Reference:

Charted here are the science education content standards covered in Chapter 8, The Nature of Water. As a result of activities provided for high school science students in this part of the curriculum, the content of the standard identified below by a check (✓) is to be understood or the abilities are to be developed by the student.

### CHAPTER 8 NATIONAL SCIENCE EDUCATION CONTENT STANDARDS, GRADES 9-12

<table>
<thead>
<tr>
<th>Unifying Concepts and Processes</th>
<th>Science as Inquiry</th>
<th>Physical Science</th>
<th>Life Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Systems, order, and organization</td>
<td>✓ Abilities necessary to do scientific inquiry</td>
<td>✓ Structure of atoms</td>
<td>✓ The cell</td>
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<tr>
<td>✓ Evidence, models, and explanation</td>
<td>✓ Understandings about scientific inquiry</td>
<td>✓ Structure and properties of matter</td>
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<tr>
<td>✓ Change, constancy, and measurement</td>
<td></td>
<td>Chemical reactions</td>
<td>Biological evolution</td>
</tr>
<tr>
<td>✓ Evolution and equilibrium</td>
<td></td>
<td>Motions and forces</td>
<td>✓ Interdependence of organisms</td>
</tr>
<tr>
<td>✓ Form and function</td>
<td></td>
<td>Conservation of energy and increase in disorder</td>
<td>Matter, energy, and organization in living systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interactions of energy and matter</td>
<td>Behavior of organisms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Earth and Space Science</th>
<th>Science and Technology</th>
<th>Science in Personal and Social Perspectives</th>
<th>History and Nature of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy in the Earth system</td>
<td>✓ Abilities of technological design</td>
<td>Personal and community health</td>
<td>Science as a human endeavor</td>
</tr>
<tr>
<td>✓ Geochemical cycles</td>
<td>✓ Understandings about science and technology</td>
<td>Population growth</td>
<td>✓ Nature of scientific knowledge</td>
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<tr>
<td>Origin and evolution of the Earth system</td>
<td></td>
<td>Natural resources</td>
<td>Historical perspectives</td>
</tr>
<tr>
<td>Origin and evolution of the universe</td>
<td>✓ Environmental quality</td>
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<td>Natural and human induced hazards</td>
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<td></td>
<td></td>
<td>Science and technology in local, national, and global challenges</td>
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</tbody>
</table>
**CHAPTER 8 CORRELATION TO OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS**

<table>
<thead>
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<tbody>
<tr>
<td>The Earth has one big ocean with many features.</td>
<td>The ocean and life in the ocean shape the features of the Earth.</td>
<td>The ocean is a major influence on weather and climate.</td>
<td>The ocean makes Earth habitable.</td>
<td>The ocean supports a great diversity of life and ecosystems.</td>
<td>The ocean and humans are inextricably interconnected.</td>
<td>The ocean is largely unexplored.</td>
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</tbody>
</table>

Reference: www.coexploration.org/oceanliteracy.

Charted here are the Ocean Literacy: Essential Principles and Fundamental Concepts introduced or covered in Chapter 8, *Life on an Ocean Planet*. Those principles and fundamental concepts checked (✓) below should be understood by the student.

For complete text of all the Fundamental Concepts under each Principle, see Section Two of this guide.
# The Nature of Water

## Chapter 8

### Chapter Scope and Sequencing

**BEGIN HERE**
- Motivate
  - Questions
  - Discussions
  - Demonstrations
- Vocabulary/Morphemes
- Expectations/Conduct
- Pre-assessment
  - Pre-concept Map
  - Pre-test

**Lab Activity #1**
- Water's Unique Properties
- The Inorganic Chemistry of Water
- Lab Activity #2
- The Organic Chemistry of Water

**Lab Activity #3**
- Giving Water a Physical

**Lab Activity #1**
- Tears of an Ocean Planet

**Lab Activity #3**
- Chemical Factors That Affect Marine Life

### Chapter 8 Flow Chart

### Chapter Scope and Sequence for Planning: The Nature of Water

<table>
<thead>
<tr>
<th>Activity</th>
<th>Topic</th>
<th>Time Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. The Water Planet</td>
<td>.3 hour</td>
<td></td>
</tr>
<tr>
<td>II. Water's Unique Properties</td>
<td>2.5 hours</td>
<td></td>
</tr>
<tr>
<td>Lecture</td>
<td>A. The Polar Molecule</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>B. The Effects of Hydrogen Bonds</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Laboratory/Activity #1</td>
<td>Water, More Than Just Wet, It's Unique</td>
<td>90 minutes</td>
</tr>
<tr>
<td>III. The Inorganic Chemistry of Water</td>
<td>3.5 hours</td>
<td></td>
</tr>
<tr>
<td>Lecture</td>
<td>A. Solutions and Mixtures in Water</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>B. Salts and Salinity</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>C. Colligative Properties of Seawater</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>D. The Principle of Constant Proportions</td>
<td>20 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>E. Dissolved Solids in Seawater</td>
<td>20 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>F. Determining Salinity, Temperature, and Depth</td>
<td>20 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>G. Why the Seas Are Salty</td>
<td>20 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>H. Salinity, Temperature and Water Density</td>
<td>20 minutes</td>
</tr>
<tr>
<td>Lecture</td>
<td>I. Acidity and Alkalinity</td>
<td>50 minutes</td>
</tr>
<tr>
<td>Laboratory/Activity #2</td>
<td>Tears of an Ocean Planet</td>
<td>180 minutes</td>
</tr>
</tbody>
</table>
LEARNING OUTCOMES

- What is a **polar molecule**?
- What properties does water have because it is a polar molecule?
- Why does ice float? How is this important to the thermal conditions on Earth?
- What are two kinds of **mixtures**? What is a **solution**?
- What is **salinity**? What are the major sea salts?
- What are the **colligative properties** of seawater? Does fresh water have these properties?
- What is the **principle of constant proportions**?
- Besides hydrogen and oxygen, what are the most abundant chemicals in seawater?
- How is the principle of constant proportions used to determine salinity? How do marine scientists determine salinity?
- Where do sea salts come from? Is the ocean getting saltier? Why or why not?
- How do temperature and salinity affect seawater density?

(Continued on the next page)

**MOTIVATIONAL STRATEGIES**

The following motivational strategies are included as suggestions for creating interest and curiosity, for providing relevance of the content, for making connections between past and present learning experiences, and for providing context for the lessons.

**Questions to Elicit Prior Student Knowledge**

To engage students and assess students’ prior knowledge of the overall chapter content and to guide their learning, you may want to ask these questions before launching into each core chapter topic.

<table>
<thead>
<tr>
<th><strong>TOPIC</strong></th>
<th><strong>QUESTION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The Water Planet</strong></td>
<td>If Earth is often referred to as “the water planet,” why is the need for water such an issue for so many? Is clean drinking water an issue for some countries?</td>
</tr>
<tr>
<td><strong>Water’s Unique Properties</strong></td>
<td>What is so unique about water and why is this significant physically and biologically?</td>
</tr>
<tr>
<td><strong>The Inorganic Chemistry of Water</strong></td>
<td>What does “inorganic” mean? What is the study of inorganic chemistry? How does the inorganic chemistry of seawater differ from that of fresh water? Why is it important that seawater contains salt?</td>
</tr>
</tbody>
</table>
The Nature of Water

**QUESTIONS TO ELICIT PRIOR STUDENT KNOWLEDGE**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Organic Chemistry of Water</td>
<td>What does “organic” mean? What is the study of organic chemistry? What does the word “organic mean when you purchase “organically grown produce?” One role marine birds play in the ecological balance is helping the sea obtain organic nitrogen and phosphorus. How do marine birds fulfill this role? How are organic materials cycled through the Earth and organisms?</td>
</tr>
<tr>
<td>Chemical Factors That Affect Marine Life</td>
<td>How do the chemical properties of seawater affect marine organisms?</td>
</tr>
</tbody>
</table>

**Marine Career Discussion**

In this chapter students learn about the nature of water – water’s unique properties and the chemistry of water. Dr. Richard Lutz is the Director of the Center for Deep-Sea Ecology and Biotechnology and is a professor at Rutgers University in the Institute of Marine and Coastal Sciences. He is interested in looking into the sea and the processes that shape the sea and the coast for clues to the origins of life on Earth and the possibility of life on other planets. Currently, Dr. Lutz is interested in the study of hydrothermal-vent environments. This is important because these are environments where life may have originated. They may also be similar to those of other extraterrestrial bodies, meaning they may also provide clues regarding the possibility of life on other planets.

As students study this chapter, ask them to think about how a solid background in science, chemistry and math would be important for a career in marine science. Studying the nature of water is most important for all.

**Mind Capture Demonstration**

These teacher demonstrations may be used to introduce this chapter or different parts of the chapter, or may be used as a team inquiry-based activity.

**Conductivity of Seawater**

1. The Nature of Water

**Inquiry:**

Ask students to brainstorm ways to measure the salinity of a sample of seawater.

**Objective:**

This “Mind Capture” demonstrates the conductivity (or the flow of electricity) of seawater, which is a simple way to measure salinity. This demonstration may also be done as a student activity if you have more materials.

**LEARNING OUTCOMES (CONTINUED)**

- What factors affect seawater’s pH? Why does pH change with depth?
- How do the proportions of organic elements in seawater differ from the proportions of sea salts?
- What is the biogeochemical cycle?
- What element is fundamental to all life?
- What are the roles of carbon in organisms?
- What are the roles of nitrogen in organisms?
- Why is phosphorous important to life?
- What is the role of silicon in marine organisms?
- What are the roles of iron and other trace metals in marine organisms?
- How can diffusion and osmosis affect marine organisms?
- What are passive and active transport?
- What are osmoregulators and osmoconformers?
Materials:
- A 9-volt battery
- A 12-volt flashlight bulb in a plastic holder
- 3 pieces of insulated copper wire (about 25 cm each)
- Seawater sample
- Distilled water

Procedure:
1. Make a saltwater sample of 35‰. To do this, you will need to combine 965 ml of tap water and 35 g of sodium chloride.
2. To make the simple conductivity-testing instrument, obtain 3 pieces of insulated copper wire. Each piece should be approximately 25 cm in length. Use scissors to remove the insulation from each end of the wire. Twist the end of one wire around a screw on the flashlight bulb holder and the end of another wire around the other screw on the holder. Connect one of these wires to one of the 9-volt battery terminals. Attach a third wire to the other terminal of the battery. Your instrument works if you put the two unattached ends together and the bulb lights.
3. Have students make a prediction about the conductivity of the two water samples. Students may say the solution is a good conductor or a nonconductor.
4. To test the conductivity of the water samples, place the two unattached ends in the distilled water sample and then the seawater sample. The ends should not be touching each other.

Results:
The bulb should light in the seawater sample, but not in the distilled water sample.

Conclude and Communicate:
Ask students what kinds of bond compounds that conduct electricity have and how could a simple conductivity meter give an estimate of the salinity. If they do not have prior knowledge of ionic bonding and the dissolve ions in seawater, you may tell the students that throughout the chapter, they will learn this.

This simple demonstration introduces students to salinity, by showing that in order for a solution to conduct electricity the compounds must have ionic bonds. As these ions dissolve in water, charged ions are formed. Conductivity, therefore, correlates to the amount of dissolved ions in water. The conductivity increases as the amount of dissolved ions increase.
2. Water Cycle Model

**Inquiry:**
This model demonstrates the water cycle. Refer students to the textbox (The Cycle of Water). It can also be used to demonstrate one way that fresh water is obtained from seawater.

**Materials:**
- A clear plastic storage-type container with a plastic top
- 50 cm of string or yarn
- Masking tape
- Small 2-3 oz paper or Styrofoam cup
- Approximately 500 ml cup of ice cubes or crushed ice
- Food coloring
- Heat source
- Seawater sample.

**Objective:**
This “Mind Capture” demonstrates a model of heat warming seawater, the resulting evaporation, rising vapor, and condensation – essentially the water cycle. This demonstration may also be done as a student activity if you have more materials.

**Procedure:**
1. Make approximately 500 ml of saltwater. Remember to make a saltwater sample of 35‰. You will need to combine 965 ml of tap water and 35 g of sodium chloride. This does not have to be exact for this demonstration. You can also add a few tablespoons of sodium chloride to water.
2. Cut the string in 4 pieces of equal length. You will use these strings to suspend the cup from the top of the container. Place four holes in the top of the cup at equal distance apart and thread each of the four strings through each one of the holes. The cup should be above the saltwater level. Tape the strings to the outside of the container.
3. Place the top upside down on the opening of the container. Carefully place the ice cubes into the top. Put a few drops of blue food coloring into the ice cubes. The food coloring is used to help students “see” that rain does not come from the melting ice.
4. Place the model near a heat source, such as a light. You will need to leave it for an hour or more. You can leave it set up overnight.

**Results:**
Ask students to predict what they think will happen. You may begin by asking them what each part of the model represents in the water cycle.

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**VOCABULARY (CONTINUED)**
- passive transport (p. 8-32)
- pH (p. 8-20)
- polar molecule (p. 8-6)
- polarity (p. 8-6)
- principle of constant proportions (p. 8-14)
- pycnocline (p. 8-19)
- refractometer (p. 8-16)
- salinity (p. 8-11)
- salinometer (p. 8-15)
- semipermeable membrane (p. 8-13)
- silica (p. 8-28)
- solute (p. 8-9)
- solution (p. 8-9)
- solvent (p. 8-9)
- surface tension (p. 8-7)
- suspension (p. 8-9)
- thermistor (p. 8-15)
- viscosity (p. 8-7)

**MORPHEMES**
- a – not, without
- calci – limestone
- diplo – two, double
- eu – good, well
- halo – salt
- hydro – water
- hyper – over, above, excess
- hypo – under, beneath
- iso – equal
- kilo – one thousand
- nutri – nourishing
- osis – condition
- peri – all around
- photo – light
- phyto – plant
- sali – salt
- semi – half
- sis – process
- strati – layer
Conclude and Communicate:

The saltwater represents the ocean. The air inside the container represents the lower atmosphere and the air outside the container near the ice represents the upper, cooler atmosphere. The suspended cup represents a rain gauge. The light represents the sun.

This demonstration provides a model of heat warming the seawater. Water will evaporate and rise. As the water vapor rises near the top of the container, it is cooled by the ice cubes, and condensation occurs. Condensation occurs on dust particles and forms precipitation, (rain droplets), which fall into the cup.

EXPECTATIONS/STUDENT CONDUCT

• Students may be involved in guided discussion as the teacher explains the content of the chapter through a teacher-led presentation. Students will be expected to respond to questions, ask questions, take notes, draw and label diagrams.
• Students may study the chapter individually as they read and respond to questions.
• Students may work in collaborative teams as they conduct inquiry-based activities and work on specific enrichment experiences and assessments.
• Students should start each chapter by familiarizing themselves with the chapter vocabulary and morphemes list. Students may develop a chapter concept map using the vocabulary list. This initial concept map can be compared with a summative concept map to determine what learning has taken place and whether misconceptions remain.
TEACHING CHAPTER 8

Instructional Strategy – Teacher Led Presentation
Exploration Through Discussion

THE NATURE OF WATER

I. The Water Planet

Reference the National Science Teachers Association (NSTA)
SciLinks Service
Topic: Properties of Water
Go To: www.scilinks.org
Code: LOP2140

Guided discussion question(s):
Because water covers approximately 71% of Earth’s surface, it may seem that there would be so much water available that the way water is used would not be an issue. Do you agree with this statement? Why or why not? Why do you think the vast majority of water on Earth can’t be used for drinking, irrigation, or industry?

1. You may have heard that water covers about 71% of the Earth’s surface. Based on that, you might think that there’s plenty of water to go around, but it’s not that simple. Politically, water has always been an issue.

2. The vast majority of water on Earth can’t be used directly for drinking, irrigation, or industry for the simple reason that it’s salt water.
   a. But, the sea provides many other resources such as food, transport by shipping, oil and gas, and recreation. However, if you recall the Cod Wars in the last chapter, then you realize that as big as the ocean is, it’s not always big enough.

3. Humans primarily need fresh water. There’s just not as much as we’d like, and not all the sources are accessible.
   a. Plenty of water exists at the poles, for instance, but it’s frozen and located far from population centers.
   b. We can condense water vapor from the atmosphere by artificial means, but only at an astounding cost.
   c. Most of the fresh water we rely on comes from underground aquifers and rivers.
4. Historically, the lack of accessible, usable, fresh water has been a source of political tension.
   a. Rivers do not always go where people want them to or people downstream dispute the use of water by people upstream.
   b. It’s easy to recognize that if a group upstream pollutes a river or diverts its flow, those downstream may suffer.

5. Consider the situation in Africa between Ethiopia and Egypt. One of the world’s longest rivers, the Nile, supplies Egypt, which is in one of the world’s driest places, with fresh water. Without the Nile, Egypt would have little water for agriculture, industry, and its people.
   a. However, the Blue Nile (one of two rivers that merge to form the Nile in Egypt) originates in Ethiopia, which struggles economically. To promote agriculture and industry, the Ethiopian government wants to divert some of the Nile’s water.
   b. The potential damage to Egypt isn’t hard to imagine; hence, the two countries have been in conflict over this issue for some time.

6. Similar issues arise within the United States. Farmers in California’s Tulelake agricultural region rely on water from Klamath Lake in Oregon.
   a. Questions regarding Native-American rights and the protection of endangered species have led to Oregon periodically cutting off water to the farmers, damaging their crops and livelihood.
   b. It remains an area of dispute between two states and two groups of people who value the same water in two important but different ways.

Guided discussion question(s): Why is it important to learn about water? One reason is that as the human population increases, the demand for fresh water will increase. Additionally, water covers 71% of Earth’s surface area and makes up more than 99% of the biosphere, the habitable area of Earth. Discuss some of the changes science has brought about to meet the demands of fresh water.

7. As the human population increases, so does the need for water. Part of the solution to meeting this demand lies in understanding what water is, where it goes, and how it cycles through nature.
8. Now let’s set aside the human perspective and look at water as if you lived in the sea like a dolphin or a fish.
   a. From this point of view, the oceans are vast. 71% only accounts for the surface area that water covers. When you consider depth and volume, the world’s oceans provide more than 99% of the biosphere—the habitable space on Earth.

9. On land the habitable space comprises the ground, a few feet or meters below ground, and rarely more than 30 meters (98 feet) above ground in trees.
   a. Some birds and insects fly high in the air, but they do not live there. This is why much of the atmosphere isn’t considered part of the biosphere.
   b. But, many whales, fish, and other organisms live midwater, seldom, if ever, nearing the bottom or the shore.
   c. Hydrothermal vents shoot hot, mineral-rich water into the ocean, providing flourishing habitats in the deepest parts of the sea. This makes the entire ocean, which averages 3,730 meters (12,238 feet) deep, part of the biosphere.
   d. While humans need fresh water for drinking, bathing, agriculture, and industry, the oceans provide resources for most life, including human life.

10. The deepest known point in any ocean is the Challenger Deep in the Mariana Trench.
   a. At 11,000 meters (36,000 feet), it’s so deep that if you put Mt. Everest into it, the top would still be more than 1,990 meters (6,527 feet) under water.
   b. This depth creates water pressure of an amazing 8 tons per square inch. That’s about the weight of four automobiles pressing down on an area the size of a typical postage stamp.
   c. Our ocean on planet Earth averages 3,730 meters (12,238 feet) deep. The world’s oceans hold more than 1.18 trillion cubic kilometers (285 million cubic miles).

As you’ve seen in previous chapters, from phytoplankton to whales, the ocean holds more life and diversity than any other place on Earth. To understand this life, you need to understand water itself. In this chapter, you’ll learn about water’s fundamental chemical properties. You’ll see why it’s an unusual molecule with characteristics that shape the nature of life on Earth. You’ll also learn how water, along with primary producers, cycles vital inorganic and organic compounds to and from the biosphere. Perhaps most important, you’ll learn that we shouldn’t take water for granted.
II. Water’s Unique Properties

By the end of this section, students will be able to answer these questions:
1. What is a polar molecule?
2. What properties does water have because it is a polar molecule?
3. Why does ice float? How is this important to the thermal conditions on Earth?

A. The Polar Molecule

What is a polar molecule?

1. Compared to many other important molecules, the water molecule is simple.
   a. You probably recognize its chemical symbol—H₂O. This means water consists of three atoms: two hydrogen and one oxygen.
   b. In contrast, the DNA molecule (deoxyribonucleic acid), which contains all of an organism’s genetic information, consists of thousands of atoms.

2. Although water is a relatively simple molecule, the way it’s held together gives it unique properties.
   a. The hydrogen atoms bond to the oxygen atom with a covalent bond. A covalent bond is formed by atoms sharing electrons.
   b. In water, the oxygen atom shares the electrons of two single-electron hydrogen atoms. This makes water a very stable molecule.

3. In water, the oxygen atom attracts the shared electrons close toward its large nucleus, creating a lopsided molecule with two hydrogen atoms on one side and an oxygen atom on the other.
   a. This puts the hydrogen nuclei, with their positively charged protons, toward the outside of the molecule on one end. The oxygen atom’s negatively charged electrons end up on the opposite side.
   b. This unequal electron sharing gives each water molecule a positive charge on the hydrogen end and a negative charge on the oxygen end, like a magnet.
   c. A molecule with positively and negatively charged ends is said to have polarity and is called a polar molecule.
   d. Because water has two positively charged and slightly separated hydrogen atoms, it technically has two positive poles, one for each hydrogen atom. For this reason, it is sometimes called a dipolar molecule.
4. The water molecule’s polarity allows it to bond with adjacent water molecules.
   a. This happens because the positively charged hydrogen end of one water molecule attracts the negatively charged oxygen end of another water molecule.
   b. This bond between water molecules is called a hydrogen bond.

5. Individual hydrogen bonds are weak compared to covalent bonds. In fact, hydrogen bonds are only 6% as strong as covalent bonds, so they easily break and reform.
   a. However, the bonds have a cumulative strength in numbers. They are strong enough to give water some of its unique properties, all of which have profound effects on organisms on Earth.

B. The Effects of Hydrogen Bonds

Reference the National Science Teachers Association (NSTA) SciLinks Service

Topic: Properties of Ocean Water
Go To: www.scilinks.org
Code: LOP2145

What properties does water have because it is a polar molecule?

1. Liquid Water. The most important characteristic of hydrogen bonds is their ability to make water a liquid at room temperature.
   a. Without them, water would be a gas (water vapor or steam) at room temperature. This is because the bonds hold the molecules together, so more energy (heat) is needed to form steam.
   b. Without hydrogen bonds, Earth would be the steam planet instead of the liquid water planet.

2. Cohesion/Adhesion. Because hydrogen bonds attract water molecules to each other, water molecules tend to stick together. This is called cohesion.
   a. Cohesion gives water a more organized structure than most liquids.

3. Water also sticks to other materials due to its polar nature. This is called adhesion.
   a. An example of this is the tendency for a raindrop to cling to the surface of a leaf. Only when there’s a lot of water and the weight exceeds the force of adhesion does the droplet flow off the leaf.
Guided discussion question(s): What affects the viscosity of a fluid? How does viscosity affect aquatic organisms?

4. Viscosity. Viscosity is the tendency for a fluid (gas or liquid) to resist flow.
   a. Most fluids change viscosity as they change temperature. Maybe you’ve put cooking oil in a cool pan and noticed that at first it flows very slowly when you tilt the pan. But, as the pan gets hot from the stove, the oil flows quickly because it becomes less viscous.

5. Because hydrogen bonds tend to hold water molecules together, they make water more viscous than it might otherwise be.
   a. As water cools, the viscosity rises more than in other liquids because hydrogen bonds resist the tendency for heat to move molecules apart. For example, a 20°C (68°F) drop in temperature increases water’s viscosity by more than 60%.
   b. This is important because it affects the energy aquatic organisms expend. In cool water, the high viscosity means drifting organisms (plankton) use less energy to keep from sinking. However, swimming animals use more energy moving through it.

Guided discussion question(s): Why is surface tension important to organisms? Why is surface tension important to life on Earth? Why are scientists interested in studying surface tension?

6. Surface Tension. The polar nature of water allows it to form a skinlike surface. This is called surface tension.
   a. Surface tension is water’s resistance to objects attempting to penetrate its surface. The cohesive nature of water at its surface (caused by hydrogen bonds holding the water molecules together) makes surface tension possible.
   b. To you, a large organism, surface tension is so weak you don’t notice it when you step into a puddle or dive into a swimming pool. To small creatures, such as the water strider (Halobates sericeus), however, surface tension is a strong force. It allows the water strider to literally stand on water.
   c. Neuston are plankton that live on the water’s surface. Many small organisms of this community rest on surface tension rather than float.
7. Scientists have a particular interest in the air/water boundary created by surface tension because they’re trying to understand how it affects gas exchange between the ocean and the atmosphere.

   a. Surface tension affects how quickly the ocean takes up atmospheric carbon dioxide and release oxygen into the atmosphere. This issue has become particularly important as carbon dioxide increases in the atmosphere from air pollution.
   
   b. Surface tension affects how much carbon dioxide the ocean absorbs to offset pollution.
   
   c. Another concern is how pollutants affect the neustonic community. Many chemicals, including soaps and detergents, tend to reduce hydrogen bonding and negate surface tension.
   
   d. Many insects supported by surface tension cannot stand on water with soap in it because the water can no longer support their weight. The insects sink just like large animals would.

   **Why does ice float? How is this important to the thermal conditions on Earth?**

8. Ice floats. When you fill a glass with water and put ice in it, the ice floats. You probably don’t even think about it. But it is actually a very unusual property.

   a. Most substances become dense and sink as they cool and turn from liquid to solid; they lose density as they heat and turn from liquid to gas.
   
   b. Water also becomes less dense as it heats and denser as it cools, but only to a point. As water cools enough to turn from a liquid into solid ice, the hydrogen bonds spread the molecules into a crystal structure that takes up more space than liquid water.
   
   c. With more volume, ice is less dense than liquid water, so it floats.

9. This property has a huge effect on this planet. By floating, ice forms a layer that insulates the water below, allowing it to retain heat and remain a liquid.

   a. If ice sank, the ocean would be entirely frozen—or at least substantially cooler—because water would not be able to retain as much heat.
   
   b. The Earth’s climate would be substantially colder—perhaps too cold for life at all.
II. The Inorganic Chemistry of Water

By the end of this section, students will be able to answer these questions:

1. What are two kinds of mixtures? What is a solution?
2. What is salinity? What are the major sea salts?
3. What are the colligative properties of seawater? Does fresh water have these properties?
4. What is the principle of constant proportions?
5. Besides hydrogen and oxygen, what are the most abundant chemicals in seawater?
6. How is the principle of constant proportions used to determine salinity? How do marine scientists determine salinity?
7. Where do sea salts come from? Is the ocean getting saltier? Why or why not?
8. How do temperature and salinity affect seawater density?
9. What factors affect seawater’s pH? Why does pH change with depth?

A. Solutions and Mixtures in Water

**What are two kinds of mixtures? What is a solution?**

1. Stir a spoonful of sugar in water and watch it dissolve. You have just created a solution, which occurs when the molecules of one substance are homogeneously (evenly) dispersed among the molecules of another substance.
   a. In this example, water acts as the solvent. A solvent is usually a liquid and the more abundant substance in a solution. In fact, water is often called the “universal solvent” because it can dissolve so many substances.
   b. The solute (in this case, sugar) is the substance being dissolved and is usually a solid or gas.

2. A mixture, on the other hand, occurs when two or more substances are closely intermingling, yet retain their individual characteristics.
   a. An example of a mixture would be India ink stirred into water. The water darkens, but if left to stand for a while, the ink settles to the bottom of the glass, leaving clear water above. When stirred, the ink and water molecules spread out evenly, creating a mixture.
   b. There are two kinds of mixtures: homogeneous and heterogeneous.

3. Homogeneous mixture – has a uniform appearance throughout. Examples: milk, fog, sugar and water, smoke, and stirred up dust in the air.
   a. A colloid is a homogeneous solution with intermediate particle size between a solution and suspension. Like milk.
4. Heterogeneous mixture – is not uniform throughout and consists of visibly different substances. Examples: India ink, oil and water, sand and water.
   a. A suspension is a heterogeneous mixture of larger, visible particles that will settle out on standing. Like sand and water.

5. Water can be part of both homogeneous and heterogeneous mixtures.
   a. Water’s polar nature makes it a good solvent. The way salt dissolves in water illustrates this.
   b. The water molecule’s polar characteristics pull apart (dissociate) the salt (sodium chloride—NaCl) crystal. In the process, the dissociated sodium and chloride become charged particles (ions) and attract the positive and negative ends of the water molecules.
   c. The negative oxygen end of the water molecule attracts the positive sodium ions, and the positive hydrogen end attracts the negative chloride ions. These bonds tend to keep the salt in solution.

6. Substances that do not separate into ions can still dissolve in water through other mechanisms.
   a. Sugar crystals, for example, break into individual molecules when dissolved. These molecules have no charge and are therefore neutral. Because of this, the molecule remains intact in solution, and the solution is said to be nonionic.
   b. As carbohydrates, sugar molecules do have carbon, hydrogen, and oxygen. Because of the individual charges of the atoms in the molecule, sugar molecules and water molecules will form hydrogen bonds.

7. Because many substances can dissolve into water in various ways, water is sometimes called the “universal solvent.”

B. Salts and Salinity

What is salinity? What are the major sea salts?

1. Although you may think salinity refers only to the sodium chloride (NaCl) dissolved in seawater, there are many other salts, including potassium chloride (KCl).
   a. Salinity, therefore, includes the total quantity or concentration of all dissolved inorganic solids, or more precisely, ions. This is the sodium chloride and everything else, commonly called the dissolved salts.

2. Scientists measure salinity in various ways.
   a. The most current methods use equipment that determine salinity based on how well water conducts electricity, using the ratio of the conductivity of the sample to the conductivity of a standard solution of potassium chloride (KCl).
3. Salinity is expressed in parts per thousand because even very small variations are significant.
   a. The abbreviation ‰ stands for “parts per thousand,” so 35‰ means 35 parts per thousand. (Note: To convert parts per thousand into percent, you divide by 10, so that 35‰ = 3.5%.)
   b. The ocean’s average salinity is 35‰.

**Guided discussion question(s):** Why does salinity vary throughout the ocean?

4. Generally the ocean’s salinity varies very little, although there is a great deal of variation in specific areas: from near zero at the mouths of rivers to more than 40‰ in confined, arid regions such as the Red Sea.
   a. The proportion of the various dissolved salts in seawater does not change, only the relative amount of water.
   b. The salinity changes when fresh water enters the ocean—such as from a river or from rain—or as water evaporates. For instance, brackish water results when fresh water mixes with seawater in estuaries. Brackish water has a salinity of 0.6‰ to 30‰.
   c. Brine, which is water saturated or nearly saturated with dissolved salt, develops in areas with high evaporation and little inflow of fresh water or where salt domes dissolve at the seafloor, as is common in the Gulf of Mexico.

5. Most dissolved salts in seawater exist as dissociated ions. Sodium chloride (rock salt, also called halite) is the most abundant of these.
   a. You can see the dissolution of sodium chloride in Figure 8-12. In the middle, the salt is depicted as a set of stacked molecules; on the left and right, it dissolves into water, becoming dissociated ions. The dissociated ions separate in solution and recombine when the water evaporates. Because the different salts exist as dissociated ions, they interact with water molecules and each other.
   b. This changes some of water’s physical properties primarily by disrupting the hydrogen bonds.

**C. Colligative Properties of Seawater**

What are the colligative properties of seawater? Does fresh water have these properties?

1. The properties of a liquid that may be altered by the presence of a solute are called colligative properties. A. Since pure water doesn’t have anything dissolved in it, it does not have colligative properties. We associate colligative properties primarily with seawater. However, natural fresh water usually has some quantity of solutes, and can have colligative properties...
properties to some degree. The strength of the colligative properties depends on the quantity of solute.

2. Raised boiling point. Seawater boils at a slightly higher temperature than pure fresh water.

3. Decreased freezing temperature. As salinity increases, water resists freezing. (This is why salt is sometimes used on the road during ice and snowstorms.)
   a. Seawater freezes at a slightly lower temperature than fresh water.

4. Ability to create osmotic pressure. A law of chemistry is that fluids flow or diffuse from areas of high concentration to areas of low concentration until the concentration equalizes.
   a. You can think of this as flowing downhill from a high area to a low area. Osmosis occurs when this happens through a semipermeable membrane, such as a cell wall. (A semipermeable membrane allows some substances to pass through, but not others.)
   b. Because it contains dissolved salts, water in seawater exists in lower concentration than in fresh water. Therefore, if there’s seawater on one side of a semipermeable membrane and fresh water on the other, a pressure exists from the fresh water’s tendency to diffuse through the membrane. This is called osmotic pressure.
   c. Remember that water flows from the lower solute concentration to the higher solute concentration.
   d. Equilibrium is reached once enough water has moved to equalize the solute concentration on both sides of the membrane.
   e. Osmosis and osmotic pressure are crucial to many biological processes.

5. Electrically conductive. The salts in seawater act as electrolytes, substances that can conduct electricity when dissolved in water.

6. Decreased heat capacity. It takes less heat to raise the temperature of seawater than to raise fresh water to the same degree.

7. Slowed evaporation. The attraction between ions and water molecules keeps water from evaporating easily.
   a. Seawater will evaporate more slowly than fresh water, all else being equal.

**Guided discussion question(s):** Why are these colligative properties of seawater important?
D. The Principle of Constant Proportions

**What is the principle of constant proportions?**

1. Almost every known, naturally occurring element—and since the development of nuclear explosives, even some non-naturally occurring ones—exists in seawater.
   a. They don’t exist in the same amounts, of course. However, no matter how much the salinity varies, the proportions of several key inorganic elements and compounds do not change.

   **Guided discussion question(s):** Why do you think this is called a principle?
   
   b. This is useful because it means that if you know how much of one element there is, you can determine how much there is of all the others.
   
   c. Only the amount of water, and therefore the salinity, changes.

2. This constant relationship of proportions in seawater is called the principle of constant proportions.
   a. The dissolved salts are called conservative constituents because they do not change proportions.

E. Dissolved Solids in Seawater

**Besides hydrogen and oxygen, what are the most abundant chemicals in seawater?**

Let’s suppose you have one kilogram of seawater with average salinity (35‰). This means that 3.5%, or 35 grams, would be dissolved solids. Based on constant proportions, this would break down to these approximate numbers:

- (Cl⁻) Chloride 18.98 g
- (Na⁺) Sodium 10.56 g
- (SO₄²⁻) Sulfate 2.65 g
- (Mg²⁺) Magnesium 1.28 g
- (HCO₃⁻) Bicarbonate 0.14 g
- (Ca²⁺) Calcium 0.40 g
- (K⁺) Potassium 0.38 g
- Other 0.61 g
The Nature of Water

F. Determining Salinity, Temperature, and Depth

How is the principle of constant proportions used to determine salinity? How do marine scientists determine salinity?

1. You can’t measure salinity by evaporating seawater and measuring what’s left. Nor can you apply heat without causing chemical reactions that would change the results. Some of the salts don’t release all the water molecules adhering to them, and if you try to dry it out with heat, chemicals decompose and react, forming gases and new compounds not found in seawater. So much for that approach.

2. Fortunately, the principle of constant proportions comes to our aid.
   a. If you know how much you have of any one seawater chemical, you can figure out the salinity.
   b. It turns out that chloride accounts for 55.04% of dissolved solids.
   c. Determining a sample’s chlorinity (the total weight of the chloride, bromine, and iodine ions) is relatively easy.
   d. The following formula for determining salinity is based on all the chloride compounds (not just rock salt—sodium chloride).

\[
\text{salinity} \; \% = 1.80655 \times \text{chlorinity} \; \% \\
\]

3. So, using some very basic arithmetic, you can figure out the salinity when you know how much chloride there is in parts per thousand. For example, suppose you have a seawater sample that tests 19.2% chlorinity.

\[
\text{salinity} \; \% = 1.80655 \times 19.2\% \\
\text{salinity} \; \% = 34.68\% \\
\]

Likewise, when you know the salinity you can determine the chlorinity.

\[
34.68\% = 1.80655 \times \text{chlorinity} \; \% \\
34.68\% = 1.80655 \times \text{chlorinity} \; \% \\
1.80655 = 1.80655 \\
19.2\% = \text{chlorinity} \; \% \\
\]

4. Most commonly, salinity is determined with a salinometer, which determines the electrical conductivity of the water.
   a. When calibrated against samples with known conductivity, salinometers are accurate to 0.01%.

5. Today, an important tool to measure the properties of seawater are the Argo floats – an array of approximately 3,000 free-drifting floats. More on the Argo float system and how they work in Chapter 11.
6. Another tool is the conductivity, temperature, and depth (CTD) sensor.
   a. The CTD is a torpedo-shaped instrument that may be deployed by itself, but often is attached to a water-sampling rosette or a submersible.
   b. The CTD’s primary function is to profile temperature and salinity (the two variables that determine density) with depth.
   c. Temperature is usually measured by a thermistor, a semiconductor having resistance that varies rapidly and predictably with temperature.
   d. Conductivity is determined by measuring the current flowing between two platinum electrodes sealed in a tube of non-conducting glass.
   e. Pressure measurements are made by measuring the natural frequency of a quartz crystal.
   f. As the CTD is lowered into the water on an electrical cable, conductivity, temperature, and depth data are transmitted to the ship and fed into computers for analysis by researchers.

7. A less accurate and inexpensive tool to determine salinity is with a refractometer. A description of how this device works is in your textbook – see the sidebar “Measuring Salinity with Light.”

G. Why the Seas Are Salty

Reference the National Science Teachers Association (NSTA) SciLinks Service

Topic: Salt Properties
Go To: www.scilinks.org
Code: LOP2150

1. With constant rain, runoff, erosion, and other natural forces, you may think that oceanic salinity is rising or falling.
   a. However, that doesn’t appear to be the case. Most oceanographers think that salinity is in a steady state and that there’s no sign of oceans becoming more or less salty. The thinking is that the sources of salt removal and addition cancel each other out.

   Where do sea salts come from? Is the ocean getting saltier? Why or why not?

2. But, where do the salts come from in the first place? One source appears to be minerals and chemicals eroding and dissolving into fresh water flowing into the ocean.
a. This means that rivers, runoff, and rain percolating through the ground into the sea bring in salts.
b. However, the salts in seawater differ from the salts delivered by rivers, so there must be other sources.
c. Waves and surf contribute by eroding coastal rock.

3. Hydrothermal vents change seawater by adding some materials while removing others.
   a. Other biological and chemical processes and reactions within the seawater and on the seafloor tend to remove salts.
   b. Scientists think these processes all counterbalance so that the average salinity of seawater remains constant. In this way, the ocean is said to be in chemical equilibrium.

H. Salinity, Temperature and Water Density

**Guided discussion question(s): Why does salinity vary throughout the ocean? Why does salinity vary with depth?**

1. Most of the ocean surface has average salinity, about 35‰ (34.7‰ to be precise).
   a. Waves, tides, and currents mix waters of varying salinity to make them more uniform.
   b. Even so, surface ocean salinity varies with the season and with the weather, particularly with rainfall and evaporation.
   c. Locations with salinity different from the average include primarily bays, semi-enclosed seas, and the mouths of large rivers.

2. Precipitation and evaporation have opposite effects on salinity.
   a. Rainfall decreases salinity by adding fresh water.
   b. Evaporation increases salinity by removing fresh water.
   c. Freshwater input from rivers lowers salinity.
   d. The average salinity is 40‰ at the surface of the Red Sea and 38‰ at the surface of the Mediterranean, because of low freshwater input and high evaporation.
   e. Conversely, abundant river input and low evaporation have resulted in salinities well below the average in the Black and the Baltic Seas, with 18‰ and 8‰, respectively.

3. Surface ocean temperatures vary as well. The most important factor is latitude: water in the equatorial region is warmer than water near the poles.
   a. Surface temperatures also vary with the seasons. The greatest seasonal variation is in the temperate ocean, in the middle latitudes, where seasonal differences in sea surface temperatures are about 10°C (18°F).
How do temperature and salinity affect seawater density?

4. Salinity and temperature also vary with depth.
   a. Density differences cause water to separate into layers. High-density water lies beneath low-density water.
   b. Water’s density is the result of its temperature and salinity characteristics: low temperature and high salinity are features of high-density water. Relatively warm, low-density surface waters are separated from cool, high-density deep waters by the thermocline, the zone in which temperature changes rapidly with depth.
   c. Salinity differences overlap temperature differences and the transition from low-salinity surface waters to high-salinity deep waters is known as the halocline.
   d. The thermocline and halocline together make the pycnocline, the zone in which density increases with increasing depth. Below the pycnocline, temperature and salinity tend to be uniform.

I. Acidity and Alkalinity

Reference the National Science Teachers Association (NSTA) SciLinks Service

Topic: Acids, Bases, Buffers
Go To: www.scilinks.org
Code: LOP2155

Guided discussion question(s): What is pH and how is it measured?

1. In the process of dissolving into water, sodium chloride dissociates and forms ions in solution. When something dissolves in water, some of the water molecules also dissociate and form ions, depending on the solutes.
   a. The water molecules can dissociate into positively charged hydrogen ions and negatively charged hydroxide ions. You can write this as: $\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^-$.

2. The relative concentration of positively charged hydrogen ions or negatively charged hydroxide ions determines the water’s acidity or alkalinity.
   a. Acidity and alkalinity are measured as pH, a scale that represents the balance between the positive hydrogen ions ($\text{H}^+$) and the negative hydroxide ions ($\text{OH}^-$) in a liquid.

3. When a solution has a lot of hydrogen ions, it is considered an acid with a pH value of 0 to less than 7.
The Nature of Water

a. A pH of 0 indicates a very concentrated acid that would burn your skin, whereas a dilute acid has a pH of 4.0 or 5.5. For example, citric acid, which gives lemons their sour taste, is a dilute acid.

b. The pH scale is logarithmic, meaning that every number in the scale is multiplied by a fixed number.

c. In the case of pH, the fixed number is 10, so that each step in the scale represents a tenfold change. Therefore, going from a pH of 6 to a pH of 7, for example, represents a tenfold decrease in acidity.

d. Solutions with lots of hydroxyl ions are considered alkaline, also called basic, solutions.

e. The pH is higher than 7, with anything over 9 considered a concentrated alkaline solution. Sodium hydroxide, for example, has a pH of 14 and is dangerous to touch.

f. Baking soda, by comparison, has a pH of about 8.

4. You can measure pH chemically or electronically.
   a. By exposing certain chemicals or chemically treated paper (litmus strips) to a sample, you can estimate pH by color change.
   b. For more precision, scientists use electronic instruments. These measure the hydrogen ions as potential voltage, which is proportional to the pH.

**What factors affect seawater’s pH? Why does pH change with depth?**

5. Pure water has a pH of 7, which is neutral. Seawater pH typically ranges from 7.8 to 8.3, which is very mildly alkaline.
   a. Freshwater bodies can have a very broad pH range, from highly acidic to highly alkaline.
   b. However, the ocean’s pH remains relatively stable due to buffering. A buffer is a substance that reduces the tendency of a solution to become too acidic or too alkaline.
   c. Seawater is buffered primarily through carbon dioxide content. Carbon dioxide combines with water in several chemical reactions that either free up or release hydrogen ions.
   d. When the water is too basic, the reactions release hydrogen ions, making it more acidic. Alternatively, when the water is acidic, other reactions bind with hydrogen ions, making it more basic.
   e. The carbon cycle is a vital but complex process that tends to keep pH relatively stable.
6. Although seawater pH is relatively stable, it changes with depth. It does this because the amount of carbon dioxide tends to vary with depth.
   a. The upper, sunlit depths, called the photic zone, have the greatest density of photosynthetic organisms. These organisms use the carbon dioxide, making the water slightly less acidic.
   b. Also, surface water is relatively warm, which tends to reduce carbon dioxide in solution. Generally, warm productive water has a pH around 8.5.

7. In the ocean’s middle depths, pH can change slightly. There may be more carbon dioxide present from the respiration of marine animals and other organisms. This makes the water somewhat more acidic with a lower pH.

8. At about 1,000 meters (3,281 feet) depth, there’s less organic activity. This results in a decrease in respiration and, consequently, carbon dioxide, so that mid-level seawater tends to be more alkaline.
   a. At about 3,000 meters (9,843 feet) and deeper, the water becomes more acidic again. This is because the decay of sinking organic material produces carbon dioxide, but there are no photosynthetic organisms to remove it.
   b. The transition between less acidic and more acidic water is known as the calcium compensation depth (CCD). Water below the CCD is acidic enough to dissolve the sinking shells, which are made of calcium carbonate, of dead organisms.
IV. The Organic Chemistry of Water

By the end of this section, students will be able to answer these questions:

1. How do the proportions of organic elements in seawater differ from the proportions of sea salts?
2. What is the biogeochemical cycle?
3. What element is fundamental to all life?
4. What are the roles of carbon in organisms?
5. What are the roles of nitrogen in organisms?
6. Why is phosphorous important to life?
7. What is the role of silicon in marine organisms?
8. What are the roles of iron and other trace metals in marine organisms?

A. Biogeochemical Cycles

How do the proportions of organic elements in seawater differ from the proportions of sea salts?

1. Organic chemistry deals mainly with chemical compounds consisting primarily of carbon and hydrogen.
2. Although the sea salts—the dissolved inorganic solids in seawater—account for the majority of dissolved solids, there are others that are organic or that interact with organisms on a significant scale.
   a. These elements are crucial to life and differ from the sea salts in several ways.
3. One difference is that the principle of constant proportions does not apply to these substances.
   a. These nonconservative constituents have concentrations and proportions that vary independently of salinity owing to biological and geological activity.
   b. For example, some organic material may be in short supply in marine environments with a high biological density. In other areas, substances may be overabundant from pollution or discharge from mineral springs.

What is the biogeochemical cycle?

4. All life depends on material from the nonliving part of the Earth.
   a. The continuous flow of elements and compounds between organisms (biological form) and the Earth (geological form) is called the biogeochemical cycle.
5. Organisms require specific elements and compounds to stay alive.
   a. Aside from gases used in respiration or photosynthesis, those substances required for life are what we call nutrients.
   b. The primary nutrient elements related to seawater chemistry are carbon, nitrogen, phosphorus, silicon, iron, and a few other trace metals.
6. When organisms die, what scavengers do not consume sinks, eventually reaching the bottom at depths below the photic zone.
   a. Bacteria and other microorganisms decompose the organic material as it sinks and on the seafloor.
   b. Decomposition leaves inorganic nutrients.
   c. Upwelling, which is an upward water flow is one force that returns inorganic nutrients to shallow water.
   d. Once in the photic zone, photosynthesis returns the nutrients to the food chain.

7. Not all elements and compounds cycle at the same rate.
   a. Some cycle rapidly, whereas others may be isolated or trapped on the seafloor for long periods.
   b. The biogeochemical cycle of the various nutrients affects the nature of organisms and where they live in the sea.

B. Carbon

Reference the National Science Teachers Association (NSTA) SciLinks Service

Topic: Carbon Cycle
Go To: www.scilinks.org
Code: LOP2160

What element is fundamental to all life?
1. Carbon is the fundamental element of life.
   a. Organisms can form long carbon chains to which other atoms can attach during biosynthesis, so that every organic compound consists of carbon chains.

What are the roles of carbon in organisms?
   b. It is a versatile foundation for a wide range of diverse chemicals. Carbon compounds form the basis for chemical energy and for building tissues.

2. The seas have plenty of carbon in several forms.
   a. Carbon dioxide from the air dissolves into the ocean.
   b. Natural mineral sources, such as carbonate rock, also contribute to the ocean’s carbon as sediments dissolve into the water.
   c. Dissolved organic carbon is formed from organisms’ excretion and from the decomposition of organic material. It is transported in global current patterns.
   d. Most of the organic carbon that finds its way into the deep sea is broken down into inorganic forms by bacteria. This action creates a “biological pump” that tends to concentrate
carbon and other nutrients with depth; this plays a central role in the global carbon cycle.

e. This “pump” transfers carbon from the atmosphere to the deep sea, where it concentrates and remains for centuries. Scientists think this accounts for about 75% of the difference between dissolved inorganic carbon concentrations at the surface and in the deep sea.

3. Carbon compounds are found in air and water and within rocks and minerals. They exist in the air as carbon dioxide, which is a by-product of respiration.

a. Carbon dioxide also enters the atmosphere from volcanic activity and fires, particularly forest fires.

b. Humans increase the amount of carbon dioxide in the atmosphere by burning fossil fuels. Carbon dioxide is found in the fossil fuels because it is absorbed by plants and animals.

c. When the organisms die, the carbon dioxide is buried with them and remains with them as they are transformed into fossil fuels. Burning these fossil fuels then releases the carbon dioxide into the atmosphere.

d. Prior to the Industrial Revolution, the carbon dioxide concentration in the air was an estimated 280 ppm (parts per million). Today it averages about 365 ppm and is increasing rapidly.

e. Carbon dioxide is a greenhouse gas and is a major contributor to the increase in temperatures, known as global warming, seen around the globe.

4. Carbon dioxide must be transformed into other carbon compounds for use by heterotrophs.

a. The movement of carbon between the biosphere and the nonliving world is described by the carbon cycle.

b. In terrestrial and aquatic environments, plants, prokaryotes, algae, and other primary producers with chlorophyll, convert carbon dioxide into carbohydrates through photosynthesis.

c. Photosynthesis is a form of fixation by which an element, such as one found in a gas, is converted, or fixed, into a new compound.

d. This is an important process because many organisms can only utilize key elements essential to life when fixed into an organic molecule.

e. Photosynthesis brings carbon from carbon dioxide into the food chain by converting it into more complex carbon compounds.
C. Nitrogen

Reference the National Science Teachers Association (NSTA) SciLinks Service
Topic: Nitrogen Cycle
Go To: www.scilinks.org
Code: LOP2165

What are the roles of nitrogen in organisms?

1. Nitrogen is another element crucial to life. Organisms require nitrogen for organic compounds such as protein, chlorophyll, and nucleic acids.
   a. Nitrogen makes up about 78% of air and 48% of gases dissolved in seawater.
   b. However, gaseous nitrogen must be converted to a chemically usable form before it can be used by living organisms.
   c. Only bacteria can “fix” nitrogen from the air into other compounds. This happens in the nitrogen cycle, during which gaseous nitrogen is fixed into nitrate (NO$_3^-$), nitrite (NO$_2^-$), and ammonium (NH$_4^+$).

2. In these forms, autotrophs take up the nitrogen and incorporate it into their systems as protein.
   a. The nitrogen passes up the food web through trophic feeding and returns through the cycle after death.
   b. At this point, the nitrogenous compounds break down during decomposition, becoming ammonia.
   c. Plants take up some of the ammonia, and the rest either dissolves into water or remains in the soil.
   d. Microorganisms convert the ammonia into nitrates and nitrites (nitrification).
   e. Nitrates from decomposed material can be buried into sediments on the ocean floor or they can go through denitrification, during which the nitrogen returns to the water column as a gas.

D. Phosphorous and Silicon

Why is phosphorous important to life?

1. Phosphorus is another element important to life because it is used in the ADP/ATP cycle, by which cells convert chemical energy into the energy required for life.
   a. Phosphorus is also part of DNA and other nucleic acids, the molecules that pass genetic information from parent to offspring.
b. Phosphorus also combines with calcium carbonate as the primary component of bones and teeth.

**What is the role of silicon in marine organisms?**

2. In the marine environment, some organisms, including diatoms and radiolarians, similarly use silicon for their shells and skeletons.
   a. Within these organisms, silicon exists as silicon dioxide, commonly called silica.
   b. In addition, most sand is made of silica because it is a common component of rocks and minerals and does not break down easily.
   c. Phosphorus and silicon convert relatively rapidly into phosphate and silica, respectively, for consumption by phytoplankton and bacteria.
   d. When they become part of shells and skeletons, however, the cycle can be considerably longer because they sink into marine sediments. Once in sediment, it takes a long time for these elements to return to the biosphere for further availability to organisms. However, in the sediments they are used by benthic organisms that rely on them for survival.

**E. Iron and Trace Metals**

**What are the roles of iron and other trace metals in marine organisms?**

1. Iron, along with several other trace metals, fits into the definition of a micronutrient.
   a. Micronutrients are essential to organisms in very small amounts.
   b. Organisms use iron for constructing specialized proteins, including hemoglobin and enzymes.
   c. In addition, plants need iron to produce chlorophyll, although iron is not part of the chlorophyll molecule. Other trace metals used in enzymes include manganese, copper, and zinc.

2. Iron is essential to marine life, especially phytoplankton, and is one of the most abundant metals on Earth.
   a. However, it’s not readily available in the sea because it does not dissolve well in seawater.
   b. The small amount that does dissolve readily reacts with other chemicals and tends to bond with particles that sink to the bottom.

3. Scientists have found that a lack of iron limits phytoplankton productivity in some parts of the ocean.
a. Thus, adding iron to seawater on a large scale would trigger a phytoplankton bloom that would draw carbon dioxide from the atmosphere. This could help reduce global warming, which is caused by rising carbon dioxide levels resulting from burning fossil fuels.

4. If this controversial proposal were enacted, it would probably be in the southern hemisphere, which is dominated by ocean.
   a. Land is the source of iron in the ocean, so the southern seas have less iron because there is less land for it to run off of or blow off of as dust.
   b. Levels of other nutrients are high there, and it is sometimes iron that limits phytoplankton populations.

5. Small-scale experiments have shown that this technique is valid. In one 2002 experiment, just over 1 metric ton (2,200 pounds) of iron was added to an area of 15 square kilometers (about 5 square miles).
   a. The scientists studied the amount of particulate organic carbon that sank from the surface and estimated that over an area of 400 square miles (1,036 square kilometers), 1,800 tons (about 4 million) pounds of carbon would have been lost from the ocean surface.
   b. Although this seems like a large number, this carbon flux is small compared to the variation that occurs naturally in this region.

6. Despite these successes, there’s no widespread support for fertilizing the ocean with iron.
   a. First, there are no data to show that the carbon dioxide decline would be permanent.
   b. Second, there would be consequences on local and global ecosystems, but these have not been studied and are hard to estimate.
V. Chemical Factors That Affect Marine Life

By the end of this section, students will be able to answer these questions:
1. How can diffusion and osmosis affect marine organisms?
2. What are passive and active transport?
3. What are osmoregulators and osmoconformers?

A. Diffusion and Osmosis

Reference the National Science Teachers Association (NSTA) SciLinks Service

Topic: Osmosis

Go To: www.scilinks.org

Code: LOP2170

How can diffusion and osmosis affect marine organisms?

1. Seawater can create osmotic pressure and that osmosis is diffusion through a semipermeable cell membrane.
   a. Diffusion is the tendency for a liquid, a gas, or a solute to flow from an area of high concentration to an area of low concentration.
   b. Heat facilitates diffusion by causing molecules to move. High temperatures speed up diffusion by speeding up the molecules.

2. Semipermeable membranes surround all living cells. They allow nutrients in and wastes out. When photosynthesis in a plant cell produces oxygen, the amount of oxygen in the cell rises.

3. Because there’s more oxygen inside the cell than outside, the oxygen diffuses out through the cell membrane.
   a. Likewise, when an animal cell consumes oxygen, there is less oxygen inside the cell than outside. The oxygen diffuses through the cell membrane into the cell.

4. Most cell membranes allow water to move through them – this is called osmosis. This means that when there’s water with different concentrations of solutes on opposite sides of a membrane, water will diffuse to the higher concentration. This has important implications with respect to marine animals.

5. The concentration of water inside an aquatic organism’s cells must be the same as the surrounding water, or water will tend to diffuse in or out of the organism’s cells.
   a. When the same concentration exists inside a cell as outside, the cells are said to be isotonic, and there is no osmotic pressure in either direction.
6. Marine fish cells have the same water concentration as the surrounding seawater and are therefore isotonic.
   a. When you put a marine fish in fresh water, however, the fish’s cells, having a higher concentration of salt than the surrounding fresh water, are then said to be hypertonic.
   b. This means they have a higher salt concentration, and water will diffuse into the cells. The cells would eventually burst from excess water pressure.

7. Suppose you put a freshwater fish in seawater. This reverses the situation.
   a. The fish cells would be hypotonic, meaning they have a lower salt concentration than the surrounding water. Water would diffuse out of the cells, and the fish would die of dehydration.

B. Active Transport, Osmoregulators, and Osmoconformers

**What are passive and active transport?**

1. So far, we’ve been discussing osmosis through a semipermeable cell membrane, which is called passive transport.
   a. Passive transport moves materials in and out of a cell by normal diffusion. The materials move through the cell naturally from areas of high concentration to areas of low concentration.
   b. Active transport is the process of a cell moving materials from low concentration to high concentration. Because active transport goes against the flow of diffusion, it requires energy.

**What are osmoregulators and osmoconformers?**

2. Active transport is important because it is one way marine organisms control the water concentration within their cells.
   a. Marine fish in particular have a regulation process that allows them to use active transport to adjust the water concentration within their cells.
   b. This allows them to adapt to changes in the salinity of the surrounding seawater. Organisms with this ability are called osmoregulators.

3. Although all fish are osmoregulators, they don’t regulate the same way.
   a. Ray-finned fish have an efficient system for maintaining a constant internal salinity, even though their internal salinity is only about one-third that of the surrounding water.
b. To replace water lost by osmosis, they consume a great deal of seawater and excrete only a small amount of urine. They have specialized glands in their gills to eliminate the excess salts taken in with the water.

c. Sharks, on the other hand, adapt by using waste urea and other chemicals to maintain their internal tissue balance with the external salinity. When the external salinity changes, so does their internal salinity to remain isotonic.

d. The urea required to maintain salinity explains why some shark species aren’t suitable food fish—their flesh smells like urine!

4. Many marine organisms, especially invertebrates, cannot control their internal water concentration.
   a. Their internal salinity rises and falls along with the surrounding seawater’s salinity.
   b. These organisms are called osmoconformers. Some osmoconformers can tolerate significant variations in salinity, but others can’t and suffer a great deal of stress.

**Instructional Strategy – Student Self-Study**

**Exploration Through Reading**

Guide students to read and study each major topic of the chapter rather than focus on the entire chapter at one time. Before reading, focus students’ attention on the guided reading questions (green in the student textbook). These are listed here for each major topic.

For each major topic in the chapter assess students’ prior knowledge. Instruct students to construct a concept map, prior to reading, using the list of vocabulary words for each major topic of the chapter. If students need help constructing a concept map, review the directions with them.

As students read about the topic, have them answer the “Study Questions” located in the textbox on the first page of each section. After students read the section have them revise their concept maps. It may be beneficial to use a different colored pen or pencil so that students can see what they have learned from reading and where their misconceptions of the subject matter lie. If you have divided students into study groups they may share their individual concept maps with their group. Study groups may then construct a summary concept page based on the feedback of the other team members.
I. The Water Planet

II. Water’s Unique Properties

Guided Reading Questions

A. The Polar Molecule
   1. What is a polar molecule?

B. The Effects of Hydrogen Bonds
   2. What properties does water have because it is a polar molecule?
   3. Why does ice float? How is this important to the thermal conditions on Earth?
III. The Inorganic Chemistry of Water

A. Solutions and Mixtures in Water
   1. What are two kinds of mixtures? What is a solution?

B. Salts and Salinity
   2. What is salinity? What are the major sea salts?
   3. What are the colligative properties of seawater? Does fresh water have these properties?

C. Colligative Properties of Seawater

D. The Principle of Constant Proportions
   4. What is the principle of constant proportions?

E. Dissolved Solids in Seawater
   5. Besides hydrogen and oxygen, what are the most abundant chemicals in seawater?

F. Determining Salinity, Temperature, and Depth
   6. How is the principle of constant proportions used to determine salinity? How do marine scientists determine salinity?

G. Why the Seas Are Salty
   7. Where do sea salts come from?
   8. Is the ocean getting saltier? Why or why not?

H. Salinity, Temperature and Water Density
   9. How do temperature and salinity affect seawater density?

I. Acidity and Alkalinity
   10. What factors affect seawater’s pH? Why does pH change with depth?

(Concept map on next page)
IV. The Organic Chemistry of Water

A. Biogeochemical Cycles
   1. How do the proportions of organic elements in seawater differ from the proportions of sea salts?
   2. What is the biogeochemical cycle?

B. Carbon
   3. What element is fundamental to all life?
   4. What are the roles of carbon in organisms?

C. Nitrogen
   5. What are the roles of nitrogen in organisms?

D. Phosphorous and Silicon
   6. Why is phosphorous important to life?
   7. What is the role of silicon in marine organisms?

E. Iron and Trace Metals
   8. What are the roles of iron and other trace metals in marine organisms?

(Concept map on next page)
V. Chemical Factors That Affect Marine Life

A. Diffusion and Osmosis
   1. How can diffusion and osmosis affect marine organisms?

B. Active Transport, Osmoregulators, and Osmoconformers
   2. What are passive and active transport?
   3. What are osmoregulators and osmoconformers?

VOCABULARY
- active transport
- diffusion
- hypertonic
- hypotonic
- isotonic
- osmoconformers
- osmoregulators
- osmosis
- osmotic pressure
- passive transport
ENRICHMENT EXPERIENCES

Elaborate (Integration of Other Sciences)

1. The Water Planet (physical science, life science, and Earth and space science).
   - Reference Figure 8-4 – The Cycle of Water.
   - Have students construct their own drawing of the water cycle.

2. Water’s Unique Properties (physical science, and science as inquiry).
   - The following tables may be used to help summarize the important and unique properties of water. These physical properties have important biological significance.
   - Using the textbook and other resources available, have students compare the properties of seawater to those of pure water.

Student Worksheet 1

Comparing Seawater and Freshwater

Using the textbook and other resources available, compare the following properties of seawater to those of pure water.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>AVERAGE SEAWATER</th>
<th>PURE WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>conductor</td>
<td>nonconductor</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>100.6°C (213°F)</td>
<td>100°C (212°F)</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>-1.9°C (28.6°F)</td>
<td>0°C (32°F)</td>
</tr>
<tr>
<td>Density</td>
<td>1.03g/cm³</td>
<td>1.00 g/cm³</td>
</tr>
<tr>
<td>Amount of dissolved salts</td>
<td>35 ‰</td>
<td>None</td>
</tr>
<tr>
<td>Relative osmotic pressure</td>
<td>less</td>
<td>greater</td>
</tr>
<tr>
<td>pH</td>
<td>8.1</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Using the textbook and inquiry activities have students think about each property of water and its comparison to other substances. Ask students to explain why this property is important physically and biologically.
**Student Worksheet 2**

*Significance of the Properties of Water*

Using the textbook and other resources available, think about each property of water and its comparison to other substances. Explain why this property is important physically and biologically.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>COMPARISON TO OTHER SUBSTANCES</th>
<th>SIGNIFICANCE PHYSICAL/BIOLOGICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical states: solid (ice), liquid(water), and gas (water vapor)</td>
<td><em>Water is the only substance that occurs as a solid, liquid, and gas within normal temperatures on Earth.</em></td>
<td><em>Water vapor transfers great amounts of heat from low latitudes to high latitudes.</em>&lt;br&gt; <em>Liquid water acts as a transport medium and facilitates chemical reactions. Organisms are composed mostly of water. Water falls as precipitation and runs off the land, dissolving many minerals.</em>&lt;br&gt; <em>Ice forms at high latitudes and protects the water and life below it from freezing. Ice formation causes more saline water to sink, forming the deep, density-driven currents.</em></td>
</tr>
<tr>
<td>Universal Solvent</td>
<td><em>Water can dissolve more substances than any other liquid.</em></td>
<td><em>This property explains why seawater is salty and why seawater carries dissolved nutrients and oxygen.</em></td>
</tr>
<tr>
<td>Surface Tension</td>
<td><em>Water has the greatest surface tension of all common liquids.</em></td>
<td><em>This property causes water to form drops and a skin-like surface. Neuston can survive on the surface because of surface tension.</em></td>
</tr>
<tr>
<td>Heat Capacity</td>
<td><em>Water has the highest heat capacity of all common liquids. Water can gain or lose more heat than other substances while undergoing an equal temperature change.</em></td>
<td><em>This property is a major factor in moderating Earth’s climate. It explains the narrow temperature ranges near the oceans compared to those inland.</em></td>
</tr>
<tr>
<td>Thermal Expansion</td>
<td><em>As water is cooled, it becomes denser until 4°C (39°F), at which point it expands.</em></td>
<td><em>Ice floats and provides a layer that insulates the water below. If ice sank, the entire water column would freeze.</em></td>
</tr>
</tbody>
</table>

3. The Inorganic Chemistry of Water
   ✓ Reference Sidebar – Data From The Depths
   ✓ In their quest to understand oceans better, oceanographers have used numerous tools. Have students design a timeline indicating the design, development, and historical significance of the tools oceanographers use and have used in the past to measure salinity, temperature, dissolved gases, nutrients, suspended matter, pH, and other characteristics of seawater.
4. The Organic Chemistry of Water (physical science, life science, and Earth and space science).
   ✔ Reference Figure 8-30 – The carbon cycle.
   ✔ Reference Figure 8-31 – The nitrogen cycle.
   ✔ Reference Figure 8-32 – The phosphorus cycle.
   ✔ Have students construct their own drawings of each of these cycles.

5. Chemical Factors That Affect Marine Life (life science, and science and technology)
   ✔ Reference Figure 8-35 - Hypertonic, isotonic, and hypotonic states.
   ✔ Reference Figure 8-36 – Passive and active transport.
   ✔ Reference Figure 8-37 – Osmoregulation.
   ✔ Have students choose a marine organism that is an osmoconformer and one that is an osmoregulator. Using the internet and library resources, discuss the biological adaptations each must make to survive in their physical environment.

Extension (Interdisciplinary Connections)

Marine Science and the Real World Questions

These questions provide students with an opportunity to apply major concepts in the chapter to real world situations. They are located at the end of the chapter.

Activity 1 – Call for Research Proposals on Water Resource Issues

We live on a water planet; yet up to 7 billion people in 60 countries will face water scarcity within the next half century. Demand for fresh water has tripled in the last 50 years and continues to escalate as population growth and economic development increase. While about 70% of the demand is for agriculture, misuse of water supplies, dumping or runoff or effluents into water, and wetlands destruction all cause availability of fresh water to decrease.

Your team has been selected to submit a proposal to a private foundation to solve a water resource issue. The issue may affect an area of the United States or another region of the world.

Teacher Directions:

In teams, have students select an important water resource issue to research and prepare a proposal for solving the issue. Many water resource issues are related to droughts in some areas and flooding in another.
Students will study the issue to determine whether previous solutions have been successful. They will take into account the values of the people involved and recommend solutions based on their research. Finally, students will present their issue and their proposed solutions to the class. The class may rank the solutions and decide on the best proposal to fund.

**Research and Proposal Guidelines:**

1. Proposals should describe the cause of the issue, whether it is a natural and/or human-made occurrence. This should include the rationale for the proposal.

2. Determine whom the issue affects. These are the “stakeholders.” Discuss the cultural, societal, and physical environment of the groups of people involved. These factors influence different stakeholder groups’ values related to the water resource issue.

3. If solutions have been proposed in the past, discuss the successes or weaknesses of these solutions. Discuss your team’s potential solutions to the issues – the proposal.

4. Evaluate each solution, by listing pros and cons for each. You should consider the values, cost, time, available resources, ecological balance, jobs, natural habitats, and historic and cultural perspectives.

5. Each team should rank their solutions based on the pros and cons for each.

6. Prepare a budget for your proposal.

7. Research and discuss possible advocacy groups or partners that may help your team resolve the particular water issue.

8. Prepare a presentation about the water-relate issue and your proposal for the private foundation.

9. Other students will represent the private foundation. As a class, you will choose the proposals to fund.

**Activity 2 – Aquarist Interview**

Have students go to a local pet store to learn about setting up an aquarium. Interview an aquarium expert about the nitrogen cycle and how it applies to setting up an aquarium.
TEACHER’S NOTES: