Ch. 2

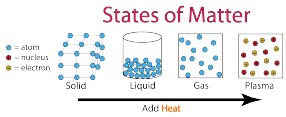
Chemistry / Water / Carbon

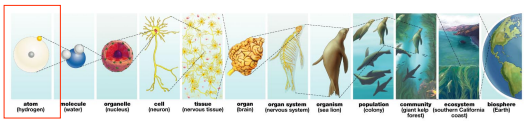
BIOL 222

CHEMISTRY

Matter

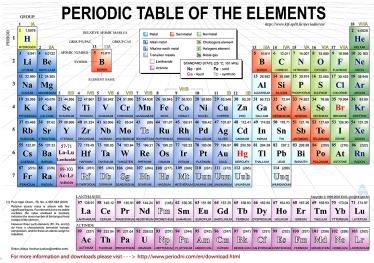
- Organisms are composed of **matter**
- Matter
  - anything that takes up space and has mass
- Matter is made up of elements
  - Lowest end of the structural organization of life





Elements

- any substance that cannot be reduced to any simpler set of constituent substances
  - through chemical means
- defined by the number of protons in its nucleus



Elements of Life

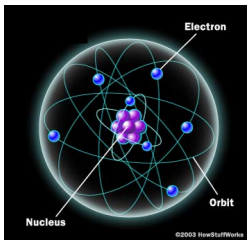
- About 25 of the 92 elements are essential to life
  - Carbon, hydrogen, oxygen, and nitrogen
    - make up 96% of living matter
  - Most of the remaining 4% consists of…
    - calcium, phosphorus, potassium, and sulfur
- **Trace elements**
  - those required by an organism in minute quantities

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)			

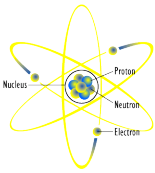
Elements made of Atoms

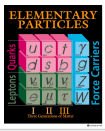
- Each element consists of unique **atoms**
- An atom is the smallest unit of matter that still retains the properties of an element



The Atom

- Atoms are composed of *subatomic particles*
- Relevant subatomic particles include:
  - **Neutrons** (no electrical charge)
  - **Protons** (positive charge)
  - **Electrons** (negative charge)
    - Actually an elementary particle





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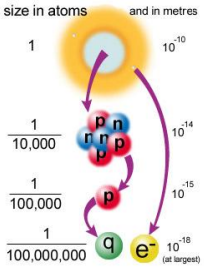
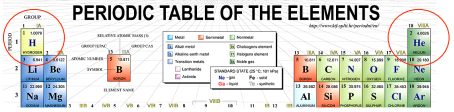
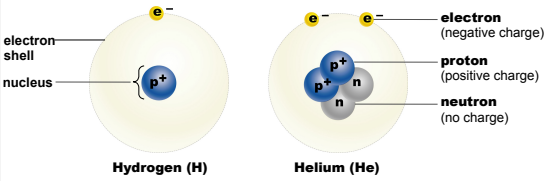
Subatomic Particles

NUCLEUS	charge	mass
proton	(+)	1 dalton
neutron	(0)	1 dalton
SHELL		
electron	(-)	~0 daltons



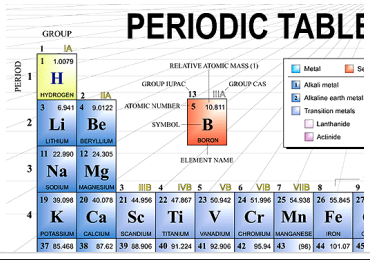
Periodic Table



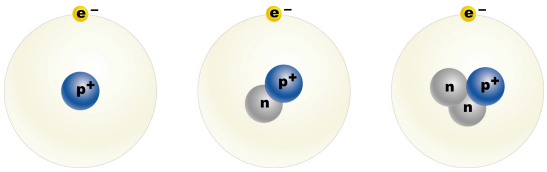


Atomic Characteristics

- Atomic number = # of protons (*never changes)*
- Mass number = # of protons + neutrons (*not quite atomic mass)*
- Isotope - Δ # neutrons



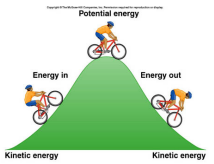
Isotopes

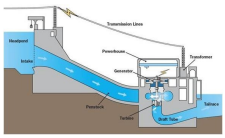


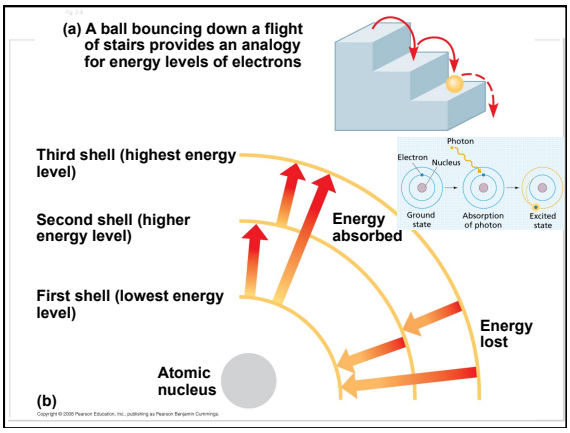
Hydrogen	Deuterium	Tritium
1 proton 0 neutrons	1 proton 1 neutron	1 proton 2 neutrons

Electron Energy Levels

- **Energy**
  - capacity to cause change or do work
- **Potential energy**
  - energy that matter has because of its location or structure
- The electrons
  - differ in their amounts of potential energy
    - due to position
- **electron shell**
  - An electron's energy level, or state of potential energy

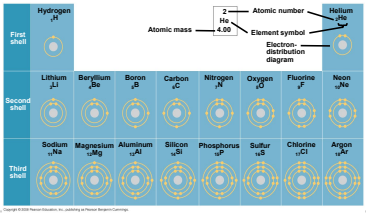






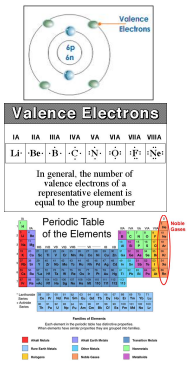
Distribution of Electrons

- The chemical behavior of an atom
  - Determined by the distribution of electrons in electron shells
  - Atoms are always seeking their lowest energy state
- The *periodic table of the elements*
  - shows the electron distribution for each element



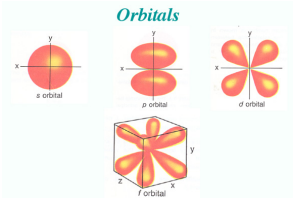
Electrons for Bonding

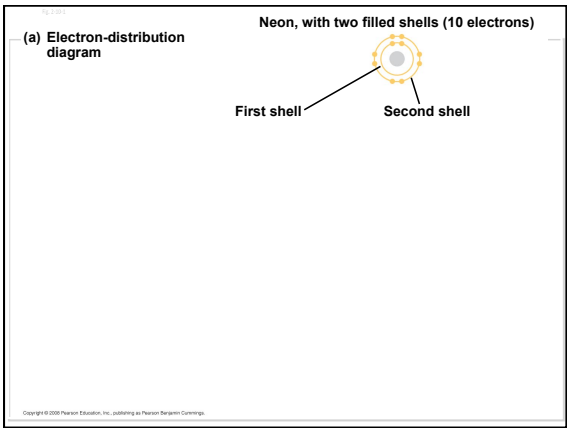
- **Valence electrons**
  - those in the outermost shell
    - **valence shell**
- Chemical behavior of an atom mostly determined by the valence electrons
- Elements with a full valence shell are chemically *inert*
  - lowest energy state
  - Noble gases



Electron Orbitals

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




Neon, with two filled shells (10 electrons)
(a) Electron-distribution diagram
First shell
Second shell
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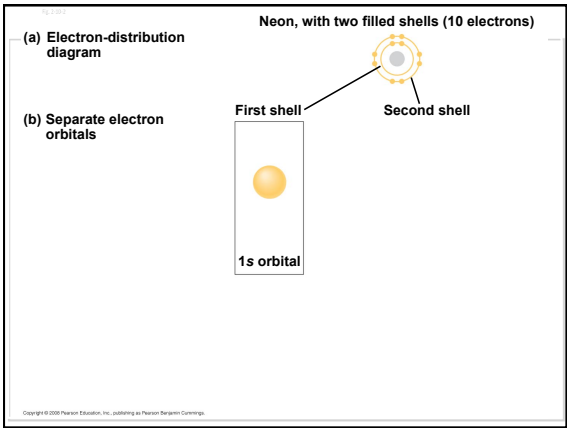
Neon, with two filled shells (10 electrons)
(a) Electron-distribution diagram
(b) Separate electron orbitals
First shell
Second shell
1s orbital
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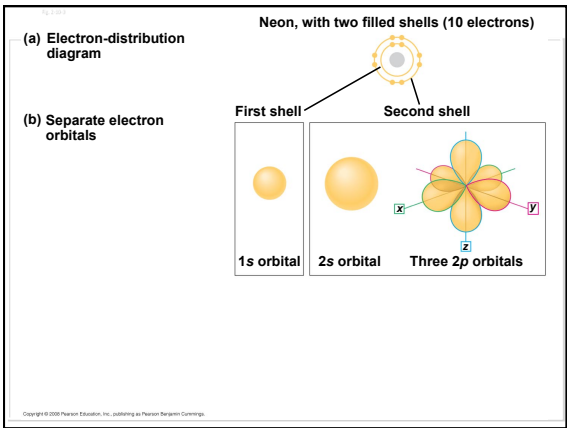
Neon, with two filled shells (10 electrons)
(a) Electron-distribution diagram
(b) Separate electron orbitals
First shell
Second shell
x
y
z
1s orbital
2s orbital
Three 2p orbitals
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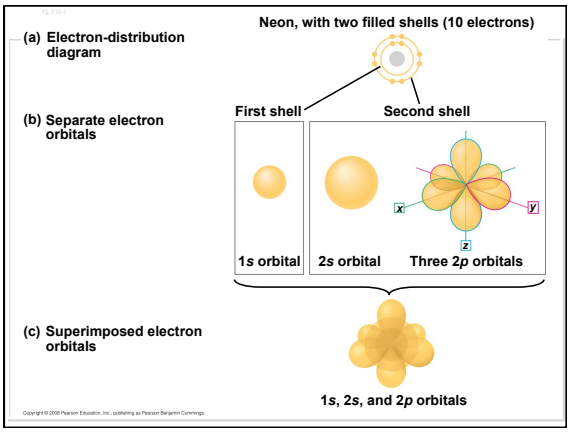
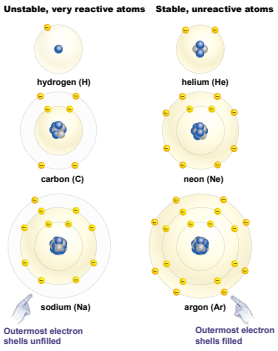


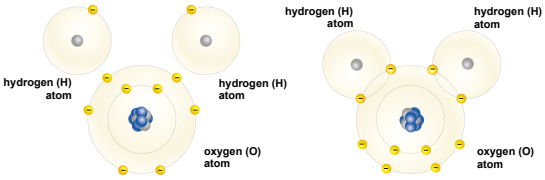
Bonding

- Chemical Bonds
  - Atoms with incomplete valence shells
    - can share or transfer valence electrons
      - with certain other atoms
- These interactions usually result in
  - atoms staying close together
    - bonding



Bonds

- **Covalent bond**
  - sharing of a pair of valence electrons by two atoms
  - shared electrons count as part of each atom's valence shell



(a) Two hydrogen atoms and one oxygen atom **(b)** One water molecule

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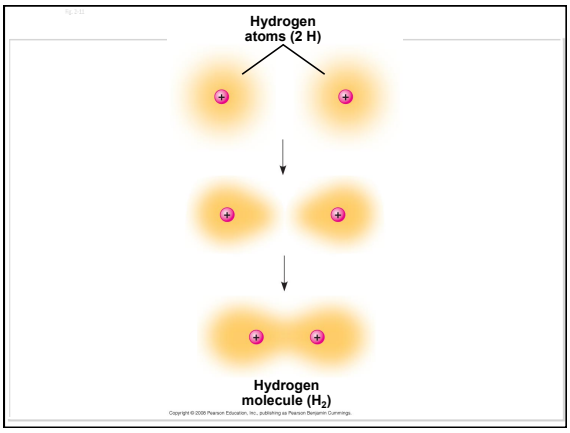
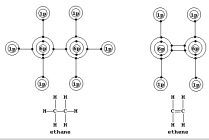


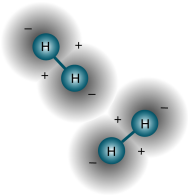
Covalent Bonds

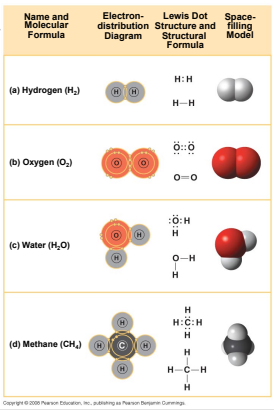
- **Molecule**
  - two or more atoms held together by covalent bonds
- **single bond,** or single covalent bond
  - sharing of one pair of valence electrons
- **double bond**, or double covalent bond
  - sharing of two pairs of valence electrons



Bond Notations

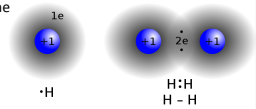
- **structural formula**
  - notation used to represent atoms and bonding
  - H–H, O=O
- **molecular formula**
  - Further abbreviation
  - H_2, O_2





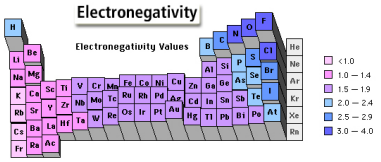
Covalent Bonds continued

- Covalent bonds
  - can form between atoms of the same element
    - or atoms of different elements
- Molecule
  - any two or more atoms bonded together
  - May be same or different elements
- Compound
  - combination of two or more *different* elements

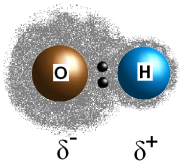


Bond Strength

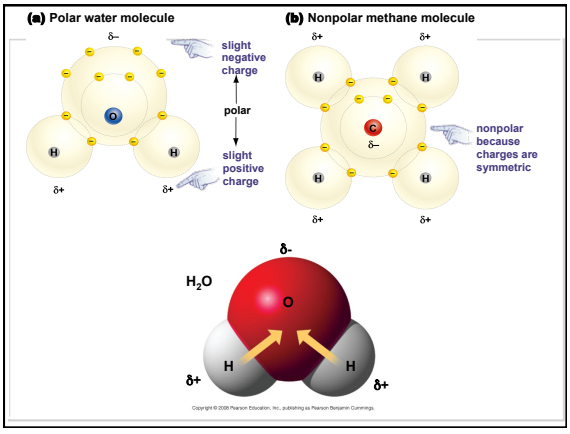
- **Electronegativity** (χ)
  - an atom's attraction for the electrons in a covalent bond
    - as well as it's own
  - More electronegative an atom
    - the more strongly it pulls shared electrons toward itself
  - Imbalances of electronegativity
    - may result in unequal sharing of electrons in a covalent bond



Types of Covalent Bonds

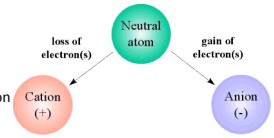


- ***nonpolar*** **covalent bond**
  - atoms share the electrons equally
- ***polar*** **covalent bond**
  - one atom is (considerably) more electronegative
    - results in unequal sharing
      - causes a partial positive and/or negative charge
        - for each atom or an entire molecule



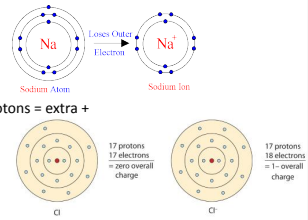
Ionic Bonds

- Large differences in electronegativities
  - Atoms sometimes strip electrons from their bonding partners
  - Example - transfer of an electron from sodium to chlorine
    - After which both atoms have charges
      - Numbers of protons (+) in each atom are no longer balanced by electrons (-)
- **Ion**
  - A charged atom (or molecule)
    - Has gained or lost an electron

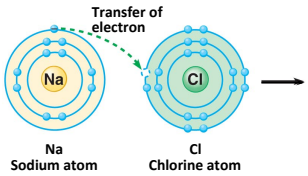


Ions

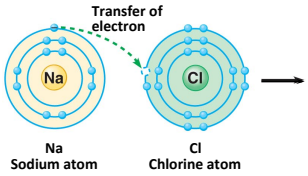
- **Cation** - positively charged ion
  - Lost an electron
    - Fewer electrons than protons = extra +
- **Anion** - negatively charged ion
  - Gained an electron
    - More electrons than protons = extra –
- **ionic bond**
  - attraction between an anion and a cation
  - Opposites charges attract



Ionic Bonds

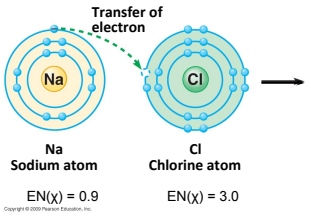


Ionic Bonds

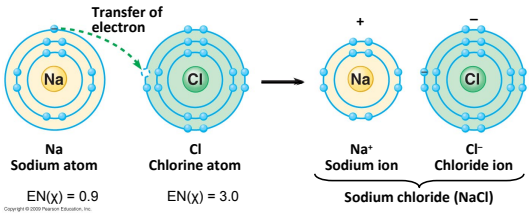


EN(χ) = 0.9

Ionic Bonds

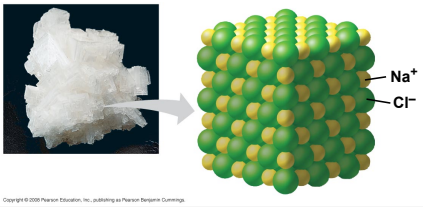


Ionic Bonds



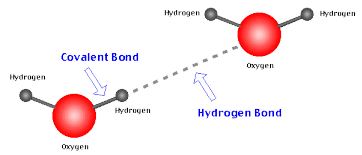
Ionic Bonds

- **Ionic compound**
  - Compounds formed by ionic bonds
  - Many are **salts**
- Salts, (NaCl, table salt), are often found in nature as crystals



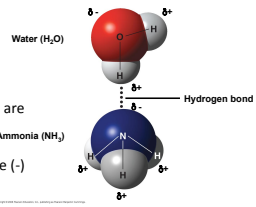
Weak Chemical Bonds

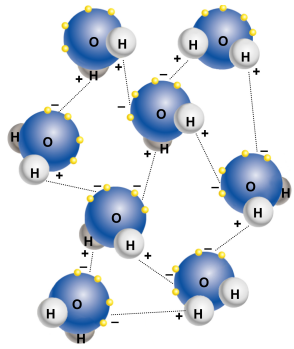
- covalent bonds
  - strongest
- ionic bonds
  - next strongest
- **hydrogen bonds**
  - weakest
  - very important
- Weak chemical bonds reinforce shapes of large molecules
  - and help molecules adhere to each other



Hydrogen Bonds

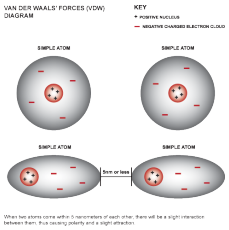
- **hydrogen bond**
  - hydrogen atom covalently bonded to one electronegative atom
    - is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms
  - attraction of H+ to an opposite charge (-)
- In water, a hydrogen atom of one water molecule (δ+)
  - will form a hydrogen bond with an unshared oxygen (δ-) electron
    - of a neighboring water molecule





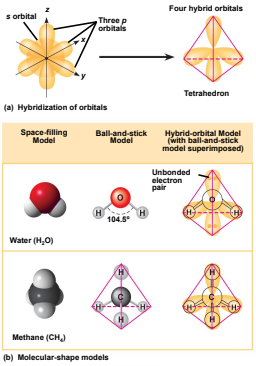
Other Interactions

- If electrons are distributed asymmetrically in large molecules
  - they can result in "hot spots" of positive or negative charge
    - localized regions of charge
- **Van der Waals interactions**
  - attractions between molecules that are close together
    - as a result of these charges
  - Collectively can be strong
    - as between molecules of a gecko's toe hairs and a wall surface



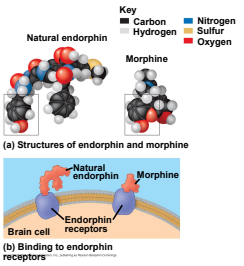
Molecular Shape and Function

- molecular shape
  - very important to its function
  - determined by the positions of its atoms' valence orbitals
- In a covalent bond
  - the *s* and *p* orbitals may hybridize
    - creating specific molecular shapes



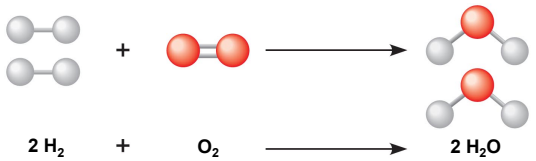
Molecular Shape

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



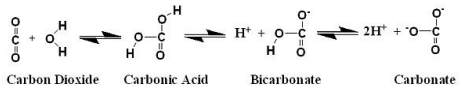
Reactions

- **Chemical reactions**
  - the making and breaking of chemical bonds
- **Reactants**
  - starting molecules of a chemical reaction
- **Products**
  - final molecules of a chemical reaction



Chemical Reactions

- All chemical reactions are reversible
  - products of the forward reaction
    - become reactants for the reverse reaction
- **Chemical equilibrium**
  - 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