Pure Water?

Adapted from American Chemical Society Activity 3, Water Hardness
http://www.chemistry.org/portal/resources/ACS/ACSContent/education/wande/resourcechem/environment/env03.pdf
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KEY CONCEPT

Water dissolves materials into it. We can test for some chemicals that form compounds with soap by looking at the height of a column of soap bubbles.

SKILLS: ***Estimating, Calculating, Observing, Recording, Investigating, Modeling***
TIME: ***30 minutes***

AUDIENCE: ***Teachers and students, grades 5 – 8, but can be adapted for younger students and used for older ones.***

OBJECTIVE

To model a substance dissolved in water, a detection method, and calculations of concentration.

SAFETY

No special precautions.

Background for teachers

CONTENT FOCUS

Water dissolves many chemicals into it. As an example and model of these dissolved chemicals, this activity investigates the interaction of Epsom salt ($MgSO_4 \cdot 7H_2O$) with soap and the reaction of soap with water. During the investigation, participants will estimate concentrations of the magnesium sulfate added to the water to make solutions.

Water hardness, which this activity models, is usually reported in parts per million. This is also a common unit for other materials found in water. For example, the US Environmental Protection Agency lists contaminants and their maximum concentrations on their website http://www.epa.gov/safewater/mcl.html#mcls

Relation to the Environment

Water hardness itself is often a problem because washing with soap in hard water leaves a soap/magnesium (or calcium or iron) precipitate (soap scum), and makes it necessary to use more soap to accomplish the washing. But, in the activity, magnesium sulfate dissolved in water is meant to represent any material dissolved in water. The soap indicator is meant to represent the method of detecting the presence of the dissolved chemical.

Chemicals dissolved in water can be useful or harmful. For example, a juice we might drink is made up of some chemicals dissolved in the water (vitamin C, for example), plus some suspended (pulp of oranges, for example). These dissolved chemicals are good for us. In fact, some calcium and magnesium salts dissolved in water make the water taste good and provide some small amount of necessary minerals. But, these same chemicals can be bad for our house pipes, for example, when they precipitate on the pipes and clog them.

ADVANCE PREPARATION

- Gather the materials. Soap flakes are hard to get, so you may need to buy Ivory Soap bars and grind them using a cheese grater or food processor. Soap takes a while to dissolve, so you may want to prepare a solution for every one to use: 10% solution: 1g soap pieces plus 9 g (9 mL) of water.
- Make straw scoops by cutting the end of a straw off at an angle. That pointed end can be used to pick up a fairly reproducible amount of a powdered material. These straw scoops will be used for the soap particles. Coffee stirrer straws can be used for smaller amounts that may be needed for the $MgSO_4$.
- Make a cubic centimeter "box" from a piece of centimeter graph paper. Cut a square of 9 centimeter squares. Fold the corner squares diagonally and fold up the side squares to make a cube without a lid. Tape to hold in place. Use this to help estimate the volume of $MgSO_4$ added.

TIPS

- In this activity, the amount of $MgSO_4$ is estimated by volume. However, this introduces a lot of error because some of the space in a portion of $MgSO_4$ is air. It would be better to measure by mass if balances that measure to tenths of milligrams were available. In that case, it would be useful to change the volume measurement of the water to mass (so units cancel): one mL water has a mass of 1 gram.
- The variation in the amount of soap added is a potential problem. It may be useful to get an estimate of the variation in the height of the soap bubbles in the blank bottle by comparing all the blanks in the classroom, or setting up a separate set of blanks with nominally the same amount of soap added. Compare that variation with the changes observed with the added $MgSO_4$.
- Hardness can be caused also by calcium salts and iron salts. Epsom salts are readily available so that is the salt used here. Calcium is sometimes available as calcium chloride, a deicer. Iron sulfate can be found in a garden supply store as a fertilizer.

The Activity

MATERIALS

- Bars of Ivory Soap, shredded with a cheese grater or food processor.
- Epsom Salts ($MgSO_4{\cdot}7H_2O$)
- Purified water—distilled or deionized so it doesn't contain magnesium, calcium, or iron.
- Empty 0.5 L water bottles, preferably all the same type, about 6 per group. Labeled 1, 2, 3…
- Small containers for the soap particles and Epsom salt. (2 oz cups, for example)
- Straws to be used for measuring the Epsom salt and soap particles, a straw scoop. (See Advance Preparation)
- Index cards to bend to use as a funnel to get materials into the narrow opening of the water bottle.
- Centimeter graph paper to use to estimate the volume of $MgSO_4$ added. (See Advance Preparation)
- Permanent markers or tape that can be written on to mark bottles and pencils.

PROCEDURE

1. **Engage** participants by taking ideas of materials that are dissolved in water and some ideas of concentration. List the ideas for discussion later.
2. **Explore** the model of dissolving Epsom salts in water and detecting that with soap by pouring 100 mL of purified water into two bottles. Into one add some Epsom salt (amount determined by participant). Add some soap pieces (amount determined by participant) to both bottles. Shake the bottles for about 30 seconds and record observations.
3. **Explain** the observations by refining the investigation. How reproducible is the level of sudsing in the purified water? How little magnesium sulfate can be detected? How can the concentration be estimated? How can the amounts of soap and magnesium sulfate be measured more reproducibly?

   For the activity, the concentration of magnesium sulfate can be estimated by estimating the volume of magnesium sulfate in terms of cubic centimeters. Put the amount of magnesium sulfate into the small cubic centimeter made from graph paper and estimate the fraction of the volume. This is added to 100 mL (cubic centimeters) of water. So, the concentration will be the amount of volume of $MgSO_4$ (say 1/10 mL) per 100 mL.

   - Label several empty water bottles (1, 2, 3…, and make a key that lists the estimated concentrations of $MgSO_4$, keeping bottle number 1 as a blank with no $MgSO_4$ added).
   - Add 100 mL of deionized water to each bottle, add varying amounts of $MgSO_4$ to the bottles, reserving bottle number one with no $MgSO_4$ added for the "blank." Record the $MgSO_4$ concentrations on the label key.
   - Then, add one straw scoop of soap to each bottle.
   - Put the lids on the bottles and shake each bottle for the same amount of time, about 30 seconds.
   - Measure and record the height of the bubbles in centimeters after letting the bottles sit for about 2 minutes so the bubbles rise to the top of the water.
   - If no sudsing occurs in the bottles with $MgSO_4$, try adding more soap to each concentration and the blank to see if it is possible to differentiate the various amounts of $MgSO_4$ in solution.
4. **Elaborate** by considering other chemicals dissolved in water and by considering other methods of detection. Discuss possible detection methods using the suggested materials in the "Engage" part of the activity.
5. **Evaluate**: Participants evaluate own understanding of concentration of chemicals dissolved in water. Consider also the use of the activity in the classroom. Will it be useful for a specific grade level? How will it need to be changed?

Extension

1. Consider the units again. Why is mg/L the same as ppm? What is a better way to measure the $MgSO_4$, if we had the equipment? (See tips)
2. How is concentration related to the drinking water standards?
3. How is detection limit of the analytical method related to the drinking water (or other) standards?
4. Test tap water to see if it is hard.

About Soap and Hard Water

Soaps are salts of fatty acids and have the general formula of $R\text{–}\overset{\overset{O}{\|}}{C}\text{–}O^{-}Na^{+}$ where R is a long hydrocarbon chain. The sodium ion (Na^{+}) can be replaced by other ions, and the properties of the soap changes. For example, if Ca^{2+} or Mg^{2+} replaces the Na+ ion (and combines with two of the negative fatty acid ions), then an insoluble precipitate, soap scum, forms. Waters with dissolved calcium or magnesium are called hard waters.

Detergents are similar but the carboxylate group ($–CO_2^{-}$) has been replaced with a sulfonate group ($–SO_3^{-}$). This salt is much more soluble in water, especially the calcium and magnesium salts.

The calcium and magnesium ions come from the dissolution of rocks as the waters travel through the ground. There are no health problems associated with hard water; however, hard water precipitates carbonate mineral deposits, scale, and incrustations on pipes, hot water heaters, boilers and cooking utensils. Water hardness can cause other problems in the home such as increased soap consumption by preventing soap and detergents from lathering by giving rise to an insoluble curdy precipitation (soap scum).

Minerals are important in solving hard water problems. Water hardness can be lessened on a small scale by softening the water. This can be done with the addition of ammonia, borax (a mineral originally mined in Death Valley), or trisodium phosphate mixed together with sodium carbonate (washing soda). Hard water can be softened on a large scale by adding just enough lime (calcium oxide, from limestone) to precipitate the calcium as carbonate to remove the calcium salts. Home water softeners commonly use natural or artificial zeolite minerals to soften the water. Zeolite minerals are hydrous aluminum silicates of sodium, calcium, potassium or barium naturally found in igneous rock. (http://www.hardwater.org/)