Cambridge IGCSE · Chemistry 0620 · Notes

Physical and chemical changes and rate of reaction

Read online at **pastopic.com/cambridge/chemistry-0620/notes/rate-of-reaction**

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Read first: **States of matter**, **Chemical energetics**

What you need to know

By the end of this topic you should be able to:

1. **Tell physical and chemical changes apart** and describe how they differ: a chemical change makes a new substance; a physical change does not.
2. **Describe how the rate of a reaction changes** when you change the **concentration** of a solution, the **pressure** of a gas, the **surface area** of a solid (the size of the pieces) or the **temperature**, or when you **add or remove a catalyst** (enzymes included).
3. **State that a catalyst speeds up a reaction and is unchanged at the end of it.**
4. **Describe practical methods for following the rate of a reaction**: measuring the volume of gas given off, or the change in mass as a gas escapes.
5. **Interpret data and graphs** from rate experiments: read values, decide when a reaction is fastest and when it has finished, and compare experiments.
6. **Extended only:** describe **collision theory** using the number of particles per unit volume, the frequency of collisions, the kinetic energy of the particles and the activation energy, E_a.
7. **Extended only:** explain each of the effects in point 2 using collision theory.
8. **Extended only:** state that a catalyst **lowers the activation energy** of a reaction.
9. **Extended only:** evaluate practical methods for following the rate of a reaction (which is more precise, what can go wrong, what must be kept the same).

Understand it

Physical and chemical changes

In a **chemical change** (a chemical reaction) the atoms are rearranged into **new substances** with new properties. Burning, rusting, cooking an egg, rotting food, neutralising an acid, cracking an alkane, fermentation and thermal decomposition are all chemical changes. Signs that one has happened: a gas is given off, a colour changes, a precipitate forms, or the temperature changes. Most chemical changes are hard to reverse.

In a **physical change** no new substance is made. The particles stay the same; only their arrangement or spacing changes. Every **change of state** (melting, freezing, boiling, evaporating, condensing, sublimation) is physical, and so are **dissolving** and **mixing**. Salt water can be evaporated to get the salt back, and ice melts back to water: physical changes are usually easy to reverse.

Two more facts to learn:

- In **both** kinds of change the **total mass stays the same** (atoms are never created or destroyed).
- A chemical change **always** makes a new substance but only **sometimes** involves a change of state (burning wax turns a solid into gases).

Watch for these:

- **Dissolving** sugar or salt in water is physical, but **adding a metal or a carbonate to an acid** is chemical (a gas and a salt form).
- **Heating** can cause either: melting ice or subliming iodine is physical; heating calcium carbonate until it decomposes is chemical.
- In equations, aqueous ions that **form a precipitate** show a chemical change. A solid dissolving into ions, ions that just stay mixed in solution, or a substance changing state shows a physical change.

What "rate" means

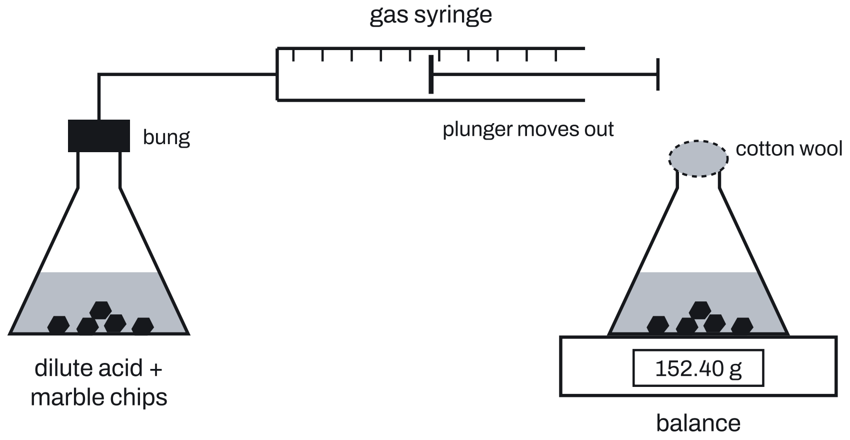
The **rate of reaction** is how fast a reactant is used up or a product is made. You can't see rate directly, so you measure something that changes during the reaction and see how fast it changes:

$$\text{average rate} = \frac{\text{amount of product formed (or reactant used)}}{\text{time taken}}$$

For example, $45\ \mathrm{cm}^3$ of gas in the first 50 s is an average rate of $45 \div 50 = 0.9\ \mathrm{cm}^3/\mathrm{s}$. The **shorter** the time to make a fixed amount of product, the **faster** the rate.

Following a reaction in the lab

Reactions that give off a gas are the easiest to follow, and are the ones examined.



- **Volume of gas.** The gas goes along a delivery tube into a **gas syringe** (or an upturned measuring cylinder or burette full of water). Start a **stop-watch** as the reactants are mixed and read the volume at regular times, or time how long it takes to collect a fixed volume. The bung must be tight so no gas escapes.
- **Mass lost.** Stand the flask on a **balance** with a loose **cotton wool plug** in the neck: it lets the gas out but stops acid spray escaping. The mass falls as the gas leaves; record it at regular times.
- To study **temperature**, you also need a **thermometer** (and a water bath to keep the temperature steady). A stop-watch is needed for every method.

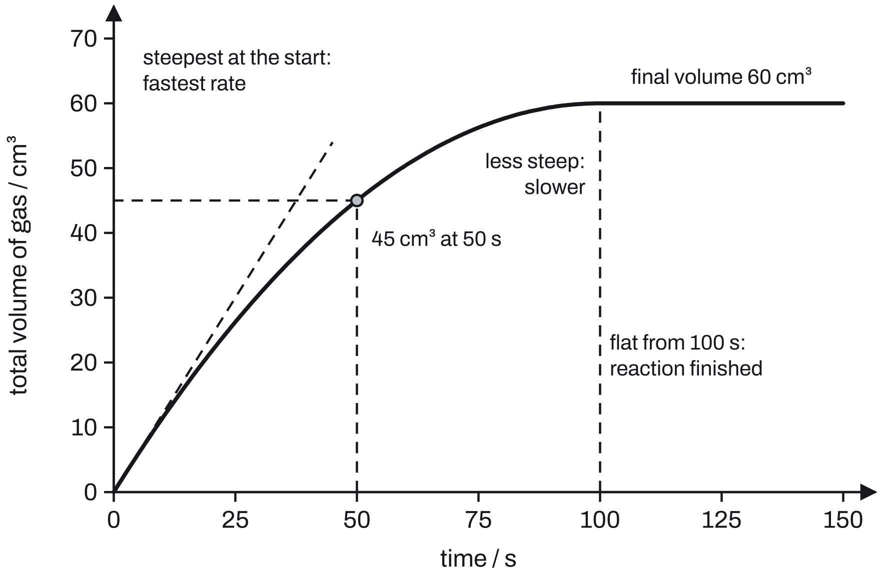
For a fair test, change **one** thing and keep everything else the same: the mass and size of the solid, the volume and concentration of the solution, and the temperature.

Extended only: evaluating the methods.

- A gas syringe measures volume more precisely than a measuring cylinder. A gas that dissolves in water (carbon dioxide a little, ammonia or chlorine a lot) can't be measured accurately over water; use a gas syringe.
- A burette isn't graduated right down to the tap, so it gives a less accurate volume than a gas syringe.
- The mass-loss method works well for a heavy gas such as carbon dioxide, but a light gas such as hydrogen changes the mass so little that the balance may barely detect it.
- Gas lost before the bung goes in, or through a leaky joint, makes every reading too low. Readings taken at intervals can't show exactly when the reaction stopped, only that it had stopped between two readings.

Reading a rate graph

Plot the volume of gas (or the mass lost) against time. The **gradient** (steepness) of the line is the rate.



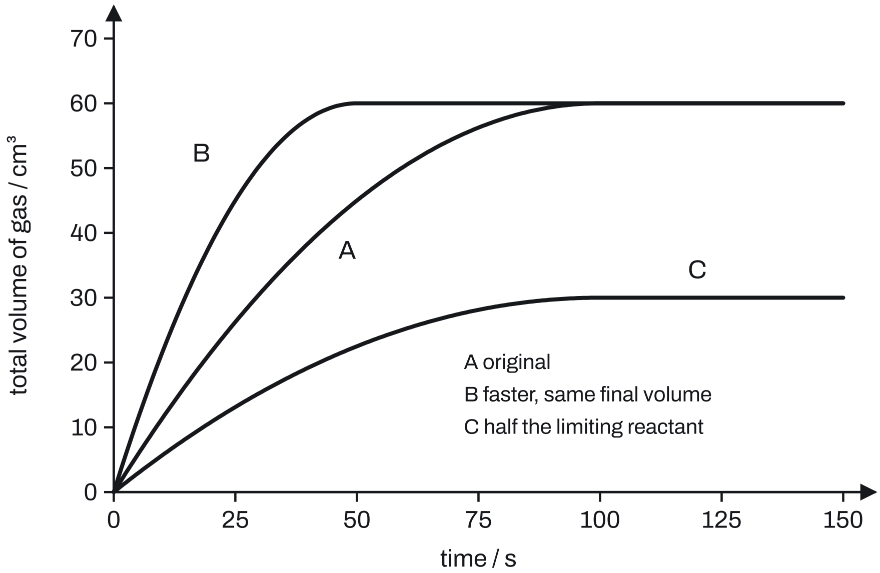
- The curve is **steepest at the start**: the rate is fastest there, because the reactants are most concentrated.
- The curve gets **less steep** as the reactants are used up, so the rate falls.
- The curve goes **flat** when the reaction has **finished**: one reactant, the **limiting reactant**, has all been used up. The other reactant is **in excess** (some is left over).
- The **final volume** depends only on **how much limiting reactant** there was. Making the reaction faster does not make more gas.

On a graph of the **mass of the flask** the line goes **down** and then flattens. On a graph of the mass of a solid reactant that is in excess, the line flattens **above zero**: some solid is left over.

What changes the rate

Change	Effect on rate	Effect on final amount of product
Higher temperature	Faster	None
More concentrated solution (same volume)	Faster	None if that solution is in excess; more if it is the limiting reactant
Diluting a solution with water	Slower	None (the same number of reactant particles)
Smaller pieces or powder (same mass)	Faster	None
Adding a catalyst (or an enzyme)	Faster	None
Higher pressure of a reacting gas	Faster	None

Doing the opposite (cooling, diluting, bigger lumps, removing the catalyst, lower pressure) makes the reaction slower. Using **more of the same solution** (a bigger volume at the same concentration) does **not** change the rate; it only changes the amount of product if that solution is the limiting reactant.



So when you draw or choose a second curve, ask two questions: **Is it faster or slower at the start?** (steeper or shallower) and **Is there more, less or the same limiting reactant?** (higher, lower or the same flat level). A faster reaction with the same limiting reactant (curve B) reaches the **same** final volume **sooner**. A slower one reaches the same final volume **later**.

Catalysts and enzymes

A **catalyst** is a substance that **increases the rate of a reaction** and is **chemically unchanged, with the same mass, at the end**. Because it isn't used up, a small amount works again and again. It does not change the amount of product made, and it does not change the energy given out or taken in. Transition elements and their compounds are often catalysts: manganese(IV) oxide speeds up the breakdown of hydrogen peroxide, and iron is used to make ammonia.

Enzymes are catalysts made by living things. They speed up reactions in the same way; take the enzyme away and the reaction slows down again.

To compare catalysts, time how long each takes to give the same volume of gas (or measure how much gas each gives in the same time): the **shortest time** (or the most gas) shows the **best** catalyst. A powdered catalyst works faster than lumps of the same catalyst, because more of its surface touches the reactants.

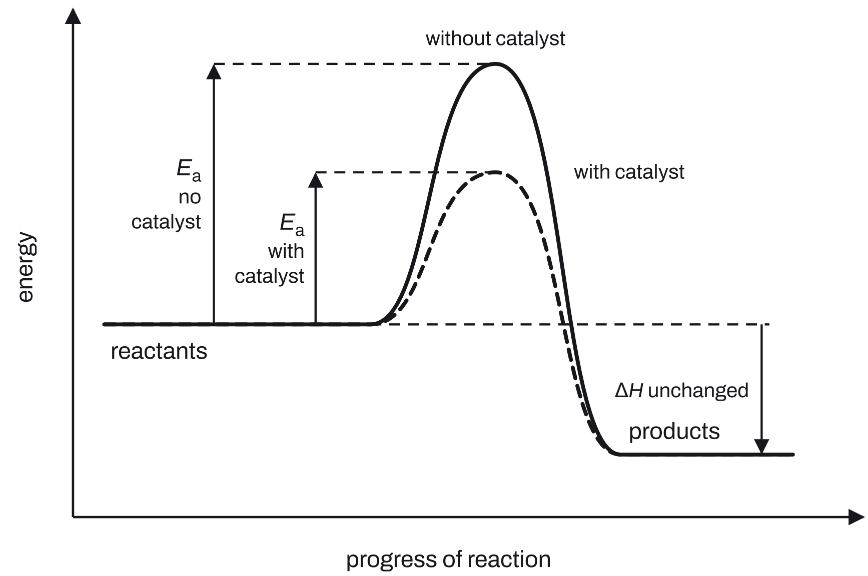
Collision theory (Extended)

Extended only. Particles can only react when they **collide**, and only a collision with at least a certain minimum energy leads to a reaction. That minimum is the **activation energy**, E_a. The rate depends on how many **successful** collisions happen **per second**, and that depends on two things:

- the **frequency of collisions** (how many collisions per second), and
- the **proportion** (fraction, percentage) of collisions with energy **equal to or greater than** E_a.

Each factor works through one or both of these:

- **Concentration.** More particles **per unit volume**, so they collide **more frequently**. Each particle has the same energy as before, so the proportion of collisions with enough energy is unchanged.
- **Pressure** (gases). Squeezing a gas into a smaller volume also puts more particles in each unit of volume: collisions become **more frequent**.
- **Surface area.** Only particles on the surface of a solid can be hit. Cutting it smaller exposes more particles, so collisions with the solid are **more frequent**.
- **Temperature.** The particles gain **kinetic energy** and move faster, so they collide **more frequently**. More importantly, a **greater proportion of collisions have energy equal to or greater than** E_a. Both effects add up, which is why a small rise in temperature speeds a reaction up a lot. The activation energy itself does **not** change.
- **Catalyst.** It gives the reaction a different route with a **lower activation energy**, so a **greater proportion of collisions have enough energy** to react. The particles' energy and the collision frequency don't change.



The products here are **lower** than the reactants, so this reaction is exothermic; products higher than the reactants would mean endothermic (see the chemical energetics note). A catalyst changes neither level.

Why the rate falls during a reaction. As reactant particles are used up, there are **fewer per unit volume**, so collisions become **less frequent** and the rate drops. When the limiting reactant is gone, there are no more collisions between reacting particles and the rate is **zero**.

Key facts and formulas

Nothing for this topic is printed in the exam except the molar gas volume, which is printed with the Periodic Table.

Formula	Status
Chemical change: a new substance forms. Physical change: no new substance (changes of state, dissolving, mixing). Mass is conserved in both	Learn it

Formula	Status
Average rate $= \dfrac{\text{amount of product formed}}{\text{time taken}}$, for example in $\mathrm{cm^3/s}$ or $\mathrm{g/s}$	Learn it
Faster: higher temperature, higher concentration, higher gas pressure, smaller pieces (bigger surface area), catalyst	Learn it
The final amount of product depends only on the amount of the limiting reactant	Learn it
Catalyst: increases the rate and is unchanged (same mass) at the end	Learn it
Concentration unit: $\mathrm{mol/dm^3}$ (or $\mathrm{g/dm^3}$)	Learn it
One mole of any gas occupies $24\ \mathrm{dm^3}$ ($24\,000\ \mathrm{cm^3}$) at r.t.p.	Given
Extended only: E_a = the minimum energy that colliding particles need to react	Learn it
Extended only: concentration, pressure, surface area: more frequent collisions; temperature: more frequent collisions **and** a greater proportion with energy $\geq E_a$	Learn it
Extended only: a catalyst lowers E_a, so a greater proportion of collisions have energy $\geq E_a$	Learn it

How to do it

In the questions we have tagged for this topic (172 questions, 2021–2025, on Papers 1–4), the types came up this often. 41 of the 172 questions mix types, so the counts add up to more than 172.

Question type	Questions
State the effect of a changed condition on rate, time to finish or final amount	59
Identify physical and chemical changes	39
Explain rate changes with collision theory	38
Read and interpret rate graphs or data	32
Draw or pick the curve for a changed condition	30
Catalysts: meaning, properties and effect	17
Choose or draw apparatus to measure rate	14
Order conditions in a results table by time taken	9
Choose the unit of concentration	3

1. State the effect of a changed condition on rate, time to finish or final amount (59 questions)

1. **Find the one thing that changed**: temperature, concentration, piece size, catalyst or gas pressure.
2. **Decide faster or slower** from the table in "Understand it".
3. **Answer the exact question asked**:
   - "effect on the **rate**": increases or decreases;
   - "effect on the **time taken**": a faster reaction takes **less time**, a slower one **more time**;
   - "effect on the **total volume** of gas when the reaction is complete": ask whether the amount of the **limiting reactant** changed. If not, write **no change**.

Variations you will meet:

- **"State two ways to increase (or decrease) the rate."** Any two of: temperature, concentration of the acid, surface area (size of the pieces), catalyst. Name the direction: "increase the temperature", "use smaller pieces".
- **"Which conditions give the fastest reaction?"** Pick powder over lumps or ribbon, the highest temperature and the highest concentration, all together.
- **"Which changes all increase the rate?"** Increasing the volume of acid, or the size of the pieces, does not; adding water lowers the concentration and slows it.
- **Fixed-time questions**: if $25\ \mathrm{cm}^3$ of gas forms in the first 30 s, then at a lower temperature **less** than $25\ \mathrm{cm}^3$ forms in the first 30 s, and the same total forms in the end.
- **Paper 4 tables** may mix rate with equilibrium: fill in the rate column from this topic and the equilibrium column from the equilibrium topic.

2. Identify physical and chemical changes (39 questions)

1. Ask: **is a new substance made?** If yes, it is chemical.
2. Changes of state, dissolving and mixing are **physical**.

Chemical	Physical
Burning (wood, fuel, magnesium), fireworks exploding	Melting, freezing, boiling, evaporating, condensing
Rusting, rotting or decomposing vegetation	Subliming (for example iodine turning to a gas)
Cooking an egg, fermenting glucose	Dissolving sugar or salt in water
Neutralising an acid, a metal or carbonate with an acid	Mixing ink and water
Thermal decomposition, cracking, polymerisation	Distilling (boiling then condensing)
A precipitate forming from two solutions	

Variations you will meet:

- **A particle diagram**: if the particles after are joined differently (new combinations of atoms), it is chemical; if the same particles have just spread out or packed together, it is physical.
- **"Which is true of both?"** The total mass stays the same.
- **"A chemical change always makes a new substance and sometimes involves a change of state."**
- **Sulfur melting** is physical; **sulfur burning** to sulfur dioxide is chemical.

3. Explain rate changes with collision theory (38 questions)

Extended only.

1. **Name the factor** that changed.
2. **Give the particle effect**:
   - concentration or pressure: **more particles per unit volume**;
   - surface area: **more particles exposed** on the surface of the solid;
   - temperature: particles have **more kinetic energy** (move faster);
   - catalyst: **lower activation energy**.
3. **Give the collision effect**, always with a time idea: "**more collisions per second**" or "**the frequency of collisions increases**".
4. **For temperature and catalysts, add the energy point**: "a **greater proportion (percentage) of collisions have energy equal to or greater than the activation energy**".

Variations you will meet:

- **Temperature, 3 marks**: kinetic energy increases; frequency of collisions increases; greater proportion of collisions with energy $\geq E_a$. For a temperature **decrease**, reverse all three.
- **Multiple-choice statements.** True: a higher temperature increases collision frequency and the energy of collisions; a higher concentration increases collision frequency. False: temperature or concentration changes E_a; every collision leads to reaction; a higher concentration raises the proportion of particles with enough energy.
- **A table of "increases / decreases / no change"** for collision frequency and the proportion of collisions with enough energy: concentration or pressure up gives increases / no change; temperature up gives increases / increases; catalyst gives no change / increases.
- **Why the rate is fastest at the start and falls to zero**: highest concentration of reactant particles at the start, so most frequent collisions; as they are used up, collisions become less frequent; when the limiting reactant is used up the reaction stops.
- **"Define activation energy"**: the minimum energy that colliding particles must have to react.

4. Read and interpret rate graphs or data (32 questions)

1. **Read the axes and units** first: volume in cm^3 or mass in g, time in s or minutes.
2. **Read a value**: go up from the time to the curve, then across to the axis (or the other way). Read to the nearest half small square.

3. **The reaction has finished** where the curve first becomes flat; the **final volume** is the height of the flat part.
4. **The rate is fastest where the curve is steepest**, which is at the start.

Variations you will meet:

- **Tables of results**: the fastest interval is the one with the **biggest increase** in volume; the reaction has finished once the volume stops changing.
- **Highest average rate** from several results: work out volume ÷ time for each. For $24\ \mathrm{cm}^3$ in 30 s, $45\ \mathrm{cm}^3$ in 36 s, $70\ \mathrm{cm}^3$ in 64 s and $96\ \mathrm{cm}^3$ in 100 s, the rates are 0.8, 1.25, about 1.09 and $0.96\ \mathrm{cm}^3/\mathrm{s}$, so the second is fastest, even though the last collected the most gas.
- **Mass graphs**: the flask's mass falls because a **gas escapes**. A solid's mass levelling off above zero shows the solid was **in excess**.
- **Why a reaction stops**: one reactant (name it, the one not in excess) has all been used up.
- **Why a table can't give the exact finishing time**: readings are only taken every so often, so the reaction stopped at some point between two readings.

5. Draw or pick the curve for a changed condition (30 questions)

1. **Start at the origin** (or at the same starting mass).
2. **Steeper start** if the change makes it faster; **shallower** if slower.
3. **Level off at the right height**:
   - same amount of limiting reactant: the **same** final volume (or mass), reached **sooner** if faster, **later** if slower;
   - more limiting reactant: **higher**; less: **lower**.
4. Draw a smooth curve that becomes **flat**, and keep it flat.

Variations you will meet:

- **Excess metal with acid**: the acid is limiting. Twice the concentration (same volume) doubles the amount of acid, so the final volume **doubles**. Diluting the same acid with water keeps the same amount of acid: **same final volume**, but slower.
- **Picking the change from two curves**: a lower final volume means less limiting reactant; a catalyst, temperature change or powder can only change the steepness, never the final volume.
- **Mass-loss graphs**: a faster reaction drops **more steeply** to the **same** final mass.

6. Catalysts: meaning, properties and effect (17 questions)

1. **Definition**, both parts: a substance that **increases the rate** of a reaction and is **unchanged at the end** (same mass, chemically the same).
2. **Effects**: faster rate; the same amount of product; the same energy change. **Extended only:** a lower activation energy, shown by a lower hump on the reaction pathway diagram with the reactant and product levels unchanged.

Variations you will meet:

- **"How does the mass of catalyst change?"** It doesn't: same mass at the end.
- **"Effect of using more catalyst on the mass of product"**: no change.
- **Ranking catalysts** from a table: the shortest time for a fixed volume, or the most gas in a fixed time, is the best catalyst. Only claim what the data shows: an oxide that gives the same result as no oxide at all is **not** a catalyst.
- **Removing the enzyme** (or catalyst): the rate decreases.

7. Choose or draw apparatus to measure rate (14 questions)

1. **Gas volume**: a flask with a **bung** and **delivery tube** leading to a **gas syringe** (or an upturned measuring cylinder over water). Label the gas syringe.
2. **Mass loss**: the flask on a **balance**, with a cotton wool plug.
3. Add a **stop-watch** for every method, and a **thermometer** when temperature is being changed.

Variations you will meet:

- **"Which reaction could be followed with a gas syringe?"** One that gives off a gas.
- **"Which method finds the rate?"** Measuring the volume of gas at timed intervals (or the time to collect a fixed volume). Counting bubbles is not accurate.
- **Drawing**: the delivery tube goes through the bung with no gaps, and the syringe is joined straight to the tube.

8. Order conditions in a results table by time taken (9 questions)

1. Decide which condition is **fastest**: highest temperature, highest concentration, or smallest pieces.
2. The fastest goes with the **shortest time**; the slowest with the longest.

For example, with times of 25 s, 52 s and 105 s for $20\ ^\circ\mathrm{C}$, $30\ ^\circ\mathrm{C}$ and $40\ ^\circ\mathrm{C}$: $40\ ^\circ\mathrm{C}$ goes with 25 s, $30\ ^\circ\mathrm{C}$ with 52 s and $20\ ^\circ\mathrm{C}$ with 105 s.

9. Choose the unit of concentration (3 questions)

Concentration is measured in $\mathrm{mol/dm^3}$ (moles of solute per cubic decimetre of solution), or in $\mathrm{g/dm^3}$. Other powers of dm, such as $\mathrm{mol/dm^2}$, are wrong.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) From this list, choose the **two** chemical changes: melting candle wax; burning candle wax; dissolving sugar in tea; rusting of an iron nail; evaporating ethanol. **[2]**

(b) Give one difference between a physical change and a chemical change. **[1]**

(c) A student reacts equal pieces of zinc with the same dilute acid at $20\ ^\circ\mathrm{C}$, $30\ ^\circ\mathrm{C}$ and $40\ ^\circ\mathrm{C}$, and times how long it takes to collect $50\ \mathrm{cm}^3$ of hydrogen. The times are 25 s, 52 s and 105 s. Match each temperature to its time. **[1]**

(d) Calculate the average rate of reaction at $40\ ^\circ\mathrm{C}$. **[1]**

(e) State two other ways to increase the rate of this reaction. **[2]**

(a) Burning candle wax **B1** and rusting of an iron nail **B1**. The others are changes of state or dissolving.

(b) A chemical change makes a new substance; a physical change does not. **B1**

(c) Hotter means faster, so shorter: $40\ ^\circ\mathrm{C}$: 25 s, $30\ ^\circ\mathrm{C}$: 52 s, $20\ ^\circ\mathrm{C}$: 105 s. **B1**

(d) $50 \div 25 = 2.0\ \mathrm{cm}^3/\mathrm{s}$. **B1**

(e) Any two of: use a higher concentration of acid; use smaller pieces (or powdered) zinc; add a catalyst. **B1 B1**

Example 2

A student adds 1.00 g of calcium carbonate chips to excess dilute hydrochloric acid and measures the total volume of carbon dioxide every 20 s.

$$\mathrm{CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2}$$

time / s	0	20	40	60	80	100	120	140
volume / cm³	0	88	150	196	226	240	240	240

(a) Name the apparatus used to measure the volume of gas. **[1]**

(b) State the volume of gas collected in the first 40 s, and the average rate over this time. **[2]**

(c) In which 20 s interval is the reaction fastest? Explain why the rate then decreases. **[2]**

(d) Explain why no more gas is produced after 100 s. **[1]**

(e) **Extended:** show that $240\ \mathrm{cm}^3$ is the volume expected at r.t.p. **[2]**

(f) The experiment is repeated with 1.00 g of **powdered** calcium carbonate. State the effect on (i) the time taken for the reaction to finish, (ii) the total volume of gas. **[2]**

(a) A gas syringe. **B1**

(b) $150\ \mathrm{cm}^3$ **B1**; average rate $= 150 \div 40 = 3.75\ \mathrm{cm}^3/\mathrm{s}$. **B1**

(c) 0–20 s: $88\ \mathrm{cm}^3$, the biggest increase. **B1** The increases then get smaller ($62, 46, 30, 14$) because the reactants are being used up (their concentration falls). **B1**

(d) All the calcium carbonate has been used up (the acid was in excess). **B1**

(e) $M_r(\mathrm{CaCO_3}) = 40 + 12 + 3 \times 16 = 100$, so $1.00 \div 100 = 0.0100$ mol. **M1** One mole of $\mathrm{CaCO_3}$ gives one mole of $\mathrm{CO_2}$: $0.0100 \times 24\,000 = 240\ \mathrm{cm}^3$. **A1**

(f) (i) Less time (it finishes sooner). **B1** (ii) No change: the same mass of calcium carbonate is used up. **B1**

Example 3

Excess magnesium ribbon reacts with $50\ \mathrm{cm}^3$ of $1.0\ \mathrm{mol/dm^3}$ hydrochloric acid. It gives $600\ \mathrm{cm}^3$ of hydrogen and finishes after 120 s.

$$\mathrm{Mg + 2HCl \rightarrow MgCl_2 + H_2}$$

For each change, state whether the reaction starts faster or slower, and give the final volume of hydrogen. All other conditions stay the same.

(a) $50\ \mathrm{cm}^3$ of $2.0\ \mathrm{mol/dm^3}$ acid is used. **[2]**

(b) $25\ \mathrm{cm}^3$ of $2.0\ \mathrm{mol/dm^3}$ acid is used. **[2]**

(c) $50\ \mathrm{cm}^3$ of water is added to the $50\ \mathrm{cm}^3$ of $1.0\ \mathrm{mol/dm^3}$ acid first. **[2]**

(d) The acid is warmed from $20\ ^\circ\mathrm{C}$ to $40\ ^\circ\mathrm{C}$. **[2]**

(e) **Extended:** explain your answer to (c) in terms of particles. **[2]**

The magnesium is in excess, so the **acid is the limiting reactant**: the final volume depends only on the moles of HCl. Originally $0.050 \times 1.0 = 0.050$ mol HCl, giving 0.025 mol $\mathrm{H_2}$, which is $0.025 \times 24\,000 = 600\ \mathrm{cm}^3$.

(a) Faster **B1**; $0.050 \times 2.0 = 0.10$ mol HCl, twice as much, so $1200\ \mathrm{cm}^3$. **B1**

(b) Faster (more concentrated) **B1**; $0.025 \times 2.0 = 0.050$ mol HCl, the same as before, so $600\ \mathrm{cm}^3$. **B1**

(c) Slower (the concentration halves to $0.50\ \text{mol/dm}^3$) **B1**; the same 0.050 mol HCl, so $600\ \text{cm}^3$. **B1**

(d) Faster **B1**; $600\ \text{cm}^3$, reached sooner. **B1**

(e) There are fewer acid particles per unit volume **B1**, so the collisions between acid particles and magnesium are less frequent (fewer per second). **B1**

Example 4

Extended. Hydrogen peroxide decomposes when manganese(IV) oxide is added.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The flask stands on a balance with a cotton wool plug. The mass falls from 85.00 g to 84.36 g and then stays the same.

(a) Explain why the mass decreases. **[1]**

(b) Calculate the mass of oxygen given off and the number of moles of hydrogen peroxide that decomposed. **[2]**

(c) Explain why the rate is highest at the start and eventually becomes zero. **[3]**

(d) The experiment is repeated at a higher temperature. Explain, in terms of collision theory, why the rate increases. **[3]**

(e) State how the mass of manganese(IV) oxide changes during the reaction, and explain how it increases the rate. **[3]**

(a) Oxygen gas escapes from the flask. **B1**

(b) $85.00 - 84.36 = 0.64$ g of oxygen, and $0.64 \div 32 = 0.020$ mol O_2. **M1** The ratio is $2\ H_2O_2 : 1\ O_2$, so 0.040 mol H_2O_2. **A1**

(c) At the start the concentration of hydrogen peroxide is highest (most particles per unit volume), so collisions are most frequent. **B1** As it is used up, there are fewer particles per unit volume, so the collisions become less frequent. **B1** When all the hydrogen peroxide has been used up there are no more reacting particles, so the rate is zero. **B1**

(d) The particles have more kinetic energy **B1**; they collide more frequently (more collisions per second) **B1**; and a greater proportion of the collisions have energy equal to or greater than the activation energy. **B1**

(e) Its mass does not change (it is unchanged at the end). **B1** It lowers the activation energy **B1**, so a greater proportion of collisions have energy equal to or greater than the activation energy. **B1**

Common mistakes

- **"More collisions" with no time idea.** Examiners reject "more collisions" and "more chance of colliding" every year. Write "**more collisions per second**" or "the **frequency** of collisions increases".

- **"More successful collisions" for temperature.** That is true of every factor, so it earns nothing. Say that a **greater proportion (percentage) of collisions have energy equal to or greater than the activation energy**, and don't write that *all* particles have that energy.
- **Saying temperature changes the activation energy.** Heating (or cooling) never changes E_a; only a catalyst does. This is one of the most chosen wrong options.
- **Saying concentration gives particles more energy.** Concentration only changes how many particles are in each unit of volume.
- **Answering about time or volume when asked about rate** (or the other way round). If the question says "effect on the rate", answer "increases" or "decreases"; don't write about the volume of gas.
- **Changing the final volume for a faster reaction.** A catalyst, a higher temperature or powder gives the **same** amount of product sooner. On a sketch the new curve must level off at the **same** height (or at a lower height if there is less limiting reactant, which examiners often find students miss).
- **Forgetting that the acid is the limiting reactant** when the solid is in excess: using a more dilute acid of the same volume gives **less** gas.
- **Sketching badly**: a new line that doesn't start at the origin, only moves away from the original line later on, or never goes flat.
- **Repeating the question**: "smaller pieces react faster because they are smaller" earns nothing. Say "larger **surface area**", then (Extended) "more frequent collisions".
- **Weak apparatus drawings**: no plunger on the gas syringe, no labels, gaps where gas escapes, or a measuring cylinder joined straight to the flask. Collect a water-soluble gas in a gas syringe, not over water.
- **Mixing up physical and chemical changes**: dissolving and evaporation are physical; burning and rusting are chemical. The temperature stays constant while a substance boils, and mass is conserved in every change.

How to get the marks

- **"State the effect"**: a single direction word (increases, decreases, no change) is enough, but it must answer the thing asked about (rate, time, or total volume).
- **"Explain in terms of particles / collision theory"**: one mark for the particle change (per unit volume, surface area exposed, kinetic energy) and one for the collisions (frequency, per second). For temperature, a third mark for the **proportion of collisions with energy** $\geq E_a$.
- **"Suggest why the reaction stops"**: name the reactant that has been **used up** (the one not in excess).
- **Graph readings**: one number with its unit; read carefully from the grid. The finishing time is where the line **first** goes flat.
- **Drawing a second line** (usually 2 marks): one for the right steepness at the start, one for levelling off at the right volume (the same, unless the limiting reactant changed).
- **Catalyst definition**: both halves, "**increases the rate**" and "**unchanged at the end**". "Speeds it up" alone gets half.
- **Apparatus drawings**: a closed flask, a delivery tube and a **labelled gas syringe** (with a plunger) are what earn the marks.

- **"State two ways"**: two different factors, each with its direction (for example "increase the temperature", "use powdered zinc").
- **Multiple choice with statements**: test each statement against the rules; one wrong statement makes the option wrong.

Quick check

1. Which of these are chemical changes? Freezing water; cooking an egg; burning magnesium; condensing steam; adding sodium to water.
2. Experiment P gives $36\ \mathrm{cm}^3$ of gas in 45 s. Experiment Q gives $60\ \mathrm{cm}^3$ in 80 s. Which has the higher average rate?
3. Marble chips react with acid in a flask on a balance. The mass falls from 152.40 g to 151.52 g, then stays the same. What mass of carbon dioxide was given off? Why does the mass stop falling? **Extended:** how many moles of $\mathrm{CO_2}$ is that?
4. **Extended:** explain, in terms of particles, why increasing the pressure of a gas-phase reaction increases the rate, and why adding a catalyst increases the rate.
5. Excess marble chips react with $40\ \mathrm{cm}^3$ of $1.0\ \mathrm{mol/dm}^3$ hydrochloric acid, giving $480\ \mathrm{cm}^3$ of carbon dioxide. For each change, say whether the rate is faster or slower and give the final volume: (i) powdered marble instead of chips; (ii) $20\ \mathrm{cm}^3$ of the acid mixed with $20\ \mathrm{cm}^3$ of water; (iii) $40\ \mathrm{cm}^3$ of $2.0\ \mathrm{mol/dm}^3$ acid; (iv) the acid warmed by $20\ ^\circ\mathrm{C}$.

Answers

1. Cooking an egg, burning magnesium and adding sodium to water (each makes new substances). Freezing and condensing are changes of state: physical.
2. P: $36 \div 45 = 0.80\ \mathrm{cm}^3/\mathrm{s}$. Q: $60 \div 80 = 0.75\ \mathrm{cm}^3/\mathrm{s}$. **P** has the higher average rate.
3. $152.40 - 151.52 = 0.88$ g of carbon dioxide. The mass stops falling when one reactant (the acid, if the marble is in excess) has been used up, so no more gas forms. $M_r(\mathrm{CO_2}) = 12 + 2 \times 16 = 44$, so $0.88 \div 44 = 0.020$ mol.
4. Higher pressure puts more gas particles in each unit of volume, so they collide more frequently (more collisions per second). A catalyst lowers the activation energy, so a greater proportion of collisions have energy equal to or greater than the activation energy.
5. The acid is limiting (0.040 mol HCl gives 0.020 mol $\mathrm{CO_2} = 480\ \mathrm{cm}^3$). (i) Faster, $480\ \mathrm{cm}^3$. (ii) Slower (half the concentration), and only 0.020 mol HCl, so $240\ \mathrm{cm}^3$. (iii) Faster, and 0.080 mol HCl, so $960\ \mathrm{cm}^3$. (iv) Faster, $480\ \mathrm{cm}^3$.

Past questions to try

- **0620/31/O/N/21 Q8**: reading an enzyme reaction's graph, sketching a new curve and ranking catalysts (Core).
- **0620/32/F/M/25 Q3**: drawing the apparatus, reading the graph and the effects of temperature, concentration and a catalyst (Core).
- **0620/41/M/J/23 Q4**: catalyst meaning, why the rate falls to zero, and collision theory for temperature (Extended).
- **0620/43/O/N/24 Q5**: parts (a)–(c), a mass-loss experiment, collision theory and sketching the line at a higher temperature (Extended).