Calculations involving gas volumes notes | CIE | A-Level Chemistry

The Molar Volume of a Gas

Avogadro's hypothesis states that equal volumes of any gas, measured under the same conditions of temperature and pressure, contain an equal number of molecules. This principle allows us to relate the volume of a gas directly to the number of moles present.

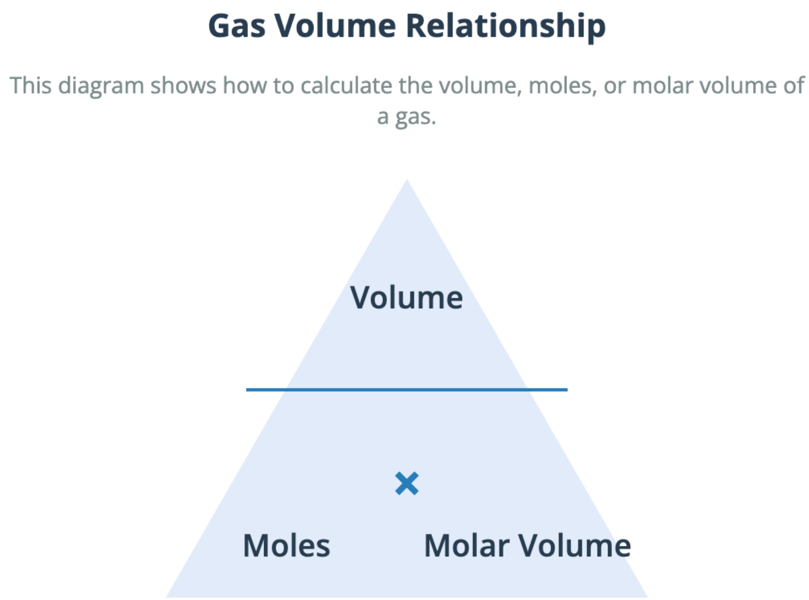
The molar gas volume is the volume occupied by one mole of any gas. At room temperature and pressure (r.t.p.), which is defined as approximately 20 °C and 1 atmosphere, the molar gas volume is 24.0 dm^3 mol^{-1}.

This means that 24.0 dm^3 of carbon dioxide, 24.0 dm^3 of hydrogen, or 24.0 dm^3 of any other gas at r.t.p. all contain exactly one mole of gas molecules.

Calculations Using Molar Gas Volume at r.t.p.

The relationship between the number of moles and the volume of a gas at r.t.p. can be expressed with two key formulas. These are fundamental for calculations involving gas volumes.

To find the volume of a gas from a known number of moles:
Volume of gas (in dm^3) = Number of moles × 24.0
To find the number of moles of a gas from a known volume:
Number of moles = Volume of gas (in dm^3) / 24.0



Example Calculation 1: Finding Volume from Mass

Calculate the volume occupied by 13.2 g of carbon dioxide gas, CO_2, at r.t.p.
(A_r values: C = 12.0, O = 16.0)

Step 1: Calculate the molar mass of CO_2.
Molar mass = 12.0 + (2 × 16.0) = 44.0 g mol^{-1}

Step 2: Calculate the number of moles of CO_2.
Number of moles = Mass / Molar mass = 13.2 g / 44.0 g mol^{-1} = 0.300 mol

Step 3: Calculate the volume of the gas.
Volume = Number of moles × 24.0 dm^3 mol^{-1} = 0.300 mol × 24.0 dm^3 mol^{-1} = 7.20 dm^3

Example Calculation 2: Finding Mass from Volume

Calculate the mass of 180 cm^3 of methane gas, CH_4, at r.t.p.
(A_r values: C = 12.0, H = 1.0)

Step 1: Convert the volume to dm^3.
Volume in dm^3 = 180 cm^3 / 1000 = 0.180 dm^3

Step 2: Calculate the number of moles of CH_4.
Number of moles = Volume / 24.0 dm^3 mol^{-1} = 0.180 dm^3 / 24.0 dm^3 mol^{-1} = 0.00750 mol

Step 3: Calculate the molar mass of CH_4.

Molar mass = 12.0 + (4 × 1.0) = 16.0 g mol^{-1}

Step 4: Calculate the mass of the gas.
Mass = Number of moles × Molar mass = 0.00750 mol × 16.0 g mol^{-1} = 0.120 g

Gas Volumes and Stoichiometry

According to Avogadro's hypothesis, the mole ratio in a balanced chemical equation is equivalent to the volume ratio for reacting gases, provided the volumes are measured at the same temperature and pressure. This allows for direct stoichiometric calculations involving gas volumes.

For example, in the synthesis of ammonia:
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$
The mole ratio is 1 : 3 : 2.
This means that 1 volume of nitrogen reacts with 3 volumes of hydrogen to produce 2 volumes of ammonia. For instance, 10 cm^3 of N_2 will react exactly with 30 cm^3 of H_2 to produce 20 cm^3 of NH_3.

Example Calculation 3: Deducing a Molecular Formula

When 40 cm^3 of a gaseous hydrocarbon was completely combusted with 240 cm^3 of oxygen (an excess), the resulting gas mixture had a volume of 200 cm^3 after cooling. After passing this mixture through aqueous sodium hydroxide, the volume reduced to 80 cm^3. All volumes were measured at r.t.p. Deduce the molecular formula of the hydrocarbon.

Step 1: Determine the volume of products.
The contraction in volume when passed through NaOH is due to the removal of CO_2.
Volume of CO_2 produced = 200 cm^3 - 80 cm^3 = 120 cm^3
The remaining 80 cm^3 must be the excess, unreacted oxygen.

Step 2: Determine the volume of oxygen that reacted.
Volume of O_2 reacted = Initial volume of O_2 - Excess volume of O_2
Volume of O_2 reacted = 240 cm^3 - 80 cm^3 = 160 cm^3

Step 3: Find the simplest whole number ratio of reacting volumes.
Let the hydrocarbon be C_xH_Y.
$C_xH_Y(g) + O_2(g) \longrightarrow CO_2(g)$
Reacting volumes: 40 cm^3 : 160 cm^3 : 120 cm^3
Simplest ratio: 1 : 4 : 3

Step 4: Use the ratios to find x and y.
From the ratio, the balanced equation starts:

$1C_xH_y(g) + 4O_2(g) \longrightarrow 3CO_2(g) + zH_2O(l)$
From balancing the carbon atoms: $x = 3$.
From balancing the oxygen atoms:
Total oxygen on left = $4 \times 2 = 8$ atoms.
Oxygen in $CO_2 = 3 \times 2 = 6$ atoms.

Therefore, oxygen atoms in water = $8 - 6 = 2$ atoms. This means $z = 2$.
$1C_3H_y(g) + 4O_2(g) \longrightarrow 3CO_2(g) + 2H_2O(l)$
From balancing the hydrogen atoms: $y = 2 \times 2 = 4$.
The molecular formula of the hydrocarbon is C_3H_4.