Chapter 2

The Chemical Context of Life

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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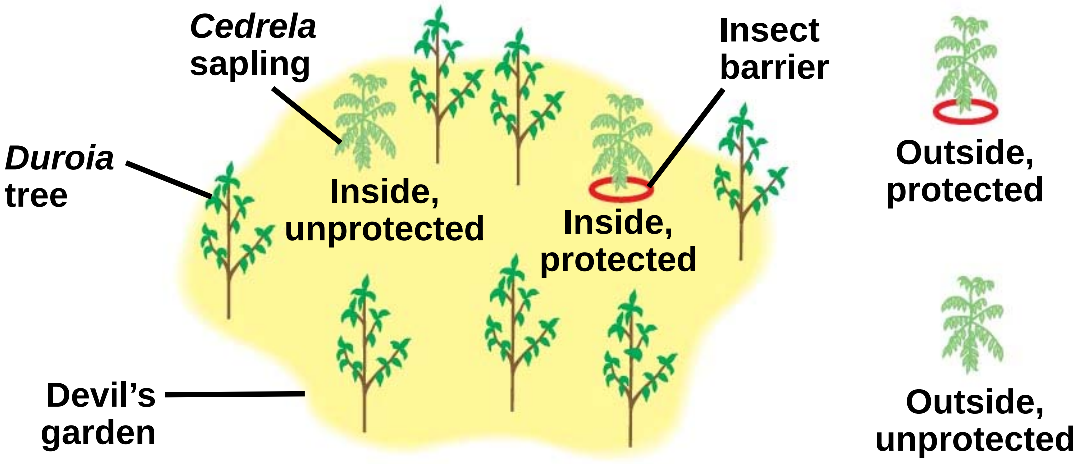
Overview: A Chemical Connection to Biology

- 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

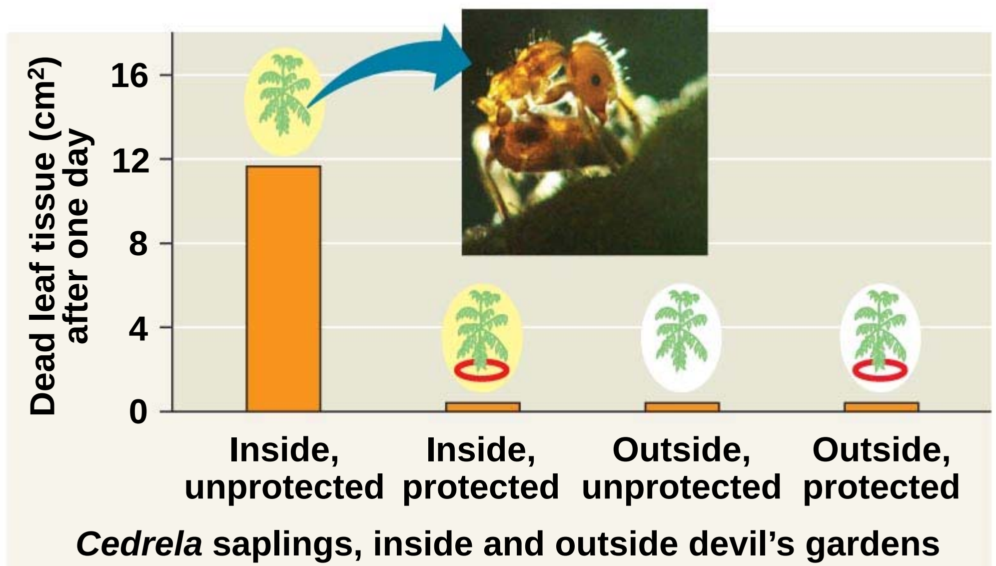


Fig. 2-UN8

Male silkworm moth

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

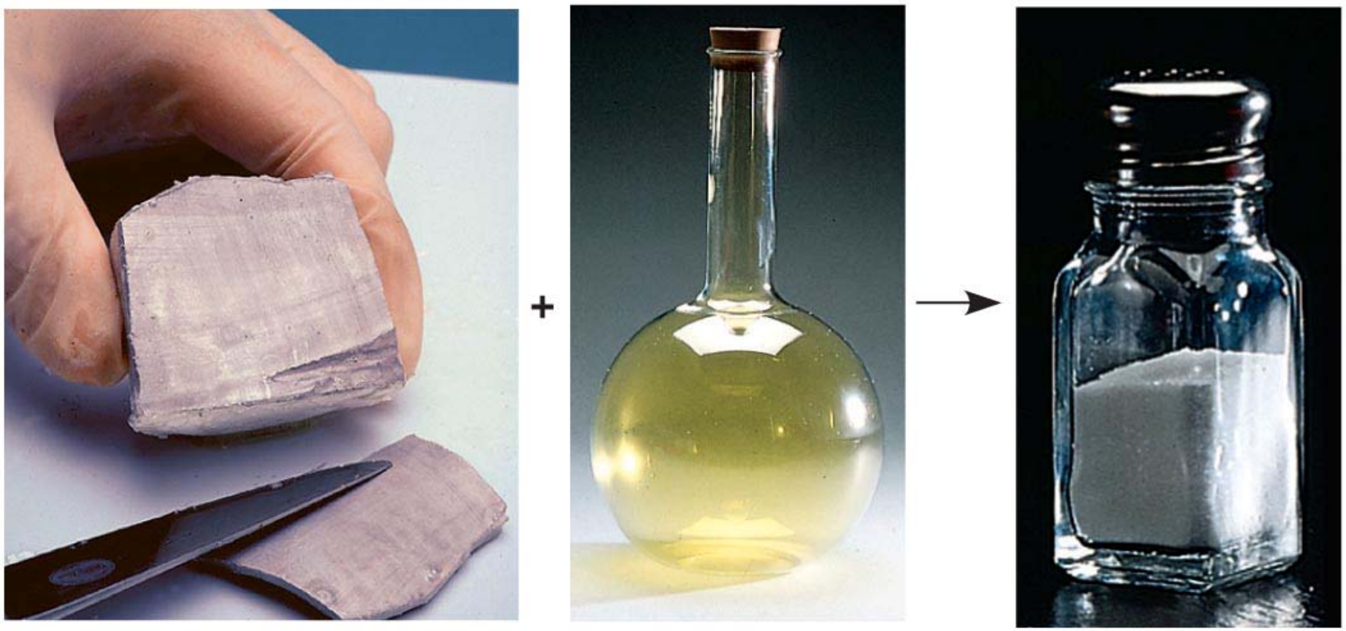
- Organisms are composed of **matter**
- Matter is anything that takes up space and has mass

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

The emergent properties of a compound



Sodium

Chlorine

Sodium chloride

Essential Elements of Life

- About 25 of the 92 elements are essential to life
- Carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) 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

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

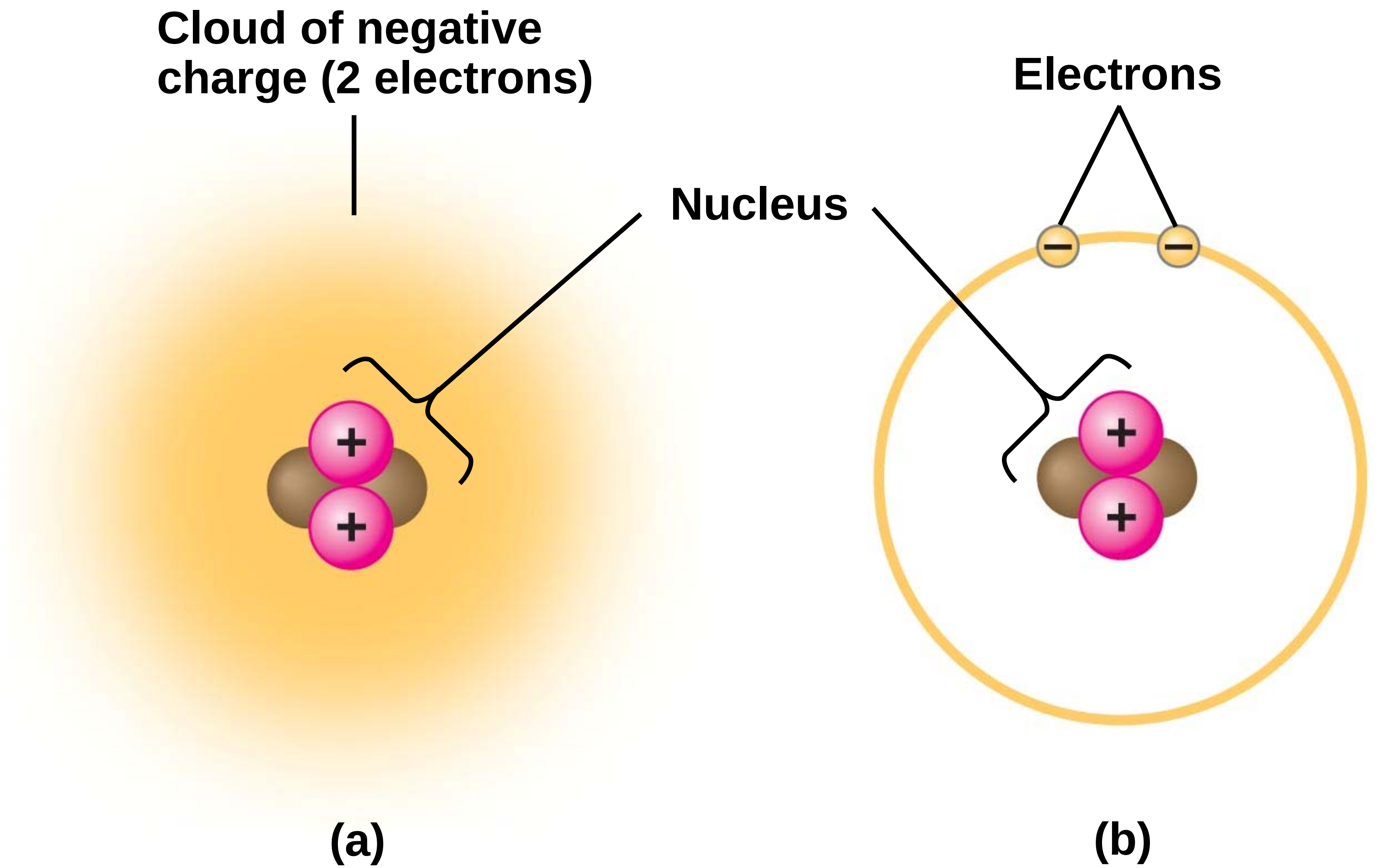
Subatomic Particles

- 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** (1.7×10^{-24} gram)

Fig. 2-5

Simplified models of a helium (He) atom



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

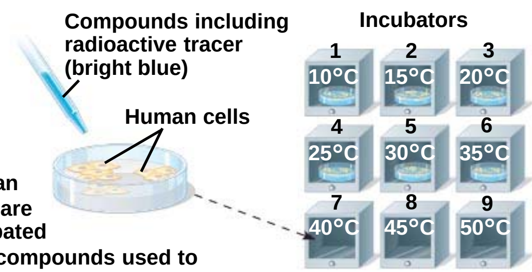
- All atoms of an element have the same number of protons but may differ in number of neutrons
- **Isotopes** are two atoms of an element that differ in number of neutrons
- **Radioactive isotopes** decay spontaneously, giving off particles and energy

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

Fig. 2-6

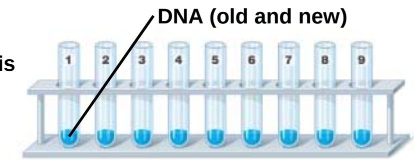
TECHNIQUE

Radioactive tracers



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.



3 The test tubes are placed in a scintillation counter.

RESULTS

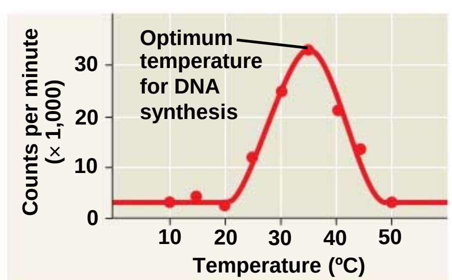
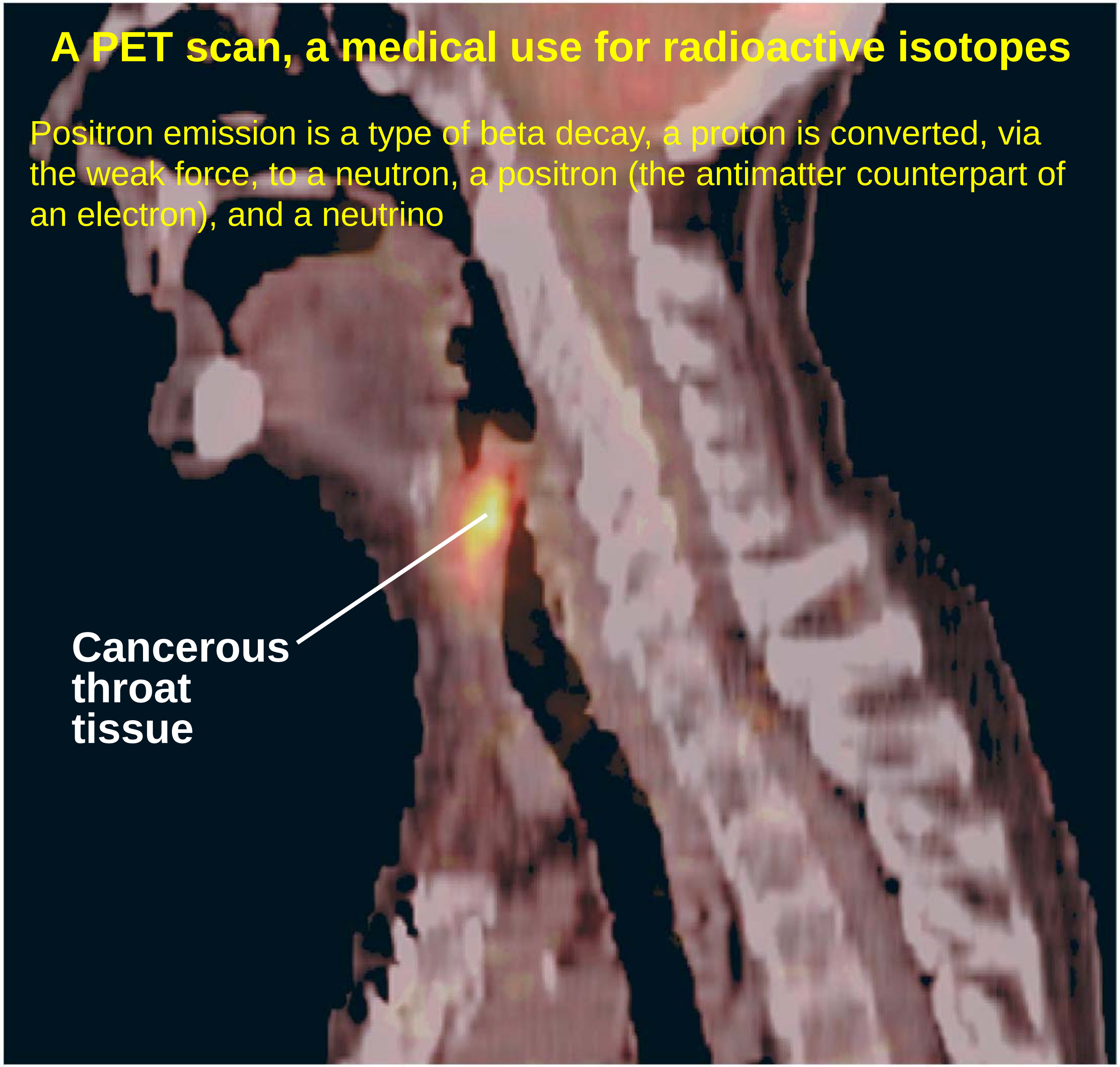


Fig. 2-7

A PET scan, a medical use for radioactive isotopes

Positron emission is a type of beta decay, a proton is converted, via the weak force, to a neutron, a positron (the antimatter counterpart of an electron), and a neutrino



生物學

核子試爆給的生物線索

原子彈試爆讓嬰兒潮世代的年齡不再是謎

撰文／索拉斯（Christine Soares）

地表上的核彈試爆導致大氣層中^{14}C激增900%，在人類組織內留下了可以用來定年的微量標記。

然後弗瑞森得知1955年後出生的人，體內都帶有天然標記。自1955年到1963年制訂「核子武器部份限定條約」為止，許多在地面上進行的核子武器試爆，釋放出大量的碳14（^{14}C）同位素到大氣中，這些^{14}C很快飄浮擴散到全球，然後植物細胞攝取了^{14}C，動物吃植物，而以動、植物為食的人類，細胞也吸收了同位素，弗瑞森現在可以追查這些^{14}C的蹤跡。

透過測量DNA分子的^{14}C含量，然後比對大氣層中^{14}C含量，弗瑞森終於建立了一套能夠回答細胞年齡疑問的試驗，2004年他將結果發表在《細胞》上，他發現人體中許多部位都比整個身體年輕許多：30多歲的受試者，消化道組織的空腸細胞還不到16歲；快40歲的受試者，其骨骼肌只有15歲。

牙齒的碳14定年法

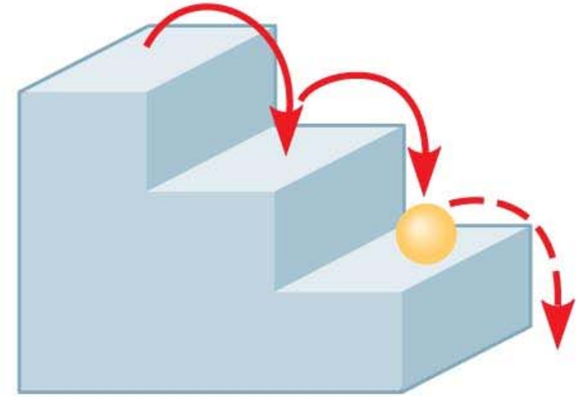
美國勞倫斯利弗摩國家實驗室的布赫茲，以及瑞典斯德哥爾摩諾貝爾醫學研究所的弗瑞森，利用細胞中的DNA含有多少原子彈試爆時代遺留下來的^{14}C，來判定身體組織的年齡。他們試驗中所用的對照組為牙齒琺瑯質，牙齒琺瑯質不含DNA，但0.4%為碳原子，而且是在生命已知特定階段形成的。科學家發現，比對牙齒琺瑯質和大氣層中^{14}C含量，可以估計出受試者的年齡，誤差在1.6年之內。而一般法醫學用牙齒磨損狀態來估計年齡的方法，誤差有5~10年。布赫茲利用牙齒的碳14定年法來幫忙鑑定2004年大海嘯罹難者的身份，他也願意協助卡崔娜颶風受害者的辨識工作。

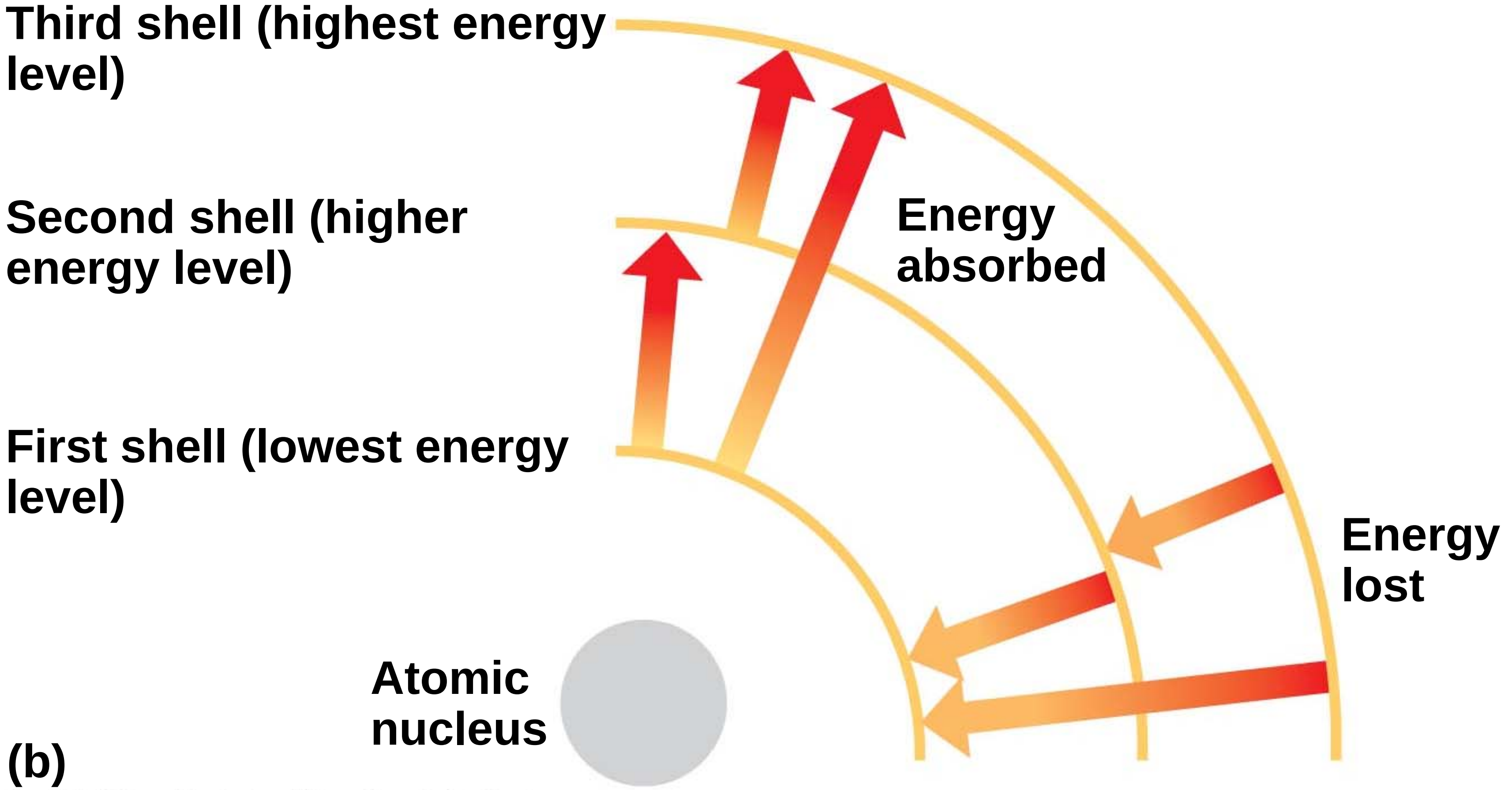
The Energy Levels of Electrons

- **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





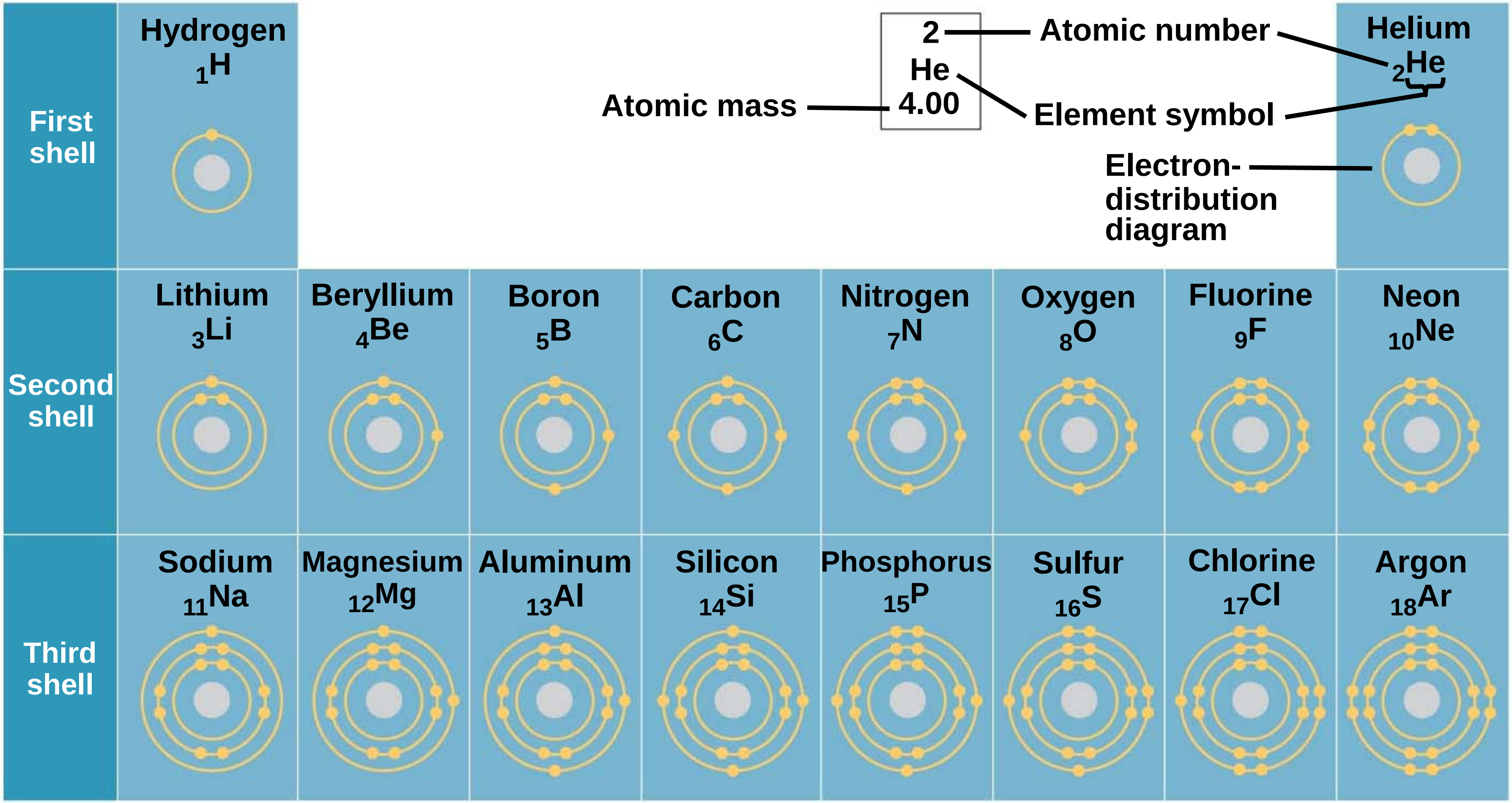
(b)

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

Electron-distribution diagrams for the first 18 elements in the periodic table



- **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

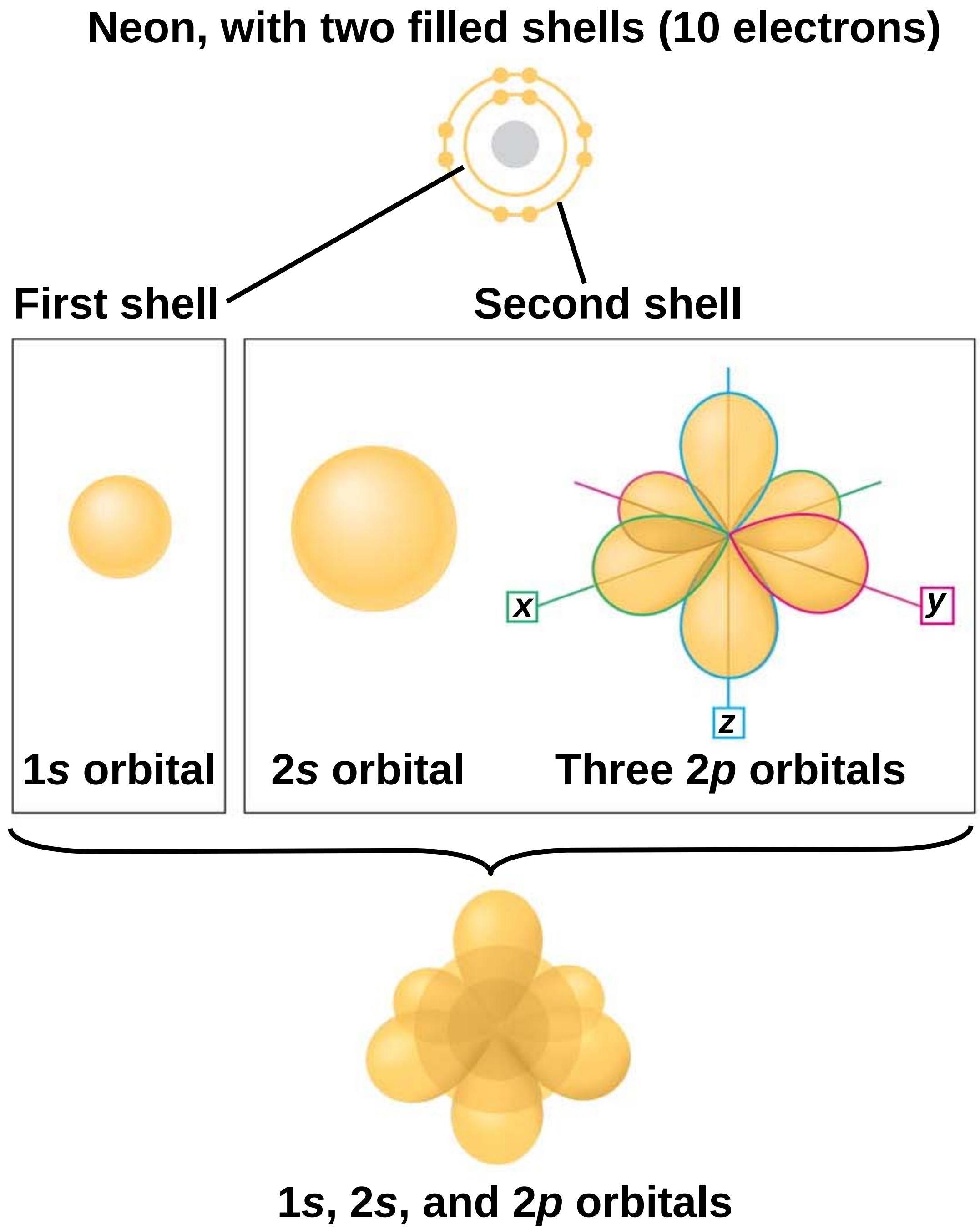
- An **orbital** is the three-dimensional space where an electron is found 90% of the time
- Each electron shell consists of a specific number of orbitals

Fig. 2-10-4

(a) Electron-distribution diagram

(b) Separate electron orbitals

(c) Superimposed electron orbitals



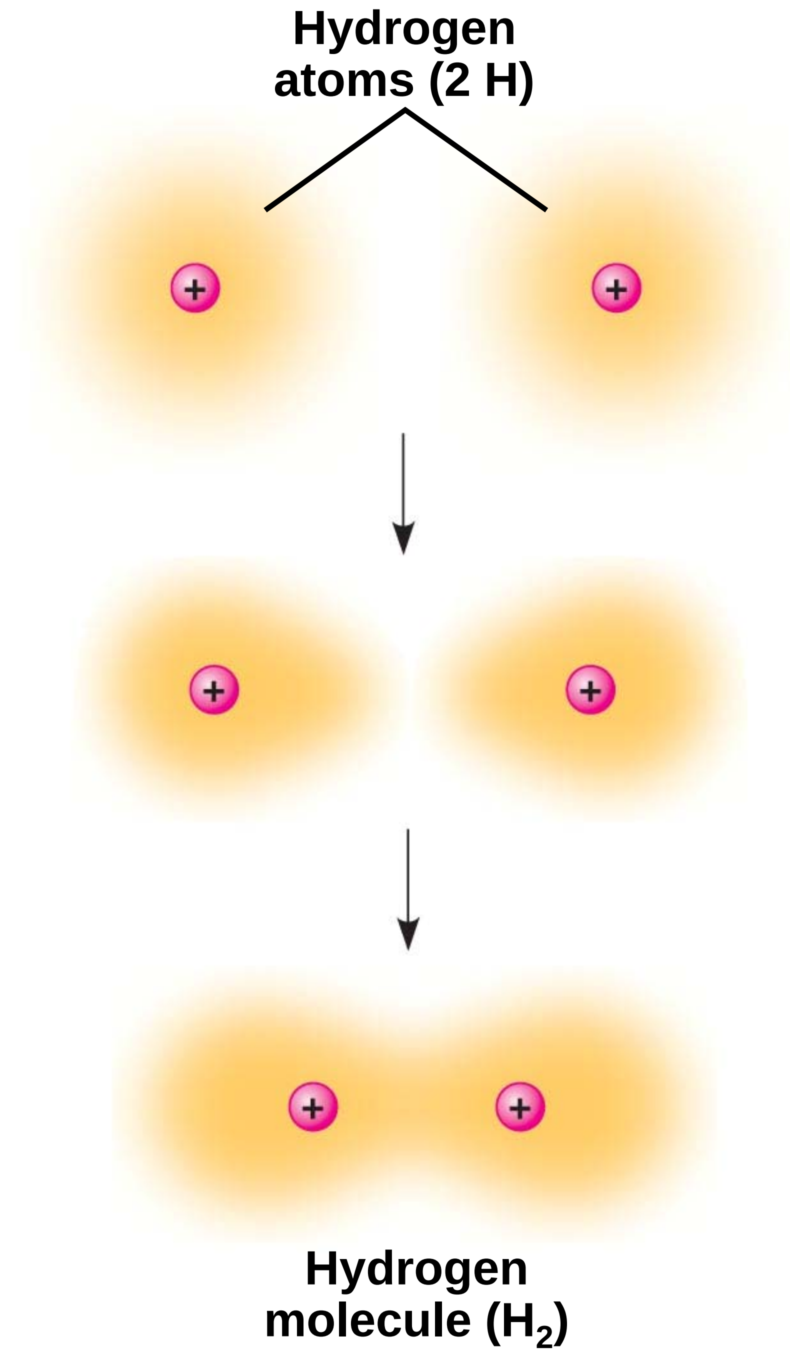
Concept 2.3: The formation and function of molecules depend on chemical bonding between atoms

- 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



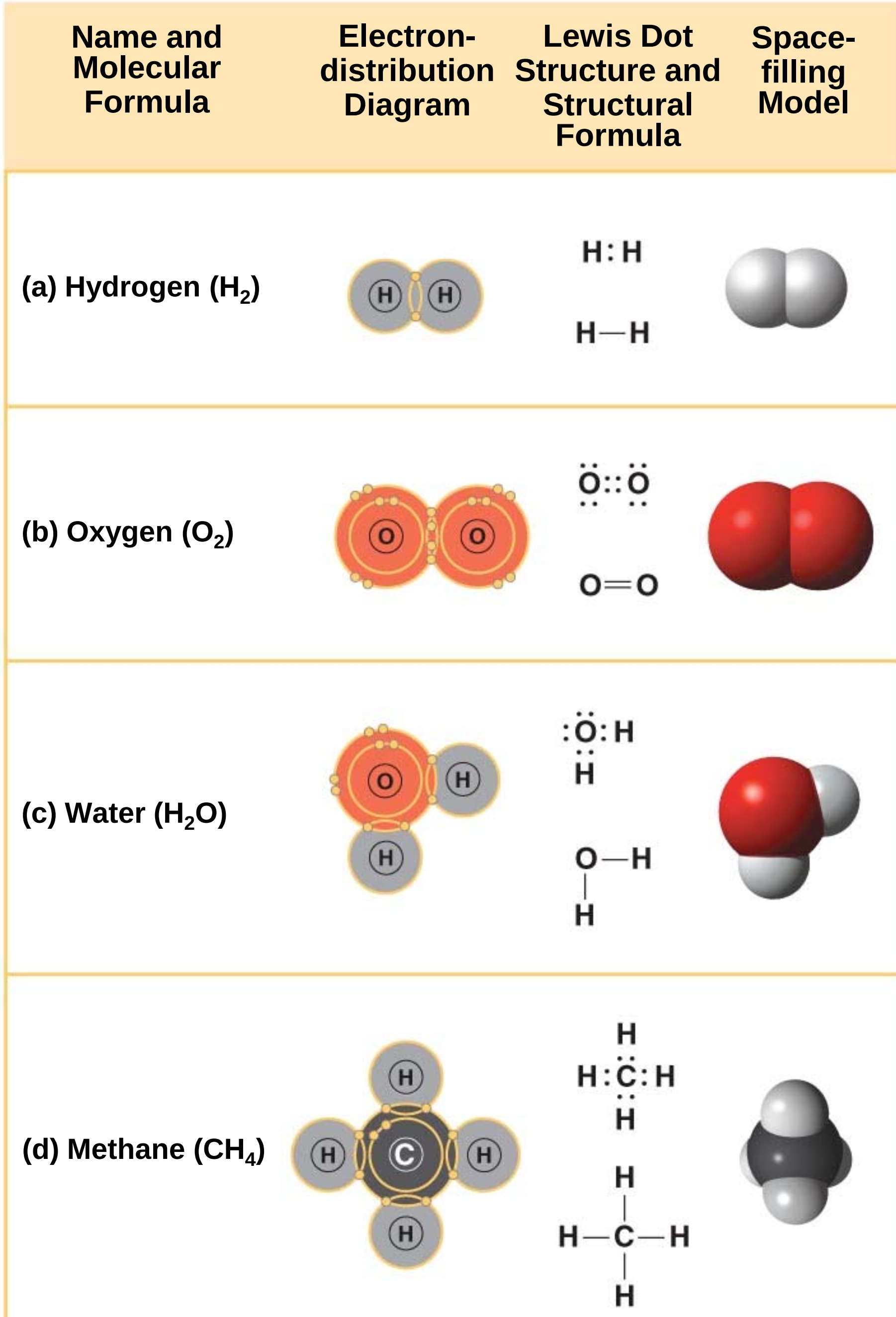
Formation of a covalent bond

- 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

Fig. 2-12

Covalent bonding in four molecules



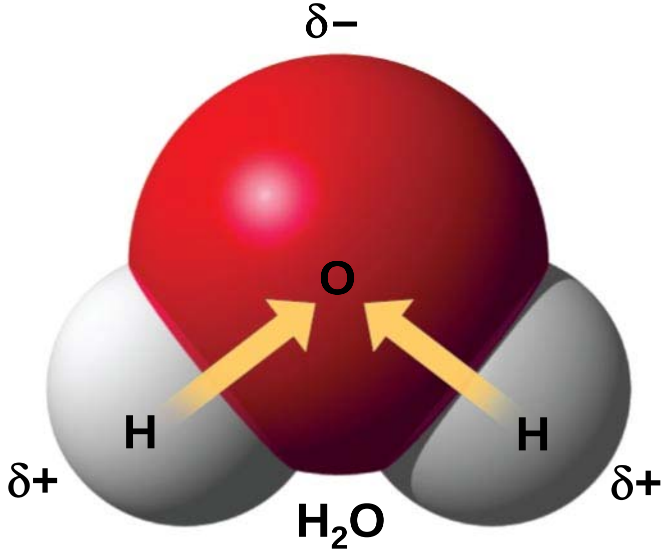
- Covalent bonds can form between atoms of the same element or atoms of different elements
- A compound is a combination of two or more *different* elements
- Bonding capacity is called the atom’s **valence**

- **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

Polar covalent bonds in a water molecule

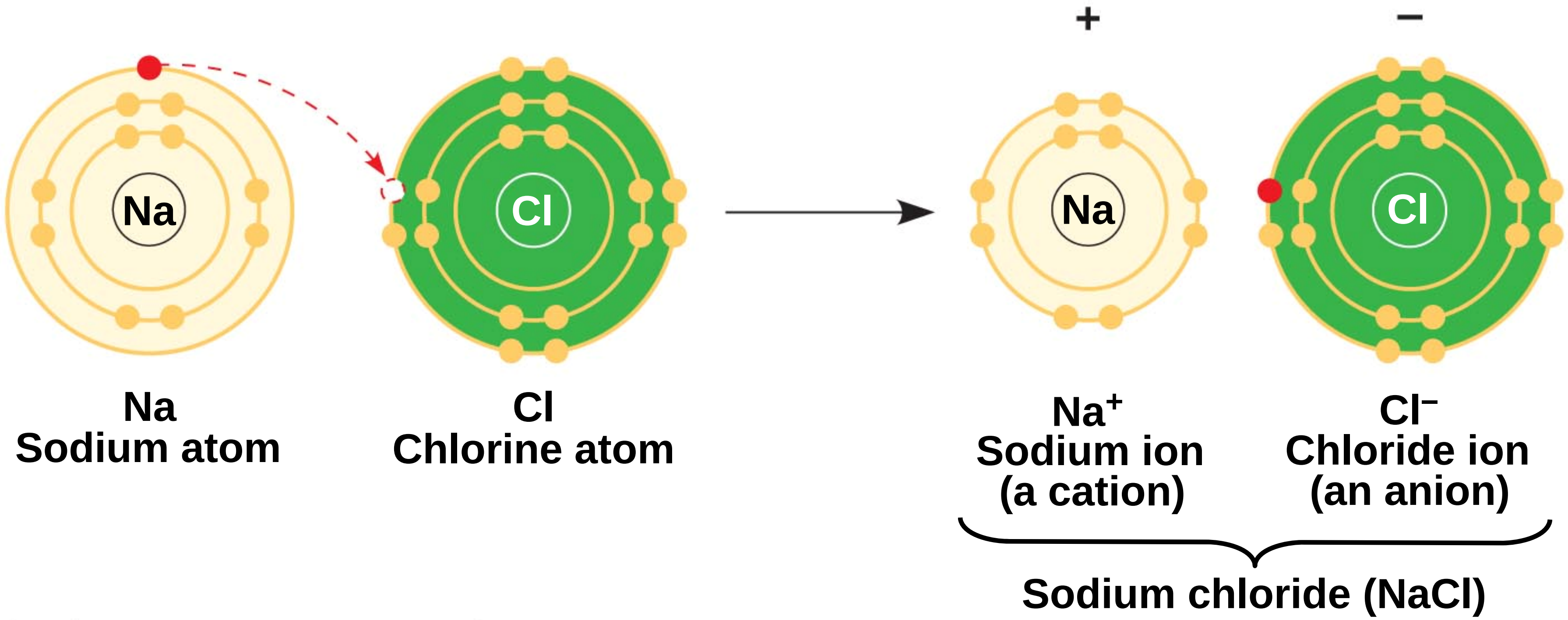


Ionic Bonds

- 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. 2-14-2

Electron transfer and ionic bonding

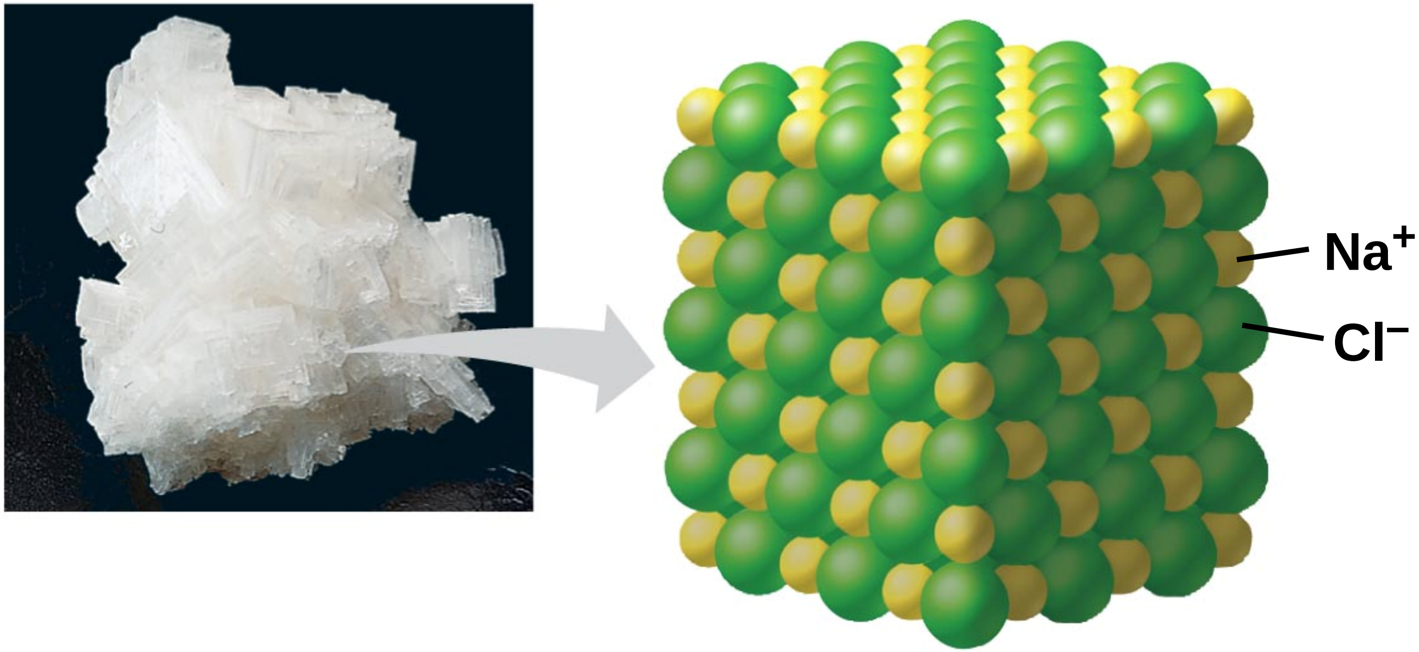


- A **cation** is a positively charged ion
- An **anion** is a negatively charged ion
- An **ionic bond** is an attraction between an anion and a cation

- 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

Fig. 2-15

A sodium chloride crystal



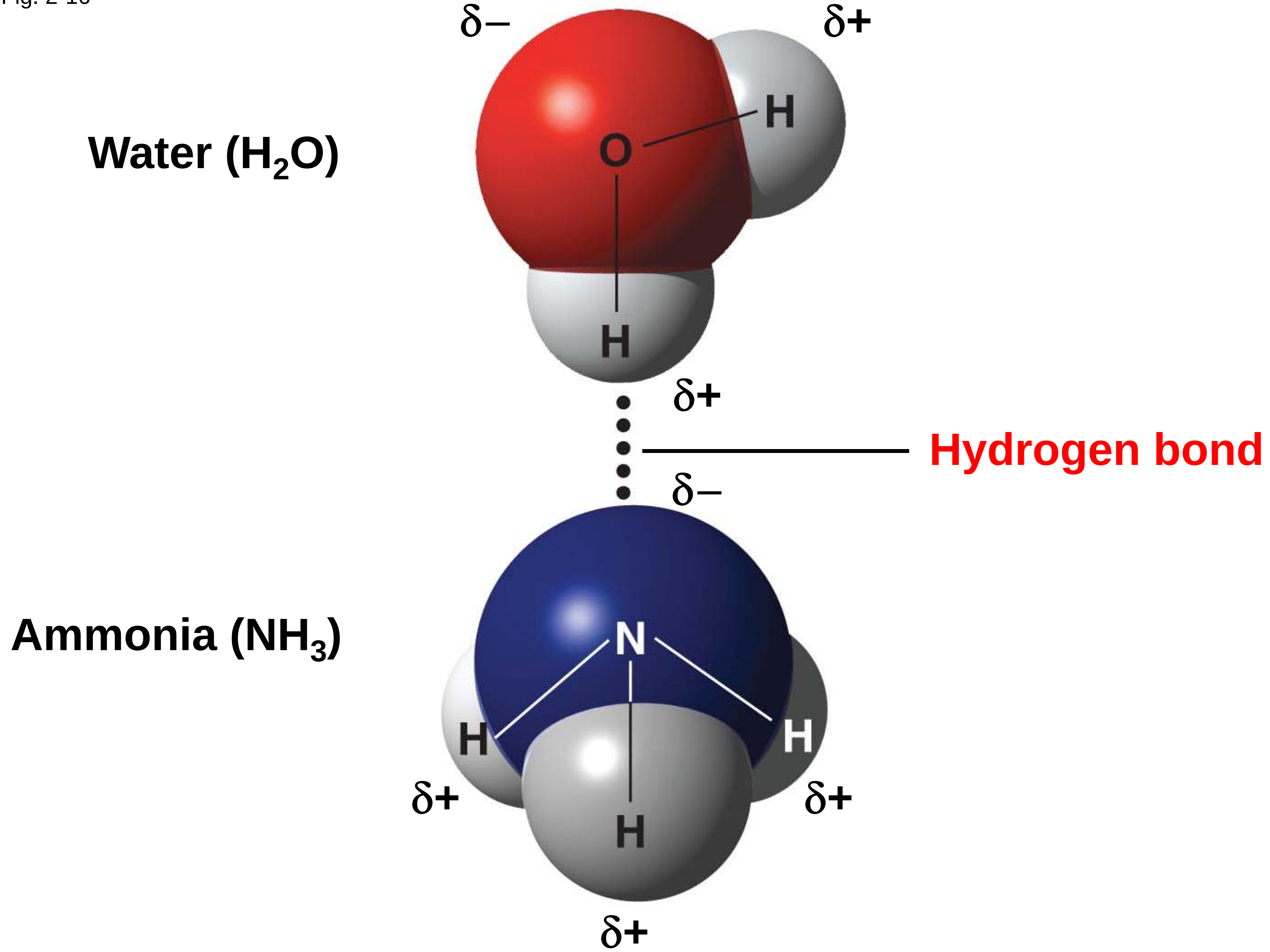
Weak Chemical Bonds

- 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

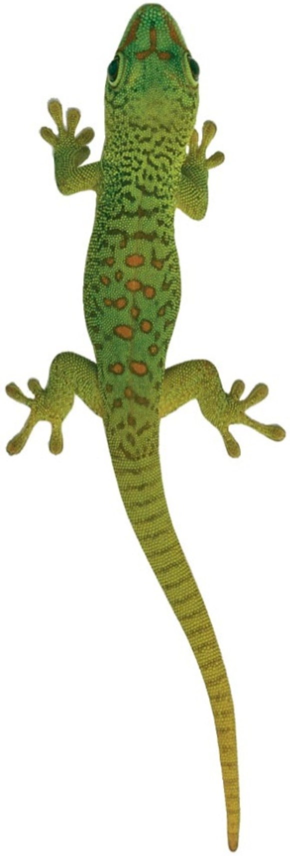
Fig. 2-16



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

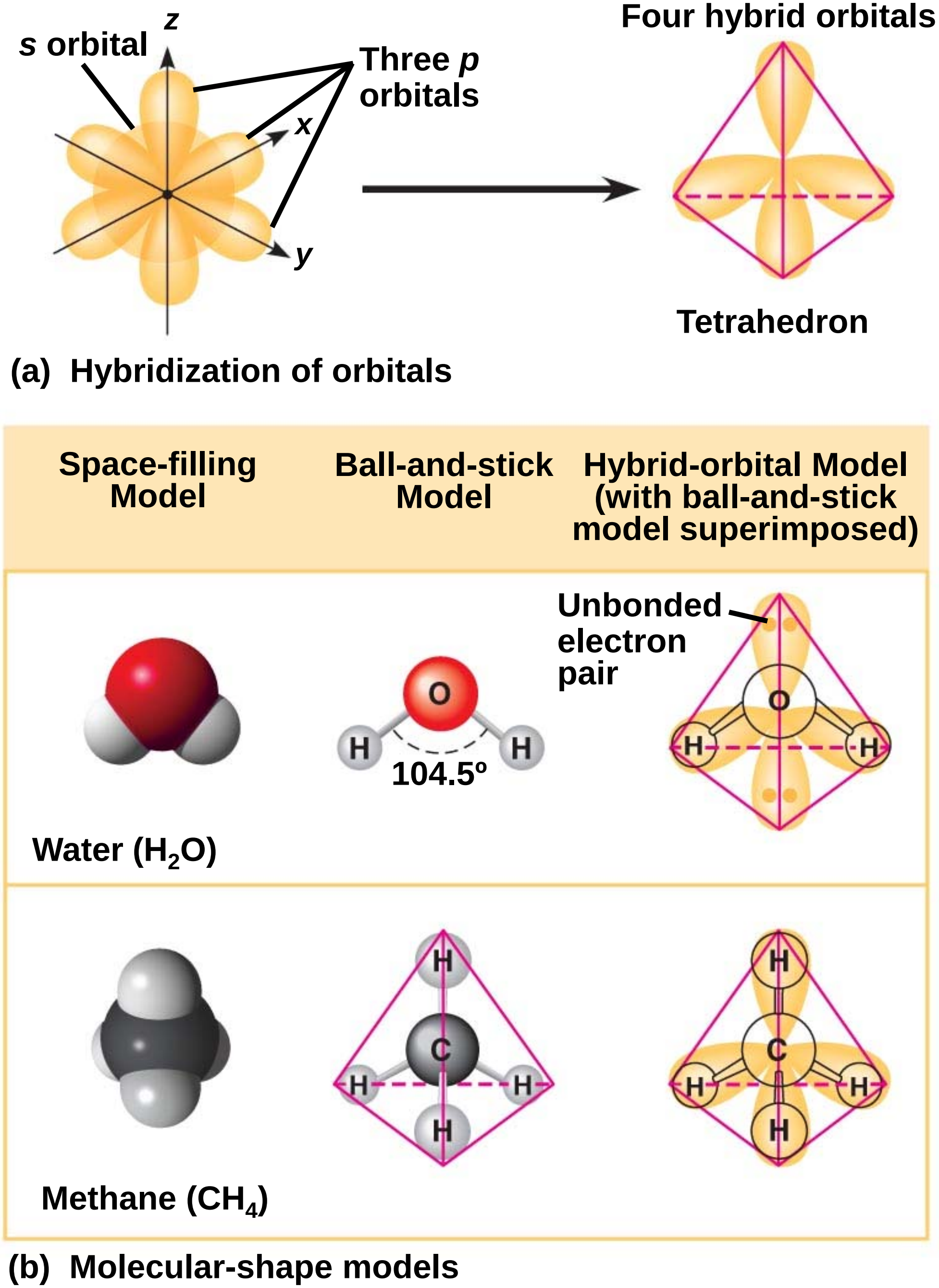


Molecular Shape and Function

- 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

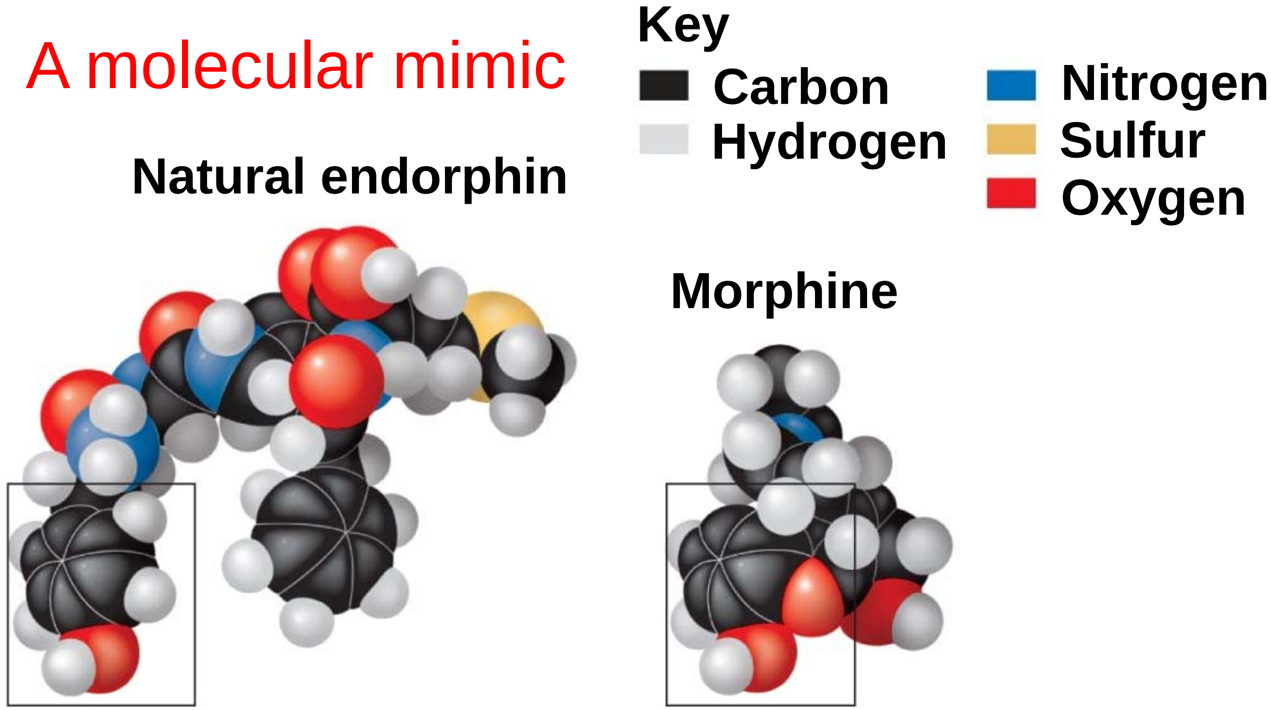
Molecular shapes due to hybrid orbitals



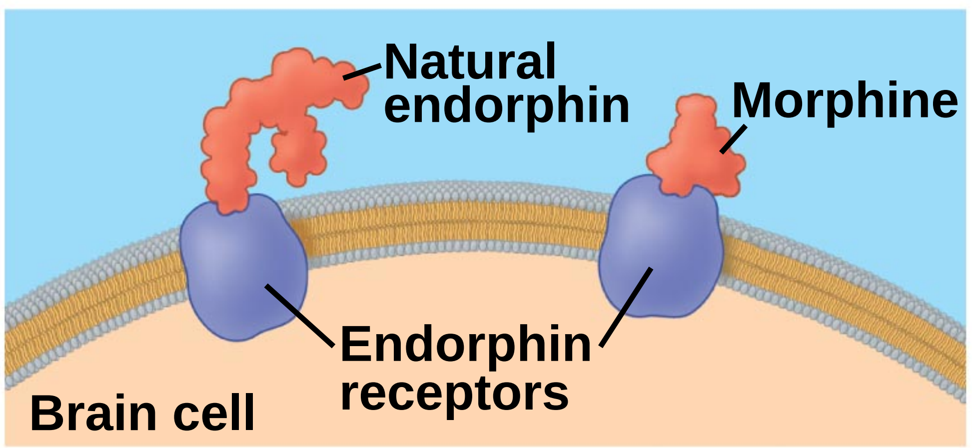
- Biological molecules recognize and interact with each other with a specificity based on molecular shape
- Molecules with similar shapes can have similar biological effects

Fig. 2-18

A molecular mimic



(a) Structures of endorphin and morphine

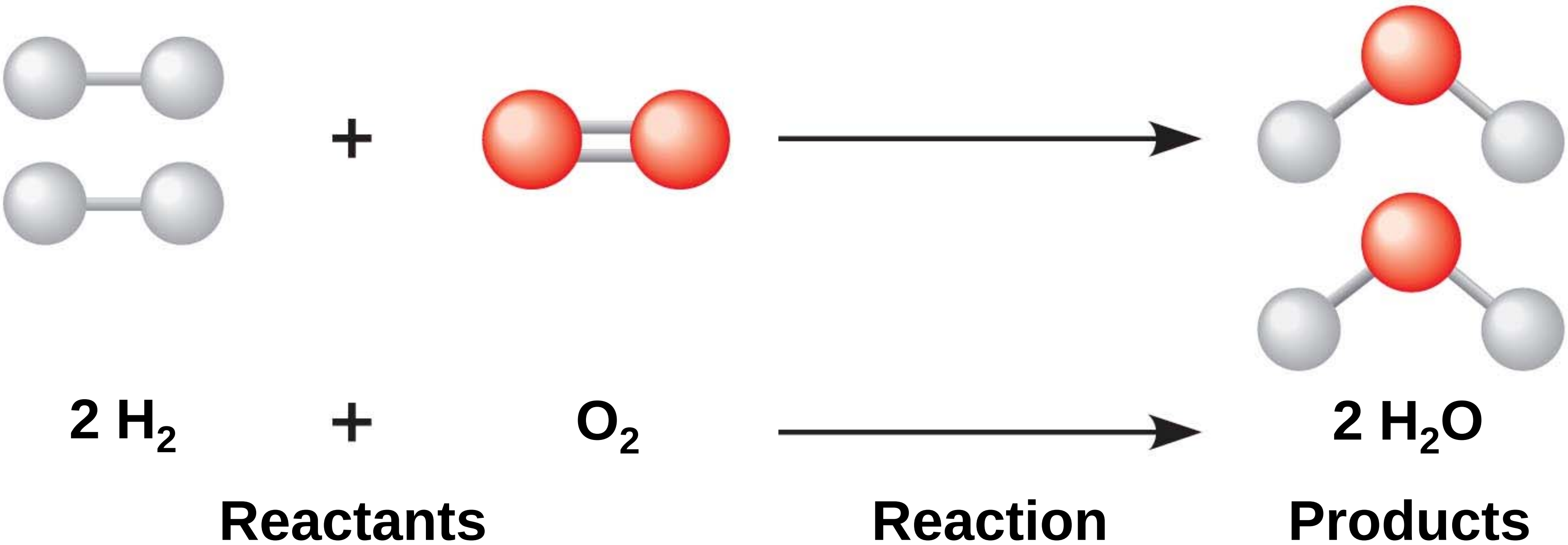


(b) Binding to endorphin receptors

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**

Fig. 2-UN2



- 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

Photosynthesis: a solar-powered rearrangement of matter

- 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

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