You may want to have students filter the stock cloudy water solution to prove that the cloudiness cannot be filtered out.

Aligning with Standards

SKILLS USED OR DEVELOPED:

Communication (note taking, oral, written—including summarization)
Comprehension (listening and reading)
Computation
Critical thinking and response
Experimentation (conducting and data analysis)
Manipulation
Observation
Research
Technological design

SPECIFIC CONTENT ADDRESSED:

Conducting experiments
Making observations
Balancing chemical equations
Weighing
Measuring volume
Making solutions
Recording data
Drawing conclusions
Colloids
Precipitation reactions
Unit conversions

NATIONAL SCIENCE EDUCATION STANDARDS MET:

Science Content Standards

- Unifying concepts and processes standard
- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Evolution and equilibrium
- Science as inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science Standards

- Structure of atoms
- Structure and properties of matter
- Chemical reactions

Science and Technology Standards

- Abilities of technical design
- Understanding about science and technology

Science in Personal and Social Perspectives Standards

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Assessing the Lesson

Step 3:

a. Measure the pH of the cloudy water with the pHydrion paper or equivalent and record your result.

The pH of the cloudy water is variable, but most likely will be around 6.

b. Explain why you think the water is cloudy. (Note: The water has been filtered, yet it is still cloudy.)

The water is still cloudy because tiny particles of soil that can pass through a filter paper are still suspended in the water. This type of solution is called a colloid, and the cloudiness of the solution is called its turbidity. The particles are large enough to scatter light passing through the liquid, giving it a murky or opaque appearance, but not large enough to fall out of solution. Colloids have particle sizes in the range of 0.1 to 0.001 microns in diameter.

c. Predict what would happen to the water if you let it sit over night.

Some suspended particles might settle out onto the bottom of the test tube, but the solution would still remain cloudy even after time.

Step 4:

a. What is the concentration of the alum solution in percentage by weight (1 mL of water = 1 g)?

Although students could take a shortcut by immediately substituting 100 g of water for the 100 mL they measure (Example 1), it is recommended that the students complete the unit conversion as shown in Example 2. Having students do the unit conversion will reinforce their understanding of the mathematical cancellation process involved in unit conversions and will help them with more complex unit conversions in the future.

Example 1: 1 g alum / 100 g water x 100 = 1% alum by weight

Example 2: 1 g alum x 1/100 mL water x 1 mL water/1 g water x 100 = 1% alum by weight

b. Write the balanced chemical equation showing the ions formed when you dissolve alum in water. The molecular formula for alum is $Al_2(SO_4)_3$.

$Al_2(SO_4)_3\ (s) \rightarrow 2\ Al^{+3}\ (aq) + 3\ SO_4^{-2}\ (aq)$

c. Measure the pH of the alum solution with pHydrion paper or equivalent and record your result. Is this solution acidic or basic?

The pH will be about 4, thus acidic.

d. Explain why you got this pH result.

Alum is the salt of a weak base. When you put the salt of a weak base into solution, the aluminum ions will pull some of the hydroxide ions out of solution, causing an increase in the hydrogen ion concentration relative to the hydroxide concentration. The result is a decrease in pH.

Step 7:

a. Explain why the hydrated lime slurry water is milky.

Slacked lime, (when lime is exposed to air and is converted into carbonate of lime and hydrate of lime), or calcium hydroxide, is highly insoluble in water. The milky color comes from the undissolved calcium hydroxide.

b. Write the balanced chemical equation showing the ions formed when you dissolve hydrated lime in water. The molecular formula for hydrated lime is $Ca(OH)_2$.

$Ca(OH)_2\ (s) \rightarrow Ca^{+2}\ (aq) + 2\ OH^{-1}\ (aq)$

c. Measure the pH of the hydrated lime slurry with pHydrion paper or equivalent and record your result. Is the solution acidic or basic?

The pH would be about 13, thus basic.

d. Explain why you got this pH result.

You are adding a weak base to water, causing the water to become more basic.

Step 8:

Write the balanced chemical equation for the reaction of aluminum sulfate and calcium hydroxide in water.

$Al_2(SO_4)_3\ (aq) + 3\ Ca(OH)_2\ (aq) \rightarrow 2\ Al(OH)_3\ (s) + 3\ CaSO_4\ (aq)$

Step 9:

a. Observations and explanation—cloudy water

The water does not change with time. It remains cloudy. The soil particles remain suspended in the water as a colloid.

b. Observations and explanation—cloudy water with alum

The water slowly becomes clearer, more solids settle on the bottom of the test tube, and tiny particles may become visible in the solution. It takes about 30 minutes to see visible changes. If the test tube stands over night, the solution becomes clearer. The tiny soil particles suspended in the water repel each other because they have the same negative charge, which prevents them from combining into larger particles. The aluminum ions neutralize the charges on the soil particles, allowing them to coagulate and settle out of the water.

c. Observations and explanation—cloudy water with alum and hydrated lime

A yellowish precipitate forms that settles onto the bottom of the test tube, leaving a clear solution of water above. The alum allows the soil particles to coagulate. The hydrated lime reacts with the alum to form the precipitate aluminum hydroxide. The aluminum hydroxide traps the particulates in the water as it settles to the bottom in a process called flocculation.

d. Explain how this chemical process might be used in purifying drinking water.

Drinking water often contains tiny particles suspended in the water as a colloid that cannot be removed by ordinary filtration. Alum is added to the water to help the dirt to coagulate forming an acidic solution. Hydrated lime is then added to neutralize the acid and create a precipitate (or floc), which attracts the dirt particles. The combined dirt and floc sinks to the bottom and is removed in the sedimentation step of water treatment. After the sedimentation step, the water is filtered and then disinfected before it can be used by the public.

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Student Instructions: Water Alchemy

Materials:

Per Student
- Safety goggles
- Laboratory apron

Per Group
- 1 gram of aluminum sulfate or alum
- 1 100-mL graduated cylinder
- 3 test tubes (20 mm x 150 mm) or equivalent per group. The diameter of the test tube is not important, but the test tube length should be at least 150 mm.
- 1 test tube rack
- tape and/or pen to mark test tubes and beakers
- 1 250-mL beaker
- 1 50-mL beaker
- 1 balance capable of weighing to 0.1 g
- 2 stirring rods
- 1 spatula
- 1 eye dropper
- pHydrion paper or equivalent
- Water source

Provided by teacher
- stock solution of cloudy water (40 g of topsoil in 800 mL of water and filtered).
- stock slurry of calcium hydroxide or hydrated lime (1 g of calcium hydroxide or hydrated lime in 200 Ll of water)

Procedure:

Step 1: Put on your safety goggles and laboratory apron.

Step 2: Label three test tubes with an identifier for the following solutions: cloudy water, cloudy water with alum, and cloudy water with alum and hydrated lime. Mark two fill lines on each test tube for where the test tube would be one-third full and one-half full. Place each test tube in a test tube rack.

Step 3: Fill each test tube to the one-third full mark with cloudy water from the cloudy water stock solution (topsoil mixed with water, then filtered) supplied by your teacher so that all three test tubes are one-third full and have the same amount of cloudy water.

a. Measure the pH of the cloudy water with the pHydrion paper or equivalent and record your result.

b. Explain why you think the water is cloudy. (Note: The water has been filtered, yet it is still cloudy.)

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c. Predict what would happen to the cloudy water if you let it sit over night.

Step 4: Using a balance, weigh out 1 g of alum into a 250-mL beaker. Measure 100 mL of water using a graduated cylinder, and add it to the 250 ml beaker with the alum. Stir the solution until all of the alum dissolves.

a. What is the concentration of the alum solution in percentage by weight (1 mL of water = 1 g)?

b. Write the balanced chemical equation showing the ions formed when you dissolve alum in water. The molecular formula for alum is $Al_2(SO_4)_3$.

c. Measure the pH of the alum solution with pHydrion paper or equivalent and record your result. Is the solution acidic or basic?

d. Explain why you got this pH result.

Step 5: Add water only to the first test tube marked "cloudy water" up to the second fill line so the test tube is one-half full. Mix the solution in the test tube by gently rapping the bottom of the test tube with your fingers. This is your control solution.

Step 6: Add the alum solution to the second and third test tubes labeled "cloudy water and alum" and "cloudy water with alum and hydrated lime" up to the second fill line on your test tubes so the two test tubes are one-half full. Mix the solutions in each test tube by gently rapping the bottom of the test tubes with your fingers.

Step 7: Stir the stock hydrated lime slurry (1.0 g of hydrated lime in 200 mL of water) supplied by your teacher and transfer about 20 mL of the slurry into a 50-mL beaker.

a. Explain why the hydrated lime slurry water is milky.

b. Write the balanced chemical equation showing the ions formed when you dissolve hydrated lime in water. The molecular formula for hydrated lime is $Ca(OH)_2$.

c. Measure the pH of the hydrated lime slurry with pHydrion paper or equivalent and record your result. Is the solution acidic or basic?

d. Explain why you got this pH result.

Step 8: Stir the hydrated lime slurry and add 10 drops of the slurry to the third test tube marked "cloudy water with alum and hydrated lime." Mix the solution in the test tube by gently rapping the bottom of the test tube with your fingers. Test the solution with pHydrion paper. If the solution is not basic, keep adding hydrated lime slurry to the test tube 5 drops at a time until the pH becomes slightly basic (pH > 7).

Write the balanced chemical equation for the reaction of aluminum sulfate and calcium hydroxide in water.

Step 9: Allow the three test tubes to stand for a few minutes. Then carefully observe what is happening in each test tube and explain the results. Hold the test tubes up to the light for closer examination. Record your observations and explanation. Your teacher may store your test tubes over night to seen what happens with time.

a. Observations and explanation—cloudy water:

b. Observations and explanation—cloudy water with alum:

c. Observations and explanation—cloudy water with alum and hydrated lime:

d. Explain how this chemical process might be used to purify drinking water.