Chapter 2

The Chemical Context of Life

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

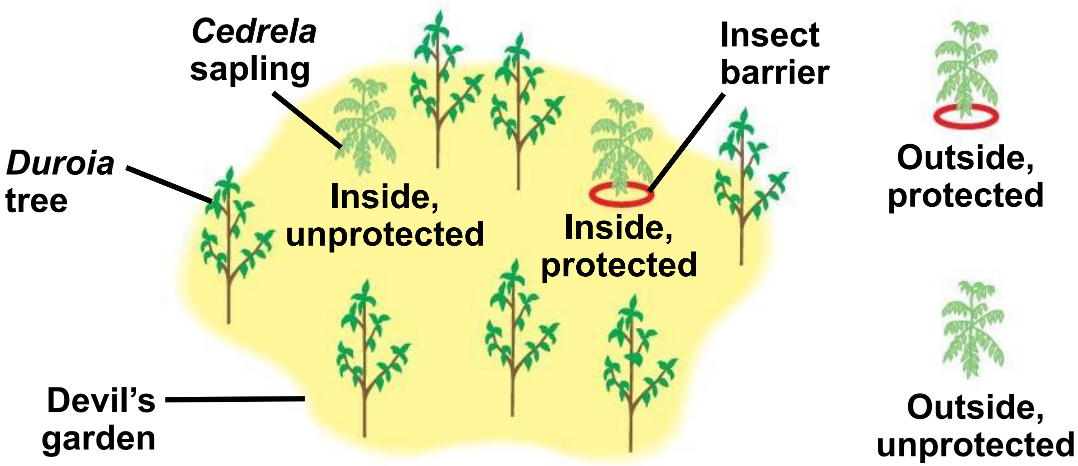
Overview: A Chemical Connection to Biology

- Biology is a multidisciplinary science
- Living organisms are subject to basic laws of physics and chemistry
- One example is the use of formic acid by ants to maintain "devil's gardens," stands of *Duroia* trees

Fig. 2-1

Fig. 2-2

EXPERIMENT



RESULTS

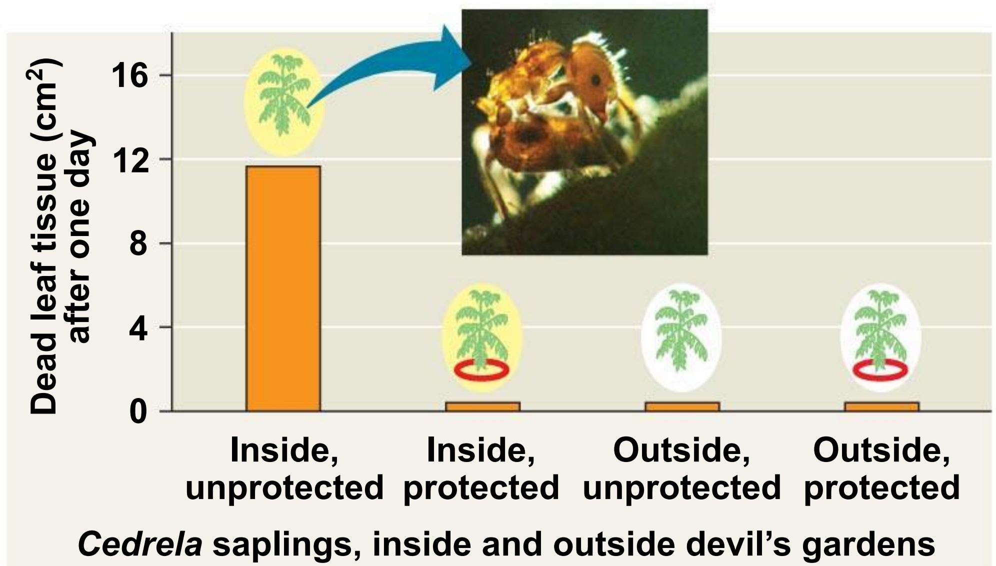


Fig. 2-2a

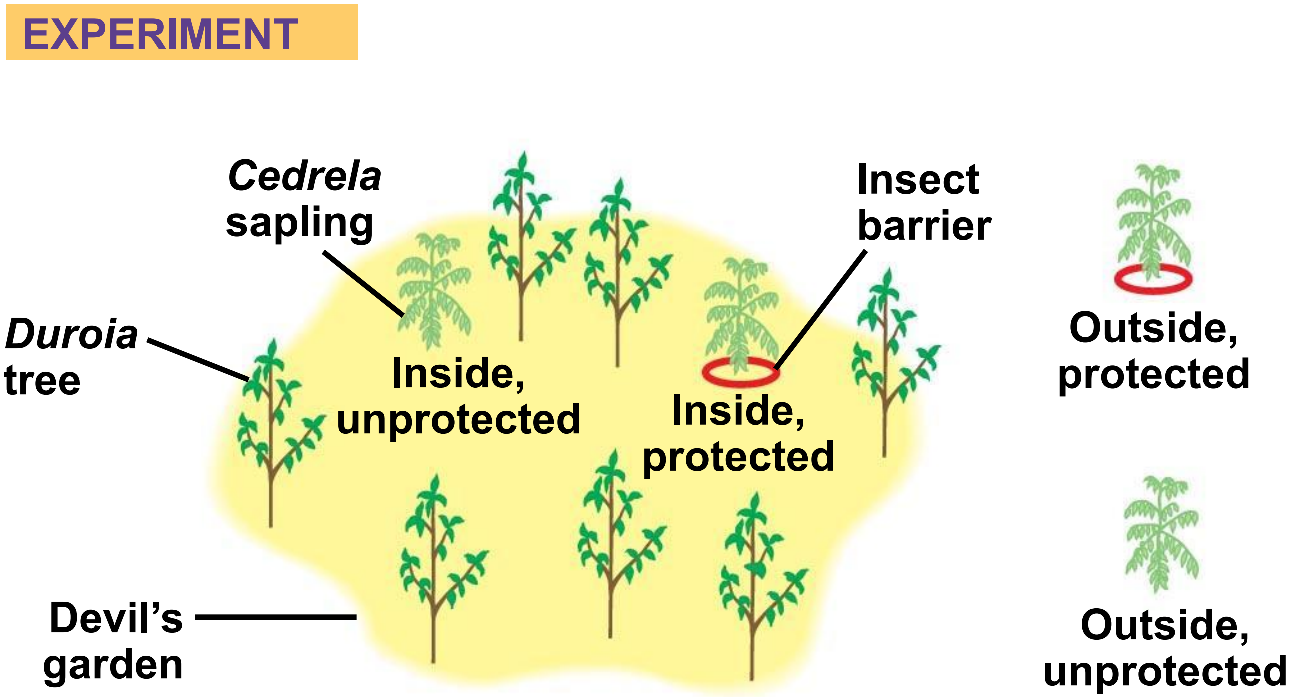
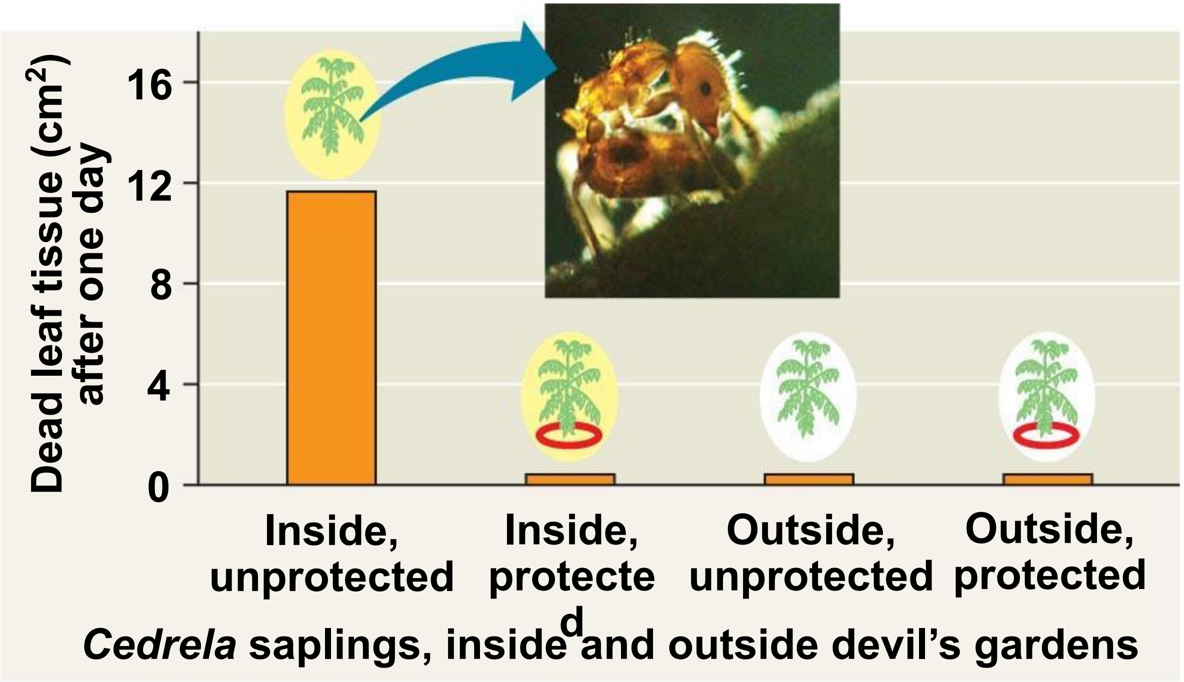

EXPERIMENT
Cedrela sapling
Insect barrier
Duroia tree
Inside, unprotected
Inside, protected
Outside, protected
Outside, unprotected
Devil's garden

Fig. 2-2b

RESULTS



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

Fig. 2-3

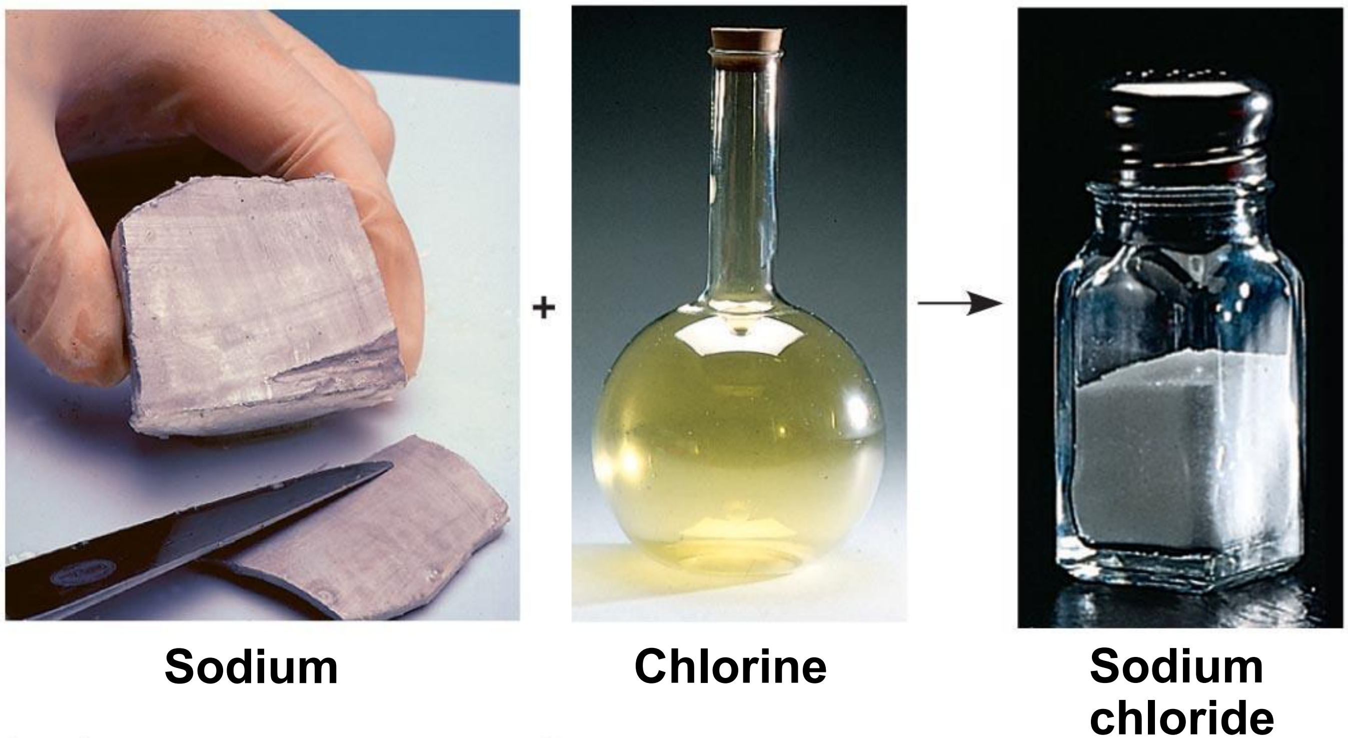
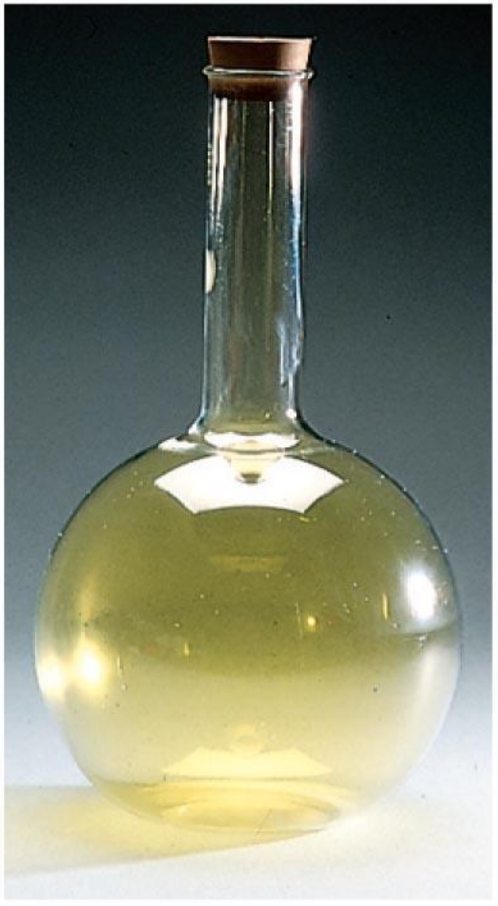


Fig. 2-3a

Sodium

Fig. 2-3b



Chlorine

Fig. 2-3c

Sodium chloride

Essential Elements of Life

- About 25 of the 92 elements are essential to life
- 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 minute quantities

Table 2-1

Table 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number (see p. 33)	Percentage of Human Body Weight
Elements making up about 96% of human body weight			
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Elements making up about 4% of human body weight			
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1
Elements making up less than 0.01% of human body weight (trace elements)			
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)			

Fig. 2-4

(a) Nitrogen deficiency

(b) Iodine deficiency

Fig. 2-4a

(a) Nitrogen deficiency

Fig. 2-4b

(b) Iodine deficiency

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

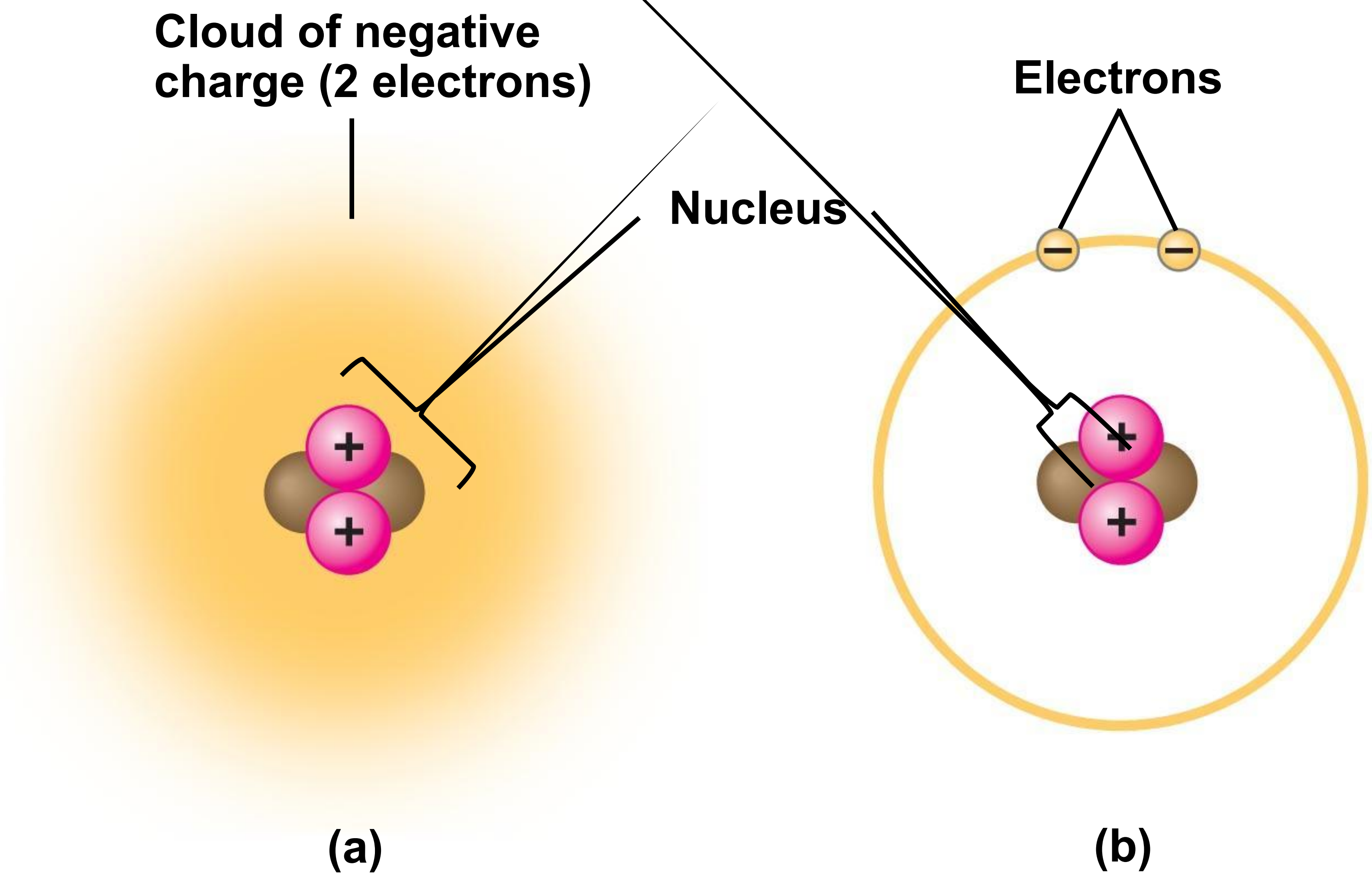
- Each element consists of unique **atoms**
- An atom is the smallest unit of matter that still retains the properties of an element

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**

Fig. 2-5



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

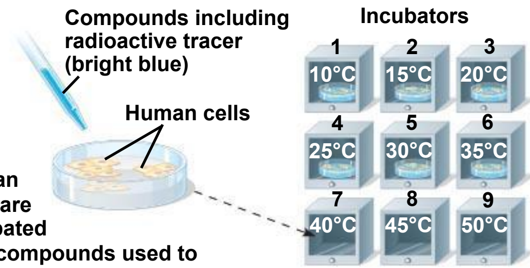
Isotopes

- 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

- Some applications of radioactive isotopes in biological research are:
  - Dating fossils
  - Tracing atoms through metabolic processes
  - Diagnosing medical disorders

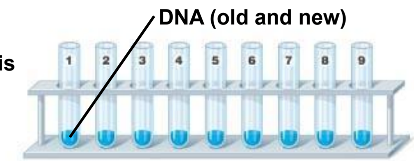
Fig. 2-6

TECHNIQUE



1 Human cells are incubated with compounds used to make DNA. One compound is labeled with ^3H.

2 The cells are placed in test tubes; their DNA is isolated; and unused labeled compounds are removed.



3 The test tubes are placed in a scintillation counter.

RESULTS

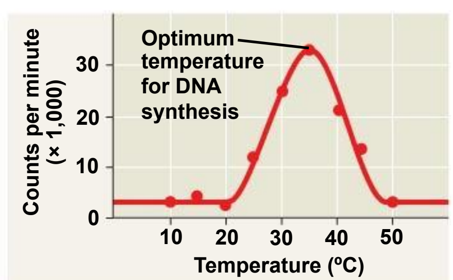
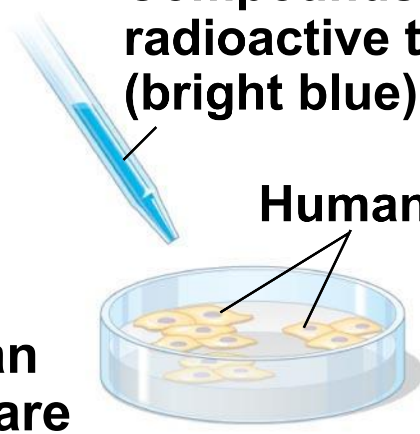
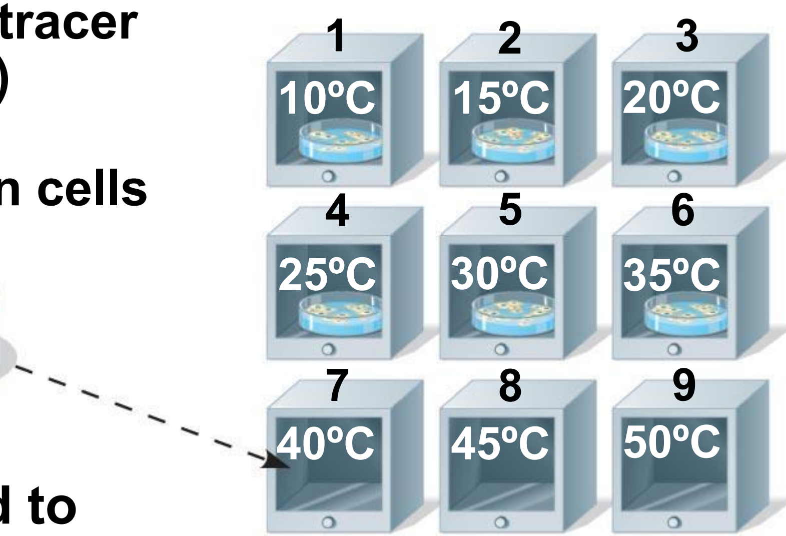


Fig. 2-6a

TECHNIQUE





1 Human cells are incubated with compounds used to make DNA. One compound is labeled with ^{3}H.

2 The cells are placed in test tubes; their DNA is isolated; and unused labeled compounds are removed.

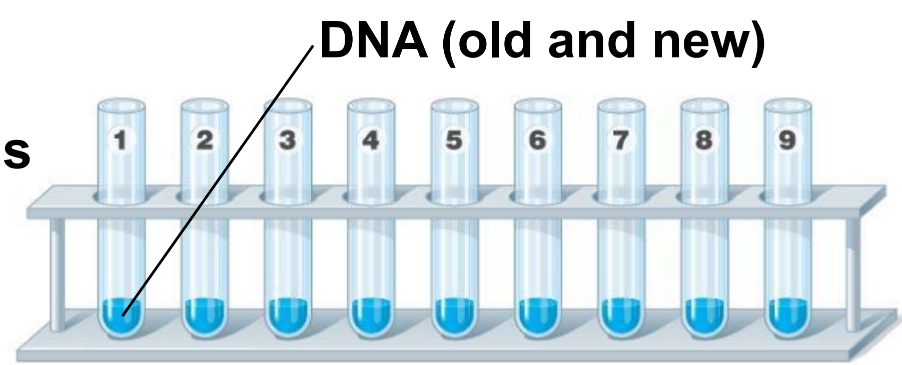


Fig. 2-6b

TECHNIQUE

3 **The test tubes are placed in a scintillation counter.**

Fig. 2-6c

RESULTS

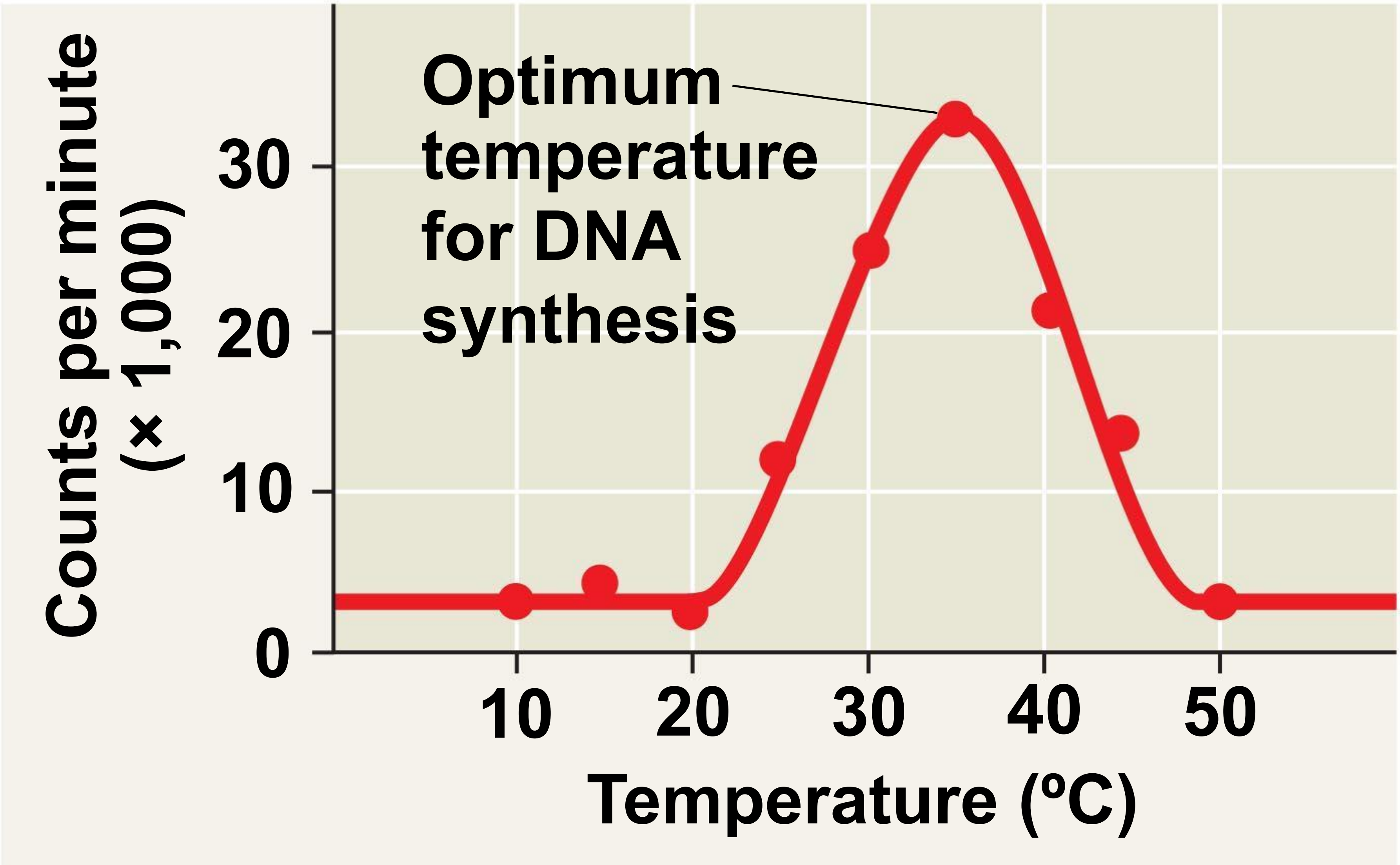
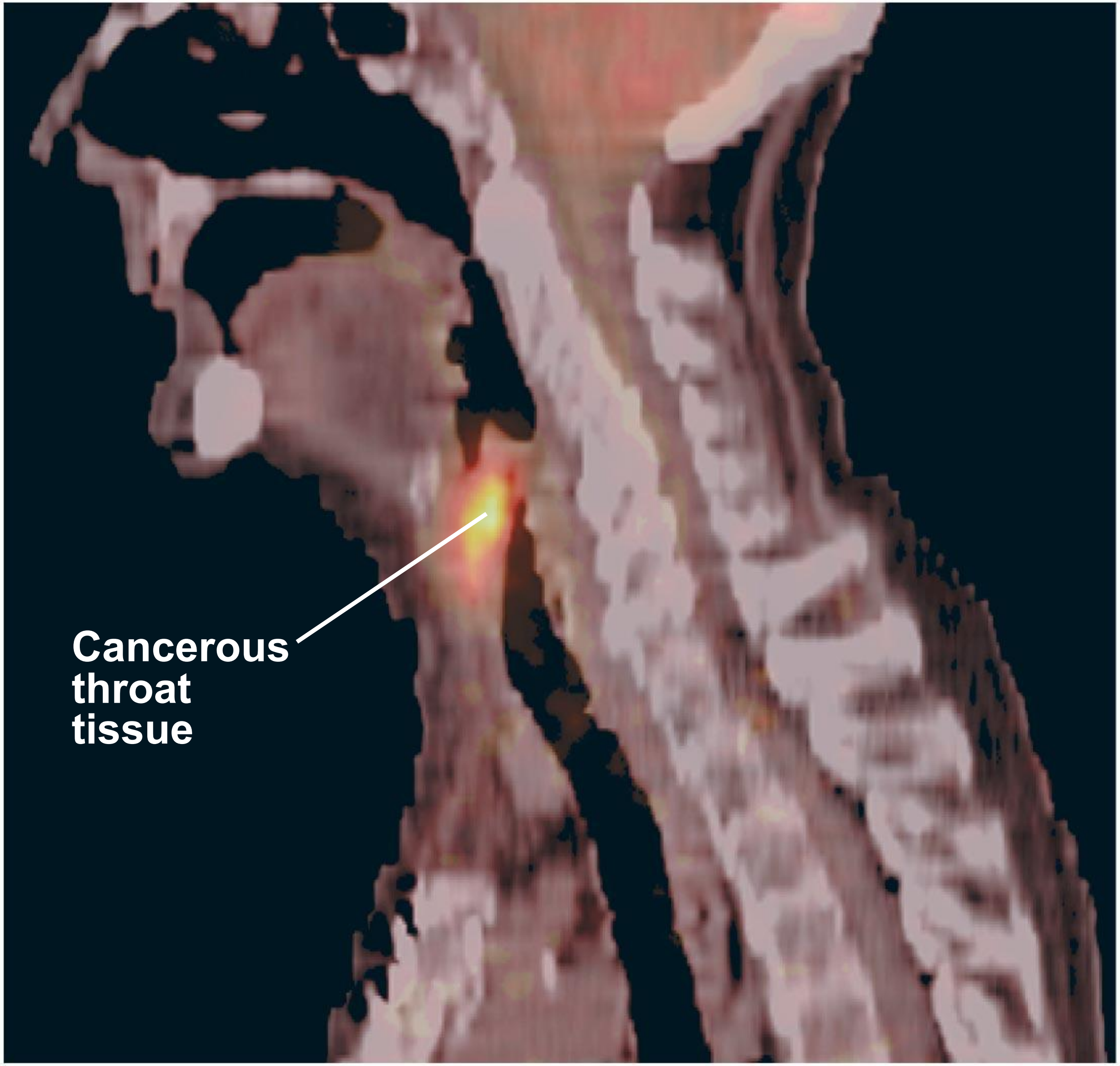


Fig. 2-7

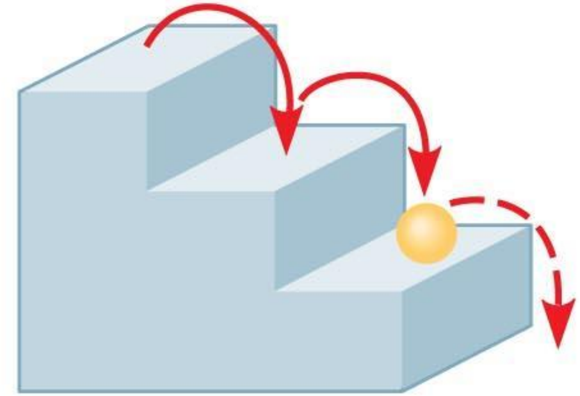


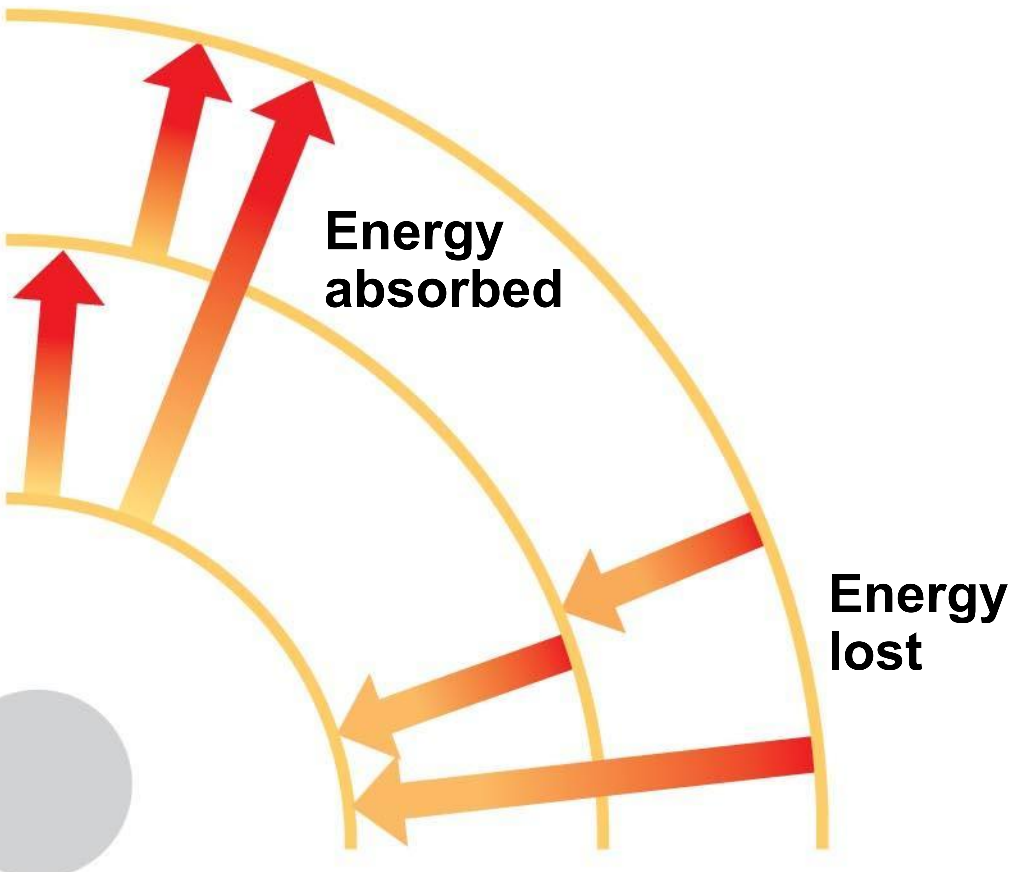
The Energy Levels of Electrons

- **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**

Fig. 2-8

(a) A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons



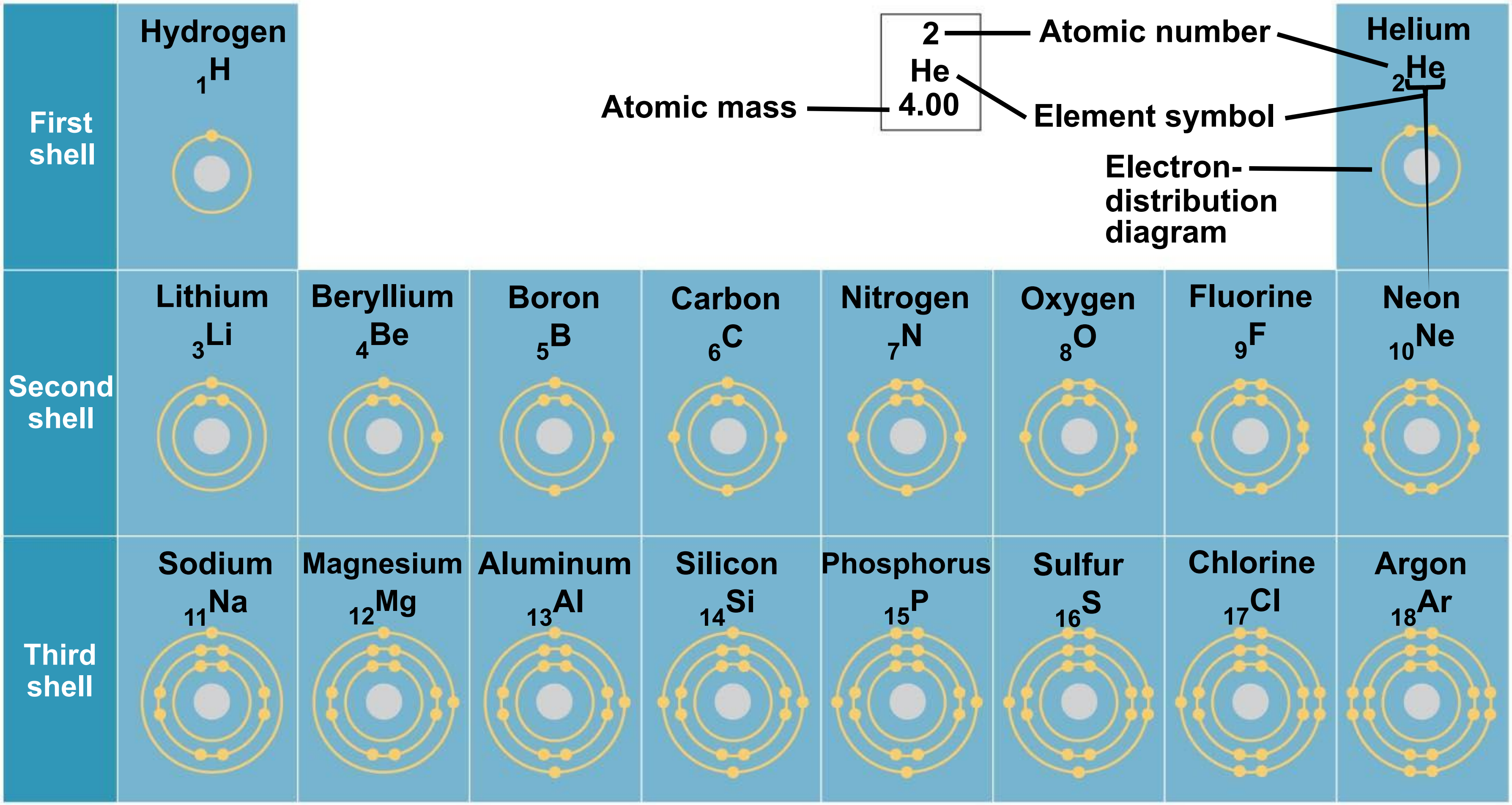


(b)

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

Fig. 2-9



First shell
Second shell
Third shell
Hydrogen
$_1H$
Helium
$_2He$
2
He
4.00
Atomic number
Element symbol
Atomic mass
Electron-distribution diagram
Lithium
$_3Li$
Beryllium
$_4Be$
Boron
$_5B$
Carbon
$_6C$
Nitrogen
$_7N$
Oxygen
$_8O$
Fluorine
$_9F$
Neon
$_{10}Ne$
Sodium
$_{11}Na$
Magnesium
$_{12}Mg$
Aluminum
$_{13}Al$
Silicon
$_{14}Si$
Phosphorus
$_{15}P$
Sulfur
$_{16}S$
Chlorine
$_{17}Cl$
Argon
$_{18}Ar$

- **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

Fig. 2-10-1

(a) Electron-distribution diagram

Neon, with two filled shells (10 electrons)

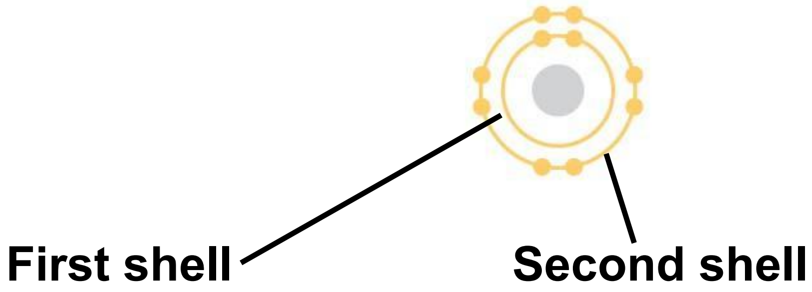


Fig. 2-10-2

Neon, with two filled shells (10 electrons)

(a) Electron-distribution diagram

(b) Separate electron orbitals

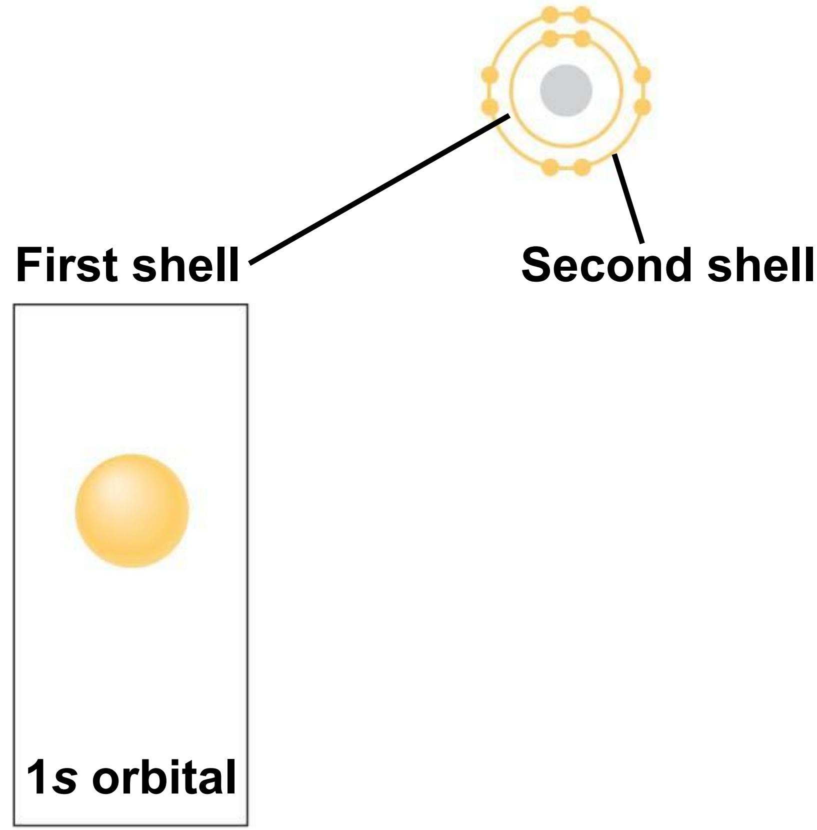


Fig. 2-10-3

(a) Electron-distribution diagram

(b) Separate electron orbitals

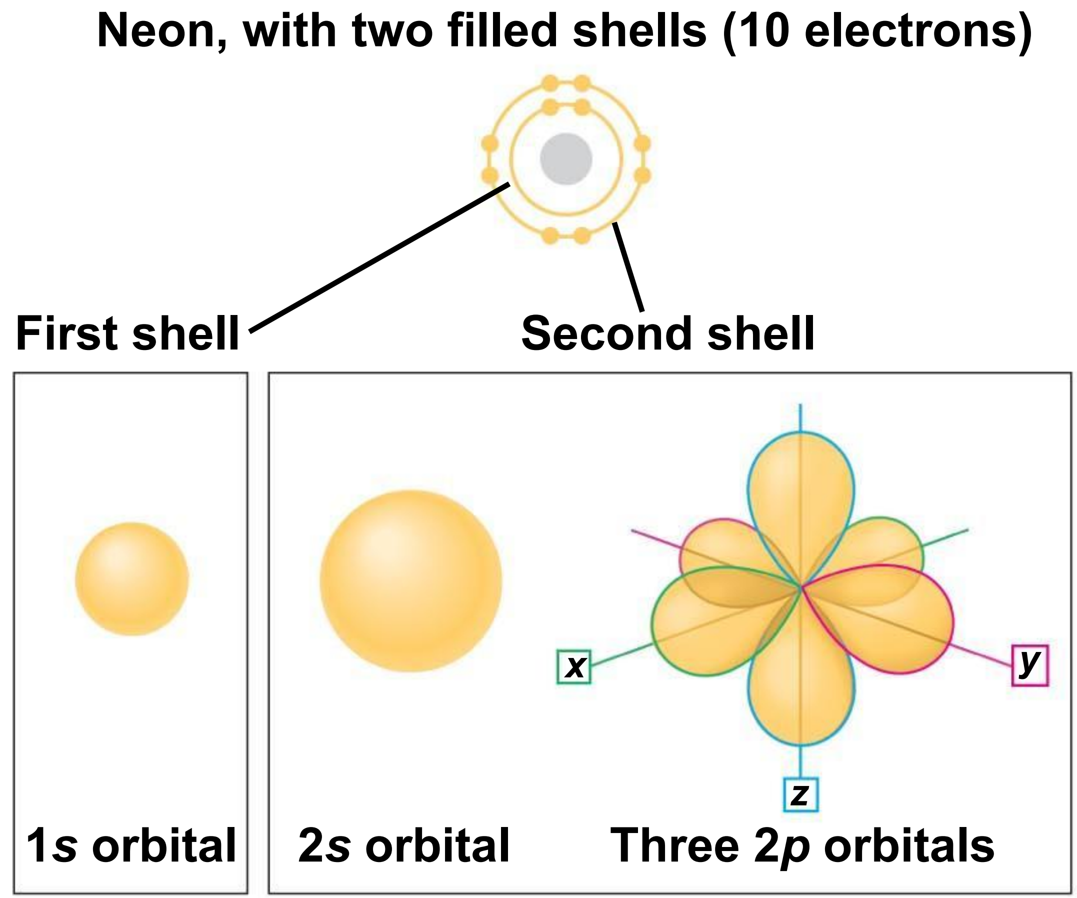
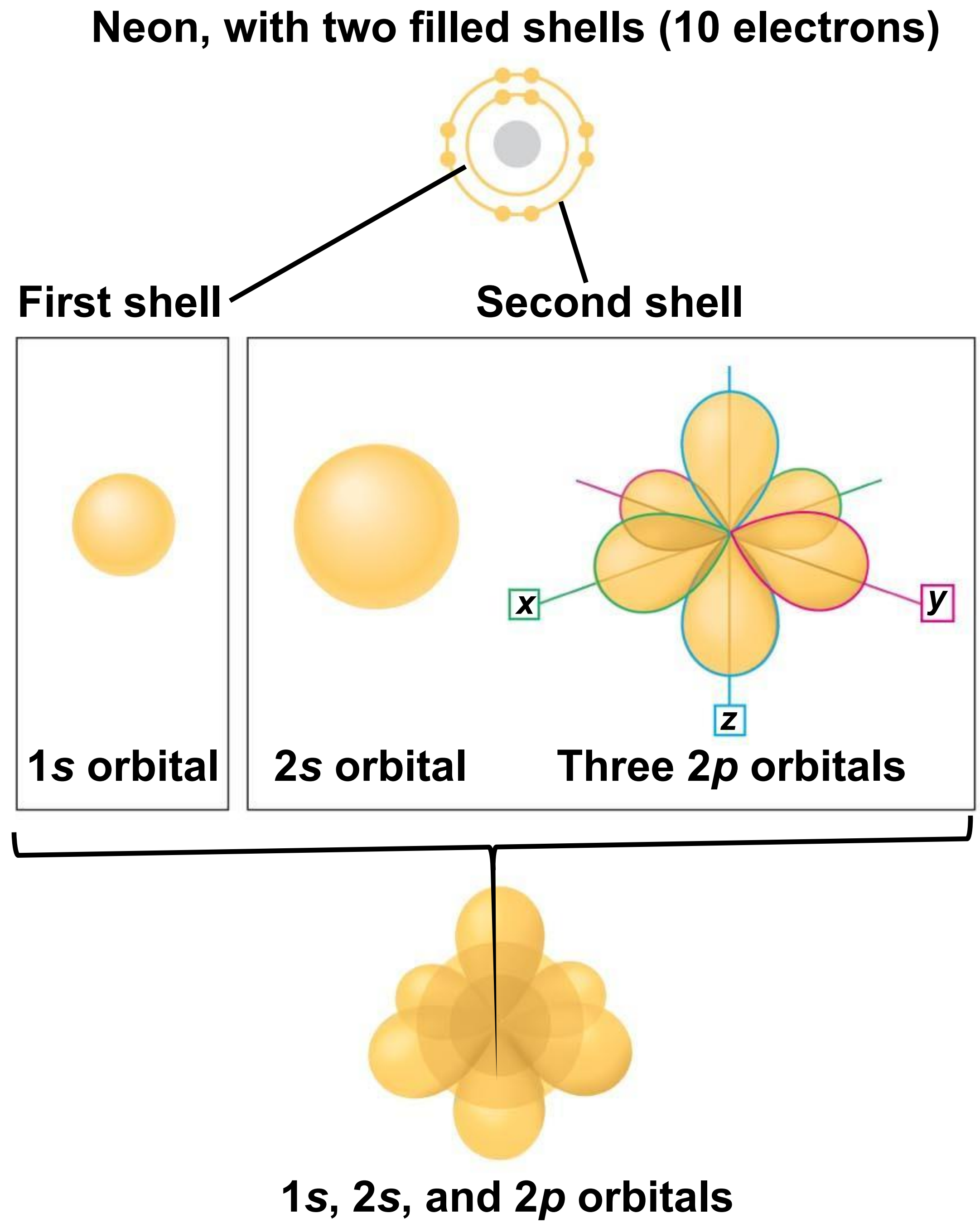


Fig. 2-10-4

(a) Electron-distribution diagram

(b) Separate electron orbitals

(c) Superimposed electron orbitals



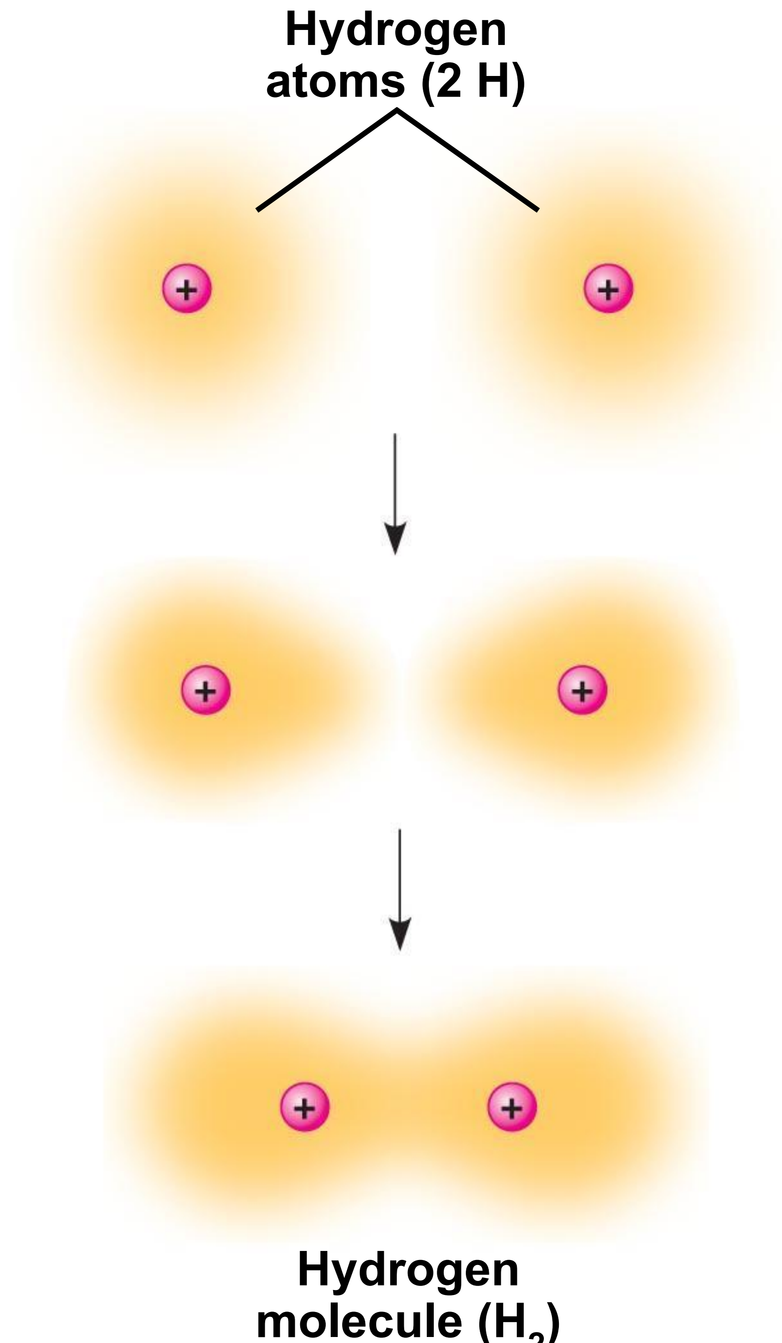
Concept 2.3: The formation and function of molecules depend on chemical bonding between atoms

- 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

Fig. 2-11



- 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

PLAY Animation: Covalent Bonds

Fig. 2-12

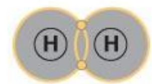
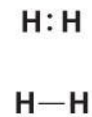
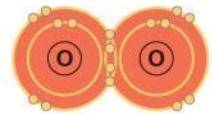
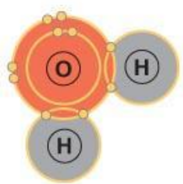
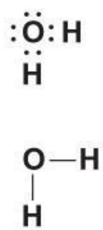
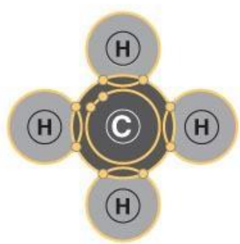
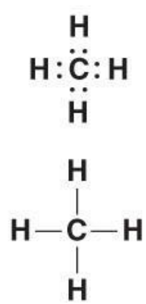
Name and Molecular Formula	Electron-distribution Diagram	Lewis Dot Structure and Structural Formula	Space-filling Model
(a) Hydrogen (H_2)			
(b) Oxygen (O_2)			
(c) Water (H_2O)			
(d) Methane (CH_4)			

Fig. 2-12a

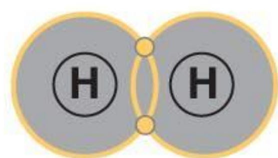
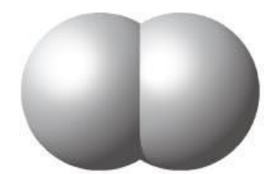
Name and Molecular Formula	Electron-distribution Diagram	Lewis Dot Structure and Structural Formula	Space-filling Model
(a) Hydrogen (H_2)		H:H H—H	

Fig. 2-12b

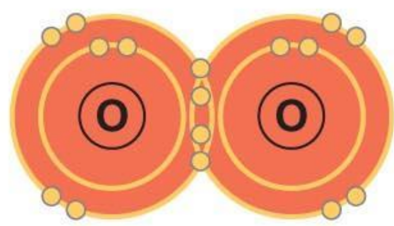
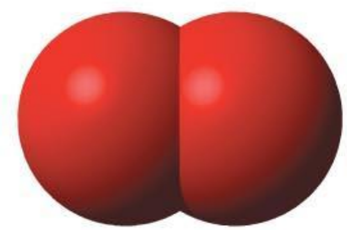
Name and Molecular Formula	Electron-distribution Diagram	Lewis Dot Structure and Structural Formula	Space-filling Model
(b) Oxygen (O_2)			

Fig. 2-12c

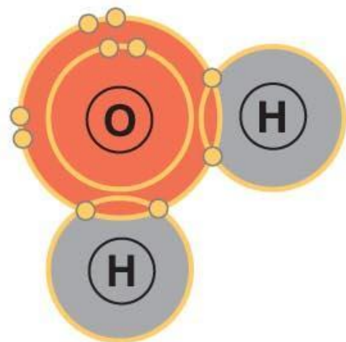
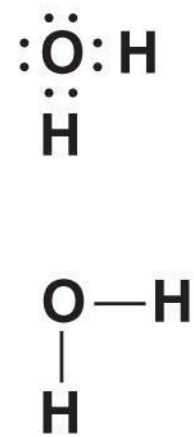
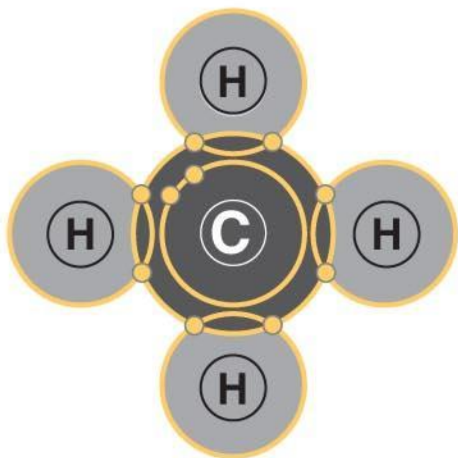
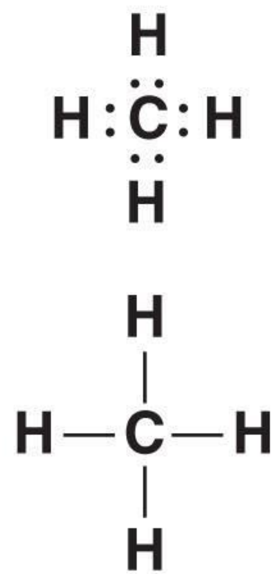
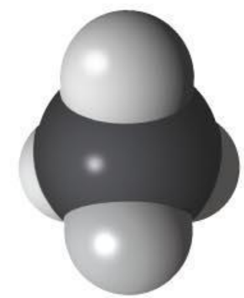
Name and Molecular Formula	Electron-distribution Diagram	Lewis Dot Structure and Structural Formula	Space-filling Model
(c) Water (H_2O)			

Fig. 2-12d

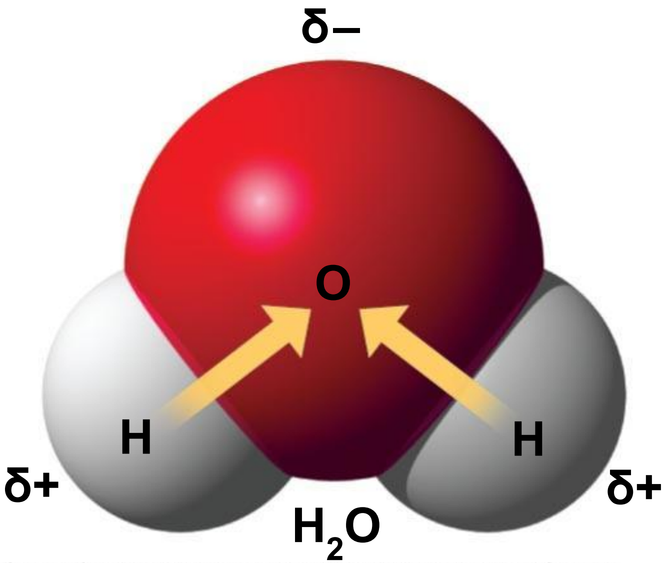
Name and Molecular Formula	Electron-distribution Diagram	Lewis Dot Structure and Structural Formula	Space-filling Model
(d) Methane (CH_4)			

- 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**

- **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

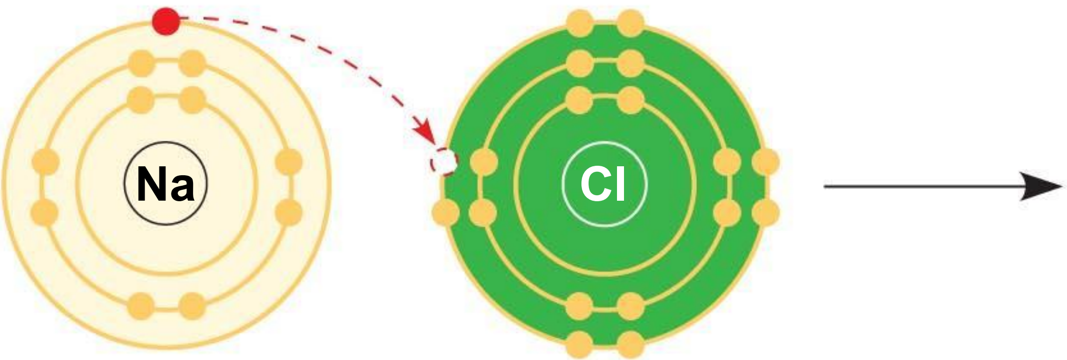
Fig. 2-13



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**

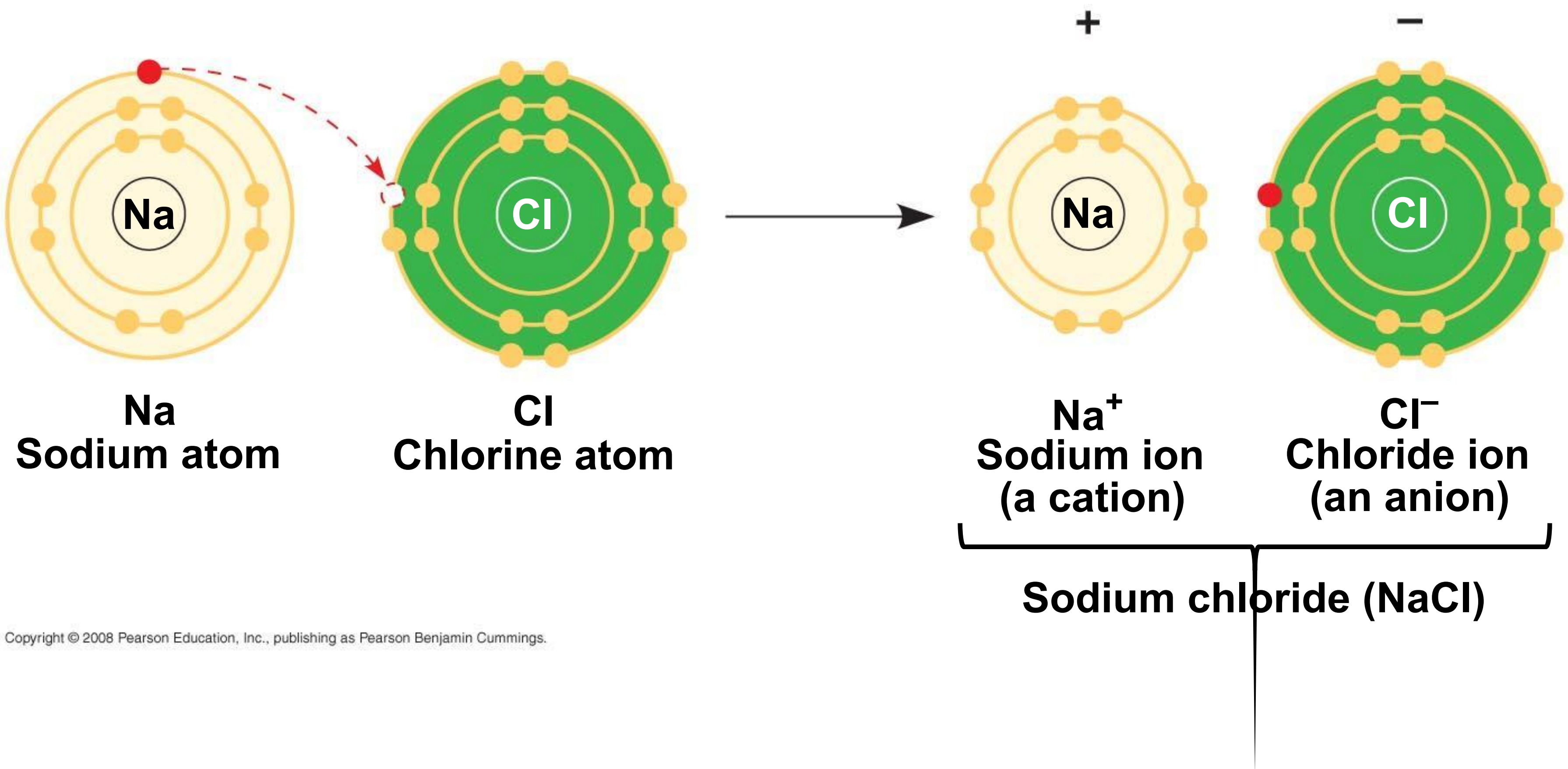
Fig. 2-14-1



Na
Sodium atom

Cl
Chlorine atom

Fig. 2-14-2

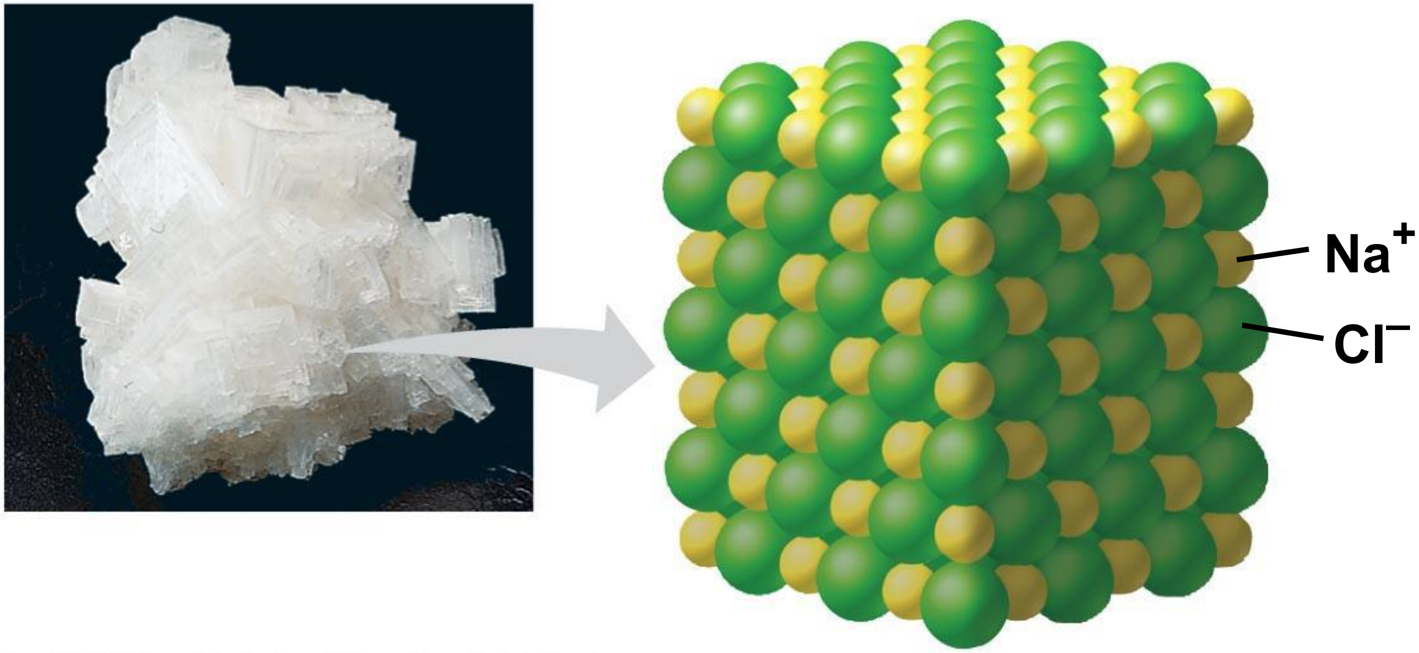

Na
Cl
+
−
Na
Cl
Na
Sodium atom
Cl
Chlorine atom
Na+
Sodium ion
(a cation)
Cl−
Chloride ion
(an anion)
Sodium chloride (NaCl)

- 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

PLAY **Animation: Ionic Bonds**

- 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

Fig. 2-15



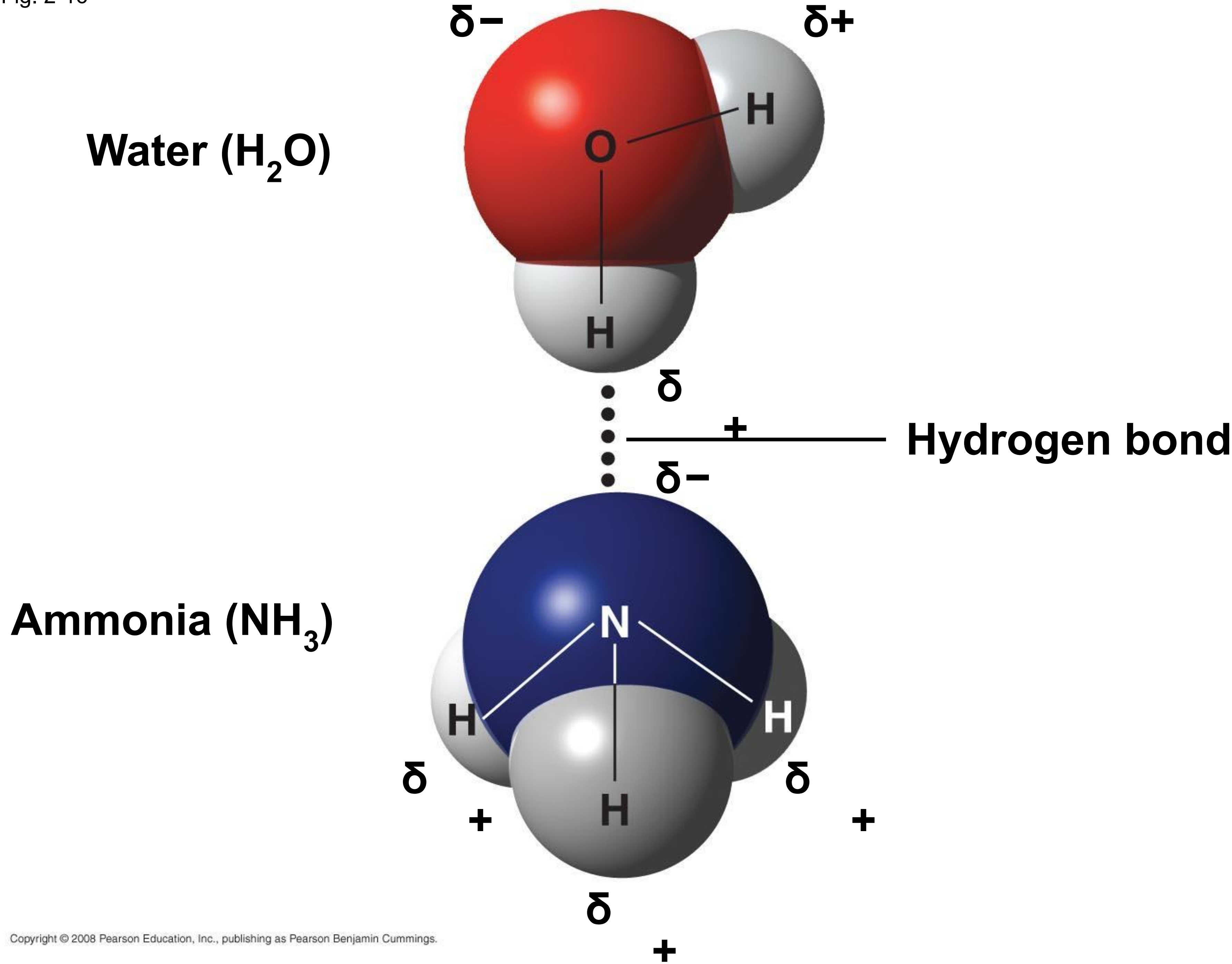
Weak Chemical Bonds

- Most of the strongest bonds in organisms are covalent bonds that form a cell's molecules
- Weak chemical bonds, such as ionic bonds and hydrogen bonds, are also important
- Weak chemical bonds reinforce shapes of large molecules and help molecules adhere to each other

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

Fig. 2-16

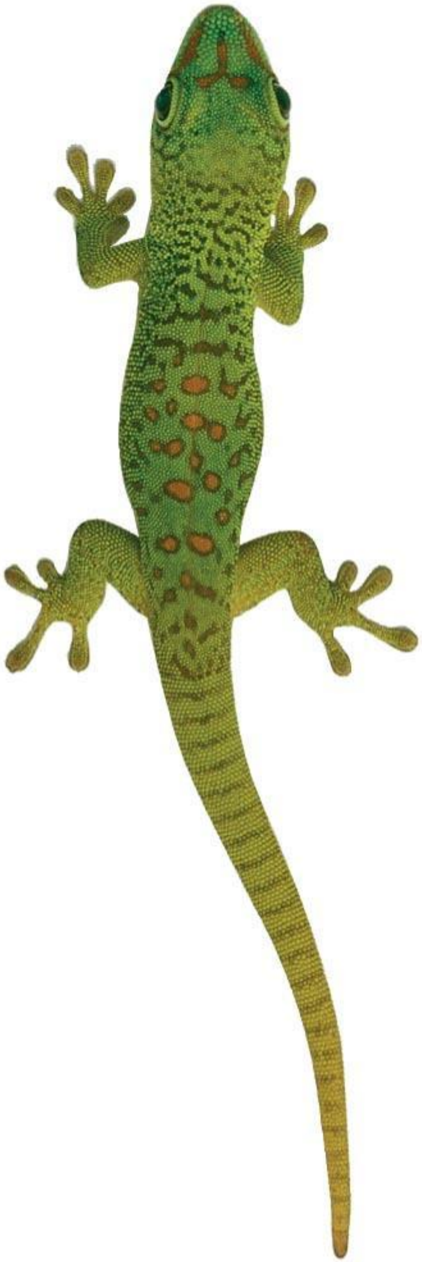


Van der Waals Interactions

- If electrons are distributed asymmetrically in molecules or atoms, they can result in “hot spots” of positive or negative charge
- **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

Fig. 2-UN1



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' valence orbitals
- In a covalent bond, the *s* and *p* orbitals may hybridize, creating specific molecular shapes

Fig. 2-17

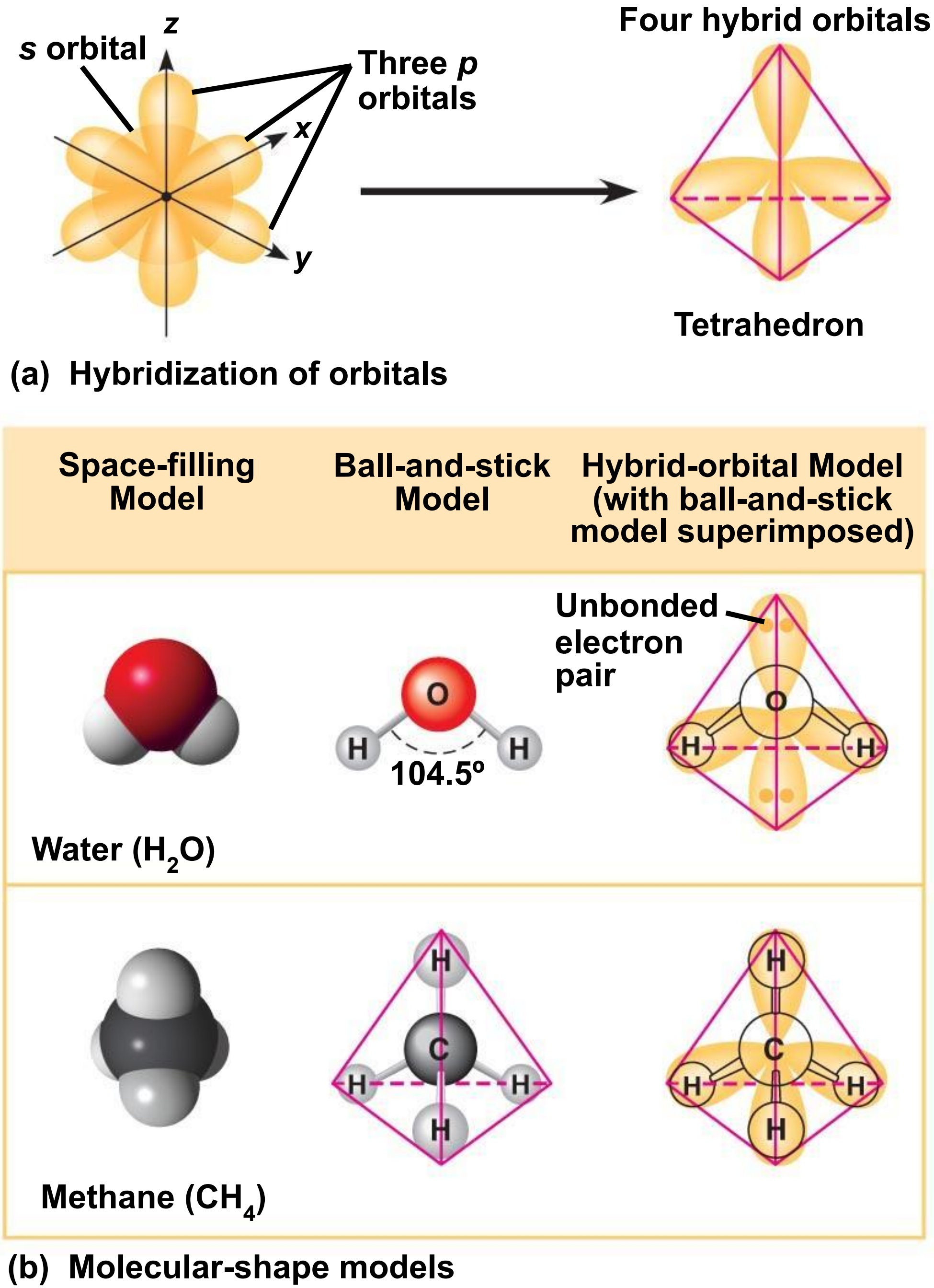
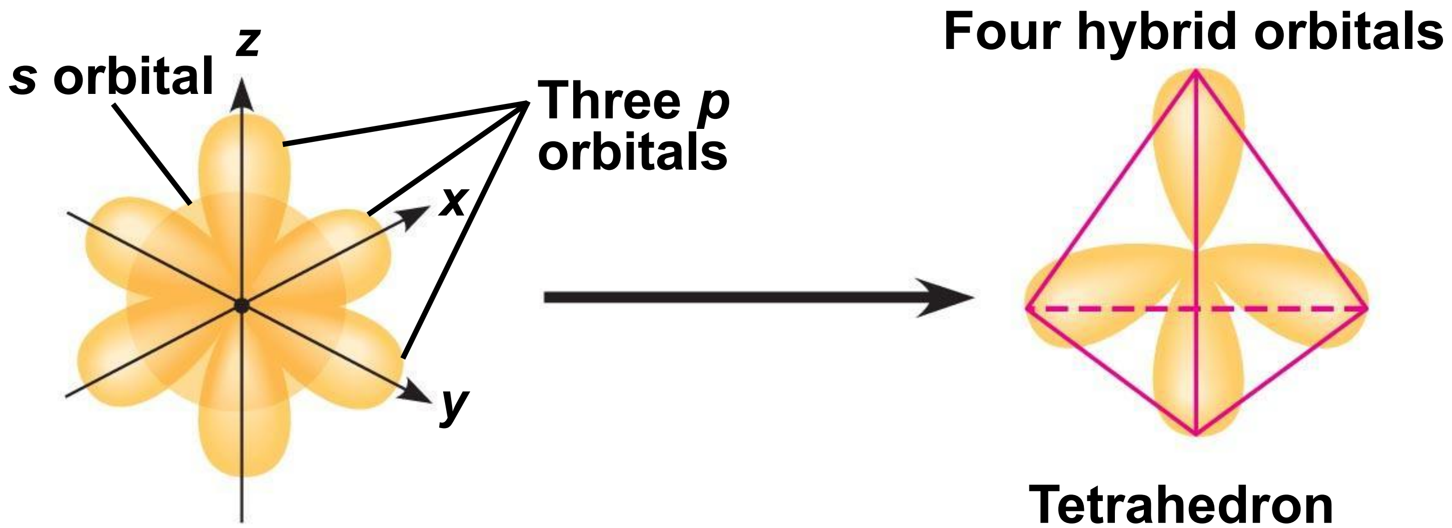
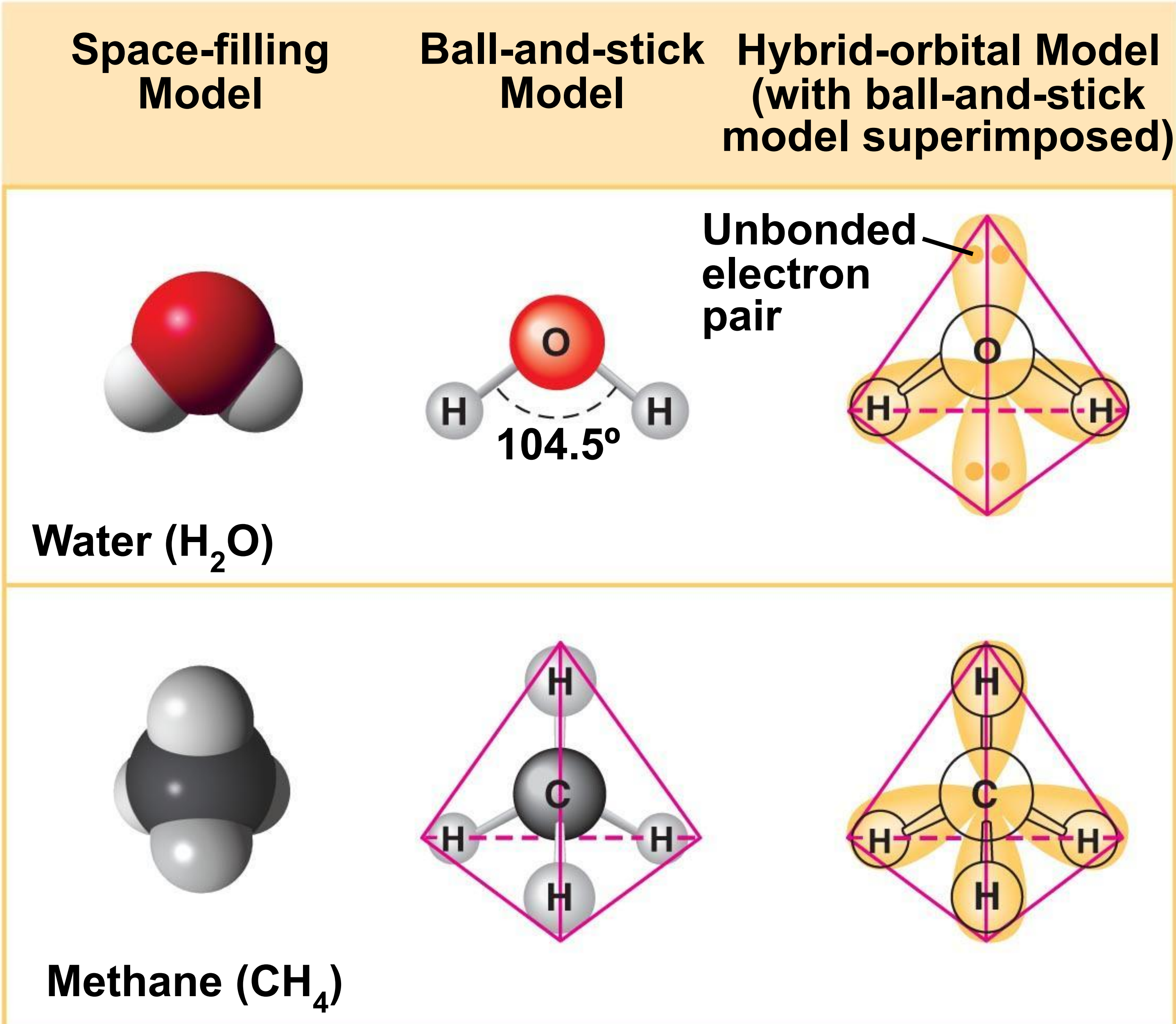

s orbital
z
x
y
Three p orbitals
Four hybrid orbitals
Tetrahedron
(a) Hybridization of orbitals
Space-filling Model
Ball-and-stick Model
Hybrid-orbital Model (with ball-and-stick model superimposed)
Unbonded electron pair
O
H
H
104.5º
O
H
H
Water (H_2O)
H
C
H
H
H
H
C
H
H
H
Methane (CH_4)
(b) Molecular-shape models

Fig. 2-17a



(a) Hybridization of orbitals

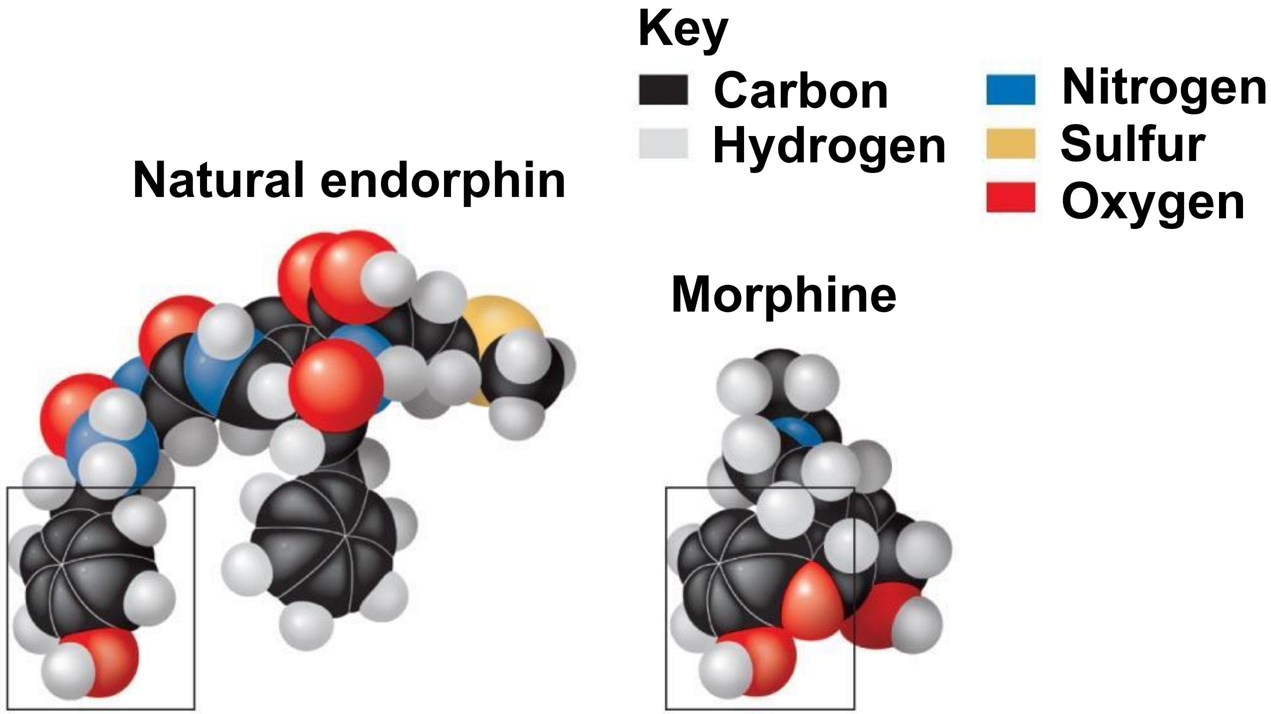
Fig. 2-17b



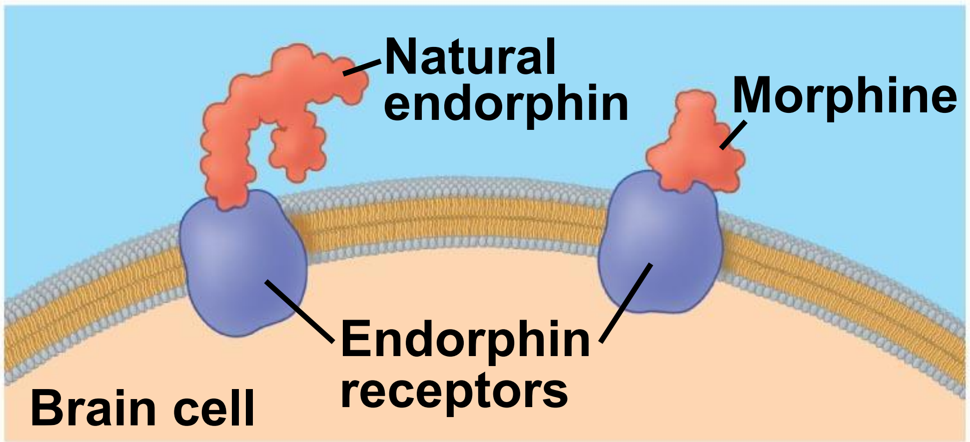
(b) Molecular-shape models

- Biological molecules recognize and interact with each other with a specificity based on molecular shape
- Molecules with similar shapes can have similar biological effects

Fig. 2-18

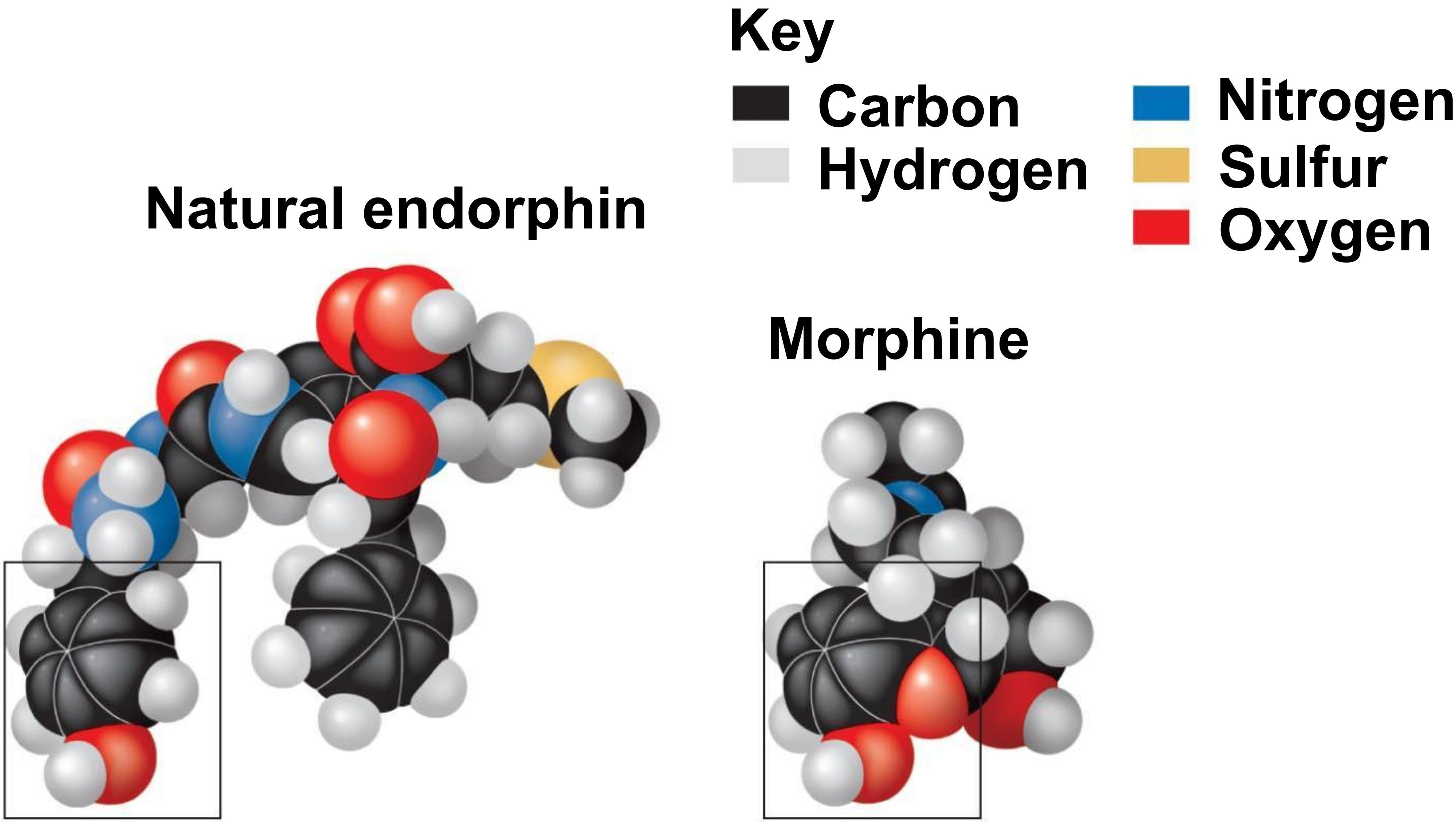


(a) Structures of endorphin and morphine



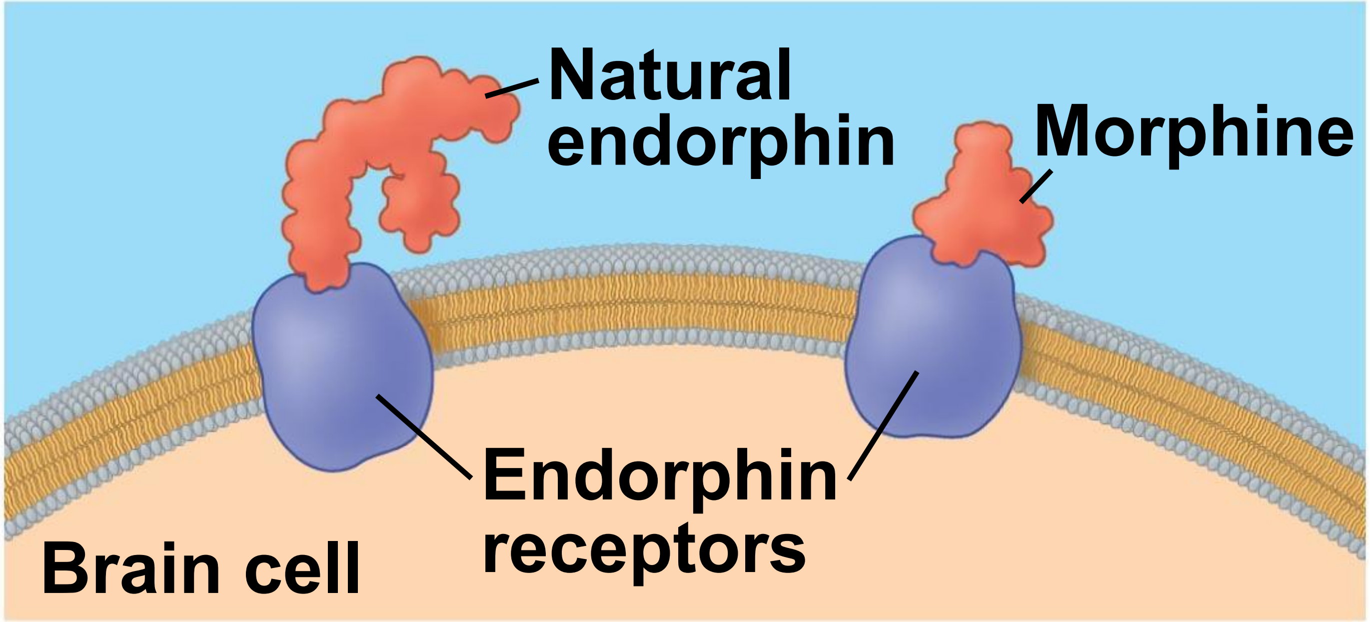
(b) Binding to endorphin receptors

Fig. 2-18a



(a) Structures of endorphin and morphine

Fig. 2-18b

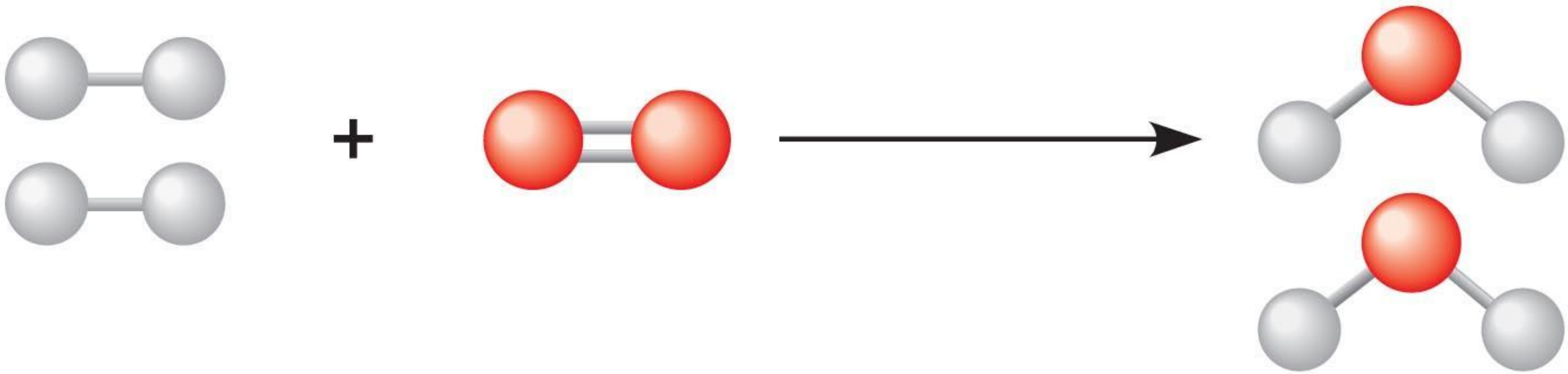


(b) Binding to endorphin receptors

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**

Fig. 2-UN2



$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

Reactants Reaction Products

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

$$6\ CO_2 + 6\ H_20 \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Fig. 2-19

- Some chemical reactions go to completion: all reactants are converted to products
- 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 reaction rates are equal

Fig. 2-UN3

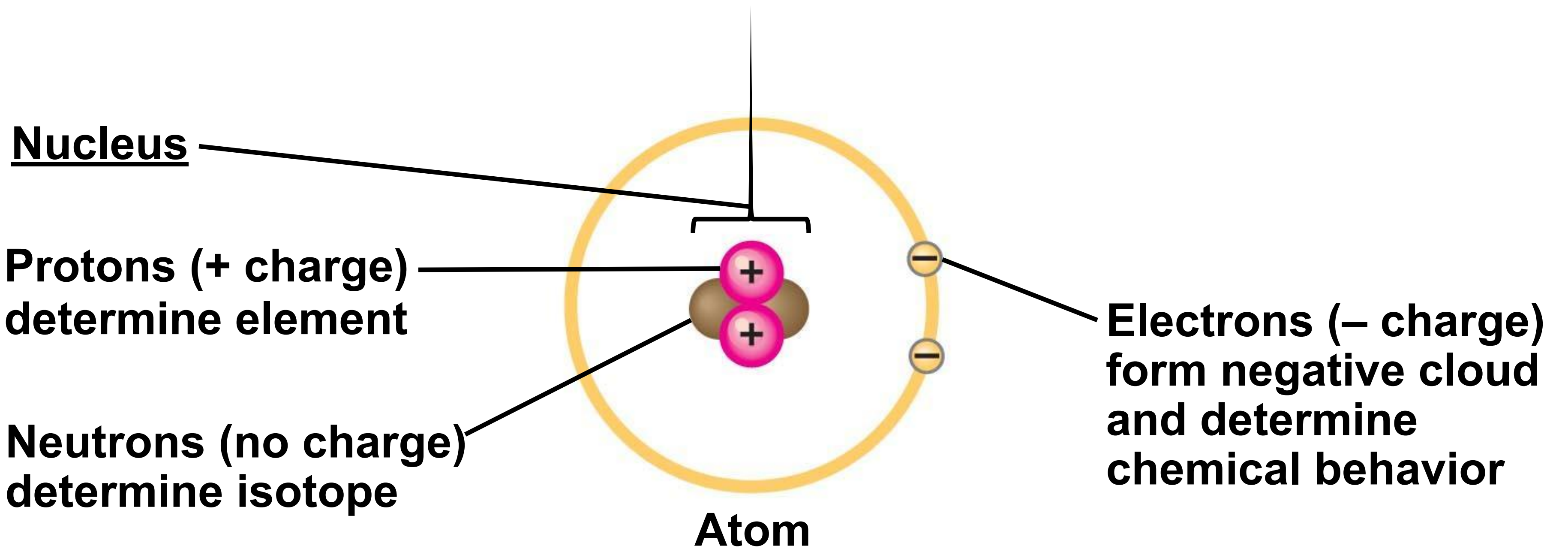

Nucleus
Protons (+ charge)
determine element
Neutrons (no charge)
determine isotope
Electrons (– charge)
form negative cloud
and determine
chemical behavior
Atom

Fig. 2-UN4

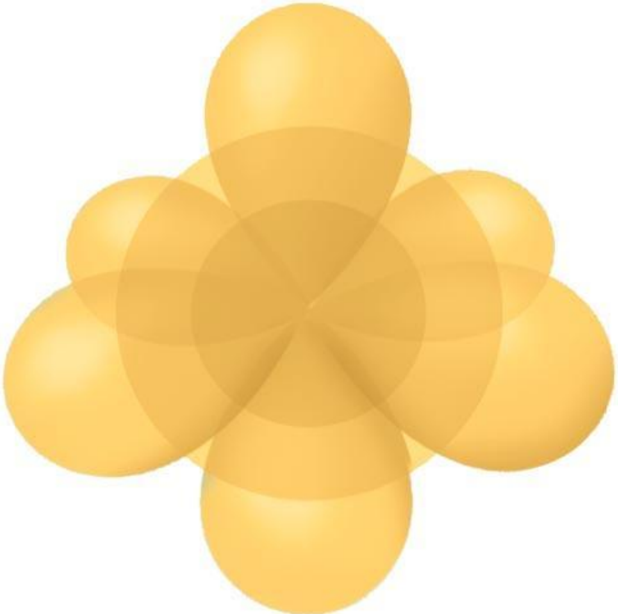


Fig. 2-UN5

Single covalent bond

Double covalent bond

Fig. 2-UN6

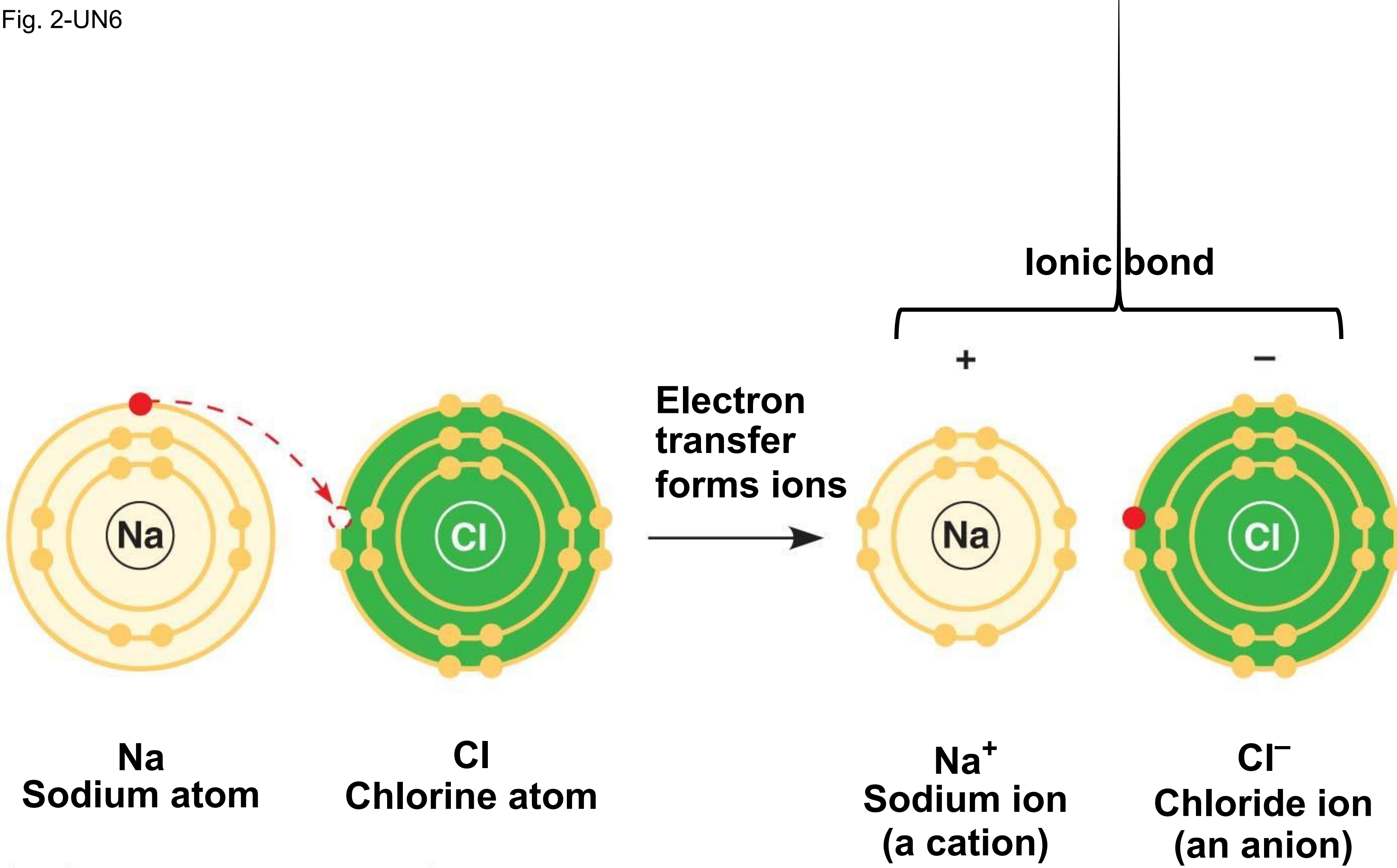
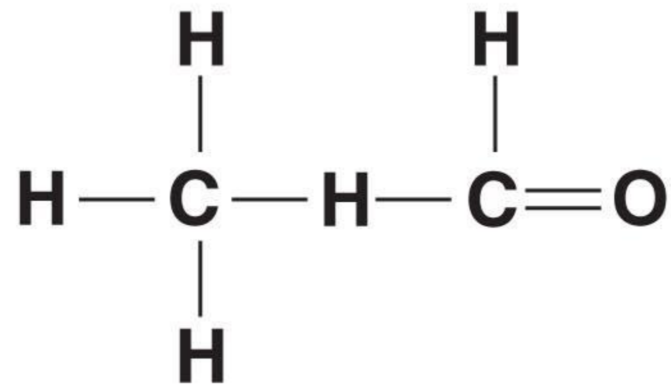
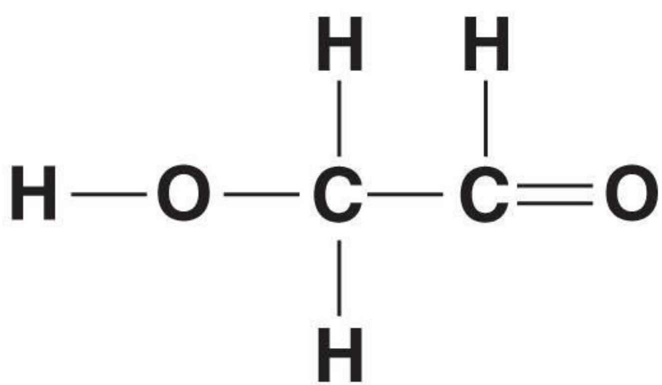

Ionic bond
+
−
Electron transfer forms ions
Na
Cl
Na
Cl
Na
Sodium atom
Cl
Chlorine atom
Na^+
Sodium ion
(a cation)
Cl^-
Chloride ion
(an anion)

Fig. 2-UN7

a.

c.





b.

d.

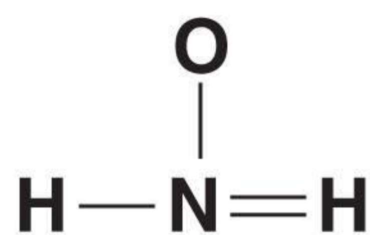


Fig. 2-UN8

Fig. 2-UN9

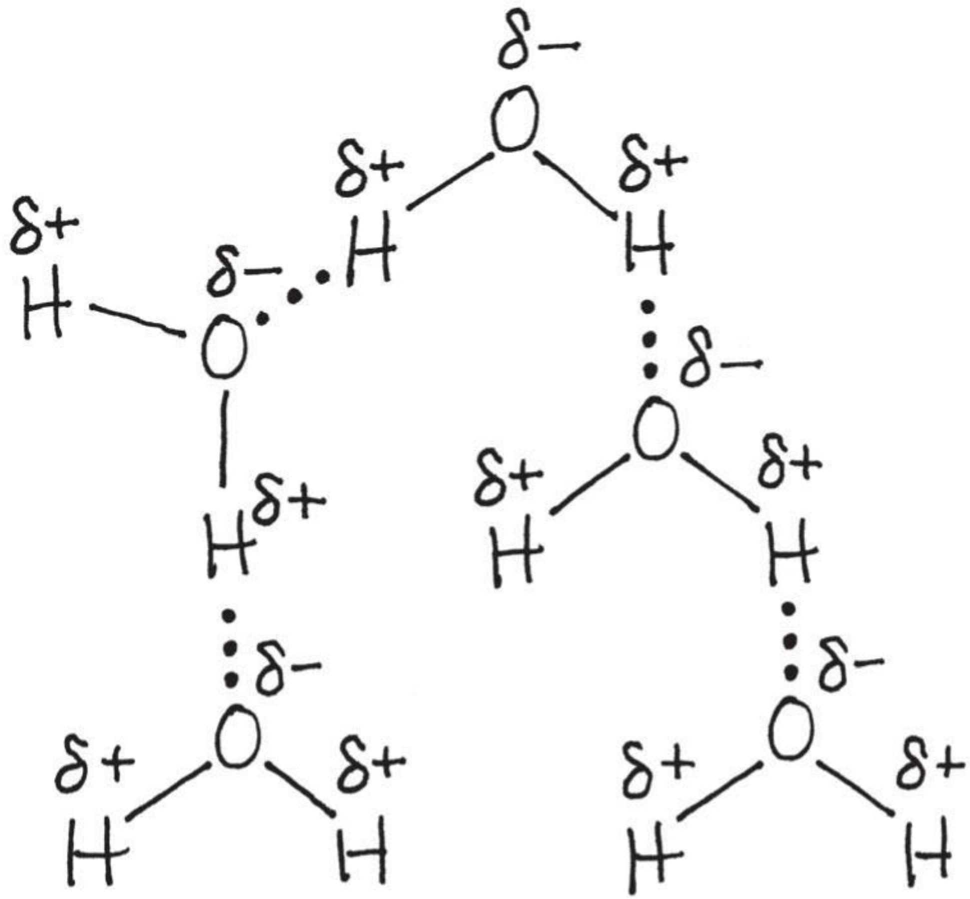


Fig. 2-UN10

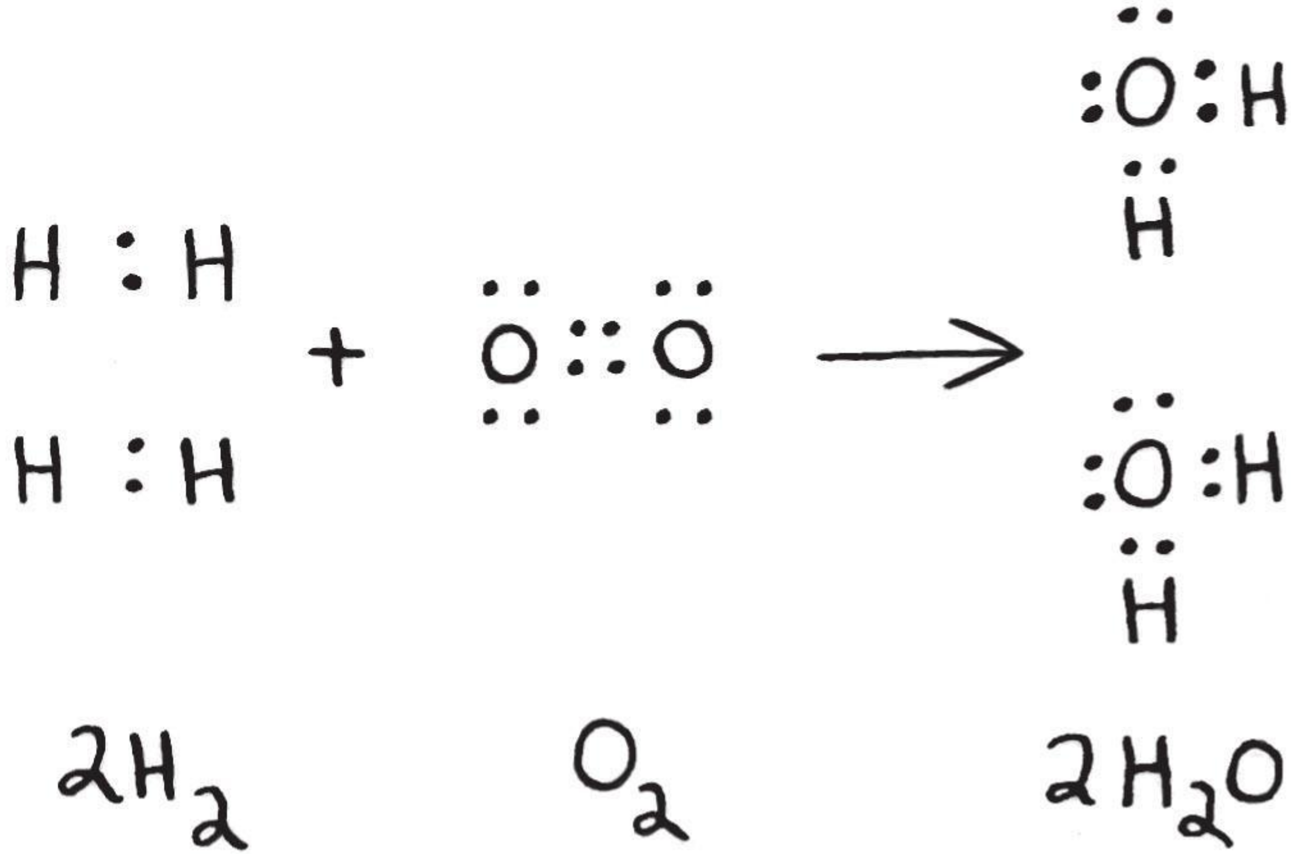
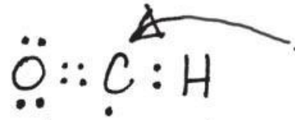
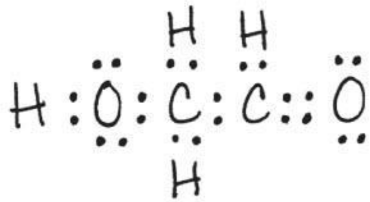


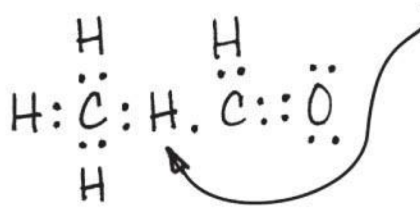
Fig. 2-UN11

a. 

This structure doesn't make sense because the valence shell of carbon is incomplete; carbon can form 4 bonds.

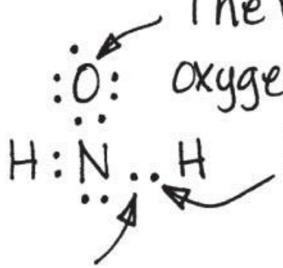
b. 

This structure makes sense because all valence shells are complete, and all bonds have the correct number of electrons.

c. 

This structure doesn't make sense because H has only 1 electron to share, so it cannot form bonds with 2 atoms.

d. This structure doesn't make sense for several reasons:



The valence shell of oxygen is incomplete; oxygen can form 2 bonds.

H has only 1 electron to share, so it cannot form a double bond.

Nitrogen usually makes only 3 bonds. It does not have enough electrons to make 2 single bonds, make a double bond, and complete its valence shell.

You should now be able to:

1. Identify the four major elements
2. Distinguish between the following pairs of terms: neutron and proton, atomic number and mass number, atomic weight and mass number
3. Distinguish between and discuss the biological importance of the following: nonpolar covalent bonds, polar covalent bonds, ionic bonds, hydrogen bonds, and van der Waals interactions