Collision theory and activation energy

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

Collision theory explains why concentration, pressure, surface area and temperature change the rate of a reaction. Expect 2 to 4 mark 'explain' questions using the ideas of collision frequency and activation energy, plus surface area to volume ratio calculations and simple proportionality.

Key facts

- Particles must collide with at least the activation energy to react
- Higher concentration or pressure → more particles in the same volume → more frequent collisions
- Higher temperature → faster particles → more frequent AND more energetic collisions
- Smaller pieces → larger surface area to volume ratio → faster reaction
- Activation energy = the minimum energy particles must have to react
- Larger surface area → more exposed particles → more frequent collisions
- Cube: surface area = 6 × side^2; volume = side^3
- Double the concentration → double the collision frequency → double the rate (in simple cases)

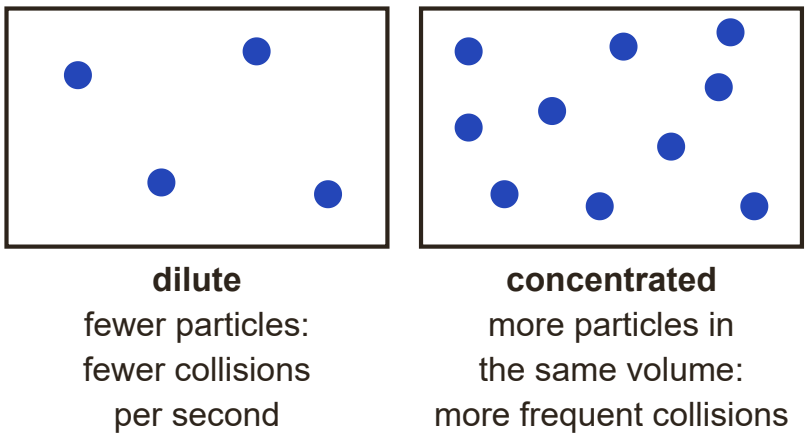
Notes

Collision theory

- Chemical reactions can only happen when reacting particles **collide** with each other **with enough energy**.
- The **activation energy** is the minimum amount of energy that particles must have to react.
- Collisions with less energy than the activation energy do not lead to a reaction: the particles just bounce apart.
- The rate depends on the **frequency** of successful collisions: the number of successful collisions per second.

Explaining each factor

- Higher **concentration** (solutions) or higher **pressure** (gases): more reactant particles in the same volume, so collisions are more frequent.

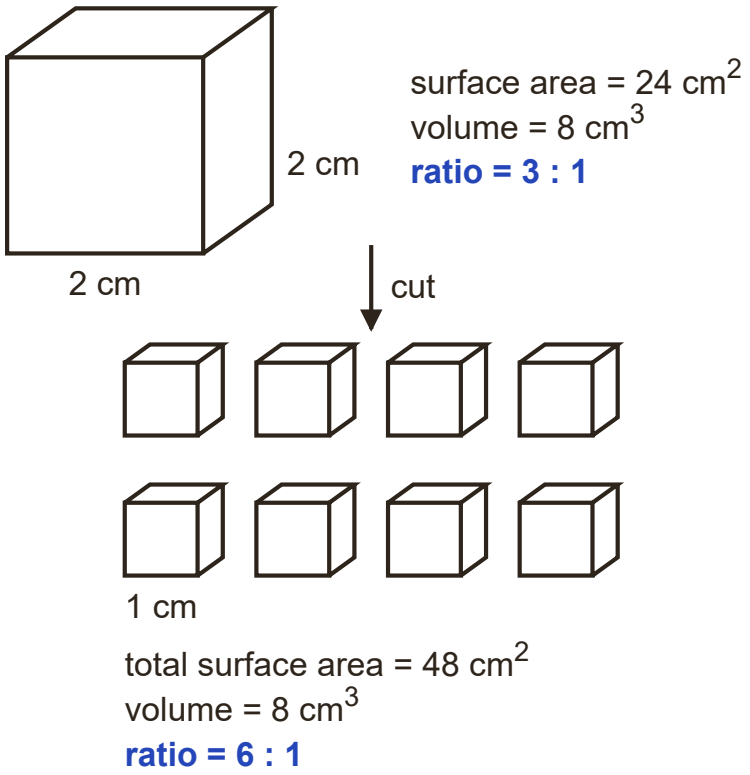


Same volume, more reactant particles, so collisions happen more often.

- Larger **surface area**: more particles of the solid are exposed to the other reactant, so collisions are more frequent.
- Higher **temperature**: particles move faster, so collisions are more frequent. The collisions are also more energetic, so a greater proportion of them have energy equal to or greater than the activation energy.
- Temperature is the only one of these factors that changes the energy of the collisions as well as their frequency.

Surface area to volume ratio

- Cutting a solid into smaller pieces does not change its total volume but increases its total surface area, so the surface area to volume ratio increases.
- A 2 cm cube: surface area = 6 × 2 × 2 = 24 cm^2, volume = 2 × 2 × 2 = 8 cm^3, ratio = 24 : 8 = 3 : 1.
- Cut it into eight 1 cm cubes: total surface area = 8 × 6 = 48 cm^2, volume still 8 cm^3, ratio = 6 : 1.

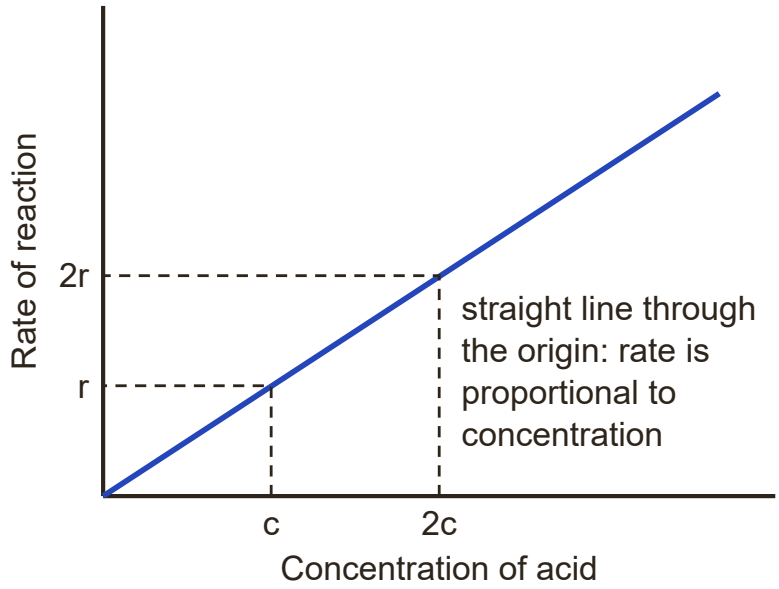


Cutting the cube up doubles the surface area but keeps the volume the same.

- The larger the ratio, the more particles are exposed, so the more frequent the collisions and the faster the reaction.

Proportionality

- Doubling the concentration of a solution gives twice as many reactant particles in the same volume.
- In simple cases this doubles the frequency of collisions, so the rate doubles: the rate is directly proportional to the concentration.



Double the concentration, double the rate: a straight line through (0, 0).

- To check data for direct proportionality: doubling one quantity should double the other, and a graph of one against the other is a straight line through the origin. Grade 8+ only

How to answer each type of question

Explain the effect of concentration, pressure or surface area 2 marks Grade 5

1. Say what happens to the particles: more in the same volume, or more exposed.
2. Link to collisions: collisions are more frequent (more collisions per second).
3. Conclude that the rate increases.

Example. Explain why magnesium reacts faster with concentrated hydrochloric acid than with dilute hydrochloric acid.

Model answer. In the concentrated acid there are more acid particles in the same volume (1), so collisions between acid particles and magnesium are more frequent (1).

Explain the effect of temperature

3 marks | Grade 5

1. Particles have more energy and move faster.
2. So collisions are more frequent.
3. And a greater proportion of collisions have energy equal to or greater than the activation energy.

Example. A student found that a reaction was faster at 40 °C than at 20 °C.
Explain why, in terms of particles.

Model answer. At 40 °C the particles have more energy and move faster (1). So they collide more frequently (1). And a greater proportion of the collisions have energy equal to or greater than the activation energy, so more collisions are successful (1).

Calculate surface area to volume ratios and explain

3 to 5 marks | Grade 7

1. Surface area of a cube = 6 × side × side.
2. Volume of a cube = side × side × side.
3. Write the ratio surface area : volume and simplify it to 'something : 1'.
4. Link: larger ratio → more particles exposed → more frequent collisions → faster reaction.

Example. A 3 cm cube of calcium carbonate is cut into 1 cm cubes.
(a) Calculate the surface area to volume ratio of the 3 cm cube.
(b) Give the surface area to volume ratio of one 1 cm cube.
(c) Explain why the small cubes react faster with hydrochloric acid than the large cube.

Model answer.

(a) surface area = 6 × 3 × 3 = 54 cm^2 and volume = 3 × 3 × 3 = 27 cm^3 (1)
ratio = 54 : 27 = 2 : 1 (1)
(b) 6 : 1 (1)
(c) The small cubes have a larger surface area to volume ratio, so more particles are exposed to the acid (1), so collisions are more frequent (1).

Use proportionality to predict a change in rate

2 marks | Grade 8

1. Say how the number of particles in the same volume changes (e.g. halves).
2. Say the frequency of collisions changes by the same factor, so the rate does too.

Example. A student repeated a reaction with the concentration of the acid halved and everything else kept the same.
Predict how the initial rate would change. Explain your prediction using collision theory.

Model answer. The initial rate would halve (1). There are half as many acid particles in the same volume, so the frequency of collisions halves (1).

Don’t lose marks

- Writing 'more collisions' instead of 'more frequent collisions' or 'more collisions per second'. The time idea is needed for the mark.
- Saying particles move faster when the concentration increases. Only a temperature rise makes particles move faster.
- Saying a higher temperature lowers the activation energy. It does not: more particles have enough energy to overcome it.
- Saying particles 'collide harder' or 'with more force' instead of 'with more energy'.
- Saying larger pieces have more surface area. For the same mass, smaller pieces have the larger total surface area.

More tips

Memory tricks

- Every rate explanation follows one chain: particles → collisions → frequency (and energy) → rate.
- Temperature is the only factor with two effects: more frequent collisions AND more energetic collisions.
- Picture activation energy as a hurdle: only particles with enough energy get over it and react.
- For a cube, surface area to volume ratio = 6 ÷ side length, so halving the side doubles the ratio.

Exam technique

- Use the key words examiners look for: frequency, collisions per second, energetic, activation energy.
- For 3-mark temperature questions, give the speed/energy point, the frequency point and the activation energy point.
- When asked to 'use collision theory', write about particles and collisions, not about the reaction 'getting excited'.
- In ratio calculations, show the surface area (cm^2) and volume (cm^3) before the ratio, so you can earn method marks.

What each grade needs

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

Grade 3 — **State that particles must collide to react**
A reaction can only happen when reactant particles collide with each other.

Grade 4 — **Define activation energy**
The minimum amount of energy that particles must have to react.

Grade 5 — **Explain concentration and pressure effects**
There are more particles in the same volume, so collisions are more frequent.

Grade 5 — **Explain the effect of surface area**
More particles of the solid are exposed to the other reactant, so collisions are more frequent.

Grade 5 — **Explain the effect of temperature fully**
Particles move faster, so collisions are more frequent and more energetic, and more of them have at least the activation energy.

Grade 7 — **Calculate surface area to volume ratio**

For a cube, surface area = 6 × side^2 and volume = side^3; smaller pieces have a larger ratio.

Grade 8

Use proportionality to predict changes in rate

E.g. doubling the concentration doubles the frequency of collisions, so the rate doubles.

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