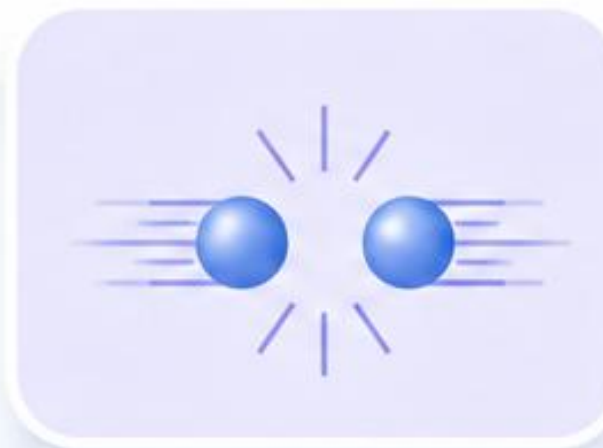
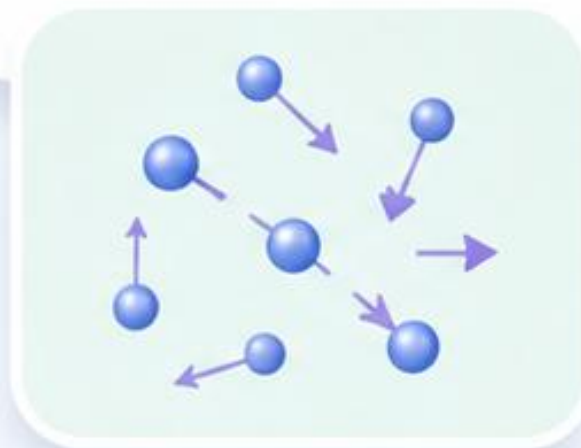
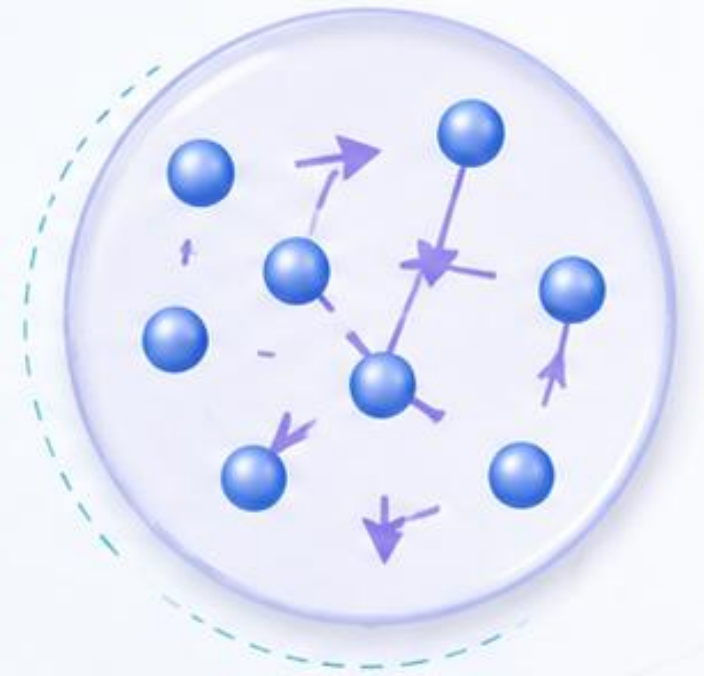
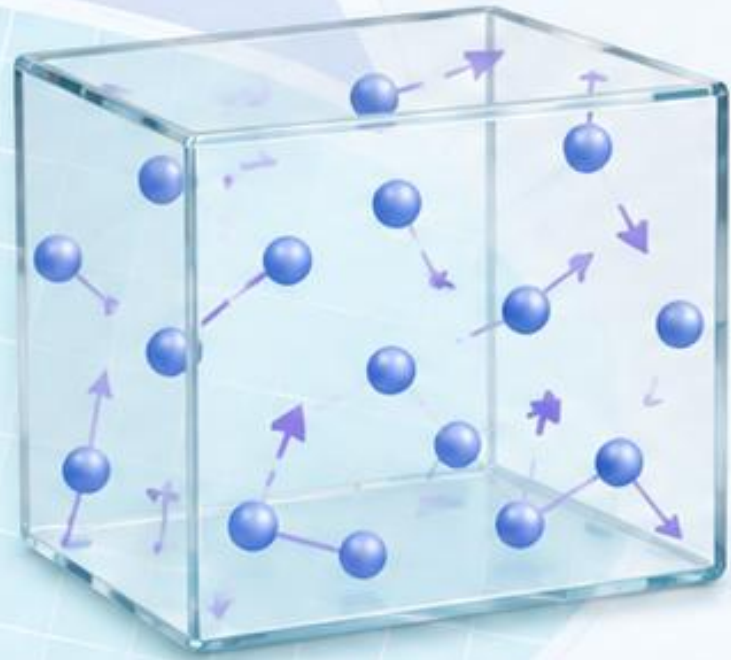


Chapter 12

Kinetic Theory

Molecules • Motion • Gas

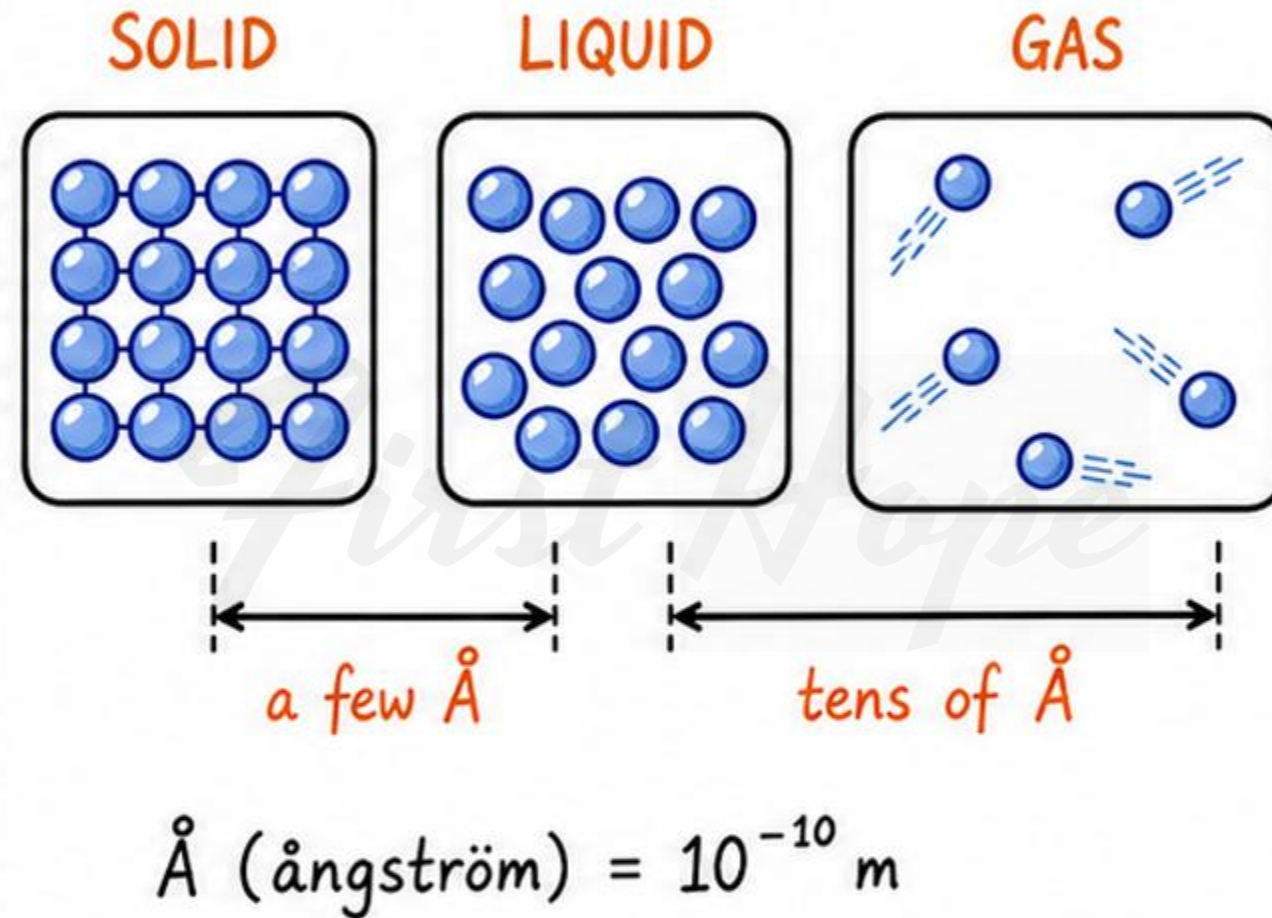


MOLECULAR NATURE OF MATTER

① MATTER IS MADE OF PARTICLES

- All matter consists of atoms or molecules.
- The typical size of an atom is about $1 \text{ \AA} = 10^{-10} \text{ m}$.
- Molecules are groups of atoms.

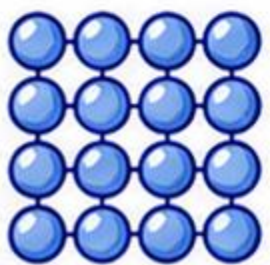
② SCALE: SOLID, LIQUID AND GAS



③ FORCES AND MOTION

- Particles are always moving.
- Intermolecular attraction acts between particles when they are at moderate separation.
- At very short separation, there is strong repulsion.
- In gases, molecules travel freely between collisions.

SOLID



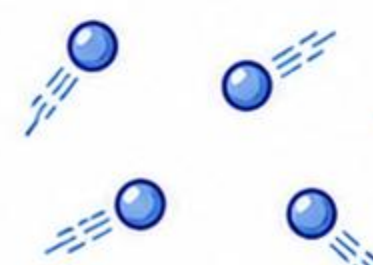
Particles in fixed positions; they vibrate about their mean positions.

LIQUID



Particles are close but not fixed; they can move past one another.

GAS

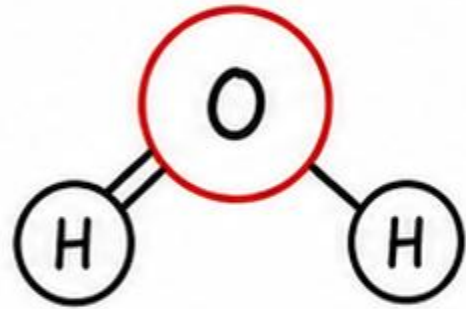


Particles are widely separated and move in random directions with high speed.

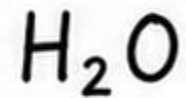
LAWS LEADING TO ATOMIC THEORY

① DALTON – FIXED PROPORTIONS

A pure compound always contains the same elements in the same proportion by mass.



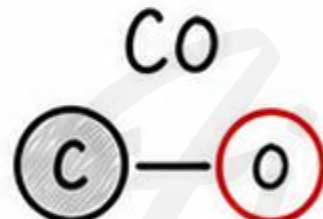
Water is always made of hydrogen and oxygen in a fixed mass ratio.



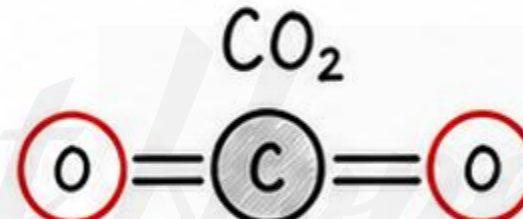
Mass ratio $\text{H} : \text{O} = 1 : 8$ (by mass)

② DALTON – MULTIPLE PROPORTIONS

When two elements form more than one compound, the masses of one that combine with a fixed mass of the other are in simple whole-number ratios.



One O atom combines with one C atom.



Two O atoms combine with one C atom.

Mass of O in $\text{CO} : \text{CO}_2 = 1 : 2$

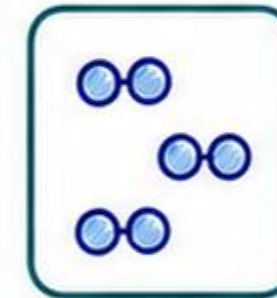
③ GAY-LUSSAC – COMBINING VOLUMES

Gases react in simple whole-number volume ratios at the same temperature and pressure.

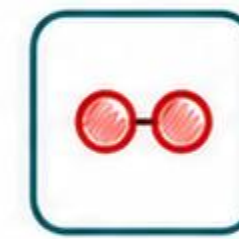
2 volumes
 H_2

1 volume
 O_2

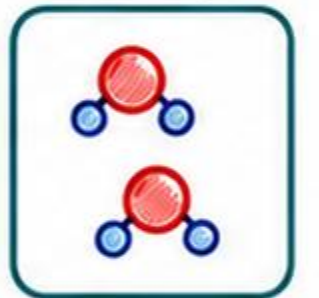
2 volumes
 $\text{H}_2\text{O}(\text{g})$



+



→



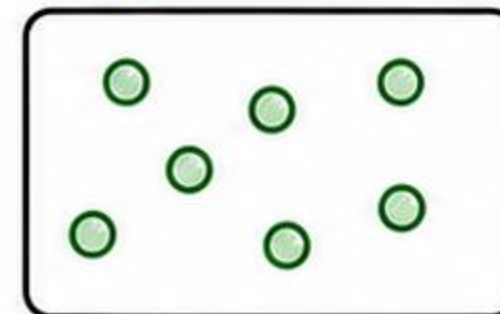
$2 \text{ volumes } \text{H}_2 + 1 \text{ volume } \text{O}_2 \rightarrow 2 \text{ volumes } \text{H}_2\text{O}(\text{g})$
(same temperature and pressure)

④ AVOGADRO'S LAW

Equal volumes of all gases at the same temperature and pressure contain equal numbers of molecules.

$V \propto N$
at constant T and P
(Temperature and Pressure)

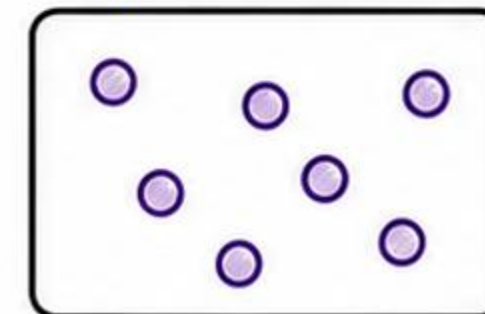
Equal volume V



N molecules

=

Equal volume V



N molecules

Same
temperature (T)
and pressure (P)

MOLE & IDEAL GAS EQUATION

COUNTING PARTICLES

- 1 mole contains Avogadro number $N_a = 6.02 \times 10^{23}$ particles.
- Number of moles (amount) is

$$\mu = \frac{N}{N_a} = \frac{M}{M_0}$$

where M = sample mass (kg or g)
and M_0 = molar mass (kg mol^{-1} or g mol^{-1}).

IDEAL GAS FORMS

- $PV = \mu RT$ (macroscopic form)
- $PV = Nk_B T$ (molecular form)
- $P = nk_B T$ (in terms of number density)

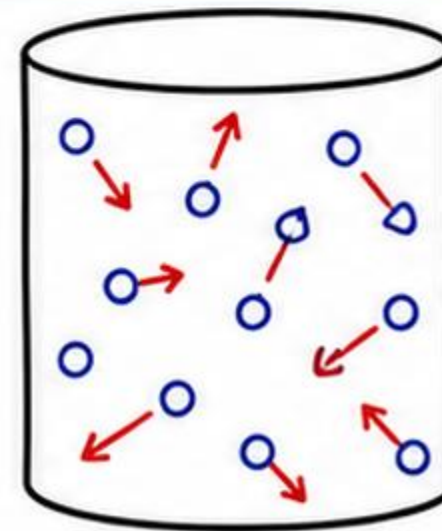
where $n = \frac{N}{V}$ is the number density (number of particles per unit volume).

CONSTANTS

- Universal gas constant,
 $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
- Boltzmann constant,
 $k_B = \frac{R}{N_a}$
 $= 1.38 \times 10^{-23} \text{ J K}^{-1}$

STP (Standard Temperature and Pressure):

- $T = 273 \text{ K}$ $\rightarrow$ temperature at STP.
- $P = 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$ $\rightarrow$ pressure at STP.
- One mole of an ideal gas occupies about 22.4 L at STP.



- $\rightarrow P$: pressure of gas
- $\rightarrow V$: volume of container
- $\rightarrow T$: absolute temperature
- $\rightarrow N$: number of particles

MOLECULAR VOLUME FRACTION — WORKED EXAMPLE

Problem: Density of liquid water is 1000 kg m^{-3} . Density of water vapour at 100°C and 1 atm is 0.6 kg m^{-3} . Estimate the fraction of the vapour volume actually occupied by molecules.

Solution:

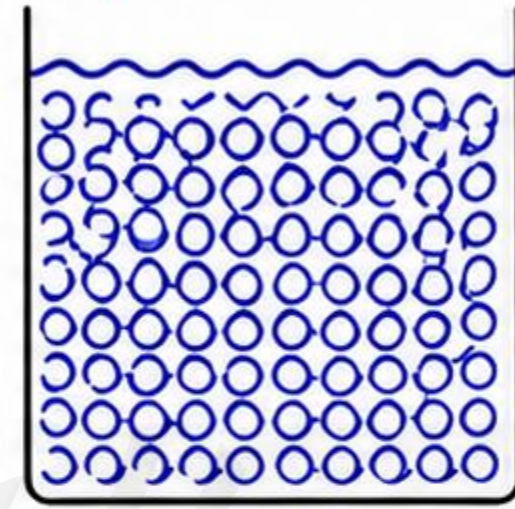
- For the same mass, $\rho = \frac{m}{V}$
$$\Rightarrow \frac{V_{\text{vapour}}}{V_{\text{liquid}}} = \frac{\rho_{\text{liquid}}}{\rho_{\text{vapour}}} = \frac{1000}{0.6} = 1.67 \times 10^3$$
- In liquid water, closely packed molecular volume is approximately the whole liquid volume.
- Therefore fraction in vapour = $\frac{V_{\text{liquid}}}{V_{\text{vapour}}} = \frac{\rho_{\text{vapour}}}{\rho_{\text{liquid}}}$

Calculation:

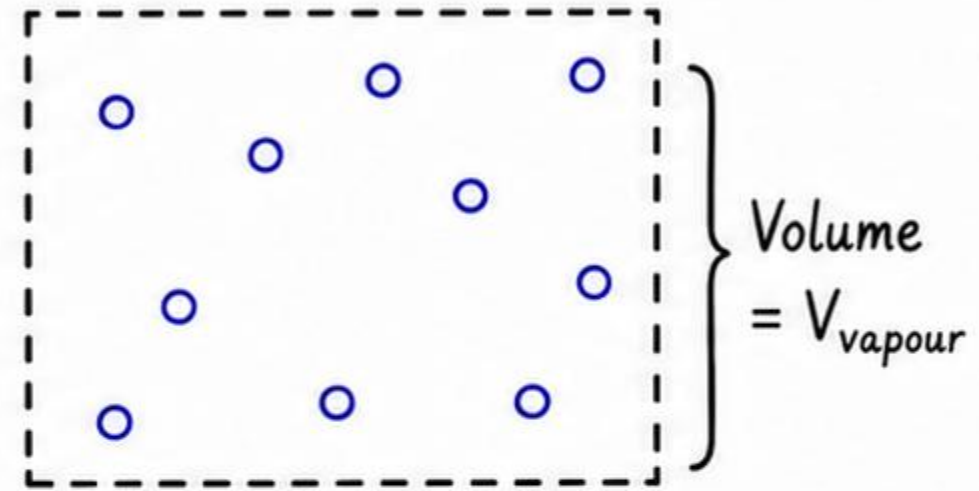
$$\text{fraction} = \frac{\rho_{\text{vapour}}}{\rho_{\text{liquid}}} = \frac{0.6}{1000} = 6 \times 10^{-4}$$

$$\text{Percentage} = 6 \times 10^{-4} \times 100 = 0.06\%$$

Equal mass (m)
Liquid water (1000 kg m^{-3})



Equal mass (m)
Water vapour (0.6 kg m^{-3})



Therefore,

$$\begin{aligned} \text{fraction in vapour} &= \frac{V_{\text{liquid}}}{V_{\text{vapour}}} = \frac{\rho_{\text{vapour}}}{\rho_{\text{liquid}}} \\ &= \frac{0.6}{1000} = 6 \times 10^{-4} \end{aligned}$$

Final Answer:

Molecular volume fraction = 6×10^{-4} (about 0.06%)

Key idea: Most of a gas is empty space.

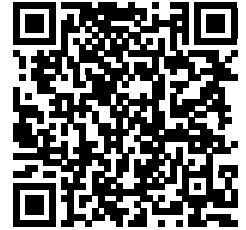


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