2.16 Rates of Reaction: 1-hour Pack

AQA 8464 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 A student reacts an excess of magnesium ribbon with 50 cm^3 of dilute hydrochloric acid, collecting the hydrogen gas produced using a gas syringe.

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

(a) Explain, in terms of collision theory, why the gradient of the graph of volume of gas against time decreases as the reaction proceeds. **(2)**

(b) Explain why the graph becomes horizontal (flat) before all of the magnesium ribbon has reacted. **(2)**

(c) State what would happen to the final (maximum) volume of gas collected if a larger excess of magnesium ribbon were used, with the same volume and concentration of hydrochloric acid. **(1)**

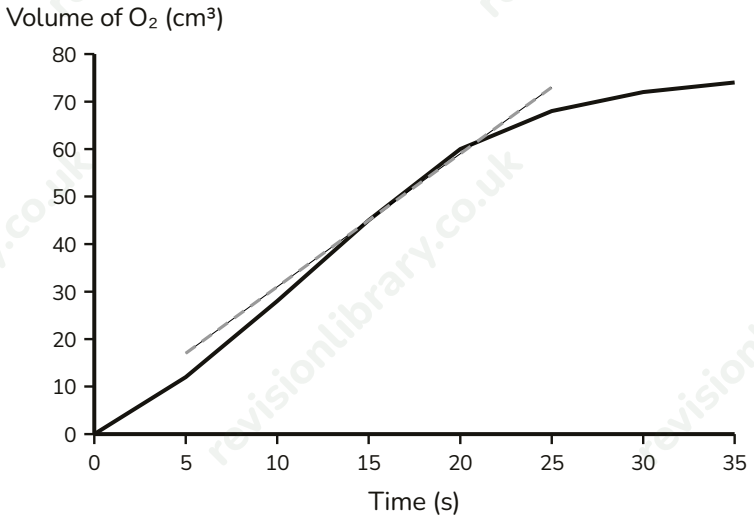
(Total for Question 1 is 5 marks)

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2 Manganese(IV) oxide catalyses the decomposition of hydrogen peroxide solution.

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

A student measures the volume of oxygen gas produced over time using a gas syringe. A tangent to the graph at t = 15 s passes through the points (5 s, 12 cm^3) and (25 s, 68 cm^3).



(a) Calculate the rate of reaction at t = 15 s. Give your answer to 3 significant figures. **(3)**

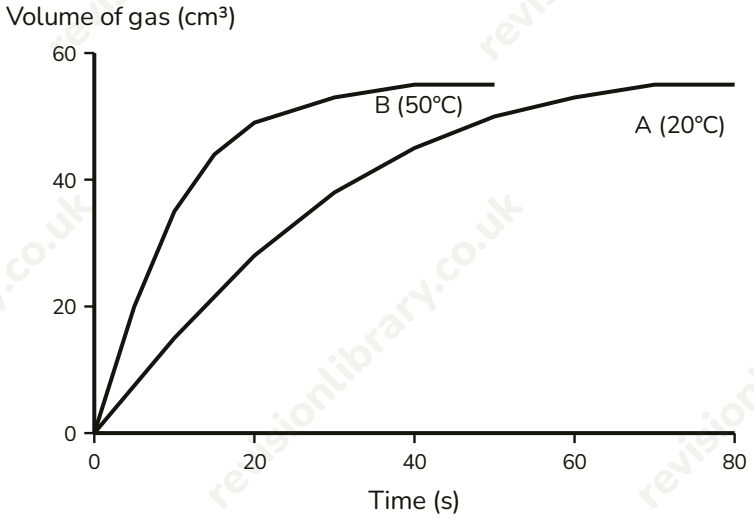
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(b) The student repeats the experiment without the manganese(IV) oxide catalyst. State and explain the effect this would have on the rate of reaction, and on the total volume of oxygen gas eventually produced. **(3)**

(Total for Question 2 is 6 marks)

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3 A student carries out the same reaction between magnesium ribbon and excess dilute hydrochloric acid at 20°C (Graph A) and 50°C (Graph B), using identical masses and concentrations in each case.



(a) State and explain which graph, A or B, would show the steeper gradient at the start of the reaction. **(2)**

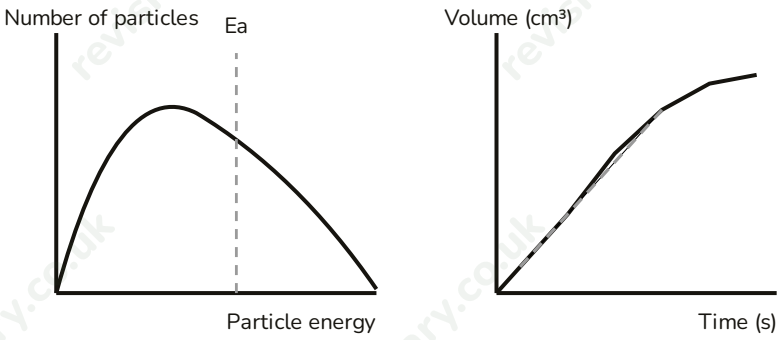
(b) State, with a reason, whether graphs A and B would reach the same final (maximum) volume of gas. **(2)**

(c) A student claims that increasing the temperature from 20°C to 50°C will exactly double the rate of reaction, because the temperature (in °C) has more than doubled. Evaluate this claim. **(3)**

(Total for Question 3 is 7 marks)

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4 The Boltzmann distribution shows the spread of energies of particles in a gas or solution at a particular temperature, and can be used to explain the effect of temperature on rate of reaction in more detail.



(a) Higher tier only. On a Boltzmann distribution graph (particle energy on the x-axis, number of particles with that energy on the y-axis, with the activation energy, Ea, marked on the x-axis), state what happens to the shape of the curve when the temperature of a reaction mixture is increased. In your answer, refer to the total area under the curve. **(3)**

(b) A tangent to the volume-time graph for this reaction at t = 8 s passes through the points (2 s, 6 cm^3) and (14 s, 42 cm^3). Calculate the rate of reaction at t = 8 s, in cm^3/s, and then convert your answer into mm^3/s (1 cm^3 = 1000 mm^3). **(3)**

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(c) The student judges the end-point of a similar disappearing-cross experiment by eye. Evaluate this method, and suggest one improvement. **(2)**

.....

(Total for Question 4 is 8 marks)

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5 A catalyst is a substance that changes the rate of a chemical reaction.

(a) Define the term 'catalyst'. **(2)**

(b) State one reason why using a catalyst is beneficial in an industrial chemical process, in terms of cost. **(2)**

(Total for Question 5 is 4 marks)

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6 A student reports that doubling temperature always doubles reaction rate. State why this statement is incorrect, using activation energy and Boltzmann distribution in your answer.

(Total for Question 6 is 2 marks)

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7 Hydrogen peroxide decomposes to oxygen and water. The table shows initial rates measured at two temperatures using a catalyst.

Temperature / °C: 25, initial rate = 0.012 mol/s
Temperature / °C: 45, initial rate = 0.048 mol/s

Calculate the factor by which the rate increases when temperature increases from 25°C to 45°C. Show your working.

(Total for Question 7 is 3 marks)

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8 A student investigates the effect of surface area on the rate of reaction between marble chips (calcium carbonate) and 1.0 mol/dm3 hydrochloric acid. The student uses large chips in Trial 1 and powdered marble in Trial 2, keeping acid volume, concentration and temperature constant. Predict and explain the difference in the rate of gas formation between Trial 1 and Trial 2.

(Total for Question 8 is 4 marks)

9 Plan a method for this investigation. In your answer you should refer to: the equipment and procedure you would use; how you would ensure your results are valid, accurate and reproducible; and how you would use your results to calculate the rate of reaction for each concentration.

(Total for Question 9 is 6 marks)

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10 A catalysed decomposition of X has activation energy of 45 kJ/mol, and the uncatalysed reaction has activation energy of 110 kJ/mol. Explain, using an energy profile diagram description, why the catalysed reaction is faster and state one limitation of catalysts in reversible reactions.

(Total for Question 10 is 4 marks)

11 A student plots a graph of volume of gas against time for the reaction between marble chips and excess dilute hydrochloric acid. The curve is steepest at the start and becomes less steep as the reaction proceeds. Explain how the student could find the rate of reaction at 20 seconds (rather than the mean rate for the whole reaction) using the graph.

(Total for Question 11 is 3 marks)

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Mark scheme · 2.16 Rates of Reaction: 1-hour Pack

Question 1

(a) the concentration of hydrochloric acid decreases as it is used up during the reaction (oe) **B1**

(a) so the frequency of collisions between reacting particles decreases, meaning fewer successful collisions occur per second, and the rate decreases (oe) **B1**

(a) Answer: As the acid is used up, its concentration falls, so collisions between reacting particles become less frequent and the rate decreases.

(b) the hydrochloric acid is the limiting reactant/is fully used up (there is excess magnesium remaining) (oe) **B1**

(b) once all of the acid has reacted, no more collisions can occur between (the remaining) reacting particles, so no more gas can be produced and the reaction stops (oe) **B1**

(b) Answer: The acid (the limiting reactant) is fully used up, so no more reacting collisions can occur, even though excess magnesium remains, so the reaction stops.

(c) the final volume of gas would stay the same (unchanged), because the amount of hydrochloric acid (the limiting reactant) determines the maximum amount of gas produced (oe) **B1**

(c) Answer: It would stay the same, because the acid (the limiting reactant) determines the maximum amount of gas produced, not the amount of magnesium.

Question 2

(a) gradient = (68 - 12) / (25 - 5) = 56 / 20 **M1**

(a) = 2.8 **M1**

(a) 2.80 cm^3/s (cso, 3 s.f.) **A1**

(a) Answer: 2.80 cm^3/s

(b) without the catalyst, the rate of reaction would be slower (a lower gradient/rate at any given time) (oe) **B1**

(b) because there is no alternative, lower-activation-energy pathway, so fewer collisions have sufficient energy to react, meaning fewer successful collisions per second (oe) **B1**

(b) the total (maximum) volume of oxygen gas produced would be unchanged/the same, because the same amount of hydrogen peroxide reacts overall; a catalyst does not affect the amount of product formed, only how quickly it forms (oe) **B1**

(b) Answer: The rate would be slower without the catalyst, because collisions need to overcome a higher activation energy, but the total volume of oxygen produced would be the same, since the catalyst only affects rate, not the amount of product.

Question 3

(a) Graph B (the experiment at 50°C) (cao) **B1**

(a) because particles have more kinetic energy at the higher temperature, so they collide more frequently and with more energy, resulting in more successful collisions per second at the start of the reaction (oe) **B1**

(a) Answer: Graph B (50°C), because particles have more energy and collide more frequently and successfully at the higher temperature.

(b) yes, the same final volume (cao) **B1**

(b) because the same amount/mass of hydrochloric acid (the limiting reactant) is used in each experiment, so the same amount of product (hydrogen gas) is eventually formed; temperature only affects how quickly the maximum volume is reached, not the total amount (oe) **B1**

(b) Answer: Yes, the same final volume, because the same amount of the limiting reactant (acid) is used each time; temperature changes only how quickly this volume is reached.

(c) the claim is not correct: the relationship between Celsius temperature and rate is not simply proportional (a doubling of Celsius temperature does not cause a doubling of rate) (oe) **B1**

(c) rate depends on the proportion of particles with energy greater than or equal to the activation energy, and this proportion increases sharply (non-linearly) with a rise in temperature, rather than in direct proportion to the Celsius value (oe) **B1**

(c) collision frequency and collision energy both change together in a complex way as temperature rises, so a simple doubling claim based on Celsius values is not a scientifically valid comparison (oe) **B1**

(c) Answer: The claim is incorrect: rate does not scale directly with Celsius temperature. It depends on the (non-linearly increasing) proportion of particles with energy above the activation energy, and on collision frequency, so a simple doubling of temperature value does not mean a doubling of rate.

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Question 4

(a) the peak of the curve moves to the right (towards higher energies) and becomes lower, so the curve becomes flatter and more spread out (oe) **B1**

(a) the total area under the curve stays the same, because the total number of particles has not changed (cao) **B1**

(a) the area under the curve to the right of the activation energy, Ea, increases, showing that a greater proportion of particles now have energy greater than or equal to the activation energy (oe) **B1**

(a) Answer: The peak shifts right and the curve flattens, but the total area under the curve stays the same (same total number of particles); the area beyond Ea increases, showing more particles now have enough energy to react.

(b) gradient = (42 - 6) / (14 - 2) = 36 / 12 **M1**

(b) 3 cm^3/s (cao) **A1**

(b) dependent on the previous A1: 3 x 1000 = 3000 mm^3/s (ecf) **dM1**

(b) Answer: 3 cm^3/s, which is 3000 mm^3/s

(c) judging by eye is subjective: different people may judge the point at which the cross disappears slightly differently (or the same person may be inconsistent), reducing the reproducibility/accuracy of the results (oe) **B1**

(c) improvement: use a light sensor/colorimeter (data logger) to measure the light transmitted or absorbed by the solution, recording when it reaches a fixed, objective threshold value, removing human judgement from the measurement (oe) **B1**

(c) Answer: Judging by eye is subjective and can vary between observers, reducing reproducibility. Using a light sensor/colorimeter with a fixed threshold value would give a more objective, reproducible measurement.

Question 5

(a) a substance that increases the rate of a chemical reaction (oe) **B1**

(a) without being used up (chemically unchanged) at the end of the reaction (oe, cao) **B1**

(a) Answer: A catalyst is a substance that increases the rate of a reaction without being used up (chemically unchanged) at the end.

(b) catalysts allow reactions to be carried out at a lower temperature and/or pressure than otherwise needed (oe) **B1**

(b) this reduces the energy costs (and equipment costs) of the process, and since the catalyst is not used up it can be reused, making it cost-effective (oe, any one linked reason) **B1**

(b) Answer: Catalysts allow lower operating temperatures and pressures, reducing energy costs, and since they are not used up they can be reused.

Question 6

temperature effect on rate is not linear; depends on activation energy and how the Boltzmann distribution shifts **B1**

raising temperature increases fraction of particles above activation energy, but factor depends on Ea and temperature change, not simply doubling **B1**

Answer: Incorrect because increasing temperature changes the fraction of particles with energy above the activation energy according to the Boltzmann distribution; the change in rate depends on Ea and temperature change, not a simple doubling.

Question 7

divides rates: 0.048 / 0.012 **M1**

4.0 cao **A1**

answer given as '4 times' or factor 4 with unitless statement **B1**

Answer: 4.0

Question 8

prediction that Trial 2 (powder) will have a faster rate or produce gas faster **B1**

state that powdered marble has greater surface area so more particles are exposed, oe **B1**

therefore more frequent collisions per unit time between acid and carbonate particles, oe **B1**

conclusion linking increased collision frequency to increased rate of gas formation, oe **B1**

Answer: The powdered marble (Trial 2) will produce gas faster because it has a larger surface area, giving more exposed particles and more frequent collisions so the reaction rate is higher.

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Question 9

Level 3 A logically sequenced method is described that would lead to a valid, reproducible outcome. The answer includes relevant equipment, how variables are controlled, how measurements are taken and repeated, and explains how the rate of reaction is calculated from the results.	**5-6**
Level 2 A method is described with some steps in a logical order. The answer includes some relevant equipment and some reference to controlling variables or repeating measurements, and some reference to calculating rate, but is not fully complete or has minor omissions.	**3-4**
Level 1 Simple statements are made about the equipment or method, with little or no logical structure. Little or no reference to controlling variables, repeats, or calculating rate.	**1-2**
Level 0 No relevant content.	**0**

Indicative content:

- Use a conical flask, bung and gas syringe (or delivery tube to an inverted measuring cylinder) to collect the gas produced.
- Use a fixed length/mass of magnesium ribbon in each repeat, cleaned with emery paper/sandpaper to remove the surface oxide layer.
- Use the same total volume of hydrochloric acid each time, varying only its concentration (e.g. by diluting with water using a measuring cylinder or burette, keeping the total volume constant).
- Add the acid to the flask, quickly insert the bung/gas syringe, and start the stop-clock at the same moment.
- Record the volume of gas produced at regular time intervals (e.g. every 10 seconds) until no more gas is produced.
- Control the temperature (e.g. using a water bath) so it does not affect the comparison between concentrations.
- Repeat each concentration at least twice (or three times), calculate a mean, and discard anomalous results.
- Plot a graph of volume of gas against time for each concentration.
- Calculate the mean rate of reaction using rate = volume of gas produced / time taken, or use the gradient of a tangent to find the rate at a specific time.
- Compare the rate at different concentrations to draw a conclusion about the relationship between concentration and rate.
- Reference to safety: wear eye protection, and keep naked flames away, since hydrogen gas is flammable.

Question 10

states that energy profile for catalysed reaction has a lower peak / lower activation energy (45 kJ/mol) than uncatalysed (110 kJ/mol)	**B1**
states that lower activation energy means more particles have enough energy to overcome the barrier so rate increases, oe	**B1**
describes that the overall energy change (delta H) is unchanged between catalysed and uncatalysed reactions, oe	**B1**
limitation: catalysts do not change equilibrium position or yield; they only speed up forward and reverse equally, or catalysts can be poisoned or deactivated, oe	**B1**

Answer: The catalysed pathway has a much lower activation energy peak (45 kJ/mol) than the uncatalysed route (110 kJ/mol), so more particles have enough energy to react and the rate is faster; the overall delta H is unchanged. Limitation: catalysts do not change the equilibrium position or final yield and can be poisoned or deactivated.

Question 11

draw a tangent to the curve at the point where time = 20 s	**B1**
calculate the gradient of the tangent by dividing the change in volume by the change in time (rise / run)	**B1**
the gradient of the tangent gives the rate of reaction (in cm3/s) at that instant, not the mean rate, oe	**B1**

Answer: Draw a tangent to the curve at t = 20 s, then calculate its gradient (change in volume / change in time); this gradient gives the instantaneous rate of reaction in cm3/s at 20 s.

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