Chemistry 120

Atoms, Elements, Molecules
and Compounds

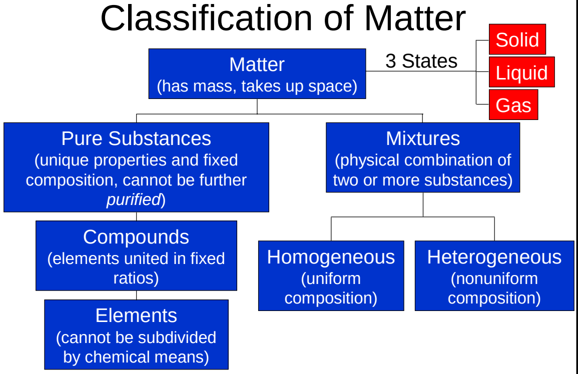
What is Chemistry?

- Chemistry is a Science of Matter and Energy
  - *Matter* has mass and takes up space
  - *Energy* the "mover" of matter
- Chemistry is the "Central Science"
  - Applicable to all sciences
- Chemists study
  - Physical and chemical properties of matter
  - Interaction of energy and matter

Properties of Matter

- Physical Properties
  - Characteristics measured without changing substance's composition
  - *Extensive* depend on amount
  - *Intensive* do not depend on amount
- Chemical Properties
  - Characteristics that describe how substance interacts with other substances
  - Measurement requires composition change

Classification of Matter



Central Theories and Laws of Chemistry

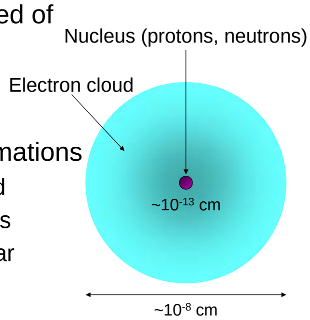
- Atomic Theory (Dalton)
  - Law of Conservation of Matter
  - Law of Constant Composition
  - Law of Multiple Proportions
  - Law of Chemical Periodicity
- Kinetic-Molecular Theory
- Laws of Thermodynamics
- Quantum Mechanics

Summary

- Matter comes in little-bitty Chunks
  - Can't be created or destroyed
  - Everything built from a small set of chunks
  - Energy makes them move around
  - Chunks are sticky to varying degrees
- Energy looks like it is continuous, but it comes in Chunks, too
  - Total energy of the Universe is constant
  - Energy likes to spread out
- Tiny Things are weird

Atomic Structure and Chemistry

- Atoms are composed of
  - *Protons*
  - *Neutrons*
  - *Electrons*
- Chemical Transformations
  - Move atoms around
  - Rearrange electrons
  - Do not affect nuclear properties



Atomic Structure and Chemistry

- Nuclear Properties define Element
  - *Atomic number* (*Z*)
  - *Mass number* (*A*)
- Properties of Atom/Element shown in Elemental Symbol (X)
  - *Z* defines element, so often omitted

$$^{A}_{Z}\mathrm{X}$$

Atomic Structure and Chemistry

- *Atomic Mass*
  - Not shown in elemental symbol
  - Mass of single atom of the element in <u>amu</u>
  - 1 amu = 1/12 mass of a carbon atom with 6 protons and 6 neutrons = 1.661×10^{-24} g
- Atomic Mass and *A* are <u>not</u> same
  - N atom with 7 protons and 7 neutrons, atomic mass = 14.0031 amu, *A* = 14
  - *Mass defect* and *nuclear binding energy*

Ions

- Formed when Atoms gain/lose Electrons
  - Lose electrons, positive charge, *cations*
  - Gain electrons, negative charge, *anions*
  - *Z* and *A* do not change
  - Valence vs. core electrons
- Ion’s Charge indicated as Superscript to right of Elemental Symbol (Number first)
  - Charge = number of electrons gained/lost
  - Examples: H^+, P^{3-}, Mn^{2+}, Cl^-

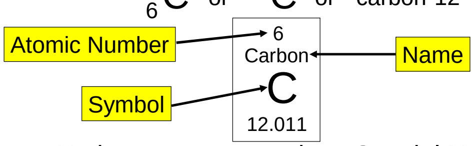
Isotopes

- Atoms of same Element with different Mass Numbers
  - *Z* is same
  - Chemistry is the same
  - Different number of neutrons
  - Atomic masses also different
- Physical and Chemical Properties related to Mass will be Different
  - May be too small to measure

Isotopes

- Isotopes are designated as follows:

$${}^{12}_{6}\mathrm{C} \quad \text{or} \quad {}^{12}\mathrm{C} \quad \text{or} \quad \text{carbon-12}$$



- Hydrogen Isotopes given Special Names
  - Protium: ${}^{1}_{1}H$
  - Deuterium: ${}^{2}_{1}H$
  - Tritium: ${}^{3}_{1}H$

Practice

Isotope Symbol	*Z*	*A*	# Protons	Electrons	# Neutrons	Name of Isotope

Isotopic Abundance

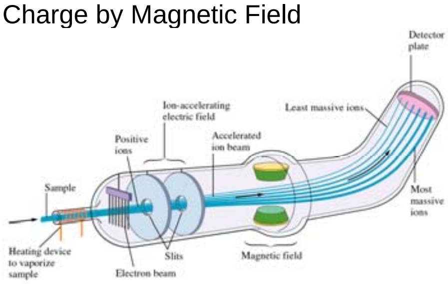
- *Percent Abundance*
  - Percentage of a given isotope in a sample

$$\% \text{ Abundance} = \left(\frac{\text{number of atoms of an isotope}}{\text{total number of atoms of the element}}\right) x100$$

- *Natural Abundance*
  - % Abundance of an isotope on earth
  - Relationship to nuclear stability
  - *Enriched* and *depleted*

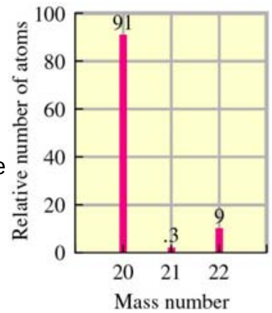
Mass Spectrometer

- Ionized Sample separated by Mass and Charge by Magnetic Field



Mass Spectrometry

- Number of Particles hitting Detector with certain *m*/*Z* depends on Number in Sample
  - Measure % abundance
  - Identify elements
- Example: Ne
  - Note x axis



Atomic Weight

- Average Mass of Element or Mass of Average Atom of an Element
  - Sum of masses of each isotope times its fractional natural abundance
  - *Apparent atomic weight*

Watch out!
- *Atomic mass* = mass of one atom or average atom
- *Isotopic mass* = mass of one atom of an isotope
- *Exact mass* ≈ isotopic mass (for molecules)
- *Atomic weight* = mass of an average atom

Atomic Weight

- Have 10 Coins; 6 weigh 15 g and 4 weigh 10 g. What is the average mass?

$$\text{average mass} = \frac{(6 \times 15\text{ g}) + (4 \times 10\text{ g})}{6+4} = 13.\text{ g}$$

or $$\text{average mass} = \left(\frac{6}{10}\right)(15\text{ g}) + \left(\frac{4}{10}\right)(10\text{ g})$$

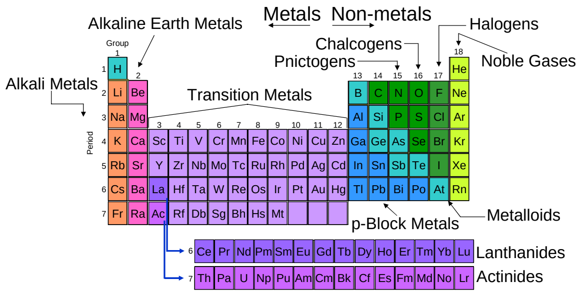
or $$\text{average mass} = (0.6)(15\text{ g}) + (0.4)(10\text{ g})$$

The average mass is the mass of the different coins times fraction of coins with that mass!

Calculating Atomic Weights

- Copper has two isotopes: ^{63}Cu (isotopic mass 62.9296 amu) at 69.20% natural abundance, and ^{65}Cu (isotopic mass 64.9278 amu). What is the atomic weight of Cu?

Periodic Table of the Elements



Special Notes on Elements

- Some Elements exist as Diatomic *Molecules* under Standard Conditions
  - H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2
- *Allotropes/Phases*
  - Forms of an element that have different arrangement of atoms in space
  - *Allotrope* usually molecular species of non-metals
  - *Phase* for metals (and for compounds)

Descriptive Chemistry of the Elements

- Metals form these monatomic Cations
  - Group 1: +1 (always)
  - Group 2: +2 (always)
  - Groups 3-10: variable, +2 and +3 common
  - Group 11: Cu +1/+2; Ag +1; Au +1/+3
  - Group 12: +2, Hg "+1"
  - Group 13: +3/+1 for In, Tl (Ga)
  - Group 14: Sn and Pb +2/"+4"
  - Group 15: Bi +3/"+5"

Descriptive Chemistry of the Elements

- Non-Metals form these monatomic Anions
  - Group 14: "-4"
  - Group 15: "-3"
  - Group 16: -2
  - Group 17: -1
  - Group 18: anions are not stable
- Metalloids are just plain weird
- Hydrogen forms +1 and -1 Ions

Compounds

- Pure Substances consisting of Elements united in fixed Ratios
  - Have definite physical & chemical properties
- *Molecular Compounds*
  - Exist as molecules (atom groups)
  - Physical transformations do not break up molecules!
- *Ionic Compounds*
  - Exist as ordered array of cations and anions
  - Physical transformations disrupt structure

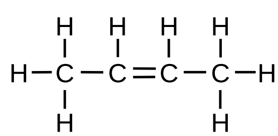
The Chemical Formula

- Identifies which Elements are present
  - Ratio of each element
  - Can be number of atoms of each element in molecule
- Metals placed First by Group, then Non-metals
  - Metals in same group are alphabetical
- For (Binary) Compounds of Non-metals
  - Rn, Xe, Kr, B, Si, C, Sb, As, P, N, H, Te, Se, S, At, I, Br, Cl, O, F

Chemical Formulas of Molecular Compounds

- Can write in Several Ways
  - *Molecular formula* (e.g., C_4H_8)
  - *Empirical formula* (e. g., CH_2)
  - *Structural formula*

$CH_3CHCHCH_3$



Chemical Formulas of Ionic Compounds

- Ionic Compounds do not exist as discrete Units, so
  - Define *formula unit* as simplest, neutral combination of cation and anion
  - Example: simplest, neutral combination of Ca^{2+} and Cl^- ions is $CaCl_2$
  - Formula unit does <u>not</u> represent the arrangement of the ions in the solid
  - Empirical formula and formula unit

Nomenclature and Conventions for Monatomic Ions

- Monatomic Anions Named as follows
  - Cl^-: *chlor-* + *-ide* = chloride ion
- Cation Name same as Element's if only one Ion formed
  - Examples: Groups 1, 2, Zn^{2+}, Cd^{2+} and Al^{3+}
  - Ca^{2+}: calcium ion
- All other Monatomic Cations named for Element, Specifying Charge
  - Fe^{3+}: iron(III) ion = "iron three ion"

Nomenclature and Conventions for Monatomic Ions

- Older Method: if two Cations exist, then One with the Higher Charge has *-ic* Suffix, the One with the Lower Charge has *-ous* Suffix added to Root
  - Fe^{3+}: ferric ion
  - Fe^{2+}: ferrous ion
  - Cu^{+}: cuprous ion
  - Cu^{2+}: cupric ion

Polyatomic Ions

- Groupings of Atoms with a Charge
  - Groupings held together like molecules
  - Form compounds with ionic bonds
  - Number of electrons gives an overall charge (related to bonding within ion)
- Handout of Common Polyatomic Ions
  - Learn nomenclature conventions
  - Memorize names, formulas and charges

Naming Ionic Compounds

- Ionic Compounds are Named with Cation First, then Anion
- First Determine whether Compound is Ionic
  - Look for metals and polyatomic ions
- Examples

NaCl	sodium chloride
$Fe(OH)_3$	iron(III) hydroxide (ferric hydroxide)
$(NH_4)_2SO_4$	ammonium sulfate
$AlPO_4$	aluminum phosphate

Naming Ionic Compounds

- Because Charge on Ions are known *usually* no need to specify the Number of each Ion
- To go from Name to Formula

ammonium hydrogenphosphate

NH_4^+ HPO_4^{2-} $\Rightarrow$ $(NH_4)_2(HPO_4)$

vanadium(III) oxide

V^{3+} O^{2-} $\Rightarrow$ V_2O_3

Watch out mercury(I) = Hg_2^{2+} and mercury(II) = Hg^{2+}!

Naming Molecular Compounds

- Look for Absence of a Metal or Common Polyatomic Ion
- *Usually* Named in Order that Element appears in Molecular Formula
- Specify Number of Each Element using Prefixes

mono- = one	*penta-* = five
di- = two	*hexa-* = six
tri- = three	*hepta-* = seven
tetra- = four	*octa-* = eight

Naming Molecular Compounds

- Examples:
  - HCl
  - NI_3
  - NO
  - N_2O
- Organic (Carbon-containing) Molecular Compounds and more complex Inorganics have their own Conventions