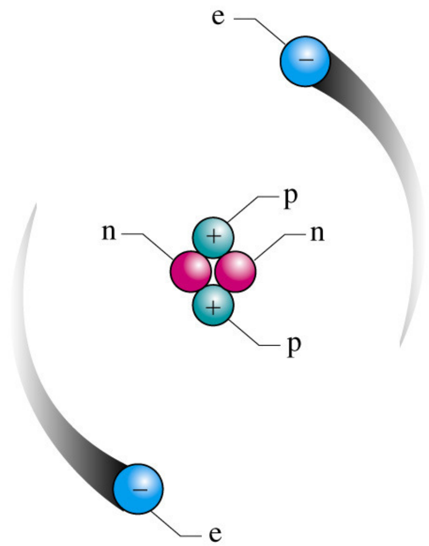
Petrucci • Harwood • Herring • Madura

Ninth Edition

GENERAL CHEMISTRY

Principles and Modern Applications



Chapter 2: Atoms and the Atomic Theory

Philip Dutton
University of Windsor, Canada

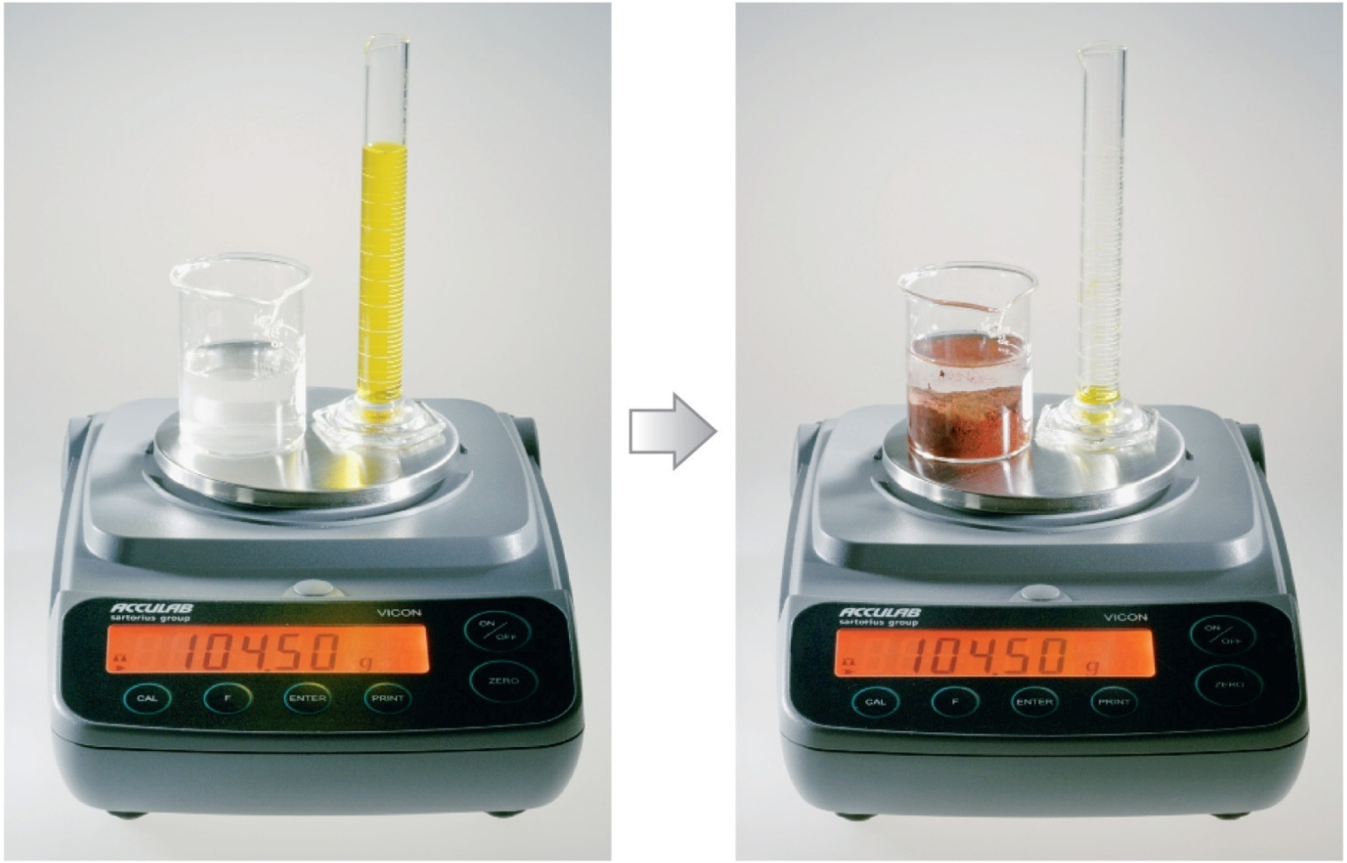
Contents

Contents

2-1 Early Discoveries and the Atomic Theory

Lavoisier 1774	Law of conservation of mass
Proust 1799	Law of constant composition
Dalton 1803-1888	Atomic Theory

Conservation of Mass



(a) (b)

Dalton's Atomic Theory

① Each element is composed of small particles called **atoms**.

② Atoms are **neither created nor destroyed** in chemical reactions.

③ All atoms of a given element are **identical.**

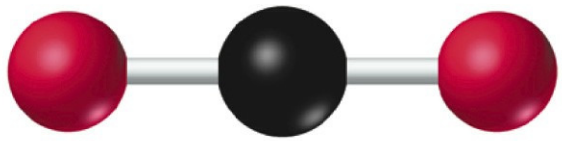
④ **Compounds** are formed when atoms of **more than one element** combine.

Consequences of Dalton's theory

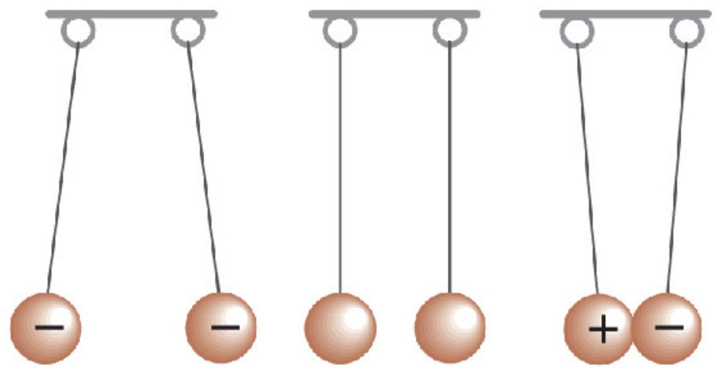
- **Law of Definite Proportions: combinations of elements are in ratios of small whole numbers.**

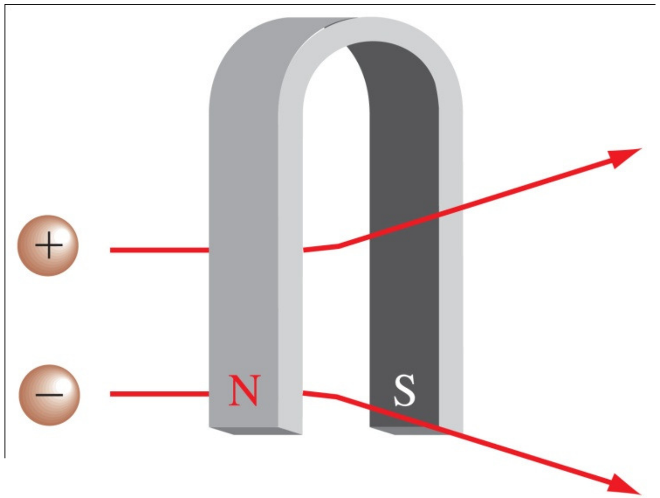
☆ **In forming carbon monoxide, 1.33 g of oxygen combines with 1.0 g of carbon.**

☆ **In the formation of carbon dioxide 2.66 g of oxygen combines with 1.0 g of carbon.**

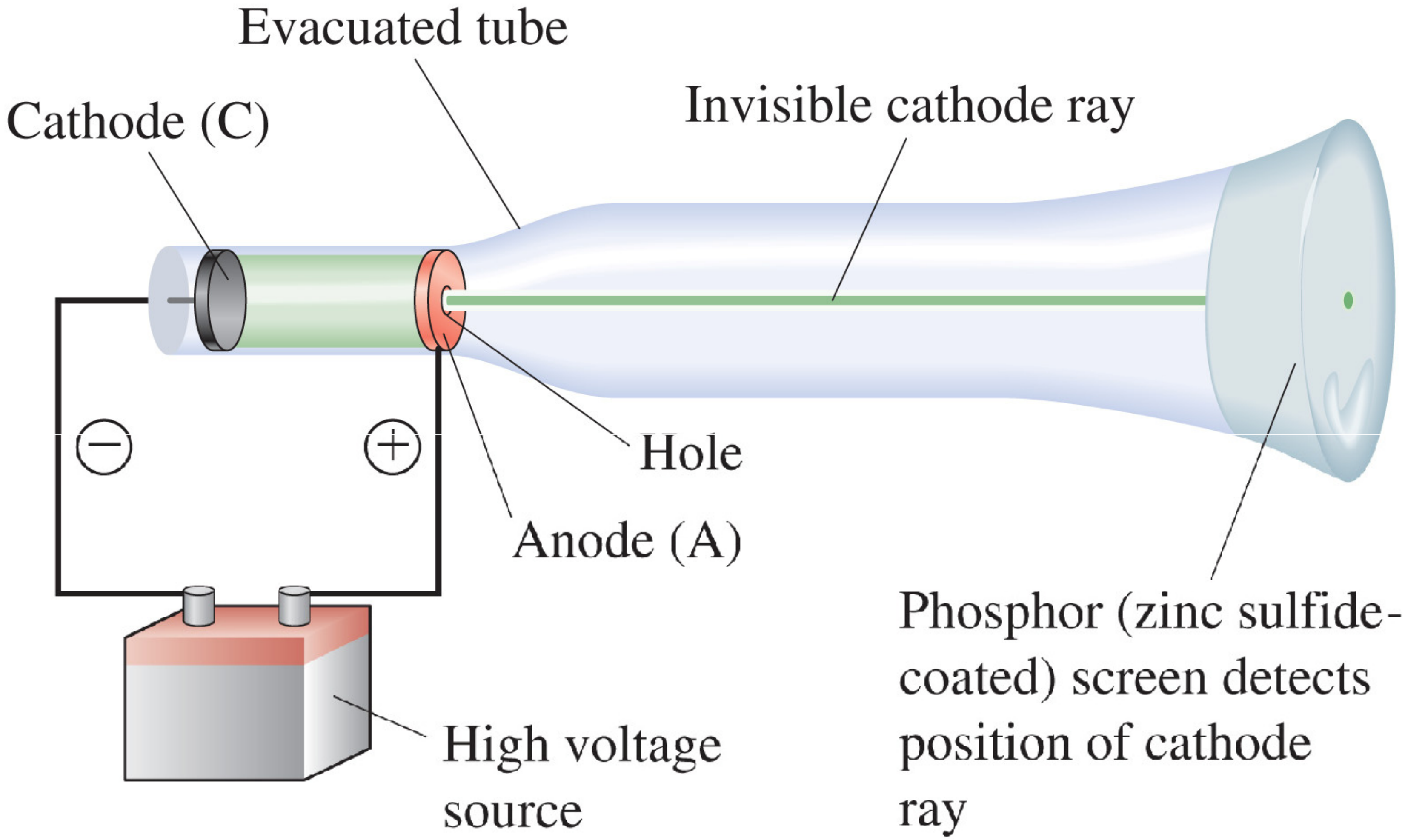


2-2 Electrons and Other Discoveries in Atomic Physics

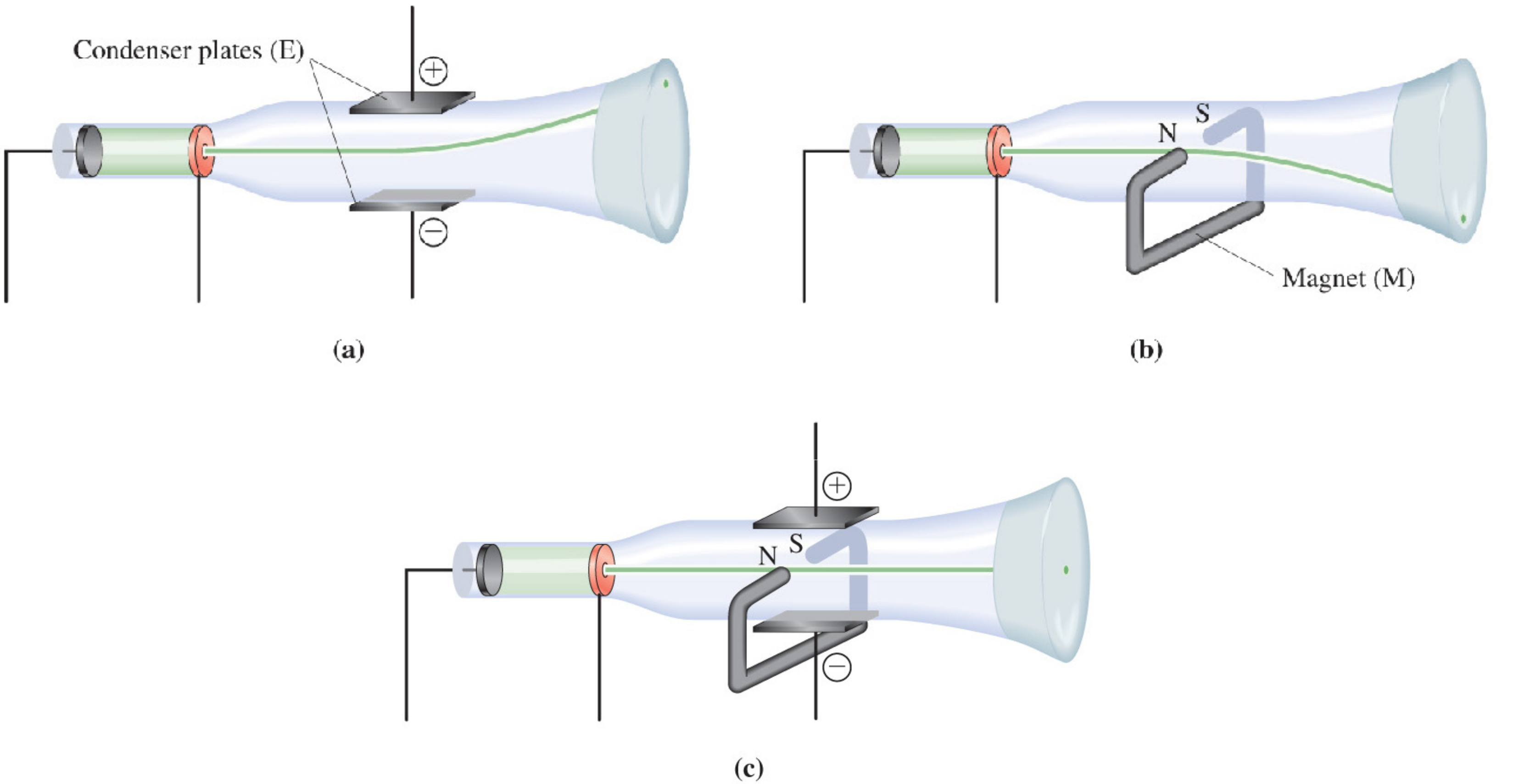




Cathode ray tube

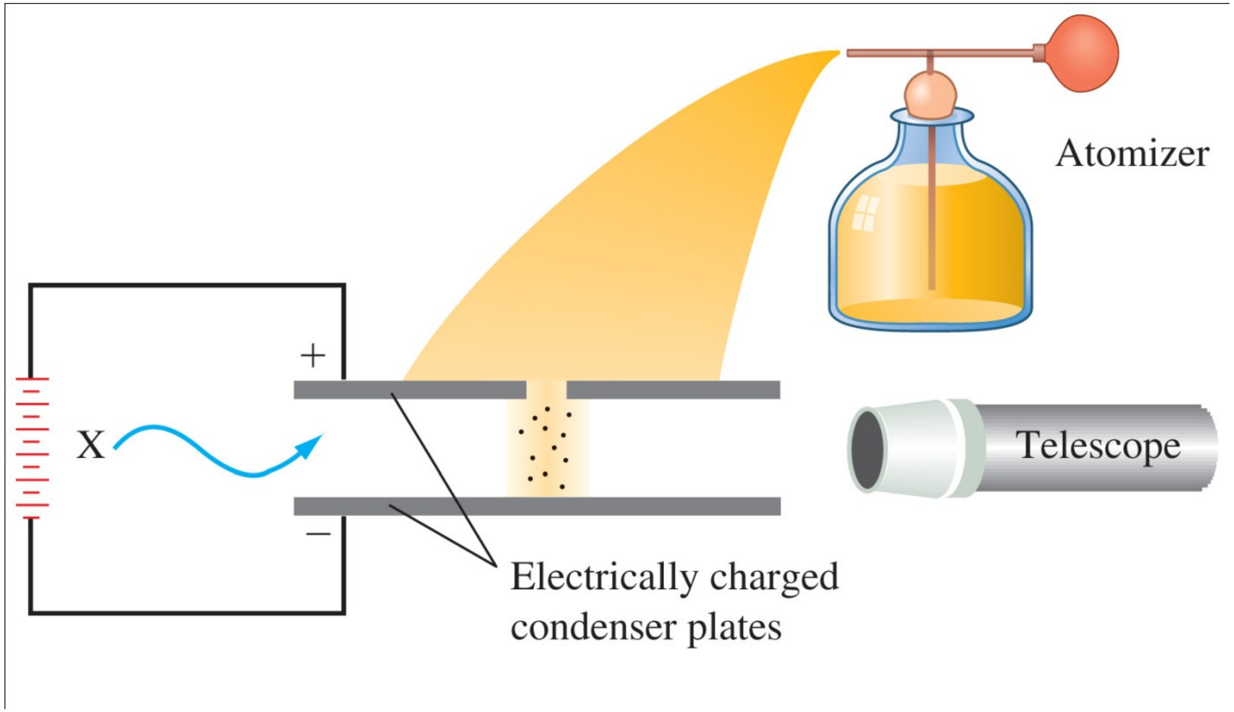


Properties of cathode rays



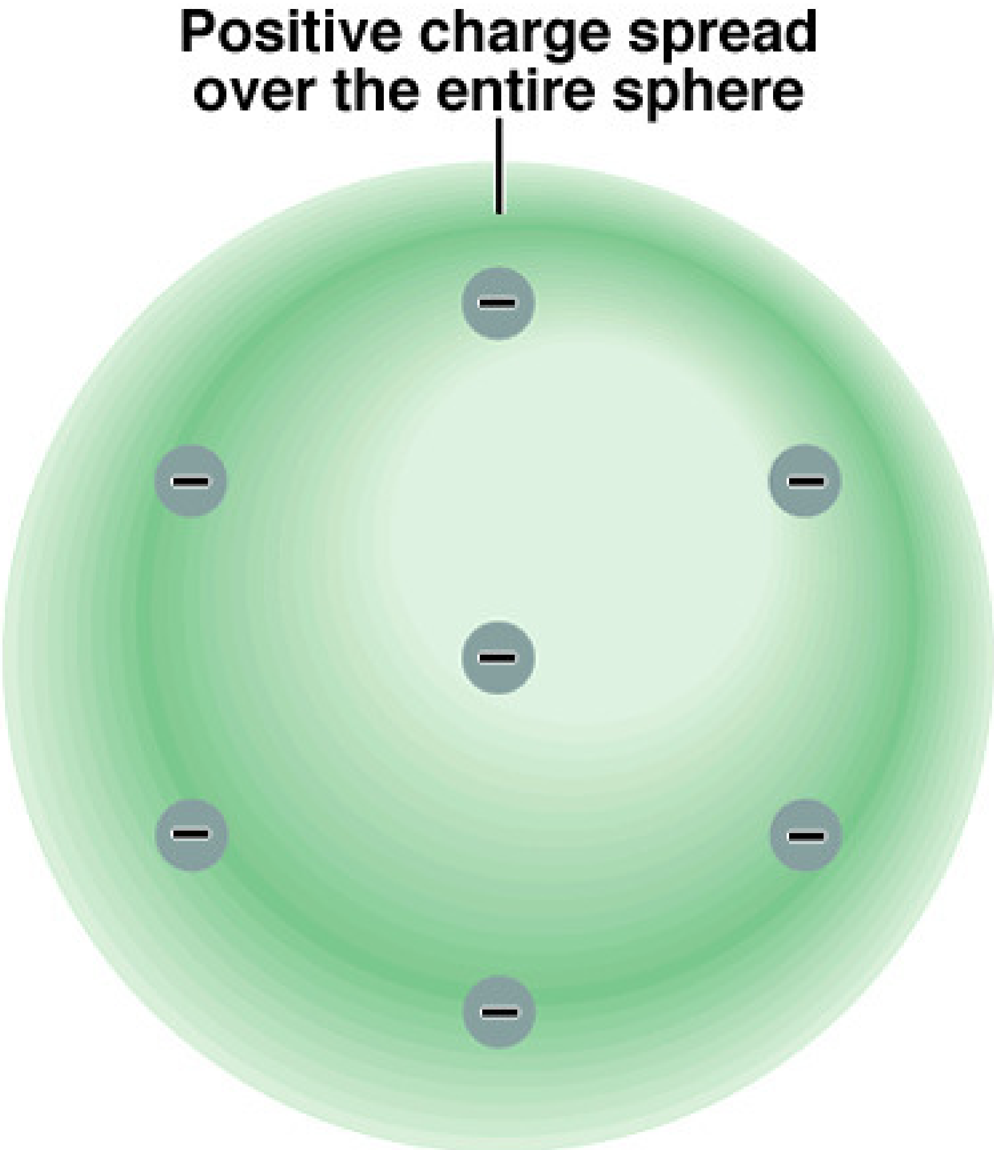
$$\text{Electron m/e} = -5.6857 \times 10^{-9} \text{ g coulomb}^{-1}$$

Charge on the electron



- ☆ From 1906-1914 Robert Millikan showed ionized oil drops can be balanced against the pull of gravity by an electric field.
- ☆ The charge is an *integral* multiple of the electronic charge, *e*.

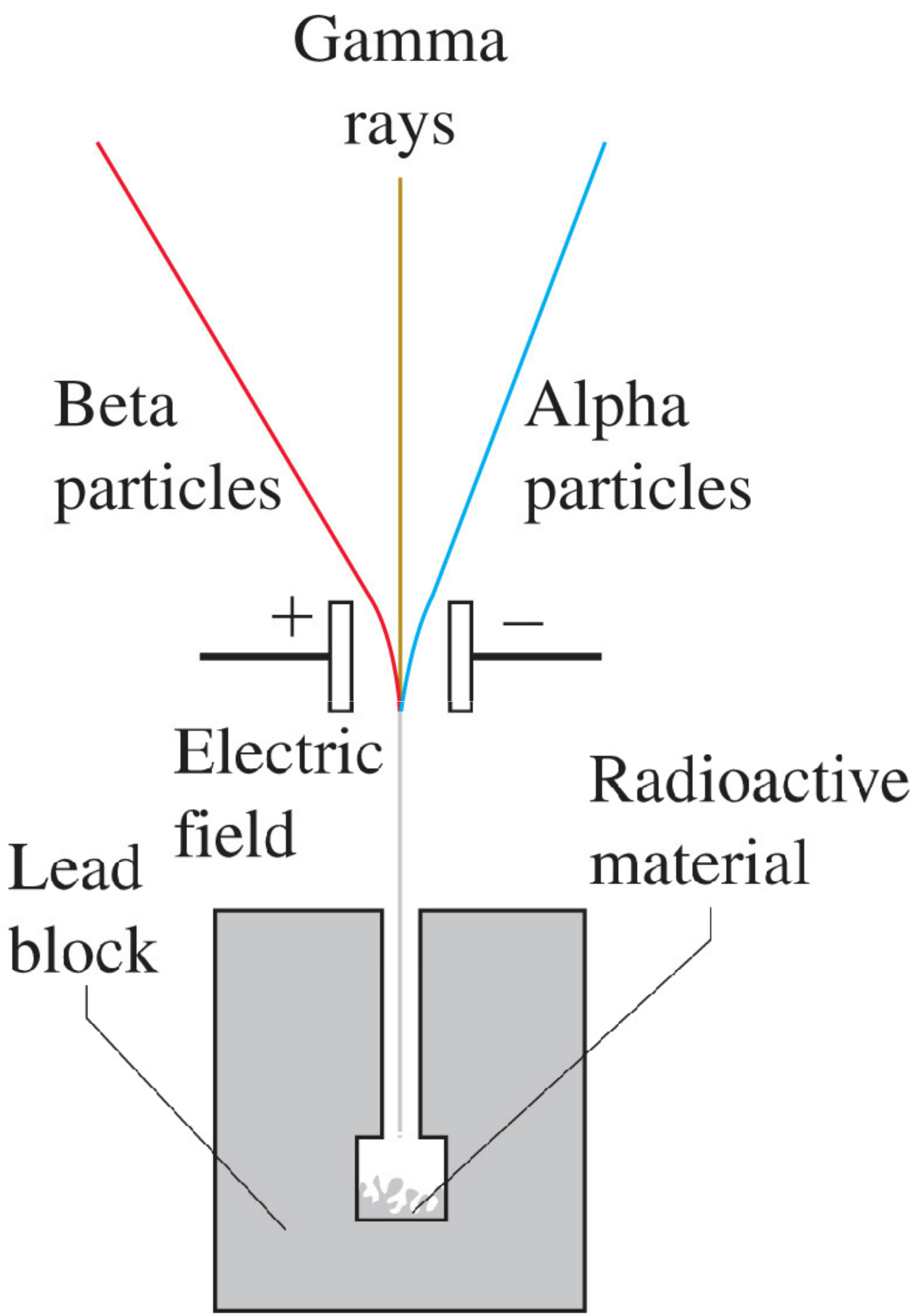
Thomson's Model of the Atom



Radioactivity

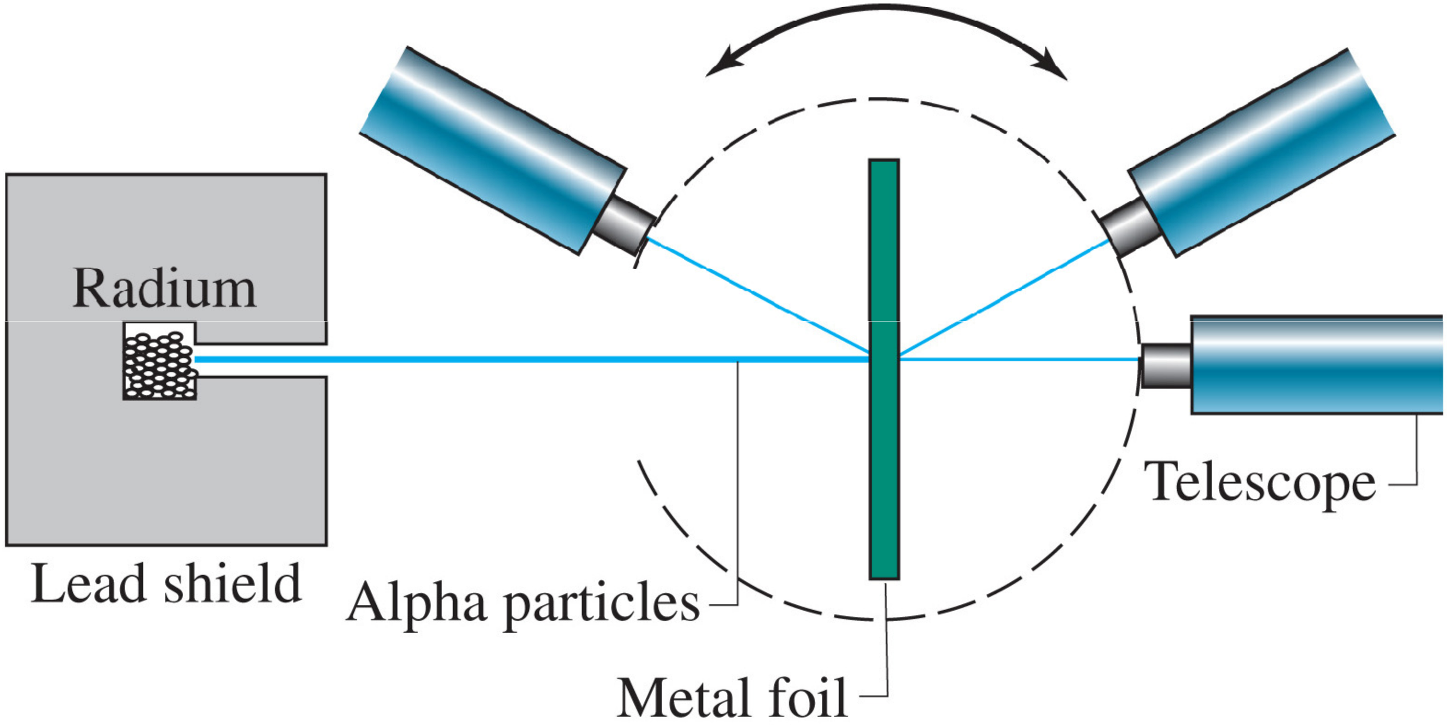
Radioactivity is the spontaneous emission of radiation from a substance.

- ☆ X-rays and γ-rays are high-energy light.
- ☆ α-particles are a stream of helium nuclei, He^{2+}.
- ☆ β-particles are a stream of high speed electrons that originate in the nucleus.

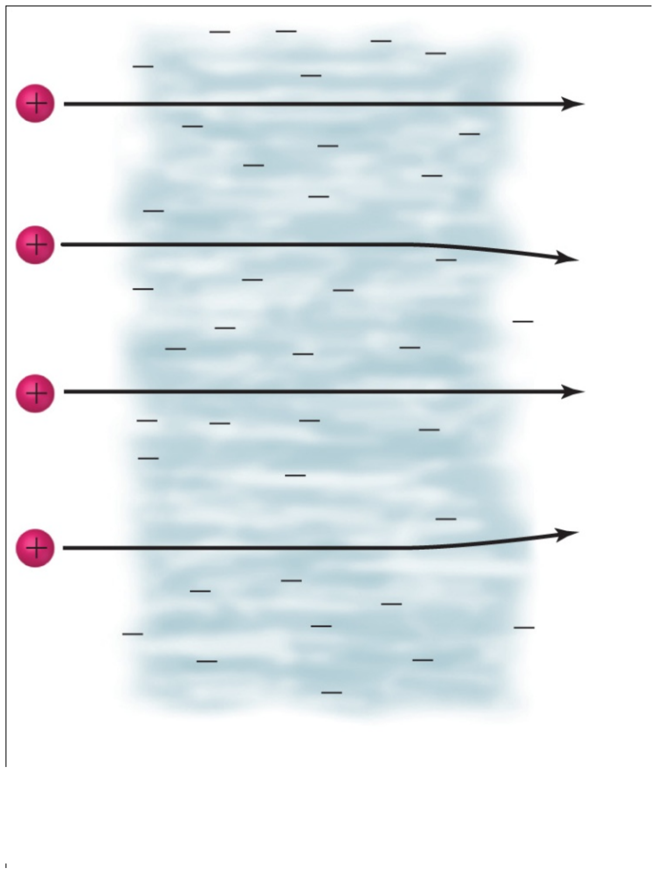

Gamma rays
Beta particles
Alpha particles
+
−
Electric field
Radioactive material
Lead block

2-3 The Nuclear Atom

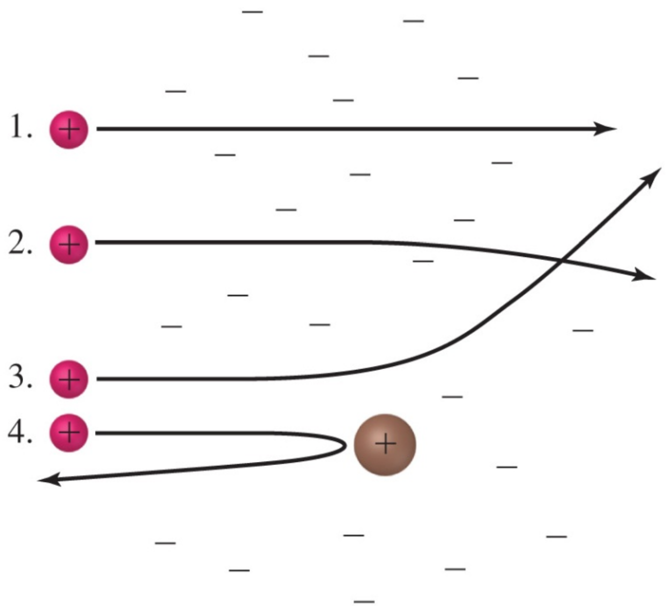
Geiger and Rutherford



The α-particle experiment

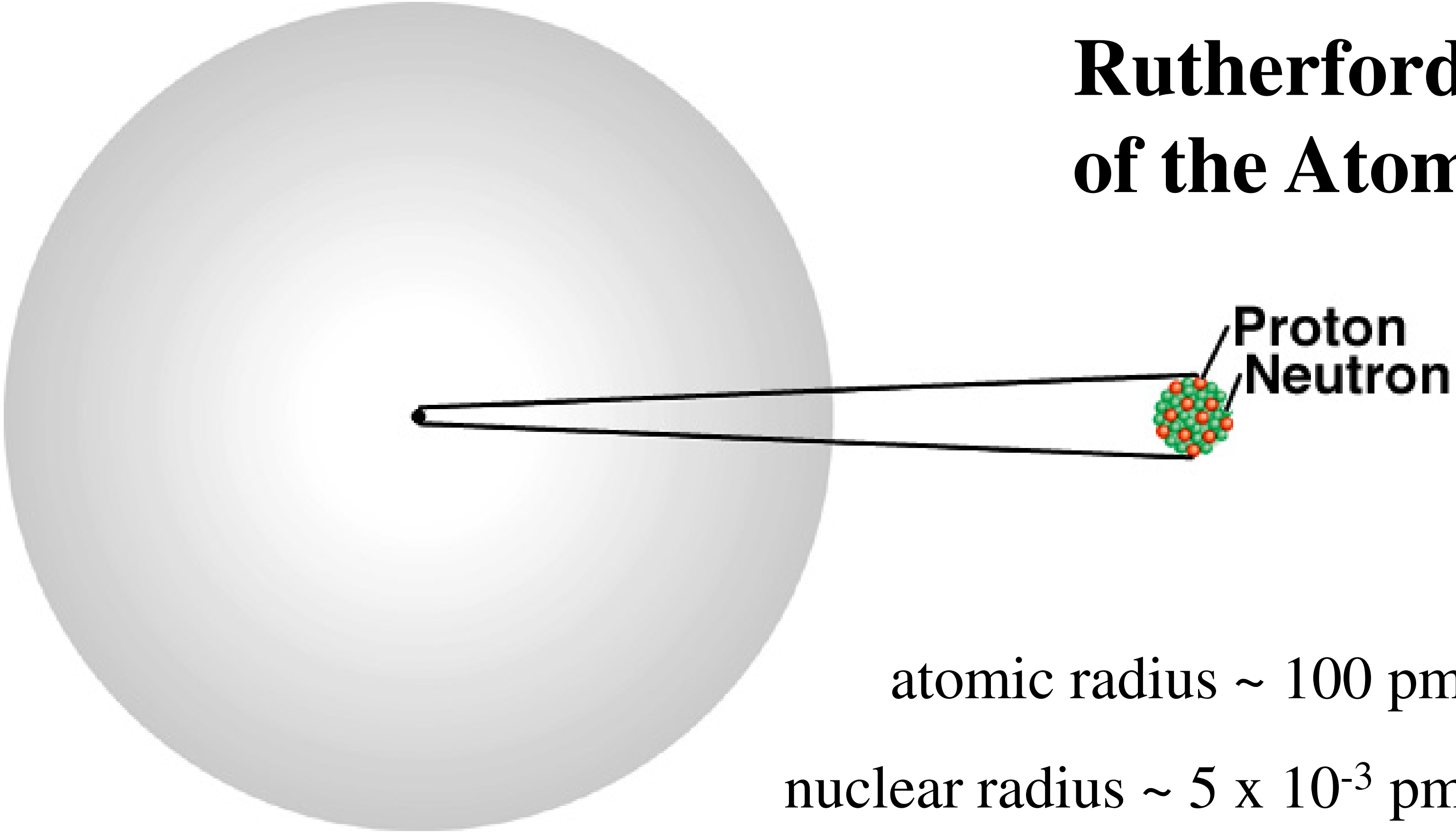


- Most of the mass and all of the positive charge is concentrated in a small region called the nucleus .



- There are as many electrons outside the nucleus as there are units of positive charge on the nucleus

Location of the Subatomic Particles



Rutherford's Model of the Atom

atomic radius ~ 100 pm = 1×10^{-10} m

nuclear radius ~ 5×10^{-3} pm = 5×10^{-15} m

If the atom is the Houston Astrodome

Then the nucleus is a marble on the 50 yard line

Chadwick's Experiment (1932)

H atoms - 1 p; He atoms - 2 p

mass He/mass H should = 2

measured mass He/mass H = 4

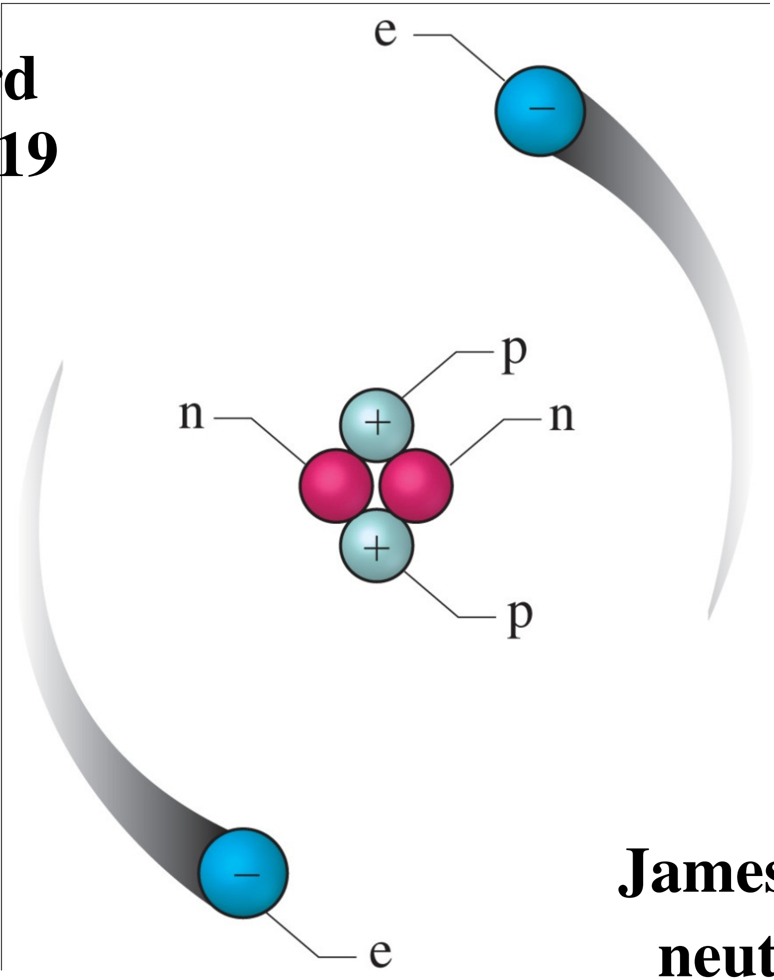
$$\alpha + {}^{9}Be \longrightarrow {}^{1}n + {}^{12}C + \text{energy}$$

neutron (n) is neutral (charge = 0)

n mass ~ p mass = 1.67×10^{-24} g

The Nuclear Atom

Rutherford
protons 1919



James Chadwick
neutrons 1932

Nuclear Structure

Atomic Diameter **10^{-8} cm**

1 Å

Nuclear diameter **10^{-13} cm**

Particle	**Mass**		**Electric Charge**	
	kg	**amu**	**Coulombs**	**(*e*)**
Electron	9.1094×10^{-31}	0.00054858	-1.6022×10^{-19}	–1
Proton	1.6726×10^{-27}	1.0073	$+1.6022 \times 10^{-19}$	+1
Neutron	1.6749×10^{-27}	1.0087	0	0

Scale of Atoms

∗**The heaviest atom has a mass of only 4.8×10^{-22} g and a diameter of only 5×10^{-10} m.**

<u>Useful units:</u>

☆ **1 amu (atomic mass unit) = 1.66054×10^{-24} kg**

☆ **1 pm (picometer) = 1×10^{-12} m**

☆ **1 Å (Angstrom) = 1×10^{-10} m = 100 pm = 1×10^{-8} cm**

Biggest atom is 240 amu and is 50 Å across.

Typical C-C bond length 154 pm (1.54 Å)

Molecular models are 1 Å /inch or about 0.4 Å /cm

2-4 Chemical Elements

∗To represent a particular atom we use symbolism:

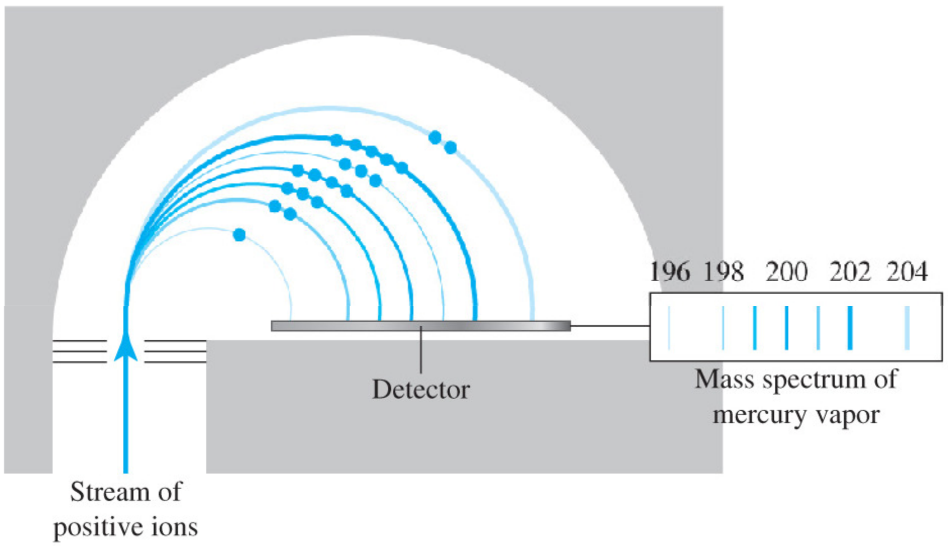
number p + number n

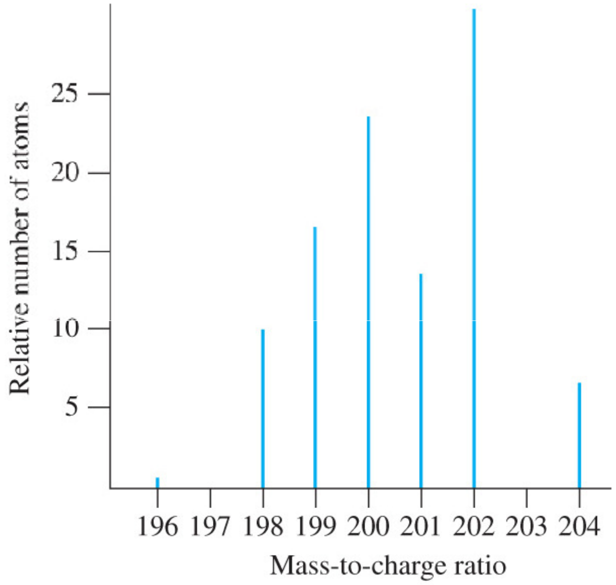
number p

$${}^{A}_{Z}\mathrm{E}^{\pm ?} \longleftarrow \text{number p} - \text{number e}$$

A= mass number Z = atomic number

Isotopic Masses





2-5 Atomic Mass

98,992 atoms of $^{12}_{6}C$ (12 u exactly)

$+$

1,108 atoms of $^{13}_{6}C$ (13.00335 u)

$\downarrow$

100,000 atoms of naturally occurring C (12.011 u)

EXAMPLE 2-6

Relating the Masses and Natural Abundances of Isotopes to the Atomic Mass of an Element. Bromine has two naturally occurring isotopes. One of them, bromine-79 was a mass of 78.9183 u and an abundance of 50.69%. What must be the mass and percent natural abundance of the other, bromine-81?

What do we know:

The sum of the percent natural abundances must be 100%.

The average mass of bromine (read from the periodic table) is the weighted contribution of the percent abundance times the mass of each contributing isotope. Recall equation 2.3.

EXAMPLE 2-6

Strategy

Identify the unknown abundance of bromine-81 by calculation. Use this value in the equation for the average mass of an element to solve for the mass of the unknown isotope. Recall equation 2.3.

Solution

Write the general equations

$$100\% = \chi_1 + \chi_2 + \chi_3 \ldots$$

$$\text{Atomic mass} = \chi_1 \times m_1 + \chi_2 \times m_2 + \chi_3 \times m_3 \ldots$$

EXAMPLE 2-6

Identify the knowns and unknowns in the specific equations

$$\text{Atomic mass} = \chi_{Br\text{-}79} \times m_{Br\text{-}79} + \chi_{Br\text{-}81} \times m_{Br\text{-}81}$$

Solve

$$100\% = \chi_{79} + \chi_{81}$$

$$\chi_{81} = 100\% - \chi_{79}$$

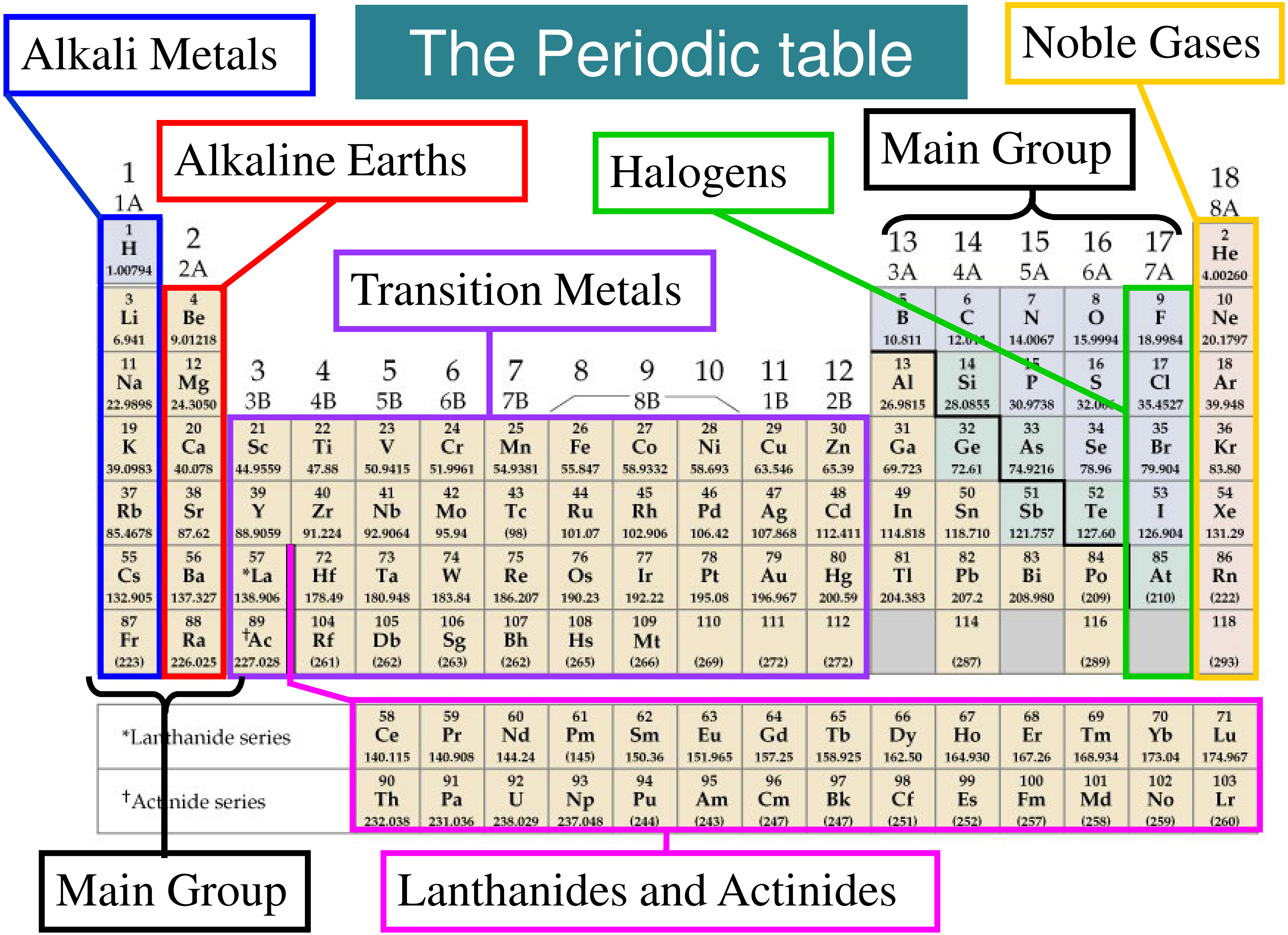
$$m_{Br\text{-}81} = \frac{\text{Atomic mass} - (\chi_{Br\text{-}79} \times m_{Br\text{-}79})}{\chi_{Br\text{-}81}}$$

EXAMPLE 2-6

Calculate

$$m_{\text{Br-81}} = \frac{79.904\text{ u} - (0.5069 \times 78.9183\text{ u})}{0.4931} = 80.92\text{ u}$$

The Periodic table



The Periodic Table

- Read atomic masses.
- Read the ions formed by main group elements.
- Read the electron configuration.
- Learn trends in physical and chemical properties.

We will discuss these in detail later

The Mole

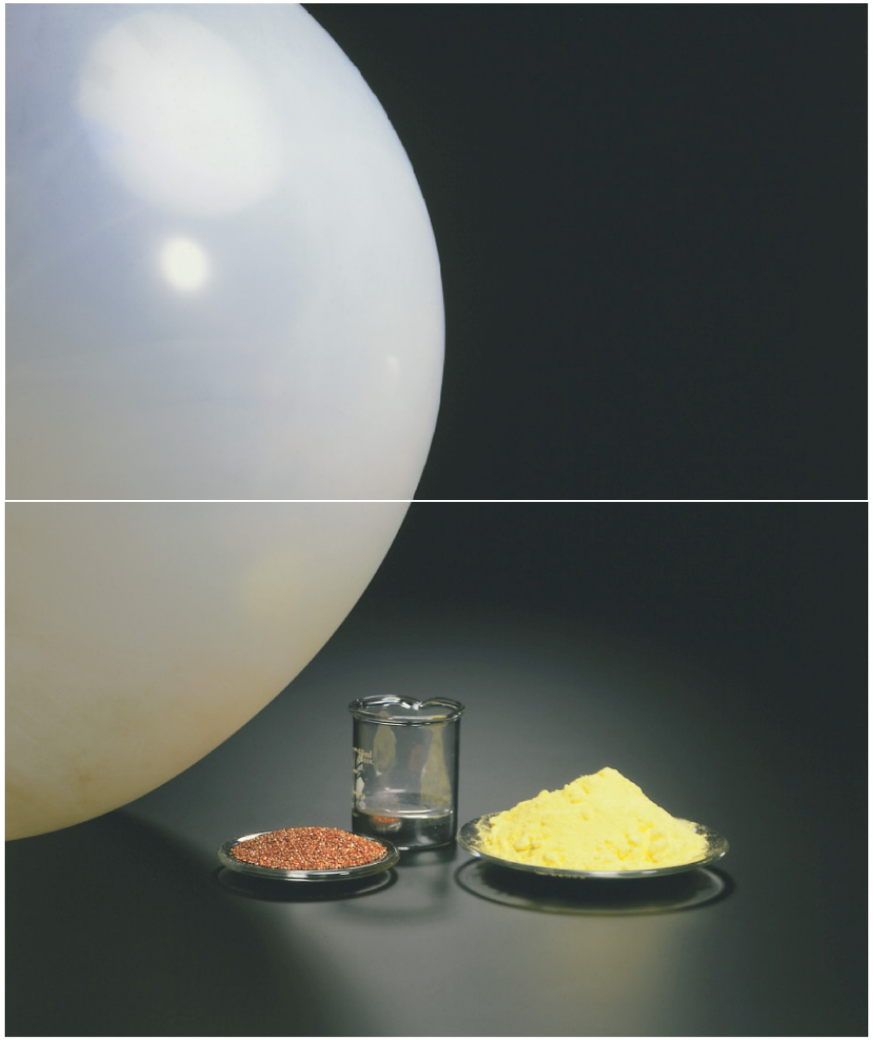
- Physically counting atoms is impossible.
- We must be able to relate measured mass to numbers of atoms.
  - buying nails by the pound or kilogram.
  - using atoms by the gram

Avogadro’s number

- The mole is an amount of substance that contains the same number of elementary entities as there are carbon-12 atoms in *exactly* 12 g of carbon-12.

$$N_A = 6.02214199 \times 10^{23}\ \text{mol}^{-1}$$

The Mole



Molar Mass

- The molar mass, *M*, is the mass of one mole of a substance.

$$M\,(\text{g/mol } ^{12}\text{C}) = \text{A}\,(\text{g/atom } ^{12}\text{C}) \times N_\text{A}\,(\text{atoms } ^{12}\text{C /mol } ^{12}\text{C})$$

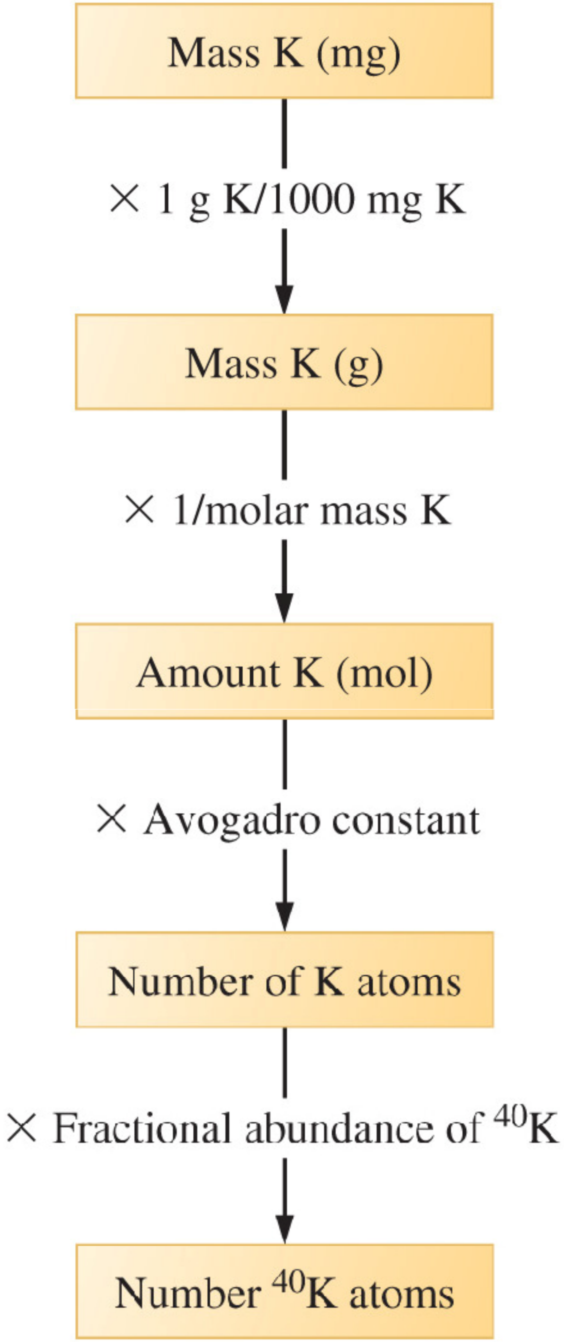
EXAMPLE 2-9

Combining Several Factors in a Calculation—Molar Mass, the Avogadro Constant, Percent Abundance. Potassium-40 is one of the few naturally occurring radioactive isotopes of elements of low atomic number. Its percent natural abundance among K isotopes is 0.012%. How many 40K atoms do you ingest by drinking one cup of whole milk containing 1.65 mg of K/mL?

Want atoms of ^{40}K, need atoms of K,

Want atoms of K, need moles of K,

Want moles of K, need total mass of K and M(K) (the molar mass).


Mass K (mg)
× 1 g K/1000 mg K
Mass K (g)
× 1/molar mass K
Amount K (mol)
× Avogadro constant
Number of K atoms
× Fractional abundance of ^{40}K
Number ^{40}K atoms

EXAMPLE 2-9

Convert concentration of K (mg/mL K) into mass of K (g K)

c_K(mg/mL) × V (mL) ➔ m_K (mg) × (1g/1000mg) ➔ m_K(g)

n_K = (1.65 mg/mL K) × (225 mL) × (1 g/1000 mg)

= 0.371 g K

Convert mass of K(g K) into moles of K (mol K)

m_K (g) × 1/M_K (mol/g) ➔ n_K (mol)

n_K = (0.371 g K) × (1 mol K) / (39.10 g K)

= 9.49×10^{-3} mol K

EXAMPLE 2-9

Convert moles of K into atoms of ^{40}K

$n_K(\text{mol}) \times N_A$ ➔ atoms $K \times 0.012\%$ ➔ atoms ^{40}K

$$\text{atoms } ^{40}K = (9.49 \times 10^{-3} \text{ mol K}) \times (6.022 \times 10^{23} \text{ atoms K/mol K})$$

$$\text{x } (1.2 \times 10^{-4}\ ^{40}K/K)$$

$$= 6.9 \times 10^{17}\ ^{40}K \text{ atoms}$$

Note that the text shows two slightly different methods.

There is often more than one correct way to solve a problem, but the strategy for the solution is often the same for any of the calculations.

End of Chapter Questions

- Problem solving is an integral part of the learning process.
- You must exercise your skills just like a varsity athlete does.
- Use your coaches, they can help you with skills for success.

