QUANTITATIVE CHEMISTRY

Balanced Chemical Equations

- **Write a chemical equation from word format into chemical format using both simple and compound/polyatomic ions. This will include the use of the STOCK NOTATION**

- 1 hydroxide nitrate nitrite chlorate permanganate
hydrogen carbonate hydrogen sulphate ethanoate (CH_3COO^-)

-2 carbonate sulphate sulphite dichromate

- 3 phosphate

+1 ammonium

1+	1-	2-	3-
NH_4^+ ammonium	OH^- hydroxide	CO_3^{2-} carbonate	PO_4^{3-} Phosphate
	ClO_3^- chlorate	SO_4^{2-} sulphate	
	NO_3^- nitrate	SO_3^{2-} sulphite	
	NO_2^- nitrite	$Cr_2O_7^{2-}$ dichromate	
	HCO_3^- hydrogen carbonate	$S_2O_3^{2-}$ thiosulphate	
	HSO_4^- Hydrogen sulphate		
	MnO_4^- Permanganate		
	CH_3COO^- Ethanoate		

- **Being able to write a balanced chemical equation showing state symbols/phase indicators**

$$3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$$

$$HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

- **Converting word equations into chemical equations**

Example : sodium carbonate is reacted with hydrochloric acid to produce sodium chloride, carbon dioxide and water.

$$Na_2CO_3 + 2HCl \longrightarrow 2NaCl + CO_2 + H_2O$$

Example : zinc reacts with hydrochloric acid to produce zinc(II) chloride and hydrogen gas

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

The Mole Concept

- The technique of being able to quantitatively measure the amount of substance present in a chemical system.
- Using the number of moles present to then calculate the mass of substance present, the volume of substance present (gases only) and the number of particles of substance present

$$n = \frac{m}{M} \qquad n = \frac{v}{Vm} \qquad n = \frac{N}{NA}$$

- **Molar mass (M) – the mass in grams of one mole of that substance**
- Molar volume (Vm) – the volume that one mole of any gas will occupy at standard temperature and pressure ($22,4 dm^3.mol^{-1}$)
- Avogadro's constant (N_A) – the number of elementary particles present in one mole of any substance

Concentration

- **Concentration – the amount of solute per unit volume of solution**

$$c = \frac{n}{V} \quad \text{or} \quad c = \frac{m}{MV} \quad \left(n = \frac{m}{M} \text{ is substituted for n in the equation} \right)$$

- **Solute – the substance dissolved that is dissolved in the solvent in the solution**
- **Solvent – the substance in which another substance is dissolved into, forming a solution.**
- **Solution – a homogeneous mixture of solute and solvent**

- Units – concentration is measured in $mol.dm^{-3}$
- Conversion of cm^3 to dm^3 – divide by 1000

Worked example 1

Calculate the concentration of an aqueous solution of sodium chloride if 127g of sodium chloride is dissolved in 375cm^3 of water.

Step 1 : calculate the no. of moles of sodium chloride

$$n = \frac{m}{M}$$

$$= \frac{127}{58{,}5}$$

Mr (NaCl) = 23 + 35.5

= 58.5g.mol-1

n = 2.17 mol of NaCl

Step 2 : convert the volume of solvent into dm^3

$$volume = \frac{375}{1000}$$

= 0.375 dm^3

Step 3 : calculate the concentration of NaCl in solution

$$c = \frac{n}{V}$$

$$= \frac{2{,}17}{0{,}375}$$

c = 5.77mol.dm^{-3}

Worked Example 2

What will be the concentration of gas if 8.75dm^3 of oxygen gas is added to a 500cm^3 container at STP ?

Step 1 : calculate the number of moles of gas

$$n = \frac{v}{Vm}$$

$$= \frac{8,75}{22,4}$$

n = 0.39 mol of O_2

Step 2 : convert the volume of the container into dm^3

$$= \frac{500}{1000}$$

v = 0.5 dm^3

Step 3 : calculate the concentration of O_2 present

$$c = \frac{n}{V}$$

$$= \frac{0,39}{0.5}$$

c = 0.78 mol.dm^{-3}

PRACTICE EXAMPLES

1. What will be the concentration of an aqueous solution of cobalt(III) nitrate if 45,15g of the solute was dissolved in 650 cm^3 of water

2. What mass of copper sulphate must be added to 550 cm^3 of water in order to make a 0,45 $mol.dm^{-3}$ solution of copper sulphate?

Task 1

3. What volume of water (in cm^3) must be added to 35g of ammonium chloride to make a 0.74 $mol.dm^{-3}$ solution of ammonium chloride?

MEMORANDUM

Question 1

1. Calculate moles of $Co(NO_3)_3$

$$n = \frac{m}{M}$$

M = 59 + (14+48) x 3

= 245 g.mol^{-1}

$$= \frac{45,15}{245}$$

$$n = 0,184 mol$$

2. Convert cm^3 to dm^3

$$v = \frac{650}{1000}$$

$$v = 0,65 \text{ dm}^3$$

3. Calculate concentration

$$c = \frac{n}{V}$$

$$= \frac{0,184}{0,65}$$

$$c = 0,28 \text{ mol.dm}^{-3}$$

MEMORANDUM

Question 2

1. Converting volume into dm^3

$$v = \frac{550}{1000}$$

$$= \underline{0{,}55\ dm^3}$$

2. Thus $c = \frac{n}{v}$

$$n = c.V$$

$$= 0{,}45\ x\ 0.55$$

$$\underline{n = 0{,}248\ mol}$$

3. $n = \frac{m}{M}$

$$m = n\ x\ M$$

$$= 0{,}248\ x\ 159{,}5$$

$$\underline{m = 39{,}55g\ of\ CuSO_4}$$

M_{CuSO_4} = 63.5+32+64

= 159,5 $g.mol^{-1}$

PRACTICE EXAMPLES

1. What will be the concentration of an aqueous solution of cobalt(III) nitrate if 45,15g of the solute was dissolved in 650 cm^3 of water

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Task 1

3. What volume of water (in cm^3) must be added to 35g of ammonium chloride to make a 0.74 $mol.dm^{-3}$ solution of ammonium chloride?

Type ONE of the shortened URLs given below into your phone browser.
Answer the question on paper and upload when done.

http://lnnk.in/EHx **https://tinyurl.com/ybndm83d**

MEMORANDUM

Question 3

1. $n = \frac{m}{M}$

$= \frac{35}{53,5}$

$\underline{n = 0,654\ mol}$

2. $c = \frac{n}{V}$

$v = \frac{n}{c}$

$= \frac{0,654}{0.74}$

$\underline{v = 0,884}$ dm^3

3. Thus converting into cm^3

$v = 0,884\ x\ 1000$

$\underline{v = 884\ \text{cm}^3}$

Stoichiometric calculations

Now we are going to consider how we apply the mole concept during chemical reactions. To begin to understand how this now works, we must recall the Law of Conservation of Mass as this is directly applied to these type of calculations

Law of Conservation of Mass : within an isolated chemical system, the total mass within that system remain constant. The law implies that mass cannot be created or destroyed, although it may be rearranged in space and changed into different types of particles; and that for any chemical process in a closed system, the mass of the reactants must equal the mass of the products.

Consider the following balanced chemical equation

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

Refer to the ***mole ratio*** of the equation. What this means is that the mole quantities of the reactants and the products are in proportion.

(ie) **two** moles of H_2 reacts with **one** mole of O_2 to produce **two** moles of H_2O.

Now that we are interpreting the balancing numbers in terms of molar quantities, these numbers now become known as **Stoichiometric Coefficients** , hence we now talk about the **stoichiometric mole ratio** of the equation.

The stoichiometric ratios ensure that the Law of conservation of mass is obeyed at all times

Worked example 1

Calculate the mass of oxygen formed when 29.4g of potassium chlorate decomposes completely to form potassium chloride according to the following balanced equation :

$$2KClO_3\ (s) \longrightarrow 2KCl\ (s) + 3O_2\ (g)$$

Step 1 – calculate the number of moles of substance present from information given in the question.

$n = \frac{m}{M}$

M = 39 + 35,5 + (3 x 16)

= 122,5 g.mol^{-1}

$= \frac{29.4}{122.5}$

n = 0,24 mol

Step 2 : Consider the mole ratio of $KClO_3$ used to O_2 formed

$KClO_3$	:	O_2
2	:	3
0,24	:	n

$n = \frac{0,24}{2}$ x 3

n = 0.36 mol of O_2 formed

Step 3:

$n = \frac{m}{M}$ M = 32 g.mol^{-1}

M

m = n x M_r

= 0,36 x 32

m = 11,52g of O_2 produced

Worked example 2

A 200g sample of calcium carbonate is treated with excess dilute hydrochloric acid. What is the total volume of carbon dioxide gas formed at STP ?

$$CaCO_3\,(s) + 2HCl \longrightarrow CaCl_2\,(aq) + CO_2\,(g) + H_2O\,(l)$$

Step 1 – calculate the number of moles of substance present from information given in the question.

$n = \frac{m}{M}$

Mr = 40 + 12 + (3 x 16)

= 100g.mol-1

$= \frac{200}{100}$

n = 2 mol

Step 2 : Consider the mole ratio of $CaCO_3$ used to produce CO_2

$CaCO_3$	:	CO_2
1	:	1
2	:	n

n = 2 mol of CO_2 formed

Step 3: Calculate the volume of CO_2 present

$n = \frac{v}{Vm}$

v = n. Vm

= 2 x 22,4

V = 44,8 dm^3 of CO_2

Practice Examples

1. Phosphorus burns in oxygen to form diphospho-pentaoxide according to the following equation.

$$4P + 5O_2 \longrightarrow 2P_2O_5$$

If 16,6g of phosphorus reacts, calculate the volume of oxygen needed to react at STP

2. Consider the reaction between sulphur dioxide and oxygen to produce sulphur trioxide

2.1 Write down the balanced chemical equation for the reaction

2.2 If 14g of sulphur trioxide is produced at STP, calculate the volume of sulphur dioxide required in the reaction.

2.3 What mass of oxygen what thus have been used up in the reaction ?

MEMORANDUM
Question 1

$$n = \frac{m}{M}$$

$$= \frac{16,6}{31}$$

$$n = 0,535\ mol$$

Ratio of P to O_2

P : O_2

4 : 5

0.535 : n

$$n = \frac{0,535}{4} \text{ x } 5$$

$$\underline{n = 0,669\ mol\ of\ O_2}$$

Thus : $n = \frac{v}{Vm}$

$$v = n\ x\ Vm$$

$$= 0,669\ x\ 22,4$$

$$\underline{v = 14,98\ dm^3}$$

MEMORANDUM
Question 2

2.1 $2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$

2.2 SO_3 : $n = \frac{m}{M}$

$= \frac{14}{80}$ ← $M(SO_3) = 32+48 = 80 g.mol^{-1}$

$n = 0{,}175\ mol$

Now, ratio of SO_2 to SO_3

SO_2	:	SO_3
2	:	2
n	:	0,175

Thus, n (SO_2) = 0,175 mol

$n = \frac{v}{Vm}$

$v = n\ x\ Vm$

$= 0{,}175\ x\ 22{,}4$

$\underline{v = 3{,}92\ dm^3}$

2.3 Now, ratio of O_2 to SO_3

O_2	:	SO_3
1	:	2
n	:	0.175

Thus n (O_2)= 0,0875 mol

$n = \frac{m}{M}$

$m = n\ x\ M$

$= 0{,}0875\ x\ 32$

$\underline{m = 2{,}8\ g\ of\ O_2}$

Stoichiometric calculations with limiting reagents

- Reactants are often reacted in amounts which do not theoretically correspond to the mole ratio of the chemical reaction.
- Sometimes there is an excess of one reagent present and a limited quantity of the other.
- If this happens , the reaction will stop when the reagent present in limited quantity is used up.
- This reagent is thus known as the **limiting reagent** which ultimately means that the amount of product formed at the end of the reaction is determined by the amount of limiting reagent itself.

Worked example :

Hydrogen sulphide gas is made by reaction 3,52g of iron(II)sulphide with 60cm^3 of dilute hydrochloric acid of concentration 2mol.dm^{-3}. What volume of hydrogen sulphide will be produced at STP ?

$$FeS + 2HCl \longrightarrow H_2S + FeCl_2$$

Step 1 : calculate the number of moles of each reactant

FeS : $n = \frac{m}{M}$

$= \frac{3.52}{88}$

n = 0,04 mol

HCl : $c - \frac{n}{V}$

n = c,V

= 2 x 0,06

n = 0,12 mol

Step 2 : Compare moles according to the mole ratio to determine limiting agent

FeS	:	HCl
1	:	2
0,04	:	0,08

Thus 0,04mol of FeS will react with only 0,08mol of HCl, thus it can be see that HCl is in excess (0,12mol) and that FeS is the limiting agent.

Step 3:

Now use limiting agent to calculate volume of H_2S

FeS	:	H_2S
1	:	1
0,04	:	0,04

Thus there are 0,04mol of H_2S produced

$n = \frac{v}{Vm}$

v = n . V_m

= 0,04 x 22,4

v = 0,896dm^3 of H_2S at STP

PRACTICE EXAMPLES

1. If 5,4g of silver is heated with 1,61g of sulphur until no further reaction occurs, calculate the mass of silver sulphide that is produced .

$$2Ag + S \longrightarrow Ag_2S$$

Task 2

2. 0.49g of magnesium reacts with 50 cm^3 of HCl of concentration 0,04$mol.dm^{-3}$

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

2.1 Which reactant will be in excess and by how much ?

2.2 What volume of hydrogen will be produced at STP

MEMORANDUM

Question 1

$$2Ag + S \longrightarrow Ag_2S$$

Ag : $n = \frac{m}{M}$

$= \frac{5,4}{108}$

$\underline{n = 0,05\ mol}$

S: $n = \frac{m}{M}$

$= \frac{1,61}{32}$

$\underline{n = 0,05\ mol}$

Compare reactants

Ag : S

2 : 1

0.05 : n

Thus n = 0,025 mol of S required

There is 0,05 mol of S in reaction, thus S in excess

<u>Therefore Ag is the limiting reagent</u>

Now Ag : Ag_2S

2 : 1

0.05 : n

Thus n = 0,025 mol of Ag_2S formed

$m = n\ x\ M$

$= 0,025\ x\ 248$

$\underline{m = 6,2\ g\ of\ Ag_2S\ formed}$

M_{Ag_2S} = 108x2 + 32

= 248 $g.mol^{-1}$

PRACTICE EXAMPLES

Task 2

2. 0.49g of magnesium reacts with 50 cm^3 of HCl of concentration 0,04mol.dm^{-3}

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

2.1 Which reactant will be in excess and by how much ?

2.2 What volume of hydrogen will be produced at STP

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Answer the question on paper and upload when done.

http://lnnk.in/ENx **https://tinyurl.com/y7aglozt**

MEMORANDUM
Question 2

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

Mg : $n = \frac{m}{M}$

$= \frac{0,49}{24,3}$

$n = 0,02\ mol$

HCl : $c = \frac{n}{V}$

$n = c\ x\ V$

$= 0,04\ x\ 0,05$

$n = 0,002\ mol$

Compare reactants

Mg	:	HCl
1	:	2
0,02	:	n

This n = 0,01 of HCl required
There is only 0,002 mol of HCl present
Thus, HCl is the limiting reagent

2.1 Hence Mg in excess by (0,02 – 0,002)
= 0,018 mol

2.2 Now HCl : H_2

2	:	1
0.002	:	n

This n = 0,001 mol of H_2 produced

$n = \frac{v}{Vm}$

$v = n\ x\ Vm$

$= 0,001\ x\ 22,4$

$v = 0.224\ dm^3$

Using stoichiometric calculations to determine percentage yield

Theoretical yield - the maximum amount of product which can be made according to the amount of reagent used based on the theoretical chemical equation.

Actual yield - The amount of products actually obtained when that reaction is performed under laboratory conditions.

Hence we talk about the actual yield from a reaction. This actual yield can be somewhat less than the theoretical yield.

We can represent this actual yield as a percentage compared to the theoretical yield.

$$\%\ yield = \frac{actual\ yield}{theoretical\ yield}\ x\ 100$$

Worked Example

Zinc is a more reactive metal than copper and can displace copper from a copper sulphate solution according to the following equation :

$$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$$

If 21,3g of copper is displaced from a 150cm^3 solution of copper sulphate solution of concentration 3mol.dm^{-3}, calculate the percentage yield of copper obtained.

Step 1 : Determine the number of moles of copper sulphate reacted

$$c = \frac{n}{V}$$

Thus n = c . V

= 3 x 0,150

n = 0,45mol of $CuSO_4$

Step 2 : Use this to calculate the theoretical mass of Cu

Mole ratio $CuSO_4$: Cu

1 : 1

Thus 0,45mol of $CuSO_4$ will produce 0,45 mol of Cu

$$n = \frac{m}{M}$$

m = n . M

= 0,45 x 63,5

m = 28,58g of Cu

Step 3: Calculate the percentage yield

$$\%yield = \frac{actual\ yield}{theoretical\ yield}\ x\ 100$$

$$= \frac{21,3}{28,58}\ x\ 100$$

% yield = 74,54 %

Practice Examples

1. In industry, the electrolysis of sodium chloride is used to make sodium hydroxide, chlorine and hydrogen gas according to the following equation :

$$2NaCl + 2H_2O \longrightarrow 2NaOH + Cl_2 + H_2$$

In one of the processes, 3507g of NaCl was electrolysed and 1344g of NaOH was produced. Calculate the percentage yield of NaOH produced.

2. Ammonium nitrate is made from ammonia gas and nitric acid according to the following reaction :

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

If 1161g of ammonium nitrate was obtained when 340,6g of ammonia was reacted, calculate the percentage yield of ammonium nitrate obtained.

MEMORANDUM

Question 1

$$2NaCl + 2H_2O \longrightarrow 2NaOH + Cl_2 + H_2$$

Actual amount of NaOH present = 1344g

Need to now calculate the theoretical amount of NaOH that would be produced if 3507g of NaCl is used

1. Convert NaCl into moles

$n = \frac{m}{M}$

$= \frac{3507}{58,5}$

$n = 59,95mol$

2. Calculate moles of NaOH

NaCl : NaOH

2 : 2

59,95 : n

n(NaOH) = 59,95mol

$m = n\ x\ M$

$= 59,95\ x\ 40$

$m = 2398g$ of NaOH

3. Calculate % yield

$\%yield = \frac{actual\ yield}{theoretical\ yield}$ x 100

$= \frac{1344}{2398}$ x 100

$\%\ yield = 56,05\%$

MEMORANDUM

Question 2

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

Actual amount of NH_4NO_3 present = 1161g

Need to now calculate the theoretical amount of NH_4NO_3 that would be produced if 340,6g of NH_3 is used

1. Convert NH_3 into moles

$$n = \frac{m}{M}$$

$$= \frac{340,6}{17}$$

$$n = 20,03mol$$

2. Calculate moles of NH_4NO_3

$NH_3 : NH_4NO_3$

1 : 1

20.03 : n

$\underline{n(NH_4NO_3) = 20,03mol}$

Thus $m = n\ x\ M$

$= 20,03\ x\ 80$

$m = 1602,4g$ of NH_4NO_3

3. Calculate % yield

$$\%yield = \frac{actual\ yield}{theoretical\ yield} \text{ x } 100$$

$$= \frac{1161}{1602,4} \text{ x } 100$$

$$\%yield = 72,45\%$$

Additional example

Task 3

Ammonia is made by the direct combination of nitrogen and hydrogen gas in the Haber process according to the following equation :

$$3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$$

If the yield of ammonia was 65% which represented 22,14g of ammonia, what mass of nitrogen was initially reacted (in grams) ?

Type ONE of the shortened URLs given below into your phone browser.
Answer the question on paper and upload when done.

http://lnnk.in/EXw

https://tinyurl.com/ybuappxo

MEMORANDUM

Additional question

$$3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$$

1. Calculate theoretical mass of NH_3

$$\%yield = \frac{actual\ yield}{theoritical\ yield} \times 100$$

$$\frac{65}{100} = \frac{28,14}{theoretical}$$

$$theoretical = \frac{28,14}{0,65}$$

$$\underline{theoretical\ \ mass = 43,29g}$$

2. Convert to moles of NH_3

$$n = \frac{m}{M}$$

$$= \frac{43,29}{17}$$

$$\underline{n = 3,09mol}$$

3. Calculate mass of N_2

N_2 : NH_3

1 : 2

n : 3,09

n(**N_2**) = 1,54mol

$$m = n\ x\ M$$

$$= 1,54\ x\ 28$$

$$\underline{m = 43,12g}$$

theoretical mass of N_2 = 43,12g