

Details



Completion Time: About one period

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How Cold is Freezing?

Overview

How can the ocean be colder than 0°C , the temperature at which water freezes? As it turns out, the concentration of the particles (in this case, the ions from the salt) in ocean water lowers the temperature at which the saltwater will freeze. Students will learn how ocean water freezes at a lower temperature than freshwater by conducting an experiment to determine the temperature of a freezer. This experiment can be performed in the classroom or at home by students in honors and AP level chemistry or can be easily modified to use in any physical science class.

Objectives

Students will learn:

- To make saltwater (NaCl) solutions of varying concentrations, including how to calculate the molality of the solution.
- To determine the freezing point depression of the saltwater solutions.
- To estimate the temperature of a freezer by observing the behavior of various concentrations of saltwater.

Lesson Preparation

The concept of the freezing point depression of saltwater is a perfect application of colligative properties and can be used as an opportunity to introduce students to the extremely cold environment of arctic and antarctic ocean waters. According to NOAA, arctic ocean water freezes at -1.9°C (<http://oceanservice.noaa.gov/facts/oceanfreeze.html>) due to the salt dissolved in it. More concentrated saltwater bodies of water (such as the Great Salt Lake in Utah) would require even colder temperatures to freeze.

If you are teaching an advanced chemistry class, prior to this experiment, the background chemistry concepts (see attached) should be covered for your students to

Materials

- Table salt, NaCl
- Water
- Fork or many toothpicks
- Kitchen measures: 1 cup, 1/4 cup, 1 tablespoon, 1 teaspoon
- OR graduated cylinders (recall that 1000 mL of water = 1 kg of water) and a balance.
- Ice cube tray with 5 or more cube slots OR 5 small (3 oz.) bathroom cups
- Household freezer
- Four household glasses larger than one cup
- Masking tape and a marker

perform the calculations for determining the freezing point depression of saltwater solution.

If you are teaching an earlier level science class, refer to the Freezing Temperatures for the Various Saltwater Solutions chart (see attached background chemistry information) to determine the freezing point of each of the successively more dilute saltwater solutions obtained in the procedure. Your students can skip Procedural steps 7 & 8.

Procedure

1. Using masking tape, label the four household glasses "A", "B", "C", and "D". Save these for step 3.
2. Dissolve one tablespoon (20 g) of table salt in exactly $\frac{1}{4}$ cup (59 mL = 0.059 kg) of tap water in each of the glasses labeled A, B, C, and D. Stir very well.
3. Set glass A aside. Glass A now contains 20 g NaCl and 0.059 kg of water.
4. Dilute the solution in glass B with an additional 0.104 cups of water (1 tablespoon and 2 teaspoons). Stir well. Glass B now contains 20 g NaCl and 0.084 kg of water.
5. Dilute the solution in glass C with an additional 0.25 cups of water ($\frac{1}{4}$ cup). Stir well. Glass C now contains 20 g NaCl and 0.118 kg of water.
6. Dilute the solution in glass D with an additional 0.75 cups of water ($\frac{3}{4}$ cup). Stir well. Glass D now contains 20 g NaCl and 0.236 kg of water.
7. Calculate the molality, m , of each of the saltwater solutions in glasses A, B, C, and D using the formula: molality, $m = \# \text{ of moles NaCl} / \# \text{ of kg water}$
8. Calculate the freezing point depression of the saltwater solutions in glasses A, B, C, and D using the formula: $\Delta T = - (K_f) (m) (i) = (1.86)(m)(2)$. This is also the freezing point of the saltwater solution in $^{\circ}\text{C}$. If you wish to see this freezing point in $^{\circ}\text{F}$, convert using the formula: $^{\circ}\text{F} = (1.8^{\circ}\text{C}) + 32$.
9. With masking tape, label five of the cube slots of the ice cube tray (or the 5 small bathroom cups) as follows "A", "B", "C", "D", and "Control".
10. Pour equal amounts of the solutions from each of the labeled glasses into the appropriate ice cube slot (or small cup). Do not fill these above $\frac{2}{3}$ full. Into the "Control" ice cube slot (or small cup), add tap water.
11. Place the ice cube tray (or small cups) into the freezer in an area that can be easily observed. Be careful not to mix or spill the solutions.
12. Every 30 minutes for 3 hours, observe the freezing process. Use a fork (or toothpick) to determine the state of each solution. Rinse the fork between testing each sample. Do not cross-contaminate the solutions with the fork. Record the state of each solution at every observation time.

Extension

Students could research the freezing temperatures of saltwater bodies near them or of how some animals and insects use this freezing point depression to keep their blood from freezing in very cold temperatures.

Resources



n/a

Assessment

The teacher can use the student lab report to assess student understanding.

Credits

This is an original lesson by Mark Paricio, mparicio@cherrycreekschools.org, adapted from his original take-home-experiment: "How Cold is my Freezer?"

National Science Education Standards (NSES):

Content Standards, Grades 9-12

Content Standard A: Science As Inquiry

- a. Abilities necessary to do scientific inquiry

Content Standard B: Physical Science

- a. Structure of atoms
- b. Structure and properties of matter
- c. Chemical reactions

Other Standards

Colorado Science Standards:

2. Matter has definite structure that determines characteristic physical and chemical properties

Students can:

- b. Gather, analyze and interpret data on chemical and physical properties of elements such as density, melting point, boiling point, and conductivity (DOK 1-2).

Background Chemistry Concepts for NaCl-water solutions:

- Molality is the number of moles of the solute, NaCl /1 kg of the solvent, H₂O.
$$m = \text{moles NaCl} / 1 \text{ kg H}_2\text{O}$$
- 1 tablespoon of table salt is approximately 20 grams of NaCl.
- The molar mass of NaCl = 23.0 (for Na) + 35.5 (for Cl) = 58.5 g/mole NaCl
- 1 cup of water is 237 grams of H₂O.
- The temperature depression, ΔT , of the normal freezing point of a solvent containing a solute with particles or ions in molal concentration, m , is given by the equation:
$$\Delta T = - (K_f) (m) (i) = \text{the freezing point of the solution in } ^\circ\text{C}$$

where:

K_f is the cryoscopic constant specific to the solvent. For water, $K_f = 1.86 ^\circ\text{C}/m$. m is the molality concentration of the solvent in the solution.

i is the “van’t Hoff factor” and equals the number of ions or particles per individual formula unit of solute. For NaCl, $i = 2$; for MgCl₃, $i = 3$.

Freezing Temperatures for the Various Saltwater Solutions

Solution	NaCl (tbsp.)	NaCl (g)	NaCl (moles)	Water (kg)	Water (mL)	Water (cups)	molality (m)	Freezing Pt ($^\circ\text{C}$)	Freezing Pt ($^\circ\text{F}$)
A	1	20	0.34	0.059	59	0.25	5.76	-21	-7
B	1	20	0.34	0.084	84	0.35	4.05	-17	2
C	1	20	0.34	0.118	118	0.50	2.88	-11	13
D	1	20	0.34	0.236	236	1.00	1.44	-5.4	22.

Observations of Solutions at Various Time in the Freezer

Solution	Time: 0:00	Time: 0:30	Time: 1:00	Time: 1:30	Time: 2:00	Time: 2:30	Time: 3:00
A	liquid						
B	liquid						
C	liquid						
D	liquid						
E	liquid						

Questions:

- Based on your observations and your answers to calculation step 3, give a range of the approximate temperature of your freezer. Explain your reasoning.
- Does tap water (or freshwater) really freeze at 0°C? Why or Why not?
- The maximum solubility of table salt, NaCl ($i = 2$) in water at 0°C is 35.7 g NaCl / 100 g H₂O.
 - Calculate the maximum molality of a NaCl solution in water at 0°C
 - Calculate the maximum freezing point depression for this NaCl solution.
- The maximum solubility of the sugar sucrose, C₁₂H₂₂O₁₁, in water at 0°C is 180 g C₁₂H₂₂O₁₁ / 100 g H₂O, a value much higher than that for NaCl. However, sucrose is NOT an electrolyte like NaCl (so $i = 1$).
 - Calculate the maximum molality of a C₁₂H₂₂O₁₁ solution in water at 0°C
 - Calculate the maximum freezing point depression for this C₁₂H₂₂O₁₁ solution.
- The maximum solubility of the salt magnesium chloride, MgCl₂ ($i = 3$) in water at 0°C is 52.9 g NaCl / 100 g H₂O.
 - Calculate the maximum molality of a NaCl solution in water at 0°C
 - Calculate the maximum freezing point depression for this NaCl solution.
- Graph the molarity of each solution (x -axis) versus the calculated freezing point (°C) of each solution. If ocean water freezes at -1.9°C, determine the approximate molality of the ocean, assuming it is primarily a NaCl solution.
- Why is MgCl₂ used on highways when the temperature reaches freezing at 0°C? At what temperature should the highway department stop using NaCl? How might the highway department keep the roads from freezing even below the temperature you mentioned? What might be a side effect of using either NaCl or MgCl₂ on the roads?