Chemistry 1 Course - Structure of matter

Chapter 1.

1. Generalities:
2. Introduction
3. Atom, nucleus, isotope
4. Stability and cohesion of the nucleus, binding energy per nucleon

1st Lesson:

1-Introduction:

Chemistry is a science that aims to study and understand the chemical, physical, and dynamic properties of substances that make up the matter that surrounds us. However, a question remains, where to start? For that, it is necessary to first acquire a certain vocabulary and fundamental concepts that allow us to understand the world of chemistry.

- Matter: is everything that is substance, from the smallest dust particle to the largest star.
- Matter is composed of anything that has mass and occupies volume in space.
- Matter is naturally present commonly in solid, liquid, or gaseous forms, and these states of matter have their own physical properties.

The solid state: has a definite volume and shape.
The liquid state: has a definite volume but no specific shape, it takes the shape of its container.
The gaseous state: has neither a definite volume nor shape, it takes the volume and shape of its container.
Ice ⇒ liquid water ⇒ water vapor
Plasma : At very high temperatures, the components of the atom separate, nuclei and electrons move independently and form a globally neutral mixture: this is referred to as plasma.
The fourth state of matter, which is found in stars and the interstellar medium (وسط ما بين النجوم),, constitutes the majority of our universe (around 99%). On Earth, it is not encountered naturally, but it is artificially produced by applying electric fields powerful enough to separate the nucleus from its electrons in gases."

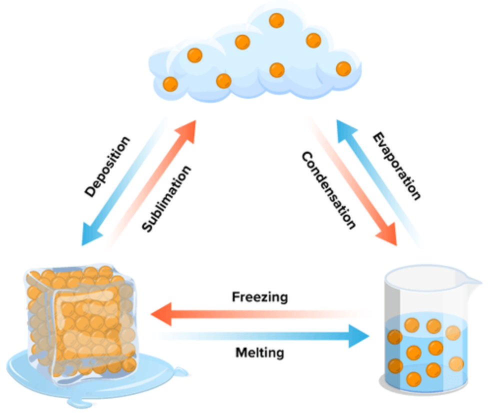
2- Changes in states of matter: (Transformation of matter)

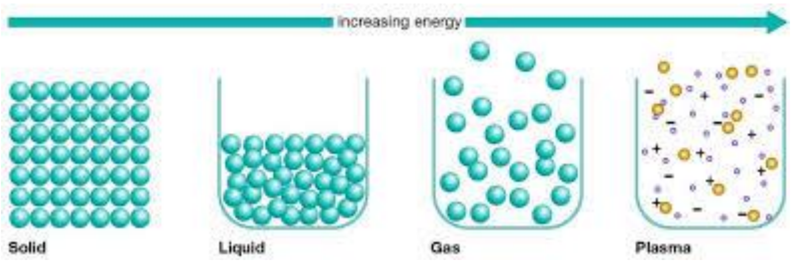
Matter undergoes permanent transformations, which can be physical (physical change of state), nuclear (transformation of the nucleus of atoms), or chemical (modification of the arrangement of atoms within chemical entities present).

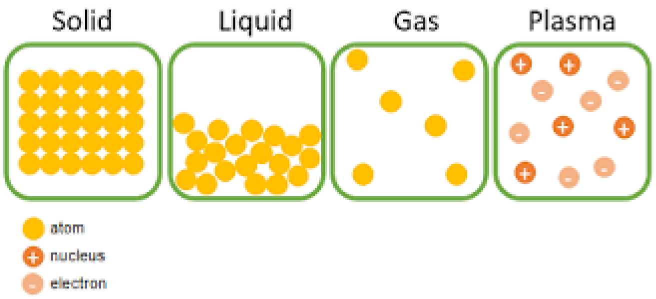
2-1 Physical change

- A physical change is a transformation that does not change the nature of a substance, it simply involves a change in its state, shape, or physical dimensions.
- A change of state is the transition from one state to another due to a change in temperature or pressure. Matter can generally transition from one state to another.

2-2 The different states of matter







- **Fusion:** transition from the solid state to the liquid state.
- **Vaporization**: transition from the liquid state to the gaseous state.
- **Liquefaction**: transition from the gaseous state to the liquid state.
- **Solidification**: transition from the liquid state to the solid state.
- **Sublimation:** transition from the solid state to the gaseous state.
- **Condensation:** transition from the gaseous state to the solid state.

Example:

- ✓ water turning into ice in the freezer.

The most classic example of sublimation is sometimes observed in winter when the atmosphere is dry. Snow (solid form of water) eventually evaporates (gaseous form of water) without leaving any puddles (liquid form of water) on the ground.

Another example:

Naphthalene, those white balls with anti-mite (anti-dust mite) properties that our grandmothers used to put in the closets, is also subject to sublimation. It eventually disappears without leaving a trace, except for its characteristic odor that proves its volatility.

Naphthalene or naphthalene or tar camphor is a polycyclic aromatic hydrocarbon, specifically a two-ring alkene, with the molecular formula C10H8. Its characteristic odor can be detected by the human sense of smell at concentrations as low as 0.04 ppm. It has been commonly used as a moth repellent.

2-3 Chemical Change

A chemical change is a transformation that changes the nature of a substance through a chemical reaction.

Examples:

- *Corrosion*: iron rusts.
- *Combustion:* wood burns to produce ash and gases.

Certain indicators can be used to recognize a chemical change:

- ✓ Formation of a gas
- ✓ Formation of a precipitate
- ✓ Change in color
- ✓ Production of energy in the form of light and heat.

Exercise of application:

Determine if each of the following statements expresses a physical or chemical change.

A) Ice melts. (Physical)
B) A piece of paper burns. (Chemical)
C) Tree leaves change color in the autumn. (Chemical)
D) Calcium chloride (KCl) dissolves in water. (Chemical)

When a salt is added to water, it dissociates, which is quite different from simple dissolution or solubilization. This process is a chemical transformation and not a physical transformation, since the starting species, solid KCl, is present in water in a different chemical form, potassium ions (K+) and chloride ions (Cl-). The physical transformation would involve changing the starting species from a solid state to a liquid state (by melting the salt at high temperature) or a gas state (by boiling it).

$$KCl \longrightarrow K^{+} + Cl^{-}$$

E) The explosion of a fireworks display. (Chemical)

Example of black powder

In the case of black powder, the reaction is as follows (Bunsen 1875):

$$2\,KNO_3 + 3C + 2S \longrightarrow K_2S + 3\,CO_2 + N_2$$

The oxidizer is potassium nitrate, and the reducers are sulfur and carbon. The gases produced are carbon dioxide and nitrogen.

F) The attraction of an iron nail by a magnet. (Physical)
G) Milk that sours. (Chemical) (sour: acidic)
H) Water evaporating. (Physical)
I) The production of a copper wire from a copper ingot. (Physical)
J) A glass breaking. (Physical)
K) The combustion of a candle. (Chemical)
L) A tomato ripening in the sun. (Chemical) (cook)

3-Model of the Atom

- Chemistry is one of the sciences that allows us to understand the world around us, the functioning of everything that surrounds us, and to answer questions that have been asked for hundreds or thousands of years.
- The study of this science requires the development of models that allow us to describe and understand the complexity of what makes up our universe.

- A model is a simplified representation of reality. It took 25 centuries for the model of the atom to be sufficiently satisfactory and to explain the possible and observable chemical reactions.
- From antiquity to the present day, great physicists and chemists have studied the universal constituent of everything: the atom.

3-1 Antiquity

For Democritus (460 - 370 BC), matter is composed of tiny and indivisible particles called "atoms" that can bind together through "hooks" to give a body, an object, its existence. But for Aristotle (384 - 322 BC), matter can be divided and results from the combination of four elements: water, air, fire, and earth.

In the absence of experimental proof, the ideas put forward by Democritus at that time remain purely philosophical.

Moreover, alchemy, in the Middle Ages, develops without concern for the atomistic conceptions of the Greeks.

3.2 The 19th century

- During this century, all theories that had been set aside are unearthed and further developed thanks to technological advancements that allow for a deep understanding of matter.
- John Dalton (1766 - 1844), an English scientist, is the first to establish the scientific foundations of the theory outlined by Democritus. There are five fundamental principles:

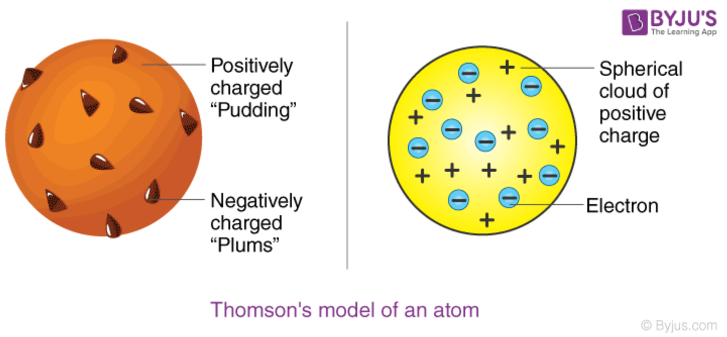
  1. All matter is made up of atoms.
  2. Atoms of the same "element" are identical.
  3. Atoms of different elements have different masses.
  4. A compound is a specific combination of atoms from one or more elements.
  5. During a chemical reaction, atoms are neither created nor destroyed but rearrange to form new compounds.

3.3 Thomson Atomic Model

- J.J. Thomson (1871 - 1937) discovered that the rays emitted by a metallic cathode, regardless of the metal, in a Crookes tube (similar to the ones used in televisions from which the air has been removed) are made up of negatively charged particles that he called "electrons": he deduced that it is a constituent element of the atom.

He imagined, in 1902, a model of the atom: a electrically neutral sphere filled with positively charged substance in which the electrons are fixed.

Thomson Atomic Model



3.3.1 Postulates of Thomson's atomic model

Postulate 1: An atom consists of a positively charged sphere with electrons embedded in it.

Postulate 2: An atom as a whole is electrically neutral because the negative and positive charges are equal in magnitude.

- Thomson atomic model is compared to watermelon. Where he considered:
- Watermelon seeds as negatively charged particles
- The red part of the watermelon as positively charged

➢ **Limitations of Thomson's atomic model**

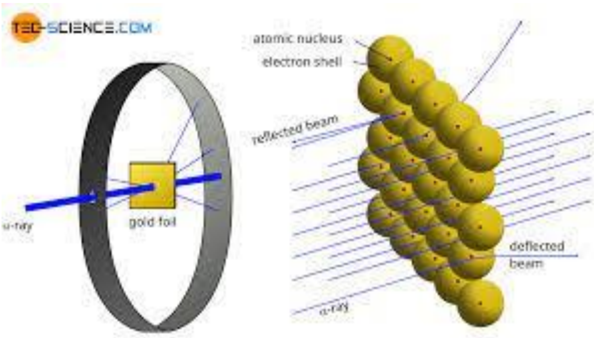
- It failed to explain the stability of an atom because his model of atom failed to explain how a positive charge holds the negatively charged electrons in an atom. Therefore, This theory also failed to account for the position of the nucleus in an atom.
- Thomson's model failed to explain the scattering of alpha particles by thin metal foils.
- No experimental evidence in its support.

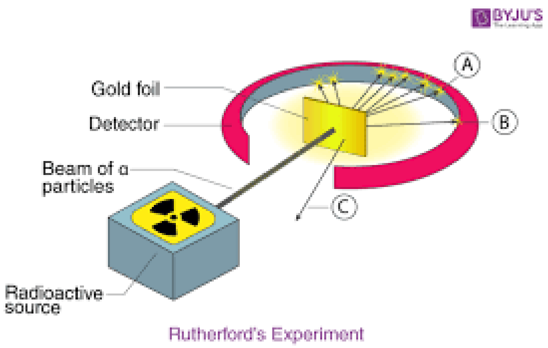
Although Thomson's model was not an accurate model to account for the atomic structure, it proved to be the base for the development of other atomic models. Find the atomic structure pdf here. The study of the atom and its structure has paved the way for numerous inventions that have played a significant role in the development of humankind. To follow more download BYJU'S – the learning app.

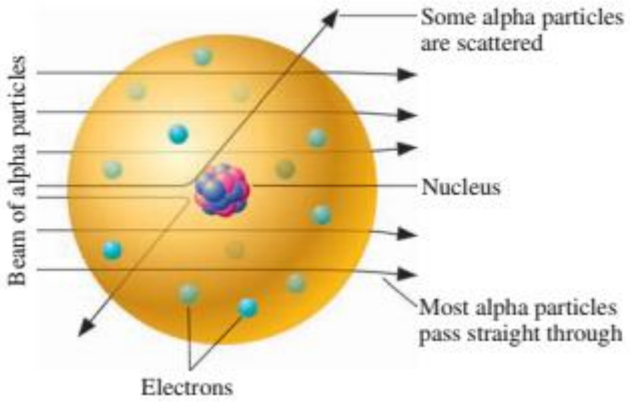
3.4 Rutherford model

E. Rutherford (1871 - 1937) experimentally demonstrates that the structure of the hydrogen atom consists of a very small nucleus surrounded by moving electrons. To prove the existence of the nucleus, Rutherford bombards a gold foil with a thickness of 0.1 µm with a beam of positively charged alpha particles ($^{4}_{2}He^{2+}$) and observes that:

- ✓ The gold foil is not damaged.
- ✓ Most of the alpha particles pass through without deviation.
- ✓ These particles cause a bright spot.
- ✓ The remaining particles are deflected (1%) and cause scintillations at various points.

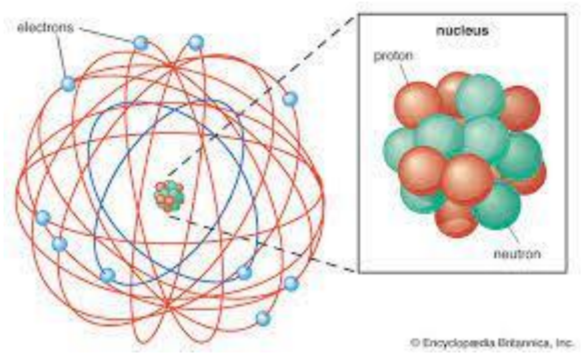






Representation of the scattering of alpha particles by a gold foil
Most of the alpha particles pass through the foil barely deflected. A few, however, collide with gold nuclei and are deflected at large angles. (The relative sizes of nuclei are smaller than can be drawn here.)

- Rutherford therefore concluded the existence of positively charged particles in the gold atom that repel the alpha particles. These particles are confined to a small part of the atom called the "nucleus".
- The model of the solar system is then adopted: the central nucleus is associated with the Sun, and the electrons orbiting around are associated with the planets.



The atom (*neutral*) = **nucleus** (*positive*) + **electron** (*negative*),

Nucleus = protons (*positive*) + neutrons (*neutral*)

$$\frac{r_{atom}}{r_{nucleus}} = \frac{10^{-10}}{10^{-15}} = 10^{+5} \Rightarrow r_{atom} = 10^{+5} \cdot r_{nucleus}$$

- Almost the entire atom is empty, its structure is lacunar.
- The nucleus is made up of nucleons: protons and neutrons.

	mass	**Charge q**
Proton	$m_p = 1{,}673.10^{-27}$ kg	$q = + 1{,}602.10^{-19}$ C
Neutron	$m_n = 1{,}675.10^{-27}$ kg	$q = 0$
Electron	$me = 9{,}109.10^{-31}$ kg	$q = - 1{,}602.10^{-19}$ C

- ✓ Radius of the nucleus ≈ 10^{-15} m
- ✓ Radius of the atom ≈ 10^{-10} m
- But in the 20th century, this commonly used model is declared false with the advancement of quantum physics.

N. Bohr, W. Pauli, and E. Schrödinger establish that the nucleus is surrounded by an "electron cloud" that is more or less dense depending on the probability of their presence.

- However, for the study of the atom and its properties, it is easier to maintain the principle of an electron cloud composed of orbitals or electron shells on which the electrons orbit.

4- Atom, molecule, element

- An atom (Ancient Greek, ἄτομος [atomos], "indivisible") is the smallest part of a simple substance that can chemically combine with another.
- "An atom is the smallest part of a substance capable of participating in a chemical reaction."
- Matter is made up of infinitely small particles or elementary grains called atoms.
- There are 118 species of atoms or elements, each designated by a symbol nucleide $^{A}_{Z}X$

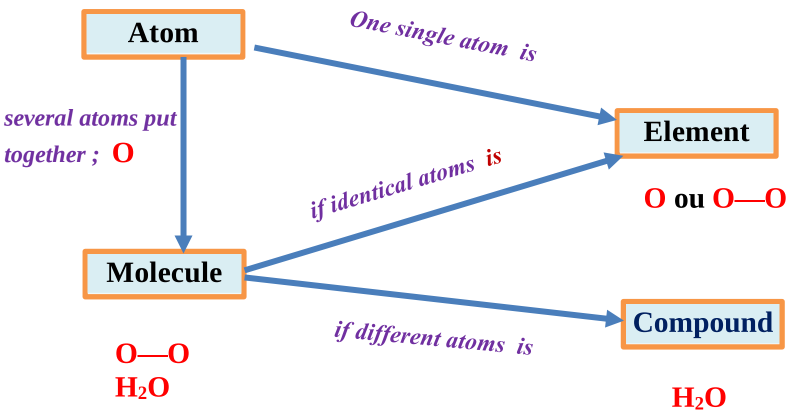
A: mass number (number of nucleons)
Z: proton number (number of charges) or atomic number.
N: neutron number

- It's from these symbols that chemical formulas can be written. e.g. H_2O (this is called the chemical formula). 2 hydrogen atoms and one oxygen atom).

- ✓ The mass of the atom is of the order of 10-26 Kg and its size is of the order of some (Angstrœms) Å.
- ✓ 1 Å = 10-8 cm = 10^{-10} m.
- ✓ All elements with the same atomic number Z correspond to the same chemical element noted.

4.1 Molecule Compound

A molecule is a collection of atoms (at least two), identical or not, joined together by chemical bonds. These bonds result from the pooling of a certain number of electrons gravitating on the outer layer of the atoms.



The Avogadro constant N_A

- The Avogadro number is named in honor of the Italian physicist and chemist Amedeo Avogadro (1776 - 1856).
- The quantity of matter in a molecule is infinitely small, it is of the same order of magnitude as that of an atom. To obtain quantities on our scale, a very large number of molecules is considered. This number is symbolized by N_A, which is called Avogadro's number.

- $N_A = 6.02214076 \times 10^{23}$ entities (atoms, molecules, ions)
- notation: $N_A = 6.02 \times 10^{23}$ mol^{-1}.

Examples:

In one mole of oxygen atoms, there are 6.02 × 1023 oxygen atoms.
In one mole of water molecules, there are 6.02 × 1023 water molecules.
In one mole of sulfate ions, there are 6.02 x 1023 sulfate ions.
In one mole of tennis balls, there are 6.02 x 1023 tennis balls.

Definition of the mole:

- By convention, the unit of quantity of matter is the mole.
- To define the mole, the number of atoms present in 12 g of carbon 12 (C^{12}) was measured, and it was found to be 6.02205×10^{23} atoms, which is Avogadro's number.
- One mole of atoms, molecules, or ions therefore contains 6.02×10^{23} atoms, molecules, or ions.
- This number is known as Avogadro's constant.
- A mole is a quantity of atoms or molecules.
- An atom, a molecule, is something microscopic. By taking a large quantity of atoms, one mole, we obtain a measurable ensemble from a macroscopic point of view. For example, we can weigh the mass of a mole of table salt (NaCl) with a simple balance, whereas we cannot weigh the mass of a molecule of NaCl.

  Examples:
- The number of copper atoms N represented by 2.5 moles is $N = 2.5 \times 6.02 \times 10^{23}$ = ***1.5×10^{24} atoms***.
- The number of moles of copper represented by 2×10^{22} copper atoms is: $2 \times 10^{22} / 6{,}02 \times 10^{23}$ = ***0.033 mole of copper atoms.***

- **Atomic mass unit (u.m.a) (a.m.u)**

  The unified atomic mass unit (symbol u or a.m.u) is a standard unit of measurement used to measure the mass of atoms and molecules.
- **In physics:**

  This unit is not part of the International System (SI), and its value is obtained experimentally. It is defined as 1/12 of the mass of an atom of the nuclide 12C (carbon), unbound, at rest, and in its ground state.

$$1 \text{ a.m.u} = \frac{1}{12} m_{^{12}_{6}C} \quad \mathbf{(1)}$$

$$1 \text{ a.m.u} = \frac{1}{12} \cdot \frac{12g}{NA} = \frac{\mathbf{1}}{\boldsymbol{NA}} \mathbf{g} = \frac{1}{6{,}022 \cdot 1023} \text{g} \Rightarrow \quad 1 \text{ a.m.u} = \frac{\mathbf{1}}{\boldsymbol{NA}} \mathbf{g}$$

$$\Rightarrow \mathbf{1\ a.m.u = 1{,}66054 \times 10^{-24}\ g = 1{,}66054 \times 10^{-27}\ kg}$$

from equation **(1)** the mass of a single carbon atom $\boldsymbol{m_{^{12}_{6}C}}$ **= 12 a.m.u**

Other useful correspondence (in chemistry) :

1 a.m.u = 1 g.mol^{-1}

mass of an atom in amu = molar mass in g/mol

The average mass of an atom in **a.m.u** and the molar mass in gram are equal.

- M ($^{16}_{8}O$) = 16 $\frac{g}{mol}$ ⇒ m_O = 16 $\frac{g}{NA}$ = 16 **amu**

Molar mass of oxygen	Mass of a single oxygen atom.

- M ($^{12}_{6}C$) = 12 g/mol ⇒ m_C = 12 **amu**

Molar mass of carbon	Mass of a single carbon atom.

Calculating the mass of the electron, proton, and neutron in atomic mass units (amu)

$m_e = 9{,}109.10^{-31}$ kg = $\frac{9{,}109.10^{-31}}{1{,}6606.10^{-27}}$ = 5,5 .10^{-4} amu

$m_p = 1{,}673.10^{-27}$ kg = $\frac{1{,}673.10^{-31}}{1{,}6606.10^{-27}}$ = 1.0074 amu

$m_n = 1{,}675.10^{-27}$ kg = $\frac{1{,}675.10^{-31}}{1{,}6606.10^{-27}}$ = 1,0087 amu

Atomic molar mass:

- The atomic molar mass **M** of a sample is the mass of one mole of that element.
- Its unit is g.mol^{-1}.

Examples:

- ✓ The mass of one mole of carbon is 12 g.
- ✓ The molar mass of carbon is 12 g.mol^{-1}.
- ✓ That is, the mass of 6.02205 .10^{23} carbon atoms.

- The mass of a single carbon atom:
- mc = 12 / 6.02205 .10^{23} = 1.99 .10^{-23} g
- **Note:** The symbol of an element represents one mole of atoms of that element.