Calculating rates of reactions

4.6.1.1 · The rate and extent of chemical change · revision notes

How to measure the rate of a reaction and calculate it from tables of results and from graphs of the amount of product formed (or reactant used) against time. Expect mean rate calculations and graph reading. On Higher tier you also calculate the gradient of a tangent to find the rate at one moment, and give rates in mol/s. These questions often link to the rates required practical.

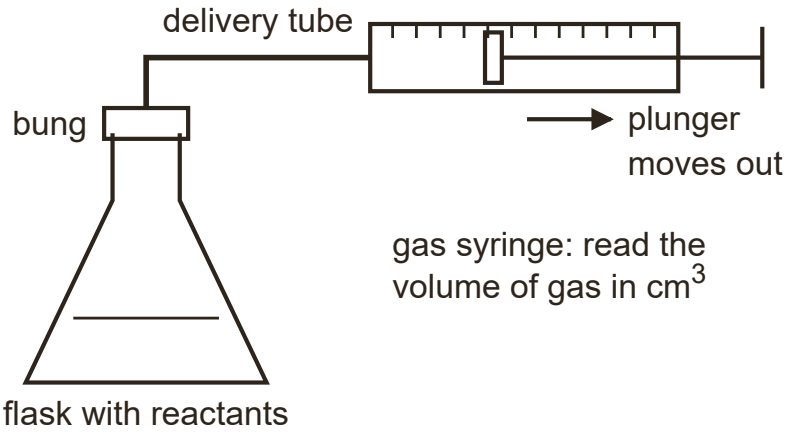
Key facts

- Mean rate = quantity of reactant used ÷ time taken
- Units of rate: g/s or cm^3/s
- Steeper curve = faster rate; horizontal line = reaction finished
- Grade 7+ only Rate at a given time = gradient of the tangent = change in y ÷ change in x
- Mean rate = quantity of product formed ÷ time taken
- Grade 7+ only Higher tier: rate in mol/s, where moles = mass ÷ M_r
- Tangent: a straight line touching the curve at one point, with the same slope as the curve there
- 1 minute = 60 s; 1 dm^3 = 1000 cm^3

Notes

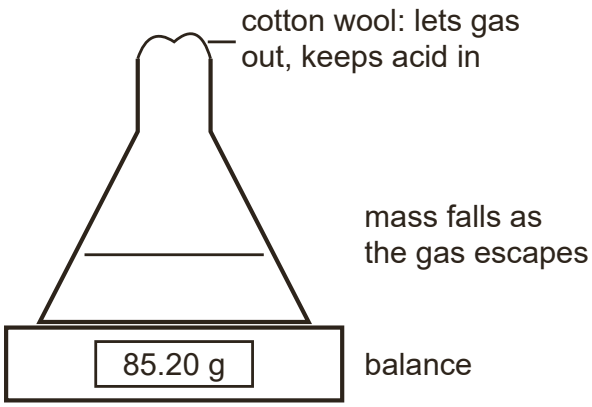
Measuring the rate

- The **rate of reaction** tells you how quickly a reactant is used up or a product is formed.
- You follow a reaction by measuring the **mass** (in g) of a reactant or product, or the **volume** of a gas (in cm^3), at regular time intervals.
- Volume of gas: collect it in a gas syringe, or in an upside-down measuring cylinder filled with water.



Collecting a gas in a gas syringe: record the volume every 10 or 30 seconds.

- Mass: if a gas escapes, stand the flask on a balance. The mass lost is the mass of gas given off.



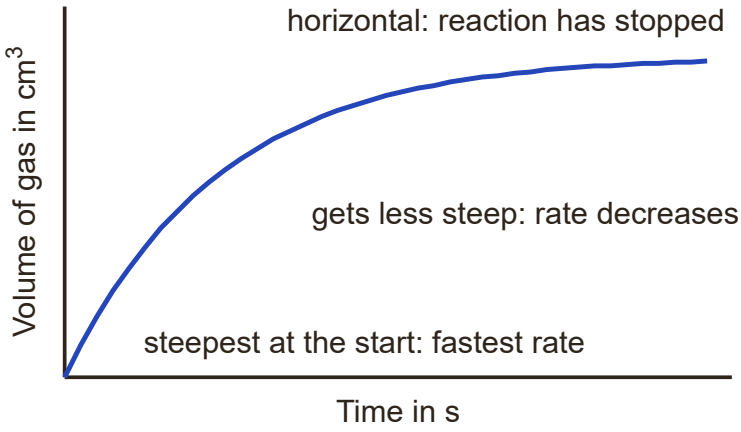
Following mass loss: the flask stands on a balance while the gas escapes.

Mean rate

- mean rate of reaction = quantity of reactant used ÷ time taken
- mean rate of reaction = quantity of product formed ÷ time taken
- The unit is the quantity unit ÷ the time unit: g/s or cm^3/s (or g/min, cm^3/min if the time is in minutes).
- Between two times, use the change in quantity ÷ the change in time (e.g. 20 s to 60 s is 40 s).
- Higher tier: the quantity may be in moles, giving a rate in **mol/s**. Convert a mass to moles first: moles = mass ÷ M_r. Grade 7+ only

Reading rate graphs

- Plot the quantity (y-axis) against time (x-axis) and draw a smooth curve of best fit.
- The steeper the curve, the faster the reaction. It is steepest at the start, when there are the most reactant particles.

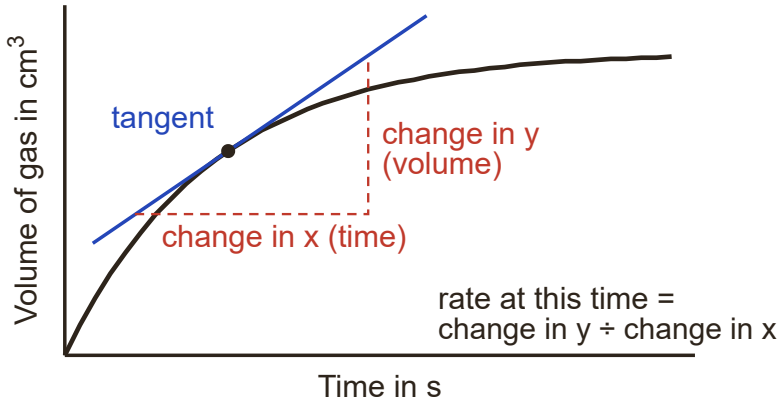


A typical rate curve. The gradient (steepness) shows the rate.

- The curve gets less steep as the reactants are used up, so the rate decreases.
- When the line becomes horizontal, the reaction has stopped because one of the reactants has been used up.
- A graph of the mass of the flask (as gas escapes) slopes down and then levels off. Here too, a steeper slope means a faster rate.

Rate at one moment: tangents

- For the rate at a particular time, draw a **tangent**: a straight line touching the curve at that time, with the same steepness as the curve there.



Tangent at one time (blue). Make the triangle large to read the values accurately.

- The steeper the tangent, the faster the rate at that moment.
- Higher tier: calculate the gradient of the tangent = change in y ÷ change in x. Use two points on the tangent (not on the curve) that are far apart. Grade 7+ only
- The unit is the y-axis unit ÷ the x-axis unit, e.g. cm^3/s. Grade 7+ only

How to answer each type of question

Calculate the mean rate of reaction

2 to 3 marks | **Grade 4**

1. Read the quantity at the start and at the end of the time interval from the table or graph.
2. Find the change in quantity and the time taken. Convert minutes to seconds if the unit asked for is per second.
3. Divide the quantity by the time and give the unit.

Example. A student reacted zinc with dilute sulfuric acid and collected the hydrogen in a gas syringe. After 2 minutes, 84 cm^3 of hydrogen had been collected.
Calculate the mean rate of reaction in the first 2 minutes.
Give your answer in cm^3/s.

Model answer.

time = 2 × 60 = 120 s (1)

mean rate = 84 ÷ 120 (1)

= 0.70 cm^3/s (1)

Explain the shape of a rate graph

2 to 3 marks | **Grade 5**

1. Describe each part: steepest at the start, then less steep, then horizontal.
2. Explain the start: the concentration of reactants is highest, so the rate is fastest.
3. Explain the slowing down: reactants are being used up, so there are fewer collisions per second.
4. Explain the flat part: one reactant has been used up, so the reaction has stopped.

Example. A student added marble chips to excess hydrochloric acid and measured the volume of carbon dioxide produced. The graph of volume against time is steepest at the start, gradually becomes less steep, and is horizontal from 150 s onwards.
Explain the shape of the graph.

Model answer. The rate is fastest at the start because there are the most reactant particles, so collisions are most frequent (1). The rate decreases because the marble chips are being used up, so there are fewer collisions per second (1). The line is horizontal after 150 s because all the marble chips have reacted, so the reaction has stopped (1).

Determine the rate at a given time from a tangent

3 to 4 marks | **Grade 7**

1. Draw a tangent at the given time with a ruler: it touches the curve there and has the same steepness.
2. Make the tangent long and choose two points on it that are far apart.
3. Gradient = change in y ÷ change in x.
4. Give the unit: the y-axis unit ÷ the x-axis unit.

Example. A student plotted the volume of oxygen produced against time when hydrogen peroxide decomposed. They drew a tangent to the curve at 40 s. The tangent passes through the points (0 s, 22 cm^3) and (80 s, 62 cm^3).
Calculate the rate of reaction at 40 s.
Give the unit.

Model answer.

change in volume = 62 − 22 = 40 cm^3 and change in time = 80 − 0 = 80 s (1)

rate = 40 ÷ 80 (1)

= 0.50 (1)

cm^3/s (1)

Calculate a mean rate in mol/s

2 to 3 marks | **Grade 7**

1. Convert the mass to moles: moles = mass ÷ M_r (use A_r for an element).
2. Make sure the time is in seconds.
3. Divide the number of moles by the time. Standard form is often the neatest way to write the answer.

Example. In an experiment, 0.60 g of magnesium reacted completely with excess hydrochloric acid in 125 s.
Calculate the mean rate of reaction in mol/s.
Relative atomic mass (A_r): Mg = 24

Model answer.

moles of magnesium = 0.60 ÷ 24 = 0.025 mol (1)

mean rate = 0.025 ÷ 125 (1)

= 2.0×10^{-4} mol/s (1)

Don’t lose marks

- Dividing the time by the quantity (giving s/cm^3) instead of the quantity by the time.
- For a mean rate between two times, using just the final reading instead of the change during that interval.
- Forgetting to convert minutes to seconds when the unit asked for is per second.
- Drawing a 'tangent' that cuts across the curve, or reading the gradient from points on the curve instead of on the tangent.

- Leaving out the unit, or writing cm^3 instead of cm^3/s.

More tips

Memory tricks

- 'Per' means 'divide by': cm^3/s means cm^3 per second, so the calculation is volume ÷ time.
- Sense check: the mean rate over the whole reaction must be lower than the rate at the very start.
- Extend a tangent across most of the graph and pick points where it crosses grid lines: the gradient is easier to read and more accurate.
- In mass-loss experiments, the mass lost is the mass of gas made, so use it as the 'quantity of product formed'.

Exam technique

- Always write the division out (e.g. 84 ÷ 120) so you can earn method marks even if the final answer slips.
- Check the unit and the number of significant figures asked for in the question (g/s, cm^3/s or mol/s).
- When asked how a graph shows the reaction has finished, say the line is horizontal (levels off), so no more product is being made.
- In tangent questions, draw on the graph in pencil with a ruler: the tangent itself usually earns a mark.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Say what the rate of reaction measures**
Rate is how quickly a reactant is used up or a product is formed.

Grade 4 — **Calculate a mean rate of reaction**
Divide the quantity of reactant used or product formed by the time taken, e.g. 30 cm^3 ÷ 20 s = 1.5 cm^3/s.

Grade 4 — **Give the correct unit for rate**
Use g/s for a mass or cm^3/s for a volume of gas, matching the units of the quantity and the time.

Grade 5 — **Interpret graphs of product formed against time**
The steeper the curve, the faster the rate; a horizontal line means the reaction has stopped.

Grade 5 — **Draw a tangent to a rate curve**
Draw a straight line that touches the curve at the chosen time; its slope is a measure of the rate at that time.

Grade 7 — **Calculate the gradient of a tangent**
Rate at that time = change in y ÷ change in x, using two points far apart on the tangent.

Grade 7 — **Calculate a mean rate in mol/s**
Convert a mass to moles with moles = mass ÷ M_r (or A_r), then divide by the time in seconds.

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