Chemistry Lecture 1 – Atoms, Molecules and Quantum Mechanics

Examkrackers MCAT Comprehensive Course, Charles Feng
http://fenguin.net/mcat — fenguin@gmail.com — (224) 532-0039

Atoms
- Nucleus (protons, neutrons) + electrons
- Elements written as \( \frac{1}{2}X \)
  - \( A = \text{mass number} = \text{protons} + \text{neutrons} \)
  - \( Z = \text{atomic number} = \text{protons} \)
  - \( X = \text{element symbol} \) (i.e. Mg)
- Isotopes: same atomic number (same # protons), diff mass number (diff # neutrons)
- Atomic weight/molar mass: from periodic table, defined in amu or g/mol (when do we use?)
  - # moles = g grams / molecular weight
- Ion: diff # electrons than protons, so has a charge (+ cation, - anion)
- Size differences:
  - For same element: cations are smaller than neutral, anions are larger than neutral
  - For same # electrons: smaller with higher atomic number b/c of more attractive force from protons

Periodic Table
- Period: horizontal row
- Group/Family: vertical column, numbered 1-18 or IA-VIIA, IIB-IIIB
- Types of elements
  - Metals:
    - Tend to lose electrons to form positive ions
    - Ductile, malleable, thermal/electrically conductive, luster (shiny)
    - Generally solids @ room temperature except mercury
    - Usually form ionic oxides
  - Transition metals: in the sunken area of the periodic table (section B groups)
  - Nonmetals: tend to gain electrons to form negative ions, usually form covalent oxides
  - Metalloids: between a metal and a nonmetal
- Groups/Families
  - Alkali metals (Group 1A): low melting point, form 1⁺ cations, react strongly with most nonmetals including water (to form hydroxides and hydrogen gas)
  - Alkaline earth metals (Group 2A): higher melting point, less reactive than 1A, form 2⁺ cations
  - Group 4A: can form four covalent bonds with nonmetals. C can form strong pi bonds, everything else can form two additional bonds for a total of 6
  - Group 5A: can form three covalent bonds. N can form strong pi bonds, everything else can form two additional bonds for a total of 5
  - Chalcogens (Group 6A): oxygen and sulfur most important, both can make strong pi bonds. Oxygen reacts with metals to form metal oxides. Pure sulfur is \( S_8 \)
  - Halogens (Group 7A): F, Cl, Br, I. All exist as diatomic molecules and like to gain electrons
  - Noble gases (Group 8A): nonreactive, normally found in nature as isolated atoms
- Diatomic molecules: H, O, N, Cl, Br, I, F
- Small atoms can form pi bonds, large atoms (3rd period or above) have d orbitals so can form more than 4 bonds
Chemistry Lecture 1 – Atoms, Molecules and Quantum Mechanics

Examkrackers MCAT Comprehensive Course, Charles Feng
http://fenguin.net/mcat — fenguin@gmail.com — (224) 532-0039

Periodic Trends
- Ionization energy: energy it takes to remove an electron
- Electronegativity: tendency to attract an electron in a bond
- Electron affinity: willingness of an atom to accept an additional electron
- Start with E: (energy of ionization, electron affinity, electronegativity) increase going LEFT-RIGHT, BOTTOM-TOP
- Don’t start with E: (atomic radius, metallic character) increase going RIGHT-LEFT, TOP-BOTTOM

SI
- Units: kg, m, s, A, K, cd, mol
- Prefixes: mega/kilo/decicenti/milli/micro/nano/pico/femto

Molecules: separate and distinct units made of atoms
- Empirical formula: relative number of atoms of one element to another
- Molecular formula: exact number of atoms per molecule
- Calculating percent composition by mass
  - For each atom, find weight of atom in molecule / total molecular weight
- Calculating empirical formula from percent mass
  - Assume a 100 gram sample, multiply by % masses to find # grams of each element
  - Find # moles of each element from the # grams
  - Divide by smallest # of moles to get empirical formula (might have to multiply by a factor to make all numbers integers)
  - If we want the molecular formula, have to use (given) total molecular weight

Bonds
- Covalent bond: shares electrons; electrons closer to more electronegative atom
- Bond dissociation energy/bond energy: energy it takes to break a bond
  - Higher bond energy = lower bond length
  - Double bonds have higher bond energy (lower length), triple bonds even higher/lower
- Compound: substance made from two or more elements

Naming compounds
- Ionic: cation + anion
  - Cations usually just name of element
  - Metals with more than one possible charge (i.e. copper) called copper (I) or copper (II)
  - Anions of elements end in -ide
  - Polyatomic anions containing oxygen end in -ite or -ate (also hypo- -ite and per- -ate)
- Acids: named after anion
  - Acids of elements = hydro- element -ic
  - Oxyacids = anion name -ic/-ous acid
- Binary molecular compounds (2 elements): leftmost/lowest, then other one w/ prefixes
Chemistry Lecture 1 – Atoms, Molecules and Quantum Mechanics

Examkrackers MCAT Comprehensive Course, Charles Feng
http://fenguin.net/mcat — fenguin@gmail.com — (224) 532-0039

Chemical reactions
- *Physical vs chemical changes*: chemical when molecular structure is changed
- Remember to balance all equations!
- **Limiting reagent**: what will get used up first
  - Find # moles available of each reactant
  - Look at ratios between coeffs in balanced equation to find out what gets used up first
- **Theoretical vs actual yield**
  - Theoretical is what’s predicted by equation, actual is what you get in an experiment
  - Percent yield: \( \text{% yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% \)

Types of Reactions
- **Combination**: \( A + B \rightarrow C \)
- **Decomposition**: \( C \rightarrow A + B \)
- **Single displacement**: \( A + BC \rightarrow B + AC \)
- **Double displacement**: \( AB + CD \rightarrow AD + CB \)

Quantum Mechanics
- **Quantum numbers**
  - *Principal quantum number* \( n \): shell level
  - *Azimuthal quantum number* \( l \): subshell/orbital shape: s, p, d, f. Can range from 0 to \( n - 1 \)
  - *Magnetic quantum number* \( m_l \): which orbital; ranges from \(-l\) to \(+l\)
  - *Electron spin quantum number* \( m_s \): \(-1/2\) or \(+1/2\)
- **Hund’s rule**: one electron will go into each available orbital before any orbital has 2 electrons
- **Aufbau principle**: electrons look for an available orbital with the lowest energy state
  \( 1s \rightarrow 2s \rightarrow 2p \rightarrow 3s \rightarrow 3p \rightarrow 4s \rightarrow 3d \rightarrow 4p \rightarrow 5s \rightarrow 4d \rightarrow 5p \rightarrow 6s \rightarrow 4f \rightarrow 5d \rightarrow 6p \ldots \)

- **Electron configuration**
  - \( Br = 1s^22s^22p^63s^23p^64s^23d^{10}4p^5 \)
  - Exceptions: \( 4s^23d^1 \rightarrow 4s^23d^2 \), \( 4s^23d^9 \rightarrow 4s^23d^{10} \)
  - For ions, make sure you have the right number of electrons
- **Heisenberg uncertainty principle**: we can never be sure about both the position and the momentum of a particle
  \[ \Delta x \Delta p \geq \frac{\hbar}{2} \]

Electromagnetic Energy
- **Planck’s quantum theory**: electromagnetic energy is quantized in discrete increments
- **For a photon**, \( E = hf \) and \( \lambda = \frac{h}{mv} \)
- **Emission spectra**
  - Electrons have specific quantized energy levels that are unique for each atom
  - When a photon of the right wavelength hits the atom, it can excite an electron to a higher energy level
  - After a while, the electron drops from the high energy level releasing another photon
  - If you use a wide spectrum of light, you can see what wavelength of photons are released to identify the material
- **Photoelectric effect**
  - Electrons can be ejected from metal by shining light on it
  - The light energy must be greater than the work function \( \Phi \) of the metal
  - The kinetic energy of ejected electron = \( hf - \Phi \)