Student maths skills worksheet

Name .... Class .... Date ....

Calculating rates from graphs

Aims

This worksheet gives you practice at calculating the rate of a reaction from data showing the quantity of product formed or the quantity of reactant used up against time. Initially you are asked to calculate the mean rate of the reaction at a specific time. Later on in the questions you are asked to calculate the actual rate at a specific time, by drawing the tangent to the curve at the specified time and calculating the gradient of the tangent.

Learning outcomes

After completing this worksheet, you should be able to:

- recall a definition for rate of reaction
- state the units for, and explain how there can be different units for measuring rate of reaction
- calculate the mean rate of reaction from given information about the quantity of reactant used or the quantity of product formed in a given time
- draw and interpret graphs showing the quantity of product formed or quantity of reactant used up against time
- draw tangents to curves and use the slope of the tangent as a measure of the rate of the reaction
- calculate the gradient of a tangent to a curve as a measure of the rate of a reaction at a specific time. (H)

Setting the scene

The **rate of a chemical reaction** tells you how fast reactants are turned into products. You can work out the rate of a reaction by finding out how quickly:

- the reactants are used up as they make products, or
- the products of the reaction are made.

Reactions start off quickly and then slow down as the reaction progresses. The **mean rate** of a reaction tells you the mean rate for the reaction after a certain amount of time. You can calculate the mean rate of a reaction by using the equation:

$$\text{mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{time}} \text{ or } \frac{\text{quantity of product formed}}{\text{time}}$$

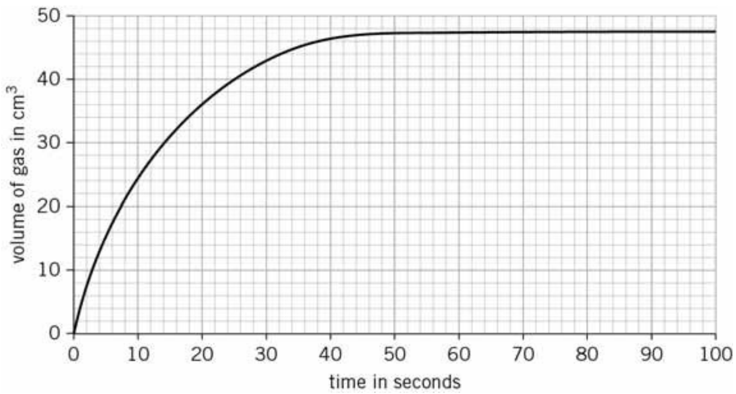
A graph can be plotted to show how the quantity of product formed or the quantity of reactant used up changes with time. The gradient of the curve at a specific time indicates the **actual rate** of the reaction at that time. The rate can be calculated by drawing a tangent to the curve at that point, followed by calculating the gradient of the tangent drawn.

Worked example

A student is investigating the rate of the reaction between magnesium and hydrochloric acid. The equation for the reaction is;

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

She measures the volume of gas produced every 10 seconds and plots the results on a graph.



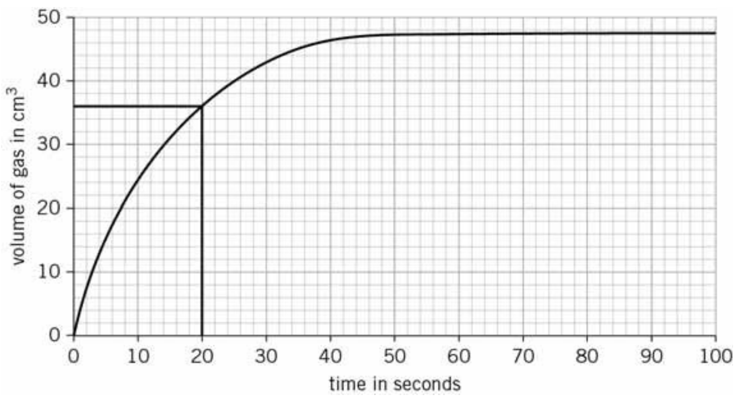
Example 1:

Calculate the **mean rate** of the reaction after 20 seconds.

Step 1

Using the graph, first of all find out the total volume of gas produced after 20 seconds.

HINT: always draw horizontal and vertical lines on the graph to help with reading the values of the axes.



After 20 seconds, 36 cm^3 of gas has been produced.

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Step 2

Then substitute the values into the equation;

$$\text{mean rate of reaction} = \frac{\text{quantity of product formed}}{\text{time}}$$

$$= \frac{36\ \text{cm}^3}{20\ \text{s}}$$

$$= 1.8\ \text{cm}^3/\text{s}$$

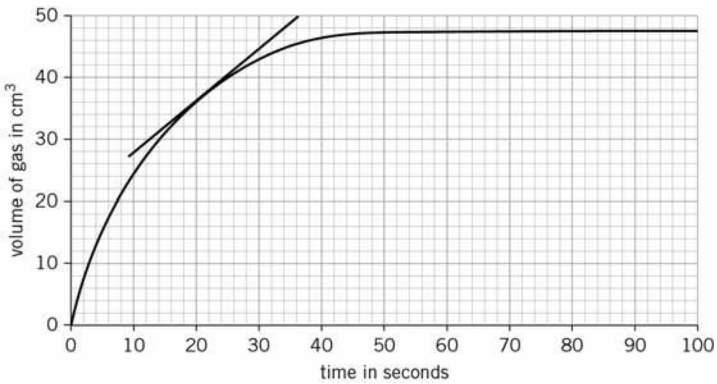
The units of rate are taken from the equation. In this case a volume in cm^3 is divided by a time in seconds, and so the units of rate are cm^3 per second or cm^3/s.

Example 2:

Calculate the rate of the reaction at 20 seconds.

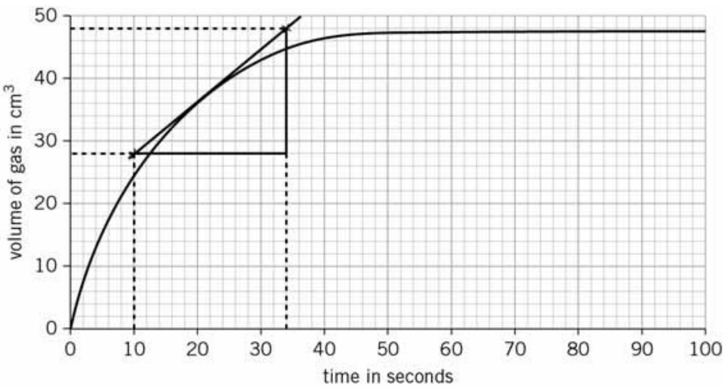
Step 1

You need to draw a tangent to the curve at the specified time (a straight line that just touches the curve at that point).



Step 2

Then construct a right angled triangle, using the tangent as its longest side. Choose two points which you can easily read the values for from the axes as the corners for the triangle and make the triangle as large as possible to reduce measurement errors.



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Step 3

Calculate the gradient of the tangent using the equation:

$$\text{gradient} = \frac{\text{change in } y}{\text{change in } x}$$

change in $y = 48\ \text{cm}^3 - 28\ \text{cm}^3 = 20\ \text{cm}^3$

change in $x = 34\ \text{s} - 10\ \text{s} = 24\ \text{s}$

$$\text{gradient} = \frac{20\ \text{cm}^3}{24\ \text{s}} = \mathbf{0.83\ cm^3/s}$$

Questions

1 Use the data provided to calculate the mean rate at the time indicated for each of the following reactions. Remember to include units.

a The decomposition of hydrogen peroxide in which 15 cm^3 of oxygen was produced after 6 minutes.

....

.... (*2 marks*)

b The reaction between sodium thiosulfate and acid in which 6 g of sulfur was produced in 24 seconds.

....

.... (*2 marks*)

c The reaction between calcium carbonate and hydrochloric acid in which 0.6 g of calcium carbonate was used up after 2.5 minutes.

....

.... (*2 marks*)

d The reaction between lithium and water in which 2.5×10^{-3} moles of hydrogen is produced in 10 seconds.

....

.... (*2 marks*)

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2 Stephen is investigating the rate of the reaction between calcium carbonate and hydrochloric acid. The equation for the reaction is;

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

He adds 5.0 g of calcium carbonate to an excess of hydrochloric acid and measures the mass of carbon dioxide given off every 10 seconds. The results of his reaction are shown in the table.

Time in seconds	Mass of CO_2 produced in grams
0	0
10	13
20	18
30	22
40	24
50	25
60	26
70	26
80	26

a Plot a graph of mass of carbon dioxide produced (*y*-axis) against time (*x*-axis). (*4 marks*)

b Calculate the mean rate of the reaction after 15 seconds.

....

.... (*2 marks*)

c After how many seconds has the reaction finished?

.... (*1 mark*)

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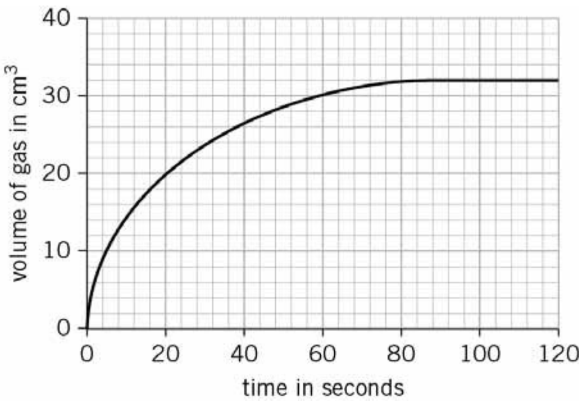
3 The graph below shows how much hydrogen was given off during the reaction between magnesium ribbon and hydrochloric acid.



a Calculate the rate of the reaction at:

i 20 seconds

....

.... (*2 marks*)

ii 40 seconds.

....

.... (*2 marks*)

b Show by calculation that the mean rate between 40 and 60 seconds is slower than the mean rate between 0 and 20 seconds.

....

.... (*2 marks*)

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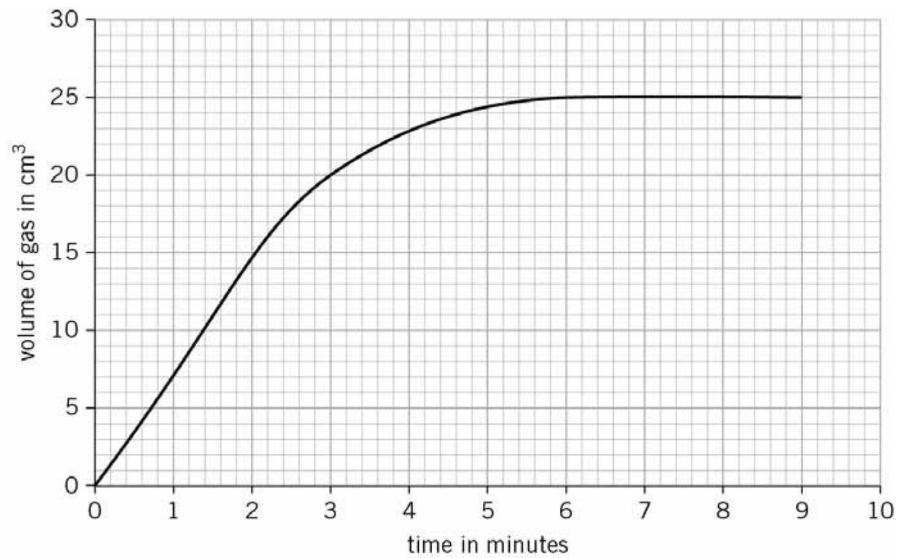
Student follow up

1 Zinc reacts with sulfuric acid to produce a salt and hydrogen gas.

A student investigates how the size of the pieces of zinc used in reaction affects the rate of the reaction.

He reacts 2.0 g of zinc granules with an excess of sulfuric acid and measures the volume of hydrogen given off.



a Name the salt produced in this reaction.

.... (*1 mark*)

b Calculate the mean rate of the reaction up to the time the reaction is complete.

....

....

.... (*3 marks*)

c Calculate the rate of the reaction at 3 minutes.

....

.... (*2 marks*)

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The student repeats the experiment using 2.0 g of powdered zinc.

d i Sketch a line on the graph to show the results you would expect with the powdered zinc. (*2 marks*)

ii Explain your reasoning behind the line you have sketched.

....

....

.... (*3 marks*)

Maths skills links

You will also need to be able to translate information between graphical and numerical form when drawing reaction profiles and when looking at life cycle assessments.

GCSE Chemistry

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Moles and mass calculations

Specification references

- C3.2.1 Moles (H)
- C3.2.2 Amounts of substances in equations (H)
- MS 1a, 1c, 3a, 3b, 3c

Aims

This worksheet gives you practice in converting mass into moles and vice versa. It also gives you practice in calculating the masses of reactants (or products) using a balanced symbol equation and the mass of another reactant (or product).

Learning outcomes

After completing this worksheet, you should be able to:

- calculate the relative formula mass for one substance when the relative formula masses are given for all the other substances in a balanced symbol equation
- interpret balanced symbol equations in terms of mole ratios
- use balanced symbol equations to calculate reacting masses.

Setting the scene

The reaction between H_2 and O_2 to make water, H_2O, is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

From the balanced symbol equation, we know that two molecules of hydrogen, H_2, react with one molecule of oxygen, O_2, to form two molecules of water, H_2O. However, when working with chemicals it is very difficult to measure the mass of an individual atom or molecule because these masses are so tiny. Instead, chemists have invented a unit that is similar to the way we might say that one dozen eggs contains 12 eggs. This unit is called a mole: 1 mole of an element contains 6.02×10^{23} atoms and 1 mole of a compound contains 6.02×10^{23} molecules or ions.

The relative atomic mass (A_r) in grams of an element contains 1 mole of atoms. The relative formula mass (M_r) in grams of a compound contains 1 mole of molecules or ions. Therefore, if we know the mass of an element or compound in grams, we can calculate the number of moles it contains using the formula:

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

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We can also use the number of moles involved in a chemical equation to calculate the number of moles – and therefore the masses – of all the other reactants or products in that equation.

Worked examples

Example 1

Calculate the number of moles in 45 g of water, H_2O.

(A_r values: O = 16, H = 1)

Step 1

First, calculate the M_r of water:

$= (2 \times H) + (1 \times O)$

$= (2 \times 1) + (1 \times 16)$

$= 18$

Step 2

Then use the equation:

$$\text{number of moles} = \frac{\text{mass (g)}}{M_r}$$

to calculate the amount in moles:

$$\text{number of moles} = \frac{45\text{ g}}{18} = 2.5\text{ mol}$$

So 45 g of water contains 2.5 moles.

Example 2

Calculate the mass of oxygen that must react to make 45 g of water.

(A_r values: O = 16, H = 1)

Step 1

First write out the balanced symbol equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Step 2

Then calculate the number of moles in 45 g of water – we know from Example 1 that the answer is 2.5 moles.

Step 3

Next, use the ratio of moles given in the balanced equation to calculate the number of moles of oxygen that must react to make 2.5 moles of water.

From the balanced equation, you can see that 2 moles of hydrogen react with 1 mole of oxygen to make 2 moles of water.

So the oxygen and the water appear in the balanced symbol equation in a 1 : 2 ratio.
Therefore, the number of moles of oxygen that must react = 2.5 mol ÷ 2 = 1.25 mol.

Step 4

Finally, calculate the mass of oxygen that contains 1.25 moles:

$\text{number of moles (mol)} \quad \frac{\text{mass (g)}}{M_r}$ therefore

$$\text{mass (g)} = \text{number of moles (mol)} \times M_r$$

M_r O_2 = (2 × O) = (2 × 16) = 32

Substituting into the equation:

mass (g) = 1.25 mol × 32 = 40

So 40 g of oxygen is needed to produce 45 g of water.

Questions

Relative atomic masses (A_r): H = 1; C = 12; N = 14; O = 16; Mg = 24; Ca = 40

1 Calculate the mass of one mole of each of the following substances:

- **a** Ammonia, NH_3
- **b** Methane, CH_4
- **c** Calcium carbonate, $CaCO_3$
- **d** Magnesium hydroxide, $Mg(OH)_2$. (*4 marks*)

2 **a** Calculate the mass of the following:

- **i** 3 moles of ammonia
- **ii** 4.5 moles of methane
- **iii** 0.2 moles of calcium carbonate
- **iv** 1.4 moles of magnesium hydroxide. (*4 marks*)

b Calculate the number of moles in the following:

- **i** 136 g of ammonia
- **ii** 160 g of methane
- **iii** 250 g of calcium carbonate
- **iv** 2.9 g of magnesium hydroxide. (*4 marks*)

c 15.3 g of an unknown substance was found to contain 0.15 moles.
Calculate the relative formula mass of the substance. (*1 mark*)

3 Calcium carbonate breaks down on heating to produce calcium oxide and carbon dioxide gas.

$$CaCO_3 \rightarrow CaO + CO_2$$

A student heats 15 g of calcium carbonate strongly in a crucible.

Relative atomic masses (A_r): Ca = 40, C = 12, O = 16.

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a Calculate the number of moles in 15 g of calcium carbonate. (*2 marks*)

b Use your answer to part **a** to determine the number of moles of calcium oxide that will be produced. (*1 mark*)

c Calculate the mass of calcium oxide produced by this reaction. (*2 marks*)

4 A student is preparing a sample of sodium nitrate, $NaNO_3$.

She mixes 17 g of sodium oxide with an excess of nitric acid. The equation for the reaction is:

$$Na_2O + 2HNO_3 \rightarrow 2NaNO_3 + H_2O$$

Relative atomic masses (A_r): Na = 23, O = 16, N = 14, H = 1.

a Calculate the number of moles in 17 g of sodium oxide. (*2 marks*)

b Calculate the maximum mass of sodium nitrate that can be produced in this reaction. (*3 marks*)

5 Aluminium and iron oxide (Fe_2O_3) react together to produce aluminium oxide (Al_2O_3). The equation for the reaction is:

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$$

Calculate the mass of iron that is produced by reacting 20 g of iron oxide with an excess of aluminium.

Relative atomic masses (A_r): Al = 27, O = 16, Fe = 56. (*4 marks*)

Maths skills links

You may also need to convert the mass of a substance into an amount in moles (and vice versa) when using moles to balance equations.