AQUARIUS

Education & Public Outreach

Can Sea Water Freeze?

Unit: *Salinity Patterns & the Water Cycle* **I Time Required:** *Four 45 min. class period* I **Grade Level:** *Middle* I **Content Standard:** *NSES Physical Science, properties and changes of properties in matter* **Ocean Literacy Principle 1e:** *Most of Earth's water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic.*

Big Idea: *Salt causes water to freeze at a lower temperature. In fact, any substance dissolved in water lowers its freezing point. The oceans do not freeze (except in extreme polar areas) because of the salinity (i.e. concentration of salt).*

Key Concepts:

- Dissolving any substance in pure water raises or lowers the freezing and boiling point.
- When water freezes - goes from the liquid state to the solid state - its molecules go from a disorganized state to an organized state.
- When water freezes to a solid, molecular motion slows down enough that the molecules become permanently fixed in an orderly arrangement called a crystal.
- The individual particles that make up salt (known as ions) arrange themselves around the water molecules. In doing so, they shield the water molecules from interactions among themselves, making it less likely that they will find each other and form ice.
- The water molecules have to be slowed down even more in the presence of salt in order to form a solid. So you have to go to a lower temperature in order to freeze water that contains salt.
- Salt is excluded in the formation of ice; therefore ice made from salt water is essentially salt-free.
- Salt water is denser than freshwater because of its salt content, and, as a result, an object is more buoyant in the ocean than in a freshwater lake. The density of salt water depends on its salinity and varies around the world.

Essential Questions:

- What happens to water when it freezes?
- How is salt used in our everyday lives?
- Why don't the oceans freeze?
- If oceans don't freeze, where do icebergs come from?
- Are icebergs salty? Is sea ice salty?
- Will an object float in saltwater and freshwater in the same way?

Knowledge and Skills:

- Demonstrate how salt affects ice by forming a hypothesis, experimenting with salt, ice, and water, and recording the results.
- Describe why salt water freezes at a lower temperature than fresh water.
- Learn that salt is left behind as salt water freezes, and that this process forms brine.
- Learn that ice is essentially salt-free whether it is formed from fresh or salt water.
- Explain the differences between sea ice and icebergs.
- Demonstrate and explain why ice floats higher in salt water than in fresh water.

Prior Knowledge:

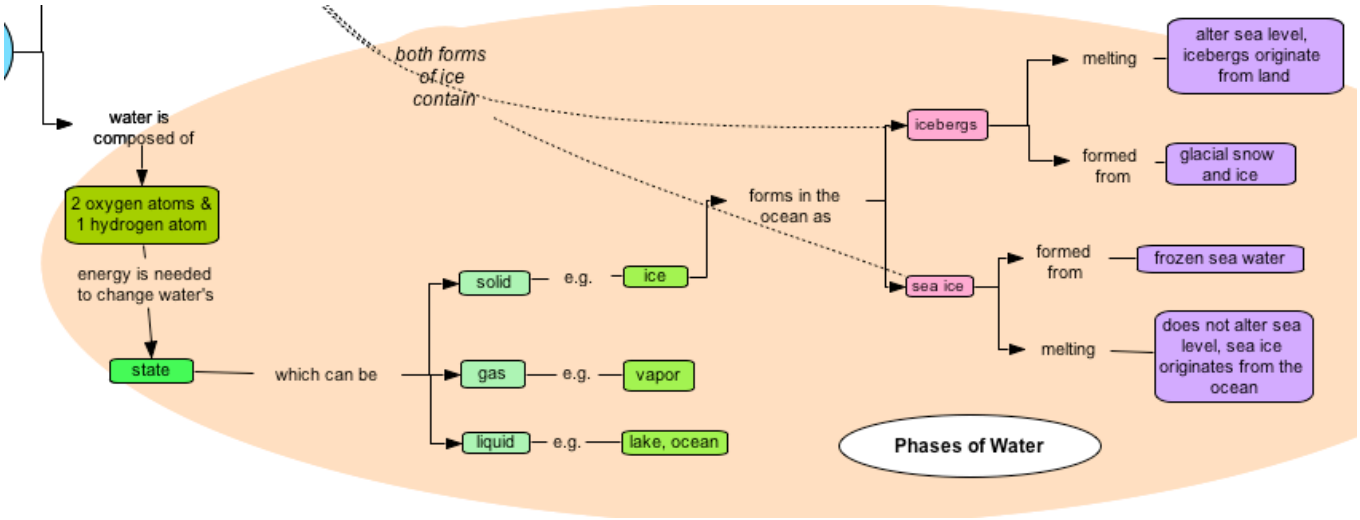
- The salt in seawater comes from the weathering of earth's land surface.
- Salinity is the measure of the amount of dissolved salts in seawater
- Water can be a liquid or a solid and can go back and forth from one form to the other.
- When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water.
- Icebergs are floating pieces of ice in the ocean that came from a glacier.

Common Preconceptions:

- The freezing point (and boiling point) of substances is fixed points and never varies.
- Ice never gets colder than 0 °C.
- Substances are always cold when they freeze.
- Salt is dissolved in the water therefore must be included in the ice when it forms.
- Because ice that melts in a drinking glass does not alter the water level, when icebergs melt they don't raise sea level.

Concept Map:

This lesson and activity relates to the branch "Phases of Water" from the comprehensive Aquarius Concept Map – *Water & its patterns on Earth's surface*



Activity 1 Background:

Under normal conditions, ordinary fresh water freezes and melts at 0°C, or 32°F. If water and ice are at **0°C**, which is the melting point of ice and the freezing point of water then molecules of ice are escaping into the water (melting), and molecules of water are being captured on the surface of the ice (freezing). When the rate of freezing is the same as the rate of melting, the amount of ice and the amount of water won't change. The ice and water are said to be in **dynamic equilibrium** with each other, therefore there is no net change in either quantity. This balance will be maintained as long as the water stays at 0°C, or unless something happens to favor one of the processes over the other. For example, when the water temperature is dropped to -10°C the molecules of water are moving more slowly, i.e. they contain less heat. These slower-moving water molecules are more easily captured by the ice, and *freezing occurs at a greater rate than melting*. Because there are more water molecules being captured by the ice (being frozen) than there are ice molecules turning to water, the net result is that the amount of water decreases, and the amount of ice increases.

Adding salt disrupts the equilibrium. The individual particles that make up salt (known as ions) arrange themselves around the water molecules. In doing so, they shield the water molecules from interactions among themselves, making it less likely that they will find each other and form ice. This means that the number of water molecules captured by the ice (frozen) is reduced, so the rate of freezing is also reduced. The rate of melting of the ice is unchanged by the presence of the salt.

In order to return the system to equilibrium, where the number of molecules of water that are freezing is equal to the number of ice molecules that are melting (remember this is the freezing/melting point), we must lower the temperature sufficiently to slow down the water molecules so that they can become part of the ice formation.

The higher the concentration of salt, the lower the freezing point drops. Any foreign substance, such as sugar, alcohol, or any chemical salt, added to the water, forms a **solute,** which will lower the freezing point and melt ice. This is why salt is used to melt snow and ice on roadways and sidewalks. Salt is also inexpensive and readily available. The melting action of salt forms **brine**, or a strong saline solution, that can penetrate below the surface of ice and packed snow. Brine prevents water from freezing and bonding to a surface. When ice melts due to the presence of salt, heat is absorbed. This is called an **endothermic reaction**.

Does the size or quality of the salt placed into solution will affect the freezing/melting point i.e. iodized table salt vs. kosher salt vs. rock salt? Actually it doesn't matter how they are packaged or processed, once dissolved the salt molecules are so tiny compared to the distance they move through the liquid that size is not a factor. (*Adapted from Worsley School Online http://www.worsleyschool.net*)

Activity 1 - Salt content changes the freezing point of water - (one 45 minute class period)
Materials: *Per Student Group - 2 plastic beakers or similar containers, crushed ice, 2 unfrozen "freeze pops," measuring cup, thermometer, graph paper, rock salt, balance - **Lab Safety Reminders** The freeze pops are not to be consumed if they are being used in a laboratory experiment. Also use a plastic beaker or scoop to distribute crushed ice, do not use a glass beaker to scoop the ice.*
Preparation: *Distribute the materials to each student group*

- Obtain two large beakers (1000 or 500 ml.) and fill them with equal weights of ice, about 2/3 full. Label the beakers A and B.
- Place a thermometer in each beaker and record the temperature of the ice. Students should take their temperature measurement once the ice has stabilized or after they've added it to the beaker (not during).
- Mix 230 grams of rock salt with the ice in Beaker A. When adding the salt do so carefully to ensure that the salt is distributed throughout the beaker and to prevent piling up on top of the ice.
- Record the temperatures in each of the beakers every 5 minutes for a total of 30 minutes. Graph temperature versus time for Beaker A and for Beaker B.
- 15 minutes into the experiment, pour another 115 grams of salt into Beaker A.
- 25 minutes into the experiment, pour another 115 grams of salt into Beaker A. Continue taking temperature readings until you have 30 minutes of data collected.
- Examine the freeze pops at the end of the experiment, and determine which one has frozen and its degree of hardness. Record the results.

Activity 1 Assessment / Questions

- Discuss why the salt-ice mixture produced a lower temperature than the ice with no salt added. (***Explanation:*** Dissolving salt in water lowers the temperature at which the water freezes, or at which the ice melts. Melting ice takes heat energy from the surroundings; in this case, heat from the unfrozen "freeze pop" is transferred to the colder brine mixture, helping to freeze the popsicle. The rate at which the ice melts depends on the rate at which heat energy flows in – the greater the temperature difference, the faster the heat transfer will be. When ice melts, the amount of heat transfer is 80 calories per gram of water, regardless of the salinity. If the ice has salt on it, it will melt at a lower temperature, and will be colder than ice melting without salt on it.)
- How might salt be used for food transportation? (For example, freight and refrigerator cars use ice and salt to cool foods.)
- Ask students to think of other applications of salt-ice interactions for industrial uses or uses around their home or neighborhood. Students may have used salt to deice sidewalks and driveways. Have students describe any observations they have seen of salt and ice interacting, or how they may use these principles in their lives.
- Discuss why oceans tend to freeze at a much lower temperature than freshwater bodies of water.

Activity 2 Background:
Sea ice is simply frozen ocean water. It forms, grows, and melts in the ocean. Sea ice forms in the **Polar** Oceans, known in the North as the Arctic and in the South as the Antarctic region. In the Arctic, there is a permanent mass of ice covering the region. Nearly all of the Southern Ocean or Antarctic sea ice is "seasonal ice," or it melts away and reforms annually. While Arctic and Antarctic ice is of vital importance to the marine mammals and birds for which it is a habitat, sea ice in the Arctic appears to play a more crucial role in regulating climate.

Sea ice forms a boundary between the relatively warm ocean and the cooler atmosphere. Sea ice floats for the same reason the ice in your drinking glass floats. It is less dense in the solid phase than it is in the liquid phase. Although sea ice is made from salty seawater, the salt molecules are rejected back into the liquid as ice forms, resulting in a briny solution. There isn't much room for salt molecules to be trapped in the close-knit structure of ice. Sea ice, like regular ice, is made of oxygen atoms and hydrogen atoms that are joined together to form a rigid net or lattice. Hydrogen bonding provides ice with its unique properties. In all known forms of ice, the water molecules retain their identities as distinct molecules and bond to other molecules by hydrogen bonding. Unlike sea ice, **icebergs**, glaciers, ice sheets, and ice shelves all originate on land. Icebergs are broken pieces of glaciers, which originate from masses of snowfall on land.

So why are sea ice and icebergs important to scientists and to you? Even though sea ice occurs primarily in the polar regions, it influences our global climate. Sea ice is important because it regulates exchanges of heat, moisture and salinity in the polar oceans. It insulates the relatively warm ocean water from the cold polar atmosphere except where cracks, or leads, in the ice allow exchange of heat and water vapor from ocean to atmosphere in winter. Sea ice affects the movement of ocean waters. It can also be an obstacle to normal shipping routes through the Northern Sea route and Northwest Passage. Finally, wildlife and people rely on sea ice to hunt and travel. Glaciers can provide clues about the effects of global warming due to their sensitivity to temperature fluctuations. Increased iceberg calving is an important indicator of climate change. Satellite imagery has allowed scientists to observe how icebergs in a remote corner of Antarctica can disrupt an entire marine ecosystem. *(Adapted from National Snow and Ice Data Center website* http://nsidc.org/sotc/sea_ice.html*)*

For the article "*Satellite imagery shows how icebergs affect Antarctica's food chain"* visit http://news-service.stanford.edu/news/2002/april24/icebergs-424.html
For more information on how scientists study polar ice formation visit http://nsidc.org/sotc/sea_ice.html
For a visual tutorial on water molecules and ice formation visit
http://www.edinformatics.com/math_science/water_ice.htm

Activity 2a. – Effects of Salinity on Freezing Rate – two 45 minute class periods to collect data
Materials: *Per Student Group –230 grams of ordinary table salt, balances, containers/boats for measuring salt, graduated cylinders, 2 plastic ice cube trays with divided watertight sections (it's important that they are standard cube trays and will not create unusual shapes), tap water, thermometer, 12, beakers (at least 300 ml) or cut 2L plastic soda bottles, metric ruler, graph paper, food coloring (optional) to color ice cubes to be used in buoyancy activity, Earth globe will be helpful during discussion.*
Preparation: *Students will need access to a freezer.*

- Begin with a background discussion with the class of the locations of the North Pole *(Arctic*) and South Pole (*Antarctic*). Use a globe to illustrate the geography of these locations during this discussion. Ask the students which Pole is NOT covered by ice (*Antarctic*) and which is covered by ice (*Arctic*). Ask the students to explain their answer. Ask students which Pole is more likely to have glaciers nearby (*North Pole*).
- Ask the class to hypothesize about the affect of water **salinity** – or amount of salt – on the formation and buoyancy of sea ice. Do they think ice formed from salt water will freeze more quickly or more slowly than fresh water? Why? Do they think that sea ice (i.e., formed from salty water) will be more buoyant or less buoyant than ice formed from fresh water (e.g., icebergs)? Why? Do they think that

the size of sea ice or icebergs affects their buoyancy (e.g., percentage above and below the water line)? Explain.

- Label 12 jars as follows: 2 marked “A”; 2 marked “B”; 2 marked “C”; and 2 marked “D.” In each jar mix salt and water solutions as follows:
    - In each jar marked "A": mix 128 grams salt with 250 mL water
    - In each jar marked "B": mix 85 g salt with 250 mL cup water
    - In each jar marked "C": mix 43 g salt with 250 mL cup water
    - In each jar marked "D": 250 mL pure tap water

NOTE: One set of jars A-D will be used to fill an ice cube tray, it’s not necessary to be exact. The other set of jars should be covered with lids, regardless of where they are store, to preserve volume. Put the second set in a refrigerator if available, otherwise set them aside in a cool, shaded area of the room.

- Label each quarter section of both ice cube trays as section A, B, C, and D.
- Pour one set of solutions A - D into their labeled sections of the ice cube tray. Ask the students to make a variety of ice cube sizes using each solution. Place the tray in the freezer.
- Using a data chart ("Freezer Experiment" table provided at bottom), students observe and record water temperature and conditions after 1 hour, 24 hours, and 48 hours. **STOP Review Safety Procedures** Water temperatures are taken in the liquid water, under any ice formations, if present. If not present, draw an “X" through that data entry. Students should describe the quality of the ice formations including degree of solidity, color, texture, volume, layering, etc.
- At the end of 48 hours and using graph paper, plot a line graph of temperatures.

Activity 2b. – Buoyancy - one 45 minute class period

- Using the second set of solutions (A - D) that were set aside from Activity 2, conduct a series of buoyancy tests. On data chart ("Buoyancy Experiment" table provided at bottom), test and record how well each kind of ice* (A, B, C, D) floats in each solution (A, B, C, D). Students should use their own judgment on how to qualify the relative buoyancy of "icebergs" in each solution. (The teacher could suggest a quantitative evaluation, using a metric ruler to measure in millimeters the visible height of ice above and below the water line. Convert these measurements to percentages to account for discrepancies in uniformity of size and shape of the ice.) **It may be helpful to add food coloring to these ice cubes to aid visibility initially, however as the ice melts, the color will obscure the view.*

Activity 2 Assessment / Questions

- Did any solution not freeze? If so, which one? Compile a list of explanations on the board as students elaborate on why this one didn’t freeze. (Although it depends upon the experimental conditions, the highest salt concentration, "A", will likely not completely freeze. Highly saline solutions such as this are called "brine.")
- Which solution was first to freeze? Why (Usually "D" is the first to freeze.) Compile a list of explanations on the board as students elaborate.
- Explain what happens to the ability of water to freeze as you add more and more salt. The graphed results should assist the students in their explanation. (The higher the salinity, the longer it takes to freeze. This is because the higher the salinity, the lower the freezing point.)

    OPTIONAL: To access an interactive animation depicting the interaction of ice, water, and a solute (e.g., salt), visit the "General Chemistry Online!" webpage, "Why does salt melt ice?" (http://antoine.frostburg.edu/chem/senese/101/solutions/faq/why-salt-melts-ice.shtml). Raise and lower the temperature and "add solute" by clicking on the banner below the "dancing" water molecules. Ask students how this animation relates to their experiment results.
- Have groups discuss whether the findings confirm their initial hypotheses on salinity. (Students may have been surprised to find that salt water freezes more slowly than fresh water and, when salt content is high enough, may not freeze at all.)
- Have groups discuss whether the findings confirm their initial hypotheses on buoyancy. They be surprised to learn their ice cubes are most buoyant in the saltiest solution, "A" in this case. Many will not have guessed that all the ice cubes would be free of salt and thus "ice type" did not affect buoyancy. In addition, they may not have guessed that the size of the ice cube does not affect the percentage above and below the water line.

- Ask students to design an experiment that would help them determine the salinity of ice cubes made from saltwater. **Tasting should not be accepted as a method or strategy**
- Is ice formed from salt water salty or fresh? (Fresh.) How does this relate to sea ice and icebergs in the Arctic and Antarctica? (Both sea ice and icebergs are essentially salt-free.) Look at the photos below: "Sea ice photos from the Arctic" and "Iceberg photos from the Antarctic". How can you explain differences in their physical appearance? (The sea ice shown is thinner and flatter having formed from seawater; the icebergs are large and layered from years of snow accumulation.) These photos could also be used as a discrepant event at the beginning, which would provide a lead-in to the activities.
- How does this relate to sea ice and icebergs in the Arctic and Antarctica? (Both sea ice and icebergs are essentially salt-free.) Look at the photos below: "Sea ice photos from the Arctic" and "Iceberg photos from the Antarctic". How can you explain differences in their physical appearance? (The sea ice shown is thinner and flatter having formed from seawater; the icebergs are large and layered from years of snow accumulation.) If earth's climate is warming, how will this affect the formation of sea ice? What effects might this have on people and animals that live in polar regions?

Vocabulary

- **brine:** A strong solution of salt and water
- **buoyancy:** In physics, an upward force on an object immersed in a fluid (i.e. a liquid or gas), enabling it to float or at least to appear to become lighter. If the buoyancy exceeds the weight, then the object floats; if the weight exceeds the buoyancy, the object sinks.
- **dynamic equilibrium:** A dynamic equilibrium will form if, at a given temperature, two reversible processes occur at the same rate
- **endothermic:** In chemistry, a type of process that absorbs heat from its surroundings
- **freezing point:** Temperature at which a liquid of specified composition solidifies under a specified pressure.
- **glacier:** A large mass of ice, formed from compacted snow, whose sides are often bounded by mountains or the walls of a valley. Ice sheets or caps, also formed from compacted snow, are so massive that they cover entire landscapes, mountains as well as valleys. Where glaciers and ice sheets flow slowly toward the sea chunks may break off and produce icebergs.
- **hypothesis:** A proposed explanation for a phenomenon.
- **iceberg:** A floating body of ice broken off a glacier. About 10% of its mass lies above the water surface.
- **polar:** Located at or near the earth's North or South pole.
- **salinity:** Of, relating to, or containing salt; salty; a measure of the amount of salt in a solution
- **sea ice:** Ice that is formed by the freezing of sea water.
- **solute:** A substance dissolved in another substance (the solvent) to create a solution.

Activity 1 Original source: *Adapted with permission from the Salt Institute's activity "Salt: The Essence of Life"* **Activity 2 Original source:** *Adapted from UCLA Marine Science Center's OceanGLOBE "Density & Salinity Lesson Plan"*

***Aquarius* Education & Public Outreach URL:** *http://aquarius.nasa.gov/*

****Lab Safety Reminders****

General Thermometer Use

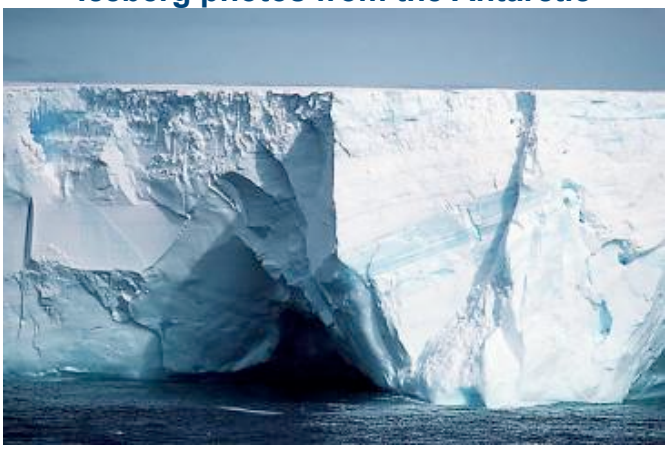
- No food items generally deemed edible are to be consumed if they are being used in a laboratory experiment.
- Glass thermometers that are alcohol filled are recommended. If mercury thermometers must be used for purposes of higher accuracy, Teflon® coated are recommended.
- Resistance thermometers, or temperature probes, should be considered as alternatives to glass
- Never use a thermometer as a stirring device or swing or shake down a thermometer.
- Never use an open flame on a thermometer bulb.
- Use extreme care when inserting or removing a thermometer from a rubber stopper.
- Choose a thermometer with an appropriate temperature range.
- Use a plastic beaker or scoop to distribute crushed ice, do not use a glass beaker to scoop ice.

FREEZER EXPERIMENT							
JAR	Starting salt / water content	*Record your observations below:*					
		1 hour in freezer		24 hours in freezer		48 hours in freezer	
		Temp	Notes	Temp	Notes	Temp	Notes
A							
B							
C							
D							

BUOYANCY EXPERIMENT				
	Ice from "A"	Ice from "B"	Ice from "C"	Ice from "D"
Solution "A"				
Solution "B"				
Solution "C"				
Solution "D"				

Sea ice photos from the Arctic

Iceberg photos from the Antarctic



Photos from Bigelow Laboratory for Ocean Sciences and the Australian Antarctic Division