# L 11—12 Chemical Calculations Knowledge Organiser

## Section 1: Key Terms

| | |
|---|---|
| 1 Relative atomic mass | Usually expressed as $A_r$, this is the mass number of an element. |
| 2 Relative formula mass | Usually expressed as $M_r$, this is the mass number of all the elements in a compound combined. |
| 3 Mole | The relative atomic mass of an element or formula mass of compound in grams. |
| 4 Avogadro constant | The amount of atoms, molecules or ions in 1 mole of a substance. The number is always $6.022 \times 10^{23}$. |
| 5 Limiting reactant | A reactant that stops the reaction from happening as it is all used up. |
| 6 Percentage yield | The actual mass of a product divided by the theoretical yield, times by 100. |
| 7 Atom economy | The relative mass of the product wanted over the relative mass of all the products formed, times by 100. |
| 8 Concentration | The amount of a solute over the amount of solution. |
| 9 Titration | A technique to find out the concentrations of an unknown substance. |

## Section 2: Working out relative atomic masds and relative formula mass

You can calculate the relative atomic mass $A_r$ of an element given the percentage abundance of its isotopes, for example, copper has two isotopes,

$^{63}Cu$ (abundance = 69%) and $^{65}Cu$ (31%).

To work out the relative atomic mass of copper from this data, imagine you had 100copper atoms. 69 copper atoms would have a relative mass of 63, and the other 31 copper atoms would have a mass of 65. then calculate the mean relative mass of these 100 atoms :

$$A_r \text{ of Cu} = \frac{(69 \times 63) + (31 \times 65)}{100} = 63.5$$

You also need to know how to work out the relative formula mass of more complex ionic compounds such as aluminium sulfate, $Al_2(SO_4)_3$

Aluminium has an $A_r$ of 27, the $A_r$ of sulfur is 32, and the $A^r$ of oxygen is 16. in this case you must multiply any atoms within the brackets by the sub-script number after the brackets. This means that the $M_r$ of aluminium sulphate is.

(27 x 2) + (32 x 3) + (16 x 12) = 54 + 96 + 192 = 342

## Section 3—Mole calculations

**Moles from masses**

Chemists prefer to use the mole when describing relative numbers of particles (atoms, molecules, or ions) in a certain mass of substance.

They use the equation:

$$\textbf{Number of moles} = \frac{\text{mass (g)}}{A_r} \quad \textbf{or} \quad \frac{\text{mass (g)}}{M_r}$$

**Masses form moles**

Sometimes you will have to work out the mass of a substance from a given number of moles.

By re-arranging:

$$\text{Number of moles} = \frac{\text{mass (g)}}{A_r} \quad \text{or} \quad \frac{\text{mass (g)}}{M_r}$$

You can calculate the mass of a certain number of moles of substance using the equation:

**Mass (g) = number of moles x $A_r$ or number of moles x $M_r$**

## Section 4—Equations

$$\text{Percentage yield} = \frac{\text{actual mass of product produced}}{\text{Maximum theoretical mass of product possible}} \times 100\%$$

$$\text{Percentage atom economy} = \frac{\text{relative formula mass of the desired product from equation}}{\text{Sum of the relative formula masses of the reactants from}} \times 100\%$$

$$\text{Concentration (g/dm}^3) = \frac{\text{amount of solute (g)}}{\text{Volume of solution (dm}^3)}$$

## Section 5—Worked Examples

When lead is extracted from its ore, galena, the first stage is the roasting of lead sulphide, PbS, to convert it to lead oxide, PbO. The lead oxide is then reduced to form lead metal. The balanced symbol equation for the first stage, with state symbols is:

$2Pb(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$

Calculate the percentage atom economy of this first stage in the process of extracting lead.

($A_r$ values: Pb = 207, S = 32, ) = 16)

**Solution**

$$\%\ \text{atom economy} = \frac{\text{Relative formula mass of the Desired product from equation}}{\text{Sum of the relative formula masses of the reactants from equation}} \times 100\%$$

$$= \frac{M_r\,(2PbO)}{[M_r\,(2PbS) + M_r\,(3O_2)]} \times 100\%$$

$$= \frac{2 \times (207 + 16)}{[2 \times (207 + 32)] + [3 \times (16 \times 2)]} \times 100\%$$

$$= \frac{2 \times (207 + 16)}{[2 \times (207 + 32)] + [3 \times (16 \times 2)]} \times 100\%$$

$$= \frac{446}{(478 + 96)} \times 100\%$$

$$= 77.7\%$$

Limestone is mainly made of calcium carbonate. In the production of calcium oxide, crushed lumps of limestone are heated in a rotating lime kiln. The calcium carbonate decomposes to make calcium oxide, and carbon dioxide gas is given off. A company processes 200tonnes of limestone a day. It collects 98.0 tonnes of calcium oxide, the useful product. What is the percentage yield of the reaction in the kiln, assuming limestone contains only calcium carbonate? ($A_r$ values: Ca = 40, C = 12, O = 16)

**Solution**

Calcium carbonate ⟶ calcium oxide + carbon dioxide

$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$

Work out the relative formula masses of $CaO_3$ and CaO:

$M_r$ of $CaCO_3$ = 40 + 12 + (16 x 3) = 100

$M_r$ of CaO = 40 + 165 = 56

So the balanced symbol equation tells you that 100 tonnes of $CaCO_3$ could make 56 tonnes of CaO, assuming 100% yield.

Therefore 200 tonnes of $CaO_3$ could make a maximum of (56 x 2) tonnes of CaO = 112tonnes (theoretical yield in this case).

$$\text{So percentage yield} = \frac{\text{Mass of product produced}}{\text{Maximum mass of product possible}} \times 100\%$$

$$= \frac{98.0}{112} \times 100\% = 87.5\%$$

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## *Section 6—Titration (Required Practical)*

A titration is carried out using a number of steps:

1.If the sample is a solid, it is **weighed** using an accurate balance, and then **dissolved** to make up a known volume of solution (usually 100cm$^3$).

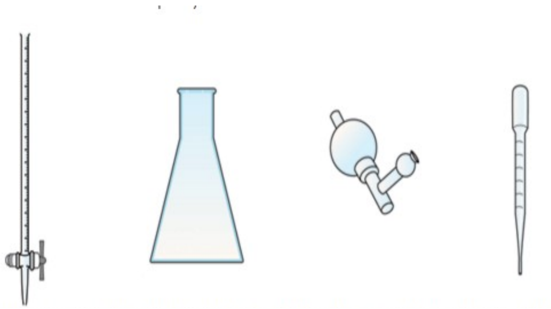
2.A **pipette** is used to measure accurately a volume of this solution - for example, 10cm$^3$. A safety pipette filler is used to draw solution into the pipette. This is emptied into a **conical flask**.

3.A few drops of an **indicator** may be added to the conical flask. This will show a change of colour when the titration is complete.

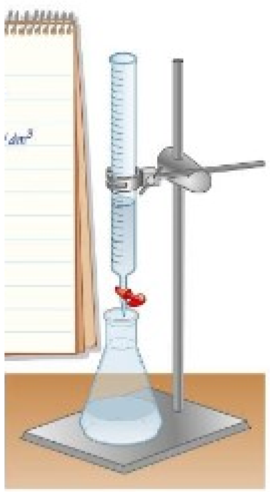
4.A second chemical is placed in a **burette**. This other solution is of a chemical that will react with the synthesised chemical sample in the conical flask. Often the solution in the burette is an **acid or alkali**, and it must be of a precise, known concentration.

5.The solution from the burette is run into the conical flask. The solution is added one drop at a time, with swirling to mix the solutions as the end-point is approached. Eventually, a colour change shows that the correct amount has been added to react completely with the synthesised chemical in the sample.

6.The volume of solution added from the burette is noted. The titration results can then be used to calculate the amount of the synthesised chemical in the sample, and therefore find its purity.



Apparatus required for titration (from left to right): burette, conical flask, safety pipette filler and pipette.



## Section 7—Titration Calculations

You should be able to use titration results to calculate the concentration of an acid or alkali. If several runs have been carried out, any irregular titres should be ignored before calculating the mean titre.

### Example

27.5 cm$^3$ of 0.2 mol/dm$^3$ hydrochloric acid is needed to titrate 25.0 cm$^3$ of sodium hydroxide solution. What is the concentration of the sodium hydroxide solution?

**Step 1: Convert all volumes to dm$^3$**

27.5 cm$^3$ = 27.5 ÷ 1000 = 0.0275 dm$^3$

25.0 cm$^3$ = 25.0 ÷ 1000 = 0.025 dm$^3$

**Step 2: Calculate the number of moles of the substance where the volume and concentration are known**

number of moles = concentration × volume

number of moles of hydrochloric acid = 0.2 × 0.0275 = 0.0055 mol (5.5 × 10$^{-3}$mol)

**Step 3: Calculate the unknown concentration**

We can say that 0.0055 mol of acid will react with 0.0055 mol of alkali

concentration of alkali = moles ÷ volume = 0.0055 ÷ 0.025 = **0.22 mol/dm$^3$**

### A quick check

You can check your answer using this quick method (but which misses out the chemical understanding that may attract full marks).

unknown concentration = known concentration × $^{\text{volume of known}}/_{\text{volume of unknown}}$

In the example above, this would be:

unknown concentration = 0.2 × $^{27.5}/_{25.0}$ = **0.22 mol/dm$^3$**