Choose the Correct Boltzmann

A Level

Maxwell-Boltzmann distributions show the proportion of molecules with particular speeds. Below are five different Boltzmann diagrams, showing distributions at two temperatures.

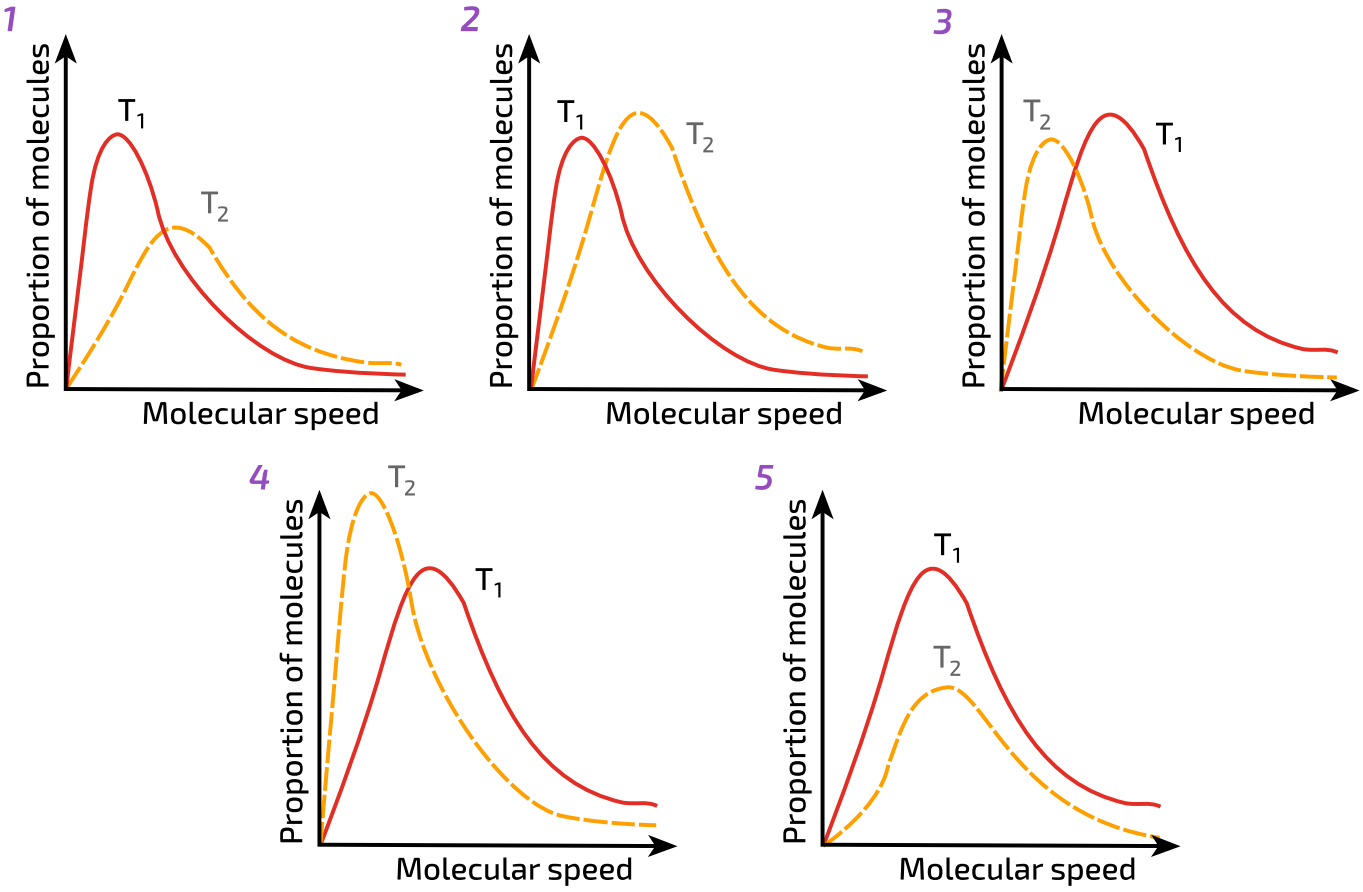

Figure 1: Five Boltzmann distributions.

Which one of the above diagrams correctly represents the Boltzmann distribution of molecular speeds at two temperatures, T_1 and T_2, where $T_2 > T_1$?

- 1
- 2
- 3
- 4
- 5

Adapted with permission from UCLES, A Level Chemistry, June 1987, Paper 3, Question 6

Examining the Maxwell-Boltzmann

A Level

This question will examine the features of the Maxwell-Boltzmann distribution, and what happens to it under various conditions.

Below is a diagram of a Maxwell-Boltzmann distribution at an arbitrary temperature (with two vertical lines that should be ignored for now).

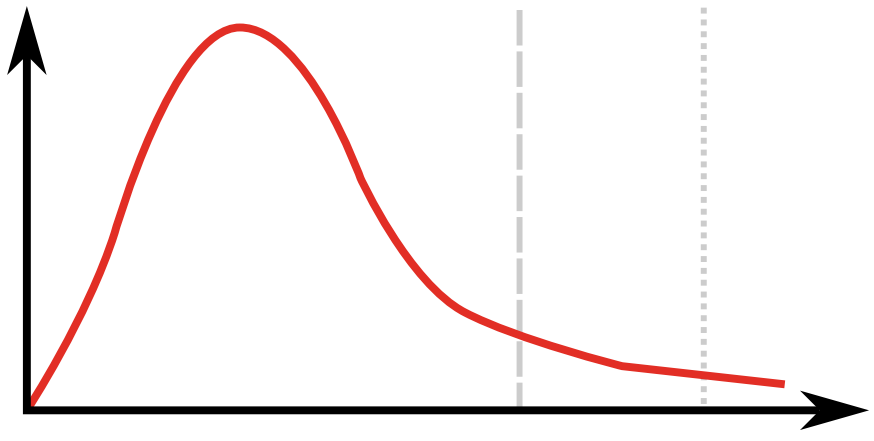

Figure 1: Maxwell-Boltzmann Distribution at an arbitrary temperature

Part A Labelling the axes

The axes on the diagram above are not labelled. What would be a suitable label for the y-axis? Choose the most appropriate.

- Number of particles
- Cumulative number of particles
- Molecular velocity
- Kinetic energy
- Time
- Molecular speed

And what would be a suitable label for the x-axis?

- Molecular speed
- Number of particles
- Proportion of particles
- Molecular velocity
- Distance
- Time

Part B Activation energy

The two vertical lines represent the point at which the particles reach the activation energy; one line for when the reaction was carried out in the presence of a catalyst, and one without catalyst.

Which line represents the activation energy when carried out in the presence of a catalyst?

- The dashed line
- The dotted line

How does this show that adding a catalyst increases the rate of reaction?

Part C Effect of temperature

If the temperature changes, the shape of the plot changes.

If the temperature was **increased**, in which direction would the **peak** of the distribution move?

- It depends on the initial temperature
- It would not move
- It depends on other factors
- To the left
- To the right

Part D Width of the peak

What is the general change to the width of the peak at a higher temperature?

- The width would not change
- The peak narrows
- It depends on the intial temperature
- The peak becomes broader
- It depends on other factors

Part E Lowered temperature

If the temperature was **lowered**, what would happen to the height of the peak?

- It depends on other factors
- It would not change
- It would increase
- It would decrease
- It depends on the initial temperature

Part F Constant feature

Which feature of the graph stays constant, regardless of changing temperature?

- The area under the graph
- The position of the peak
- The mean molecular speed
- The height of the peak
- The gradient at the origin

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Two Boltzmann Distributions

A Level

This question investigates the effect of changing temperature on the Maxwell-Boltzmann distribution.

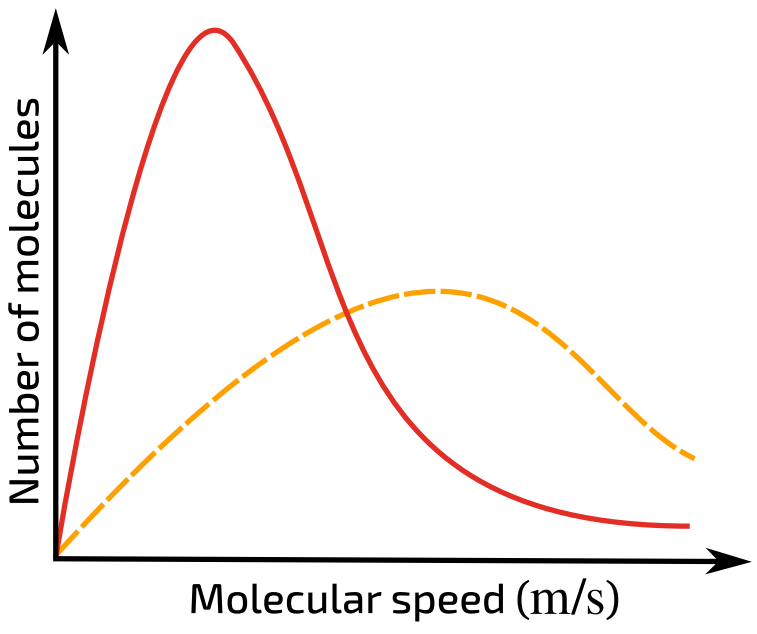

Figure 1: Maxwell-Boltzmann graph at two temperatures.

Part A Temperature

Which line shows the distribution at a higher temperature?

- The line with the higher peak.
- The line with the lower peak.

Part B Extending the distribution

What would be seen if the plots were extended to a very large molecular speed?

- The plots will tend to the same non-zero value
- The plots will reach zero, the one at lower temperature first
- The plots will tend to zero
- The plots will reach zero, the one at higher temperature first
- The plots will each tend to different non-zero values

Part C Effect on rate

It is suggested that there is an arbitrary molecular speed at which collisions between particles will result in a chemical reaction. Given this, what is the effect of a temperature increase on the rate of reaction?

- At higher temperature, the particles will collide with too much energy, so the rate of reaction will decrease.
- At higher temperature, the particles will not react, so the rate will decrease.
- At a higher temperature, more particles will have sufficient speed and hence energy to react, so the rate of reaction will increase.
- At higher temperature, the particles will collide more often, but with the same energy, so the rate of reaction will increase.

Part D Naming

For the particle with the energy described above, what is this energy commonly called?

- Particle energy
- Enthalpy
- Heat energy
- Reaction energy
- Activation energy

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Three Boltzmann Distributions

A Level

In this question the effect of temperature on the Maxwell-Boltzmann distribution will be explored.

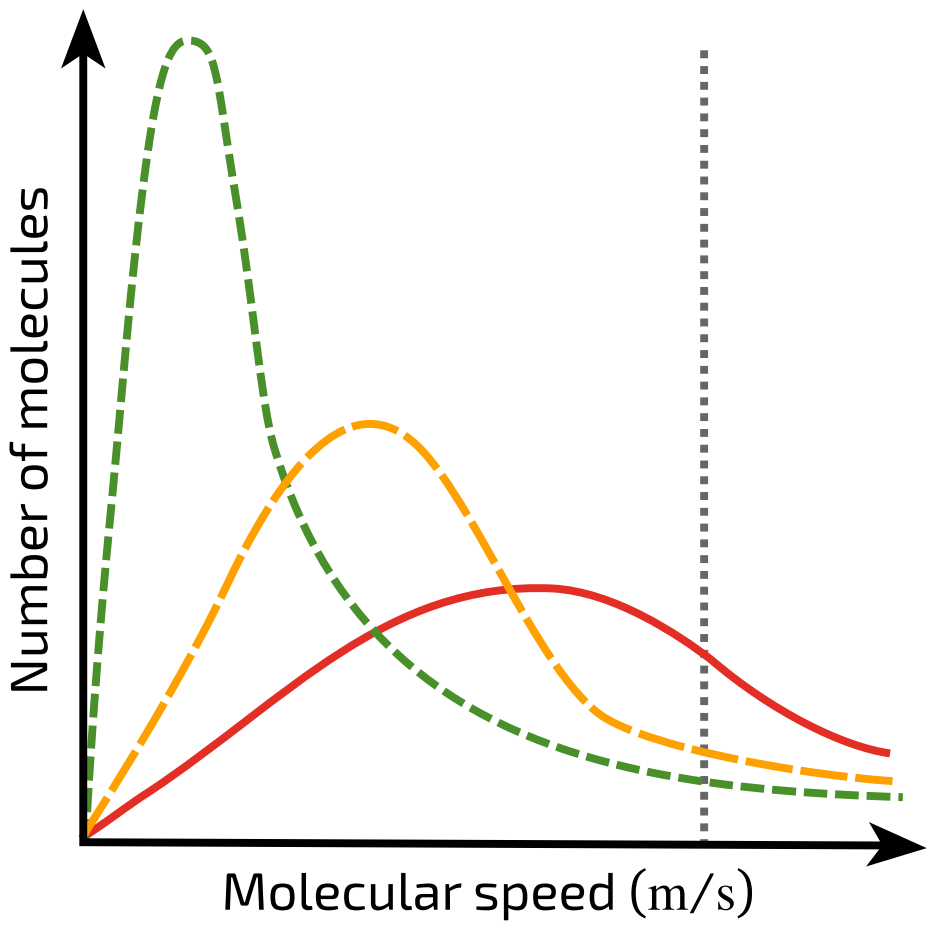

Figure 1: Maxwell-Boltzmann distributions at different temperatures

Part A Highest temperature

Which line on the diagram represents the distribution at the highest temperature?

- The red (solid) line
- The yellow (long dashed) line
- The green (short dashed) line
- The grey (dotted) line

Part B Lowest temperature

Which line represents the distribution at the lowest temperature?

- The grey (dotted) line
- The red (solid) line
- The green (short dashed) line
- The yellow (long dashed) line

Part C Activation energy

The grey dotted line represents the activation energy. How could the activation energy be lowered?

- By introducing a catalyst
- By lowering the energy of the reaction mixture
- By giving the particles more kinetic energy
- By increasing the temperature
- By increasing the concentrations of the reactants

Part D Lowering the activation energy

If the activation energy was lowered, which way would the vertical line move on the diagram?

- To the right
- It would not move
- To the left

Part E Net effect

What would be the net effect of this shift?

- The temperature at which half of the particles have the required activation energy would increase
- A greater number of particles would have sufficient energy to chemically react
- Fewer particles would have sufficient energy to chemically react
- There would be no change in the number of particles that would have enough energy to react

Part F Low activation energy

Imagine the activation energy was very low, so that the vertical line was on the left half of the diagram above. If a catalyst was then added, at which of the three temperatures would there be the greatest increase in the number of particles that have sufficient energy to react?

- The middle temperature
- The number of particles with sufficient energy would increase by the same amount for each of the three temperatures
- The highest temperature
- The lowest temperature

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Proportion Exceeding E_a

A Level

C C C

The distribution of the number of molecules with energy E is given in the sketch for two temperatures, T_1 and a higher temperature, T_2. The letters P, Q, R refer to the separate and differently shaded areas. The activation energy is marked on the energy axis.

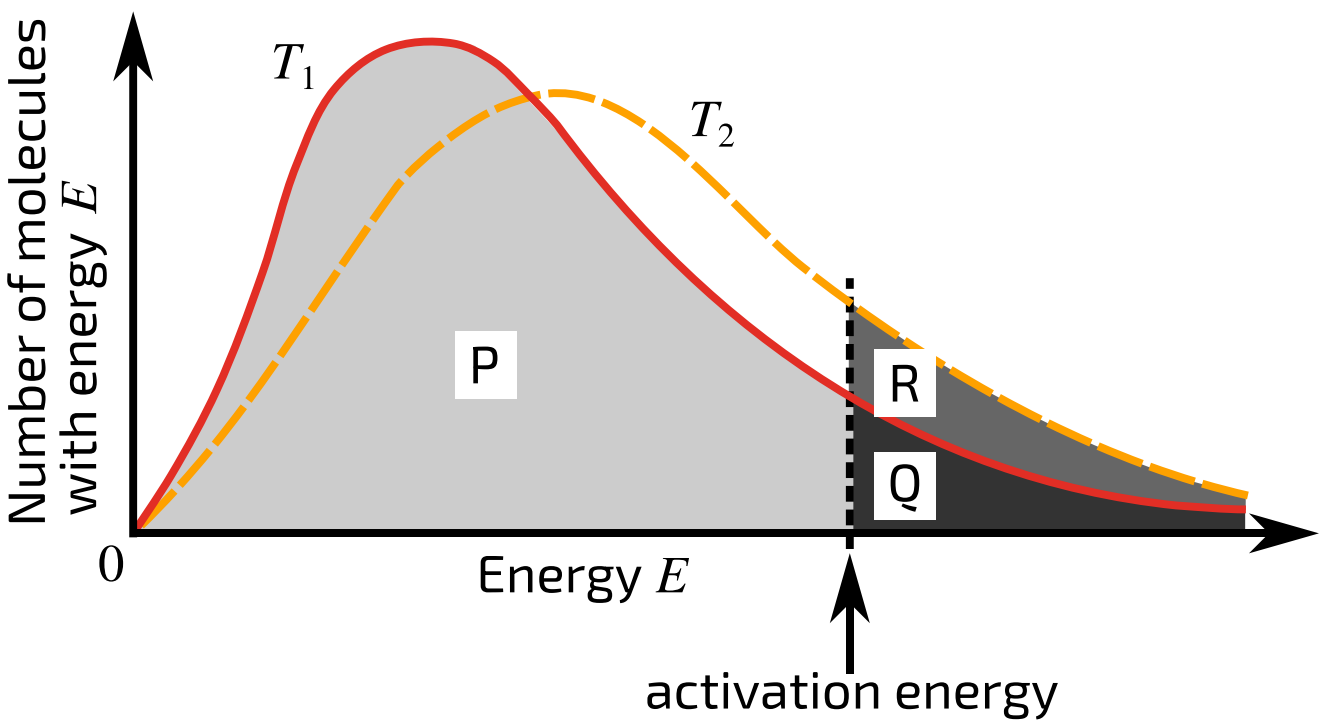

Figure 1: Two Maxwell-Boltzmann distributions

Find an expression which gives the fraction of the molecules present which have at least the activation energy at the higher temperature T_2.

The following symbols may be useful: `P, Q, R`

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Rate of Gas Production

GCSE A Level

The following table contains data collected from an experiment carried out to determine the rate of a general reaction, which can be represented by the following equation:

$$\mathrm{A\,(aq)} + \mathrm{B\,(s)} \longrightarrow \mathrm{C\,(g)} + \mathrm{D\,(aq)}$$

The volume of gas C was measured over time using a gas syringe.

Time / seconds	**Volume of gas produced /** $\mathrm{cm^3}$
0	0.0
5	1.2
10	1.9
15	2.4
20	2.7
25	2.9
30	3.0
35	3.1
40	3.1

Part A Reaction end

Using the data in the table, when did the reaction stop?

Part B Average rate

What is the average rate of reaction from its start until the reaction's end?

Part C Increasing the rate

What could be done to speed up the rate of this reaction from the following options?

- Introducing an inert solvent
- Decreasing the surface area of solid B
- Decreasing the temperature
- Adding a catalyst
- Decreasing the concentration of reactant A

Part D Instantaneous rate

How would the instantaneous rate of reaction be determined?

- Plot the data, join up the points with straight lines and use the gradient of one of these straight lines to determine the rate at any time.
- Divide the total change in volume by the total change in time.
- Plot the data, draw a smooth line of best fit and draw a tangent at the required time. The gradient of this tangent is the instantaneous rate.
- Take the difference in volume between two data points, and divide by the difference in time.

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Average Rate of Reaction

GCSE P P P A Level P P P

An experiment was carried out by a student to determine the rate of a certain reaction, and how the rate changed over time. The reaction involved a solid being added to a solution, and the solid dissolving, subsequently producing a gas. The change in the mass of the reaction vessel was recorded over time to give information on the rate of reaction. A table of the data that was collected is given below.

Time / seconds	**Total mass of reaction vessel /** g
0	3.79
10	3.22
20	2.69
30	2.16
40	1.69
50	1.35
60	1.16
70	1.06
80	1.01
90	0.99
100	0.97
110	0.95
120	0.93

Part A Average rate of reaction 1

What is the average rate of the reaction up to $40\,\mathrm{s}$? Give your answer in terms of the mass of gas produced.

Part B Average rate of reaction 2

What is the average rate of reaction between $80\,\mathrm{s}$ and $120\,\mathrm{s}$? Give your answer in terms of the mass of gas produced.

Part C Instantaneous rate

By plotting a graph, calculate the instantaneous rate of reaction at $25\,\mathrm{seconds}$? Give your answer in terms of the mass of gas produced.

Part D Instantaneous rate 2

What is the instantaneous rate of reaction at $60\,\mathrm{seconds}$? Give your answer in terms of the mass of gas produced.

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Rate of Hydrogen Production

GCSE P P P A Level P P P

The graph below shows how the total volume of hydrogen, produced by the reaction between hydrochloric acid and an excess of magnesium, varies with time.

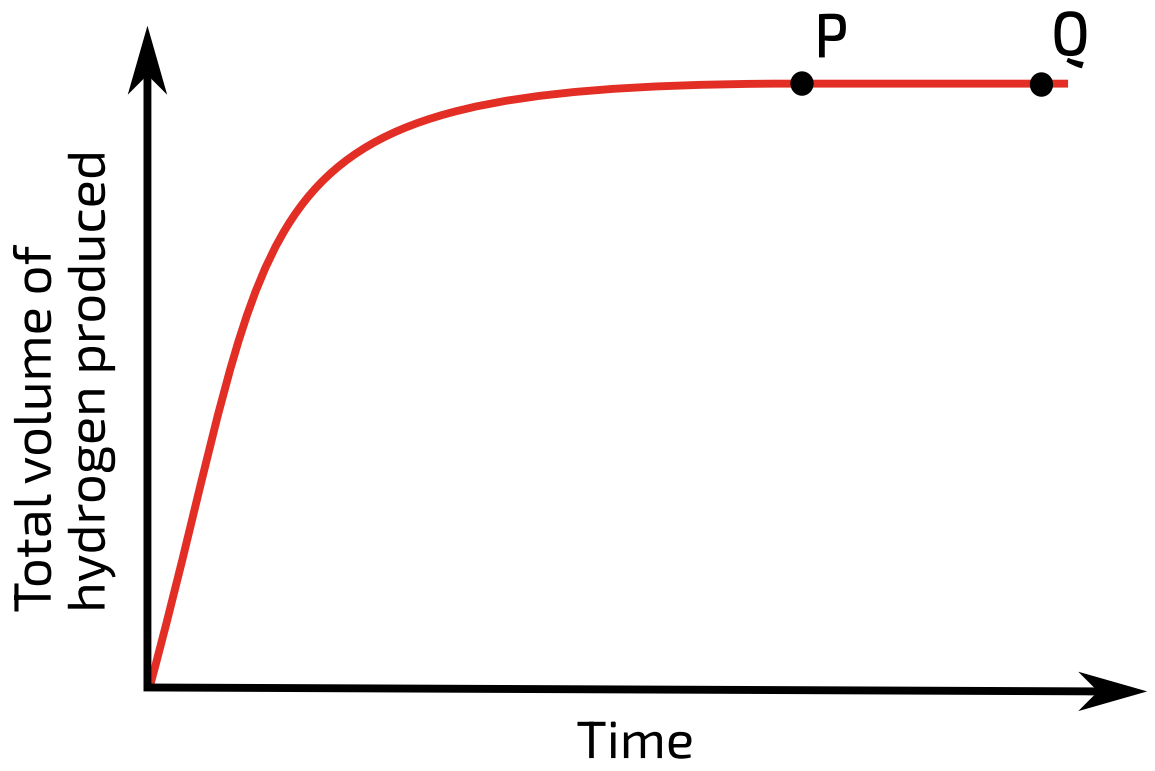

Figure 1: Graph showing the volume of hydrogen produced with time.

Part A Equation

Write the equation for this reaction, balancing to use the lowest integer coefficients possible. Include state symbols.

Part B PQ

Which one of the following statements about the section PQ of the curve is correct?

- The rate of reaction is increasing.
- The rate of production of hydrogen is at a maximum.
- The reaction is continuing at a constant rate.
- All the magnesium has reacted.
- No more hydrogen is being produced.

Part C Reaction end

The graph shows the reaction stopping at point P. Under what conditions could the reaction stop at point Q?

- Double the concentration of acid, and halve the volume used.
- Same amount of acid used, but with a smaller amount of magnesium used, so the acid was now significantly in excess.
- Same mass of magnesium, but with a smaller surface area.
- Double the amount of acid used (the magnesium is still in excess).
- Same initial conditions, but with a catalyst added.

Adapted with permission from UCLES, O Level Chemistry, June 1986, Paper 1, Question 9

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Interchanging Graphs

A Level

In two separate experiments, experiment A and experiment B, a substance was decomposed and the gas evolved was collected. The graph below shows the total volume of gas collected against time for each experiment.

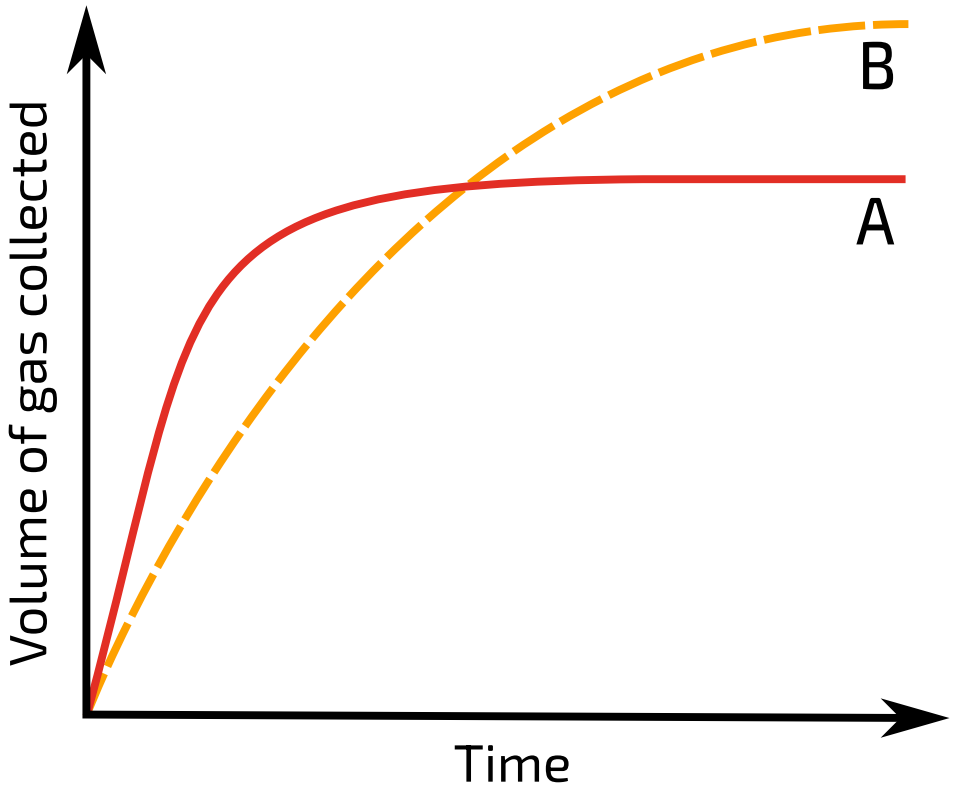

Figure 1: Volume of gas collected against time

Below are some graphs showing possible rates of reaction against time for the two experiments.

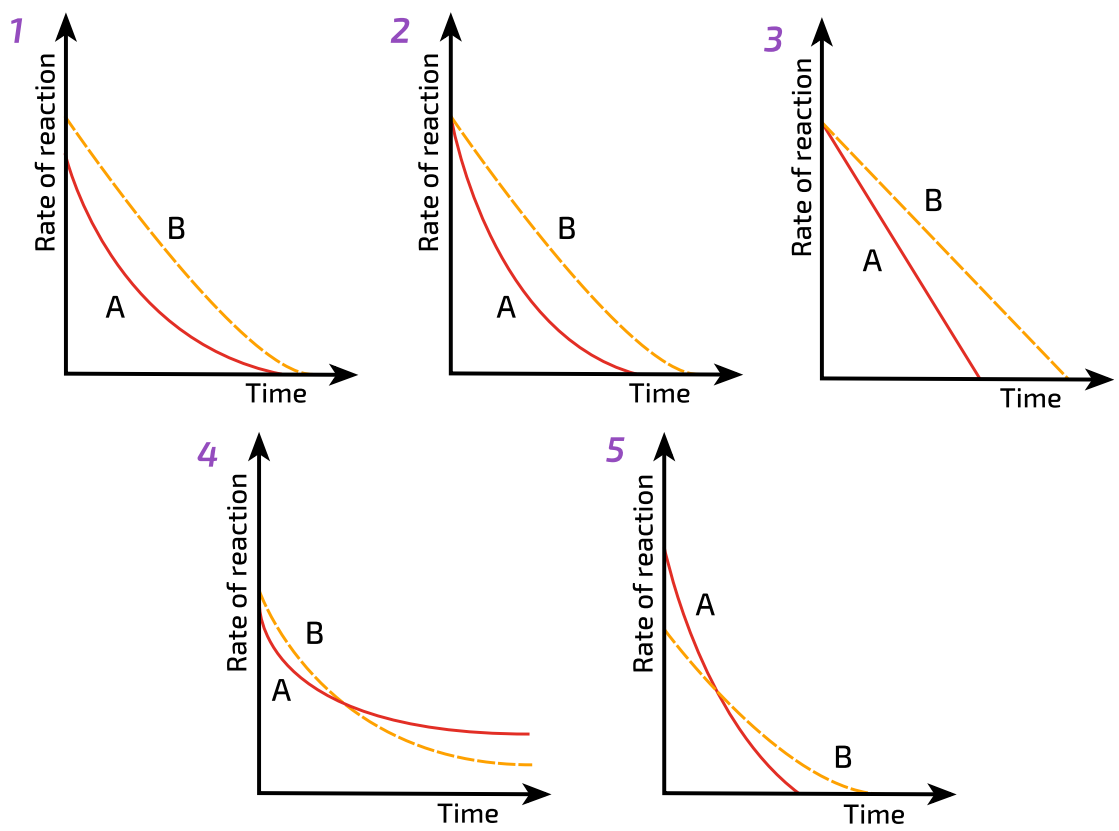

Figure 2: The rate against time for the five different experiments.

Which one of the above graphs shows how the rate of reaction varied with time in the experiments A and B?

- 1
- 2
- 3
- 4
- 5

Adapted with permission from UCLES, O Level Chemistry, June 1985, Paper 1, Question 17

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Marble Chips

GCSE A Level

Marble chips, assumed to be made up solely of $\mathrm{CaCO_3\,(s)}$ in this experiment, react with dilute hydrochloric acid according to the following reaction:

$$\mathrm{CaCO_3\,(s) + HCl\,(aq) \longrightarrow CaCl_2\,(aq) + CO_2\,(g) + H_2O\,(l)}$$

The rate of this reaction was investigated by measuring the volume of gas produced over time. $16\,\mathrm{g}$ of marble chips and an excess of dilute acid was used, and the experiment was carried out at $25\,^\circ\mathrm{C}$.

The results of the experiment are given in the table below.

Time / seconds	**Volume of gas produced /** $\mathrm{dm^3}$
0	0.00
10	0.23
20	0.35
30	0.44
40	0.51
50	0.56
60	0.60
70	0.63
80	0.64
90	0.64

Part A Plotting the graph

Plot a graph of the data, and draw a smooth line of best fit.

How would the initial gradient of the graph change if the reaction was instead carried out at $40\,^{\circ}\mathrm{C}$?

- The initial gradient would be smaller.
- The initial gradient would not change.
- The initial gradient would be zero, as the reaction would not proceed at this temperature.
- More information is needed to answer this.
- The initial gradient would be greater.

Part B Initial gradient

How would the initial gradient change if a single piece of marble of mass $16\,\mathrm{g}$ was used instead of many smaller marble chips with total mass $16\,\mathrm{g}$?

- The initial gradient would be zero, as the reaction would not proceed.
- More information is needed to answer this.
- The initial gradient would be greater.
- The initial gradient would be smaller.
- The initial gradient would not change.

Part C Collision theory

In terms of particles, why would the rate of reaction increase if the reaction were carried out with concentrated, instead of dilute, hydrochloric acid?

Part D Average rate of reaction

Use your graph to calculate the average rate of reaction over the first $60\,\text{seconds}$.

Part E Instantaneous rate of reaction

Use your graph to determine the rate of reaction at $50\,\text{seconds}$ (the instantaneous rate). Give your answer to 1 significant figure.

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