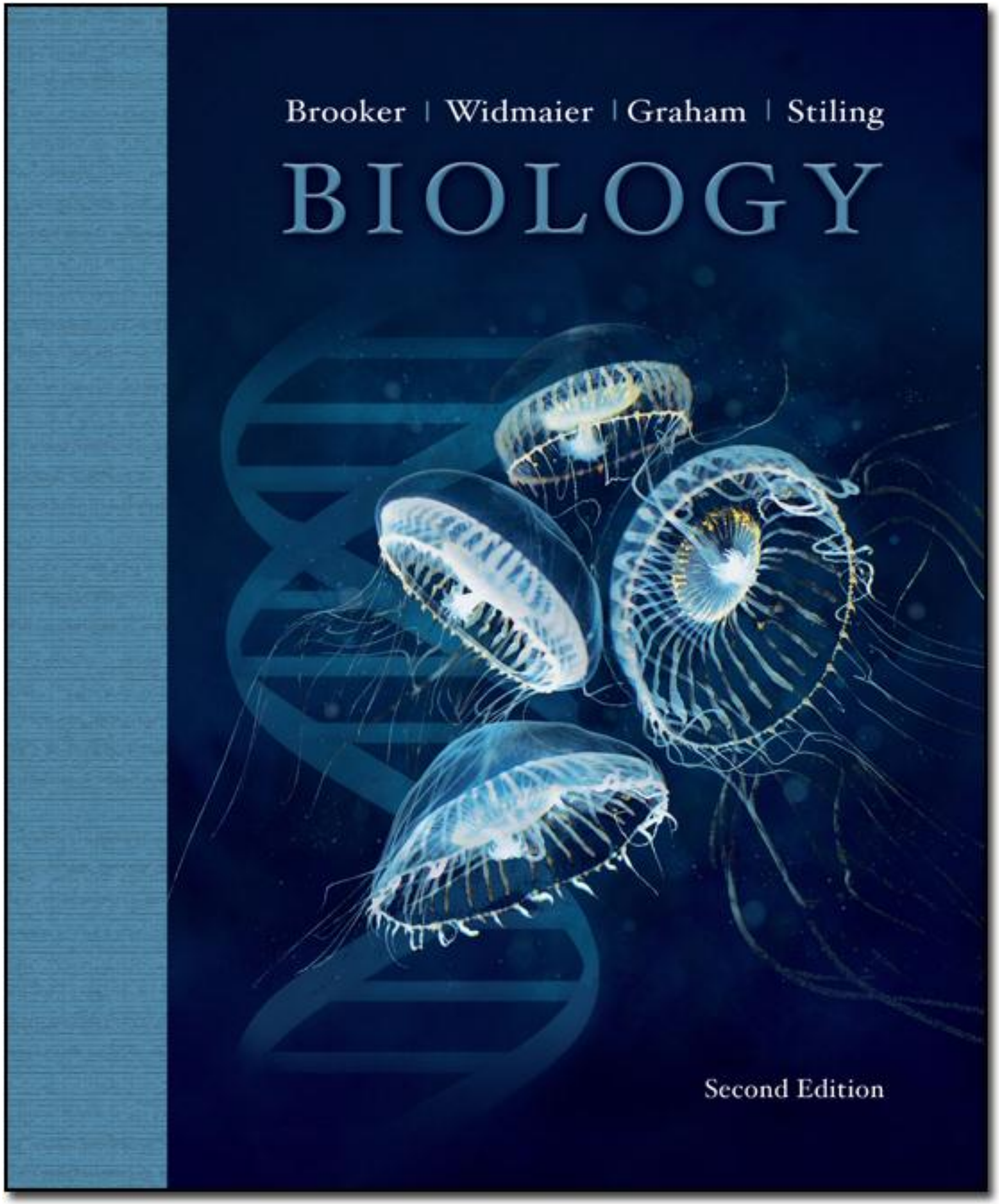
CHAPTER 2 LECTURE SLIDES



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Biology

- Based on the principles of chemistry and physics
- All living organisms are a collection of atoms and molecules
- All life forms composed of matter
  - Anything that contains mass and occupies space

Atoms

- Smallest functional units of matter that form all chemical substances
- Cannot be further broken down into other substances by ordinary chemical or physical means
- Each specific type of atom is a chemical element

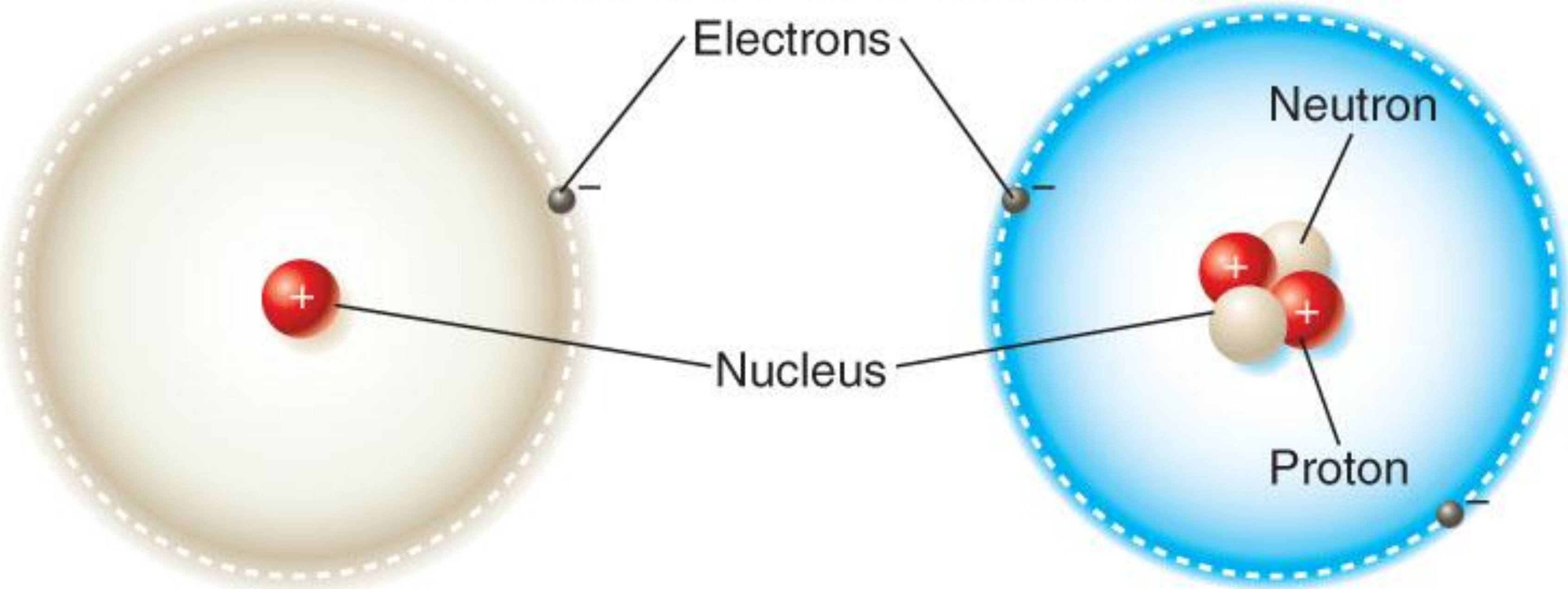
- Three subatomic particles
  - Protons- positive, found in nucleus, same number as electrons
  - Neutrons- neutral, found in nucleus, number can vary
  - Electrons- negative, found in orbitals, same number as protons
- Entire atom has no net electric charge

Table 2.1 Characteristics of Major Subatomic Particles

Particle		Location	Charge	Mass relative to electron
Proton		Nucleus	+1	1,836
Neutron		Nucleus	0	1,839
Electron		Around the nucleus	−1	1

Electrons occupy orbitals

- Scientists initially visualized an atom as a mini solar system
  - This is an oversimplified but convenient image
- Electrons travel within regions surrounding the nucleus (orbitals) in which the probability is high of finding that electron
- Can be depicted as a cloud



Hydrogen

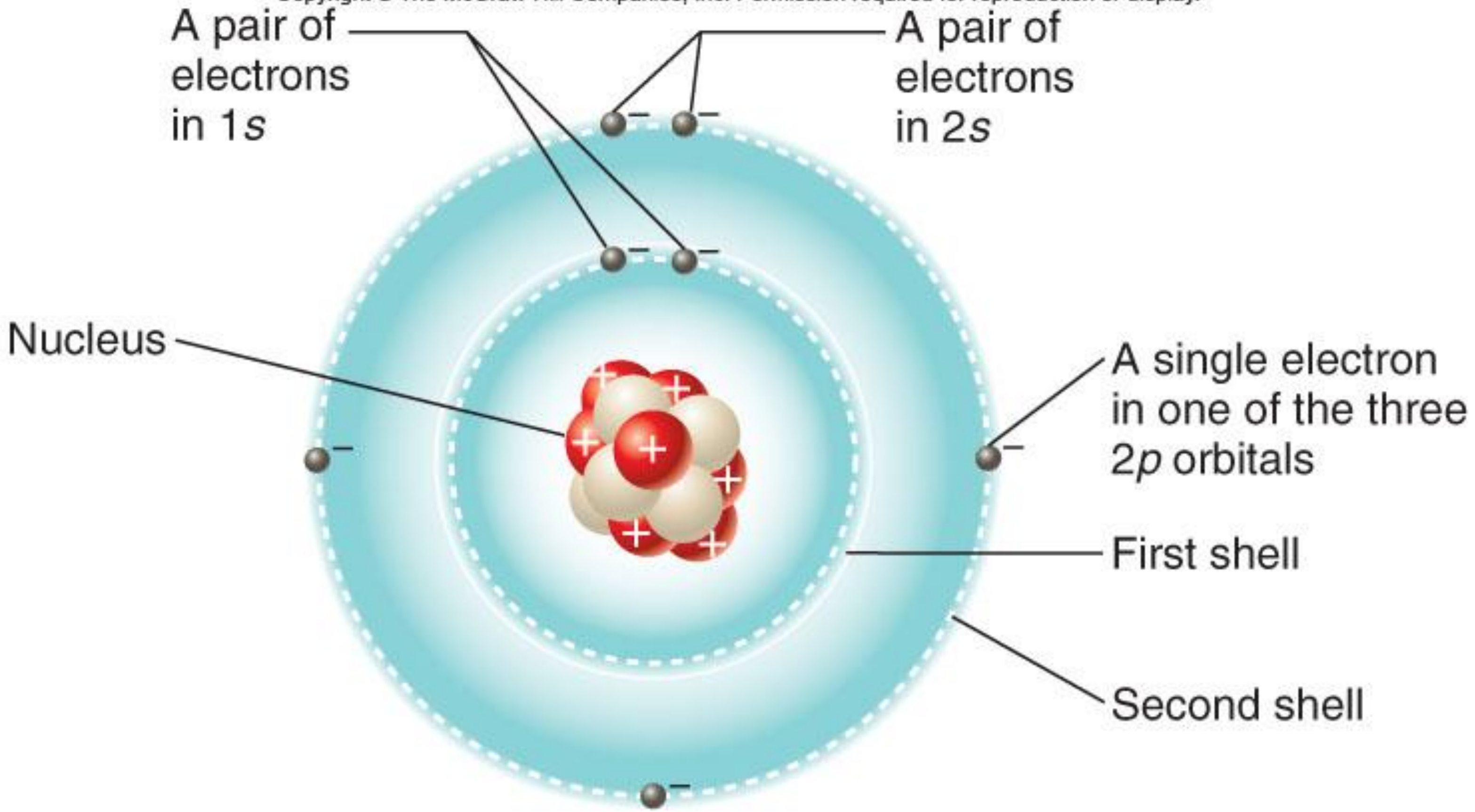
1 proton
1 electron

Helium

2 protons
2 neutrons
2 electrons

Nitrogen example

- A nitrogen atom has seven protons and seven electrons
  - 2 electrons fill 1st shell
  - 5 electrons in 2nd shell
  - Outer 2nd shell is not full
    - Electrons in the outer shell that are available to combine with other atoms are called the valence electrons



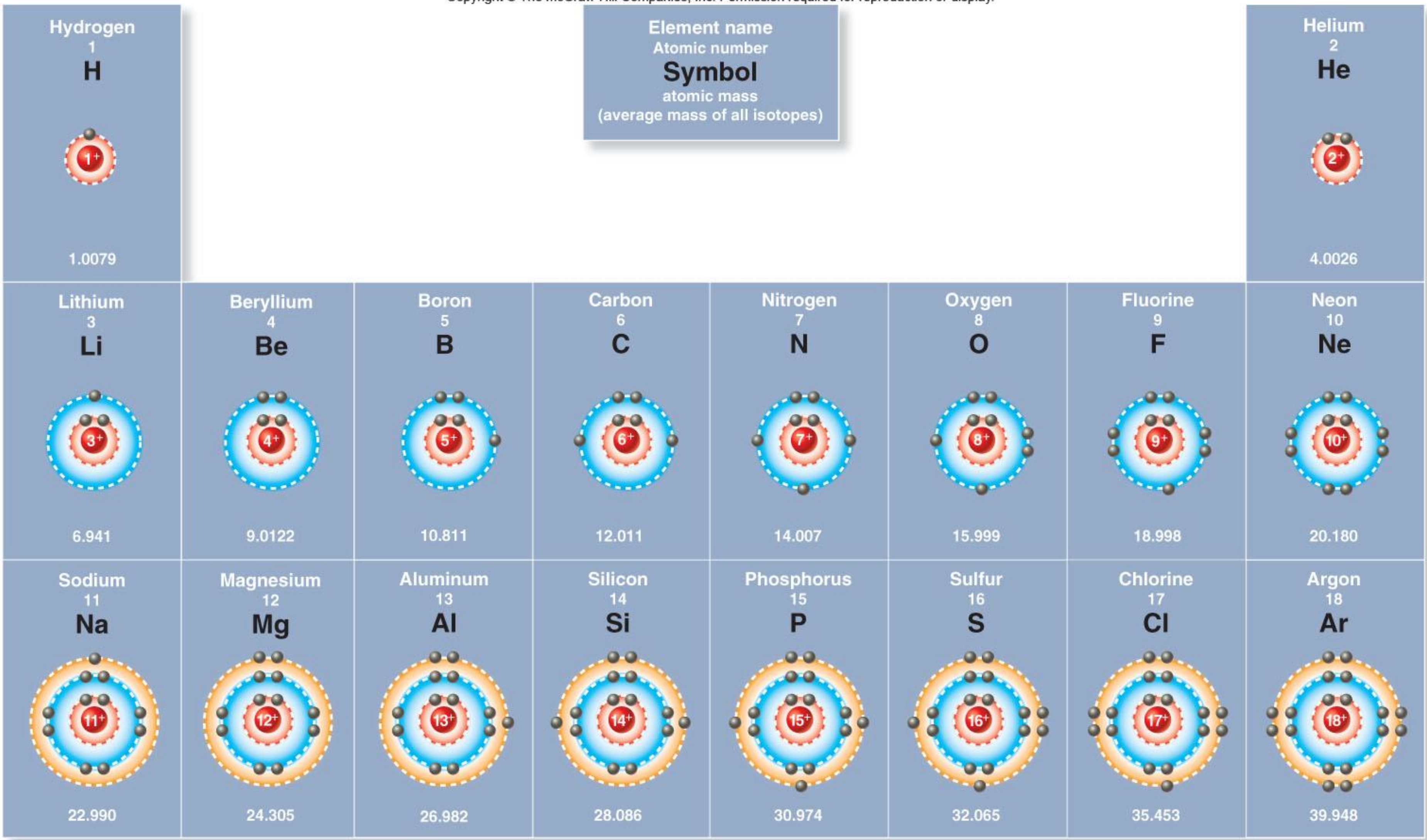
(a) Simplified depiction of a nitrogen atom (7 electrons; 2 electrons in first shell, 5 in second shell)

Protons

- Number of protons distinguishes one element from another
- Atomic number
  - Also equal to the number of electrons in the atom so that the net charge is zero

Periodic table

- Organized by atomic number
- Rows correspond to number of electron shells
- Columns, from left to right, indicate the numbers of electrons in the outer shell
- Similarities of elements within a column occur because they have the same number of electrons in their outer shells, and therefore they have similar chemical bonding properties


Element name
Atomic number
Symbol
atomic mass
(average mass of all isotopes)
Hydrogen 1 H 1.0079
Helium 2 He 4.0026
Lithium 3 Li 6.941
Beryllium 4 Be 9.0122
Boron 5 B 10.811
Carbon 6 C 12.011
Nitrogen 7 N 14.007
Oxygen 8 O 15.999
Fluorine 9 F 18.998
Neon 10 Ne 20.180
Sodium 11 Na 22.990
Magnesium 12 Mg 24.305
Aluminum 13 Al 26.982
Silicon 14 Si 28.086
Phosphorus 15 P 30.974
Sulfur 16 S 32.065
Chlorine 17 Cl 35.453
Argon 18 Ar 39.948

Units of Atomic Mass

- Dalton
  - Unit of measurement for atomic mass
  - Also known as atomic mass unit (amu)
  - One dalton (Da) equals 1/12 the mass of a carbon atom
  - Carbon has an atomic mass of 12 Daltons

Isotopes

- Multiple forms of an element that differ in the number of neutrons
- ^{12}C contains 6 protons and 6 neutrons
- ^{14}C contains 6 protons and 8 neutrons
- Atomic masses are averages of the weights of different isotopes of an element

Hydrogen, oxygen, carbon, and nitrogen

- Typically make up about 95% of the atoms in living organisms
  - Hydrogen and oxygen occur primarily in water
  - Nitrogen is found in proteins
  - Carbon is the building block of all living matter
- Mineral elements - less than 1%
- Trace elements - less than 0.01%
  - Essential for normal growth and function

Table 2.2 Chemical Elements Essential for Life in Most Organisms*

Element	Symbol	% Human body mass	% All atoms in human body
Most abundant in living organisms (approximately 95% of total mass)			
Oxygen	O	65	25.5
Carbon	C	18	9.5
Hydrogen	H	9	63.0
Nitrogen	N	3	1.4
Mineral elements (less than 1% of total mass)			
Calcium	Ca		
Chlorine	Cl		
Magnesium	Mg		
Phosphorus	P		
Potassium	K		
Sodium	Na		
Sulfur	S		
Trace elements (less than 0.01% of total mass)			
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		

* While these are the most common elements in living organisms, many other trace and mineral elements have reported functions. For example, aluminum is believed to be a cofactor for certain chemical reactions in animals, but it is generally toxic to plants.

Chemical bonds and molecules

- Molecule
  - 2 or more atoms bonded together
- Molecular formula
  - Contains chemical symbols of elements found in a molecule
  - Subscript indicates how many of each atom are present
- Compound
  - Molecule composed of 2 or more elements

3 types of bonds

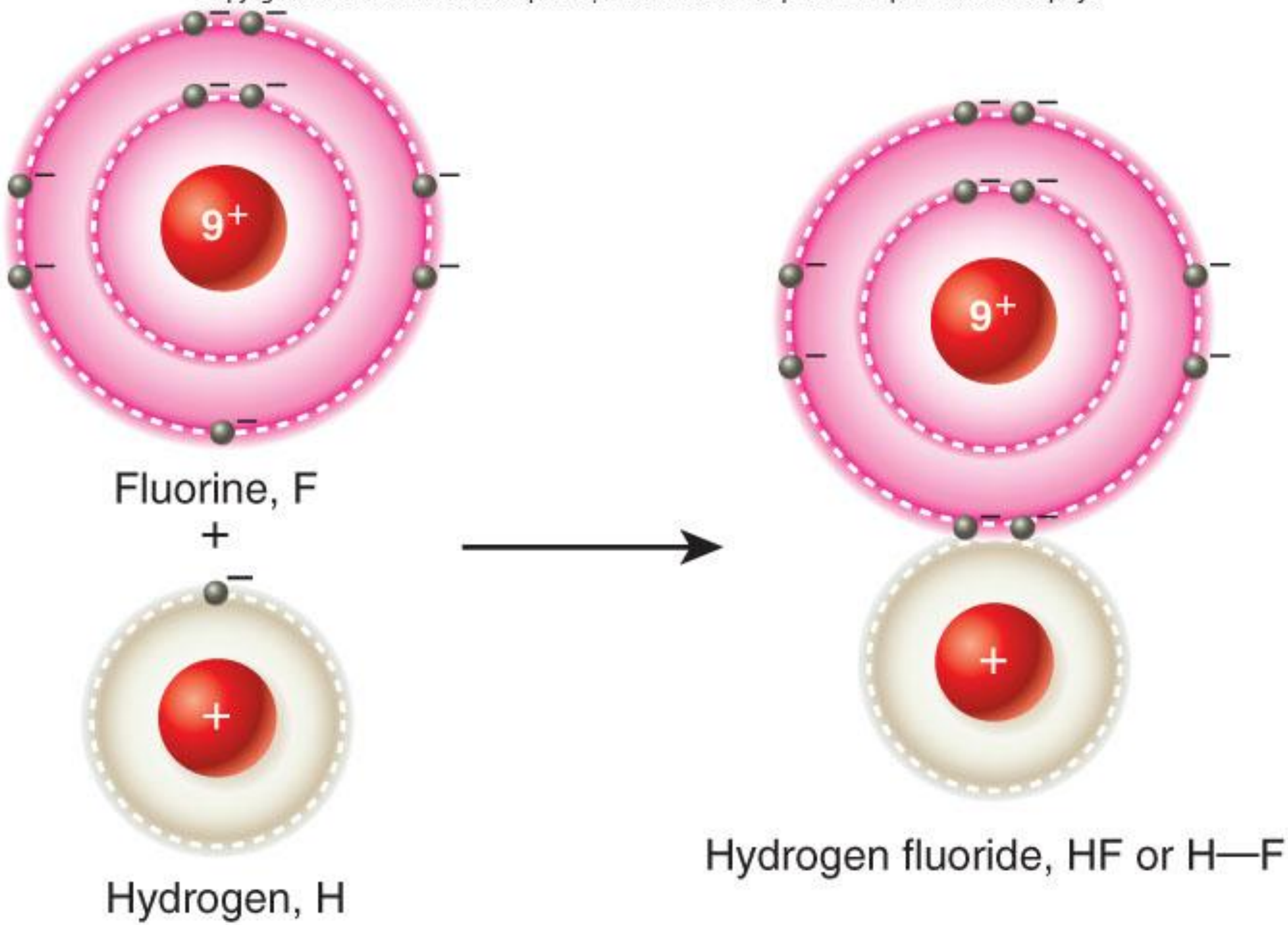
1. Covalent
   - Polar covalent
   - Nonpolar covalent
2. Hydrogen
3. Ionic

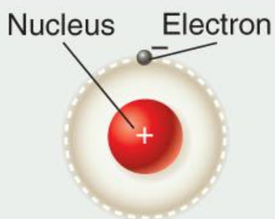
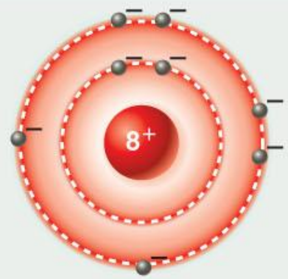
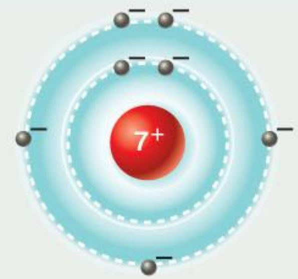
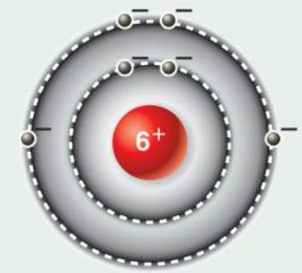
Covalent bonds

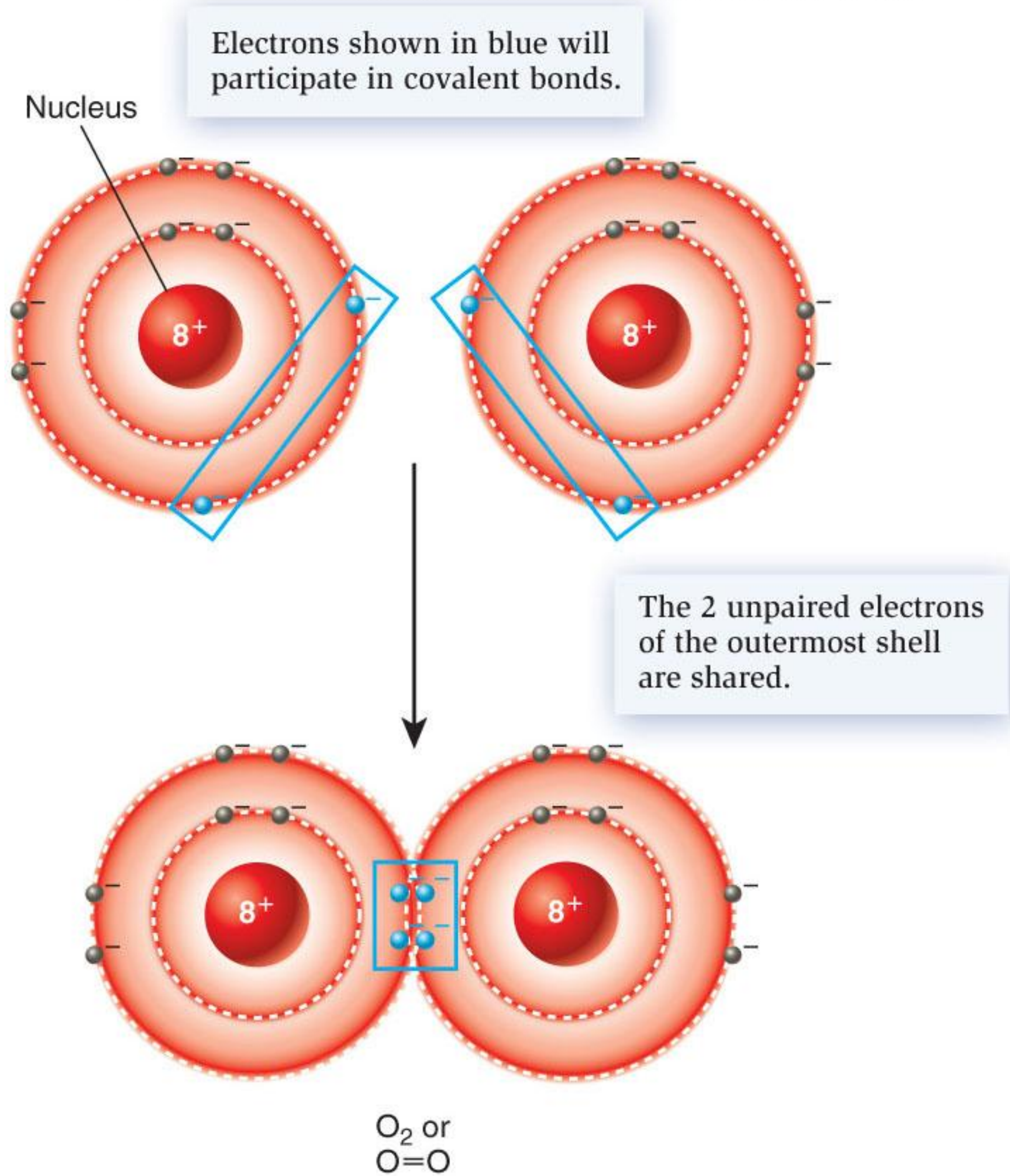
- Atoms share a pair of electrons
- Occurs between atoms whose outer electron shells are not full
- Covalent bonds are strong chemical bonds, because the shared electrons behave as if they belong to each atom
- Can share …
  - 1 pair of electrons – single bond H-F
  - 2 pairs of electrons – double bond O=O
  - 3 pairs of electrons – triple bond

Octet rule

- Atoms are stable when their outer shell is full
- For many atoms, the outer shell fills with 8 electrons
- One exception is hydrogen, which fills its outer shell with 2 electrons


9+
Fluorine, F
+
+
Hydrogen, H
9+
+
Hydrogen fluoride, HF or H—F

Atom name	Hydrogen	Oxygen	Nitrogen	Carbon
				
Electron number needed to complete outer shell (typical number of covalent bonds)	1	2	3	4


Electrons shown in blue will participate in covalent bonds.
Nucleus
8+
8+
The 2 unpaired electrons of the outermost shell are shared.
8+
8+
O_2 or
O=O

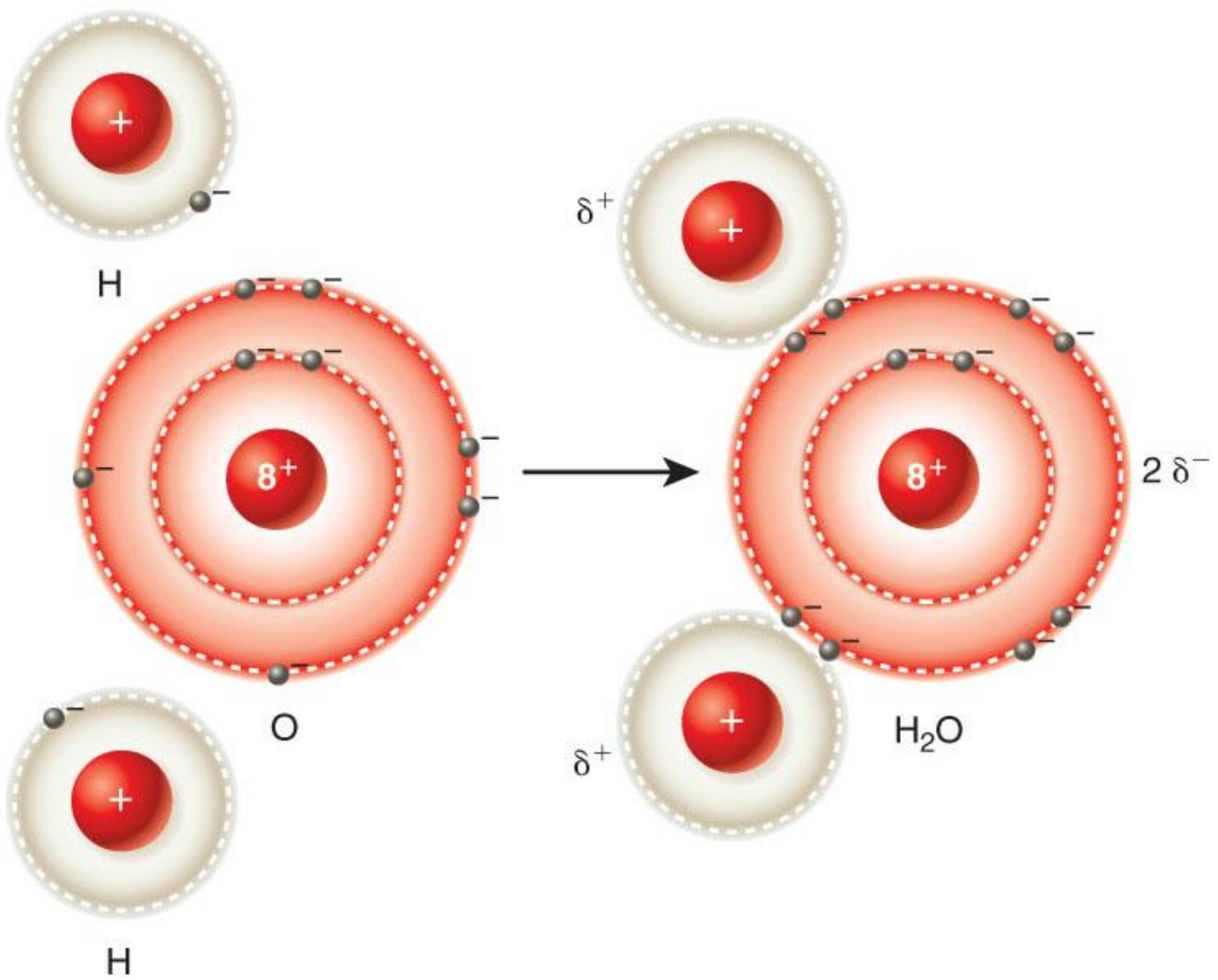
Polar covalent bonds

- When two atoms with different electronegativities form a covalent bond, the shared electrons are more likely to be in the outer shell of the atom of higher electronegativity rather than the atom of lower electronegativity
- Polar covalent bonds occur because the distribution of electrons around the atoms creates a polarity, or difference in electric charge, across the molecule

Water

- Classic example of polar covalent bonds
- Electrons tend to be in the more electronegative oxygen atom rather than either of the less electronegative hydrogen atoms
- Molecule has a partial negative charge region and a partial positive charge region

In water, the shared electrons spend more time near the oxygen atom. This gives oxygen a partial negative charge ($2\,\delta^-$) and each hydrogen a partial positive charge (δ^+).



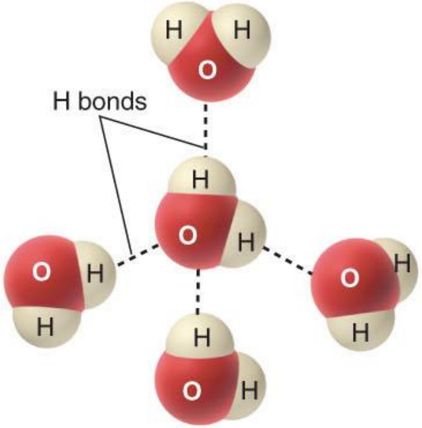
Nonpolar covalent bonds

- Bonds between atoms with similar electronegativities
- Equal sharing of electrons

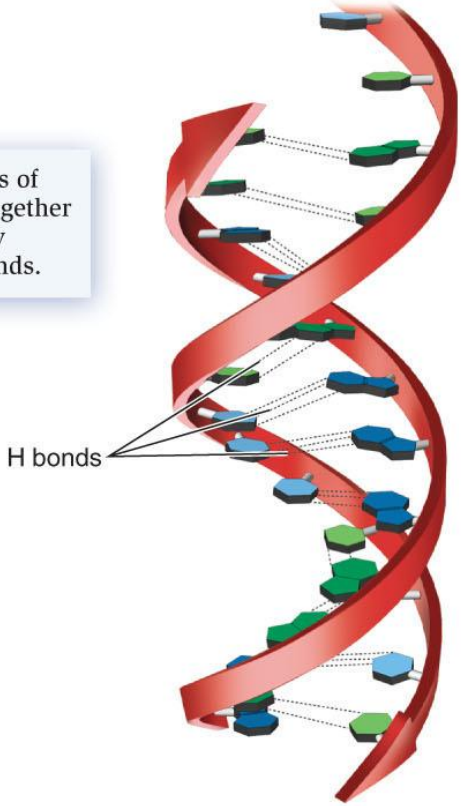
Hydrogen bonds

- Hydrogen atom from one polar molecule attracted to an electronegative atom
- Represented as dashed or dotted lines
- Collectively, strong bond overall
  - Holds DNA strands together
- Individually, weak bonds can form and break easily

The hydrogen bond (H bond) is a weak attraction between a partially positive hydrogen and a partially negative atom such as oxygen.

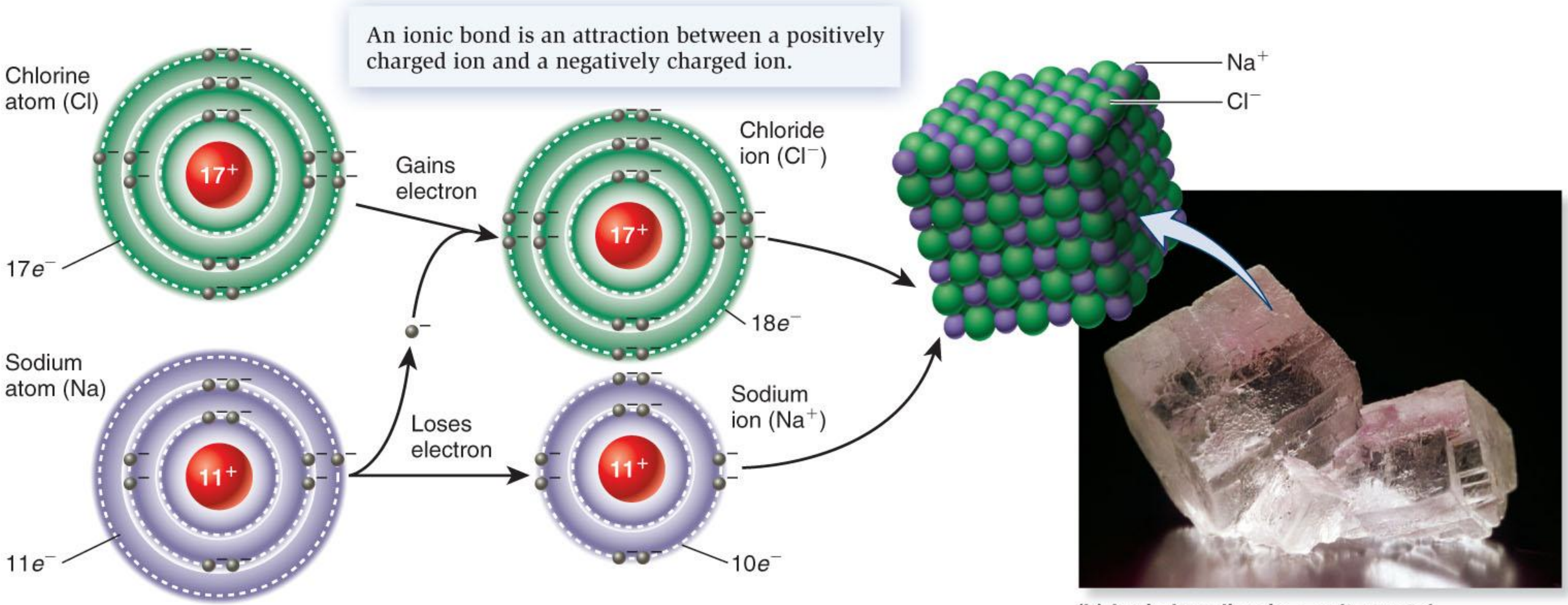


A DNA molecule consists of 2 twisted strands held together along its entire length by millions of hydrogen bonds.



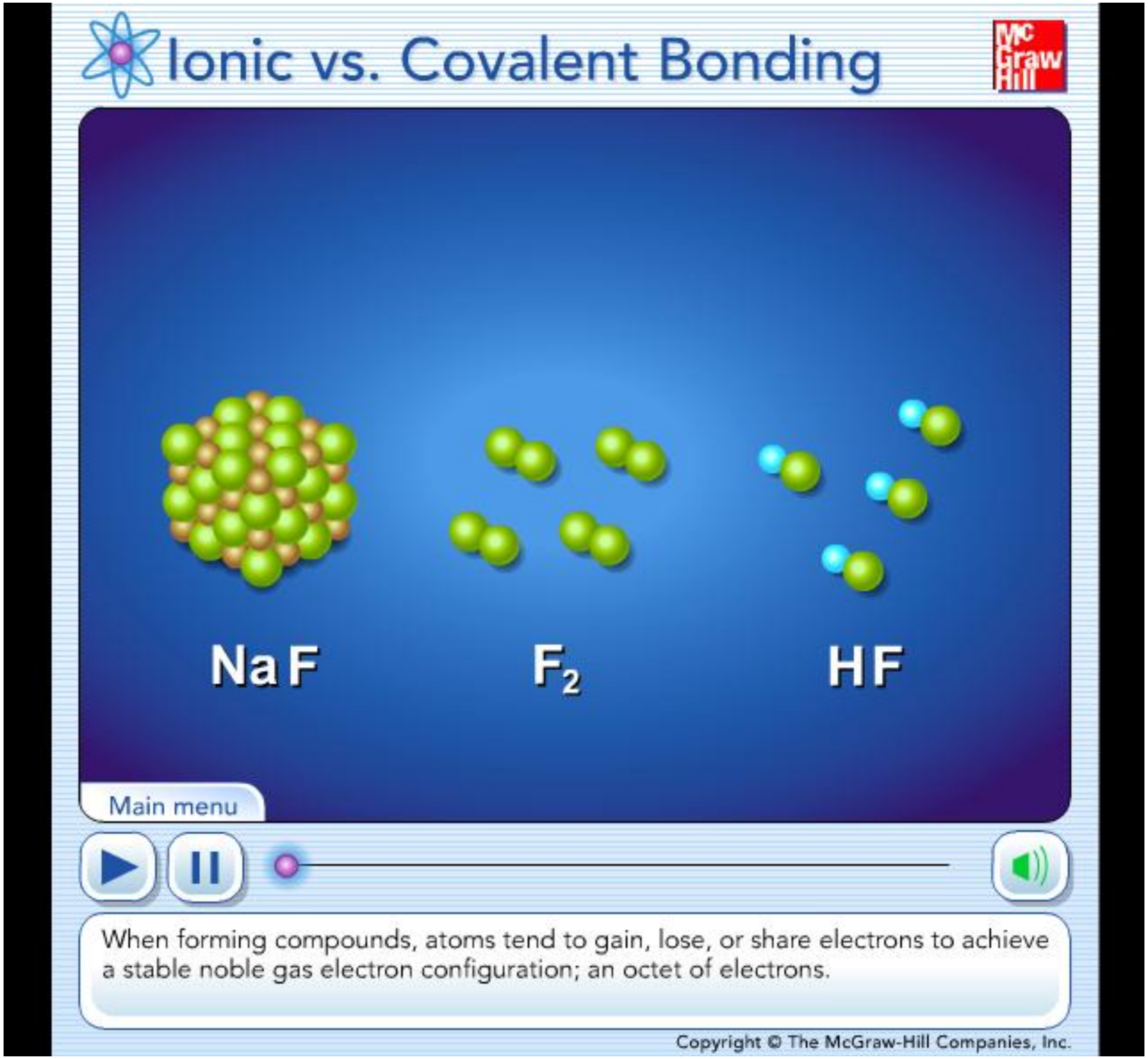
Ionic bonds

- An ion is an atom or molecule that has gained or lost one or more electrons
  - Now has a net electric charge
- Cations- net positive charge
- Anions- net negative charge
- Ionic bond occurs when a cation binds to an anion



(a) Formation of an ionic bond

(b) Ionic bonding in a salt crystal


Ionic vs. Covalent Bonding
NaF
F_2
HF
Main menu
When forming compounds, atoms tend to gain, lose, or share electrons to achieve a stable noble gas electron configuration; an octet of electrons.
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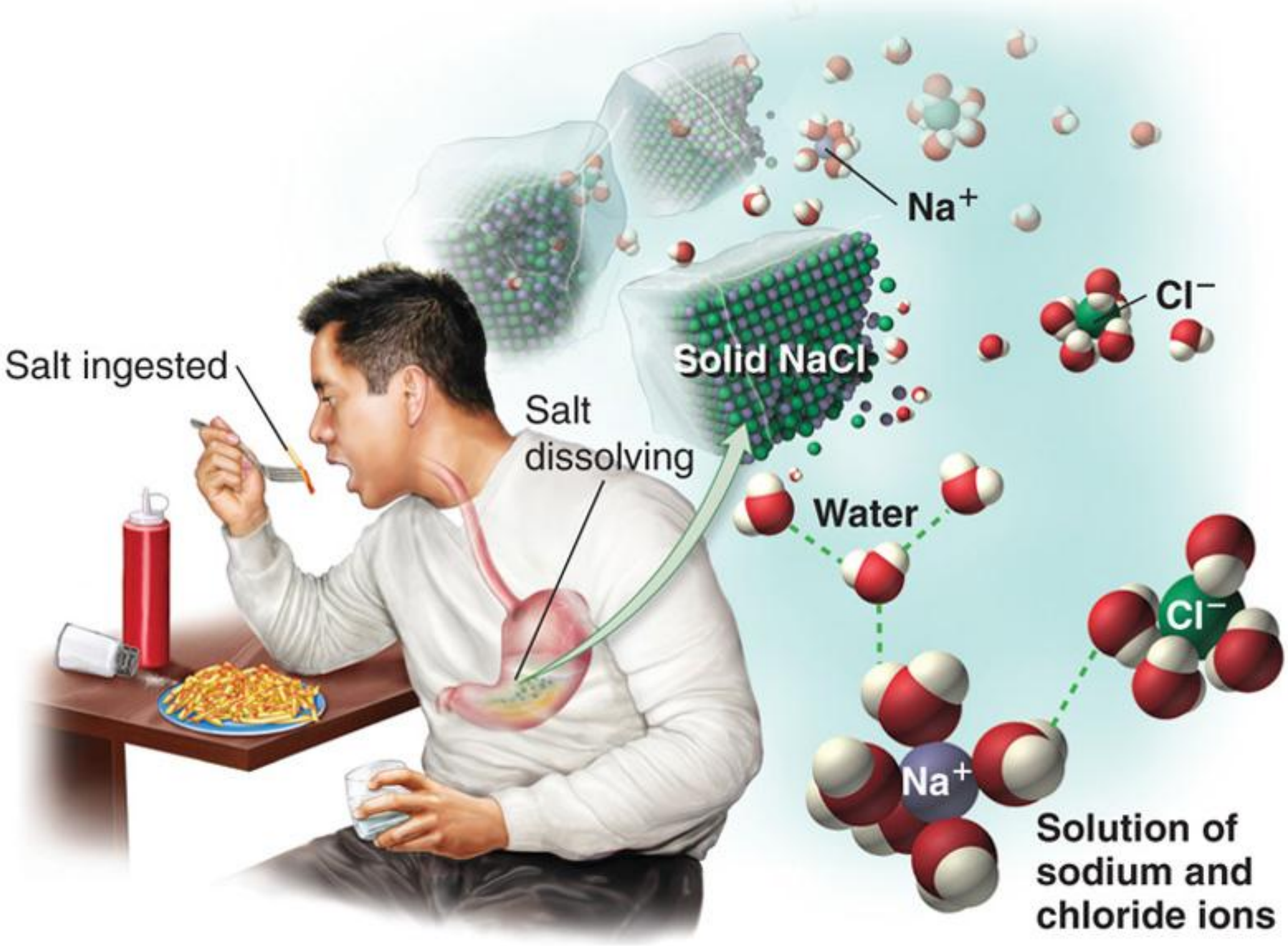
Chemical Reactions

- Occurs when one or more substances are changed into other substances
  - Reactants → products
- Share many properties
  - All require a source of energy
  - Reactions in living organisms often require a catalyst (enzymes)
  - Tend to proceed in a particular direction but will eventually reach equilibrium
  - Occur in liquid environment - water

Properties of water

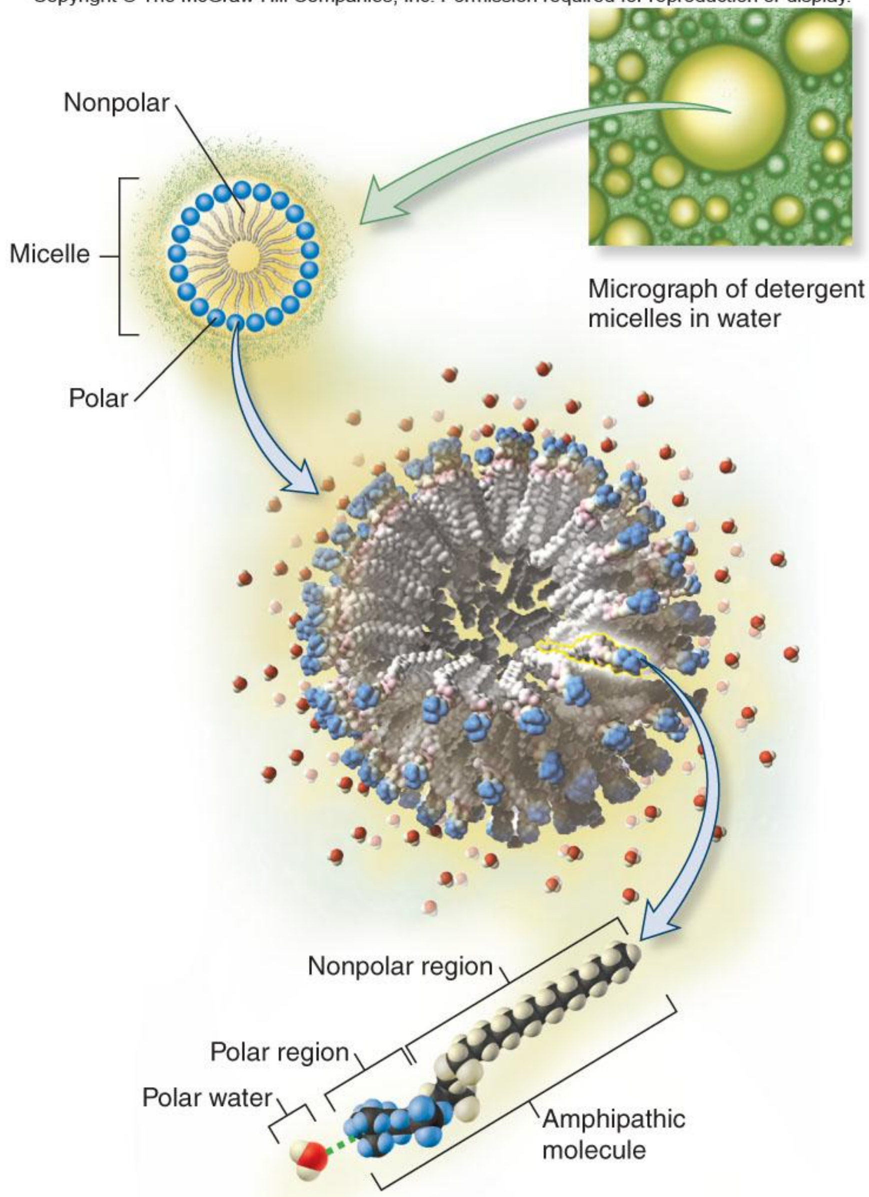
- A solution is made up of the
  - Solvent- liquid
  - Solutes- substances dissolved in solvent
- Aqueous solution- water is the solvent
- Ions and molecules that contain polar covalent bonds will dissolve in water



Na+
Cl−
Salt ingested
Solid NaCl
Salt dissolving
Water
Cl−
Na+
Solution of sodium and chloride ions

- Hydrophillic- “water-loving”
  - Readily dissolve in water
  - Molecules that contain ionic and/or polar covalent bonds
- Hydrophobic- “water-fearing”
  - Do not readily dissolve in water
  - Nonpolar molecules like hydrocarbon
- Amphipathic molecule
  - Have both polar/ionized and nonpolar regions
  - May form micelles in water

- Polar (hydrophilic) regions at the surface of the micelle
- Nonpolar (hydrophobic) ends are oriented toward the interior of the micelle



(Top): © Jeremy Burgess/Photo Researchers, Inc.

Solutions

- Concentration
  - Amount of a solute dissolved in a unit volume of solution
  - 1 gram of NaCl was dissolved in 1 liter of water = 1 g/L
- Molarity
  - Number of moles of a solute dissolved in 1 L of water
  - 1 mole of a substance is the amount of the substance in grams equal to its atomic or molecular mass

H_2O in 3 states of matter

- Solid (ice), liquid (water), and gas (water vapor)
- Changes in state, such as changes between the solid, liquid, and gas states of H_2O, involve an input or release of energy
  - Heat of vaporization
  - Heat of fusion
- Water is extremely stable as a liquid

Colligative properties of water

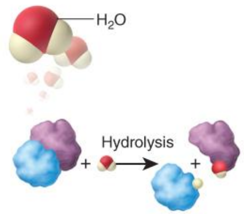
- Temperature at which a solution freezes influenced by amounts of dissolved solutes
- Addition of solutes to water lowers its freezing point below 0°C and raises its boiling point above 100°C
- Some animals produce antifreeze molecules that dissolve in their body fluids, thereby lowering the freezing point of the fluids and preventing their blood and cells from freezing in the extreme cold

(a) Emerald rockcod in the waters of Antarctica

(b) Wasp larvae, which can withstand freezing temperatures

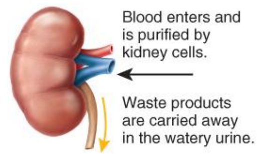
Not just a solvent

- Water has many important functions in living organisms
  - Participates in chemical reactions
    - Hydrolysis or dehydration (condensation)
  - Provides force or support
  - Removes toxic waste components
  - Evaporative cooling
  - Cohesion and adhesion
  - Surface tension



(a) Water participates in chemical reactions.

(b) Water provides support. The plant on the right is wilting due to lack of water.



(c) Water is used to eliminate soluble wastes.

(d) Evaporation helps some animals dissipate body heat.

(f) Water in saliva serves as a lubricant during—or as shown here, in anticipation of—feeding.

(g) The surface tension of water explains why this water strider doesn't sink.

b: © Aaron Haupt/Photo Researchers; d: © Rainer Drexel/Bilderberg/Peter Arnold; f: © Anthony Bannister/Gallo Images/Corbis; g: © OSF/Photolibrary

Acids and Bases

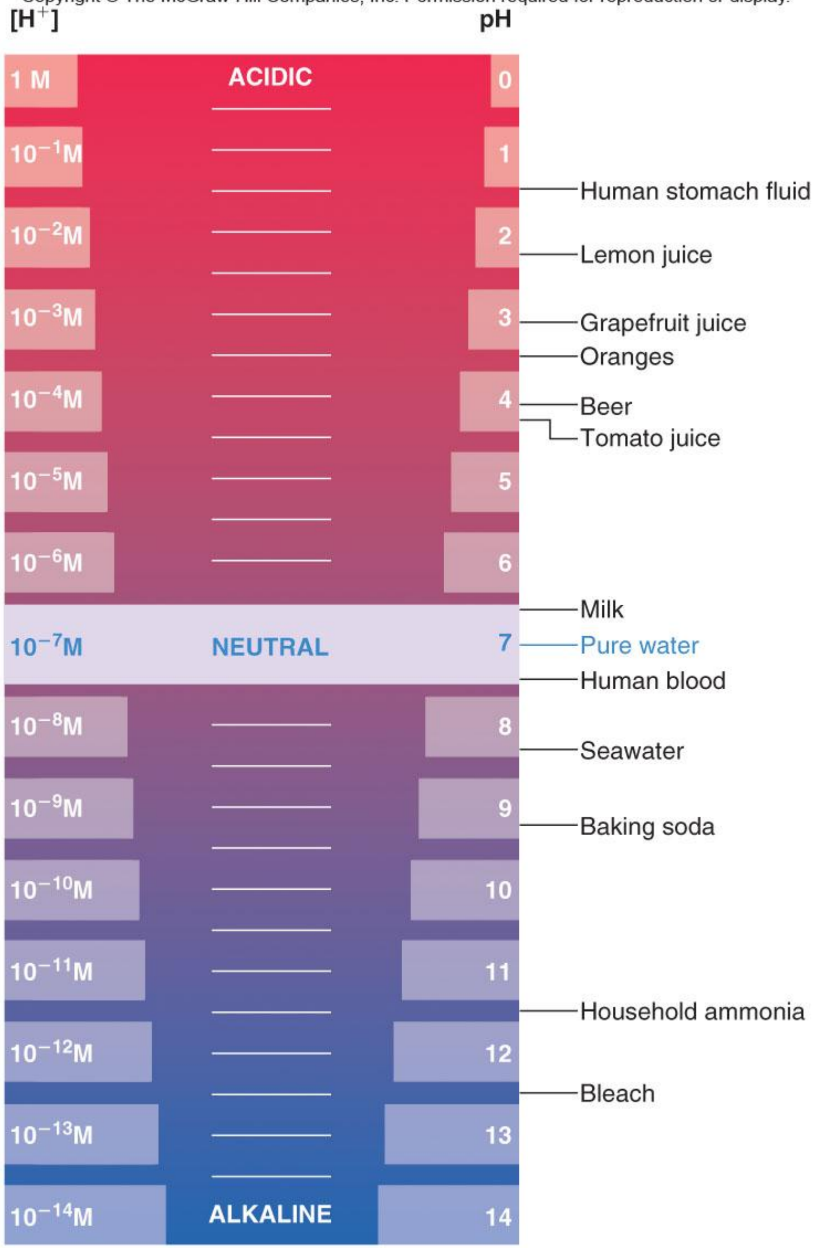
- Pure water has the ability to ionize to a very small extent into hydrogen ions (H^+) and hydroxide ions (OH^-)
- In pure water

  $[H^+][OH^-] = [10^{-7}\ M][10^{-7}\ M] = 10^{-14}\ M$

- Acids are molecules that release hydrogen ions in solution
  - A strong acid releases more H^+ than a weak acid
- Bases lower the H^+ concentration
  - Some release OH^-
  - Others bind H^+

pH

- pH = $\log_{10} [H^+]$
- Acidic solutions are pH 6 or below
- pH 7 is neutral
- Alkaline solutions are pH 8 or above


[H+]
pH
1 M
ACIDIC
0
10−1M
1
Human stomach fluid
10−2M
2
Lemon juice
10−3M
3
Grapefruit juice
Oranges
10−4M
4
Beer
Tomato juice
10−5M
5
10−6M
6
Milk
10−7M
NEUTRAL
7
Pure water
Human blood
10−8M
8
Seawater
10−9M
9
Baking soda
10−10M
10
10−11M
11
Household ammonia
10−12M
12
Bleach
10−13M
13
10−14M
ALKALINE
14

- The pH of a solution can affect
  - The shapes and functions of molecules
  - The rates of many chemical reactions
  - The ability of two molecules to bind to each other
  - The ability of ions or molecules to dissolve in water

Buffers

- Organisms usually tolerate only small changes in pH
- Buffers help to keep a constant pH
- An acid-base buffer system can shift to generate or release H^+ to adjust for changes in pH

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

(carbonic acid) (bicarbonate)