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).

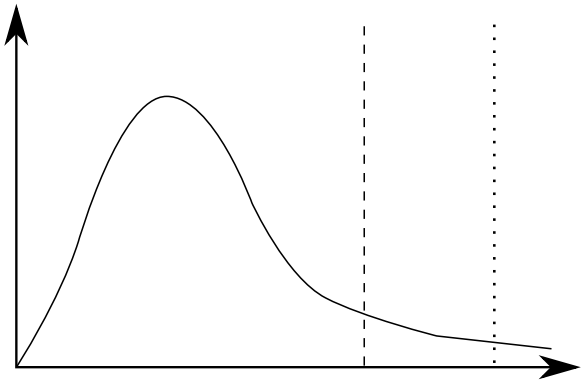

Figure 1: Maxwell-Boltzmann Distribution at an arbitrary temperature

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
- Molecular speed
- Time
- Kinetic energy

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

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

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 dotted line
- The dashed 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?

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

Part E Lowered temperature

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

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

Part F Constant feature

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

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

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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.

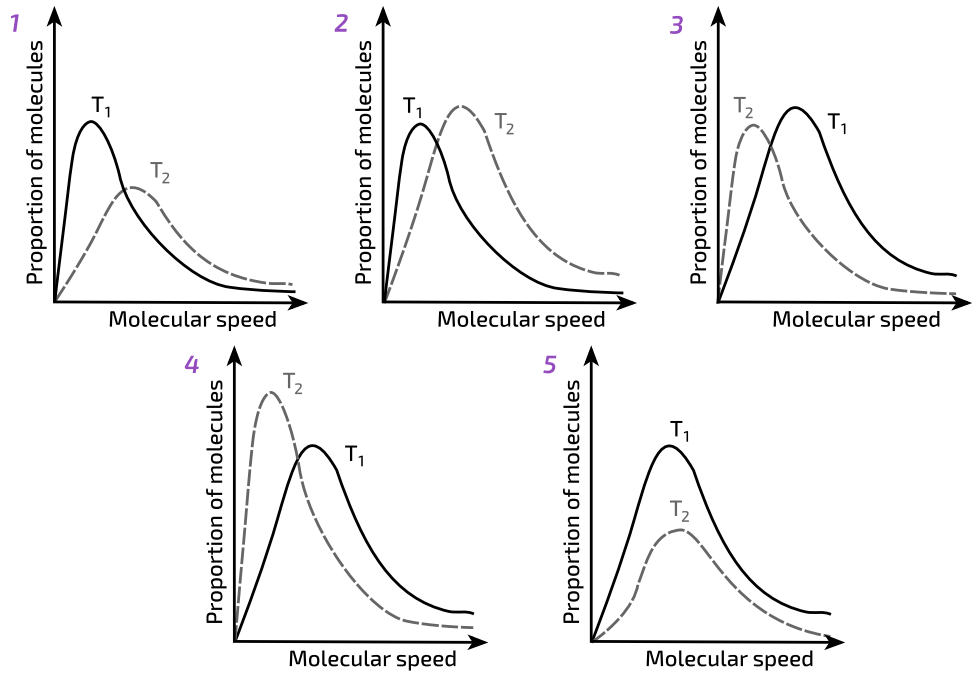

Figure 1: Boltzmann Distributions

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

Rate of Hydrogen Production

GCSE A Level

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.

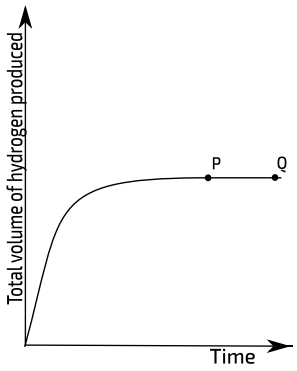

Figure 1: Graph showing the volume of hydrogen produced with time.

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 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.
- The rate of reaction is increasing.

Part C Reaction end

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

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

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

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

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.
- The initial gradient would not change.
- The initial gradient would be greater.
- More information is needed to answer this.
- The initial gradient would be smaller.

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 $60\,\mathrm{seconds}$.

Part E Instantaneous rate of reaction

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

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Two Boltzmann Distributions

A Level

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

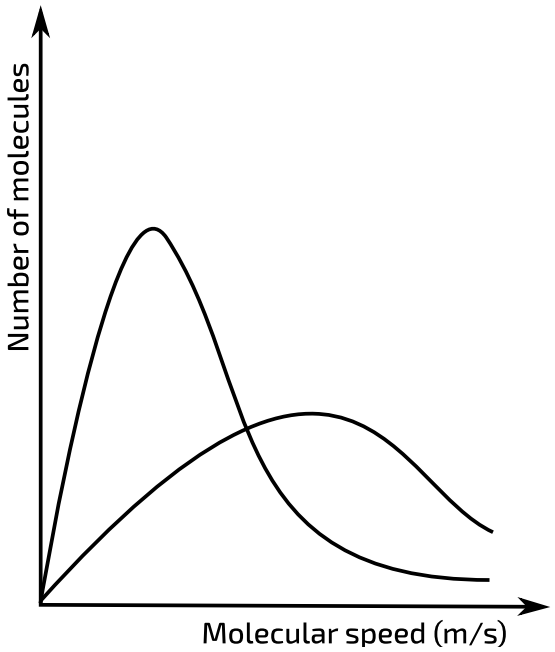

Figure 1: Maxwell-Boltzmann Graph at two temperatures

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

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 more often, but with the same energy, so the rate of reaction will increase.
- 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 with too much energy, so the rate of reaction will decrease.

Part D Naming

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

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

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Three Boltzmann Distributions

A Level

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

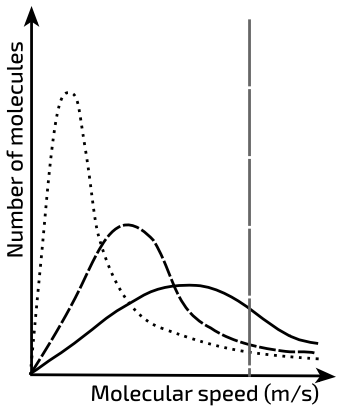

Figure 1: Maxwell-Boltzmann distributions at different temperatures

Part A Highest temperature

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

- The vertical dashed line
- The dashed line
- The dotted line
- The solid line

Part B Lowest temperature

Which line represents the distribution at the lowest temperature?

- The solid line
- The dotted line
- The dashed line
- The vertical dashed line

Part C Activation energy

The vertical dashed line represents the activation energy. How could the activation energy be lowered?

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

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
- To the left
- It would not move

Part E Net effect

What would be the net effect of this shift?

- A greater number of 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
- Fewer particles would have sufficient energy to chemically react
- The temperature at which half of the particles have the required activation energy would increase

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

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Maxwell-Boltzmann Distribution

The speeds of molecules in a gas can be described by a probability distribution called the Maxwell-Boltzmann distribution.

$$P(v) = Av^2 \exp\left(-\frac{\frac{1}{2}mv^2}{kT}\right)$$

m = mass of molecule, T = temperature, v = speed of molecule, k = Boltzmann's constant

Part A Finding A

Determine A in terms of k, m, and T. *

*Note $\int_{-\infty}^{+\infty} e^{-x^2}\,dx = \sqrt{\pi}$, and this function is symmetric about 0.

The following symbols may be useful: `A, T, k, m, pi`

Part B Most likely speed

Determine the most likely speed.

The following symbols may be useful: `T, k, m, pi`

Part C Average speed

Determine the average speed.

The following symbols may be useful: `T, k, m, pi`

Part D Average squared speed

Determine the average squared speed of the molecules by integration, and hence the average random kinetic energy of a nitrogen molecule at $20\,^{\circ}\mathrm{C}$ in electron volts ($1\,\mathrm{eV} = 1.602 \times 10^{-19}\,\mathrm{J}$).

d)i) | d)ii)

Average squared speed:

The following symbols may be useful: `T, k, m, pi`

Average random kinetic energy of a nitrogen molecule:

Part E Ammonia and hydrochloric acid

If concentrated ammonia solution is placed on a pad at one end of a sealed tube, and concentrated hydrochloric acid is placed on a pad at the other end, after a while a ring of white crystals forms in the tube.

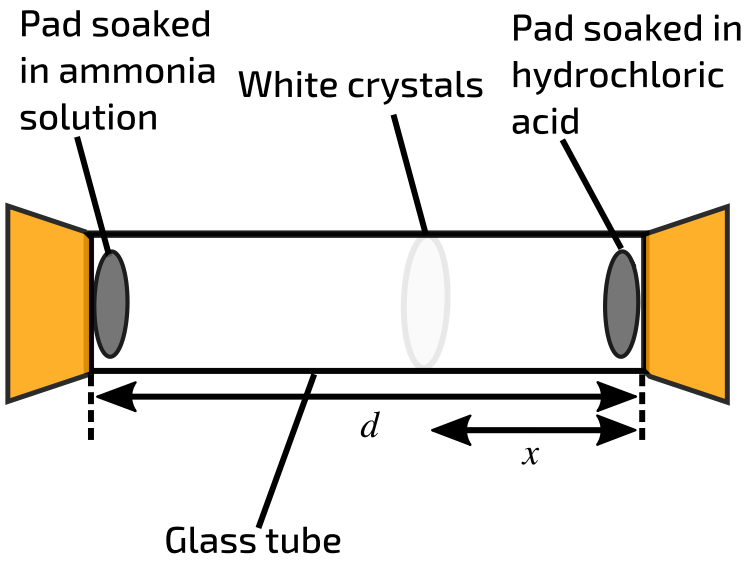

Figure 1: Diagram of sealed tube. d = distance between pads. x = distance from crystals to HCl pad.

What are the white crystals?

Taking the diffusion speeds of the gas molecules to be proportional to their root mean square speeds, if d, the distance from one pad to the other, is $2.00\,\mathrm{m}$ where does the ring form? (Give x the distance from the HCl end)

Proportion exceeding E_a

A Level

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.

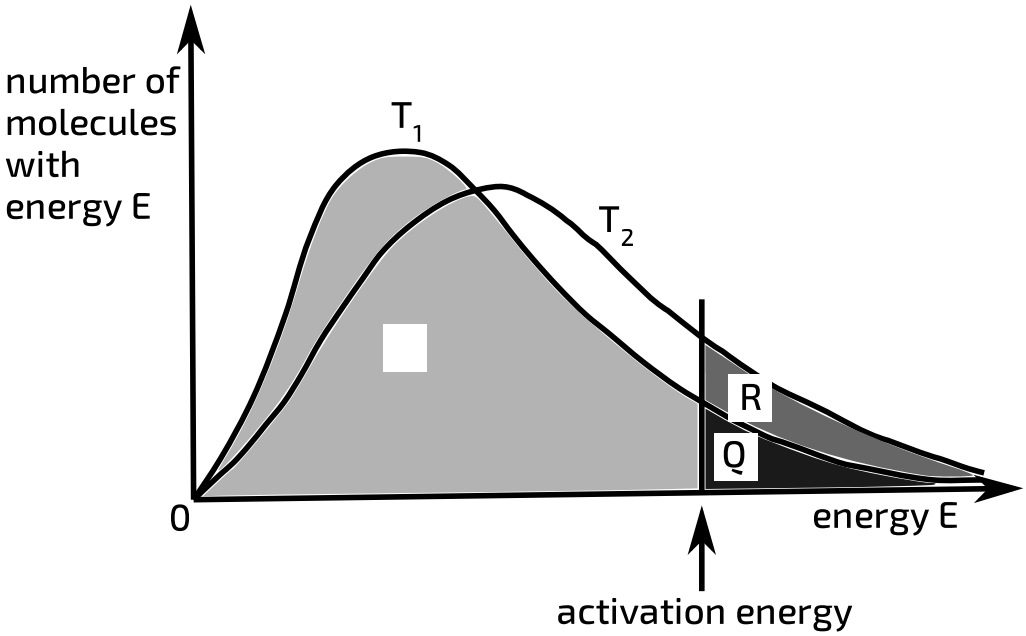

Figure 1: Two Maxwell-Boltzmann distributions

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`

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:

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

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?

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

Part D Instantaneous rate

How would the instantaneous rate of reaction be determined?

- 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.
- Divide the total change in volume by the total change in time.
- 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.

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Average Rate of Reaction

GCSE A Level

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 $40\,\text{s}$? 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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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.

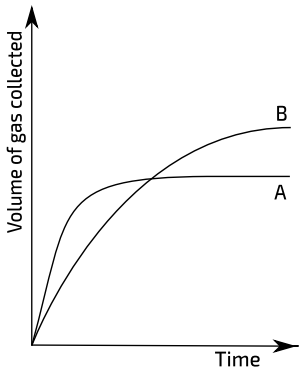

Figure 1: Volume of gas collected against time

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

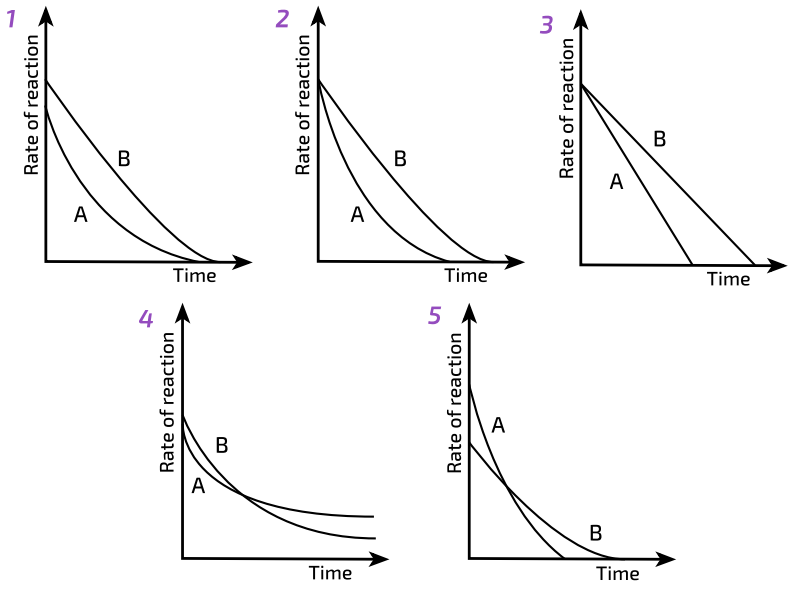

Figure 2: The rate against time for the five different experiments.

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