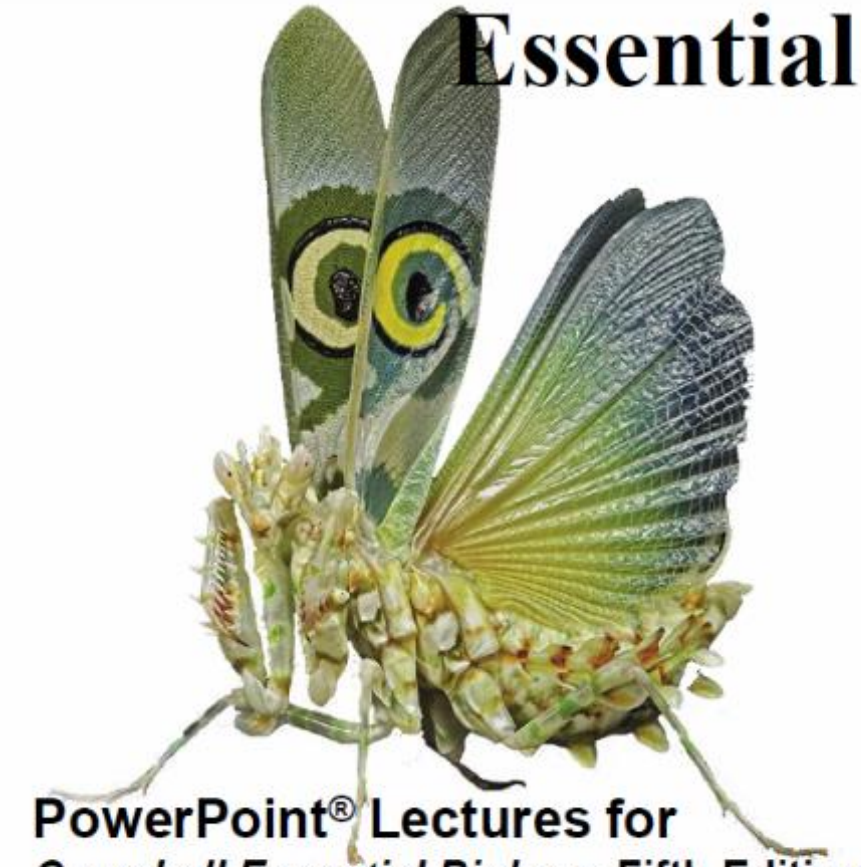
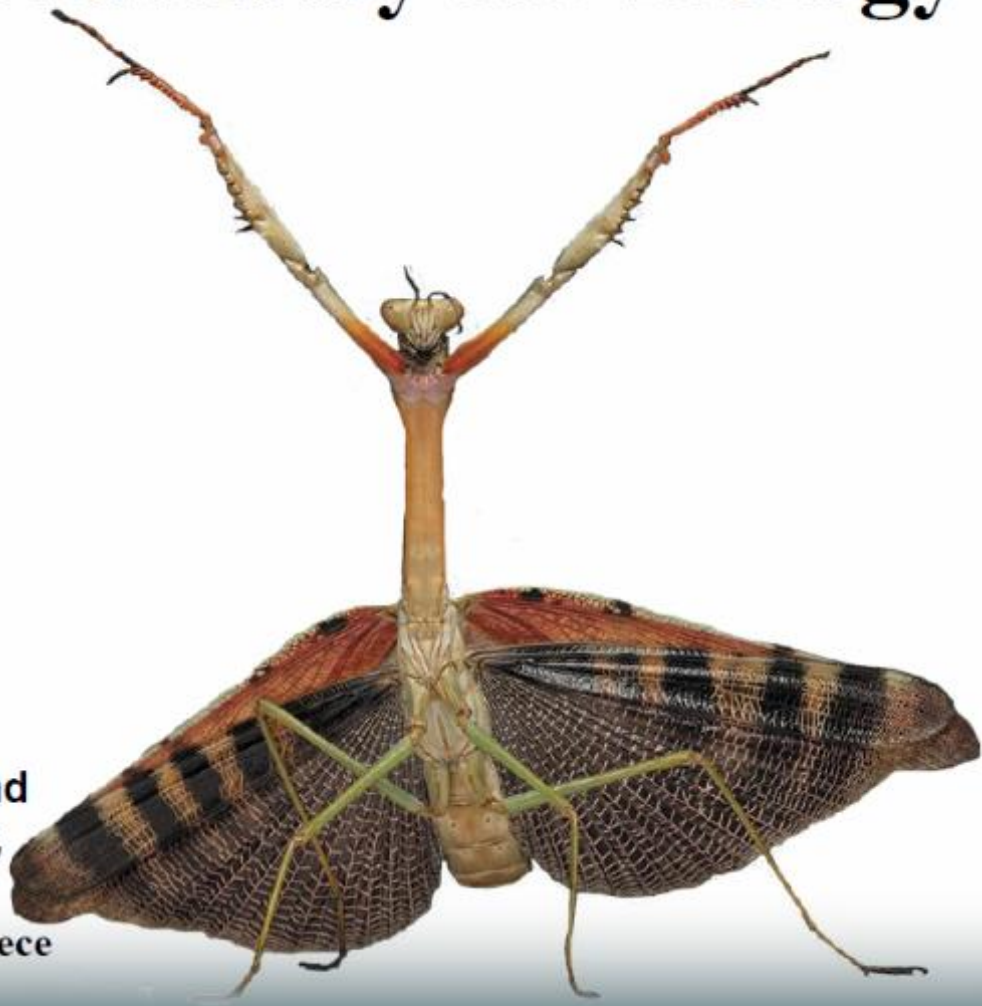
Chapter 2

Essential Chemistry for Biology





PowerPoint® Lectures for
***Campbell Essential Biology,* Fifth Edition, and**
***Campbell Essential Biology with Physiology,* Fourth Edition**
– Eric J. Simon, Jean L. Dickey, and Jane B. Reece

Lectures by Edward J. Zalisko

Biology and Society: More Precious than Gold

- A drought is
  - a period of abnormally dry weather that changes the environment and
  - one of the most devastating disasters.

Figure 2.0

Biology and Society: More Precious than Gold

- Droughts can cause
  - severe crop damage,
  - shortages of drinking water,
  - dust storms,
  - famine,
  - habitat loss, and
  - mass migration.

Biology and Society: More Precious than Gold

- Throughout human history, droughts have helped wipe out societies and even whole civilizations.
- Droughts are catastrophic because life cannot exist without water.

SOME BASIC CHEMISTRY

- Take any biological system apart, and you eventually end up at the chemical level.
- Chemical reactions are always occurring in the human body.

Matter: Elements and Compounds

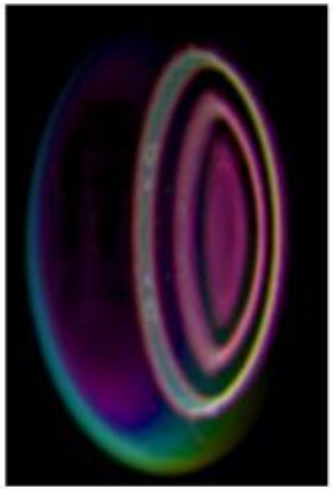
- **Matter** is anything that occupies space and has mass.
- Matter is found on Earth in three physical states:
  - solid,
  - liquid, and
  - gas.

Matter: Elements and Compounds

- Matter is composed of chemical elements.
  - An **element** is a substance that cannot be broken down into other substances by chemical reactions.
  - There are 92 naturally occurring elements on Earth.
- All of the elements are listed in the periodic table.

The five states of matter:

BOSE-EINSTEIN CONDENSATE



SOLIDS

LIQUIDS

GASES

PLASMAS (only for low density ionized gases)

Lower Temperature

Higher Temperature

Figure 2.1a

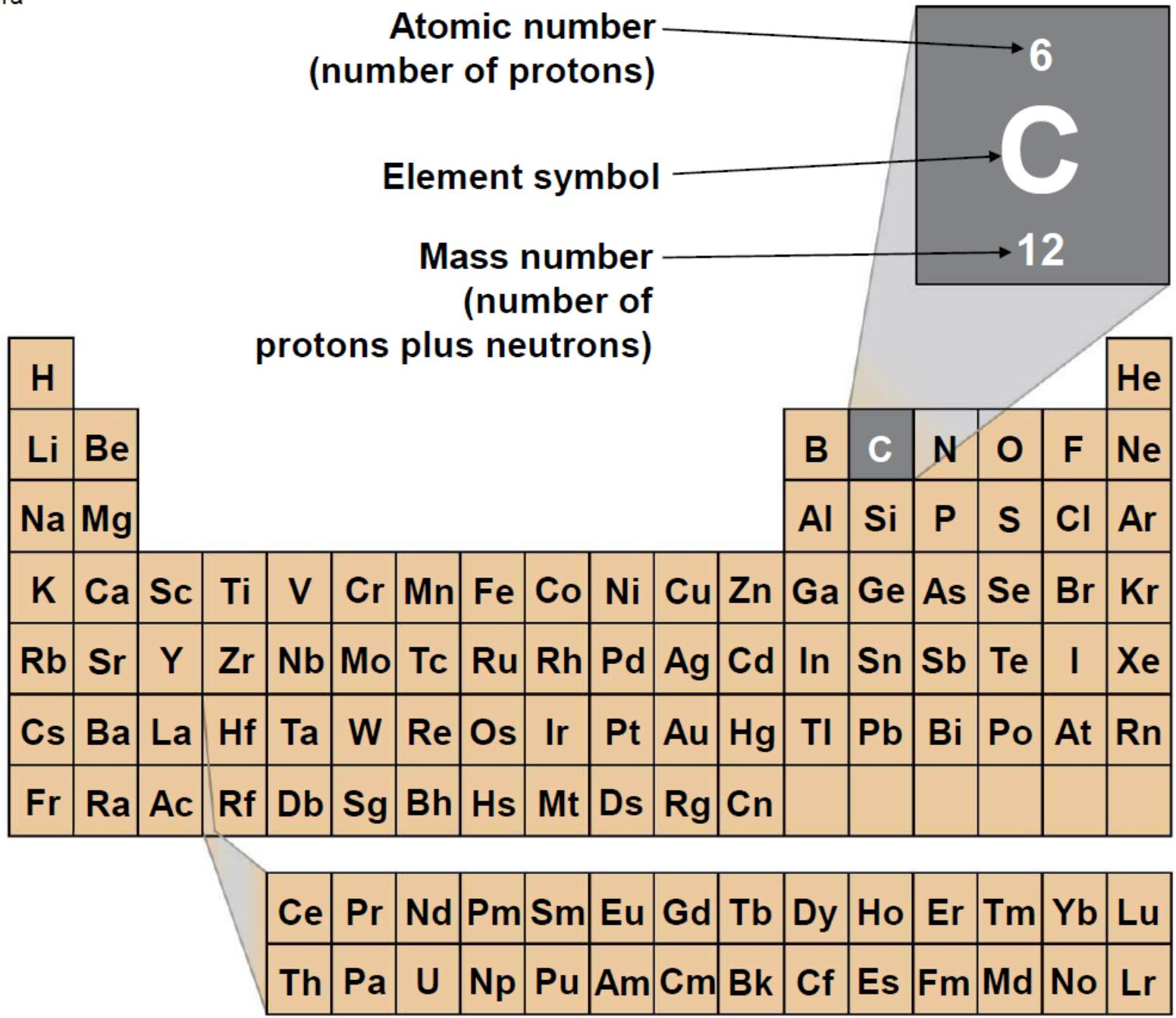


Figure 2.1b

Mercury (Hg)

Figure 2.1c

Copper (Cu)

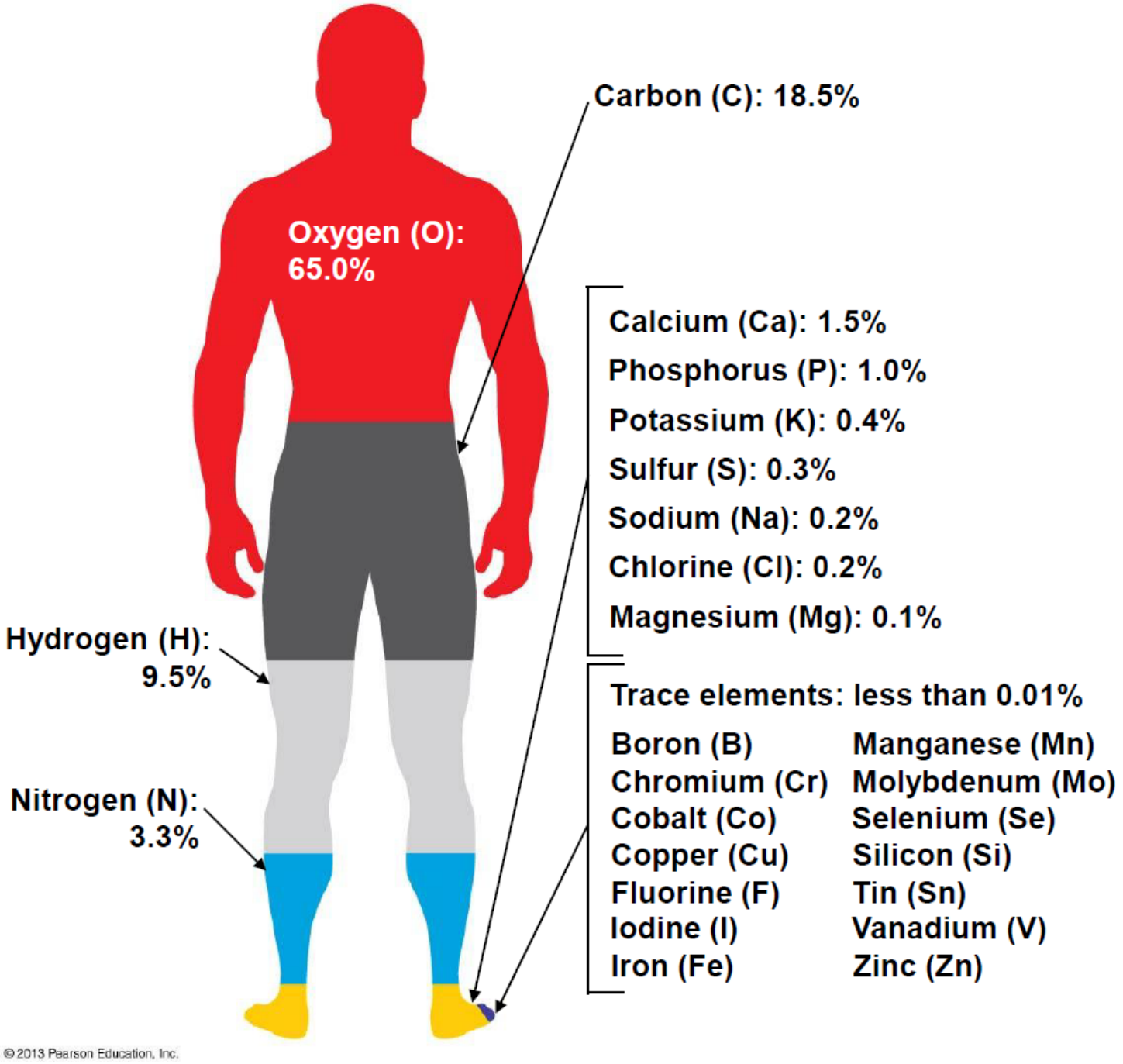
Figure 2.1d

Lead (Pb)

Matter: Elements and Compounds

- Twenty-five elements are essential to people.
- Four elements make up about 96% of the weight of most cells:
  - oxygen,
  - carbon,
  - hydrogen, and
  - nitrogen.

Figure 2.2

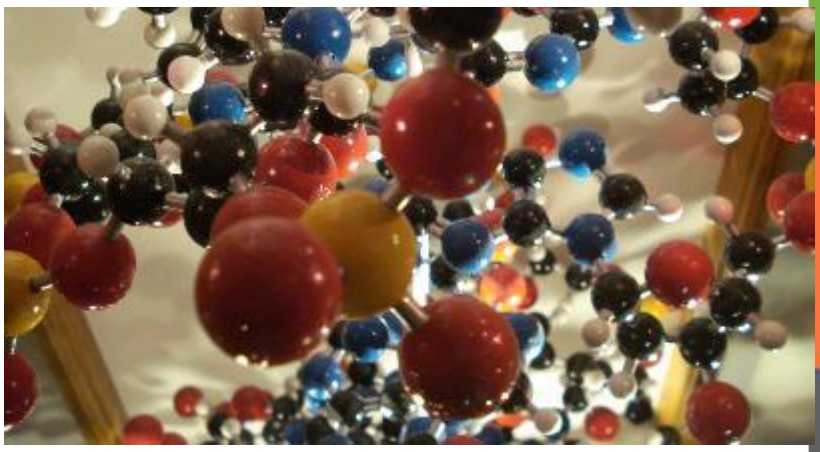


Matter: Elements and Compounds

- **Trace elements** are
  - required in only very small amounts and
  - essential for life.
- An iodine deficiency causes goiter.
- Fluorine
  - is added to dental products and drinking water and
  - helps to maintain healthy bones and teeth.

Figure 2.3

ATOMS ARE THE BUILDING BLOCKS OF MOLECULES



- Life is composed of matter
- Matter:
  - occupies space
  - has mass
- **Elements** are unique forms of matter
  1. Specific chemical properties
  2. Specific physical properties

ELEMENTS AND THE LIVING WORLD

- Elements cannot be broken down into smaller substances
- Each element is designated by a chemical symbol (one or two letters)
    - Sulfur = S
    - Calcium = Ca

- **Four most common elements of living organisms**
- Carbon C
- Oxygen = O
- Hydrogen = H
- Nitrogen = N

ELEMENTS AND THE LIVING WORLD

Comparing the elements of living organisms to the non-living world

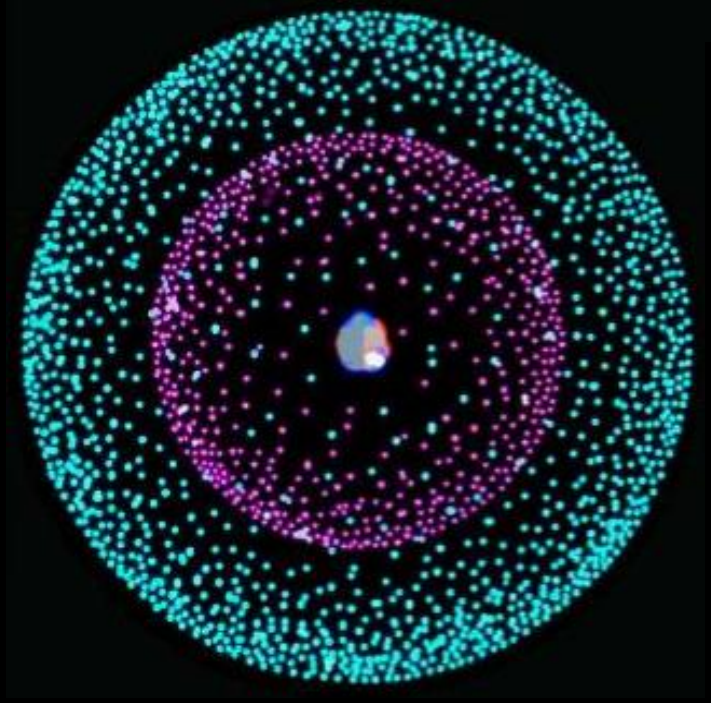
Element	Life (Humans)	Atmosphere	Earth's Crust
Oxygen (O)	65%	21%	46%
Carbon (C)	18%	trace	trace
Hydrogen (H)	10%	trace	0.1%
Nitrogen (N)	3%	78%	trace

Matter: Elements and Compounds

- Elements can combine to form compounds.
  - **Compounds** are substances that contain two or more elements in a fixed ratio.
  - Common compounds include
    - NaCl (table salt) and
    - H_2O (water).

ATOM

THE ATOM
THE BUILDING BLOCK OF EVERYTHING



Atoms

- Each element consists of one kind of atom.
  - An **atom** is the smallest unit of matter that still retains the properties of an element.

The Structure of Atoms

- Atoms are composed of subatomic particles.
  - A **proton** is positively charged.
  - An **electron** is negatively charged.
  - A **neutron** is electrically neutral.
- Most atoms have protons and neutrons packed tightly into the nucleus.
  - The **nucleus** is the atom's central core.
  - Electrons orbit the nucleus.

Figure 2.4

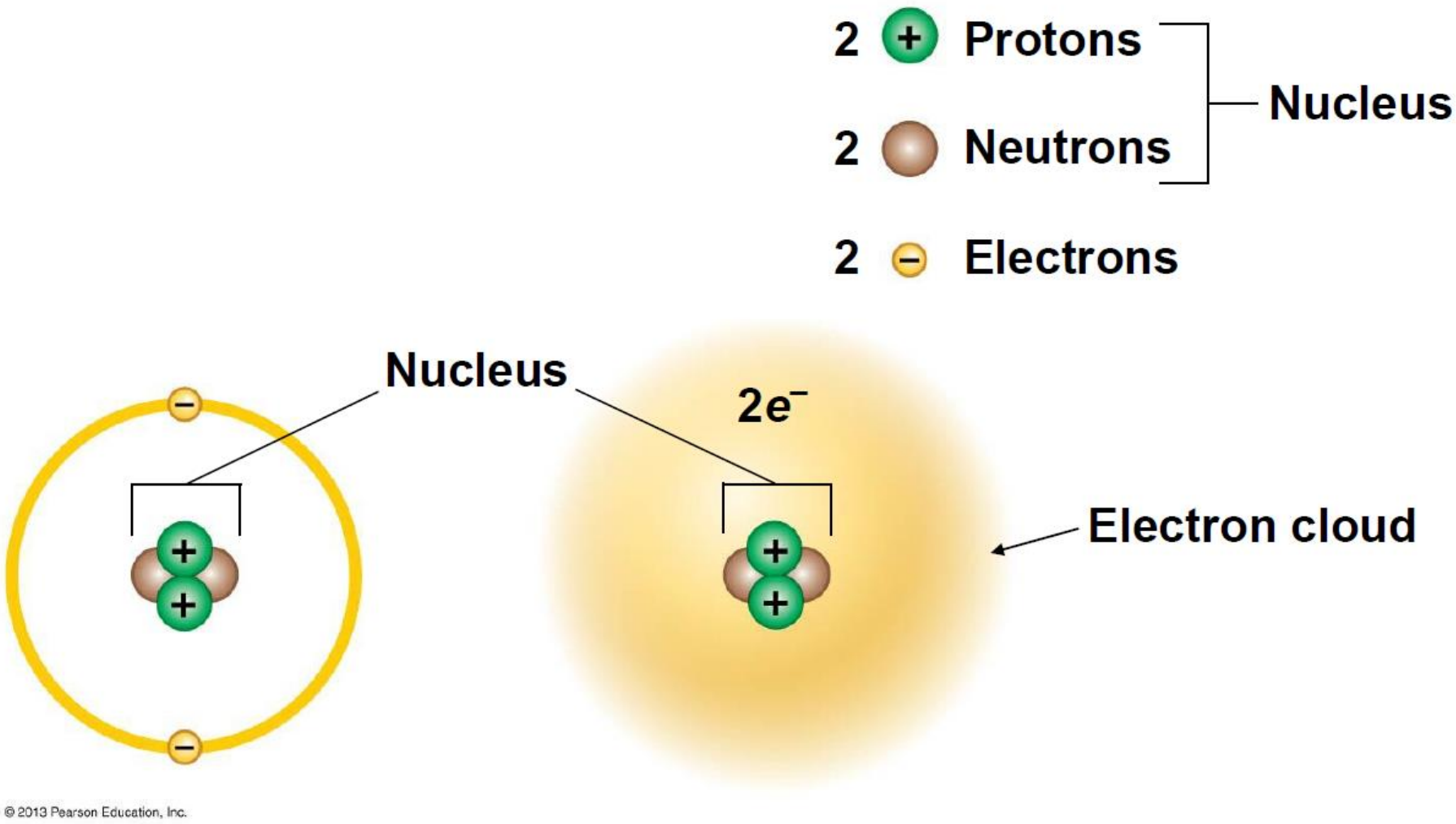
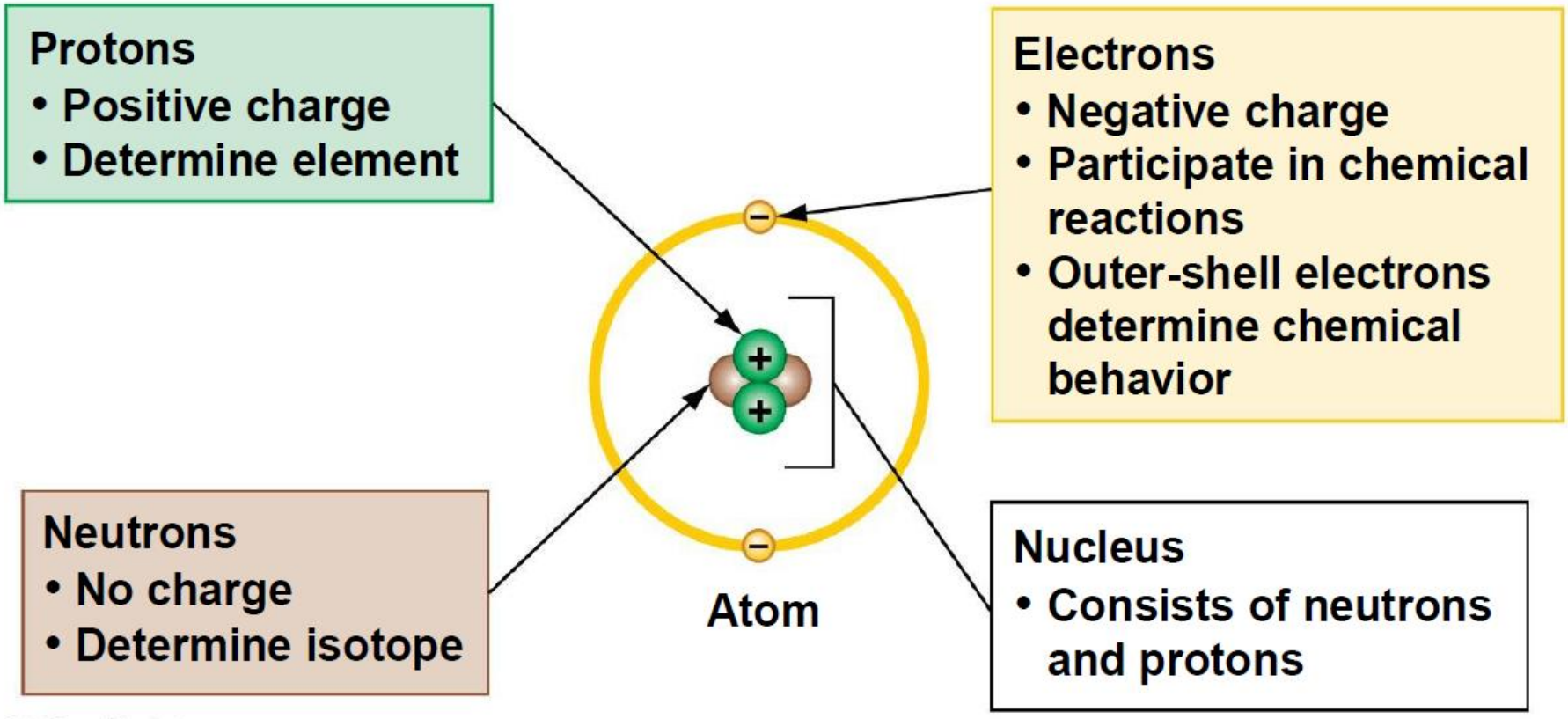


Figure 2.UN05



KEY PROPERTIES OF SUB-ATOMIC PARTICLES

	Charge	Mass (amu)	Location
Proton	+1	1	nucleus
Neutron	0	1	nucleus
Electron	-1	0	orbitals

WHAT'S THE DIFFERENCE BETWEEN ATOMIC NUMBER AND ATOMIC MASS?

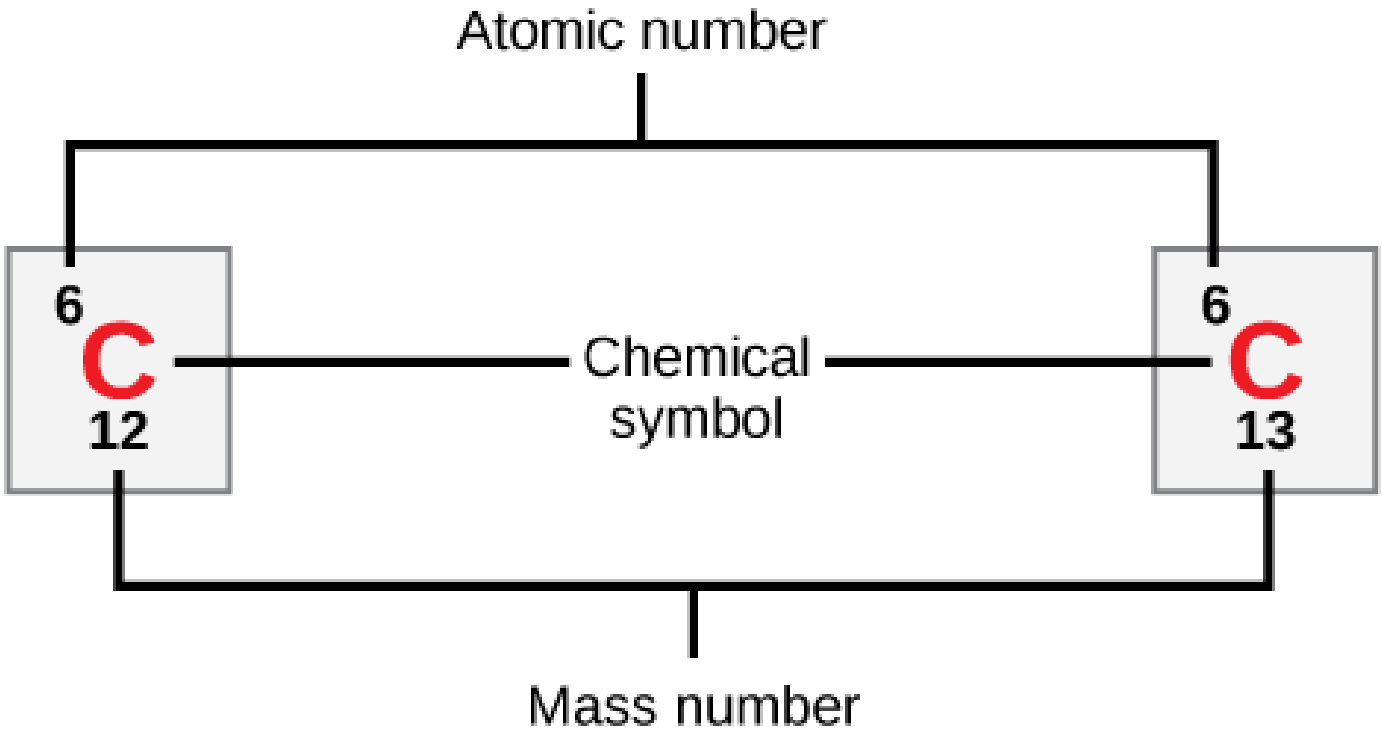
Atoms of each element have a standard number of protons and electrons

- **Atomic Number is the number of protons**
  - Each element has a distinct atomic number

- **Atomic Mass is the mass of the atom, roughly equal to number of protons and neutrons**
  - The number of neutrons can vary in an element
  - Elements with different number of neutrons are **isotopes**
  - Electrons don't need to be included in calculation of atomic mass
  - Atomic mass is expressed in atomic mass units (amu)

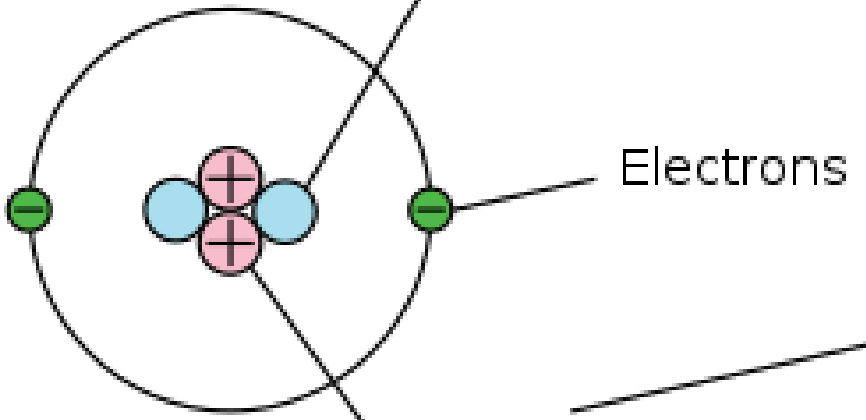
- We can calculate the number of neutrons in an element by subtracting the atomic number from the atomic mass

FIGURE 2.3 ATOMIC MASS VS. ATOMIC NUMBER



Carbon has an atomic number of six, and two stable isotopes with mass numbers of twelve and thirteen, respectively. Carbon-12's atomic mass is approx. 12.11.

Atomic / mass number - this is the sum of the protons and neutrons



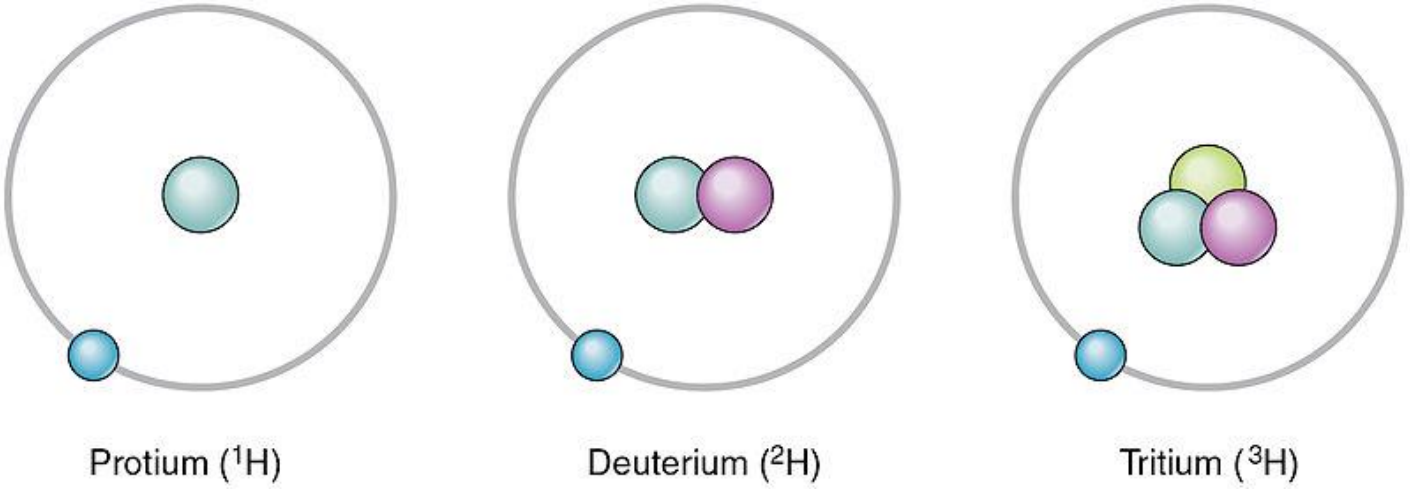
$$^{4}_{2}He$$

ISOTOPES

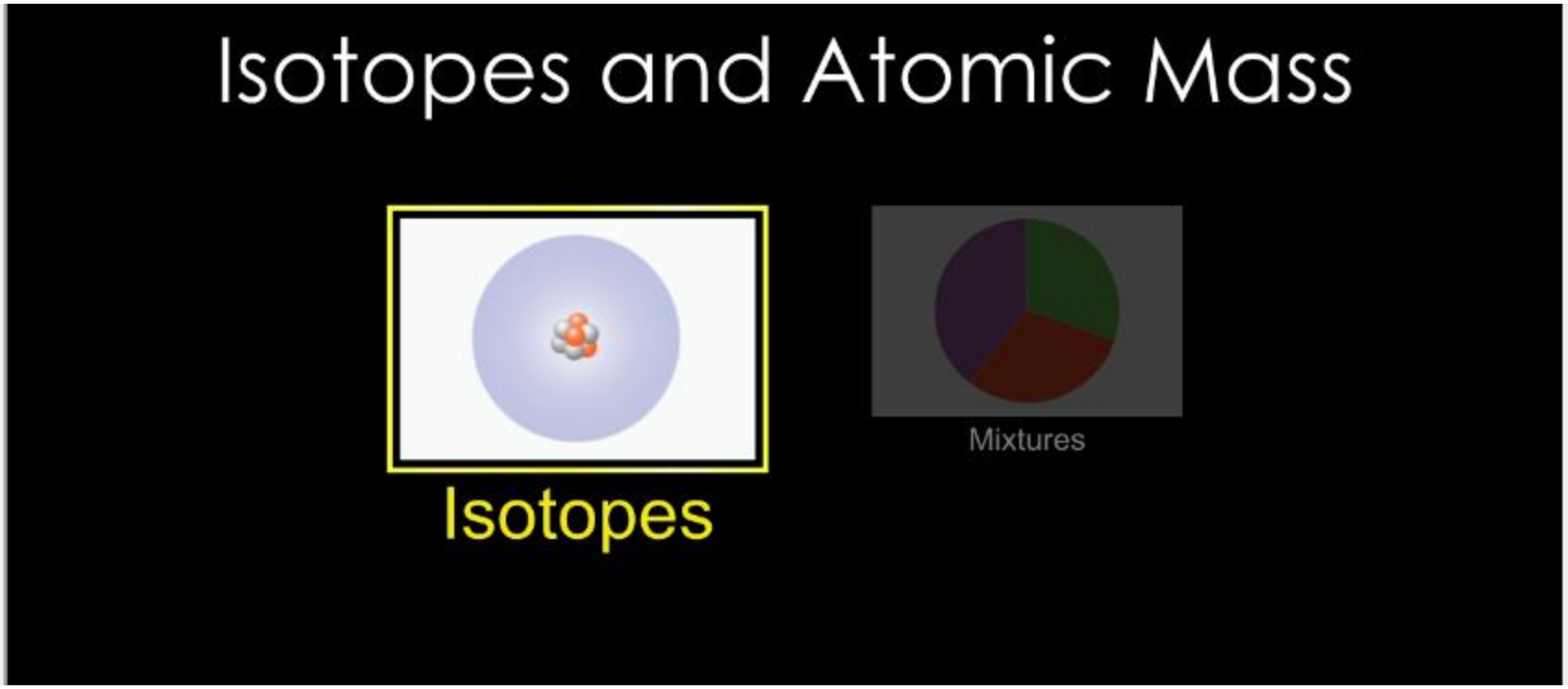
Forms of an element with different numbers of neutrons, and thus different mass numbers

Example:

- ^{1}H has 0 neutrons
- ^{2}H has 1 neutron
- ^{3}H has 2 neutrons



ISOTOPE SIMULATION



https://phet.colorado.edu/sims/html/isotopes-and-atomic-mass/latest/isotopes-and-atomic-mass_en.html

ISOTOPES CAN BE USED AS A RESEARCH TOOL

Radioisotopes – isotopes that emit neutrons, protons, and electrons

Radiometric dating takes advantage of this natural phenomenon

Example: Over time Carbon-14 decays to Nitrogen-14. Researchers can compare Carbon-14 in atmosphere to carbon-14 in fossils remains and estimate fossil age

The age of carbon-containing remains less than about 50,000 years old, such as this pygmy mammoth, can be determined using carbon dating.

For older objects, scientists analyze the presence of isotopes of uranium (which decays to lead), potassium, or rubidium.

The Structure of Atoms

- Elements differ in the number of subatomic particles in their atoms.
  - The number of protons, the **atomic number**, determines which element it is.
  - **Mass** is a measure of the amount of material in an object.
  - An atom's **mass number** is the sum of the number of protons and neutrons in its nucleus.

Isotopes

- **Isotopes** are alternate mass forms of an element.
- Isotopes
  - have the same number of protons and electrons but
  - differ in their number of neutrons.

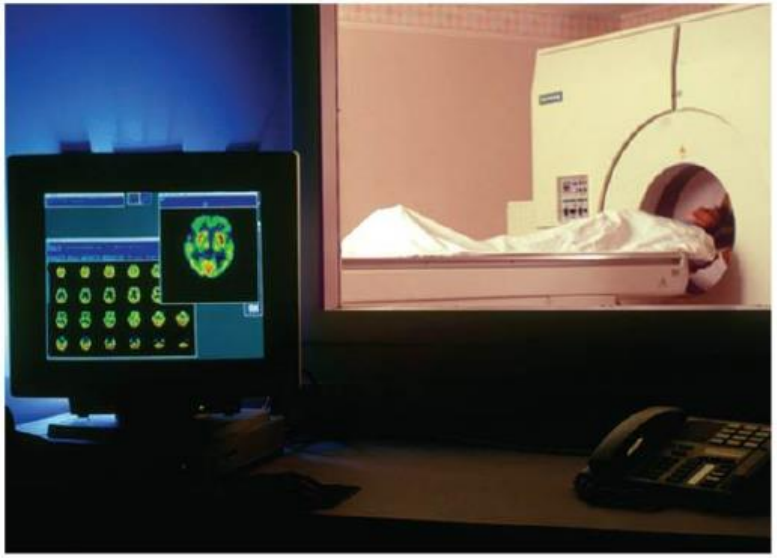
Table 2.1 Isotopes of Carbon

	Carbon-12	Carbon-13	Carbon-14
Protons	6	6	6
Neutrons	6	7	8
mass number	12	13	14
Electrons	6	6	6

Isotopes

- The nucleus of a **radioactive isotope** decays spontaneously, giving off particles and energy.
- Radioactive isotopes have many uses in research and medicine.
  - They can be used to determine the fate of atoms in living organisms.
  - They are used in PET scans to diagnose heart disorders and some cancers.

Figure 2.5



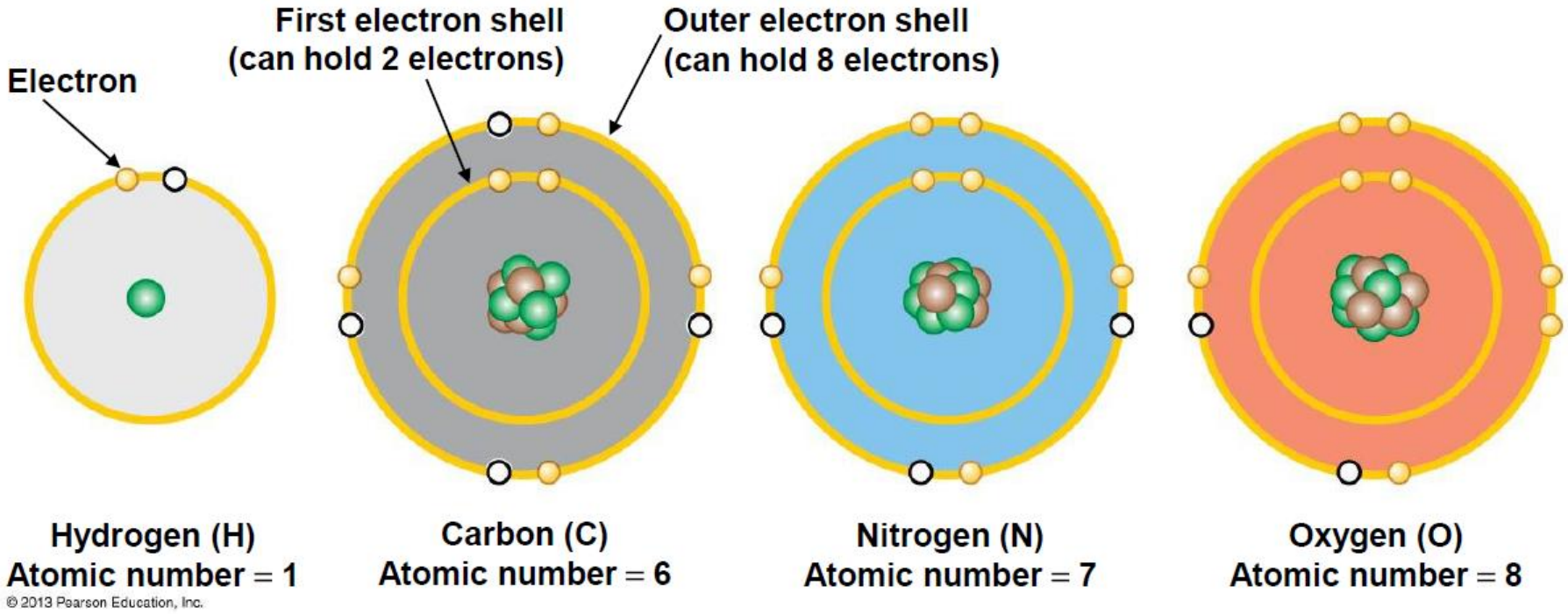
Isotopes

- Uncontrolled exposure to radioactive isotopes can harm living organisms by damaging DNA.
  - The 1986 Chernobyl nuclear accident released large amounts of radioactive isotopes.
  - Naturally occurring radon gas may cause lung cancer.

Electron Arrangement and the Chemical Properties of Atoms

- Of the three subatomic particles, only electrons are directly involved in the chemical activity of an atom.
- Electrons orbit the nucleus of an atom in specific electron shells.
- The farther an electron is from the nucleus, the greater its energy.
- The number of electrons in the outermost shell determines the chemical properties of an atom.

Figure 2.6



Periodic Table of the Elements

1																	18
1 H Hydrogen 1.008	2											13	14	15	16	17	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3	4	5	6	7	8	9	10	11	12	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.732	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

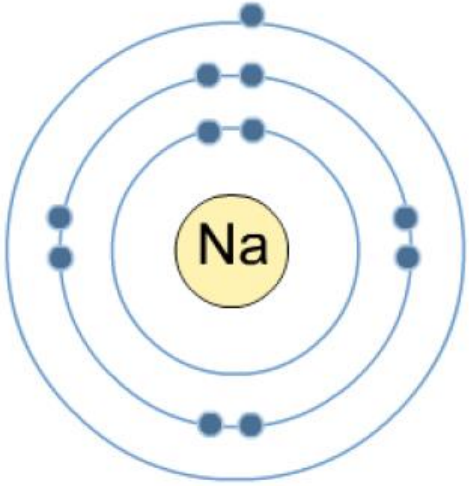
Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide

Chemical Bonding and Molecules

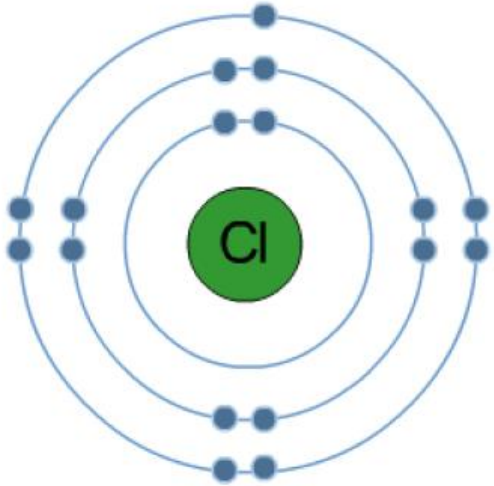
- Chemical reactions enable atoms to give up or acquire electrons, completing their outer shells.
- Chemical reactions usually result in atoms
  - staying close together and
  - being held together by attractions called **chemical bonds**.

Ionic Bonds

- When an atom loses or gains electrons, it becomes electrically charged.
  - Charged atoms are called **ions**.
  - **Ionic bonds** are formed between oppositely charged ions.

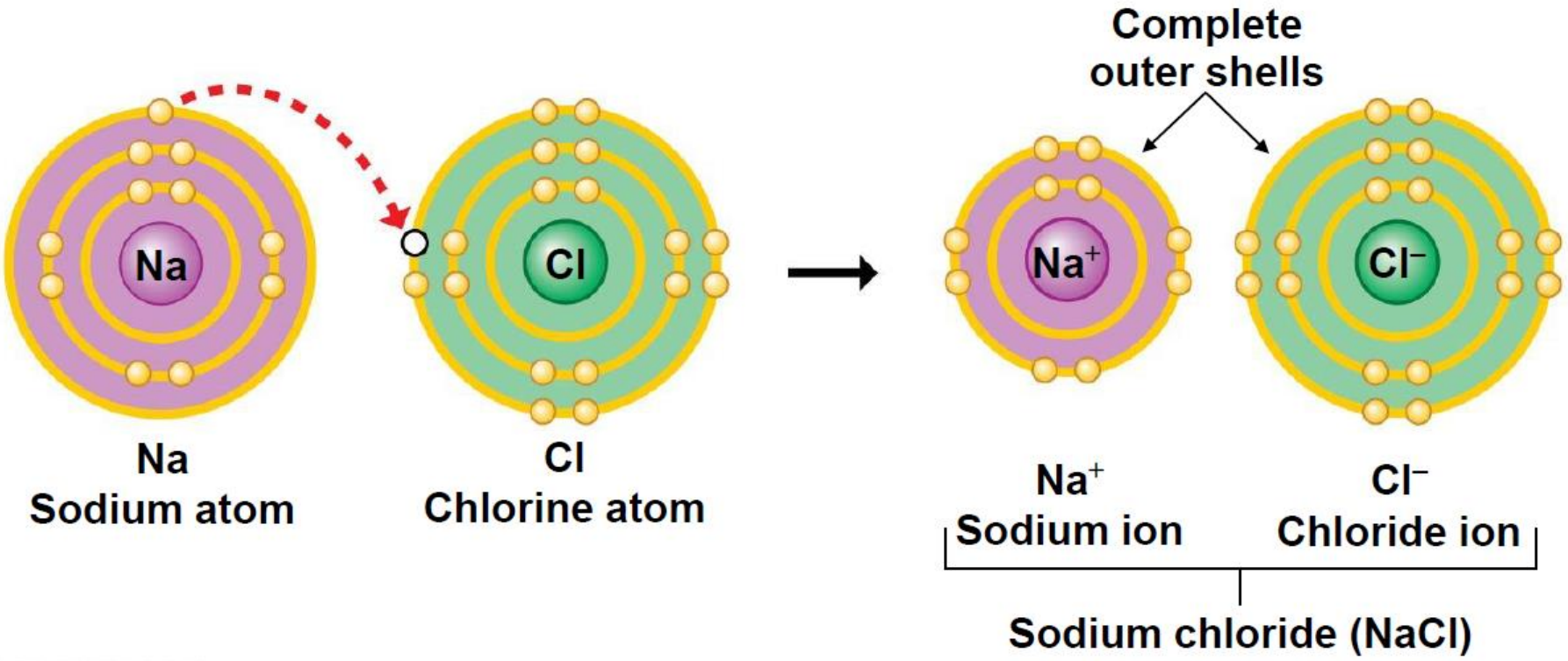


Sodium (Na)
11 protons
11 electrons



Chlorine (Cl)
17 protons
17 electrons

Figure 2.7-2



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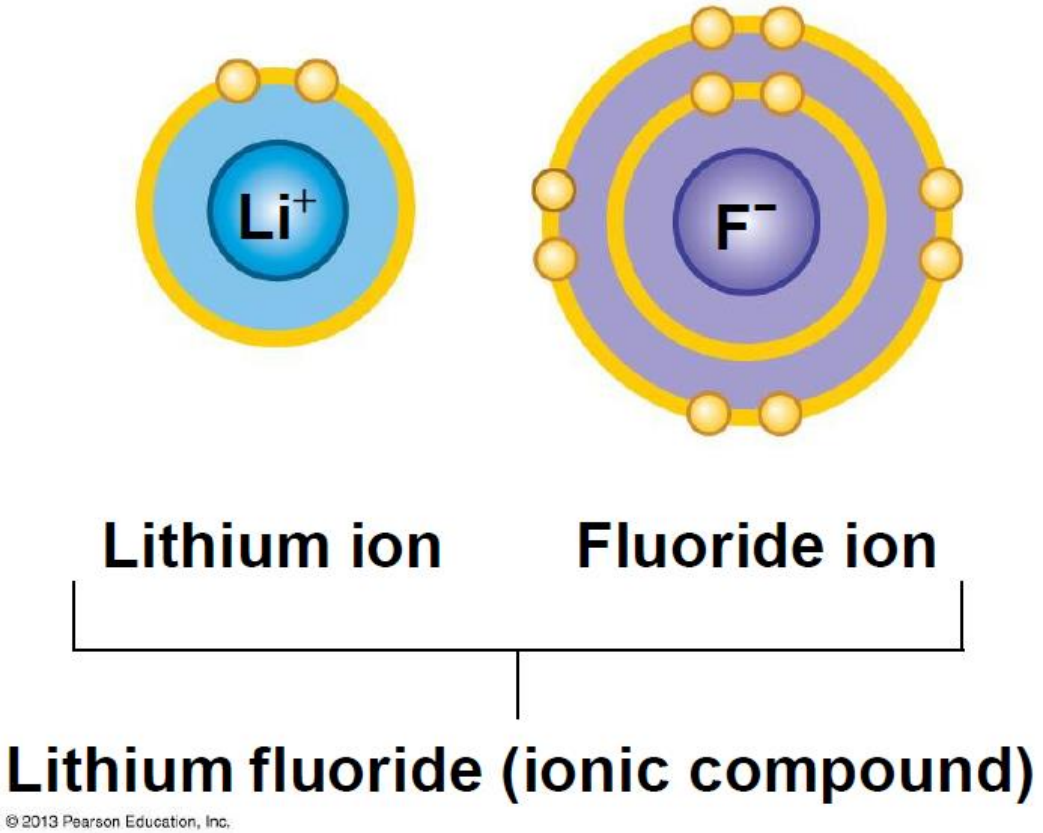
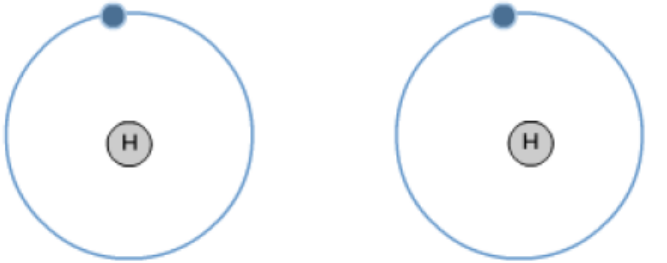


Covalent Bonds

- A **covalent bond** forms when two atoms *share* one or more pairs of outer-shell electrons.
- Covalent bonds are the strongest of the various bonds.
- Covalent bonds hold atoms together in a **molecule**.
- The number of covalent bonds an atom can form is equal to the number of additional electrons needed to fill its outer shell.



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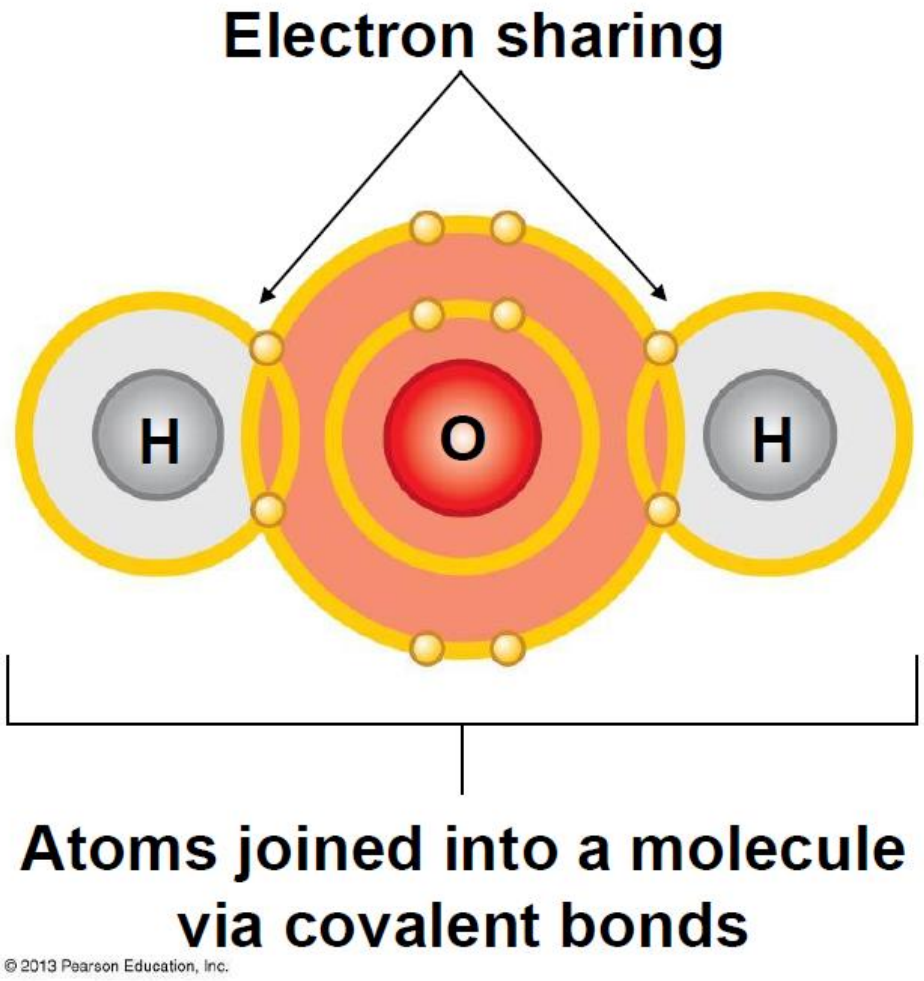
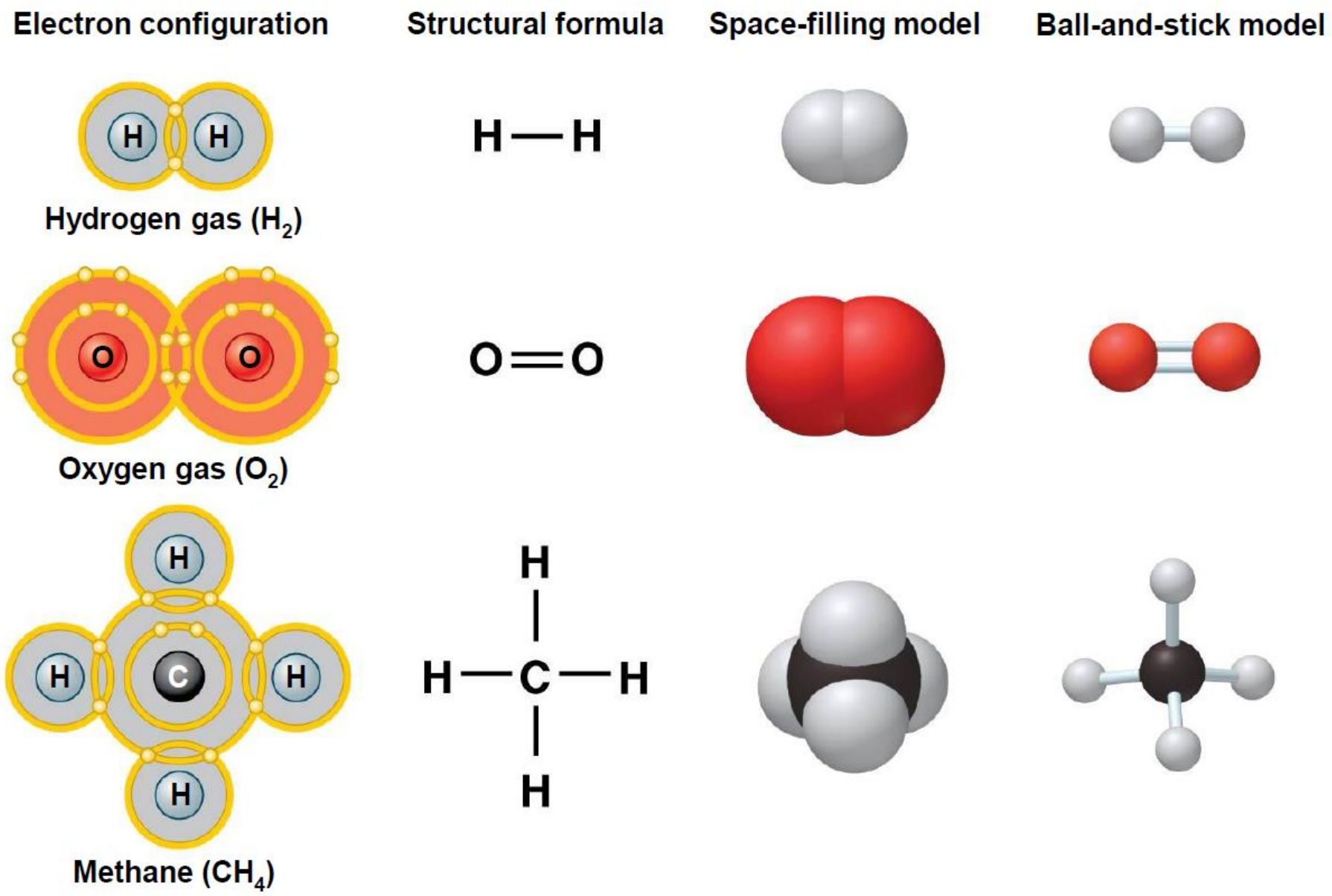
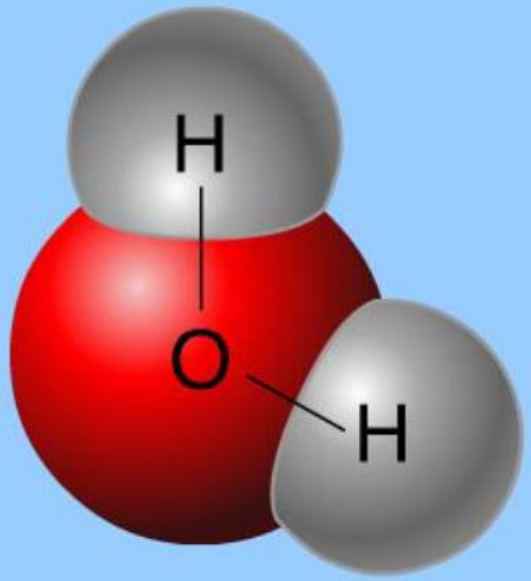


Figure 2.8



Hydrogen Bonds

- Water is a compound in which the electrons in its covalent bonds are not shared equally.
  - This causes water to be a **polar molecule**, one with an uneven distribution of charge.



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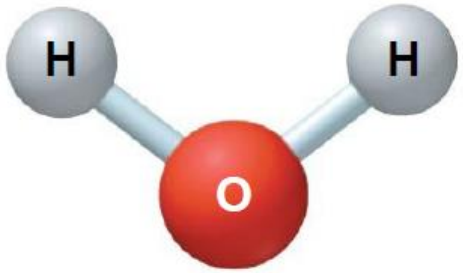

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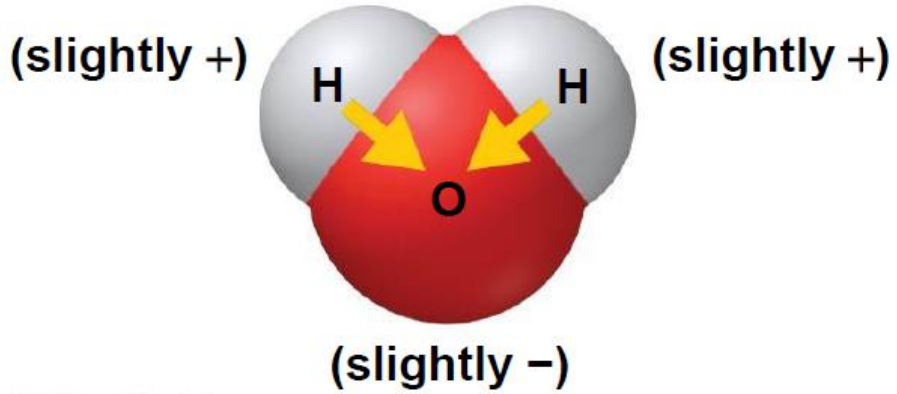
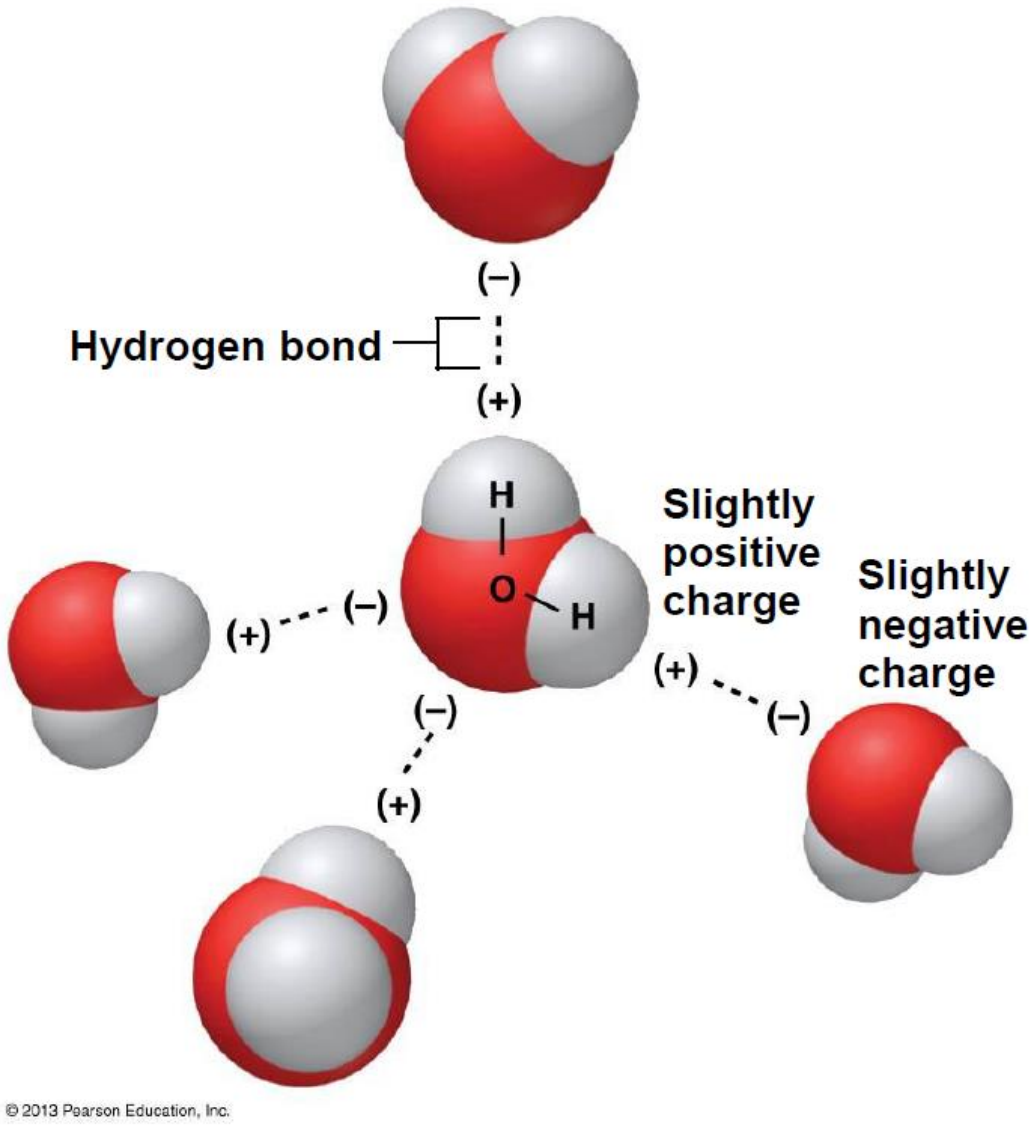


Hydrogen Bonds

- The polarity of water results in weak electrical attractions between neighboring water molecules.
  - These weak attractions are called **hydrogen bonds**.

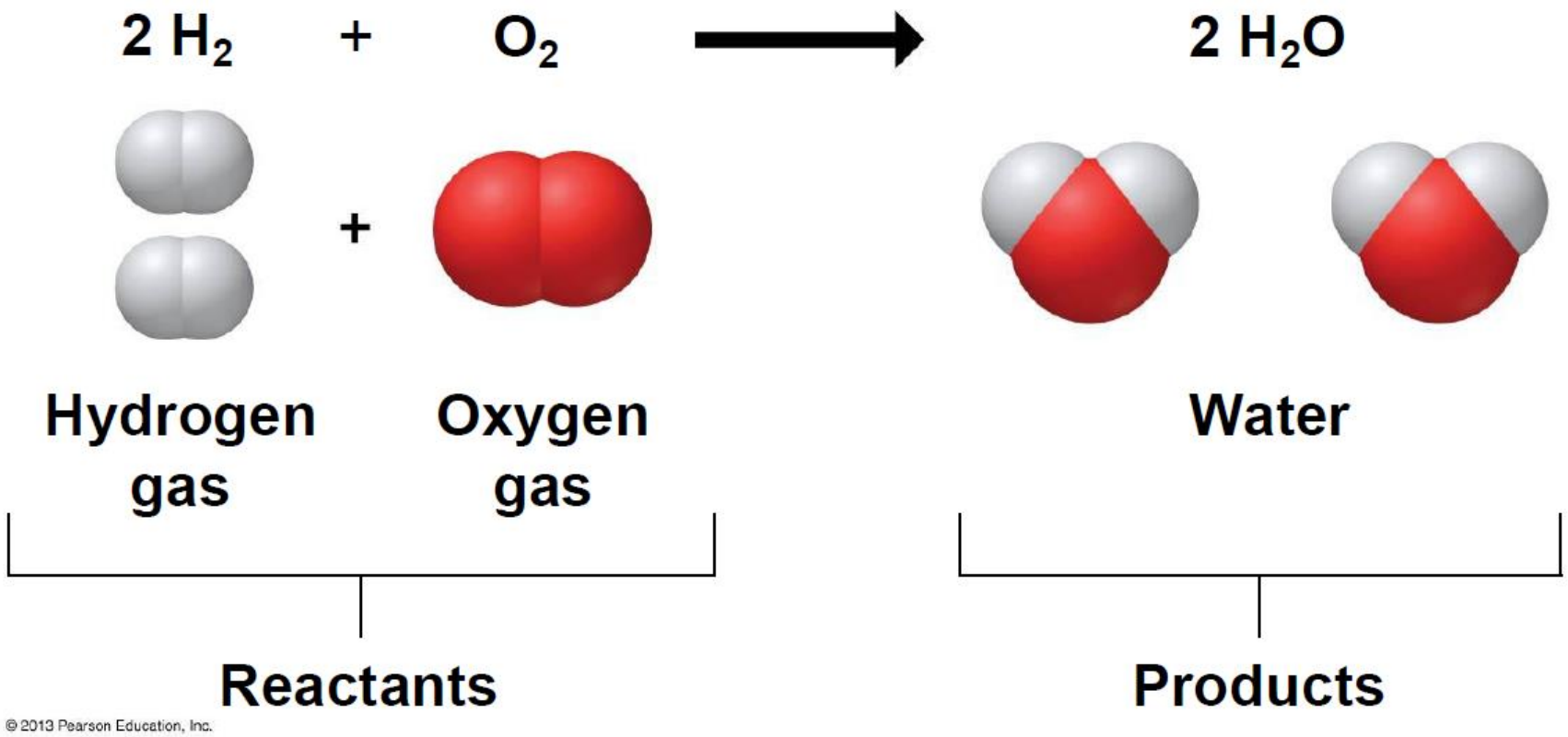
Figure 2.9



Chemical Reactions

- Cells constantly rearrange molecules by breaking existing chemical bonds and forming new ones.
  - Such changes in the chemical composition of matter are called **chemical reactions**.
  - A simple example is the reaction between oxygen gas and hydrogen gas that forms water.

Figure 2.UN03



Chemical Reactions

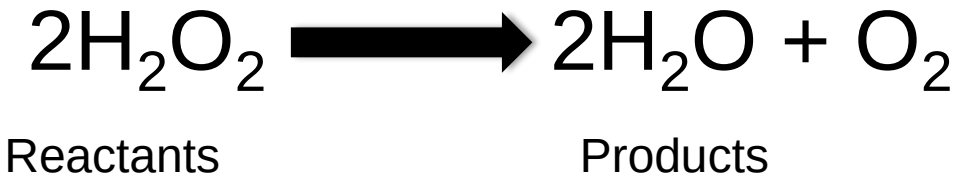
- Chemical reactions include
  - **reactants**, the starting materials, and
  - **products**, the end materials.
- Chemical reactions
  - can rearrange matter
  - but cannot create or destroy matter.

ELECTRONS DETERMINE HOW ATOMS INTERACT

Chemical reactions are changes in distribution of electrons between atoms

CHEMICAL REACTIONS

- **Reactants** – substances used at beginning of reaction
- **Products** – substances formed at the end of the reaction



CHEMICAL REACTION CAN BE REVERSIBLE OR IRREVERSIBLE

$2H_2O_2 \longrightarrow 2H_2O + O_2$

Irreversible reaction: proceeds in one direction until all the reactants are used up

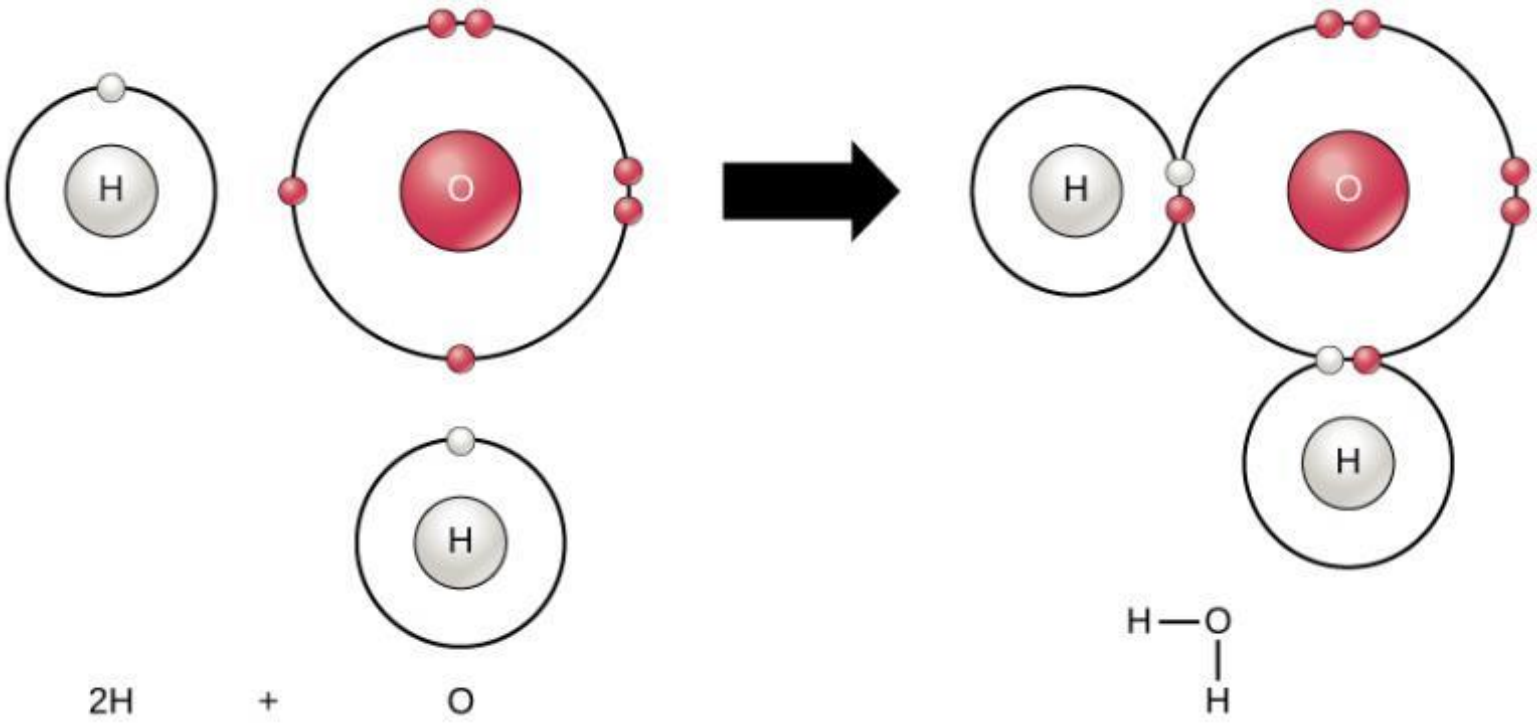
$HCO_3^- + H^+ \longleftrightarrow H_2CO_3$

Reversible reaction: Reactants are converted to products but some product can be converted back to reactant

HOW DO ATOMS BOND TO FORM MOLECULES?

Chemical bond: the attractive force that links atoms together to form molecules

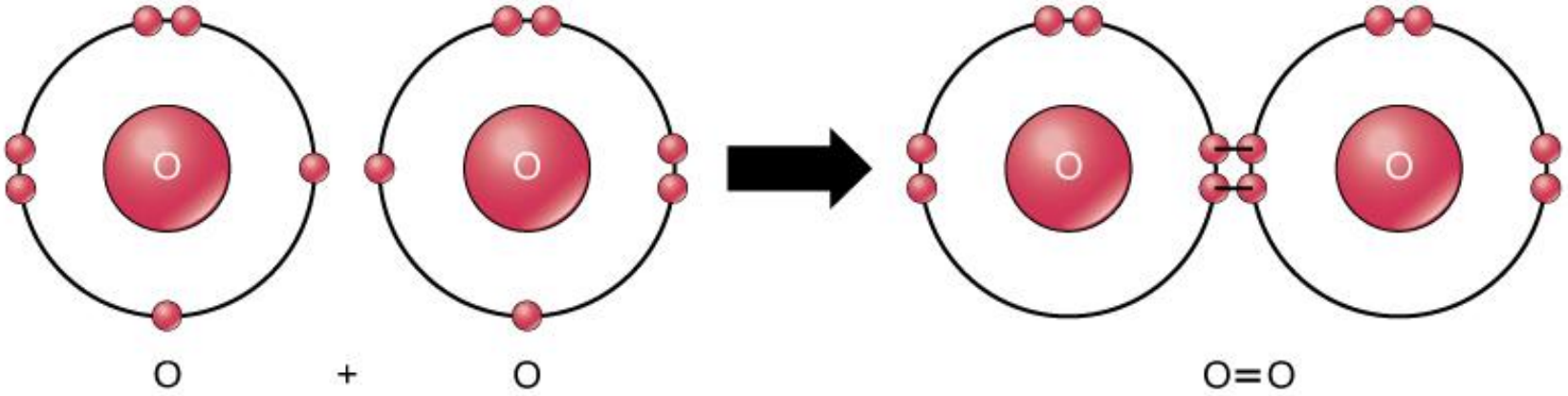
2.9 COVALENT BONDS – ELECTRONS ARE SHARED



Two or more atoms may bond with each other to form a molecule.

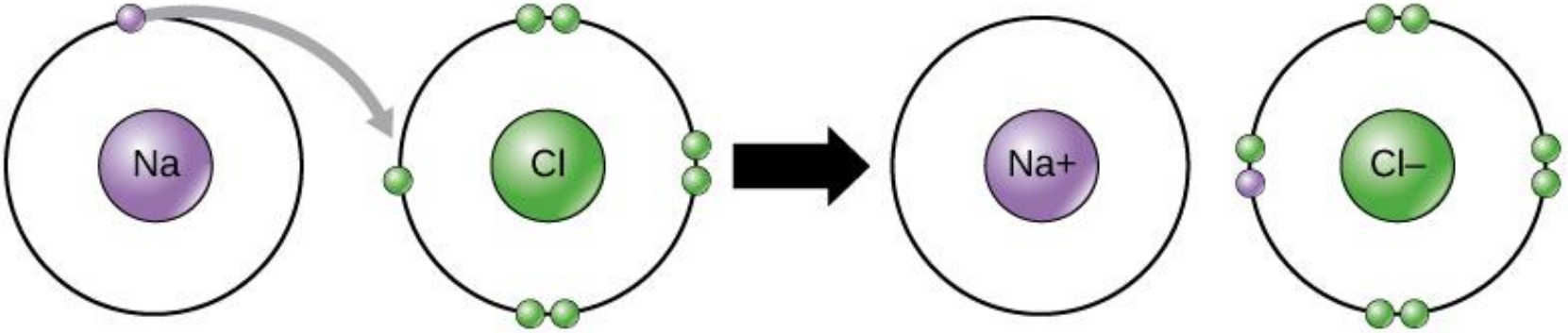
When two hydrogens and an oxygen **share** electrons via **covalent bonds**, a water molecule is formed.

MORE THAN ONE SET OF ELECTRONS CAN BE SHARED



The oxygen atoms in an O_2 molecule are joined by a **double bond**.

IONIC BONDS – ATOMS GIVE UP OR GAIN ELECTRONS



In the formation of an **ionic compound**, metals **lose electrons** and nonmetals **gain electrons** to achieve an octet.


AMoeba Sisters
PreSeNt

WATER AND LIFE

- Life on Earth began in water and evolved there for 3 billion years.
  - Modern life remains tied to water.
  - Your cells are composed of 70–95% water.
- The abundance of water is a major reason Earth is habitable.

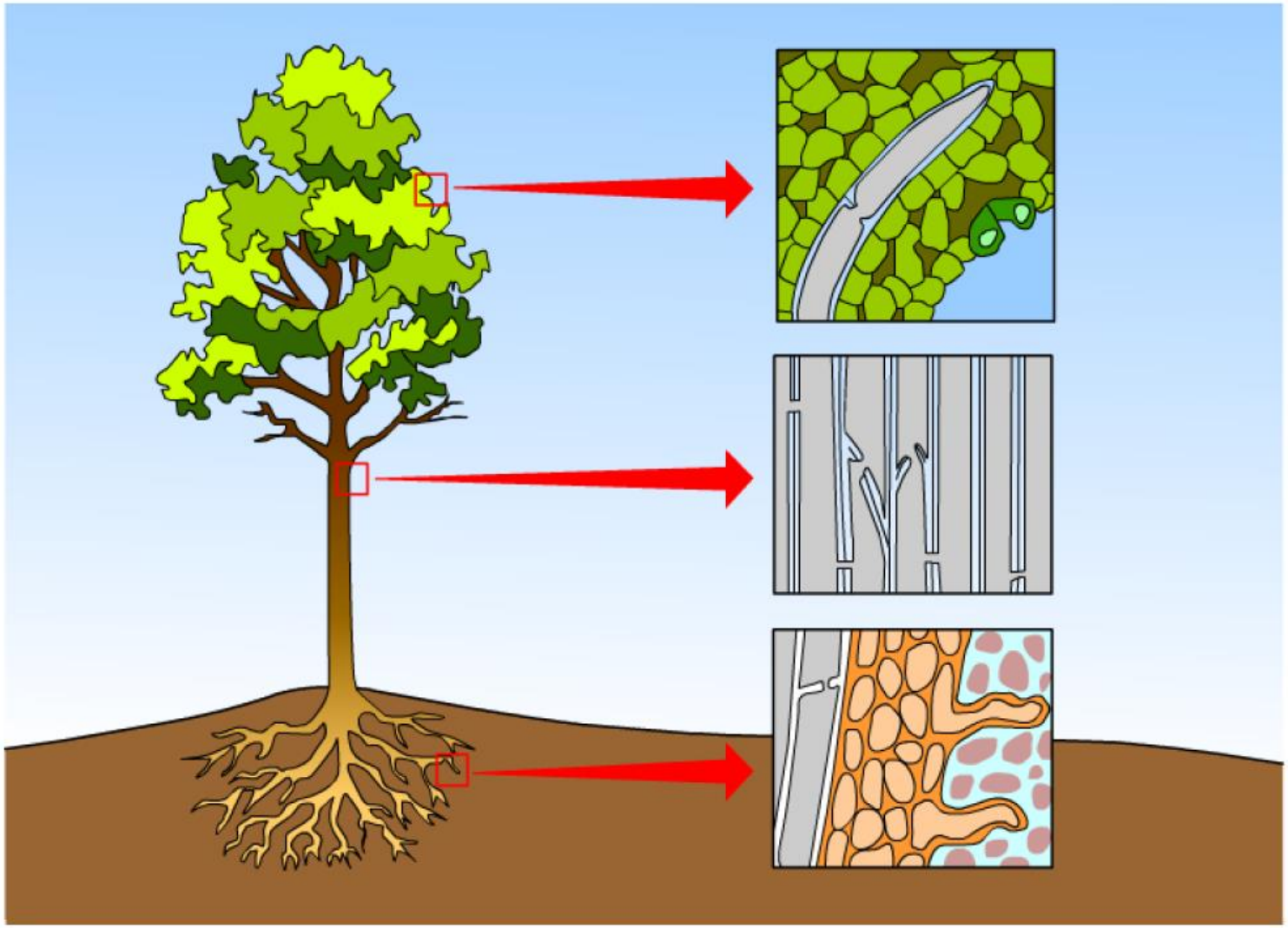
Figure 2.10

Water's Life-Supporting Properties

- The polarity of water molecules and the hydrogen bonding that results explain most of water's life-supporting properties.
  - Water molecules stick together.
  - Water has a strong resistance to change in temperature.
  - Frozen water floats.
  - Water is a common solvent for life.

The Cohesion of Water

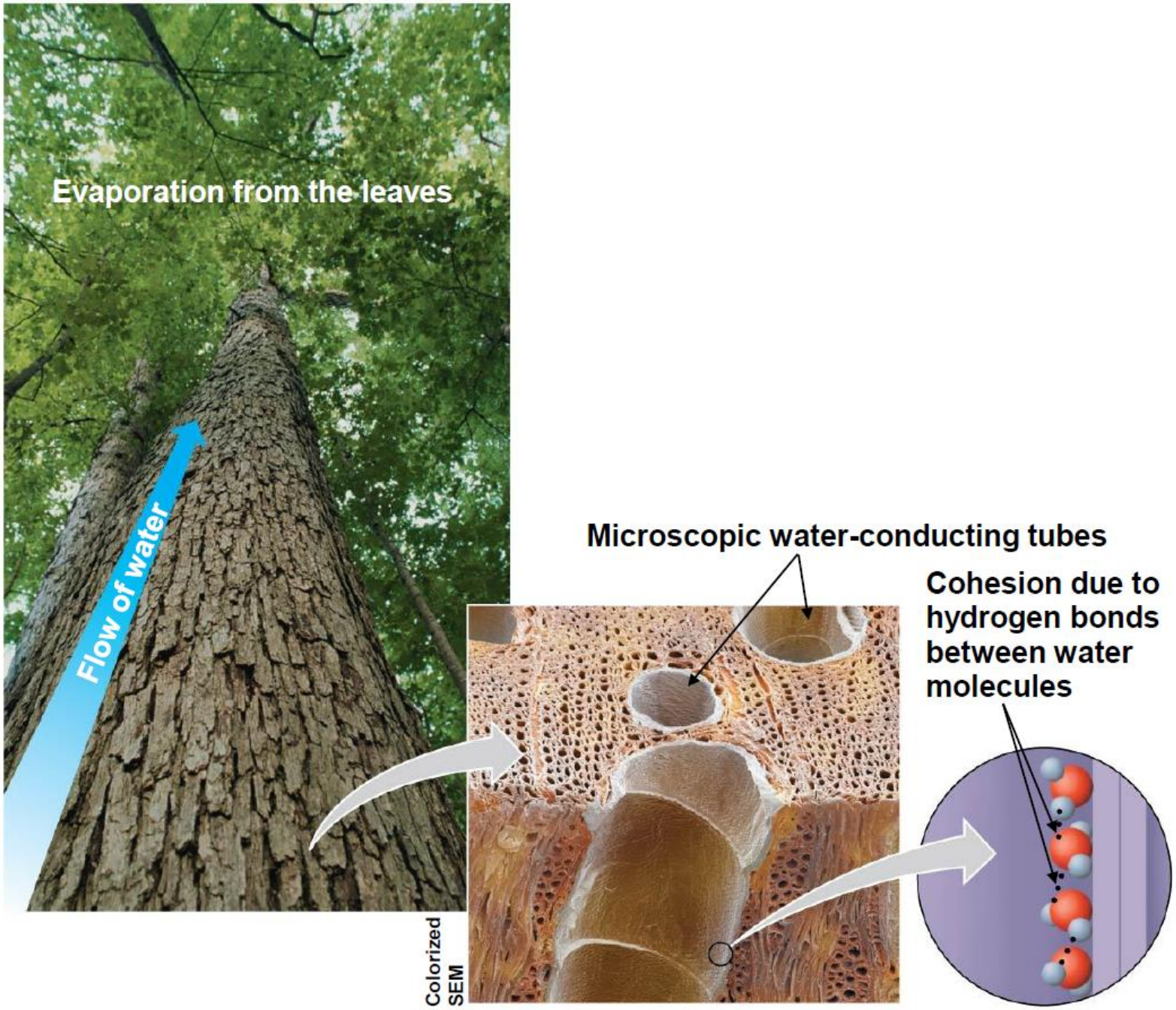
- Water molecules stick together as a result of hydrogen bonding.
  - This tendency of molecules of the same kind to stick together is called **cohesion**.
  - Cohesion is vital for the transport of water from the roots to the leaves of plants.



Animation: Water Transport

Right-click slide / select “play”

Figure 2.11



The Cohesion of Water

- Surface tension is the measure of how difficult it is to stretch or break the surface of a liquid.
  - Hydrogen bonds give water an unusually high surface tension.

COHESION IN WATER

Cohesion

Water molecules at the liquid-gas interface stick together due to hydrogen bonding

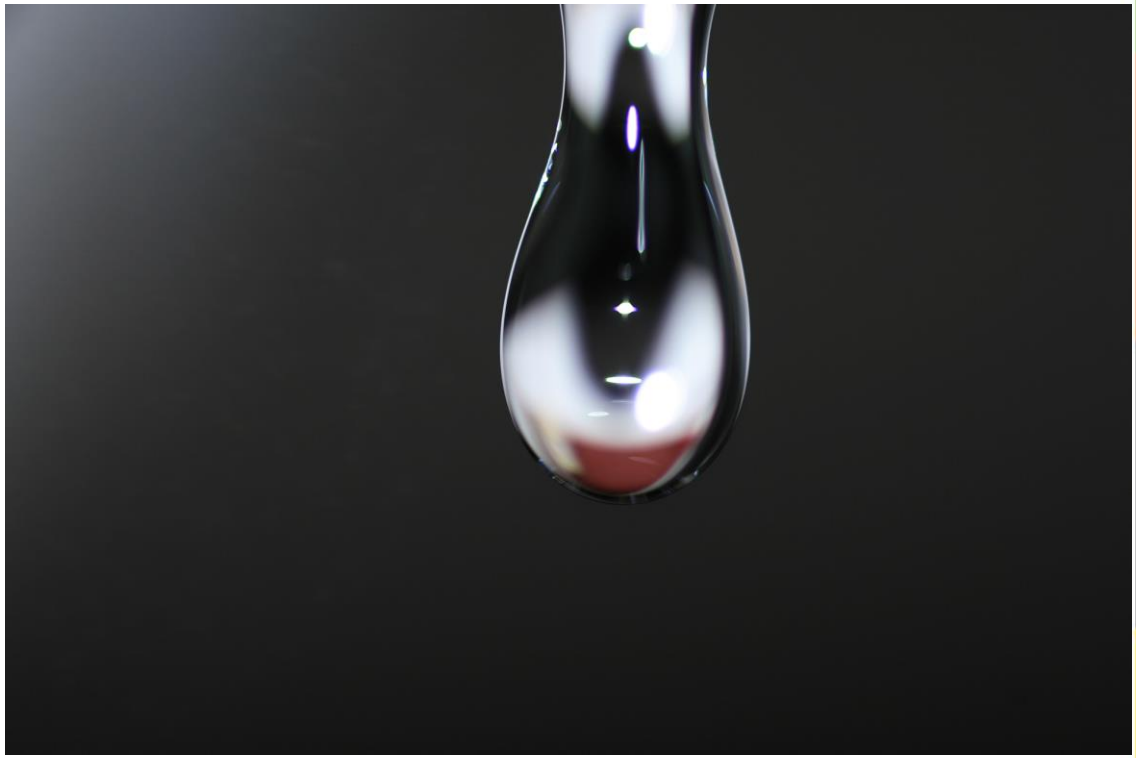


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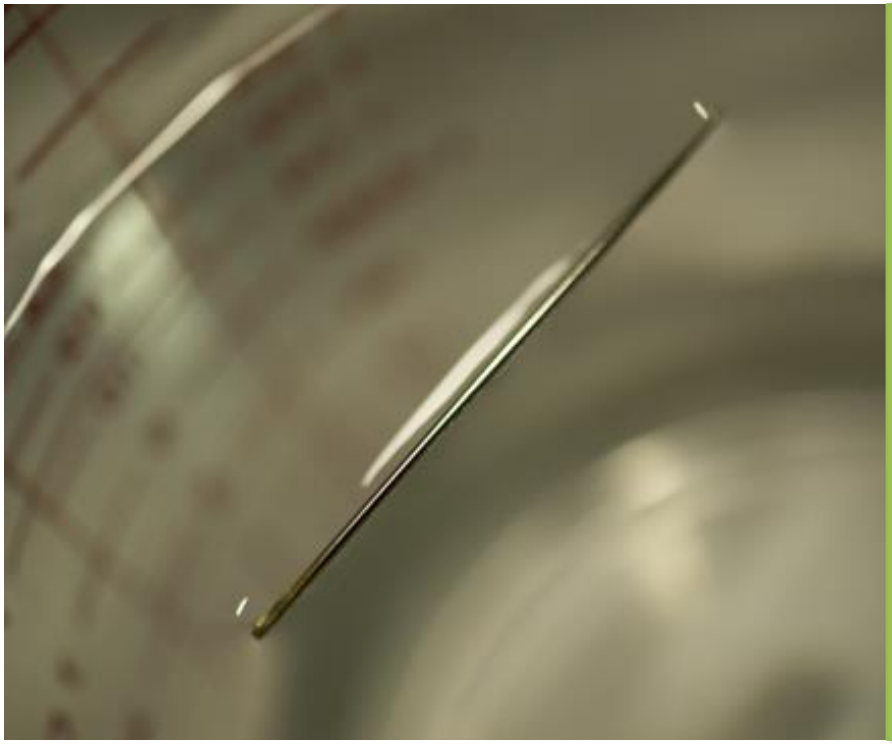
Figure 2.12

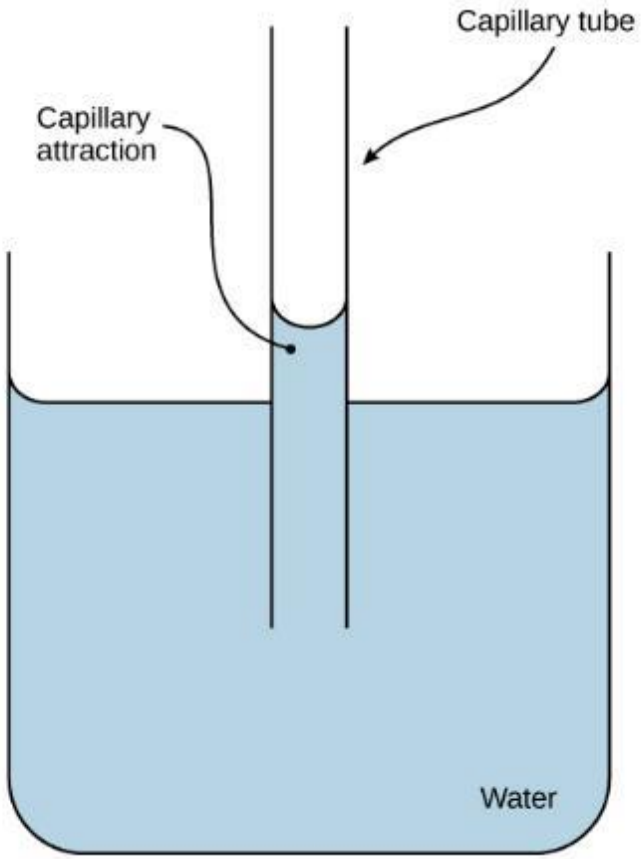
COHESION ALLOWS FOR DEVELOPMENT OF SURFACE TENSION



Surface Tension: capacity of a substance to withstand being ruptured when placed under tension or stress

The weight of the needle is pulling the surface downward; at the same time, the surface tension is pulling it up, suspending it on the surface of the water and keeping it from sinking. Notice the indentation in the water around the needle. (credit: Cory Zanker)

WATER EXHIBITS UNIQUE PROPERTIES



Capillary action in a glass tube is caused by the adhesive forces exerted by the internal surface of the glass exceeding the cohesive forces between the water molecules themselves. (credit: modification of work by Pearson-Scott Foresman, donated to the Wikimedia Foundation)

Adhesion – An attraction between water molecules and other molecules

Water moves up tube because the molecules of water are attracted to the charged surface of the glass tube

How Water Moderates Temperature

- Because of hydrogen bonding, water has a strong resistance to temperature change.
- Heat and temperature are related, but different.
  - **Heat** is the amount of energy associated with the movement of the atoms and molecules in a body of matter.
  - **Temperature** measures the intensity of heat.
- Water can absorb and store large amounts of heat while only changing a few degrees in temperature.

How Water Moderates Temperature

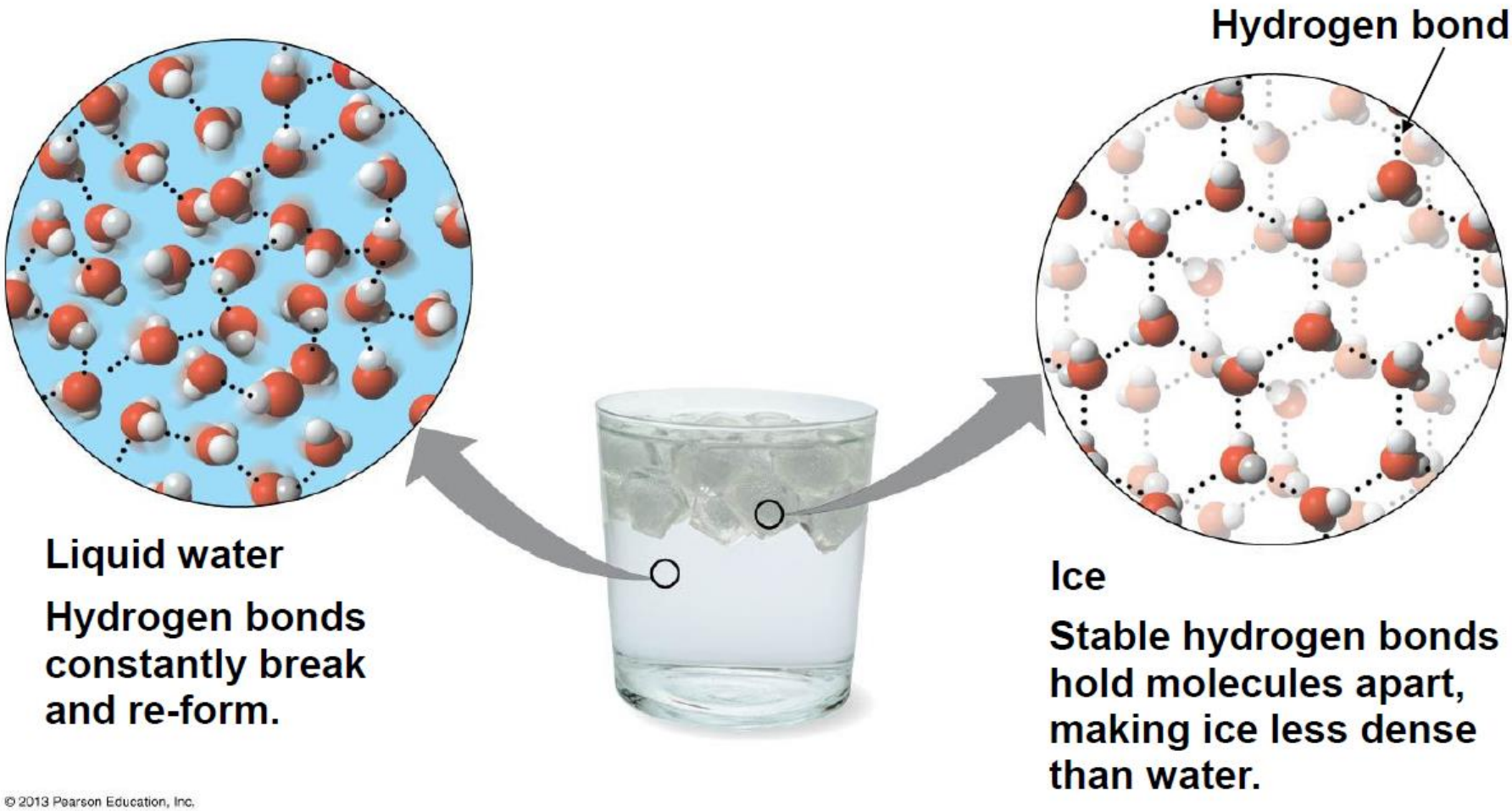
- Water can moderate temperatures.
  - Earth's giant water supply causes temperatures to stay within limits that permit life.
  - **Evaporative cooling** occurs when a substance evaporates and the surface of the liquid remaining behind cools down.

Figure 2.13

The Biological Significance of Ice Floating

- When water molecules get cold enough, they move apart, forming ice.
- A chunk of ice has fewer water molecules than an equal volume of liquid water.
- Ice floats because it is less dense than liquid water.

Figure 2.14



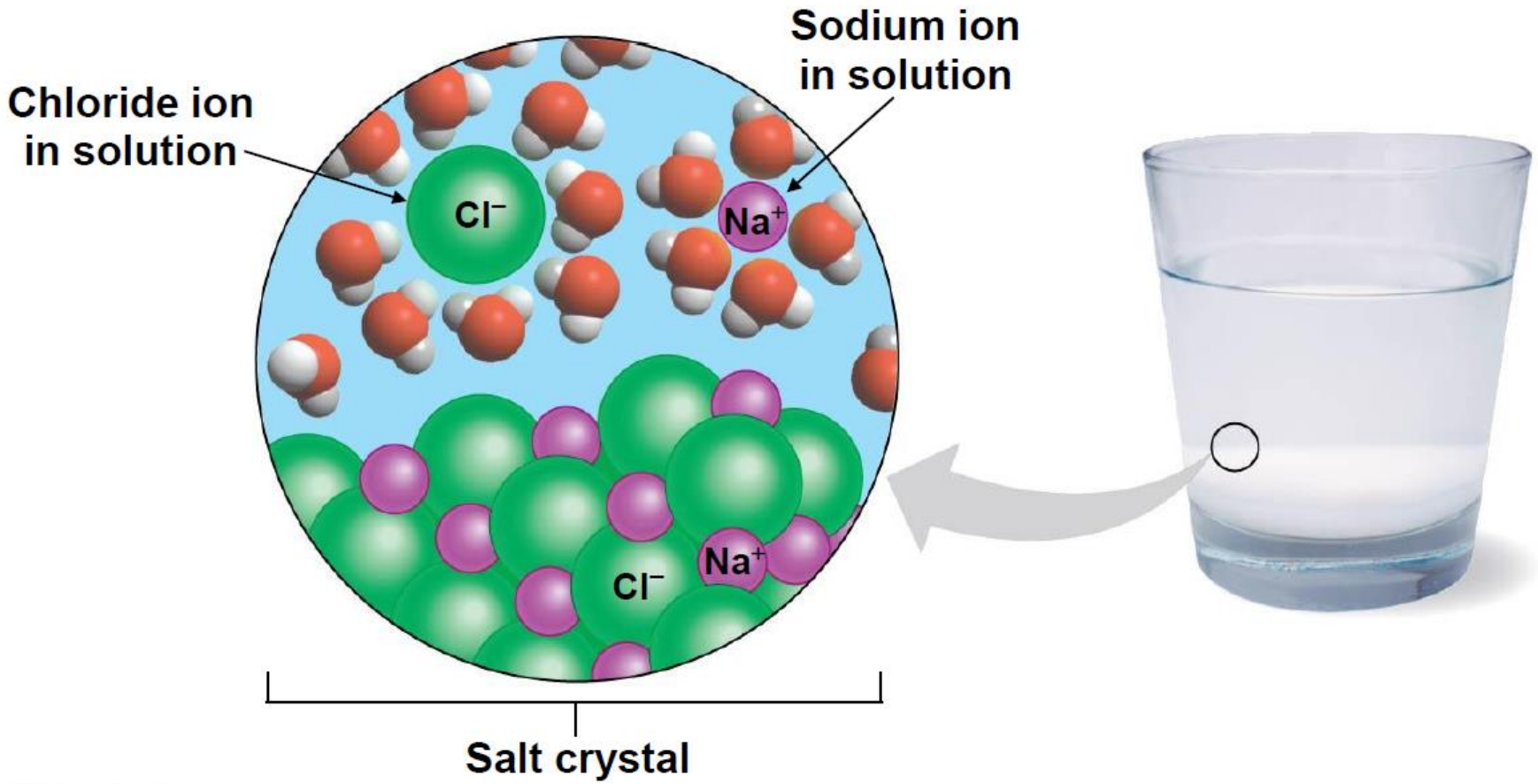
The Biological Significance of Ice Floating

- If ice did not float, ponds, lakes, and even the oceans would freeze solid.
- Life in water could not survive if bodies of water froze solid.

Water as the Solvent of Life

- A **solution** is a liquid consisting of a homogeneous mixture of two or more substances.
  - The dissolving agent is the **solvent**.
  - The dissolved substance is the **solute**.
- When water is the solvent, the result is an **aqueous solution**.

Figure 2.15



The Process of Science: Can Exercise Boost Your Brain Power?

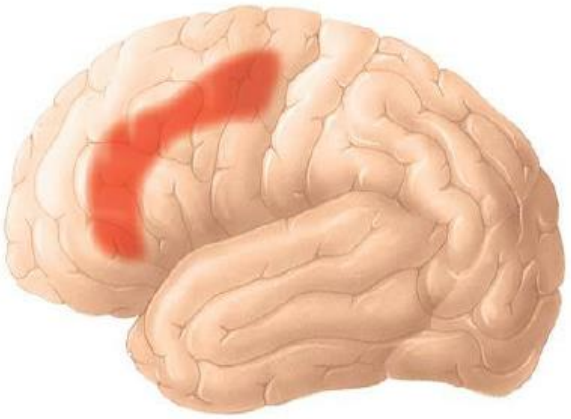
- **Observation**: Human brains shrink as we age.
- **Question**: Can aerobic exercise slow or reverse brain loss?
- **Hypothesis**: MRI scans will reveal differences between people who regularly exercised aerobically and those who did not.

Figure 2.UN04

The Process of Science: Can Exercise Boost Your Brain Power?

- **Prediction**: Brains of active people shrink less than the brains of less active people.
- **Experiment**: Twenty-nine people in their 60s and 70s exercised for three one-hour sessions per week. A control group of 29 people engaged in non-aerobic stretching exercises for the same periods.
- **Results**: The aerobic group showed significant increases in brain volume compared to the non-aerobic group.

Figure 2.16



Acids, Bases, and pH

- A chemical compound that releases H^+ to a solution is an **acid**.
- A compound that accepts H^+ and removes them from solution is a **base**.
- To describe the acidity of a solution, chemists use the **pH scale**.

Figure 2.17

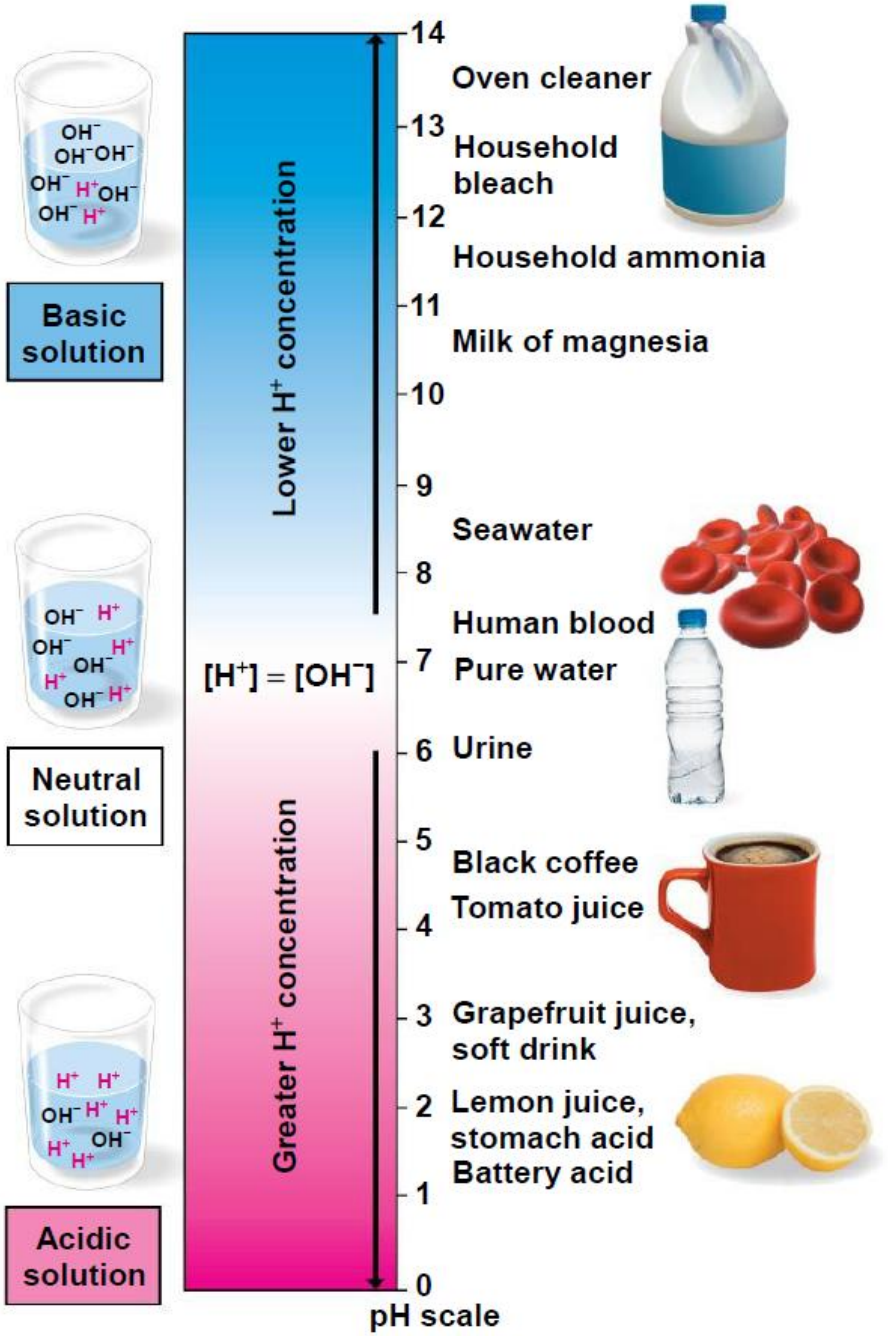
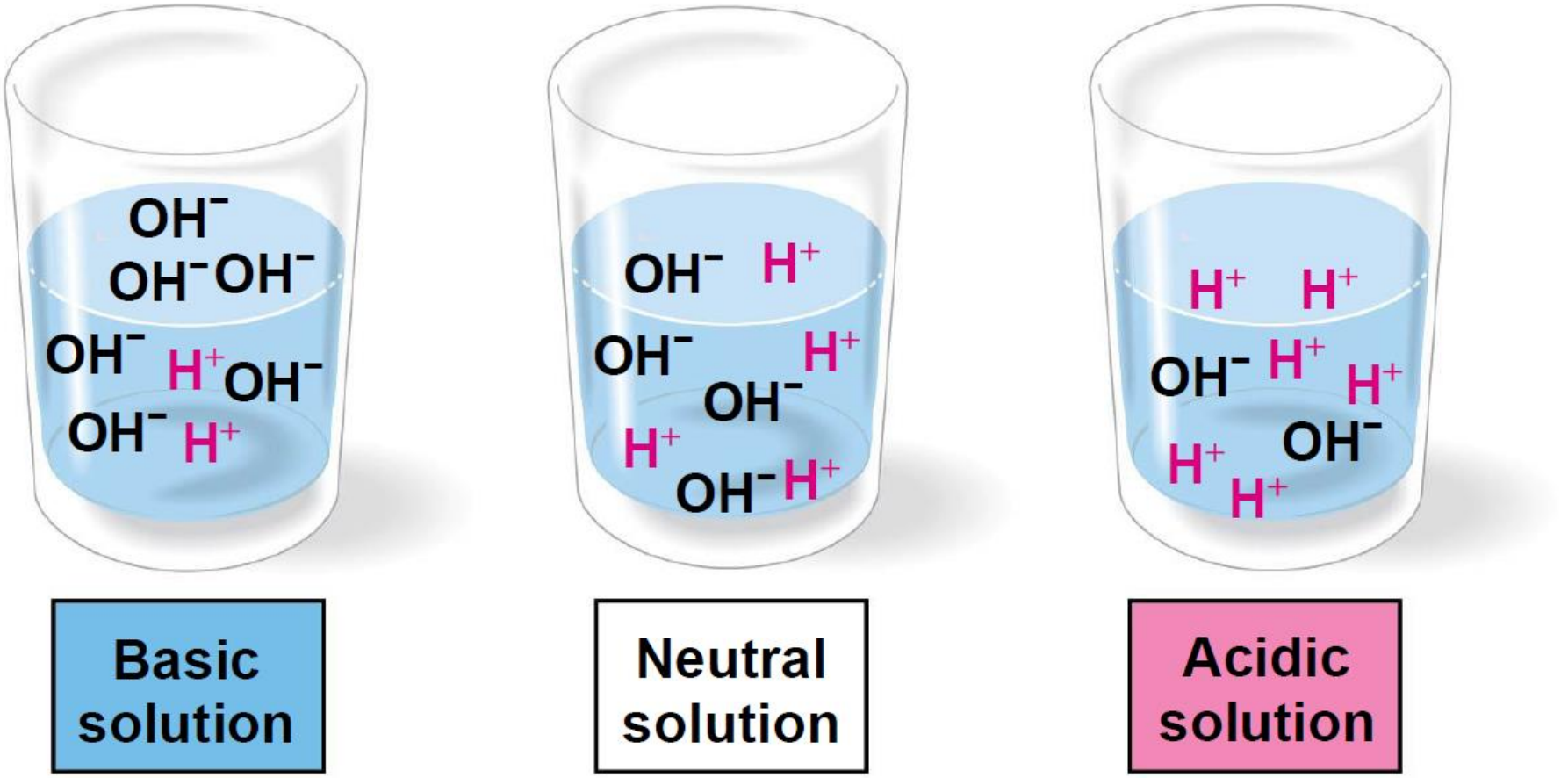


Figure 2.17a



Acids, Bases, and pH

- **Buffers** are substances that resist pH change.
- Buffers
  - accept H^+ ions when they are in excess and
  - donate H^+ ions when they are depleted.
- Increases in global CO_2 concentrations may lead to
  - the acidification of the oceans and
  - ecological disasters.

Figure 2.18

Evolution Connection: The Search for Extraterrestrial Life

- If life similar to ours has evolved elsewhere in the universe, then it too would depend upon water.
- Researchers at NASA missions have found evidence that water was once abundant on Mars.
- Microbial life may exist below the Martian surface.

Figure 2.19