THE MOLE and AVOGADRO'S CONSTANT (L). 4.1

The mole is the number of "particles" present in 1 gram formula mass **(1 GFM)** of a substance. The "particles" may be **atoms** when the substance is an element; **molecules** when the substance is a covalent compound, or **ion**s in the case of an ionic compound. The number of "particles" present in 1 mole of substance is extremely large and is known as Avogadro's Constant (symbol L = 6.02 x 10^{23}). The precise definition of a mole is that it is the amount of substance, which contains as many particles as there are carbon atoms in exactly 12.000 grams of carbon-12.

Examples of 1 mole

1 mole of oxygen gas O_2	L = 6.02 x 10^{23} molecules	32 g
1 mole of sodium chloride NaCl	L = 6.02 x 10^{23} formula units	68.5g
1 mole of glucose $C_6H_{12}O_6$	L = 6.02 x 10^{23} molecules	180g

Mole and Mole Number Calculations

What numbers of molecules are present in 0.218 moles of water?

1 mol => 6.02 x 10^{23} molecules

0.218 mol = 0.218 x 6.02 x 10^{23} molecules

= 1.31 x 10^{23} molecules

How many moles of oxygen contains 2.25 x 10^{24} molecules

6.02 x 10^{23} molecules => 1 mol

2.25 x 10^{24} molecules = $\frac{2.25 \times 10^{24}}{6.02 \times 10^{23}}$

= 3.74 mol

PARTICLES PRESENT IN COMPOUNDS

In the case of **covalent compounds**, the particles present are **molecules**. **Ionic compounds** consist of **ions.**

EXAMPLE.

Carbon dioxide is a gas produced when fossil fuels burn in a plentiful supply of oxygen. Although not a pollutant as it is present naturally in air it does contribute to global warming.It is important that we know exactly how much carbon dioxide is being produced in any given time.

a)What mass of carbon dioxide is produced when 0.8g of methane are burned in air? (Assume plentiful supply)

CH_4 + 2 O_2 => CO_2 + 2 H_2O

1 mol 2 mol 1 mol 2 mol

16g 44g

1g 44/16 g

0.8g 0.8 x 44/16 g

= 2.2g of CO_2

b) How many **carbon dioxide molecules** are there in this mass of carbon dioxide (CO_2)?
b) How many **oxygen atoms** are there in this mass of carbon dioxide?
c) What is the **total number of atoms** in this mass of carbon dioxide?

a) 1 mole of CO_2 weighs 44 g 1 mole of CO_2 contains 6.02 x 10^{23} CO_2 molecules.

Thus, 44 g of CO_2 = 6.02 x 10^{23} CO_2 molecules

1g of CO_2 = 1/44 x 6.02 x 10^{23} CO_2 molecules

Therefore, 2.2 g of CO_2 = 2.2 x 1/44 x 6.02 x 10^{23} CO_2 molecules

= 3.01x 10^{22} CO_2 molecules (0.301 x 10^{23})

b) In every CO_2 molecule there are 2 oxygen atoms
Therefore, 3.01 x 10^{22} CO_2 molecules, contains 2 x 3.01x 10^{22} atoms of oxygen.

= 6.02 x 10^{22} oxygen atoms

c) In every CO_2 molecule there are 3 atoms
Therefore, 3.01 x 10^{22} CO_2 molecules, contains 3 x 3.01x 10^{22} atoms of oxygen

= 9.03 x 10^{22} atoms

Try these

1. How many molecules are present in
   a) 3 mol of glucose? ----------
   b) 2.5 mol of ammonia? ----------
   c) 0.2 mol of ethanol? ----------

2. How many moles are present in each of the following
   a) 1.204×10^{30} molecules of methane? ----------
   c) 1.806 x 10 24 molecules of ethanoic acid? ----------

3. a) What mass of magnesium oxide is formed when 3.6 g of magnesium is burned in excess oxygen? ----------
   b) How many magnesium ions does this represent? ----------
   c) How many oxide ions does this represent? ----------
   d) What is the total number of ions represented? ----------

4. a) What mass of calcium carbonate must be heated in order to obtain 1.1 g of carbon dioxide? ----------
   b) How many calcium ions are represented by this? ----------
   c) How many carbon dioxide molecules are present in 1.1 g ? ----------

5. How many atoms are present in
   a) 6 g of magnesium metal? ----------
   b) 13g of zinc metal? ----------
   c) 28 g of nitrogen gas? ----------

6 Which of the following contains Avogadro's constant of molecules

   a) 16 g of O_2
   b) 60 g of C_2H_6
   c) 96g of SO_2
   d) 160g of Br_2

7. Which of the following contains Avagadro's constant of atoms
   a) 2g of hydrogen H_2
   b) 8g of helium He
   c) 14g of lithium Li
   d) 16g of oxygen O_2

8. Calculate the mass of
   a) Na_2S that contains 6.02×10^{23} sodium ions? ----------
   b) Al_2O_3 that contains 6.02×10^{23} oxide ions? ----------
   c) Na_2CO_3 that contains 6.02×10^{23} ions in total? ----------

Mole and Gas Volume 4.2

The ***Molar Volume*** of a gas means its volume per mole. (Units l mol^{-1})
The volume of 1 mol of gas is constant at any fixed temperature and pressure.

1a. Molar volumes for gases.
If the mass of a measured volume of gas is known then the molar volume of the gas can be calculated.

Example 1a. In an experiment it was found that the mass of 976 cm3 of oxygen was 1.30g.
Calculate its molar volume. [GFM O_2 = 32g]

1.30g = 976 cm^3

1 g = $\frac{976}{1.30}$ cm^3

32 g = $\frac{976}{1.30}$ x 32 = 24,024 cm^3 [24 l]

1b. Molar Volumes from densities.
Densities on page 3 of the data book are given in g cm^{-3}

Example 1b. If the density of fluorine is 0.0017 g cm^{-3}, what is its molar volume? [GFM F_2 = 38g]

0.0017 g = 1 cm^3

1g = 1/0.0017 cm^3

38 g = 38 x 1/0.0017 cm^3 = 22.35 l

Gas	Density (gcm-3)	[molar volume] s.t.p.
argon	**0.0018**	
helium	**0.0002**	
oxygen	**0.0017**	**22.35 l**
krypton	**0.0037**	
hydrogen	**0.00009**	

2 Gas volume and moles or mass
When given a volume of gas and knowing its molar volume the number of moles 'n' can be calculated. Similarly by determining its GFM the mass of any volume of gas can be determined when its molar volume is known.

Example 2a What is the amount (in moles) of nitrogen, N_2 , in 441 cm^3? [molar volume = 24.5 l mol^{-1}]

24.5 l = 1 mol

1 l = 1/24.5

0.441 l = 0.441 x 1/24.5 = 1.8 x 10^{-2} mol

Example 2b What is the mass in g of nitrogen in 441 cm^3 ?[molar volume = 24.5 l mol^{-1}] [GFM = 28g]

24.5 l = 28 g

1 l = 28/23.5

0.441 l = 0.441 x 28/24.5 = 5.04 x 10^{-1} g

3. Gas volume and number
When given a volume of gas and its molar volume, the number of particles present can be calculated. Alternatively given the number of particles the volume can be calculated.

Example 3a What volume of carbon dioxide gas, CO_2 , contains 1.25 x 10^{22} molecules? [molar volume = 24.08 l mol^{-1}]

6.02 x 10^{23} molecules = 24.08 l

1 molecule = $\frac{24.08}{6.02 \times 10^{23}}$

1.25 x 10^{22} molecules = $\frac{24.08}{6.02 \times 10^{23}}$ x 1.25 x 10^{22} l = 2 x 10^{-1} l

Examples to try
1. What is the volume of 3.47g of silicon tetrafluoride , SiF_4, when its molar volume is 24.2 l mol^{-1}?
2. What is the mass of hydrogen, H_2, in 605 cm^3 if its molar volume is 24.2 l
3. What is the mass of hydrogen sulphide gas, H_2S , in 360 cm3 when its molar volume is 22.6 l?
4. What is the number of water molecules in 0.6 l of steam when its molar volume is 30.1 l mol^{-1}?
5. The densiity of oxygen gas at 50ºC and 1 atmos. pressure was found to be 1.2 g l^{-1}, what is its molar volume at this temperature and pressure?
6. What volume of carbon dioxide gas is released when 5 g of calcium carbonate is heated.[molar volume = 24 l mol^{-1}]

Calculations involving comparisons 4.3

This topic deals with various quantities by comparing them in terms of 'n' number of moles.
Quantities may be given in mass, gas volume, volume and molarity and number of formula units.

Mass The mass of a substance is given in grammes. [g] To change to moles we divide the mass by the gram formula mass.[GFM]

Examples How many moles are present in

a) 60 g of calcium carbonate? $CaCO_3$ GFM = 100g

n = mass/GFM =60/100 = 6×10^{-1} mol

b) 9.8 g of sulphuric acid?
c) 6g of glucose?
d) 430g of hexane?
e) 0.4g of sodium hydroxide?

Gas Volume The gas volume can be given in litres or cm^3. The molar volume must also be known. In all examples below the molar volume at 20ºC and 1 atmosphere will be assumed to be 24 l mol^{-1}.

Examples How many moles are present in

a. 100 cm^3 of methane?

$$n = \frac{\text{volume in litres}}{\text{molar volume}} = 0.1/24 = 4.2 \times 10^{-3} \text{mol}$$

b. 5 l of oxygen?
c. 800 l of ammonia?
d. 500 cm^3 of sulphur dioxide?
e. 650 cm^3 of ethane?

Volume and Molarity

The number of moles can be determined by using the formula n= MV where M is molarity in mol l^{-1}
V is volume in litres

or n =MV/1000 where M is molarity in mol l^{-1}
V is volume in cm^3

Examples How many moles are present in

a) 250 cm^3 of 0.1 M hydrochloric acid?

$$n = MV/1000 = \frac{0.1 \times 250}{1000} = 2.5 \times 10^{-2} \text{mol}$$

b) 50 l of 2 M sulphuric acid?
c) 500 cm^3 of 1 M sodium carbonate?
d) 2 l of 0.01 M potassium permanganate?
e) 400 cm^3 of 4 M nitric acid?

Number of formula units

The number of moles is determined by dividing the number of formula units by 6.02×10^{23}.

Examples How many moles are present in

a. 1.806×10^{20} molecules of nitrogen dioxide?

$$n = \frac{1.806 \times 10^{20}}{6.02 \times 10^{23}} = 3.0 \times 10^{-4} \text{ mol}$$

b) 3.01×10^{40} formula units of sodium chloride?
c) 9.03×10^{25} atoms of gold?
d) 1,000,000 atoms of copper?
e) 2.709×10^{30} atoms of gold?

CALCULATIONS ABOUT EXCESS.

When two substances react unless the reacting quantities have been carefully worked out then one is likely to be in excess. The limiting reactant is the one which is not in excess and therefore determines the quantities of products

Example:- a) Which reactant will remain in excess after 100 ml of 1 mol l-1 hydrochloric acidis added to 10.6 g of sodium carbonate? [GFMNa_2CO_3] = 106 g
b) Calculate the amount of reactant in excess.
c) What mass of carbon dioxide will be produced in the reaction?

The equation for the reaction is :-

Na_2CO_3 + 2HCl => 2NaCl + CO_2 + H_2O
1 mol 2 mol 2 mol 1 mol 1 mol

a) Since the amounts of both reactants is given it is necessary to first determine which one is present in excess. To do this we will calculate the number of moles of each present at the start of the experiment.

The number of moles of sodium carbonate in 10.6 g of calcium carbonate can be calculated using:-

Number of moles = Mass of substance / Gram Formula mass. = 10.6/106 = 0.1 mol

The number of moles of hydrochloric acid used can be calculated using:-

Number of moles = Concentration x Volume (in litres) = 1 x 0.1 = 0.1 mole

From the equation 1 mole of Na_2CO_3 reacts with 2 moles of HCl and so 0.1 mole of Na_2CO_3 will react with 0.2 moles of HCl

As there is less than 0.2 moles of hydrochloric acid available it is the **sodium carbonate that is in excess**.

b) The 0.1 moles of hydrochloric acid that is available will only react with 0.1/2 = 0.05 moles of sodium carbonate and so the excess amounts to 0.1 - 0.05 = **0.05 moles**.
c) Thelimiting reactant is used to calculate the mass of products

Na_2CO_3 + 2HCl => 2NaCl + CO_2 + H_2O
1 mol **2 mol** 2 mol **1 mol** 1 mol

2 mol = 44g

1 mol = 44/2g

0.1 mol = 44/2 x 0.1 = 2.2 g

EXAMPLES FOR PRACTICE.

1. 3.25 g of zinc is reacted with 50 cm^3 of 1.0 mol l^{-1} hydrochloric acid.
   a) Which reagent is present in excess.
   b) Use the limiting reactant to alculate the mass of zinc chloride that will be produced.

Equations is $Zn(s) + 2HCl(aq) \Rightarrow ZnCl_{2(aq)} + H_{2(g)}$

2. 10 cm^3 of 1.0 mol l–1 sodium sulphate solution is reacted with 25 cm^3 of 1.0 mol l^{-1} barium chloride solution.

   a) Which reactant is present in excess?
   b) Calculate the mass of precipitate formed.

Equation is:- $Na_2SO_{4(aq)} + BaCl_{2(aq)} \Rightarrow BaSO_{4(s)} + 2NaCl_{(aq)}$

3. 8 g of copper(II) oxide is reacted with 50 cm^3 of 1.0 mol l^{-1} sulphuric acid.

   a) Write a balanced equation for the reaction.
   b) Which reagent is in excess?
   c) What mass of copper(II) sulphate salt is formed?

Gases in Reactions 4.4

1 mole of every gas will occupy the same volume. This can be applied to balanced equations.

$CH_{4\ (g)}$	+	$2\ O_{2(g)}$	=>	$CO_{2(g)}$	+ $2\ H_2O_{(l)}$	balanced equation
1 mol		2 mol		1 mol	2 mol	mole relationship
1 vol		2 vol		1 vol	0 vol	gas volume relationship

Note Water is a liquid at room temperature and its volume compared to gases is negligible At temperatures above 100°C it will be gaseous and its volume must be taken into account

Complete the following for each alkane

$C_2H_{6(g)}$	+	$O_{2(g)}$	=>	$CO_{2(g)}$	+ $H_2O_{(l)}$	balanced equation
						mole relationship
						gas volume relationship
$C_3H_{8(g)}$	+	$O_{2(g)}$	=>	$CO_{2(g)}$	+ $H_2O_{(l)}$	balanced equation
						mole relationship
						gas volume relationship
$C_4H_{10(g)}$	+	$O_{2(g)}$	=>	$CO_{2(g)}$	+ $H_2O_{(l)}$	balanced equation
						mole relationship
						gas volume relationship

Using relationships

When 50 cm^3 of hexene is burned in oxygen

a) What volume of oxygen is needed for complete combustion?
b) What volume of carbon dioxide is produced?
c) i. What volume of water is produced at 20°C?
ii. What volume of water is produced at 120°C?

$C_6H_{12(g)}$	+	$9\ O_{2(g)}$	=>	$6\ CO_{2(g)}$	+ $6\ H_2O_{(l)}$	balanced equation
1mol		9 mol		6 mol	6 mol	mole relationship
1 vo		9 vol		6 vol	------	gas volume relationship (At 20°C)
50 cm^3		450 cm^3		300 cm^3	0 cm3	

a) 450 cm^3 of oxygen gas is needed for complete combustion.

b) 300 cm^3 of carbon dioxide is produced in the reaction.

c) i Water produced is negligible.
ii 300 cm^3 of water is produced.

Examples What volume of oxygen is needed and what volume of carbon dioxide produced when

1. 60 cm^3 of butene is burned?

2. 100 cm^3 of ethene is burned?

Reactant gas in excess

Unless exact quantities of reactant gases are used one of the reactant gases will be in excess. For example which gas is in excess and by how much when 100 cm^3 of hydrogen is burned in 100 cm^3 of oxygen?

$2\ H_{2(g)}$ +	$O_{2(g)}$	=>	$2\ H_2O_{(l)}$	balanced equation
2 mol	1 mol		2 mol	mole relationship
2 vol	1 vol		--	gas volume relationship
100 cm^3	100 cm^3			Gas at start
100cm^3	50 cm^3			Gas used
	50cm^3			Excess gas

Oxygen is in excess by 50 cm^3

Examples to try

1. Which gas is in excess and by how much when 50cm^3 of pentane is burned in 500 cm^3 of oxygen?

2. What gas is in excess and by how much when 40 cm^3 of ammonia(NH_3) is burned in 30 cm^3 of oxygen to form nitrogen and water?

Final total gas volume

The final gas volume depends not only on the gases produced but also on the unreacted gases left over.

What is the total volume of gas at 1 atmos. and 20^oC when 50 cm^3 of methane is burned in 200 cm^3 of oxygen.?

$CH_{2(g)}$ +	$2O_{2(g)}$	=>	$CO_{2(g)}$	+	$2\ H_2O_{(l)}$	balanced equation
1 mol	2 mol		1 mol		------	mole relationship
1 vol	2 vol		1 vol		-----	gas volume relationship
50 cm^3	200 cm^3					Gas at start
50 cm^3	100 cm^3					Gas used
	100 cm^3		50cm^3			Excess gas + Gas produced

150 cm^3 of gas consisting of 100 cm^3 O_2 and 50 cm^3 of CO_2 are left at end.

Examples to try

What is the total volume of gas and what does it consist of when

1. 20cm^3 of propane is burned in 200 cm^3 of oxygen?

2. 50cm^3 of butene is burned in 500 cm^3 of oxygen?

3. 150 cm^3 of carbon monoxide, CO, has reacted with 500cm^3 of hydrogen, H_2, to form methane and water.

$$CO_{(g)} + 3\ H_{2(g)} \Rightarrow CH_{4(g)} + H_2O_{(l)}$$

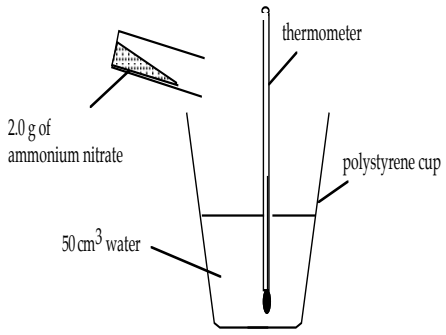
L = 6.02×10^{23}

Chemical Energy 4..5

When chemical reactions take place there are usually energy changes associated with them. Reactions which give out heat are called exothermic and reactions which take in heat are called endothermic.

Enthalpy This is a measure of the chemical energy stored wiithin the chemicals. Its chemical symbol is H and it is usually measured in kJ (kilojoules)

An endothermic reaction



The enthalpy of solution is the amount of energy given out, or taken in, when one mole of a substance dissolves in water. For example, the enthalpy of solution of ammonium nitrate (NH_4NO_3) can be determined using the apparatus shown below. When 2.0 g of ammonium nitrate was added to 50 cm^3 of water at 20..6°C the temperature fell until it reached 17.5°C. From these results we can determine the enthalpy of solution.

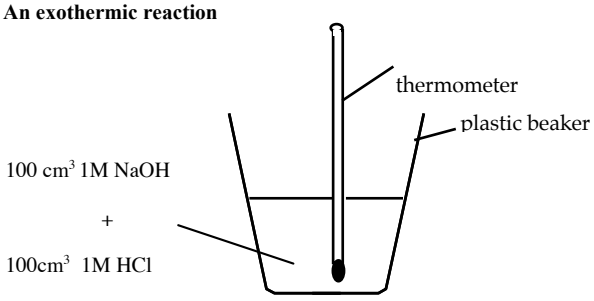
Temperature drop ΔT = _____ °C

Amount of heat energy absorbed = ΔH = c m ΔT= _____ x _____ x _____= _____ kJ.
Note c = 4.18 kJ kg^{-1} $°C^{-1}$ [c is the heat capacity of water]

This tells us that _____ of heat energy is absorbed when 2.0 g of ammonium nitrate dissolves in water.
GFM ammonium nitrate (NH_4NO_3) = _____ g.

Therefore when 1 mole of ammonium nitrate dissolves the heat energy absorbed = _____kJ mol^{-1}

An exothermic reaction



The following results were obtained:-

Initial temperature of solutions	**= 18.6°C**
Final temperature of mixture	**= 25.4°C**
Temperature rise (ΔT)	**= _____°C**

Amount of heat energy given out ΔH = c m ΔT = _____ x _____ x ____

= _____ kJ

Note this is for 0.1 mol of H_2O formed.

The heat of neutralisation (ΔH neutralisation) = _____ kJ mol^{-1}

NaOH + HCl => NaCl + H_2O

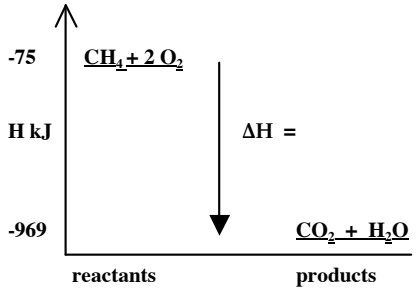
0.1 mol 0.1 mol 0.1 mol 0.1 mol

Enthalpy changes
When a chemical reaction takes place there can be a change in the stored chemical energy, this is called an enthalpy change

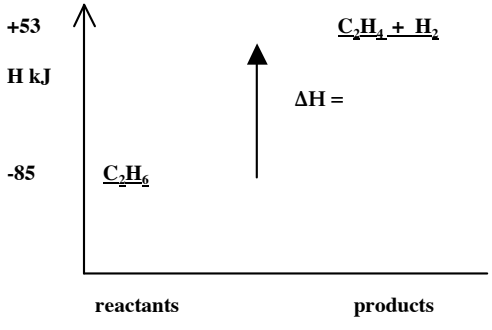
$\Delta H = H_{[products]} - H_{[reactants]}$

Calculate the ΔH for both the reactions below

1. Combustion of ethane



2. . Cracking of ethane



Reaction and Enthalpy Change 4.6

Most chemical reactions involve a change in enthalpy. In this section we will be looking at

1. Enthalpy of combustion ΔH_c
   This is the enthalpy change when 1 mole of a substance completely burns in air or oxygen

ΔH_c butane $\quad$ **C_4H_{10} + 13/2 O_2 => 4 CO_2 + 5 H_2O** $\quad$ **ΔH_c = -2877 kJ mol^{-1}**

ΔH_c hexane

ΔH_c octane

ΔH_c ethene

ΔH_c hydrogen

2. Enthalpy of solution
   This is the change when 1 mole of a substance dissolves in water.

$\Delta H_{solution}$ $\quad$ $NaCl_{(s)}$ $\quad$ => $\quad$ $Na^+_{(aq)}$ + $Cl^-_{(aq)}$

$\Delta H_{solution}$ $\quad$ $MgBr_{2(s)}$ $\quad$ =>

$\Delta H_{solution}$ $\quad$ $Al(NO_3)_{2(s)}$ $\quad$ =>

$\Delta H_{solution}$ $\quad$ NH_4NO_3 $\quad$ =>

3 Enthalpy of neutralisation of an acid
   This is the change when an acid is neutralised to form 1 mole of water

$\Delta H_{neutralisation}$ $\quad$ HCl + NaOH => NaCl + H_2O $\quad$ **ΔH = -57 kJ mol^{-1}**

$\Delta H_{neutralisation}$ $\quad$ H_2SO_4 + 2 NaOH => Na_2SO_4+ 2 H_2O $\quad$ **ΔH = - 114 kJ**

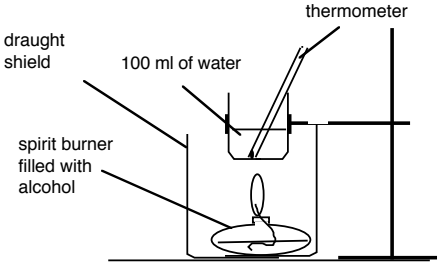
1/2 H_2SO_4 + NaOH => 1/2 Na_2SO_4 + H_2O $\quad$ **ΔH = -57 kJ mol-1**

Examples

a) 1.0g of potassium nitrate were dissolved in 50g of distilled water, the temperature fell by 1.7°C. Calculate the enthalpy of solution.

b) 20 cm^3 of 2M HNO_3 temperature = 20.0 °C were mixed with 20 cm^3 of 2M KOH temperature = 18.0°C.Temperature after mixing was 32..0°C. Calculate the enthalpy of neutralisation..

c) 0.36g of ethanol were burned in air and this heated 0.1 kg of water by 10°C. Use this information to calculate the enthalpy of combustion of ethanol.



Note **In this experiment the results are low because**

1. Heat is lost to surroundings
2. Incomplete combustion