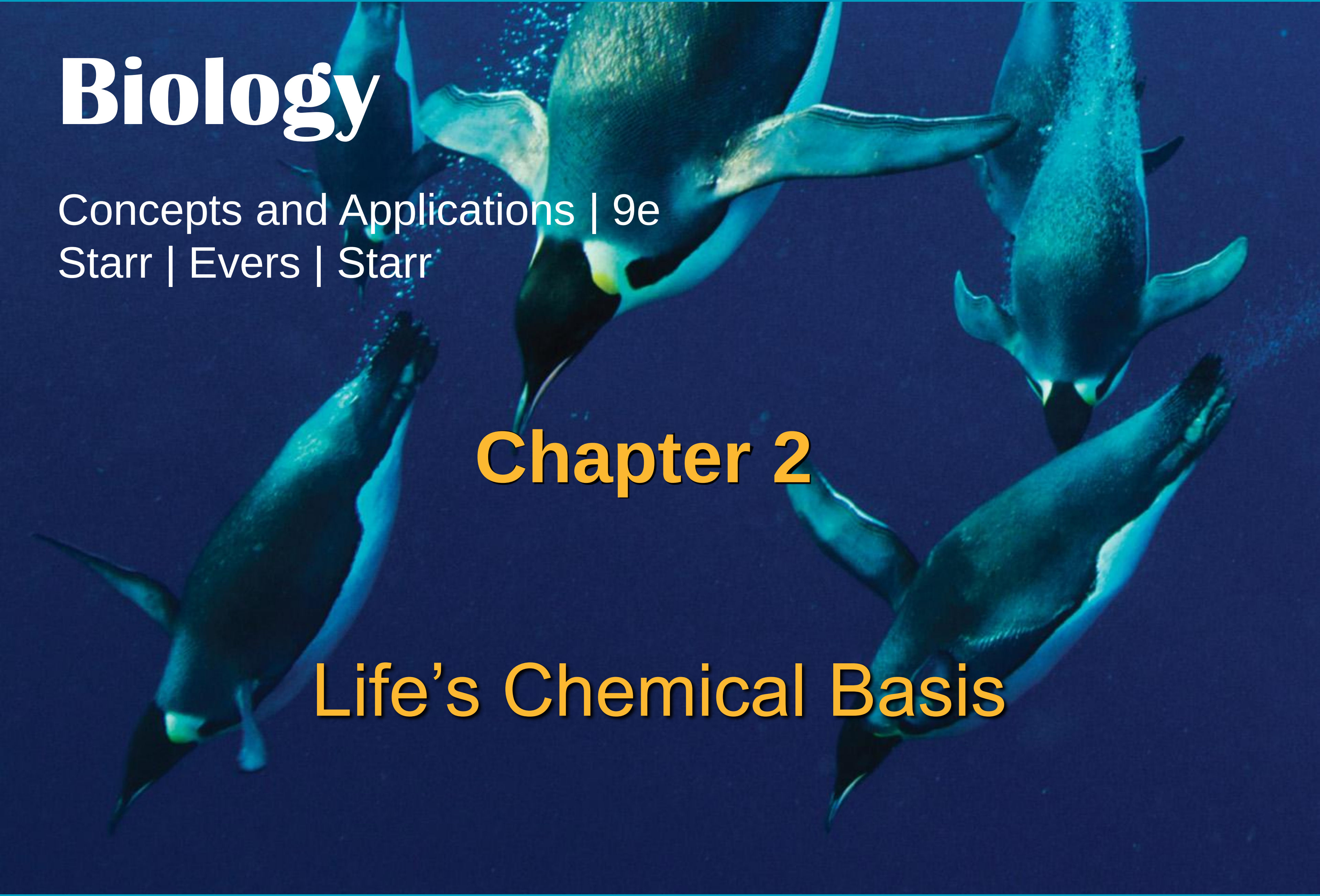

Biology

Concepts and Applications | 9e

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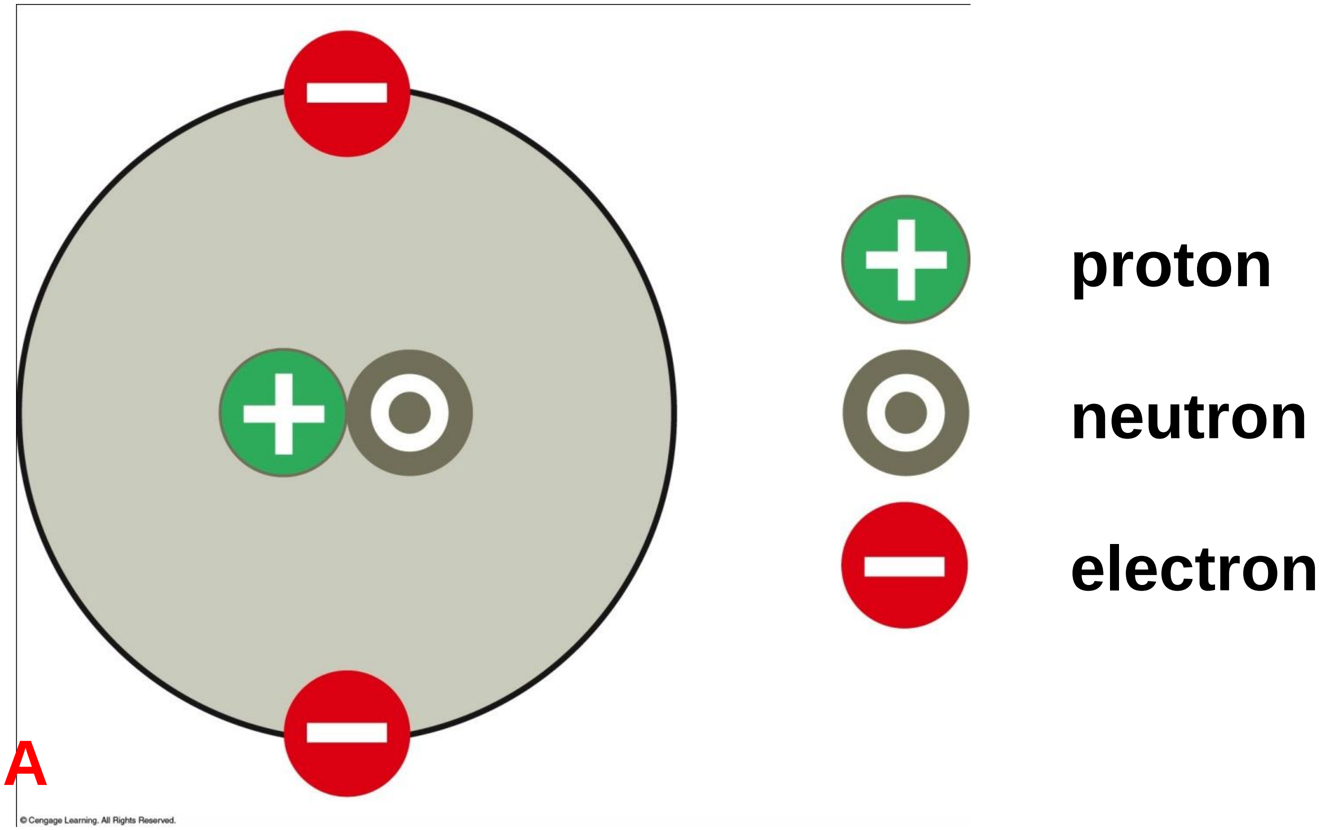
Chapter 2

Life’s Chemical Basis

2.1 What Are the Basic Building Blacks of All Matter?

- Positively charged *protons* (p^+) and uncharged *neutrons* are found in an atom's *nucleus* (core)
- Negatively charged *electrons* (e^-) move around the nucleus
  - Charge: electrical property; opposite charges attract, and like charges repel

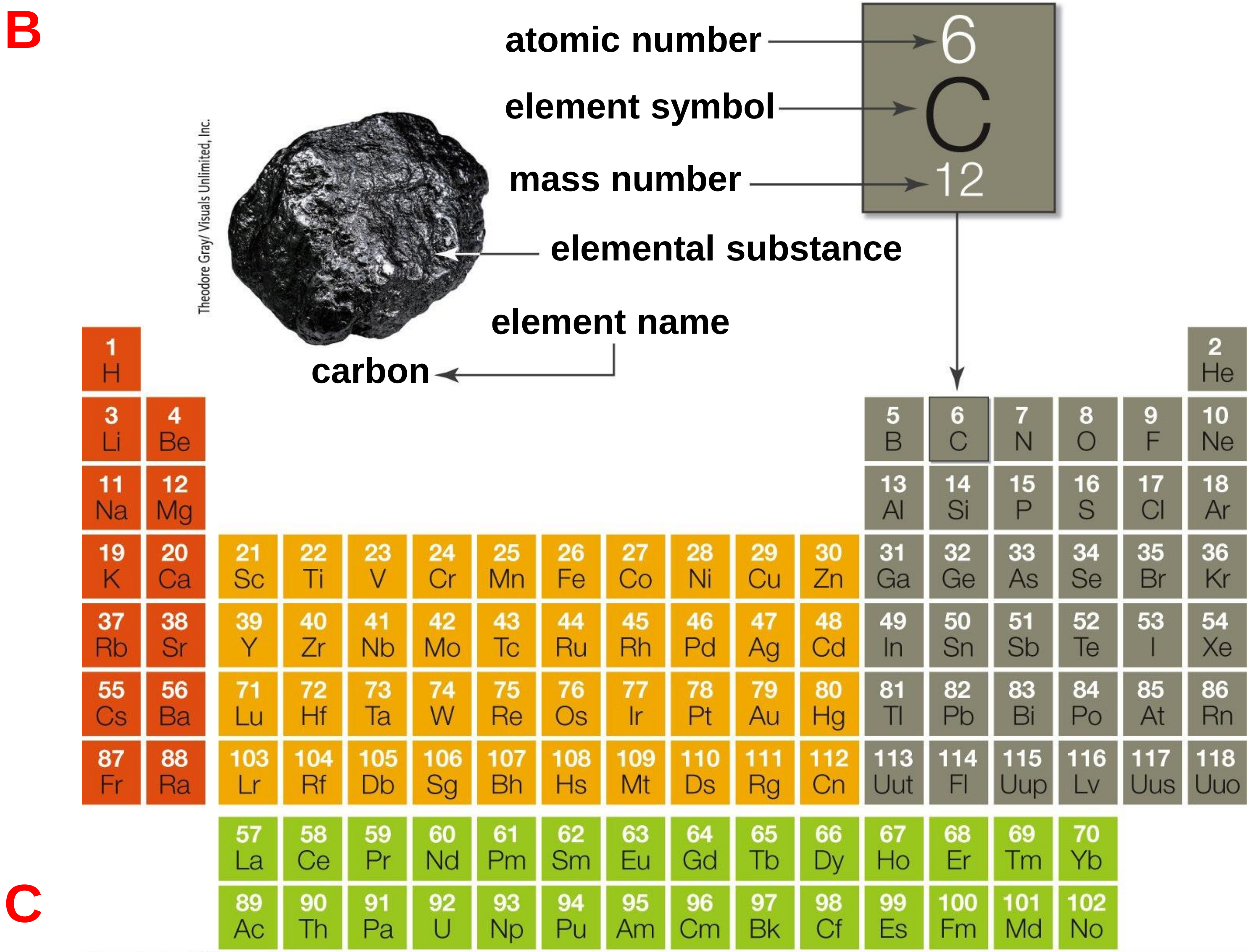
What Are the Basic Building Blacks of All Matter? (cont'd.)



What Are the Basic Building Blacks of All Matter? (cont'd.)

- A typical atom has about the same number of electrons and protons
- Atomic number: number of protons in the atomic nucleus
- Element: pure substance that consists only of atoms with the same number of protons
- Periodic table: tabular arrangement of all known elements by their atomic number

What Are the Basic Building Blacks of All Matter? (cont'd.)



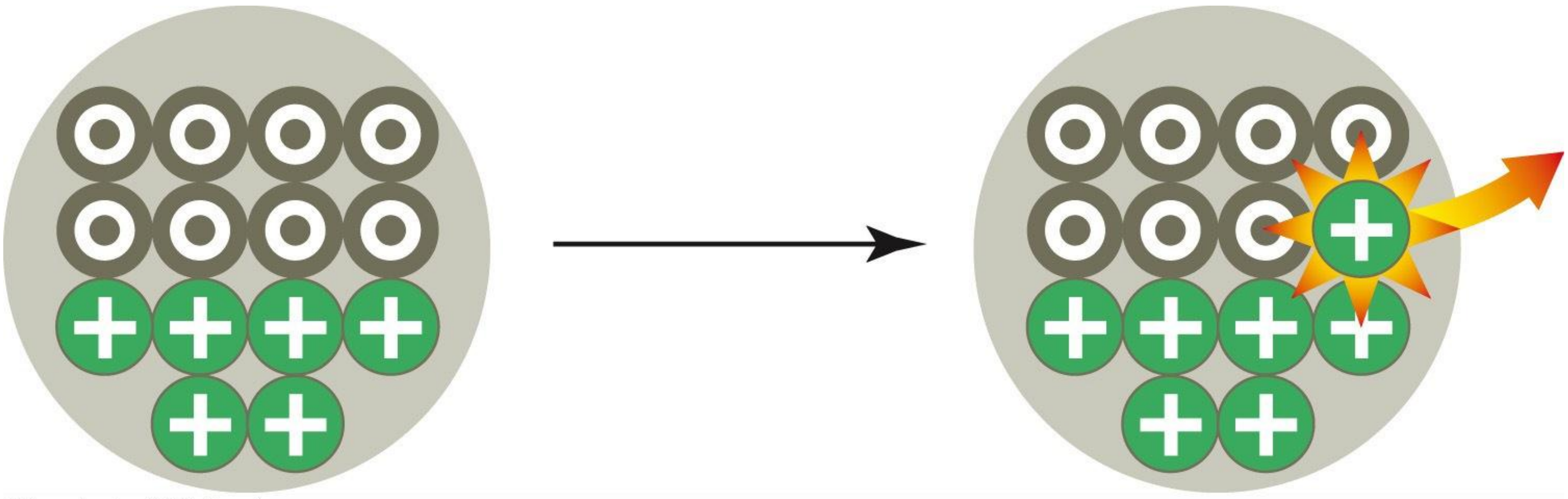
Isotopes and Radioisotopes

- Although all atoms of an element have the same number of protons, they can differ in the number of other subatomic particles
- Isotopes: forms of an element that differ in the number of neutrons their atoms carry
- Mass number: total number of protons and neutrons in the atomic nucleus

Isotopes and Radioisotopes (cont'd.)

- Radioisotope: isotope with an unstable nucleus
- Radioactive decay: process by which atoms of a radioisotope emit energy and/or subatomic particles when their nucleus spontaneously breaks up

Isotopes and Radioisotopes (cont'd.)



nucleus of ^{14}C, with 6 protons, 8 neutrons

nucleus of ^{14}N, with 7 protons, 7 neutrons

Tracers

- All isotopes of an element generally have the same chemical properties regardless of the number of neutrons in their atoms
- Radioisotopes can be used as tracers to study biological processes
  - Tracer: any substance with a detectable component

2.2 Why Do Atoms Interact?

- Electrons occupy different orbitals: volumes of space around an atom's nucleus
- Orbitals are filled from lower to higher energy
- The farther an electron is from the nucleus, the greater its energy

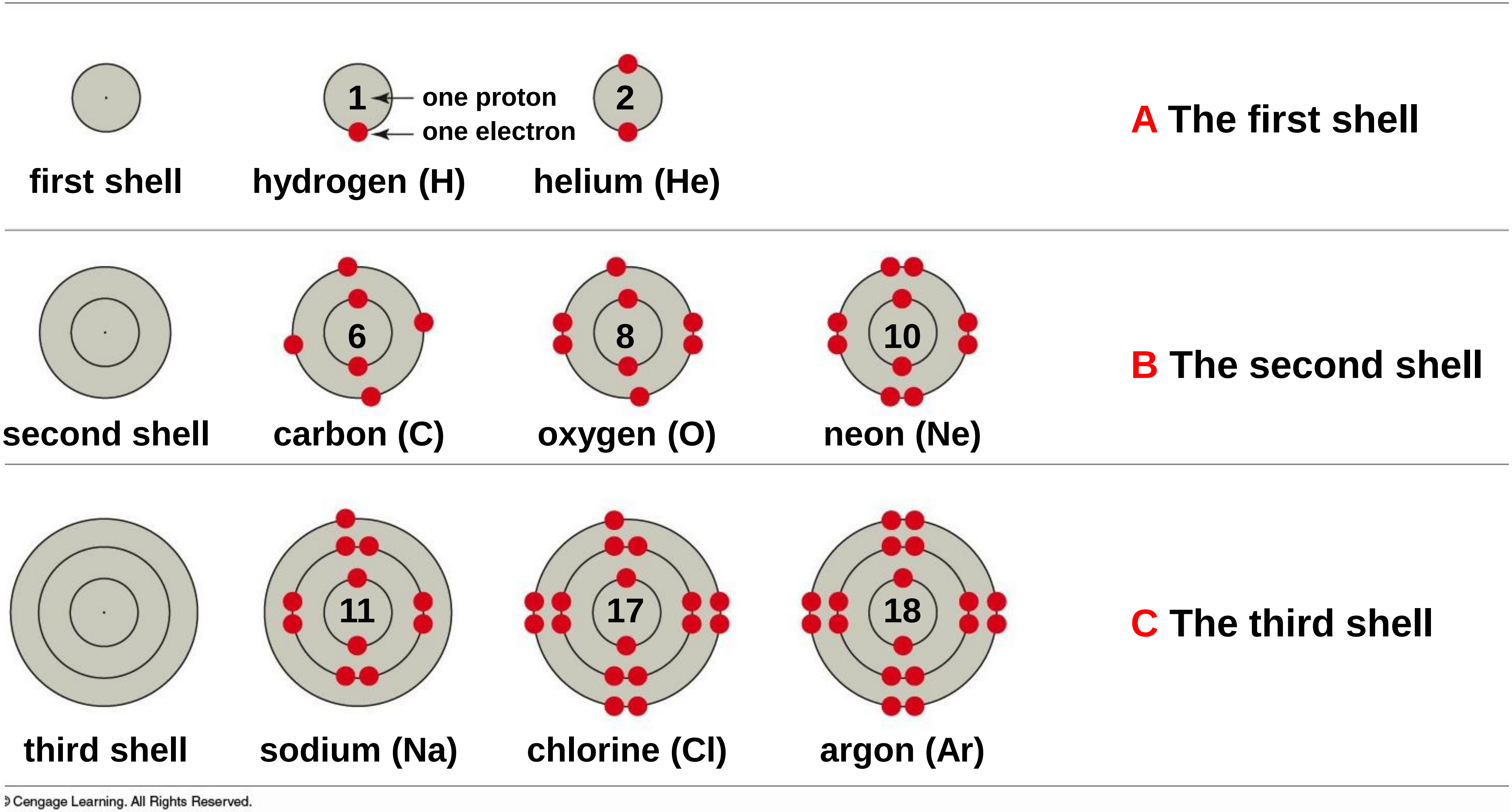
Why Do Atoms Interact? (cont'd.)

- An electron can move to a higher energy orbital if an input gives it a boost
  - Electron then immediately emits the extra energy and moves back down to the lower energy orbital

Why Do Atoms Interact? (cont'd.)

- A *shell model* helps us visualize how electrons populate atoms
- Nested "shells" correspond to successively higher energy levels
- Each shell includes all of the orbitals on one energy level

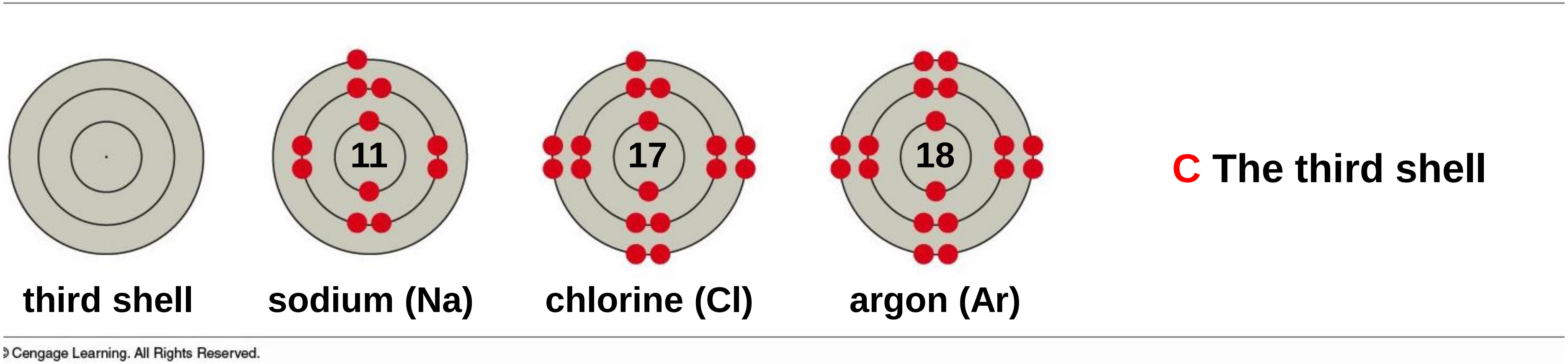
Why Do Atoms Interact? (cont'd.)



About Vacancies

- No vacancies: an atom's outermost shell is filled with electrons
  - Most stable state
- Vacancy: an atom's outermost shell has room for another electron
  - Chemically active; atoms interact with one another
  - Example: sodium atom has one electron in its outer (third) shell, which can hold eight

About Vacancies (cont'd.)

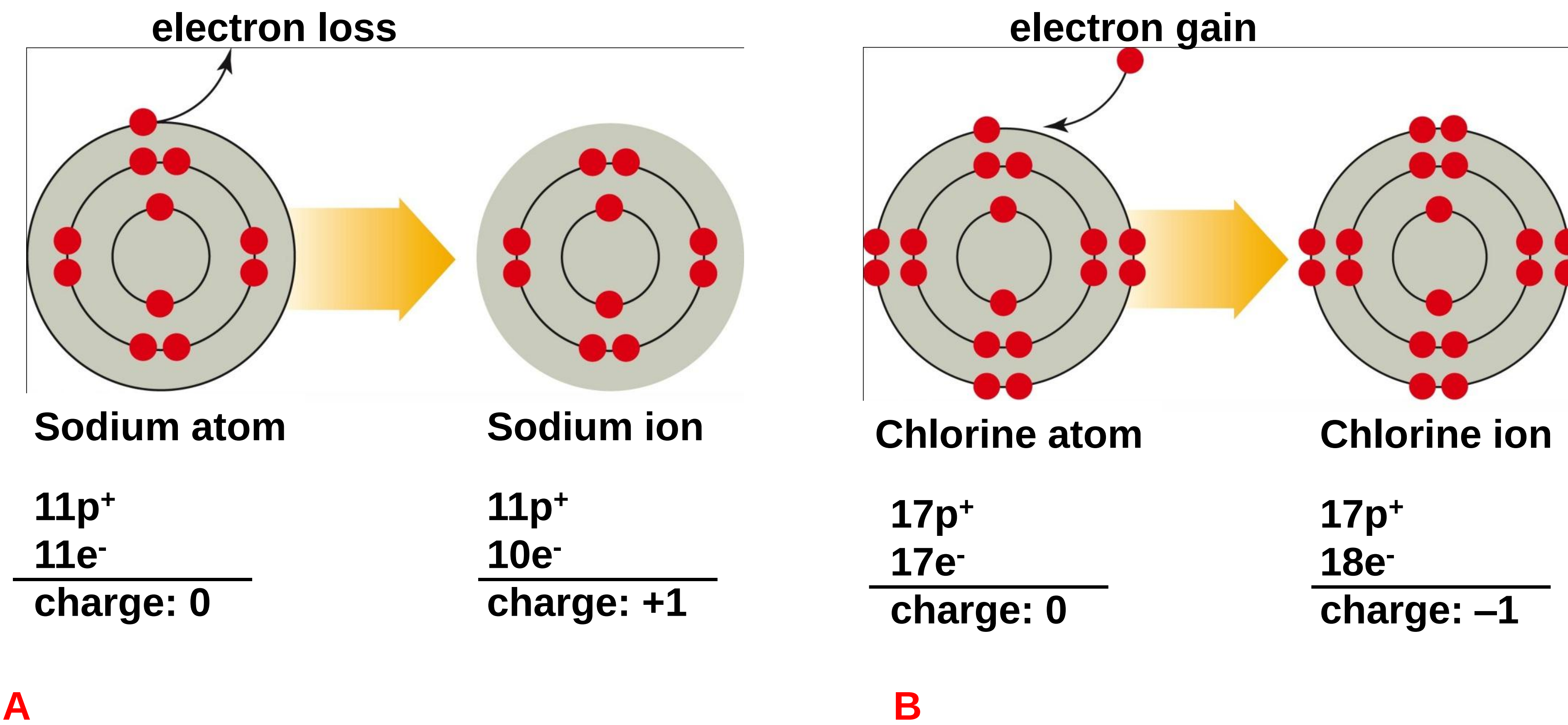


C The third shell

About Vacancies (cont'd.)

- Solitary atoms that have unpaired electrons are called *free radicals*
  - Typically very unstable
- Atoms with an unequal number of protons and electrons are called *ions*
  - Carry a net (overall) charge

About Vacancies (cont'd.)



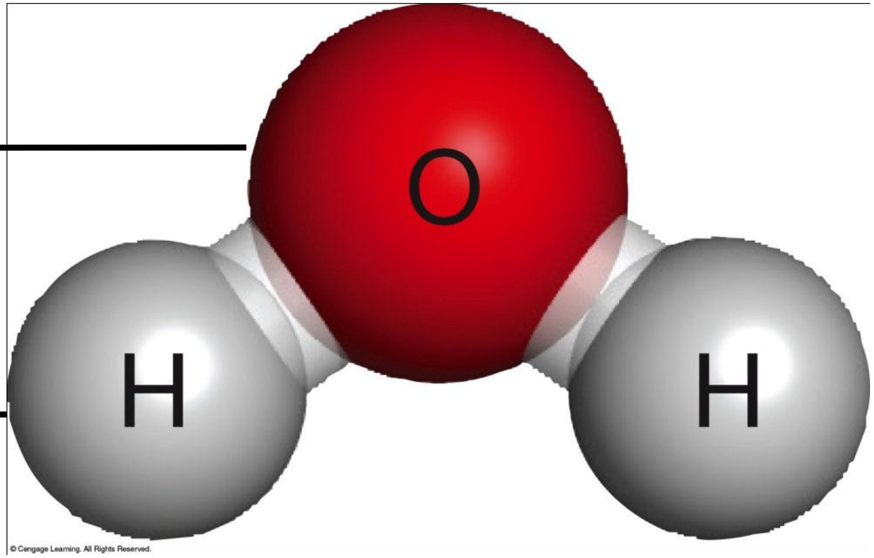
2.3 How Do Ions Interact in Chemical Bonds?

- An atom can get rid of vacancies by participating in a chemical bond with another atom
  - Chemical bond: attractive force that arises between two atoms when their electrons interact
  - Compound: molecule that has atoms of more than one element

How Do Ions Interact in Chemical Bonds? (cont'd.)

one oxygen atom

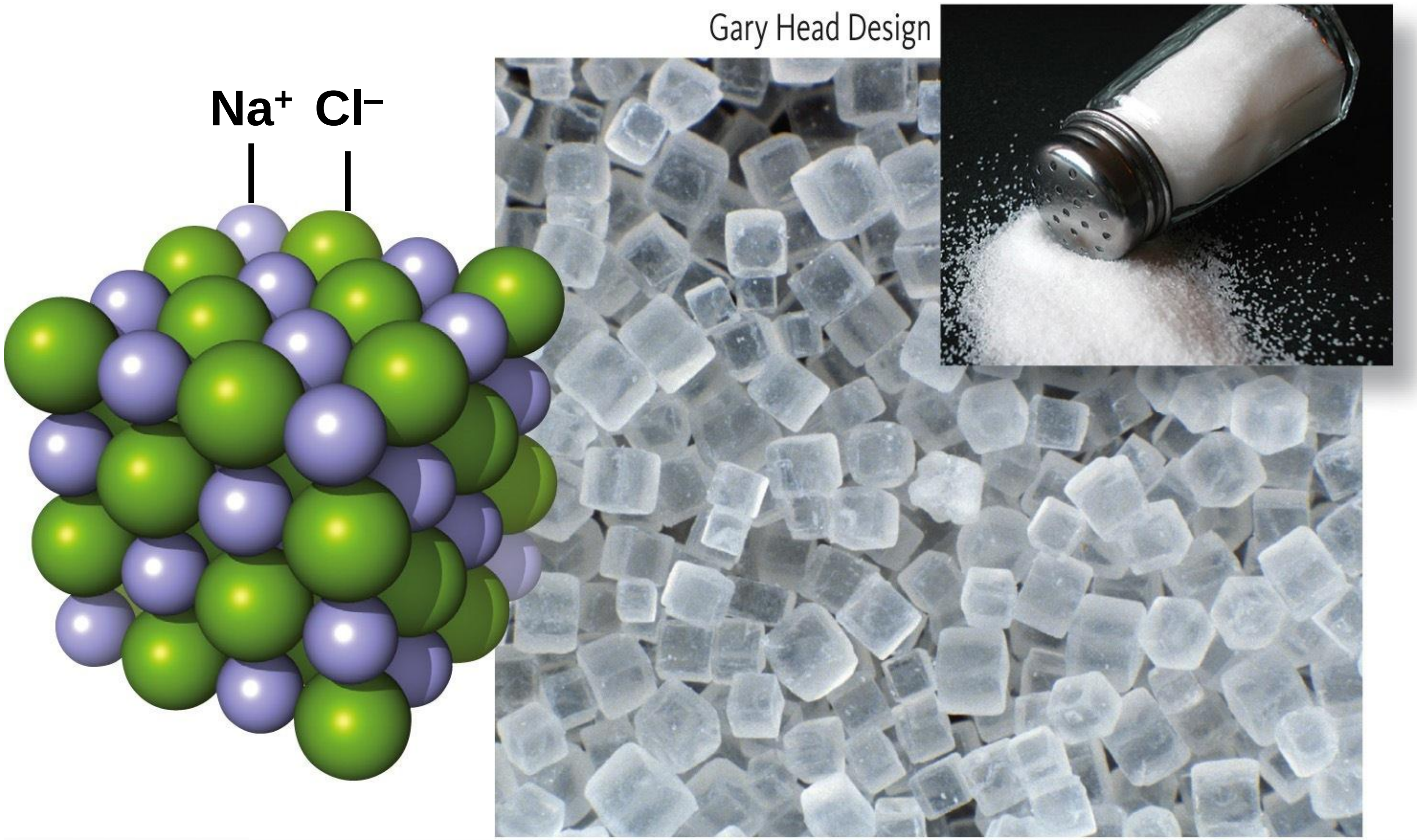
two hydrogen atoms



Ionic Bonds

- Ionic bond: strong mutual attraction links ions of opposite charge
  - Ionically bonded sodium and chloride ions make up sodium chloride (NaCl; table salt)

Ionic Bonds (cont'd.)

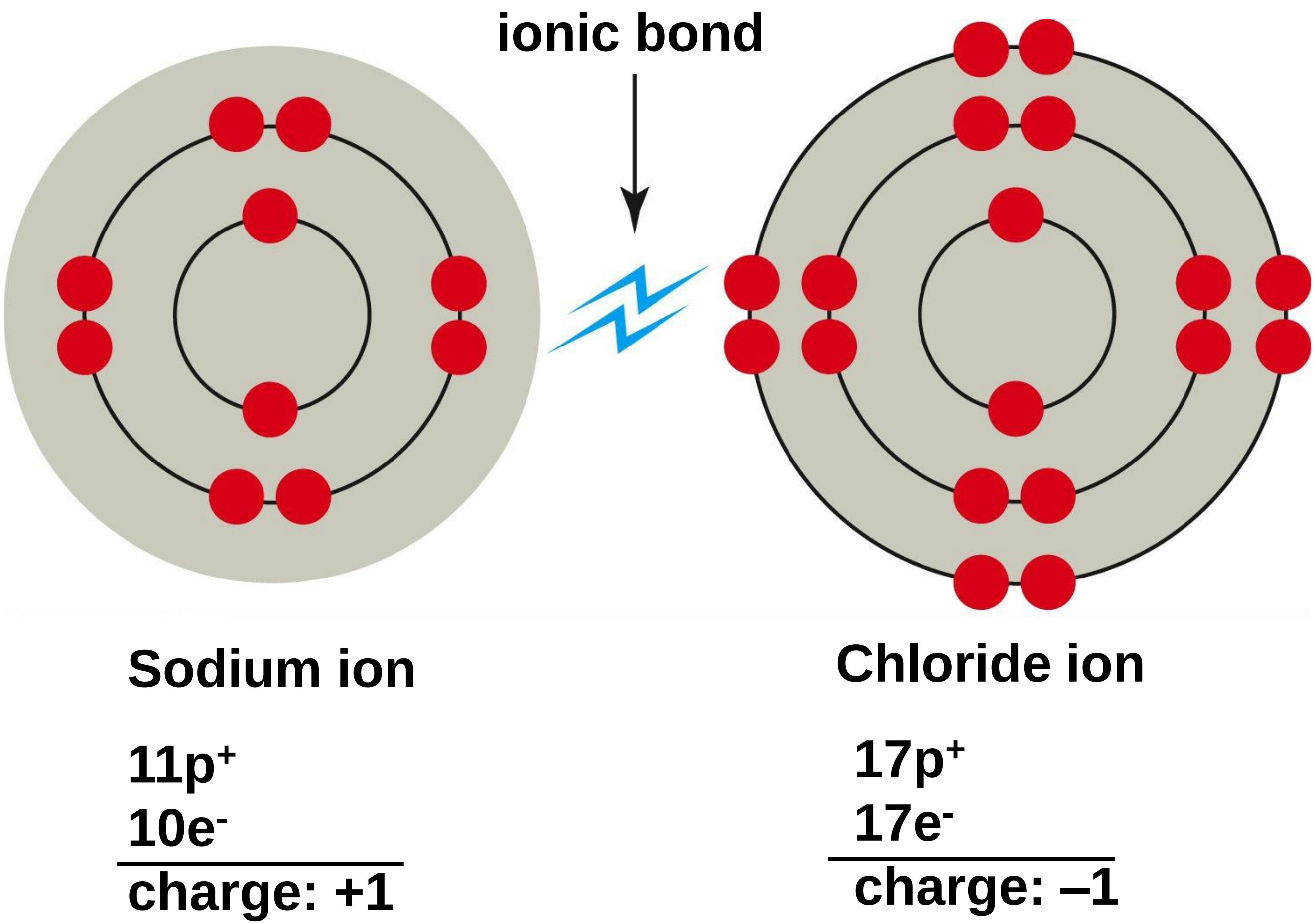


A

Ionic Bonds (cont'd.)

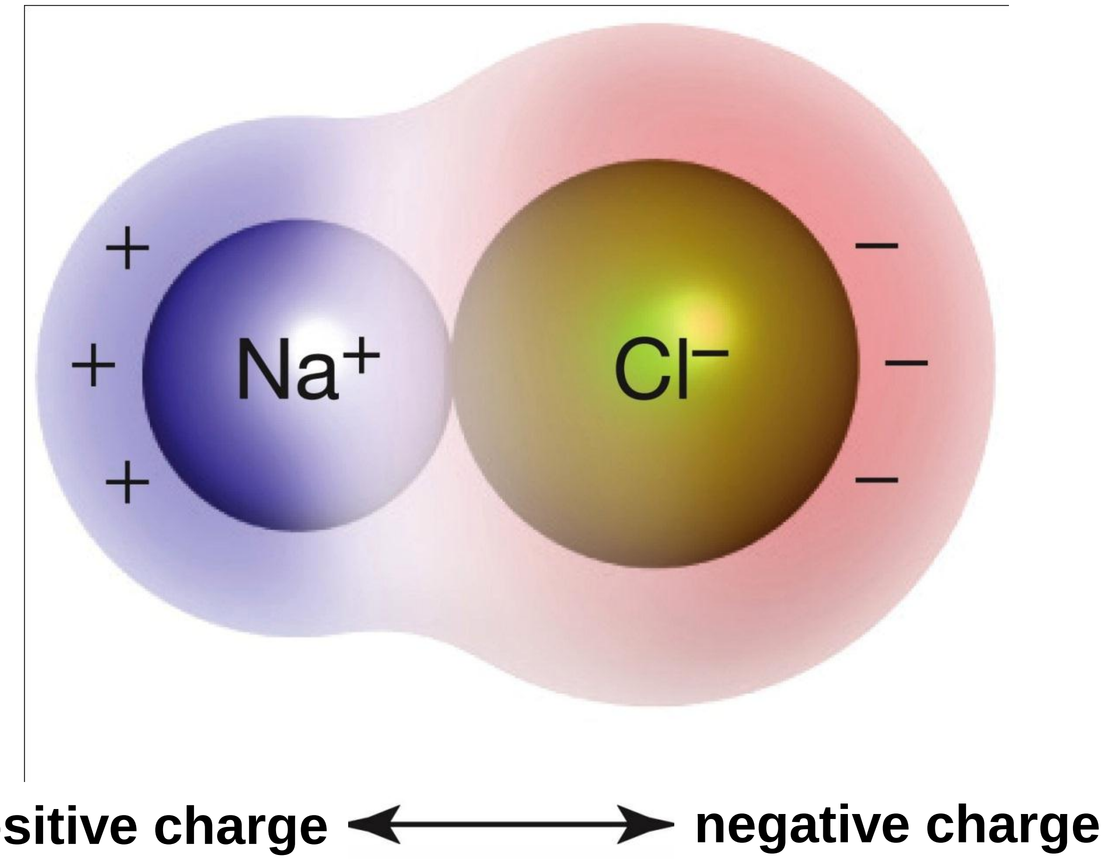
- Ions retain their respective charges when participating in an ionic bond
  - Polarity: separation of charge into positive and negative regions
  - A NaCl molecule is polar because the chloride ion keeps a very strong hold on its extra electron
  - Electronegativity: measure of the ability of an atom to pull electrons away from other atoms

Ionic Bonds (cont'd.)



B

Ionic Bonds (cont'd.)

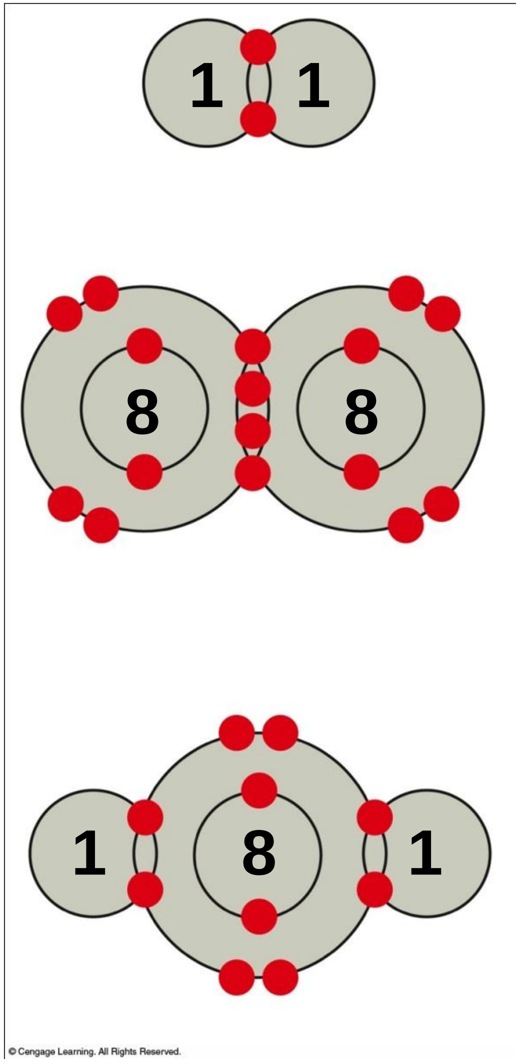


C

Covalent Bonds

- Covalent bond: two atoms share a pair of electrons
  - Formed between atoms with a small or no difference in electronegativity
  - Covalent bonds are often stronger than ionic bonds (but not always)

Covalent Bonds (cont'd.)



MOLECULAR HYDROGEN **(H—H)**

MOLECULAR OXYGEN **(O=O)**

WATER **(H—O—H)**

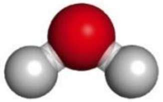
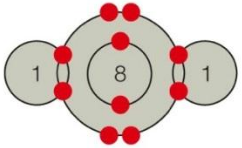
Covalent Bonds (cont'd.)

- Structural formulas: lines between atoms represent the number of covalent bonds
  - Example: H-H
    - H_2 has one covalent bond between the atoms
  - Example: O=O
    - A double bond links the two oxygen atoms
  - Example: N≡N
    - A triple covalent bond links the two nitrogen atoms

Covalent Bonds (cont'd.)

TABLE 2.1

Ways of Representing Molecules

Common name:	Water	Familiar term.
Chemical name:	Dihydrogen monoxide	Describes elemental composition.
Chemical formula:	H_2O	Indicates unvarying proportions of elements. Subscripts show number of atoms of an element per molecule. The absence of a subscript means one atom.
Structural formula:	H—O—H	Represents each covalent bond as a single line between atoms.
Structural model:		Shows relative sizes and positions of atoms in three dimensions.
Shell model:		Shows how pairs of electrons are shared in covalent bonds.

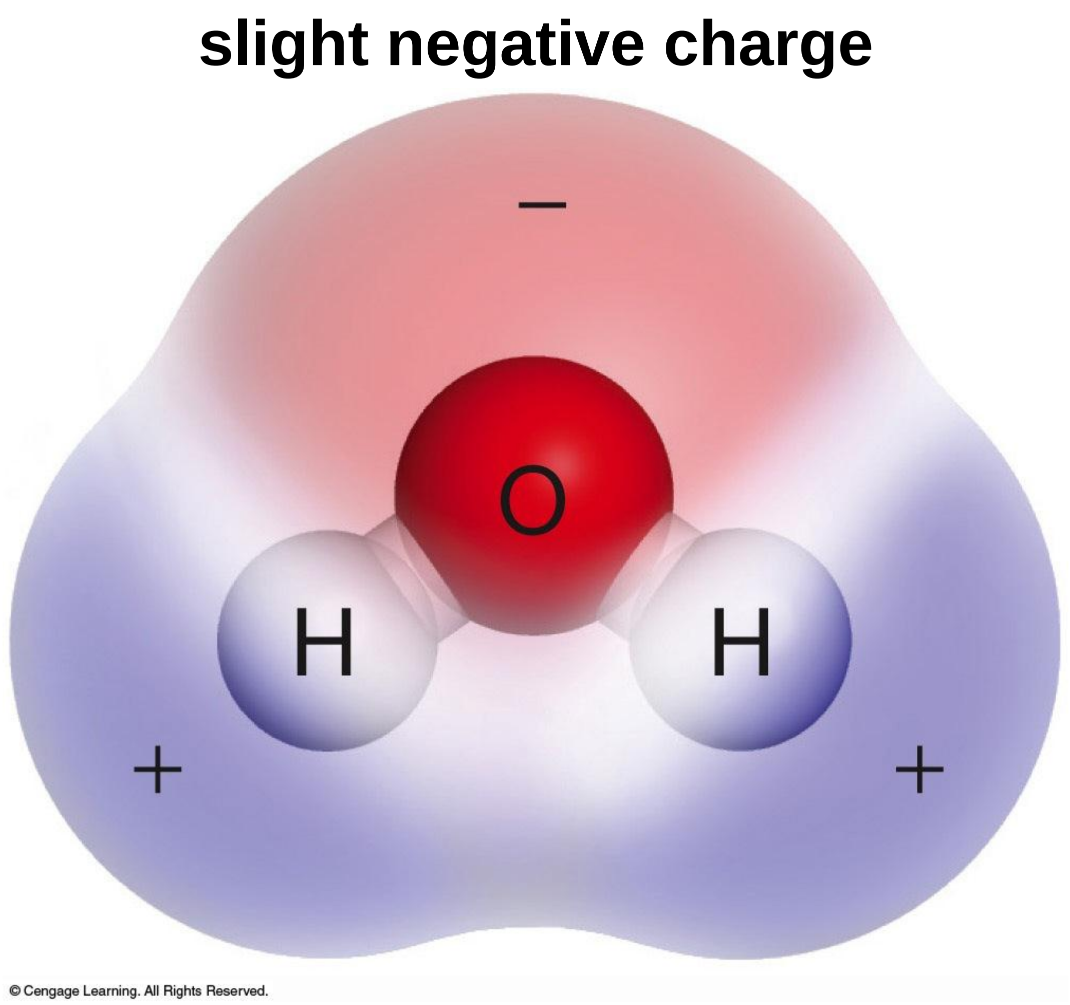
Covalent Bonds (cont'd.)

- Covalent bonds in compounds are usually polar
- Atoms share electrons unequally in a polar covalent bond
  - Example: water molecules

2.4 What Are The Life Sustaining Properties of Water?

- Hydrogen bonding in water
  - Water has unique properties that arise from the two polar covalent bonds in each water molecule
  - In water, the oxygen atom carries a slight negative charge; the hydrogen atoms carry a slight positive charge

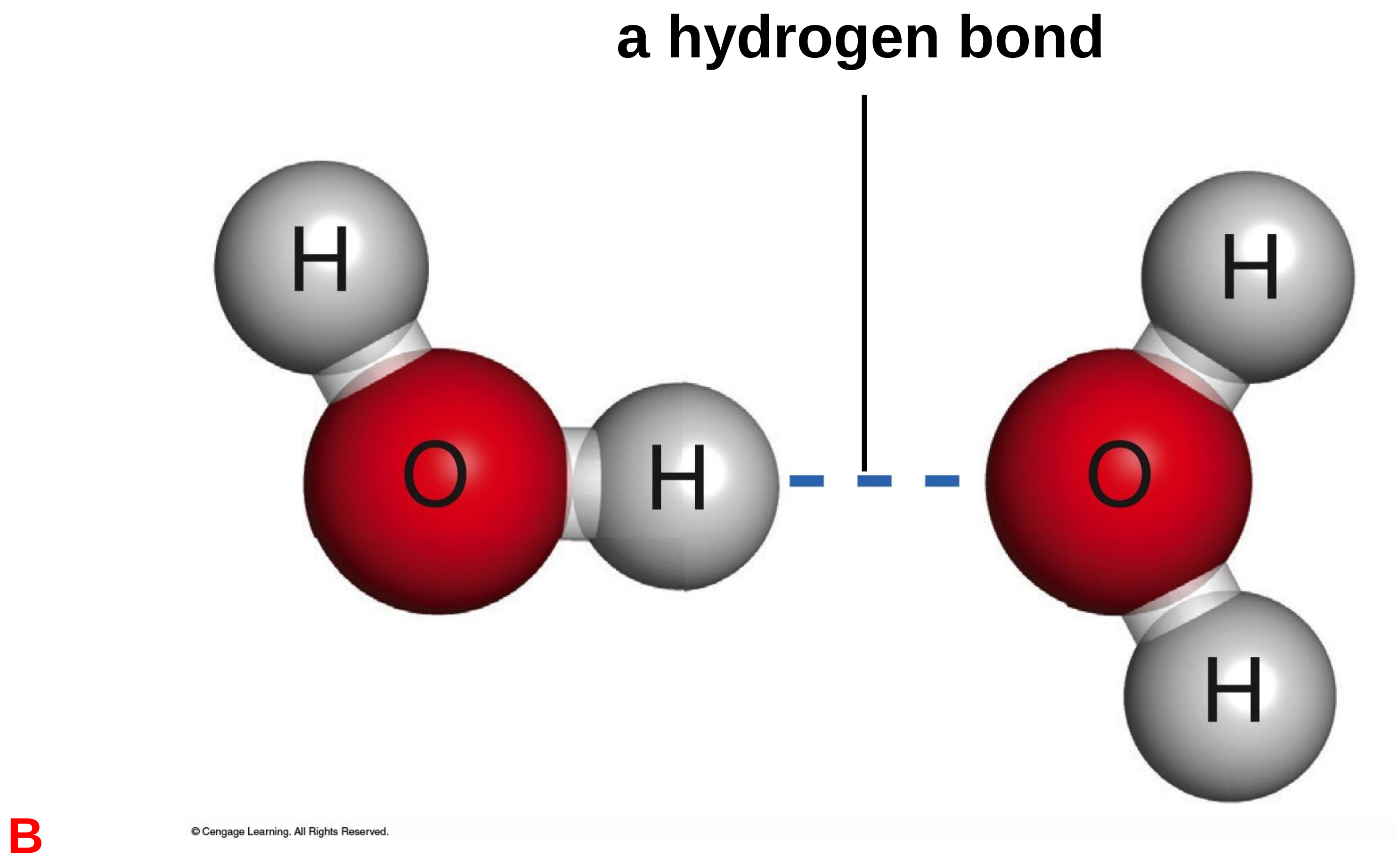
What Are The Life Sustaining Properties of Water? (cont'd.)



What Are The Life Sustaining Properties of Water? (cont'd.)

- Hydrogen bonding in water (cont'd.)
  - The polarity of individual water molecules attracts them to one another
  - This type of interaction is called a *hydrogen bond*
    - Hydrogen bond: attraction between a covalently bonded hydrogen atom and another atom taking part in a separate polar covalent bond

What Are The Life Sustaining Properties of Water? (cont'd.)



What Are The Life Sustaining Properties of Water? (cont'd.)

- Hydrogen bonding in water (cont'd.)
  - Hydrogen bonds form and break much more easily than covalent or ionic bonds
    - Collectively they are quite strong
  - Hydrogen bonds stabilize DNA and protein structures
  - Extensive hydrogen bonding among water molecules gives liquid water several special properties that make life possible

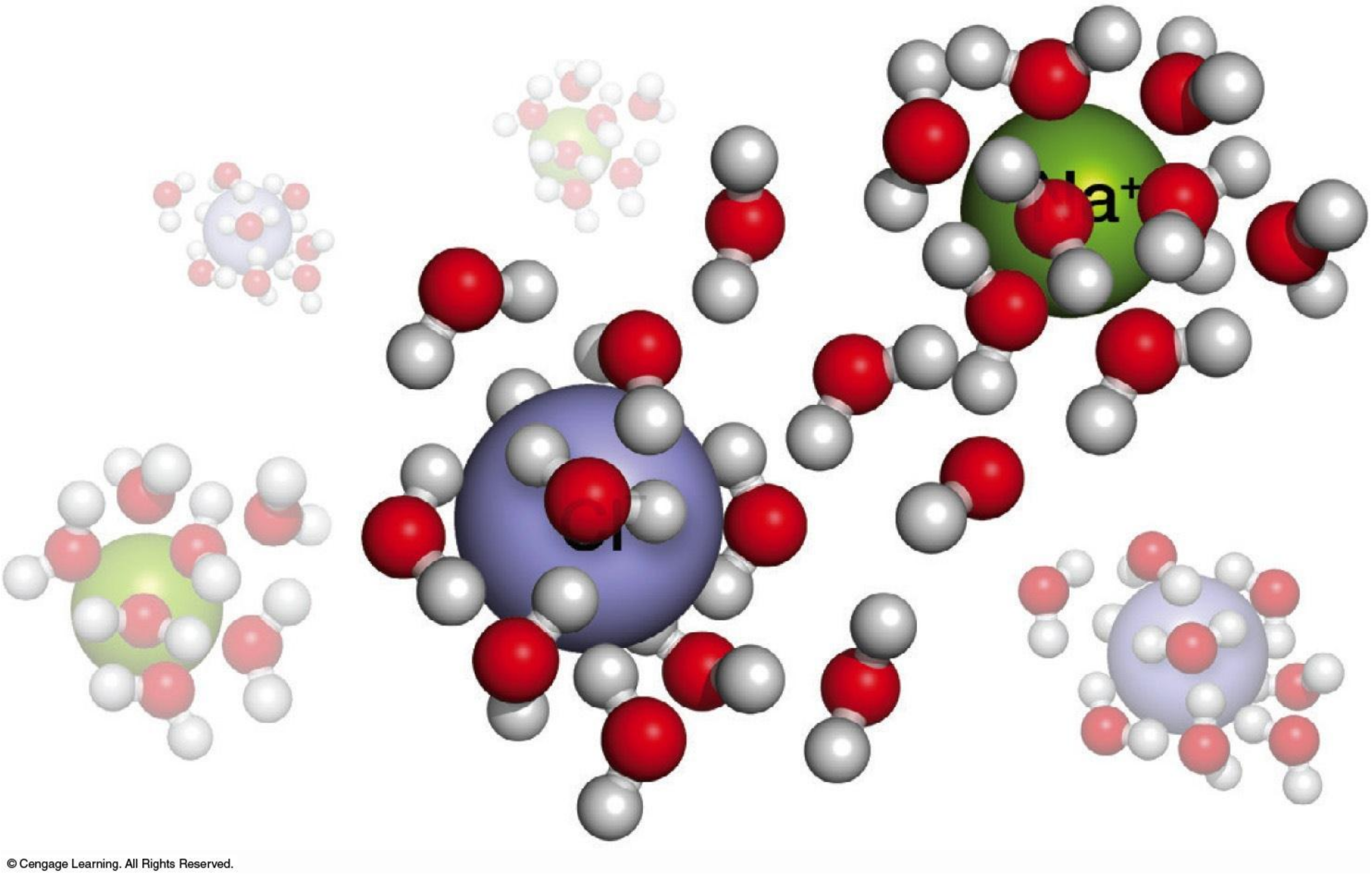
Water's Special Properties

- Water is an excellent solvent
  - Substances that dissolve easily in water are *hydrophilic*
  - Ionic solids, such as sodium chloride (NaCl), dissolve in water:
    - The slight positive charge on each hydrogen atom in a water molecule attracts negatively charged Cl^-
    - The slight negative charge on the oxygen atom attracts positively charged Na^+

Water's Special Properties (cont'd.)

- Hydrogen bonds among many water molecules are collectively stronger than an ionic bond between two ions
  - The solid dissolves as water molecules tug the ions apart and surround each one

Water's Special Properties (cont'd.)



Water's Special Properties (cont'd.)

- Water is an excellent solvent (cont'd.)
  - Salt: releases ions other than H^+ and OH^- when it dissolves in water (e.g., NaCl)
  - Solute: a dissolved substance
  - Solution: uniform mixture of solute completely dissolved in solvent
    - Chemical bonds do not form between molecules of solute and solvent
  - Nonionic solids (e.g., sugars) dissolve easily in water due to hydrogen bonding with water

Water's Special Properties (cont'd.)

- Water is an excellent solvent (cont'd.)
  - Substances that resist dissolving in water are *hydrophobic* (e.g., oils)
  - Oils consist of nonpolar molecules, and hydrogen bonds do not form between nonpolar molecules and water

Water's Special Properties (cont'd.)

- Water has cohesion
  - Cohesion: tendency of molecules to resist separating from one another
  - Water has cohesion because hydrogen bonds collectively exert a continuous pull on its individual molecules

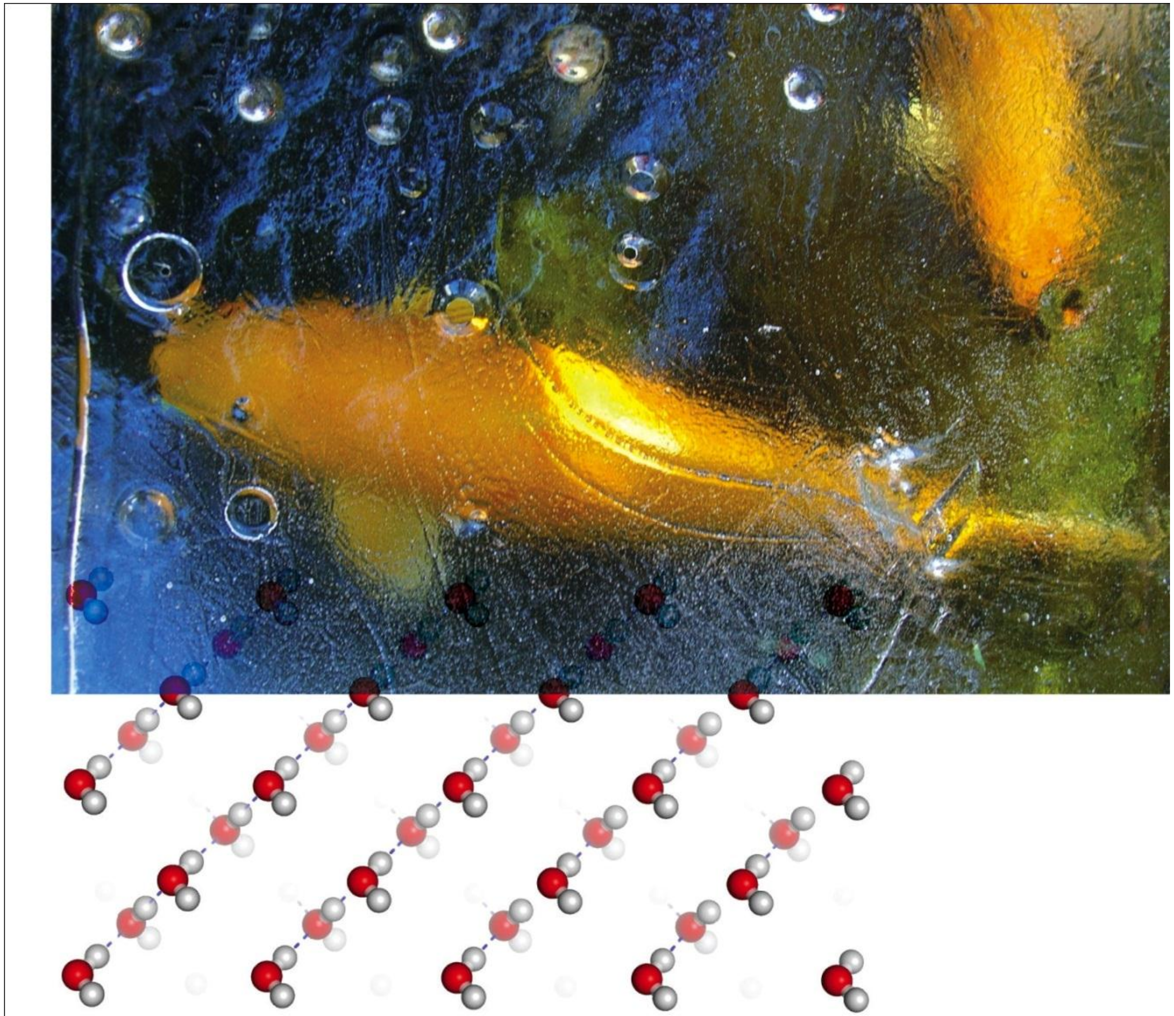
Water's Special Properties (cont'd.)

- Water has cohesion (cont'd.)
  - Cohesion takes energy
    - Evaporation (transition of a liquid to a vapor) is resisted by hydrogen bonding among water molecules

Water's Special Properties (cont'd.)

- Water stabilizes temperature
  - Temperature: measure of molecular motion
  - Because of hydrogen bonding, it takes more heat to raise the temperature of water compared with other liquids
  - Below 0°C (32°F), water molecules become locked in the bonding pattern of ice
    - Sheets of ice that form on the surface of ponds, lakes, and streams insulate the water
    - Protects aquatic organisms during cold winters

Water's Special Properties (cont'd.)



top, Vicki Rosenberg, www.flickr.com/photots/roseofredrock; bottom, © Cengage Learning.

2.5 Why Are Hydrogen Ions Important in Biological Systems?

- When water is liquid, some of its molecules spontaneously separate into hydrogen ions (H^+) and hydroxide ions ($OH^–$)
- These ions can combine again to form water:

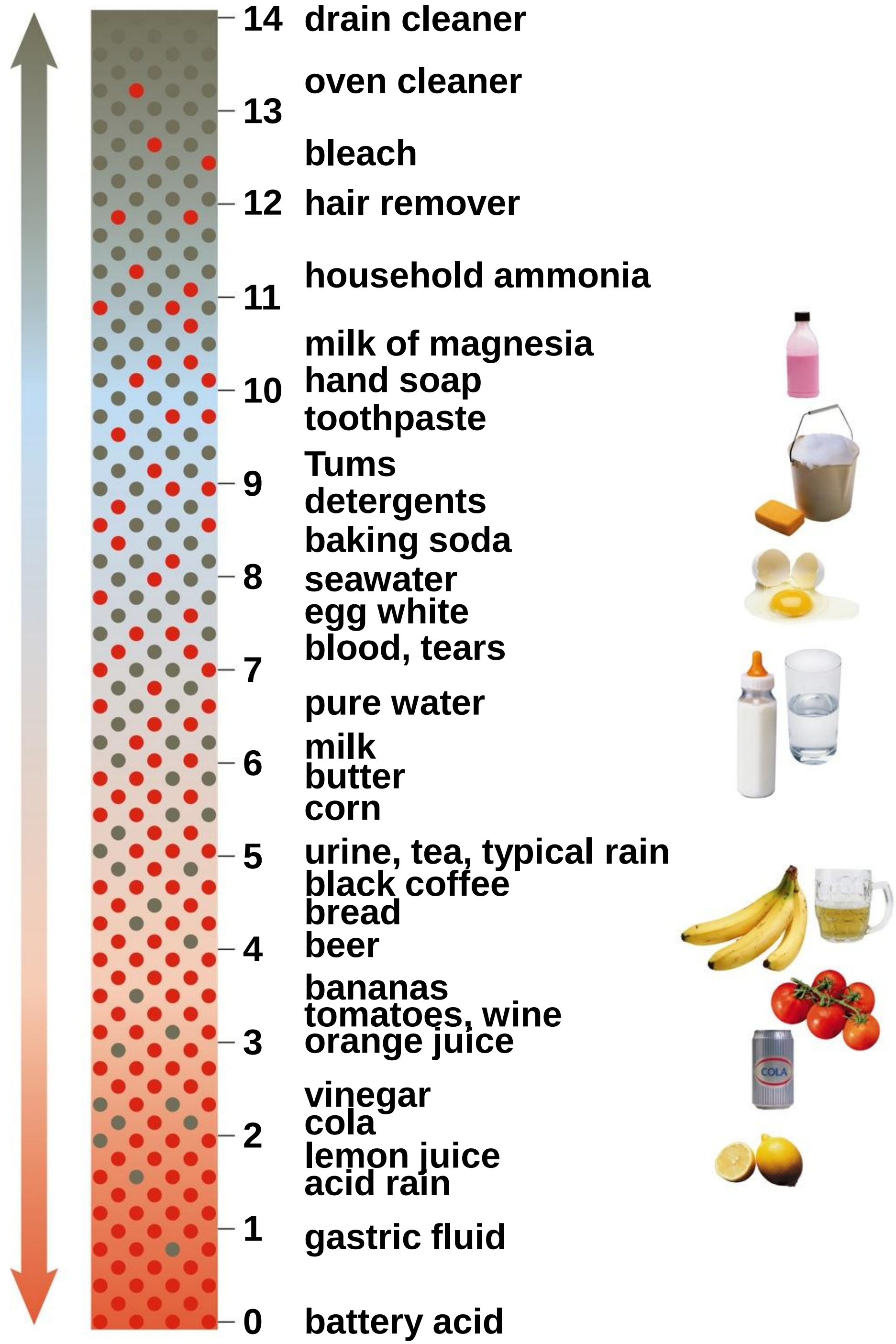
$$H_2O \longrightarrow H^+ + OH^- \longrightarrow H_2O$$

H_2O		H^+	+	$OH^–$		H_2O
water	$\longrightarrow$	hydrogen ions		hydroxide ions	$\longrightarrow$	water

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- Concentration: amount of solute per unit volume of solution
- pH: measure of the number of hydrogen ions in a fluid
- Base: accepts hydrogen ions in water
  - Above pH 7
- Acid: releases hydrogen ions in water
  - Below pH 7

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)



Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- Buffer: set of chemicals that can keep the pH of a solution stable by alternately donating and accepting ions that contribute to pH

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- The fluids inside cells stay within a consistent range of pH because they are buffered
- Most biological molecules can function properly only within a narrow range of pH
  - Buffer failure can be catastrophic in a biological system

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- Burning fossil fuels such as coal releases sulfur and nitrogen compounds that affect the pH of rain
  - Rainwater is not buffered
  - In places with a lot of fossil fuel emissions, the rain and fog can be more acidic than vinegar

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- The corrosive effects of acid rain is visible in urban areas

W. K. Fletcher/Science Source

Why Are Hydrogen Ions Important in Biological Systems? (cont'd.)

- Acid rain drastically changes the pH of water in soil, lakes, and streams
- Such changes can overwhelm the buffering capacity of fluids inside organisms, with lethal effects

2.6 Mercury Rising

- Mercury is a naturally occurring element
- Most of it is safely locked away in rocks
  - Volcanic activity and human activity release it into the atmosphere

Mercury Rising (cont'd.)

- Microbes combine airborne mercury with carbon to form methylmercury
  - Unlike mercury alone, methylmercury easily crosses skin and mucous membranes
- When mercury enters the body, it damages the nervous system, brain, kidneys, and other organs

Mercury Rising (cont'd.)

- It takes months or years for mercury to be cleared from the body
  - The toxin can build up to high levels if even small amounts are ingested on a regular basis
- Large predatory fish have a lot of mercury
  - U.S. Environmental Protection Agency recommends that adult humans ingest less than 0.1 microgram of mercury per kilogram of body weight per day

Mercury Rising (cont'd.)

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