Chapter 2 – Atomic Structure and Nomenclature

Section 1 - Atomic Structure

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Introduction

- The first time anyone thought of atom as a small particle was a Greek philosopher, Democritus during 5th century. He proposed that atoms were indivisible particles making up everything.
- Now we have a little better understanding of atomic structure, but new discoveries are still being made.
- In the study of atomic structure we will study the atomic theory, the nuclear model of the atom.
- As elements were being discovered it became critical to have them in some order hence the design of the periodic table. We will study how the periodic table is arranged and what information we can obtain from it.

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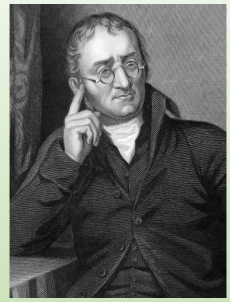
Dalton's Atomic Theory

John Dalton an English scientist, in 1808, first proposed the atomic theory.

1. All matter is composed of indivisible **atoms**.
2. An **atom** is an extremely small particle of matter that retains its identity during chemical reactions.
3. An **element** is a type of matter composed of only one kind of atom.
4. A **compound** is composed of atoms of two or more elements chemically combined in fixed whole number proportions.
5. A **chemical reaction** involves rearrangement of atoms in the reacting substances to give new chemical combinations as products. No atom is created nor destroyed in this process. (This is also known as the ***Law of Conservation of Matter***)



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Example: Combination of oxygen and carbon to form carbon dioxide.

O_2 + C ⟶ CO_2

Law of Definite Proportions

This law demonstrates that the same elements will be in the **same** mass ratio no matter how many different samples of a given compound are analyzed.

Sample	Mass of O (g)	Mass of C (g)	Ratio (g O: g C)
124 g carbon dioxide	89.3	33.5	2.66:1
50.4 g carbon dioxide	36.6	123.8	2.66:1
88.6 g carbon dioxide	64.3	24.1	2.66:1

Sample	Mass of O (g)	Mass of C (g)	Ratio (g O: g C)
16.3 g carbon monoxide	9.31	6.98	1.33:1
50.4 g carbon monoxide	14.7	11.1	1.33:1
88.6 g carbon monoxide	50.4	37.8	1.33:1

Law of Multiple Proportions

This law demonstrates that the ratio of combination of two elements will be in a fixed ratio: for example, CO_2 and CO will always occur in a 2:1 ratio no matter how much mass there might be.

$$\frac{\text{ratio of O to C in carbon dioxide}}{\text{ratio of O to C in carbon monoxide}} = \frac{2.66}{1.33} = 2:1$$

Atomic Structure

- The atom has three main particles: electron, proton and neutron. Neutrons and protons are found in the nucleus (center of the atom) and electrons are outside the nucleus. The properties of these particles are given in the table below.
- There were many scientists over 30 years, involved in determining the structure of the atom, and its still not quite done!
- The next few slides cover a bit of the history of discovery of these particles.

Particle	Found in	Charge	Mass
Neutron (n)	Nucleus	None	1 amu* 1.675×10^{-24} g
Proton (p)	Nucleus	+	1 amu 1.675×10^{-24} g
Electron (e)	Outside nucleus	-	0.000545 amu 9.109×10^{-28} g

*amu = atomic mass unit

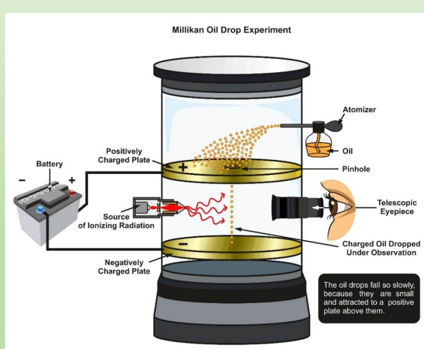
Discovery of the Electron

- J.J. Thompson discovered the electron in 1897.
- He used hydrogen gas in a cathode ray tube and observed that the “ray” coming out of the gas was deflected by a magnetic plate.
- He concluded that the particles making up the ray were negative, and no matter which element he used, he got the same results.
- He named these particles electron. He then calculated the mass to charge ratio.

  (-1.76×10^8 C/g; C = *coulomb*)
- See this video to get an idea of how this experiment works. http://youtu.be/O9Goyscbazk

Robert Milliken’s Experiment

- The charge on the electron was calculated by Robert Milliken (around 1915) from his “oil drop experiment”: -1.66022×10^{-19} C
- Using Thompson’s mass/charge ratio and then the charge from this experiment, the mass of the electrons was determined.



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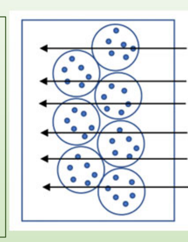
Rutherford's Gold Foil Experiment

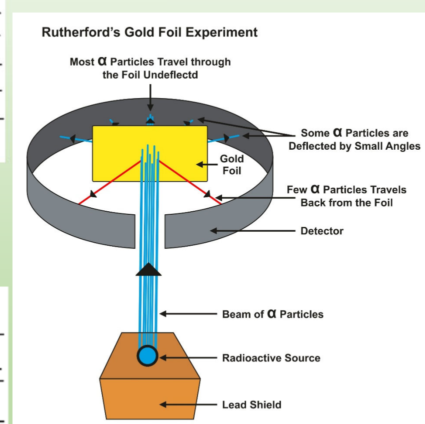
- Logically, if there was a negative particle there should be a positive charge. The location of this positive particle (proton) was not known.
- Rutherford, around 1911, helped to establish the location of protons in the atom using his gold foil experiment. He concluded that protons were found clustered together in the center of the atom, rather than all over the atom.
- See the next slide to see the explanation of this experiment.
- Watch this video on YouTube to see this experiment. http://youtu.be/5pZj0u_XMbc

Rutherford's Gold Foil Experiment

On radiating the atom with a positive radiation, he expected radiation to completely go through the atom at all locations. He expected that the positive was distributed all over the atom (plum pudding model). However, this was not observed



Expected result



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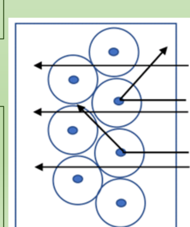
The gold foil emitted radiation at specific locations and some radiation bounced back which was completely unexpected.

He concluded that the positive protons were located as one big mass in the center of atom rather that distributed all over the atom. This is the nuclear model of atom.



Actual result

The Final Particle - Neutron

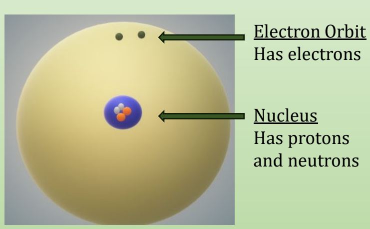
All this was great, but there was one problem: if Hydrogen has a mass of 1 and has 1 proton, then Helium should be a mass of 2 because it has two protons; however, Helium has a mass of 4.

Hence there must be another particle.

- James Chadwick in 1932 discovered the last particle, neutron which is also present in the nucleus.
- It was the last to be discovered because it is neutral.
- It has the same mass as a proton.

Atomic Structure and Properties

- Atom has electrons, protons and neutrons.
- Neutrons and protons are in the nucleus whereas electrons are outside.
- Mass of the atom is primarily in the nucleus from the neutrons and protons. Electrons are not measured in the mass of the atom.
- In an electrically neutral atom, the number of protons and electrons are equal.



Solved Problem: Learning about the of history of the atom
Answer the following questions about the history of the discovery of the atom and its subatomic particles.

a) Who is credited with determining the presence of atomic nucleus?
Rutherford.

b) What type of experiment helped to discover the location of protons? And how did it work?
The gold foil experiment helped to discover location of protons. When positive radiation was passed through atoms, some radiation went through the atom, but some bounced back and hit the gold foil surrounding the atom. This indicated there was a positive center in the atom.

c) What was the purpose of Milliken's oil drop experiment?
To determine the charge on the electron.

d) Which subatomic particle was discovered first and by whom?
Electron was discovered by JJ Thompson.

Atomic Number and Mass Number

In chemistry we represent an element by a symbol, one or two alphabets, and write two numbers that give information on the number of particles it has. These two numbers are:

- **Atomic number (Z)** is the number of protons
- **Mass number (A)** is the number of protons and neutrons of an atom.

- Identity of atom is determined by the number of protons.

Mass number
(number of protons + neutrons)

$^{A}_{Z}X$ Atom Symbol

Atomic number
(number of protons)

- The periodic table is arranged by the atomic number hence the atomic number on the top.
- On a closer look at the periodic table, you will note that the mass number is not a whole number. Why? (next slide)..

Isotopes

If the mass is addition of two particles, then the mass number should be a whole number– but generally it's not; so there must be something else going on. And that is the existence of **isotopes**.

- **Isotopes are elements with the same atomic number but different mass number.**
- **Isotopes have the same number of protons but different number of neutrons.**

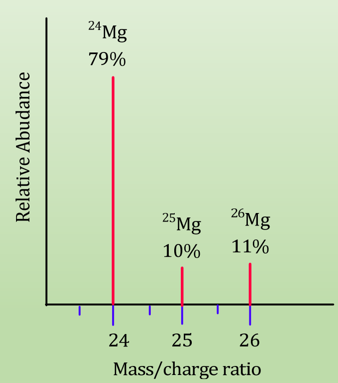
Each element has some isotopes. One cannot predict how many isotopes or what the mass will be. This has to be determined experimentally.

It is interesting to note that the presence of isotopes challenges Daltons atomic theory in which he states that all atoms are the same in an element. Well…they technically still are since the number of protons in the isotopes are the same and only neutrons change, the element is still the same.

Isotope Analysis

The best way to know how many isotopes, their masses, and ratio (relative abundance) is by using the analytical instrument, the Mass Spectrophotometer.

The element is injected into the instrument and then analyzed by passing the ions formed through a magnetic field. The isotopes exit field in order of lightest to heaviest. The resulting graph looks like shown on the right, where the abundance of each isotope and its mass can be seen. Using this data, one can calculate the average mass of a naturally existing element.



Calculation of Atomic Mass

Magnesium from the previous slide has three naturally occurring isotopes. The mass and percent abundance of each isotope is given below. To find the average mass, we calculate the mass contribution of each of the naturally occurring isotope as shown below.

Percent Abundance (%)	Fractional Abundance (%/100)	Mass (amu)	Mass From Isotope
11	0.11	26.00	0.11 x 26 = **2.86**
10	0.10	25.00	0.10 x 25 = **2.50**
79	0.79	24.00	0.79 x 24 = **18.96**
Addition of all fractions of mass contribution of isotopes gives the actual mass			**24.32**

Key Words and Concepts

- Daltons Atomic Theory
- Law of conservation of matter
- JJ Thompson
- Milliken's oil drop experiment
- Rutherford's gold foil experiment
- Electron, Proton, neutron
- Nuclear model of the atom
- Atomic number
- Atomic mass
- Isotopes