Chapter 2 Atoms and Elements

Early Philosophy of Matter

- Some philosophers believed that matter had an ultimate, tiny, indivisible particle
  - ✓ Leucippus and Democritus
- Other philosophers believed that matter was infinitely divisible
  - ✓ Plato and Aristotle
- Since there was no experimental way of proving who was correct, the best debater was the person assumed correct, i.e., Aristotle

Scientific Revolution

- in the late 16th century, the scientific approach to understanding nature became established
- for the next 150+ years, observations about nature were made that could not easily be explained by the infinitely divisible matter concept

Reaction of Sodium with Chlorine to Make Sodium Chloride

- the mass of sodium and chlorine used is determined by the number of atoms that combine
- since only whole atoms combine and atoms are not changed or destroyed in the process, the mass of sodium chloride made must equal the total mass of sodium and chlorine atoms that combine together

7.7 g Na + 11.9 g Cl_2 → 19.6 g NaCl

Proportions in Sodium Chloride

a 100.0 g sample of sodium chloride contains 39.3 g of sodium and 60.7 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{60.7\text{ g}}{39.3\text{ g}} = 1.54$$

a 200.0 g sample of sodium chloride contains 78.6 g of sodium and 121.4 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{121.4\text{ g}}{78.6\text{ g}} = 1.54$$

a 58.44 g sample of sodium chloride contains 22.99 g of sodium and 35.44 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{35.44\text{ g}}{22.99\text{ g}} = 1.541$$

Oxides of Carbon

- carbon combines with oxygen to form two different compounds, carbon monoxide and carbon dioxide
- carbon monoxide contains 1.33 g of oxygen for every 1.00 g of carbon
- carbon dioxide contains 2.67 g of oxygen for every 1.00 g of carbon
- since there are twice as many oxygen atoms per carbon atom in carbon dioxide than in carbon monoxide, the oxygen mass ratio should be 2

$$\frac{\text{mass of oxygen that combines with 1 g of carbon in carbon dioxide}}{\text{mass of oxygen that combines with 1 g of carbon in carbon monoxide}} = \frac{2.67\text{ g}}{1.33\text{ g}} = 2$$

CHEMICAL LAWS – LECTURE QUESTIONS

LAW OF CONSERVATION OF MASS

A 7.12 g sample of magnesium is heated with 1.80 g of bromine. All the bromine is used up, and 2.07 g of magnesium bromide is produced. What mass of magnesium remains unreacted?

Law of Definite Proportions

A 0.100 g sample of magnesium, when combined with oxygen, yields 0.166 g of magnesium oxide. What masses of magnesium and oxygen must be combined to make exactly 2.00 g of magnesium oxide?

Law of Multiple Proportions

The following data were obtained for compounds of iodine and fluorine:

Compound	Mass of Iodine (g)	Mass of Fluorine (g)
A	1.000	0.1497
B	0.500	0.2246
C	0.750	0.5614
D	1.000	1.0480

If the formula for compound A is IF, what are the formulas for compounds B, C, and D?

Workshop 2A on CHEMICAL LAWS

LAW OF CONSERVATION OF MASS

When 10.00 g of marble chips, calcium carbonate, are treated with50.0 mL of hydrochloric acid (d = 1.096 g/mL), the marble chips dissolve resulting in a solution and releasing the gas carbon dioxide. The final solution weighed 60.4 g. How many liters of carbon dioxide was released if the density of the gas is 1.798 g/L?

Law of Definite Proportions

Galena, a mineral of lead and sulfur contained 2.030 g of lead in a 2.345 g sample. (a) calculate the mass of sulfur in the sample. (b) calculate the mass fraction of lead. © calculate the mass percent of lead. (d) How much reactant is needed to produce 15.000 g of product, galena?

Combined Laws

Aluminum metal reacts with bromine, a red-brown liquid with a noxious odor. The reaction is vigorous and produces aluminum bromide, a white crystalline material. A sample of 27.062 g of aluminum yields 266.705 g of aluminum bromide. How many grams of bromine will react with 15.00 g of Al?

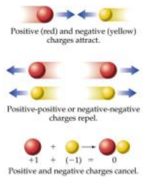
Dalton's Atomic Theory

- Dalton proposed a theory of matter based on it having ultimate, indivisible particles to explain these laws

1) Each element is composed of tiny, indestructible particles called atoms
2) All atoms of a given element has the same mass and other properties that distinguish them from atoms of other elements
3) Atoms combine in simple, whole-number ratios to form molecules of compounds
4) In a chemical reaction, atoms of one element cannot change into atoms of another element
   - ✓ they simply rearrange the way they are attached

Some Notes on Charge

- Two kinds of charge called + and –
- Opposite charges attract
  - ✓ + attracted to –
- Like charges repel
  - ✓ + repels +
  - ✓ – repels –
- To be neutral, something must have no charge or equal amounts of opposite charges



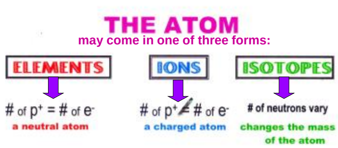
Radioactivity

- in the late 1800s, Henri Becquerel and Marie Curie discovered that certain elements would constantly emit small, energetic particles and rays
- these energetic particles could penetrate matter
- Ernest Rutherford discovered that there were three different kinds of emissions
  - ✓ alpha, α, particles with a mass 4x H atom and + charge
  - ✓ beta, β, particles with a mass ~1/2000th H atom and – charge
  - ✓ gamma, γ, rays that are energy rays, not particles

ATOMIC THEORY OF MATTER

Table of the subatomic particles in an atom

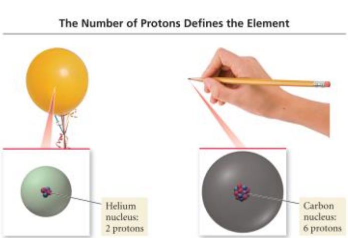
	symbol	charge	Mass
Proton	p or p+	+1	1 amu
Electron	e-	-1	$^{1}/_{1837}$ amu
Neutron	n	0	1 amu



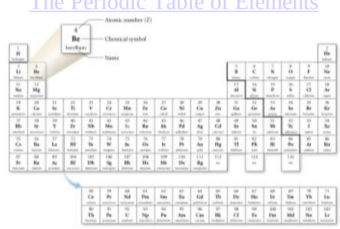
Subatomic Particle	Mass g	Mass amu	Location in atom	Charge	Symbol
Proton	1.67262 x 10^{-24}	1.00727	nucleus	+1	p, p^+, H^+
Electron	0.00091 x 10^{-24}	0.00055	empty space	-1	e, e^-
Neutron	1.67493 x 10^{-24}	1.00866	nucleus	0	n, n^0

Elements

- each element has a unique number of protons in its nucleus
- the number of protons in the nucleus of an atom is called the **atomic number**
  - ✓ the elements are arranged on the Periodic Table in order of their atomic numbers
- each element has a unique name and symbol
  - ✓ symbol either one or two letters
    - ➢ one capital letter or one capital letter + one lowercase



The Periodic Table of Elements



Structure of the Nucleus

- Soddy discovered that the same element could have atoms with different masses, which he called **isotopes**
  - ✓ there are 2 isotopes of chlorine found in nature, one that has a mass of about 35 amu and another that weighs about 37 amu
- The observed mass is a weighted average of the weights of all the naturally occurring atoms
  - ✓ the percentage of an element that is 1 isotope is called the isotope's **natural abundance**
  - ✓ the atomic mass of chlorine is 35.45 amu

Isotopes

- all isotopes of an element are chemically identical
  - ✓undergo the exact same chemical reactions
- all isotopes of an element have the same number of protons
- isotopes of an element have different masses
- isotopes of an element have different numbers of neutrons
- isotopes are identified by their **mass numbers**
  - ✓protons + neutrons

Isotopes

- Atomic Number
  - ✓Number of protons
  - ✓Z
- Mass Number
  - ✓Protons + Neutrons
  - ✓Whole number
  - ✓A
- Abundance = relative amount found in a sample

Neon

Symbol	Number of Protons	Number of Neutrons	A, Mass Number	Percent Natural Abundance
Ne-20 or $^{20}_{10}Ne$	10	10	20	90.48%
Ne-21 or $^{21}_{10}Ne$	10	11	21	0.27%
Ne-22 or $^{22}_{10}Ne$	10	12	22	9.25%

Practice Problems for isotopes

Complete the following table:

Symbol	Atomic #	Charge	Mass number	# of proton	# of neutrons	# of electrons
H	1	0	3	1	2	1
Li	3	0	10	3	7	2
Al	13	0	27	13	14	13
Ni	28	+2	58	28	30	26
Pt	78	+4	198	78	120	74

Atomic Mass

17 Cl 35.45 Chlorine

- we previously learned that not all atoms of an element have the same mass
  - ✓isotopes
- we generally use the average mass of all an element's atoms found in a sample in calculations
  - ✓however the average must take into account the abundance of each isotope in the sample
- we call the average mass the **atomic mass**

$$\text{Atomic Mass} = \sum (\text{fractional abundance of isotope})_n \times (\text{mass of isotope})_n$$

Lecture Questions on Isotopes

A T O M I C M A S S

1. An element consists of 90.51% of an isotope with a mass of 19.992 amu, 0.27% of an isotope with a mass of 20.994 amu, and 9.22% of an isotope with a mass of 21.990 amu. Calculate the average atomic mass and identify the element.

2. The average atomic weight of lithium is 6.941 amu. The two naturally occurring isotopes of lithium have the following masses: ^{6}Li, 6.01512 amu; ^{7}Li, 7.01600 amu. Calculate the percent abundance of ^{6}Li and ^{7}Li in naturally occurring lithium.

WORKSHOP 2B on Isotopes

1. The element with an atomic number 53 contains many protons, neutrons, and electrons?

2. The mass of one atom of an isotope is 9.746×10^{-23} g. One atomic mass unit has the mass of 1.6606×10^{-24} g. The atomic mass of this isotope is?

3. (Element X has three naturally occurring isotopes, 24X (isotopic mass 23.9850 amu, abundance 78.99%), 25X (isotopic mass 24.9858 amu, abundance 10.00%), and 26X (isotopic mass 25.9826 amu, abundance 11.01%). Calculate the average atomic mass.

4. The element silver has two naturally occurring isotopes: ^{109}Ag and ^{107}Ag with a mass of 106.905 amu. Silver consists of 51.82% ^{107}Ag and has an average atomic mass of 107.868 amu. Calculate the mass of ^{109}Ag.

Reacting Atoms

- when elements undergo chemical reactions, the reacting elements do not turn into other elements
  - ✓Statement 4 of Dalton's Atomic Theory
- this requires that all the atoms present when you start the reaction will still be there after the reaction
- since the number of protons determines the kind of element, the number of protons in the atom does not change in a chemical reaction
- however, many reactions involve transferring electrons from one atom to another

Charged Atoms

- when atoms gain or lose electrons, they acquire a charge
- charged particles are called **ions**
- when atoms gain electrons, they become negatively charged ions, called **anions**
- when atoms lose electrons, they become positively charged ions, called **cations**
- ions behave much differently than the neutral atom
  - ✓e.g., The metal sodium, made of neutral Na atoms, is highly reactive and quite unstable. However, the sodium cations, Na^{+}, found in table salt are very nonreactive and stable
- since materials like table salt are neutral, there must be equal amounts of charge from cations and anions in them

Atomic Structures of Ions

- Nonmetals form anions
- For each negative charge, the ion has 1 more electron than the neutral atom
  - ✓ F = 9 p^+ and 9 e^-, F^- = 9 p^+ and 10 e^-
  - ✓ P = 15 p^+ and 15 e^-, P^{3-} = 15 p^+ and 18 e^-
- Anions are named by changing the ending of the name to ***-ide***

fluorine	$F + 1e^- \rightarrow F^-$	fluoride ion
oxygen	$O + 2e^- \rightarrow O^{2-}$	oxide ion

Atomic Structures of Ions

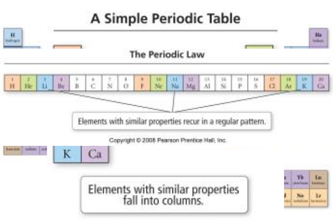
- Metals form cations
- For each positive charge, the ion has 1 less electron than the neutral atom
  - ✓Na atom = 11 p^+ and 11 e^-, Na^+ ion = 11 p^+ and 10 e^-
  - ✓Ca atom = 20 p^+ and 20 e^-, Ca^{2+} ion = 20 p^+ and 18 e^-
- Cations are named the same as the metal

sodium	$Na \rightarrow Na^+ + 1e^-$	sodium ion
calcium	$Ca \rightarrow Ca^{2+} + 2e^-$	calcium ion

Mendeleev

- order elements by atomic mass
- saw a repeating pattern of properties
- **Periodic Law** – When the elements are arranged in order of increasing atomic mass, certain sets of properties recur periodically
- put elements with similar properties in the same column
- used pattern to predict properties of undiscovered elements
- where atomic mass order did not fit other properties, he re-ordered by other properties
  - ✓Te & I

Periodic Pattern

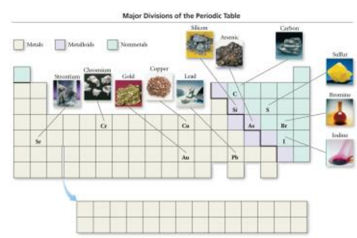


Periodic Pattern

nm H_2O a/b **H** 1 H_2						
m Li_2O **Li** b 7 LiH	m/nm BeO **Be** a/b 9 BeH_2	nm B_2O_3 **B** a 11 $(BH_3)_n$	nm CO_2 **C** a 12 CH_4	nm N_2O_5 **N** a 14 NH_3	nm O_2 **O** 16 H_2O	nm **F** 19 HF
m Na_2O **Na** b 23 NaH	m MgO **Mg** b 24 MgH_2	m Al_2O_3 **Al** a/b 27 (AlH_3)	nm/m SiO_2 **Si** a 28 SiH_4	nm P_4O_{10} **P** a 31 PH_3	nm SO_3 **S** a 32 H_2S	nm Cl_2O_7 **Cl** a 35.5 HCl

m = metal, nm = nonmetal, m/nm = metalloid

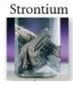
a = acidic oxide, b = basic oxide, a/b = amphoteric oxide



Metals

- solids at room temperature, except Hg
- reflective surface
  - ✓shiny
- conduct heat
- conduct electricity
- malleable
  - ✓can be shaped
- ductile
  - ✓drawn or pulled into wires
- lose electrons and form cations in reactions
- about 75% of the elements are metals
- lower left on the table

Strontium

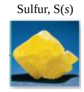


Copper

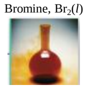
Nonmetals

- found in all 3 states
- poor conductors of heat
- poor conductors of electricity
- solids are brittle
- gain electrons in reactions to become anions
- upper right on the table
  - ✓except H

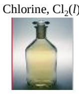
Sulfur, S(*s*)



Bromine, Br_2(*l*)



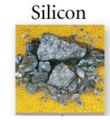
Chlorine, Cl_2(*l*)



Metalloids

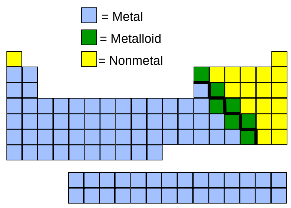
- show some properties of metals and some of nonmetals
- also known as semiconductors

Silicon



Properties of Silicon
shiny
conducts electricity
does not conduct heat well
brittle

Patterns in Metallic Character

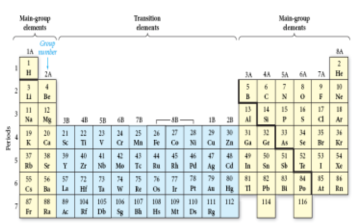


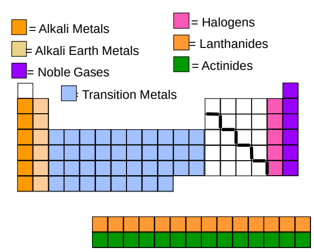
The Modern Periodic Table

- Elements with similar chemical and physical properties are in the same column
- columns are called **Groups** or **Families**
  - ✓designated by a number and letter at top
- rows are called **Periods**
- each period shows the pattern of properties repeated in the next period

The Modern Periodic Table

- Main Group = Representative Elements = “A” groups
- Transition Elements = “B” groups
  - ✓all metals
- Bottom Rows = Inner Transition Elements = Rare Earth Elements
  - ✓metals
  - ✓really belong in Period 6 & 7





Important Groups - Hydrogen

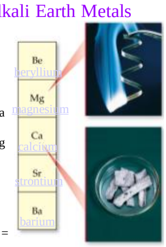
- nonmetal
- colorless, diatomic gas
  - ✓very low melting point and density
- reacts with nonmetals to form molecular compounds
  - ✓HCl is acidic gas
  - ✓H_2O is a liquid
- reacts with metals to form hydrides
  - ✓metal hydrides react with water to form H_2
- HX dissolves in water to form acids

Important Groups - Alkali Metals

- Group IA = Alkali Metals
- hydrogen usually placed here, though it doesn’t belong
- soft, low melting points, low density
- flame tests → Li = red, Na = yellow, K = violet
- very reactive, never find uncombined in nature
- tend to form water-soluble compounds, therefore crystallized from seawater then molten salt electrolyzed
  - ➢colorless solutions
- react with water to form basic (alkaline) solutions and H_2
  - **$2 Na + 2 H_2O \rightarrow 2 NaOH + H_2$**
  - ➢**releases a lot of heat**

Important Groups - Alkali Earth Metals

- Group IIA = Alkali Earth Metals
- harder, higher melting, and denser than alkali metals
  - ✓Mg alloys used as structural materials
- flame tests → Ca = red, Sr = red, Ba = yellow-green
- reactive, but less than corresponding alkali metal
- form stable, insoluble oxides from which they are normally extracted
- oxides are basic = alkaline earth
- reactivity with water to form H_2 → Be = none; Mg = steam; Ca, Sr, Ba = cold water

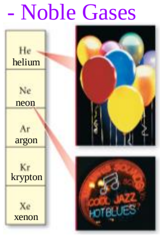


Important Groups - Halogens

- Group VIIA = Halogens
- nonmetals
- F_2 and Cl_2 gases; Br_2 liquid; I_2 solid
- all diatomic
- very reactive
- Cl_2, Br_2 react slowly with water
  - $Br_2 + H_2O \rightarrow HBr + HOBr$
- react with metals to form ionic compounds
- HX all acids
  - ✓HF weak < HCl < HBr < HI

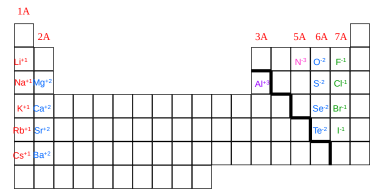
Important Groups - Noble Gases

- Group VIIIA = Noble Gases
- all gases at room temperature
  - ✓ very low melting and boiling points
- very unreactive, practically inert
- very hard to remove electron from or give an electron to



Ion Charge and the Periodic Table

- the charge on an ion can often be determined from an element's position on the Periodic Table
- metals are always positively charged ions, nonmetals are negatively charged ions
- for many main group metals, the charge = the group number
- for nonmetals, the charge = the group number - 8

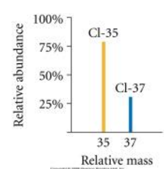


Mass Spectrometry

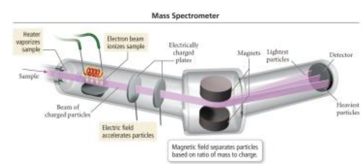
- masses and abundances of isotopes are measured with a **mass spectrometer**
- atoms or molecules are ionized, then accelerated down a tube
  - ✓ some molecules into fragments are broken during the ionization process
  - ✓ these fragments can be used to help determine the structure of the molecule
- their path is bent by a magnetic field, separating them by mass
  - ✓ similar to Thomson's Cathode Ray Experiment

Mass Spectrum

- a mass spectrum is a graph that gives the relative mass and relative abundance of each particle
- relative mass of the particle is plotted in the *x*-axis
- relative abundance of the particle is plotted in the *y*-axis



Mass Spectrometer



Counting Atoms by Moles

- If we can find the mass of a particular number of atoms, we can use this information to convert the mass of an element sample into the number of atoms in the sample.
- The number of atoms we will use is 6.022 x 10^{23} and we call this a **mole**
  - ✓ 1 mole = 6.022 x 10^{23} things
    - ➢ Like 1 dozen = 12 things

Chemical Packages - Moles

- mole = number of particles equal to the number of atoms in 12 g of C-12
  - ✓ 1 atom of C-12 weighs exactly 12 amu
  - ✓ 1 mole of C-12 weighs exactly 12 g
- The number of particles in 1 mole is called **Avogadro's Number = 6.0221421 x 10^{23}**
  - ✓ 1 mole of C atoms weighs 12.01 g and has 6.022 x 10^{23} atoms
    - ➢ the average mass of a C atom is 12.01 amu

Relationship Between Moles and Mass

- The mass of one mole of atoms is called the **molar mass**
- The molar mass of an element, in grams, is numerically equal to the element's atomic mass, in amu
- The lighter the atom, the less a mole weighs
- The lighter the atom, the more atoms there are in 1 g

Mole and Mass Relationships

Substance	*Weight of 1 atom*	*Pieces in 1 mole*	*Weight of 1 mole*
hydrogen	1.008 amu	6.022×10^{23} atoms	1.008 g
carbon	12.01 amu	6.022×10^{23} atoms	12.01 g
oxygen	16.00 amu	6.022×10^{23} atoms	16.00 g
sulfur	32.06 amu	6.022×10^{23} atoms	32.06 g
calcium	40.08 amu	6.022×10^{23} atoms	40.08 g
chlorine	35.45 amu	6.022×10^{23} atoms	35.45 g
copper	63.55 amu	6.022×10^{23} atoms	63.55 g

1 mole sulfur 32.06 g

1 mole carbon 12.01 g

Workshop 2C on the Periodic Table

1. Which of the following statements concerning the element iodine is <u>not correct</u>?
   - a) **Iodine gives up electrons readily**
   - b) **Iodine is in the fifth period of the periodic table**
   - c) **Iodine has chemical properties similar to those of chlorine**
   - d) **Iodine is a halogen**
   - e) **One molecule of iodine contains two atoms**

2. With respect to location in the periodic table, metals are on the _____, nonmetals on the________ and the two are separated by the ______.

3. The molar mass of sodium is_______________, of phosphorous is __________, of oxygen is _________. What is the molar mass of sodium phosphate?

4. If one (1) atom of an element weighs $2.0 \times 10^{-2}3$ grams, what is the symbol for that element?

5. Which has the LEAST mass:
   - a) 0.19 moles of CaCO3
   - b) 6.12×10^{22} formula units of Fe2O3
   - c) 1 mole of oxygen molecules
   - d) 15.9 moles of hydrogen molecules
   - e) 5.0 moles of helium gas

6. List the most common ion for the first 20 elements.

Experiment 2: Measurements

- Density & specific gravity are related
- Library Skills: computer vs books, variation of terms: look up density or metals as headers in index. More than one way to reach a topic.
- When using books, units can be used to list information.
- Elements vs alloys with metals, inorganic vs organic, aqueous, salt.

Experiment 2: Measurements

- Goggles, calculators, lab notebooks, closed toes shoes, appropriate clothes needed every day for the rest of semester.
- Clean aisles, use shelves for coats, computers, books, backpacks, purses, etc. uncluttered desks for experimentation.
- No food or drinks in lab
- Clean all equipment after use, return to proper place, keep “shared” items in front NOT at your workstation.

Experiment 2: Measurements

- More Precise? Buret vs graduated cylinder
- Reading calipers
- Timing! You will have limited time to complete labs SO perform the experiment first then start calculations
- Use lab notebook for EVERYDAY notes then the report sheet is filled out at home neatly, in ink, pristine.
- Pre-read experiment & know what, why, and how.
- Do not follow directions blindly, contemplate why you are doing said action, adjust to variables
- No lined white paper, carbon-copies only. Detailed for final
- Discuss with classmates.