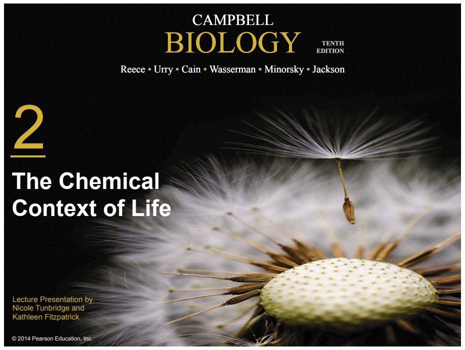


A Chemical Connection to Biology

- Biology is the study of life
- Living organisms and their environments are subject to basic laws of physics and chemistry
- One example is the use of formic acid by ants to protect themselves against predators and microbial parasites

Figure 2.1

Figure 2.1a

Concept 2.1: Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of **matter**
- Matter is anything that takes up space and has mass

Elements and Compounds

- Matter is made up of elements
- An **element** is a substance that cannot be broken down to other substances by chemical reactions
- A **compound** is a substance consisting of two or more elements in a fixed ratio
- A compound has characteristics different from those of its elements

Figure 2.2

Sodium Chlorine Sodium chloride

Figure 2.2a

Sodium

Figure 2.2b

Chlorine

Figure 2.2c

Sodium chloride

The Elements of Life

- About 20–25% of the 92 elements are essential to life **(essential elements)**
- Carbon, hydrogen, oxygen, and nitrogen make up 96% of living matter
- Most of the remaining 4% consists of calcium, phosphorus, potassium, and sulfur
- **Trace elements** are those required by an organism in only minute quantities

Table 2.1

Table 2.1 Elements in the Human Body

Element	Symbol	Percentage of Body Mass (including water)	
Oxygen	O	65.0%	96.3%
Carbon	C	18.5%	
Hydrogen	H	9.5%	
Nitrogen	N	3.3%	
Calcium	Ca	1.5%	3.7%
Phosphorus	P	1.0%	
Potassium	K	0.4%	
Sulfur	S	0.3%	
Sodium	Na	0.2%	
Chlorine	Cl	0.2%	
Magnesium	Mg	0.1%	

Trace elements (less than 0.01% of mass): Boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), zinc (Zn)

Case Study: Evolution of Tolerance to Toxic Elements

- Some elements can be toxic, for example, arsenic
- Some species can become adapted to environments containing toxic elements
  - For example, some plant communities are adapted to serpentine

Figure 2.3

Figure 2.3a

Figure 2.3b

Figure 2.3c

Concept 2.2: An element's properties depend on the structure of its atoms

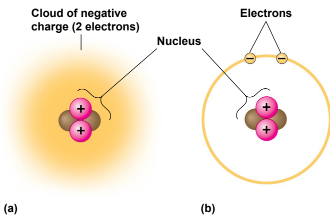
- Each element consists of unique atoms
- An **atom** is the smallest unit of matter that still retains the properties of an element

Subatomic Particles

- Atoms are composed of subatomic particles
- Relevant subatomic particles include
  - **Neutrons** (no electrical charge)
  - **Protons** (positive charge)
  - **Electrons** (negative charge)

- Neutrons and protons form the **atomic nucleus**
- Electrons form a cloud around the nucleus
- Neutron mass and proton mass are almost identical and are measured in **daltons**

Figure 2.4



Atomic Number and Atomic Mass

- Atoms of the various elements differ in number of subatomic particles
- An element's **atomic number** is the number of protons in its nucleus
- An element's **mass number** is the sum of protons plus neutrons in the nucleus
- **Atomic mass**, the atom's total mass, can be approximated by the mass number

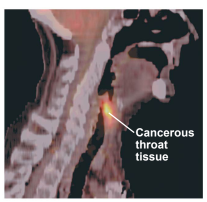
Isotopes

- All atoms of an element have the same number of protons but may differ in number of neutrons
- **Isotopes** are two atoms of an element that differ in number of neutrons
- **Radioactive isotopes** decay spontaneously, giving off particles and energy

Radioactive Tracers

- Radioactive isotopes are often used as diagnostic tools in medicine
- Radioactive tracers can be used to track atoms through metabolism
- They can also be used in combination with sophisticated imaging instruments

Figure 2.5



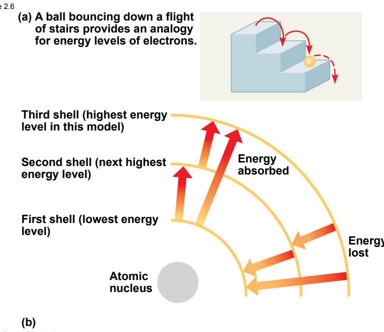
Radiometric Dating

- A "parent" isotope decays into its "daughter" isotope at a fixed rate, expressed as the **half-life**
- In **radiometric dating**, scientists measure the ratio of different isotopes and calculate how many half-lives have passed since the fossil or rock was formed
- Half-life values vary from seconds or days to billions of years

The Energy Levels of Electrons

- **Energy** is the capacity to cause change
- **Potential energy** is the energy that matter has because of its location or structure
- The electrons of an atom differ in their amounts of potential energy
- An electron's state of potential energy is called its energy level, or **electron shell**

Figure 2.6



Electron Distribution and Chemical Properties

- The chemical behavior of an atom is determined by the distribution of electrons in electron shells
- The periodic table of the elements shows the electron distribution for each element

Figure 2.7

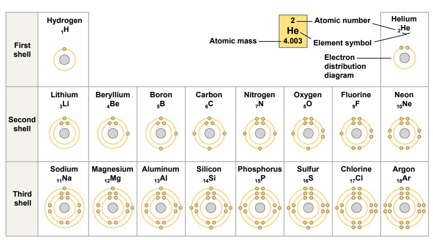


Figure 2.7a

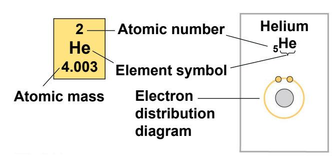


Figure 2.7b

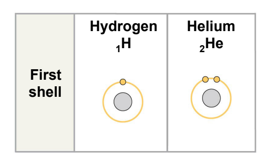


Figure 2.7c

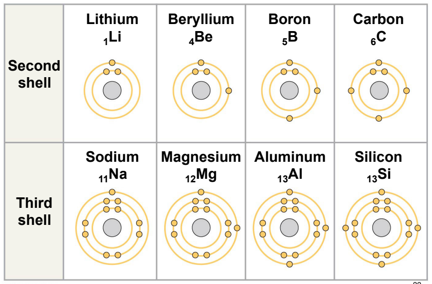
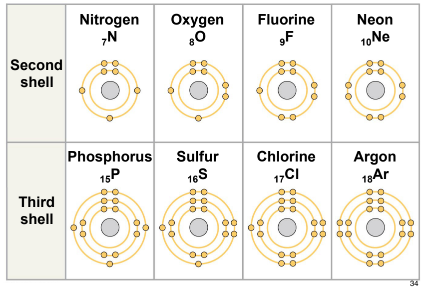


Figure 2.7d



- **Valence electrons** are those in the outermost shell, or **valence shell**
- The chemical behavior of an atom is mostly determined by the valence electrons
- Elements with a full valence shell are chemically inert

Electron Orbitals

- An **orbital** is the three-dimensional space where an electron is found 90% of the time
- Each electron shell consists of a specific number of orbitals

Figure 2.8

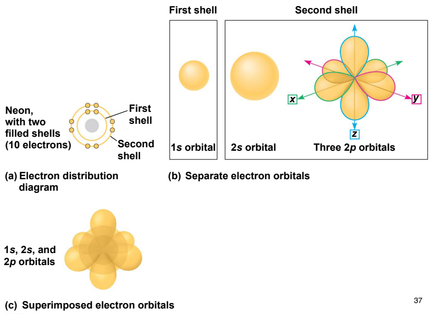


Figure 2.8a

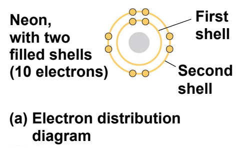


Figure 2.8b

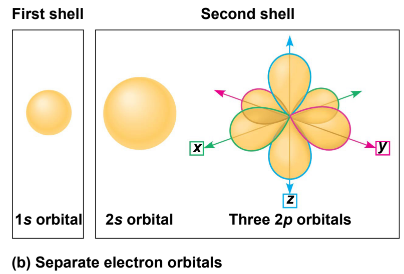
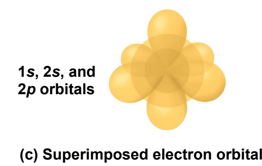


Figure 2.8c



Concept 2.3: The formation and function of molecules depend on chemical bonding between atoms

- Atoms with incomplete valence shells can share or transfer valence electrons with certain other atoms
- These interactions usually result in atoms staying close together, held by attractions called **chemical bonds**

Covalent Bonds

- A **covalent bond** is the sharing of a pair of valence electrons by two atoms
- In a covalent bond, the shared electrons count as part of each atom's valence shell

Figure 2.9-1

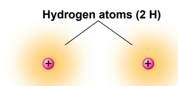


Figure 2.9-2

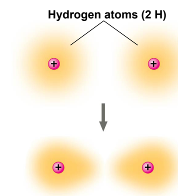
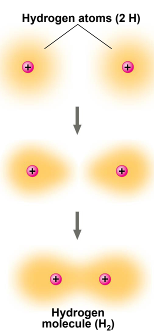


Figure 2.9-3



- A **molecule** consists of two or more atoms held together by covalent bonds
- A single covalent bond, or **single bond**, is the sharing of one pair of valence electrons
- A double covalent bond, or **double bond**, is the sharing of two pairs of valence electrons

- The notation used to represent atoms and bonding is called a **structural formula**
  - For example, H—H
- This can be abbreviated further with a **molecular formula**
  - For example, H_2

Figure 2.10

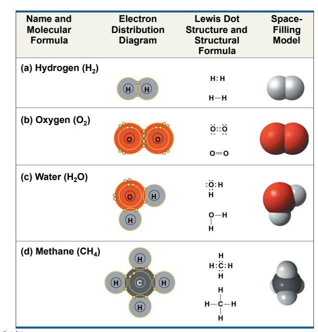


Figure 2.10a

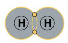
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(a) Hydrogen (H_2)		H:H H—H	

Figure 2.10b

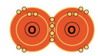
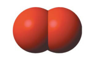
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(b) Oxygen (O_2)		Ö::Ö O═O	

Figure 2.10c

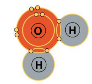
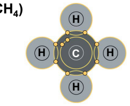
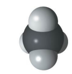
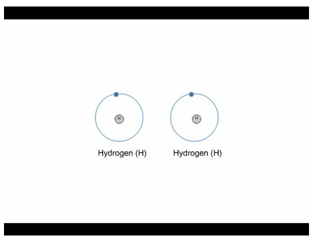
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(c) Water (H_2O)		:Ö:H H O—H | H	

Figure 2.10d

Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(d) Methane (CH_4)		H H:C:H H H | H—C—H | H	

Animation: Covalent Bonds

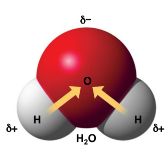


- Covalent bonds can form between atoms of the same element or atoms of different elements
- A compound is a combination of two or more different elements
- Bonding capacity is called the atom's **valence**

- Atoms in a molecule attract electrons to varying degrees
- **Electronegativity** is an atom's attraction for the electrons in a covalent bond
- The more electronegative an atom, the more strongly it pulls shared electrons toward itself

- In a **nonpolar covalent bond**, the atoms share the electron equally
- In a **polar covalent bond**, one atom is more electronegative, and the atoms do not share the electron equally
- Unequal sharing of electrons causes a partial positive or negative charge for each atom or molecule

Figure 2.11



Ionic Bonds

- Atoms sometimes strip electrons from their bonding partners
- An example is the transfer of an electron from sodium to chlorine
- After the transfer of an electron, both atoms have charges
- A charged atom (or molecule) is called an **ion**

Figure 2.12-1

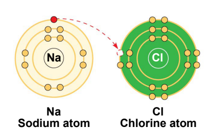
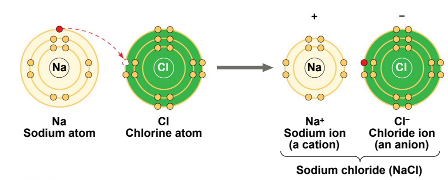
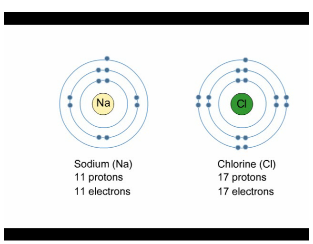


Figure 2.12-2



Animation: Ionic Bonds



- A **cation** is a positively charged ion
- An **anion** is a negatively charged ion
- An **ionic bond** is an attraction between an anion and a cation

- Compounds formed by ionic bonds are called **ionic compounds**, or **salts**
- Salts, such as sodium chloride (table salt), are often found in nature as crystals

Figure 2.13

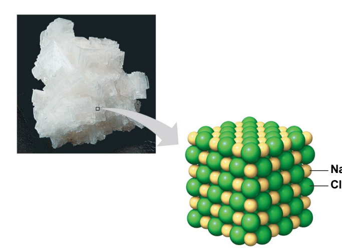


Figure 2.13a

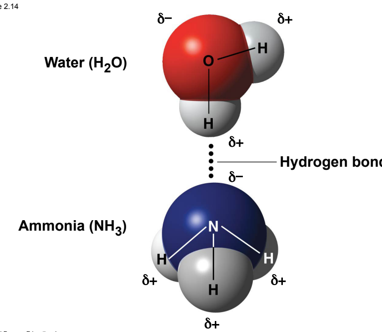
Weak Chemical Bonds

- Most of the strongest bonds in organisms are covalent bonds that form a cell’s molecules
- Weak chemical bonds are also indispensable
- Many large biological molecules are held in their functional form by weak bonds
- The reversibility of weak bonds can be an advantage

Hydrogen Bonds

- A **hydrogen bond** forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms

Figure 2.14



Van der Waals Interactions

- If electrons are distributed asymmetrically in molecules or atoms, they may accumulate by chance in one part of a molecule
- **Van der Waals interactions** are attractions between molecules that are close together as a result of these charges

- Collectively, such interactions can be strong, as between molecules of a gecko’s toe hairs and a wall surface

Figure 2.UN02

Molecular Shape and Function

- A molecule’s shape is usually very important to its function
- A molecule’s shape is determined by the positions of its atoms’ orbitals
- In a covalent bond, the *s* and *p* orbitals may hybridize, creating specific molecular shapes

Figure 2.15

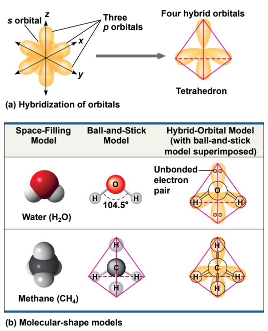
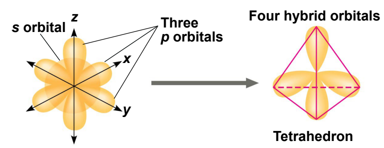
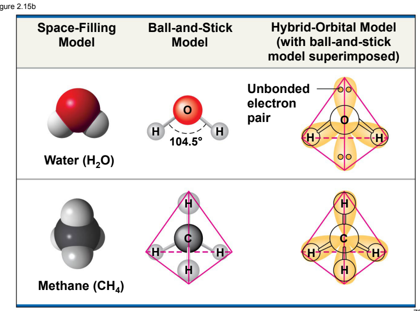


Figure 2.15a



(a) Hybridization of orbitals

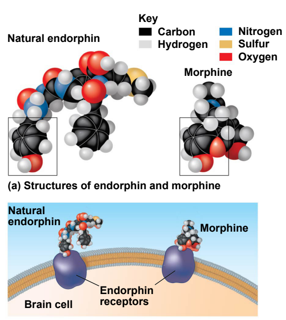
Figure 2.15b



(b) Molecular-shape models

- Molecular shape is crucial in biology because it determines how biological molecules specifically recognize and respond to one another
- Opiates, such as morphine, and naturally produced endorphins have similar effects because their shapes are similar and they bind the same receptors in the brain

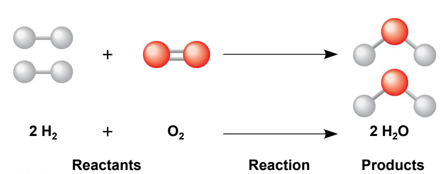
Figure 2.16



Concept 2.4: Chemical reactions make and break chemical bonds

- **Chemical reactions** are the making and breaking of chemical bonds
- The starting molecules of a chemical reaction are called **reactants**
- The final molecules of a chemical reaction are called **products**

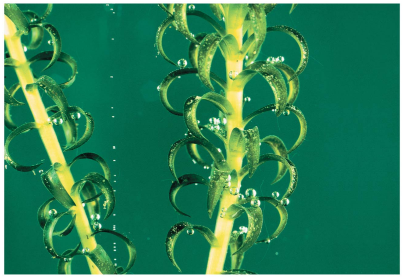
Figure 2.UN03



- Photosynthesis is an important chemical reaction
- Sunlight powers the conversion of carbon dioxide and water to glucose and oxygen

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Figure 2.17



- All chemical reactions are reversible: products of the forward reaction become reactants for the reverse reaction
- **Chemical equilibrium** is reached when the forward and reverse reactions occur at the same rate
- At equilibrium the relative concentrations of reactants and products do not change

Figure 2.UN01a

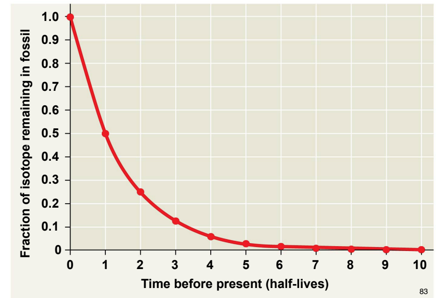


Figure 2.UN01b

Neanderthal fossils

Figure 2.UN04

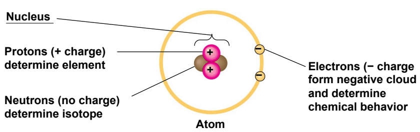


Figure 2.UN05

Figure 2.UN06

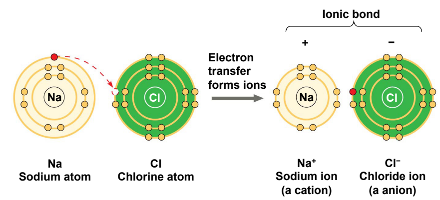


Figure 2.UN07

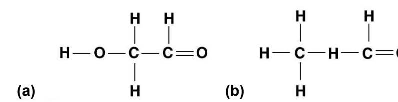


Figure 2.UN08

Figure 2.UN09