MOLE CONCEPT

What is the Mole Concept?

The mole concept is a convenient method of expressing the amount of a substance. Any measurement can be broken down into two parts the numerical magnitude and the units that the magnitude is expressed in. For example, when the mass of a ball is measured to be 2 kilograms, the magnitude is '2' and the unit is 'kilogram'.

When dealing with particles at an atomic (or molecular) level, even one gram of a pure element is known to contain a huge number of atoms. This is where the mole concept is widely used. It primarily focuses on the unit known as a 'mole', which is a count of a very large number of particles.

Atoms and molecules are pretty small (understatement!) and, as scientists are interested in being able to describe quantities of matter in terms of the mass and number of particles contained per unit mass, this poses a problem.

Measuring the mass of individual atoms, we find that one hydrogen atom has a mass of about 1.66 x 10-27g

This number is far too small to be useful and so it makes sense to deal with quantities of atoms which can be measured in the laboratory.

- Hydrogen as a standard
- Carbon as a standard
- Avogadro's number

The Hydrogen Standard :

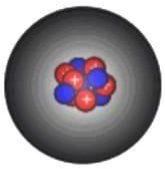
Hydrogen is the smallest atom and it was original used as the standard by which all the other atoms were compared. It was assigned a value of 1 unit and other atoms masses calculated compared to hydrogen atoms.

The ^{1}H isotope has a mass assigned a value of exactly 1 atomic mass unit. This was the original reference.

The ^{1}H isotope

The Carbon 12 Standard :

Nowadays the ^{12}C isotope is used as a reference for comparison of relative atomic masses. This isotope has the assigned mass of 12.00000, all other atoms are measured relative to ^{12}C



The ^{12}C isotope

Measured on this scale hydrogen atoms (on average) have a relative mass of 1.00797

Carbon atoms have a relative mass of 12.01111 on average. Although this seems strange at first sight, it is because carbon has several isotopes ^{12}C, ^{13}C, and ^{14}C and the relative mass of carbon is given as the weighted average of all of the isotopes in a naturally occurring sample. Clearly the average must be greater than 12.0000.

Most tables use the relative atomic masses rounded up to one or two decimal places.

Carbon atoms have a mass approximately 12 times that of a hydrogen atom, therefore they have a RELATIVE mass of 12.

Molar Mass :

The molar mass of a substance is defined as the total mass of one mole of the substance. It is often represented in terms of 'grams per mole' (g/mol). However, the SI unit of this quantity is kg/mol. Molar mass can be represented by the following formula:

Molar mass of a Substance = (Mass of the Substance in grams)/ (Number of Moles)

For example, the molar mass of water is approximately 18.015 g/mol, which is the mass of N_A number of water molecules.

Gram Atomic Mass and Gram Molecular Mass

The gram atomic mass of an element is the mass of one mole of that element. Similarly, the gram molecular mass of a compound refers to the mass of a single mole of the compound. Therefore, the gram atomic mass of hydrogen is approximately 1.007g and the gram molecular mass of water is approximately 18.015g.

Avogadro's Numbers :

Avogadro's number or constant is the number to which the mass of an atom must be multiplied to give a mass in grams numerically equal to its relative atomic mass.

Example :

Hydrogen has a relative atomic mass of 1 therefore 6.02×10^{23} hydrogen atoms have a mass of 1g

Carbon has a relative mass of 12 therefore 6.02×10^{23} carbon atoms have a mass of 12g

Magnesium has a relative atomic mass of 24 therefore 6.02×10^{23} magnesium atoms have a mass of 24g

This gives rise to two important definitions.

The amount of any substance containing an Avogadro number of particles of that substance is called a mole. 1 mole of any substance has a mass equal to its relative mass expressed in grams.

Example:

1 mole of magnesium contains 6.02×10^{23} magnesium atoms

1 mole of magnesium has a mass of 24g

12g of magnesium is equivalent to 1/2 moles = 0.5 moles of magnesium

12g of magnesium contains 1/2 moles of magnesium atoms = $0.5 \times 6.02 \times 10^{23} = 3.01 \times 10^{23}$ magnesium atoms

Atomic and Molecular Mass :

The atomic mass of an element is the mass of one atom of the element expressed in atomic mass units (amu). It accounts for the abundance of the various isotopes of the element and assigns an average value to the mass of one atom of the element.

For example, the atomic mass of carbon is 12.011 atomic mass units since carbon samples generally contain 98.89% of the carbon-12 isotope, 1.11% of carbon-13, and trace amounts of carbon-14. However, the atomic masses of these isotopes are different.

The atomic mass of a carbon-12 atom is 12 atomic mass units, but that of a carbon-13 atom is 13 amu. The atomic mass of an element is roughly equal to the sum of all the protons and neutrons present in its nucleus.

The molecular mass of an element is the sum of the atomic masses of all its constituent elements. This quantity is also represented in terms of atomic mass units. Therefore, the molecular mass of water is equal to the sum of the atomic masses of its constituents - hydrogen and oxygen.

The atomic mass of hydrogen is 1.00794 amu and that of oxygen is 15.9994. Since water molecules contain 2 hydrogen atoms and only one oxygen atom, the molecular mass of H_2O is 18.0154 amu.

Atomic mass unit (or amu) :

The atomic mass unit (amu) is equal to $(1/12)^{th}$ mass of one atom of carbon-12 isotope.

1 amu = 1/12 x mass of one C-12 atom

≈ mass of one nucleon in C-12 atom.

= 1.66 x 10^{-24} g or 1.66 x 10^{-27} kg

- **One amu is also called one Dalton (Da).**
- **Today, amu has been replaced by 'u' which is known as unified mass**

Atomic & molecular mass :
Atomic mass is the mass of 1 atom of a substance, it is expressed in amu.

- Atomic mass = R.A.M. x 1 amu

Molecular mass is the mass of 1 atom of a substance, it is expressed in amu.

- Molecular mass = Relative molecular mass x 1 amu

Note : Relative atomic mass is nothing but the number of nucleons present in the atom.

Provided the number of carbon atoms is equal to the number of hydrogen atoms the mass of carbon is always 12 times the mass of hydrogen.

Clearly there will be a specific number of hydrogen atoms that when weighed have a mass of 1g and that the same number of carbon atoms MUST have a mass of 12g. This number, named after its discoverer is called Avogadro's number.

Avogadro's constant = 6.02×10^{23}

The relationship between moles, mass and number of particles can be expressed by simple formulae :

Moles formulae

1. Number of particles = moles x Avogadro's number
2. $\text{Moles} = \frac{\text{mass}}{\text{relative mass}}$

These formulae can be used to find any quantity when the other two quantities are known.