2.3 AVOGADRO'S LAW AND SOME DEDUCTIONS

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🎯 **Learning outcomes**

After the completion of the chapter, the students should be able to:

✓ State Avogadro's hypothesis and explain its significance

✓ Derive the relationship: Molecular Mass = 2 × Vapour Density

✓ Show that the gram molecular volume of any gas is 22.4 L at NTP

✓ Calculate Avogadro's number (N_a)

Development of Avogadro's hypothesis

The Mystery of the Half-Atom: A Chemistry Story

In 1808, two big ideas landed on the scene.

Gay-Lussac noticed something cool: when gases react, their volumes mix in simple ratios—like 1:1, 1:2, or 2:3.
Dalton had his own idea: elements combine in simple whole-number ratios *by atoms* (think H_2O, not $H_2O_{0.5}$).

Then **Berzelius** mixed them. He guessed:

"Under the same temperature and pressure, equal volumes of gases contain the same number of atoms."

Uh-oh. When he tested this with hydrogen and oxygen, it led to a problem. For water formation, his idea forced oxygen and hydrogen to split into **half-atoms**. But Dalton's theory said: *No half-atoms allowed!* 💧

Enter **Avogadro**, the problem solver. He said: "You're confusing two things."

- **Atom** = the smallest part of an element that reacts (may not exist alone).
- **Molecule** = the smallest part of a substance that *can* exist freely.

With that, he fixed Berzelius's idea into **Avogadro's Hypothesis**:

Equal volumes of gases (same T & P) contain the same number of ***molecules****, not atoms.*

Mystery solved. Half-atoms disappeared. Chemistry moved on. 🧪✨

Definition of Avogadro's Hypothesis

> **"Equal volumes of all gases (or vapours) under similar conditions of temperature and pressure contain the same number of molecules."**

e.g., if a litre of hydrogen, oxygen, nitrogen, or carbon dioxide is taken separately at **NTP,** then each of them contains the same number of molecules.

Mathematically, $\boxed{V \propto n}$

Where V = volume of gas; n = number of molecules

At constant temperature and pressure, doubling the volume doubles the number of molecules, & vice versa

Avogadro's Hypothesis

NTP = Normal Temperature and Pressure: 0°C temperature and 1 atm pressure. This is the standard reference condition used in calculations throughout this course.

Important deductions from Avogadro's Hypothesis

Molecular mass = 2× vapour density

The **vapour density (V.D.)** is the ratio of the mass of a given volume of a gas or vapour to the mass of the same volume of hydrogen, under the same conditions of temperature and pressure.

i.e.,

$$\text{vapour density} = \frac{\text{mass of a certain volume of gas}}{\text{mass of the same volume of hydrogen}}$$
$$\text{at similar conditions of temperature and pressure}$$

Let the chosen volume of the gas contain 'n' molecules. By Avogadro's hypothesis, this number is the same for the gas and for hydrogen under identical conditions. Then,

$$\text{v.d.} = \frac{mass\ of\ n\ molecules\ of\ gas}{mass\ of\ n\ molecules\ of\ hydrogen}$$

$$\text{v.d.} = \frac{mass\ of\ 1\ molecule\ of\ gas}{mass\ of\ 1\ molecule\ of\ hydrogen} \quad \ldots\ldots\ldots\ldots\ldots\ 1$$

The Molecular mass of a compound/element is a number that shows how many times the molecule is heavier than one atom of hydrogen.

$$\text{i.e., Molecular mass} = \frac{mass\ of\ one\ molecule\ of\ gas}{mass\ of\ 1\ atom\ of\ hydrogen} \quad \ldots\ldots\ldots\ldots 2$$

Dividing equation 2 by 1, we get,

$$\frac{molecular\ mass}{vapour\ density} = \frac{\dfrac{mass\ of\ 1\ molecule\ of\ gas}{mass\ of\ 1\ atom\ of\ hydrogen}}{\dfrac{mass\ of\ 1\ molecule\ of\ gas}{mass\ of\ 1\ molecule\ of\ hydrogen}}$$

$$= \frac{mass\ of\ 1\ molecule\ of\ hydrogen}{mass\ of\ 1\ atom\ of\ hydrogen}$$

$$= \frac{mass\ of\ 2\ atoms\ of\ hydrogen}{mass\ of\ 1\ atom\ of\ hydrogen} = 2$$

∴ Molecular mass = 2 × vapour density

Gram molecular volume of all gases contains 22.4 L at NTP

(Molar volume of all gases equals 22.4 L at NTP)

We know that,
Molecular mass = 2 × vapour density

$$= 2 \times \frac{mass\ of\ the\ given\ volume\ of\ gas}{\begin{array}{c} mass\ of\ \text{the}\ same\ volume\ of\ hydrogen \\ at\ same\ temperature\ and\ pressure \end{array}}$$

Let us consider 1 litre of gas at NTP,

$$\text{Molecular mass} = 2 \times \frac{mass\ of\ 1\!-\!litre\ gas\ at\ NTP}{mass\ of\ 1\ litre\ of\ hydrogen\ at\ NTP}$$

It has been found that the mass of 1 litre of hydrogen gas at NTP is 0.08986 grams. So,

$$\text{Molecular mass} = 2 \times \frac{mass\ of\ 1\ litre\ of\ gas\ at\ NTP}{0.08986}$$

Or, molecular mass in grams = $\frac{2}{0.08986} \times$ mass of 1 L of gas at NTP

∴ molecular mass in grams = 22.4 L gas at NTP

∴ Gram molecular mass = 22.4 L gas at NTP

This volume (22.4 L) is called the **gram molecular volume** or **molar volume** of a gas at NTP

3. Deduction of Avogadro's number

Avogadro's number (N_A) is the number of molecules present in one gram molecular mass (one mole) of any gas (or substance). Its value is approximately **6.023×10^{23}** molecules per mole.

Let us consider H_2 gas to deduce this number
We know,
The Molecular mass of H_2 = 2
1 gram molecular mass of H_2 = 2 gm
Let w gram = mass of one 1-atom
Then, 2w gram is the mass of the H_2 molecule.
2gram is the mass of 1/w H_2 molecule.
This implies
1 gram molecular mass of H_2 contains 1/w H_2 molecule.
This constant number of molecules is Avogadro's number, which is calculated as:
$\frac{1}{w} = \frac{1}{1.67 \text{ x } 10\text{^}23} = 6.023 \text{ x } 10^{23}$
i.e., 1 gram molecular mass of any gas contains Avogadro's number of molecules ($6.023 \text{ x } 10^{23}$).

Important Distinction

- Avogadro's number (6.023×10^{23}) applies to any substance — solid, liquid, or gas. One mole of iron, water, or glucose contains the same number of particles.
- The molar volume of 22.4 L applies only to gases at NTP. It **does not apply to solids or liquids**.

Concept	Key Statement
Avogadro's Hypothesis	Equal volumes of all gases at the same T & P contain the same number of molecules.
Vapour Density	V.D. = (mass of given volume of gas) / (mass of same volume of H_2) at same T & P
Deduction 1	Molecular Mass = 2 × Vapour Density
Deduction 2	Gram Molecular Volume of any gas = 22.4 L at NTP
Deduction 3	Avogadro's number $N_a = 6.023 \times 10^{23}$ molecules per mole

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