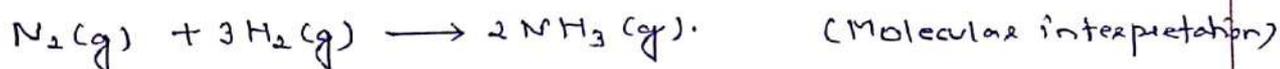


## Stoichiometry

Stoichiometry is the calculation of quantities of reactant and products involved in a chemical reaction. It is based on chemical equation & on the relationship between mass & moles.

A chemical equation can be interpreted as follows :



1 molecule of  $\text{N}_2$  + 3 molecule of  $\text{H}_2$   $\longrightarrow$  2 molecule of  $\text{NH}_3$

1 mole of  $\text{N}_2$  + 3 mole of  $\text{H}_2$   $\longrightarrow$  2 mole of  $\text{NH}_3$  (Mole interpretation).

28g of  $\text{N}_2(\text{g})$  + 6g of  $\text{H}_2$   $\longrightarrow$  34g of  $\text{NH}_3$  (Mass interpretation)

1 vol. of  $\text{N}_2(\text{g})$  + 3 vol. of  $\text{H}_2$   $\longrightarrow$  2 vol. of  $\text{NH}_3$  (Volume interpretation).

Calculation based on chemical equation can be divided as:

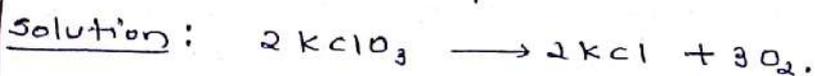
- (1) Calculation based on mole-mole relationship.
- (2) Calculation based on mass-mass relationship.
- (3) Calculation based on mass-volume relationship.
- (4) Calculation based on volume-volume relationship.

1) Calculation based on mole-mole relationship.

In such calculation, number of moles of reactants are given & those of products are required. Conversely, if number of moles of products are given, then number of moles of reactant are required.

Example.1: Oxygen is prepared by catalytic decomposition of Potassium chlorate ( $\text{KClO}_3$ ). Decomposition of potassium chlorate gives potassium chloride ( $\text{KCl}$ ) & oxygen ( $\text{O}_2$ ). How

many moles & how many gram of  $KClO_3$  are required to produce 2.4 mole  $O_2$ ?



2 moles of  $KClO_3 = 3$  mole of  $O_2$ .

3 moles of  $O_2$  formed by 2 moles of  $KClO_3$ .

$\therefore$  2.4 mole of  $O_2$  formed by  $\left(\frac{2}{3} \times 2.4\right)$  moles of  $KClO_3$ .  
 $= 1.6$  moles of  $KClO_3$ .

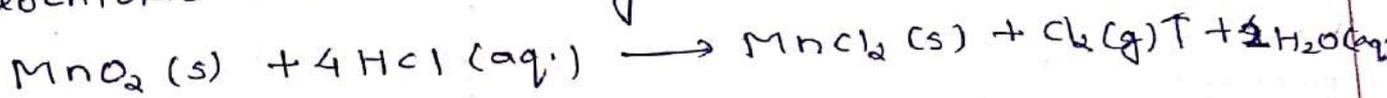
$\therefore$  Mass of  $KClO_3 =$  number of moles  $\times$  molar mass  
 $= 1.6 \times 122.5$   
 $= 196g$ .

2) Calculation based on mass-mass relationship.

In making necessary calculations, following steps are followed:

- write down balanced chemical equation.
- write down theoretical amount of reactants & products involved in the reaction.
- calculate the unknown amount of substance using unitary method.

Example: 2: Chlorine is prepared in the laboratory by treating manganese dioxide ( $MnO_2$ ) with aqueous hydrochloric acid according to the reaction:



How many gram of  $HCl$  will react with 5g of  $MnO_2$ ?

Solution: 1 mole of  $MnO_2$  react with 4 mole of  $HCl$

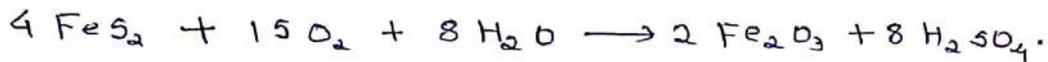
87g of  $MnO_2$  react with 146g of  $HCl$ .

5g of  $MnO_2$  react with  $= \frac{146g}{87g} \times 5 = 8.39g$  of  $HCl$ .

Example: 3: How many Killogram of pure  $H_2SO_4$  could be obtained from 1kg of pyrites ( $FeS_2$ ) according to the following reaction:



Soln: Final balanced chemical Equation:



4 mole of  $FeS_2$  yield 8 mole of  $H_2SO_4$ .

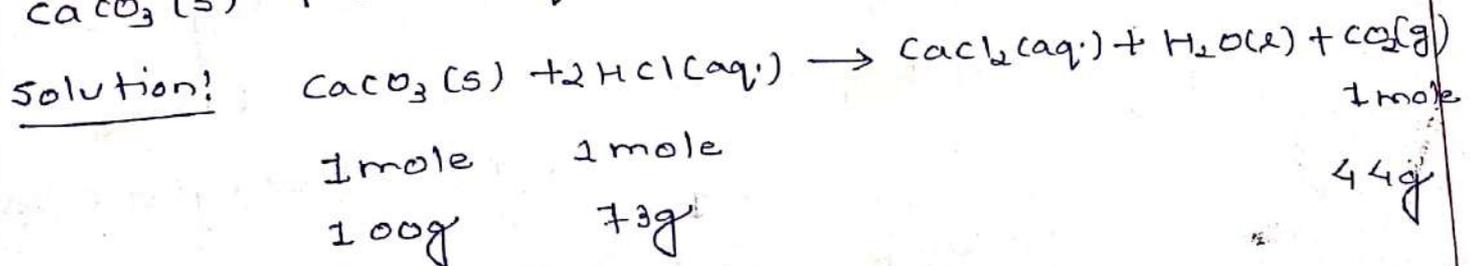
$$4 \times 120g \text{ of } FeS_2 = 8 \times 98g \text{ of } H_2SO_4$$

$$1000g \text{ of } FeS_2 \text{ will yield } H_2SO_4 = \left( \frac{8 \times 98}{4 \times 120} \times 1000g \right) = 1.63 \text{ Kg.}$$

Limiting Reagent:

Limiting Reagent or reactant is the reactant that is entirely consumed when a reaction goes to completion. The reactants which are not completely consumed in the reaction are called excess reagent.

Example: 4. If 10g of  $CaCO_3$  is treated with 10g of  $HCl$ , how many grams of  $CO_2$  can be generated according to the following reaction:



100g of  $CaCO_3$  gives 44g of  $CO_2$

20g of  $\text{CaCO}_3$  will give  $\frac{44}{100} \times 20\text{g} = 8.8\text{g}$  of  $\text{CO}_2$ .

Let HCl be completely consumed,

73g of HCl gives 44g of  $\text{CO}_2$ .

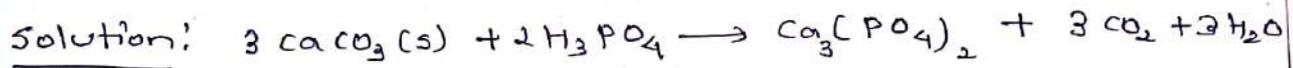
20g HCl will give  $\frac{44\text{g}}{73} \times 20\text{g} = 12.054\text{g}$  of  $\text{CO}_2$ .

Since  $\text{CaCO}_3$  give least amount of product  $\text{CO}_2$ . Hence  $\text{CaCO}_3$  is limiting reagent. Amount of  $\text{CO}_2$  formed will be 8.8g.

Example 5: 100g sample of calcium carbonate is reacted with 70g of orthophosphoric acid. calculate-

(a) The number of gram of calcium phosphate that could be produced.

(b) The number of gram of excess reagent that will remain unreacted.



Mole: 3 mole 2 mole 1 mole

Mass: 300g 196g 310g

300g of  $\text{CaCO}_3$  produce  $\text{Ca}_3(\text{PO}_4)_2 = 310\text{g}$

100g of  $\text{CaCO}_3$  would produce,

$$\text{Ca}_3(\text{PO}_4)_2 = \frac{310}{300} \times 100 = 103\text{g} = 0.33\text{mole}$$

196g of  $\text{H}_3\text{PO}_4$  produce  $\text{Ca}_3(\text{PO}_4)_2 = 310\text{g}$  or 1mole

70g of  $\text{H}_3\text{PO}_4$  would produce  $\text{Ca}_3(\text{PO}_4)_2$ .

$$= \frac{310}{196} \times 70 = 110.7\text{g} \text{ or } 0.356\text{mole}$$

The above value suggest that  $\text{CaCO}_3$  is the limiting agent. Hence calcium phosphate formed is 103g or 0.33 mole.

b) For producing 103g of  $\text{Ca}_3(\text{PO}_4)_2$ ,  $\text{H}_3\text{PO}_4$  required will be,

$$= \frac{196}{310} \times 103 = 65.12 \text{ g.}$$

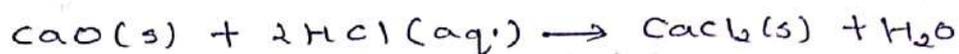
Mass of remaining  $\text{H}_3\text{PO}_4 = (70 - 65.12) = 4.88 \text{ g.}$

Calculation involving Percent yield

$$\text{Percent yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100.$$

The amount of product that is actually obtained is known as actual yield.

Example 6: For the reaction:



1.23g of CaO is reacted with excess of hydrochloric acid & 1.85g of  $\text{CaCl}_2$  is formed. What is the percent yield?

Solution: The balanced equation is:



56g of CaO produce  $\text{CaCl}_2 = 111\text{g}$

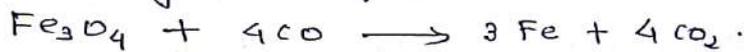
1.23g of CaO produce  $\text{CaCl}_2 = \frac{111\text{g}}{56\text{g}} \times 1.23\text{g}.$   
 $= 2.43\text{g}$  of  $\text{CaCl}_2$ .

Thus theoretical yield = 2.43g.

Actual yield = 1.85g.

Percent yield =  $\frac{1.85}{2.43} \times 100 = 76.1\%$

Example: 8. Magnetite  $\text{Fe}_3\text{O}_4$ , can be converted into metallic iron by heating with carbon monoxide can be represented by this equation:



How many kilogram of  $\text{Fe}_3\text{O}_4$  must be processed in this way to obtain 5 kg of iron, if the process is 85% efficient?

Solution: 1 mole of  $\text{Fe}_3\text{O}_4$  (232 g) = 3 mole Fe (168 g)

$$\begin{aligned} \text{Amount of } \text{Fe}_3\text{O}_4 \text{ required for 5 kg iron} &= \frac{232}{168} \times 5 \text{ kg} \\ &= 6.904 \text{ kg} \end{aligned}$$

Since, the efficiency of the reaction is 85%, hence the actual required amount of  $\text{Fe}_3\text{O}_4$  will be,

$$= \frac{100 \times 6.904}{85} \text{ kg} = 8.12 \text{ kg}$$

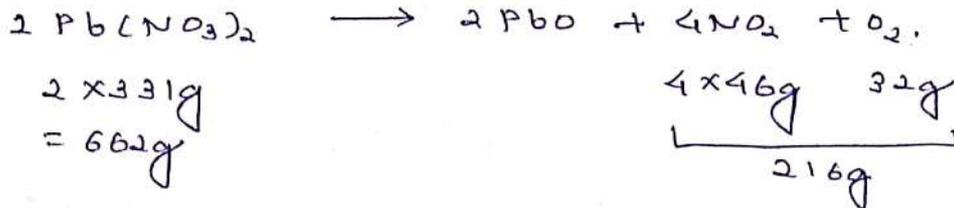
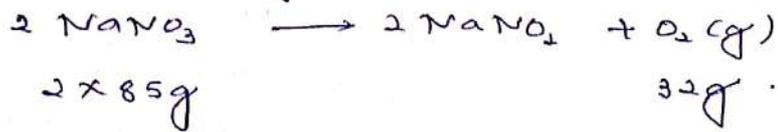
Analysis of the mixture:

In such problem, one of the component is supposed to be xg & the other will be the difference from total. Balanced chemical reaction for the reaction of both component are now written & the total amount of the common product produced by the component of the mixture is calculated. It is equated with the data given & the unknown factor are, thus worked out.

Example: 9. A solid mixture (5g) containing of lead nitrate & sodium nitrate was below  $600^\circ\text{C}$ , until the mass of the residue was constant. If the loss in mass is 28%. Find the amount of lead nitrate & sodium nitrate

(8)

Solution: Let the amount of  $\text{NaNO}_3$  in the mixture be  $x$ g. The amount of  $\text{Pb}(\text{NO}_3)_2$  in the mixture =  $(5-x)$ g.



170g of  $\text{NaNO}_3$  evolve oxygen = 32g.

$x$ g of  $\text{NaNO}_3$  evolve =  $\frac{32}{170} \times x$ g

662g of  $\text{Pb}(\text{NO}_3)_2$  evolve gases = 216g.

$(50-x)$ g of  $\text{Pb}(\text{NO}_3)_2$  evolve gases =  $\frac{216}{662} \times (50-x)$ g

$$\text{Total loss} = \left( \frac{32}{170} \times x \text{g} + \frac{216}{662} \times (5-x) \right)$$

loss give =  $\frac{28}{100} \times 5 \text{g} = 1.4 \text{g}$ .

in the problem

$$\frac{32x}{170} + \frac{216}{662} (5-x) = 1.4$$

On solving,  $x = 1.676 \text{g}$ .

Mass of  $\text{NaNO}_3 = 1.676 \text{g}$ .

Mass of  $\text{Pb}(\text{NO}_3)_2 = (5 - 1.676) \text{g} = 3.324 \text{g}$ .



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# Assignment

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- Q.1 1 gm sample of  $\text{KClO}_3$  was heated under such conditions that a part of it decomposed according to the equation (1)  $2\text{KClO}_3 \longrightarrow 2\text{KCl} + 3\text{O}_2$  and remaining underwent change according to the equation.
- $$(2) \quad 4\text{KClO}_3 \longrightarrow 3\text{KClO}_4 + \text{KCl}$$
- If the amount of  $\text{O}_2$  evolved was 146.8 ml at S.T.P., calculate the % by weight of  $\text{KClO}_4$  in the residue.
- Q.2 A sample of calcium carbonate contains impurities which do not react with a mineral acid. When 2 grams of the sample were reacted with the mineral acid, 375 ml of carbon dioxide were obtained at  $27^\circ\text{C}$  and 760 mm pressure. Calculate the % purity of the sample of  $\text{CaCO}_3$ ?
- Q.3 One gram of an alloy of aluminium and magnesium when heated with excess of dil. HCl forms magnesium chloride, aluminium chloride and hydrogen. The evolved hydrogen collected over mercury at  $0^\circ\text{C}$  has a volume of 1.2 litres at 0.92 atm pressure. Calculate the composition of the alloy.
- Q.4 A sample containing only  $\text{CaCO}_3$  and  $\text{MgCO}_3$  is ignited to CaO and MgO. The mixture of oxides produced weight exactly half as much as the original sample. Calculate the percentages of  $\text{CaCO}_3$  and  $\text{MgCO}_3$  in the sample.
- Q.5 Determine the percentage composition of a mixture of anhydrous sodium carbonate and sodium bicarbonate from the following data:  
wt. of the mixture taken = 2g  
Loss in weight on heating = 0.124 g.
- Q.6 A 10 g sample of a mixture of calcium chloride and sodium chloride is treated with  $\text{Na}_2\text{CO}_3$  to precipitate calcium as calcium carbonate. This  $\text{CaCO}_3$  is heated to convert all the calcium to CaO and the final mass of CaO is 1.62g. Calculate % by mass of NaCl in the original mixture.
- Q.7 In a gravimetric determination of P an aqueous solution of  $\text{NaH}_2\text{PO}_4$  is treated with a mixture of ammonium and magnesium ions to precipitate magnesium ammonium phosphate  $\text{Mg}(\text{NH}_4)\text{PO}_4 \cdot 6\text{H}_2\text{O}$ . This is heated and decomposed to magnesium pyrophosphate,  $\text{Mg}_2\text{P}_2\text{O}_7$  which is weighed. A solution of  $\text{NaH}_2\text{PO}_4$  yielded 1.054 g of  $\text{Mg}_2\text{P}_2\text{O}_7$ . What weight of  $\text{NaH}_2\text{PO}_4$  was present originally ?
- Q.8 By the reaction of carbon and oxygen, a mixture of CO and  $\text{CO}_2$  is obtained. What is the composition of the mixture obtained when 20 grams of  $\text{O}_2$  reacts with 12 grams of carbon ?
- Q.9 A mixture of nitrogen and hydrogen. In the ratio of one mole of nitrogen to three moles of hydrogen, was partially converted into  $\text{NH}_3$  so that the final product was a mixture of all these three gases. The mixture was to have a density of 0.497 g per litre at  $25^\circ\text{C}$  and 1.00 atm. What would be the mass of gas in 22.4 litres at S.T.P? Calculate the % composition of this gaseous mixture by volume.
- Q.10 Direct reaction of iodine ( $\text{I}_2$ ) and chlorine ( $\text{Cl}_2$ ) produces an iodine chloride,  $\text{I}_x\text{Cl}_y$ , a bright yellow solid. If you completely used up 0.508 g of iodine and produced 0.934 g of  $\text{I}_x\text{Cl}_y$ , what is the empirical formula of the compound? Later experiment showed the molar mass, of  $\text{I}_x\text{Cl}_y$  was 467 g/mol. What is the molecular formula of the compound ? (I = 127)
- Q.11 Equal weights of mercury and  $\text{I}_2$  are allowed to react completely to form a mixture of mercurous and mercuric iodide leaving none of the reactants. Calculate the ratio of the wts of  $\text{Hg}_2\text{I}_2$  and  $\text{HgI}_2$  formed.

- Q.12 Titanium, which is used to make air plane engines and frames, can be obtained from titanium tetrachloride, which in turn is obtained from titanium oxide by the following process :
- $$3 \text{TiO}_2(\text{s}) + 4\text{C}(\text{s}) + 6\text{Cl}_2(\text{g}) \longrightarrow 3\text{TiCl}_4(\text{g}) + 2\text{CO}_2(\text{g}) + 2\text{CO}(\text{g})$$
- A vessel contains 4.15 g  $\text{TiO}_2$ , 5.67 g C and; 6.78 g  $\text{Cl}_2$ , suppose the reaction goes to completion as written, how many gram of  $\text{TiCl}_4$  can be produced ? (Ti = 48)
- Q.13 A chemist wants to prepare diborane by the reaction
- $$6 \text{LiH} + 8\text{BF}_3 \longrightarrow 6\text{LiBF}_4 + \text{B}_2\text{H}_6$$
- If he starts with 2.0 moles each of  $\text{LiH}$  &  $\text{BF}_3$ . How many moles of  $\text{B}_2\text{H}_6$  can be prepared.
- Q.14 When you see the tip of a match fire, the chemical reaction is likely to be
- $$\text{P}_4\text{S}_3 + 8\text{O}_2 \longrightarrow \text{P}_4\text{O}_{10} + 3\text{SO}_2$$
- What is the minimum amount of  $\text{P}_4\text{S}_3$  that would have to be burned to produce at least 1.0 g of  $\text{P}_4\text{O}_{10}$  and at least 1.0 g of  $\text{SO}_2$
- 

## Answer Key

- Q.1 49.9%
- Q.2 76.15%                      Q.3 Al = 0.546 g; Mg = 0.454 g                      Q.4 28.4%, 71.6%
- Q.5 % $\text{NaHCO}_3$  = 16.8, %  $\text{Na}_2\text{CO}_3$  = 83.2                      Q.6 67.9%                      Q.7 1.14 gm
- Q.8 CO :  $\text{CO}_2$  = 21 : 11                      Q.9 12.15 gm; 14.28%,  $\text{H}_2$  42.86%,  $\text{NH}_3$  42.86%
- Q.10  $\text{ICl}_3$ ,  $\text{I}_2\text{Cl}_6$                       Q.11 0.532 : 1                      Q.12 9.063 gm                      Q.13 0.250
- Q.14 1.14 g