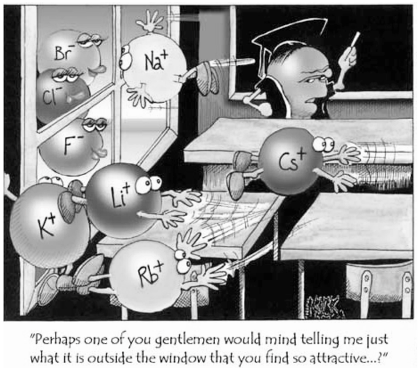
Atoms, Molecules and Ions

Chapter 2 and Chapter 3 (3.1)

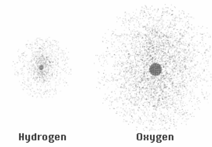
"Chapter 2 Part 1"



Chemistry 221
Professor
Michael Russell

Last update: 4/29/24

ATOMS AND ELEMENTS

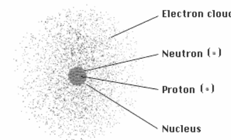


Elements: the building blocks of Nature

Atoms: the smallest pieces of an element

Atoms contain protons, neutrons and electrons

Protons and neutrons in the nucleus



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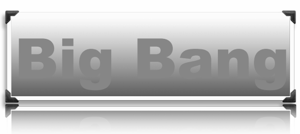
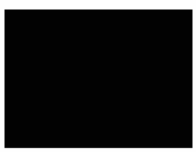
Where Does Matter Come From?

FROM THE





The universe is 13.77 billion years old

Hydrogen and Helium important

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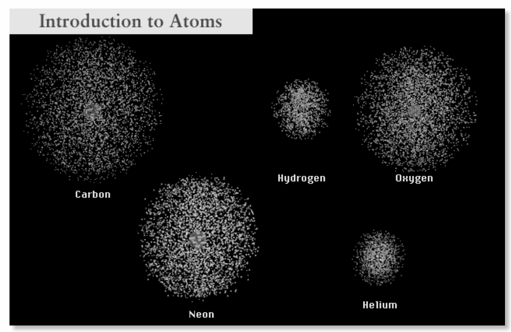

Also Carbon, Oxygen and Neon

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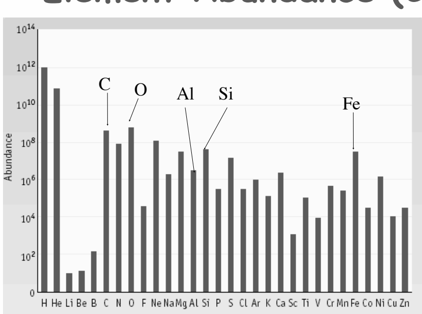
Element Abundance (Cosmic)



Most abundant elements in the Earth's

- **Crust**: Silicon ***and*** oxygen
- **Atmosphere**: nitrogen ***and*** oxygen

http://www.webelements.com/

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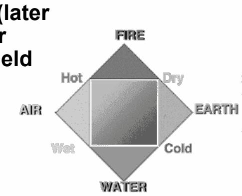
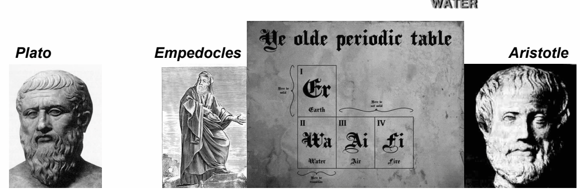
Early Models of the Atom - Empedocles & Aristotle

Empedocles' theory of matter (later modified by Aristotle) with four "elements" (coined by Plato) held for approximately 2000 years!

Element "mixtures" produce "properties" of hot, wet, etc.



Plato ***Empedocles*** ***Aristotle***



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Early Models of the Atom - Democritus

DEMOCRITUS (460 - 370 BCE)
was a contemporary of Plato

Atoms have *structure* and *volume*

"Gold can be divided into smaller pieces only so far before the pieces no longer retain the properties of gold"

Smallest unit of matter = *atomos*, atoms

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JOHN DALTON
(1766 - 1844)

The "Newton" of Chemistry

1804 - Proposed Atomic Theory

"Atoms cannot be created or destroyed"

"Atoms of one element are different from other element's atoms" - proposed *relative* scale of atomic masses (now the *amu*)

"Chemical change involves bond breaking, bond making and rearrangement of atoms"

Did not include Democritus' ideas that atoms have structure

1 atomic mass unit (amu) **= 1.66054 * 10^{-24} g =** *1 Dalton (Da)*

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The Discovery of Atomic Structure: Electricity

BEN FRANKLIN:

Key Theories:
- **+ and - charges**
- **Opposites attract, like repel**
- **Charge is *conserved***
- **Force inversely proportional to distance**

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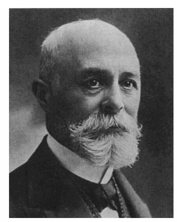

Radioactivity

Henri Becquerel (1896) discovered radioactivity while studying uranium ore
Emits new kind of "ray"
Rays pass unimpeded through many objects
Rays produce image on photographic plate (silver emulsion)

But MARIE CURIE opened the door...

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MARIE CURIE

the "Newton of Radioactivity"

Substances disintegrated upon emission of rays - *radioactive*

Challenged Dalton's idea on "indestructible atoms" - more comprehensive theory

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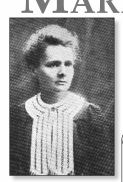
MARIE CURIE

the "Newton of Radioactivity"



She (and *Rutherford*) found three types of radiative processes:

- alpha **- a helium cation -** α
- beta **- supercharged electrons -** β
- gamma **- high energy emission -** γ

***Note* that α and β are massive and charged, but γ radiation has no charge or mass**

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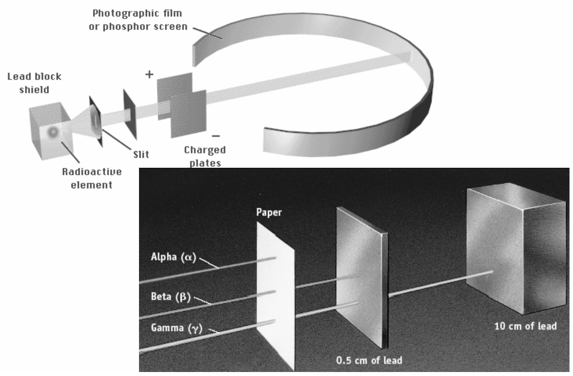
Discovering the Radioactive Particles



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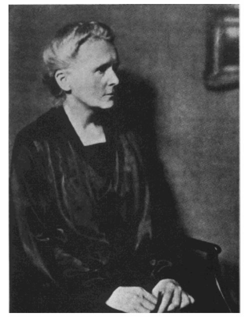
Marie Curie



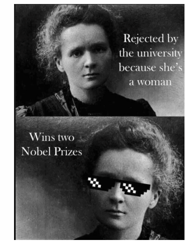
1903 - discovered radium, polonium

1911 - isolated pure radium (bought her own samples!)

1919 - American Association of University Women raised $150K for 1 g of radium, continued work

1934 - died of leukemia *killed by her work*

"Nothing in life is to be feared. It is only to be understood."



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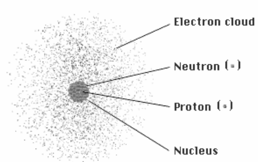
ATOM COMPOSITION



The atom is mostly empty space

protons & neutrons in nucleus

Atom electrically neutral *if* the # protons = # electrons

electrons in space around nucleus

***Extremely small!* One teaspoon of water has 3 times as many atoms as the Atlantic Ocean has teaspoons of water.**

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ATOMIC COMPOSITION

(Three Particles Handout)

Protons
- positive electrical charge
- mass = 1.672623×10^{-24} g
- relative mass = 1.0073 atomic mass units (amu) where 1 amu = $1.66054 * 10^{-24}$ g

Electrons
- negative electrical charge
- relative mass = 0.0005486 amu

Neutrons
- no electrical charge
- mass = 1.0087 amu

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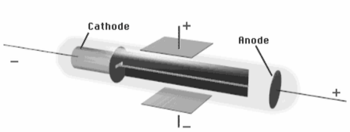
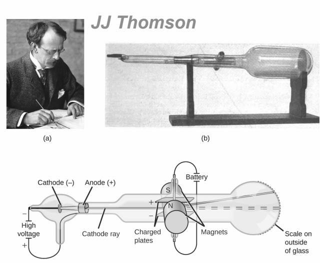
ELECTRONS

Charge to mass ratio of the electron discovered in 1897 by JJ Thomson using Cathode Ray Tubes (CRT)



JJ Thomson



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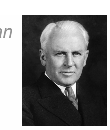
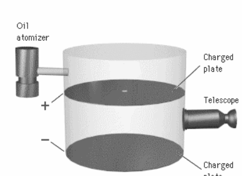
ELECTRONS

Robert Millikan



Charge to mass ratio of the electron discovered in 1897 by JJ Thomson using Cathode Ray Tubes (CRT)

Robert Millikan discovered the mass of the electron in 1913



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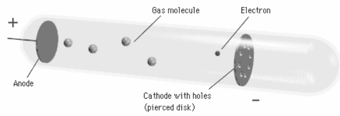
PROTONS

Discovered in 1919 by Rutherford while using canal ray tubes and hydrogen gas



1,837 times more massive than electron
Opposite charge (same magnitude) as electron

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NEUTRONS

Most difficult particle to discover - no charge, no voltage/magnet tests

Chadwick detected neutrons in 1932
n more massive than p or e,
used mass spectrometer

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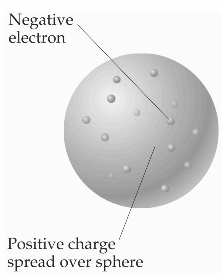
THE ATOM: *Plum Pudding Model*

JJ Thomson (discoverer of the electron) proposed the "plum pudding" model of the atom in 1904:

Large volume, negative "spheres" in a positive "cloud" of low density

Rutherford proposed the correct model



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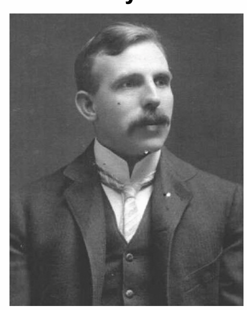
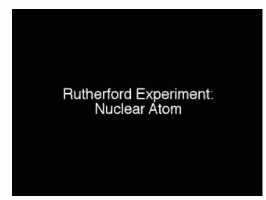
The modern view of the atom was developed by Ernest Rutherford in 1910.





Low density atom with a highly dense, positively charged nucleus

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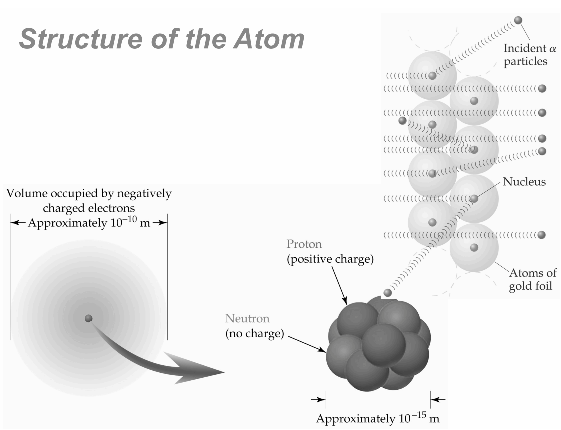
Structure of the Atom



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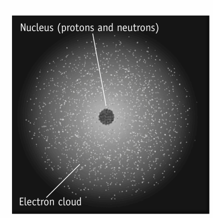
THE ATOM: *Summary*

Protons and neutrons in nucleus; electrons circle outside

Most of the mass of an atom is in the nucleus; electrons have ~0.05% mass

Nucleus very dense; most of atom's volume *empty*

Atom electrically neutral *if* the # protons = # electrons



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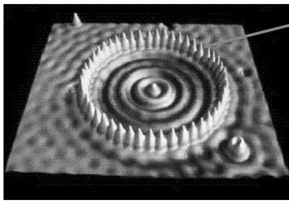
How Large is an Atom?



Circle consists of 48 Fe atoms

Radius of circle is 71 Angstroms where
1 Å = 10^{-10} m

STM image of “quantum corral” of iron atoms

See http://www.almaden.ibm.com/vis/stm for STM or Scanning Tunneling Microscopic images of atoms.

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Atomic Number, Z

All atoms of the same element have the same number of protons in the nucleus, Z.

13	← atomic number
Al	← symbol
26.9815	← atomic weight

Z distinguishes atoms from one another!

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Atomic Number, Z

All atoms of the same element have the same number of protons in the nucleus, Z.

13	← atomic number
Al	← symbol
26.9815	← atomic weight

Henry Moseley determined the atomic number for each element in 1914 using x-ray scattering

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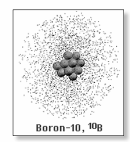
Mass Number, A

Mass Number, A
A usually in units of amu
A = # protons + # neutrons
A boron atom can have
A = 5 p + 5 n = 10 amu

Method to display A, Z and element symbol: A → 10, Z → 5: $^{10}_{5}B$



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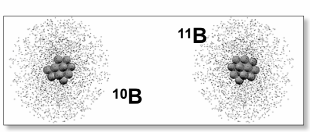
Isotopes

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

Boron-10 (^{10}B) has 5 p and 5 n

Boron-11 (^{11}B) has 5 p and 6 n



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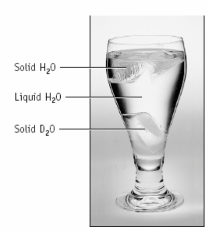
Hydrogen Isotopes

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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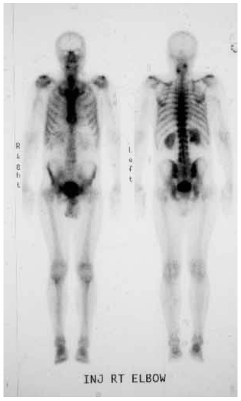

Isotopes & Their Uses

Bone scans with radioactive technetium-99.

$^{99}_{43}Tc$

Emits gamma rays

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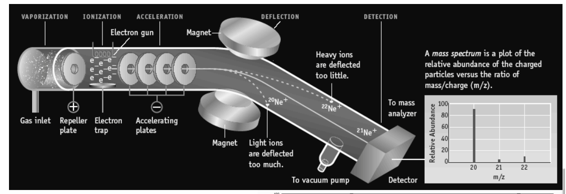
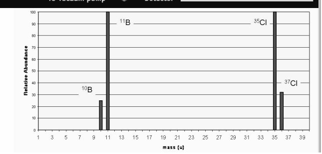
Masses of Isotopes

determined with a mass spectrometer





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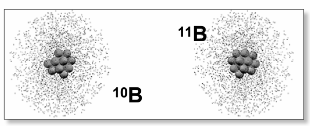
Isotopes



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.

To calculate the atomic weight for boron:

= (abundance$_1$ * mass$_1$) + (abundance$_2$ * mass$_2$)

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

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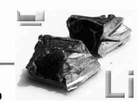
Isotopes & Atomic Weight

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

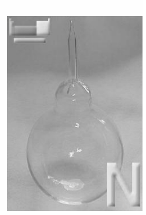
Average atomic mass =

= (abundance$_1$ * mass$_1$) + (abundance$_2$ * mass$_2$)

= (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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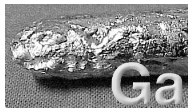
Isotopes



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

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%)

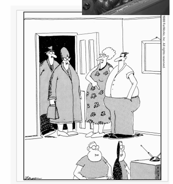
Average atomic mass of Sb: **121.760**

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



"Bob and Ruth! Come on in. … Have you met Russell and Bill, our 1.5 children?"

Average kids per family in Oregon: 1.7-1.8 *(2019)*

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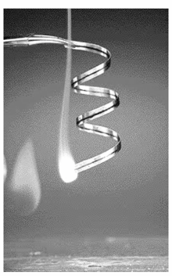
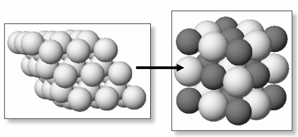
Counting Atoms



Mg burns in air (O_2) to produce white magnesium oxide, MgO.

How can we figure out how much oxide is produced from a given mass of Mg?



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Counting Atoms

Chemistry is a quantitative science - we need a "counting unit."

The MOLE!

A mole is similar to a *dozen* - you can have a dozen roses, a dozen donuts - you can also have a mole of roses, or a mole of donuts

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Particles in a Mole

Avogadro's Number (N_A), *named for* **Amedeo Avogadro,** *1776-1856*

6.02214076 x 10^{23}

A mole is the amount of *any* substance containing 6.022 x 10^{23} particles

$\frac{6.022 \times 10^{23} \text{ Cu atoms}}{1 \text{ mole Cu}}$ $\frac{1 \text{ mole } CO_2}{6.022 \times 10^{23} \text{ molecules } CO_2}$

Memorize 6.022 x 10^{23}! Always use this value for N_A!

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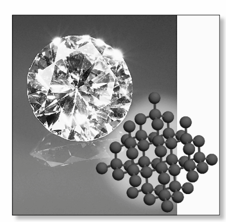
Molar Mass

1 mol of ^{12}C
= 12.00 g of C
= 6.022 x 10^{23} atoms of C

12.00 g of ^{12}C is its MOLAR MASS

Taking into account all of the isotopes of C, the molar mass of C is 12.011 g/mol



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Try to use at least four sig figs for molar mass

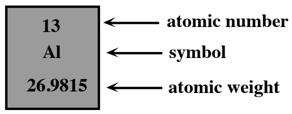
Molar Mass

1 mol of ^{12}C = 12.00 g of C = 6.022 x 10^{23} atoms of C

12.00 g of ^{12}C is its MOLAR MASS

Taking into account all of the isotopes of C, the molar mass of C is 12.011 g/mol

Find molar mass from periodic table



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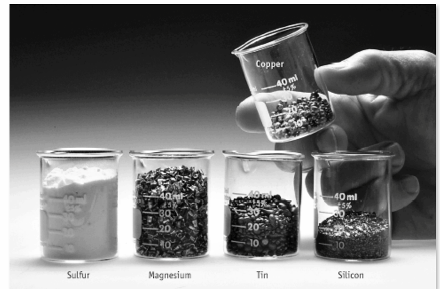
One mole Amounts



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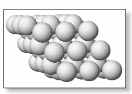

PROBLEM: What amount of Mg is represented by 0.200 g? How many atoms?

Mg has a molar mass of 24.3050 g/mol.

$$0.200\ \text{g} \bullet \frac{1\ \text{mol}}{24.31\ \text{g}} = 8.23 \times 10^{-3}\ \text{mol}$$

0.00822706...

How many atoms in this piece of Mg?

$$8.23 \times 10^{-3}\ \text{mol} \bullet \frac{6.022 \times 10^{23}\ \text{atoms}}{1\ \text{mol}}$$

= 4.96 x 10^{21} atoms Mg

4.956106....E21

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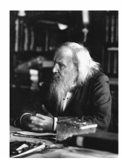
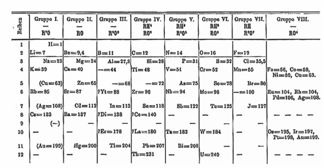
Periodic Table

Dmitri Mendeleev developed the modern periodic table. Argued that element properties are *periodic functions of their atomic weights*.

We now know that element properties are periodic functions of their ATOMIC NUMBERS.

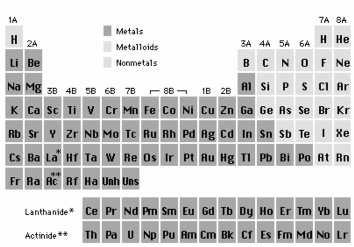


Dmitri Mendeleev



MAR

Periods in the Periodic Table



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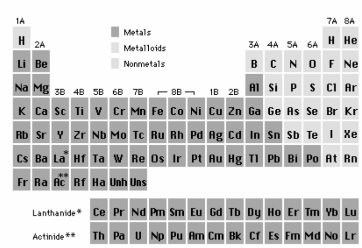
Groups in the Periodic Table



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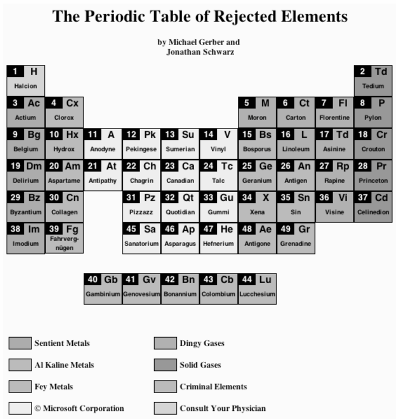
Rejected Elements in the Periodic Table



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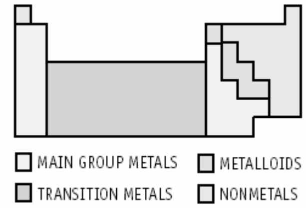
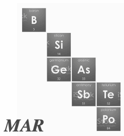
Periodic Table

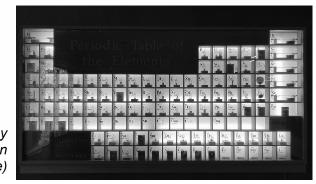
Periodic Table has the following:

- A groups: **main group elements**
- B groups: **transition metals**
- Lanthanides
- Actinides
- metals
- nonmetals
- metalloids





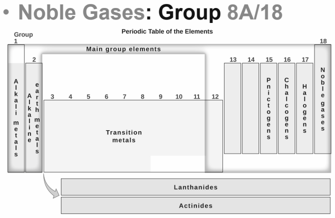
Common Metalloids



Periodic Table Display at University of Oregon (Eugene)

MAR

- Alkali Metals: **Group** 1A/1
- Alkaline Earth Metals: **Group** 2A/2
- Icosagens ("Twisted Metals"): **Group** 3A/13
- Crystallogens: **Group** 4A/14
- Pnictogens **("to choke"): Group** 5A/15
- Chalcogens **("chalk formers"): Group** 6A/16
- Halogens **("salt formers"): Group** 7A/17
- Noble Gases: **Group** 8A/18



Periodic Table

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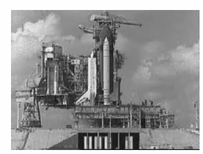
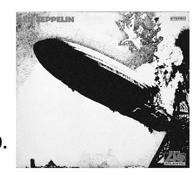
Hydrogen



Shuttle main engines use H_2 and O_2



The Hindenburg crash, May 1939.

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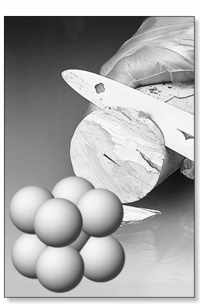
Group 1A: Alkali Metals: Li, Na, K, Rb, Cs, Fr



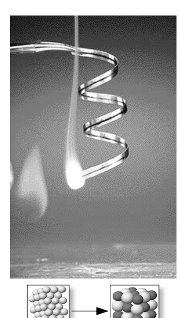
Extreme reactivity with water!

Sodium cut with a knife

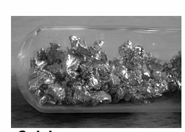
Solids at room temperature, violently react with water

MAR

Group 2A: Alkaline Earth Metals Be, Mg, Ca, Sr, Ba, Ra

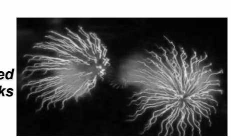


MgO



Calcium

Ba gives green fireworks



Sr gives red fireworks

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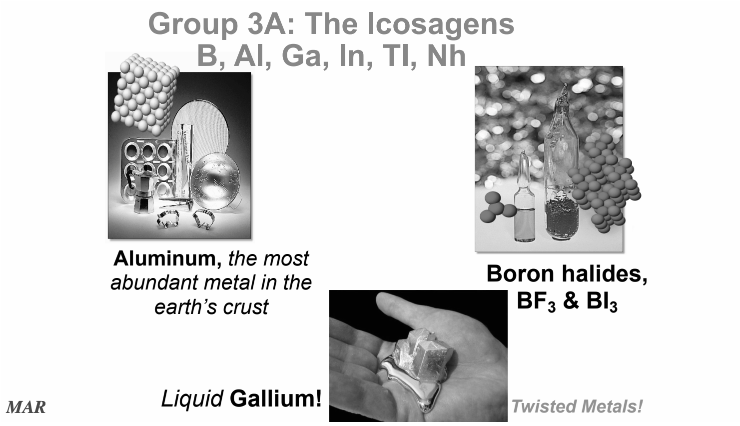
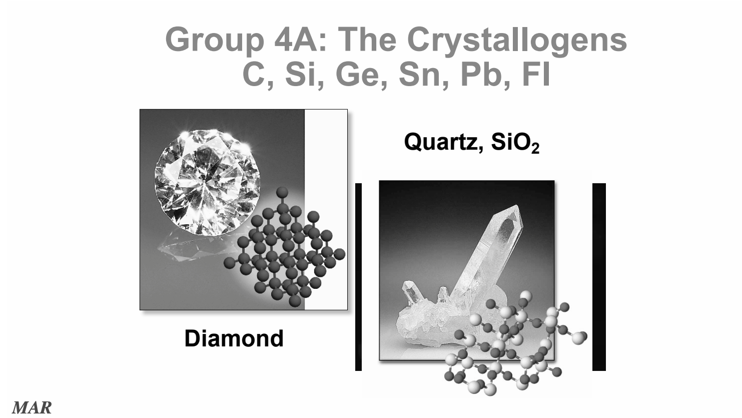
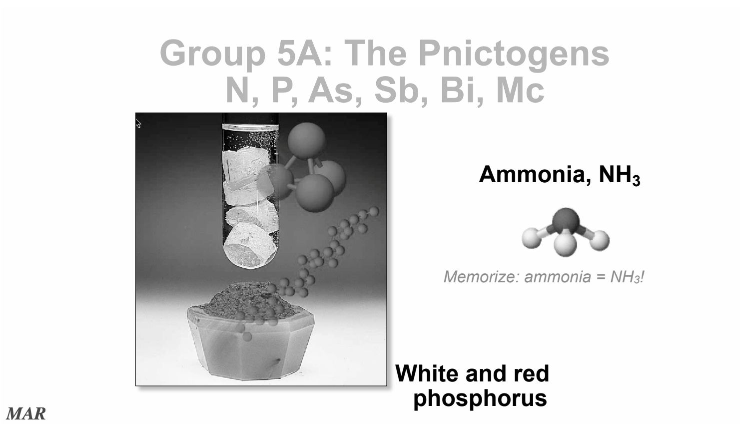
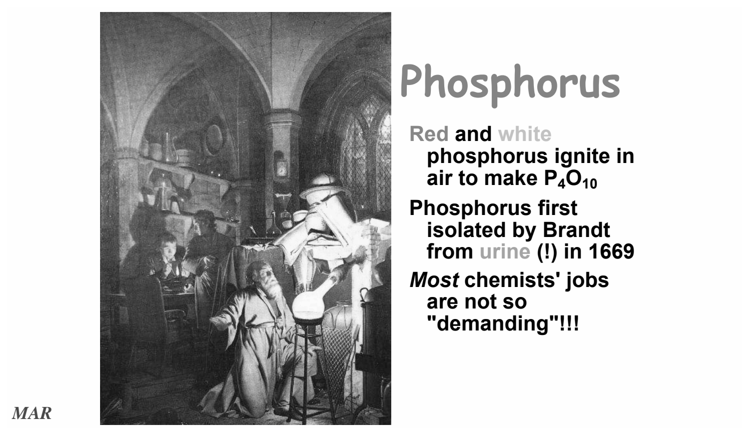
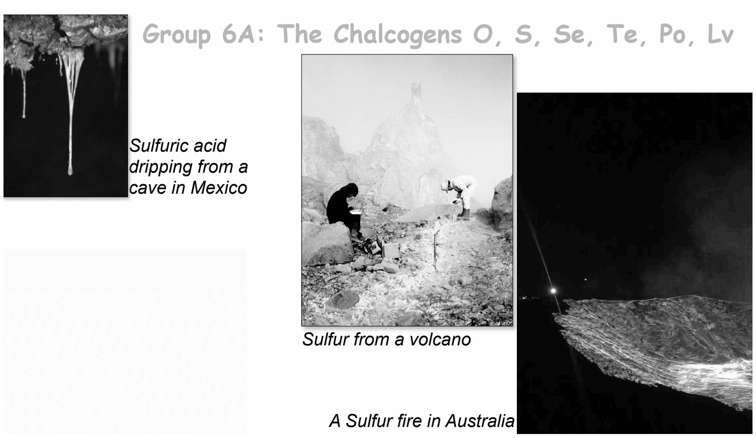
Alkaline Earth Metals occur naturally only in compounds (except Be)


Group 3A: The Icosagens
B, Al, Ga, In, Tl, Nh
Aluminum, the most abundant metal in the earth's crust
Boron halides, BF3 & BI3
Liquid Gallium!
Twisted Metals!
MAR


Group 4A: The Crystallogens
C, Si, Ge, Sn, Pb, Fl
Quartz, SiO2
Diamond
MAR


Group 5A: The Pnictogens
N, P, As, Sb, Bi, Mc
Ammonia, NH3
Memorize: ammonia = NH3!
White and red phosphorus
MAR

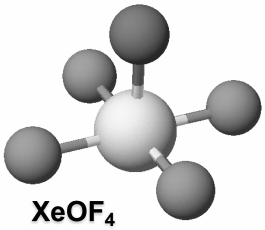

Phosphorus
Red and white phosphorus ignite in air to make P4O10
Phosphorus first isolated by Brandt from urine (!) in 1669
Most chemists' jobs are not so "demanding"!!!
MAR


Group 6A: The Chalcogens O, S, Se, Te, Po, Lv
Sulfuric acid dripping from a cave in Mexico
Sulfur from a volcano
A Sulfur fire in Australia
MAR

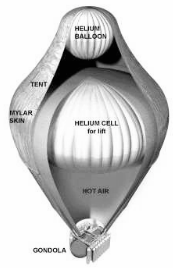

Group 7A:
The Halogens
F, Cl, Br, I, At, Ts

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

All gases at room temperature; considered unreactive until 1962



$XeOF_4$



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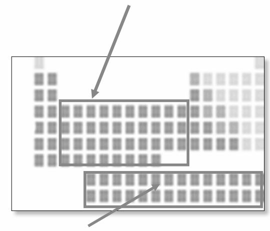
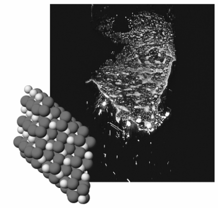
Transition Metals

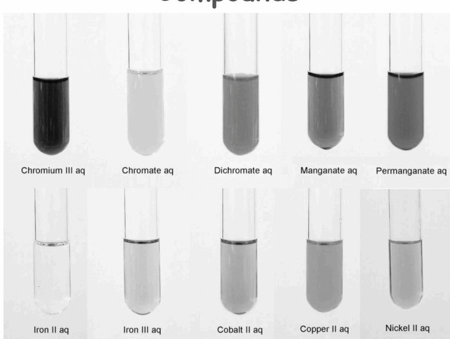




Iron in air gives iron(III) oxide

MAR

Colors of Transition Metal Compounds



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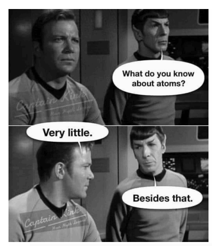
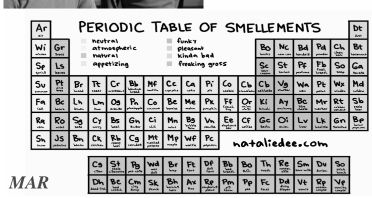
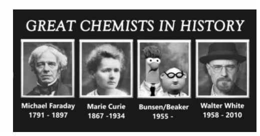
End of Chapter 2 Part 1



See also:

- *Chapter Two Part 1 Study Guide*
- *Chapter Two Part 1 Concept Guide*
- *Important Equations (following this slide)*
- *End of Chapter Problems (following this slide)*





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Important Equations, Constants, and Handouts from this Chapter:

- **alpha, beta, gamma radiation**
- **the "gold foil experiment"**
- **protons, neutrons, electrons**
- **mass number, atomic number**
- **isotopes**
- **atomic weight and molar mass**
- **Avogadro's number**

$$\begin{matrix} A \longrightarrow \\ Z \longrightarrow \end{matrix} {}^{10}_{5}B$$

A mole is the amount of *any* substance containing 6.022 x 10^{23} particles

Periodic table: **groups, periods, metals, metalloids, nonmetals, alkali, alkaline earth, halogens, noble gases, transition metals, lanthanides, actinides,** ***how to find the molar mass of an element!***

MAR

End of Chapter Problems: ***Test Yourself***

1. How many protons in a magnesium atom with 15 neutrons? What is the mass number of this isotope?
2. How many neutrons in: ${}^{60}_{27}Co$
3. Thallium has two stable isotopes, ${}^{203}Tl$ and ${}^{205}Tl$. Knowing that the atomic weight of thallium is 204.4, which isotope is the more abundant of the two?
4. Gallium has two naturally occurring isotopes, ${}^{69}Ga$ and ${}^{71}Ga$, with masses of 68.9257 u and 70.9249 u, respectively. Calculate the percent abundances of these isotopes of gallium.
5. Calculate the mass in grams of 2.5 mol of aluminum.
6. Calculate the amount (moles) represented by 0.012 mol Li. How many atoms of Li are present?
7. A cylindrical piece of sodium is 12.00 cm long and has a diameter of 4.5 cm. The density of sodium is 0.971 g/cm^3. How many atoms does the piece of sodium contain? (The volume of a cylinder is V = π x r^2 x length.)
8. In the following list, tell which element is: a metalloid, a transition metal, a halogen, a noble gas, a lanthanide, an alkali metal: Gd, Se, Cs, W, Xe, Cl

MAR

End of Chapter Problems: *Answers*

1. 12 protons, mass number = 27
2. 33 neutrons
3. 205
4. ^{69}Ga abundance is 60.12%, ^{71}Ga abundance is 39.88%
5. 68 g Al
6. 1.7×10^{-3} mol Li, 1.0×10^{21} atoms Li
7. 4.9×10^{24} atoms Na
8. A metalloid (Se), a transition metal (W), a halogen (Cl), a noble gas (Xe), a lanthanide (Gd), an alkali metal (Cs)

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