chemistry course and tutorial series"structure of matter"

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Objectifs

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.

Chapter 1 : fondamental notions

1. 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.

2. Notion of atoms and molecules

2.1. Atoms

Matter is made up of elementary particles called atoms. *An atom is considered to be the smallest particle of an element*[1]* and is, according to Greek etymology, indivisible and indestructible. There are 111 types of atom, each different from the other in structure, mass and physical and chemical properties. Each element is designated by an abbreviation or symbol:

where : A: mass number; Z: charge number.

The first letter of the symbol is always in upper case and the second in lower case.

The atom is an infinitely small quantity of matter, with a mass of the order of 10^{-26} Kg, and a radius of the order of 1 *Angstrom** (Å).

1 Å= 10^{-8} cm = 10^{-10} m

A copper penny (left) contains approximately 3 × 1022 copper atoms (several dozen are represented as brown spheres at the right), each of which has the same chemical properties.

2.2. The molecule

- The atom does not often exist in a free state, but combines with other elements to form molecules (the combination of two (2) or more atoms). These molecules can be diatomic (N_2, Cl_2, HCl.......etc) or polyatomic (CH_3COOH, H_3PO_4,........etc).
- A pure substance: this is a substance containing only identical molecules; it can be simple or compound.
- If these atoms are identical, the substance is a simple pure substance. Example: Ozone: Cl_2 , O_3, N_2,
- If these atoms are different, the substance is a compound. Example: methane: CH_4, salt: NaCl.

3. The state of matter

There are three states of matter: solid; liquid and gas.[1] They have different properties, which can be explained by looking at the arrangement of their particles.

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).

• They keep their shape and have a constant volume when they change container (particles are in fixed positions).

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).

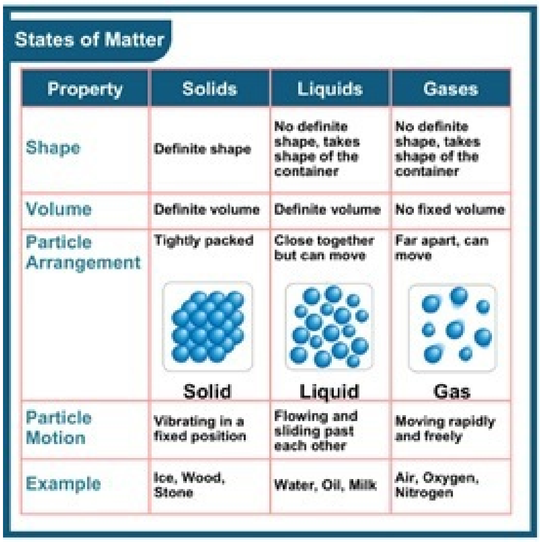
• They have constant volume (particles are close together).

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

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).



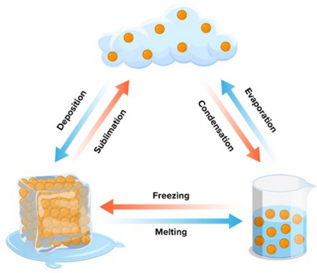
States of Matter

Property	Solids	Liquids	Gases
Shape	Definite shape	No definite shape, takes shape of the container	No definite shape, takes shape of the container
Volume	Definite volume	Definite volume	No fixed volume
Particle Arrangement	Tightly packed Solid	Close together but can move Liquid	Far apart, can move Gas
Particle Motion	Vibrating in a fixed position	Flowing and sliding past each other	Moving rapidly and freely
Example	Ice, Wood, Stone	Water, Oil, Milk	Air, Oxygen, Nitrogen

States of matter

Example: Water can be in a solid state (below 0°C), a liquid state (from 0 to 100°C) and a vapour state (above 100°C). The points 0°, 100° represent the points of equilibrium between two states (solid - liquid and liquid - vapour).

The transition between states is shown in the diagram below:



changing state of matter

4. Notions of Mole, Molecular Mass, Atomic Mass and Avogadro's Number

4.1. 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.

4.2. 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. https://www.youtube.com/watch?v=dHJmOH38agY

4.3. 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.

4.4. 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.

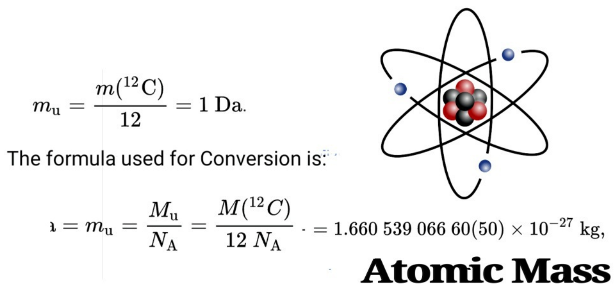
Example: ρ = 1,8 g/mL means that 1 mL of the solution weights 1,8 g).

4.5. 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.

4.6. Atomic mass unit (AMU)

In physics and chemistry, a unit for expressing masses of atoms, molecules, or subatomic particles. An atomic mass unit[2] 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*∗.



Atomic mass unit

5. Qualitative aspect of matter (Classification of matter)

5.1. Mixtures

a mixture is a substance composed of different molecules (NaCl + water ; oil + water). A distinction is made between:

a) Heterogeneous mixtures

Heterogeneous mixtures are mixtures where we can distinguish, with the naked eye or with the aid of a magnifying instrument, the particles of the bodies that make them up. These are mixtures made up of more than one phase (water+ oil + vinegar).

2. https://www.politicalfunda.com/2022/11/atomic-mass-atomic-mass-definition-units-and-facts.html

b) Homogeneous mixtures

Homogeneous mixtures are mixtures where we cannot distinguish the particles from the bodies that make them up. These are mixtures made up of a single phase (air, mixture of two gases, ...).

5.2. 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.

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

b) 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 iodine in alcohol known as 'tincture of iodine', iodine is the solute. Similarly, in carbonated drinks (Soda water), carbon dioxide gas is the solute.

5.3. 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: : $n_1 = C_1 . V_1$

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

5.4. 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.

Let the following chemical reaction occur:

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

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.

6. Concentrations

Concentration refers to the amount of a substance (solute) present in a specific volume of solution. It's usually expressed in different units, such as moles per litre (M), grams per litre (g/L), percent volume/volume (% v/v), percent weight/volume (% w/v), and percent weight/weight (% w/w).

6.1. The molarity

Molarity (M) is one of the most commonly used measures of concentration in chemistry. It is defined as the number of moles of solute present in one litre of solution (mol x L^{-1} = mol x dm^{-3} = mol/L = mol/dm = M) it can be used if the molar weight (MW) of the substance is known.

To calculate molarity, the formula used is:

$$V = \frac{m}{\rho};V = \frac{1}{10^{-3}} = 10^3 mL = 1L$$

Formule 1

Where, C= molarity, n = substance amount in moles, V = final volume of the solution in L.

or directly from the definition. A direct proportionality between the concentration (c) and a related substance amount (n) is used.

-1 M solution (read: one molar solution) means that 1 L of the solution contains 1 mol of a substance.

-0,5 M solution (read: half molar solution) means that 1 L of the solution contains 0,5 mol of a substance.

-Molarity is dependent on temperature since it involves the volume of the solution, which can expand or contract with temperature changes.

6.2. Molality (m)

Molality (m), on the other hand, is defined as the number of moles of solute present in one kilogram of solvent. Unlike molarity, molality is not affected by temperature as it involves the mass of the solvent, which remains constant irrespective of temperature. To calculate molality, the formula used is

$$m = \frac{n_{solute}}{W_{solvent}}$$

Formule 2

Where, n_{solute} stands for the number of moles of solute and $V_{solvent}$ is the weight of the solvent in kilograms.

6.3. Mass concentration

The mass titre of a solution is equal to the mass m of solute divided by the volume V of the solution. of the solution, expressed in $g.L^{-1}$.

$$Cm = \frac{m}{V}$$

Formule 3

where: Cm = mass concentration in $g.L^{-1}$; m mass of the solute in g and V the solution volume in L.

6.4. Normality

Normality in Chemistry is one of the expressions used to measure the concentration of a solution. It is abbreviated as 'N' and it is mainly used as a measure of reactive species in a solution and during titration reactions or particularly in situations involving acid-base chemistry.

As per the standard definition, normality is described as the number of gram or mole equivalents of solute present in one litre of a solution. When we say equivalent, it is the number of moles of reactive units in a compound.

6.5. Percent concentration (g/100 g or ml/100 mL or g/100 mL)

It is generally expressed as parts of a solute per 100 parts of total solution (per cent = per one hundred)

a) Weight per unit weight (w/w)

It is expressed in grams of solute per 100 g of the solution (g/100g of solution) **for example:**

10% (w/w) solution of NaOH means that 100 g of the solution contain 10 g of NaOH (it is prepared from 10g of NaOH and 90g of H_2O) 10% (w/w) solution of KCl means that 100 g of the solution contain 10 g of KCl (it is prepared from 10g of KCl and 90g of H_2O)

i) Volume per unit volume (v/v)

It is expressed in millilitres of solute per 100 mL of the solution (ml/100 mL of solution) **for example**:

5% (v/v) solution of alcohol means that 100 mL of the solution contain 5 mL of alcohol (it is prepared from 5 mL of alcohol and the rest of water to reach 100 mL of the solution)

b) weight per unit volume (w/v)

It is expressed in grams of solute per 100 mL of the solution (g/100 mL of solution) **for example**:

2% (w/v) solution of KOH means that 100 mL of the solution contain 2 g of KOH.

c) Mole Fraction

There are several ways to indicate the concentration of a solution, and mole fraction is one of them. A mole fraction is a unit of concentration. In the solution, the relative amount of solute and solvents are measured by the mole fraction, and it is represented by "X."

Mole fraction is the number of moles of a specific component in the solution divided by the total number of moles in the given solution.

Consider a solution consisting of two substances, A and B, then the mole fraction of each substance is:

$$X_A = \frac{Mol_A}{Mol_A + Mol_B}, X_B = \frac{Mol_B}{Mol_A + Mol_B}$$

Formule 4

-In the given mixture, the sum of all the mole fractions is equal to one. XA + XB = 1

-The multiplication of the mole fraction by 100 gives the mole percentage.

-Mole fraction is a unitless and dimensionless expression.

d) Mass fraction

In a mixture, the mass fraction is the amount of mass of one substance, divided by the mass of the total mixture. The sum of all the mass fractions is equal to 1. Mass fraction can also be expressed, with a denominator of 100, as percentage by mass.

Consider a solution consisting of two substances, A and B, then the mass fraction of each substance is:

$$W_A = \frac{m_A}{m_A + m_B}, W_B = \frac{m_B}{m_A + m_B}$$

Formule 5

With W: Mass fraction and m: Mass of one substance (kg).

Glossaire

Angstrom

a unit of length equal to one hundred-millionth of a centimetre, used mainly to express wavelengths and interatomic distances.

Antoine Lavoisier

Antoine Laurent Lavoisier, ci-devant de Lavoisier, né le 26 août 1743 à Paris et guillotiné le 8 mai 1794 à Paris, est un chimiste, philosophe et économiste français, souvent présenté comme le père de la chimie moderne

Avogadro

Lorenzo Romano Amedeo Carlo Avogadro, Count of Quaregna and Cerreto was an Italian scientist, most noted for his contribution to molecular theory now known as Avogadro's law, which states that equal volumes of gases under the same conditions of temperature and pressure will contain equal numbers of molecule

John Dalton

John Dalton FRS was an English chemist, physicist and meteorologist. He introduced the atomic theory into chemistry. He also researched colour blindness, which he had; as a result, colour blindness is known as Daltonism in several languages

Webographie

https://www.cusd80.com/cms/lib/AZ01001175/Centricity/Domain/2155/Zumdahl%20Chapter%207%20A