ELEMENTS, ATOMS, AND COMPOUNDS

2.1 Organisms are composed of elements, in combinations called compounds

- Living organisms are composed of **matter**, which is anything that occupies space and has mass (weight).
- Matter is composed of chemical elements.
  - An **element** is a substance that cannot be broken down to other substances.
  - There are 92 elements in nature—only a few exist in a pure state.

Periodic Table of Elements

Atomic #
Symbol
Name
Atomic Mass

C Solid
Hg Liquid
H Gas
Rf Unknown

Metals: Alkali metals, Alkaline earth metals, Lanthanoids, Actinoids, Transition metals, Poor metals
Nonmetals: Other nonmetals, Noble gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Ptable.com

Table 2.1

TABLE 2.1 ELEMENTS IN THE HUMAN BODY

Element	Symbol	Percentage of Body Weight (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 human body weight: 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)

2.1 Organisms are composed of elements, in combinations called compounds

- A **compound** is a substance consisting of two or more different elements in a fixed ratio.
- Compounds are more common than pure elements.
- Sodium chloride, table salt, is a common compound of equal parts of sodium (Na) and chlorine (Cl).

2.1 Organisms are composed of elements, in combinations called compounds

- About 25 elements are essential to life.
- Four elements make up about 96% of the weight of most living organisms. These are
  - oxygen,
  - carbon,
  - hydrogen, and
  - nitrogen.
- **Trace elements** are essential but are only needed in minute quantities.

2.2 CONNECTION: Trace elements are common additives to food and water

- Some trace elements are required to prevent disease.
  - Without iron, your body cannot transport oxygen.
  - An iodine deficiency prevents production of thyroid hormones, resulting in goiter.

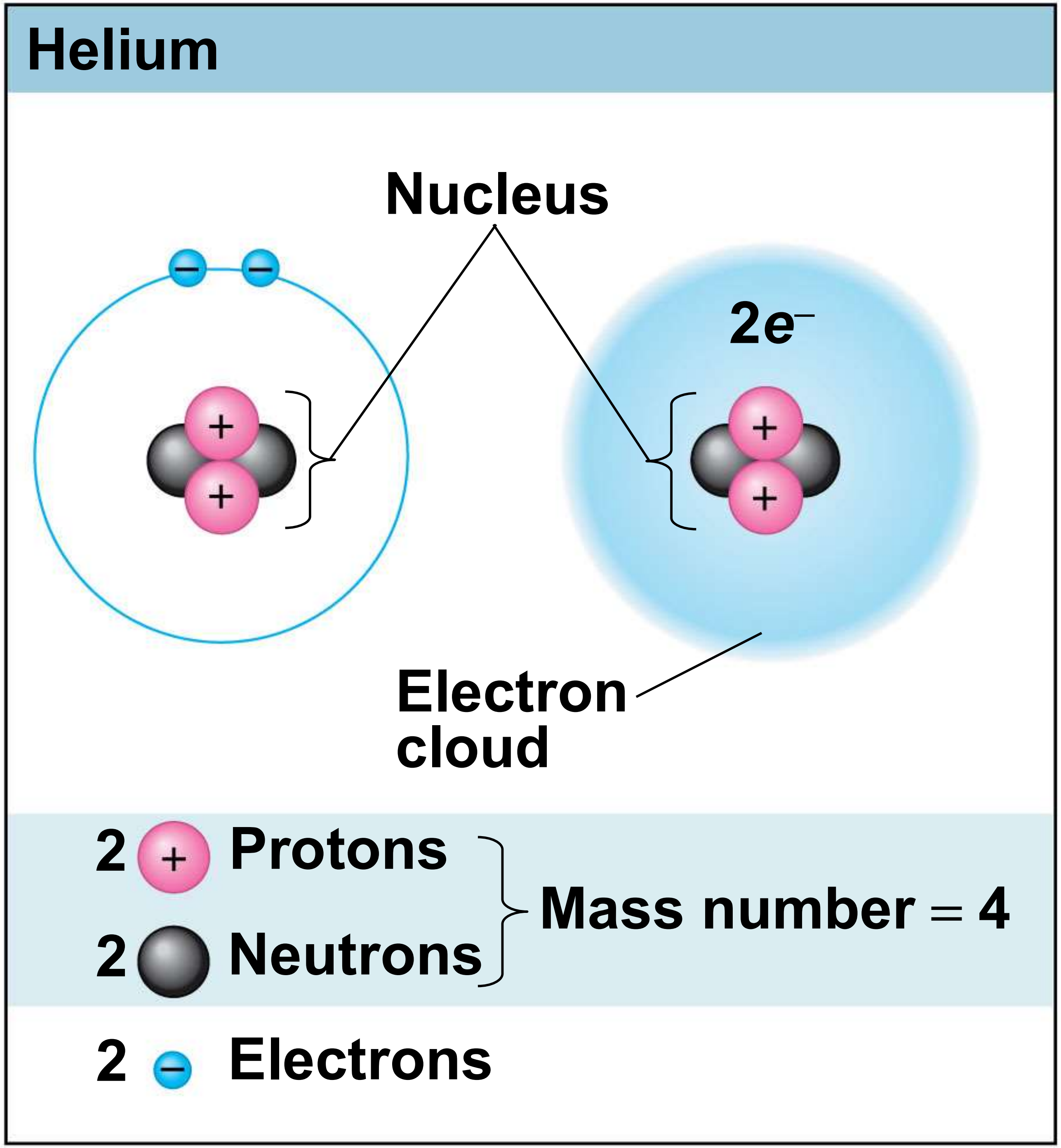
2.3 Atoms consist of protons, neutrons, and electrons

- Each element consists of one kind of atom.
- An **atom** is the smallest unit of matter that still retains the properties of an element.
- Three subatomic particles in atoms are relevant to our discussion of the properties of elements.
  - **Protons** are positively charged.
  - **Electrons** are negatively charged.
  - **Neutrons** are electrically neutral.

2.3 Atoms consist of protons, neutrons, and electrons

- Neutrons and protons are packed into an atom's **nucleus.**
- Electrons orbit the nucleus.
- The negative charge of electrons and the positive charge of protons keep electrons near the nucleus.
- Nearly all the mass of an atom is in the nucleus (protons + neutrons). Electrons do have mass but is negligible compared to the nuclear particles.

Figure 2.3A



Helium
Nucleus
2e⁻
Electron cloud
2 Protons
2 Neutrons
Mass number = 4
2 Electrons

2.3 Atoms consist of protons, neutrons, and electrons

- The number of protons is the atom's **atomic number.**
- An atom's **mass number** is the sum of the number of protons and neutrons in the nucleus.
- The **atomic mass** is approximately equal to its mass number.

2.3 Atoms consist of protons, neutrons, and electrons

- Although all atoms of an element have the same atomic number, some differ in mass number.
- Different **isotopes** of an element have
  - the same number of protons,
  - but different numbers of neutrons.
- Different isotopes of an element behave identically in chemical reactions.
- In **radioactive isotopes**, the nucleus decays spontaneously, giving off particles and energy.

Most elements exist as a mixture of the element in its most stable state plus its isotopes

TABLE 2.3 ISOTOPES OF CARBON

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

C-12 and C-13 are stable isotopes of carbon, The percentage of C-12 in nature is 98.89% whereas C-13 is only 1.11%. C-14 is unstable in nature, 1 in a trillion carbons.

Atomic mass of an element is actually the weighted average of its isotopes. Example C is 12.0107 mass units

2.4 CONNECTION: Radioactive isotopes can help or harm us

- Living cells cannot distinguish between isotopes of the same element.
  - Therefore, radioactive compounds in metabolic processes can act as tracers.
  - This radioactivity can be detected by instruments.
  - Using these instruments, the fate of radioactive tracers can be monitored in living organisms.

2.4 CONNECTION: Radioactive isotopes can help or harm us

- Radioactive tracers are frequently used in medical diagnosis.
- Sophisticated imaging instruments are used to detect them.
  - An imaging instrument that uses positron-emission tomography (PET) detects the location of injected radioactive materials.
  - PET is useful for diagnosing heart disorders, cancer, and in brain research.

2.4 CONNECTION: Radioactive isotopes can help or harm us

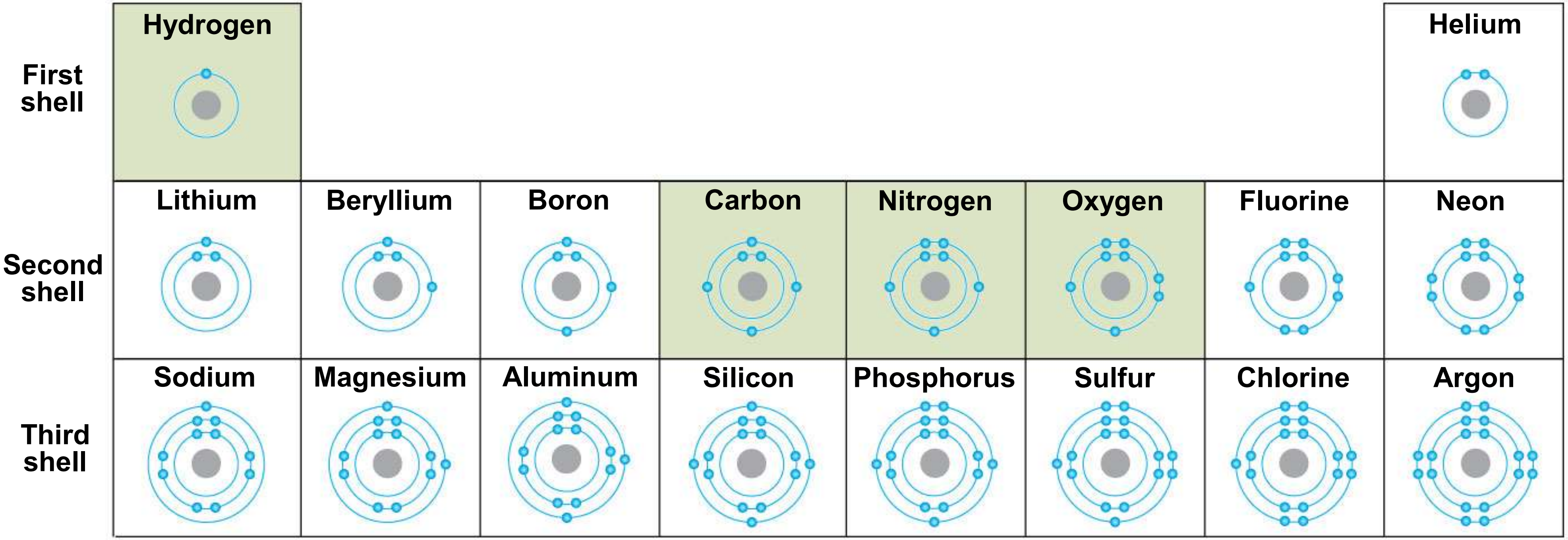
- In addition to benefits, there are also dangers associated with using radioactive substances.
  - Uncontrolled exposure can cause damage to some molecules in a living cell, especially DNA.
  - Chemical bonds are broken by the emitted energy, which causes abnormal bonds to form.

CHEMICAL BONDS

2.5 The distribution of electrons determines an atom's chemical properties

- Of the three subatomic particles—protons, neutrons, and electrons—only electrons are directly involved in chemical activity.
- Electrons occur in energy levels called **electron shells**.
  - Information about the distribution of electrons is found in the periodic table of the elements.

Figure 2.5



First shell
Second shell
Third shell
Hydrogen
Helium
Lithium
Beryllium
Boron
Carbon
Nitrogen
Oxygen
Fluorine
Neon
Sodium
Magnesium
Aluminum
Silicon
Phosphorus
Sulfur
Chlorine
Argon

2.5 The distribution of electrons determines an atom's chemical properties

- An atom may have one, two, or three electron shells surrounding the nucleus.
  – The number of electrons in the outermost shell determines the chemical properties of the atom.
  – Atoms whose outer shells are not full tend to interact with other atoms, participating in chemical reactions.

2.5 The distribution of electrons determines an atom's chemical properties

- Atoms with incomplete outer shells tend to react so that both atoms end up with completed outer shells.
- These atoms may react with each other by sharing, donating, or receiving electrons.
- These interactions usually result in atoms staying close together, held by attractions called **chemical bonds**.

2.6 Covalent bonds join atoms into molecules through electron sharing

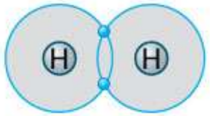
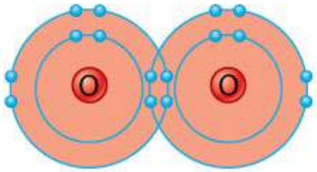
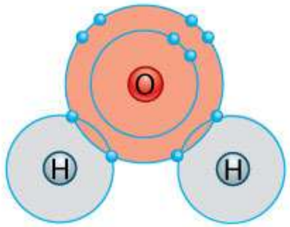
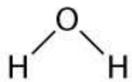
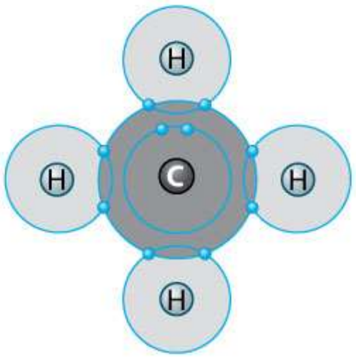
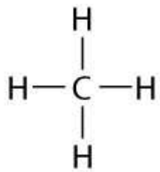
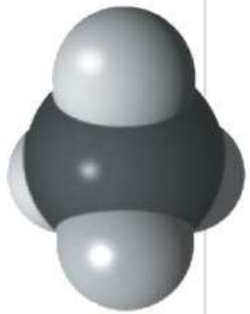
- The strongest kind of chemical bond is a **covalent bond** in which two atoms share one or more outer-shell electrons.
- Two or more atoms held together by covalent bonds form a **molecule**.

2.6 Covalent bonds join atoms into molecules through electron sharing

- A covalent bond connects two hydrogen atoms in a molecule of the gas H_2.
- There are four alternative ways to represent common molecules.

Table 2.6

TABLE 2.6 ALTERNATIVE WAYS TO REPRESENT FOUR COMMON MOLECULES

Molecular Formula	Electron Distribution Diagram	Structural Formula	Space-Filling Model
H_2 Hydrogen		H—H (Single bond)	
O_2 Oxygen		O=O (Double bond)	
H_2O Water			
CH_4 Methane			

2.6 Covalent bonds join atoms into molecules through electron sharing

- Atoms in a covalently bonded molecule continually compete for shared electrons.
  - The attraction (pull) for shared electrons is called **electronegativity.**
  - More electronegative atoms pull harder.

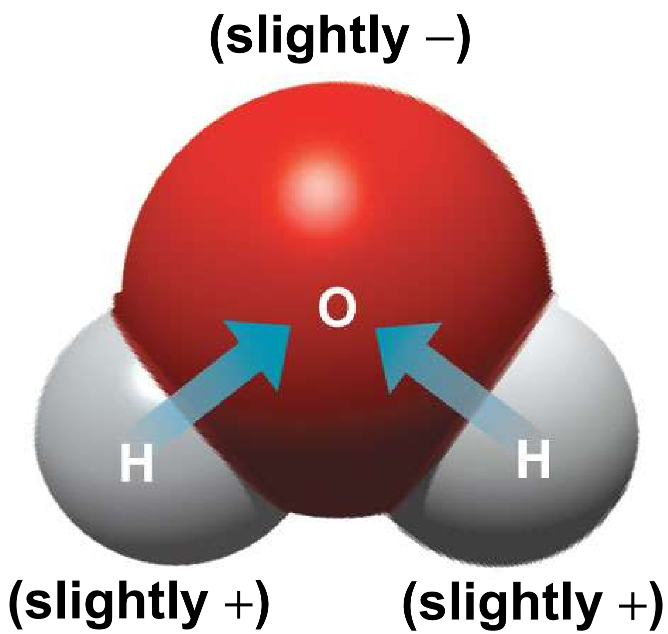
2.6 Covalent bonds join atoms into molecules through electron sharing

- In molecules of only one element, the pull toward each atom is equal, because each atom has the same electronegativity.
- The bonds formed are called **nonpolar covalent bonds.**

2.6 Covalent bonds join atoms into molecules through electron sharing

- Water has atoms with different electronegativities.
  - Oxygen attracts the shared electrons more strongly than hydrogen.
  - So, the shared electrons spend more time near oxygen.
  - The oxygen atom has a slightly negative charge and the hydrogen atoms have a slightly positive charge.
  - The result is a **polar covalent bond.**
  - Because of these polar covalent bonds, water is a **polar molecule**.

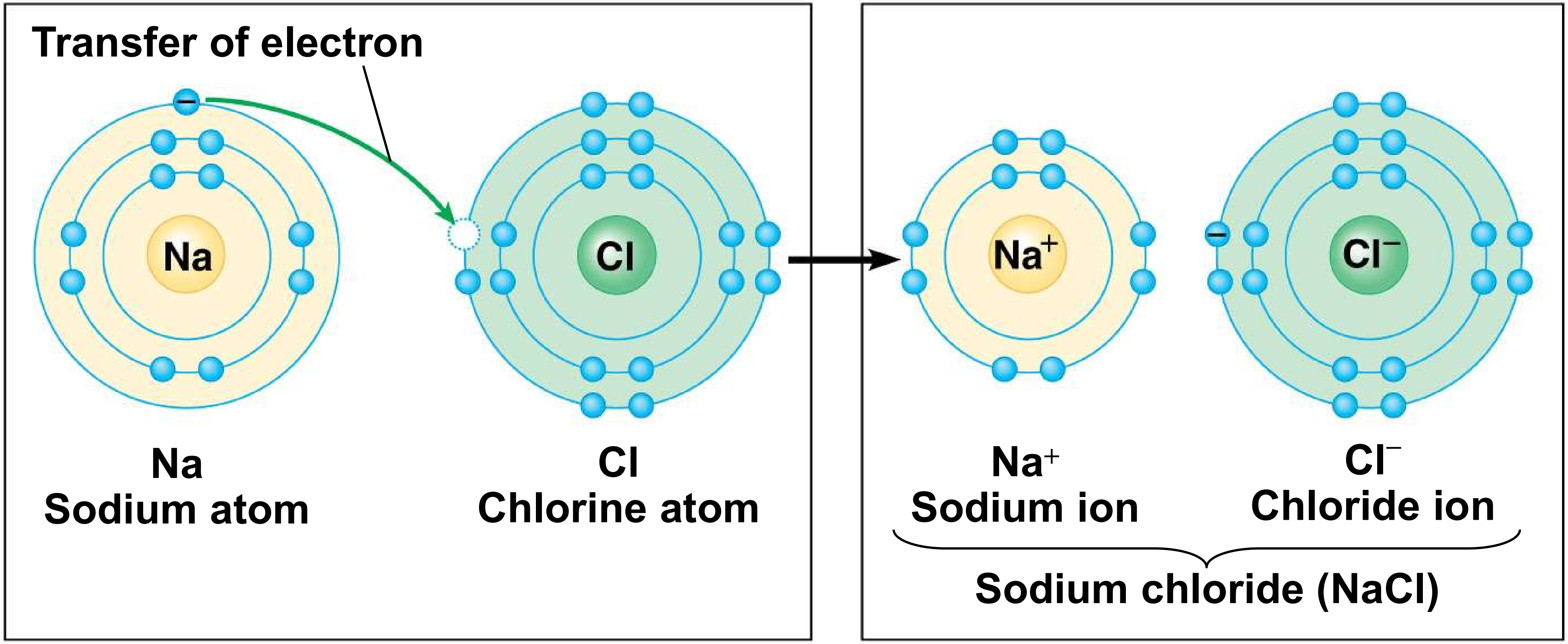
Figure 2.6



2.7 Ionic bonds are attractions between ions of opposite charge

- An **ion** is an atom or molecule with an electrical charge resulting from gain or loss of electrons.
  - When an electron is lost, a positive charge results.
  - When an electron is gained, a negative charge results.
- Two ions with opposite charges attract each other.
  - When the attraction holds the ions together, it is called an **ionic bond**.
  - **Salt** is a synonym for an ionic compound.

Figure 2.7A_s2



2.8 Hydrogen bonds are weak bonds important in the chemistry of life

- Most large molecules are held in their three-dimensional functional shape by weak bonds.
- Hydrogen, as part of a polar covalent bond, has a partial positive charge.
- The charged regions on molecules are electrically attracted to oppositely charged regions on neighboring molecules.
- Because the positively charged region is always a hydrogen atom, the bond is called a **hydrogen bond**.

2.9 Chemical reactions make and break chemical bonds

- Remember that the structure of atoms and molecules determines the way they behave.
  - Remember that atoms combine to form molecules.
  - Hydrogen and oxygen can react to form water:

$$2H_2 + O_2 \longrightarrow 2H_2O$$

2.9 Chemical reactions make and break chemical bonds

- The formation of water from hydrogen and oxygen is an example of a **chemical reaction.**
- The **reactants** (H_2 and O_2) are converted to H_2O, the **product**.
- Chemical reactions do not create or destroy matter.
- Chemical reactions only rearrange matter.

2.9 Chemical reactions make and break chemical bonds

- Photosynthesis is a chemical reaction that is essential to life on Earth.
  - Carbon dioxide (from the air) reacts with water.
  - Sunlight powers the conversion to produce the products glucose and oxygen.

WATER'S LIFE-SUPPORTING PROPERTIES

2.10 Hydrogen bonds make liquid water cohesive

- The tendency of molecules of the same kind to stick together is **cohesion.**
  - Cohesion is much stronger for water than other liquids.
  - Most plants depend upon cohesion to help transport water and nutrients from their roots to their leaves.
- The tendency of two kinds of molecules to stick together is **adhesion**.

2.10 Hydrogen bonds make liquid water cohesive

- Cohesion is related to **surface tension**—a measure of how difficult it is to break the surface of a liquid.
  - Hydrogen bonds give water high surface tension, making it behave as if it were coated with an invisible film.
  - Water striders stand on water without breaking the water surface.

2.11 Water's hydrogen bonds moderate temperature

- Because of hydrogen bonding, water has a greater ability to resist temperature change than other liquids.
  - **Heat** is the energy associated with movement of atoms and molecules in matter.
  - **Temperature** measures the intensity of heat.
- Heat is released when hydrogen bonds form.
- Heat must be absorbed to break hydrogen bonds.

2.11 Water's hydrogen bonds moderate temperature

- When a substance evaporates, the surface of the liquid that remains behind cools down, in the process of **evaporative cooling**.
- This cooling occurs because the molecules with the greatest energy leave the surface.

2.12 Ice is less dense than liquid water

- Water can exist as a gas, liquid, or solid.
- Water is less dense as a solid than a liquid because of hydrogen bonding.
- When water freezes, each molecule forms a stable hydrogen bond with its neighbors.
  - As ice crystals form, the molecules are less densely packed than in liquid water.
  - Because ice is less dense than water, it floats.

2.13 Water is the solvent of life

- A **solution** is a liquid consisting of a uniform mixture of two or more substances.
  - The dissolving agent is the **solvent.**
  - The substance that is dissolved is the **solute.**
  - An **aqueous solution** is one in which water is the solvent.

2.13 Water is the solvent of life

- Water's versatility as a solvent results from the polarity of its molecules.
- Polar or charged solutes dissolve when water molecules surround them, forming aqueous solutions.
- Table salt is an example of a solute that will go into solution in water.

2.14 The chemistry of life is sensitive to acidic and basic conditions

- In aqueous solutions, a small percentage of water molecules break apart into ions.
  - Some are hydrogen ions (H^+).
  - Some are hydroxide ions (OH^-).
  - Both types are very reactive.

2.14 The chemistry of life is sensitive to acidic and basic conditions

A compound that releases H^+ to a solution is an **acid**.

- Strong acid: HCl; weak acid: CH3COOH (vinegar)

A compound that accepts H^+ is a **base**.

- Strong base: NaOH (sodium hydroxide); weak base: NH3 (ammonia)

- The **pH scale** describes how acidic or basic a solution is.
  - The pH scale ranges from 0 to 14, with zero the most acidic and 14 the most basic.
  - Each pH unit represents a tenfold change in the concentration of H^+.

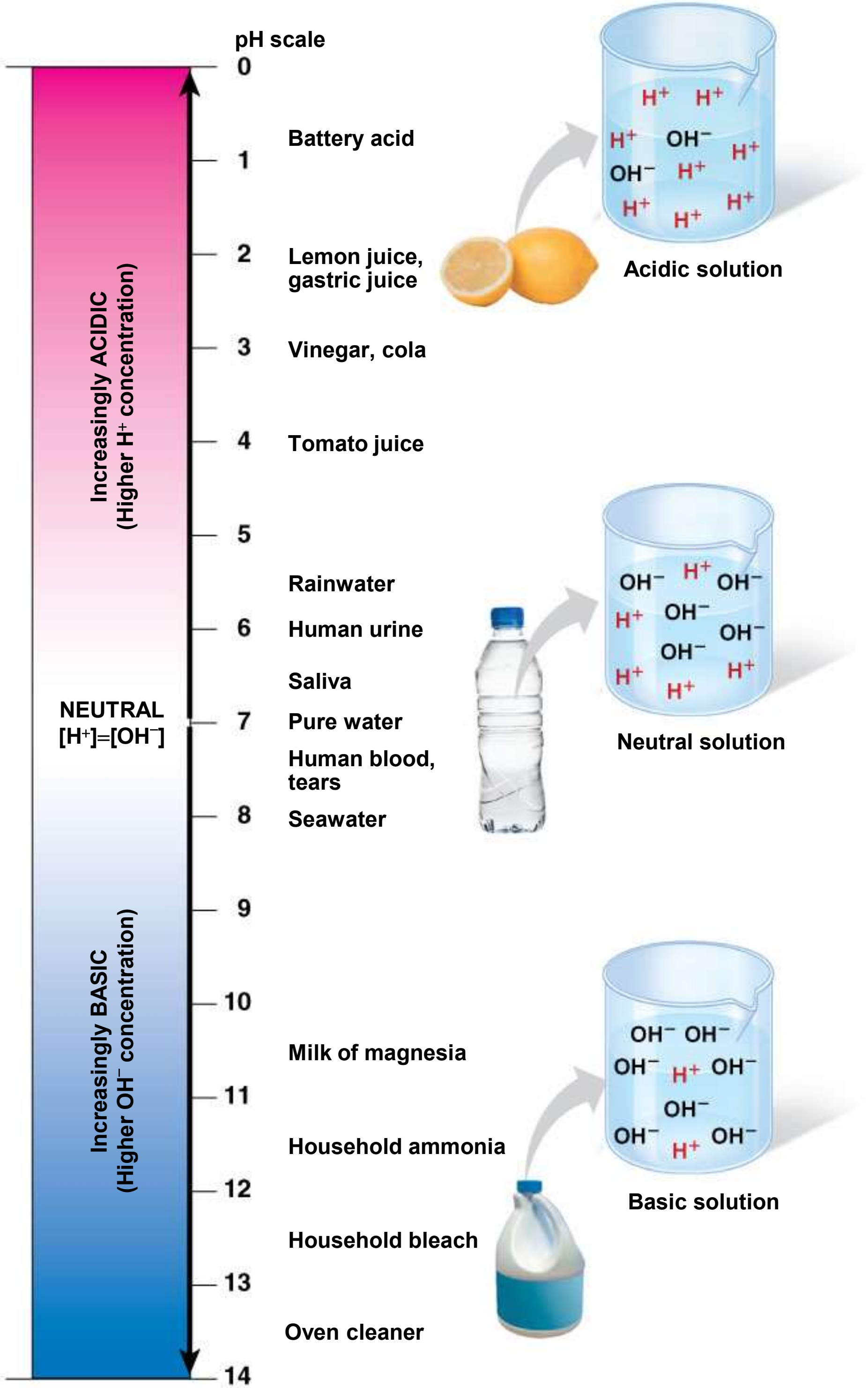
2.14 The chemistry of life is sensitive to acidic and basic conditions

- A **buffer** is a substance that minimizes changes in pH. Buffers
  - accept H^+ when it is in excess and
  - donate H^+ when it is depleted.

A buffer solution (more precisely, pH buffer or hydrogen ion buffer) is an aqueous solution consisting of a mixture of a weak acid and its conjugate base, or vice versa. Its pH changes very little when a small amount of strong acid or base is added to it

EXAMPLE: the bicarbonate system in red blood cells

Figure 2.14


pH scale
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Increasingly ACIDIC
(Higher H+ concentration)
NEUTRAL
[H+]=[OH−]
Increasingly BASIC
(Higher OH− concentration)
Battery acid
Lemon juice, gastric juice
Vinegar, cola
Tomato juice
Rainwater
Human urine
Saliva
Pure water
Human blood, tears
Seawater
Milk of magnesia
Household ammonia
Household bleach
Oven cleaner
H+ H+ H+ OH− H+ OH− H+ H+ H+ H+
Acidic solution
OH− H+ OH− H+ OH− OH− OH− H+ H+ H+
Neutral solution
OH− OH− OH− H+ OH− OH− OH− H+ OH−
Basic solution

2.15 CONNECTION: Acid precipitation and ocean acidification threaten the environment

- When we burn fossil fuels (coal, oil, and gas), air-polluting compounds and CO_2 are released into the atmosphere.
  - Sulfur and nitrous oxides react with water in the air to form acids.
  - These acids fall to Earth as **acid precipitation**, which is rain, snow, or fog with a pH lower than 5.2.
  - CO_2 dissolving in seawater lowers ocean pH in a process known as **ocean acidification**.