OCR A Chemistry A-Level

Module 2 - Foundations in Chemistry

Amount of a Substance

Notes and Example Calculations

Answers given at the end of the booklet

Atomic Masses

Relative Atomic Mass

The mass of an atom compared to carbon-12 on a scale where carbon is exactly 12.

Relative Isotopic Mass

The mass of an isotope compared to carbon-12 on a scale where carbon is exactly 12 .

Isotope

An atom of an element with different number of neutrons.

Example 1

Calculate the relative atomic mass of Lithium. The isotopes are in the ratio of 7 atoms of Li-6 to every 101 atoms Li-7.

Step 1: Find the total number of atoms.

⇒108

Step 2: Calculate the total mass of 108 atoms.
Multiply the number of atoms for that particular isotope by the mass number of the isotope. Repeat for the other isotope then add these numbers together.

⇒ (7 x 6) + (101 x 7) = 749

Step 3: Calculate the average mass of 1 atom.
Divide the total mass by total number of atoms.

⇒ 749 / 108 = **6.9**

However, the relative abundance of the isotopes can also be represented as percentages.

Example 2

A sample of bromine contains 54% bromine-79 and 46% bromine-81. Calculate the relative atomic mass.

(In this example you don't have to find the total number of atoms, the total abundance of both isotopes is 100%)

Step 1: Calculate the total mass of the bromine atoms.
Multiply the percentage abundance for that particular isotope and the mass number of the isotope together.
Repeat for the other isotope and add these numbers together.

⇒ (54 x 79) + (46 x 81) = 7992

Step 2: Calculate the average mass of 1 atom.
Divide the total mass by the total abundance.

7992 / 100 = **79.92**

Worked Exam Style Questions

Question 1

Europium, atomic number 63, is used in some television screens to highlight colours. A chemist analysed a sample of europium using mass spectrometry. The results are shown in the table below.

isotope	relative isotopic mass	abundance (%)
^{151}Eu	151.0	47.77
^{153}Eu	153.0	52.23

Using the table above, calculate the relative atomic mass of the europium sample. Give your answer to two decimal places. [2 marks]

Step 1: Calculate the total mass of the Europium atoms.

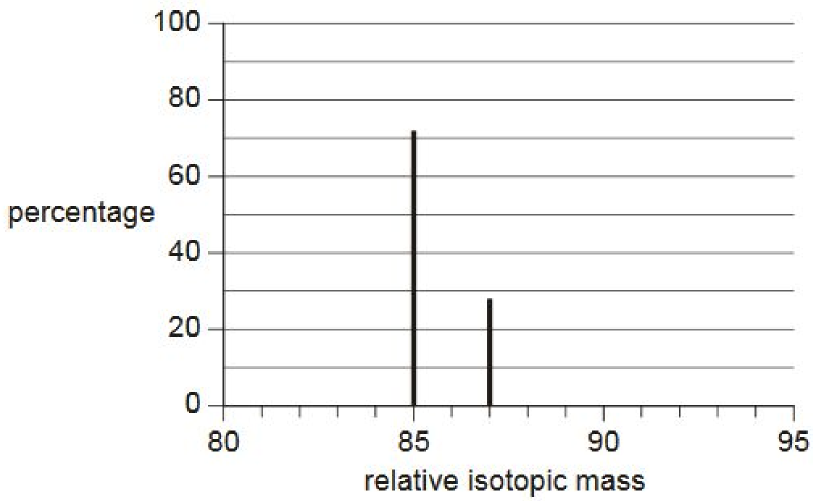
⇒ (151 x 47.77) + (153 x 52.23) = 15204.46

Step 2: Calculate the average mass of one atom.

⇒ 15204.46 / 100 = **152.04**

Question 2

A sample of rubidium was analysed in a mass spectrometer to produce the mass spectrum below.



(i) Use this mass spectrum to help you complete the table below.

isotope	percentage	number of		
		protons	neutrons	electrons
^{85}Rb				
^{87}Rb				

[3]

(ii) Calculate the relative atomic mass of this rubidium sample. Give your answer to three significant figures.

A_r = ...

[2]

In this question the relative abundance of each isotope is represented on a mass spectra, however the method of how to calculate the relative atomic mass is the same.

Step 1: Use the spectra data to find the percentage abundance of each isotope.
Read this off the y-axis.

⇒ The abundance Rb-85 is 72% and for Rb-87 is 28%

Step 2: Calculate the total mass for the Rb atoms.

⇒ (72 x 85) + (28 x 87) = 8556

Step 3: Calculate the average mass of 1 mole of atoms.

⇒ 8556 / 100 = **85.56**

Try these questions ...

1.

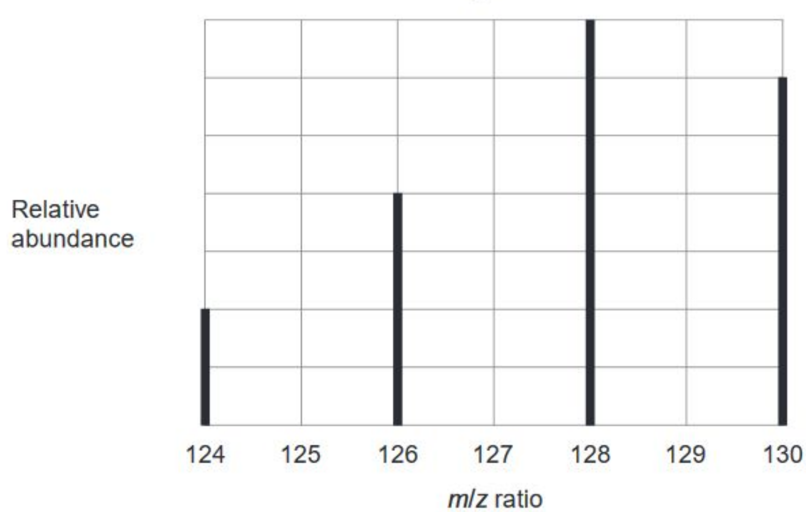
A sample of magnesium contained ^{24}Mg: 78.60%; ^{25}Mg: 10.11%; ^{26}Mg: 11.29%.

Calculate the relative atomic mass of this sample of Mg.

Give your answer to **four** significant figures. [2 marks]

2.) The mass spectrum of a sample of tellurium is shown in **Figure 1**.

Figure 1



) (i) Use **Figure 1** to calculate the relative atomic mass of this sample of tellurium.
Give your answer to one decimal place.

[3 marks]

The Mole

A mole is a measure of the amount of any substance. It contains the same number of particles, equal to the number of carbon-12 atoms in exactly 12g of the isotope.

Molar Mass (Mr)

Example 1
What is the molecular formula mass of NaCl?

⇒ Atomic mass: Na = 23 and Cl = 35.5

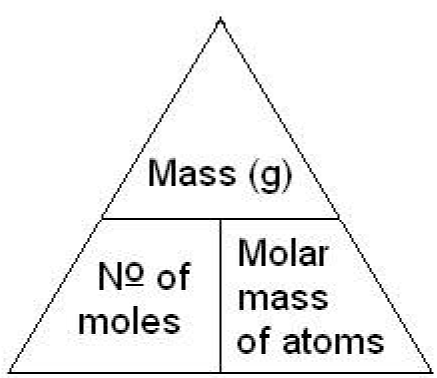
⇒ Mr = 23 + 35.5 = **58.5**

Example 2
What is the molecular formula mass of $AgNO_3$.

⇒ Atomic mass: Ag = 107.9 , N = 14 and O = 16

⇒ Mr = 107.9 + 14 + (16 x 3) = **169.9**

What is the link between moles, mass and molar mass of atoms?



Mass = Mr x Moles

Mr = Mass / Moles

Moles = Mass / Mr

Example 3
How many moles are in 40 grams of water?

Step 1: Work out the Mr of water H_2O.

⇒ Atomic mass: H = 1 and O = 16

⇒ Mr = 1 + 1 + 16 = 18

Step 2: Calculate the number of moles, using the formula: moles = mass / Mr

⇒ 40 / 18 = **2.2 moles**

Example 4:
How many grams are in 3.7 moles of Na_2O?

Step 1: Work out the Mr of Na_2O?

⇒ Atomic mass: Na = 23 and O = 16

⇒ Mr =23 + 23 + 16 = 62

Step 2: Work out the mass in grams using the formula: mass = Mr x moles

⇒ 62 x 3.7 = **229.4 g**

Worked Exam Style Questions

Question 1

In the sixteenth century, a large deposit of graphite was discovered in the Lake District.

People at the time thought that the graphite was a form of lead.

Nowadays, graphite is used in pencils but it is still referred to as 'pencil lead'.

A student decided to investigate the number of carbon atoms in a 'pencil lead'. He found that the mass of the 'pencil lead' was 0.321 g.

(i) Calculate the amount, in mol, of carbon atoms in the student's pencil lead.

Assume that the 'pencil lead' is pure graphite.

answer .... mol

Step 1: Find the relative atomic mass of carbon.

⇒ 12

Step 2: Calculate the number of moles using the formula: moles = mass / Mr

⇒ 0.321/12 = **<u>0.02675</u>**

Question 2

Antimony is found naturally in a number of minerals including stibnite. Stibnite typically contains 5% of Sb_2S_3. Antimony can be obtained by reducing Sb_2S_3 with scrap iron.

$$Sb_2S_3 + 3Fe \rightarrow 2Sb + 3FeS$$

(i) How many moles of Sb_2S_3 are in 500 kg of a typical sample of stibnite containing 5% by mass of Sb_2S_3?

molar mass of Sb_2S_3 = 340 g mol^{-1}; relative atomic mass of Sb = 122

(ii) Calculate the mass of antimony that could be obtained by processing 500 kg of stibnite.

mass = ……………… kg

[2]

Step 1: Work out 5% of 500 kg to work out the mass of Sb_2S_3 in the sample

⇒ 5 / 100 x 500 = 25 kg

(Remember to convert to grams; therefore 25000 g)

Step 2: Work out the number of moles of Sb_2S_3 by using the formula: moles = mass / Mr

⇒ 25000 / 340 = **<u>73.5 moles</u>**

Try these questions…

3. Barium metal can be extracted from barium oxide, BaO, by reduction with aluminium.

$$6BaO + 2Al \rightarrow 3Ba + Ba_3Al_2O_6$$

Calculate the mass of barium metal that could be produced from reduction of 500 g of barium oxide using this method.

answer = ………………………… g

[Total 4 marks]

4. Nickel makes up 25% of the total mass of a fifty pence coin. A fifty pence coin has mass of 8.0 g.

(i) Calculate how many **moles** of nickel atoms are in a fifty pence coin.

answer ....mol

[2]

5. Aqueous silver nitrate can be used as a test for halide ions. A student decided to carry out this test on a solution of magnesium chloride. The bottle of magnesium chloride that the student used showed the formula $MgCl_2.6H_2O$.

The student dissolved a small amount of $MgCl_2.6H_2O$ in water and added aqueous silver nitrate to the aqueous solution.

(i) What is the molar mass of $MgCl_2.6H_2O$?

molar mass = ... g mol^{-1}

[1]

Empirical Formula

The empirical formula of a substance is the simplest whole number ratio of atoms of each element present.

Example 1:
Analysis showed that 0.6175 g magnesium reacted with 3.995 g of bromine to form a compound. Find the empirical formula of this compound. Atomic masses: Mg = 24.3 , Br = 79.9

Step 1: Work out the molar ratio of the atoms.

⇒	Mg	Br
Mass:	0.6175	3.995
Moles:	0.6175 / 24.3 = 0.025	3.995 / 79.9 = 0.05

Step 2: Divide by the smallest number (in this case 0.025) to find the whole number ratio.

⇒ Mg	Br
0.025 / 0.025 = 1	0.05 / 0.025 = 2

Step 3: Write the empirical formula.

⇒ **$MgBr_2$**

Example 2:
Analysis of a compound showed the following percentage composition by mass: Na = 74.2 , O = 25.8 (Ar: Na = 23 , O = 16)

Step 1: Find the molar ratio of atoms.

⇒	Na	O
% mass	74.2	25.8
moles	74.2 ÷ 23 = 3.226	25.8 ÷ 16 = 1.613

Step 2: Divide by the smallest number to find the whole number ratio.

⇒ Na	O
3.226 / 1.613 = 2	1.613 / 1.613 = 1

Step 3: Write the empirical formula.

⇒ **Na_2O**

Example 3:
A empirical formula of CH_2 and a relative molecular mass of 70. What is its molecular formula?

Step 1: Find the empirical formula mass of CH_2. (Ar: C = 12 , H = 1)

⇒ 12 + 1 + 1 = 14

Step 2: Work out the number of CH_2 units in a molecule.

⇒ 70 / 14 = 5

Step 3: Work out the molecular formula by multiplying the empirical formula by 5.

⇒ (5 x CH_2) = **C_5H_{10}**

Worked Exam Style Question

Question 1

Rubidium forms an ionic compound with silver and iodine. This compound has a potential use in miniaturised batteries because of its high electrical conductivity.

The empirical formula of this ionic compound can be calculated from its percentage composition by mass: Rb, 7.42%; Ag, 37.48%; I, 55.10%.

Calculate the empirical formula of the compound.

Step 1: Find the molar ratio of atoms.

⇒	Rb	Ag	I
%mass	7.42%	37.48%	55.10%
(÷by Ar)	7.42 ÷ 85.5	37.48 ÷ 108	55.10 ÷ 127
	=0.0868	= 0.347	= 0.434

Step 2: Divide by the smallest number to find the whole number ratio.

⇒ Rb	Ag	I
0.0868 / 0.0868	0.347 / 0.0868	0.434 / 0.0868
= 1	= 4	= 5

Step 3: Write the empirical formula.

⇒ **$RbAg_4I_5$**

Try these questions …

6. Bromine forms three compounds with phosphorus. The compounds have the molecular formulae PBr_3, PBr_5 and P_2Br_4.

(iii) Compound **A** is one of the three bromides of phosphorus above. It has the following percentage composition by mass: P, 16.2%; Br, 83.8%.

Use this percentage composition to calculate the empirical formula and to determine the identity of compound **A**.

empirical formula ....

identity of compound **A** ....

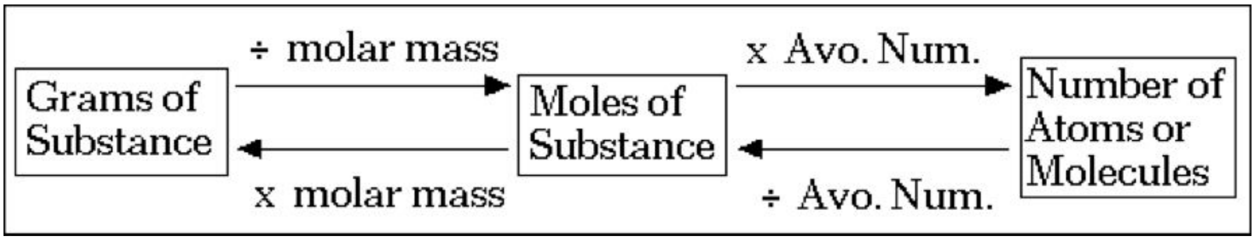
[3]

7. A compound of iron contains 38.9% by mass of iron and 16.7% by mass of carbon, the remainder being oxygen.

(i) Determine the empirical formula of the iron compound.

Avogadro's Constant

The Avogadro constant , N_A , is the number of atoms per mole of the carbon-12 isotope ($6.02 \times 10^{23}\ mol^{-1}$).



Example 1:
How many atoms are there in 8 moles of sodium?

Step 1: Use the equation: no. of atoms = moles x N_A

⇒ $6.02 \times 10^{23} \times 8 =$ **<u>4.816×10^{24}</u>**

Example 2:
How many atoms are there in 48 g of water.

Step 1: Calculate the number of moles in 48 g of water.

⇒ 48 / 18 = 2.67

Step 2: Calculate the number of water molecules.

⇒ $2.67 \times 6.02 \times 10^{23} = 1.605 \times 10^{24}$

Step 3: Calculate the number of atoms.
In each water molecule (H_2O) there are 3 atoms therefore to work the total number of atoms, multiply the number of water moles by 3.

$1.605 \times 10^{24} \times 3 =$ **<u>4.815×10^{24}</u>**

Try this question…

8.

Nickel makes up 25% of the total mass of a fifty pence coin. A fifty pence coin has mass of 8.0 g.

(i) Calculate how many **moles** of nickel atoms are in a fifty pence coin.

answer ....mol

[2]

(ii) Calculate the **number** of atoms of nickel in a fifty pence coin.

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

answer .... atoms

[1]

9.

Silicon reacts with chlorine to form molecules of silicon tetrachloride, $SiCl_4$.

How many molecules are present in 8.505 g of $SiCl_4$?

[3 marks]

Water of Crystallisation

Water molecules form an essential part of the crystal structure of some compounds, known as water of crystallisation.

Example 1:

A hydrated carbonate of an unknown Group 1 metal has the formula $X_2CO_3.10H_2O$ and is found to have a relative formula mass of 286. What is the Group 1 metal?

Step 1: Work out the relative formula mass of the compound without the metal.
(Ar: C = 12 , O = 16 , H = 1)

⇒ 12 + (16 x 3) + (20 x 1) + (16 x 10) = 240

Step 2: Work out the atomic mass of the two Group 1 metal atoms.

⇒ 286 - 240 = 46

46 / 2 = 23
The atomic mass of the element is 23

Step 3: Look on the Periodic Table to find the element

Ar = 23 = **Na, sodium**

Example 2 :
11.25 g of hydrated copper sulphate, $CuSO_4.xH_2O$, is heated until it loses all of its water. Its new mass is found to be 7.19 g. What is the value of x?

Step 1: Work out the mass of the water lost.

⇒	$CuSO_4$	xH_2O
mass	7.19	4.06

(11.25 - 7.19 = 4.06)

Step 2: Calculate the moles of the salt and the water. (Moles = Mass / Mr)

⇒ Mr of $CuSO_4$ = 159.6 Mr of H_2O = 18

Moles of $CuSO_4$ = 7.19/159.6
= 0.045

Moles of H_2O = 4.06/18
= 0.226

Step 3: Divide by the smallest number to find the whole number ratio.

$CuSO_4$	H_2O
0.045 / 0.045 = 1	0.226 / 0.045 = 5

X = **5**

Worked Exam Style Question

Question 1

Epsom salts can be used as bath salts to help relieve aches and pains. Epsom salts are crystals of hydrated magnesium sulfate, MgSO4•***x***H2O. A sample of Epsom salts was heated to remove the water. 1.57 g of water was removed leaving behind 1.51 g of anhydrous $MgSO_4$.

(i) Calculate the amount, in mol, of anhydrous $MgSO_4$ formed. [2]

Mr of $MgSO_4$ = 120.4
Moles = 1.51 / 119.4
= **0.0126**

(ii) Calculate the amount, in mol, of H_2O removed. [1]

Mr of H_2O = 18
Moles = 1.57 / 18
= **0.0872**

(iii) Calculate the value of ***x*** in $MgSO_4$•***x***H_2O.

0.0872 / 0.0125 = **6.976**

[1]

Try these questions...

10.
A sample of hydrated magnesium sulphate, $MgSO_4.xH_2O$, is found to contain 51.1% water. What is the value of x?

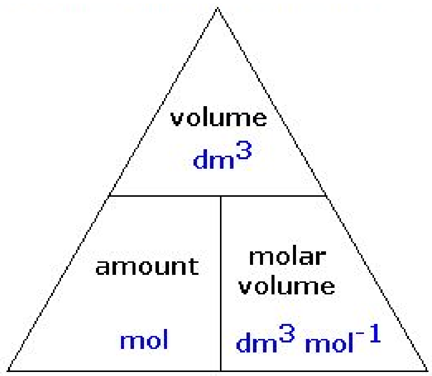
11.
13.2 g of a sample of zinc sulphate, $ZnSO_4.xH_2O$, was strongly heated until no further change in mass was recorded. On heating, all the water of crystallisation evaporated as follows:

$$ZnSO_4.xH_2O \rightarrow ZnSO_4 + xH_2O.$$

Calculate the number of moles of water of crystallisation in the zinc sulphate sample given that 7.4 g of solid remained after strong heating.

Moles and Gas Volumes

Molar gas volume is the volume per mole of a gas. The units of molar volume are $dm^3\ mol^{-1}$. At room temperature and pressure, the molar volume is 24 $dm^3\ mol^{-1}$.



Volume = Moles x 24
Moles = volume / 24

If the volume is in cm^3 then:
Volume = Moles x 24000
Moles = volume / 24000

Example 1:
What is the volume (dm^3) of 24 moles of CO_2 gas?

⇒ 24 x 24 = 576 dm^3

Example 2:
20.0 g of calcium nitrate is heated at until it fully decomposes. The gas collected is cooled to room temperature.

$$2Ca(NO_3)_2(s) \rightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$$

a) Find the volume of nitrogen dioxide evolved.

Step 1: Calculate the moles of calcium nitrate.

⇒ 20 / 164.1 = 0.122

Step 2: Using stoichiometry work out the number of moles of nitrogen dioxide.

The molar ratio between calcium nitrate and nitrogen dioxide;
⇒ 2 : 4

Therefore the number of moles of nitrogen dioxide is;

⇒ 0.122 x 2 = 0.244

Step 3: Calculate the volume of nitrogen dioxide.

⇒ Volume = 24 x Moles

24 x 0.244 = **5.85 dm^3**

b) Find the volume of oxygen evolved.

Step 1: Using stoichiometry work out the number of moles of oxygen.

Calcium nitrate : oxygen
2 : 1

⇒ 0.122 / 2 = 0.061

Step 2: Calculate the volume of oxygen.

⇒ Volume = 24 x Moles

24 x 0.061 = **1.464 dm^3**

c) Find the total volume of gas evolved.

1.464 + 5.85 = **7.314 dm^3**

Worked Exam Style Question

Question 1

In 2000, the mass of CO_2 emitted in the UK was equivalent to 1 kg per person in every hour.

(i) Calculate the volume of 1 kg of carbon dioxide. Assume that 1 mole of CO_2 occupies 24 dm^3.

volume = ... dm^3

[2]

Step 1: Calculate the number of moles in 1 kg of carbon dioxide.

⇒ 1 kg = 1000g

1000 / 44 = 22.7

Step 2: Calculate the volume of carbon dioxide.

⇒ Volume = 24 x Moles

22.72 x 24 = **545 dm^3**

Try these questions…

12.

Europium, atomic number 63, reacts with oxygen at room temperature.

$$4Eu + 3O_2 \rightarrow 2Eu_2O_3$$

Calculate the volume of oxygen, in cm^3, required to fully react with 9.12 g of europium at room temperature and pressure.

[2 marks]

13.

An aqueous solution of aluminium chloride can be prepared by the redox reaction between aluminium metal and dilute hydrochloric acid.

A student reacts 0.0800 mol of aluminium completely with dilute hydrochloric acid to form an aqueous solution of aluminium chloride.

The equation for this reaction is shown below.

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

(b) Calculate the volume of hydrogen gas formed, in dm^3, at room temperature and pressure.

[2 marks]

Ideal Gas Equation

The volume (*V*) occupied by by a certain number of moles of any gas (*n*) has a pressure (*P*) at temperature (*T*) in Kelvin. The link between for these variables is expressed in the following equation:

$$P\,V = n\,R\,T$$

R is known as the gas constant.

The variables in the ideal gas equation must be in the correct SI units:

Pressure - measured in Pascals (1 atm = 101325 Pa)
Volume - measure in cubic metres (1 m^3 = 1000 dm^3)
Temperature - measured in Kelvin (0 °C = 273 K)
Gas constant - 8.314 $Jmol^{-1}K^{-1}$ (This value is given in data booklet)

Example 1:
Find the volume of 4g O_2 when it is heated to 60 °C at 1 atm of pressure. Give your answer in dm^3, to 2 significant figures.

Step 1: Calculate the number of moles of O_2 using the equation: moles = mass / Mr

⇒ 4 / 32 = 0.125 mol

Step 2: Rearrange the ideal gas equation to find the volume.

⇒ V = nRT / P

Step 3: Put the values (converted to correct units where needed) into the equation.

⇒ $V = \frac{0.125 \times 8.314 \times 333}{101325}$

= 3.42 x 10^{-3} m^3

= **<u>3.42 dm^3</u>**

Example 2:

At 25 °C and 100 kPa a gas occupies a volume of 20 dm^3. Calculate the new temperature of the gas if:

a) The volume is decreased to 10 dm^3 at constant pressure.

Step 1: Calculate the number of moles of this gas. (rearrange the ideal gas equation in order to do this)

⇒ n = pV / RT

$$= \frac{100000 \times 0.02}{8.314 \times 298}$$

= 0.807 mol

Step 2: Rearrange the ideal gas equation to find the temperature and insert values. (converting between units where necessary)

⇒ T = pV / nR

$$= \frac{100000 \times 0.01}{0.807 \times 8.314}$$

= **149 K**

b) The pressure is decreased to 50 kPa at constant volume.

Step 1: Convert 50 kPa into pascals.

⇒ 50 x 1000 = 50000 Pa

Step 2: Input the values into the rearrange equation.

$$\Rightarrow T = \frac{50000 \times 0.02}{0.807 \times 8.314}$$

= **149 K**

Worked Exam Style Question

Question 1

A sample of ammonia gas occupies a volume of 1.53×10^{-2} m^3 at 37 °C and a pressure of 100 kPa. (The gas constant $R = 8.314$ J K^{-1} mol^{-1})

Calculate the amount, in moles, of ammonia in this sample. [3]

Step 1: Rearrange the ideal gas equation to calculate the number of moles.

⇒ n = pV / RT

Step 2: Input the values into the equation. (converting values to SI units where necessary)

$$\Rightarrow n = \frac{100000 \times 1.53 \times 10^{-2}}{8.314 \times 310}$$

= **0.59 mol**

Try these questions...

14. Norgessaltpeter decomposes on heating as shown by the following equation.

$$2Ca(NO_3)_2(s) \quad 2CaO(s) + 4NO_2(g) + O_2(g)$$

A sample of Norgessaltpeter was decomposed completely.

The gases produced occupied a volume of 3.50×10^{-3} m^3 at a pressure of 100 kPa and a temperature of 31 °C.

(The gas constant $R = 8.314$ J K^{-1} mol^{-1})

(i) Calculate the total amount, in moles, of gases produced.

(3)

(ii) Hence calculate the amount, in moles, of oxygen produced.

(1)
(Total 4 marks)

Moles and Solutions

A solute dissolves in a solvent to form a solution, the concentration of this solution is how much solute is dissolved in a given amount of the solvent. The units of concentration moles per dm^{-3}.

You can work out the concentration of a solution by using the equation:

$$concentration = \frac{no.\ of\ moles}{volume}$$

$$volume = \frac{no.\ of\ moles}{concentration}$$

$$no.\ of\ moles = concentration \times volume$$

Example 1:
What is the amount, in mol, of NaOH dissolved in 20 cm^3 of an aqueous solution of concentration 0.0125 $moldm^{-3}$?

Step 1: Work out the number of moles using the equation: moles = concentration x volume

⇒ 0.0125 x (20/1000) = **2.5×10^{-4} mol**

Example 2:
Find the mass of potassium hydroxide required to prepare 200 cm^3 of a 0.2 moles per dm^3 solution.

Step 1: Find the amount of KOH in mol, required in the solution.

⇒ 0.2 x 0.2 = 0.04

Step 2: Convert moles to grams. (Mass = Mr x Moles)

Mr of KOH = 39.1 + 16 + 1 = 56.1

⇒ 56.1 x 0.04 = **2.244 g**

Worked Exam Style Question

Question 1

Chlorine can be prepared by reacting concentrated hydrochloric acid with manganese(IV) oxide.

$$4HCl(aq) + MnO_2(s) \rightarrow Cl_2(g) + MnCl_2(aq) + 2H_2O(l)$$

(a) A student reacted 50.0 cm^3 of 12.0 mol dm^{-3} hydrochloric acid with an excess of manganese(IV) oxide.

(i) Calculate how many moles of HCl were reacted.

answer = ... mol

[1]

⇒Use the formula: moles = concentration x volume

12 x 0.05 = **<u>0.6 moles</u>**

Question 2

25.0 cm^3 of a 0.10 mol dm^{-3} solution of sodium hydroxide was titrated against a solution of hydrochloric acid of unknown concentration. 27.3 cm^3 of the acid was required. What was the concentration of the acid?

Step 1: Write a balanced equation of this reaction.

⇒ $NaOH + HCl \rightarrow NaCl + H_2O$

Step 2: Work out the number of moles of NaOH.

⇒ $0.025 \times 0.10 = 2.5 \times 10^3$

Step 3: Using molar ratio calculate the concentration of HCl

Molar ratio between NaOH : HCl = 1:1

⇒ moles of HCl = 2.5×10^3

Concentration = Mole / Volume

= 2.5×10^3 / 0.0273 = **0.0916 moldm^{-3}**

Try these questions…

15.

A student was given 200 cm^3 of solution **X** in which sodium hydroxide, NaOH, and sodium hydrogencarbonate, $NaHCO_3$, had **both** been dissolved.

The student carried out **two different** titrations on samples of solution **X** using 0.100 mol dm^{-3} sulfuric acid, H_2SO_4.

- In the first titration, **both** NaOH **and** $NaHCO_3$ were neutralised.
- In the second titration, **only** NaOH was neutralised.

The student's results for the titrations of 25.0 cm^3 samples of solution **X** are shown.

volume of H_2SO_4 needed to neutralise **both** NaOH **and** $NaHCO_3$	29.50 cm^3
volume of H_2SO_4 needed to neutralise **only** NaOH	18.00 cm^3

(a) (i) Calculate the amount, in mol, of H_2SO_4 used to neutralise **only** the NaOH in 25.0 cm^3 of solution **X**.

1

(ii) Calculate the concentration, in mol dm^{-3}, of NaOH in solution **X**.

1

(b) (i) Calculate the amount, in mol, of $NaHCO_3$ in the 200 cm^3 of solution **X**.

2

(ii) Calculate the mass of $NaHCO_3$ in the 200 cm^3 of solution **X**.

Give your answer to **three** significant figures. 1

Percentage Yield

It is assumed when writing fully balanced equations that 100 % yield (all reactants converted into products) is achieved however this is not practically achievable most chemical reactions are not 100 % yield for various reasons.

The formula for percentage yield is:

$$\% \text{ yield} = \frac{\text{Experimental mass} \times 100}{\text{Theoretical mass}}$$

Example 1:
When 5.00 g of $KClO_3$ is heated it decomposes according to the equation:

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

a) Calculate the theoretical yield of oxygen.

Step 1: Calculate the moles of $KClO_3$.

Mr of $KClO_3$ = 122.6

⇒ moles = 5.00 / 122.6 = 0.0408 moles

Step 2: Using the molar ratio work out the theoretical yield of oxygen.

The molar ratio: $KClO_3 : O_2$
0.0408 : 0.0612

⇒ Mass = Mr x mole
= 0.06 mol x 32
= **1.958 g**

b) Give the % yield if 1.78 g of O_2 is produced.

Step 1: Use the percentage yield equation to work out the % yield of O_2.

⇒ 1.78 / 1.958 = **90.9 %**

c) How much O_2 would be produced if the percentage yield was 78.5%?

Step 1: Rearrange the percentage yield equation.

⇒ Actual yield = (% yield / 100) x theoretical yield

Step 2: Substitute the values into this rearranged equation.

⇒ (78.5/100) x 1.958 = **1.537 g**

Worked Exam Style Question

Question 1

Magnesium reacts with oxygen as shown in the equation below:

$$2Mg + O2 \rightarrow 2MgO$$

Calculate the percentage yield of the reaction, given that burning 2.32 g of magnesium produced 2.39 g of magnesium oxide. [4 marks]

Step 1: Work out the number of moles of magnesium

⇒ 2.32 / 24.3 = 0.095 moles

Step 2: Using molar ratio work out the theoretical yield of magnesium oxide

⇒ Molar ratio Mg : MgO
1:1

Therefore theoretically there should be 0.095 mol MgO.

Step 3: Calculate the mass of magnesium oxide produced.

Mass = moles x Mr

⇒ 0.095 x 40.3 = 3.83

Step 4: Use the % yield equation to work out the % yield for this reaction.

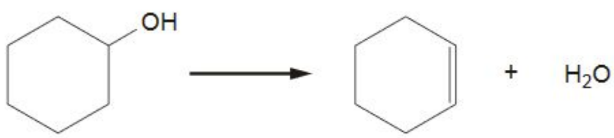
⇒ % yield = Actual yield / theoretical yield x 100

2.39 / 3.83 x 100 = **62.4 %**

Try these questions …

16.

Alkenes can be prepared by the dehydration of alcohols with an acid catalyst.
Cyclohexene can be prepared by the dehydration of cyclohexanol, shown below.



A student reacted 7.65 g of cyclohexanol, $C_6H_{12}O$, and obtained 0.0268 mol of cyclohexene.

(ii) Calculate the percentage yield of cyclohexene.

answer = ... %

[3]

17.

Bromobutane, $CH_3CH_2CH_2CH_2Br$, can be reacted with hot aqueous sodium hydroxide to prepare butan-1-ol.

$$CH_3CH_2CH_2CH_2Br + OH^- \rightarrow CH_3CH_2CH_2CH_2OH + Br^-$$

A student reacted 8.72 g of bromobutane with an excess of OH^-. The student produced 4.28 g of butan-1-ol.

(i) Calculate the amount, in mol, of $CH_3CH_2CH_2CH_2Br$ reacted.

$CH_3CH_2CH_2CH_2Br$, Mr = 136.9

[1 mark]

(ii) Calculate the amount, in mol, of $CH_3CH_2CH_2CH_2OH$ produced.

[2 mark]

(iii) Calculate the percentage yield.

Quote your answer to **three** significant figures.

[1 Mark]

Atom Economy

A chemical reaction can produce a by-product which is also considered as waster as well as the desired product. Atom economy reflects the efficiency of a reaction producing the desired product.

Atom Economy:

$$\% \text{ atom economy} = \frac{\text{Mr of desired product} \times 100}{\text{Mr of reactants}}$$

Example 1:

Milk of magnesia is an antacid that helps to relieve indigestion.

Milk of magnesia contains magnesium hydroxide, $Mg(OH)_2$.

A pharmaceutical company makes magnesium hydroxide using the following reaction

$$MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$$

The sodium chloride, NaCl, made is a **waste product**.

Look at the table of relative formula masses.

Substance	Relative formula mass, M_r
$MgCl_2$	95
NaOH	40
$Mg(OH)_2$	58
NaCl	58.5

(a) Calculate the **atom economy** for the manufacture of magnesium hydroxide.

Step 1: Use the equation to work out the atom economy

⇒ Desired product = $Mg(OH_2)$, Mr = 58
⇒ By-product = NaCl , Mr = 58.5

58 / 116.5 = **49.8 %**

Example 2:

What is the percentage atom economy in forming ethene by this reaction?

$C12H26 \rightarrow C10H22 + C2H4$

Step 1: Work out the molecular mass of ethene.

⇒ Ar: C = 12 , H = 1

(12 x 2) + 4 = 28

Step 2: Work out the molecular mass of decane.

⇒ (12 x 10) + 22 = 142

Step 3: Calculate the atom economy.

⇒ 28 / 170 x 100 = **16.5%**

Worked Exam Style Questions

Question 1

Look at the equations. They show how aspirin can be made.

salicylic acid + ethanoyl chloride → aspirin + hydrogen chloride

$C_7H_6O_3 + C_2H_3OCl \rightarrow C_9H_8O_4 + HCl$

Look at the table. It shows some information about the compounds involved in making aspirin.

Compound	Formula	Relative formula mass
salicylic acid	$C_7H_6O_3$	138
ethanoyl chloride	C_2H_3OCl	78.5
aspirin	$C_9H_8O_4$	180
hydrogen chloride	HCl	36.5

Calculate the atom economy [2 marks]

Step 1: Work out the molecular mass of hydrogen chloride using the periodic table.

⇒ (Ar : H - 1, Cl - 35.5)

1 + 35.5 = 36.5

Step 2: Use the atom economy equation to work out the atom economy.

⇒ 180 / 216.5 = **83.1 %**

Try these questions…

18.

Stowmarket Synthetics manufacture ethanoic acid, $C_2H_4O_2$, by two different processes.

Process **1** $C_2H_6O + O_2 \rightarrow C_2H_4O_2 + H_2O$

Process **2** $CH_4O + CO \rightarrow C_2H_4O_2$

Look at the table of relative formula masses.

Compound	**Formula**	**Relative formula mass, M_r**
ethanol	C_2H_6O	46
oxygen	O_2	32
ethanoic acid	$C_2H_4O_2$	60
water	H_2O	18
methanol	CH_4O	32
carbon monoxide	CO	28

Stowmarket Synthetics know that the **atom economy** of a process is important.

Water is a waste product in process **1**.

Show that the atom economy for making ethanoic acid by process **1** is 77%.

19.

Hydrogen peroxide has the molecular formula H_2O_2.

Hydrogen peroxide can be manufactured by reacting barium peroxide, BaO_2, with sulfuric acid, H_2SO_4.

$$BaO_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O_2$$

Barium sulfate, $BaSO_4$, is a waste product.

Look at the table of relative formula masses, M_r.

formula	relative formula mass, M_r
BaO_2	169
H_2SO_4	98
$BaSO_4$	233
H_2O_2	34

(a) Show that the **atom economy** for the reaction is 12.7%.

Answers

Q1.

(ii) $$\frac{24 \times 78.60 + 25 \times 10.11 + 26 \times 11.29}{100}$$

OR 18.8640 + 2.5275 + 2.9354

OR 24.3269 ✓

A_r = 24.33 (to 4 sig figs) ✓

ALLOW *two marks for A_r = 24.33 with no working out*

ALLOW *one mark for ecf from incorrect sum provided final answer is between 24 and 26 and is to 4 significant figures, e.g. 24.3235* ✗ *gives ecf of 24.32* ✓

2

Q2.

(124 × 2) + (126 × 4) + (128 × 7) + (130 × 6) or 2428	1	M1 for top line
19 19	1	M2 for correct denominator
127.8	1	127.8 with no working shown scores 3 marks
Or	Or	
(124 x 10.5) + (126 x 21.1) + (128 x 36.8) + (130 x 31.6)	1	
100	1	Mark for 100 dependent on top line correct
127.8	1	

Q3.

M(BaO) = 137 + 16 = 153 ✓
moles BaO = 500/153 or 3.268 mol ✓
moles Ba = 3.268/2 or 1.634 ✓
mass Ba formed = 1.634 × 137 = 224 g ✓

accept 223.856209/223.86/223.9 g.
if 6 mol BaO forms 3 mol Ba, award 3rd mark

Alternative method
mass 6BaO=918 g ✓
mass 3Ba = 411 g ✓
1g BaO forms 411/918 g Ba ✓
500 g BaO forms 223.856209/223.86/223.9 g Ba ✓

[4]

Q4.

mass of Ni = 2.0g ✓
moles of Ni = 2.0/58.7 mol = 0.0341/0.034 mol ✓
(1 mark would typically result from no use of 25% → 0.136 mol) 2
2nd mark is for the mass of Ni divided by 58.7

Q5.

(i) 203.3 g mol^{-1} ✓ 1
Accept 203

Q6.

ratio P : Br = 16.2/31 : 83.8/79.9
/= 0.52 : 1.05
/= 1 : 2 ✓
Empirical formula = PBr_2 ✓
Correct compound = P_2Br_4 /phosphorus(II) bromide but **not** PBr_2 ✓ 3

Q7.

%O = 44.4 **(1)**
(if incorrect %O, AE–1)
(if %O omitted can score max 1 for FeC_2)

ratio Fe:C:O = $\frac{38.9}{55.8}$: **(or 50)** $\frac{16.7}{12.0}$: $\frac{44.4}{16.0}$ **(if use At, CE)**

= 1 : 2 : 4

$Fe\,C_2\,O_4$ **(1)**

Q8.

(i) mass of Ni = 2.0g ✓
moles of Ni = 2.0/58.7 mol = 0.0341/0.034 mol ✓
(1 mark would typically result from no use of 25% → 0.136 mol) 2
2nd mark is for the mass of Ni divided by 58.7

(ii) number of atoms of Ni = $6.02 \times 10^{23} \times 0.0341$ 1
= 2.05×10^{22} / 2.1×10^{22} atoms ✓
Can be rounded down to 2.1 or 2.0 or 2 (if 2.0)
From 8 g, ans = 8.18/8.2×10^{22}
(and other consequential responses)

[3]

Q9.

Answer	Marks	Guidance
First check the answer on the answer line. **If answer =** 3.01×10^{22} award 3 marks 170.1 ✓ (**ALLOW** in working shown as 28.1 + 35.5 x 4) Correctly calculates amount of molecules 8.505 / 170.1 = 0.05(00) mol ✓ Correctly calculates number of molecules $0.05 \times 6.02 \times 10^{23} = 3.01 \times 10^{22}$ ✓	3	**ALLOW** 0.301×10^{23} for three marks If there is an alternative answer, check to see if there is any ECF credit possible using working below. **ALLOW** ECF from incorrect molar mass of $SiCl_4$ **ALLOW** 0.05(00) (mol) for two marks **ALLOW** ECF for incorrect number of mol of $SiCl_4$ **ALLOW** calculator value or rounding to 3 significant figures or more **BUT IGNORE** 'trailing' zeroes, eg 0.200 allowed as 0.2. **DO NOT ALLOW** any marks for: $8.505 \times 6.02 \times 10^{23} = 5.12 \times 10^{24}$

Q10. 100 – 51.1 = 48.9

24 + 32 + 64 = 120

48.9 / 120 = 0.4075

Moles of $MgSO_4$ - 51.1 / 18 = 2.8389

Moles of H2O - 2.8389 / 0.4075 = 6.967 = 7 moles of H_2O.

x=7

Q11. $ZnSO_4$ = 65 + 32 + 64 = 161

H_2O = 2 + 16 = 18

7.4g / 161 = 0.045963 Moles of $ZnSO_4$

13.2g – 7.4g = 5.8g

5.8g / 18 = 0.3222 Moles of H_2O

0.3222 / 0.045963 = 7 times more H_2O.

x=7

Q12.

Answer	Mark	Guidance
Check the answer line. **If answer = 1080** cm^3 **award 2 marks** Amount of Eu = 9.12/ 152.0 = 0.06(00) mol ✓ Amount of O_2 = 0.0600 x 3/4 = 0.045(0) mol **and** Volume of O_2 = 0.0450 x 24000 = 1080 cm^3 ✓	2	**If there is an alternative answer, check to see if there is any ECF credit possible using working below.** **ALLOW** calculator value or rounding to 2 significant figures or more but **IGNORE** 'trailing zeroes' eg 0.200 is allowed as 0.2. **ALLOW** incorrectly calculated *amount* of Eu x 3/4 and x 24000 correctly calculated for 2nd mark Eg 2605.7 would come from (9.12/63) x 3/4 x 24000 (note: a mass of Eu x 3/4 and x 24000 would not score M2)

Q13.

FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 2.88 dm^3 award 2 marks Mol of H_2 = 0.12 ✓ Volume of H_2 = 0.12 x 24.0 = 2.88 dm^3 ✓	**2**	 ALLOW ECF from incorrectly calculated moles of H_2 0.08 x 24 = 1.92 gets 1 mark

Q14.

T = 304(K) and P = 100 000 (Pa)

Only T and P correctly converted 1

$$\frac{100\,000 \times 3.50 \times 10^{-3}}{8.31 \times 304} \text{ OR } n = \frac{PV}{RT}$$ 1

0.139 (mol)

Allow <u>0.138 – 0.139</u> 1

Q15.

(a)	**(i)**	Mol of H_2SO_4 = 0.100 x 18.00/1000 = 1.80 x 10^{-3} mol ✓	1	**ALLOW** calculator value or rounding to 2 significant figures or more but **IGNORE** 'trailing zeroes' throughout Q4. eg 0.200 is allowed as 0.2
	(ii)	Mol of NaOH in = 1.80 x 10^{-3} x 2 x 1000/25.0 = 0.144 mol dm^{-3} ✓	1	**ALLOW** ECF for (a)(i) x 2 x 1000/25
(b)	**(i)**	**Check the answer line.** **If answer = 0.0184 mol award 2 marks** Mol of $NaHCO_3$ in 25.0 cm^3 = [0.100 x 11.50/1000] x 2 = 0.00230 mol ✓ Mol of $NaHCO_3$ in 200 cm^3 = 0.00230 x 200/25.0 = 0.0184 mol ✓	2	**If there is an alternative answer, check to see if there is any ECF credit possible using working below.** **ALLOW** for an alternative method for M1 Total mol of H_2SO_4 used = [0.100 x 29.50/1000] = 0.00295 mol Mol of H_2SO_4 reacting with $NaHCO_3$ = 0.00295 – answer to (a)(i) Expected answer = .00295 – 0.00180 = 0.00115 mol Mol of $NaHCO_3$ in 25.0 cm^3 = 0.00115 x 2 = 0.00230 mol **ALLOW** ECF for **mol** of $NaHCO_3$ x 200/25.0 For ECF in M2 titration values of 11.50 or 29.50 must have been used in M1 Second marking point is for scaling up number of mol of $NaHCO_3$ by 200/25.0 (Usually seen as '8')
	(ii)	Mass of $NaHCO_3$ = 0.0184 x 84.0 = 1.55 g ✓ **(must be three significant figures)**	1	**ALLOW** ECF for **(b)(i)** x 84.0 correctly calculated and rounded to three significant figures.

Q16.

M_r(cyclohexanol) = 100 ✓

amount of cyclohexanol = 0.0765 mol ✓

percentage yield = 35.0% ✓

ALLOW *full marks for correct answer with no or limited working out*

ALLOW *ecf from wrong molar mass i.e. 7.65 ÷ molar mass*

ALLOW *ecf from wrong amount in moles i.e. [0.0268 ÷ moles] × 100*

ALLOW *35%*

ALLOW *two marks for 0.35%*

If M_r of 82 is used then % yield will be 28.7 or 29 and this is worth two marks

3

Q17.

(i) 8.72/136.9 = 0.0637 mol **(1)**

(ii) M_r butan-1-ol = 74(.0) **(1)**

moles = 4.28/74.0 = 0.0578 mol **(1)** 2

(iii) 0.0578/0.0637 × 100 = 90.7% **(1)** 1

[4]

Q18.

atom economy = $\frac{60}{60+18}$ / $\frac{60}{46+32}$ / $\frac{60}{78}$ (1) **but** atom economy = $\frac{60}{60+18}$ × 100 / $\frac{60}{46+32}$ × 100 / $\frac{60}{78}$ × 100 (2)	2	**allow** atom economy formula in words for one mark i.e. atom economy = $\frac{\text{total Mr of desired products}}{\text{total Mr of all products}}$ x 100 (1)

Q19.

Answer	Marks	Guidance
$\frac{34}{267}$ x 100 (1)	1	**allow** $\frac{34}{(233+34)}$ x100 / $\frac{34}{(98+169)}$ x 100 the mark is for the working out and not the answer