Biochemical Concepts

Section 4.1
Characteristics of Living Things

No matter how different living things appear, they all have certain characteristics in common.

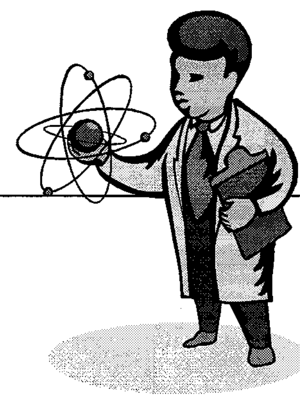
Common Characteristics of ALL Living Things

- All living things are made of one or more cells.
- All living things have a way to reproduce.
- All living things grow and develop.
- All living things share a universal genetic code.
- All living things must obtain material and use the energy from it.
- All living things maintain a fairly stable internal environment.
- All living things are able to respond to changes in their environment.
- As a group, all living things change over time.

All living things are made of various chemicals. In order to understand life, you must understand some basic concepts of chemistry. The chemistry of living organisms is called biochemistry, and it includes the concepts of atomic structure, chemical bonding, and pH, all of which are important to living organisms. In this section we will look at these concepts more closely.

Biochemical Concepts

Section 4.2
The Atom



Pre-View 4.2

- **Matter** – anything that has mass and occupies space
- **Atom** – the smallest portion of an element
- **Nucleus** – the center part of an atom that contains protons and neutrons
- **Proton** – a particle in an atom found in the nucleus that has a positive electrical charge
- **Neutron** – a particle in an atom found in the nucleus that has no electrical charge
- **Electron** – a particle in an atom that has a negative electrical charge

Matter is anything that occupies space and has mass. Everything that you see around you, living and non-living, is made up of matter. Even things you can't see, like air and microscopic organisms, are made up of matter. Atoms, although invisible to the naked eye, make up matter. In fact, the atom is considered the smallest unit of matter. Atoms combine to form substances called compounds. Atoms, compounds, and mixtures of both make up the visible and invisible matter around us. So, let's first take a closer look at atoms.

Atoms

Atoms are the basic building blocks of the universe. An atom is the smallest possible portion of an element. For example, if you continued to split a sample of gold in half, you would eventually get a piece so small that it could not be separated anymore without losing the properties of gold. That "smallest piece" of the element gold would be one *atom* of gold.

Subatomic Particles

Everything is comprised of atoms, but what are atoms themselves composed of? The atom is made up of three basic particles: the proton, the neutron, and the electron. Even smaller particles, called quarks, make up protons and neutrons. As our technology improves, so does our understanding of these "subatomic" particles.

The three subatomic particles (protons, neutrons, electrons) are found in specific locations in the atom. The atom itself is composed of two regions: the nucleus and the electron cloud. The **nucleus**, or center of the atom, is the location of the protons and the neutrons. The *electron cloud* is a region around the nucleus through which fast moving electrons travel. See figure 4-1.

Model of an Atom

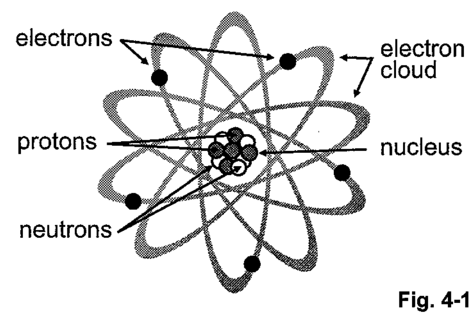


Fig. 4-1

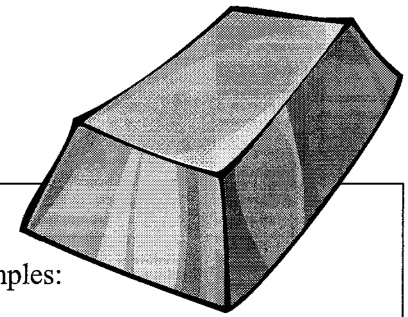
Protons have a positive electric charge while **neutrons**, as the name suggests, are neutral. Since these are the only two particles in the nucleus of the atom, the nucleus as a unit is positively charged.

Electrons are negatively charged particles that move around, or orbit, the nucleus at high speeds. Electrons are the only atomic particle NOT found in the nucleus, so the electron cloud is a negatively charged region.

Most atoms have the same number of electrons in the electron cloud as they have protons in the nucleus. Since each electron has a negative charge and each proton has a positive charge, this equal number of protons and electrons results in a neutral atom. A *neutral atom* has neither a positive nor a negative charge because the charges "cancel out."

Biochemical Concepts

Section 4.3
Elements and the Periodic Table



Pre-View 4.3

- **Element** – substance that cannot be separated into a simpler substance; examples: *carbon, oxygen, gold*
- **Periodic table** – an orderly arrangement of elements based on their atomic numbers
- **Atomic number** – an element's position in the periodic table based on (and equal to) the number of protons it has in its nucleus
- **Isotopes** – atoms of the same element that have different numbers of neutrons in the nucleus
- **Atomic mass** – the mass contained in an element's nucleus, which is equal to the number of protons plus the number of neutrons
- **Electron energy level** – the distance at which electrons travel around the nucleus of an atom

Elements

If all atoms are made up protons, neutrons, and electrons, what makes one atom different from another atom? The answer to that question is the number of protons in the nucleus. The number of protons in the nucleus of an atom determines the type of element. A chemical **element** is a substance that cannot be separated into simpler substances. Common elements are hydrogen, oxygen, iron, and gold. An atom of hydrogen has one proton, an atom of oxygen has 8 protons, an atom of iron has 26 protons, and an atom of gold has 79 protons. Any atom that has eight protons is an oxygen atom.

The Periodic Table

All the different elements, over 100 of them, are arranged in the *periodic table*, which can be found in Appendix A. All periodic tables give the same basic information for each element, but some include more information than others. Most periodic tables include *atomic number*, *chemical symbol*, and *atomic mass*. Periodic tables may also give the element name and the number of electrons in each energy level. These items are labeled in figure 4-2. Review each of these items below.

Atomic Number

The periodic table is organized by atomic number. The atomic number is determined by the number of protons in the element's nucleus. For example, the element carbon has an atomic number of six and therefore has six protons in its nucleus.

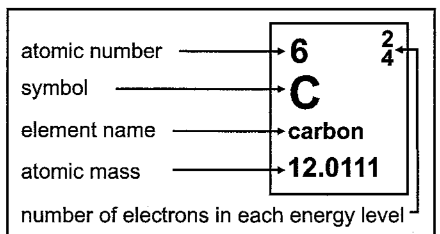


Fig. 4-2

In a neutral atom, the atomic number also represents the number of electrons that surround the nucleus. A neutral atom of carbon has 6 electrons.

The atomic number does NOT directly tell you how many neutrons are in the nucleus. The number of neutrons in any one element may vary. Atoms of the same element that have different numbers of neutrons are called **isotopes**. For example, carbon has one isotope that has 6 neutrons, another isotope that has 7 neutrons, and a third isotope that has 8 neutrons.

Chemical Symbol
Each element has a universal symbol that is usually one or two letters. Many symbols begin with the first letter of the element name like C for carbon, but others do not. (Iron is Fe, silver is Ag, and gold is Au.)

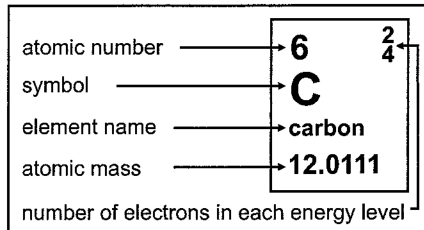


Fig. 4-2

Element Name
Some periodic tables give the name of the element as well as the symbol. Others have only the symbol. It is a good idea to memorize the symbols for the most common elements.

Atomic Mass
Protons and neutrons, which are both found in the nucleus of the atom, have a mass of one *atomic mass unit* (AMU) each. The mass of an electron, however, is thousands of times less. Since the electrons' mass is so very small compared to the mass of the protons and neutrons, the *atomic mass* of an atom comes from adding the number of protons to the number of neutrons. The measurable mass of an atom is ALL found in the nucleus.

*number of **protons** + number of **neutrons** = **atomic mass***

If adding the number of protons and the number of neutrons in an atom gives the atomic mass, then that number should be a whole number and not a decimal number, right? Then why are most atomic masses in the periodic table decimal numbers? The answer to that question is explained by isotopes. The atomic mass given in the periodic table is the *average* mass of all isotopes for that element. For example, consider carbon. The carbon isotope with 6 neutrons has an atomic mass of 12, the isotope with 7 neutrons has an atomic mass of 13, and the isotope with 8 neutrons has an atomic mass of 14. The average mass of all these isotopes as they are found in nature is 12.011.

Electrons in Each Energy Level
Some periodic tables give information about the location of electrons. Electrons orbit the nucleus at different distances, which are called **energy levels.** The first energy level closest to the nucleus holds 2 electrons. The second energy level holds 8 electrons. The third energy level holds 18 electrons, and so on. The electrons nearest to the nucleus are held more tightly than those farther away from the nucleus. Look at carbon in figure 4-2. It has electrons at two energy levels, and the outermost energy level contains four electrons.

Atoms can gain, lose, or share electrons in their outermost energy level with other atoms, and this ability is the basis for chemical reactions.

Biochemical Concepts

Section 4.4
Reactivity

Pre-View 4.4

- **Chemical compound** – a chemical combination of two or more atoms or elements
- **Chemical reaction** – process that occurs when one substance is changed into another
- **Reactivity** – an element's ability or tendency to combine with another element
- **Valence electrons** – the electrons found in the outer energy level of an atom
- **Octet rule** – tendency of atoms to gain, lose, or share electrons with other atoms in order to have 8 electrons in their outer energy level
- **Chemical bond** – the attractive force between atoms that is formed when atoms transfer or share their electrons
- **Electron dot diagram** – a diagram of an atom that represents its valence electrons as dots around the chemical symbol

There are only about 118 elements known to man. Why then do we have the incredible number of substances that exist in our world today? Many of these substances are **compounds**, or chemical combinations of two or more elements. These combinations of elements occur during **chemical reactions**.

When elements react to form compounds, the compounds are abbreviated by using the chemical symbols of elements and subscripts. This combination of symbols and subscripts is called a *chemical formula*. The subscript in a chemical formula indicates how many atoms of each element are present in one molecule of that compound. For example, H_2O is the chemical formula for water. Its chemical formula indicates that one molecule of H_2O has two atoms of H, hydrogen, and one atom of O, oxygen. (If the symbol has no subscript after it, it is understood to be one.)

Why Elements Combine

An element's ability to combine is called **reactivity** and is based on the configuration of electrons in its outer energy level. These outer level electrons are called **valence electrons**. The first two elements on the periodic table, hydrogen and helium, are the only elements with electrons found in just the first energy level. Since this first level can hold only two electrons, these elements are chemically stable with two valence electrons. The other 116 elements on the periodic table become stable when they have eight valence electrons.

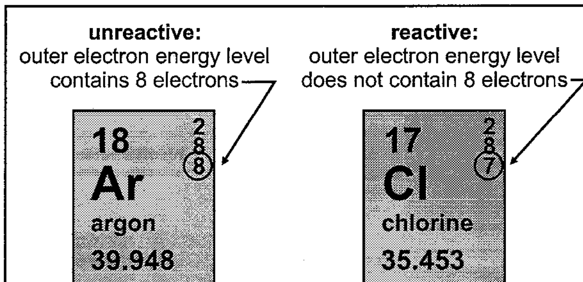


Fig. 4-3

The "inert" or "noble" gas family is the only group that has eight valence electrons on its own. With this stable arrangement of outer electrons, the noble gases do not ordinarily form compounds. They are considered unreactive, which is why they are referred to as "inert." The periodic table entry for argon, a noble gas, is shown in figure 4-3. Notice that the outer energy level has 8 electrons, so it is unreactive. The periodic table entry for chlorine is also shown in figure 4-3. Notice that its outer energy level has 7 electrons. The element of chlorine is reactive.

How then do elements like chlorine reach that same level of stability? These other elements need to *gain, lose,* or *share* electrons to become stable.

Reactivity

Look again at the element of chlorine in figure 4-4. It has 7 valence electrons, and it would like to have 8 to be stable. If it gains one electron, it would be stable. But where would the electron come from? If you guessed that it would come from another element, you are correct. Consider the element of sodium also shown in figure 4-4. Notice that it has 1 valence electron. If it lost that 1 valence electron, it would have 8 electrons in its outer electron energy level. When sodium loses an electron and "gives" it to chlorine, a chemical reaction occurs. A **chemical reaction** changes one or more substances into one or more different substances. Sodium and chlorine combine to form a chemical compound called sodium chloride, also known as table salt. Sodium chloride is a totally different substance than either chlorine or sodium.

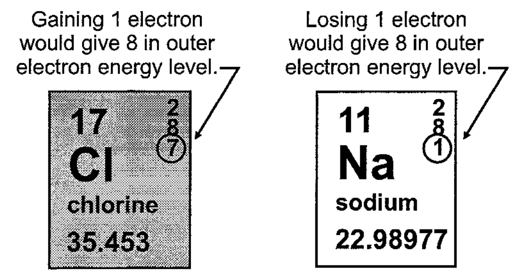


Fig. 4-4

So to become stable, reactive elements will gain, lose, or share electrons with one or more other elements in order to have eight electrons in their outer electron energy level. This principal is known as the **octet rule**. The transfer or sharing of electrons becomes the force, or attraction, that holds the elements together. This attraction is called a **chemical bond**.

> **Note:** Atoms tend to gain or lose the least number of electrons as possible. For example, chlorine will gain one electron, not lose seven, in order to be stable. On the other hand, sodium will lose one electron, not gain seven.

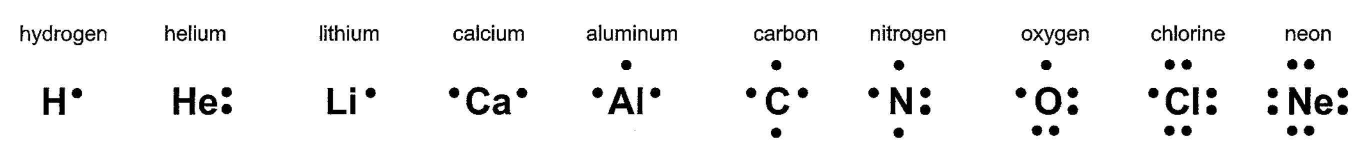
Electron Dot Diagrams

By understanding valence electrons and the octet rule, you can predict how elements will react. To visualize the valence electrons, electron dot diagrams can be drawn. The valence electrons are drawn as dots around the element's symbol. The element's symbol has four sides: top, bottom, left, and right. Each side can have two dots for a total of eight possible dots. In general, the dots are distributed on each side as equally as possible.

Look again at the periodic table. Before you can draw an electron dot diagram, first you must determine the number of valence electrons for an element. Even if you are not given the number of electrons in each electron shell, you can still determine the number of valence electrons in many elements by looking at the group number. Group IA, the first group on the left, has 1 valence electron. Group IIA has 2 valence electrons. Skip over the B Group elements and look at Group IIIA; it has 3 valence electrons. How many valence electrons do you think Group IVA elements have? If you guessed 4, you are correct. The Roman numeral of the A Group elements tells you how many valence electrons each element in that group has. Notice that Group VIIIA has 8 valence electrons (except for helium), and these are the noble gases.

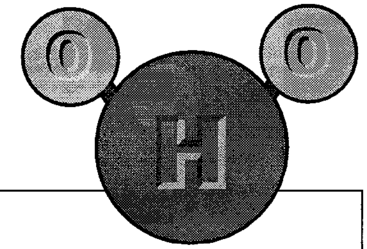
Dot diagrams for common elements are given below. Notice that helium is a little different because both dots are together. Remember that helium has only one electron energy level, and that first level holds only 2 electrons. Therefore, both electrons are shown together.

Electron Dot Diagrams for Common Elements



Biochemical Concepts

Section 4.5
Covalent and Ionic Bonding



Pre-View 4.5

- **Chemical bond** – a connection made between atoms when electrons are attracted, shared, or transferred
- **Ionic bond** – a bond formed when elements *transfer* (gain or lose) electrons
- **Ion** – an electrically charged "atom" that has either gained or lost electrons
- **Covalent bond** – a bond formed when elements *share* electrons
- **Organic compound** – carbon-containing compounds that make up living tissue

Chemical Bonds

A chemical reaction involves the making and breaking of chemical bonds. **Chemical bonds** are formed when outer electrons are attracted, shared, or transferred from one atom to another atom in order to fill the outer electron shells. There are two main types of chemical bonds that you should know.

Ionic Bonds

Ionic bonds are formed when elements *gain* or *lose* electrons as was the case we considered earlier for sodium and chlorine. Review some basics.

Remember that atoms are neutral when they have the same number of positively charged protons in the nucleus as they have negatively charged electrons whirling around the nucleus. The protons and neutrons in the nucleus of the atom are held together by very powerful forces, and under normal circumstances, atoms don't gain or lose protons (positive charges). On the other hand, they *can* gain or lose negatively charged electrons. When an atom gains or loses electrons, it becomes "charged" and is no longer neutral. This charged atom is called an **ion**.

An atom that gains one or more electrons becomes a **negative ion**. It is "negative" because electrons have a negative charge. When an atom has more electrons than protons, its net charge is negative.

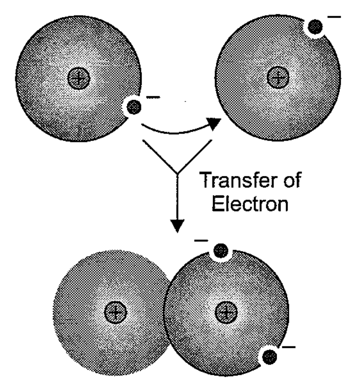


Fig. 4-5 Ionic Bond

An atom that loses one or more electrons becomes a **positive ion**. It has a net positive charge because it has more positively charged protons than negatively charged electrons.

Remember, reactive elements usually want to have 8 electrons in their outer electron energy level. When one element gains electrons and another element loses electrons, an ionic bond is formed as shown in figure 4-5.

Electron Dot Diagram for Sodium Chloride

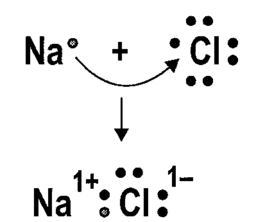


Fig. 4-6

In an electron dot diagram, each dot that is not paired with another dot represents an electron that can be used in a chemical bond. Look again at sodium and chlorine, but this time, look at their electron dot diagrams as seen in figure 4-6. Notice that the sodium has only one unpaired electron. The chlorine has six electrons that are paired and one electron that is not paired. When a sodium atom comes in contact with a chlorine atom, the sodium atom loses its electron and becomes a sodium ion. The chlorine atom gains the electron, fills its outer electron energy level with 8 electrons, and becomes a chloride ion. These ions are bonded together to form the compound sodium chloride, NaCl. The overall net charge of sodium chloride is zero. The positive one charge from the sodium ion is cancelled by the negative one charge from the chloride.

Covalent Bonds

The other type of chemical bond is a **covalent bond**. In covalent bonds, the electrons are not lost or gained; they are shared between two atoms. As a result, the outer electron shells of those two atoms overlap. Covalent bonds form when two or more elements want to fill their outer electron shell, but none of the elements are strong enough to "take" an electron from any of the other elements. Atoms that combine with one or more covalent bonds form a *molecule*. In a covalent bond, the elements do not form ions. The attraction, or bond, between the elements is formed from the shared electrons as shown in figure 4-7.

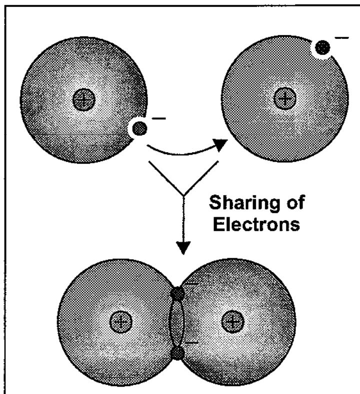


Fig. 4-7 Covalent Bond

Examples of common covalent compounds are H_2O (water), CO_2 (carbon dioxide), and CH_4 (methane). Diatomic molecules are also covalent and are formed when two atoms of the same element combine. Examples are several atmospheric gases: oxygen O_2, nitrogen N_2, hydrogen H_2, chlorine Cl_2, etc. Like ionic bonds, the net charge on the covalent compound is zero.

Electron Dot Diagram for Water

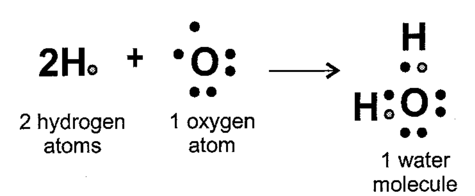


Fig. 4-8

Electron dot diagrams can also be used to show how covalent compounds share electrons. Look at figure 4-8. A molecule of water is formed when an atom of oxygen bonds with two atoms of hydrogen. The oxygen atom has two unbonded valence electrons. Each hydrogen atom has one unbonded valence electron. The hydrogen atoms share their electrons with the oxygen atom so that all atoms have full outer electron energy levels. Remember that hydrogen has only one electron energy level that will hold only two electrons instead of eight.

Organic compounds, which are the compounds that make up living tissues, are also formed with covalent bonds. Organic molecules have one or more carbon atoms, designated with the abbreviation C, combined with hydrogen, H, and sometimes combined with oxygen, O, or nitrogen, N.

Atomic Bonding Summary

Ionic Bonds
- form ions
- gain or lose outer shell electrons
- fill outer electron shell

Covalent Bonds
- form molecules
- share outer shell electrons
- fill outer electron shell

How can you tell which type of bond is present between elements? Here are some hints:

When metals (on the left side of the periodic table) bond with non-metals (on the right side of the periodic table), the result is generally an ionic bond. Common metals found in ionic compounds are Lithium, Li, Sodium, Na, Magnesium, Mg, Potassium, K, and Calcium, Ca.

When non-metals bond together, the bond is generally covalent. Common non-metals include hydrogen, H, carbon, C, nitrogen, N, oxygen, O, and chlorine, Cl.

Examples of Ionic Compounds and Covalent Compounds

Ionic	Covalent
NaCl	H_2O
$CaCl_2$	NH_3
MgF_2	H_2
$Ca_3(PO_4)_2$	CH_4
MgS	$C_6H_{12}O_6$
$CaCO_3$	C_6H_6

Biochemical Concepts

Section 4.6
The Chemistry of Water

Pre-View 4.6

- **Polar molecule** – a molecule that has a partial positive charge on one end and a partial negative charge on the other end
- **Hydrogen bond** – in the case of water molecules, the weak bond that occurs when the hydrogen in one water molecule is attracted to the oxygen in another water molecule
- **Cohesion** – the attraction between molecules of the same kind
- **Surface tension** – the film-like quality on the surface of a liquid that is caused by the attraction of the liquid molecules to themselves
- **Adhesion** – the attraction of one type of molecule to a different type of molecule
- **Capillary action** – the tendency of a liquid to draw up into a narrow tube due to the liquid's properties of cohesion and adhesion
- **Specific heat** – the amount of heat needed to raise the temperature of one gram of a substance one degree Celsius
- **Solvent** – a substance that dissolves another

Water — good old H_2O — is the most abundant compound in most living organisms, but it's made of only two elements, hydrogen and oxygen. What makes it so special?

Water has many qualities that make it important to living things:

- It is transparent, so it lets sunlight pass through it to reach organisms that live underwater.
- It can form positively or negatively charged particles called ions.
- It is a universal solvent that can dissolve many substances easily so that they can be transported by the blood or other body fluids.
- It is found inside our cells and around our cells.
- It exists as a liquid at room temperature, and its frozen state floats and does not sink.

A Covalent Polar Molecule

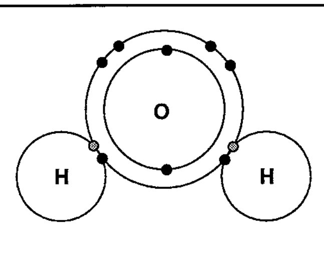


Fig. 4-9
Water Molecule

In a water molecule, covalent bonds hold the oxygen and hydrogen atoms to each other. Remember, a covalent bond is a bond formed by the *sharing* of electrons.

In a water molecule, however, the electrons are not shared equally. Since an oxygen atom has 8 protons (with 8 positive charges) and the two hydrogen atoms have one proton each (one positive charge each), the oxygen atom in a water molecule attracts electrons more strongly than the hydrogen atoms. The oxygen has more positive charge to attract the negative charge of the electrons. The unshared electrons in the oxygen atom push the hydrogen atoms down at an angle, so the water molecule ends up looking like the diagram in figure 4-9.

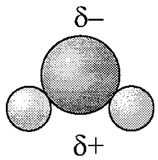


Fig. 4-10
Polarity of Water

This shape is very important and gives water molecules unique properties. The oxygen side of the molecule has a slightly negative charge, and the hydrogen side of the molecule has a slightly positive charge, which makes it a **polar molecule** (figure 4-10). Polar molecules have a partial positive charge on one side and a partial negative charge on the other side. The symbol δ means *partial.*

Hydrogen Bonding

Since water molecules have a positive charge on one side and a negative charge on the other side, the positive side of one water molecule will attract the negative side of another water molecule. This type of attraction is particularly strong in covalent molecules that contain hydrogen, and this attraction can form weak bonds called **hydrogen bonds**.

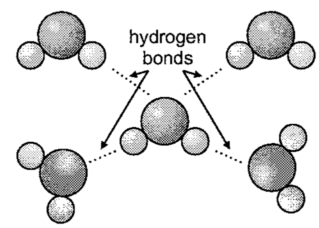


Fig. 4-11
Hydrogen Bonds

Hydrogen bonds form *between* water molecules. These bonds, as seen in figure 4-11, are not the bonds that hold one water molecule together, but they can hold two or more molecules of water together. In fact, one water molecule can form as many as four hydrogen bonds at one time.

Cohesion and Adhesion

Cohesion is the attraction of like molecules to themselves. Since water molecules are strongly attracted to one another and form hydrogen bonds, water is very cohesive. The cohesion of water can especially be observed on its surface as **surface tension**, the property of water that gives a skin-like quality on its surface. Surface tension allows insects like water striders to “skate” across the surface of a pond. Because of this cohesive force, the molecules at the surface of water are pulled in so that drops of water can form like beads on a smooth surface. For example, water molecules tend to clump together into drops rather than evenly wetting a surface.

Adhesion is the attraction between unlike substances. Water’s hydrogen bonds also make it adhesive because water molecules are attracted to other polar molecules. For example, water forms a meniscus when put into container because the water molecules are attracted to the glass. Some of the water molecules closest to the glass will climb up the glass because of adhesion. This action causes the curve you see when measuring water in a graduated cylinder.

The properties of cohesion and adhesion cause water to exhibit **capillary action**. When a tube, or capillary, (such as a straw) is placed into water, the adhesive property of water causes it be attracted to the sides of the tube. The cohesive property of water causes other water molecules to cling to the ones that adhere to the tube. As a result of these two properties, water will climb up the tube against the force of gravity. Plants use capillary action to draw water into their stems.

Water and Temperature

Because of hydrogen bonding, water is a liquid at room temperature. Consider the difference in a molecule like carbon dioxide. Carbon dioxide is also made up of three covalently bonded atoms, but since it is not polar, it is a gas at room temperature and only becomes a liquid at very cold temperatures.

Water’s bonds also allow water to float when it is frozen, which means it is less dense than its liquid state. Most compounds become more dense when they are frozen. If ice sank, frozen bodies of water would not be able to support aquatic life.

Because of hydrogen bonding, water also has a high specific heat. **Specific heat** is the energy needed to raise the temperature of one gram of a substance by one degree Celsius. Compared to other substances, it takes a lot of heat to raise the temperature of water.

The high specific heat of water is an important property of water. Since most living things are made up of a large percentage of water, the water regulates and maintains a fairly constant temperature in living things.

Not only does water regulate the temperature of living organisms, it also helps to regulate the temperature of the earth. Water covers around 70% of the planet, so it absorbs a large amount of energy from the sun without causing large changes in water temperature.

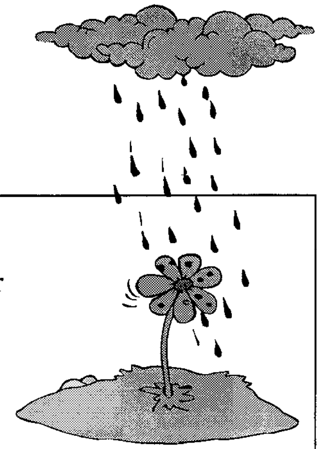
Universal Solvent

Water is called the **universal solvent** because it will dissolve more types of substances than any other solvent. A *solvent* is something that dissolves something else. A substance that is dissolved is called a *solute*. For example, water will dissolve salt. Water is the solvent, and salt is the solute. Together, the mixture is called a *solution*.

Being a good solvent makes water extremely important to life process. Water makes up 60 to 80 percent of all living organisms, and it makes up 65 to 70 percent of the human body in particular. Water is used to transport nutrients in living organisms. Water is critically important to the way our cells function. Many biochemical reactions that occur in the cell need water. Plants use certain minerals and nutrients from the soil only once they are dissolved in water and transported into the roots. It's easy to see why water is so essential to life.

Biochemical Concepts

Section 4.7
Ions and pH



Pre-View 4.7

- **Ion** – an atom or molecule that has gained or lost electrons so that it has a positive or negative charge
- **Biological process** – any process that occurs in a living organism, such as muscle movement in animals or photosynthesis in plants
- **pH** – a measure of the acidity or alkalinity of a substance
- **Acid** – a solution with more hydrogen ions than hydroxide ions; having a pH less than 7
- **Base** – a solution with more hydroxide ions than hydrogen ions; having a pH greater than 7
- **Buffer** – a substance that prevents the pH of a solution from changing even if a small amount of an acid or a base is added

Ions

Ionic bonds are bonds between atoms that have gained or lost electrons. Table salt, NaCl, has an ionic bond between one atom of sodium, Na, and one atom of chlorine, Cl. What happens when you stir salt into water? The salt disappears, or dissolves.

Ionic compounds, like NaCl, dissolve into water because the water breaks apart the ionic bond so that the compound is separated into its ions. Remember, **ions** are atoms or molecules that have an electrical charge because they have either gained or lost electrons. Salt that is dissolved into water separates into sodium ions, Na^+, and chloride ions, Cl^-.

How does water have this ability to break ionic bonds? See figure 4-12 below. Remember that water is a polar molecule with a partial positive side and a partial negative side. The positively charged hydrogens in the water molecule attract the negatively charged chloride ion. The negatively charged oxygen in the water molecule attracts the positive sodium ion. These attractions are strong enough to break the ionic bond and to separate a particle of salt into its ions.

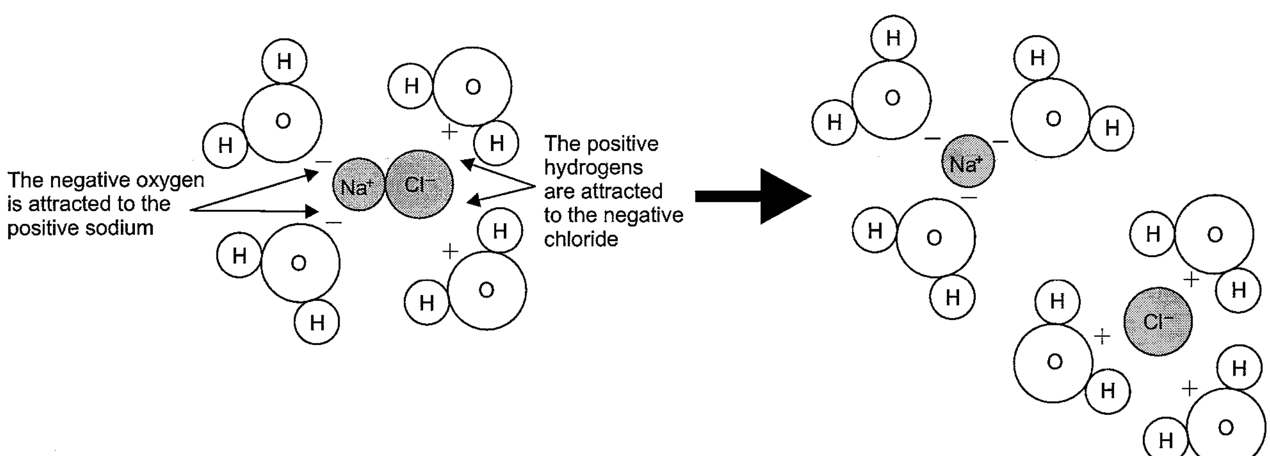


Fig. 4-12
Water molecules surround a particle of salt and pull apart the ionic bond

Ions in Living Organisms

Ions are very important in **biological processes**, which are the processes that occurs in a living organism. Since living organisms are made up of a large percentage of water, the water carries important ions to all the tissues of the organism. You will see how ions play a role in biological processes throughout this book, but for now, here's a quick summary that shows some of the ways ions are important in living organisms.

Importance of Ions in Biological Processes

Within Cells:

- In cells, sodium, potassium, calcium and other ions play an important role in the cells of living organisms, particularly in the role of cell membranes.
- Ions are charged particles, but overall, a cell must be electrically neutral. The charge of positive ions must be equal to the charge of negative ions within each cell. To maintain neutrality, a cell often uses potassium (K^+) if positive ions are needed or hydrogen phosphate (HPO_4^{2-}) if negative ions are needed.
- Ions are vital for electron transfer, a process in which electrons are moved from one place to another and a process that is essential for many types of chemical reactions that occur inside cells. Enzymes that play a role in some of these reactions often contain ions as well.

Within the Body:

- The fluid outside of cells carries all kinds of ions, but overall, this fluid must also be electrically neutral (have an overall charge of zero). The body often uses sodium (Na^+) and chloride (Cl^-) to keep fluids electrically neutral.
- The calcium ion (Ca^{2+}) is a major component of bones and teeth. It has other important functions as well, such as helping blood to clot, allowing muscles to move, and controlling heartbeat.
- Magnesium (Mg^{2+}) is another important ion. Magnesium is involved in the action of nerves and muscles and is necessary for the activity of certain enzymes. It is also present in bones and teeth along with Ca^{2+}.
- The wrong amount of ions can cause diseases. Anemia can result from not enough iron, Fe^{2+}. Too much table salt (NaCl) can cause water retention (edema) and high blood pressure in some people.

pH

Water not only dissolves and transports ions from ionic compounds, but it also can form ions from its own components. A molecule of water has a neutral charge, but the molecule can split into a positively charged hydrogen ion (H^+) and a negatively charged hydroxide (OH^-) ion.

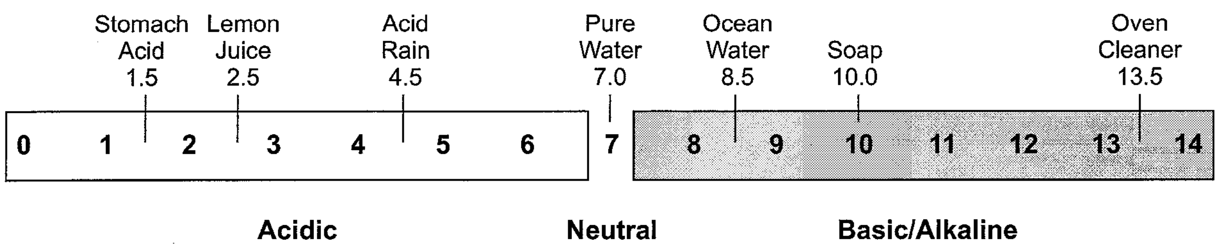
The pH scale is a measure of the concentration of H^+ ions in a solution. The more H^+ ions a solution has, the lower the pH of that solution is. The pH scale is normally shown as going from 0 to 14, with 7 being neutral. Pure water has a pH of 7; it is neutral. Any solution with a pH lower than 7 is **acidic** and has a higher concentration of H^+ ions than OH^- ions. Any solution with a pH higher than 7 is **alkaline** or **basic** and has fewer H^+ ions than OH^- ions. Your body is made for each system to work best within certain pH ranges.

Section 4.7, continued
Ions and pH

Acids are compounds that form H^+ ions in solution. These hydrogen ions attach to other water molecules to form hydronium ions, H_3O^+. Several examples of acids and their pHs are given in the diagram below.

Acid rain is a fairly weak acid with a pH of about 4.5, but it can cause environmental damage. What is acid rain and how is it produced? The burning of fossil fuels causes sulfur dioxide gas and nitrogen oxide gas to be released into the atmosphere. These gases react with water in the atmosphere to form sulfuric acid and nitric acid. The water that precipitates from the air in the form of rain, snow, fog, etc., is now acidic. Acid rain can leach minerals from the soil that are important for plant growth. Acid rain can also lower the pH of lakes and result in the death of aquatic animals.

Bases are compounds that produce OH^- ions in solution. Ocean water is a little basic with a pH of about 8.5. Soap has a pH of 10, and oven cleaner is very basic — its pH is 13.5. Your blood has a pH of 7.4 — slightly basic. When you exercise, your body produces more carbon dioxide (CO_2) than it normally does. When carbon dioxide dissolves, it forms carbonic acid, H_2CO_3, so a rise in CO_2 levels can cause the pH of the blood to drop. If it gets too low, a signal is sent to your brain that causes you to breathe deeper and faster to help get rid of the extra CO_2. Eventually the pH of your blood goes back to normal, and you start breathing normally again.



Just so that you know, most solutions will measure a pH between 0 and 14, but there are exceptions to nearly every rule! Very concentrated acids can measure a negative pH, and very concentrated bases can measure a pH above 14.

Strong Acids and Strong Bases

The terms "strong acid" and "strong base" do not necessarily correspond to the pH of a solution. It is the concentration of H^+ ions and OH^- ions that determines the pH.

The definition of a strong acid is one that completely ionizes in water. For example, hydrochloric acid, HCl, is a strong acid because when it dissolves in water, it forms H^+ ions and Cl^- ions. On the other hand, acetic acid, HC_2HO_2, is a weak acid because it only partially ionizes in water. It forms some H^+ ions and some $C_2HO_2^-$ ions, but some of it will remain as HC_2HO_2 in the solution without separating into ions. Will a strong acid have a lower pH that a weak acid? Only if the concentration of H^+ ions is greater in the strong acid.

A strong base also completely ionizes in water. Sodium hydroxide, NaOH is a strong base that forms Na^+ and OH^- ions when dissolved. Ammonium hydroxide, NH_4OH, is a weak base because some of it will break apart into NH_4^+ and OH^- ions, but the rest of it will remain together as NH_4OH.

Neutralizing Acids and Bases

When an acid comes into contact with a base, both substances are neutralized. The H^+ ions from the acid will combine with the OH^- ions in the base to form water molecules. Having an equal number of H^+ ions and OH^- ions results in a neutral pH of 7. What happens when vinegar with a pH of 2.4 is mixed with baking soda having a pH of 8.4? A chemical reaction occurs, and part of that reaction converts equal numbers of H^+ ions and OH^- ions into molecules of water. The bubbling from the reaction is carbon dioxide also being formed. If the number of H^+ ions and OH^- ions is unequal, the resulting solution will still be either acidic or basic depending on which unreacted ions are still in solution.

pH in Living Organisms

Living organisms rely on many complex chemical reactions to live. Each type of chemical reaction will occur only within a narrow range of pH. For example, the acid that your stomach produces has a pH of around 1.5. That sounds really strong, but your food would not digest properly if your stomach didn't produce that acid. Your stomach makes a special type of protein called an enzyme that helps break down food. Each type of enzyme needs a certain pH, or it will not work. If your stomach stopped producing acid, the enzymes could not do their job. Your food wouldn't be broken down, and you could not get all the nutrients from it.

Plants also have pH preferences, and most grow best in soils that are acidic. If soil pH is too high, nutrients in the soil are less available. Remember, plants get most of their required nutrients from the soil, and the nutrients must be dissolved in the water surrounding the soil before they can be transported into the plant usually through its roots. Gardeners will often adjust the pH of soil before planting. For example, if the pH of soil is too low, lime can be added to increase the pH. If the pH of soil is too high, peat moss or sulfur can be added to lower it.

In complex organisms like human beings, different pHs may be needed for different areas or organs of the body. To keep the pH of an area (or organ) fairly constant, living organisms use buffers. **Buffers** are compounds that prevent a change in pH even when a small amount of additional acid or base is added. For example, a bicarbonate buffer system is used in blood to keep the pH of blood from changing. If a living organism doesn't have the ability to keep pH fairly constant, it cannot survive.