CHP 3 The Structure of Matter and the Chemical Elements

A branch of science that deals with the composition, structure, properties and reactions (transformations) of matter.

DESCRIPTION OF MATTER

(anything that has mass and occupies space)

Substances that are visible and invisible

Substances that are living and nonliving

Matter doesn't include energy, in its various forms

(E.g., heat, light, electricity)

All transformations of matter involve energy changes. Chemist are interested in the energy changes that occur when matter is transformed.

States of Matter (p. 76)

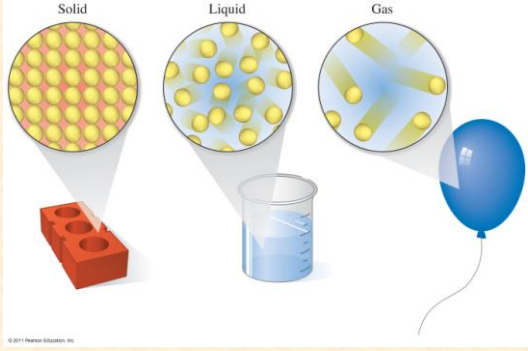
Three states of matter exist

I. Solid

II. Liquid

III. Gas

3.1 "Stuff" Is Matter, Continued



3.1 Solids, Liquids and Gases

States of Matter

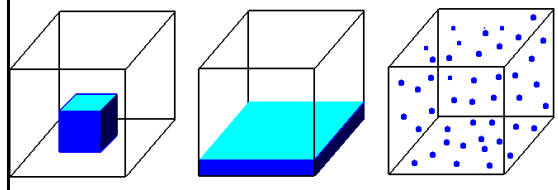
- Common states of matter are solid, liquid, or gas.
- A ***solid*** has a definite shape and volume. Particles in a solid are tightly packed.
- A ***liquid*** has a definite volume, but its shape changes depending on the container it is in. Particles in a liquid are less orderly and move about freely.
- A ***gas*** has no definite volume or shape. Particles in a gas are disordered and rapidly moving.

PROPERTIES OF THE PHASES OF MATTER

	SOLIDS	LIQUIDS	GASES
SHAPE	Definite – independent of container	Indefinite dependent on container	Indefinite dependent on container
VOLUME	Definite- independent on container	Definite- dependent on container	Indefinite dependent on container

States of Matter

Glenn Research Center

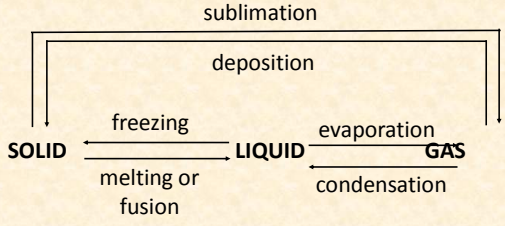


Solid	Liquid	Gas
Holds Shape	Shape of Container	Shape of Container
Fixed Volume	Free Surface	Volume of Container
	Fixed Volume	

PROPERTIES OF THE PHASES OF MATTER

	SOLIDS	LIQUIDS	GASES
Temperature	LOW T	HIGHER T	HIGHEST T

Physical Change



3.2 The Chemical Elements

Classification of Matter

Matter

Mixture
Variable Composition

- **Mixtures** = different samples may have the same pieces in different percentages. Two or more pure substances.
  - salt water

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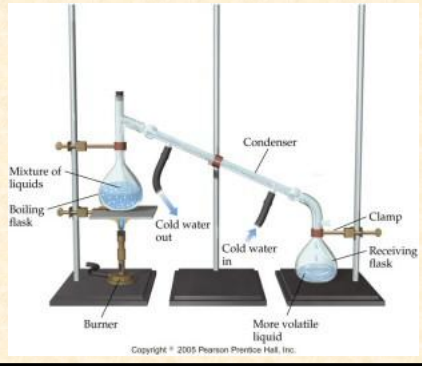
Distillation



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Classification of Matter

Matter

Mixture
Variable Composition

Pure Substance
Constant Composition

- **Pure Substance** = all samples are made of the same atoms or molecules in the same percentages
  - Salt ((NaCl) → Sodium and Chlorine
  - Water (H_2O) → Hydrogen and Oxygen

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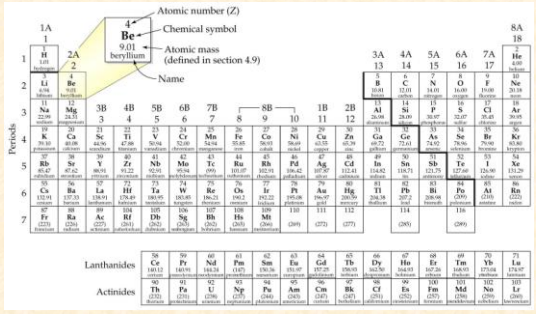
Elements

- each element has a unique name and symbol
- Hydrogen – H
- Oxygen – O
- Sodium – Na
- Chlorine – Cl
- There are 116 known elements
- Know the names and symbols of the first 36 elements + Ba, Au, Ag, I, Pb, Sn, Hg, Cd, Pt, Sr, U, Xe

3.3 The Periodic Table of Elements



3.3 Mendeleev and the Periodic Law

- order elements by atomic mass
- saw a repeating pattern of properties
- **Periodic Law** – When the elements are arranged in order of increasing relative mass, certain sets of properties recur periodically
- used pattern to predict properties of undiscovered elements

Periodic Pattern

nm H_2O a/b
H
1 H_2

m Li_2O b	m/nm BeO a/b	nm B_2O_3 a	nm CO_2 a	nm N_2O_5 a	nm O_2	nm OF_2
Li	Be	B	C	N	O	F
7 LiH	9 BeH_2	11 $(BH_3)_n$	12 CH_4	14 NH_3	16 H_2O	19 HF

Periodic Pattern

nm H_2O a/b
H
1 H_2

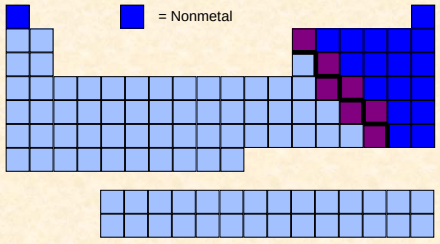
m Li_2O b	m/nm BeO a/b	nm B_2O_3 a	nm CO_2 a	nm N_2O_5 a	nm O_2	nm OF_2
Li	Be	B	C	N	O	F
7 LiH	9 BeH_2	11 $(BH_3)_n$	12 CH_4	14 NH_3	16 H_2O	19 HF
m Na_2O b	m MgO b	m Al_2O_3 a/b	nm/m SiO_2 a	nm P_4O_{10} a	nm SO_3 a	nm Cl_2O_7 a
Na	Mg	Al	Si	P	S	Cl
23 NaH	24 MgH_2	27 (AlH_3)	28 SiH_4	31 PH_3	32 H_2S	35.5 HCl

Mendeleev's Predictions for Ekasilicon (Germanium)

Property	*Silicon's Props*	*Tin's Props*	*Predicted Value*	*Measured Value*
Atomic Mass	28	118	72	72.6
Color	Grey	White metal	Grey	Grey-White
Density	2.32	7.28	5.5	5.4
Reaction w/ Acid & Base	Resists Acid, Reacts Base	Reacts Acid, Resists Base	Resists Both	Resists Both
Oxide	SiO_2	SnO_2	Eks_1O_2	GeO_2

Periodicity

= Metal
= Metalloid
= Nonmetal



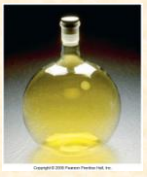
PerTable Movie

Metals

- solids at room temperature, except Hg
- shiny
- conduct heat
- conduct electricity
- malleable
- ductile
- about 75% of the elements are metals
- lower left on the table

Nonmetals

- found in all 3 states
- poor conductors of heat
- poor conductors of electricity
- solids are brittle
- upper right on the table



Metalloids

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

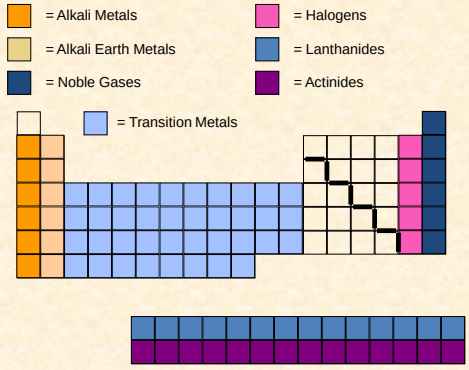
Properties of Silicon
shiny
conducts electricity
does not conduct heat well
brittle

The Modern Periodic Table

- Elements with similar chemical and physical properties are in the same column (**Groups** or **Families)**
- Rows are called **Periods**

The Modern Periodic Table

- Main Group = Representative Elements = 'A' groups
- Transition Elements = 'B' groups
- Bottom rows = Inner Transition Elements = Rare Earth Elements



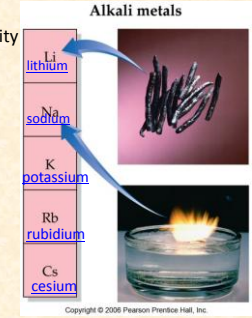
Important Groups - Hydrogen

- nonmetal
- colorless, diatomic gas
- reacts with nonmetals to form molecular compounds
- reacts with metals to form hydrides
- Many compounds form acids in water

Important Groups – IA, Alkali Metals

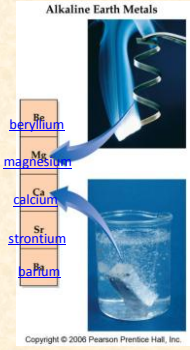
- hydrogen doesn't belong
- soft, low melting points,low density
- very reactive, never find uncombined in nature
- tend to form water soluble compounds
- react with water to form basic (alkaline) solutions and H_2

Alkali metals and water



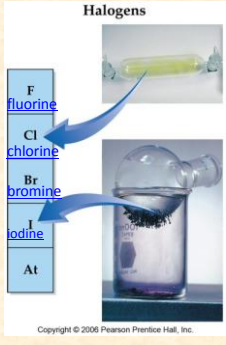
Important Groups – IIA, Alkali Earth Metals

- harder, higher melting, and denser than alkali metals
- reactive, but less than corresponding alkali metal
- form stable, insoluble oxides
- oxides are basic
- react with water to form H_2



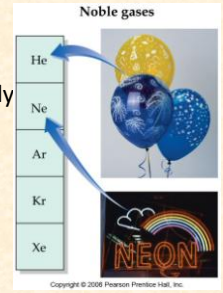
Important Groups – VIIA, Halogens

- nonmetals
- very reactive
- Cl_2, Br_2 react slowly with water
- react with metals to form ionic compounds
- Forms acid when combined with hydrogen
  - HF weak < HCl < HBr < HI



Important Groups – VIIIA, Noble Gases

- all gases at room temperature,
- very unreactive, practically inert



3.4 The Structure of the Elements

Atoms

- Smallest piece of an element is called an **atom**

- Infinitely Divisible
  - for any two points there is always a point between
- Ultimate Particle
  - upon division eventually a particle is reached which can no longer be divided

"Nothing exists except atoms and empty space; everything else is opinion." - Democritus 460–370 B.C.

Dalton's Atomic Theory

1. Elements are composed of atoms
   - tiny, hard, unbreakable, spheres
2. All atoms of an element are identical
3. Atoms combine in simple, whole-number ratios to form molecules of compounds
   - Law of Constant Composition
   - Chemical Formulas

John Dalton
(1766-1844)

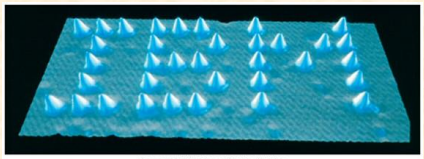
Dalton's Atomic Theory

4. In chemical reactions, atoms are not broken or changed into another type.
   - atoms are not created or destroyed, just rearranged
     - Law of Conservation of Mass

Sizes of Atoms

- using compositions of compounds and assumed formulas, Dalton was able to determine the **relative** masses of the atoms
  - Dalton based his scale on H = 1 amu
  - unit = **atomic mass unit**
- absolute sizes of atoms
  - mass of H atom= 1.67×10^{-24}g
  - Diameter ~ 1×10^{-10} m
  - volume of H atom = 2.1×10^{-25}cm^3

Modern Evidence for Atoms

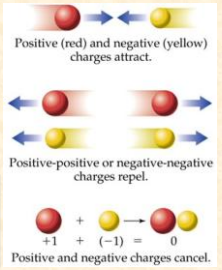


nanotechnology

Some Notes on Charge

Two Kinds of Charge called + and –

- Opposite Charges Attract
- Like Charges Repel
- To be Neutral, something must have no charge or equal amounts of opposite charges



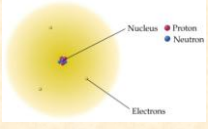
- Work done by J.J. Thomson and others proved that the atom had pieces called **electrons**

cathode ray tube

- Thomson found that electrons are much smaller than atoms and carry a negative charge
  - the mass of the electron is 1/1836th the mass of a hydrogen atom
  - the charge on the electron is the fundamental unit of charge which we will call –1 charge units

Subatomic Particle	Mass g	Mass amu	Location in atom	Charge	Symbol
Proton	1.67 x 10^{-24}	1	nucleus	+1	p, p^+, H^+
Electron	0.0009 x 10^{-24}	~0	empty space	-1	e, e^-
Neutron	1.67 x 10^{-24}	1	nucleus	0	n, n^0

The Modern Atom



- Protons, neutrons and electrons
- The nucleus – protons and neutrons
- The electrons move outside the nucleus

The nuclear atom

1) The atom contains a tiny dense center called the **nucleus**
   - Nucleus = baseball; atom = 2.5 mi, electron = period
2) The nucleus has essentially the entire mass of the atom
3) The nucleus is positively charged
4) The electrons move around in the empty space of the atom surrounding the nucleus
5) For the ***atom to be neutral there must be equal numbers of protons and electrons***
6) The nucleus also contains neutrons…mass and proton repulsion.

Ions

- Atoms acquire a charge by gaining or losing electrons
- Ion Charge = # protons – # electrons
- ions with a + charge are called **cations**
- ions with a – charge are called **anions**

Atomic Structures of Ions

- Metals form cations
- Cations are named the same as the metal

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

Atomic Structures of Ions

- Nonmetals form anions
- 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

Determining the Number of Protons and Electrons in an Ion

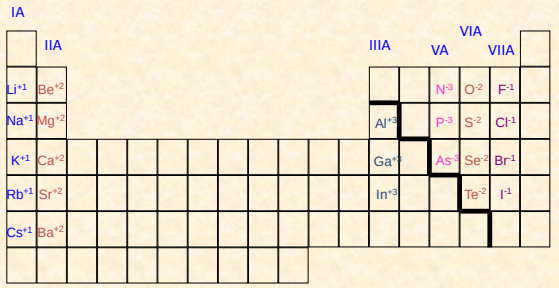
Find the number of protons and electrons in the Ca^{2+} ion

Atomic Structures of Ions

Ion	p^{+}	e^{-}
Cl^{-1}		
K^{+1}		
S^{-2}		
Sr^{+2}		

Ion Charge & the Periodic Table

- metals are always positive ions
  - for many main group metals, the charge = the group number
- nonmetals are negative ions
  - for nonmetals, the charge = the group number - 8



Isotopes

- The same element can have atoms with different masses, called **isotopes**
- The observed mass is a weighted average of the weights of all the naturally occurring **isotopes**

- all isotopes of an element are chemically identical
- all isotopes of an element have the same number of protons
- isotopes of an element have different numbers of neutrons
- isotopes are identified by their **mass numbers**

Neon

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

Determining the Number of Protons and Neutrons from Isotope Symbols

How many protons and neutrons in the chromium-52

Practice - Complete the following table

	Atomic Number	Mass Number	Number of Protons	Number of Electrons	Number of Neutrons
Calcium-40					
Carbon-13					
Aluminum-27^{+3}					

3.5 Common Elements

Noble Gases (Group VII) and metals are monatomic

H, N, O, F, Cl, Br, I are diatomic

3.6 Relating Mass to Number of Particles

AVERAGE ATOMIC MASS –weighted average mass of all the isotopes

MOLAR MASS – mass in grams of 1 mole of an element