Quest
INVESTIGATING OUR WORLD

# Winter

## High School Lesson Plan

## Overview

Winter in northern New England can present some challenges for animal survival. Freezing temperatures pose threats to all organisms whose bodies are predominately composed of water. This lesson helps students explore many fascinating aspects of water, ice, and snow. It also sheds light on the adaptations that organisms have made over time to overcome the harsh winter elements of New England.

## Introduction

This teaching unit is designed for biology, chemistry, or integrated science classes. It explores the dynamic nature of water, the water molecule, and its fascinating hexagonal ice-crystal structure, which can create such unusual features as snowflakes.

Ice can also be damaging to organisms. Students will explore some of the freeze-prevention strategies that organisms use to overcome the problem of internal freezing.

For chemistry students, this lesson provides an opportunity for them to see real-life applications of their knowledge of molecules in living organisms. For biology students, the lesson allows for more in-depth exploration of the reasons behind biological interactions.

## Time Allotment

This lesson requires approximately six to eight 45-minute classroom periods to complete.

## Accessing Prior Knowledge

Students should have a basic understanding of atomic structure before beginning this lesson. They should be aware that all matter is made up of minute particles called *atoms*, and that atoms comprise a positively charged nucleus with neutron and protons, surrounded by a negatively charged cloud of electrons. The attraction between these electric forces holds atoms together.

Students should also know that a substance comprising one single type of atom is called an *element*. Elements vary according to the number of protons, neutrons, and electrons they have. The structure of each element determines its nature and the way it reacts with other elements.

Maine Mathematics and Science Alliance
QUEST lessons are developed in partnership with Maine Mathematics and Science Alliance

Maine Public Broadcasting Network · New Hampshire Public Television · Vermont Public Television PBS · NSF

Major funding for Quest is provided by the National Science Foundation. Additional funding is provided by the Maine Department of Inland Fisheries and Wildlife, Maine Forest Products Council, and Irving Woodlands LLC.

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A substance composed of two or more atoms is called a *molecule*. When two different types of atoms chemically combine, they form a compound. Molecules of a compound are the smallest portion that still retains the properties of that *compound*. Students should be aware that molecules are bonded together by the atoms' sharing or transferring of electrons.

Additionally, students should realize that atoms and molecules are perpetually in motion; however, the degree of motion varies with temperature. It is important that students understand the basic relationship between states of matter and molecular motion. In solids, atoms are closely packed together and rigid, only vibrating; in liquids, molecules have higher energy and are more loosely packed; in gases, molecules have even more energy and move freely.

Finally, students should have a basic knowledge of cells and the fact that all living things are composed of cells. Within cells, many of the basic functions of an organism are carried out. About two thirds of the weight of cells is accounted for by water.

## Concepts to Clarify

Most students have difficulty understanding the microscopic size of particles. This can lead to trouble conceptualizing the interactions of particles.

Students may also have difficulty thinking of the matter that comprises living organisms as being the same matter that makes up nonliving objects. Animals are made of bone, skin, and muscle; plants are made of leaves, roots, and stems; the nonliving environment is rocks, water, and air[1]. Students can usually understand that living things are made up of cells, but not that cells are, in turn, made up of molecules[2].

## CONNECTIONS TO THE STANDARDS

| National Science Education Standards | Benchmarks for Science Literacy | Maine Learning Results | New Hampshire Curriculum Framework | Vermont Learning Standards |
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| **B. Structure and Properties of Matter**<br><br>Bonds between atoms are created when electrons are paired up by being transferred or shared. … atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.<br><br>The physical properties of compounds reflect the nature of the interaction among its molecules. These interactions are determined by the structure of the molecules…<br>Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart…<br><br>Standard C: The cell: | **4D. Structure of Matter**<br><br>Atoms are made of a positive nucleus surrounded by negative electrons… Atoms form bonds to other atoms by transferring or sharing electrons.<br><br>Atoms often join with one another in various combinations in distinct molecules or in repeating three-dimensional crystal patterns.<br><br>The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials.<br><br>**5C. Cells**<br><br>Every cell is covered by a membrane that controls what can enter and leave the cell. …<br><br>The work of the cell is carried out by the many different molecules it assembles … | **Science and Technology**<br><br>E2. Analyze how matter is affected by changes in temperature, pressure, and volume.<br><br>E5. Describe how atoms are joined by chemical bonding.<br><br>C1. Relate the parts of a cell to its function.<br><br>C3. Discuss the function of the important "molecules of life." | **Life Science**<br><br>3d. Students will demonstrate an increasing ability to understand fundamental structures, functions…of… plants, and animals.<br><br>Use tools and models to demonstrate that all cells have specialized structures that carry out specialized functions, e.g., microscopic evidence, photographic evidence.<br><br>Describe/explain homeostasis (the maintenance of internal stability within organisms), i.e., regulation and communication between parts of the body on a macrocellular scale.<br><br>5b. Students will demonstrate an increasing ability to understand that matter is composed of dynamic interactive units or particles and that all the properties and changes in matter can be explained in terms of the forces involved in the interactions of these units. | **The Living World: Organisms, Evolution and Interdependence**<br><br>Demonstrate understanding of the uniqueness of the cell in different organisms (plants, animals, microorganisms) and the structures and functions of the cell (e.g., chemical reactions, diffusion of materials, direction by DNA of the synthesis of proteins, regulation, differentiation).<br><br>**Matter, Motion, Forces, and Energy**<br><br>Demonstrate an understanding of the atomic structure of matter in relationship to the periodic table, bonding, elements, and compounds. |

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| Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out cell functions …<br><br>Cell functions are regulated. …This regulation allows cells to respond to their environment and to control or coordinate cell growth and division. | | | Explain that the arrangement, configuration and/or motion of atoms, molecules, and ions of a particular substance determine the structure and, thus, the properties of that substance | |

## Materials Needed

- TV and VCR
- *QUEST Winter* videotape
- Chart paper
- Whiteboards and markers (optional)
- Atomic models or rigid foam balls (2 sizes), plain and colored toothpicks, uncooked spaghetti
- Various materials in liquid and solid states
- Snowflake images and/or microscope slides
- Illustrations or photos of plant and animal cells and tissues
- Dialysis tubing
- 60% glucose solution
- Beakers
- Water
- Balance to .1g accuracy
- Goldenrod gall fly larvae
- Knife
- Tweezers (optional)
- Beakers with screen netting and rubber bands, or mason jars with tops
- Student Handout 1: Hydrogen and Oxygen Summary Sheet
- Student Handout 2: Atomic Exercise!
- Student Handout 3: Growing Your Own Snow Crystals
- Student Handout 4: Effect of Solute Concentration on the Rate of Osmosis
- Student Handout 5: Letter from a Nature Watcher
- Student Handout 6: Quest At Home – Check Out the Flakes!

# 1. Introducing the Concepts

## Activity 1

### Step 1

Pose the following question to students: "The bodies of many organisms, including humans, have water temperatures between 60 and 95 degrees. How can these organisms survive when the external temperature is below the freezing point of water?" Discuss student responses briefly, but make no judgments at this time.

### Step 2

Show the *QUEST* video to the class.

### Step 3

After viewing, have students brainstorm a list of all the strategies that organisms use to avoid freezing in the wintertime. Write their ideas on chart paper or a whiteboard, and leave the list up in the classroom. Explain that in this unit, students will be focusing on the techniques described near the end of the video on freeze avoidance or freeze tolerance in animals. To understand these strategies better, students will first gain a better understanding of the development of ice crystals and, hence, the properties of water.

# 2. Exploring the Concepts

Students will be working in teams for the following activities. If possible, group together three students of mixed abilities for each team.

## Activity 2

### Step 1

Begin by showing again the first half of the video (up through the end of the discussion about CRREL and controlling ice jams, and before the discussion of subnivean animals in winter). While watching, students should note down any detailed information in the video about snow and ice crystals.

### Step 2

Have student teams each make a list of facts they have gathered from the video. Chart this information by asking for an idea from each team in turn, then repeating the process until all ideas are shared.

Key points presented in the video:

- No two snowflakes are alike.
- Snowflakes are really multiple ice crystals.

- Snowflakes have multiple shapes: six-sided "stars," plates, columns.
- Snowflake shapes are based on the molecular structure of water – Mickey Mouse, a face and two ears ($H_2O$).
- Snowflakes change shape as they settle in a snowpack; crystals become smaller and smaller as they melt and reform.
- In snowpack, smaller crystals melt and merge into larger ones, creating more space in snowpack.
- Snowpack can become "brittle."
- Crystal can become hexagonal "logs."
- You can see layers of snowflakes as you look down through snowpack.
- In rivers, ice crystals form in a suspension called *frazil ice*.
- Frazil ice can collect on the bottom of rivers and "grow" as more and more crystals form around it.
- Frazil ice can change the flow of rivers, cause ice jams, and create floods.
- Engineering designs have been developed to prevent ice jams – e.g., granite blocks to act as sieves.

### Step 3

Ask students which of the facts they have listed might be most important to understand in trying to answer the question you posed earlier (at the beginning of Activity 1) about body temperatures and the freezing point of water.

In the following activities, teams would benefit greatly from having their own portable whiteboards for taking notes, making drawings, or sharing information. Check to make sure that team members take turns being the "scribe."

## Activity 3

### Step 1

In teams, on whiteboards if available, students should compare and contrast the properties of water, ice, and snow. (For example, water is clear, ice is cloudy, snow is white. Water flows, ice is rigid (solid), snow is solid. Ice is tightly packed, snow is loosely packed, etc.)

### Step 2

Ask teams to share their comparisons. If it is not mentioned, ask for similarities in terms of molecular structure and phase. (For example, all $H_2O$ molecules have two atoms of hydrogen and one atom of oxygen. Water is in a liquid phase, so its molecules are more active than in ice and snow, which are in the solid phase, and where the molecules are locked together and only vibrating.) Students often have trouble identifying snow as a solid. Move slowly on this point; don't force students to just accept what you say as the truth. Try to see whether, through their learning experiences, they can see that snow is a crystal, is rigid, and hence is a solid.

### Step 3

Ask student teams to each draw a water molecule on their whiteboards. Then ask them to describe the molecular structure to you so that you can draw it on chart paper for the whole class. Allow only one student to give you the description, but encourage any further suggestions or questions. (Even if students give you some incorrect information, consider it a start to their understanding. Through instruction, you can slowly bring their thinking to a more sophisticated level.)

### Step 4

Ask students if they would see this same molecular structure when looking both at water and at ice. Discuss responses, then ask what would happen if they used a microscope. Be sure that they understand the scale being used when they describe water molecules. The particle density of water (the number of particles in a given volume) is $3.35 \times 10^{28}$ molecules per cubic meter. Ask, "What does $10^{28}$ mean?" (It is the power of 10 by which to multiply 3.35.)

Ask a student to write out the value 335 with 26 zeros. Ask students what the density would be in 1 cubic centimeter (335 with 20 zeros, 1/1,000,000 of a cubic meter;

(multiply $3.35 \times 10^{28}$) $(1 \times 10^{6})) = 3.35 \times 10^{22}$)

Have students draw a 1-cubic-centimeter box. Have them imagine the size of the particles that would allow 33,500,000,000,000,000,000,000 particles to fit into that space.[3]

# 3. Developing the Concepts

## Activity 4

### Step 1

Begin by asking students what they know about the atoms that make up water molecules. Ask them where these elements are in the periodic table and what that can tell us about them. Ask students to describe the atomic structure of these elements in terms of energy shells and electron saturation. When students have recalled all possible data, distribute Student Handout 1 (Hydrogen and Oxygen Summary Sheet) and Student Handout 2 (Atomic Exercise!). Have students gather in their teams to develop a response to the task described in Handout 2.

### Step 2

Based on what they know about hydrogen, oxygen, atomic structure, and bonds, teams need to draw how they think hydrogen and oxygen atoms are joined into molecules of water. (Use of the whiteboards here helps students visualize; it also elicits questions that might further student understanding.) Ask teams to label each part of their drawing and be prepared to explain their reasoning.

[3] Bloomfield, Louis A. *How Things Work: The Physics of Everyday Life*. New York: John Wiley and Sons, 1997, p. 137. These distances have all been determined through x-rays of water molecules.

## Proficiency Guidelines

Team drawings should identify the atomic structure of each element and its distribution of electrons in energy shells. (These drawings will subsequently be used by teams to justify the type of bonds they think these molecules have. Their explanations should include the following information: Hydrogen has one electron and oxygen has eight – two in its inner energy shell and six in the outer shell. As a result, the atoms are held together through sharing electrons in a covalent bond. The two electrons – one shared with each hydrogen atom – complete the outer energy shell of oxygen. With both bonds, the oxygen energy shell is saturated with eight electrons. Each hydrogen atom shares one of the oxygen atoms, saturating their outer shell.)

### Step 3

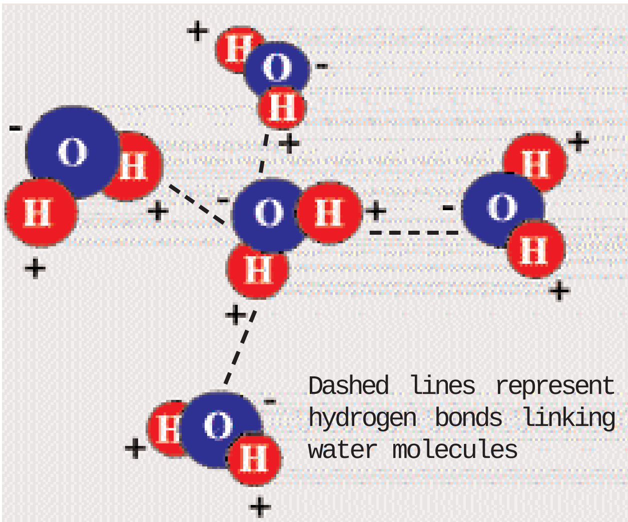
While teams are working, circulate to probe each team's understanding and reasoning. When everyone is ready, ask one team to present their ideas. Allow time for other students to ask questions. Encourage dialogue among students after each presentation so that all can achieve maximum understanding. If any students have identified the polar nature of the water molecule, have them describe it for the rest of the class. If not, convey to students this important feature of water molecules, which allows the cohesion of water. (Oxygen atoms attract electrons more than hydrogen; this causes the hydrogen atoms to attach to one end of the oxygen, thus making the molecule asymmetrical. This, in turn, causes a slight charge to be evident on either side of the molecule. A positive charge on the hydrogen side is attracted to the negative charge on the oxygen side. This is called a hydrogen bond. Hence, water molecules have a greater attraction to each other. *Hydrogen bonds* are weaker than ionic or covalent bonds, but together they can give the substance strength. An example sometimes used is its similarity to Velcro™, in which many small bonds together make a strong connection.)

### Step 4

Have teams go back to their original drawings of the water molecule from Activity 3. Ask students to suggest any changes they may want to make based on the new information they have gained. Teams should now draw a second image, showing proper placement of the hydrogen atoms and labeling the polar charges.

### Step 5

Ask teams to hypothesize on their whiteboards about how they imagine many molecules of water would be joined together as a liquid. Have them also either use molecular models (if available) or create their own, using rigid foam balls of two sizes and colors, plain toothpicks, and uncooked spaghetti. They should create models of liquid water with two molecules of water. (The larger balls are oxygen, the smaller are hydrogen. The plain toothpicks are covalent bonds, the spaghetti are hydrogen bonds. Hydrogen bonds, which are weaker, are formed between water molecules.) Have teams share their drawings and models.




From Steinberg, June B., *The Molecular Basis of Life.*
© June B. Steinberg
(2000 http://faculty.nl.edu/jste/bonds.htm).

If time allows, transition the discussion into talking about changes in state from liquid to solid. Or, begin the next class with this topic.

## Step 6

Ask students to describe again how the water molecules would be acting if they were a liquid. (They would be close together but could move by each other.) Ask how different they would be if they were a solid. (They would be rigid and just vibrating, or "jiggling.")

To explain the other unusual characteristic of water, ask students if they could create a rule about density and change of state -- such as, "When materials move from gas to liquid to solid, they become denser." Have a demonstration of various materials in both states, always with a solid immersed in a liquid. Ask students how they would know which of the materials is denser.

Ask students what they think about water. Float some ice cubes in water. Ask, "Which is denser, liquid water or ice?" Explain that because of the hydrogen bonds, water is slightly different in character than other substances. It becomes denser and denser until it reaches 4°C, then it becomes less dense.

> Introduce students to Van der Waals force: *"the relatively weak electrostatic attraction of an atom's nucleus for another atom's electron swarm. This force helps liquid water become more dense down to the temperature of 4°C (39.2°F). Below that temperature, the hydrogen bonds take over; roughly put, the nuclei of each water molecule's two atoms of hydrogen, though bound to their own oxygen atom, carry a tiny positive electric charge that catches onto anything with a egative charge, such as some electrons in other water molecules' oxygen atoms. The hydrogen bond, in balance with other forces at work on this scale, demands a certain space between the molecules."*[4]

4 Water As a Solid Citizen http://www.gi.alaska.edu/ScienceForum/ASF13/1362.html

## Step 7

Ask the teams to now use their models to demonstrate the structure of ice. Have them replace the uncooked spaghetti in their models with colored toothpicks to form a rigid structure between the molecules. Help them remember that the bond has slightly lengthened as the molecules have become less dense. Probe students' thinking about motion within the various states of matter; remind them that molecules and atoms are never totally still – they are still vibrating in their electron shells.

## Step 8

Now have each team of three decide which two team members will represent hydrogen and which one will represent oxygen. Have them discuss how they could have the whole class represent the bonding of hydrogen and oxygen, how they could represent liquid water, and how they could represent ice. Now have one member of each team go to one of three newly formed working groups, each of which represents one of the three states of matter. Have these working groups decide how the class will represent each of the three molecular concepts and who will narrate the action. Members should then return to their home teams and explain the strategy. All members of the class should stand up, and as a whole group should first form a water molecule, then move as liquid water, and finally move as solid ice.

## Step 9

Tell the class that because of its molecular structure, water actually freezes most frequently into a hexagonal crystal. It is also known that water collects around particles of dust in the atmosphere as it begins to form ice crystals. Taking the part of a dust particle, see if six teams of three students each can form a shape around you that has six sides. Then have the other students ("molecules") attach themselves to the hydrogen atoms.

The structure of these atoms actually requires a very specific distance and angle to form the lattice structure found in ice crystals. The angle of bonding has been determined to be 104.5°. To approximate this, have all of the "oxygen atoms" stand so that they are facing an imaginary "12:00 noon" position. Now, they should stretch out their arms horizontally to form a straight line (180°). Next, keeping their left arms in place (at the 9:00 position), they should move their right arms from pointing at 3:00 to pointing at 12:02 or so (one sixth of the way between 12:00 and 3:00). This would be approximately a 105° angle. Now have all of the hydrogen atoms attach themselves to the oxygen atoms at this angle. Ask students, "Does this hexagon take a more uniform shape?"[5]

## Step 10

Have students apply this new knowledge about the angle of bonding to their earlier models. Have each team make an ice crystal with six water molecules. Check on their drawings to make any corrections.

## Step 11

Using a table cleared of materials, ask the teams to now join all of their crystal models together, remembering the hydrogen bonds based on the polarity of the water molecule. Be sure to have something rep-

[5] Snow Crystal Designer Snowflake Galleries (http://www.its.caltech.edu/~atomic/snowcrystals/designer/design-

resenting a dust particle at the center of their crystal. When they are done, ask students if the shape reminds them of anything they have seen in nature – something that bears some resemblance to a partial snowflake. Have them look at slides or images of snowflakes to compare the shapes.

Remind students again of the scale they are working in. If the scale of their water molecule models (approximately 6 cm in diameter) of an ice crystal (actually .3 nm in diameter, a nanometer being 1 billionth of a meter), the ratio would be $3 \times 10^{-10}$m:$6 \times 10^{-2}$ m, which is approximately a scale of 1:20 million. In other words, the ice crystal model is 20 million times larger than an actually ice crystal. If we were to represent our shoulder width (40 cm) on that scale, we would be 80,000,000 meters (or 80,000 km, roughly two circumferences around the earth.

**Note**: The following are directions for making slides of snowflakes.

*To prepare snowflake slide:*
1. Place slides and a liquid plastic spray-on resin (available at art or craft stores; usually used to make casting molds) outside. Allow them to reach the same temperature as the snowflakes.

2. Holding a slide sideways (to prevent snow from falling on it while it is being prepared), spray the slide with resin. Then turn it upright to catch snowflake(s) on the resin. Resin will coat each snowflake and leave the imprint of its shape.

3. Leave the slide(s) outside for a few hours to set.

Other suggestions: Use black felt to catch the snowflakes; then transfer snowflakes to the slides. It may also be helpful to use clothespins to hold the slides; this can prevent them from warming up in your hand.

## Extension Activity (Optional)

### Step 1

If time and materials allow, have the class build crystal-growing chambers as described in Student Handout 3.

Tell students that, since we cannot directly examine individual molecules of water, they will be examining the transition of water to ice by growing ice crystals. Tell them that in teams, they will prepare their crystal-growing chambers. Distribute the handout, and allow student teams time to construct their chambers as directed. (They will actually begin their observations during the following class.)

### Step 2

Once the chambers are constructed, have students read the next set of directions on Student Handout 3 and write their predictions of what they think will happen once they add the dry ice.

### Step 3
Teams should now load their chambers with dry ice and begin their experiments. Have students make written observations during the entire process. After 15 minutes, have them compare their findings. Did they all get similar results? Chart a list of characteristics of the crystals they have grown. Can students relate any visible characteristics to what they know about the atomic structure of water, ice, and snow?

## Activity 5

Students will now begin to explore the potential for damage caused by intercellular and intracellular freezing in organisms. They will also examine some of the strategies various species have evolved for survival under these circumstances.

### Step 1
Many students may not realize how much the human body – like most living organisms – is composed of water. Some interesting facts they might like to know:

- 60-90% of the weight of living organisms is made up of water. Blood in animals and sap in plants is mostly water.
- The adult human body is composed of approximately 55-60% water. The brain is composed of 70% water, as is skin; blood is 82% water; the lungs are nearly 90% water.
- In adult humans, intercellular (between cells) fluid is 27% water; intracellular (within cells) fluid is 67% water.
- Intercellular space can be as small as 3 nanometers. (Based on calculations at beginning of unit, this would allow 10 ice crystals to form between cells.)

### Step 2
Revisit the list made back in Activity 1 that describes the various strategies organisms use to minimize the impact of freezing temperatures. With what students now know about freezing, brainstorm and record some ideas on the kinds of damage that might occur to organisms if their internal water were to freeze.

### Step 3
Review the second half of the video, which discusses the responses of various species to freezing temperatures. Ask students to note specific details about how insects and frogs respond to winter temperatures. Have teams each make a concept map or outline of the details of the strategies used by these species.

## Activity 6

### Step 1
To help student visualize the potential damage to organisms from ice crystals, have them draw their

ideas on their whiteboards, or show them illustrations of a plant and/or animal cell to determine intracellular damage. Then review tissues to illustrate intercellular structure.[6]

Here are some specific responses that have been discovered about damage caused by the freezing of body fluids:

> "When cells freeze, life is not simply "put on ice" – it is generally disrupted irreparably. Cells are killed by freezing as a result of all sorts of irreversible disasters. The protein molecules that orchestrate the cell's chemical processes unwind and lose their ability to function. Cell membranes are slashed apart by the sharp edges of tiny ice crystals, and the membranes themselves become leaky as their constituent molecules clump together and solidify like cooling fat in a pan. And if the extra cellular fluids of the body, like blood, begin to freeze, the cells themselves run the risk of dehydration as their water is sucked out. When a solution freezes, the ice crystals reject the solute, and so the solute's concentration in the remaining water increases (for this reason, the saltiness of seawater increases when part of it freezes into sea ice). The increase in solute concentration when blood plasma freezes sets up a so-called osmotic pressure, which sucks water out of cells and leaves them dehydrated."[7]

As stated in the video (and recorded in the students' concept map), many organisms – particularly insects – use glycerol, a sugar alcohol solution based on the glucose molecule, in their bodies to prevent freeze damage to their cells. This solution is very similar to the antifreeze we use in vehicles. Frogs, however, use glucose, a normal blood sugar for vertebrates. These organisms flood their body cavities with these solutions to prevent freezing or minimize its damage. The effect is twofold: First, the solutions have lower freezing temperatures; in some instances, plants can actually lower their freezing temperature to –40C by replacing their normal intercellular fluid with an antifreeze solution. Second, other species have created a solution that minimizes the size of the ice crystals by limiting the availability of pure water. Thus, their systems become slush instead of rigid ice.

Glucose is a simple sugar ($C_6H_{12}O_6$). In its solid form it is a crystal – it too can form a hexagonal ring with polarity. As a result, when mixed with water, the polar water molecules surround the glucose molecule, leaving it as the same compound but isolating the molecules. When freezing occurs, these water molecules are no longer "available" for building ice crystals. In frogs, glucose can transport through the cell membranes, allowing them to "tie up" and disperse any water within the cell. If freezing does occur, it will only allow small ice crystals, not extended chains. In fact, the glucose level in frogs rises almost 100 times normal levels when freezing occurs. This transport of glucose to the cells is actually triggered by ice crystal formations on the frogs' skin. (For more information, visit *http://www.exploratorium.edu/frogs/woodfrog/index.html*.)

However, this strategy is not without peril. One of the key benefits of the freeze-protection approach is that it keeps ice crystals out of the cells and in the intercellular space, where they can do less damage. Yet, it is a delicate balance; due to the nature of diffusion, as the concentration of glucose increases outside the cell

[6] A reference that provides images and information about the scale of these visuals is the On-Line Biology Book, Chapter II – Cells II: Cellular Organization by M.J. Faradee (`http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookTOC.html`).

[7] Philip Ball. Life's Matrix: A Biography of Water (`http://www.fathom.com/feature/35612`).

walls, water will flow from the less concentrated solution inside the cell to the more concentrated one outside the cell until both solutions are equal. As a result, if an organism floods its body with glucose, water is drawn out of the cells into the intercellular space, causing dehydration of the cells. This can damage the organelles within the cells. In order to survive, the organisms adapted for this response to cold must also be adapted to dehydration. Frog cells, for example, are able to tolerate a 50% loss of fluid.

### Step 2

Students will now explore the process of diffusion across a semipermeable membrane to investigate its possible effects. The solution used will mimic the glucose solution that frogs use to make their bodies freeze-resistant. The solution will be modified slightly by using sucrose instead of glucose (glucose is a simple sugar; sucrose is a double sugar, with one molecule of glucose and one of fructose).

Students will use a 60% sucrose solution. They will fill a semipermeable membrane with water, weigh it, and place it in a set amount of 60% solution. This will model the frog's body. In addition, students will place water within water and sucrose within water. After a lapse of time, students will remove the semipermeable membrane, reweigh it, and examine the amount of fluid in the beakers. Based on the changes measured, they will be able to determine the direction in which the fluids traveled through the membrane.

Distribute Student Handout 4 (Effect of Solute Concentration on the Rate of Osmosis). Review with students the experiment as described on the handout.

### Step 3

Have students proceed with the experiment. While they are waiting between measurements of their dialysis bags, present them with the frozen goldenrod gall flies (see Appendix A). These insects use glycerol – a first cousin of the antifreeze we use in cars – to prevent freeze damage. Bring a gall into the classroom directly from the freezer, or from outside if temperatures are subzero.

Open the gall and remove the cold, hard larvae. Note the time with students. Let the gall and larvae rest at room temperature; have students observe their behavior. Note how long it takes before they are almost active (only a few minutes). **Note:** Although they do not fly far, you may want to have the gall flies in covered beakers to observe. These flies can actually be put back in the freezer and refrozen.

### Step 4

After students have completed the osmosis experiment, ask the teams to draw each beaker on their whiteboard, illustrate the direction of water flow across the semipermeable membrane, and write a descriptive sentence about what happened in each solution. Discuss the implications for organisms. Does this verify the potential for dehydration in frogs when they flood their bodies with glucose?

# 4. Synthesizing and Applying the Concepts

## Activity 7

### Step 1
Distribute copies of Student Handout 5 (Letter from a Nature Watcher). Have students read the letter, which is from a member of the fictional New England Journal of Nature Watchers.

### Step 2
Ask students to write a response to this "concerned nature watcher." Their responses should include both a description of some types of damage that may occur to the wood frog, and the frog's mechanism(s) for preventing the damage.

Students should be able to use their lab and class notes to respond to the letter. Allow them also to do additional research to help them clarify points. If possible, have them do their work in class to assure equal access to materials and resources.

## Scoring

Separate scores should be produced for (1) communications skills, (2) reasoning, and (3) scientific understanding. To meet the standards:

(1) **Communication** should be clear, include accurate grammar, and (where possible) include illustrations. To exceed the standard, metaphors may be used to enhance the reader's understanding.

(2) **Reasoning** should follow a logical progression. Students should be able to identify that it would be possible for a frog to freeze, but that it has protections. They should support each position with evidence.

(3) **Scientific understanding** should be demonstrated by students' appropriately applying the facts that they have learned. Students should be able to identify that some frogs could freeze since a large portion of their bodies are composed of water. Water, when frozen, creates ice crystals, which could damage cell parts and membranes. Water also expands when frozen; this could burst cells or damage organ tissues. However, students should be able to indicate the process that wood frogs use to flood their bodies with glucose, which acts to lower their freezing temperature. This, too, endangers the frog with dehydration of the cells, but some frogs are adapted to be able to lose up to 50% of their cellular fluid.

# 5. Extending the Concepts

## Activity 8

In this take-home family activity, students and family members are given instructions on how to prepare slides of snowflakes to examine. They are also provided with a list of snow-related Web sites in northern New England to investigate and discuss.

### Career Opportunities

Two broad areas of possible career development are especially appropriate to this lesson: biochemistry and hydrology.

**Biochemistry** examines how organisms function and how they interact with their environment on a molecular level. Some biochemists work in labs in the field of medicine, exploring how disease affects us and how to develop new drugs to combat illnesses. Other biochemists might study how other organisms have developed immunity to certain diseases. Many who start in the field of biochemistry then become involved in biotechnology, working to genetically understand and modify organisms to enhance their capability to survive (such as making agricultural crops disease-resistant or drought-resistant).

**Hydrology** examines how water moves through the ground, the watersheds, and the atmosphere. Hydrologists explore various patterns of precipitation; determine groundwater flow; anticipate droughts and floods; and manage rivers, streams and their aquatic environments. Their background is usually in earth science or earth systems science, which looks at the interactions of water, earth, and atmosphere.

### Community Connections

Communities work with hydrologists to be sure that water flows through the appropriate parts of our towns, cities, and fields without disrupting human, plant, and animal life. Have students conduct research within their own community, including what they might investigate at City Hall. Ask students to find out if there are certain waterways that are diverted or fed into existing streams and rivers. Are these areas fairly populated? What happens to these areas during the winter months? Have students report on their findings.

## Resources

Snow Crystal Primer
*http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm*

About Water and Ice
*http://www.nyu.edu/pages/mathmol/modules/water/info_water.html*

Water As a Solid Citizen
*http://www.gi.alaska.edu/ScienceForum/ASF13/1362.html*

On-line Biology Book
*http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookTOC.html*

**Frozen Alive!** *http://www.naturenorth.com/winter/frozen/frozen.html*

**In Praise of Snow** *http://www.theatlantic.com/unbound/flashbks/snow/snow.htm*

**Life's Matrix: A Biography of Water** *http://www.fathom.com/feature/35612*

# Hydrogen and Oxygen Summary Sheet [1]

## Hydrogen

Symbol: H
Atomic number: 1
Number of protons/electrons: 1
Number of neutrons: 0
Electronic configuration: 1 electron in the first energy shell
Bond length: H-H .74 picometer (picometer = .001 nanometer = $1 \times 10^{-12}$ meter)
Description: Hydrogen is the lightest element. It makes up about 90% of the universe by weight. As water, it is essential to life on Earth.

## Oxygen

Symbol: O
Atomic number: 8
Number of protons/electrons: 8
Number of neutrons: 8
Electronic configuration: 2 electrons in first energy shell, 6 in second energy shell
Bond length: O-O 120.74 picometer (picometer = .001 nanometer = $1 \times 10^{-12}$meter)
Description: One fifth of Earth's atmosphere is oxygen. Two thirds of the human body is oxygen. Nine tenths of water is oxygen.

[1] Adapted from: Bentor, Yinon. Chemical Element.com--Oxygen. (Aug. 12, 2002) (http://www.chemicalelements.com/elements/o.html) and WebElementsTM, the periodic table at http://www.webelements.com. © 1993-2002 Mark Winter.

# Atomic Exercise!

Draw your ideas about exactly *how* hydrogen and oxygen atoms are joined into molecules of water. (If you have access to a whiteboard, this will make your work much easier to visualize.)

Label each part of your drawing, and be prepared to explain your reasoning. Your drawings should identify each of the following:

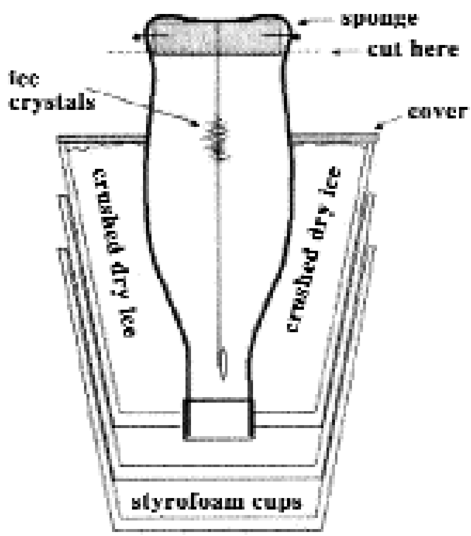
- the atomic structure of each element
- the distribution of electrons in energy shells in each element
- the type of bond you think the molecules have (with evidence in your drawing to prove your point)

(Optional Activity)

# Growing Your Own Snow Crystals

It is simple, inexpensive, and fun to grow your own snow crystals, using little more than a plastic soda bottle and some rigid foam cups. Anyone can do it! This page describes how to set up this experiment and what you can expect to see.

## Creating the Apparatus




For each crystal-growing chamber, the parts list is as follows:

- 1 used 20-oz plastic soda bottle
- 3 large-diameter rigid foam cups (32 oz, 5" tall)
- 1 small kitchen sponge (1/2 inch thick)
- Scissors
- 4 straight pins
- A short length of nylon fishing line (thinner is better; 1-pound test is good)
- A strong sewing needle
- 1 paper clip
- Paper towels
- 3 lbs dry ice for a single experiment
- 2 plastic grocery bags
- Hammer or other blunt object
- Plastic gloves

### Step 1

After rinsing out the soda bottle, use a sharp knife to cut the bottle in two. Your cut should be about 1/2 inch above the bottom, as shown in the diagram. Using the sewing needle, now poke a hole in the center of the bottle bottom. Also poke four holes into the sides of the bottle bottom. Cut the sponge to fit inside the bottle bottom; hold the sponge in place by pushing the four straight pins through the side holes and anchoring the sponge.

### Step 2

Thread the fishing line into the sewing needle. Push the needle through the hole in the bottle bottom, then through the sponge. Tie a knot in the end of the line that entered the bottle first so that it can hold the paper clip. Then, gently pull on the other end of the line so that, when the bottle is inverted and reassembled, the string can swing freely inside, as shown in the diagram. Now attach the other end of the line to the bottle bottom with tape.

### Step 3

Place the inverted bottle inside the three foam cups, as shown, so that the bottom of the soda label is at the same height as the top of the cups (see diagram). There should be about 1 inch of clear space between the sides of the bottle and the top edge of the cups. **Be sure not to push the bottle too far down in the cups,** as the crystals will not form properly.

**Your snow crystal growth chamber should now look like the one shown in the diagram. You are ready to grow some snow crystals!**

## Growing the Crystals

To cool down the apparatus, you will be using crushed dry ice. **Safety note:** Keep in mind that **dry ice is very cold** (about -60˚C); **wear gloves when handling it**. Other than being cold, dry ice is perfectly safe, as it consists of nothing more than solid carbon dioxide. Dry ice doesn't melt; it *sublimes* (changes from a solid to a gas when warmed), producing carbon dioxide gas in the process.

### Step 1

Place the dry ice inside two plastic grocery bags and pound on it with a hammer (or other blunt object) to crush it. (This works best on a hard surface like concrete or asphalt.) Dry ice is much softer than water ice, and it crushes very easily.

Put the crushed dry ice back into its cooler. Then use a spoon to transfer some of the dry ice into the foam cups around your crystal-growing chamber (see diagram). Fill the cups to the top, and cover them with a piece of cardboard cut to shape or with some paper-towel strips. It's also a good idea to wrap some paper towels around the top of the styrofoam cups to keep them from "sweating." Be sure that the dry ice is in contact with the chamber walls as high up as possible. Crystals don't grow well if there is not enough dry ice in the cups!

### Step 2

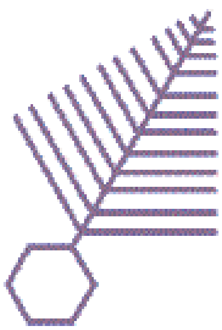
Pull the top off the chamber (the bottle bottom with the sponge). Wet the sponge with tap water, and put the bottle back together.

### Step 3

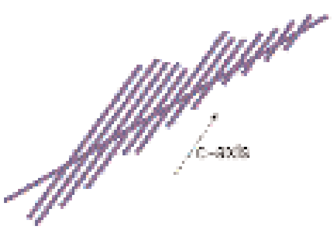
Observe! Small ice crystals should begin forming on the string after 5 to10 minutes. After 20 minutes, you should have a pretty good bunch of crystals. (A magnifying glass is useful, but not essential, for crystal viewing.) When things get crowded, you can pull the top off the chamber, wipe the string clear with your fingers, and try again. You should also knock the crystals off the walls of the chamber -- swinging the paper clip around accomplishes this nicely. One charge of dry ice will last for about 6 hours; more can be added as needed.

# Crystal Viewing Guide

**FISHBONES AND DENDRITES.** If you look closely, you can observe both needlelike and platelike crystal growth in your chamber. The easiest forms to identify (especially if you let the crystals grow to a large size) are the dendrites, which form at -15°C. Above those will be the fishbones, which are a type of needle growth that grows at -5°C.



**Dendrites**. The drawing shows what a -15°C dendrite should look like. It has a distinctive fernlike character, and the angles between the branches and the stem are nearly exactly 60 degrees. The hexagonal plate in the drawing shows the crystal orientation. (For more information about this growth form, see the Resources section at the end of this teaching unit.)



**Fishbones**. The -5°C fishbones are harder to recognize, since they don't exhibit clean 60-degree angles like the dendrites. These crystals have a featherlike appearance, and each of the individual branches is a needlelike crystal growing along the *a*-axis[1]. The photo above shows a particularly good fishbone crystal grown in a soda-bottle growth chamber.

[1] For more information, refer to the Snow Crystal Primer as noted in the Resources section.

# Science Lessons[1]

What you see in your snow crystal growth chamber demonstrates many important concepts from the world of physics. In a nutshell, water evaporates from the wet sponge and diffuses through the air in the bottle. When the water vapor mixes with the cold air in the lower part of the bottle, the air becomes supersaturated – meaning that the water vapor will condense as ice onto any convenient object. Thus, ice crystals will form on the string and on the walls of the bottle. This apparatus – warm on top and cool on the bottom – is called a *diffusion chamber.* Let's look at this in more detail.

## Saturated Air

If you take a container, add a bit of water, and close the top, then the air in the container soon becomes *saturated* with water vapor. Saturated air has a relative humidity of 100 percent. Saturated air is the equilibrium state whenever there's lots of water around. Thus when it's raining, or foggy, the humidity of the air outside is close to 100 percent.

## Supersaturated Air

In the growth chamber we create *supersaturated* air, which has a relative humidity of over 100 percent (in fact, it's around 200 percent). In physics, this is called a *nonequilibrium state* or a metastable state. Left to itself, a box of supersaturated air will not stay supersaturated, since water or ice will condense onto the walls of the box and the humidity will drop to 100 percent (the equilibrium or stable state). Supersaturated air is made all the time in the atmosphere (typically when warm, moist air mixes with cooler air); it is responsible for rain and snow.

Supersaturated air condenses into water droplets if the temperature is above 0˚C. It condenses to ice crystals (snow) if the air temperature is below 0˚C. Note that snow crystals are *not* just frozen water droplets. Rather, they are crystals that grow in supersaturated air that is below freezing.

## Nucleation

Interestingly enough, supersaturated air doesn't automatically condense to produce droplets of rain (or snow). This only happens when there is some nucleation site on which condensation can occur. (This is why we call supersaturated air a metastable state – it's not stable, but it can "hang around" for quite a while.) The reason for this is that very tiny droplets of water (or ice), just a few hundred molecules or so, have a higher vapor pressure than bulk water (or ice). The molecules in such small droplets aren't bound very strongly, which means they come off easily; this is another way of saying that they have a higher vapor pressure. If such small droplets form in supersaturated air, they don't grow; rather, they just evaporate away. If a large droplet forms, it will grow – but large droplets can't just appear spontaneously out of thin air.

1 From Snow Crystals (http://www.its.caltech.edu/~atomic/snowcrystals/project/project.htm).

In our growth chambers, we provide a string to nucleate ice crystal growth. On a microscopic scale, there are scratches and other imperfections on the string, and even individual water molecules can bind to these imperfections. Once we get a small ice crystal started, it will continue growing. In the atmosphere there are lots of dust particles, which these make dandy nucleation sites. Rain droplets and snow crystals usually each contain a dust particle on which the growth first got started.

## Diffusion

In your growth chamber, the top is warm and the bottom is cool. Since warm air is lighter than cool air, the air in the chamber doesn't undergo convection. The air at the top of the chamber becomes saturated with water vapor because it is right next to the moist sponge. At this point, the humidity is 100 percent. Diffusion happens because the air and water molecules are all moving and colliding with one another, which mixes things up on a microscopic scale. (If you open a bottle of perfume in a still room, or put a drop of food coloring in a still glass of water, it is also diffusion that does the mixing.)

In your growth chamber, diffusion causes the water molecules to diffuse down from the top. As they diffuse down, they mix into a region where the air temperature is much lower. This is like taking saturated air and cooling it down; the air becomes supersaturated, so ice crystals can form.

## Faceted Crystal Growth

Why do ice crystals form facets? This is because of the molecular structure of the ice crystal. If we take an ice crystal and cut it in some random direction, the resulting surface will typically be quite rough on a molecular scale. The molecule-sized kinks will be very attractive to water molecules in the vapor. Thus, the ragged surface will grow quickly in supersaturated air. If we cut the crystal along a special plane, however (one of the crystal facets), then the resulting surface will be very smooth, without any molecule-size kinks. Molecules in the vapor phase don't stick well to such a smooth surface; therefore, it tends to grow much more slowly than on a ragged surface.

Consider starting your crystals with a spherical ice droplet. Wherever the surface is ragged, the crystal will grow rapidly, but along the facets the crystal will grow slowly. The ragged surfaces fill in, leaving nothing but faceted surfaces. We're soon left with a slow-growing faceted crystal, as observed.

# Effect of Solute Concentration on the Rate of Osmosis

Adapted from Fredericks, Tom, *Introduction to Cell Biology*, Laboratory Exercise #3: Diffusion, Osmosis and Membranes. Rochester, NY: Rochester Institute of Technology. (*http://www.rit.edu/~gtfsbi/IntroCB/lab3.htm*).

## Introduction

The rate at which osmosis occurs is a function of the solute concentration of the cell and the solute concentration of the extracellular environment (*osmotic potential*). In this exercise, you will use an artificial membrane to construct an artificial cell containing "intercellular" fluids of varying concentrations (osmotic potentials). These "cells" will be exposed to two different extracellular environments.

### *Materials per student team:*

Dialysis tubing sufficient for three bags
3 dialysis bags
String to tie tubing
60% glucose solution
3 beakers
Water
Balance to at least .1 g accuracy

## Procedure

1. Soften each piece of dialysis tubing in water. For each piece, fold over one end of the tubing and tie it off with a thread.

2. Fill the bags as follows:
   (1) 15 ml $H_2O$
   (2) 15 ml 60% sucrose
   (3) 15 ml $H_2O$

As each bag is filled, remove the air by gently squeezing the bottom of the bag to bring the liquid to the top. Press the sides of the bag together so that the air does not reenter. Fold over the end of the bag and tie the end securely with thread. Wipe each bag dry, then weigh it to the nearest 0.1 g. Record the weights in your notebook.

3. Place bags (1) and (2) in separate beakers of water. Place bag (3) in a beaker of 60 % sucrose.

4. At 10-minute intervals, remove the bags from the beakers, carefully wipe off all liquid, and weigh each bag separately. Record the weights.

5. At the end of the class period, plot the change of weight of each bag against time.

# Letter from a Nature Watcher

October 15, 2002

Concerned Nature Watcher
Forest, Maine 00006

Dear Nature Watcher Naturalist,

Please help me. I was out walking in the woods yesterday. It has been a beautiful week, but I can feel the snow coming. Forecasters are predicting a few days of hard freeze.

While I was walking, I kicked up some leaves as I was searching for some edible mushrooms. To my surprise, I saw a wood frog. It was very sluggish, but still it hopped off. I was very concerned because of the impending freeze. I tried to catch it, but it went into some brush, and I could not follow.

I know frogs are under threat because of changes to their habitats. I am very concerned about this one. Won't it freeze? If it does, won't it be killed? I would appreciate it if you could explain to me if the frog will freeze, how will it be hurt? Can I find it and bring it inside until it heals? Or will it have gone somewhere so that it won't freeze?

Thank you,
Concerned Nature Watcher

# Check Out the Flakes!

**You're on a Quest!**

Go on a quest for snowflakes! Snowflakes are a powerful source to cleanse our atmosphere – and create chaos when we want to go somewhere. Gathering data on the patterns of snowfalls gives us information on our undersupply and oversupply of water.

***Materials needed:***

- Computer with Internet access
- Pen and paper for notes
- Microscope slide
- Magnifying glass
- Black felt
- Clothespins
- Liquid plastic spray-on resin (*available at art or craft stores; usually used to make casting molds*)

## Investigate with your family!

■ Find out the most severe snowfall your family has experienced. What year did it happen? How many inches fell?

| Year | Number of inches fell | Remarks on snowfall |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Contact your local weather bureau to determine how much snow fell the previous season. Compare the snowfall to other areas of the United States by visiting this Web site:

**U.S. Snow Monitoring Web:** *http://lwf.ncdc.noaa.gov/oa/climate/research/snow/days.html*

Compare the information between northern New England and other regions of the United States. Document your findings.

## Experiment on your own!

Ever wonder how snowflakes can create so much snow? You can make slides of snowflakes to examine.

Compare the images you viewed to those on the California Institute of Technology Web site, located at *http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm*

On a snowy day, place slides and a liquid plastic spray-on resin outside to reach the same temperature as the snow. When they have reached the right temperature, follow these steps:

### Step 1

Holding each microscope slide sideways (to prevent snow from falling on it before you are ready), spray the slide with resin.

### Step 2

Turn the slide upright to catch snowflake(s) on the resin. Resin will coat the snowflake; then the snowflake will leave an imprint of its shape.

### Step 3

Leave the slide outside for a few hours to set.

You may want to use black felt to catch the snowflakes, then transfer the snowflakes to the slides. It may also be useful to use clothespins to hold each slide to prevent them from warming up in your hand.

**Write a description of:** Facts you discover about the snowflakes you examined. Are they alike – or different?

## Electronic Quest

You'll find a ton of information from these articles on snowflakes and snowfalls on these Web site!

***In Praise of Snow*** by Cullen Allen, *Atlantic Monthly*, January 1995
http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm

**Mount Washington Observatory** http://www.mountwashington.org/index.html

**New England's Changing Climate, Weather, and Air Quality** http://www.neci.sr.unh.edu/neccwaq.html

**National Weather Service's Northeast River Forecast Center** http://www.erh.noaa.gov/nerfc/index.shtml

QUEST lessons are developed in partnership with Maine Mathematics and Science Alliance

Major funding for Quest is provided by the National Science Foundation. Additional funding is provided by the Maine Department of Inland Fisheries and Wildlife, Maine Forest Products Council, and Irving Woodlands LLC.