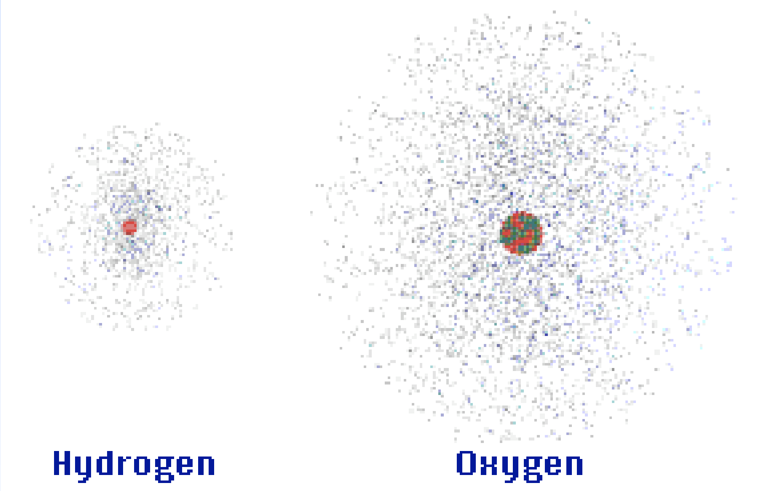
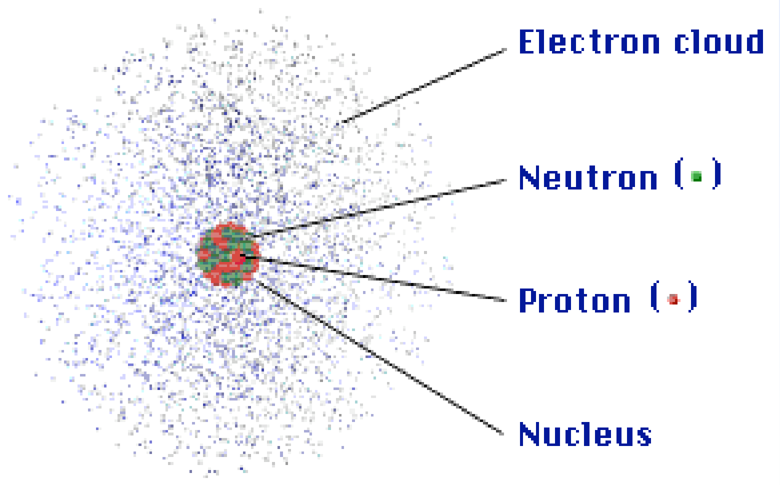
Atoms and Elements
Chapter 2

Chemistry 221
Professor Michael Russell

ATOMS AND ELEMENTS





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Where Does Matter Come From?

FROM THE

Big Bang

Hydrogen and Helium important

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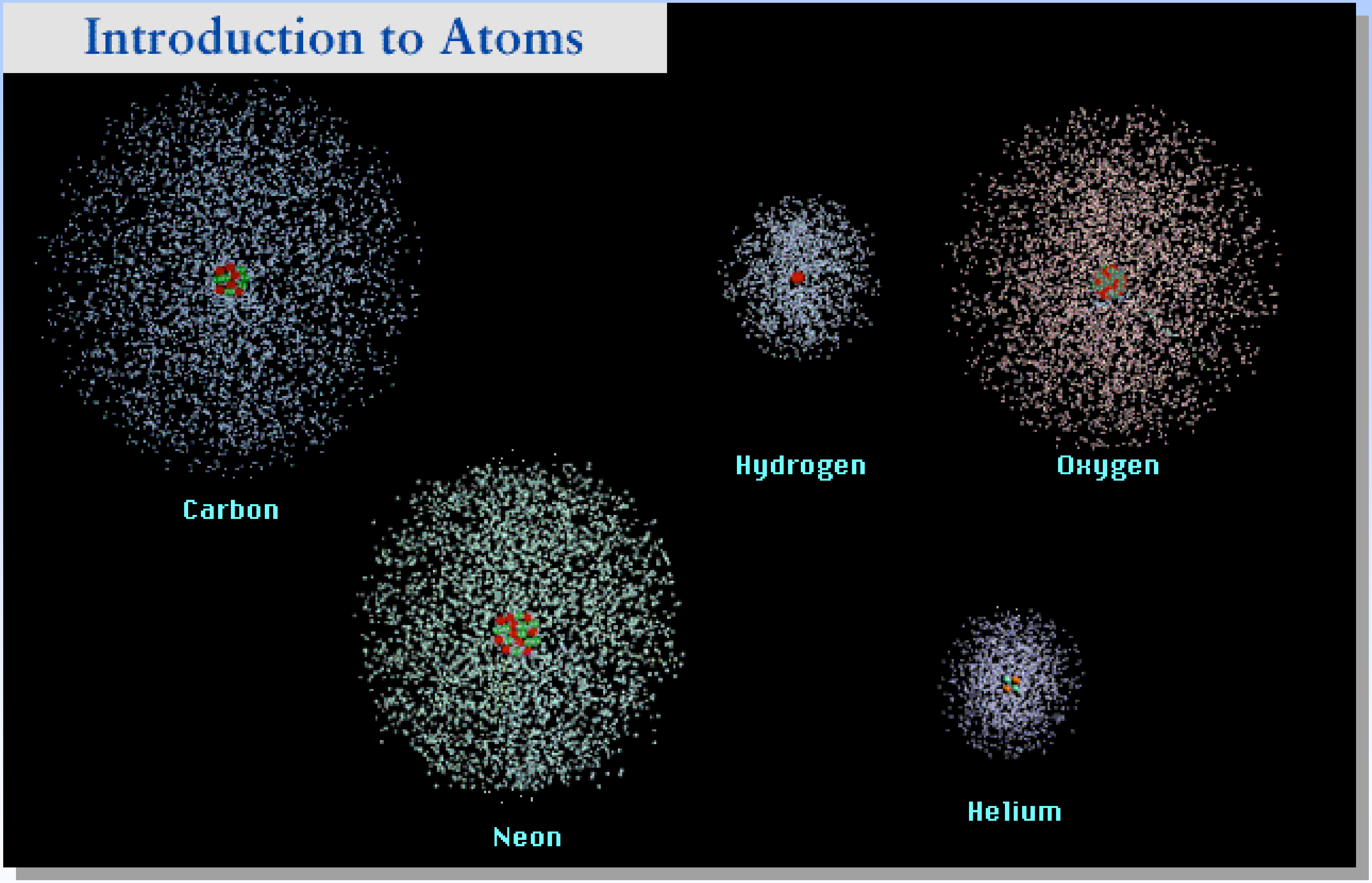

Also Carbon, Oxygen and Neon

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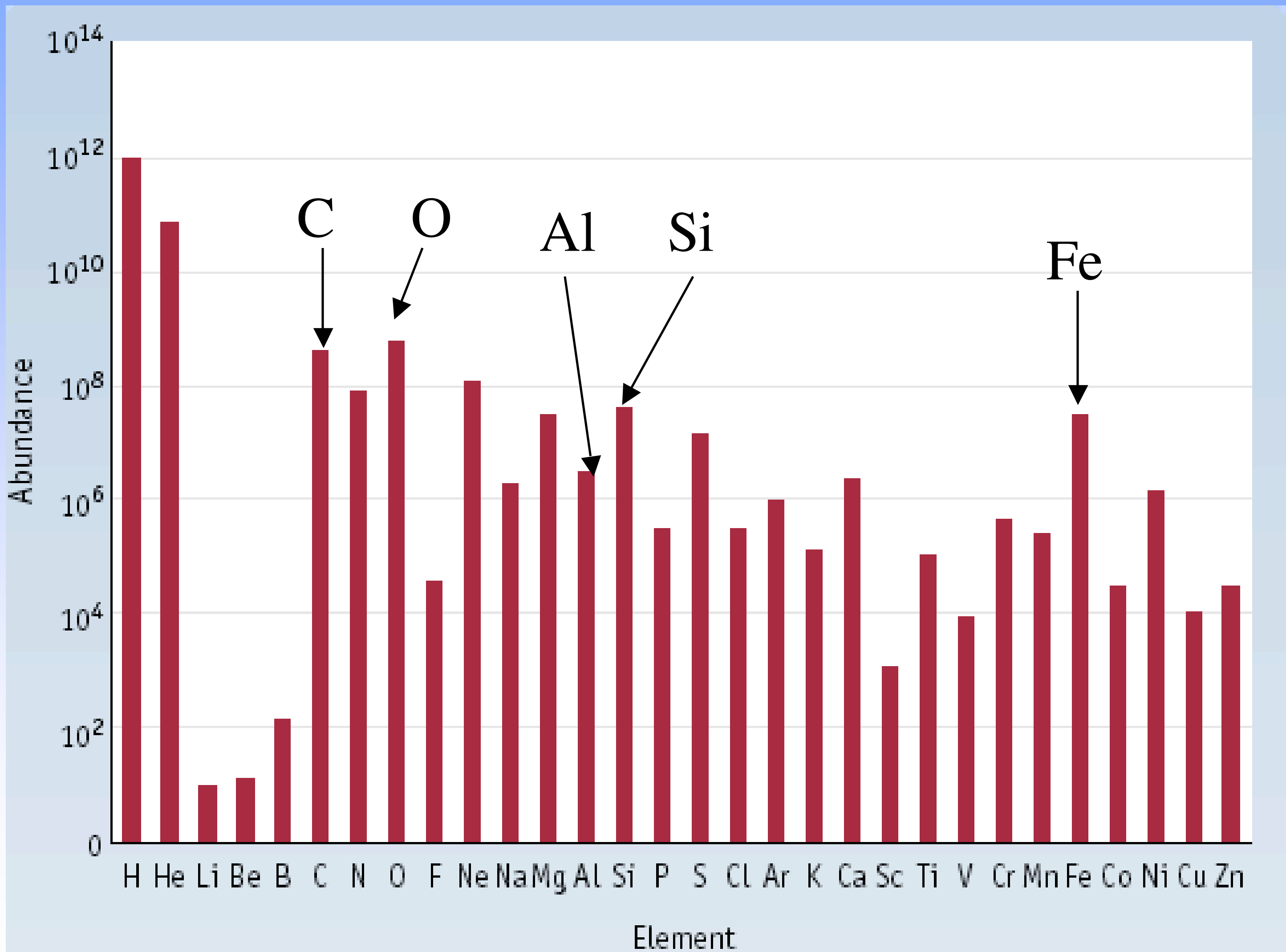
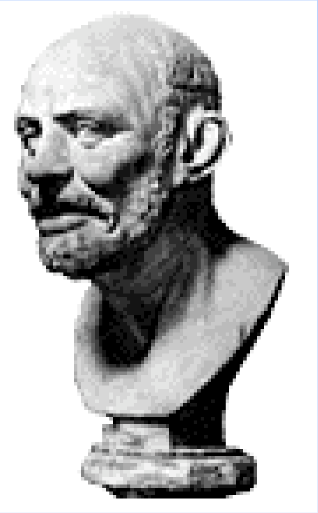
Element Abundance



http://www.webelements.com/

Early Models of the Atom

DEMOCRITUS (460 - 370 BC)



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 (*handout*)

"Atoms cannot be created or destroyed"

"Atoms of one element are different from other element's atoms"

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

Studied gases to develop his theory

Did not include Democritus' ideas that atoms have structure

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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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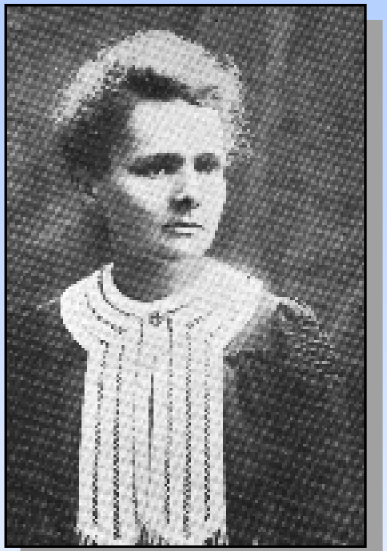
Radioactivity

- **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...

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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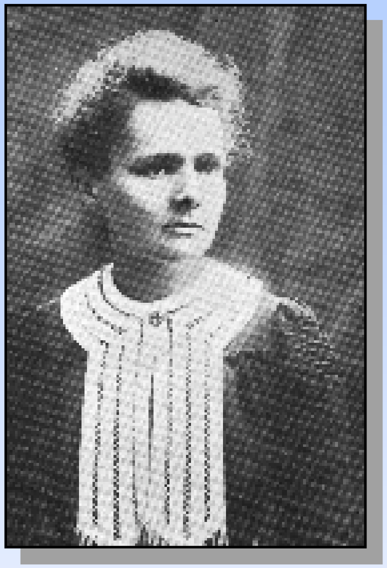
Marie Curie



the "Newton of Radioactivity"

She found three types of radiative processes:

alpha - a helium cation - □

beta - supercharged electrons - □

gamma - high energy emission - □

Note that □ and □ are massive and charged, but □ radiation has no charge or mass

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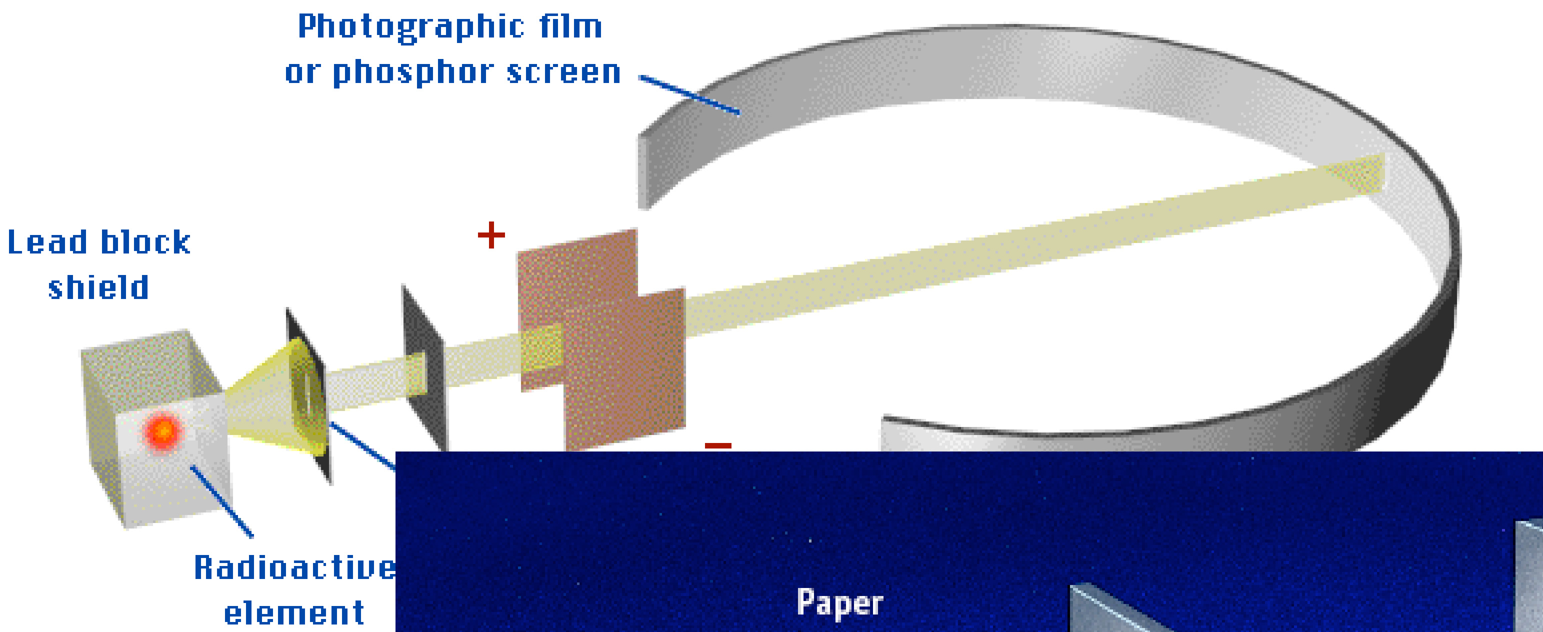
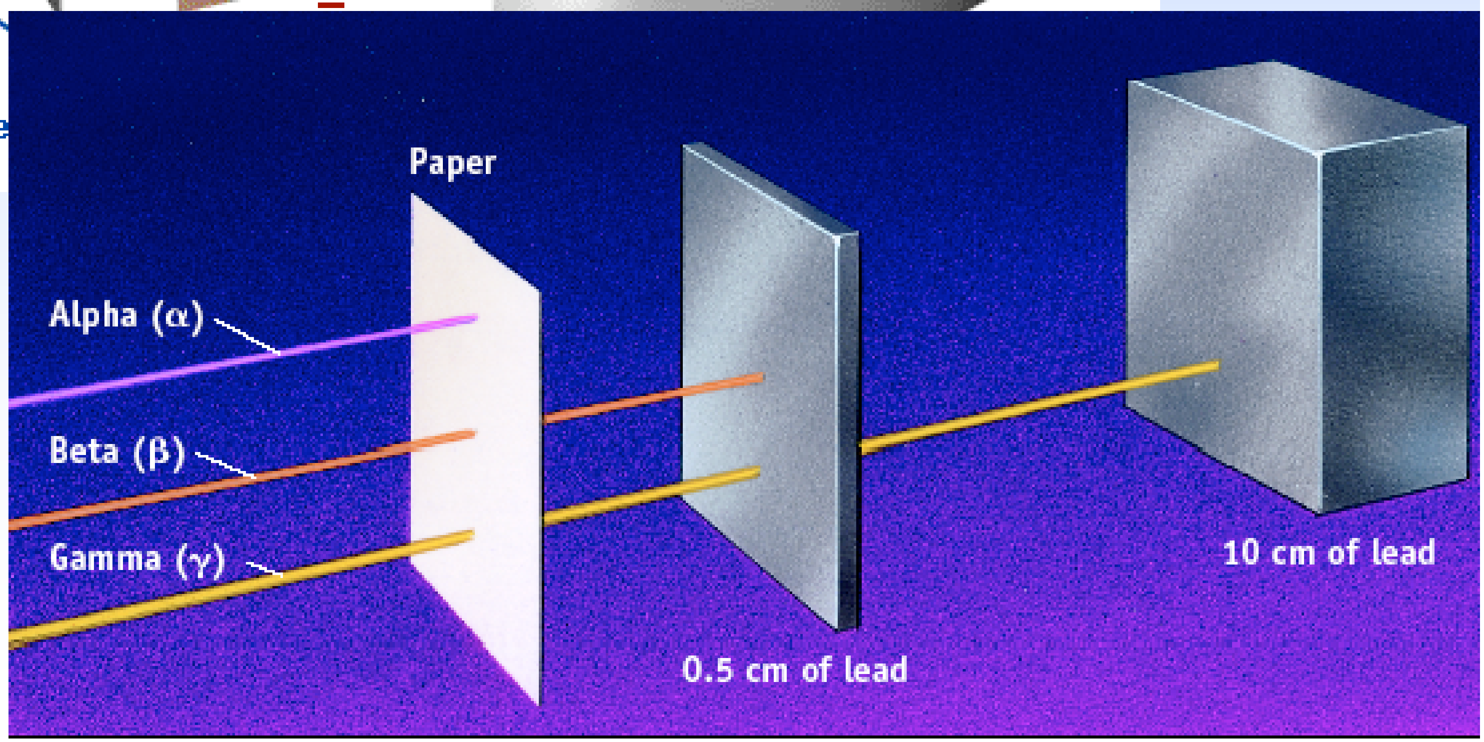
Discovering the Radioactive Particles





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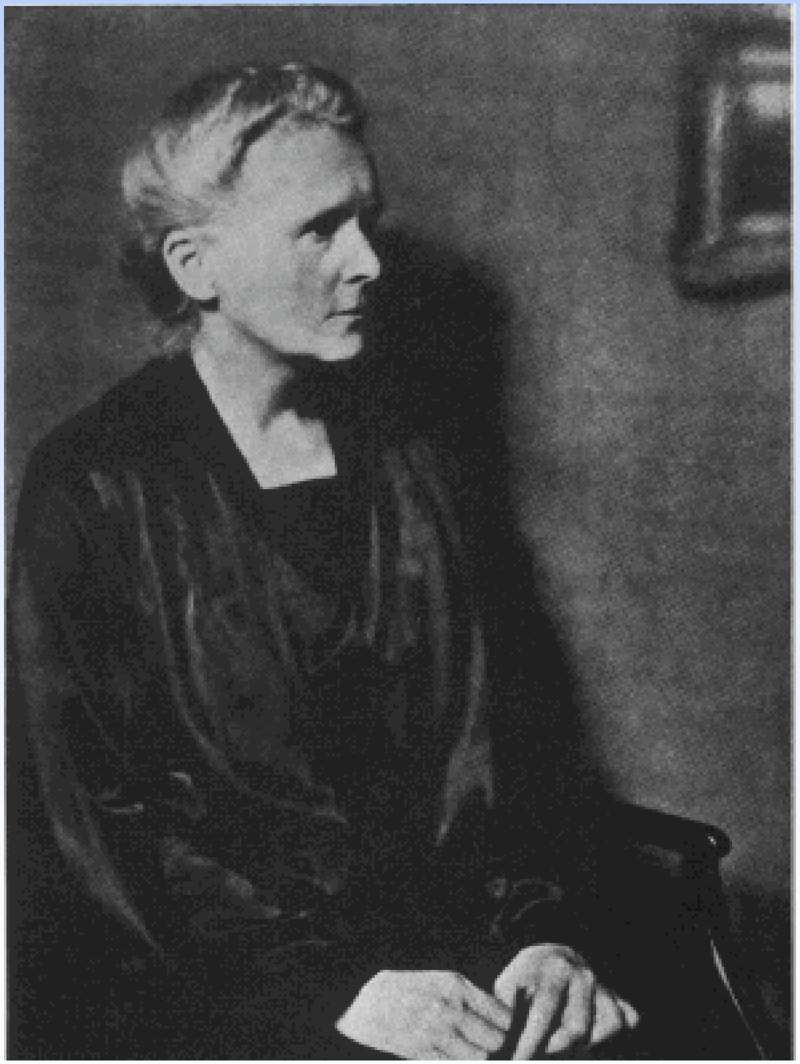
MARIE CURIE



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

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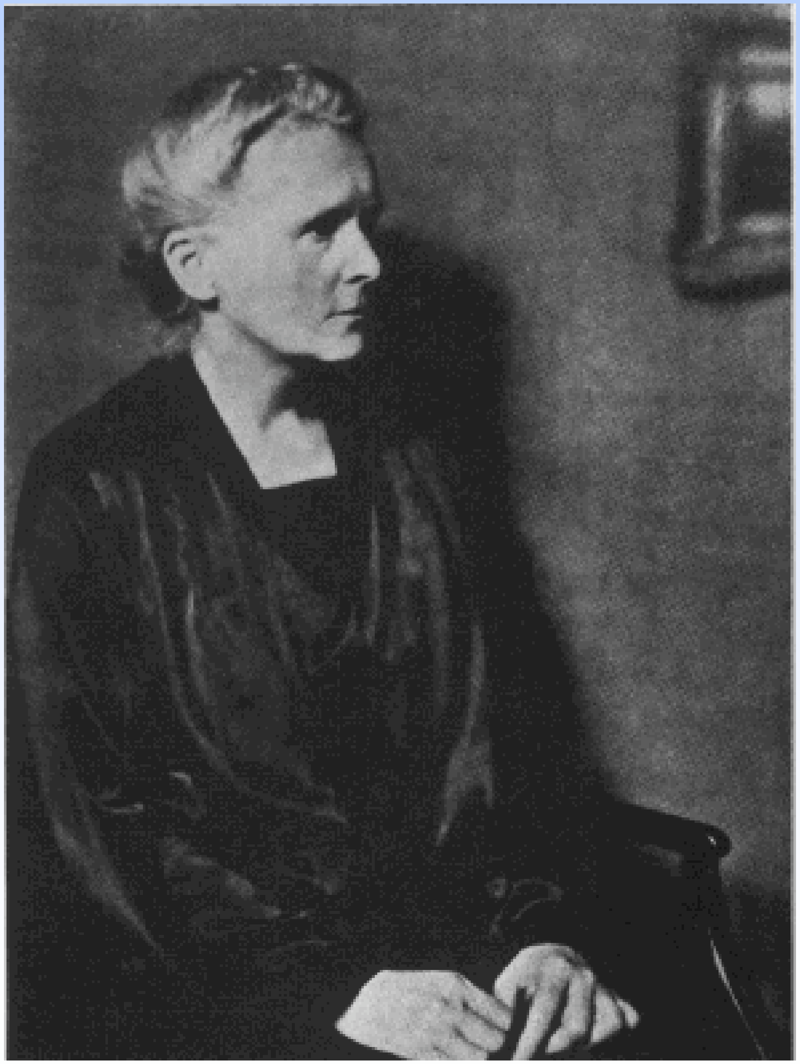
MARIE CURIE



Two time winner of Nobel Prize

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

"One never notices what has been done; one can only see what remains to be done."

Great chemist, physicist and scientist

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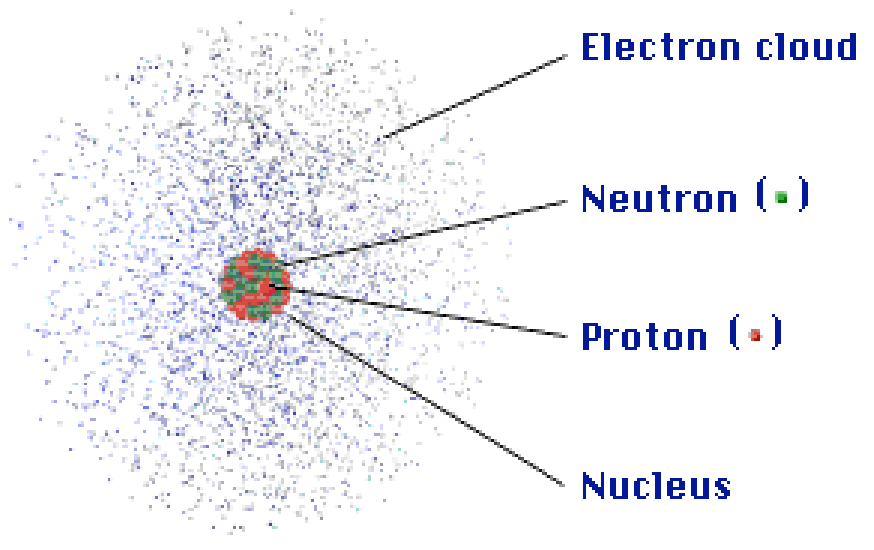
ATOM COMPOSITION



The atom is mostly **empty space**

protons & **neutrons** in **nucleus**

electrons = # **protons**

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.

MAR

ATOMIC COMPOSITION

(Three Particles Handout)

- **Protons**
  - positive electrical charge
  - mass = 1.672623 x 10^{-24} g
  - relative mass = 1.007 atomic mass units (amu)
- **Electrons**
  - negative electrical charge
  - relative mass = 0.0005 amu
- **Neutrons**
  - no electrical charge
  - mass = 1.009 amu

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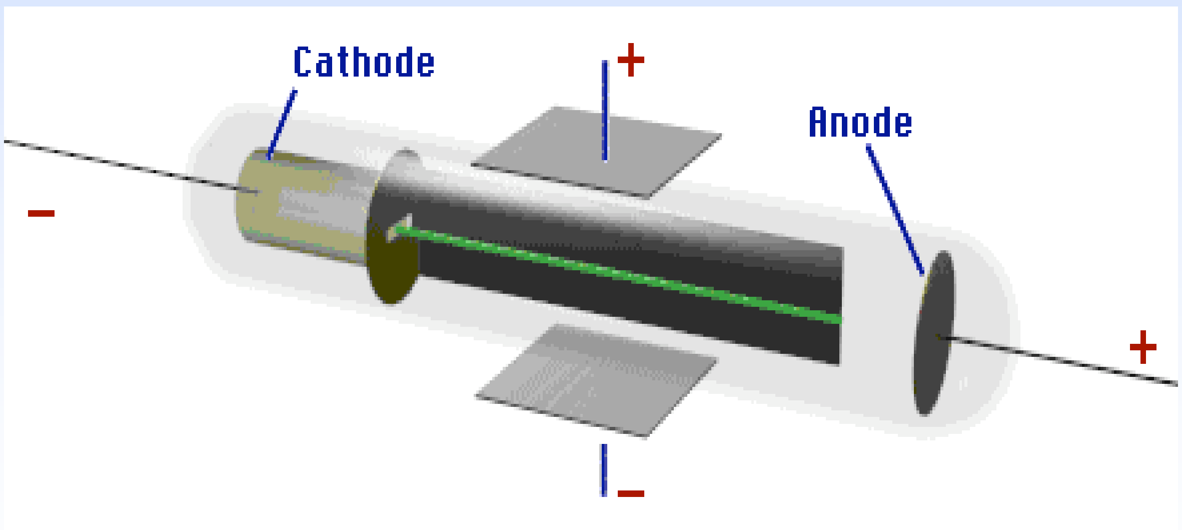
ELECTRONS

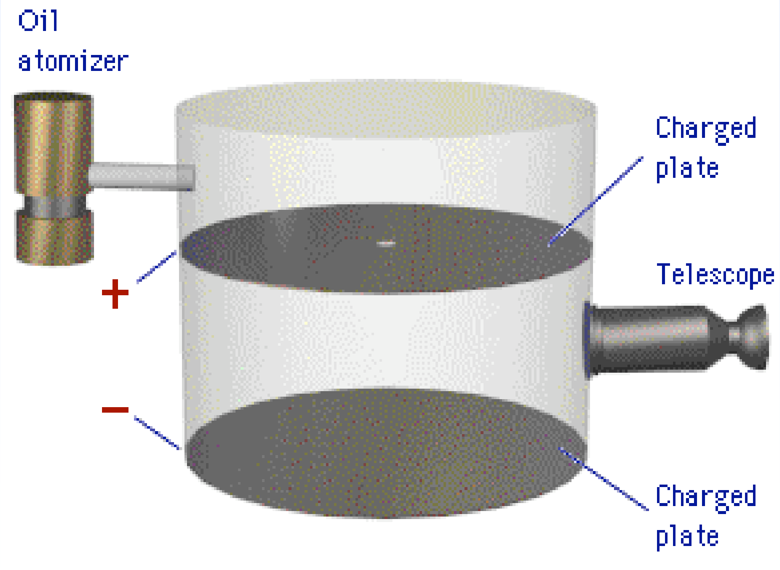
Charge to mass ratio of the electron discovered in 1897 by JJ Thompson using Cathode Ray Tubes (CRT)



ELECTRONS

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

Robert Millikan discovered the mass of the electron in 1913



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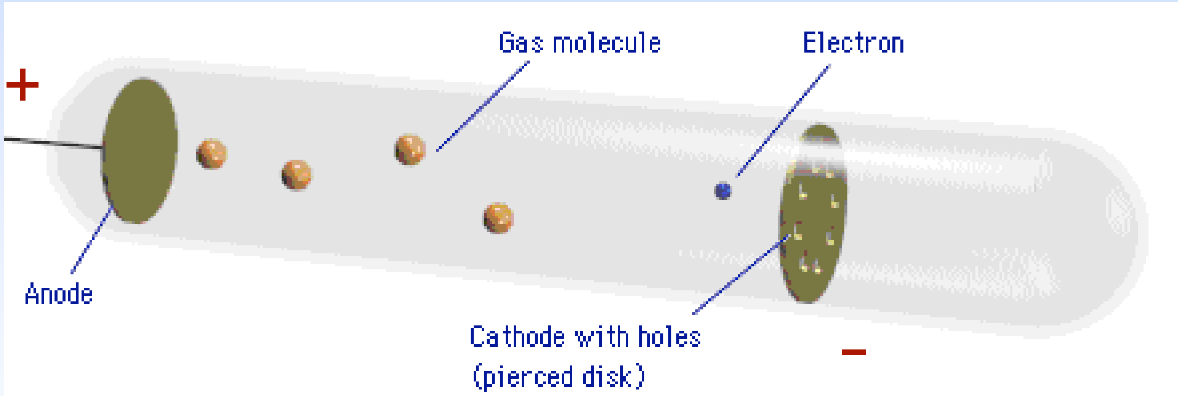
PROTONS

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

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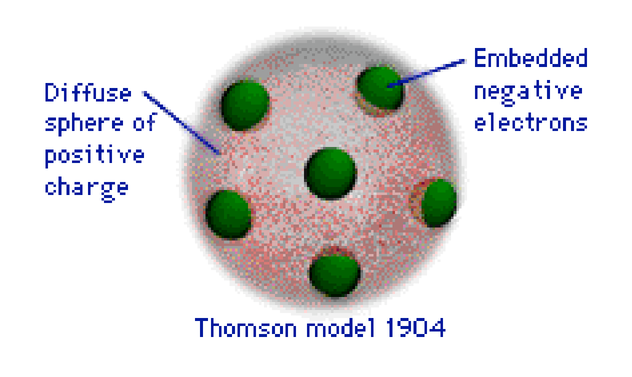
THE ATOM: *Plum Pudding Model*

JJ Thompson (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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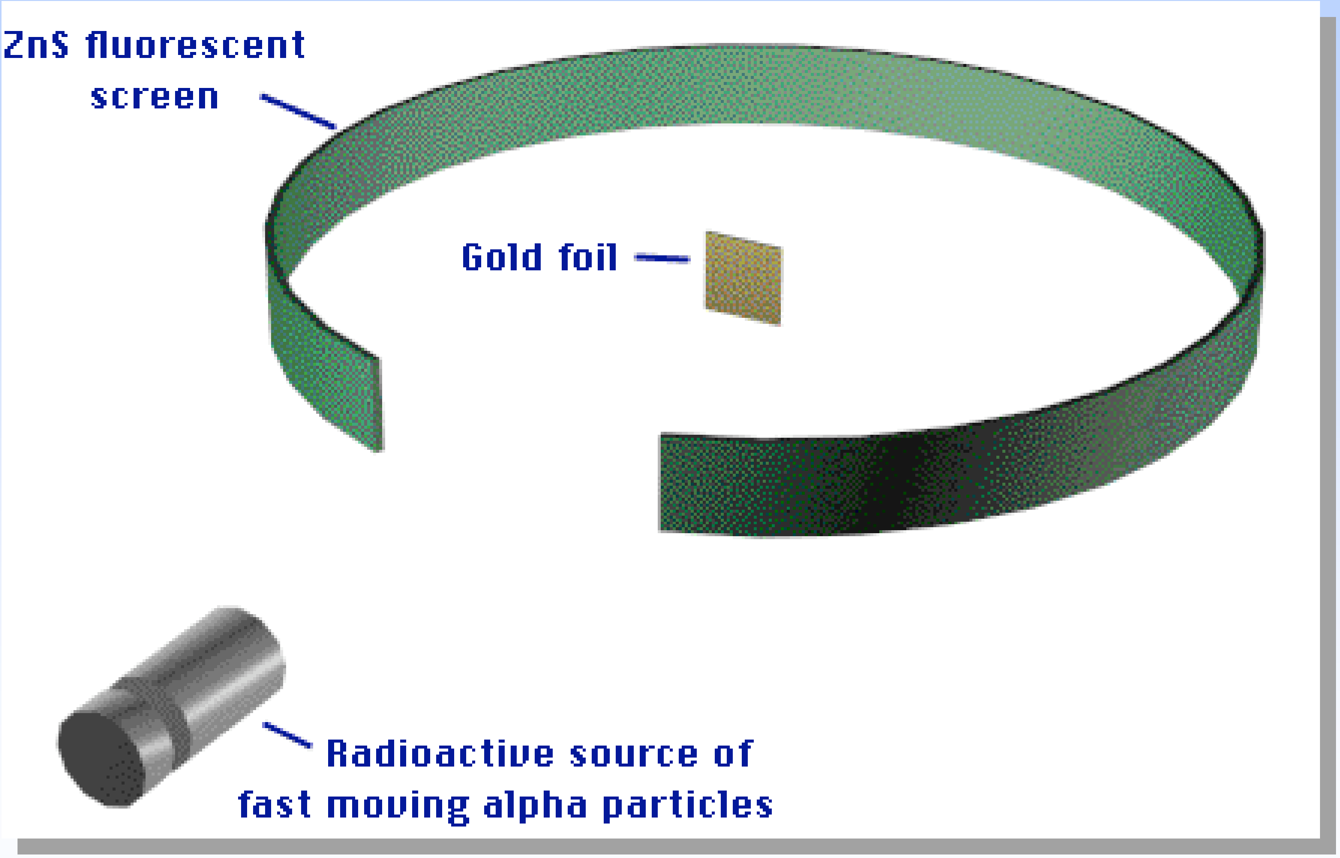
The modern view of the atom was developed by Ernest Rutherford in 1909.



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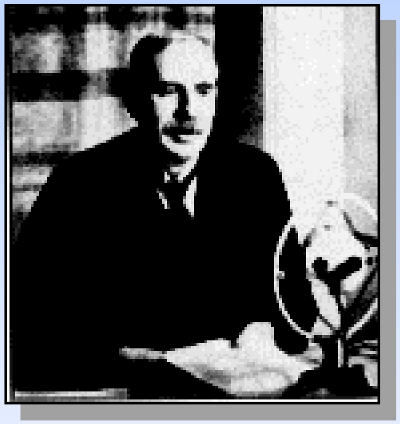
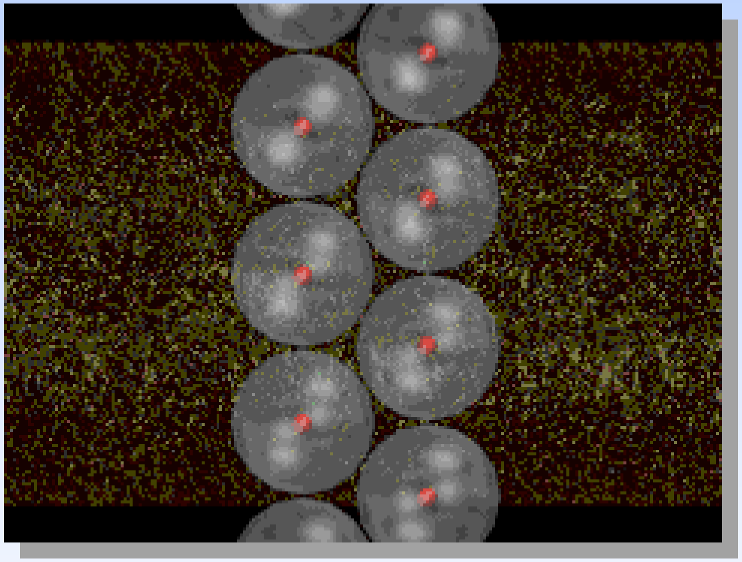
RUTHERFORD





Low density atom with a highly dense, positively charged nucleus

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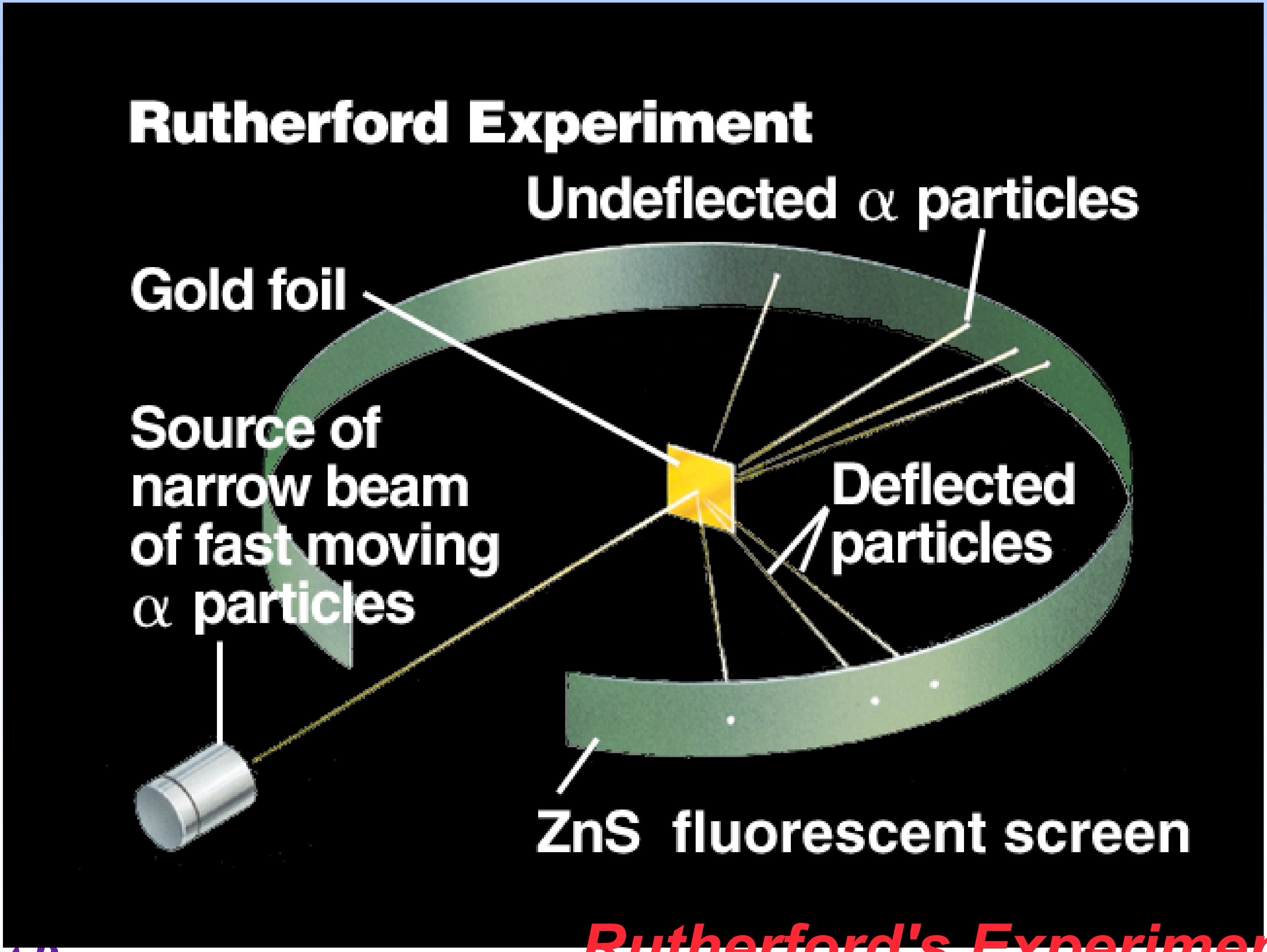

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Rutherford's Experiment

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 # protons = # electrons

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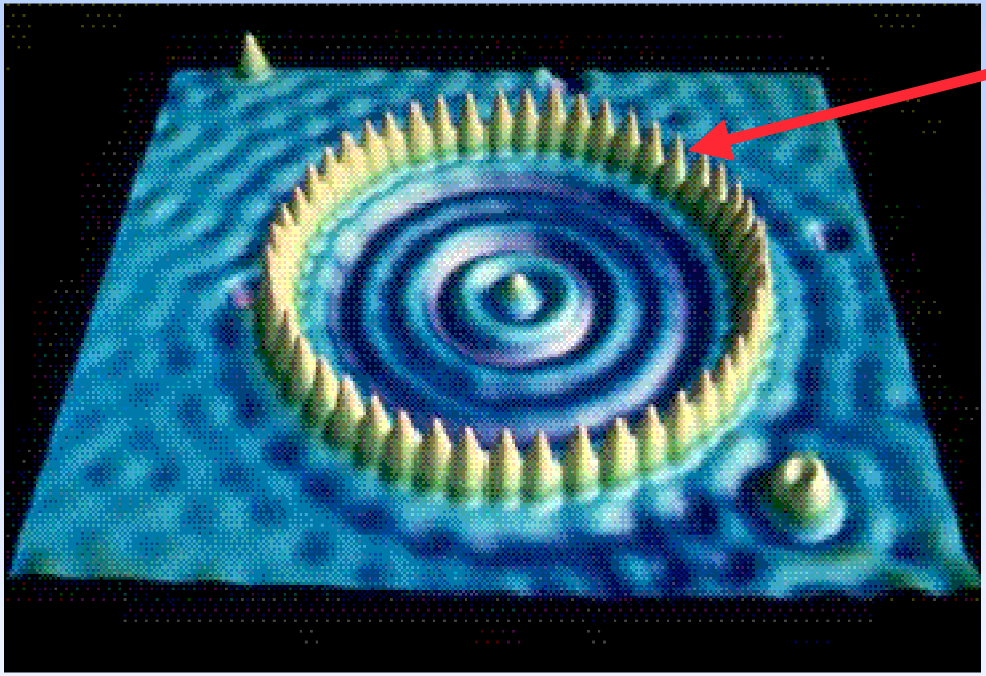
How Large is an Atom?



STM image of “quantum corral” of iron atoms

Circle consists of 48 Fe atoms

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

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

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Made using 35 Xe atoms on a Ni surface
by Don Eigler at IBM (1989)
Pioneer in nanotechnology field

PREPARE
FOR A JOURNEY
INTO
INNER SPACE

We use special mass numbers for atoms since they are so small

1 teaspoon **of water has 3 times as many atoms as the Atlantic Ocean has teaspoons of water!** ***Wow!***

Atomic Mass Units (amu) defined as $^{1}/_{12}$ of a carbon-12 atom

1 amu = $1.66 * 10^{-24}$ g,

somewhat smaller than protons and neutrons

Size of the Atom

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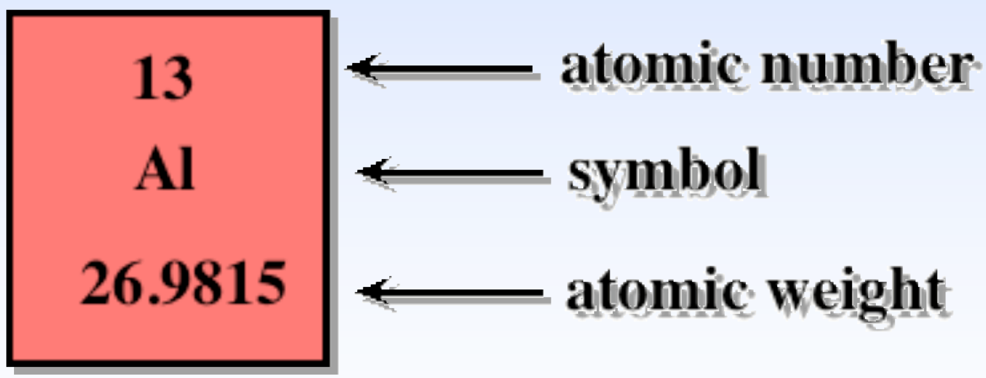
Atomic Number, Z

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



Z distinguishes atoms from one another!

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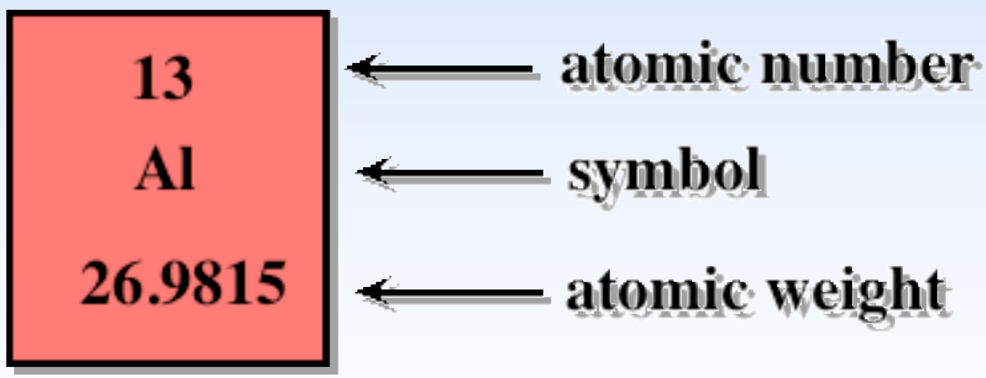
Atomic Number, Z

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



- **All carbon atoms have 6 protons**
- **All aluminum atoms have 13 protons, *etc.***

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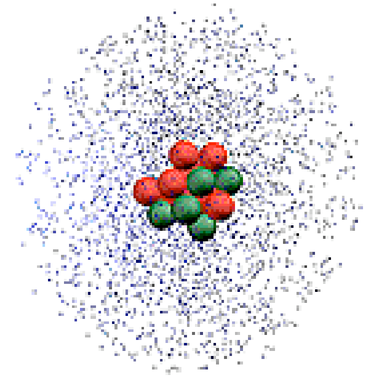
Mass Number, A

- **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

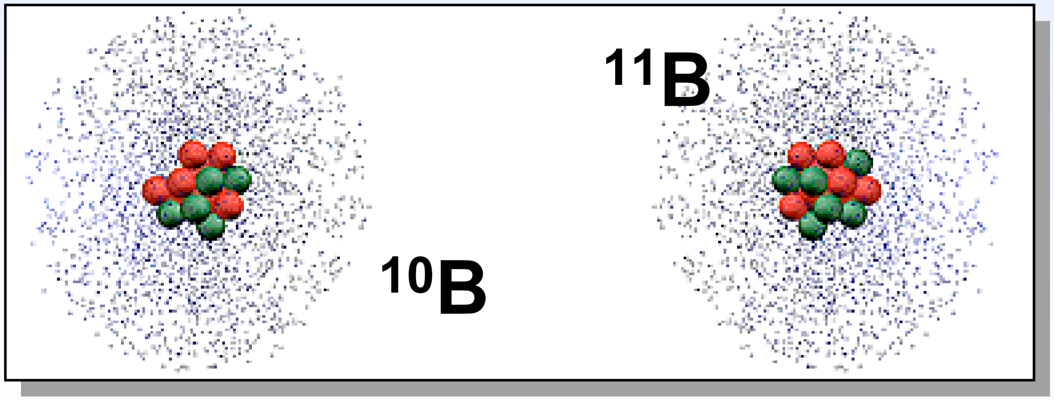
$^{10}_{5}\mathrm{B}$



Boron-10, ^{10}B

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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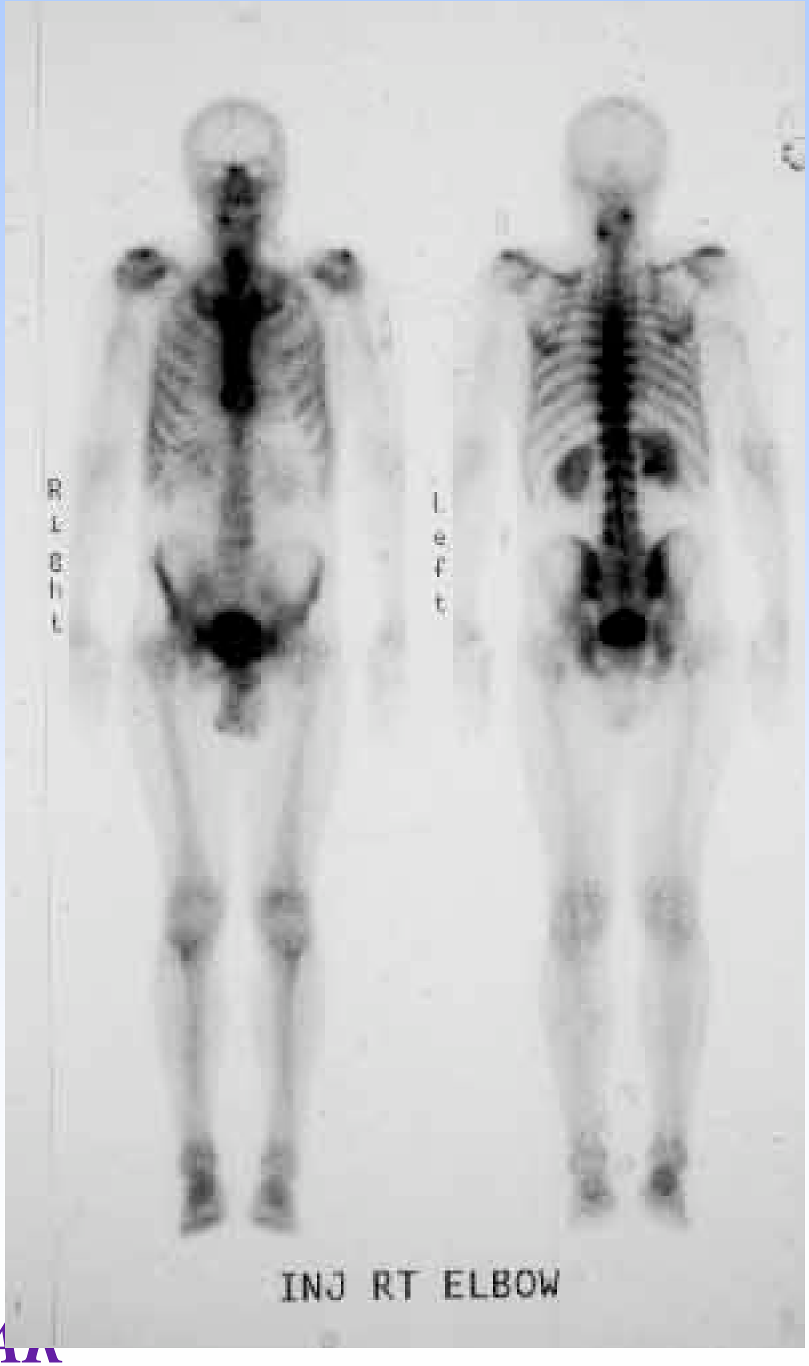

Isotopes & Their Uses

Bone scans with radioactive technetium-99.

$^{99}_{43}Tc$

Emits gamma rays

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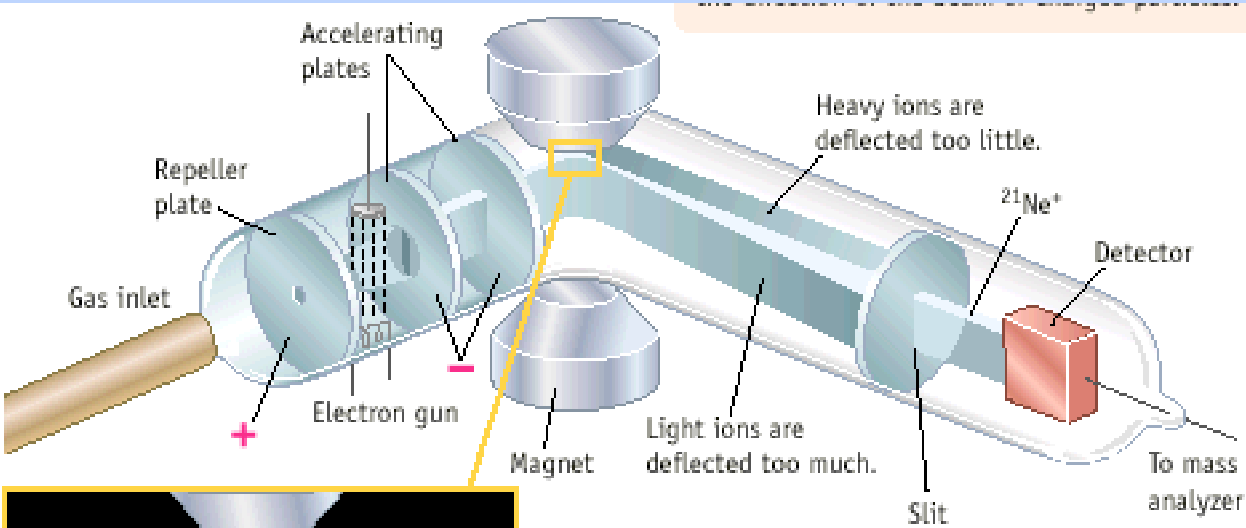
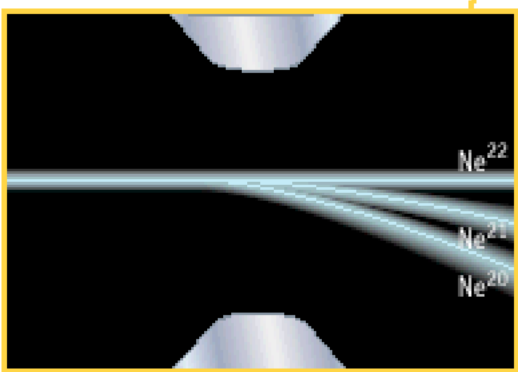
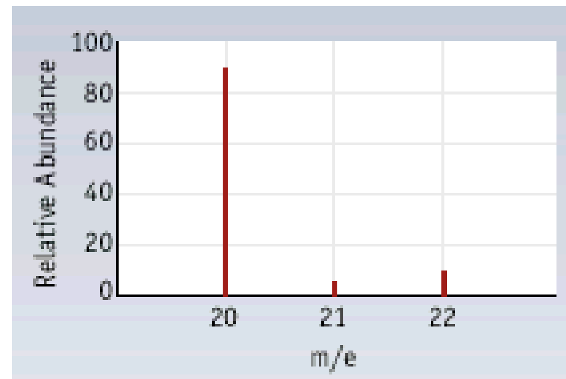
Masses of Isotopes

determined with a mass spectrometer





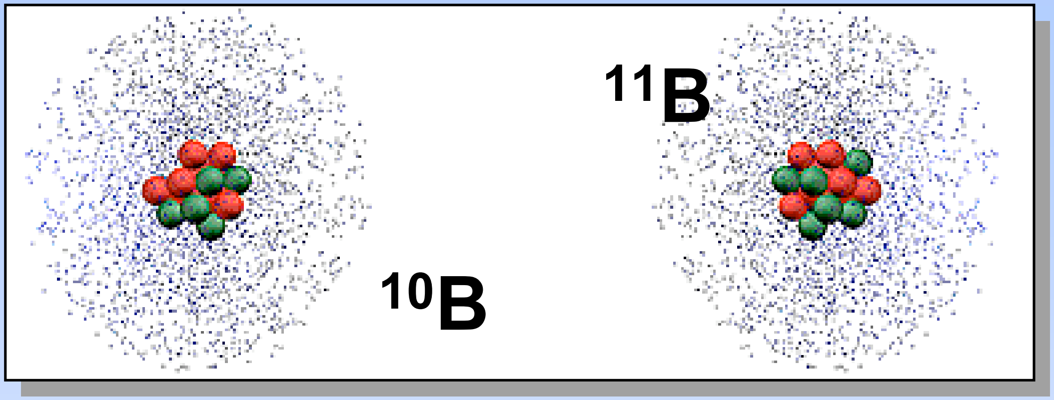
The magnetic field causes the beam to curve (see Chapter Focus). The radius of curvature depends on the mass and charge of the particles (as well as the accelerating voltage and strength of the magnetic field).



A *mass spectrum* is a plot of the relative abundance of the charged particles versus the ratio of mass/charge. Here particles of $^{21}Ne^+$ are focused on the detector, whereas beams of ions of $^{20}Ne^+$ and $^{22}Ne^+$ (of lighter or heavier mass) experience greater and lesser curvature, respectively, and so fail to be detected. By changing the magnetic field, a beam of charged particles of different mass can be focused on the detector, and a spectrum of masses is observed.

Figure 2.5 Mass spectrometer.

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

Example: **Nitrogen has two main isotopes, ^{14}N (14.0031 amu, 99.63%) and ^{15}N (15.0001 amu, 0.37%). Calculate the average atomic mass.**

Solution

Average atomic mass =

= (0.9963*14.0031) + (0.0037*15.0001)

= 13.9513 + 0.0555

= 14.0068 amu

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Isotopes

Example: **Nitrogen has two main isotopes, ^{14}N (14.0031 amu) and ^{15}N (15.0001 amu) with an average atomic mass of 14.0068. Calculate the % abundance of each isotope.**

Solution

Average atomic mass =

$$14.0068 = x(^{14}N)*14.0031 + y(^{15}N)*15.0001$$

Let $z = x(^{14}N)$

$$1 = x(^{14}N) + y(^{15}N) = z + y(^{15}N)$$

so $y(^{15}N) = 1 - z$

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Isotopes

Example: **Nitrogen has two main isotopes, ^{14}N (14.0031 amu) and ^{15}N (15.0001 amu) with an average atomic mass of 14.0068. Calculate the % abundance of each isotope.**

Solution

$$14.0068 = x(^{14}N)*14.0031 + y(^{15}N)*15.0001, \textit{ or}$$

$$14.0068 = z*14.0031 + (1 - z)*15.0001$$

Solve for z

$$z = x(^{14}N) = 0.9963 \quad (99.63\%)$$

$$y(^{15}N) = 1 - z = 0.0037 \quad (0.37\%)$$

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Isotopes

Nitrogen has two main isotopes, ^{14}N (14.0031 amu) and ^{15}N (15.0001 amu) with an average atomic mass of 14.0068.

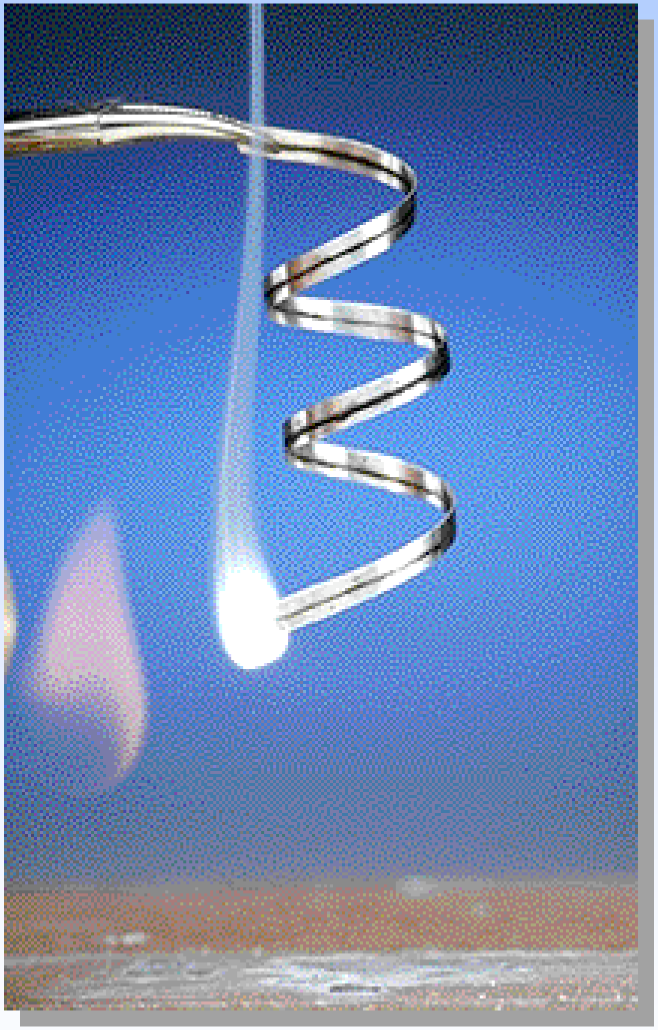
Will you have one atom of nitrogen with 14.0068 amu?

No!

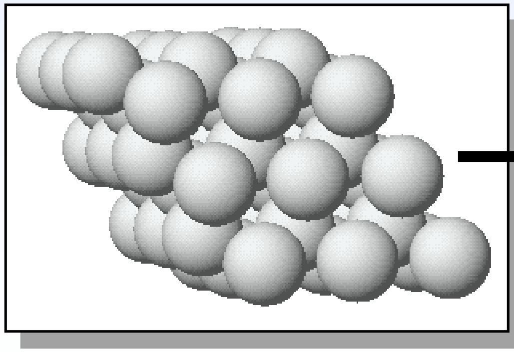
One atom of nitrogen will have a mass of 14.0031 amu 99.63% of the time

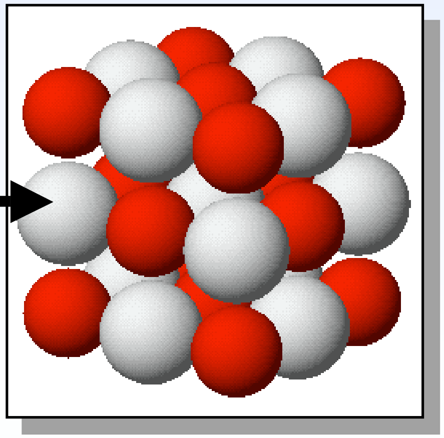
One atom of nitrogen will have a mass of 15.0001 amu 0.37% of the time

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?

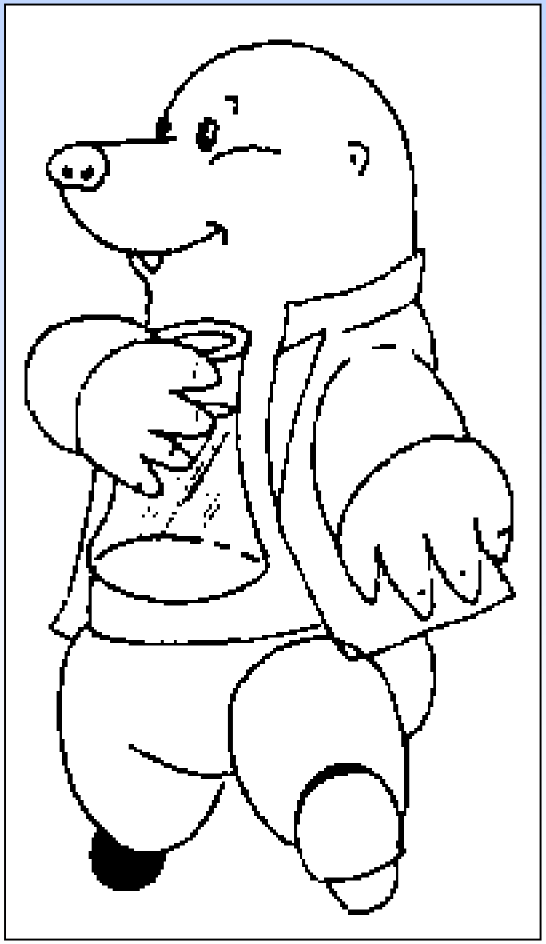




Counting Atoms

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

MOLE



1 mole is the amount of substance that contains as many particles (atoms, molecules) as there are in 12.0 g of ^{12}C.

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Particles in a Mole

Avogadro's Number

Amedeo Avogadro
1776-1856

$6.02214199 \times 10^{23}$

There is Avogadro's number of particles in a mole of any substance.

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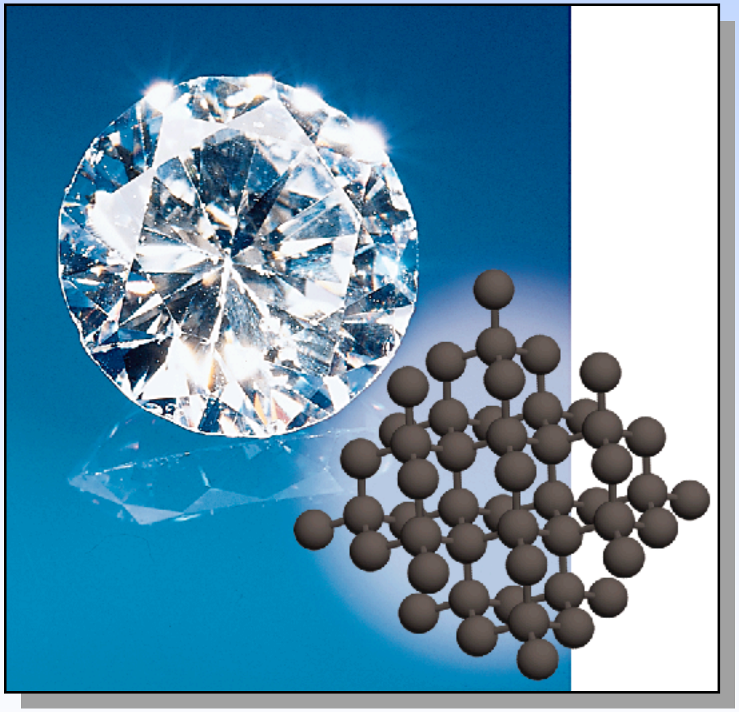
Molar Mass

1 mol of ^{12}C
= 12.00 g of C
= 6.022×10^{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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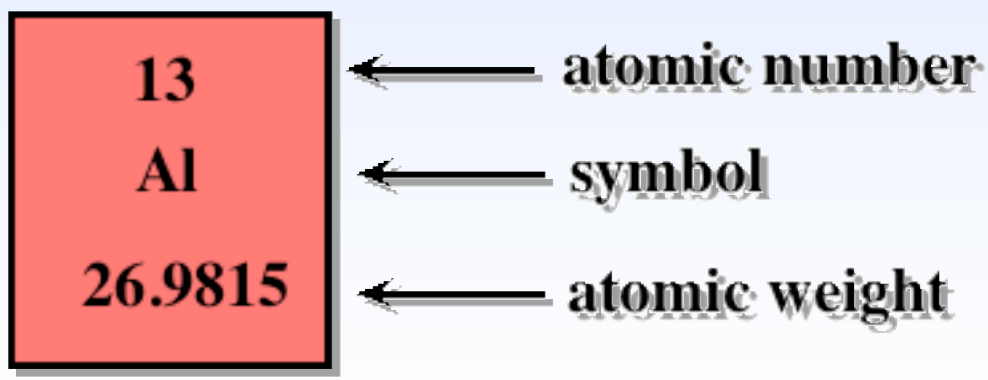
Molar Mass

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

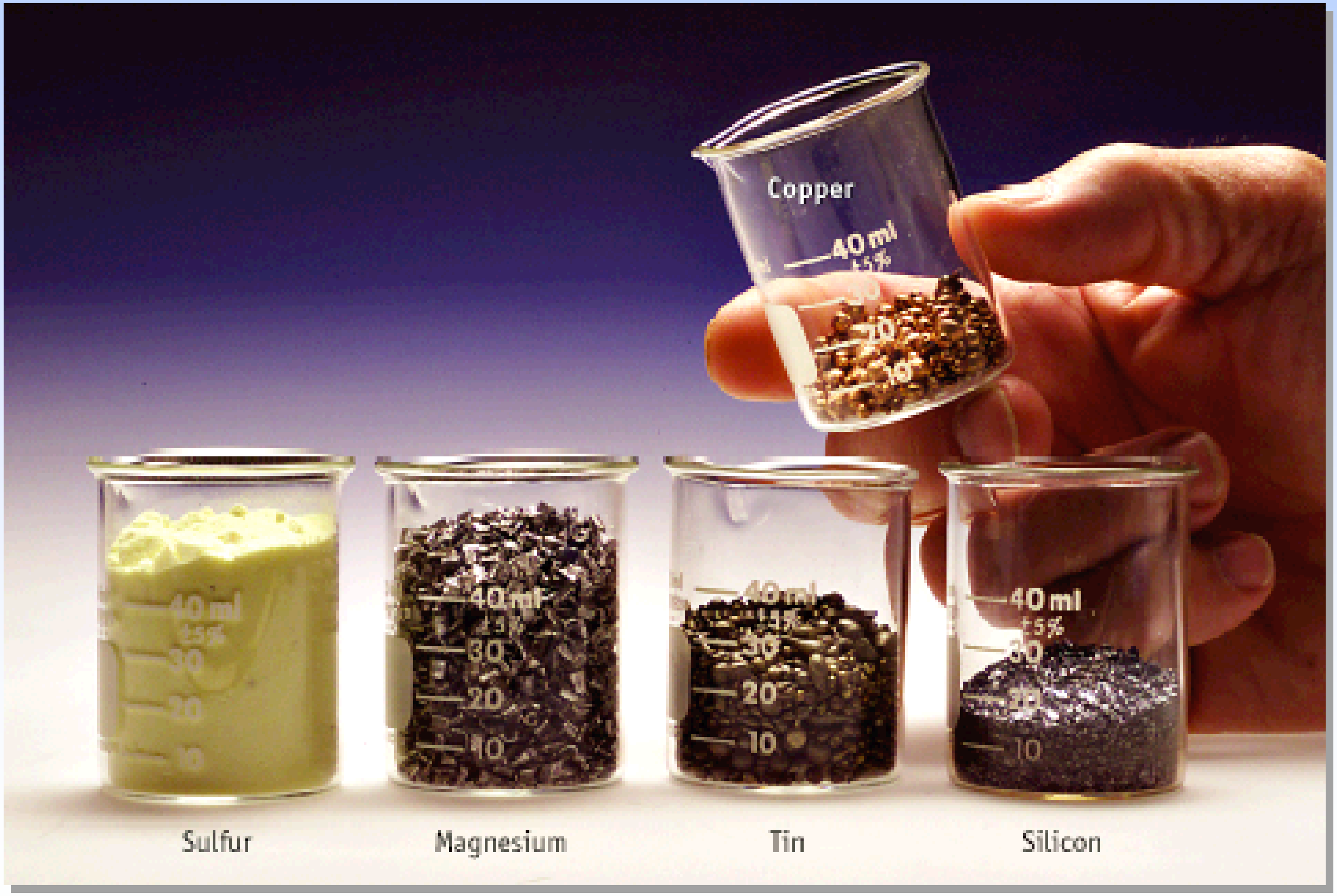
12.00 g of ^{12}C is its MOLAR MASS

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



One-mole Amounts



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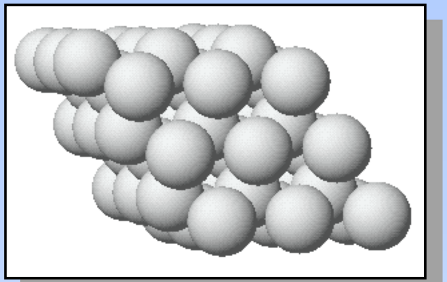

PROBLEM: What amount of Mg is represented by 0.200 g? How many atoms?

Mg has a molar mass of 24.3050 g/mol.

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

How many atoms in this piece of Mg?

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

$= 4.95 \times 10^{21}$ atoms Mg

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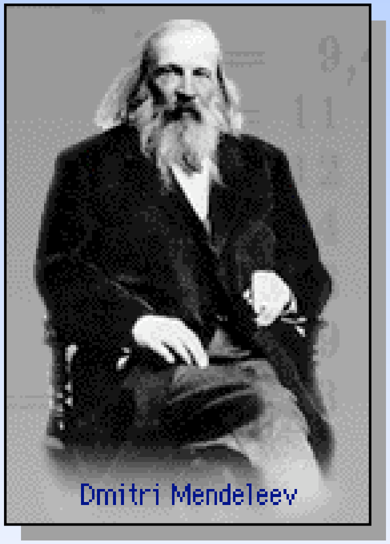
Periodic Table

- 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.



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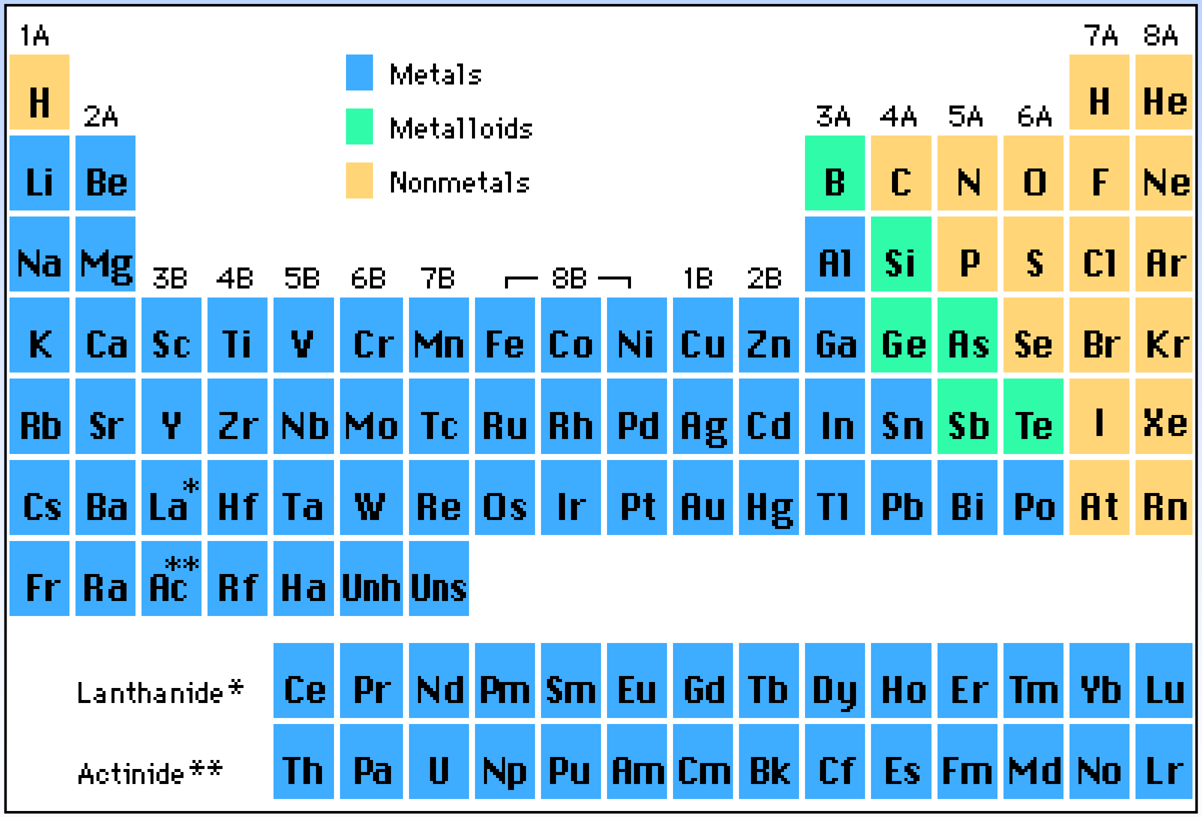
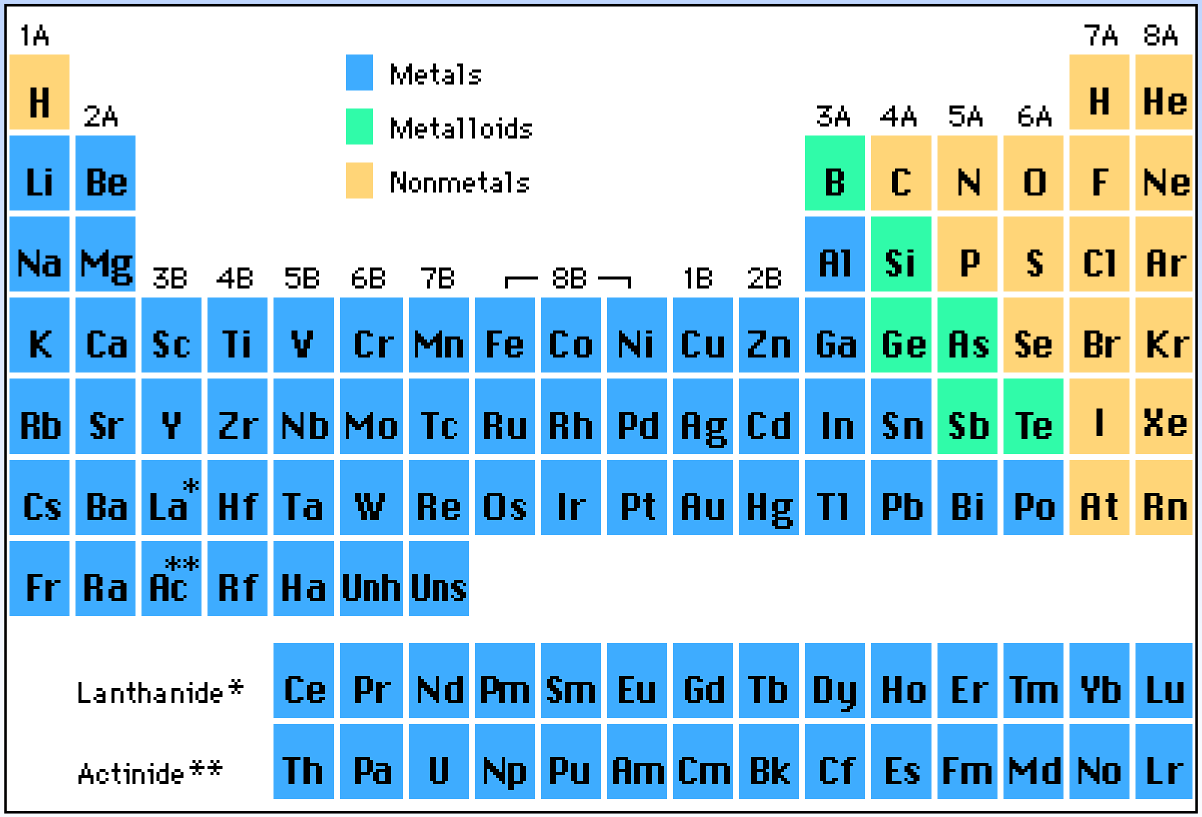
Periods in the Periodic Table



Groups in the Periodic Table



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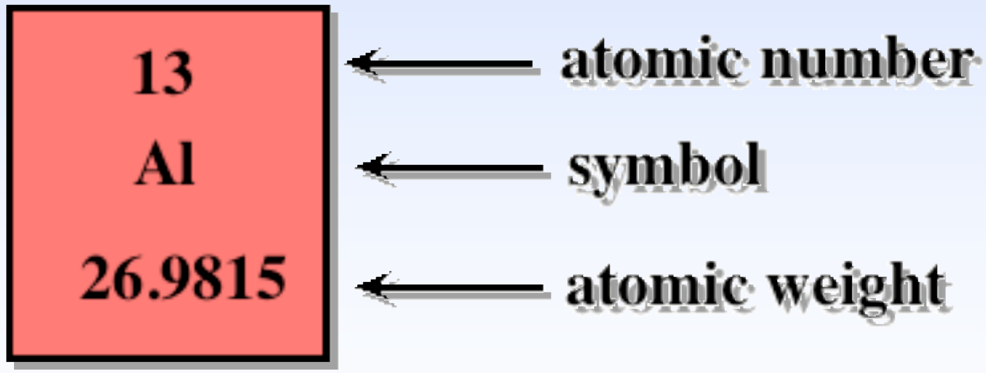
Periodic Table

Periodic Table organized around the atomic number, Z.



Entries include Z, average atomic mass, element symbol, *etc.*

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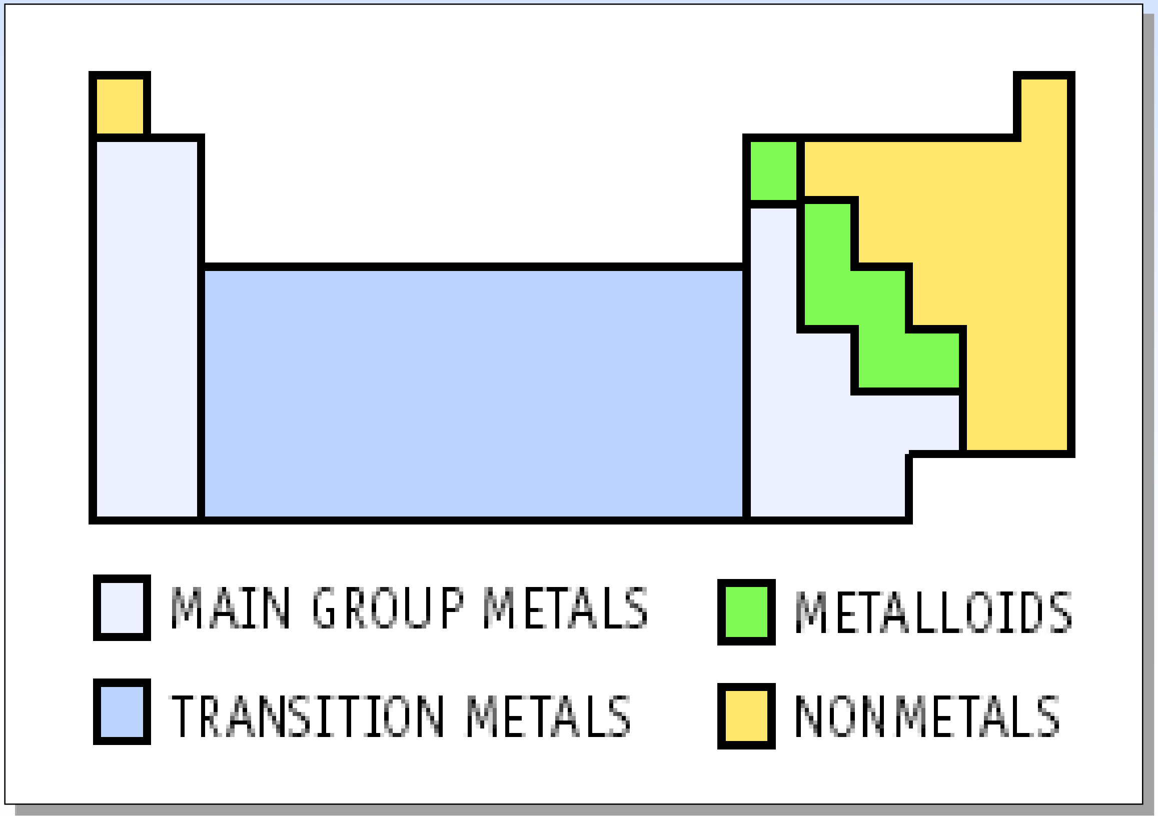
Periodic Table

Periodic Table has the following:

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



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Periodic Table

Important Group A Categories:

- Alkali Metals (1A): M^{+} compounds
- Alkaline Earth Metals (2A): M^{2+} compounds
- "Twisted" Metals (3A): M^{3+} compounds
- Pnictogens (5A): E^{3-} compounds
- Chalcogens ("chalk formers") (6A): E^{2-}
- Halogens ("salt formers") (7A): X^{-}
- Noble Gases (8A): *aka* "inert" or "rare earth"

Note that Mg^{2+} + O^{2-} -> MgO, *etc.*

balance of charge!

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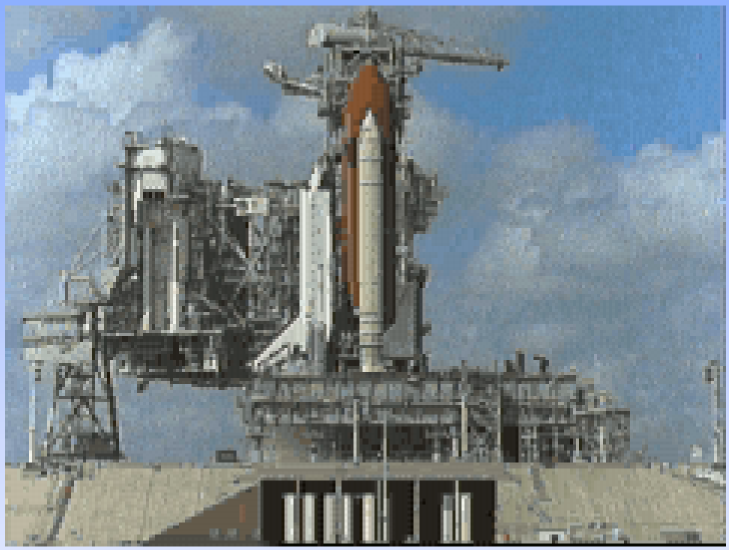
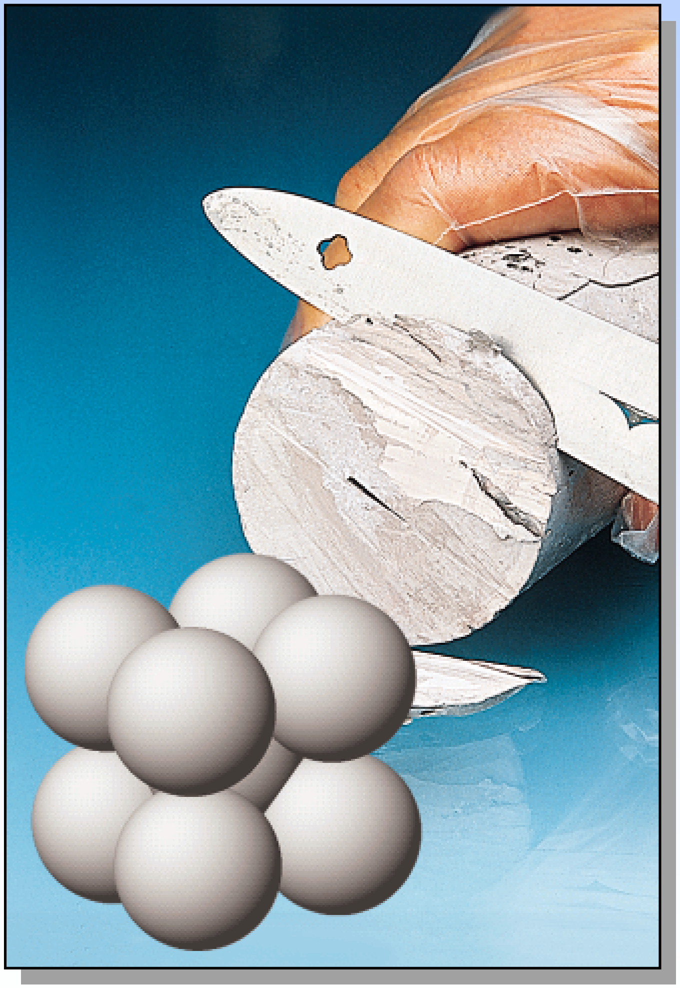
Hydrogen



Shuttle main engines use H_2 and O_2

The Hindenburg crash, May 1939.

Group 1A: Alkali Metals

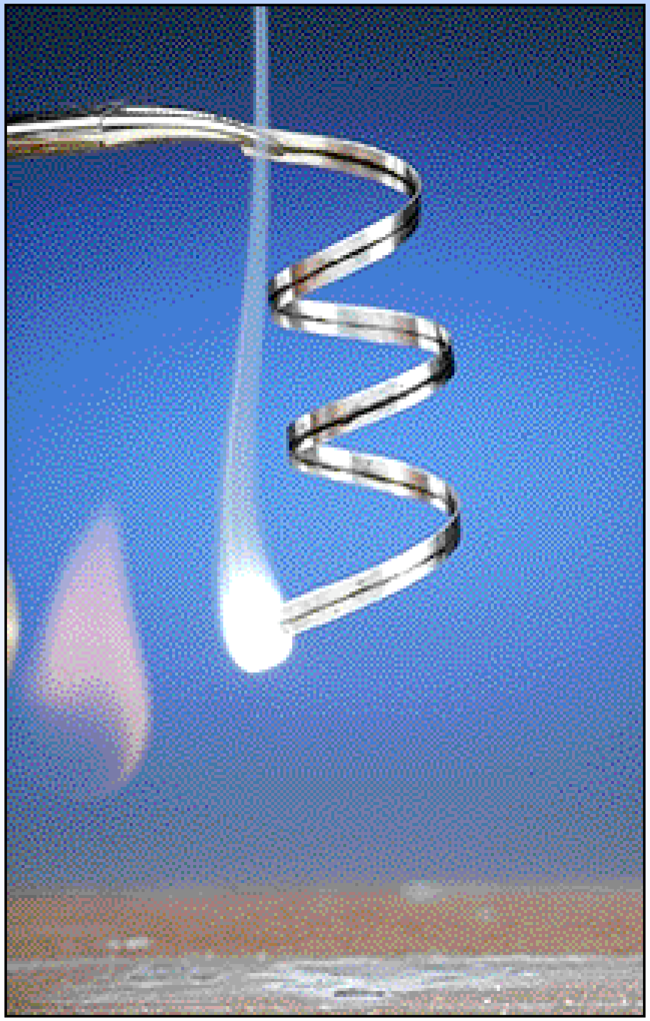


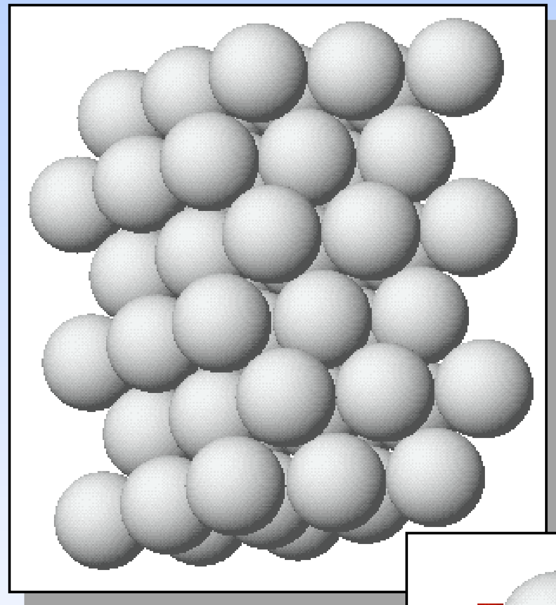
Reaction of potassium + H_2O

Cutting sodium metal

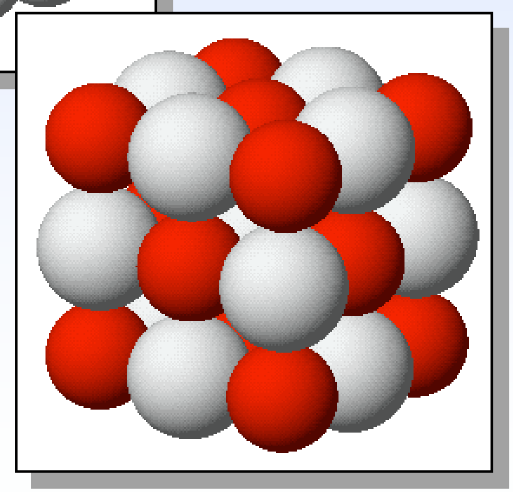
MAR

Group 2A: Alkaline Earth Metals



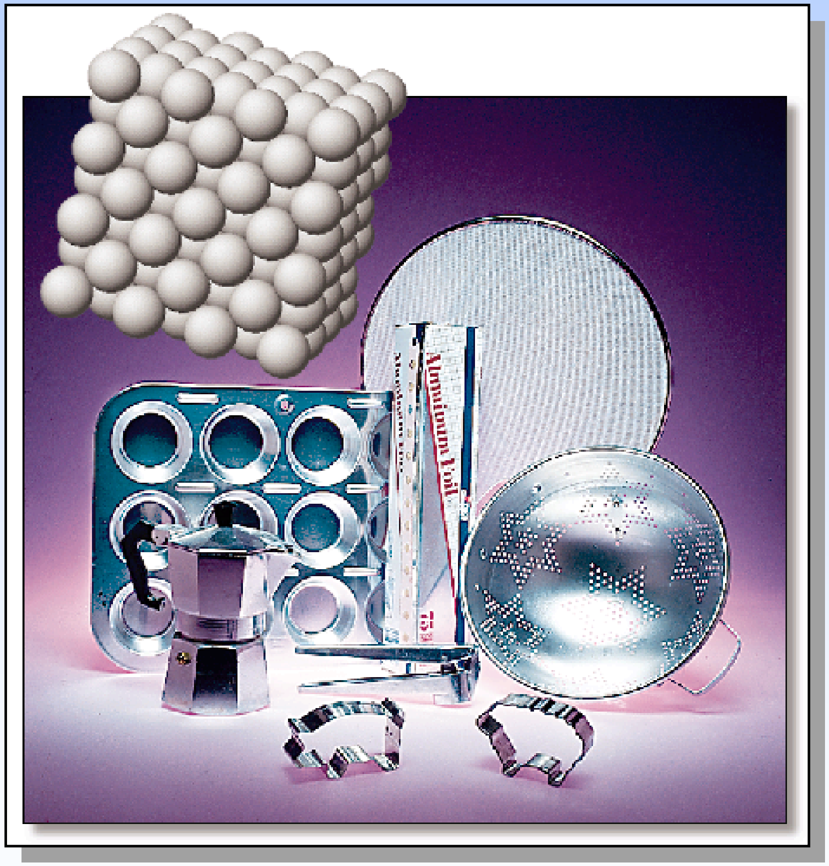


Magnesium

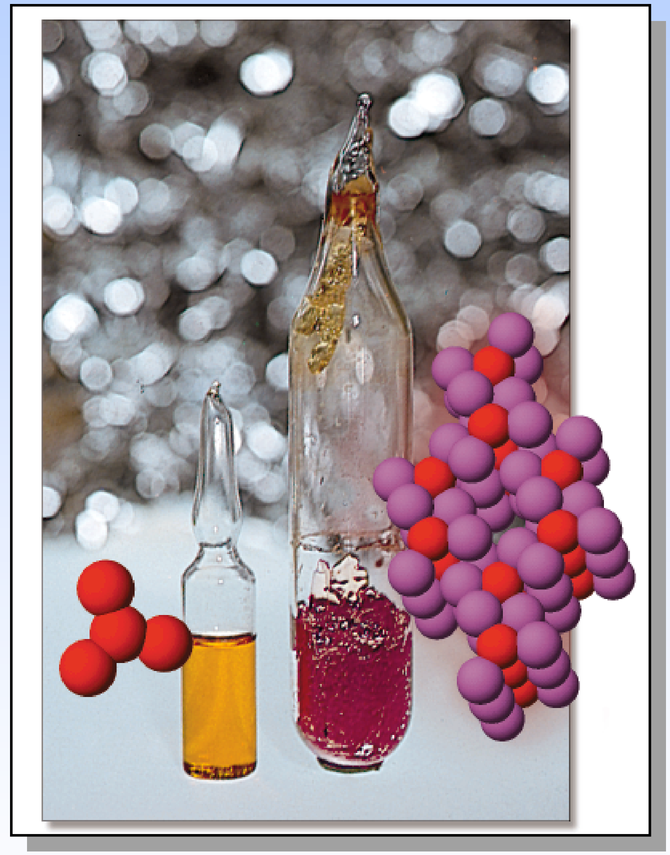


Magnesium oxide

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



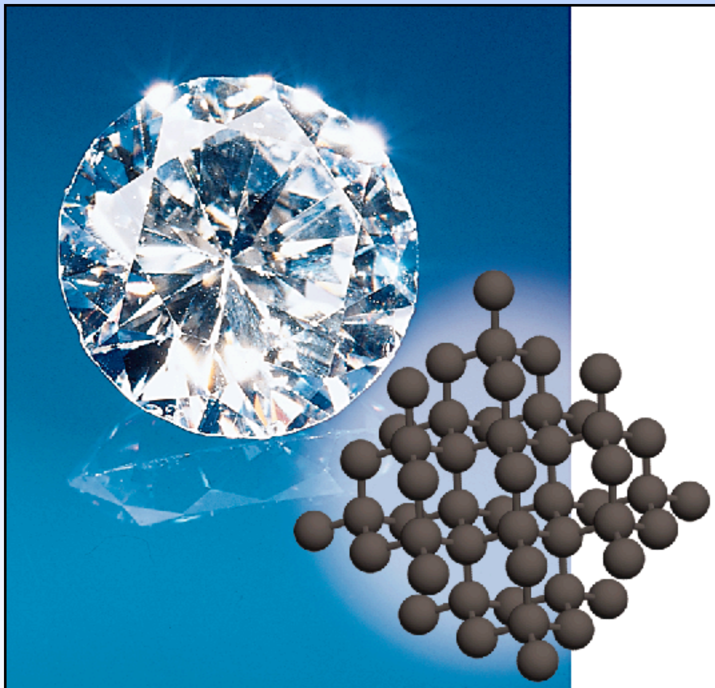
Aluminum



Boron halides, BF_3 & BI_3

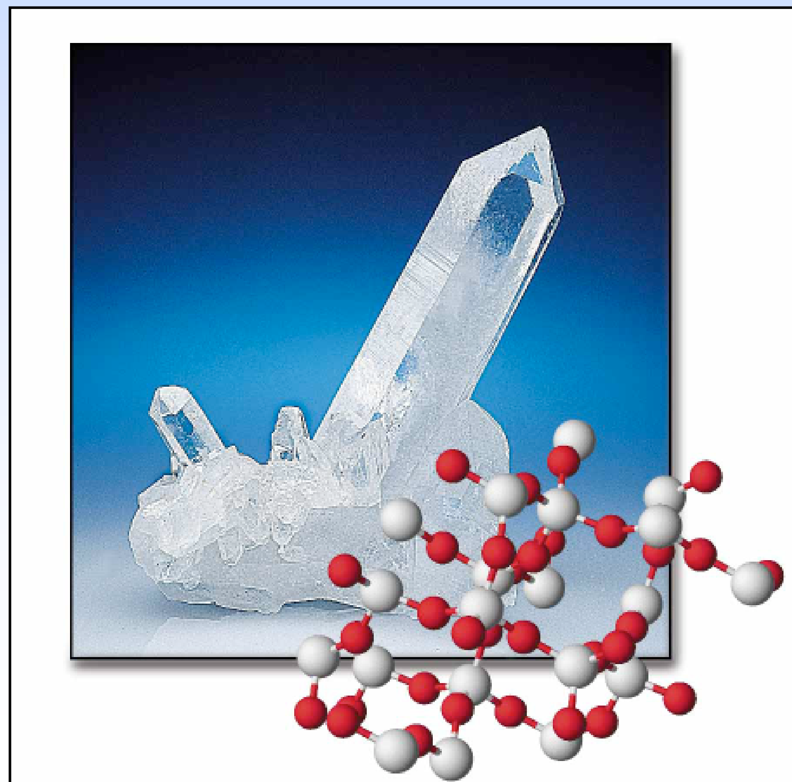
MAR

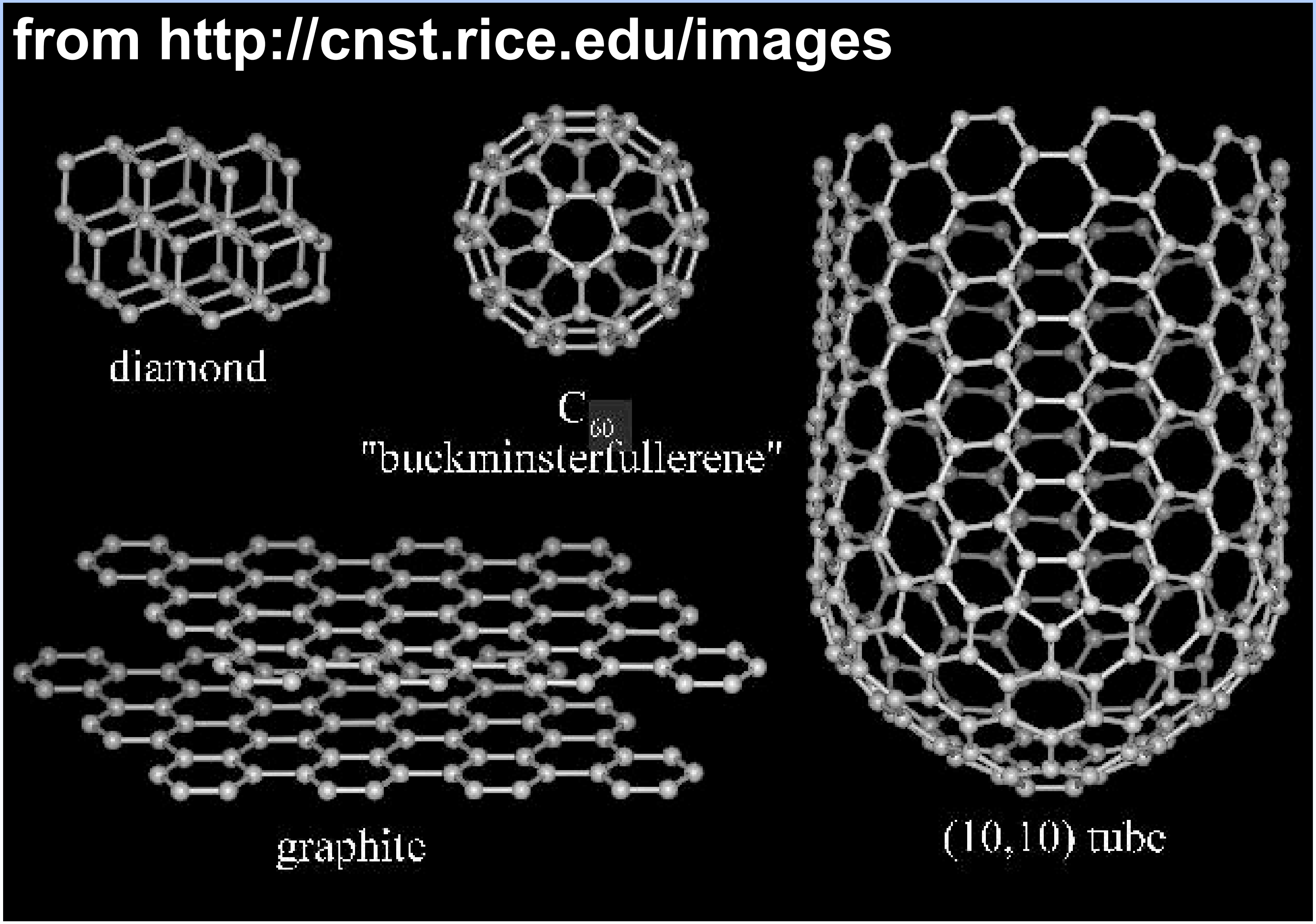
Group 4A: C, Si, Ge, Sn, Pb



Diamond

Quartz, SiO_2

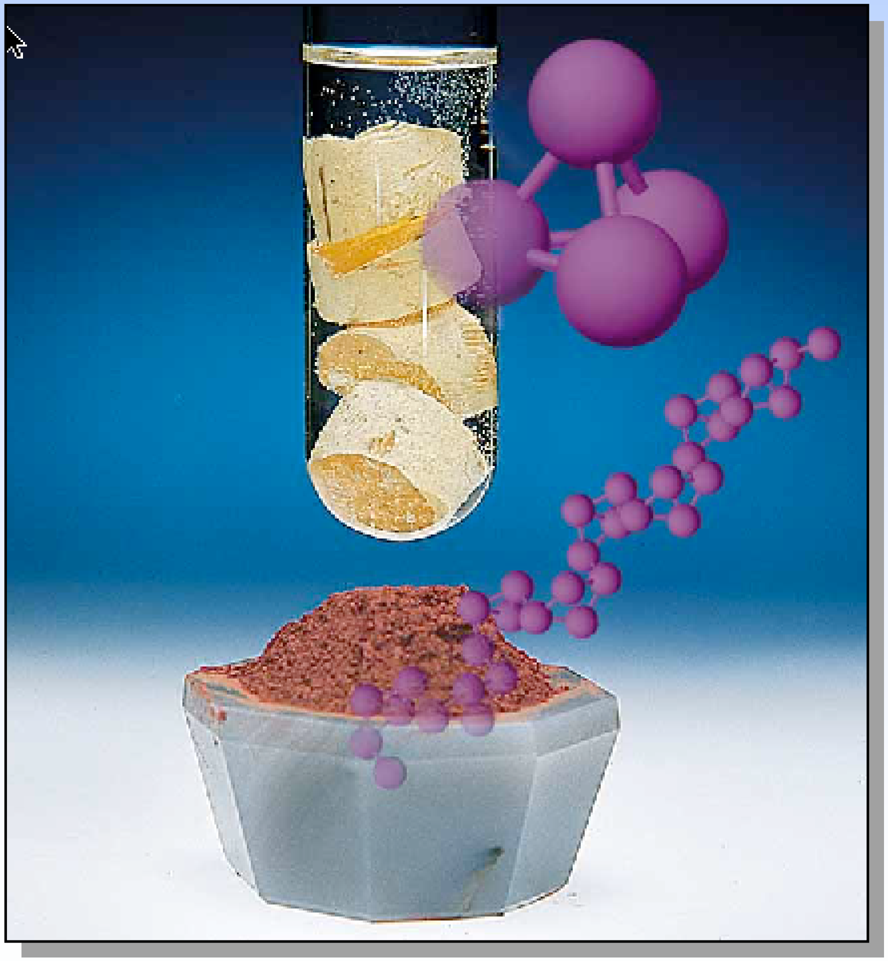


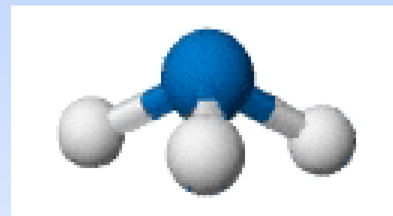


MAR

Allotropes of Carbon

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

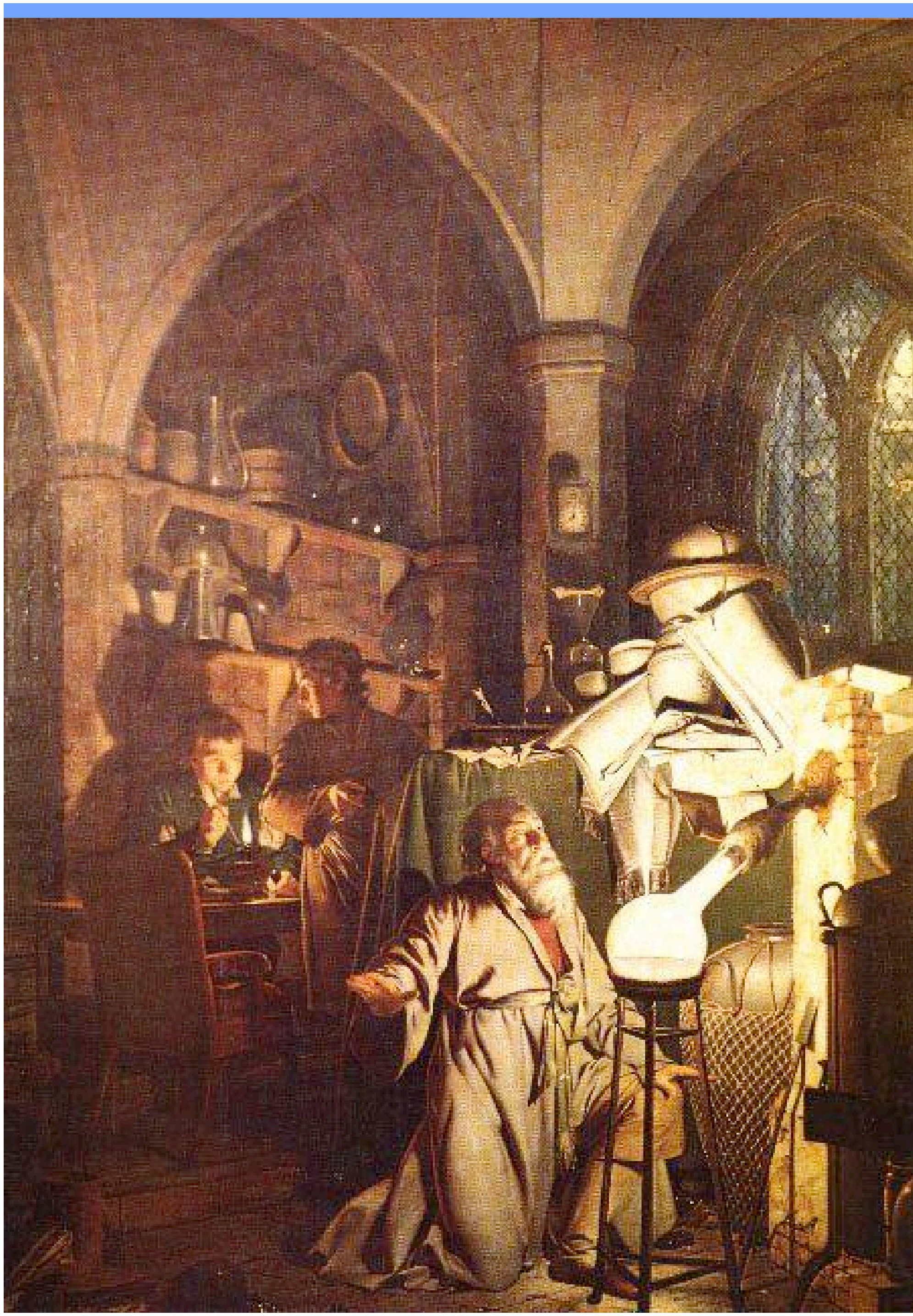




Ammonia, NH_3

White and red phosphorus

MAR



Phosphorus

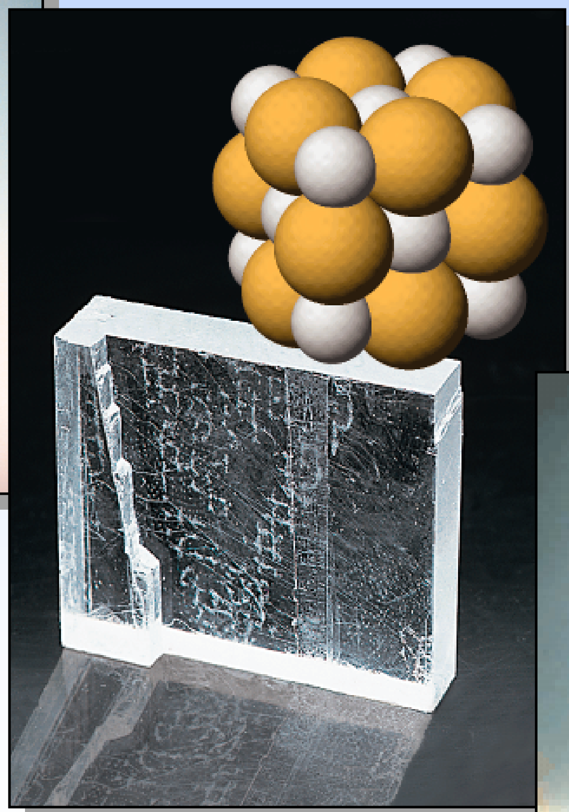
- **Phosphorus first isolated by Brandt from urine (!) in 1669**
- ***Most* chemists' jobs are not so "demanding"!!!**

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

Sulfuric acid dripping from a cave in Mexico

Sulfur from a volcano

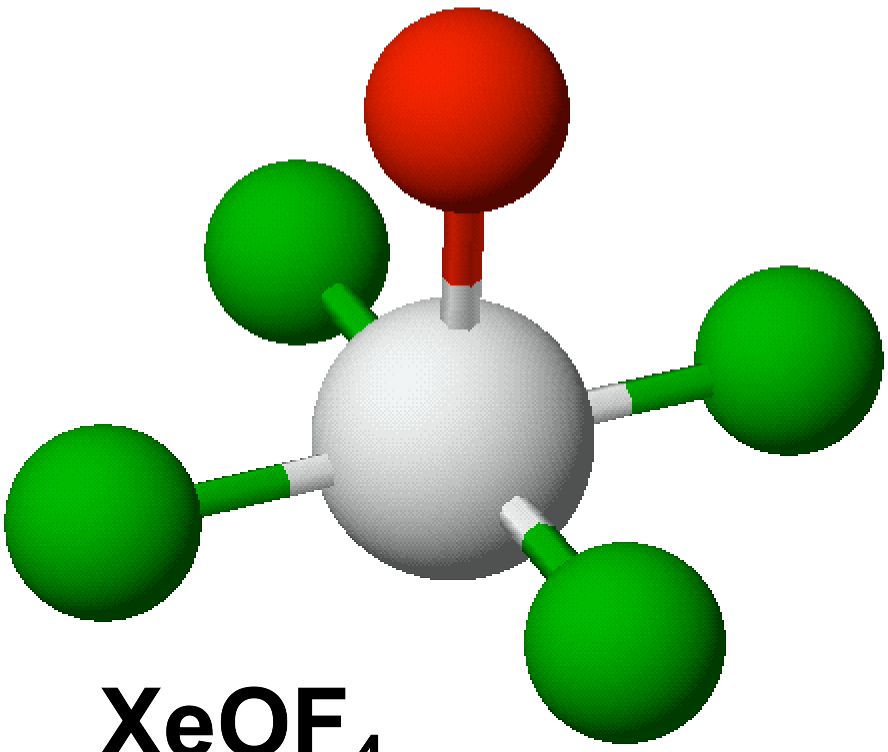
Group 7A:
F, Cl, Br, I, At



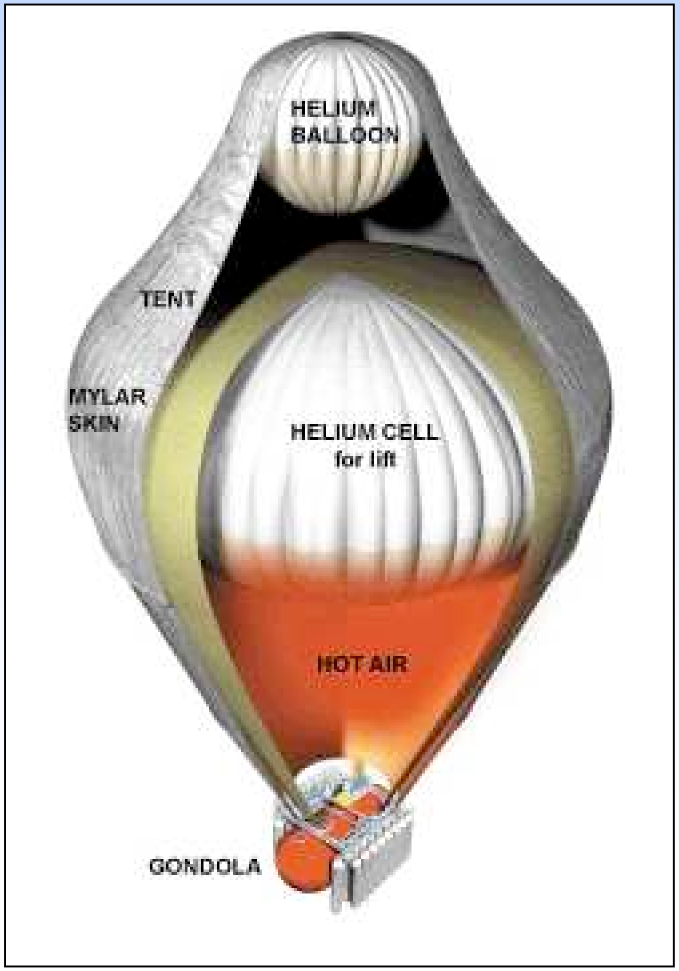
MAR

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

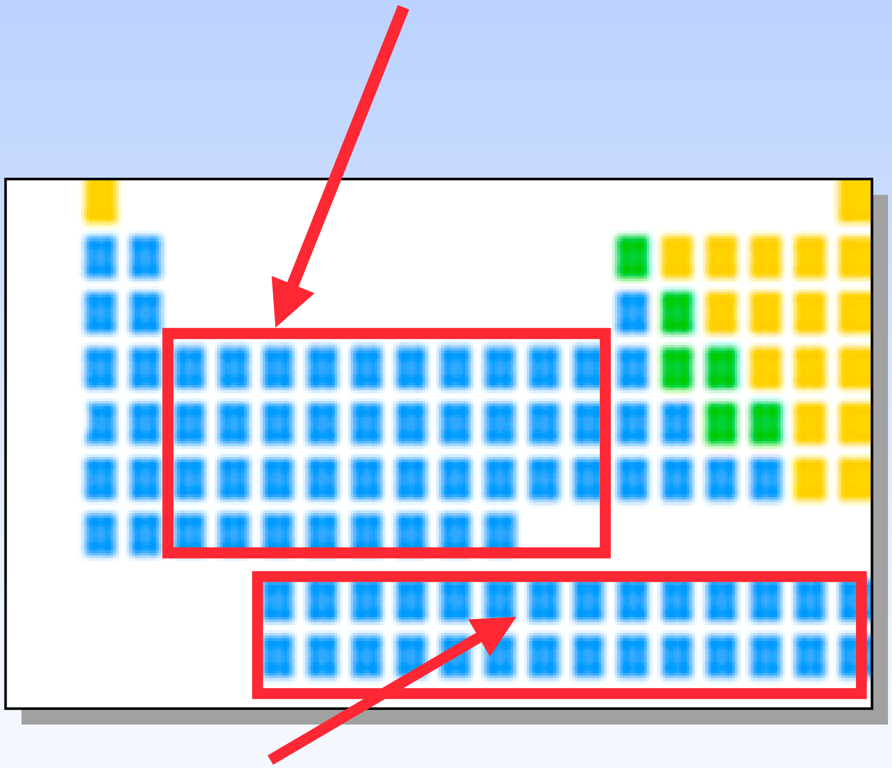
- Lighter than air balloons
- “Neon” signs



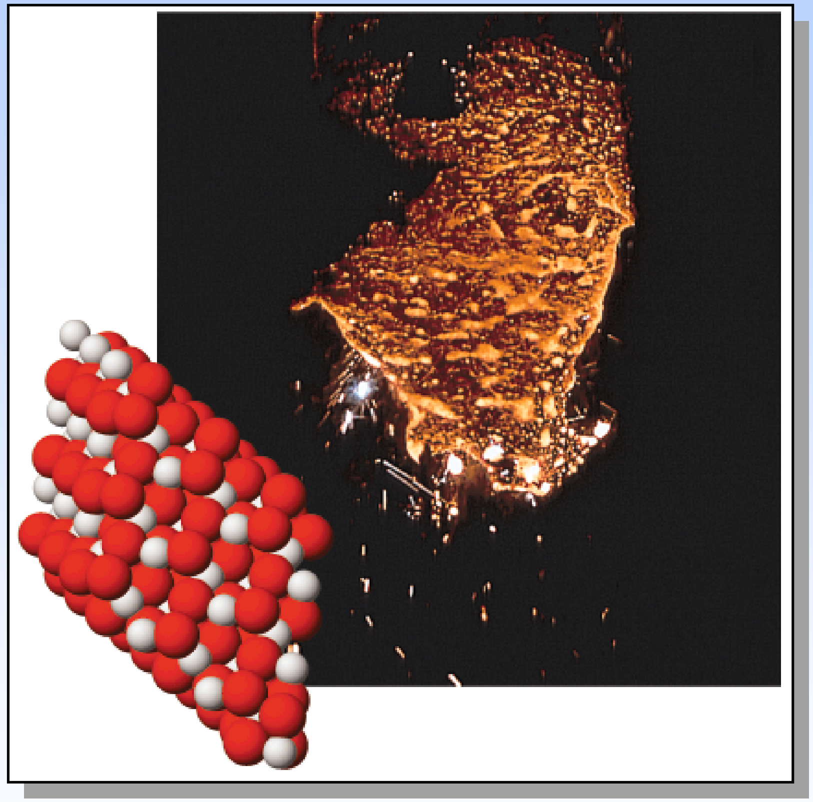
$XeOF_4$



Transition Elements

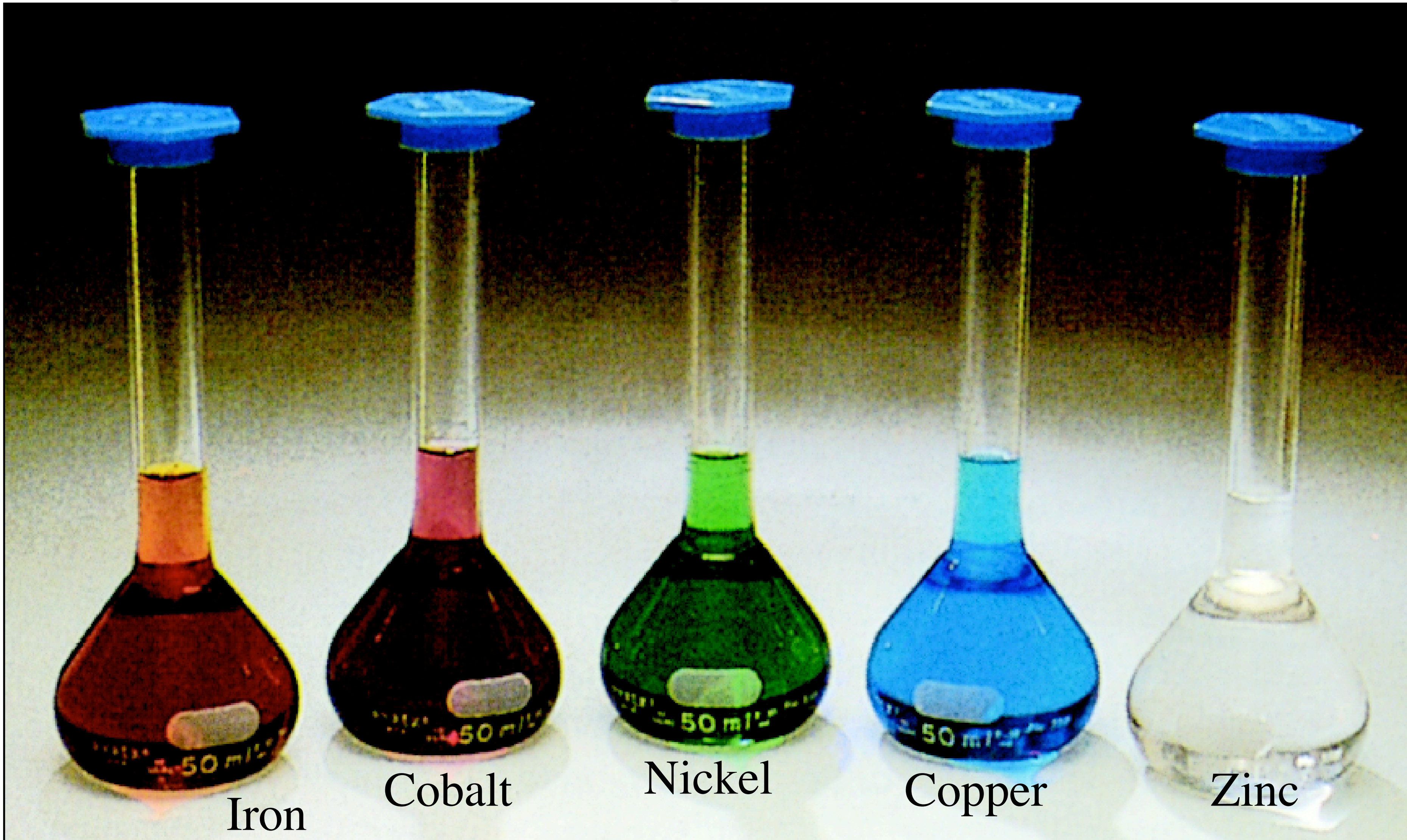


Lanthanides and actinides



Iron in air gives iron(III) oxide

Colors of Transition Metal Compounds



End of Chapter 2

See also:

- *Chapter Two Study Guide*
- *Chapter Two Concept Guide*