Focus on the Concepts

This chapter explores the chemicals of life—the ordering of atoms into molecules and the interactions of molecules in shaping and affecting living things. As you study the chapter, focus on the following concepts:

- Living things are made of about 25 chemical elements. Atoms are the smallest particles of an element, and atoms of each element are made of a characteristic number of protons, neutrons, and electrons.

- Arrangement of electrons determines the chemical properties of an atom—how it will bond to other atoms. Sometimes atoms share electrons, forming covalent bonds and making a molecule. Sometimes atoms gain and lose electrons, forming ions, which join via ionic bonds. Atoms of different elements combine in specific arrangements and ratios to form compounds.

- In a chemical reaction, chemical bonds break and reform, rearranging atoms and changing reactants into products. Living things carry out a myriad of chemical reactions, changing matter in numerous ways.

- Two atoms of hydrogen and one of oxygen bond covalently to form a water molecule. Unequal sharing of electrons makes the covalent bonds of a water molecule polar. The polarity of water molecules causes them to link up via weak hydrogen bonds, which give water many of its peculiar and important properties, such as cohesion.

- Water molecules can break apart to form hydrogen (H+) and hydroxide (OH-) ions. Acids are compounds that add hydrogen ions, and bases remove hydrogen ions. The pH scale describes how acidic or basic a solution is.

Review the Concepts

Work through the following exercises to review the concepts in this chapter. For additional review, check out the activities at www.masteringbiology.com. The website offers a pre-test that will help you plan your studies.
Exercise 1 (Modules 2.1–2.2)

Write the chemical symbol for each of the following elements, and state whether it is one of the four elements used by living things in large amounts (L) to make most biological molecules, whether it is used in moderate amounts (M), or whether it is a trace element (T) required in small amounts.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Amount</th>
<th>Element</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1. Magnesium</td>
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<tr>
<td></td>
<td></td>
<td>2. Oxygen</td>
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<tr>
<td></td>
<td></td>
<td>3. Zinc</td>
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<tr>
<td></td>
<td></td>
<td>4. Hydrogen</td>
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<tr>
<td></td>
<td></td>
<td>5. Copper</td>
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<tr>
<td></td>
<td></td>
<td>6. Iodine</td>
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<tr>
<td></td>
<td></td>
<td>7. Carbon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. Calcium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. Phosphorus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10. Nitrogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11. Sodium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12. Iron</td>
</tr>
</tbody>
</table>

Exercise 2 (Modules 2.1–2.2)

A compound is a substance that contains two or more elements in a fixed ratio. Indicate with a checkmark which of the following are elements and which are compounds. (You will have to guess on some!)

<table>
<thead>
<tr>
<th>Element</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Table salt</td>
<td></td>
</tr>
<tr>
<td>2. Calcium</td>
<td></td>
</tr>
<tr>
<td>3. Water</td>
<td></td>
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<tr>
<td>4. Vitamin A</td>
<td></td>
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<tr>
<td>5. Carbon</td>
<td></td>
</tr>
<tr>
<td>6. Sulfur</td>
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<tr>
<td>7. Carbon dioxide (CO₂)</td>
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</tr>
<tr>
<td>8. DNA</td>
<td></td>
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<tr>
<td>9. Iodine</td>
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<tr>
<td>10. Protein</td>
<td></td>
</tr>
</tbody>
</table>
Exercise 3  (Modules 2.3-2.4)

These modules introduce atoms. It is most important to know what the three important subatomic particles are, where they are located in an atom, and that atoms of different elements differ because they contain different numbers of protons. Some atoms not covered in these modules are compared in the following. You can figure out the subatomic particles they contain based on the concepts in the modules. First, fill in the blanks. Then sketch each atom, labeling and coloring protons red, neutrons gray, and electrons blue. (Coloring will help you focus on and remember which is which.)

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>Number of Protons</th>
<th>Number of Neutrons</th>
<th>Number of Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Carbon-12</td>
<td>C</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2. Nitrogen-14</td>
<td></td>
<td>7</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Chlorine-35</td>
<td></td>
<td></td>
<td>35</td>
<td>17</td>
<td></td>
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<tr>
<td>4. Oxygen-16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>5. Oxygen-17</td>
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</tbody>
</table>
Exercise 4 (Modules 2.5–2.8)

Atoms of five elements important to life are diagrammed below. Pay particular attention to their electron shells. Remember that atoms with unfilled outer electron shells participate in chemical reactions that allow them to attain complete outer shells: 2 electrons for a hydrogen atom, 8 electrons for most other elements important to life.

NITROGEN (N)  
Atomic number = 7

CHLORINE (Cl)  
Atomic number = 17

HYDROGEN (H)  
Atomic number = 1

CALCIUM (Ca)  
Atomic number = 20

Oxygen  
Atomic number = 8

1. Using the information and diagrams above, show how nitrogen could form covalent bonds with several hydrogen atoms, forming a molecule of ammonia. What would be the molecular formula for ammonia?

2. Using the information and diagrams just shown, show how oxygen and hydrogen atoms share electrons to form a molecule of water. What is the molecular formula for water? Which atom in a water molecule is the most electronegative? Where does the water molecule carry a slight negative charge? A slight positive charge?
3. Now show how two water molecules might be attracted by a hydrogen bond. How strong are hydrogen bonds? A water molecule can hydrogen bond with how many other water molecules?

4. Given the information and diagrams just shown, show how electrons would be transferred between calcium and chlorine atoms to form calcium and chloride ions, which would then attract each other (via ionic bonds) to form the salt calcium chloride, CaCl₂. (Hint: An atom can gain or lose more than one electron.)

**Exercise 5 (Module 2.9)**

This module introduces chemical reactions, chemical processes in which bonds are made and broken. A common chemical reaction in many cells is one that changes hydrogen peroxide (H₂O₂) into water and oxygen gas:

\[ 2\text{H}_2\text{O}_2 \rightarrow \underline{\text{___}} \text{H}_2\text{O} + \text{O}_2 \]

Hydrogen peroxide is a harmful by-product of many reactions. Cells get rid of it by carrying out the reaction shown, converting it to harmless water and oxygen. What are the reactants in this reaction? What are the products? Label them in the blanks below the equation. Note that the equation for a chemical reaction must be “balanced.” Since atoms cannot be created or destroyed in a chemical reaction—only rearranged—the numbers of atoms on both sides must be equal. In this example, there are four hydrogen atoms in the two hydrogen peroxide molecules on the left. After the reaction occurs, the hydrogen atoms reappear in the water on the right. Similarly, the four oxygen atoms in the hydrogen peroxide molecules on the left reappear in the water and oxygen molecule on the right. How many water molecules must be formed to account for all the atoms in the H₂O₂ molecules? Write the correct number in the small blank in front of H₂O.
Exercise 6 (Modules 2.6–2.13)

Review the properties of water by filling in the blanks in the following story.

When Amy came through the door, she found Liz poised over a glass of water, ready to drop a needle into the glass. Amy asked, "Liz, what are you trying to do? Trying to kill your roommate with a poisoned needle? Or is this another of your 'experiments'?

"We're studying the __________ basis of life in my biology class," Liz replied. "Atoms, molecules, bonds, reactions. I don't get some of the stuff she's teaching us, so I need to do some experiments to figure it out."

Amy scrolled through her text messages and rolled her eyes. "Another experiment. Welcome to Geek-O-Rama."

Liz gently placed the needle on the water surface. "Watch this," she said. The needle rested in a dimple on the surface of the liquid.

"Whoa—How'd you do that?"

"I didn't. The water did. Water molecules have a tendency to stick together, which is called ____________. The water molecules are stuck together so tightly at the surface that they form a film that can support the weight of the needle. Bugs can walk on it. It's called ____________.

"O.K. You got me. At the risk of getting too much information, how do the water molecules do it? What's so special about water?"

Liz explained, "A water molecule is H₂O, right? It is made up of one __________ atom and two __________ atoms. The atoms stay together because they __________ electrons. This holds them together. A shared pair of electrons forms a chemical bond called a __________ bond between each hydrogen atom and the oxygen atom. Now, if the electrons were shared evenly, the bond would be called a __________ covalent bond. But they are not shared evenly. The oxygen tends to 'hog' the electrons away from the hydrogens. It has a greater attraction for electrons; it is more __________ than hydrogen—"

"TMI! TMI! Just tell me what this has to do with floating needles."

"Well, because the oxygen atom attracts the electrons more strongly, the shared electrons are closer to the oxygen than to the hydrogens, giving the oxygen a slight __________ charge. Because the electrons are pulled away from the protons in the nuclei of the hydrogen atoms, the hydrogens are left with slight __________ charges. So the bonding electrons are shared unevenly, producing a __________ covalent bond between each hydrogen atom and the oxygen atom. In fact, the whole water molecule is polar, even though the molecule as a whole is electrically __________."

Amy was getting impatient. "So what does that have to do with surface tension? And what's the biology connection?"

Liz went on, "Well, it is their polarity that causes water molecules to stick together. The __________ charged oxygen of one water molecule is attracted to the __________ charged hydrogens of other water molecules. These special bonds between water molecules are called __________ bonds. These bonds
form a network at the water's surface, creating surface tension strong enough to support
the needle. Each water molecule can connect with \( 17 \) others. Hydrogen
bonds are weak, but important. For example, they are responsible for holding the two
strands of a \( 18 \) molecule together, and for maintaining the shape of
\( 19 \) molecules.

Now Liz was on a roll. "Hydrogen bonds give water some peculiar properties.
For example, water is the only common substance on Earth that naturally exists in all three
states of matter \( 20 \) \( 21 \) \( 22 \). And lots of things will dissolve in water; it is a versatile \( 23 \) Blood
plasma, for example, is an \( 24 \) solution containing many different
\( 25 \) or dissolved substances, such as salt and blood sugar. In fact,
salts are really good at dissolving in water, because the \( 26 \) bonds of salts
interact with the polar water molecules, which pulls the salt crystals apart. And thousands
of different chemical changes, or chemical \( 27 \) are carried out in the
aqueous solution inside living cells."

Amy got up and opened the bathroom door, looked inside, and said, "It's steamy
in there. Are you going to take a bath?"

Liz replied, "No, that's just another experiment. I'm trying to figure out the
difference between heat and temperature."

"Are they different?"

"Yes. \( 28 \) is the total amount of energy resulting from the
movement of molecules in a body of matter, like a bathtub full of water.
\( 29 \) measures the intensity of movement. I compared the amount of heat
in a cup of water at 98°C and a bathtub of water at 45°C. In the \( 30 \) the
intensity of movement of water molecules was greater, but the \( 31 \) held
more heat energy. I knew it did because the bathtub of water added more heat to the room
as it cooled, warming up the room more than the cup of hot water did.

"It doesn't take a genius to figure that out."

"I just wanted to see it for myself. Water has a great capacity to store heat, by the
way. When water is heated, a lot of the energy goes into breaking the \( 32 \) between water molecules before the molecules can move faster. For instance, if you had a
kilogram of water and a kilogram of rock, the same amount of heat would raise the temperature of the water \( 33 \) than the temperature of the rock. This means
water can soak up a lot of heat, and its temperature will go up only a few degrees."

"And when water cools a few degrees, it \( 34 \) a lot of heat."

"Correct. And since animals are mostly water, this helps us control our body temperature. It also stabilizes the temperatures of the ocean and coastal areas. In the summer,
the ocean \( 35 \) heat, and in the winter, it \( 36 \) heat."

Amy's eyes narrowed. "So why do we sweat when we are hot? Wouldn't we
want to hang onto all that good water?"

Liz was ready with an answer. "No, not necessarily. Because of their strong
hydrogen bonds, it takes a lot of heat energy to get a water molecule moving
\( 37 \) enough to \( 38 \), to separate from its neighbors."
This gives water an unusually high cooling possible. The hottest — or fastest moving — water molecules evaporate first, taking a lot of heat energy with them and leaving the cooler — slower — molecules behind. So sweating cools you off on a hot day.”

Amy looked at the clock and said, “Arrgh — It’s 3:30. I told Sara I’d meet her at the ice rink at 3:30. Thanks to the science lesson, I’m gonna be late!”

Liz rambled on. “Ice. Now, ice is very interesting. In ice the water molecules are locked into a crystal, linked by hydrogen bonds, but farther apart than they are in liquid water. This means that ice is dense than liquid water, so it This is important to life, because…”

But Amy was already out the door. Liz had a puzzled expression on her face as she opened the freezer and scooped out a handful of ice cubes. She muttered, “Hmm… I wonder if the water level in a cold drink changes as floating ice melts…”

Exercise 7  (Modules 2.14–2.15)

Practice using the pH scale by giving the approximate pH of each of the following. Some are listed in the modules; others you can estimate from the information given.

1. Tomato juice  7. Concentrated nitric acid (very acidic)
2. Human blood plasma  8. Acid precipitation
3. Vinegar (moderately acidic)  9. Drain cleaner (very basic)
4. Pure water  10. Antacid pills (mildly basic)
5. Cola (moderately acidic)  11. Human urine
6. Household ammonia  12. Gastric juice
Review basic chemical terminology by completing this crossword puzzle.

**Across**
1. A __ is a subatomic particle with no electrical charge.
2. ____ is the energy due to movement of molecules in a body of matter.
3. ____ measures the intensity of heat.
4. Electrons are shared unequally in a ____ covalent bond.
5. ____ contains two or more elements in a fixed ratio.
6. ____ bond is formed when two atoms share electrons.
7. ____ is a positively charged particle from the nucleus of an atom.
8. ____ donates H⁺ ions to solutions.
9. ____ is a liquid containing a uniform mixture of substances.
10. ____ bond forms when two ions of opposite charges attract each other.
11. ____ is the substance dissolved in a solution.
12. Acid ____ is caused by pollutants that combine with water in the air.
13. ____ is anything that occupies space and has mass.
14. ____ donates H⁻ ions to solutions.
15. ____ accepts H⁺ ions and removes them from solution.
16. ____ is the tendency of water molecules to stick together.
17. ____ is the smallest particle of an element.
18. ____ is a subatomic particle that circles an atom’s nucleus.
19. ____ is a charged atom or molecule.
20. ____ is anything that occupies space and has mass.
21. ____ is a positively charged particle from the nucleus of an atom.
22. ____ donates H⁺ ions to solutions.
23. ____ is a liquid containing a uniform mixture of substances.
24. ____ is the tendency of water molecules to stick together.