Chapter 1: Fundamentals

Objectives

By the end of this fisrt chapter, the student will be able to:

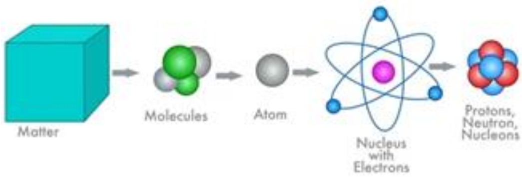
- Understand the different states of matter and distinguish between the qualitative and quantitative aspects of matter.
- To provide examples of the importance of chemistry in everyday life.
- Understand the notion of quantity of matter and all types of concentration in chemistry.

Introduction

The aim of general chemistry, and specifically the structure of matter, is to study the chemical concepts that enable us to describe the composition of matter and understand the nature of chemical reactions.

These concepts make it possible to predict most of the properties of atoms and the way they combine to form molecules. Chapter 1 starts with the basics to give an overview of matter and its macroscopic aspects.

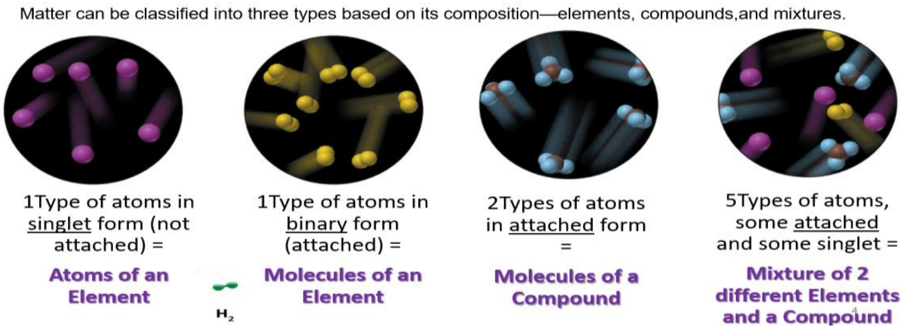
Matter is anything that has mass and volume. The definition of matter is often taken to mean anything composed of atoms and molecules, so when zooming a sample of matter with a powerful microscope, we can see different shapes and different things.



Thus, matter is anything made of protons, neutrons, and electrons.

1- Classification of matter

Matter can be classified into three types based on its composition—elements, compounds,and mixtures..



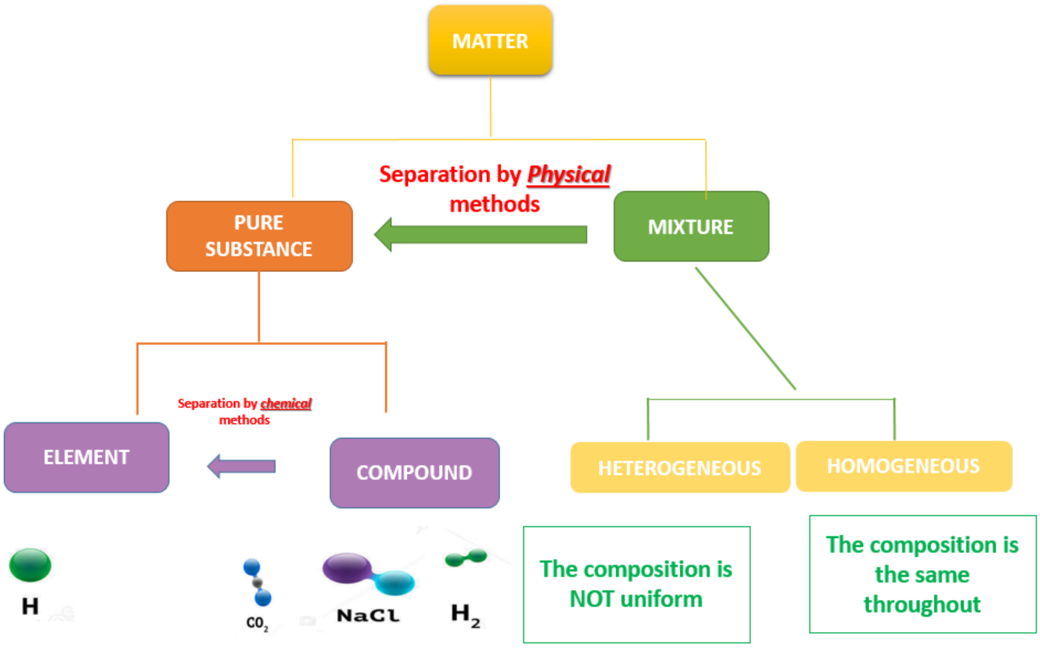
a-An element is the simplest type of matter with unique physical and chemical properties. It consists of only one kind of atom and, therefore, cannot be broken down into a simpler type of matter by any physical or chemical methods. Each element has a name. ***b-A compound*** consists of two or more different elements that are bonded chemically. Unlike an element, a compound can be broken down into simpler substances—its component elements.

c-A mixture consists of two or more substances (elements and/or compounds) that are physically mixed together, not chemically combined. The components retain their individual properties, can be present in any proportion, and can be separated by physical changes.

Most of the matter around us consists **of mixtures of pure substances**. Gasoline, soil, and air are all mixtures. The main characteristic of a mixture is that it has variable composition. Mixtures can be classified as homogeneous (having visibly indistinguishable parts) or heterogeneous (having visibly distinguishable parts).

d-A homogeneous mixture is called a solution. Air is a solution consisting of a mixture of gases. is a complex liquid solution. Steal is a solid solution of iron and carbon. Sand in water and iced tea with ice cubes are examples of heterogeneous mixtures.

e-Heterogeneous mixtures usually can be separated into two or more homogeneous mixtures or pure substances (for example, the ice cubes can be separated from the tea).



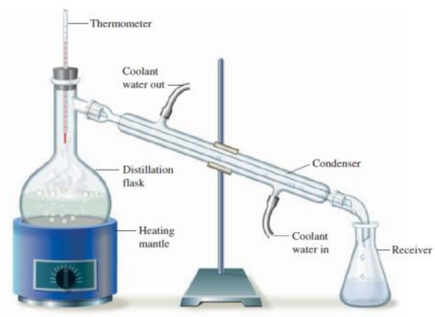
2- Identifying physical and chemical changes

To understand how matter is classified by its chemical constitution, we must distinguish between physical and chemical changes and between physical and chemical properties.

a- A physical change is a change in the form of matter but not in its chemical identity. Changes of physical state are examples of physical changes.

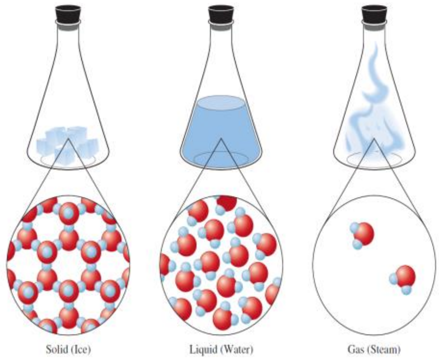
For instance, you can dissolve sodium chloride (table salt) in water. The result is a clear liquid, like pure water.

***b-A chemical change*,** or chemical reaction, is a change in which one or more kinds of matter are transformed into a new kind of matter or several new kinds of matter. The rusting of iron, during which iron combines with oxygen in the air to form a new material called rust, is a chemical change. The original materials (iron and oxygen) combine chemically and cannot be separated by any physical means.To recover the iron and oxygen from rust requires a chemical change or a series of chemical changes.



3- States of matter

There are three states of matter: solid; liquid and gas. They have different properties, which can be explained by looking at the arrangement of their particles.



a-Solids: Solids contain particles arranged in a lattice structure. The particles vibrate in their fixed positions. This explains properties of solids:

They can't be compressed (particles are already tightly packed together).

b-Liquids: Liquids contain particles that roll around each other and settle on the bottom of their container. The particles are generally slightly further apart than in a solid. (Water is an exception – ice particles are slightly further apart than liquid water, which is why ice floats.) This explains properties of liquids:

• They change shape when poured into a different container (particles roll over each other and settle on the bottom).

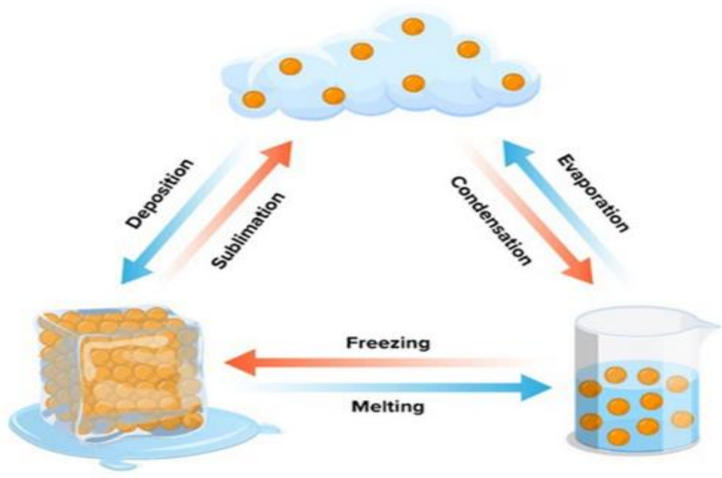
• They have constant volume (particles are close together).

• They are slightly compressible. (There are slight spaces between particles.)

c-Gases: Gases contain particles that move around very quickly. The particles travel in straight lines until they bounce off another particle or a surface. Gas particles are widely spaced and tend to be only slightly attracted to each other. This explains properties of a gas:

• They fill available space (slight attraction between particles).

• They are very compressible (particles are widely spaced).



changing state of matter

Melting Point: This is the temperature at which a substance transitions from a solid state to a liquid state.

Boiling Point: This is the temperature at which a substance transitions from a liquid state to a gaseous state.

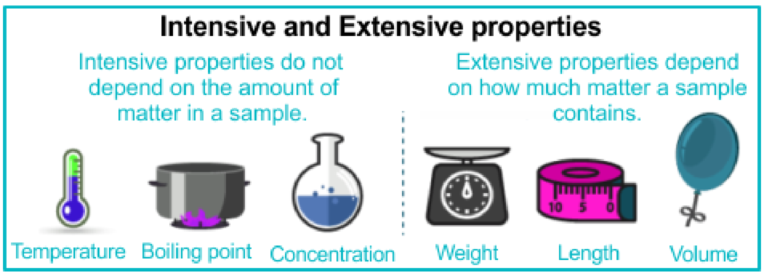
Sublimation Temperature: This is the temperature at which a substance transitions directly from a solid state to a gaseous state without passing through the liquid state.

Condensation Temperature: This is the temperature at which a substance transitions from a gaseous state to a liquid state.

Freezing Point: This is the temperature at which a substance transitions from a liquid state to a solid state.

4- Extensive and Intensive Properties

Some variables are dependent on the amount of substance present; these are called extensive properties. On the other hand, intensive properties are independent of the amount of substance. Mass and volume, for example, are extensive properties, but density is an intensive property.



5- Notions of Mole, Molecular Mass, Atomic Mass and Avogadro's Number

a- Avogadro's number

The specific number of molecules in one gram-mole of a substance, defined as the molecular weight in grams, is $6.02214076 \times 10^{23}$, a quantity called Avogadro's number, or the Avogadro constant. For example, the molecular weight of oxygen is 32.00, so that one gram-mole of oxygen has a mass of 32.00 grams and contains $6.02214076 \times 10^{23}$ molecules.

b- The mole

Since any sample of matter contains a very large number of atoms, a unit of measurement was created to count them, the mole.

A mole of any substance contains Avogadro's number 6.022×10^{23} entities of that substance.

1 mole of atoms or molecules =*6.02×10^{23}*atoms or molecules

c- Molar weight (MW)

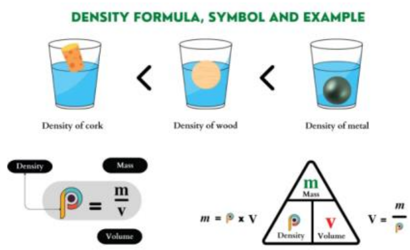
Molar weight (MW) is the mass of one mole of a substance in grams (g/mol). The MW of a molecule is a sum of relative atomic weights Ar (expressed in grams per mole) of all elements building the molecule. The values of MW are found in the Periodic table.

Example: the MW of H = 1, N = 14, O = 16

molar weight of HNO_3 = 1x1 + 1x14 + 3x16 = 63 g/mol.

d- Density

Density of a solution (ρ) is the mass of a specified volume of the solution
(g/cm3 = g/mL = kg/dm^3 = kg/L); it is often labeled on a bottle containing the solution.
Example: ρ = 1,8 g/mL means that 1 mL of the solution weights 1,8 g).



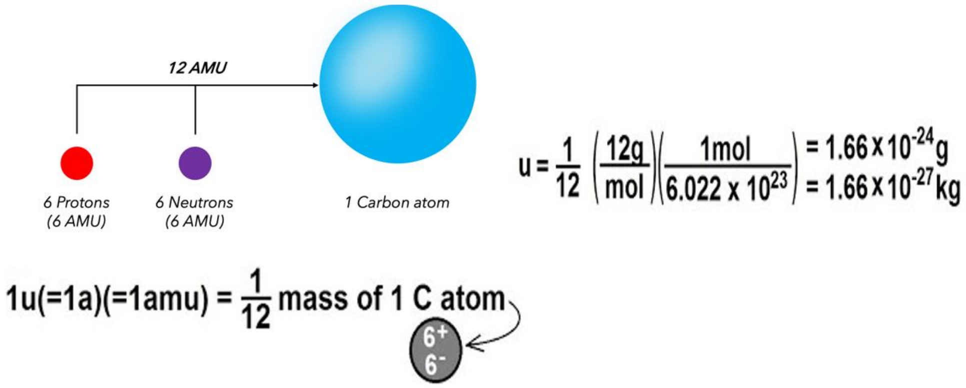
e- Molar volume

This is the volume occupied by one mole of substance in the gaseous state. Under Normal Pressure and Temperature conditions (P= 1 Atm, T= 0°C=273 K), one mole of gaseous substance occupies a volume of 22.4 L.

$$v = \frac{nRT}{P} = \frac{(1{,}000\,atm)(0{,}08206\,L.atm/K.mol)(273{,}5\,K)}{1.000\,atm} = 22{,}4\,L$$

f- Atomic mass unit (AMU)

In physics and chemistry, a unit for expressing masses of atoms, molecules, or subatomic particles. An *atomic mass unit*[1] is equal to 1/12 the mass of a single atom of carbon-12. The mass of an atom consists of the mass of the nucleus plus that of the electrons, so the atomic mass unit is not exactly the same as the mass of the proton or neutron. Atomic mass units are also called daltons (Da), for chemist John Dalton.



6- Law of Matter Conservation (Antoine Lavoisier)

the law of conservation of mass was discovered by Antoine Lavoisier in 1789 (French chemist), this law states that in chemical reactions the total mass of reagents equals the total mass of products. No atoms are lost or created during chemical reactions, only rearranged, maintaining a consistent mass throughout.

$$a\ A + b\ B \rightarrow c\ C + d\ D$$

The reacting species A and B are called reagents and the resulting species C and D are called products. The chemical reaction must obey the law of conservation:

- Of mass (the mass of the product formed must be equal to the mass of the reagents)
- Of charge
- Of matter.

a- Stoichiometry

Stoichiometry is the calculation of the quantities of reactants and products involved in a chemical reaction. It is based on the chemical equation and on the relationship between mass and moles.

b- Balancing Chemical Equations

To balance the equation, you select coefficients that will make the numbers of atoms of each element equal on both sides of the equation.

Look at the chemical equation for atoms of elements that occur in only one substance on each side of the equation. Begin by balancing the equation in one of these atoms.

c- The limiting reactant

The **limiting reactant** (or **limiting reagent**) is *the reactant that is entirely consumed when a reaction goes to completion.* A reactant that is not completely consumed is often referred to as an *excess reactant.* Once one of the reactants is used up, the reaction stops. This means that:

The moles of product are always determined by the starting moles of limiting reactant.

Problem In a preparation of ClF_3, 0.750 mol of Cl_2 reacts with 3.00 mol of F_2.

(a) Find the limiting reactant.

(b) Write a reaction table.

$$Cl_2 + 3F_2 \longrightarrow 2ClF3$$

Solution **(a)** Determining the limiting reactant:
Finding amount (mol) of ClF_3 from amount (mol) of Cl_2:

$$\text{Amount (mol) of } ClF_3 = 0.750 \cancel{\text{mol } Cl_2} \times \frac{2 \text{ mol } ClF_3}{1 \cancel{\text{mol } Cl_2}} = 1.50 \text{ mol } ClF_3$$

Finding amount (mol) of ClF_3 from amount (mol) of F_2:

$$\text{Amount (mol) of } ClF_3 = 3.00 \cancel{\text{mol } F_2} \times \frac{2 \text{ mol } ClF_3}{3 \cancel{\text{mol } F_2}} = 2.00 \text{ mol } ClF_3$$

In this case, Cl_2 is limiting because it forms fewer moles of ClF_3.

(b) Writing the reaction table, with Cl_2 limiting:

Amount (mol)	$Cl_2(g)$	+	$3F_2(g)$	$\longrightarrow$	$2ClF_3(g)$
Initial	0.750		3.00		0
Change	−0.750		−2.25		+1.50
Final	0		0.75		1.50

7- Qualitative aspect of matter

a- ***The solution:*** This is a homogeneous mixture of pure substances that do not react with each other. The majority constituent (In large proportion) is called solvent and the dissolved substances are solutes.

b- ***Solvent :***the component of a solution which dissolves the other component in itself is called solvent. A solvent constitutes the larger component of the solution.

c- ***Solute*** the component of the solution which dissolves in the solvent is called solute. The solute is the smaller component of the solution.

For example, a solution of sugar in water is solid in the liquid. Here, sugar is the solute and water is the solvent.

d- ***Dilution*** Diluting a solution means obtaining a new solution that is less concentrated than the initial by adding solvent. The initial solution is called the stock-solution, and the diluted solution is called the sub-solution. After dilution, the quantity of substance is the same. We can write :

Before dilution: : $n_1 = C_1 . V_1$; $n_2 = C_2 . V_2$

After dilution:Number of moles is the same**:** $n_1 = n_2 \Rightarrow C_1 . V_1 = C_2 . V_2$

8- Concentrations

a- Molarity or (Molar concentration)

Molarity or (Molar concentration) (*M or Mol/L*), is a useful concentration unit for many applications in chemistry. **Molarity is defined as the number of moles of solute in exactly 1 liter (1 L) of the solution:**

$$M = \text{molarity} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

b- Mass concentration

Mass concentration) (*g/L*), is defined as the weight of solute in exactly 1 liter (1 L) of the solution:

$$\textbf{mass concentration} = \frac{\textbf{weight of solute in grams}}{\textbf{1 liter of solution}}$$

c- Normality

Normality is defined as the number of *equivalents* per liter of solution, where the definition of an equivalent depends on the reaction taking place in the solution.

$$N = eq \times C$$ (C → Molarity)

For an acid–base reaction :

Eq= Number of H^+ or OH^- ion

$$H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$$ (Eq= 2)

For oxidation–reduction reactions :

Eq= Number of electrons

$$MnO_4^- + 5e^- + 8H^+ \longrightarrow Mn^{2+}\ 4H_2O$$ (Eq= 5)

d- Mole and mass Fraction

- ***Fraction***

If the solution has a solvent and the solute, a mole fraction gives a concentration as the ratio of one component to the total components present in the solution. It is denoted by x. Suppose we have a solution containing A as a solute and B as the solvent.

- ***Mole fraction***

Let n_A and n_B be the number of moles of A and B present in the solution respectively. So, mole fractions of A and B are given as:

$$X_a = \frac{n_a}{n_a + n_b} \qquad X_b = \frac{n_b}{n_a + n_b}$$

- ***Mass fraction***

Let m_A and m_B be the weight of A and B present in the solution respectively. So, mass fractions of A and B are given as:

$$X_a = \frac{m_a}{m_a + m_b} \qquad X_b = \frac{m_b}{m_a + m_b}$$

- ***Mole Percentage***

$$X_a = \frac{n_a}{n_a + n_b} \times 100 \qquad X_b = \frac{n_b}{n_a + n_b} \times 100$$

- **Masse pourcentage**

$$X_a = \frac{m_a}{m_a + m_b} \times 100 \qquad X_b = \frac{m_b}{m_a + m_b} \times 100$$

e- Mass by Volume Percentage (W/V)

It is defined as the mass of a solute dissolved per 100mL of the solution.

Mass of solute → In 100 mL of solution

$$\% \; w/V = \frac{\text{Mass of component A in the solution}}{\text{Total Volume of the Solution}} \times 100$$

f- Mass Percentage (w/w):

It is defined as the mass of a solute contained in 100g of the solution.

Mass of solute (g) → 100 g of solution

$$\% \; w/w = \frac{\text{Mass of component A in the solution}}{\text{Total mass of the solution}} \times 100$$

g- Volume Percentage (V/V)

It is defined as the volume of a solute contained in 100 mL of the solution

Volume of solute (mL) → 100 mL of solution

$$\% \; V/V = \frac{\text{Volume of component A in the solution}}{\text{Total volume of solution}} \times 100$$