

ELEVENTH EDITION

CAMPBELL

# BIOLOGY

URRY • CAIN • WASSERMAN  
MINORSKY • REECE



## Chapter 2

# The Chemical Context of Life

Lecture Presentations by  
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# A Chemical Connection to Biology

- Biology is the study of life
- 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



# 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



**Na**  
**Sodium**

+



+

**Cl**  
**Chlorine**

→



→

**NaCl**  
**Sodium chloride**

# The Elements of Life

- About 20–25% of the 92 natural elements are required for 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 required by an organism in only minute quantities

**Table 2.1** Elements in the Human Body

| Element  | Symbol | Percentage of Body Mass<br>(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
- 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



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

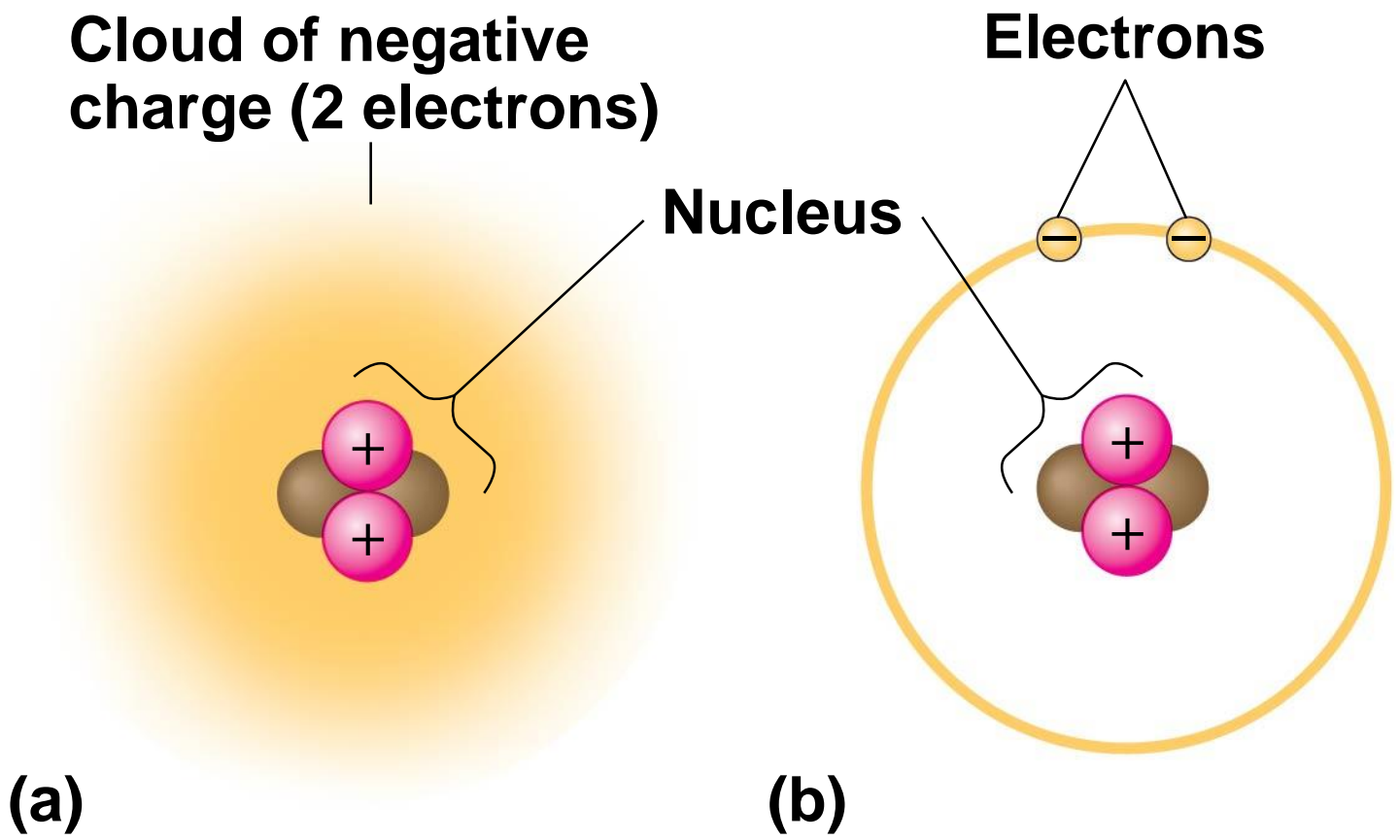
- Each element consists of unique atoms
- An **atom** is the smallest unit of matter that still retains the properties of an element

# 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” of negative charge 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



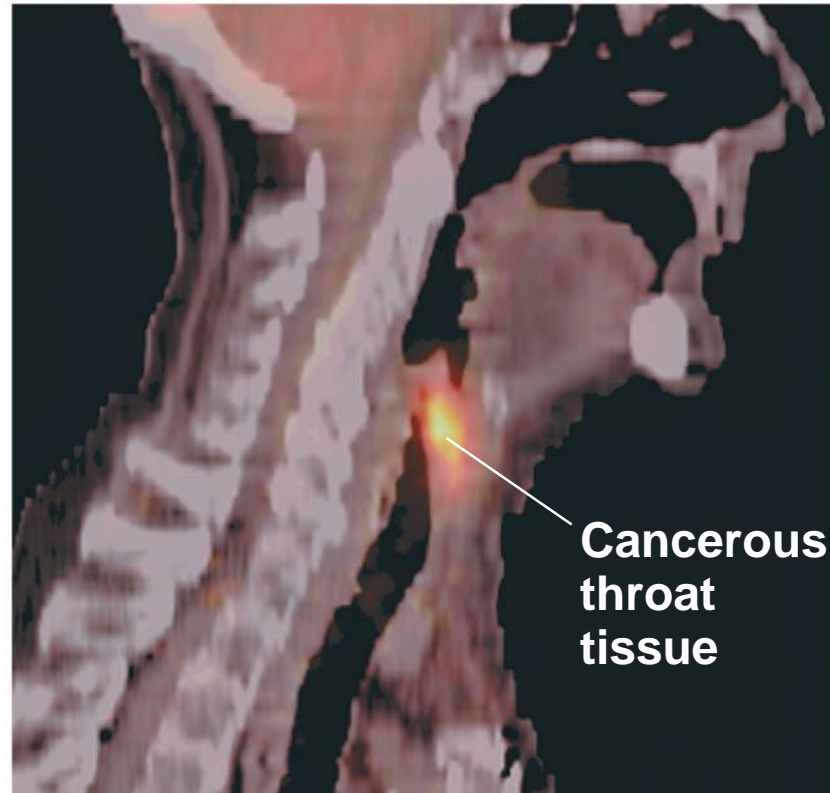
# Isotopes

- 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



**Cancerous  
throat  
tissue**

# ***Radiometric Dating***

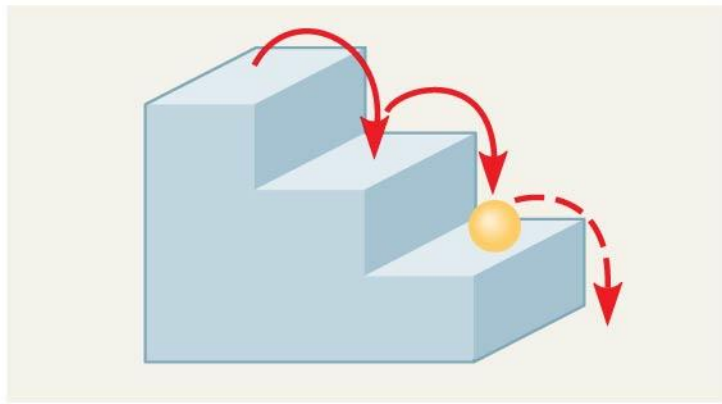
- A “parent” isotope decays into its “daughter” isotope at a fixed rate, expressed as the **half-life**
- In **radiometric dating**, scientists measure the ratio of different isotopes and calculate how many half-lives have passed since the fossil or rock was formed
- Half-life values vary from seconds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

(a) A ball bouncing down a flight of stairs can come to rest only on each step, not between steps.

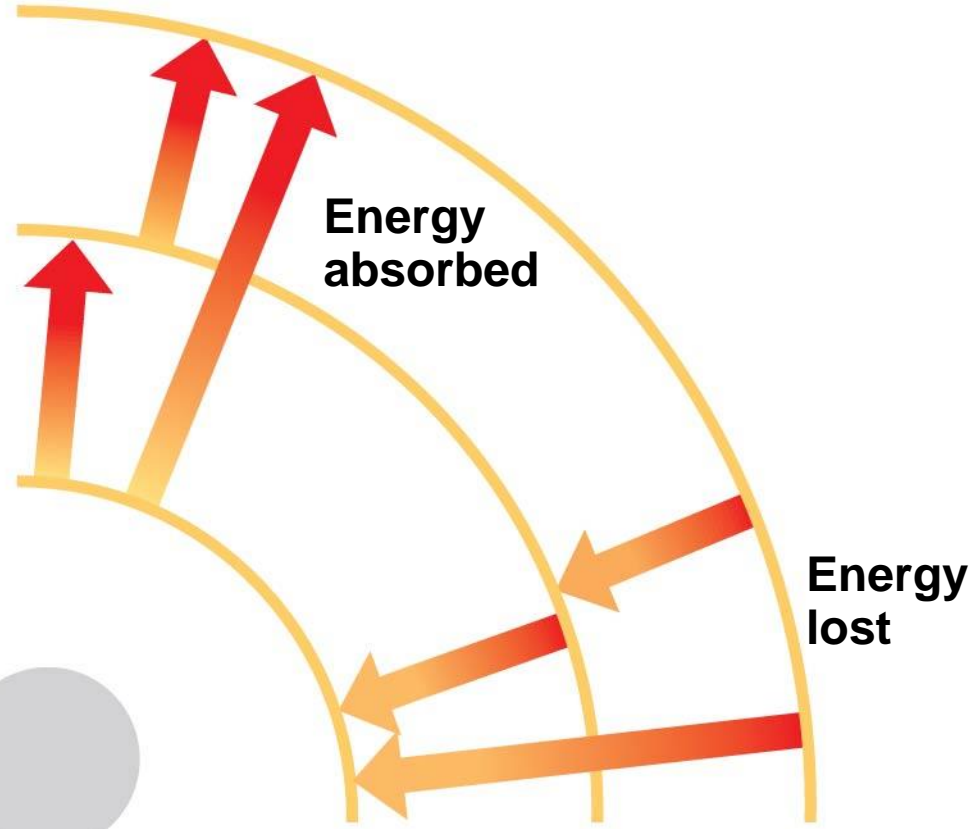


Third shell (highest energy level in this model)

Second shell (higher energy level)

First shell (lowest energy level)

Atomic nucleus



(b)

# 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




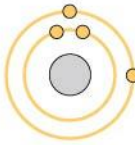
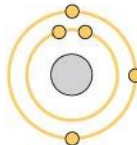
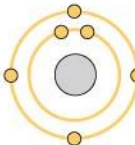
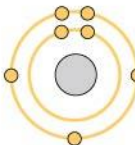
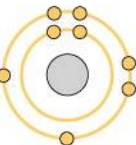
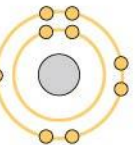
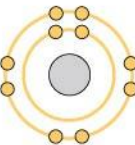
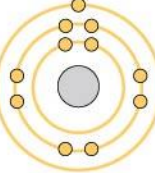
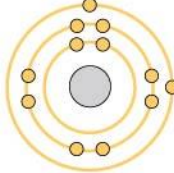
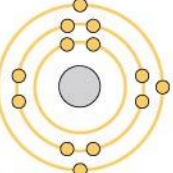
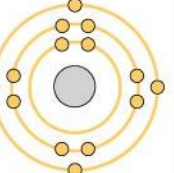
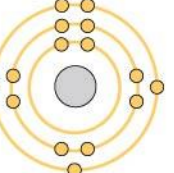
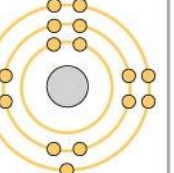
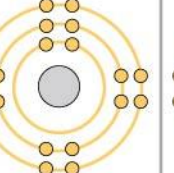
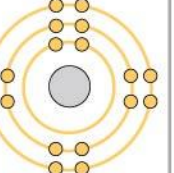
|                            |  |   |  |  |   |   |  |   |
|----------------------------|--|---|--|--|---|---|--|---|
| <p><b>First shell</b></p>  | <p><b>Hydrogen</b><br/><math>{}^1_1\text{H}</math></p>        | <div style="display: flex; align-items: center; justify-content: center;"> <div style="border: 1px solid black; padding: 5px; margin-right: 10px;"> <p>2<br/><b>He</b><br/>4.003</p> </div> <div style="margin-right: 10px;"> <p>Atomic number</p> </div> <div style="margin-right: 10px;"> <p>Element symbol</p> </div> <div style="margin-right: 10px;"> <p>Atomic mass</p> </div> <div style="margin-right: 10px;"> <p>Electron distribution diagram</p> </div> </div> |  |  |   |   |  | <p><b>Helium</b><br/><math>{}^2_2\text{He}</math></p>        |
| <p><b>Second shell</b></p> | <p><b>Lithium</b><br/><math>{}^3_3\text{Li}</math></p>        | <p><b>Beryllium</b><br/><math>{}^4_4\text{Be}</math></p>   | <p><b>Boron</b><br/><math>{}^5_5\text{B}</math></p>             | <p><b>Carbon</b><br/><math>{}^6_6\text{C}</math></p>            | <p><b>Nitrogen</b><br/><math>{}^7_7\text{N}</math></p>           | <p><b>Oxygen</b><br/><math>{}^8_8\text{O}</math></p>         | <p><b>Fluorine</b><br/><math>{}^9_9\text{F}</math></p>          | <p><b>Neon</b><br/><math>{}^{10}_{10}\text{Ne}</math></p>    |
| <p><b>Third shell</b></p>  | <p><b>Sodium</b><br/><math>{}^{11}_{11}\text{Na}</math></p>  | <p><b>Magnesium</b><br/><math>{}^{12}_{12}\text{Mg}</math></p>    | <p><b>Aluminum</b><br/><math>{}^{13}_{13}\text{Al}</math></p>  | <p><b>Silicon</b><br/><math>{}^{14}_{14}\text{Si}</math></p>  | <p><b>Phosphorus</b><br/><math>{}^{15}_{15}\text{P}</math></p>  | <p><b>Sulfur</b><br/><math>{}^{16}_{16}\text{S}</math></p>  | <p><b>Chlorine</b><br/><math>{}^{17}_{17}\text{Cl}</math></p>  | <p><b>Argon</b><br/><math>{}^{18}_{18}\text{Ar}</math></p>  |



Figure 2.7a

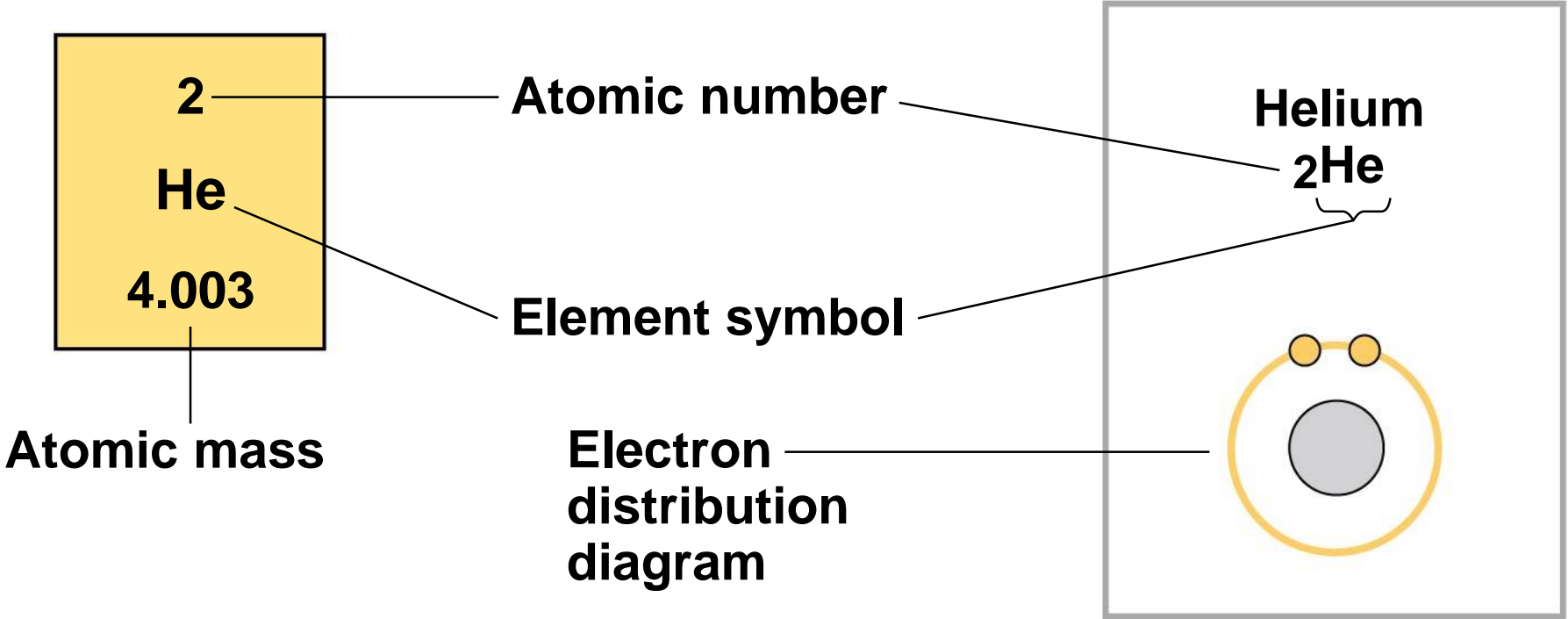


Figure 2.7b

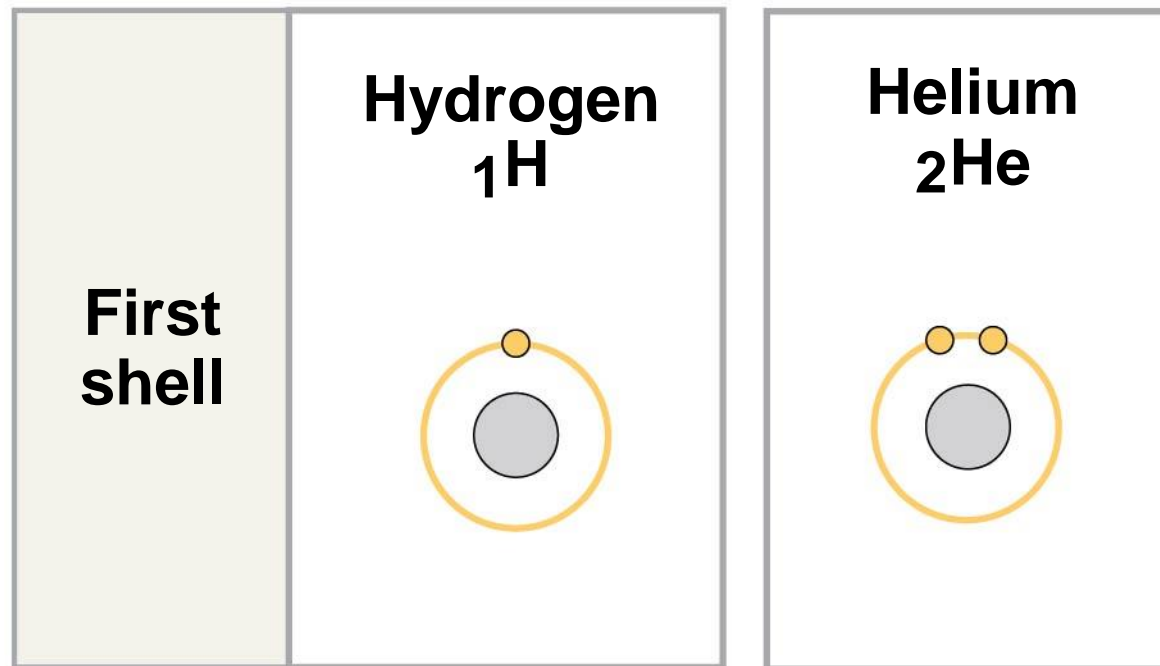


Figure 2.7c

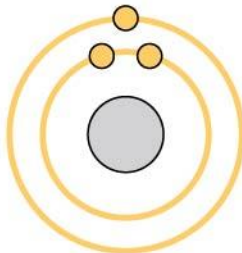
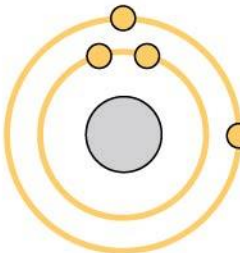
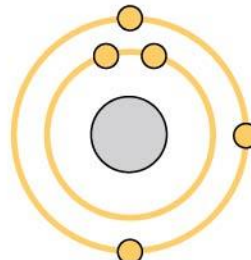
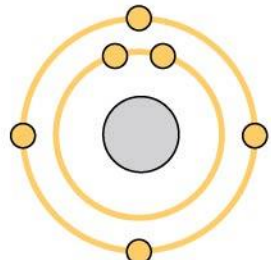
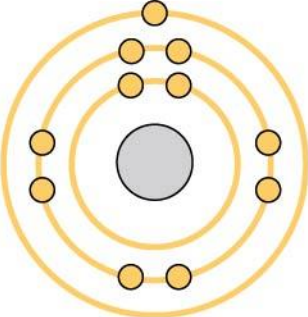
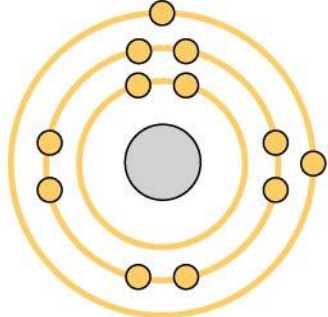
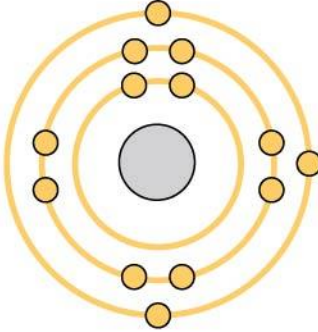
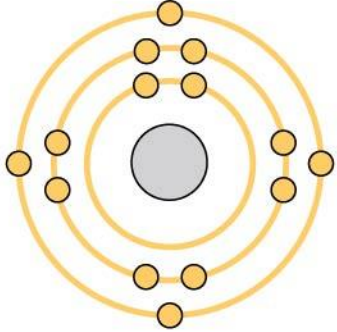
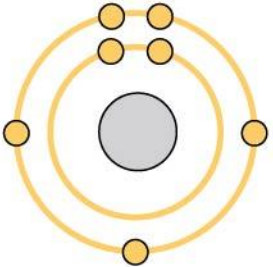
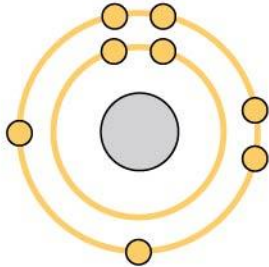
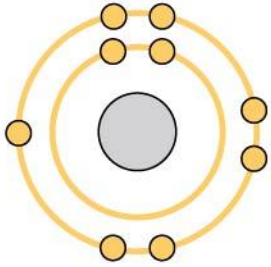
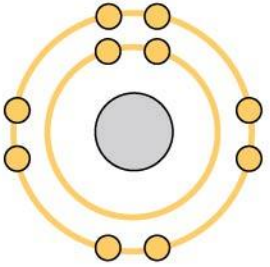
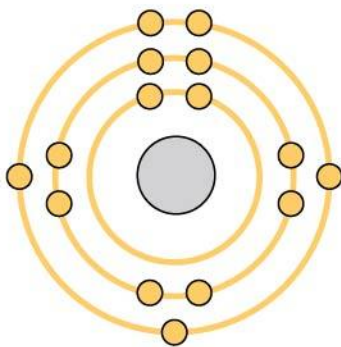
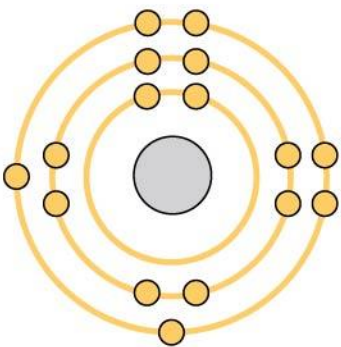
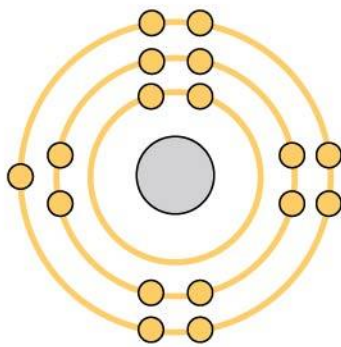
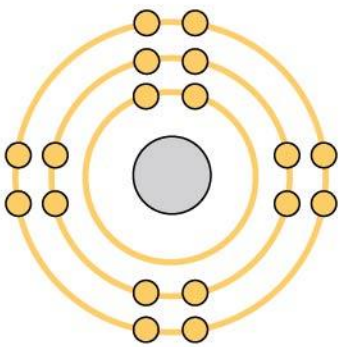
|                            |   |   |   |  |
|----------------------------|---|---|---|--|
| <p><b>Second shell</b></p> | <p><b>Lithium</b><br/><b><math>3\text{Li}</math></b></p>   | <p><b>Beryllium</b><br/><b><math>4\text{Be}</math></b></p>    | <p><b>Boron</b><br/><b><math>5\text{B}</math></b></p>        | <p><b>Carbon</b><br/><b><math>6\text{C}</math></b></p>      |
| <p><b>Third shell</b></p>  | <p><b>Sodium</b><br/><b><math>11\text{Na}</math></b></p>  | <p><b>Magnesium</b><br/><b><math>12\text{Mg}</math></b></p>  | <p><b>Aluminum</b><br/><b><math>13\text{Al}</math></b></p>  | <p><b>Silicon</b><br/><b><math>14\text{Si}</math></b></p>  |

Figure 2.7d

|                     |   |  |  |   |
|---------------------|---|--|--|---|
| <b>Second shell</b> | <b>Nitrogen</b><br><b>7N</b><br>     | <b>Oxygen</b><br><b>8O</b><br>   | <b>Fluorine</b><br><b>9F</b><br>    | <b>Neon</b><br><b>10Ne</b><br>   |
| <b>Third shell</b>  | <b>Phosphorus</b><br><b>15P</b><br> | <b>Sulfur</b><br><b>16S</b><br> | <b>Chlorine</b><br><b>17Cl</b><br> | <b>Argon</b><br><b>18Ar</b><br> |

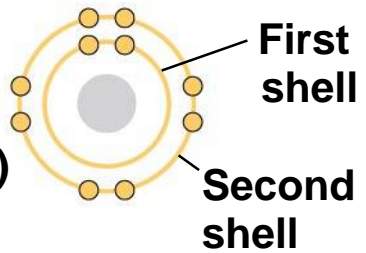
- **Valence electrons** are those in the outermost shell, or **valence shell**
- The chemical behavior of an atom is mostly determined by the valence electrons
- Elements with a full valence shell are chemically inert

# Electron Orbitals

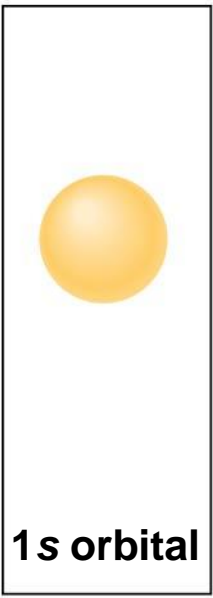
- An **orbital** is the three-dimensional space where an electron is found 90% of the time
- Each electron shell consists of a specific number of orbitals

Figure 2.8

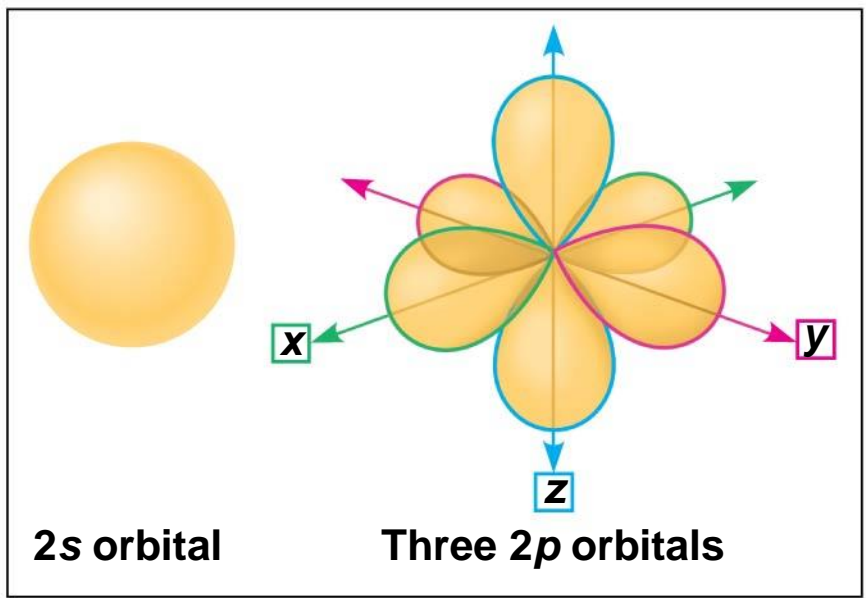
Neon,  
with two  
filled shells  
(10 electrons)



First shell



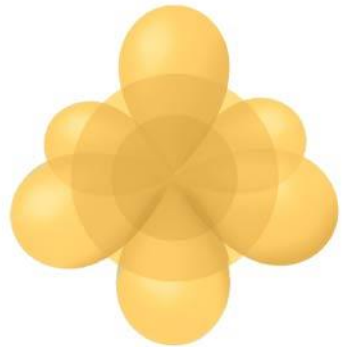
Second shell



(a) Electron distribution diagram

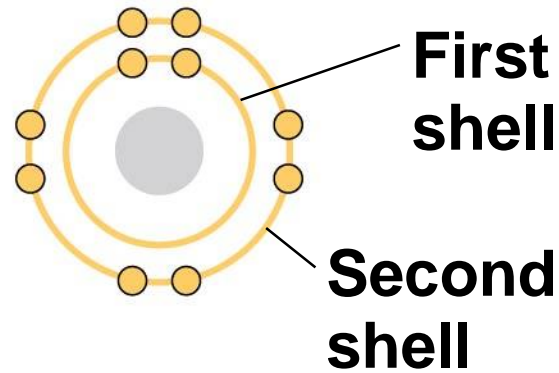
(b) Separate electron orbitals

1s, 2s, and  
2p orbitals



(c) Superimposed electron orbitals

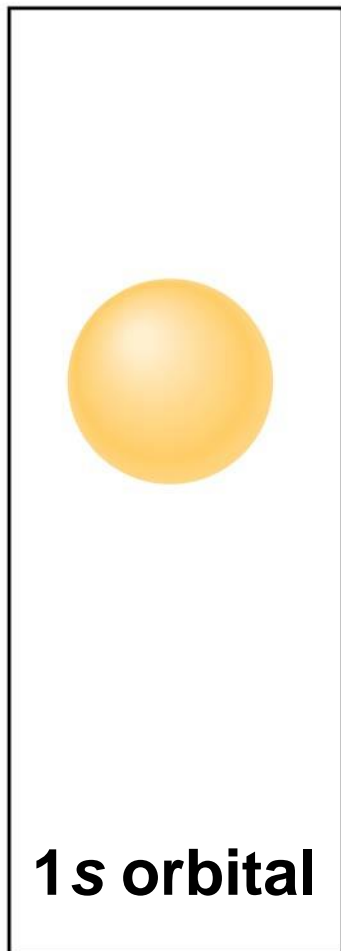
**Neon,  
with two  
filled shells  
(10 electrons)**



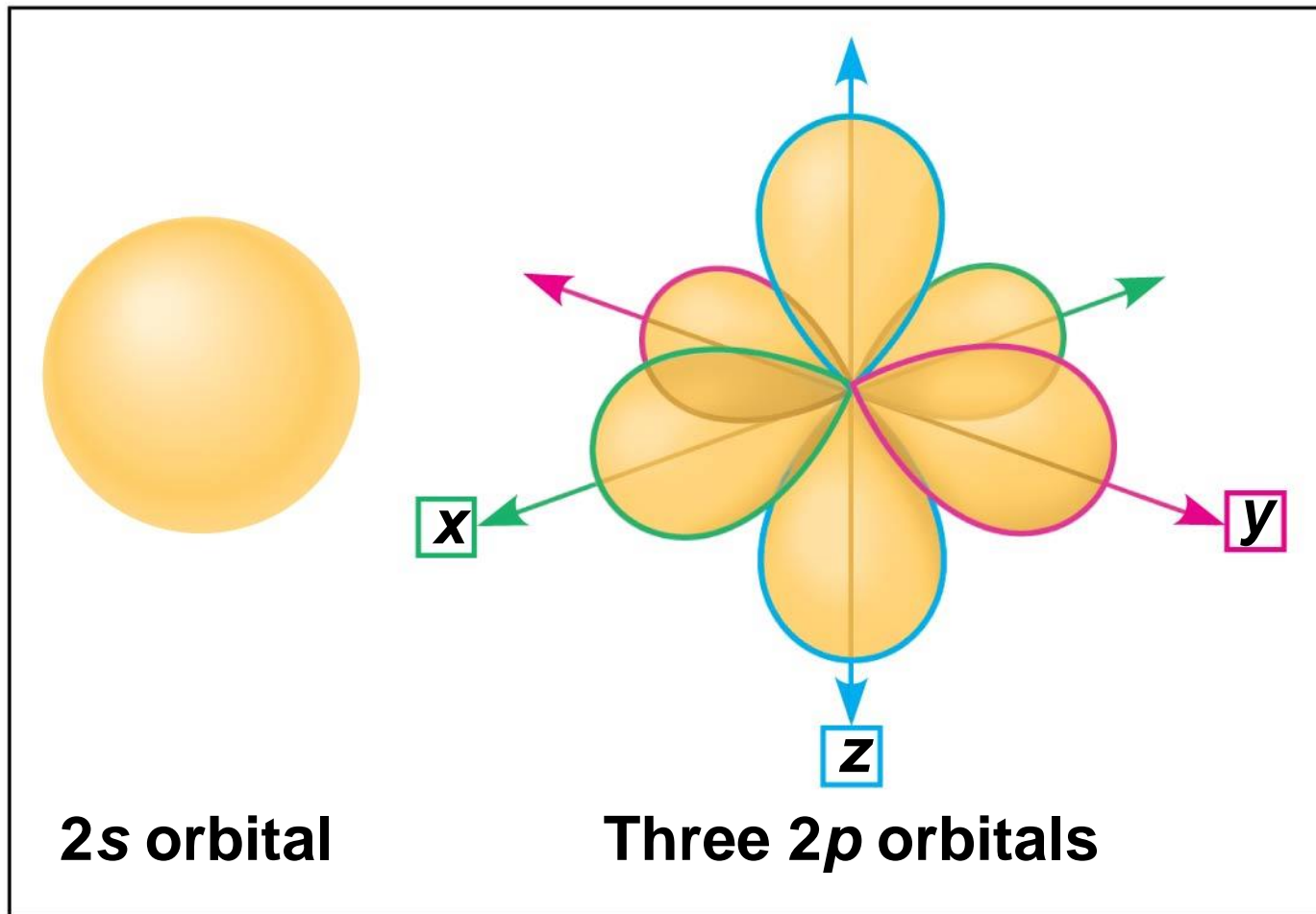
**(a) Electron distribution diagram**



### First shell

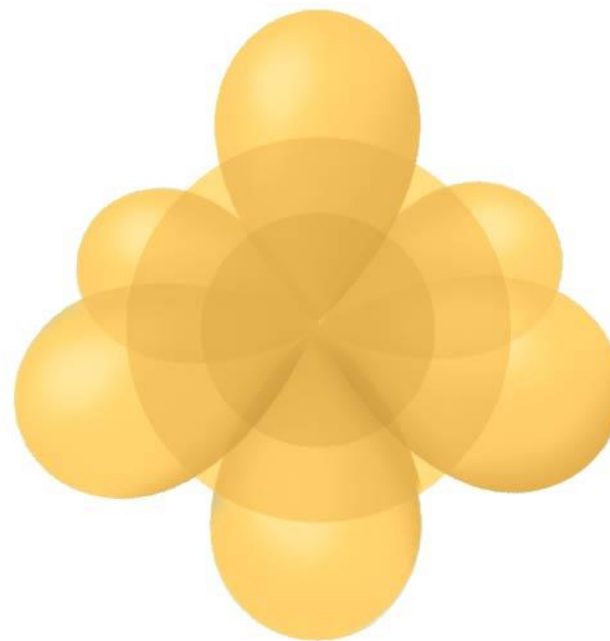


### Second shell



**(b) Separate electron orbitals**

**1s, 2s, and  
2p orbitals**



**(c) Superimposed electron orbitals**

## **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

Hydrogen atoms (2 H)

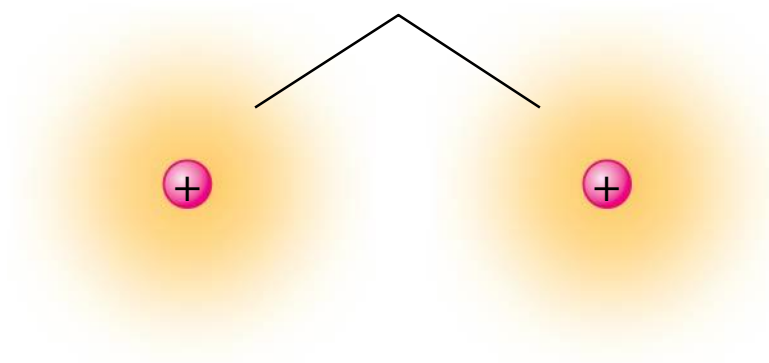


Figure 2.9\_2

Hydrogen atoms (2 H)

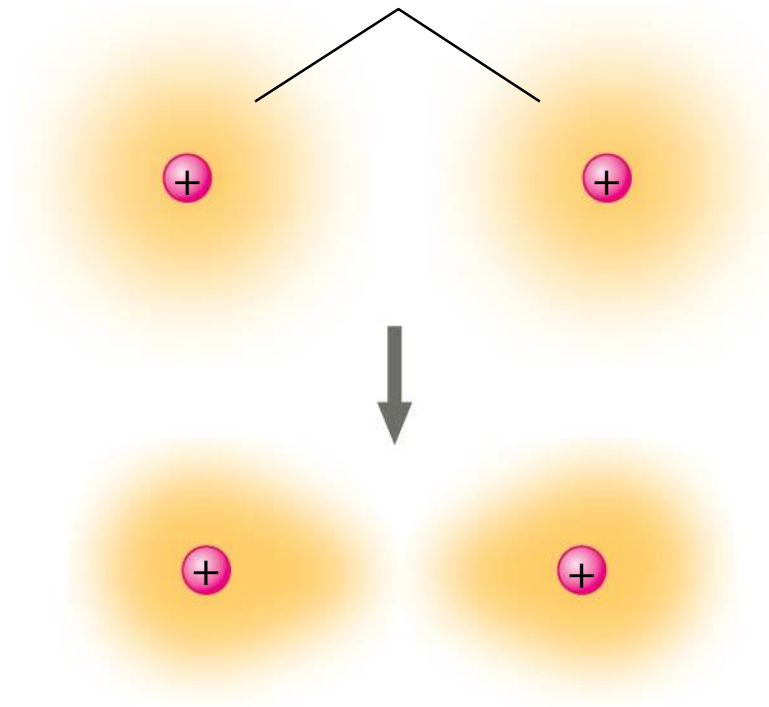
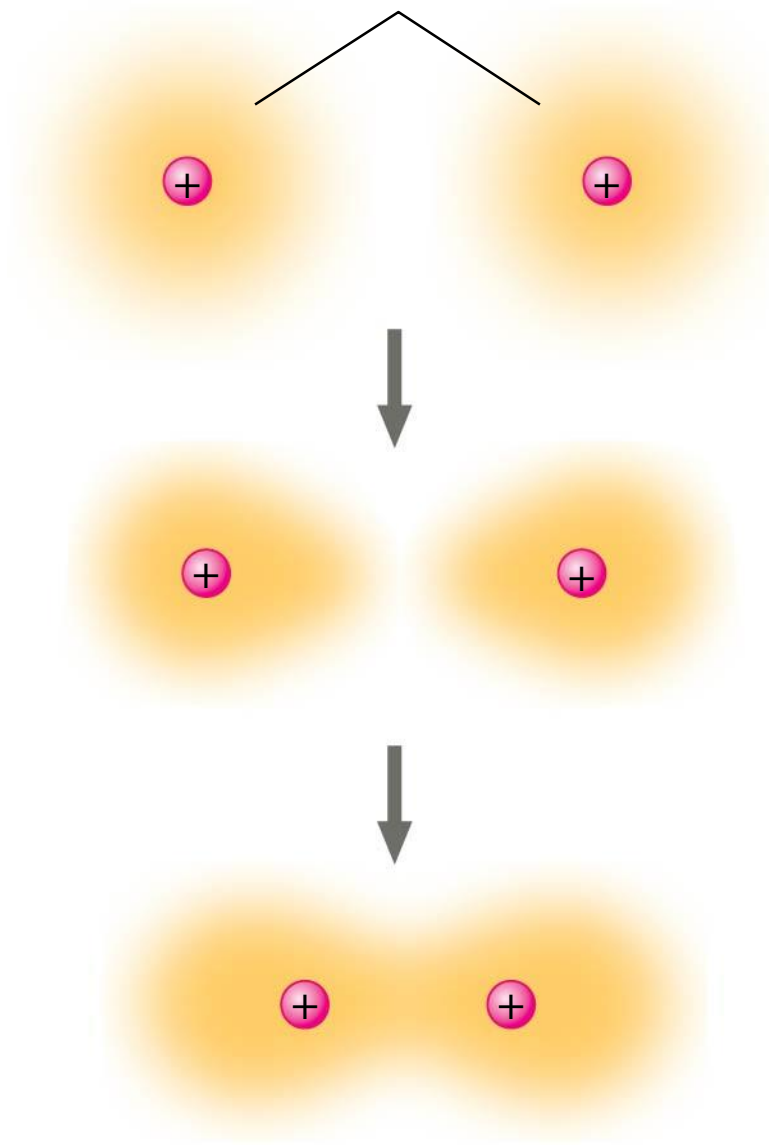


Figure 2.9\_3

Hydrogen atoms (2 H)



Hydrogen  
molecule (H<sub>2</sub>)

- 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<sub>2</sub>

Figure 2.10

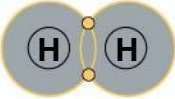

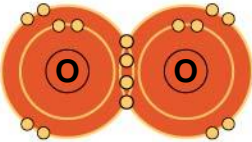

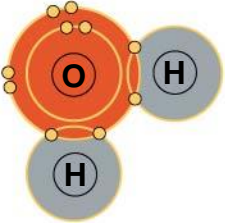

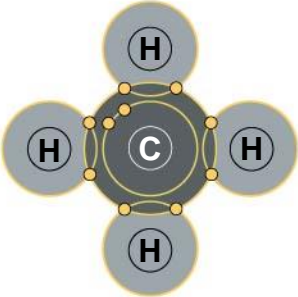

| Name and Molecular Formula     | Electron Distribution Diagram  | Lewis Dot Structure and Structural Formula | Space-Filling Model   |
|--------------------------------|--|--|---|
| (a) Hydrogen (H <sub>2</sub> ) |     | H:H<br>H—H                                 |    |
| (b) Oxygen (O <sub>2</sub> )   |    | Ö::Ö<br>O=O                                |    |
| (c) Water (H <sub>2</sub> O)   |     | :Ö:H<br>H<br>O—H<br>H                      |    |
| (d) Methane (CH <sub>4</sub> ) |  | H<br>H:C:H<br>H<br>H<br>H—C—H<br>H         |  |

Figure 2.10a

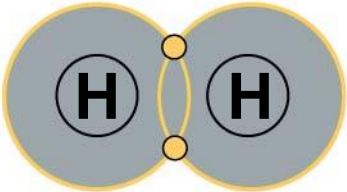
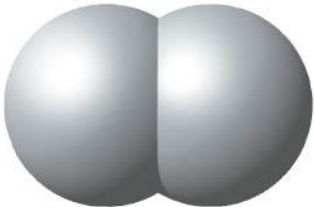
| <b>Name and Molecular Formula</b>   | <b>Electron Distribution Diagram</b>   | <b>Lewis Dot Structure and Structural Formula</b> | <b>Space-Filling Model</b>  |
|-------------------------------------|--|---|---|
| <b>(a) Hydrogen (H<sub>2</sub>)</b> |  | $\text{H}:\text{H}$<br>$\text{H}-\text{H}$        |  |

Figure 2.10b

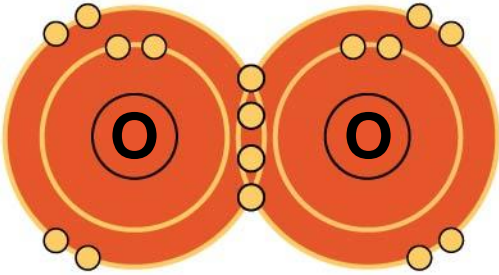
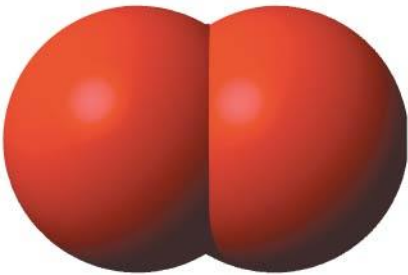
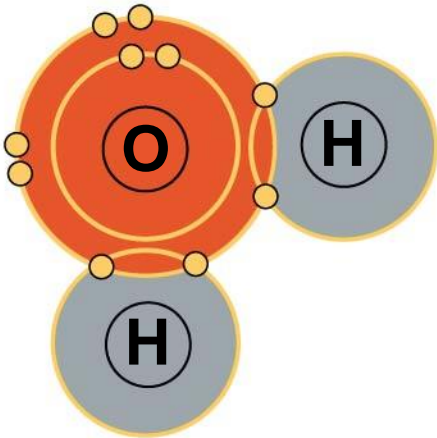
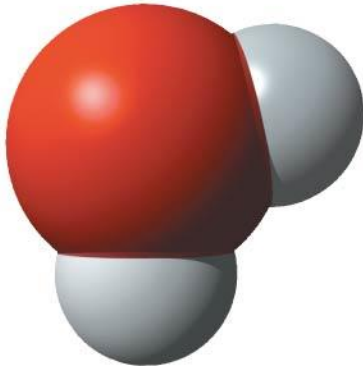
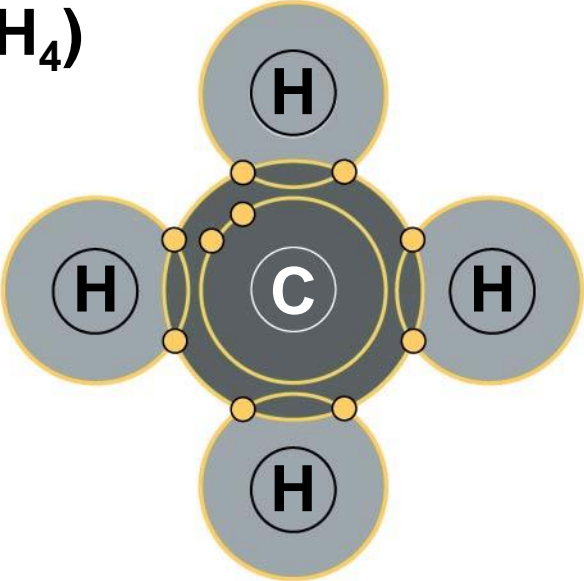
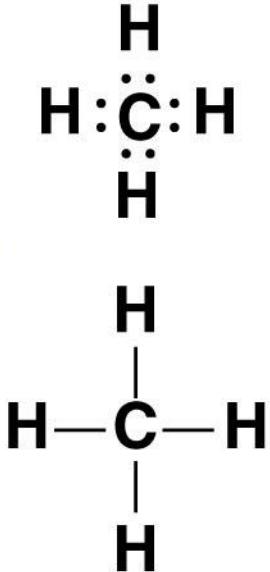
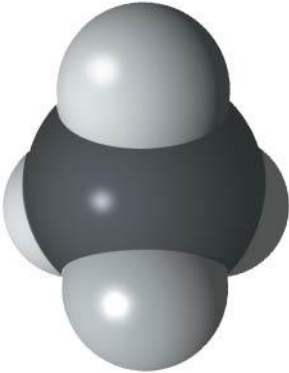
| Name and Molecular Formula   | Electron Distribution Diagram   | Lewis Dot Structure and Structural Formula                | Space-Filling Model  |
|------------------------------|---|---|--|
| (b) Oxygen (O <sub>2</sub> ) |  | $\ddot{\text{O}}::\ddot{\text{O}}$<br>$\text{O}=\text{O}$ |  |

Figure 2.10c

| Name and Molecular Formula   | Electron Distribution Diagram   | Lewis Dot Structure and Structural Formula  | Space-Filling Model  |
|------------------------------|---|---|--|
| (c) Water (H <sub>2</sub> O) |  | $\begin{array}{c} \text{:}\ddot{\text{O}}\text{:H} \\ \ddot{\text{H}} \end{array}$<br>$\begin{array}{c} \text{O}-\text{H} \\   \\ \text{H} \end{array}$ |  |

| Name and Molecular Formula          | Electron Distribution Diagram   | Lewis Dot Structure and Structural Formula   | Space-Filling Model  |
|-------------------------------------|---|--|--|
| <b>(d) Methane (CH<sub>4</sub>)</b> |  |  |  |

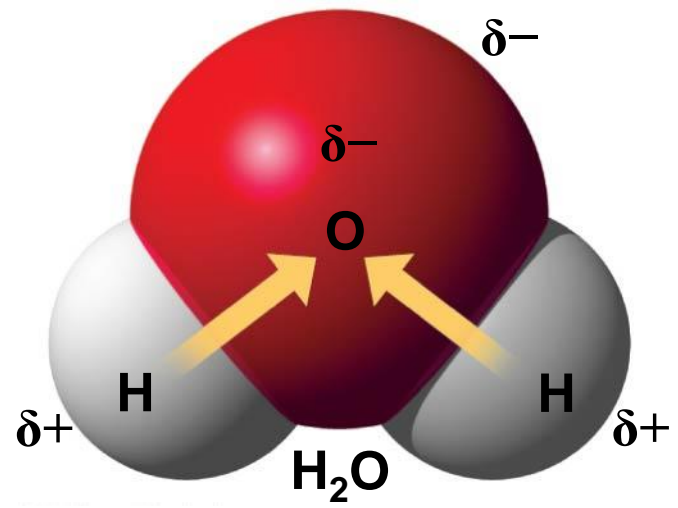
- Bonding capacity is called the atom's **valence**
- Covalent bonds can form between atoms of the same element or atoms of different elements
- A compound is a combination of two or more different elements

- 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 is, 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

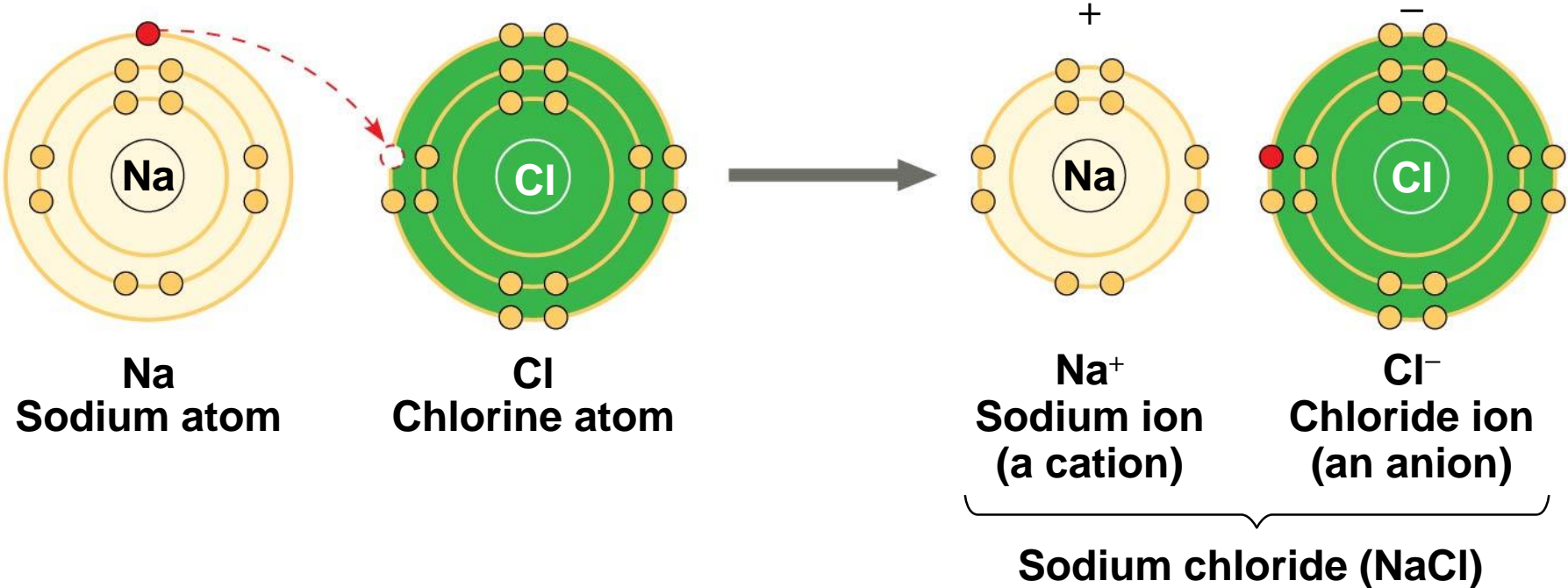
Figure 2.11



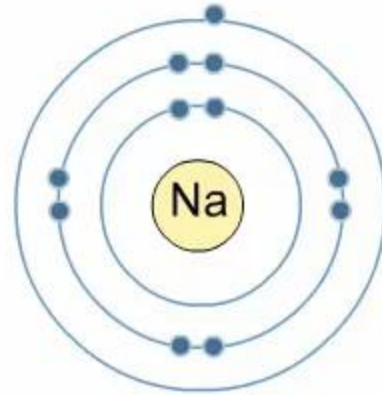
# Ionic Bonds

- 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**

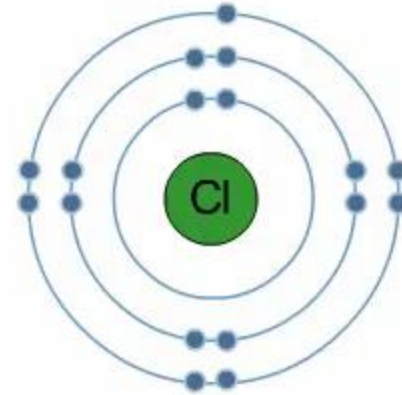
Figure 2.12\_2



# Animation: Ionic Bonds



Sodium (Na)  
11 protons  
11 electrons

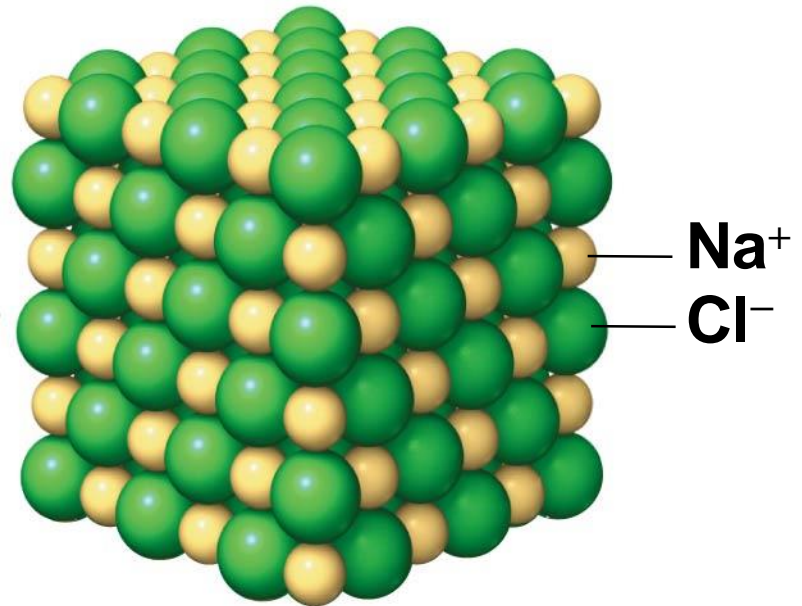


Chlorine (Cl)  
17 protons  
17 electrons

- 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





# Weak Chemical Interactions

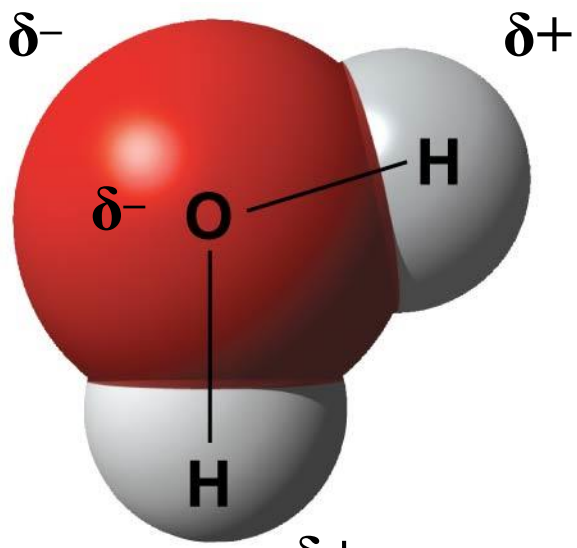
- Most of the strongest bonds in organisms are covalent bonds that form a cell's molecules
- Many large biological molecules are held in their functional form by weak bonds
- The reversibility of weak bonds can be an advantage

# *Hydrogen Bonds*

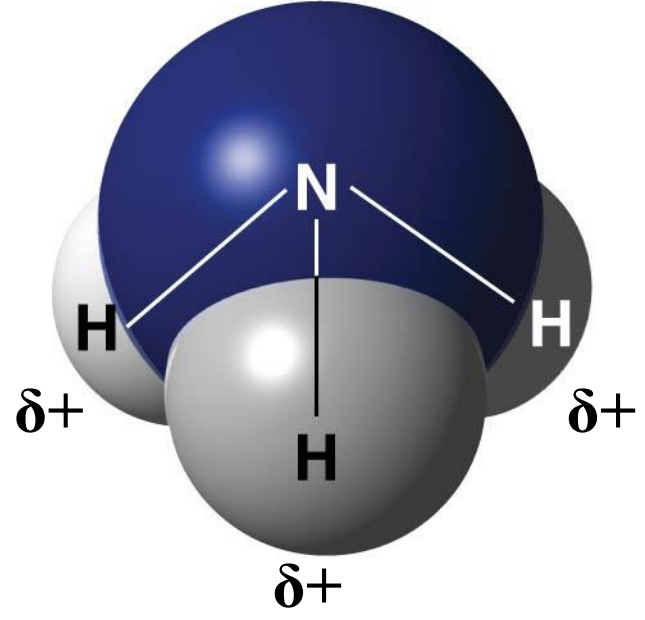
- A **hydrogen bond** forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms

Figure 2.14

**Water (H<sub>2</sub>O)**



**Ammonia (NH<sub>3</sub>)**



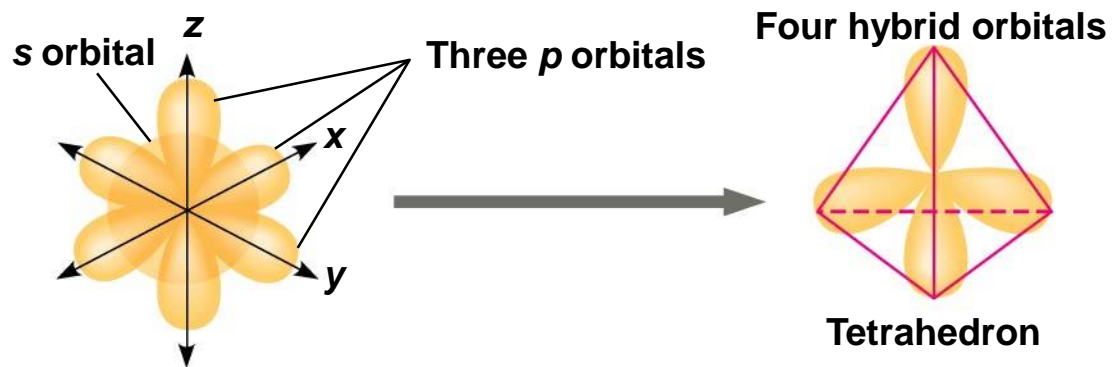
# *Van der Waals Interactions*

- If electrons are not evenly distributed, 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

# Molecular Shape and Function

- A molecule's size and shape are key 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

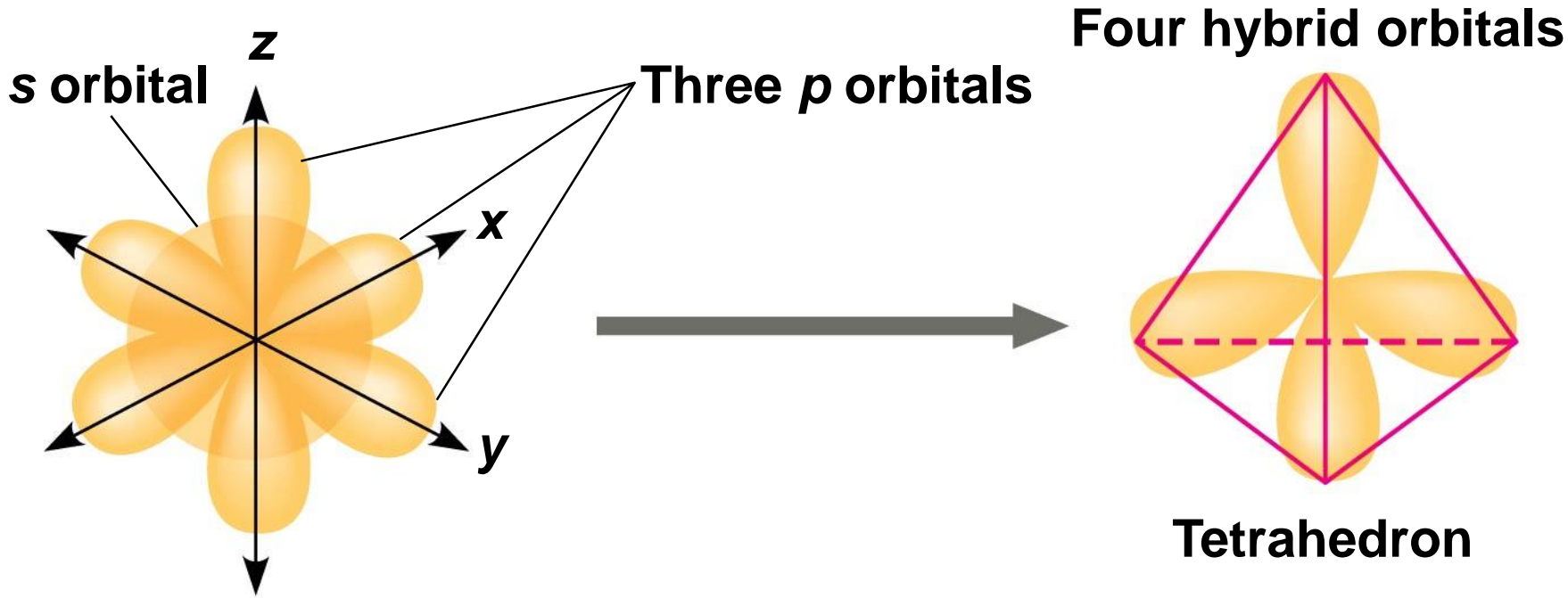


(a) Hybridization of orbitals

| Space-Filling Model                    | Ball-and-Stick Model | Hybrid-Orbital Model (with ball-and-stick model superimposed) |
|--|----------------------|---|
| <p><b>Water (H<sub>2</sub>O)</b></p>   | <p><b>104.5°</b></p> | <p><b>Unbonded electron pairs</b></p>                         |
| <p><b>Methane (CH<sub>4</sub>)</b></p> |                      |   |

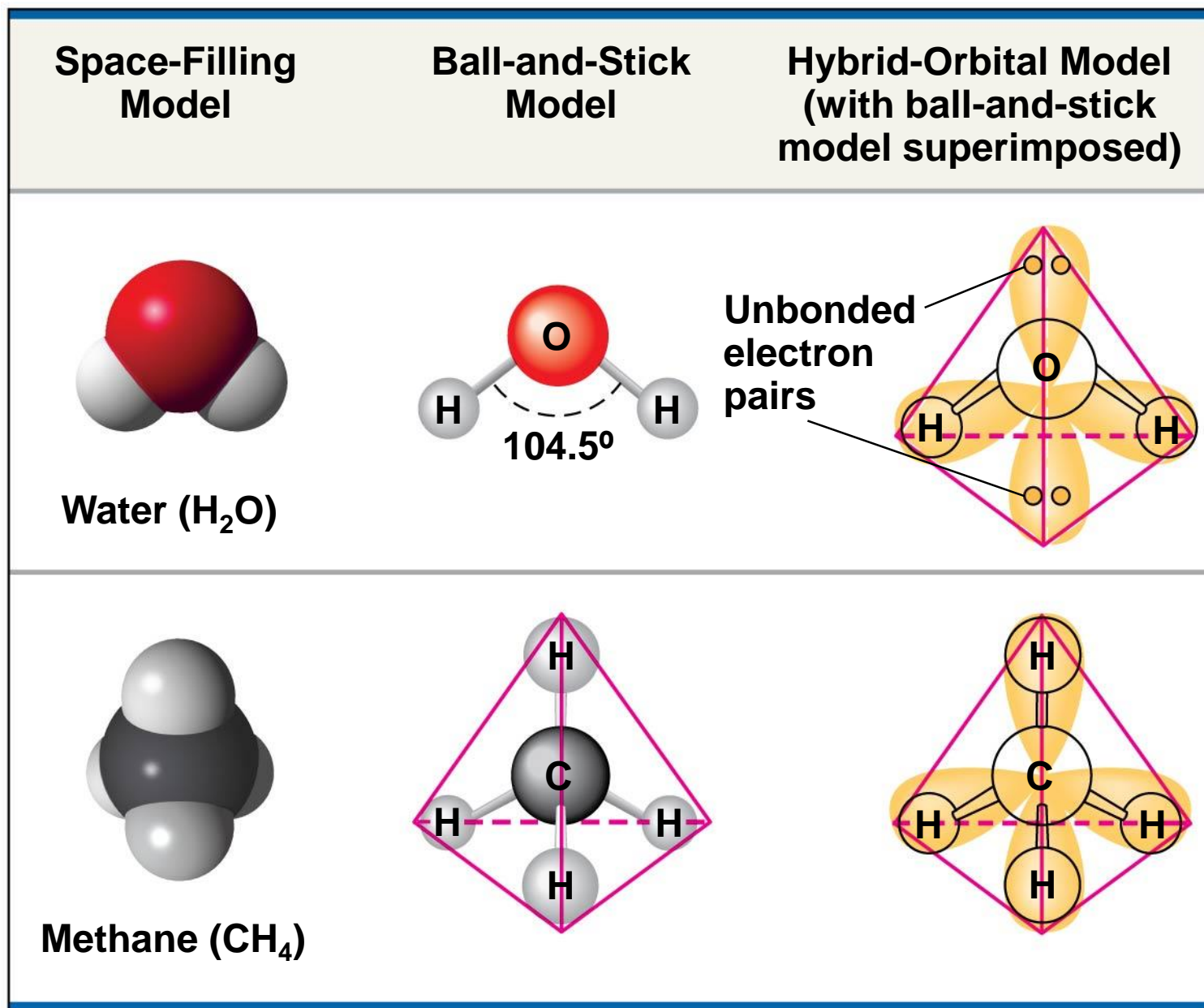
(b) Molecular-shape models

Figure 2.15a



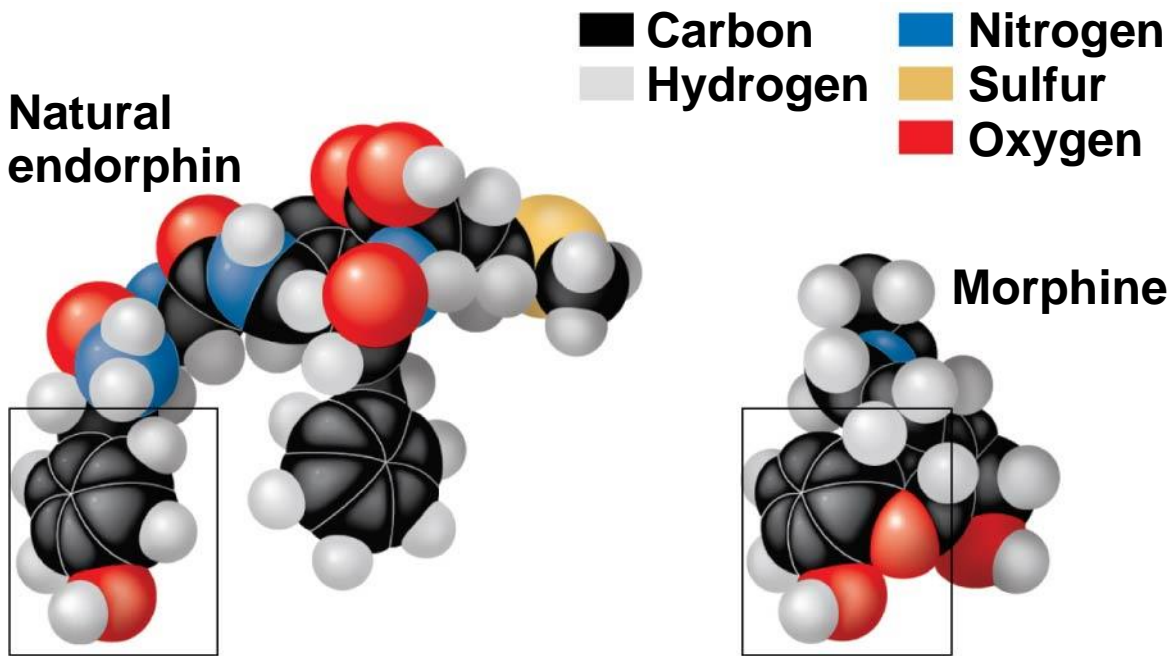
**(a) Hybridization of orbitals**



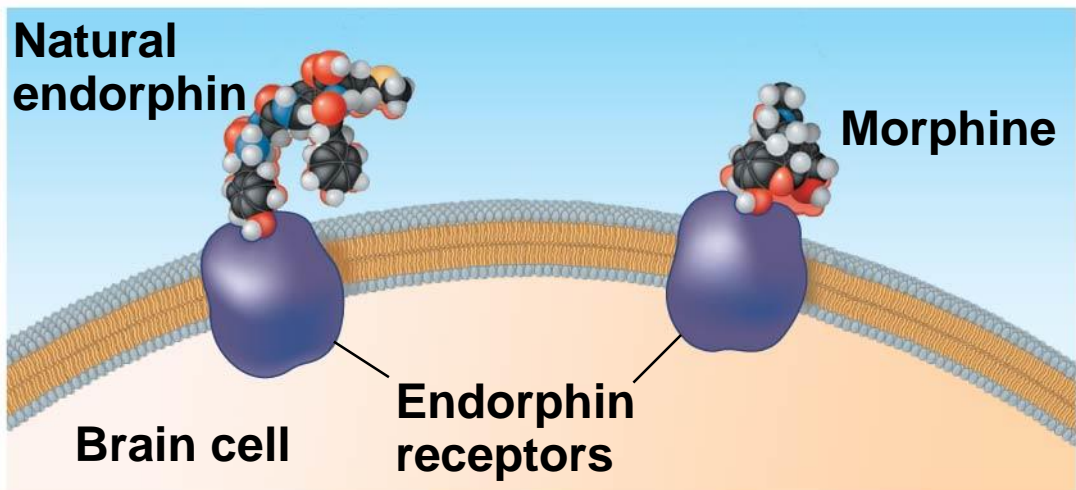
**(b) Molecular-shape models**

- Molecular shape determines how biological molecules 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



**(a) Structures of endorphin and morphine**

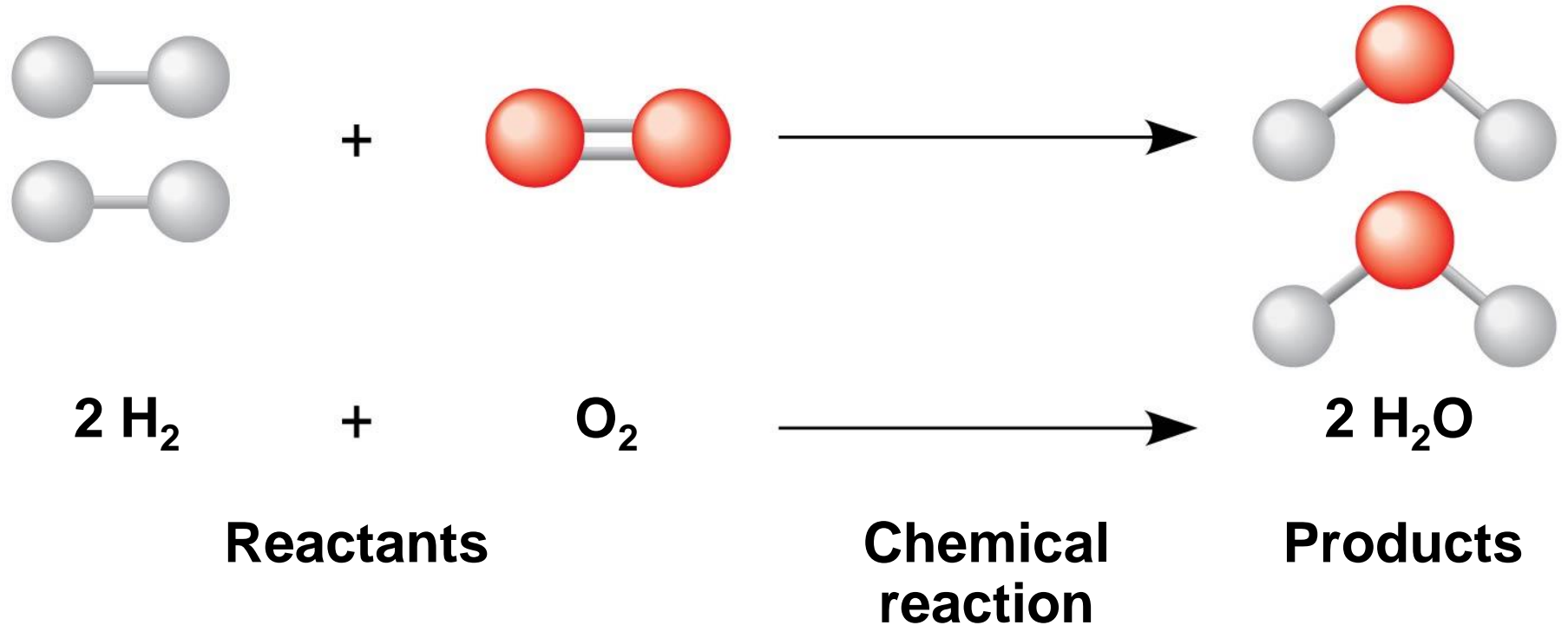


**(b) Binding to endorphin receptors**

## 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



Figure 2.17



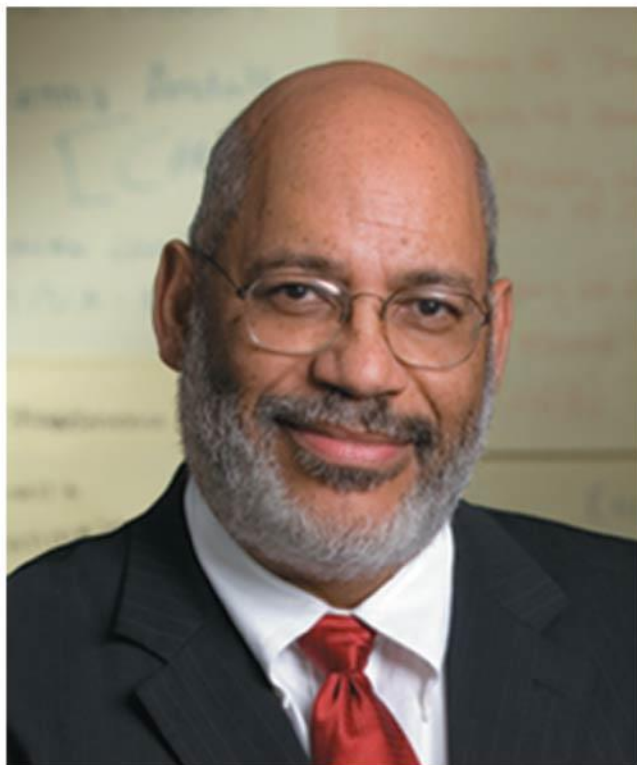
- All chemical reactions are reversible: Products of the forward reaction become reactants for the reverse reaction
- The two opposite-headed arrows indicate that a reaction is reversible





- **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

## UNIT 1: THE CHEMISTRY OF LIFE



**Dr. Lovell Jones**



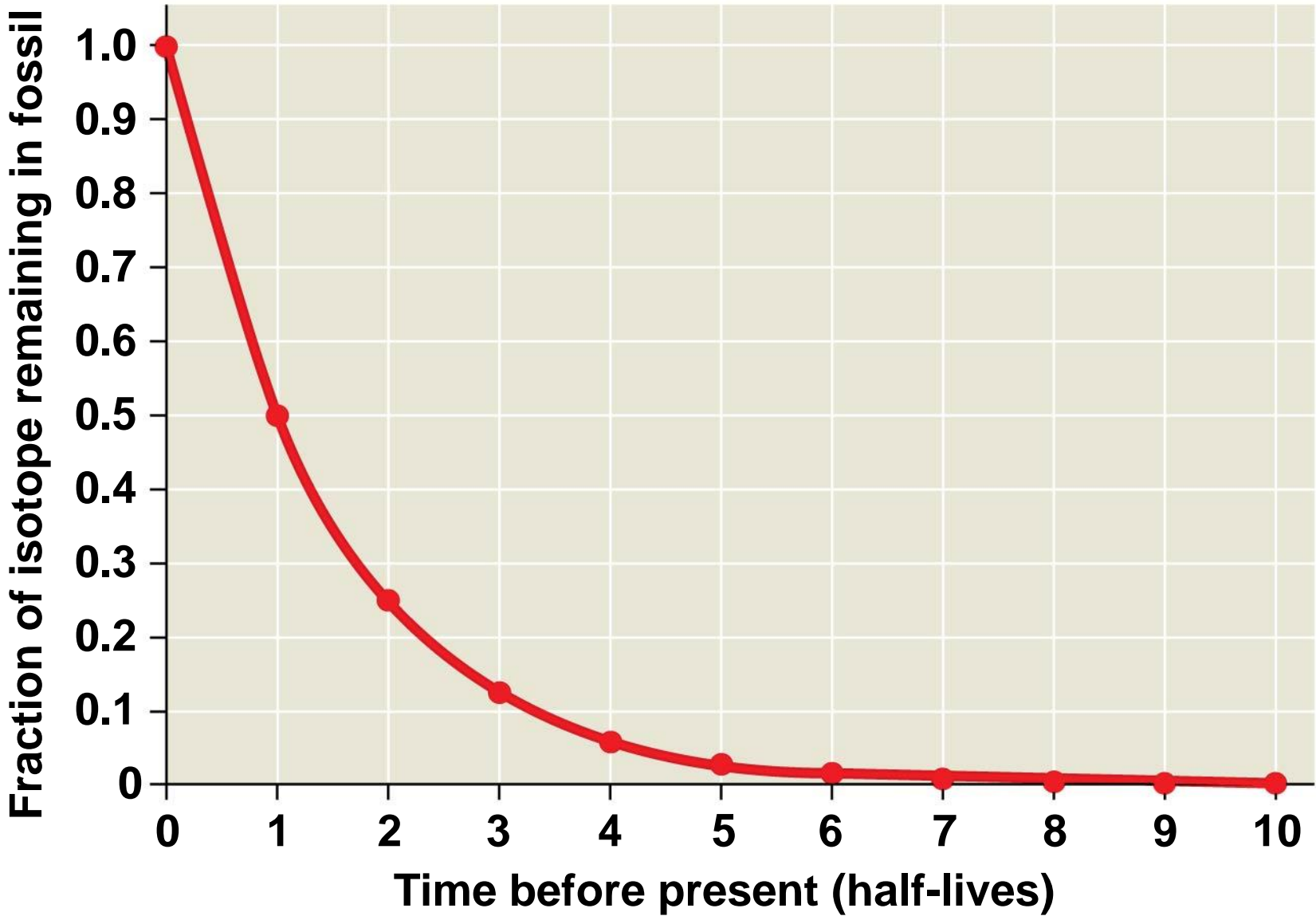
**Dr. Lovell Jones in his lab, where he has studied the relationship between hormones and cancers**

**“Studying biochemistry in a holistic way is going to be the key to the answers we need.”**



**Dr. Lovell Jones in his lab, where he has studied the relationship between hormones and cancers**

Figure 2.UN01a



Data from R. Pinhasi et al., Revised age of late Neanderthal occupation and the end of the Middle Paleolithic in the northern Caucasus, *Proceedings of the National Academy of Sciences USA* 147:8611–8616 (2011). doi 10.1073/pnas.1018938108

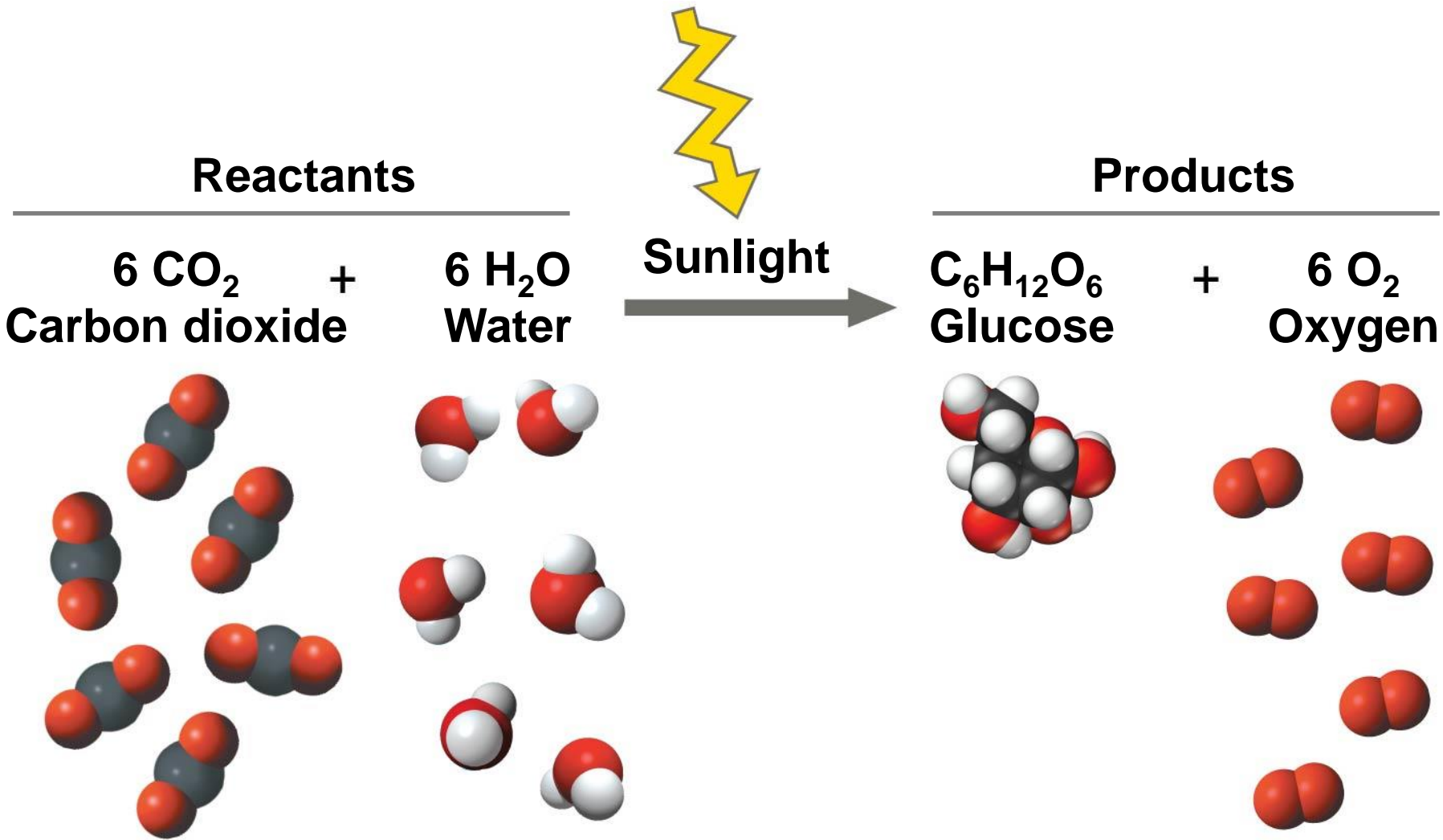


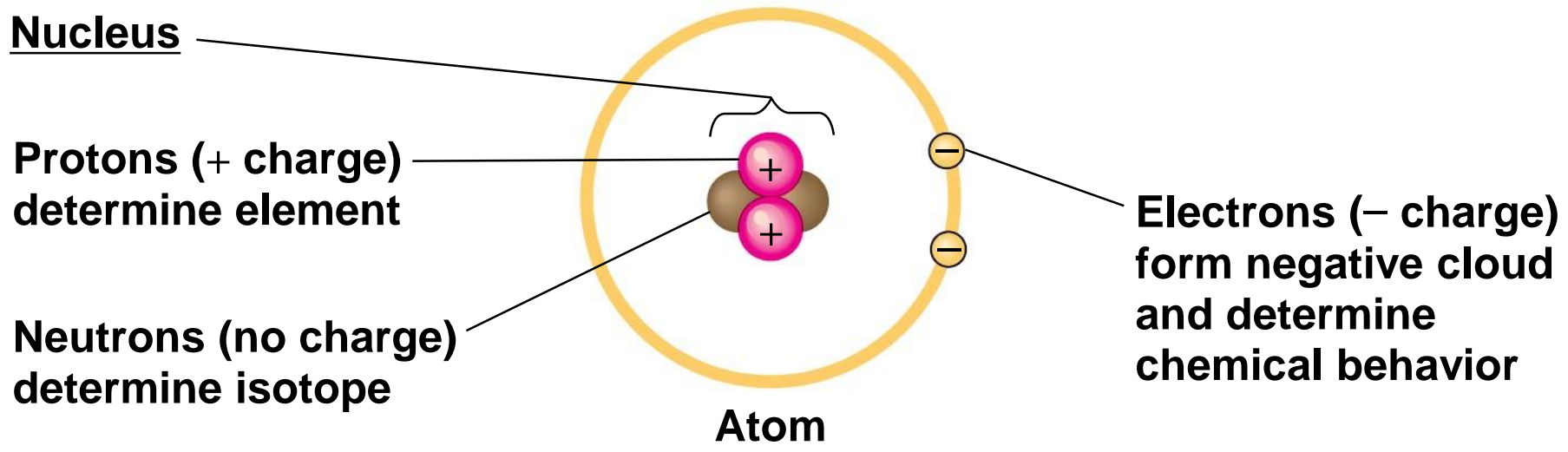
**Neanderthal fossils**

Figure 2.UN02



Figure 2.UN04







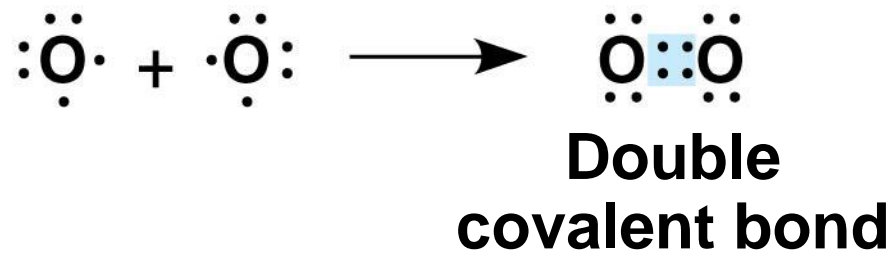
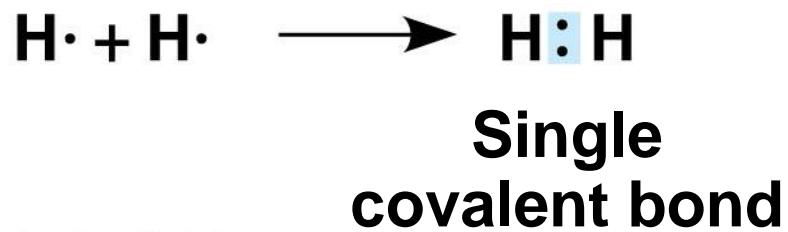
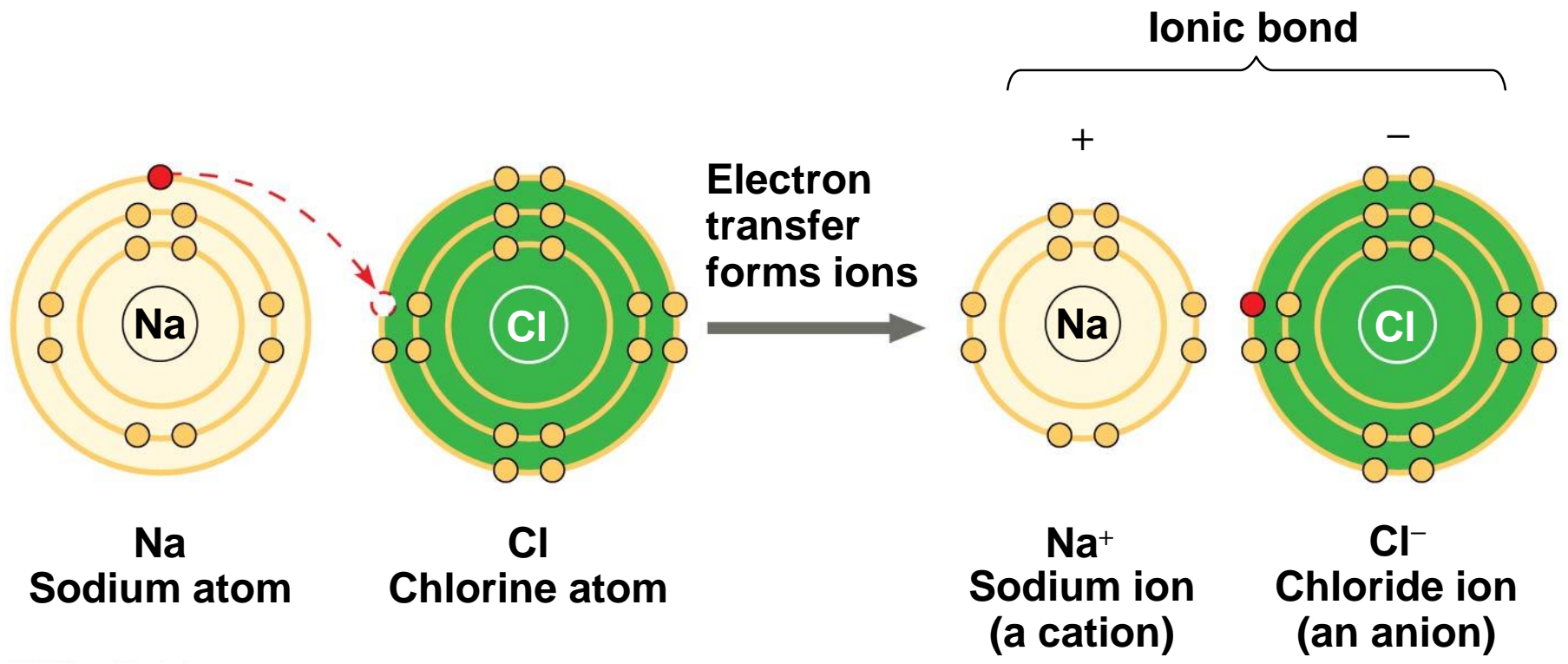


Figure 2.UN07



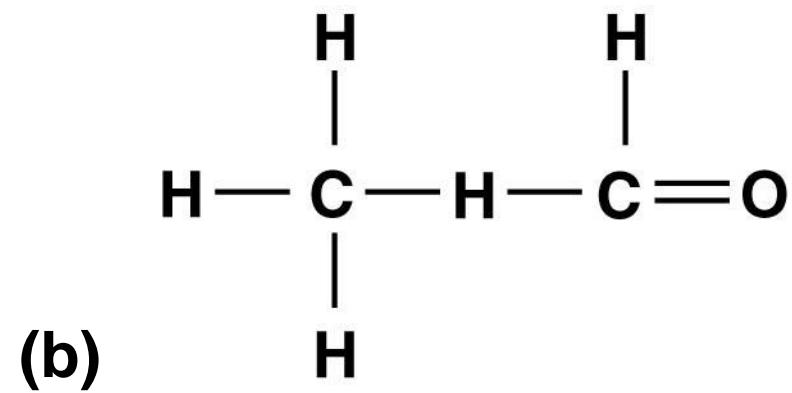
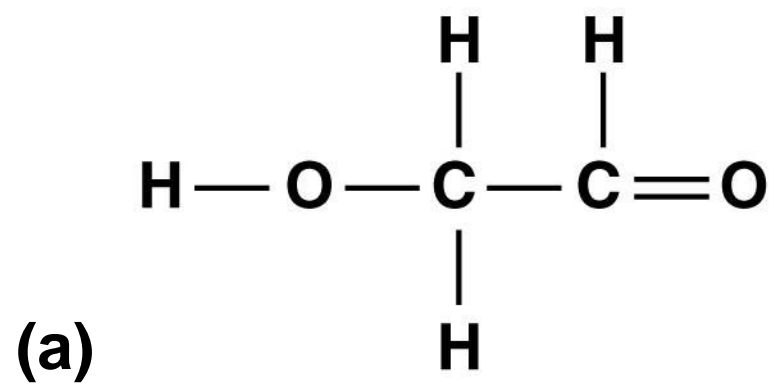


Figure 2.UN09



Figure 2.UN10

