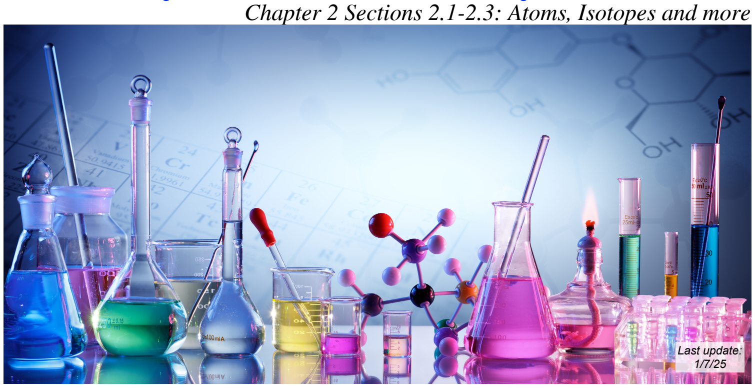
Chemistry 151: Basic Chemistry

Chapter 2 Sections 2.1-2.3: Atoms, Isotopes and more



Basic Terms of Chemistry

Matter: Anything that has mass and occupies space – things you can see, touch, taste, or smell.

Property: a characteristic that can be used to describe a substance.

Size, color, temperature are familiar properties of matter. Less familiar properties include:

Chemical composition: what matter is made of.

Chemical Reactivity: how matter behaves, *reactions*.

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Physical and Chemical Change

A Physical Change does not alter the chemical makeup of a substance. Change is reversible.

Example: Melting of solid ice; only change in form takes place and change is reversible.

A Chemical Change alters chemical composition of a substance. Change is irreversible.

Example: Rusting of iron; iron combines with oxygen and produces a new substance (rust).

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States of Matter

Matter exist in three forms: *solid*, *liquid*, and *gas*.

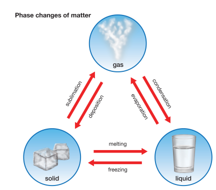
Solids have definite shape and volume.

Liquids have definite volume but changes shape to fill containers.

Gases have neither definite volume or definite shape.

Most substances, such as **water**, can exist in all three states depending on the temperature.

The conversion of a substance from one state into another is known as *change of state*.



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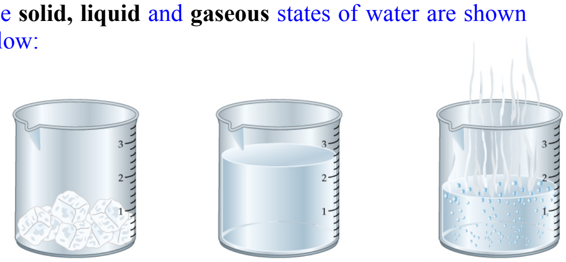
The **solid, liquid** and **gaseous** states of water are shown below:



(a) Ice: A solid has a definite volume and a definite shape independent of its container.

(b) Water: A liquid has a definite volume but a variable shape that depends on its container.

(c) Steam: A gas has both variable volume and shape that depend on its container.

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More on the Kinetic Molecular Theory (KMT) of Matter in CH 221!

Classification of Matter

Pure Substance: Uniform in its chemical composition and properties. Sugar (a compound) and water (compound) are pure substances.

Elements and **Compounds** can be pure.

Mixture: Composition and properties may vary. Different amounts of sugar dissolved in water will determine sweetness of water.

Mixtures can be **heterogeneous** (single phase) or **homogeneous** (single phase)

Sugar water is a homogeneous mixture, sand is a heterogeneous mixture

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Elements and Compounds

Elements cannot be broken down chemically into simpler substances, "building blocks" of nature.

Hydrogen, oxygen, and nitrogen are example of elements.

Chemical Compounds can be broken down into elements or other compounds.

Water is a chemical compound since it can be broken down into hydrogen and oxygen.

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Mixtures and compounds contain more than one substance. What's the difference?

Mixture:

Sugar water (variable proportions) $\xrightarrow[\text{change}]{\text{physical}}$ Sugar (compound) + Water (compound)

Mixtures broken down to compounds or elements by physical changes

Compound:

Water (fixed proportions) $\xrightarrow[\text{change}]{\text{chemical}}$ hydrogen (element) + oxygen (element)

Compounds broken down to elements by chemical changes

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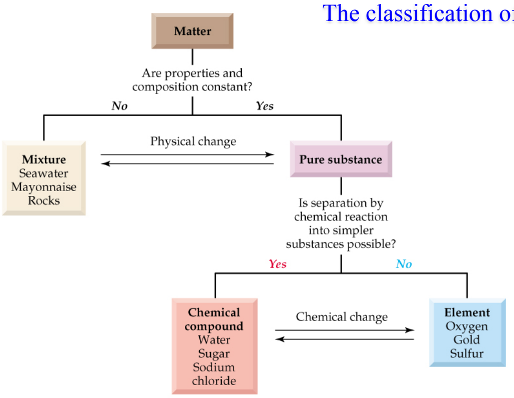
The classification of matter scheme:



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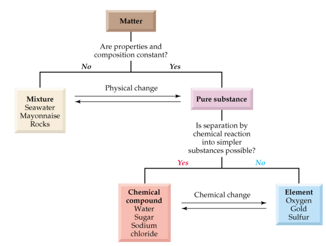
Test yourself:



pizza
Coke
water
silicon
iron
rust

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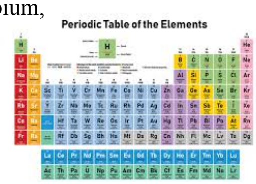
Chemical Elements and Symbols

Approximately 118 Elements are known - they are listed on the periodic table.

Only 90 of these elements occur naturally, remaining elements synthesized in lab.

Some familiar elements are iron, tin, carbon, oxygen, hydrogen, sulfur, etc.

Some possibly unfamiliar elements are niobium, rhodium, thulium, californium, etc.



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Chemical Symbols

Each element has its own unique *symbol*.

One or *two* letter symbols are used to represent elements.

First letter is always *capitalized* and the second letter is always a *lower case*.

Some symbols came from elements' modern names such as 'H' for hydrogen, 'O' for oxygen, 'N' for nitrogen, etc.

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Chemical Symbols

A few symbols for elements from their *Latin* names. *Example:* 'Na' for sodium from Latin *Natrium*.

Naturally occurring elements are not equally abundant. Oxygen and silicon together: 75% of earth's crust.

Chemical Formula: A notation for a chemical compound using element symbols and subscripts to show how many atoms of each element are present.

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The formula for water is H_2O.

H_2O indicates that two hydrogens and one oxygen combined together to produce water.

Every formula described similarly

H_2O: 2 H atoms, 1 O atom

CH_4: 1 C atom, 4 H atoms

$C_{12}H_{22}O_{11}$: 12 C atoms, 22 H atoms, 11 O atoms

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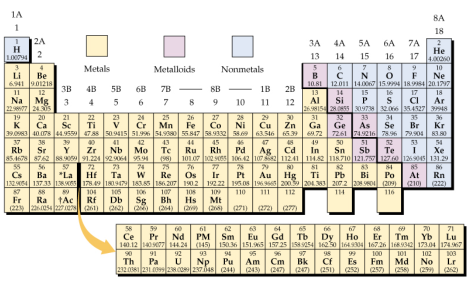
Elements and the Periodic Table



Metals, nonmetals and metalloids appear in distinct places on the periodic table

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Metals (left side)

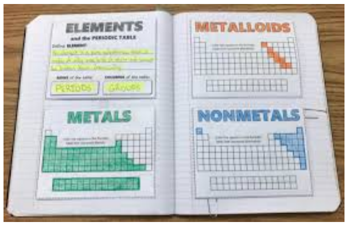
- Solids at room temperature (except Hg)
- Good conductor of heat & electricity
- Malleable, give up electrons

Nonmetals (right side)

- Eleven gases, five solids, one liquid (Br)
- Like to absorb electrons generally

Metalloids (between)

- Properties between metals and nonmetals
- Used in semi-conductors



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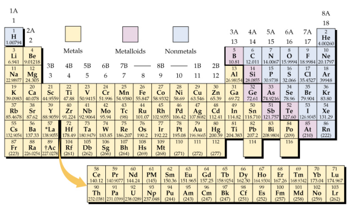
Test yourself:



Metal, Metalloid or Nonmetal:

Li
Au
Si
Se
Cl
Ne

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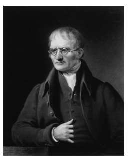

John Dalton

John Dalton's Atomic Theory

Chemistry founded on four fundamental assumptions about **atoms** and **matter** which make up the modern **Atomic Theory**:

1. All matter is composed of atoms.
2. The atoms of an element differ from the atoms of all other elements.
3. Chemical compounds consist of atoms combined in specific ratios.
4. Chemical reactions change only the way the atoms are combined in compounds; the atoms themselves are unchanged.

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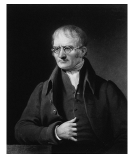
John Dalton's Atomic Theory

John Dalton



Atoms are the smallest pieces of elements.

You can divide an element down to the atom... but if you divide an atom, it will no longer be the same element.

Molecules are the smallest pieces of compounds.

You can divide compounds down to the molecule... but if you divide a molecule, it will break into individual atoms (or smaller molecules.)

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Atomic Theory

Atoms are composed of tiny **subatomic particles** called **protons**, **neutrons**, and **electrons.**

Since the masses of atoms are so small, their masses are expressed on a *relative mass scale*. That is, one atom is assigned a mass, and all others are measured relative to it.

Relative atomic mass scale based on carbon atoms with 6 protons and 6 neutrons. This carbon atom is assigned a mass of *exactly* 12 atomic mass units **(amu)**. **1 amu = 1.66 * 10^{-24} g**

Mass of proton = 1.007 amu

Mass of oxygen = 16.00 amu

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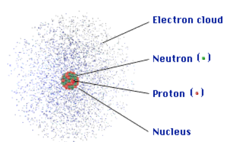
Atomic Theory

Subatomic particles not distributed randomly throughout atoms.

Protons and **neutrons** packed closely together in a dense core called the **nucleus**.

Electrons move about rapidly around core through a large, mostly empty volume of space in atom.



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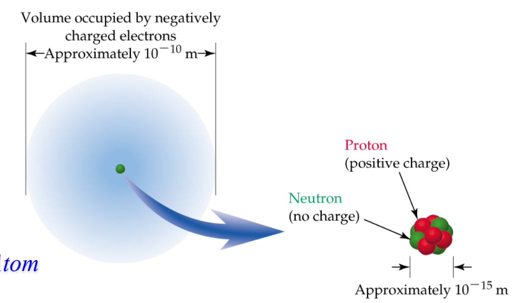
Diameter of a <u>nucleus</u> is only about 10^{-15} m.

Diameter of an <u>atom</u> is only about 10^{-10} m.



The Structure of an Atom

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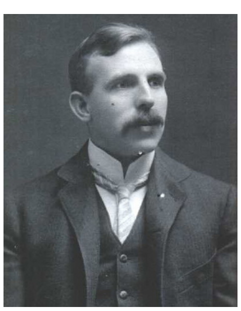
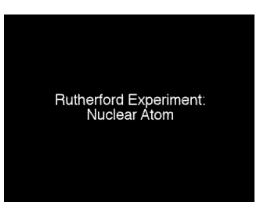
The modern view of the atom was developed by Ernest Rutherford in 1910.





Low density atom with a highly dense, positively charged nucleus

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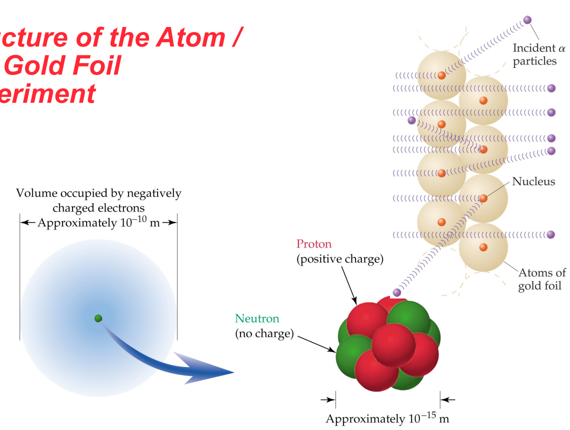
Structure of the Atom / The Gold Foil Experiment



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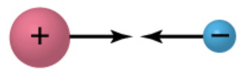
Attraction / Repulsion

Structure of atoms determined by an interplay of different **attractive** and **repulsive forces**.

Unlike charges attract - the *negatively charged electrons* held close to nucleus by attraction to *positively charged protons*



Protons and electrons attract one another

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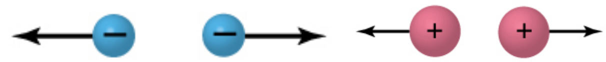
Attraction / Repulsion

Like charges repel each other - *negatively charged electrons* try to get as far apart as possible

Positively charged protons in nucleus also repel, but they are held together by a unique attraction called *nuclear strong force* *(Chemistry 222)*



Electrons repel one another

Protons repel one another

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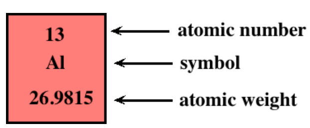
Element and Atomic Number

Atomic Number (Z): Number of protons in an atom

Elements defined by number of protons in the nucleus.

Atoms are neutral overall with no net charge; hence, number of positive protons equals number of negative electrons in the atom.

Mass Number (A): The total number of protons *and* neutrons in an atom.



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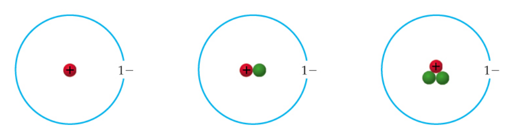
Isotopes and Atomic Weight

Isotopes are atoms with identical atomic numbers (Z) but different mass numbers (A)

Protium, deuterium, and tritium are isotopes of hydrogen.

- Protium: one proton (Z=1) and no neutrons (A=1)
- Deuterium: one proton (Z=1) and one neutron (A=2)
- Tritium: one proton (Z=1) and two neutrons (A=3)



Protium—one proton (●) and no neutrons; mass number = 1

Deuterium—one proton (●) and one neutron (●); mass number = 2

Tritium—one proton (●) and two neutrons (●); mass number = 3

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Atomic and Mass Numbers

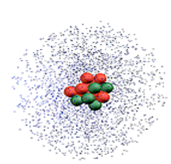
Atomic Number, Z

Z = # protons *(defines element)*

Mass Number, A

A = # protons + # neutrons

A boron atom can have
A = 5 p + 5 n = 10 amu



Boron-10, ^{10}B

Method to display A, Z and element symbol:

$$\begin{matrix} A \rightarrow 10 \\ Z \rightarrow 5 \end{matrix} B$$

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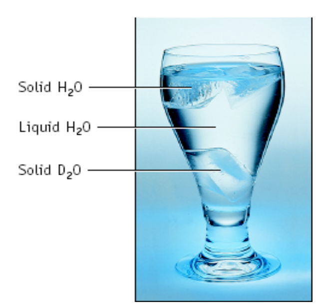
Hydrogen Isotopes

Hydrogen has *three* isotopes

$^{1}_{1}H$ **1 proton and 0 neutrons, protium**

$^{2}_{1}H$ **1 proton and 1 neutron, deuterium**

$^{3}_{1}H$ **1 proton and 2 neutrons, tritium**
radioactive



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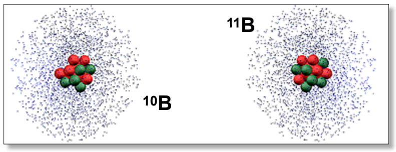
Isotopes Overview

Atoms of the same element (same Z) but different mass number (A).

Boron-10 has 5 p and 5 n: $^{10}_{5}B$

Boron-11 has 5 p and 6 n: $^{11}_{5}B$



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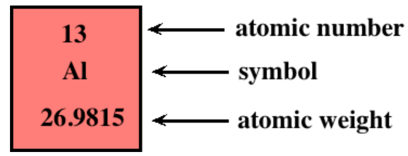
Atomic Weight: The weighted average mass of an element's atoms in a large sample that includes all naturally occurring isotopes of that atom.

Atomic number and atomic weight displayed in periodic table *(but not mass number!)*



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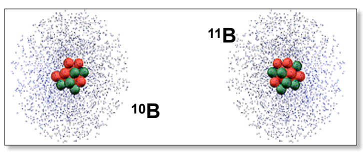
Isotopes



Because of the existence of isotopes, the mass of a collection of atoms has an average value.

Average mass = ATOMIC WEIGHT

Boron is 20% ^{10}B and 80% ^{11}B. That is, ^{11}B is 80 percent abundant on earth.

For boron atomic weight

= 0.20 (10 amu) + 0.80 (11 amu) = 10.8 amu

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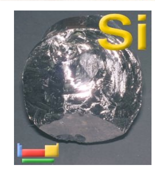
Isotopes & Atomic Weight

Because of the existence of isotopes, the mass of a *collection* of atoms has an average value.

^{6}Li = 7.5% abundant and ^{7}Li = 92.5%

Atomic weight of Li = ______________



^{28}Si = 92.23%, ^{29}Si = 4.67%, ^{30}Si = 3.10%

Atomic weight of Si = ______________

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Isotopes

Example: **Nitrogen has two main isotopes, ^{14}N (14.0031 amu, 99.6299%) and ^{15}N (15.0001 amu, 0.3701%). Calculate the average atomic mass.**

Solution

Average atomic mass =

= (0.996299*14.0031) + (0.003701*15.0001)

= 13.9512745 + 0.05551537

= 14.0068 amu

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Isotopes

Example: **Gallium has two main isotopes, ^{69}Ga (68.9257 amu) and ^{71}Ga (70.9249 amu) with an average atomic mass of 69.723. Calculate the % abundance of each isotope.**

Solution

Average atomic mass =

69.723 = *x*(^{69}Ga)*68.9257 + *y*(^{71}Ga)*70.9249

but also

1 = *x*(^{69}Ga) + *y*(^{71}Ga) *(2 percentages equal 100%)*

so ***y*(^{71}Ga) = 1 - x(^{69}Ga)**

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Isotopes

Example: **Gallium has two main isotopes, ^{69}Ga (68.9257 amu) and ^{71}Ga (70.9249 amu) with an average atomic mass of 69.723. Calculate the % abundance of each isotope.**

Solution

69.723 = *x*(^{69}Ga)*68.9257 + *y*(^{71}Ga)*70.9249, *or*

69.723 = x*68.9257 + (1 - x)*70.9249

69.723 = x*68.9257 + 70.9249 - 70.9249x

Solve for x, get:

***x*(^{69}Ga) = 0.6012 (60.12%)**

***y*(^{71}Ga) = 1 - x = 0.3988 (39.88%)**

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Isotopes

Antimony has two main isotopes:

^{121}Sb (120.9038 amu, 57.20%) *and*

^{123}Sb (122.9042 amu, 42.80%)

Average atomic mass of Sb: **121.760**

Will you have one atom of antimony with 121.760 amu?

No!

One atom of antimony will have a mass of 120.9038 amu 57.20% of the time

One atom of antimony will have a mass of 122.9042 amu 42.80% of the time

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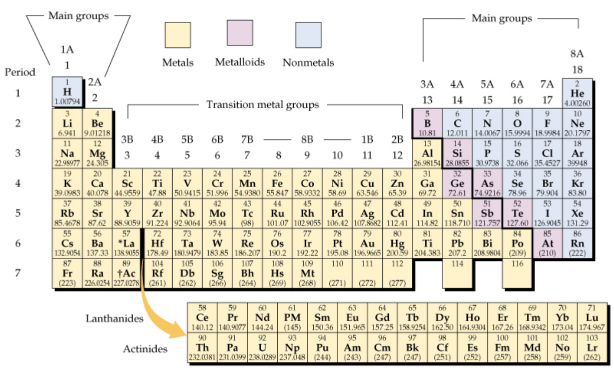

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The Periodic Table

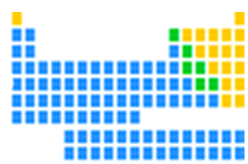
The Periodic Table

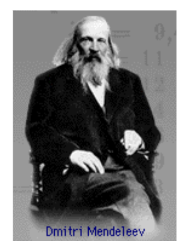
Beginning in upper left corner, elements are arranged by increasing atomic number

Seven horizontal rows called ***periods***

Eighteen vertical columns called ***groups***.

Elements in a given group have similar chemical properties (i.e. lithium, sodium, potassium, etc. in group 1A have similar properties)





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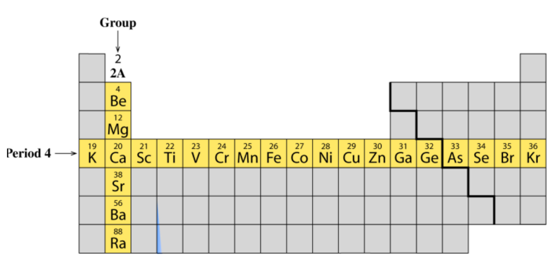
Groups and Periods



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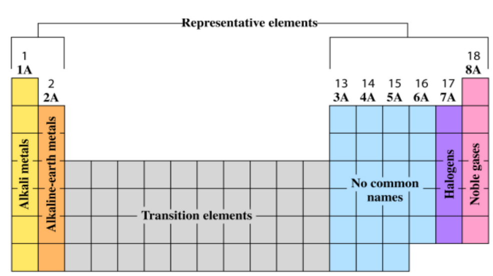
Groups on the Periodic Table

Several groups of elements are known by common names.



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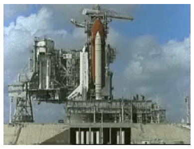
Hydrogen



Shuttle main engines use H_2 and O_2

The Hindenburg crash, May 1939.

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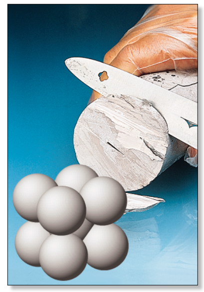
Group 1A: Alkali Metals



Sodium cut with a knife

Extreme reactivity with water!

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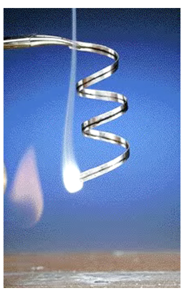
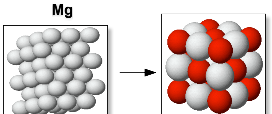
Solids at room temperature, violently react with water



Mg



MgO

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Group 2A: Alkaline Earth Metals

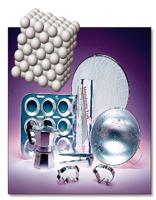
Ba gives green fireworks

Calcium

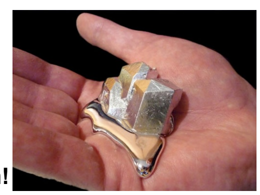
Sr gives red fireworks

Alkaline Earth Metals occur naturally only in compounds (except Be)

Group 3A: The Icosagens B, Al, Ga, In, Tl



Aluminum, *the most abundant metal in the earth's crust*

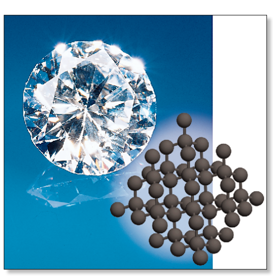


MAR *Liquid* **Gallium!**

Boron halides, BF_3 & BI_3

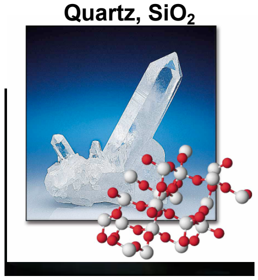
Twisted Metals!

Group 4A: The Crystallogens: C, Si, Ge, Sn, Pb



Diamond

Quartz, SiO_2



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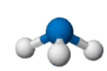
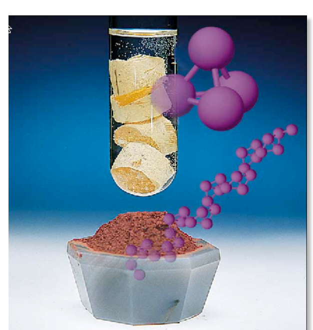
Group 5A: The Pnictogens N, P, As, Sb, Bi

Ammonia, NH_3

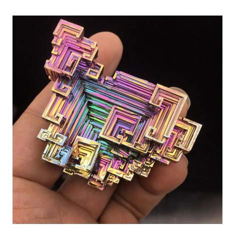


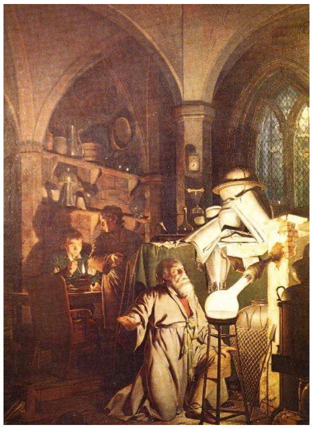
Memorize: ammonia = NH_3!



White and red phosphorus

Bismuth





Phosphorus

Red and white
phosphorus ignite in air
to make P_4O_{10}

Phosphorus first isolated
by Brandt from urine (!)
in 1669

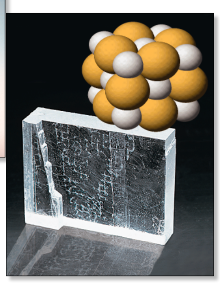
Most chemists' jobs are
not so "demanding"!!!

Group 6A: The Chalcogens O, S, Se, Te, Po

Sulfuric acid
dripping from
a cave in
Mexico

Sulfur from a volcano

MAR

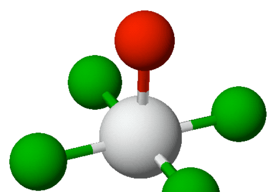


Group 7A:
The Halogens
F, Cl, Br, I, At

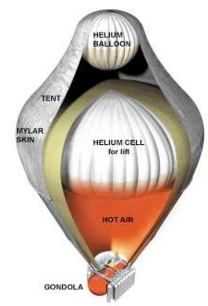
MAR

Group 8A: Noble Gases
He, Ne, Ar, Kr, Xe, Rn

All gases at room temperature;
considered unreactive until 1962

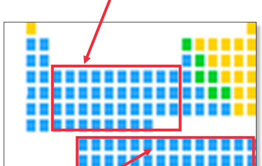


$XeOF_4$

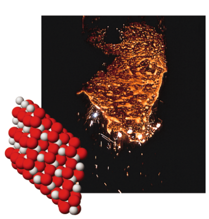


MAR

Transition Metals



Lanthanides and actinides



Iron in air gives
iron(III) oxide

MAR

End of Chapter 2 (2.1-2.3)