INSTANT SLUSH

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Chemical Concepts:

- partial pressure
- gas solubility
- Henry's Law
- colligative properties—freezing point depression

Discussion:

The solubility of carbon dioxide in water is dependent upon the temperature, the partial pressure of CO_2 above the liquid, and the pH of the water. The production of carbonated drinks involves the dissolving of CO_2 at low temperature and high pressure resulting in a saturated solution. Soda water is bottled under high pressure in order to maintain the level of dissolved CO_2. When a bottle of soda is first opened one can hear the familiar "sssssst" due to the escaping CO_2. This lowers the partial pressure of the CO_2 above the liquid, which lowers the solubility of the CO_2 in the liquid (Henry's Law). The excess CO_2 solute begins to come out of the solution (gas bubbles are visible).

When a sealed bottle of soda is covered in ice, the liquid inside does not freeze due to the dissolved substances in the liquid (including the CO_2). The freezing point of a liquid solvent is lowered when a solute is dissolved in it. The greater the amount of dissolved solute the lower the freezing point of the solution. The chemical nature of the solute does not influence the degree the freezing point is lowered; only the total numbers of solute particles present per kg of solvent (colligative properties). A sealed bottle of soda usually will not freeze above -10^{o}C.

In this demonstration a sealed bottle of soda water is chilled in an ice-salt mixture to a temperature around -8^{o}C. The bottle is then removed and the cap is loosened. The familiar "ssssst" is heard, bubbles of escaping CO_2 can be seen leaving the liquid, and the liquid begins freezing from the top and continues downward until nearly all of the liquid is frozen. This phenomenon can be explained, at least partially, through our knowledge of colligative properties. When the CO_2 escapes from the liquid after the cap is loosened, the concentration of the remaining solution is lowered (fewer particles dissolved per kg). The lower concentration results in less of a freezing point depression—the solution will freeze at a higher temperature. The liquid begins to freeze when the concentration is lowered sufficiently so that the temperature is now below the freezing point of the mixture.

NOTE: There has been a significant amount of discussion concerning the explanation of this phenomenon. It has been argued that the concept of freezing point depression does not fully explain what occurs.

Materials:

- 12oz. or 16oz. glass bottle of soda water (remove the label)
- Ice/salt or ice/acetone bath
- Thermometer (optional)

Safety:

- The temperature of the ice/salt bath may drop sufficiently to freeze the liquid in the bottle of soda. The bottle may break due to the expansion of the water as it freezes. It is recommended that one keep an eye on the temperature using a thermometer. Wear protective leather gloves and safety goggles.
- If using an ice/acetone bath, be sure there is adequate ventilation. Do not dispose of acetone in the sink.

Procedure:

- Let an unopened glass bottle of soda (seltzer) water cool completely surrounded by an ice/salt or ice/acetone bath until thermal equilibrium (about 20 minutes) is reached.
- Carefully, lift the bottle partially out of the bath and show the students that the soda is still completely liquid.
- Break the seal to open the bottle. Be sure the students' view of the bottle is not obstructed.
- Slowly lift the bottle out of the bath allowing students to see the freezing of the liquid.

NOTE: If small glass bottles of soda water are not available in your area, small bottles of Perrier™ water work well, although they are more expensive. Club soda tends to work best.

Pedagogical Applications

1. Prepare in advance the salt/ice bath with the bottle of soda water. Also prepare a second ice only bath with a bottle of soda water. Have a third bottle of soda, which is at room temperature.
2. Hold up the room temperature bottle of soda water and ask the students what they would observe (see and hear) when the lid is loosened. Enter into a discussion as to why the dissolved gas comes out of solution and the effect on the concentration of the remaining solution. Review Henry's Law.
3. Show the students the bottle of soda water that is in the ice only bath. Let them see that the temperature is around $0^{o}C$ yet the solution inside the bottle is not frozen. Enter into a discussion as to why the solution has not yet begun to freeze. Be sure the ideas associated with colligative properties (freezing point depression) and the effect changing the concentration has on the freezing point. Finally get

the students to suggest ways to get the solution to freeze: lower the temperature and/or lower the concentration.

4. Show the students the third bottle of soda that is in the ice/salt bath. Let them see the temperature is now well below 0^oC and that the liquid inside is still not frozen (hopefully). Let them explain why it is still not frozen. Then ask the students what will happen when the cap is loosened. Allow for all possible predictions. Get the students to offer explanations for their predictions.
5. Perform the demonstration.
6. Follow up discussion should center on what happened and why. Get students to verbalize the explanation for the phenomenon. Be sure students who offered alternative predictions are involved in explaining what actually happened.