Cambridge (CIE) IGCSE Co-ordinated Sciences (Double Award): Chemistry

Your notes

The Mole & the Avogadro Constant

Contents

The mole & the Avogadro Constant

Extended tier only

- Chemical amounts are measured in moles
- The mole, symbol mol, is the SI unit of **amount of substance**
- One mole of a substance contains the same number of the stated particles
  - This can be atoms, molecules or ions
- One mole contains **6.02×10^{23}** particles; this number is known as the **Avogadro Constant**
- For example:
  - One mole of sodium (Na) contains 6.02×10^{23} atoms of sodium
  - One mole of hydrogen (H_2) contains 6.02×10^{23} molecules of hydrogen
  - One mole of sodium chloride (NaCl) contains 6.02×10^{23} formula units of sodium chloride
- The mass of 1 mole of a substance is known as the **molar mass**
  - For an element, it is the same as the **relative atomic mass** written in grams
  - For a compound, it is the same as the **relative molecular** or **formula mass** in grams

The mole & volume of gas

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Molar volumes of gas

- **Avogadro's Law** states that at the same **temperature** and **pressure**, equal amounts of gases occupy the **same volume** of space
  - e.g. 1 mole of hydrogen gas occupies the same volume as 1 mole of methane gas
- 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 triangles can be derived:

Molar gas volume (dm^3) formula triangle

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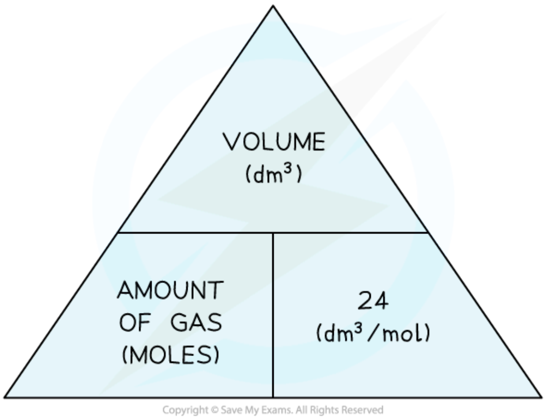
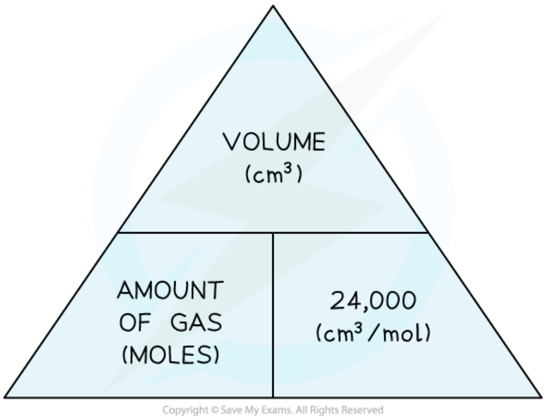


This shows the relationship between moles of gas, volume in dm^3 and the molar volume

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

Molar gas volume (cm³) formula triangle



This shows the relationship between moles of gas, volume in cm^3 and the molar volume

- The formula can be used to calculate the number of moles of gases from a given volume or vice versa
  - Simply cover the one you want and the triangle tells you what to do
- For example, to find the volume of a gas:
  - **Volume = Moles x Molar Volume**

Examples of Converting Moles to Volume Table

Gas	Amount (moles)	Volume
Hydrogen	3	(3 x 24) = 72 dm^3 (3 x 24000) = 72000 cm^3

Carbon dioxide	0.25	$(0.25 \times 24) = 6\ dm^3$ $(0.25 \times 24000) = 6000\ cm^3$
Oxygen	5.4	$(5.4 \times 24) = 129.6\ dm^3$ $(5.4 \times 24000) = 129600\ cm^3$
Ammonia	0.02	$(0.02 \times 24) = 0.48\ dm^3$ $(0.02 \times 24000) = 480\ cm^3$

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- For example, to find the number of moles of a gas:
  - **Moles = Volume ÷ Molar Volume**

Examples of Converting Volume to Moles Table

Gas	Volume	Moles
Methane	$225.6\ dm^3$	$(225.6 \div 24) = 9.4$ mol
Carbon monoxide	$7.2\ dm^3$	$(7.2 \div 24) = 0.3$ mol
Sulfur dioxide	$960\ dm^3$	$(960 \div 24) = 40$ mol
Oxygen	$1200\ cm^3$	$(1200 \div 24000) = 0.05$ mol

Examiner Tips and Tricks

- You are not expected to know the value of Avogadro's constant
- But, you do need to know the equation as well as how to use and re-arrange it

Linking moles, mass & Mr

Extended tier only

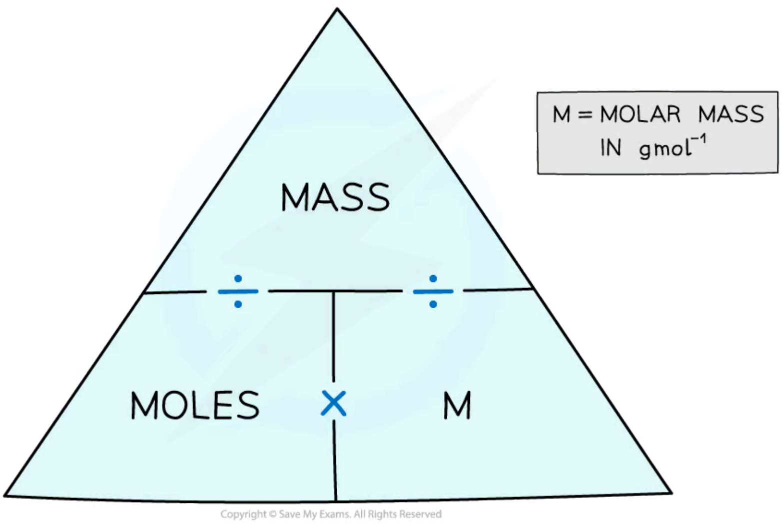
- One mole of any element is equal to the relative atomic mass of that element in **grams**
- If you had 1 mole of carbon atoms in your hand, that number of carbon atoms would have a mass of 12 g (because the A_r of carbon is 12)
    - So, one mole of helium atoms has a mass of 4 g (A_r of He is 4)
    - One mole of lithium has a mass of 7 g (A_r of Li is 7) and so on
- One mole of any compound is the **relative molecular mass** or relative formula mass in **grams**
- To find the mass of one mole of a compound, add up the relative atomic masses
    - For example, carbon dioxide has an *Mr* of:
      (1 x C) + (2 x O)
      (1 x 12) + (2 x 16) = 44

Moles, mass and relative mass

- The number of moles of any chemical can be calculated using:

$$\text{Moles} = \frac{\text{mass}}{M_r}$$

- We can use the following formula triangle to convert between moles, mass in grams and the molar mass:



Formula triangle for moles, mass and molar mass

- Calculating the number of moles of an element uses the same equation, but with relative atomic mass replacing M

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Worked Example

What is the mass of 0.250 moles of zinc?

Answer:

- From the Periodic Table, the relative atomic mass of Zn is 65
  - So, the molar mass is 65 g / mol
- The mass is calculated by **moles x molar mass**:
  - 0.250 mol x 65 g / mol = **16.25 g**

Worked Example

How many moles are in 2.64 g of sucrose, $C_{12}H_{22}O_{11}$ (M_r = 342)?

Answer:

- The molar mass of sucrose is 342 g / mol
- The number of moles is found by **mass ÷ molar mass**:
  - $\frac{2.64}{342}$ = **7.72×10^{-3} mol**

Examiner Tips and Tricks

Always show your workings in calculations as its easier to check for errors and you may pick up credit if you get the final answer wrong.

Calculating moles & masses

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- The mole, symbol mol, is the SI unit of **amount of substance**
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  - This number is known as the **Avogadro constant**

- For example:
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Your notes

Worked Example

For magnesium chloride, $MgCl_2$, calculate the number of:

1. Molecules in 1 mole
2. Atoms in 1 mole
3. Chloride ions in 1 mole
4. Magnesium ions in 2 moles

Answers:

1. The formula is $MgCl_2$, so 1 mole of $MgCl_2$ is:
    - $1 \times 6.02 \times 10^{23} = 6.02 \times 10^{23}$ molecules
2. There are 3 atoms in $MgCl_2$, so 1 mole of $MgCl_2$ contains:
    - $3 \times 6.02 \times 10^{23} = 18.06 \times 10^{23}$ atoms
3. There are 2 chloride ions in $MgCl_2$, so 1 mole of $MgCl_2$ contains:
    - $2 \times 6.02 \times 10^{23} = 12.04 \times 10^{23}$ chloride ions
4. There is 1 magnesium ion in $MgCl_2$, so 2 mole of $MgCl_2$ contains:
    - $2 \times (1 \times 6.02 \times 10^{23}) = 12.04 \times 10^{23}$ magnesium ions

Worked Example

In 15.7 g of water ($M_r = 18$):

1. How many molecules are there?
2. How many atoms are there?

Answers:

1. The number of molecules:
    - The molar mass of water is 18 g / mol
    - The number of moles is found by **mass ÷ molar mass**
        - 15.7 g ÷ 18 g / mol = **0.872 mol**
    - There are 6.02×10^{23} molecules of water in 1 mole of water
    - So, in 0.872 moles of water, there are:
        - $6.02 \times 10^{23} \times 0.872 = \mathbf{5.25 \times 10^{23}}$ molecules
2. The number of atoms:

- In each molecule of water, there are 3 atoms (2 hydrogen atoms, one oxygen atom)
- So, the number of atoms in 15.7 g = $3 \times 5.25 \times 10^{23}$ = **1.58×10^{24}** atoms

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Reacting masses

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- Chemical / symbol equations can be used to calculate:
  - The **moles** of reactants and products
  - The **mass** of reactants and products
- To do this:
  - Information from the question is used to find the amount in moles of the substances being considered
  - Then, the **ratio** between the substances is identified using the balanced chemical equation
  - Once the moles have been determined they can then be converted into grams using the relative atomic or relative formula masses

Worked Example

Magnesium undergoes combustion to produce magnesium oxide.

The overall reaction that is taking place is shown in the equation below.

$$2Mg\ (s) + O_2\ (g) \longrightarrow 2\ MgO\ (s)$$

Calculate the mass of magnesium oxide that can be made by completely burning 6.0 g of magnesium in oxygen in the following reaction:

$A_r(O) = 16 \quad A_r(Mg) = 24$

Answer:

1. Calculate the moles of magnesium
   - Moles = $\frac{\text{mass}}{M_r} = \frac{6}{24} = 0.25$
2. Use the molar ratio from the balanced symbol equation
   - 2 moles of magnesium produce 2 moles of magnesium oxide
   - The ratio is 1 : 1
   - Therefore, 0.25 moles of magnesium oxide is produced
3. Calculate the mass of magnesium oxide
   - Mass = moles x M_r = 0.25 moles x (24 + 16) = 10 g

Your notes

Worked Example

In theory, aluminium could decompose as shown in the equation below.

$$2Al_2O_3 \longrightarrow 4Al + 3O_2$$

Calculate the maximum possible mass of aluminium, in tonnes, that can be produced from 51 tonnes of aluminium oxide.

$$A_r(O) = 16 \quad A_r(Al) = 27$$

Answer:

1. Calculate the moles of aluminium oxide
   - Mass = 51 tonnes x 10^6 = 51 000 000 g
   - M_r of aluminium oxide = (2 x 27) + (3 x 16) = 102
   - Moles = $\frac{\text{mass}}{M_r} = \frac{51\ 000\ 000}{102}$ = 500 000
2. Use the molar ratio from the balanced symbol equation
   - 2 moles of aluminium oxide produces 4 moles of aluminium
   - The ratio is 1 : 2
   - Therefore, 2 x 500 000 = 1 000 000 moles of aluminium is produced
3. Calculate the mass of aluminium
   - Mass = moles x M_r = 1 000 000 moles x 27 = 27 000 000 g
   - Mass in tonnes = $\frac{27\ 000\ 000}{10^6}$ = 27 tonnes

Examiner Tips and Tricks

Remember: The molar ratio of a balanced equation gives you the ratio of the amounts of each substance in the reaction.

Limiting reactants

- A chemical reaction stops when one of the reactants is used up
- The reactant that is used up first is the **limiting reactant**, as it limits the duration and hence the amount of product that a reaction can produce
  - The one that is remaining is the **excess** reactant
  - The limiting reagent is the reactant which is **not present in excess** in a reaction
- The amount of product is therefore **directly proportional** to the amount of the limiting reactant added at the beginning of a reaction

Determining the limiting reactant

- In order to determine which reactant is the limiting reagent in a reaction, we have to consider the amounts of each reactant used and the molar ratio of the balanced chemical equation
- When performing reacting mass calculations, the limiting reagent is always the number that should be used, as it indicates the maximum possible amount of product that can form
  - Once all of a limiting reagent has been used up, the reaction cannot continue
- The steps are:
  1. Convert the mass of each reactant into moles by dividing by the molar masses
  2. Write the balanced equation and determine the molar ratio
  3. Look at the equation and compare the moles

Worked Example

9.2 g of sodium is reacted with 8.0 g of sulfur to produce sodium sulfide, Na_2S.

Which reactant is in excess and which is the limiting reactant?

Relative atomic masses (A_r): Na = 23; S = 32

Answer:

1. Calculate the moles of each reactant
   - Moles = $\frac{\text{mass}}{M_r}$
   - Moles Na = $\frac{9.2}{23}$ = 0.40
   - Moles S = $\frac{8.0}{32}$ = 0.25
2. Write the balanced equation and determine the molar ratio
   - $2Na + S \rightarrow Na_2S$
   - So, the molar ratio of Na : S is 2 : 1
3. Compare the moles
   - To react completely 0.40 moles of Na requires 0.20 moles of S
   - Since there are 0.25 moles of sulfur:
     - S is in excess
     - Therefore, Na is the limiting reactant

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