Lesson 2:
The Science of Water

Teacher Materials

Contents

The Science of Water: Teacher Lesson Plan

Orientation

Water is one of the most unique and ubiquitous substances on our earth. Water's structure and properties account for many of the phenomena in our bodies and on our earth. This lesson reviews some of the science basics of water. If your students have not yet had a chemistry class, they may find some of this information overwhelming. These lessons are not intended to take the place of chemistry, where more intensive study is devoted to the variety of topics reviewed here.

- The Science of Water PowerPoint slide set introduces the structure of water that accounts for water's unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.
- The Science of Water Lab Activities are set-up as lab stations. Their overall purpose is to give the students hands-on opportunities to experience some of the properties of water. Students may move through the stations throughout one or two periods, depending upon your schedule. You may also choose to eliminate one more of the stations to save time. Two of the stations are paper-pencil activities, and have no special requirements for lab equipment.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the driving questions of the unit.
- The Science of Water Student Quiz can be used as a formative or summative assessment of student learning through homework, an in-class group activity, or as an in-class individual assessment, depending on your goals.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

1. Why are water's unique properties so important for life as we know it?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.

Key Knowledge and Skills (KKS)

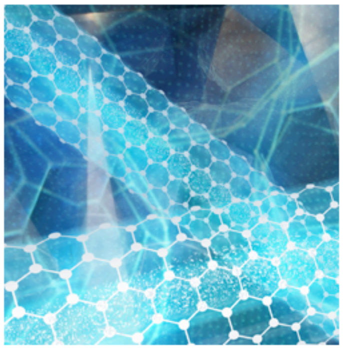
Students will be able to:

(Numbers correspond to learning goals overview document)

4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

The Science Of Water Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Science of Water PowerPoint Slides, using the question slides and teacher's notes to start class discussion.	50 min	The Science of Water PowerPoint Slides & Teacher Notes Computer and projector
Day 2 (50 min)	Students work in pairs or small groups at the Science of Water Lab Activities. Tell students to follow the posted directions to complete the lab at each station, moving to the next station when the current one is completed. Each student should complete their own Student Worksheet, although they may consult with other group members or the teacher.	50 min	The Science of Water Lab Activities: Student Directions posted at each Lab Station. Photocopies of the Science of Water: Student Worksheet
	Homework: Have students fill out the Reflecting on the Guiding Questions: Student Worksheet	*10 min*	Photocopies of Reflecting on the Guiding Questions: Student Worksheet
Day 3 (35 min)	Have students work in pairs or small groups to discuss their reflections on the Guiding Questions	10 min	Student's copies of their Reflecting on the Guiding Questions Worksheet
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	
	Administer the Science of Water: Student Quiz during class, as an individual or group exercise, or as homework.	15 min	Photocopies of The Science of Water: Student Quiz



The Science of Water

We are surrounded by water; we are made of water

NanoSense
the basic sense behind nanoscience

Water in our World

- Water is necessary for life
- Water in our atmosphere helps to keep the planet warm
- Our bodies are composed of and dependent on water

Source: http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-earth.html

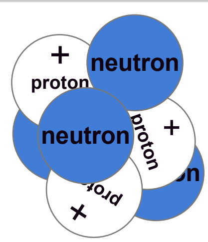
A Quick Overview

Of some of the science basics

What are some of the properties of water that make it so essential to life on our planet?

All Matter is Composed of Atoms

- **The atom is composed of**
  - A nucleus made of neutrons and protons
  - An electron "cloud" composed of electrons



Representation of a nucleus

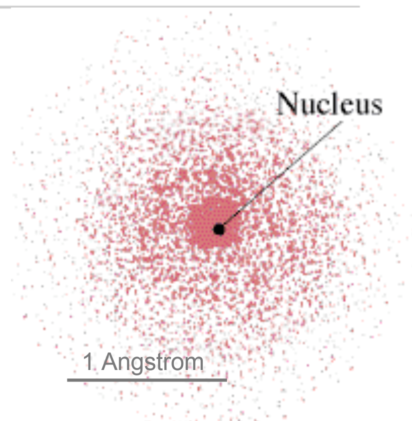
- **Protons and neutrons have nearly identical masses, but their charge is different**
  - Protons have a positive (+) electrical charge and neutrons do not have an electrical charge

Subatomic Particles Composing the Atom

Subatomic Particle	Charge	Size	Location
Proton	+1	1	Part of the nucleus
Neutron	0	1	Part of the nucleus
Electron	-1	0	Electron "cloud" (outside of the nucleus)

The Quantum Atom

- **We can only describe areas of probability where we might find an electron**
  - Electrons are constantly moving
  - Electrons have a specific amount (quantum) of energy, related to their position from the nucleus



Red dots represent areas of probability

Source: http://physics.usc.edu/~bars/135/LectureNotes/QuantumMechanics.htm

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Probability

- **Suppose you had a new dartboard. What would it look like after you had played darts with it for six months?**
  - Can you predict accurately where the next dart you throw will go?
  - Can you predict an area where the next dart is likely to go?

Source: www.amisane.org/images/dartboard2.jpg

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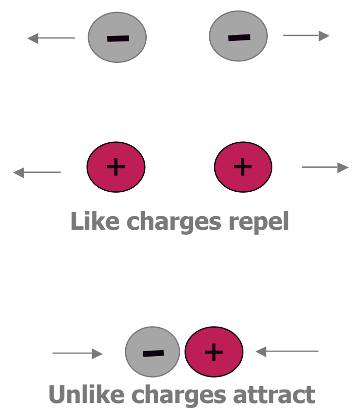
Question

Why do we care about what atoms are made of?

Electric Charge

- Electric charge is a basic force that causes movement



Net Charge of an Atom or Ion

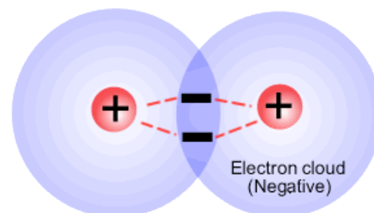
- **The charge on any substance is a result of the total number (#) of**
  - Protons (p) + charges, in the nucleus, and
  - Electrons (e-) - charges, outside the nucleus

- **If the # of…. then the net charge is….**
  - p = e- neutral (atom)
  - p > e- positive (ion)
  - e- > p negative (ion)

Atoms Bond

- **The outer electrons of both atoms are mutually attracted to the nuclei**
  – Oppositely charged particles form a bond, representing a lower energy state for each of the atoms, ***releasing energy***

The electrons experience a force of attraction from both nuclei. This negative - positive - negative attraction holds the two particles together



This attraction is called a chemical bond one pair of electrons constitutes ONE bond

Nature always wants to be in the lowest energy state!

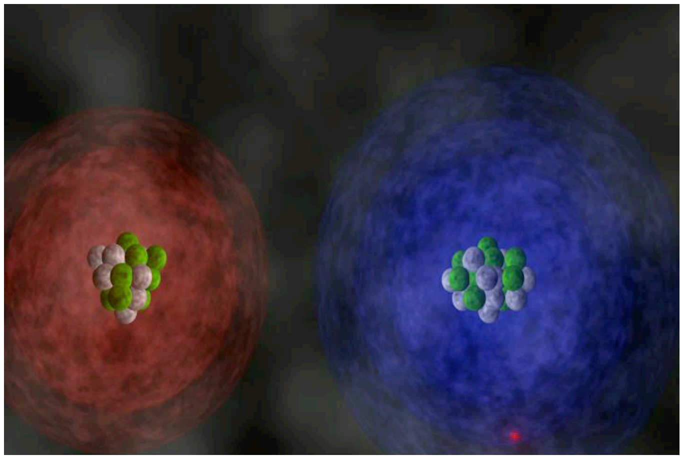
Source: ibchem.com/IB/ibfiles/ bonding/bon_img/cov3.gif

Why are Bonds Formed?

Bonds are formed because of the electrostatic attraction between atoms.

In doing so, the atoms achieve a lower energy state.

Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)

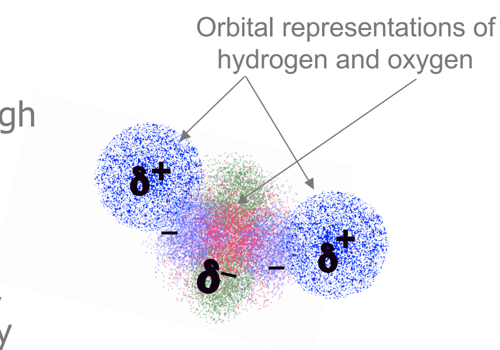


Click the image above to view the animation in your web browser, or go to http://nanosense.org/download/finefilters/Nacl_SD.mov

Source: http://visservices.sdsc.edu/projects/discovery/Nacl_SD.mov

Forming a Water Molecule

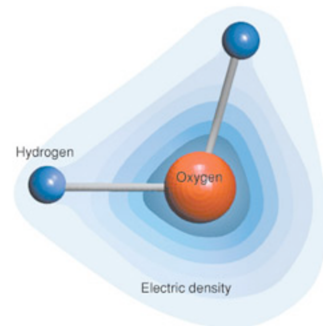
- **Unequal attraction to bonding electrons**
  - Oxygen is a strong electron grabber (high electronegativity)
  - Hydrogen's electron cloud tends to hang out close to oxygen, leaving H's positively charged nucleus all by itself



A water molecule

Electron Density is Uneven

- **The average electron density around the oxygen atom in a water molecule is about 10 times greater than the density around the hydrogen atoms**
  - This non-uniform distribution of positive and negative charges, called a dipole, leads to the substance's unusual behavior

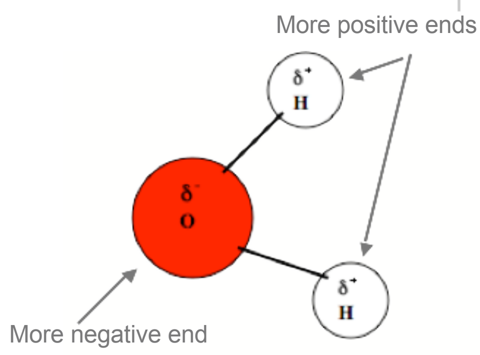


A water molecule, with electron density represented by the shaded blue areas

Source: http://www.llnl.gov/str/October05/Mundy.html

Water is a Polar Molecule

- **The unequal distribution of charges on the water molecule make it a *polar* molecule**
  - One end is more negative, and one end is more positive



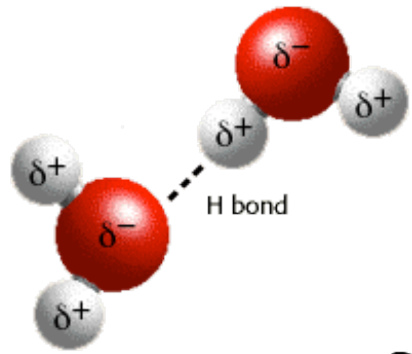
A water molecule

δ- means partial negative charge
δ+ means partial positive charge

Hydrogen Bonding I

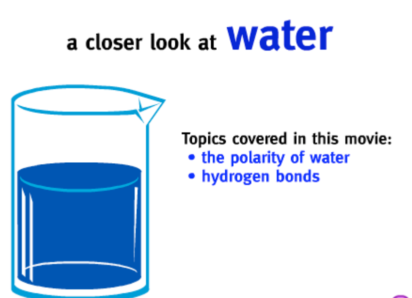
- The partial negative end of the oxygen atom is attracted to the partial positive end of the H atom on an adjacent molecule
- Hydrogen bonds give water its unique properties

Hydrogen bonding between water molecules



Source: http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html

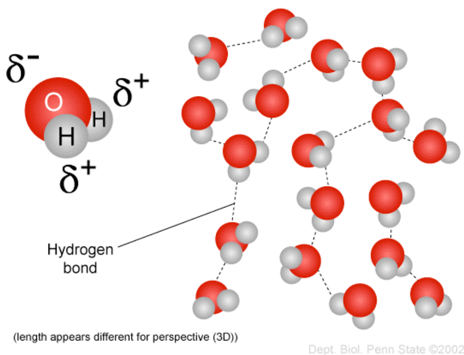
Hydrogen Bonding II



Click the image above to view the animation in your web browser, or go to http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

Hydrogen Bonding Representation

- In water, hydrogen bonds form between the partially negatively charged oxygen atom and the partially positively charged hydrogen atom



Water molecules, with the hydrogen bonds represented by the dotted lines

Source: www.personal.psu.edu/.../ bonddiagram.gif

Unique Properties of Water

- Universal solvent
- Exists in nature as a solid, liquid, and gas
- The density of ice is less than liquid water
- High surface tension
- High heat capacity
- Exists as a liquid at room temperature

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High Surface Tension

- Allows water to form drops
- Allows water to form waves
- Water drops can "adhere" to surfaces even though gravity is pulling on them

Source: Photo 2004 Edward Tsang

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Can You Explain Why this Drop Sticks to the Leaf and Grows Larger?

Source: http://www.azeemazeez.com/photos/wallpaper/water800.jpg

Or How this Spider Can Walk on Water?

Source: http://static.flickr.com/82/237875014_4d579d57c5.jpg

Adhesion

- **Adhesive forces are attractive forces that occur between two unlike substances**
- **In a narrow glass tube**
  - Water molecules are more strongly attracted to the tube than they are to each other (cohesion)
  - The cup shape formed at the top of the water is called a **meniscus**

Source: http://www.wtamu.edu/~crobinson/SoilWater/meniscus2.jpg

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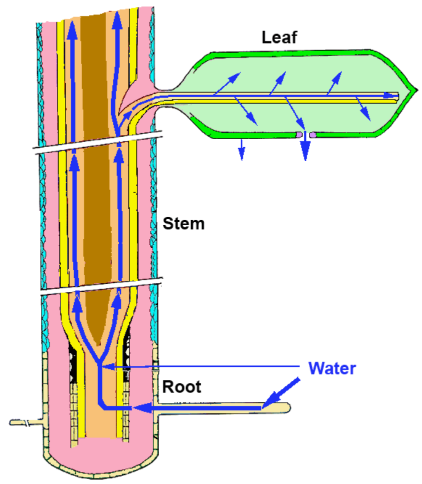
Water Climbs Trees!

- **Evapotranspiration**
  - The tiny tubes in the root hairs suck up water from the soil
  - Inside the plant are more hollow tubes (xylem) for transporting water through the plant
  - Finally, water exits the plant through the tiny openings in its leaves (stomata)



Source: Adapted from http://www.ualr.edu/botany/transpiration2.gif

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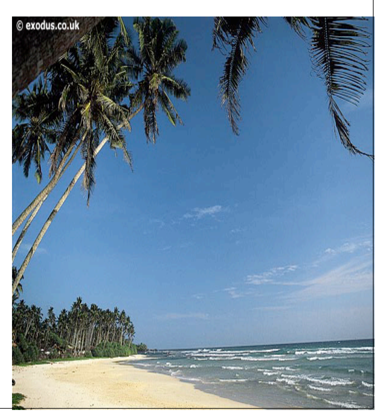
High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

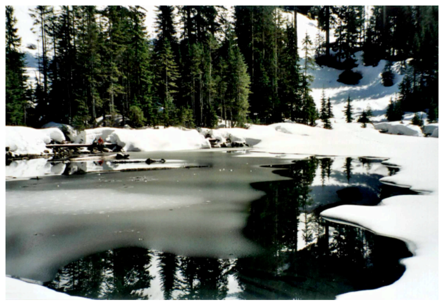
- **Specific heat**
  - The amount of energy required to change 1 gram of a substance 1 °C
- **Water has high specific heat**
  - Absorbs large amounts of heat energy before it begins to get hot
  - Releases heat energy slowly
  - Moderates the Earth's climate and helps living organisms regulate their body temperature



Source: http://www.exodus.co.uk/pictures/d03hp120c.jpg

Solid, Liquid, and Gas

- Water is the only substance which exists under normal conditions on earth as a solid, a liquid, and a gas



Source: http://www.eskimo.com/~captain/slidesho/Lake_Twenty_Two_Partly_Frozen_Over_and_Snow_Covered.jpg

Ice is Less Dense than Water I

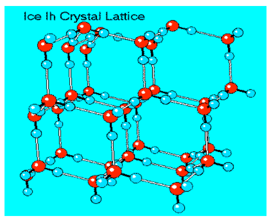
Density of H_2O at different temperatures

Temperature ºC	Density g/cm³
0 (solid)	0.9150
0 (liquid)	0.9999
4	1.0000
20	0.9982
100 (gas)	0.0006

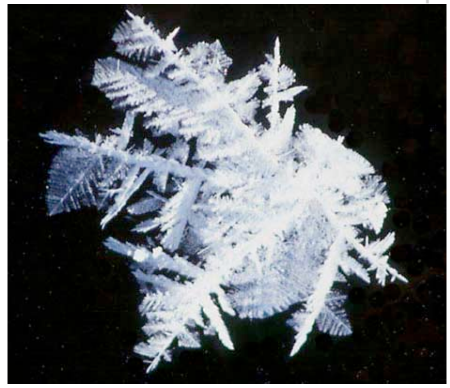
Source: http://www.wildthingsphotography.com

Ice is Less Dense than Water II

- **This is a very rare property!**



Crystal lattice structure of ice



Ice crystal

Sources: http://www.learner.org/jnorth/images/graphics/t/ice_crystal_Greg_Rob.jpg
http://www.solarnavigator.net/images/ice_crystal_lattice.gif

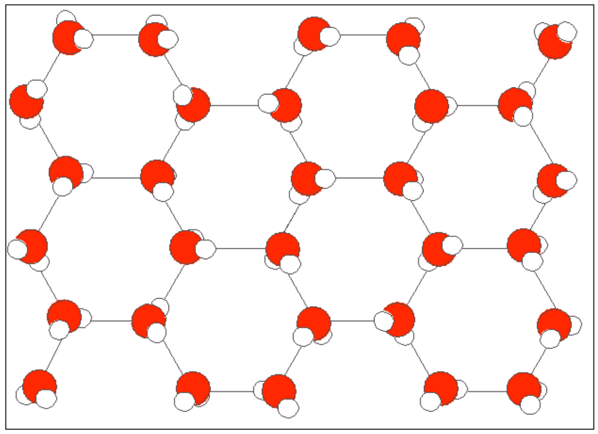
Questions

Can you imagine if ice did not float?

How do you think that would affect the world?

Ice Melting

- **Notice that ice has an open lattice structure that collapses when it melts**



Click the image above to view the animation in your web browser, or go to http://nanosense.org/download/finefilters/MeltingIce.mov

Water is a Universal Solvent

- **Water is a polar molecule with one end more positive and one end more negative**
  - Being polar allows water to dissolve nearly any substance with an unequal distribution of charges
  - Water is the best substance that is universally used for transporting dissolved substances

Water dissolves more substances than any other liquid

Source: http://www.chemistryland.com/CHM107Lab/Lab7/Slime/PourStirPoly2.jpg

Important Points

- What are water’s unique properties?
- What is water’s structure, and how does it cause these properties?
- What would our world or life be like without water?

The Science of Water: Teacher Notes

Overview

This presentation gives students a sense of the structure of water in terms of its shape and charges. The traditions of science have been represented here to give students a picture of how modern science talks about the structure of atoms and charge distribution. Several representations of water are included in this slide set. The big "take away" for students is that hydrogen bonding creates stronger than normal (for substances of a similar molecular mass) bonds between water molecules. Those relatively strong bonds are the reason we see water's unusual properties: high surface tension, high boiling temperature, adhesion, cohesion, low vapor pressure, high specific heat, "universal solvent," the density of the solid form being less than that of the liquid form, and being a liquid at room temperature.

Students may have difficulty with some of the ideas represented in these slides, depending on their background. If students have a weak background in chemistry, it is suggested that the emphasis in these slides be on the shape and charge distribution of the water molecule as it relates to the above-mentioned properties of water.

Slide 1: The Science of Water

Ask students to think about where water is in this world, and what forms water comes in (solid, liquid, gas). Tell students that the focus of this lesson is on the special structure and characteristics of water that make it such a unique substance, a substance that we all depend upon for living.

Slide 2: Water in our World

Our planet is habitably warm because the sun's rays (electromagnetic radiation), filtered through the atmosphere, collide into the earth. When they reach the surface of the earth, the earth absorbs some of the rays, heating the earth. Some of the sun's rays are radiated back into the atmosphere as longer energy waves, infrared rays or heat. The gases in our atmosphere "trap" these energy waves, preventing them from escaping our atmosphere. The earth would be impossibly cold to live upon without this phenomenon, known as the "greenhouse" effect. Water is one of the greenhouse gases. There is much current concern over the amount of greenhouse gases entering the atmosphere and heating our planet to a growing degree. The emphasis of this attention has been mostly on the gases emitted from the combustion of fossil fuels, in other words, man's contribution to greenhouse gases as a result of using gasoline to fuel vehicles.

The human body is composed of water, among other substances. The total amount of water ranges from 50-80%, depending on age, amount of fat present, and other factors. The usual figure used for the amount of water in the normal adult body is 70%. Water is a major component of our blood, our lymph, our serous membranes, and other structures.

Slide 3: A Quick Overview

This set of slides presents a quick overview of the science of water. Each of the topics touched upon, such as models of the atom, bonding, charge distribution, physical properties, and chemical properties are big topics themselves. This set of slides is intended to present an overview only.

Discussion Question for Students: What are some of the properties of water that make it so essential to life on our planet?

You may want your students to brainstorm what they already know about water's unique properties. This is a good way to reveal students' prior knowledge and to uncover any misconceptions about the properties of water.

Slide 4: All Matter is Composed of Atoms

Most students have heard about the particles that compose the atom, as well as the basic structure. They probably will know that the nucleus, while being very, very small compared with the overall volume of an atom, comprises the mass of an atom. The neutron and proton are nearly identical masses compared with the negligible mass of an electron.

The purpose of this slide is to build knowledge about water's unique structure, starting from the basics, with an emphasis on the charge characteristics of a water molecule. The structure to emphasize in this slide is the positively charged nucleus (of a "generic" atom). This will determine the overall charge distribution as well as the net charge on atoms joined together to form molecules.

Slide 5: Subatomic Particles Composing the Atom

This chart represents a simplified version of the relative size, location, and charges of the proton, neutron, and electron.

For reference, a proton has a mass of 1.672×10^{-27} kg and a charge of +1, a neutron has a mass of 1.675×10^{-27} kg and no charge. An electron has a charge of -1 (the same magnitude as a proton's charge, but opposite in direction). The electron is described as having characteristics of a particle and a wave, depending upon the situation. (The photoelectric effect demonstrated by Einstein illustrates the particle behavior of an electron and Young's double slit experiment demonstrated an electron's wave behavior.)

All things point to the electron having no measurable size at this time, although our ability to measure incredibly small objects is limited.

Slide 6: The Quantum Atom

Again, the electron cloud representation as determined by quantum mechanics is shown here. The big points are:

1. The dots that represent the orbital cloud indicate a probability distribution of where an electron might be found. The more dense areas of the cloud represent areas of higher probability. The less dense, as depicted by the decreasing density of dots as one moves farther away from the nucleus, the less probability there is of finding an electron.

2. Electrons are constantly moving really, really fast. That means that the electric charge they carry is moving really, really fast as well. This overall or "net" electric charge distribution is what determines all bonding.
3. Electrons have a "quanta" of energy. Bohr learned that electrons could gain or lose only a specific quantum of energy. To illustrate this, think about a glass that you can fill with water, and stop filling at any position. Electrons are not like that. You may only "fill" by specific increments. These increments are individual to each electron in each atom. They can be measured when an electron "loses" energy by releasing a photon of light. This photon of light can be measured in terms of its wavelength, making it possible to determine its energy.

Slide 7: Probability

This slide is to help students to visualize the idea of a probability distribution in a more concrete way.

Slide 8: Question Slide

Questions for Students: What do students think? Why do we care about what atoms are made of?

This is another time that, within a class discussion, you may be afforded the opportunity to see what students understand and the discussion may allow any misconceptions to surface. Misconceptions are important to address, as they are very powerfully embedded in students' understanding of the world. They are resistant to being replaced with more accurate scientific information.

Slide 9: Electric Charge

Traditional curriculum underemphasizes the role of electric charge in chemistry. Often forces are addressed in physical science curriculum during middle school classes or in physics as an advanced course in high school. It is important for students to realize that these "swarms" of electrons represent an attractive (to positive charges) and repulsive (to negative charges) moving force. This is a very dynamic concept.

Slide 10: Net Charge of an Atom or Ion

This slide is to remind students that the net charge of an atom comes from the total amount of protons (positive charge) in the nucleus and the total amount of electrons (negative charge) in that atom. In addition to that, there may be an equal distribution of electric charge around some atoms, resulting in a polar molecule (a molecule that has a separation of charges).

Slide 11: Atoms Bond

This slide focuses on how opposite charges will form a bond and that a bond between two atoms represents a *lower energy state* for both of the atoms bonded together than if they were not bonded. Students may or may not know this. One of the laws of nature is that matter will always move to the lowest energy state possible. The lowest energy state is the most stable position for matter to obtain.

Slide 12: Why are Bonds Formed?

This slide highlights again that bonds are formed because of the attraction of oppositely charged particles. What causes atoms or particles to have opposite charges is not covered by this unit. That is another extensive subject that is beyond the scope of this slide set. This subject is a typical component in college preparatory chemistry.

Slide 13: Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)

This is an animation that depicts a bond forming between sodium and chlorine. It is just to give students a sense of the swirling, moving electrons as the two atoms are held in close proximity. The video clip should play automatically when in the "view presentation" mode. If it does not play, click on the image to view the animation in your web browser.

Slide 14: Forming a Water Molecule

This is a depiction of the orbital representation of two hydrogen atoms and an oxygen atom, bonded, and their distribution of charges when they come together to form a water molecule.

The slide mentions "electronegativity." Electronegativity is a man-made composite value of the relative amount of each of the elements to attract an electron to itself. To obtain this value, several measures of each of the atoms are considered: first and second ionization energies, disassociation energy, and electron affinities. Linus Pauling was the first among many others to create this value. It has trends in the periodic table. Four is the highest electronegative number, assigned to fluorine, while one is the lowest.

To determine the type of bond that two atoms make, one must subtract the electronegative value of each atom. Though this is a continuum scale, if this difference is approximately 0.5, the bond is considered a non-polar covalent. If the difference is between 0.5 and 1.6 (this varies), then the bond between the two atoms is a polar covalent one. If the difference in the electronegativity values of the two atoms is greater than 1.6 (or so) then the bond is an ionic bond.

Slide 15: Electron Density is Uneven

This slide depicts the density of the distribution of negative charges on the water molecule. This representation is somewhat controversial on the part of teachers. Some students expressed liking this representation, however, because it helped them to visualize an uneven distribution of electrons. The shaded area represents the strongest distribution of negative charges and the lighter areas represent the lower distribution of negative charges. The big point of this slide is to communicate the idea that on the water molecule there is a partial positive end and a partial negative end.

Slide 16: Water is a Polar Molecule

A more detailed picture of the water molecule further illustrates the previous slide.

If students have not seen the symbol δ^+ (partial positive charge) and δ^- (partial negative charge), this would be a good time to explain these commonly used symbols.

Slide 17: Hydrogen Bonding I

Hydrogen bonding occurs in small molecules with a highly electronegative nonmetal element (N, Cl, O, F) that bonds with hydrogen. The attraction of hydrogen's lone electrons toward the highly electronegative atom results in a separation of charge on the molecule. Water is the most famous case of this. Hydrogen bonding occurs ***between*** adjacent molecules. While it is weaker than ionic or covalent bonding, which occurs between atoms to form molecules or ionic compounds, it is a stronger bond than Van der Walls forces that occur between adjacent molecules.

Slide 18: Hydrogen Bonding II

This is a clever animation that illustrates hydrogen bonding. If you have a hard time enabling the link embedded into this PowerPoint slide, try:

http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

Slide 19: Hydrogen Bonding Representation

The water molecule in the center shows the partial positive and negative charges. The illustration on the right depicts these charges among several individual water molecules that are bonded (represented by the dotted line) negative end to positive end.

Slide 20: Unique Properties of Water

Although there are more unique properties of water, the ones listed on this slide are generally thought to be the most important. This slide will serve as an introduction to these properties. Each of these properties is explained further in the following slides.

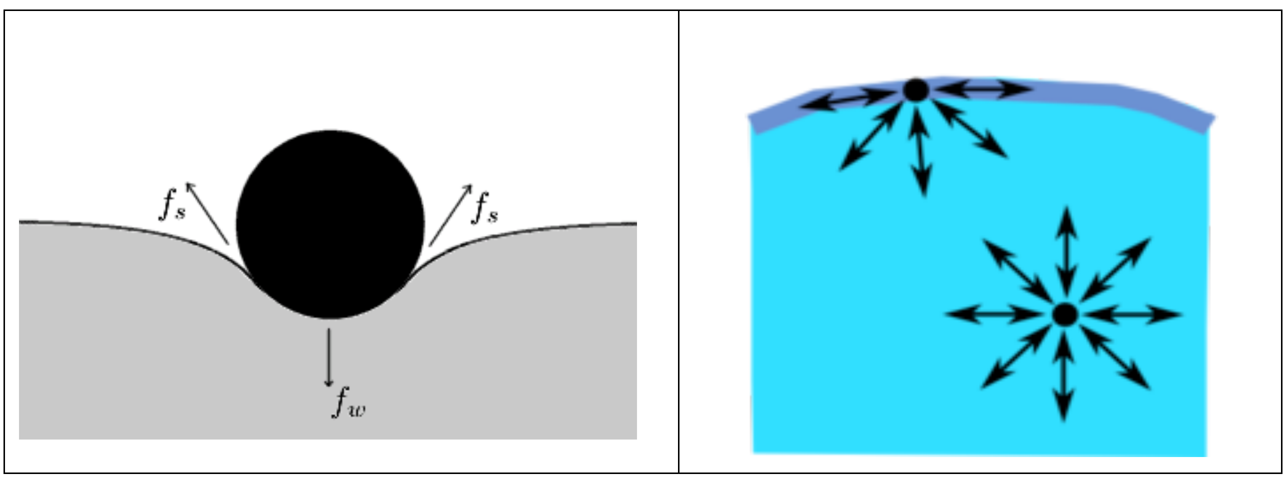


Figure 1. Surface of water with forces that prevent a particle from sinking (left) and forces of two water molecules (right).

Slide 21: High Surface Tension

This slide introduces the concept of surface tension. One way of describing surface tension is to point out that sometimes water acts like a "skin." This results from the surface water molecules clinging to each other and NOT to the air molecules over them.

The images in Figure 1 above are two different representations of surface tension. The image on the left shows the surface of water with forces strong enough to prevent a particle from sinking. The image on the right shows the forces of two water molecules. The water molecule at the surface has fewer force arrows attracting it to the other water molecules than the water molecule below it that is surrounded on all sides by other water molecules.

Slide 22: Question Slide

Question for Students: Can you explain why this drop sticks to the leaf and grows larger?

Ask students to explain how water forms drops AND how water sticks to the leaf, instead of gravity pulling it down.

Slide 23: Question Slide

Question for Students: Or how this spider can walk on water?

The spider has very light feet that don't "puncture" the water. The water behaves like a skin, buoying up the spider.

Slide 24: Adhesion

Adhesion occurs when the water molecules are more attracted to the sides of a small diameter tube than they are to each other. This accounts for phenomena like the meniscus in tubular glassware, or for the capillary action that draws water up into the xylem (small tubes throughout a plant that transmit water) of a plant.

Slide 25: Water Climbs Trees!

The basis of water moving through plants is that, like a small graduated cylinder, water is more attracted to the sides of the plants than to other water molecules. The water climbs up the plants' tubes for transporting water (xylem), and the water molecules attach to each other, pulling them along as well (cohesion).

An additional assignment would be to have students use ChemSense (chemsense.org) to animate water molecules moving through a plant. Another would be to have students illustrate, at the molecular level, water moving through a plant.

Slide 26: High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

Definition: Specific heat is the amount of energy required to change 1 gram of a substance 1^{o} Celsius.

Water has a relatively high specific heat. This means that it will absorb a lot of heat energy before raising the temperature of the water. If you live near a large body of water, the air temperature will not be as hot during the day. The water absorbs a lot of the heat, making air temperature milder than it is inland. When the sun goes down, the water slowly releases the heat that it has absorbed during the daytime. The night air temperature is warmer than the air inland. Climates are milder near large bodies of water than they are away from water.

Warm-blooded animals regulate their internal temperatures by being composed of large amounts of water. This water is slow to heat and slow to cool, moderating temperatures from outside of the body to inside the body. During periods of extreme heat, animals can release heat by sweating. The sweat on the outside of the skin absorbs energy as it evaporates off of the skin, cooling the temperature of the skin beneath the sweat.

Slide 27: Solid, Liquid, and Gas

Have students think about any other substance that is found naturally on earth in more than one phase of matter. Water is the only one to exist naturally in all three phases.

Slide 28: Ice is Less Dense than Water I

This table illustrates that water is the most dense at $4^{o}C$. Have students examine the figures for the density of water at different temperatures.

Slide 29: Ice is Less Dense than Water II

This slide is just a visual to illustrate a macro-picture of an ice crystal and a nano-picture of ice as a solid. The crystal lattice structure of ice literally expands the structure of water as a solid, which will then collapse and become denser when melted.

Slide 30: Question Slide

Questions for Students: Can you imagine if ice did not float? How do you think that would affect the world?

Slide 31: Ice Melting

Click on the image to view the animation in your web browser. This will show the water molecules losing the bonds between them, collapsing and moving faster as the phase changes from solid to liquid.

Slide 32: Water is a Universal Solvent

Water is often described as a universal solvent. This is not really accurate. Water can dissolve polar or ionic substances. Water cannot dissolve nonpolar substances. Water's positive end and negative end have nothing to be differentially attracted to in a nonpolar substance. Water also cannot dissolve ionic substances that are more attracted to each other than they are to the overall force of the water molecules that surround the ions. This process of dissolving is known as solvation.

Slide 33: Important Points

Have students discuss these questions and review the important concepts presented in this lesson.

The Science of Water Lab Activities: Teacher Instructions

Overview

There are three sets of curricular materials for these labs:

1. **The Science of Water Lab Activities: Teacher Instructions.** This document, which includes the purpose, safety precautions, and procedures for each lab station, and a complete list of materials for each station.
2. **The Science of Water Lab Activities: Student Instructions.** The set of directions for students is to be printed and posted at each of the appropriate lab stations. They include a statement of purpose, safety precautions, materials needed, and procedures for the students to follow.
3. **The Science of Water Lab Activities: Student Worksheet.** Each student should be given this worksheet onto which they will record their observations. The worksheet also includes questions about each lab, designed to stimulate the student to think about how the lab demonstrates concepts fundamental to the mechanisms that make water a unique substance.

Each of the following labs is designed to demonstrate a specific aspect of the unique chemistry of water. The lab is set up at multiple stations. Each student or group of students will conduct investigations at each station.

Post the appropriate student instructions at each station for students to follow. There needs to be running tap water and paper towels at each lab station. No dangerous substances are recommended for this lab.

The lab stations are:

- Lab Station A: Surface Tension Lab
- Lab Station B: Adhesion/Cohesion Lab
- Lab Station C: Can You Take the Heat?
- Lab Station D: Liquid at Room Temperature Data Activity
- Lab Station E: Now You See It, Now You Don't, A Dissolving Lab
- Lab Station F: Predict a New World! Inquiry Activity

Materials

A complete list of materials can be found at the end of the set of teacher instructions.

Time Duration

Although the set of laboratory experiences is designed to occupy an entire class period, each lab will vary in the time that it takes to complete. If time is short, you may have students share their data with each other at the end of the class period. Also Lab Stations D and F are paper and pencil labs. You may want to assign these to students as homework or as a warm-up rather than as a separate lab station.

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a “skin” at the surface, and a comparison of water’s surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school’s safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about 4” x 4”, of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.
2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.
3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

1. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.
2. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7mm in diameter), 8-24 inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

1. Check to make sure all of the materials needed are at your lab station.
2. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
3. Record the height of each of the tubes in the table on your worksheet every 2 minutes.

4. After 10 minutes, release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
5. Answer the questions about this experiment on your lab sheet.

Teacher Notes

Try to obtain five different diameters of tubing. These are available through many different suppliers.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0^o C.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.
- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids, with a thermometer held by a thermometer clamp that is to be inserted about midway into the liquid.

- 2 equal amounts, about 100-mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or 2 250-mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).
- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.
2. Take the initial temperature reading of each of the liquids.
3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.
4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

   DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data Table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

1. Examine the data table. Look for relationships between the physical properties of some of these substances.
2. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
3. Answer the questions about this experiment on your lab worksheet.

Teacher Notes

If you are short of time, this activity can be done as homework or as a warm-up assignment. If you need extra lab station space, this activity can be conducted at the students' desks.

Water is Weird!
Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

Data Table 1: Physical Properties of Some Substances

Substance	Formula	Molar mass, grams	State of matter at normal room conditions	Color	Specific Heat J/g K	Density of gas, liquid, or solid	Boiling Temperature, ^{o}C
Water	H_2O	18.0	liquid	colorless	4.19	0.997 g/cm^3	100
Methane	CH_4	16.0	gas	colorless		0.423^{-162} g/cm^3	-161.5
Ammonia	NH_3	17.0	gas	colorless		0.70 g/L	-33
Propane	C_3H_8	44.1	gas	colorless		0.493^{25} g/cm^3	-42.1
Oxygen	O_2	32.0	gas	colorless	0.92	1.308 g/L	-182.9
Carbon dioxide	CO_2	44.0	gas	colorless		1.799 g/L	-78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	0.534 g/cm^3	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	1.74 g/cm^3	1090

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt
- Granulated sugar
- Iodine crystals

Procedures

1. Fill 3 plastic cups 1/3 to 1/2 full with water.
2. Fill 3 plastic cups 1/3 to 1/2 full with oil.
3. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
4. Stir each for about 20 seconds or until dissolved.
5. Record your observations in the table on your lab sheet.
6. Repeat this procedure with sugar.
7. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.
8. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World!
Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- Place a fish bowl with some fish and live plants at this station

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

   Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

   What will be the impact of this change?

Figure 1. Beautiful lake in early winter. [1]

2. Discuss this with your lab partner.
3. Answer the questions about this experiment on your lab worksheet.

Reference

1. http://snow.reports.co.nz/snow_ida_800.jpg

Teacher Notes

This assignment can be homework assigned before this lesson, if there is not sufficient time to do this as a lab activity, or if you prefer.

Materials List

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water, and a dropper for each
- A square, about 4” x 4”, of wax paper
- Hot plate
- Thermometer
- Ice water (without the ice)
- 4 pieces of 8-24 inches of capillary tubing of varying small sized dimensions, no greater than 7mm
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on stands that will stabilize the tubing to remain upright in a straight position
- 2 equal amounts, about 100-mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or beakers
- 2 thermometers
- 2 Bunsen burners or a hot plate
- 2 ring stands, with screens if needed, to hold Erlenmeyer flasks or beakers
- 2 additional clamps to hold the thermometers in place
- Cold water bath for cooling the Erlenmeyer flasks
- 6 plastic cups
- 6 plastic spoons
- Water at room temperature
- Oil at room temperature
- Granulated salt
- Granulated sugar
- Iodine crystals
- A timer with a second hand
- Glassware tongs or heat resistant mitts
- 100-mL graduated cylinder

The Science of Water: Quiz Answer Key

Write down your ideas about each question below.

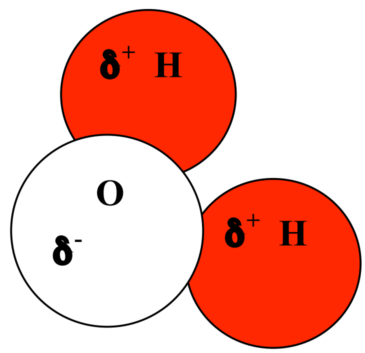
1. Why does all bonding occur between atoms, ions, and molecules?

All bonding occurs because of the attraction of opposite charges.

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

$+$ = positive charge — = negative charge

δ^+ = partial positive charge δ^- = partial negative charge



3. Explain the term "polar" molecule.

A polar molecule has a more positive end and a more negative end. These can be permanent or they can be temporary.

4. Why does water have an increased surface tension compared to most other liquids?

A water molecule has a greater surface tension relative to other liquids because the water molecules are more strongly attracted to the other water molecules surrounding them on all sides, as compared with the water molecules at the surface, which are surrounded by air (mostly nitrogen and oxygen gases). Water is not attracted to air molecules.

5. What is "hydrogen bonding"? What makes these bonds unique?

Hydrogen bonding is the bonding that occurs between adjacent water molecules. (Alhough our focus is on water, there are other molecules that exhibit hydrogen bonding as well as water.) The positive end of one water molecule is attracted to the negative end of the next water molecule. This is why water is a liquid at room temperature. A definition of hydrogen bonding is: The attraction of one end of a small, highly electronegative nonmetal atom in a molecule to the hydrogen end, more electropositive, end of an adjacent molecule.

6. a. Define or describe "specific heat."

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0° C.

b. How does water's specific heat have an impact on our climate?

The temperature of the air near large bodies of water is more moderate than the temperature of air that is not near a large body of water. For instance, for cities bordering the ocean, the ocean absorbs heat during the day, making air temperatures cooler than they would be inland. At night, the ocean slowly releases the heat absorbed during the day, making the air temperatures warmer than they are inland.

7. Is water's specific heat, compared to other liquids:

High ☒ or Average ☐ or Low ☐ ?

8. Are water's melting and boiling temperatures, compared to other liquids:

High ☒ or Average ☐ or Low ☐ ?

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

The temperature of the water stays at 100° C during boiling.

b. Explain what the energy is being used for that is heating the water at the boiling temperature.

The heat energy being continually added to a pot of water during boiling is used to break the bonds of attraction (hydrogen bonding) between water molecules, so that each individual water molecule may change from the liquid phase to the gas phase.

10. Explain how a spider can walk on water.

The surface tension of the water is greater than the pull of the gravity on the spider's little feet.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

Property of Water	**Explanation of Property**	**Phenomenon Property Causes**
High boiling temperature	It takes a relatively large amount of energy to boil water compared with other small nonmetal liquids.	Water at sea level must reach 100^oC before it will boil.
High surface tension	The surface of water acts like a "skin."	Spiders can walk on water.
High specific heat	Water absorbs a relatively large amount of energy to raise its temperature 1^o C.	Climate near large bodies of water is moderate compared with climate further away from large bodies of water.
Solid is less dense than liquid	Water expands in volume when frozen.	Ice floats rather than sinks.
Universal solvent	Water dissolves positive and negatively charged particles.	Water is not found "pure" in nature because it dissolves so much of what it comes into contact with.

Reflecting on the Guiding Questions: Teacher Instructions

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing.

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know: