

Revision Checklist :4.3 Quantitative Chemistry

Conservation of Mass

The law of conservation of mass states that **no atoms** are **lost or made** during a chemical reaction so the mass of the products equals the mass of the reactants

This means that chemical reactions can be represented by symbol equations which are balanced in terms of the numbers of atoms of each element involved on both sides of the equation.

Balancing Equations

- know how to balance chemical equations
 $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$ (The 2 is put in front of the HCl to balance the numbers of H's and Cl's on both sides)
 $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$ (The 2 is put in front of the MgO to balance with the 2O's on the left and then a 2 needs to be put in front of the Mg to balance with the 2Mg's on the right.)
- Remember when balancing equations you cannot change the formulae

Relative Formula Mass

The relative formula mass (*Mr*) of a compound is the sum of the relative atomic masses (*Ar*) of the atoms in the numbers shown in the formula.

Be able to work out the relative formula mass (*Mr*) of a substance using data from the periodic table.
e.g. the *Mr* of $\text{CaCO}_3 = 40 + 12 + (16 \times 3) = 100$

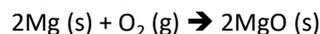
Balanced chemical equations

In a balanced chemical equation, the sum of the relative formula masses of the reactants in the quantities shown equals the sum of the relative formula masses of the products in the quantities shown

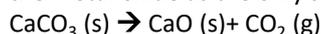
Mass changes when a reactant or product is a gas

Some reactions may appear to involve a change in mass but this can usually be explained because a reactant or product is a gas and its mass has not been taken into account

When a metal reacts with oxygen the mass of the oxide produced is greater than the mass of the metal.



In **thermal decompositions** of metal carbonates, carbon dioxide is produced which escapes into the atmosphere leaving the metal oxide as the only solid product.



Chemical measurements

Whenever a measurement is made there is always some uncertainty about the result obtained.

The **range** of a set of measurements about the **mean** can be used as a measure of uncertainty.

Example: Calculate the mean and uncertainty of the following volumes in cm^3 : 20.10, 20.20, 20.00, 20.05, 20.25

$$\text{Mean} = (20.10 + 20.20 + 20.00 + 20.05 + 20.15) / 5 = 20.10 \text{ cm}^3$$

$$\text{Uncertainty} = \pm 0.10 \text{ cm}^3 \text{ (all readings are within } \pm 0.10 \text{ of mean)}$$

Moles

Chemical amounts are measured in moles.
The symbol for the unit mole is **mol**.

The mass of one mole of a substance in grams is numerically equal to its relative formula mass.

One mole of a substance contains the same number of the stated particles, atoms, molecules or ions as one mole of any other substance.

For example in one mole of carbon (C) the number of atoms is the same as the number of molecules in one mole of carbon dioxide (CO_2).

The number of atoms, molecules or ions in a mole of a given substance is the **Avogadro constant**.
The value of the Avogadro constant is 6.02×10^{23} per mole.

be able to work out the number of moles of a given substance from its mass using the equation

$$\text{moles} = \text{mass} / \text{Mr} \text{ or rearranged to } \text{mass} = \text{Mr} \times \text{moles}$$

Example 1: Calculate the number of moles in 35.0g of CuSO_4

$$\begin{aligned}\text{moles} &= \text{mass}/M_r \\ &= 35.0 / (63.5 + 32 + 16 \times 4) \\ &= 0.219 \text{ mol}\end{aligned}$$

Many questions will involve changes of units

$$\begin{aligned}1000 \text{ mg} &= 1\text{g} \\ 1000 \text{ g} &= 1 \text{ kg} \\ 1000 \text{ kg} &= 1 \text{ tonne}\end{aligned}$$

Example 2: Calculate the number of moles in 75.0mg of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

$$\begin{aligned}\text{moles} &= \text{mass}/M_r \\ &= 0.075 / (40 + 32 + 16 \times 4 + 18 \times 2) \\ &= 4.36 \times 10^{-4} \text{ mol}\end{aligned}$$

Calculate the percentage by mass of an element in a compound

$$\text{percentage by mass} = \frac{\text{number of atoms of element} \times \text{Ar of element}}{M_r \text{ of compound}} \times 100$$

Example 3. Calculate the percentage by mass of oxygen in calcium sulfate (CaSO_4)

$$\begin{aligned}\text{percentage by mass} &= \frac{\text{number of atoms of element} \times \text{Ar of element}}{M_r \text{ of compound}} \times 100 \\ &= \frac{4 \times 16}{(40 + 32 + 16 \times 4)} \times 100 \\ &= 47 \%\end{aligned}$$

Avogadro's Constant

The number of atoms, molecules or ions in a mole of a given substance is the Avogadro constant. The value of the Avogadro constant is 6.02×10^{23} per mole.

Avogadro's Constant can be used for atoms, molecules and ions

1 mole of copper atoms will contain 6.02×10^{23} atoms

1 mole of carbon dioxide molecules will contain 6.02×10^{23} molecules

1 mole of sodium ions will contain 6.02×10^{23} ions

$$\text{No of particles} = \text{number of moles} \times \text{Avogadro's constant}$$

Example 4 : Calculate the number of tin atoms in a 6.00 g sample of Tin metal.

Step 1 calculate the number of moles

$$\begin{aligned}\text{moles} &= \text{mass}/A_r \\ &= 6 / 119 \\ &= 0.0504 \text{ mol}\end{aligned}$$

Step 2 use Avogadro's number to calculate no of atoms

$$\begin{aligned}\text{Number of atoms} &= \text{moles} \times 6.02 \times 10^{23} \\ &= 0.0504 \times 6.02 \times 10^{23} \\ &= 3.04 \times 10^{22}\end{aligned}$$

Example 5 Calculate the mass of 1 atom of sodium

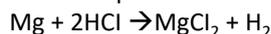
$$\begin{aligned}\text{Mass of 1 atom} &= \text{mass of 1 mole of sodium}(A_r)/\text{Avogadro's number} \\ &= 23 / 6.02 \times 10^{23} \\ &= 3.82 \times 10^{-23} \text{ g}\end{aligned}$$

Reacting mass questions

The masses of reactants and products can be calculated from balanced symbol equations.

Chemical equations can be interpreted in terms of moles.

For example:



shows that one mole of magnesium reacts with two moles of hydrochloric acid to produce one mole of magnesium chloride and one mole of hydrogen gas.

General method for reacting mass questions

step 1: work out the number of moles of the substance for which the mass has been given.

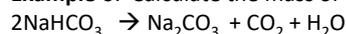
$$\text{Using number of moles} = \frac{\text{mass}}{Mr}$$

step 2: use the ratios of moles in the balanced equation to work out the moles of the other substance

Step 3: work out the mass of the second substance

$$\text{Using mass} = \text{moles} \times Mr$$

Example 6: Calculate the mass of carbon dioxide produced from heating 5.5 g of sodium hydrogencarbonate.



Step 1: work out moles of sodium hydrogencarbonate

$$\begin{aligned} \text{moles} &= \text{mass} / Mr \\ &= 5.5 / 84 \\ &= 0.0655 \text{ mol} \end{aligned}$$

Step 2: use balanced equation to give moles of CO_2

$$\begin{aligned} 2 \text{ moles NaHCO}_3 &: 1 \text{ moles CO}_2 \\ \text{So } 0.0655 \text{ HNO}_3 &: 0.0328 \text{ moles CO}_2 \end{aligned}$$

Step 3: work out mass of CO_2

$$\begin{aligned} \text{Mass} &= \text{moles} \times Mr \\ &= 0.0328 \times 44 \\ &= 1.44 \text{ g} \end{aligned}$$

Working out the balancing numbers from masses

The balancing numbers in a symbol equation can be calculated from the masses of reactants and products by converting the masses in grams to amounts in moles and converting the numbers of moles to simple whole number ratios.

Example 7. A sample of lead was heated strongly in oxygen. It was found that 8.28g of lead reacts with 0.64g of oxygen to form a lead oxide.

There are two possible lead oxides that could be formed: lead (II) oxide (PbO) and lead (IV) oxide (PbO_2)

Determine which is the correct equation.



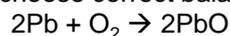
Step 1: calculate moles of each chemical whose mass is given

$$\begin{array}{ll} \text{Moles of Pb} = \text{mass} / Ar & \text{Moles of O}_2 = \text{mass} / Mr \\ = 8.28 / 207 & = 0.64 / 32 \\ = 0.04 \text{ mol} & = 0.02 \text{ mol} \end{array}$$

Step 3: divide each moles in step 2 by the smallest number of moles to get a whole number ratio

$$\begin{array}{ll} \text{Pb} = 0.04/0.02 & \text{O}_2 = 0.02/0.02 \\ = 2 & = 1 \end{array}$$

Step 4 choose correct balanced equation:



Limiting Reactant

In a chemical reaction involving two reactants, it is common to use an **excess** of one of the reactants to ensure that all of the other reactant is used.

The reactant that is completely used up is called the **limiting reactant** because it limits the amount of products.

The number of moles of the limiting reactant will determine the number of moles of product formed.

Not all of the excess reactant will react.

General method for Limiting Reactant Questions

step 1: work out the number of moles of the substance for each reactant.

$$\text{Using number of moles} = \frac{\text{mass}}{Mr}$$

step 2: use the ratios of moles in the balanced equation to work out which reactant is the limiting reactant

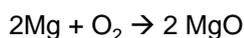
Step 3: use the ratios of moles in the balanced equation to convert the moles of the limiting reactant to the moles of a product

Step 4: work out the mass of the product

$$\text{Using mass} = \text{moles} \times Mr$$

Some questions may only ask you to calculate which reactant is in excess. In those questions only do the first two steps in the above method

Example 8: 5.0g of magnesium are reacted with 6.0g of oxygen to make magnesium oxide. What is the limiting reactant and calculate the mass of magnesium oxide that will be formed?



step 1: calculate the number of moles of the substance for each reactant.

$$\begin{aligned} \text{Work out moles of Mg} \\ \text{Moles} &= \text{mass} / Ar \\ &= 5/24 \\ &= 0.208\text{mol} \end{aligned}$$

$$\begin{aligned} \text{Work out moles of O}_2 \\ \text{Moles} &= \text{mass} / Mr \\ &= 6/32 \\ &= 0.188 \text{ mol} \end{aligned}$$

step 2: use the ratios of moles in the balanced equation to work out which reactant is the limiting reactant

Using ratio of 2Mg: 1 O₂ from balanced equation

0.208 moles of Mg should react with 0.104 of O₂

but we have 0.188 mol of O₂ so O₂ is in excess and **Mg is limiting reactant**

step 3: use the ratios of moles in the balanced equation to convert the moles of the limiting reactant to the moles of a product

Ignore excess moles of O₂ and use moles of Mg to work out moles of MgO

There are 0.208 mol of Mg, so using ratio of 2Mg:2MgO from balanced equation there must be 0.208 mol of MgO

step 4: calculate the mass of the product

$$\begin{aligned} \text{Mass} &= \text{moles} \times Mr \text{ of MgO} \\ &= 0.208 \times 40 \\ &= 8.32 \text{ g} \end{aligned}$$

Concentration calculations

The concentration of a solution can be measured in g/dm^3 or mol/dm^3 .

$$\text{Concentration (in mol/dm}^3\text{)} = \text{moles/volume (in dm}^3\text{)}$$

$$\text{Concentration (in g/dm}^3\text{)} = \text{mass (in g) / volume (in dm}^3\text{)}$$

The volume in the above equation must be in dm^3 . Volumes are often given in cm^3 .
To convert cm^3 into dm^3 divide by 1000

Example 9: Calculate the concentration of a solution in g/dm^3 made by dissolving 500mg of NaNO_3 in 250 cm^3 water.

Convert units $500 \text{ mg} = 0.50\text{g}$

$250\text{cm}^3 = 0.25\text{dm}^3$

$$\begin{aligned}\text{Conc in g/dm}^3 &= \text{mass/volume} \\ &= 0.50 / \mathbf{0.25} \\ &= 2.0 \text{ g /dm}^3\end{aligned}$$

Example 10: Calculate the concentration in mol/dm^3 of a solution made by dissolving 5.00g of Na_2CO_3 in 250 cm^3 water.

$$\begin{aligned}\text{moles} &= \text{mass}/M_r \\ &= 5.00 / (23 \times 2 + 12 + 16 \times 3) \\ &= 0.0472 \text{ mol}\end{aligned}$$

$$\begin{aligned}\text{conc} &= \text{moles/volume} \\ &= 0.0472 / \mathbf{0.25} \\ &= 0.189 \text{ mol/dm}^3\end{aligned}$$

Example 11 Calculate the mass of sodium chloride needed to make 100cm^3 of 0.100 mol/dm^3 NaCl solution.

$$\begin{aligned}\text{moles} &= \text{conc} \times \text{volume} \\ &= 0.1 \times \mathbf{0.1} \\ &= 0.01 \text{ mol}\end{aligned}$$

$$\begin{aligned}\text{mass} &= \text{mol} \times M_r \\ &= 0.01 \times (23+35.5) \\ &= 0.585 \text{ g}\end{aligned}$$

To convert a concentration in g/dm^3 to mol/dm^3 divide by M_r

Example 12: A solution of HCl has a concentration of 1.825g/dm^3 . Calculate the concentration of the solution in mol/dm^3

$$\begin{aligned}\text{Conc in mol/dm}^3 &= \text{conc in g/dm}^3 / M_r \\ &= 1.825 / 36.5 \\ &= 0.05 \text{ mol/dm}^3\end{aligned}$$