CAIE IGCSE Chemistry

3.3 The mole and the Avogadro constant

Notes

State that concentration can be measured in g /dm^3 or mol/dm^3

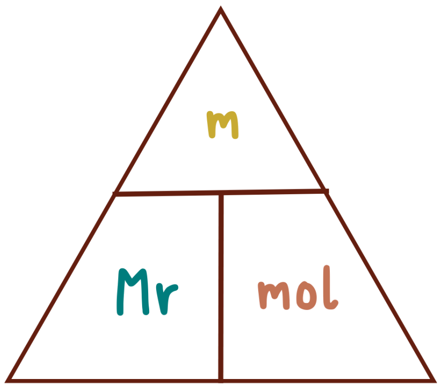
- The concentration of a substance is the amount of solute dissolved in a measured volume of solution
- The concentration can be measured in g/dm^3 or mol/dm^3
- To convert between the two units, the mass needs to be converted to moles (or vice versa) using the formula triangle involving M_r, mol, mass

(Extended only) State that the mole, mol, is the unit of amount of substance and that one mole contains 6.02×10^{23} particles, e.g. atoms, ions, molecules; this number is the Avogadro constant

- The mole, mol, is the unit for the amount of substance
- The number of atoms, molecules or ions in 1 mole of a given substance is the Avogadro constant: 6.02×10^{23}

(Extended only) Use the relationship amount of substance (mol) = mass (g)/ molar mass (g /mol) to calculate:

- The formula triangle for the relationship between amount of substance (mol), mass (g) and molar mass (g/mol) can be used to calculate the following:



- The molar mass is the same as the M_r (relative molecular mass) numerically but the molar mass has a unit (g/mol) whereas the M_r is a unitless quantity.
- E.g The M_r of calcium is 40, but the molar mass of calcium is 40g/mol

(a) Amount of substance

- To calculate for the: $Amount\ of\ substance\ (mol)\ =\ Mass\ \div M_r$
- E.g. Calculate the amount of substance in 426g of sodium sulfate (Na_2SO_4).

1. Calculate the M_r of Na_2SO_4
   (23 x 2) + 32 + (16 x 4) = 142
2. Mass ÷ M_r
   426 g ÷ 142 = 3 moles of Na_2SO_4

(b)Mass

- To calculate the: $Mass\ of\ a\ substance\ =\ M_r \times mol$
- E.g Calculate the mass of 0.5 moles of sodium (Na)

1. Find the M_r of Na on periodic table = 23
2. Mass= M_r x mol
   23 x 0.5 = 11.5g

(c) Molar mass

- To calculate the: $Molar\ mass\ =\ mass\ \div\ mol$
- E.g. Find the molar mass of $AlCl_3$ (moles= 4 and mass = 534g)
- Mass ÷ Mol
  534 g ÷ 4 mol = 133.5 g/mol

- To check your answer you can find the M_r of $AlCl_3$ by using the atomic masses (A_r) of each element from your periodic table:
  27 + (3 x 35.5) = 133.5

(d) Relative atomic mass (A_r) or relative molecular/formula mass (M_r)

- To calculate the A_r or M_r of a substance, use the same process as finding the $Molar\ mass\ =\ mass\ \div\ mol$
- E.g Find the relative molecular mass (M_r) of CaCOH (2 moles and mass = 138g)
- Mass ÷ Mol = Molar mass
  138g ÷ 2 moles = 69 g/mol
- The relative molecular mass is a unitless quantity so the M_r of CaCOH is 69

- To check your answer you can find the M_r of CaCOH by using the atomic masses (A_r) of each element from your periodic table:
  40 + 12 + 16 + 1 = 69

(e) Number of particles, using the value of the Avogadro constant

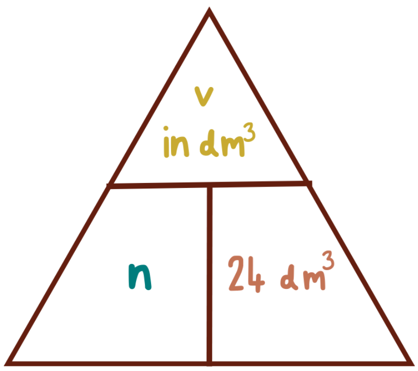
- The number of particles (atoms, molecules, ions) can be found using:
  - Avogadro constant= 6.02×10^{23}
  - The amount of substance (number of moles)

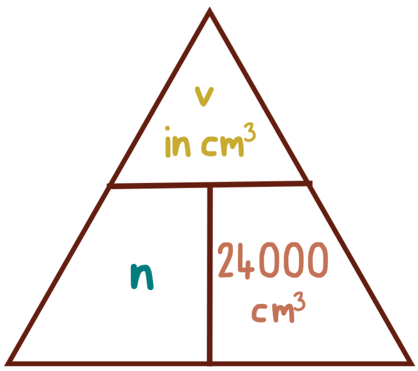
- E.g. Calculate the number of carbon dioxide molecules in 1.5 moles of CO_2
  Number of particles = Avogadro constant x amount of substance
  Number of CO_2 molecules= $6.02 \times 10^{23} \times 1.5$
  Number of CO_2 molecules= 9.03×10^{23}

- BUT if the question asked for the number of atoms in 1.5 moles of CO_2, an extra step is involved:
  Number of CO_2 molecules= 9.03×10^{23}
  There are 3 atoms in each CO_2 molecule (2 O atoms and 1 C atom), so…
  Number of atoms in 1.5 moles of CO_2= $9.03 \times 10^{23} \times 3$
  = 2.71×10^{24} atoms

(Extended only) Use the molar gas volume, taken as 24dm^3 at room temperature and pressure, r.t.p., in calculations involving gases

- Equal amounts in mol. of gases occupy the same volume under the same conditions of temperature and pressure (e.g. RTP)
- Volume of 1 mol. of any gas at RTP (room temperature and pressure: 20˚C and 1 atmosphere pressure) is 24 dm^3
- This sets up this formula triangle:





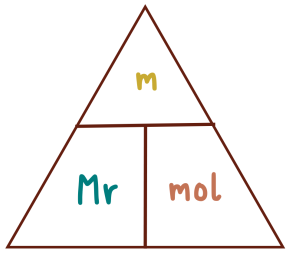
- Both triangles are the same, the only difference is spotting whether the question uses cm^3 or dm^3 for the volumes and molar gas volume

(Extended only) Calculate stoichiometric reacting masses, limiting reactants, volumes of gases at r.t.p., volumes of solutions and concentrations of solutions expressed in g /dm^3 and mol/dm^3 , including conversion between cm^3 and dm^3

<u>*Calculating stoichiometric reacting masses:*</u>

E.g Calculate the mass of oxygen needed to react with 24g of magnesium to form magnesium oxide: $2Mg (s) + O_2(g) \rightarrow 2MgO (s)$

1. Identify which formula(s) you will need to use ->
2. Find the M_r of oxygen: 32 since the A_r of 1 oxygen atom is 16
3. Find the M_r of magnesium: 24 (the 2 in front of Mg is ignored as it is the balancing number)
4. Find the mol of magnesium: mass of Mg ÷ M_r of Mg
   24 ÷ 24= 1
5. Calculate the mol of oxygen using the balancing numbers:
   If 2 moles of magnesium = 1, then 1 mole of oxygen = 0.5
6. Calculate the mass of oxygen: M_r of O_2 x mol of O_2
   32 x 0.5 =16g



<u>*Calculating limiting reactants:*</u>

- A reaction will finish when one of the reactants are all used up, that reactant is known as the **limiting reagent/reactant** and it determines how much product is formed
- The other reactant that is leftover is the reactant that is **in excess**
- By working out the mass of the limiting reactant, we can determine the mass of the product:

E.g. 0.96 g of magnesium reacts with 2.19g of hydrochloric acid:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

What mass of magnesium chloride is formed?

1. Work out the moles for both reactants:
   Formula: Moles= Mass ÷ M_r
   Moles of Mg = 0.96 ÷ 24 = 0.04 Moles of HCl= 2.19 ÷ 36.5= 0.06

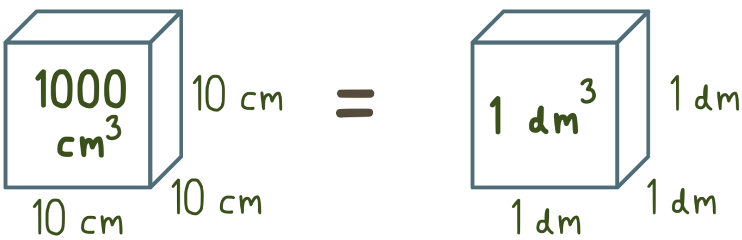
2. Use the molar ratio of the reactants to determine which is the limiting reactant
   Mg : HCl is 1:2 so 1 mole of Mg : 2 moles of HCl
   0.04 mol of Mg: 0.08mol of HCl
   But there is only 0.06mol of HCl so HCl is the limiting reactant

3. Use the molar ratio of the limiting reactant and the product to find the moles of product formed
   HCl : $MgCl_2$ is 2:1
   0.06mol of HCl: 0.03mol of $MgCl_2$

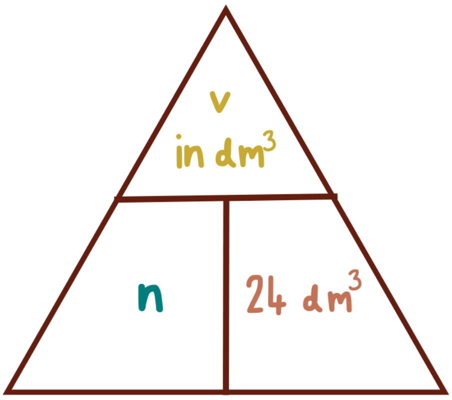
4. Work out the mass of product formed:
   Mass of $MgCl_2$: 0.03 mol x M_r of $MgCl_2$
   M_r of $MgCl_2$: 24 + (35.5 x 2) = 95
   Mass of $MgCl_2$: 0.03 x 95 = 2.85g

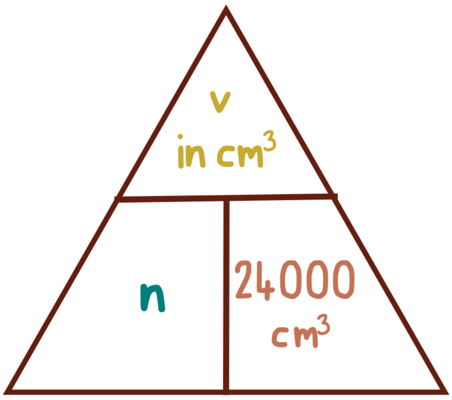
Converting between cm^3 and dm^3

- It is important to remember that these are cubic/volume units so it isn't as simple as converting from cm to dm
- Imagine a cube with sides 1dm x 1dm x 1dm so the volume would naturally be $1dm^3$
- 1dm = 10cm
- So the same cube is also 10cm x 10cm x 10cm so the volume would be $1000cm^3$
- Therefore $1dm^3 = 1000cm^3$
  - Converting cm^3 to dm^3 : ÷1000
  - Converting dm^3 to cm^3 : x1000



Calculating volumes of gases at r.t.p





E.g. Calculate the volume of 0.75mol of oxygen at room temperature and pressure (Molar gas volume= $24dm^3$)

$$Volume\ of\ gas\ in\ dm^3 = Number\ of\ moles \times 24\ dm^3$$

Volume of oxygen= 0.75 x 24 = 18 dm^3

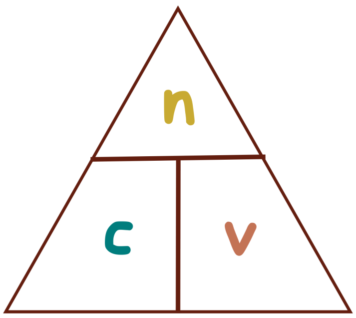
E.g. Calculate the volume of 0.5mol of hydrogen at room temperature and pressure (Molar gas volume= $24000cm^3$)

$$Volume\ of\ gas\ in\ cm^3 = Number\ of\ moles \times 24000\ cm^3$$

Volume of hydrogen= 0.5 x 24000 = 12000 cm^3

Calculating the volume and concentration of solutions in g/dm³ and mol/dm³

- To find the volume or concentration (in mol/dm^3) of a solution this formula triangle is used:
  - n= number of moles (mol)
  - c= concentration (mol/dm^3)
  - v= volume of solution (dm^3)
- Many questions will require you to know and convert between dm^3 and cm^3
  - Converting cm^3 to dm^3 : ÷1000
  - Converting dm^3 to cm^3 : x1000
- The units for concentration can also be shown as M (for 'molar')



- Converting between g/dm^3 and mol/dm^3:
    - mol/dm^3 -> g/dm^3 multiply by the M_r
    - g/dm^3-> mol/dm^3 divide by the M_r

E.g. $200cm^3$ of hydrochloric acid contains 0.25 mol of dissolved hydrogen chloride. Calculate the concentration in mol/dm^3 and g/dm^3
To calculate the

$$Concentration\ of\ a\ solution\ =\ Number\ of\ moles\ \div\ Volume$$

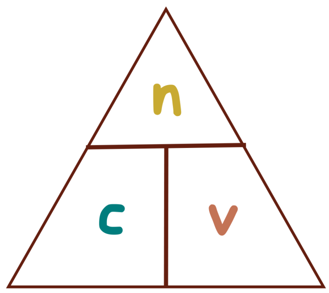
1. Convert the volume in cm^3 to dm^3
   $200cm^3 \div 1000 = 0.2dm^3$
2. Calculate the concentration in mol/dm^3 : Number of moles ÷ Volume
   $0.25 \div 0.2 = 1.25\ mol/dm^3$
3. To convert to g/dm^3:
   Calculate the M_r of HCl: 1 + 35.5 = 36.5
   mol/dm^3 -> g/dm^3 multiply by the M_r
   1.25 x 36.5 = 45.625 g/dm^3

(Extended only) Use experimental data from a titration to calculate the moles of solute, or the concentration or volume of a solution

- The experimental data from a titration can be used to calculate the concentration or volume or moles of a solution, using the formula triangle relating the three
- Titration questions will require converting between dm^3 and cm^3
    - Converting cm^3 to dm^3 : ÷1000
    - Converting dm^3 to cm^3 : x1000

E.g. 25 cm^3 of dilute hydrochloric acid (HCl) is neutralised by 20 cm^3 of 0.5 mol/dm^3 sodium hydroxide (NaOH). What is the concentration of the hydrochloric acid?

1. Convert volumes from cm^3 to dm^3
   $25cm^3 = 0.025dm^3$ $20cm^3 = 0.020dm^3$
2. Work out the moles of NaOH:
   $$Number\ of\ moles\ =\ Concentration\ \times\ Volume$$
   0.5 x 0.02 = 0.01 mol
3. Work out the mole ratio by balancing the chemical equation: HCl + NaOH -> NaCl + H_2O
   1:1 ratio so number of moles of NaOH= number of moles of HCl
   So number of moles of HCl = 0.01mol
4. Work out the concentration of HCl:
   $$Concentration\ =\ Number\ of\ moles\ \div\ Volume$$
   $0.01\ \div\ 0.025 = 0.4mol/dm^3$



(Extended only) Calculate empirical formulae and molecular formulae, given appropriate data

- Remember:
  Empirical formula: the **simplest whole number ratio** of atoms of each element in a compound
  Molecular formula: the **actual number** of atoms of each element in a compound
- Finding the empirical formula:
  E.g. Find the empirical formula of the following compound using their percentage masses: Al 20.2% Cl 79.8%
  1. Write the relative atomic masses (A_r) of each element
     Al = 27 Cl = 35.5
  2. Divide the percentage masses by the A_r of each element
     Al= 20.2 ÷ 27 = 0.748 Cl= 79.8 ÷ 35.5 = 2.248
  3. Divide by the smallest answer from step 2 to find the ratio of atoms of each element
     Al= 0.748 ÷ 0.748 = 1 Cl= 2.248 ÷ 0.748 = 3
     This is the simplest whole number ratio for Al : Cl = 1:3
     So the answer is $AlCl_3$
- Tip: Set out your working into a table to ensure each step is correctly done
  E.g. Calculate the empirical formula for a compound containing 7.83g of Iron (Fe) and 3.37g of oxygen (O)

Element	Fe	O
Relative atomic mass (A_r)	56	16
Mass (in g)	7.83	3.37
Work out the moles	7.83g ÷ 56 = 0.14	3.37 ÷ 16 = 0.21
Divide by the smallest number to find the molar ratio	0.14 ÷ 0.14 = 1	0.21 ÷ 0.14 = 1.5
Multiply by x to reach lowest whole number ratio	1 x 2 = 2	1.5 x 2 = 3
Empirical formula	Fe_2O_3	

- Finding the molecular formula: Use the Mr to find the actual number of atoms of each element after finding the empirical formula
  E.g Deduce the molecular formula for the compound with empirical formula CH_2O and has an M_r of 180
  1. Find the M_r of the empirical formula: 12 + (2 x 1) + 16 = 30
  2. Divide the M_r of the molecular formula by the Mr of the empirical formula:
     180 ÷ 30 = 6
  3. Multiply each element in the empirical formula by the answer in step 2:
     1 atom of C x 6 = 6 atoms of C in the compound
     2 atoms of H x 6 = 12 atoms of H in the compound
     1 atom of O x 6 = 6 atoms of O in the compound

  Answer: The molecular formula is $C_6H_{12}O_6$

(Extended only) Calculate percentage yield, percentage composition by mass and percentage purity, given appropriate data

Calculating the percentage yield

- It is not always possible to obtain the calculated (theoretical) amount of a product for 3 reasons:
  1. Reaction may not go to completion because it is reversible
  2. Some of the product may be lost when it is separated from the reaction mixture
  3. Some of the reactants may react in ways different to the expected reaction

- To calculate the percentage yield, the following formula can be used:

$$Percentage\ yield = \frac{Actual\ amount\ of\ product\ produced}{Theoretical\ amount\ of\ product\ possible} \times 100$$

- To calculate the theoretical yield of a substance, find the mass by: Mr x Moles

E.g 32g of sodium hydroxide reacts with hydrochloric acid. 16.2g of sodium chloride was produced. Calculate the percentage yield of sodium chloride

$$NaOH + HCl \rightarrow NaCl + H_2O$$

1. Calculate the theoretical yield of sodium chloride (NaCl):
   a. Find the M_r of sodium hydroxide and sodium chloride
      NaOH = 23 + 16 + 1 = 40 NaCl= 23 + 35.5 = 58.5

b. Calculate the moles of sodium hydroxide:
   32g ÷ 40 = 0.8mol of NaOH
   The molar ratio between NaOH:NaCl is 1:1 so there are 0.8mol of NaCl
c. Calculate the theoretical mass of NaCl:
   0.8 x 58.5 = 46.8g

2. Calculate the percentage yield of NaCl:

$$Percentage\ yield\ =\ \frac{Actual\ amount\ of\ product\ produced}{Theoretical\ amount\ of\ product\ possible}\ \times\ 100$$

$$\text{Percentage yield of NaCl} = \frac{16.2\ g}{46.8\ g} \times 100 = 34.6\ \%$$

Percentage composition by mass

To calculate the percentage of an element in a compound the following formula is used:

$$Percentage\ mass\ =\ \frac{Total\ A_r\ of\ the\ element}{M_r\ of\ the\ compound}\ \times\ 100$$

E.g. Calculate percentage of magnesium in magnesium carbonate, $MgCO_3$

1. Work out the M_r of the compound: 24 + 12 + (16 x 3) = 84
2. Work out the Total A_r of the element
   There is only 1 atom of magnesium in the compound so the total mass of Mg is 24 x 1 = 24
3. Input your data into the equation
   % mass = (Total A_r of the element ÷ M_r of the compound) × 100
   % mass of Mg = (24 ÷ 84) × 100 = 28.6%

Percentage purity

- To calculate the percentage purity of a substance, the following formula is used:

$$Percentage\ purity = \frac{Mass\ of\ the\ pure\ substance}{Total\ mass\ of\ sample} \times 100$$

- It is possible you will need to calculate the mass from the moles first

E.g. A solution of sodium chloride contains 0.64g of NaCl in 100g of water. Calculate the percentage purity by mass of NaCl.

$$Percentage\ purity = \frac{Mass\ of\ the\ pure\ substance}{Total\ mass\ of\ sample} \times 100$$

$$Percentage\ purity\ of\ NaCl = \frac{0.64g}{100g} \times 100 = 0.64\%$$