Freshwater & Saltwater

OVERVIEW

In this lesson students investigate the difference that salt concentration, or salinity, makes to the kind of ice that forms at cold temperatures. Students qualitatively assess the difference in hardness and flexibility, and quantitatively assess the difference in the freezing and melting points to try to unravel the differences between freshwater ice and saltwater ice.

FLOW

1. Read the Background section
2. Experiment set-up
3. Ice freezes
4. Salt vs. freshwater teacher demo
5. Experiment
6. Summarize results
7. Discussion Questions

ACTIVITY TIME

120 minutes

+ 2 - 4 hours for ice to freeze.

LEARNING OUTCOMES

- List the major differences between sea ice and freshwater ice.
- Explain the effect that salinity has on the freezing point of water.
- Explain why knowledge of sea ice is important for people living in the Arctic.
- Identify the importance of correlating Inuit Knowledge with scientific knowledge.

CONTENTS

STUDENT OVERVIEW

WHY?

Saltwater and freshwater ice are composed differently and form ice types that vary in their freezing temperatures, flexibility, porous nature and activity in the environment.

WHAT?

- Buoyancy of freshwater vs. saltwater ice cubes.
- Melting points of those ice cubes.
- Strength of freshwater vs. saltwater ice.
- Qualitative and quantitative measuring tools.

HOW?

- Review the Background section
- Prepare for and complete the experiment
- Record your results
- Discussion Questions

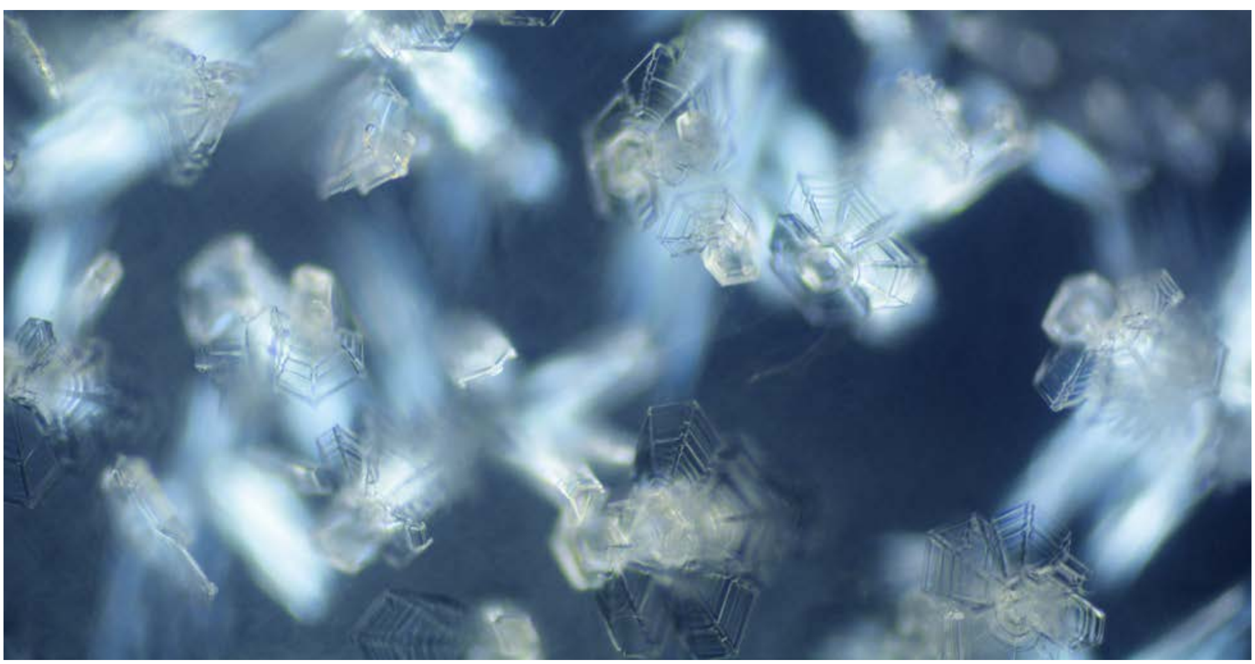

IMAGE 1 Top edges of ice crystals under microscope (M. Bilovitskiy[1]).

BACKGROUND

Knowledge of sea ice is important in order to safely travel over it. In many areas of the North, sea ice dynamics are changing, and ice conditions have become less predictable. For instance, in 2009, senior hunter Peter Kattuk from Sanikiluaq noticed that there was more snow than normal on the sea ice in some places: “The snow is not freezing. It’s kind of warmer so it’s not getting hard on the ground,” Peter said, “So, it’s like cooking oil. Melting the ice.”(P. Kattuk[2]).

Hudson and James bays are connected to the ocean and contain salt water, but many rivers bring freshwater to the bays as well. Systems with a mix of fresh and saltwater are called estuaries. An important trend has been observed in the Arctic; a freshening of the surface layer of seawater. This affects the formation and properties of the sea ice that forms in the fall, how it breaks and piles up during the winter, and how it breaks-up during the spring. Further complicating this issue are indications that large scale hydroelectric projects reverse the seasonality of rivers by dumping large amounts of freshwater into the ocean during the winter instead of during the spring melt. 2013 was a very cold winter in Quebec. This resulted in very high electricity usage and the associated release of freshwater from dams. Plumes of water, much fresher than normal, were detected in several locations near the Belcher Islands. Why is this important and what is the difference between sea ice and freshwater ice anyway?

The **freezing point** of freshwater is 0°C. The presence of dissolved salts in ocean water lowers the freezing point to about -1.8°C by disrupting the formation of **hydrogen bonds** between water molecules.

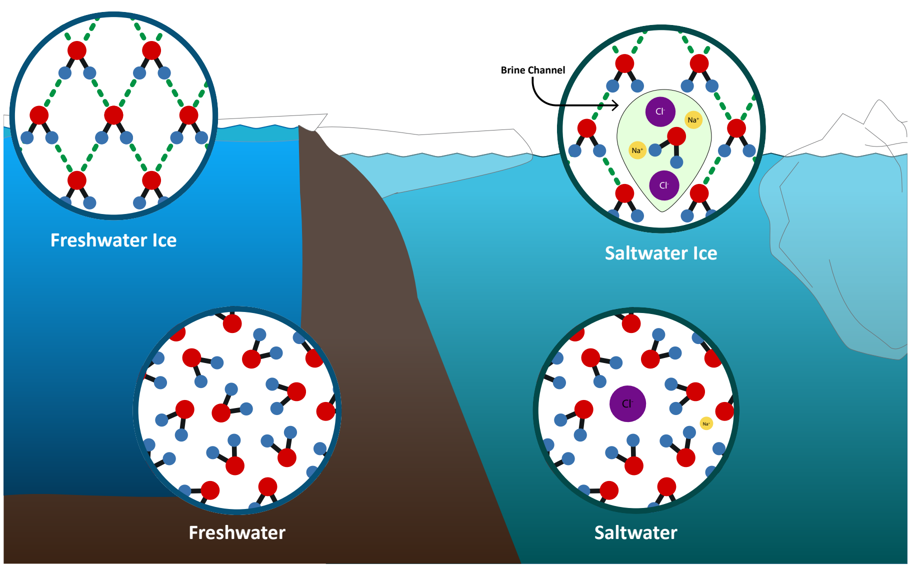

FIGURE 1 A 2D illustration of fresh and saltwater ice molecules are shown for clarity but a 3D representation is required to accurately depict atomic structure.

VOCABULARY

Qualitative: Observations based on what the observer sees. Often visual.

Quantitative: Describing or measuring a quantity (ex. temperature, length).

Estuary: A body of water where salty and freshwater come together, often found in bays near the mouths of rivers.

Salinity: The concentration of dissolved salts in a liquid.

Brine channels: Small holes in ice formed when salt is not completely forced out of developing sea ice by brine rejection.

Density: The mass of a substance per unit of volume.

Hydrogen bonds: Intermolecular bonds that form between the negatively charged oxygen atom of a water molecule and the positively charged hydrogen atoms of surrounding water molecules.

Lattice: A crystalline arrangement of atoms or molecules.

Qinu / frazil ice: The earliest stage of ice formation when ice has a slushy consistency suspended in water. This occurs when the ice particles are loose and soft and have not yet frozen to the point of becoming ice.

Freezing point: The temperature at which water becomes ice.

PREPARATION

MATERIALS

- Thermometer (1 per group or class)
- Pitchers for preparing batches of salt water (2)
- Shallow 250-500mL containers (4 per group) transparent and wide enough for students to place their hand on the surface of the ice
- Large glass bowl or small aquarium
- Table salt
- Tap water
- Measuring cup
- Spoons/stir sticks
- Labelling tape
- Food colouring
- Ice cube tray

NOTES

- Set-up needs to be done in advance of the main experiment. Although it can be done solely by the teacher, the set-up can also be done by student.
- The freeze stage requires 2-4 hours of freezing time in a freezer or outside if temperatures are below -2°C.

> *The sea ice should be stable enough to support your hand, but neither the freshwater ice nor the saltwater ice should be completely solid.*

- The test run data in *Table 1*, was carried out in a residential freezer at the coldest setting and includes approximate timing and observations from the freeze stage.

FIGURE 2 Setup Diagram

SET-UP

1. Tell students that you are going to be doing an experiment to further their understanding of salt water but they first need to prepare batches of saltwater and freshwater.
2. Following the Worksheet (pg. 8), each group should:

   A. Label 2 pitchers “Saltwater” and “Freshwater”
   B. Label 4 containers A through D
   C. Label containers A and C “Saltwater”
   D. Label containers B and D “Freshwater”

3. Divide the class into groups and distribute sets of pitchers and containers to each. Instruct students to label their containers. Fill the pitchers with about 1L of warm water.
4. Add one heaping tablespoon of salt to the “Saltwater” pitcher for every litre of water added (1 tsp per cup, or ~3% by volume. Avoid using excess salt as this will increase freezing time).
5. Stir to thoroughly dissolve the salt. Store the saltwater and freshwater in the fridge until 2 hours before the experiment start.

Freeze

6. Take an initial water temperature reading for containers A and B.
7. At least 2 hours before class, pour 250-500mL (1-2 cups) of saltwater and freshwater into the appropriate labelled trays. Set them in the freezer or outdoors to freeze (must be at least -2°C).
8. Fill several wells of an ice cube tray with the remaining saltwater, and several with tap water. Use two colours of food colouring to clearly distinguish the salt and freshwater treatments.
9. Check on the ice every 30-45 minutes while it freezes. If conducting the set-up with students, have them record time, the water temperature and observations in *Table 1* on the Worksheet (pg. 8). They can also be encouraged to draw what they see as the ice forms since the ice crystals grow very differently.
10. Periodically during the freezing process use a knife to keep a small hole in the ice open so that students will be able to measure the temperature of the water directly under the ice with their thermometers.

PROCEDURE

PART I: INTRODUCTION

FIGURE 3 The saltwater ice cube should melt faster and sink deeper than the freshwater ice cub.

1. Fill a large glass bowl or aquarium with cold water. Place one coloured saltwater and one freshwater ice cube into the bowl. Ask students to hypothesize which one has higher **salinity**. Ask them what evidence they based their decision on.

   - *Which one floats more*
   - *Appearance*

2. Check back on the demonstration after a few minutes. Ask students to describe what has happened and why.

   Since the presence of salt lowers the melting point to -1.8ºC, the salty ice cube should appear to melt faster than the freshwater cube. Additionally, saltier water is denser than freshwater, so the melting saltwater should sink towards the bottom.

3. Ask the class to think of a reason why the melting freshwater may also initially sink?

   Cold water is denser than warm water and therefore sinks.

4. Review the structure of water molecules. Invite students to draw a water molecule on the board and illustrate the **lattice** structure for solid freshwater compared to solid saltwater, including **brine channels** in saltwater as shown in *Figure 1*.

5. As a class come up with the question this experiment will help answer, such as:

   - *What are the differences between ice formed with freshwater and saltwater?*
   - *What can the physical properties of different kinds of ice tell us about winter sea ice safety?*

6. Explain that to answer these question they will be making both **quantitative** and **qualitative** observations of ice.

7. Review the definition of these terms from the Vocabulary (pg. 3). As a class, brainstorm words that could be connected to each term. This will demonstrate the differences between the two methods, while giving them a reference point for vocabulary.

   - *Quantitative words: measurement, temperature, length, weight, height.*
   - *Qualitative words: ice crystals, liquid, solid, thick, thin, blue.*

8. Explain the quantitative methods that students will use to test their hypotheses include measuring water temperature with a thermometer and ice thickness with a ruler. Have the groups develop a hypothesis for the water temperature and ice thickness based on what they already know about salt and freshwater using "if...then" phrases. Examples include:

- *If the salt molecules prevent hydrogen bonds from forming as salt water freezes, then the freshwater ice should freeze faster and be thicker than the saltwater ice.*
- *If the salt molecules decrease the freezing point of water, then the water under the salt water ice should be colder than the water under the freshwater ice.*

9. Explain the qualitative methods for the experiment, observing ice hardness and physical appearance. Qualitative data usually involves more subjectivity, and in this case involves a comparison between the apparent, perceived hardness between freshwater ice and saltwater ice. Examples include:

- *If salt water ice has brine channels, which make it more porous and irregular than freshwater ice, then it should be less hard than freshwater ice.*
- *If freshwater ice is more brittle, then it should crack more easily.*

PART II - MEASUREMENTS AND ANALYSIS

10. Have the students retrieve containers A and B (they should be partially frozen at this point). Have them measure the temperature of the water and the thickness of the ice. Students should note their observations in the student guidebook.
11. Now retrieve containers C and D (fully frozen). Have students evaluate the visual differences in the 2 kinds of ice and come up with 3-4 descriptive words for each. Students will use a butter knife or pencil to test the hardness of the ice in containers C and D, simulating the harpoons used by many Inuit to test the ice when traveling over it. Have the students write down their observations. Under the headings "Saltwater" and "Freshwater" have each group write down their descriptive words/observations.
12. Drain any melted water, then add a few drops of food colouring to the surface of each type of ice, near an edge. Have students observe what happens. This will illustrate how saltwater ice is more porous and less brittle than freshwater ice. The dye should be transported by capillary action through the brine channels of the saltwater ice, and along the fissures in the freshwater ice.

    If you have to use opaque containers, you can first turn the ice out onto a tray to make this staining easier to observe.

13. Using the class' quantitative data, calculate the mean (average) temperature and thickness of both types of ice.
14. Using the class' qualitative data, note any words that appear more than once.
15. Evaluate the differences between the ice. Did these results support the students' hypotheses?
16. Ask your student to summarize the differences between saltwater and freshwater. Write this down in a chart and post it on the wall of the classroom for students to reference later.
17. As a class, complete the Discussion Questions (pg. 11).

WORKSHEET

SET-UP

1. Label materials.

   - **A** Label 2 pitchers "Saltwater" and "Freshwater"
   - **B** Label 4 containers A through D
   - **C** Label containers A and C "Saltwater"
   - **D** Label containers B and D "Freshwater"

FIGURE 4 Set-up diagram

2. Fill each pitcher with 1L of warm water.
3. Add one heaping tablespoon of salt to the "Saltwater" pitcher.
4. Stir the saltwater to thoroughly to dissolve the salt.
5. Put the pitchers in the fridge.
6. At least 2 hours before the experiment, pour 250-500mL (1-2 cups) of freshwater and saltwater into the appropriate labelled trays. Set them in the freezer or outdoors to freeze (must be at least -2°C).
7. Check on the ice every 30-45 minutes while it freezes and record the time, the water temperature and observations in *Table 1.*

Time	Temp A (˚C)	Temp B (˚C)	Observations
12:00	*8*	*8*	*Both containers set into the freezer.* *A is freshwater and B contains saltwater.*
12:30	*0*	*0*	*A has a thin skim of ice.* *B has no ice"*
12:45	*0*	*-1.8*	*A ice getting thicker. Cracks easily/shatters when tapped with a butter knife.* *B Frazil ice appear (crystals suspended in liquid.)*
1:15	*0*	*-2.5*	*A ice getting thicker. Harder to crack, but still fractures in long lines.* *B ice chunks getting larger, float as slush on the surface.*
1:45	*0*	*-3*	*A ice is getting thicker. Very hard, can chip but can't crack through.* *B becoming more solid but can still easily dig through with a knife.*

TABLE 1 Ice freezing data table. (Answer Key - Our test run was carried out in a residential freezer at the coldest setting. After 45 mins, the freshwater ice almost completely covered the surface, while saltwater contained some ice crystals.

EXPERIMENT

8. Take containers A and B out of the freezer. Measure the temperature of the water and the thickness of the ice. Record the values below and also on the board at the front of the class. Write down what the ice looks like and any observations that you think might be important.

   A Temperature A: ________ Thickness A: __________

   Observations:

   ____

   ____

   ____

   ____

B Temperature B: ________ Thickness B: __________

Observations:

____

____

____

____

9. Take containers C and D out of the freezer. They should both be frozen solid. What are the differences between the two different types of ice? Come up with 3-4 descriptive words for each.

C Words describing ice in container C:

____

____

____

____

D Words describing ice in container D:

____

____

____

____

10. Use a butter knife or pencil to test the hardness of the ice in containers C and D, simulating the harpoons used by Inuit to test the ice when traveling over it. Write down any observations. Also write your group's observations on the board.

C Observations when breaking ice in container C:

____

____

____

____

D Observations when breaking ice in container D:

____

____

____

____

DISCUSSION QUESTIONS

1. How would a freshwater ocean be different from a saltwater ocean in terms of sea ice?

   A freshwater ocean would freeze at a higher temperature, at around 0º Celsius, instead of around -1.8º Celsius. This would result in much more sea ice on the planet, and very different climatic conditions around the globe.

2. Would sea ice be safer to travel over if it was composed of fresher or saltier ice? Why?

   Hardness is not the only consideration when considering the safety of traveling over sea ice. As students probably observe, the saltwater ice tends to be more flexible than the rigid and hard freshwater ice. For this reason, sea ice formed from water with more dissolved salts can be safer to travel on as it is more flexible, and if the temperatures are sufficiently low can be nearly as hard as freshwater ice. Sea ice with lower salinity can be less safe to travel on as it cracks very cleanly and easily. Most of the sea ice traveled over by hunters on skidoos is called landfast ice, or sea ice attached to the land. When the tide changes, it can crack the ice near the shoreline, and the salt concentration of the ice can influence both how it cracks and how the ice breaks apart in the spring.

IMAGE 2 Saltwater ice, left, and freshwater ice, right. (J.Heath)

LINKS

Sanikiluaq Sea Ice Project
Traditional Knowledge interviews with 3 hunters from Sanikiluaq covering the major changes in the regional sea ice environment over the last 35 years.
https://arcticeider.com/links/fws1

SOURCES

Cover photo by J. Heath.

1 Top edges of ice crystals under microscope by Maxim Bilovitskiy, 2015. https://commons.wikimedia.org/wiki/File:Ice_crystals_3.jpg. Used under CC BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0.

2 Peter Kattuk: Sea ice observations. (n.d.). Retrieved September 01, 2016, from http://eloka-arctic.org/communities/sanikiluaq/hunters/peter_kattuk.html

Hexagonal ice lattice diagram by Jessica Fries-Gaither, Ohio State University, 2011. http://beyondpenguins.ehe.osu.edu/teaching-about-snowflakes-a-flurry-of-ideas-for-science-and-math-integration. Used under CC BY-SA 3.0, https://creativecommons.org/licenses/by-sa/3.0.

ATTRIBUTION

PRIMARY

- Karl Hardin

CONTRIBUTORS

- Joel Heath
- Jackie Kidd
- Misha Warbanski
- Evan Warner