Edexcel GCSE Chemistry

Your notes

Quantitative Analysis

Contents

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Using Concentrations in mol/dm3

Using Concentrations in mol/dm3

- It is more useful to a chemist to express concentration in terms of moles per unit volume rather than mass per unit volume
- Concentration can therfore be expressed in moles per decimetre cubed
- We can modify the concentration formula to include moles
  - The units in the answer can be written as mol dm^{-3} or mol / dm^3:

$$\text{concentration}(\text{mol dm}^{-3}) = \frac{number\ of\ moles\ of\ solute\ (mol)}{volume\ of\ solution\ (dm^3)}$$

- You may have to convert from g dm^{-3} into mol dm^{-3} and vice versa depending on the question
  - To go from g dm^{-3} to mol dm^{-3}:
    - Divide by the molar mass in grams
  - To go from mol dm^{-3} to g dm^{-3}:
    - Multiply by the molar mass in grams

Examiner Tips and Tricks

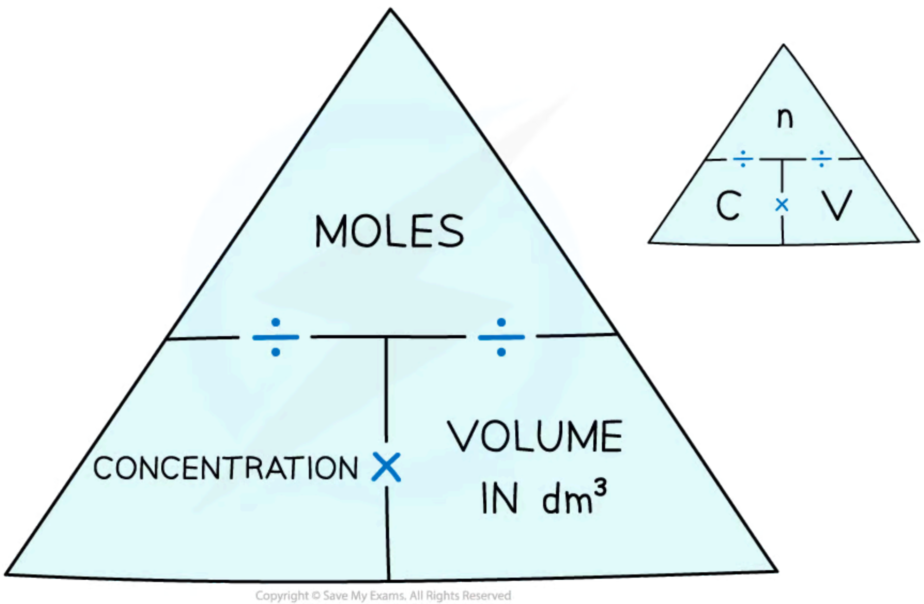
Don't forget your unit conversions:

To go from cm^3 to dm^3 : divide by 1000

To go from dm^3 to cm^3 : multiply by 1000

The Concentration Formula Triangle

Your notes



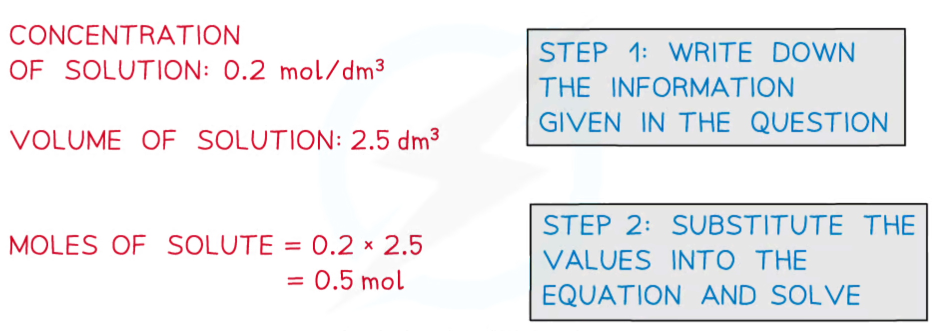
The concentration-moles formula triangle can help you solve these problems

- The following examples show how to do this step-by-step

Worked Example

Calculate the amount of solute, in moles, present in 2.5 dm^3 of a solution whose concentration is 0.2 mol dm^{-3}.

Answer:



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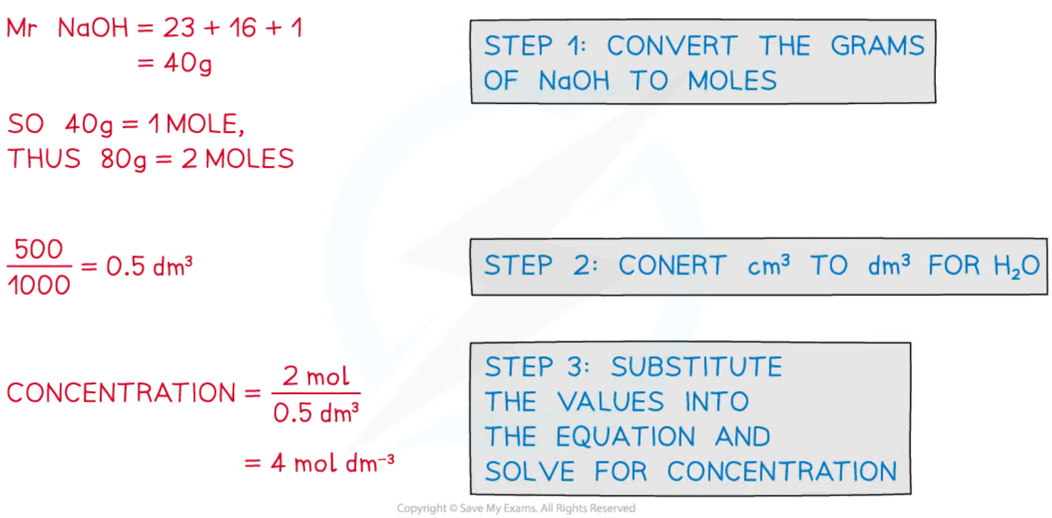
Worked Example

Calculate the concentration of a solution of sodium hydroxide, NaOH, in mol dm^{-3}, when 80 g is dissolved in 500 cm^3 of water.(Na= 23, H= 1, O= 16).

Answer:



Examiner Tips and Tricks

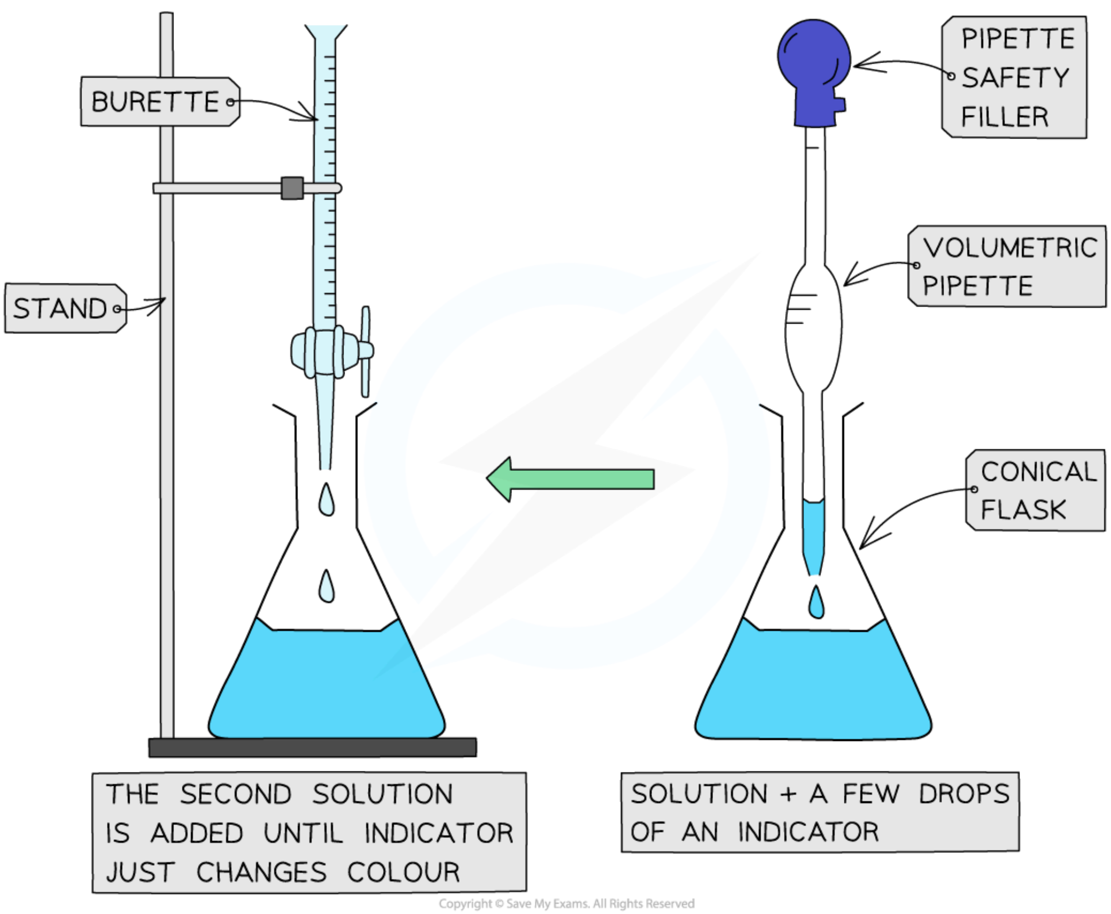
You are not given the concentration-moles formula triangle in exams so you have to learn it. It is a good idea to write it down before you start a problem, so you get all the parts in the correct place.

Core Practical: Acid-Alkali Titration

Core Practical: Acid-Alkali Titration

- Titrations are a method of analysing the **concentration** of solutions
- Acid-base titrations are one of the most important kinds of titrations
- They can determine exactly how much alkali is needed to neutralise a quantity of acid – and vice versa
- You may be asked to calculate the **moles** present in a given amount, the **concentration** or **volume** required to **neutralise** an acid or a base
- Titrations can also be used to prepare **salts**

How to carry out a titration



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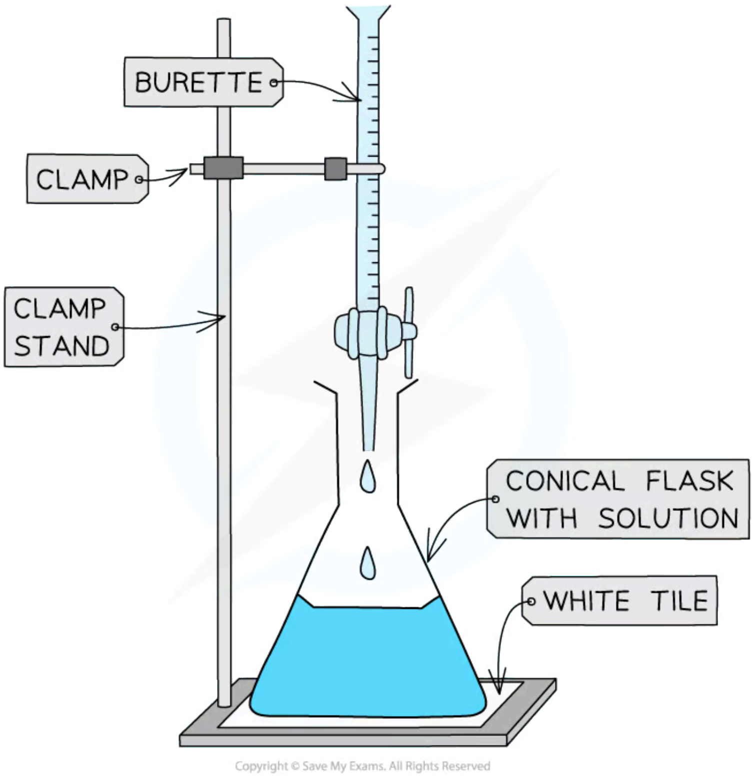

Performing a titration

Method:

1. Use the pipette and pipette filler and place exactly 25 cm^3 sodium hydroxide solution into the conical flask
2. Place the conical flask on a white tile so the tip of the burette is inside the flask
3. Add a few drops of a suitable indicator to the solution in the conical flask
4. Perform a rough titration by taking the burette reading and running in the solution in 1 – 3 cm^3 portions, while swirling the flask vigorously
5. Quickly close the tap when the end-point is reached (sharp colour change) and record the volume, placing your eye level with the meniscus
6. Now repeat the titration with a fresh batch of sodium hydroxide
7. As the rough end-point volume is approached, add the solution from the burette one drop at a time until the indicator just changes colour
8. Record the volume to the nearest 0.05 cm^3

9. Repeat until you achieve two concordant results (two results that are within 0.1 cm^3 of each other) to increase accuracy

Results:

Record your results in a suitable table, e.g:

Rough Titre / cm^3	Titre 1 / cm^3	Titre 2 / cm^3	Mean / cm^3
15.50	14.90	15.00	14.95

Examiner Tips and Tricks

Use a funnel to fill the burette but be sure to remove it before starting the practical as it can drip liquid into the burette, making the initial reading false.

Hazards, risks and precautions

Hazard symbol to show substances that are harmful to health

- Dilute hydrochloric acid is not classified as hazardous at the concentrations typically used in this practical, however it may still cause harm to the eyes or the skin
- Sodium hydroxide may be considered to be harmful to health, depending on the concentration used as it is irritating to the eyes and skin
- For both sodium hydroxide and hydrochloric acid, avoid contact with the skin and use safety goggles

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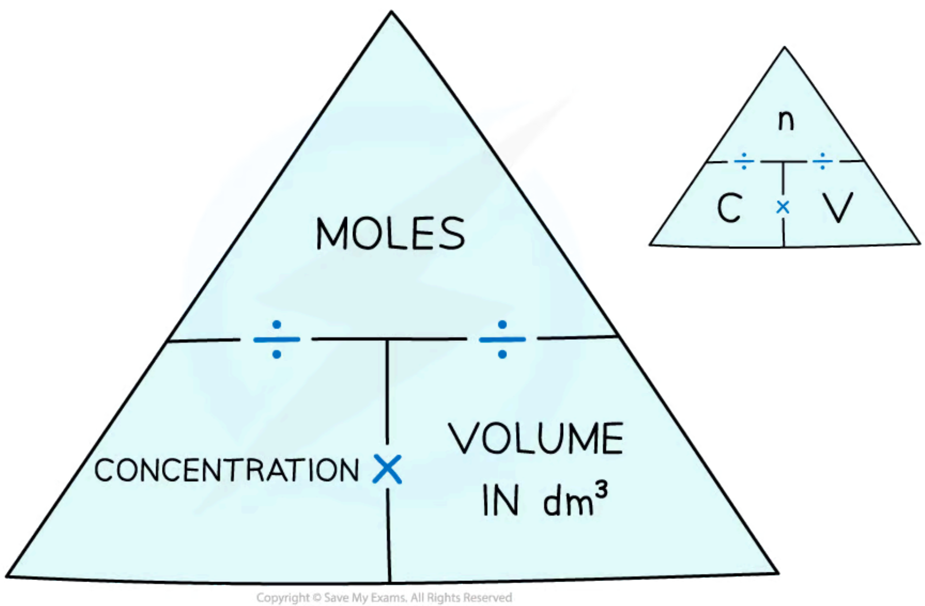
Titration Calculations

Your notes

Titration Calculations

- Once a titration is completed and the average titre has been calculated, you can now proceed to calculate the unknown variable using the formula triangle as shown below



Formula triangle showing the relationship between concentration, number of moles and volume of liquid

- The steps in a titration calculation are:

Step 1: Write out the balanced equation for the reaction

Step 2: Calculate the moles of the known solution given the volume and concentration

Step 3: Use the equation to deduce the moles of the unknown solution

Step 4: Use the moles and volume of the unknown solution to calculate the concentration

Worked Example

Your notes

A solution of 25.0 cm^3 of hydrochloric acid was titrated against a solution of 0.100 mol dm^{-3} NaOH and 12.1 cm^3 were required for a complete reaction. Determine the concentration of the acid.

Answer:

- **Step 1:** Write the equation for the reaction:

$$\mathbf{HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)}$$

- **Step 2:** Calculate the number of moles of the NaOH

Moles = (volume ÷ 1000) x concentration

Moles of NaOH = 0.012 dm^3 x 0.100 mol dm^{-3} = 1.21 x 10^{-3} mol

- **Step 3:** Deduce the number of moles of the acid

Since the acid reacts in a 1:1 ratio with the alkali, the number of moles of HCl is also 1.21 x 10^{-3} mol

This is present in 25.0 cm^3 of the solution

- **Step 4:** Find the concentration of the acid

Concentration = moles ÷ volume

Concentration of HCl =1.21 x 10^{-3} mol ÷ 0.025 dm^3 = **0.0484 mol dm^{-3}**

Yield

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Yield

Yield

- **Yield** is the term used to describe the amount of **product** you get from a reaction
- In practice, you **never** get 100% yield in a chemical process for several reasons
- These include:
  - Some reactants may be left behind in the **equipment**
  - The reaction may be **reversible** and in these reactions a high yield is never possible as the products are continually turning back into the reactants
  - Some products may also be lost during **separation** and **purification** stages such as filtration or distillation
  - There may be **side reactions** occurring where a substance reacts with a gas in the air or an **impurity** in one of the reactants
  - Products can also be lost during **transfer** from one container to another

Actual & Theoretical Yield

- The **actual yield** is the recorded amount of product obtained
- The **theoretical yield** is the amount of product that would be obtained under perfect practical and chemical conditions
- It is calculated from the balanced equation and the reacting masses
- The **percentage yield** compares the actual yield to the theoretical yield
- For economic reasons, the objective of every chemical producing company is to have as high a percentage yield as possible to increase profits and reduce costs and waste

Percentage Yield

- The percentage yield is a good way of measuring **how successful** a chemical process is
- There are often several methods of creating a compound and each method is called a **reaction pathway**
- Reaction pathways consist of a sequence of reactions which must occur to produce the required product

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- Companies often investigate and try out different reaction pathways and these are then **compared** and **evaluated** so that a manufacturing process can be chosen
- The percentage yield of each pathway is a significant factor in this decision making process
- The equation to calculate the percentage yield is:

$$percentage\ yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

Worked Example

Copper(II) sulfate may be prepared by the reaction of dilute sulfuric acid on copper(II) oxide. A student prepared 1.6 g of dry copper(II) sulfate crystals. Calculate the percentage yield if the theoretical yield is 2.0 g.

Answer:

- Actual yield of copper(II) sulfate = 1.6 g
- Percentage yield of copper(II) sulfate = (1.6 / 2.0) x 100
- Percentage yield = **80%**

Examiner Tips and Tricks

The actual yield can be determined by experiment only, while the theoretical yield can be calculated assuming there is 100% conversion of reactants to products.

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Atom Economy

Atom Economy

- Along with the percentage yield, **atom economy** is used to analyse the **efficiency** of reactions
- Most reactions produce more than one product and very often some of them are not **useful**
- Atom economy studies the amount of **reactants** that get turned into useful products
- It illustrates what **percentage** of the **mass** of reactants become useful products
- It is used extensively in the analysis of systems and procedures in industries, in an effort to obtain **sustainable development**
- It is also a very important analysis for **economic** reasons as companies prefer to use processes with higher atom economies
- The higher the atom economy of a process then the **more sustainable** that process is
- The atom economy formula is:

$$\text{Atom economy} = \frac{\text{total } M_r \text{ of desired product}}{\text{total } M_r \text{ of all products}} \times 100$$

Worked Example

Hydrogen gas is obtained from methane in a process called steam-methane reforming. The reaction is as follows:

$$CH_4\,(g) + H_2O\,(g) \rightarrow CO\,(g) + 3H_2\,(g)$$

Calculate the atom economy of this reaction.

Answer:

- **Step 1:** Calculate the total M_r of all products:
  - Total M_r = CO + $3H_2$
  - Total M_r = (12 + 16) + (3 x 2 x 1) = 34
- **Step 2:** Calculate the M_r of the desired product:
  - M_r of $3H_2$ = (3 x 2 x 1) = 6
- **Step 3:** Substitute the values into the percentage atom economy equation:

Your notes

- Atom economy = $\frac{\text{total } M_r \text{ of desired product}}{\text{total } M_r \text{ of all products}} \times 100$
- Atom economy = $\frac{6}{34} \times 100$ = 17.6%
- Therefore, in this process 82.4 % of reactant material is wasted
  - 100 - 17.6 = 82.4 %

Examiner Tips and Tricks

Unwanted byproducts can sometimes be put to use so although a low atom economy is a sign that a process is not green (sustainable) it doesn't necessarily imply that the process is not economically viable.

Choosing a Reaction Pathway

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Choosing a Reaction Pathway

- Reactions that have low atom economies use up a lot of **resources** and produce a lot of **waste material** which then needs to be **disposed** of, a very expensive procedure
- These reactions are thus **unsustainable** as they use up too much raw material to manufacture only a small amount of product
- They are not **economically attractive** as raw materials tend to be **expensive,** as does **waste disposal** which requires chemicals, equipment, space and transport
- Companies continually analyse reactions and processes and evaluate several factors in an effort to improve **efficiency**
- Atom economy, percentage yield, rates of reaction and equilibrium position are important factors which need to be considered when choosing a reaction pathway
- High percentage yields and fast reaction rates are desirable attributes in industrial chemical processes
- In reversible reactions, the **position** of the equilibrium may need to be changed in favour of the products by altering reaction conditions
- If the waste products can be **sold** or **reused** in some way that would improve the atom economy
- Alternative methods of production could also be considered that may produce a more **useful by-product**

Examiner Tips and Tricks

Look for information on percentage yield, atom economy, rate and equilibria in questions on this topic. Your answer should then be based on evaluating (for example by comparing the pros and cons of) this information.

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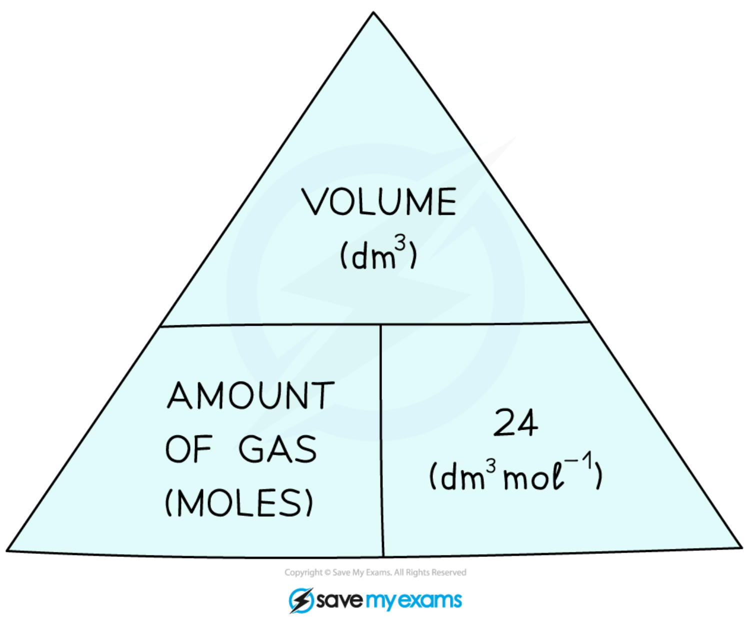
Molar Volume

Molar Volume

- At room temperature and pressure, the volume occupied by one mole of any gas was found to be **24** dm^3 or **24,000** cm^3
- This is known as the **molar gas volume at RTP**
- RTP stands for "room temperature and pressure" and the conditions are **20 °C** and **1 atmosphere** (atm)
- From the molar gas volume the following formula triangle can be derived:

The Molar Volume Formula Triangle



Formula triangle showing the relationship between moles of gas, volume in dm^3 and the molar volume

- If the volume is given in cm^3 instead of dm^3, then divide by 24,000 instead of 24:

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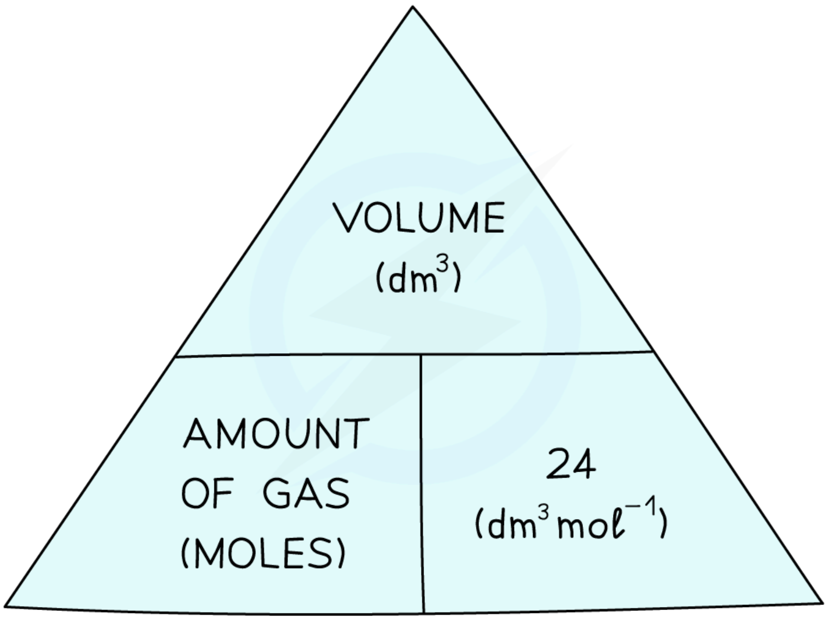

Formula triangle showing the relationship between moles of gas, volume in cm^3 and the molar volume

Moles into Volume

- Here are some examples of how you can manipulate the relationship to find the volume of gas from a given number of moles

Volume = Moles x Molar Volume

Examples of Converting Moles into Volumes Table

Your notes

Name of Gas	Amount of Gas	Volume of Gas
Hydrogen	3 mol	(3 × 24) = 72 dm^3
Carbon Dioxide	0.25 mol	(0.025 × 24) = 6 dm^3
Oxygen	5.4 mol	(5.4 × 24,000) = 129,600 cm^3
Ammonia	0.02 mol	(0.02 × 24) = 0.48 dm^3

Volume into Moles

- Rearranging the formula allows you to calculate the amount of gas in moles from a given volume at RTP

Moles = Volume ÷ Molar Volume

Examples of Converting Volumes into Moles Table

Name of Gas	Volume of Gas	Amount of Gas
Methane	225.6 dm^3	(225.6 ÷ 24) = 9.4mol
Carbon Monoxide	7.2 dm^3	(7.2 ÷ 24) = 0.3 mol
Sulfur Dioxide	960 dm^3	(960 ÷ 24) = 40 mol
Oxygen	1200 cm^3	(1200 ÷ 24000) = 0.05 mol

Reacting Masses into Gas Volumes

- Sometimes in problem-solving we have to convert between the mass of a gas and its volume
- This is a two step problem which requires first converting the mass into moles and then from moles into gas volume
- The following example illustrates this:

Worked Example

What is the volume of 154 g of nitrogen gas at RTP?

Answer:

Step	Working out
1. Calculate the moles of nitrogen, remembering that nitrogen gas is diatomic	Mr of N_2 = $2 \times 14 = 28g$ Moles of $N_2 = \frac{154}{28} = 5.5$ moles
2. Calculate the volume of gas from the molar volume equation	$5.5 \times 24 = 132\ dm^3$

Examiner Tips and Tricks

Make sure you use the correct units as asked by the question when working through reacting gas volume questions.

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Avogadro's Law

Avogadro's Law

Volumes of gases

- In 1811 the Italian scientist Amedeo **Avogadro** developed a theory about the volume of gases
- **Avogadro's law** (also called **Avogadro's hypothesis)** enables the mole ratio of reacting gases to be determined from volumes of the gases
- **Avogadro** deduced that equal volumes of gases must contain the same number of molecules
- At room temperature and pressure(**RTP**) **one mole** of any gas has a volume of **24 dm^3**
- The units are normally written as **dm^3 mol^{-1}**(since it is 'per mole')
- The conditions of **RTP** are
  - a temperature of **20 °C**
  - pressure of **1 atmosphere**

Stoichiometric relationships

- The stoichiometry of a reaction and **Avogadro's Law** can be used to deduce the **exact volumes** of gaseous reactants and products
- Remember that if the gas volumes are not in the same ratio as the coefficients then the amount of product is determined by the limiting reactant so it is essential to identify it first

Worked Example

Example 1

What is the total volume of gases remaining when 70 cm^3 of ammonia is combusted completely with 50 cm^3 of oxygen according to the equation shown?

$4NH_3$ (g) + $5O_2$ (g) → 4NO (g) + $6H_2O$

Answer:

Step 1: From the equation deduce the molar ratio of the gases, which is NH_3 : O_2 : NO or 4:5:4 (water is not included as it is in the liquid state)

Step 2: We can see that oxygen will run out first (the **limiting reactant**) and so 50 cm^3 of O_2 requires 4/5 x 50 cm^3 of NH_3 to react = 40 cm^3

Step 3: Using Avogadro's Law, we can say 40 cm^3 of NO will be produced

Step 4: There will be of 70–40 = 30 cm^3 of NH_3 left over

Therefore **the total remaining volume will be 40 + 30 = 70 cm^3 of gases**

Your notes

Worked Example

Example 2

The complete combustion of propane gives carbon dioxide and water vapour as the products:

C_3H_8 (g) + $5O_2$ (g) → $3CO_2$ (g) + $4H_2O$ (g)

Determine the volume of oxygen needed to react with 150 cm^3 of propane and the total volume of the gaseous products.

Answer

Step 1: The balanced equation shows that 5 moles of oxygen are needed to completely react with 1 mole of propane

Step 2: Therefore the volume of oxygen needed would be = 5 moles x 150 cm^3 = **750 cm^3**

Step 3: The total number of moles of gaseous products is = 3 + 4 = 7 moles

Step 4: The total volume of gaseous products would be = 7 moles x 150 cm^3 = **1050 cm^3**