Application of Chemistry

Task 2 Amount of substance

3.1 Rearranging equations

In chemistry, you sometimes need to rearrange / change the subject of an equation to find the desired values.

For example, you may know the amount of a substance in moles (n) and the mass of it you have in g (m), and need to find its relative mass (Mr).

The amount of substance (n) is equal to the mass you have (m) divided by the molar mass (Mr):

n = m/Mr or moles = mass / relative mass

You need to rearrange the equation to make the relative mass (Mr) the subject.

Multiply both sides by the relative mass (Mr):

$Mr \times n = m$

Then divide both sides by the amount of substance (n):

Mr = m/n

Practice questions

GCSE

1 Rearrange the equation $c = \frac{n}{V}$ to make:

a n the subject of the equation

b V the subject of the equation.

2 Rearrange the equation $PV = nRT$ to make:

a n the subject of the equation

b T the subject of the equation.

3.2 Calculating concentration

The concentration of a solution (a solute dissolved in a solvent) is a way of saying how much solute, in moles, is dissolved in 1 dm^3 or 1 litre of solution. $1000cm^3 = 1dm^3$

Concentration is usually measured using units of mol dm^{-3}. (It can also be measured in g dm^3.)

The concentration of the amount of substance dissolved in a given volume of a solution is given by the equation:

$$c = \frac{n}{V}$$

where n is the amount of substance in moles, c is the concentration, and V is the volume in dm^3.

The equation can be rearranged to calculate:

the amount of substance n, in moles, from a known volume and concentration of solution

the volume V of a solution from a known amount of substance, in moles, and the concentration of the solution.

Practice questions

GCSE

3 Calculate the concentration, in mol dm^{-3}, of a solution formed when 0.2 moles of a solute is dissolved in 50 cm^3 of solution.

4 Calculate the concentration, in mol dm^{-3}, of a solution formed when 0.05 moles of a solute is dissolved in 2.0 dm^3 of solution.

5 Calculate the number of moles of NaOH in an aqueous solution of 36 cm^3 of 0.1 mol dm^{-3}.

4 Molar calculations and equations

4.1 Calculating masses and gas volumes

The balanced equation for a reaction shows how many moles of each reactant and product are involved in a chemical reaction.

If the amount, in moles, of one of the reactants or products is known, the number of moles of any other reactants or products can be calculated.

The number of moles (*n*), the mass of the substance (*m*), and the molar mass (*Mr*) are linked by:

n = m/Mr

Note: The molar mass of a substance is the mass per mole of the substance. For $CaCO_3$, for example, the atomic mass of calcium is 40.1, carbon is 12, and oxygen is 16. So the molar mass of $CaCO_3$ is:

40.1 + 12 + (16 × 3) = 100.1. The units are g mol^{-1}.

Look at this worked example. A student heated 2.50 g of calcium carbonate, which decomposed as shown in the equation:

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

The molar mass of calcium carbonate is 100.1 g mol^{-1}.

a Calculate the amount, in moles, of calcium carbonate that decomposes.

n m/Mr = 2.50/100.1 = 0.025 mol

b Calculate the amount, in moles, of carbon dioxide that forms.

From the balanced equation, the number of moles of calcium carbonate = number of moles of carbon dioxide = 0.025 mol

Practice questions

A level

1 In a reaction, 0.486 g of magnesium was added to oxygen to produce magnesium oxide.

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

a Calculate the amount, in moles, of magnesium that reacted.

b Calculate the amount, in moles, of magnesium oxide made.

c Calculate the mass, in grams, of magnesium oxide made.

2 Oscar heated 4.25 g of sodium nitrate. The equation for the decomposition of sodium nitrate is:

$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$

a Calculate the amount, in moles, of sodium nitrate that reacted.

b Calculate the amount, in moles, of oxygen made.

3 0.500 kg of magnesium carbonate decomposes on heating to form magnesium oxide and carbon dioxide. Give your answers to 3 significant figures.

$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

a Calculate the amount, in moles, of magnesium carbonate used.

b Calculate the amount, in moles, of carbon dioxide produced.

Percentage Yield and Atom Economy

Moving from GCSE Science to A Level can be a daunting leap. You'll be expected to remember a lot more facts, equations, and definitions, and you will need to learn new maths skills and develop confidence in applying what you already know to unfamiliar situations.

This worksheet aims to give you a head start by helping you:

- to pre-learn some useful knowledge from the first chapters of your A Level course
- understand and practice of some of the maths skills you'll need.

Learning objectives

After completing these worksheets you should be able to:

- calculating percentage yield and percentage error
- calculating atom economy

TASK 4: Percentage yields and atom economy

Part 1: Calculating percentage yield

Chemists often find that an experiment makes a smaller amount of product than expected. They can predict the amount of product made in a reaction by calculating the percentage yield.

The percentage yield links the actual amount of product made, in moles, and the theoretical yield, in moles:

$$\text{percentage yield} = \frac{\text{actual amount (in moles) of product}}{\text{theoretical amount (in moles) of product}} \times 100$$

Look at this worked example. A student added ethanol to propanoic acid to make the ester, ethyl propanoate, and water.

$C_2H_5OH + C_2H_5COOH \rightarrow C_2H_5COOC_2H_5 + H_2O$

The experiment has a theoretical yield of 5.00 g.

The actual yield is 4.50 g.

The molar mass of $C_2H_5COOC_2H_5$ = 102.0 g mol^{-1}

Calculate the percentage yield of the reaction.

Actual amount of ethyl propanoate: n (number of moles) = $\frac{\text{Mass (m)}}{\text{Relative Mass (Mr)}}$ = 4.5/102 = 0.0441 mol

Theoretical amount of ethyl propanoate: = n = $\frac{m}{Mr}$ = 5.0/102 = 0.0490 mol

percentage yield = (0.0441/0.0490) × 100% = 90%

Practice questions GCSE (See task 1: Maths skills for examples on significant figures)

4 Calculate the percentage yield of a reaction with a theoretical yield of 4.75 moles of product and an actual yield of 3.19 moles of product. Give your answer to 3 significant figures.

5 Calculate the percentage yield of a reaction with a theoretical yield of 12.00 moles of product and an actual yield of 6.25 moles of product. Give your answer to 3 significant figures.

Practice questions A-level

1. Write the equation for the reaction between iron (III) phosphate and sodium sulphate to form Iron (III) sulfate and sodium phosphate. (**See task 3 on balancing equations and chemical formula**)
2. If I perform this reaction with 25g of iron (III) phosphate and an excess of sodium sulphate, how many grams of iron (III) sulphate can I make?
3. If 18.5g of iron (III) sulphate are actually made when I do this reaction, what is my percentage yield?
4. Is the answer for question 3 reasonable? Explain.
5. If I do this reaction with 15g of sodium sulphate and get 65.0% yield, how many grams of sodium phosphate will I make?

Calculating percentage error in apparatus

The percentage error of a measurement is calculated from the maximum error for the piece of apparatus being used and the value measured:

$$\text{percentage error} = \frac{\text{maximum error}}{\text{measured value}} \times 100\%$$

Look at this worked example. In an experiment to measure temperature changes, an excess of zinc powder was added to 50 cm^3 of copper(II) sulfate solution to produce zinc sulfate and copper.

$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

The measuring cylinder used to measure the copper(II) sulfate solution has a maximum error of ±2 cm^3.

Worked examples:

a Calculate the percentage error.

percentage error = (2/50) × 100% = 4%

b A thermometer has a maximum error of ±0.05 °C.

Calculate the percentage error when the thermometer is used to record a temperature rise of 3.9 °C. Give your answer to 3 significant figures.

percentage error = (2 × 0.05)/3.9 × 100% = 2.56%

(Notice that two measurements of temperature are required to calculate the temperature change so the maximum error is doubled.)

Practice questions A-level

1. A gas syringe has a maximum error of ±0.5 cm^3. Calculate the maximum percentage error when recording these values. Give your answers to 3 significant figures.

a 21.0 cm^3 **b** 43.0 cm^3

1. A thermometer has a maximum error of ±0.5 °C. Calculate the maximum percentage error when recording these temperature rises. Give your answers to 3 significant figures.

a 12.0 °C **b** 37.6 °C

Part 2: Calculating atom economy

Atom economy

The idea of yield is useful, but from a Green Chemistry and sustainable development perspective, it is not the full picture. This is because yield is calculated by considering only one reactant and one product. One of the key principles of Green Chemistry is that processes should be designed so that the maximum amount of all the raw materials ends up in the product and a minimum amount of waste is produced. A reaction can have a high percentage yield but also make a lot of waste product. This kind of reaction has a low atom economy. Both the yield and the atom economy have to be taken into account when designing a green chemical process.

$$CaCO_3 \rightarrow CaO + CO_2$$

RMM or Mr : 100 56 44

If we split up the formulae, we can look at what happens to each atom in the reaction. The atoms shown below in bold end up in the product we want, the rest do not:

Ca C O O O → Ca O + C O O

Waste box: 1C

From the original atoms, one C atom and two O atoms are wasted – they are not in the final, useful product.

Green chemists define atom economy as:

$$\text{\% Atom economy} = \frac{\text{Mass of wanted product(s)}}{\text{Total mass of products}} \times 100$$

So for this example,

$$\text{\% Atom economy} = \frac{56}{100} \times 100 = 56\%$$

Step-by-step: How to calculate atom economy

Step 1. Write out the balanced equation.

Step 2. Calculate the relative molecular mass of each of the products.

Step 3. Calculate the total mass of all the products (remember to account for any numbers in front of the symbols, eg $2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$).

Step 4. Work out which of the products are wanted and calculate their mass (again, do not forget any numbers in front of the symbols).

Apply the formula: $\text{\% Atom economy} = \frac{\text{Mass of wanted product(s)}}{\text{Total mass of products}} \times 100$

Practice questions (A-level):

1. Iron is extracted from its ore using carbon: $2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$ .What is the atom economy of this reaction?

2. Titanium can be extracted from its ore by two different methods. One uses a more reactive metal to displace the titanium:

$TiO_2 + 2\ Mg \rightarrow Ti + 2\ MgO$

The second method is electrolysis of the ore. The overall reaction for this method is: $TiO_2 \rightarrow Ti + O_2$

a) Calculate the atom economy for each reaction.

b) Which method is 'greener'? What else might you want to know before making a final decision?

c) Oxygen is a useful product and can be sold. What is the atom economy of the electrolysis if the oxygen is collected and sold?

3. Alkanes can be cracked to form alkenes. Decane can be cracked to form two products:

$C_{10}H_{22} \rightarrow C_2H_4 + C_8H_{18}$

a) If only the alkene can be sold, what is the atom economy of this process?

b) If both products can be sold, what is the atom economy?

c) Explain why your answers to (a) and (b) are different.

4. The key reaction in the Haber process for making ammonia is:

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

a) What is the atom economy of this reaction? (You should not need to do a calculation.)

b) What does the symbol suggest about the likely yield of this reaction?

5. Explain why using reactions with high atom economy is important for sustainable development.