Advanced Higher Chemistry

Unit 2 - Chemical Reactions

STOICHIOMETRY

Learning Outcomes
Questions
&
Answers

Previous Knowledge

The ***amount*** of a substance is denoted by the symbol ***'n'*** and it has the units ***'mols'***.

One mole is defined as that amount of substance which contains as many elementary entities as there are atoms in exactly 12g of carbon-12 (^{12}C).

> *'elementary entities' can be atoms, molecules or formula units (in the case of ionic compounds).*

This number of entities is also known as ***'Avogadro's constant'*** and is denoted by the symbol ***'L'*** and it has the units ***'mol^{-1}'***.

> $L = 6.02 \times 10^{23}\ mol^{-1}$

The ***Gram Formula Mass*** can be used to calculate the *number of moles* present in a particular ***mass*** of a substance.

Avogadro's constant can be used to calculate the *number of moles* present in a particular ***number*** of entities present in a substance.

The ***Molar Volume*** can be used to calculate the *number of moles* present in a particular ***volume*** of a gas.

> *The actual volume varies according to temperature and pressure.*
>
> *At the* ***same*** *temperature and pressure, one mole of any gas occupies the same volume as one mole of any other gas.*

The ***Concentration*** *(mol l^{-1})* and ***Volume*** *(in litres)* can be used to calculate the *number of moles* of solute present in a ***solution***.

> $C = n / V$

The ***Quantity of electricity*** *(Q, in colulombs)* and the appropriate ***ion-electron equation*** can be used to calculate the *number of moles* of a substance that would be deposited at an electrode during ***electrolysis***.

> *Q = Current (in Amps) x time (in seconds)* $\qquad$ $Q = I \times t$

Warming up Exercise 1 - Avogadro's Constant

1. Calculate the number of
- ***a)*** molecules in 3 mol of propane
- ***b)*** atoms in 0.25 mol of ethyl methanoate
- ***c)*** ammonium ions in 100 mol of ammonium phosphate

2. Calculate the amount (number of moles) of aluminium oxide that will contain 2.63 x 10^{28} oxide ions.

3. A mixture of tetrachlomethane (CCl_4) and trichloromethane (CCl_3) contains 0.1 mol of hydrogen atoms and 0.5 mol of carbon atoms. calculate the number of moles of chlorine atoms in the mixture.

Warming up Exercise 2 - Molar Quantities

1. Calculate the amount of substances (number of moles) present in each of the following:
- ***a)*** 10.6g of magnesium hydroxide
- ***b)*** 9.5 *l* of propane at 273K and 1 atmosphere of pressure (assume that the molar volume of a gas under such temperature and pressure conditions is 24.2 *l* mol^{-1}).
- ***c)*** 1.65 x 10^{28} molecules of benzene.

2. Calculate the number of moles of solute required to prepare $250cm^3$ of a 0.100 mol l^{-1} solution of oxalic acid.

3. 0.0263 mol of nickel was deposited at the negative electrode when a current of 1.5A was passed through a solution of nickel(II) sulphate. Calculate, to the nearest minute, the time taken to deposit this amount of nickel.

4. Calculate the mass of a sulphur dioxide molecule.

5. What mass of copper(II) sulphate crystals ($CuSO_4.5H_2O$) would be contained in $100cm^3$ of a 2.50 mol l^{-1} solution ?

6. How many ions contained in 10.0g of ammonium phosphate ?

7. $200cm^3$ of nitrogen at a certain temperature and pressure has a mass of 0.206g. Use this information to calculate the volume occupied by the same mass of ethane at the same temperature and pressure.

8. $100cm^3$ of a solution of potassium sulphate contains 4.02 x 10^{22} potassium ions. Calculate the concentration of this potassium sulphate solution.

Ex1 ***1.a)*** *1.8069 x 10^{24} molecules* ***b)*** *1.65632 x 10^{24} atoms* ***c)*** *1.8069 x 10^{26} ions* ***2.*** *14562.569 mol*
3. *1.9 mol*

Ex2 ***1.a)*** *0.183 mol* ***b)*** *0.392 mol* ***c)*** *27395 mol* ***2.*** *0.025 mol* ***3.*** *56 minutes* ***4.*** *1.063 x 10^{-22} g*
5. *62.375 g* ***6.*** *1.62 x 10^{23}* ***7.*** *187 cm^3* ***8.*** *0.333 mol l^{-1}*

Warming up Exercise 3 - Equations

1. Ammonia reduces copper(II) oxide to copper. The other products of the reaction are water and nitrogen.

Calculate the mass of copper produced and the volume of ammonia consumed when 56.4g of copper(II) oxide are reduced in this way. (Assume the molar volume is 25.6 l mol^{-1})

2. Oxygen can be converted into ozone (O_3) by passing an elecrical discharge through it.

Calculate the number of ozone molecules that would be formed if 16g of oxygen were completely converted into ozone.

3. Calculate the volume of oxygen that would be required to react completely with 5.0 l of ethane.

4. 8.8g of iron were heated with 5.0 l of chlorine.

Calculate the mass of iron(III) chloride that would be formed.
(Assume molar volume = 24 l mol^{-1}).

5. Ammonia burns in an atmosphere of oxygen to produce nitrogen and water.

Calculate the volume composition of the gas mixture which will result on burning 60 cm^3 of ammonia in 40 cm^3 of oxygen. (Assume all volume measurements were made at 25°C and at a constant pressure).

6. In an experiment, 60g of ethanol were oxidised and produced 0.85 mol of ethanoic acid. The latter was then converted into an ester, methyl ethanoate, on reaction with excess methanol. The percentage yield of ester in the esterification process was 65%.

Calculate

a) the percentage yield of ethanoic acid in the oxidation process

b) the mass of ester finally obtained

c) the overall percentage yield of ester based on the original quantity of ethanol.

Answers

Ex3. 1. 45.05g of Cu, 12.11 l of NH_3 ***2.*** 2.005 x 10^{23} O_3 molecules ***3.*** 17.5 l of O_2 ***4.*** Fe in excess, Cl_2 is limiting factor, 22.6g of $FeCl_3$ produced. ***5.*** NH_3 in excess by 6.66 cm^3, 26.67 cm^3 of N_2 produced. ***6. a)*** % yield of ethanoic acid = 65.17% ***b)*** 40.89g of ester **c)** overall yield =42.36%

Chemical Analysis

Any 'new knowledge' needed for Advanced Higher is likely to be picked up during the practical work and write-ups done for the Prescribed Practicals. Mole questions in Advanced Higher are likely, therefore, to be placed in the context of a Chemical Analysis.

The following is simply a list of the Learning Outcomes for this section.

2.1 *A **quantitative** reaction is one in which the substances react completely according to the mole ratios given by the balanced (**stoichiometric**) equation.*

2.2 ***Volumetric analysis** involves using a solution of accurately known concentration in a quantitative reaction to determine the concentration of another substance.*

2.3 *A solution of accurately known concentration is known as a **standard solution**.*

2.4 *A standard solution can be prepared directly from a **primary standard**.*

2.5 *A primary standard must have, at least, the following characteristics:*

high state of purity (analar reagent)
stability
solubility
reasonably high formula mass

2.6 *The volume of reactant solution required to **just** complete the reaction is determined by **titration***

2.7 *The **equivalence point** is the point at which the reaction is **just** complete.*

*The '**end-point**' is the point at which a change is **observed** and is associated with the equivalence point.*

*An **indicator** is a substance which changes colour at the end-point.*

2.8 ***Acid/base titrations** are based on neutralisation reactions*

2.9 ***Complexometric titrations** are based on complex forming reactions.*

***EDTA** is an important complexometric reagent.*

2.10 ***Redox titrations** are based on redox reactions. Substances such as potassium permanganate(VII), which can act as their own indicators, are very useful reacants in redox titrations*

2.11 *In **Gravimetric analysis** the mass of an element or compound present in a substance is determined by chemically changing that substance into some other substance of known chemical composition, which can be readily isolated, purified and weighed.*

Exercise 4 - Volumetric Analysis

1. A standard solution of sodium carbonate was prepared by dissolving 5.06g of the anhydrous solute in water and making it up to 500 cm^3. 25.0 cm^3 portions of this solution were titrated against hydrochloric acid giving an average titre volume of 19.2 cm^3.

Calculate the concentration of the acid.

2. 1.8g of iron(II) ammonium sulphate, $Fe(NH_4)_2(SO_4)_2.6H_2O$, was dissolved in 35 cm^3 of distilled water. The solution was then diluted to 50 cm^3 using dilute sulphuric acid. The final solution was titrated against potassium permanganate solution and 40 cm^3 of the permanganate solution were required to reach the end-point at which all the iron(II) ions had been converted to iron(III) ions.

Calculate the concentration of the potassium permanganate solution.

3. Hardness in water is caused by the presence of calcium and magnesium ions. It can be expressed quantitatively in ***ppm*** (parts per million) of calcium carbonate. e.g a water sample with a hardness of 50 ppm would contain the equivalent of 50g of calcium carbonate per million grams of water.

In an experiment to determine the hardness of some tap water, a 50.0 cm^3 sample was pipetted into a conical flask along with 10 cm^3 of a buffer solution and a few drops of Eriochrome Black T indicator. On titration, 9.8 cm^3 of 0.0100 mol l^{-1} EDTA solution were required to reach the end-point.

Calculate the hardness of the tap water in ppm of calcium carbonate assuming that the density of water is 1.00 g cm^{-3}.

4. The percentage of calcium carbonate in a sample of limestone can be determined by ***back titration*** as follows:

2.0g of limestone were dissolved in 60.0 cm^3 of 0.50 mol l^{-1} hydrochloric acid. After the reaction was completed, insoluble impurities were removed by filtration and the amount of unreacted acid was determined by titration with 0.10 mol l^{-1} sodium hydroxide solution. On first adding the alakali a white precipitate formed which immediately dissolved in the unreacted acid.

60.0 cm^3 of the 0.10 mol l^{-1} sodium hydroxide were required to neutralise the unreacted acid.

a) Calculate the number of moles of hydrochloric acid that had reacted with the limestone.

b) Calculate the percentage (by mass) of calcium carbonate in the sample of limestone.

c) What is the white precipitate ?

5. Compound fertilisers are mixtures of chemicals which provide elements essential for plant growth. A certain fertiliser contains ammonium phosphate as the only source of nitrogen and phosphorus. In an experiment to estimate the percentage nitrogen present in a sample of fertiliser, the following estimation was carried out:

1.40g of the fertiliser was weighed and then heated with 25 cm^3 of 2.0 mol l^{-1} sodium hydroxide solution. The gas given off was absorbed in 50 cm^3 of 0.50 mol l^{-1} hydrochloric acid solution. When the reaction was finished, unreacted hydrochloric acid was titrated with 0.10 mol l^{-1} sodium hydroxide solution. 50 cm^3 of the alkali were needed for neutralisation.

a) Name the gas given off when the fertiliser is heated with sodium hydroxide.

Q5 contd

b) State whether high accuracy is required in measuring the volume of

i) the 2.0 mol l^{-1} sodium hydroxide solution

ii) the 0.50 mol l^{-1} hydrochloric acid solution

iii) the 0.50 mol l^{-1} sodium hydroxide solution

c) Write the equation for the reaction of the gas referred to in ***a)*** with hydrochloric acid.

d) Calculate the number of moles of hydrochloric acid which reacted with the gas.

e) Calculate the percentage (by mass) of nitrogen in the fertiliser.

6. A metal chloride (6.05g) was dissolved in water and the solution made up to a final volume of 100cm^3. A solution of silver(I) nitrate containing 34.0 g l^{-1} was titrated against 20.0 cm^3 of the metal chloride solution. The end-point was detected when 50.0 cm^3 of the silver(I) nitrate solution had been added.

a) Calculate the concentration (in mol l^{-1}) of the silver(I) nitrate solution.

b) What mass of metal is present in the metal chloride sample ?

c) Use the experimental results to establish that the metal chloride is rubidium chloride. (The relative atomic mass of rubidium is 85.4)

Answers

Ex 4. ***1.*** 0.25 mol l^{-1} ***2.*** 0.023 mol l^{-1} ***3.*** 1960 ppm ***4. a)*** 0.024 mol HCl reacted ***b)*** 60% ***c)*** calcium hydroxide ***5. a)*** ammonia, NH_3 ***b) i)*** low accuracy (measuring cylinder) ***ii)*** high accuracy (pipette) ***iii)*** high accuracy (burette) ***c)*** $NH_3 + HCl \rightarrow NH_4Cl$ ***d)*** 0.020 moles HCl ***e)*** 20% N by mass ***6. a)*** 0.2 mol l^{-1} ***b)*** 4.275g ***c)*** 0.05 mol of metal = 4.275g so 1mol = 85.5g so metal = rubidium

Exercise 5 - Gravimetric Analysis

1. When nickel(II) ions in solution are reacted with dimethylglyoxime ($C_4H_8N_2O_2$) in ethanol, a red complex of nickel(II) ions and dimethylglyoxime is precipitated. The stoichiometric equation for the reaction is:

$$Ni^{2+}_{(aq)} \quad + \quad 2\,C_4H_8N_2O_2 \quad \rightarrow \quad Ni(C_4H_8N_2O_2)_{2\,(s)} \quad + \quad 2\,H^+_{(aq)}$$

0.2811g of a nickel(II) salt were dissolved in water and completely reacted with dimethylglyoxime.
The red precipitate weighed 0.2890g.

a) What is the name given to this type of chemical analysis

b) Calculate the ***i)*** mass of nickel(II) ions in the complex

ii) percentage of nickel in the original salt

c) Nickel(II) ions can also be determined by a complexometric titration method.

i) Name a suitable reagent for this method.

ii) Give one advantage and one disadvantage of this method compared with the precipitation method given below.

2. Before 1947, 'silver' coins were made from an alloy of silver, copper and nickel. To determine the metal composition, a coin weighing 10.00g was dissolved in nitric acid and the resulting solution was diluted to 1000 cm^3 in a standard flask. A 100 cm^3 portion was treated in the following way.

0.20 mol l^{-1} hydrochloric acid was added to this solution until precipitation of silver(I) chloride was complete. The precipitate was recovered by filtration. It was washed and dried and found to weigh 0.600g.

a) *i)* Calculate the percentage by mass of silver in the coin.

ii) How could you test that precipitation was complete ?

The filtrate was treated to reduce the copper(II) ions to copper(I) ions. Ammonium thiocyanate solution was added to precipitate the copper as copper(I) thiocyanate.

$$Cu^{2+}_{(aq)} \quad + \quad CNS^{-}_{(aq)} \quad \rightarrow \quad CuCNS_{(s)}$$

After filtration, drying and weighing, the precipitate was found to weigh 0.310g.

b) Calculate the percentage by mass of copper in the coin.

3. Gunmetal is an alloy of mainly copper and tin. The copper contant is sufficiently high to be worth recovering from gunmetal scrap. In order to determine the approximate percentage of copper in a sample, the following estimation was carried out.

0.500g of the gunmetal sample was weighed into a beaker and 50% nitric acid solution was added. When the metal had dissolved, the solution was cooled and diluted. At this stage an insoluble tin compound was formed and this was filtered off.

Sodium carbonate was added to the filtrate and the thick, green, gelatinous precipitate was filtered, washed and dried. The green precipitate was heated strongly in in a crucible until decomposition was complete and a black powder obtained.

Results:	*mass of crucible + black powder*	= 26.658g
	mass of crucible	= 26.101g

a) Write an equation for the decomposition of the green precipitate to the black powder.

b) Calculate the percentage copper in the gunmetal alloy.

4. A barium salt (4.18g) was heated strongly in a crucible over a bunsen flame. Only oxygen was evolved during this time and on heating to constant mass and cooling in a dessicator, the residue of barium chloride was found to weigh 2.83g. (The relative atomic mass of barium is 137).

a) Explain what is meant by 'heating to constant mass'.

b) Use the experimental results to establish the formula of the original barium salt.

Answers

Ex5 ***1. a)*** gravimetric analysis ***b) i)*** 5.9×10^{-2}g ***ii)*** 21% ***c) i)*** EDTA ***ii)*** quicker (no filtering), less accurate (bigger errors) / difficult end-point ***2. a) i)*** 45.16% ***ii)*** once ppt has settled, add some more HCl and watch to see if more ppt forms ***or*** after filtering, add HCl to filtrate and see if more ppt forms ***b)*** 16.2%

3. a) $CuCO_3 \rightarrow CuO + CO_2$ ***b)*** 88.98% ***4. a)*** heating until there is no more change in weight