Freezing Point Depression: Can oceans freeze?
Teacher Advanced Version

Freezing point depression describes the process where the temperature at which a liquid freezes is lowered by adding another compound. It depends only on the number of dissolved particles in solution. This is known as a **colligative property**. For example, water freezes at 0°C, but when a **solute** such as salt or sugar is added to a **solvent** (water), the freezing point decreases. In order to see the freezing point depression of saltwater and how it changes with varying amounts of solute concentration, you will use 5 cups with water and varying amounts of salt and measure each individual temperature. Then, using the volume of the water and the volume of the solute, you will find the **concentration** of the solution expressed in **molality**. In the second part of the lab, you will use two freezer bags to observe how readily water freezes when surrounded by saltwater.

California Science Content Standards:

- **3. Conservation of Matter and Stoichiometry: The conservation of atoms in chemical reactions leads to the principles of conservation of matter and the ability to calculate the mass of products and reactants.**
- 3d. Students know how to determine the molar mass of a molecule from its chemical formula and a table of atomic masses and how to convert the mass of a molecular substance to moles, number of particles, or volume of gas at standard temperature and pressure.
- **6. Solutions: Solutions are homogeneous mixtures of two or more substances.**
- 6a. Students know the definitions of solute and solvent.
- 6c. Students know temperature, pressure, and surface area affect the dissolving process.
- 6d. Students know how to calculate the concentration of a solute in terms of grams per liter, molarity, parts per million, and percent composition.
- **6e. Students know the relationship between the molality of a solute in a solution and the solution's depressed freezing point or elevated boiling point.
- **7. Chemical Thermodynamics: Energy is exchanged or transformed in all chemical reactions and physical changes of matter.**
- 7a. Students know how to describe temperature and heat flow in terms of the motion of molecules (or atoms).

Key Concepts:

- A **solution** is a mixture composed of two or more substances. In a solution, the **solute** dissolves into another substance, referred to as the **solvent.**
- A solution's **colligative properties** refer to the number of dissolved particles contained in the solution and are not dependent on the identity of the solutes.
- A solution's **concentration** refers to the amount of solute mixed in with the solvent (e.g.10% saline solution).
- **Molality** is the number of moles of solute per kilogram of solvent and can be expressed in the following equation:

$$\frac{\text{Moles of solute (mol)}}{\text{Mass of solvent (kg)}} = \text{Molality of solution (mol/kg)}$$

- When water freezes, energy is released in the form of heat. This is why ice has a lower temperature than water. When ice melts, energy is absorbed, increasing the temperature.

Materials (Part 1):

- 5 foam cups
- Water
- Ice
- Salt
- Sugar
- Thermometer
- 100mL graduated cylinder
- Measuring cup
- 1 tablespoon and teaspoon
- Access to the Periodic Table of Elements
- Stirring rod
- Strainer
- Graph paper (if available)

Materials (Part 2):

- 1 gallon freezer bag
- 1 quart freezer bag
- 1 cup
- Crushed ice
- Salt
- Gloves or towel

Part 1 – Calculating Molality

1. **Separate the table on the last page of the lab for use during the lab.**

2. **Set up 5 cups in a line in front of you.**

3. **Label the cups** - "0mL of Salt", "10mL of Salt", "20mL of Salt", "30mL of Salt", and "Sugar".

4. **Fill the measuring cup to about 100mL of crushed ice. Slowly pour water into the cup until the ice/water mixture reaches 100mL.** (If your measuring cup does not measure in mL, 100mL is a little less than half a cup.) **Fill the first 4 salt cups with 100mL of ice/water.**

5. **Measure out each respective amount of salt, using tablespoons and teaspoons.**
   Note: 1 teaspoon=5mL and 1 tablespoon=15mL.

6. **Stir the amount of salt into each cup until the salt dissolves.** Note: If the saltwater is not continually stirred, the salt will pile up at the bottom. **Stir slowly to ensure salt dissolves. Also, for 30mL of solute, add the solute in portions.** (Example: 10mL first and then 20mL later).

Q1. Why does the 10mL of salt dissolve more readily than the 30mL of salt? How does the temperature of the solution affect the solubility of the solution?

Both 10mL of salt and 30mL of salt when in solution with ice and water are saturated solutions, yet 10mL of salt dissolves more readily with ice water because it is a lesser amount that needs to dissolved. If the water were at a higher temperature, the salt would dissolve with much more ease; this is because at a higher temperature, the bonds of the salt break more easily.

Q2. What other factors can you think of that might affect the solubility of the solution?

The amount of stirring as well as pressure and surface area contribute to the solubility of the solution.

7. **After you have stopped stirring, wait for the temperature to reach equilibrium.** This temperature is the "freezing point" of the solution. *Record the temperatures in Column B.*

Q3. How did the temperature change by incrementing the amount of salt in the water?

Answers vary based on student data, but the freezing point should decrease with the addition of more salt.

8. **Using a strainer, strain the ice out of each cup. Measure the volume of the remaining liquid (salt water) using the graduated cylinder.** *Record the results in Column C.*

9. Now, in the final foam cup, **add 30mL of sugar solute into 100mL of cold water.** *Record the freezing temperature below:*

Temperature:______ *Student Answer* ______

Q4. How does the freezing temperature obtained by sugar water compare to the freezing temperature obtained when 30mL of salt were added to the same amount of water?

The salt solute depresses the freezing point more than the sugar solute.

Concept Questions

Find the molal concentration of each solution using the equation below, but first find the moles of solute and mass of solvent. Follow the steps below to find these values.

$$\text{Molality (mol/kg)} = \frac{\text{Moles of solute (mol)}}{\text{Mass of solvent (kg)}}$$

First find the moles of solute (numerator):

First find the mass of the salt in grams. To find the mass of the salt, follow the example below:

$$\text{Volume of Solute (mL)} \times \text{Density of Salt (g/mL)} = \text{Mass of Salt (g)}$$

The volume of salt solute can be found in Column A of the table, and the density of salt is 2.2 g/mL. Calculate the mass of salt for each cup.
Students should use the above equation as below for each volume of salt.

Column A Value x 2.2 g/mL = Mass of Salt (g)

Record your answer in Column D.

Next, using the grams of salt, find the moles of salt. First, find the Molar Mass of salt (NaCl) using a periodic table

Q5. Find the Molar Mass of Na and Cl, then add those together to get the Molar Mass of NaCl(salt).

*Molar Mass of Na:_ ~22.99_ Molar Mass of Cl: _~35.45_ Molar Mass of NaCl (salt): _58.44_*

Using the grams of solute and the molar mass, calculate the moles of NaCl salt:

$$\text{Mass of salt} \times \frac{\text{1 mole}}{\text{Molar mass of NaCl (g/m)}} = \text{Moles of salt (mol)}$$

$$\textit{Column D Value \_\_\_ (g)} \times \frac{\textit{1 mole}}{\textit{Molar mass of NaCl \_\_\_\_\_(g/m)}} = \textit{Moles of Salt\_\_\_ (mol)}$$

The grams of salt were just entered in Column D of the table and the Molar Mass of salt is above so use the following equation to calculate the Molar Mass of salt for each cup.
Students should use the above equation as below for each mass of salt.

Record your answers in Column E above.

Now find the mass of solvent (denominator):

First, convert the volume (mL) of the strained water to kilograms (kg). (mL ÷ 1000 = kg)
Students should convert all the mL volumes to kg using the below equation.

Column C Value _________ ÷ 1000 = Volume of Solvent __________ (kg)

Record your answers in Column F.

Now, use the original equation to find the molality of the solution in molal units.

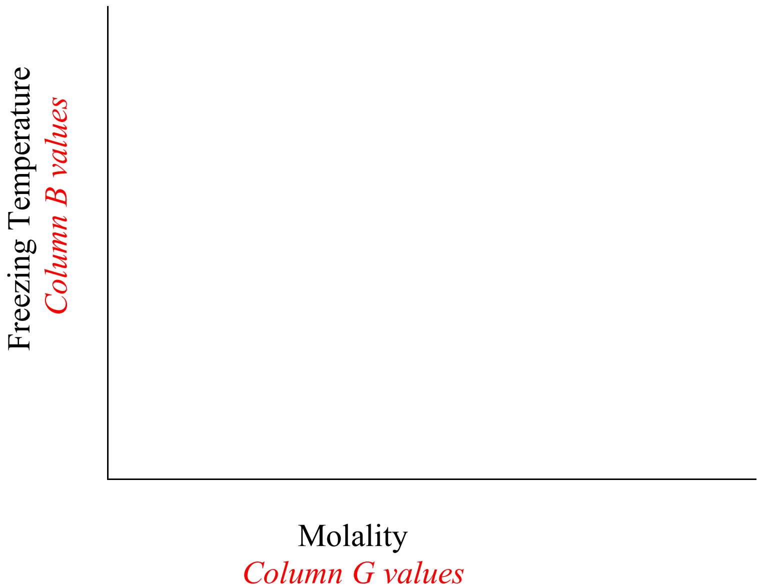
$$\text{Molality (mol/kg)} = \frac{\text{Moles of solute (mol)}}{\text{Mass of solvent (kg)}}$$

Students should use the above equation as below for each mass of salt.

Column E Value _______ (m) ÷ Column F Value _______ (kg) = Molality _______(m)

Record your answers in Column G above.

Q6. Plot a molality vs. temperature graph. Describe the relationship.
Molality is Column G in your table and temperature is Column B.
As the molality increases the freezing point decreases.



Q7. What freezing gtemperature would you predict if 40 mL of salt was placed in the water?

Based on the above graph the students should predict a temperature ~5°C colder then the temperature of the solution with 30mL of salt.

Q8. Why does salt depress the freezing temperature more than sugar? (Hint: covalent bonding vs. ionic bonding)

The salt solute is able to depress the freezing point more than the sugar solute because the salt is ionically bonded while the sugar solute is covalently bonded. Because salt is ionically bonded, its ions are able to fully dissociate in solution.

Instructions for Part 2

1. Add crushed ice into the gallon freezer bag until the bag is ¼ full. Take the temperature.
Record below:
Temperature:____ Student Answer should be near 0°C

2. Add two cups of salt into the gallon freezer bag.

3. Squeeze out as much air as possible and close the gallon bag.

4. Mix until the ice has completely melted. The bag will get very cold so put on gloves or hold the bag in a towel to protect your hands. **Rub your hands against the ice in order to melt the ice faster. Take the temperature**. *Record below.*

*Temperature:*____________ *Student Answer* ____________

Q9. How did the addition of salt change the temperature? How is this similar to the first part of the lab?

This part of the lab is similar in that the addition of salt depresses the freezing point.

Q10. If the temperature is below 0°C, the freezing point of water, why is the saltwater not frozen?

The salt water is not frozen because by adding a salt to water, the freezing point decreases, lowering to more than 0°C.

5. **Open the quart-size freezer bag and pour 1 ounce (2 tablespoons) of water into it.**

6. **Close the quart-size bag and put it inside the gallon freezer bag.**

7. **Let it sit for one minute.**

8. **Remove the quart size bag.**

Q11. Describe your observations below:

Various student observations will be given, however water in quart-sized bag should be frozen

Concept Questions

Q12. Is it possible to make the salt water colder and colder forever just by adding more salt? Why or why not?

This is not possible. The freezing point of saturated salt water (i.e. there's no way to dissolve any more salt in it no matter how hard you tried), is -21.1 degrees Celsius, which would also be the coldest temperature for a salt water solution.

Q13. Why does the water inside the smaller freezer bag freeze so easily? Explain in terms of heat flow.

Heat flows from warmer objects to colder objects until it reaches the same temperature; similarly, in this case, the heat from the smaller bag transferred to the larger bag until the water inside the smaller bag froze.

Q14. Why is the ocean able to maintain temperatures lower than 0°C without turning into ice?

Small lakes and rivers often freeze due to harsh winter temperatures, but oceans never completely freeze due to their large quantity of salt.

References:
1. Freezing Point Depression Lab:
http://www.nphsscience.com/Dogancay/chem_h/labs/hlab09_fpdepression.pdf
2. Freezing Water in a Bag: http://www.hometrainingtools.com/article.asp?ai=1272&bhcd2=124871522

Results Table for Part 1

Column A	Column B	Column C	Column D	Column E	Column F	Column G
Solute	Temperature (C^{o})	Strained Water (mL)	Mass of Salt (g)	Moles of Salt	Kilograms of Water	Molality
0 mL salt	*0 ºC*					
10 mL salt	*decreasing*	*~60-90mL*	*21.65 g*	*0.37 mol*	*~0.06-0.09 kg*	*~4 - 6*
20 mL salt	*decreasing*	*~60-90mL*	*43.3 g*	*0.74 mol*	*~0.06-0.09 kg*	*~8 - 12*
30 mL salt	*decreasing*	*~60-90mL*	*64.95 g*	*1.11 mol*	*~0.06-0.09 kg*	*~12 - 18*
30 mL sugar	*Near 0 ºC*					

The values in the table are approximate. Students answers could vary greatly depending on experimental conditions. The temperatures will be decreasing values with the increased amounts of salt.