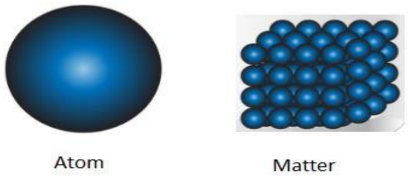
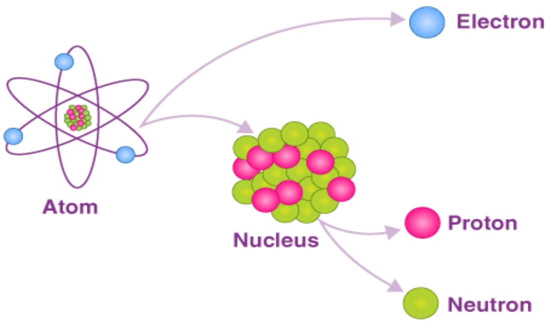
Structure of the atom

1. Definitions

Matter is formed from elementary grains: atoms.

The atom is an electrically neutral unit with a central part, the nucleus (protons + neutrons), and around which are electrons.





1.1 The nucleus

The nucleus contains two types of massive particles:

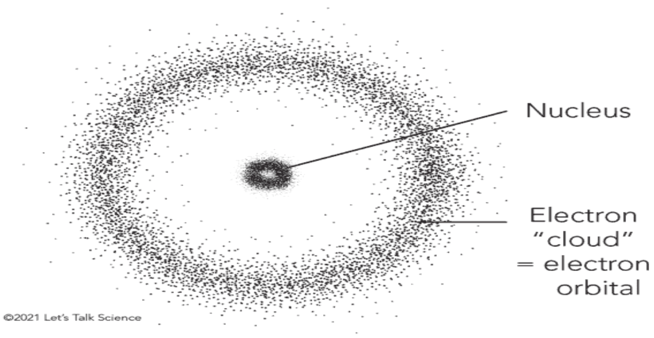
-The proton has a charge q_p= +1,60.10^{-19} C (coulombs) which corresponds to the elementary charge for a mass of 1,673. 10^{-27}Kg.

- **The neutron** has zero charge (q_n= 0) for a mass similar to the proton 1,675. 10^{-27}Kg.

Note:

- Neutrons and protons make up nucleons, which are held together by strong interaction.
- Protons and Neutrons have similar masses but completely different charges.
- The nucleus has a positive charge equal to the number of protons Z multiplied by the proton charge: $\mathbf{Q_{nucleus} = Z.e}$

1.2 The electronic cloud



It corresponds to all the electrons. An electron has a charge of q_e= -1,60.10^{-19} C and a mass of 9,11. 10^{-31}Kg. It is therefore 1800 times lighter than the proton. Its charge is negative and just the opposite of that of the proton.

Note:

- An atom has as many electrons as protons (its overall charge is therefore zero) and the universe contains exactly the same number of protons as electrons.
- The electrons occupy all the space in matter.
- The nucleus contains most of the atom's mass.
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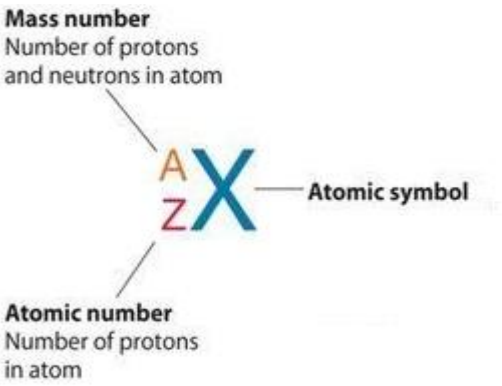
The table below summarizes information on the three fundamental particles of the atom:

Particle	Symbol	Mass (in Kg)	Charge (in C)
Proton	p	$1.6726 .10^{-27}$	$+ 1.6O22 .10^{-19}$
Neutron	n	$1.6749 .10^{-27}$	0
Electron	e^-	$9.1095 .10^{-31}$	$- 1.6022. 10^{-19}$

1.3 Element identification

1.3.1 Representation

Each chemical element has its own symbol. It is always written with a capital letter, followed by a small letter:



Z is **atomic number** or **charge number**, and refers to the number of protons (it is also the number of electrons for a neutral atom). For any element, the charge of the nucleus (protons) is $q_p = +Z.e$. Similarly, the charge of the electrons is $\mathbf{q_e = -Z.e}$.

A is **mass number** and refers to the number of nucleons (protons + neutrons).

If N represents the number of neutrons, the relationship is: **A = Z + N.**

1.3.2 Isotopes:

Isotopes are atoms with the same atomic number Z but different mass numbers A. An element may have one or more isotopes. It is not possible to separate them by chemical reactions, but this can be done using physical techniques such as mass spectroscopy.

Example:

1.3.3 Atomic mass

The atomic mass is equal to the sum of the masses of the atom's constituents:

$$\mathbf{m_{at} = Z.m_e + Z.m_p + N.m_n \ (kg)}$$

The use of this unit is inconvenient, so chemical units that are easier to handle have been chosen; the reference term being carbon 12.
By definition, the unit of atomic mass, u.m.a, is (l/12)th of the mass atom of carbon 12 (^{12}C).

$$\mathbf{u.m.a = (1/12\ ).mC}$$

1.3.4 Mole and molar mass

On our scale, we reason in terms of a certain quantity of matter called a mole: The mole is the number of atoms in 12g of carbon 12; this number is called **Avogadro's number.**

$$\mathbf{Na = 6.023.\ 10^{23}\ (\ 1\ mole=6.023.10^{23}\ atoms).}$$

By definition: One mole of carbon12 atoms weighs 12g.
This means that: The mass of Na atom of 12C = 12g
Therefore : The mass of a 12C atom = 12g/ Na = $1.9923.10^{-23}$ g = $1.9923.10^{-26}$ kg.
1 u.m.a = 1/12 (mc) = 1/12 (12/Na) = 1/Na = 1.66. 10^{-24} g =1.66 . 10^{-27} kg.

$$\mathbf{1\ u.m.a = 1.66\ .\ 10^{-27}\ kg.}$$

1.3.5 Molar mass

The mass of one mole of atoms of an element is called the molar mass of the atom.

$$\mathbf{M = m.Na.}$$

Example: mNa = 3.8. 10-23g so MNa = 3.8. 10-23. 6.023. 1023 = 23 g/mol.

1.3.6 Average atomic mass

In general, an element has one or more isotopes, so the atomic mass will be the sum of the proportions of each isotope.

$$\mathbf{m_{average} = \Sigma(xi.\ mi)\ u.m.a.}$$

Similarly, the molar mass will be : $\mathbf{M_{average} = \Sigma(xi.\ Mi)\ (g/mol).}$
$\mathbf{x_i}$: natural abundance factor of isotope **i** of atomic mass **Mi**.
Example:

	$^{35}_{17}Cl$	$^{37}_{17}Cl$
Mass number	35	37
Abundance	75.4%	26.4%

The average atomic mass of Cl is: M_{Cl}= 35.0,754 + 37. 0,264 =35,492 g/mol.

1.3.7 Binding energy (cohesion) of the nucleus

Binding energy of nucleons.
The mass of a nucleus ($M_{nucleus}$) is less than the sum of the masses of its constituent protons and neutrons: **Z.mp +N.mn > M nucleus**

Where m_p and m_n: the masses of the proton and neutron; Z: the atomic number and N the number of neutrons.

$(Z.m_p + N.m_n) - M_{nucleus} = \Delta m$ is called the mass defect of the nucleus and is calculated according to Einstein's equivalence principle.

$$\mathbf{E = \Delta m.C^2} \quad \text{(E: the binding energy of the nucleus).}$$

E is the energy liberated during the reaction:

Z protons +N neutrons------->Nucleus + E.

This is called the binding energy (cohesion) of the nucleus.

Application: Determine the loss of mass during the formation of the uranium nucleus $^{235}_{92}U$ from its nucleons.

Data: m_p = 1,007284 u.
m_n = 1,00866 u.
m_U = 234,9942 u.

Solution: $92\ ^1_1P + 143\ ^1_0n \longrightarrow\ ^{235}_{92}U$

Δm = (92. 1,007284 + 143. 1,00866)- 234.9942.

Δm = 1.9134 u.

Binding energy per nucleon

The binding energy per nucleon of a nucleus, noted E_A, is the ratio of its binding energy to the mass number A of the nucleus.

$$\mathbf{E_A = E/A}$$

Example: for a Helium nucleus (^4_2He) E = 4.540 10^{-12} J.

Calculate the binding energy per nucleon in J, eV and MeV.

Note

$$\mathbf{1eV = 1{,}6022\ 10^{-19}\ J}$$
$$\mathbf{1\ MeV = 10^6\ eV = 1{,}6022\ 10^{-13}\ J}$$

Therefore we have : EA= E/A = 4.540 10^{-12}/4= 1,1351.10^{-12}J

1,1351.10^{-12}J. 10^6 eV /1,6022 10^{-13} J = 7.08.10^6 eV = 7.08 MeV/nucleon.

Note:

E_A is used to compare the stability of nucleus. The higher the binding energy per nucleon, the more stable the nucleus.

Mass-energy equivalence:

Einstein's relation:

Einstein's postulate: "**a system of mass m possesses energy when at rest**".

$$\mathbf{E = m.c^2}$$

According to Einstein, the loss mass is transformed into energy that maintains the cohesion of the nucleons in the nucleus.