The Colligative Properties of Solutions

Strand	Phases of Matter and Kinetic Molecular Theory	
Topic	Investigating properties of matter	
Primary SOL	CH.5	The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include g) colligative properties.
Related SOL	CH.1	The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include h) use of appropriate technology including computers, graphing calculators, and probeware for gathering data, communicating results, and using simulations to model concepts.

Background Information

Colligative properties are properties of solutions that depend on the amount of solute particles in the solution (concentration) and are independent of the nature of the solute. Freezing point depression, boiling point elevation, vapor pressure lowering, and osmotic pressure are all colligative properties.

When water is the solvent, the boiling point of water will increase 0.512°C for each 76 grams of propylene glycol (antifreeze) added to 1,000 grams of water. The freezing point of water will decrease 1.86°C for each 76 grams of propylene glycol added to 1,000 grams of water.

In this activity, students determine the boiling and freezing points of various solutions. They notice that density is a good indicator of boiling point. When students determine the freezing point of the solutions, they notice that as the density increases, the freezing point steadily decreases but then begins to increase. This discrepant event helps students realize that density is correlated to, but is not the cause of, the changes in the boiling and freezing points.

This laboratory exercise gives students an opportunity to notice that as antifreeze is added to a solution, the density of the solution increases. As the density of the solution increases, the boiling point of the solution also increases and the freezing point decreases initially but then begins to increase.

Materials

Note: Check to be sure that use of these materials by students at your school is allowed.
Skills-Development-Lab Activity:

- Safety goggles
- Graduated cylinder
- Triple beam or electronic balance
- Ten 15-mL test tubes with stoppers
- Test tube rack
- Commercial antifreeze (environmentally safe antifreeze is recommended)

- 2.5 mL corn syrup (optional)
- 7.5 mL propylene glycol (optional)

Inquiry-Lab Activities:

- Solutions of various percent antifreeze prepared in the skills-development lab
- Thermometer or temperature probe
- Boiling chips
- Hot plate or burner
- Styrofoam cup

Vocabulary

antifreeze, boiling point elevation, colligative properties, density, freezing point depression, osmosis, osmotic pressure, vapor, vapor pressure

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Skill-Development-Lab Activity

Introduction

1. Have a class discussion about the calculation of density and the proper use of a balance. Students may need instruction about boiling point and freezing point determination, depending on their previous lab experience.
2. Explain that boiling points of water-antifreeze solutions are easy to determine in a laboratory and require minimal equipment, although students will need to be extremely careful. Determining the freezing points of water-antifreeze solutions is much more difficult due to the extreme cold required. However, since substances melt and freeze at the same temperature, the freezing points of water-antifreeze solutions are equal to the melting points of the equivalent ice-antifreeze solutions, which are easily determined.
3. Explain that density is a characteristic property of matter: different substances exhibit different densities. Density is defined as the mass of a substance divided by its volume. Tell students that in the lab, they will determine the densities of water, antifreeze, and various solutions of antifreeze and water.

Procedure

CAUTION! Ethylene-glycol-based antifreeze is highly toxic. Biodegradable antifreeze is recommended in order to eliminate many disposal problems. For another safe alternative substance with the same density as toxic antifreeze, use a mixture of 2.5 mL corn syrup added to 7.5 mL propylene glycol. Additionally, the use of boiling chips will help prevent super-heating.

1. Have students determine and record on a data chart the mass of a clean, dry 10-mL graduated cylinder.
2. Have students fill the graduated cylinder with 10.0 mL of tap water and determine and record on their data chart the mass of the graduated cylinder plus the water.
3. Instruct students to empty the water and dry the graduated cylinder.
4. Next, have students carefully fill the graduated cylinder with 10 mL of antifreeze and then determine and record the mass of the graduated cylinder plus the antifreeze.
5. Have students pour the antifreeze into a labeled test tube and save it for the next experiment.

6. Tell students to pour 1.0 mL of antifreeze into the dry graduated cylinder and then fill it to 10.0 mL with water. They should record the mass and then pour this solution into a test tube labeled "10% solution." Have them save the solution for the next experiment.
7. Tell students to pour 2.0 mL of antifreeze into another dry graduated cylinder and then fill it to 10.0 mL with water. They should record the mass and then pour this solution into a test tube labeled "20% solution." Have them save this solution for the next experiment.
8. Have students make 10.0 mL each of 30%, 40%, 50%, 60%, 70%, 80%, and 90% antifreeze solutions, recording the mass of each solution, labeling according to its percentage, and saving for the next experiment.
9. Instruct students to clean up appropriately.
10. Finally, have students calculate the density of each of the solutions that were prepared and then graph density versus percent solution of antifreeze. Let pure water be 0% antifreeze and pure antifreeze be 100% antifreeze. Ask, "Is density a good indicator of concentration?" Have them explain their reasoning. Have them describe the general shape and trends in the graph they constructed.

Inquiry-Lab Activities

1. The boiling points of the various water-antifreeze solutions: Have students pour 2 to 3 mL of one of the solutions to be tested in a clean test tube and add a boiling chip to prevent super-heating. Instruct them in the safe way to expose the test tube to the heat source. Have them measure the boiling point by recording the temperature at which the liquid first starts to boil. Remind them that the boiling point changes upon prolonged boiling of a solution; therefore, they should record the boiling point as early as possible. Have students repeat this process for each of the nine solutions, recording the boiling points in their data charts.
2. The freezing points of the various water-antifreeze solutions: Have students measure 90 grams of ice and place it in a Styrofoam cup. Next, have them place a thermometer in the ice and stir carefully, reading the temperature every 30 seconds until the temperature remains constant. Inform them that this is the melting point of ice and that the freezing point of water equals the melting point of ice. Have students then add 10 grams of antifreeze to the 90 grams of ice in the cup and measure the freezing point of the 10% antifreeze solution by recording the lowest temperature reached. Record the freezing point in their data chart. You may wish to assign various lab stations the following ice-antifreeze mixtures: 80 grams ice to 20 grams antifreeze, 70 grams ice to 30 grams antifreeze, 60 grams ice to 40 grams antifreeze, 50 grams ice to 50 grams antifreeze, 40 grams ice to 60 grams antifreeze, 30 grams ice to 70 grams antifreeze, 20 grams ice to 80 grams antifreeze. Record the results on the chalkboard or the overhead.

Assessment

- **Questions**
  - What happened to the freezing point when you had at least 50% antifreeze? Why did this happen?
  - How is density related to boiling point and freezing point? How do you know?

- **Journal/Writing Prompts**
  - Explain what happened to the density of the water-antifreeze solution as the percentage of antifreeze changed.
  - Discuss the fact that antifreeze is used in a car's radiator to help prevent it from freezing or boiling over.
  - Now that you have experimented with different percent concentrations of water-antifreeze and know how changing percent concentration of antifreeze affects the boiling and freezing points of the solutions, explain what percent solution would be most effective in preventing freezing and boiling in your car's radiator. Describe how you came to this conclusion.
- **Other**
  - Use the formal written lab report as an evaluation tool.

Extensions and Connections (for all students)

- Have students go to specified cars in the parking lot and use a hydrometer to measure the specific gravity of the antifreeze in the vehicles and compare it to the bottle specifics.

Strategies for Differentiation

- Have students use probeware software to record the collection of data.
- Have students color code the information from the procedure to its corresponding part on the data table.
- Have students help one another by manipulating the equipment and/or recording information for the group.