

OCR A - LEVEL CHEMISTRY A • H432

CHEMISTRY



EXAM QUESTION PACK

3.2.2-3.2.3 REACTION RATES AND EQUILIBRIUM

SCORE

/153

PERCENTAGE

%

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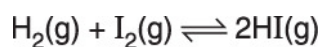
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- 1 A student mixes hydrogen and iodine at room temperature and pressure and allows the mixture to reach dynamic equilibrium.



$$\Delta H = -9 \text{ kJ mol}^{-1}$$

equilibrium 3.1

- (i) A closed system is required for dynamic equilibrium to be established.

State **one** other feature of this dynamic equilibrium.

----- [1]

- (ii) The student heats the equilibrium mixture keeping the volume constant.

Predict how the composition of the equilibrium mixture changes on heating.

Explain your answer.

----- [2]

- (iii) Predict and explain what effect, if any, an increase in the pressure would have on the position of the equilibrium.

effect -----

explanation -----

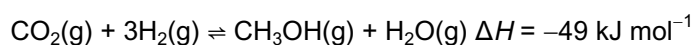
----- [1]

2(a) State le Chatelier's principle.

----- [1]

(b) Methanol, CH₃OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.



High pressures and low temperatures would give a maximum equilibrium yield of methanol.

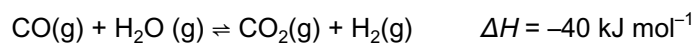
(i) Explain this statement in terms of le Chatelier's principle.

----- [3]

(ii) Explain why the actual conditions used by the chemical industry might be different.

----- [2]

3 Carbon monoxide reacts with steam in the following reaction equation:



Which change will shift the position of equilibrium to the right hand side of the equation?

- A decrease in pressure
- B increase in pressure
- C decrease in temperature
- D increase in temperature

Your answer ☐

[1]

4 Which statement is **not** correct for a system in dynamic equilibrium?

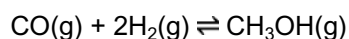
- A The concentrations of products and reactants are the same.
- B The equilibrium can be achieved from both sides.
- C The rate of the forward reaction is equal to the rate of the reverse reaction.
- D The system is closed.

Your answer ☐

[1]

5(a) This question looks at equilibrium reactions used by industry for preparing important chemicals.

Methanol can be manufactured by reacting carbon monoxide with hydrogen.



An equilibrium mixture contains $3.10 \times 10^{-3} \text{ mol dm}^{-3}$ CO, $2.40 \times 10^{-3} \text{ mol dm}^{-3}$ H₂ and an unknown concentration of CH₃OH.

(i) Write an expression for the equilibrium constant, K_c .

[1]

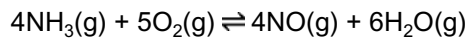
(ii) The value of K_c for this equilibrium is $14.6 \text{ dm}^6 \text{ mol}^{-2}$.

Determine the equilibrium concentration methanol, CH₃OH(g).

Give your answer to **three** significant figures.

equilibrium concentration of CH₃OH(g) = _____ $\text{dm}^6 \text{ mol}^{-2}$ [2]

(b) Ammonia is used in the manufacture of nitric acid. The first stage of this process is a dynamic equilibrium.



(i) When the temperature is increased, K_c for this reaction decreases.

State the effect, if any, on the equilibrium yield of NO in this reaction.

Explain your answer.

----- [1]

(ii) Which element has been oxidised and which element has been reduced in the reaction?

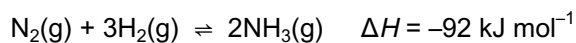
Include signs with the oxidation numbers.

Oxidised ----- Oxidation number change from ----- to -----

Reduced ----- Oxidation number change from ----- to -----

[2]

- 6 Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.



A mixture of N_2 and H_2 was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

N_2	1.20 mol dm^{-3}
H_2	2.00 mol dm^{-3}
NH_3	$0.877 \text{ mol dm}^{-3}$

- (i) Calculate a value for K_c for this equilibrium.

$$K_c = \text{-----} \text{ dm}^6 \text{ mol}^{-2} \quad [3]$$

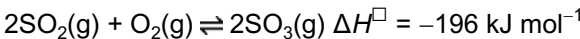
- (ii) Explain how the following changes would affect the amount of NH_3 present in the equilibrium mixture.

Use of a catalyst:

A higher temperature:

[3]

7



This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.

Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

[6]

- The equilibrium mixture under these conditions has the following concentrations of SO_2 and O_2 .

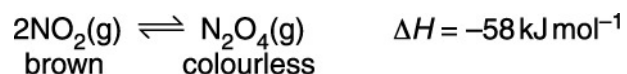
- Using the value of K_c , explain whether the equilibrium position will be towards the right or towards the left under these conditions.
- Calculate the concentration of SO_3 in the equilibrium mixture.

[4]

9(a) This question is about equilibrium and catalysts.

The equilibrium between NO_2 and N_2O_4 gases is set up in a gas syringe at room temperature.

The two gases are different in appearance.



Using le Chatelier's principle, predict and explain how the following changes would affect the appearance of the equilibrium mixture.

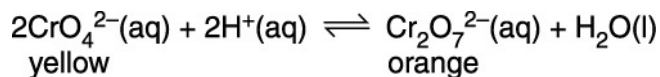
(i) The gas mixture is compressed by pushing in the plunger of the gas syringe.

----- [2]

(ii) The gas syringe is placed in a warm water bath.

----- [2]

- (b) When potassium chromate(VI), K_2CrO_4 , is dissolved in water an equilibrium is set up. The position of equilibrium is well to the left and the solution is a yellow colour.



The addition of aqueous acid turns the solution an orange colour.
Aqueous alkali is then added and the solution turns a yellow colour.

Explain these observations in terms of le Chatelier's principle.

[2]

- 10 The reversible reaction below is allowed to reach equilibrium.



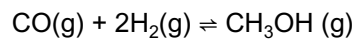
Which change in conditions would be expected to shift the equilibrium position towards the products?

- A decrease the pressure
- B decrease the temperature
- C increase the pressure
- D increase the temperature

Your answer

[1]

11 A chemist investigates the equilibrium that produces methanol:



The chemist mixes CO(g) with H₂(g) and leaves the mixture to react until equilibrium is reached.
The equilibrium mixture is analysed and found to contain the following concentrations.

Substance	Concentration/mol dm ⁻³
CO (g)	0.310
H ₂ (g)	0.240
CH ₃ OH(g)	0.260

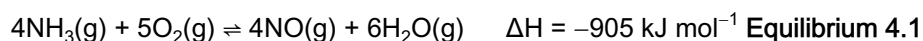
Calculate the numerical value of K_c for this equilibrium.

Give your answer to an **appropriate** number of significant figures.

$K_c = \text{-----} \text{ dm}^6 \text{ mol}^{-2} \text{ [2]}$

12(a) The reaction of ammonia, NH_3 , with oxygen to form nitrogen monoxide, NO , is an important industrial process.

The equation for this reaction is shown in **equilibrium 4.1** below.



Write an expression for the equilibrium constant, K_c , in **equilibrium 4.1**.

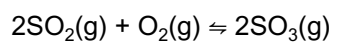
[1]

(b) Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in **equilibrium 4.1**.

- Explain your prediction in terms of le Chatelier's principle.
- State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors.

[5]

13 The reversible reaction below is at equilibrium.



$$\Delta H = -197 \text{ kJ mol}^{-1}$$

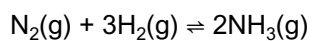
Which changes in pressure and temperature would shift the equilibrium position towards the products?

	Pressure	Temperature
A	Decrease	Decrease
B	Decrease	Increase
C	Increase	Decrease
D	Increase	Increase

Your answer

[1]

14 The reversible reaction below is at equilibrium.



What is the expression for K_c ?

A
$$\frac{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3}{[\text{NH}_3(\text{g})]^2}$$

B
$$\frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3}$$

C
$$\frac{[\text{N}_2(\text{g})] + 3[\text{H}_2(\text{g})]}{2[\text{NH}_3(\text{g})]}$$

D
$$\frac{2[\text{NH}_3(\text{g})]}{[\text{N}_2(\text{g})] + 3[\text{H}_2(\text{g})]}$$

Your answer

[1]

15 A catalyst is added to a system in equilibrium.

What is the effect on the rates of the forward and reverse reactions?

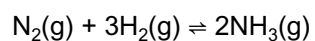
- A There is no effect on the rate in either direction.
- B Both rates increase by the same factor.
- C The rate in the forward direction increases by a greater factor than the reverse direction.
- D The rate in the reverse direction increases by a greater factor than the forward direction.

Your answer

[1]

16 This question is about ammonia, NH_3 .

In industry, ammonia is made from nitrogen and hydrogen. This is a reversible reaction, as shown in **equilibrium 24.1** below.



$$\Delta H = -92 \text{ kJ mol}^{-1}$$

Equilibrium 24.1

- (i) Explain how le Chatelier's principle can be used to predict the conditions of temperature and pressure for a maximum **equilibrium** yield of ammonia.

[4]

(ii) Using certain conditions, **equilibrium 24.1** has the equilibrium concentrations in the table.

Substance	Equilibrium concentration / mol dm ⁻³
N ₂ (g)	1.25
H ₂ (g)	2.75
NH ₃ (g)	0.862

Calculate the numerical value for K_c for **equilibrium 24.1** under these conditions.

Give your answer to an **appropriate** number of significant figures and in **standard form**.

$K_c = \dots\dots\dots$ [2]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	Rate of the forward reaction is equal to the rate of the reverse reaction ✓ OR concentrations do not change ✓	1	ALLOW both reactions occur at same rate IGNORE conc. of reactants = conc. of products Examiner's Comments A good proportion of candidates recognised the need to provide one of the key features of a dynamic equilibrium as outlined in the specification.
		ii	More H₂ and I₂ OR less HI ✓ (equilibrium position shifts) to the left AND (Forward) reaction is exothermic OR reverse reaction is endothermic OR in the endothermic direction ✓	2	Mark each point independently ALLOW more reactants OR less products Note: ALLOW suitable alternatives for to the left e.g. towards reactants OR towards H₂ / I₂ OR in reverse direction OR favours the left. ALLOW gives out heat for exothermic ALLOW takes in heat for endothermic IGNORE responses in terms of rate Examiner's Comments This question required candidates to apply le Chatelier's Principle to the equilibrium and in addition predict the effect it would have on the composition of the mixture. Most candidates were able to predict and explain the shift in the position of equilibrium and the most able stated the effect on the composition of the mixture. Candidates should be encouraged to read questions carefully to ensure they address all aspects in their response.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	No effect AND Same number of (gaseous) moles on both sides ✓	1	ALLOW same number of molecules on each side Examiner's Comments This question was answered very well and most candidates picked up this mark.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	a		The (position of a dynamic) equilibrium shifts to minimise (the effect of) any change ✓	1	ALLOW suitable alternatives for 'shifts' and 'minimises' IGNORE 'reaction shifts' Examiner's Comments Most candidates were able to describe le Chatelier's principle.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Pressure: Right-hand side has fewer (gaseous) moles / molecules OR left-hand side has more (gaseous) moles / molecules ✓ Temperature: Statement that: (Forward) reaction is exothermic OR (forward) reaction gives out heat OR reverse reaction is endothermic OR reverse reaction takes in heat ✓ Equilibrium Lower temperature / cooling AND increasing pressure shifts (equilibrium position) to the right ✓	3	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC DO NOT ALLOW fewer atoms on right-hand side OR more atoms on left-hand side. IGNORE comments about the 'exothermic side' or 'endothermic side' Equilibrium mark is for stating that BOTH low temperature and high pressure shift equilibrium to the right (Could be separate statements) Note: ALLOW suitable alternatives for 'to right', e.g.: towards products OR towards CH_3OH / H_2O OR in forward direction OR favours the right IGNORE Increases yield of CH_3OH / products (<i>in question</i>) IGNORE responses in terms of rate Examiner's Comments A good discrimination was achieved by this question. The most able candidates gave succinct responses which related the low temperature and high pressure to the change in equilibrium position. Candidates are encouraged to write as accurately as possible in this type of question. For example, the effect of pressure is best explained by reference the relative number of moles on each side of the equation. A statement about the nature of the forward reaction, in this case exothermic, is appropriate to explain the effect of temperature.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Low temperature gives a slow rate OR high temperatures needed to increase rate ✓ High pressure is expensive (to generate) OR high pressure provides a safety risk ✓	2	ALLOW high pressure is dangerous IGNORE high pressure is explosive Examiner's Comments Most candidates identified high pressures as either dangerous or requiring expensive equipment. The strongest responses linked low temperature with a slow rate of reaction.
			Total	6	
3			C	1	
			Total	1	
4			A	1	
			Total	1	
5	a	i	$K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}$	1	
		ii	$[\text{CH}_3\text{OH}] = 14.6 \times (3.10 \times 10^{-3}) \times (2.40 \times 10^{-3})^2$ (1) $= 2.61 \times 10^{-7} \text{ (mol dm}^{-3}\text{) (1)}$	2	
	b	i	Yield decreases AND Equilibrium (position) has moved to the left	1	allow moved towards reactants OR moved towards CO and H ₂
		ii	Oxidised Nitrogen AND -3 AND +2 (1) Reduced Oxygen AND 0 AND -2 (1)	2	
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6		i	<i>Expression:</i> $K_c = [\text{NH}_3]^2 / [\text{H}_2]^3 [\text{N}_2] \text{ (1)}$ <i>Calculation:</i> $= (0.877)^2 / (2.00)^3 (1.20) \text{ (1)}$ $= 0.0801 \checkmark \text{ (dm}^6 \text{ mol}^{-2}\text{)}$	3	square brackets required allow from 1 sig fig up to calculator display correct answer alone scores all marks
		ii	<i>Catalyst:</i> No effect, it only changes the rate of reaction (1) <i>Higher temperature:</i> Forward reaction is exothermic (1) so position of equilibrium moves to the left and there will be less NH_3 (1)	3	
			Total	6	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
7	<i>* Please refer to the marking instruction point 10 for guidance on how to mark this question.</i> (Level 3) All/most points covered and clearly linked. Must have points taken across all of the headings in the indicative points for Level 3. <i>The explanations show a well-developed line of reasoning linked to appropriate suggestions which is clear and logically structured. The compromises are relevant and well thought out and clearly linked to the explanations.</i> (5–6 marks) (Level 2) Suggests correct conditions with explanations OR comments on compromises with reference to yield AND rate effect. <i>The explanations are linked to appropriate suggestions and show a line of reasoning with some structure. The compromises are relevant but may not be clearly linked to the explanation.</i> (3–4 marks) (Level 1) Comments on conditions with some explanation OR comments on compromise with reference to yield OR rate. <i>The comments about yield / rate with explanation are basic and communicated in an unstructured way. The compromises may not be relevant with lack of reasoning.</i> (1–2 marks) No response or no response worthy of credit. (0 marks)	6	Indicative scientific points may include Yield - Increasing pressure increases yield of SO₃ - Decreasing temperature increases yield of SO₃ Explanation (pressure) more moles / molecules on the reactant side ORA (temp.) the forward reaction is exothermic ORA Rate - Increasing pressure increases rate - Increasing temperature increases rate Compromise - Choose a higher temperature which creates a reduced yield but in a shorter space of time ignore reference to increase pressure leading to safety / cost issues

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	6	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
8	a	EQUILIBRIUM CONDITIONS 3 MAX 4 marking points ☐ 3 max ✓✓✓ Mark first three CORRECT responses seen Temperature: (Forward) reaction is exothermic/ΔH is negative OR (Forward) reaction gives out heat ✓ Pressure: Right-hand side has fewer (gaseous) moles OR 3 (gaseous) moles form 2 (gaseous) moles ✓ Equilibrium shift Correct equilibrium shift in terms of temperature ✓ Correct equilibrium shift in terms of pressure ✓ INDUSTRIAL CONDITIONS Low temperature gives a slow rate/slower reaction OR high temperatures needed to increase rate ✓☐ (High) pressure provides a safety risk OR (High) pressure is expensive (to generate) /uses a lot of energy ✓☐	5	FULL ANNOTATIONS MUST BE USED ALLOW suitable alternatives for 'towards right', e.g.: towards SO_3/products OR in forward direction OR 'favours the right' ALLOW reverse reaction is endothermic /ΔH is positive/takes in heat For moles, ALLOW molecules/particles ORA for reverse reaction IGNORE responses in terms of activation energy ALLOW high pressure is dangerous/explosive ALLOW 'These conditions are expensive' Statement subsumes pressure as 'these' will apply to pressure (required for this mark) and temperature ALLOW ORA e.g. Lower pressure → less danger/uses less energy IGNORE 'It's expensive' Link with pressure required <u>Examiner's Comments</u> This longer answer was answered very well with the majority of candidates able to score 4 or 5 marks. Most candidates explained how the position of equilibrium shifts in response to low temperature and high pressure. The commonest omission was the link between low temperature and a slow reaction rate.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		<i>Value of K_c 1 mark</i> K_c is small OR $K_c < 1$ AND equilibrium (position) is towards left ✓	4	<i>FULL ANNOTATIONS MUST BE USED</i> ALLOW suitable alternatives for 'towards left, e.g.: towards SO_2/O_2 OR towards reactants OR in reverse direction OR 'favours the left

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	<i>Calculation: FIRST CHECK ANSWER</i> IF $[\text{SO}_3] = 0.876$ OR 0.88 (mol dm^{-3}) award all 3 marks available for calculation K_c expression 1 mark $\frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]}$ OR $\frac{[\text{SO}_3]^2}{2.00^2 \times 1.20}$ ✓ Evaluation of K_c $[\text{SO}_2]^2[\text{O}_2]$ 1 mark $K_c[\text{SO}_2]^2[\text{O}_2] = 0.160 \times 2.00^2 \times 1.20$ $= 0.768$ ✓ Calculation of $[\text{SO}_3]$ <i>ONLY available from correct evaluation for 2nd mark</i> $[\text{SO}_3] = \sqrt{(0.160 \times 2.00^2 \times 1.20)}$ $= 0.876$ (mol dm^{-3}) ✓		Square brackets required in K_c expression ALLOW ECF from $\frac{[\text{SO}_3]}{[\text{SO}_2]^2[\text{O}_2]}$, i.e. no $[\text{SO}_3]^2$ ALLOW 0.77 (2 SF) ALLOW 0.88 (2 SF) up to calculator value of 0.876356092 correctly rounded IF K_c expression is inverted 2nd and 3rd marks are available by ECF: $[\text{SO}_3]^2 = \frac{2.00^2 \times 1.20}{0.160}$ OR 30 ✓ $[\text{SO}_3] = \sqrt{30} = 5.48$ OR 5.5 ✓ Any other K_c expression → NO MARKS, e.g. $\frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 + [\text{O}_2]} \rightarrow \sqrt{0.832} \rightarrow 0.912$ NO Marks <u>Examiner's Comments</u> Given that K_c is new to AS level in the reformed specification, this part was attempted well. However, writing a correct K_c did cause problems for weaker candidates, who sometimes inverted the expression, used the + sign from the equation, obtaining a denominator of $[\text{SO}_2]^2 + [\text{O}_2]$, or omitted the square from $[\text{SO}_2]^2$ and $[\text{SO}_3]^2$. Some excellent answers were seen and this part differentiated very well between candidates of different abilities. Answer: $[\text{SO}_3] = 0.876 \text{ mol dm}^{-3}$
	Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9	a	i	Equilibrium (position) shifts to right AND turns paler (brown) ✓ Right-hand side has fewer (gaseous) moles / molecules OR left-hand side has more (gaseous) moles / molecules ✓	2	ALLOW turns colourless IGNORE initially goes darker (brown) Note: ALLOW suitable alternatives for 'to right', e.g.: towards products OR towards N_2O_4 OR in forward direction OR favours the right IGNORE responses in terms of rate Examiner's Comments The effect of pressure on the position of an equilibrium is well known by candidates. Most were able to apply le Chatelier's principle accurately stating the equilibrium shifted to the right as that was the side with fewest moles of gas. However a significant proportion of the cohort did not comment on the effect on the appearance of the equilibrium mixture.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Equilibrium (position) shifts to left AND turns darker / deeper (brown) ✓ (Forward) reaction is exothermic OR (forward) reaction gives out heat OR reverse reaction is endothermic OR reverse reaction takes in heat ✓	2	ALLOW turns brown Note: ALLOW suitable alternatives for 'to left', e.g.: towards reactants OR towards NO₂ OR in reverse direction OR favours the left IGNORE comments about the 'exothermic side' or 'endothermic side' ALLOW 'equilibrium (position) shifts left AND in the endothermic direction' for second marking point IGNORE responses in terms of rate Examiner's Comments As with part (a)(i), candidates demonstrated an excellent grasp of le Chatelier's principle but it was only the most able candidates who referred to the appearance of the equilibrium mixture. Candidates should be encouraged to read questions carefully to ensure they include all the required information in their responses.
	b		Addition of acid [H⁺] OR H⁺ increases AND equilibrium (position) shifts to right ✓ Addition of alkali Alkali reacts with H⁺ OR alkali removes H⁺ AND equilibrium (position) shifts to left ✓	2	ANNOTATE ANSWER WITH TICKS AND CROSSES IGNORE amount of acid increases (<i>in question</i>) ALLOW (added) acid reacts with CrO₄²⁻ Note: ALLOW suitable alternatives for 'to right', e.g.: towards products OR towards Cr₂O₇²⁻ / H₂O OR in forward direction OR favours the right ALLOW H⁺ + OH⁻ → H₂O ALLOW alkali reacts with (added) acid Note: ALLOW suitable alternatives for 'to left', e.g.: towards reactants OR towards CrO₄²⁻ / H⁺ OR in reverse direction

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					OR favours the left IGNORE just H^+ concentration decreases (needs role of alkali) IGNORE concentration of water increases (needs role of alkali) Examiner's Comments This question discriminated well and the strongest candidates provided succinct responses with the correct level of scientific content. The first mark was awarded for recognition that adding an acid would increase the concentration of H^+ ions, causing the equilibrium to shift to the right. Most candidates realised this was the case. However, it was not uncommon to see vague responses that simply re-stated the information in the question, rather than focussing on the effect it would have on the species in the equilibrium equation. The second mark proved more difficult. The strongest candidates identified that the added alkali would remove H^+ ions from the equilibrium mixture, and some supported this statement with an equation. Many however, simply stated that the equilibrium would shift left to reduce the concentration of the alkali without attempting to relate it to the equation provided. Candidates are advised to consider the chemical equations provided with a question as they will help form the basis from which to build a response.
			Total	6	
10			B	1	Examiner's Comments This question discriminated very well with most able candidates obtaining the correct answer.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11			FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 14.6 (dm⁶ mol⁻⁶) award 2 marks K_c expression $(K_c =) \frac{[\text{CH}_3\text{OH}]}{[\text{CO}] [\text{H}_2]^2}$ OR $\frac{0.26}{0.31 \times 0.24^2}$ OR 14.56 ✓ Answer to 3 SF 14.6 (dm⁶ mol⁻²) ✓	2	FULL ANNOTATIONS MUST BE USED IF there is an alternative answer, check to see if there is any ECF credit possible using working below. ALLOW calculated value 14.5609319 correctly rounded to 3 or more SF for 1st marking point ALLOW ECF to 3 SF ONLY from inverted K_c expression → 0.0687 DO NOT ALLOW $\frac{[\text{CH}_3\text{OH}]}{[\text{CO}] + [\text{H}_2]^2} = 0.707$ (no marks) Examiner's Comments Most candidates were able to obtain a value of 14.56 using a correct K_c expression, but a significant number of candidates were unable to give their answer to an appropriate number of significant figures. Candidates should use the least accurate data provided, here three significant figures, and to indicate the appropriate number of significant figures in the final answer. Other common errors included the inverted K_c expressions and use of $[\text{CO}] + [2\text{H}_2]$, rather than $[\text{CO}] [\text{H}_2]^2$, as the denominator. Answer = 14.6 dm⁶ mol⁻²
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12	a		$(K_c =) \frac{[\text{NO}(\text{g})]^4 [\text{H}_2\text{O}(\text{g})]^6}{[\text{NH}_3(\text{g})]^4 [\text{O}_2(\text{g})]^5} \checkmark$	1	Square brackets required IGNORE state symbols <u>Examiner's Comments</u> Generally, this question was well answered with only a small proportion of candidates adding the values together instead of multiplying.
	b		EQUILIBRIUM CONDITIONS Temperature: 1 mark (Forward) reaction is exothermic/ΔH is negative OR (Forward) reaction gives out heat $\checkmark$ Pressure: 1 mark Left-hand side has fewer (gaseous) moles OR 9 (gaseous) moles form 10 (gaseous) moles $\checkmark$ OPTIMUM EQUILIBRIUM CONDITIONS: 1 mark (for maximum yield of NO) Low temperature AND low pressure $\checkmark$ RATE: 1 mark Low temperature/pressure gives a slow rate/slower reaction so high temperatures / higher pressure needed to increase rate OR frequency of collisions $\checkmark$ INDUSTRIAL CONDITIONS / OPERATIONAL FACTORS: 1 mark High pressure provides a safety risk OR Higher temperatures increase energy costs / reduce yield / shift equilibrium to left OR (High) pressure is expensive (to generate) / uses a lot of energy $\checkmark$	5	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC ALLOW reverse arguments Answer MUST relate temp/pressure to rate / frequency of collisions ALLOW Temperature / pressure not too high because yield reduced IGNORE stated temperatures and pressures IGNORE catalyst <u>Examiner's Comments</u> Most candidates answered this question very well, with the most common mark being 4/5. Many candidates put a lot of effort into explaining, in depth, Le Chatelier's principle, which was not required. The first three marking points were credited to most candidates. Responses were confident in their descriptions of equilibrium shifts and many candidates then went on to qualify their

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					answers with operational factor considerations and/or rate. The explanation for pressure was described less commonly than temperature and many candidates did not appreciate that increased rate would lead to a decreased equilibrium yield. Exemplar 3 (c) Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in equilibrium 4.1. to p ↓ - Explain your prediction in terms of Le Chatelier's principle. - State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors. low temperature so as to shift the position of equilibrium to the right while favouring forward reaction. This is because forward reaction is exothermic ($\Delta H = -ve$). low pressure so as to shift position of equilibrium to the right, as a decrease in pressure causes the equilibrium to move towards the direction with more gas molecules (right). These two conditions will minimise the change caused so maximum product (i.e. NO and H_2O) are formed. A higher temperature is used so as to increase the rate of reaction. Otherwise reaction is too slow. A slightly higher pressure is also used to increase reaction rate but not too high pressure as it is dangerous and does not promote safety for workers. This candidate scored all five marks for this well-reasoned approach to the question.
			Total	6	
13			C	1	Examiner's Comments This question was a good discriminator with well-prepared candidates usually selecting the correct option of C. Incorrect responses were reasonably evenly split across the other options, suggesting guesses and poor preparation.
			Total	1	
14			B	1	Examiner's Comments Most candidates responded with the correct response of B. The most common incorrect response was the inverse expression shown in A.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15			B	1 (AO1.1)	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16		i	Pressure: Right-hand side has fewer (gaseous) moles OR 4 (gaseous) moles form 2 (gaseous) moles ✓ High pressure ✓ Temperature: (Forward) reaction is exothermic/ΔH is negative OR (Forward) reaction gives out heat ✓ Low temperature ✓	4 (AO1.2) (AO2.1) (AO1.2) (AO2.1)	FULL ANNOTATIONS MUST BE USED ALLOW suitable alternatives for right-hand side, e.g.: towards NH_3/products OR forward direction OR increases yield For moles, ALLOW molecules/particles ALLOW reverse reaction is endothermic /ΔH is positive/takes in heat ORA for reverse reaction <u>Examiner's Comments</u> This question was answered well with many candidates being given all 4 marks. Most candidates identified that there are fewer gaseous moles of products and that an increase the pressure will shift the equilibrium position to the right. Although the exothermic nature of the forward reaction was usually identified, candidates sometimes muddled the temperature conditions required, with 'higher temperature' being seen often instead of 'low temperature'. Lower attaining candidates often seemed to confuse equilibrium (in this question) with rates.
		ii	FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 2.86×10^{-2} award 2 marks K_c expression	2 (AO2.6×2)	IF there is an alternative answer, check for any ECF credit possible using working below. ALLOW calculated value 0.02858291 correctly rounded to 3 or more SF for 1st marking point

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	$(K_c =) \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \text{ OR } \frac{0.862^2}{1.25 \times 2.75^3}$ OR 0.02858 ✓ Answer to 3 SF and in standard form $K_c = 2.86 \times 10^{-2} \checkmark$		ALLOW ECF to 3 SF and standard form ONLY from inverted K_c expression $\rightarrow 3.50 \times 10^1$ DO NOT ALLOW $\frac{[\text{NH}_3]^2}{[\text{N}_2] + [\text{H}_2]^3}$ = 0.0337 (no marks) IGNORE attempts at units <u>Examiner's Comments</u> Exemplar 5 $K_c = \frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]} \rightarrow \frac{[0.862]^2}{[2.75]^3 [1.25]}$ $= 0.029 \text{ to } 2\text{sf.} \rightarrow 2.9 \times 10^{-2}$ $K_c = 2.9 \times 10^{-2} \text{ to } 2\text{sf.} \quad [2]$ This part discriminated well. Most candidates were able to write the correct expression for K_c as the starting point of the calculation. Candidates often got into a muddle in calculating K_c, perhaps due to issues inputting the calculation into their calculators. The question asked for 'an appropriate number of significant figures and in standard form'. As the provided data was all to 3 significant figures, this also indicates the required number of significant figures in the answer. A calculated value to 2 significant figures was often seen (see the response); also 0.0286 rather than the standard form: 2.86×10^{-2}. Some responses showed K_c inverted or added, rather than multiplying the two reactants in the denominator. Other candidates wrote the correct equilibrium expression but were then used 2.75^2, rather than 2.75^3, to obtain the standard form answer of 7.786×10^{-2} or 0.0786 with no standard form. Candidates are advised to check back through calculations to see if they have made any such errors.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	6	

1 Reaction rates can be increased or decreased by changing conditions of temperature and pressure.

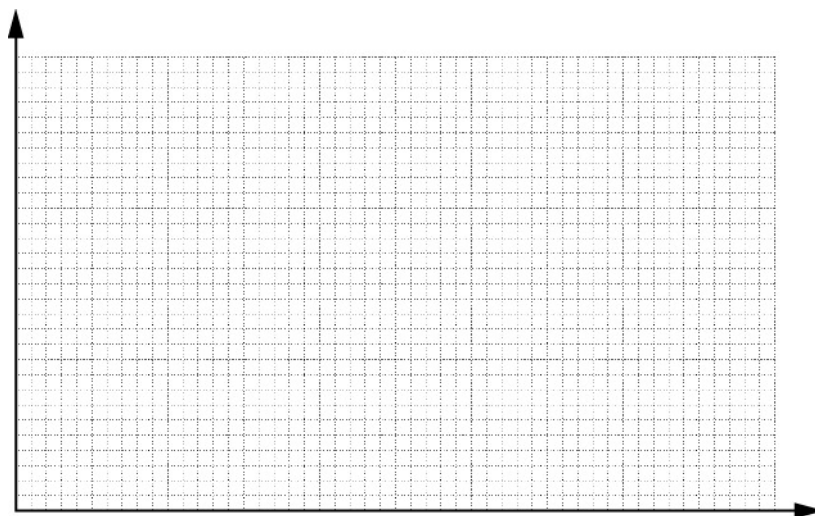
(i) Explain how increasing the temperature increases the rate of reaction.

Include a labelled sketch of the Boltzmann distribution, on the grid below.

Label the axes.



Your answer needs to be clear and well organised using the correct terminology.

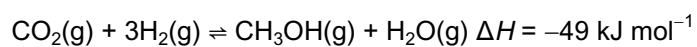


[4]

(ii) Describe and explain the effect of decreasing the pressure on the rate of a reaction.

2(a) Methanol, CH₃OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.

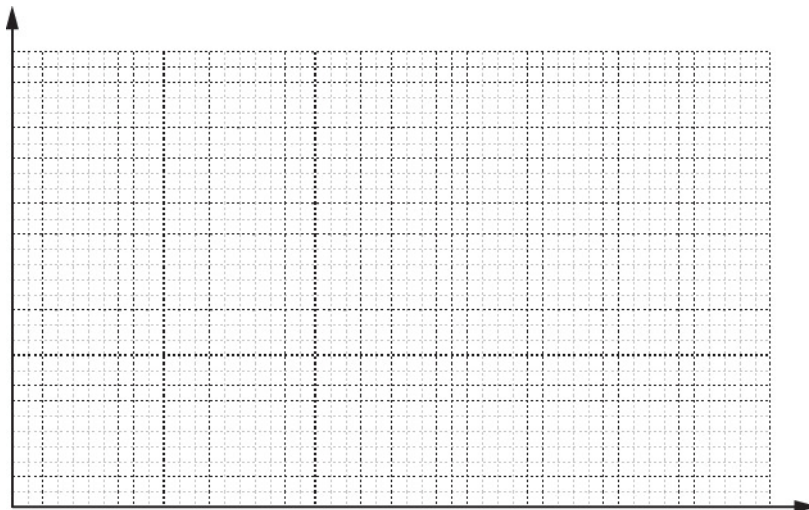


Describe and explain the effect of increasing the pressure on the reaction **rate**.

----- [2]

(b) The manufacture of methanol uses a catalyst.

- Sketch a labelled diagram of the Boltzmann distribution on the grid provided.
- Label your axes.
- Using your Boltzmann distribution, explain how the catalyst increases the rate of reaction.



[4]

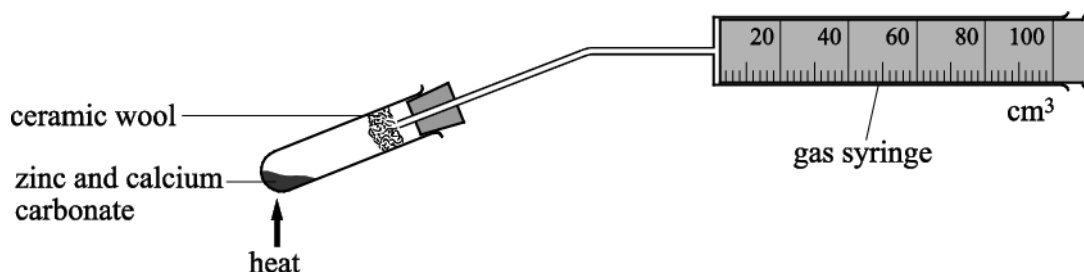
(c) Explain why the use of a catalyst can reduce the demand for energy.

[1]

- 3 Carbon monoxide can be made in the laboratory by heating a mixture of zinc metal and calcium carbonate. An equation for this reaction is shown below.



A student carried out the reaction of zinc (Zn) and calcium carbonate (CaCO_3) in a fume cupboard. The student measured the volume of gas produced.



A mixture containing 0.27 g of powdered zinc and 0.38 g of powdered CaCO_3 was heated strongly for two minutes. The volume of gas collected in the 100 cm^3 syringe was then measured. The experiment was then repeated.

The student repeated the experiment in (c) using different quantities of zinc and calcium carbonate.

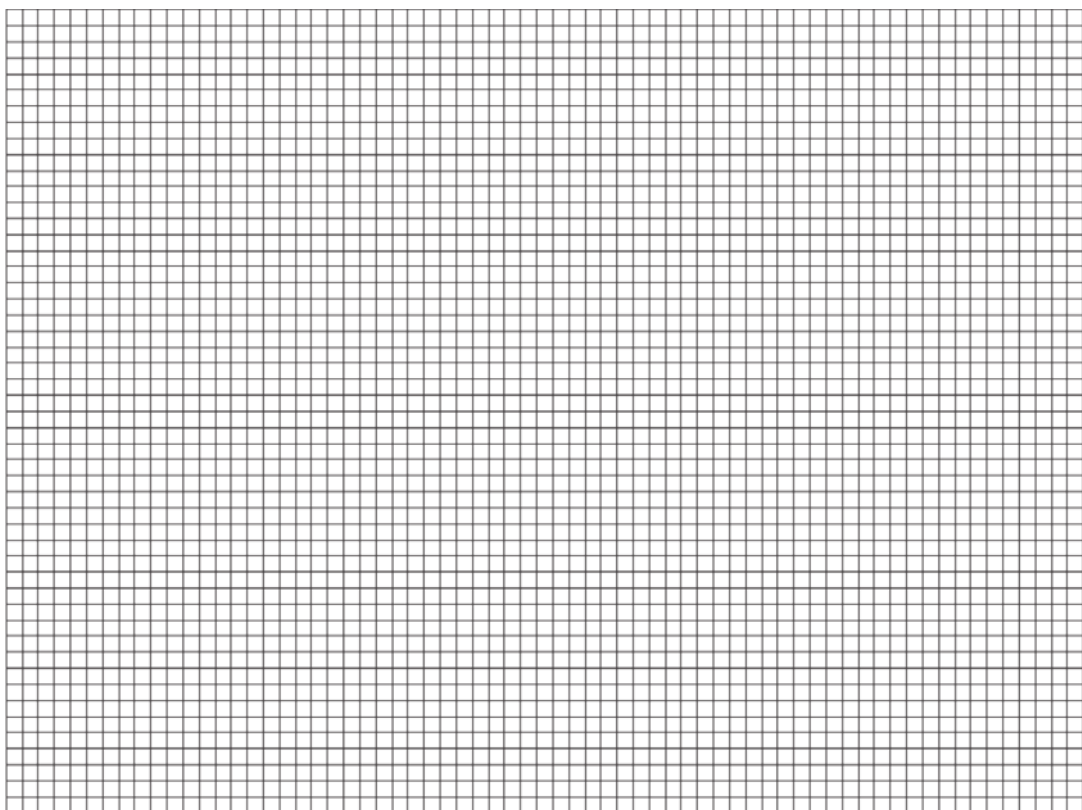
The student measured the total volume of gas collected over time.

The student's results are shown below.

Time / s	Total volume of gas collected / cm^3
0	0
20	13
40	42
60	56
80	65
100	72
120	72

- (i) Plot a graph from the data provided.

Include a line of best fit.



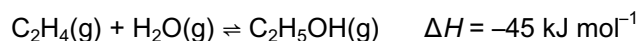
[3]

(ii) Using the graph, determine the rate of reaction, in $\text{cm}^3 \text{s}^{-1}$, after 50 s.

Show your working on your graph.

rate after 50 s = _____ $\text{cm}^3 \text{s}^{-1}$ [2]

- 4 Every year, two million tonnes of ethanol are produced worldwide by hydration of ethene obtained from crude oil.



This reaction is typically carried out using a catalyst at 300 °C and 6000 kPa.

The catalyst allows the reaction to reach equilibrium more quickly at the given temperature and pressure.

- (i) State the catalyst used in this reaction.

-----[1]

- (ii) Outline how a catalyst increases the rate of a chemical reaction.

-----[2]

- 5 Which statement explains why the rate of a reaction increases when the temperature is increased?

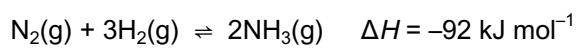
- A The activation energy for the reaction decreases.
- B The activation energy for the reaction increases.
- C The proportion of molecules exceeding the activation energy decreases.
- D The proportion of molecules exceeding the activation energy increases.

Your answer

☐

[1]

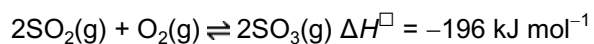
- 6 Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.



Describe and explain the effect of increasing the pressure on the rate of this reaction.

----- [2]

7(a) The following reaction is used in industry to make sulfur trioxide gas, SO_3 .



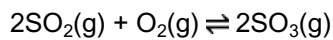
This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.

Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

[6]

(b) An experiment is carried out to find the rate of this reaction:



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

Time / s	0	50	100	150	200	250	300	350
Concentration of SO_3 / mol dm^{-3}	0	0.024	0.034	0.038	0.039	0.040	0.041	0.041

- (i) Plot a graph from the data provided.
Include a line of best fit.



[3]

- (ii) Use the graph to determine the **initial** rate of this reaction.

Show your working below and on the graph.

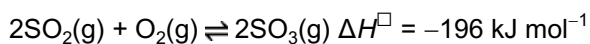
initial rate = _____ mol dm⁻³ s⁻¹ [2]

(iii) This experiment is repeated in the presence of a catalyst.

Draw and label a line **on the graph** to show the results of the catalysed experiment over the same time period.

[1]

(c) A solid catalyst, vanadium(V) oxide, V₂O₅, is used in industry to increase the rate of the production of sulfur trioxide, SO₃, in this reaction.



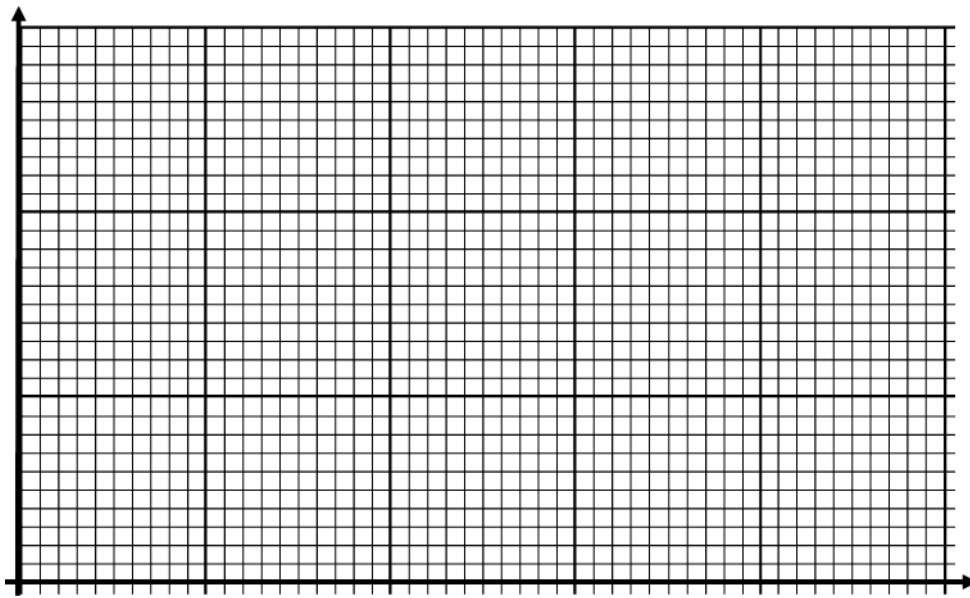
(i) Explain, with a reason, whether V₂O₅ is a homogeneous or heterogeneous catalyst.

----- [1]

(ii) The use of catalysts in industrial processes can be beneficial to the environment.
State **one** reason for this.

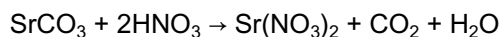
----- [1]

(iii) Using a fully labelled Boltzmann distribution on the grid below, explain why adding a catalyst increases the rate of a reaction.



[4]

8(a) A student investigates the reaction between strontium carbonate and dilute nitric acid.



The rate of reaction is determined from the loss in mass over a period of time.

(i) Explain why there is a loss in mass during the reaction.

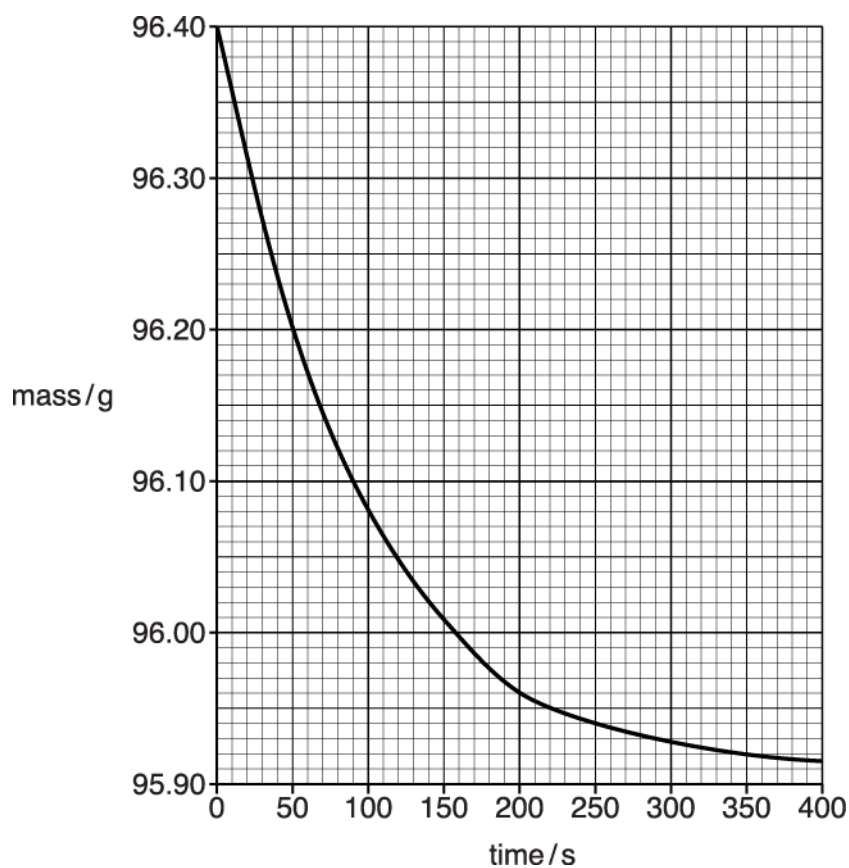
----- [1]

(ii) An excess of strontium carbonate, SrCO_3 , is mixed with 20.0 cm^3 of 1.25 mol dm^{-3} nitric acid, HNO_3 .

Calculate the mass of SrCO_3 that reacts with the HNO_3 .

mass = ----- g [3]

(b) The student plots a graph of total mass (reagents + container) against time.



(i) Describe and explain the change in the rate of the reaction during the first 200 seconds of the experiment.

----- [2]

(ii) Using the graph, calculate the rate of reaction, in g s^{-1} , at 200 seconds.

Show your working on the graph.

rate of reaction = _____ g s⁻¹ [2]

- (c) Outline a method that could be used to obtain the results that are plotted on the graph.

Your answer should include the apparatus required and the procedure for the experiment.

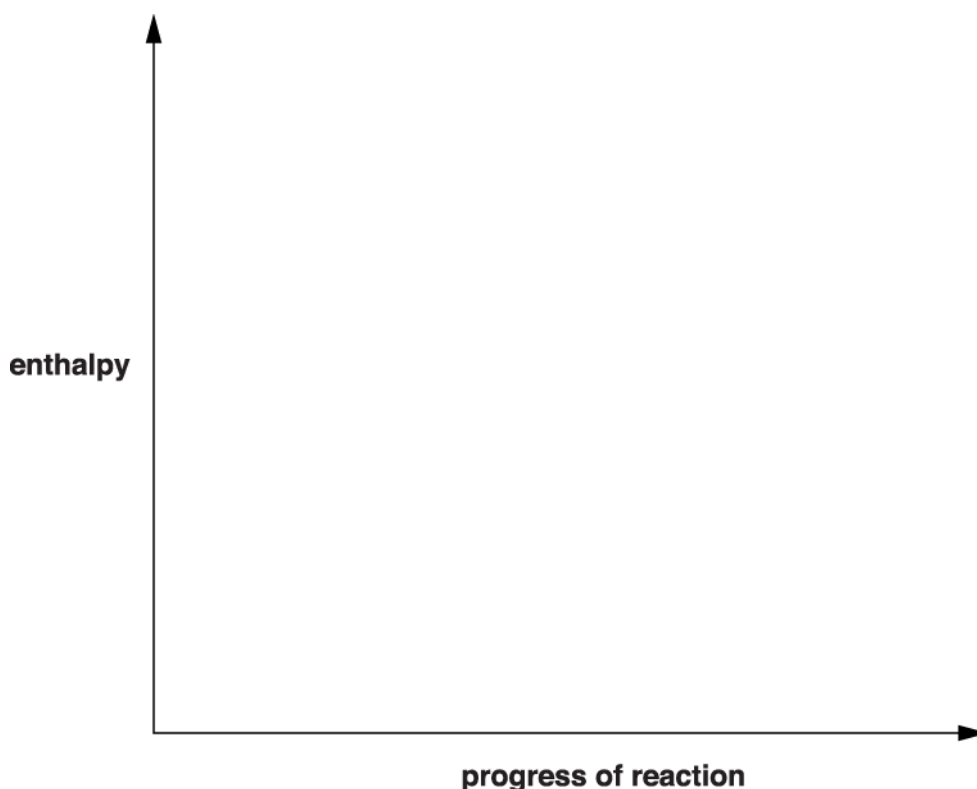
----- [3]

9(a) Catalysts can be used to change the rate of some chemical reactions.

- (i) Zinc and sulfuric acid react together to form a solution of zinc sulfate, ZnSO_4 , and hydrogen gas. The reaction is exothermic.

The rate of the reaction increases when a catalyst is added.

- Complete the enthalpy profile diagram for this reaction using the formulae of the reactants and products.
- Label activation energies, E_a (without catalyst) and E_c (with catalyst).
- Label the enthalpy change of reaction, ΔH .



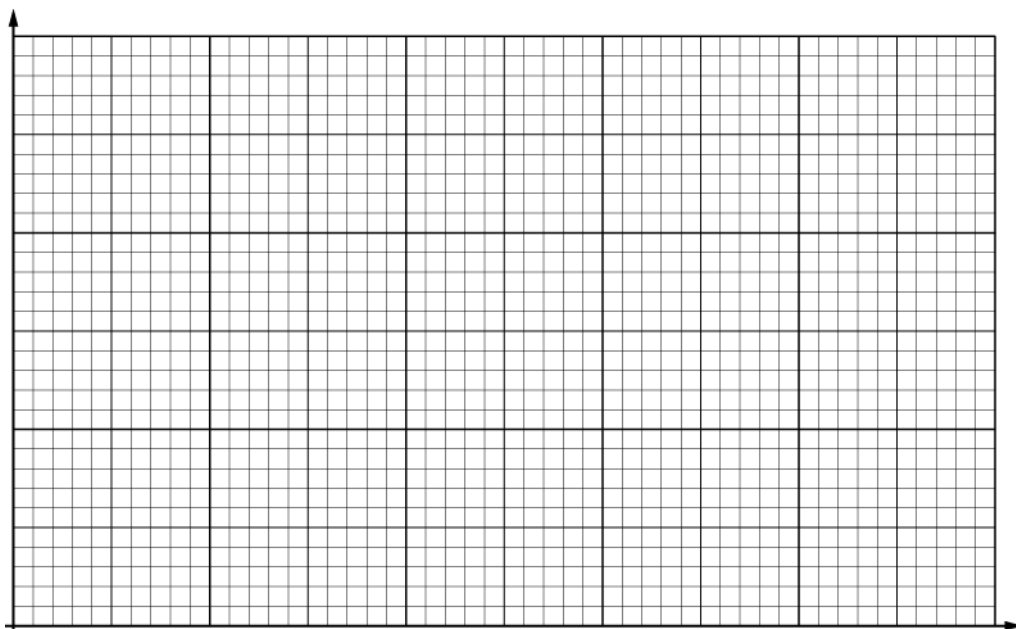
[3]

- (ii) Using a Boltzmann distribution, explain how a catalyst increases the rate of a chemical reaction.

Include a labelled sketch of your Boltzmann distribution on the grid below. Label the axes and any other important features.



Your answer needs to be clear and well organised using the correct terminology.



[4]

(b) The chemical industry uses catalysts for many of its reactions.

- (i) State an example of a catalyst used by the chemical industry and write the equation for the reaction that is catalysed.

catalyst

equation

[1]

- (ii) State **two** ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

.....
.....
.....
.....

[2]

10

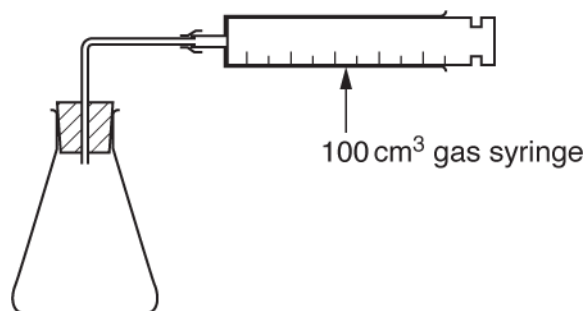


A student was asked to carry out an experiment to determine the initial rate of reaction of zinc and hydrochloric acid.

The student plans to collect a total of about 72 cm³ of hydrogen at RTP and to use an excess of zinc.

The student selects the following apparatus:

- the apparatus shown in the diagram
- 100 cm³ measuring cylinder
- stop clock
- 2 decimal place balance



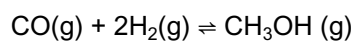
Outline how the student could carry out the experiment and explain how the results could be processed graphically.

Show all working in your calculations.

.....
.....

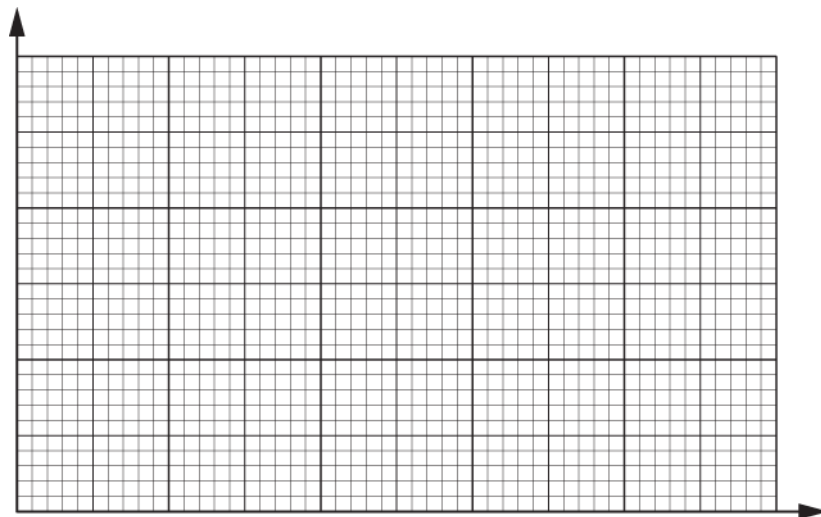
[6]

11(a) Methanol can be prepared industrially by reacting carbon monoxide with hydrogen in the presence of a copper catalyst. This is a reversible reaction.



Using the Boltzmann distribution model, explain why the rate of a reaction increases in the presence of a catalyst.

You are provided with the axes below, which should be labelled.



[4]

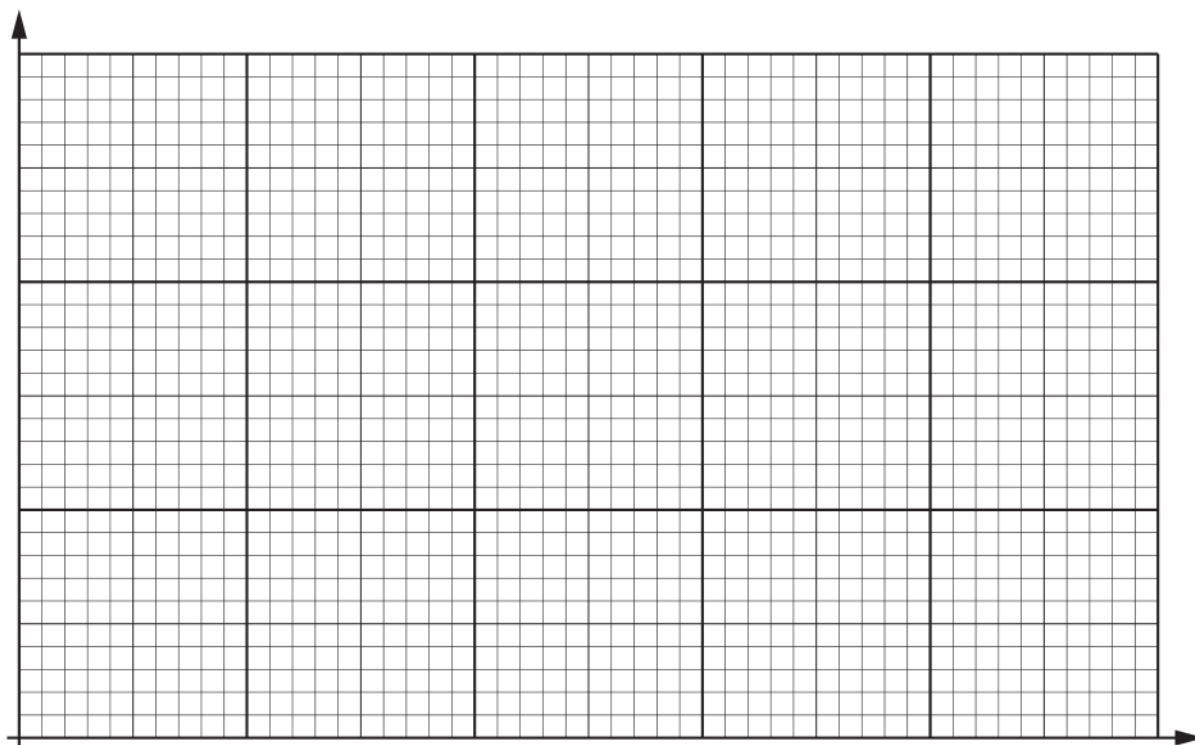
(b) The reaction for the production of methanol in the presence of the copper catalyst is carried out at 200–300 °C.

Explain why use of the catalyst reduces energy demand and benefits the environment.

[2]

12 Using the Boltzmann distribution model, explain how the rate of a reaction is affected by temperature.

You are provided with the axes below, which should be labelled.



[4]

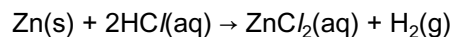
13 What is the **main** reason for the increase in reaction rate with increasing temperature?

- A The activation energy decreases.
- B The activation energy increases.
- C More molecules have an energy greater than the activation energy.
- D The molecules collide more frequently.

Your answer

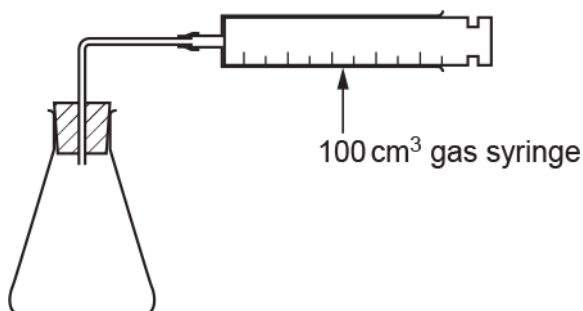
[1]

14(a) Zinc reacts with hydrochloric acid, $\text{HCl}(\text{aq})$, as shown in the following equation.



A student investigates the rate of this reaction.

The student uses the apparatus in the diagram.



The student's method is outlined below:

- Pour 50.0 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ HCl}$ into the conical flask.
- Add 0.200 g of zinc (an excess), and quickly attach the delivery tube and gas syringe.
- Measure the volume of gas collected every 20 seconds until the reaction stops.

The student obtains the results shown in **Table 4.1**.

Time / s	0	20	40	60	80	100	120	160	200
Volume of gas / cm^3	0	16	27	37	39	50	53	58	58

Table 4.1

(i) On the graph paper in **Fig. 4.1**, label the x axis and plot the results in **Table 4.1**. [1]

(ii) Circle any anomalous results present in the graph you have drawn in **Fig. 4.1**. [1]

(iii) Draw a best-fit smooth curve on the graph you have drawn in **Fig. 4.1**. [1]

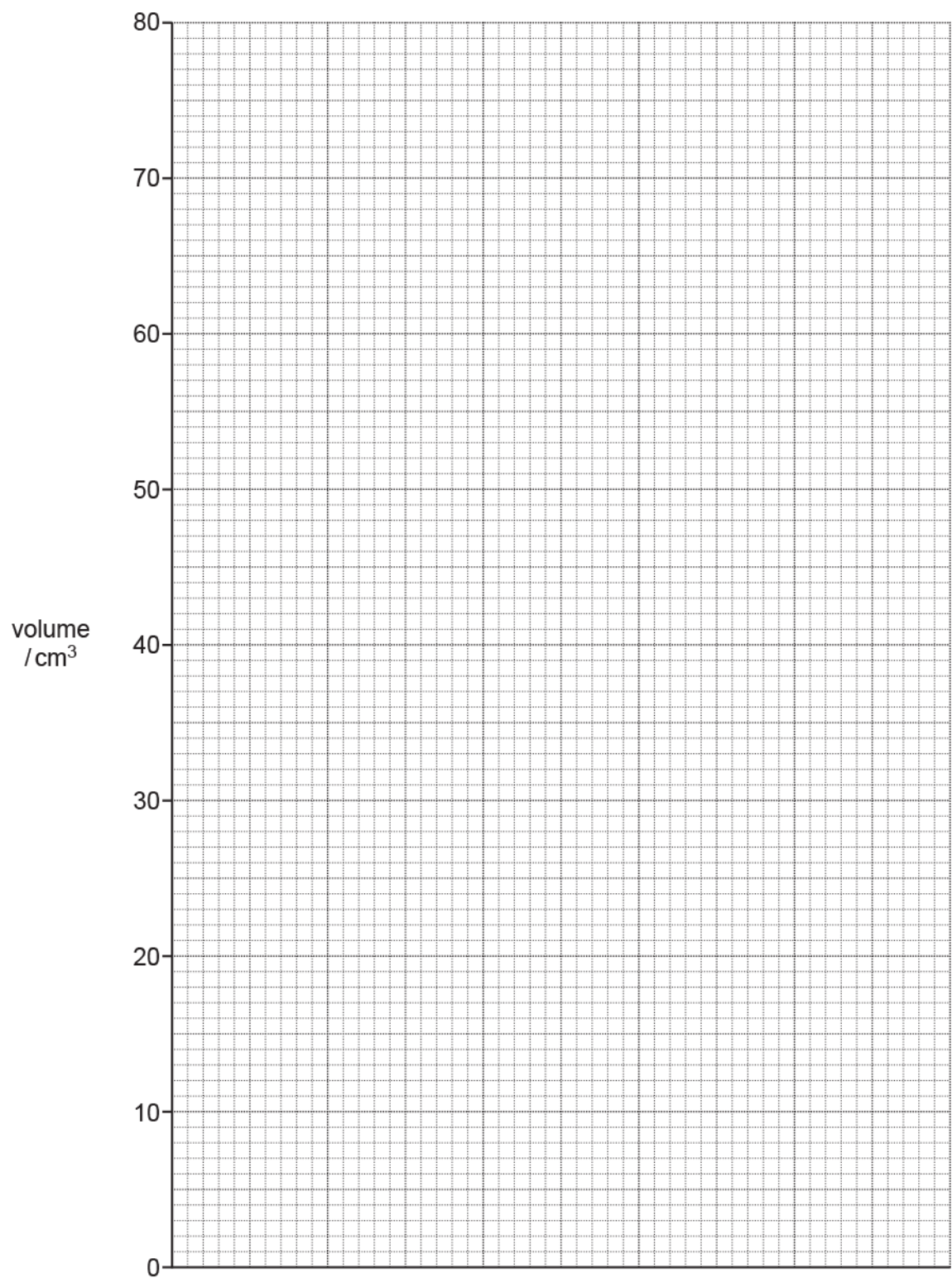


Fig. 4.1

(b) The student repeats the experiment using:

- zinc with the same mass (0.200 g) and same surface area
- the same temperature and pressure
- 40.0 cm³ of 0.125 mol dm⁻³ HCl, instead of 50.0 cm³ of 0.100 mol dm⁻³ HCl.

On your graph in Fig. 4.1 sketch the curve you would expect in this experiment.

[2]

(c) The graph shows that rate of reaction decreases over time.

Explain why, in terms of collision theory.

[2]

(d)

- (i) The rate of the reaction between zinc and hydrochloric acid can be increased using a solution of copper(II) sulfate as a catalyst.

Explain how a catalyst increases the rate of reaction.

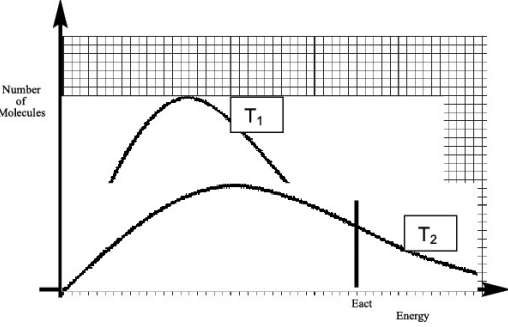
[2]

- (ii) Why is it difficult to classify the solution of copper(II) sulfate as a homogeneous or heterogeneous catalyst in this reaction?

[1]

END OF QUESTION PAPER

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
1	i  axes labelled (number of) molecules and (kinetic) energy ✓ Correct drawing of a two Boltzmann distributions i.e. both curves must start within the first small square nearest to the origin AND must not touch the x axis at high energy ✓ Drawing of Boltzmann distribution at two different temperatures with higher and lower temperature clearly identified (ie $T_2 > T_1$) ✓ QWC - (At a higher temperature) more molecules have energy above activation energy OR greater area under the curve above the activation energy ✓	4	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC Candidates do not need E_a on graph ALLOW particles instead of molecules on the y axis DO NOT ALLOW atoms instead of particles / molecules ALLOW ECF for the incorrect use of atoms (instead of molecules / particles) DO NOT ALLOW enthalpy on the x-axis DO NOT ALLOW increase of more than one small square at high energy end of curve. Maximum of curve for higher temperature to right AND lower than maximum of lower temperature curve AND above lower temp line at higher energy Higher temp line should intersect lower temp line once DO NOT ALLOW lower activation energy QWC requires more molecules have or exceed activation energy / E_a. IGNORE more molecules have enough energy to react for the QWC mark (as not linked to E_a) ORA if states the effect when the temperature is lower IGNORE (more) successful collisions Examiner's Comments Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams to illustrate the effect of increasing the temperature on the rate of reaction.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Occasionally curves that did not start at the origin and/or ended up touching the x- axis were seen, but these were less common than in previous sessions. Candidates should be aware that, when two curves are required, each curve should be clearly labelled. Unlabelled curves was a common reason why candidates only scored three marks and not four.
		ii	(Decreasing the pressure) decreases the rate of reaction AND Decreased concentration of molecules OR Number of molecules remains the same but the volume increases OR Less molecules per (unit) volume ✓ Less frequent collisions ✓	2	Correct effect on rate must be linked to reason for the first marking point. ALLOW molecules are further apart IGNORE less crowded ALLOW particles or atoms for molecules ALLOW 'space' for volume DO NOT ALLOW area instead of volume ALLOW collisions occur less often OR decreased rate of collision IGNORE less chance of collisions 'less collisions' alone is not sufficient IGNORE successful Examiner's Comments Most candidates recognised that a decrease in pressure would lower the concentration of the particles resulting in a decreased rate of reaction. The examiners were encouraged that a significant proportion of the cohort scored the second mark by relating the decreased rate with the frequency of collisions, rather than vaguer responses just in terms of collisions.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	a		Increased rate AND greater concentration of molecules / more molecules per (unit) volume ✓ More collisions per second / more frequent collisions ✓	2	ALLOW particles for molecules IGNORE atoms Response must imply a volume and not area ALLOW more molecules in the same space OR more molecules in the same volume OR same number of molecules in a smaller volume IGNORE molecules are closer together (<i>no idea of volume</i>) ALLOW collisions more often OR increased rate of collision IGNORE more chance of collisions 'more collisions' alone is not sufficient (<i>no rate</i>) IGNORE 'successful' Examiner's Comments The effect of pressure on reaction rate is well known by candidates at this level and many candidates scored one or two marks in this part. The examiners were encouraged that a significant proportion of the cohort scored the first mark by relating the increased rate to the increased concentration of the molecules, rather than vaguer responses in terms of the relative proximity of the molecules. Weaker responses focused on the equilibrium rather than an explanation of how the rate is affected. Candidates are advised to take note of key terms in questions, especially those in bold, as they often give guidance as to what is expected.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
b	Correct drawing of Boltzmann distribution curve ✓ Axes labelled: y axis: (number of) molecules AND x axis: energy ✓ Catalyst lowers the activation energy (by providing an alternative route) ✓ (With a catalyst a) greater proportion of molecules with energy greater than activation energy OR (With a catalyst a) greater proportion of molecules with energy equal to the activation energy ✓	4	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC Curve must start at origin. The limit of acceptability is that the curve must start within the first small square nearest the origin. Curve must not touch the x-axis at higher energy IGNORE a slight inflexion on the curve DO NOT ALLOW two curves DO NOT ALLOW a curve that bends up at the end by more than one small square ALLOW particles instead of molecules on y axis DO NOT ALLOW enthalpy for x-axis label DO NOT ALLOW atoms instead of particles or molecules ALLOW ECF for the subsequent use of atoms (instead of molecules or particles) ALLOW annotations on Boltzmann distribution diagram ALLOW (with a catalyst) more molecules have sufficient energy to react IGNORE (more) successful collisions Examiner's Comments Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams. The majority of candidates scored maximum marks in this part. Failure to identify that more molecules have an energy greater than the activation energy when a catalyst is used, was a common reason why only three marks were scored.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Allows reactions to take place at lower temperatures ✓	1	ALLOW less heat (required) IGNORE references to pressure IGNORE references to less energy (<i>in question</i>) e.g. lowers E_a Examiner's Comments The strongest candidates identified that lower temperatures could be used with a catalyst and hence reduce the energy demand of a reaction.
			Total	7	
3		i	axes: labels correct, AND units AND scales chosen so that the plotted points occupy at least half the graph grid in both the x and y directions (1) ALL points plotted correctly (1) Best curve drawn through points AND ignoring point at 20 s (1)	3	
		ii	<i>Tangent</i> tangent drawn to curve at $t = 50$ s (1) <i>Calculation of rate from the gradient of tangent drawn</i> e.g. rate = $\frac{64}{94} = 0.68 \text{ (cm}^3 \text{ s}^{-1}\text{)}$ (1)	2	Annotate tangent on graph Note: This mark can only be awarded from a tangent allow ecf for tangent drawn at different time from 50 s allow $\pm 10\%$ of gradient of tangent drawn allow 2 sig figs up to calculator value allow trailing zeroes, e.g. 0.7 for 0.070 ignore '–' sign for rate Note: if candidate calculates rate via ln 2 method, consult with TL
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
4		i	phosphoric acid / H_3PO_4	1	if both name and formula are given, the formula must be correct, but allow minor errors in an attempt at the name
		ii	(allows the reaction to proceed via a route with) lower activation energy ... (1) ... so that a greater proportion of molecules exceed the activation energy (1)	2	allow a sketch of an energy profile diagram as long as the catalysed and uncatalysed E_a are both labelled allow 'more molecules exceed the activation energy' allow a sketch of a Boltzmann distribution as long as both axes and both E_a values are labelled
			Total	3	
5			D	1	
			Total	1	
6			(Increase in pressure) increases the rate and because molecules are closer together... (1) ... so there are more collisions per unit time (1)	2	allow more particles per unit volume not molecules move faster or have more energy
			Total	2	

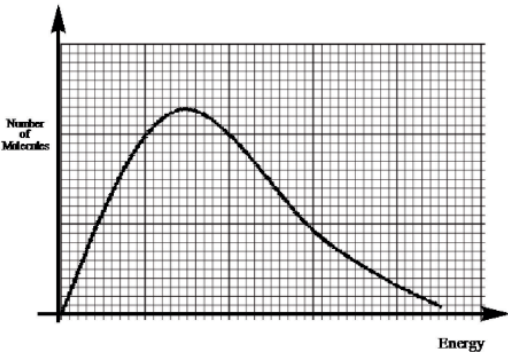
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
7	a	<i>* Please refer to the marking instruction point 10 for guidance on how to mark this question.</i> (Level 3) All/most points covered and clearly linked. Must have points taken across all of the headings in the indicative points for Level 3. <i>The explanations show a well-developed line of reasoning linked to appropriate suggestions which is clear and logically structured. The compromises are relevant and well thought out and clearly linked to the explanations.</i> (5–6 marks) (Level 2) Suggests correct conditions with explanations OR comments on compromises with reference to yield AND rate effect. <i>The explanations are linked to appropriate suggestions and show a line of reasoning with some structure. The compromises are relevant but may not be clearly linked to the explanation.</i> (3–4 marks) (Level 1) Comments on conditions with some explanation OR comments on compromise with reference to yield OR rate. <i>The comments about yield / rate with explanation are basic and communicated in an unstructured way. The compromises may not be relevant with lack of reasoning.</i> (1–2 marks) No response or no response worthy of credit. (0 marks)	6	Indicative scientific points may include Yield - Increasing pressure increases yield of SO₃ - Decreasing temperature increases yield of SO₃ Explanation (pressure) more moles / molecules on the reactant side ORA (temp.) the forward reaction is exothermic ORA Rate - Increasing pressure increases rate - Increasing temperature increases rate Compromise - Choose a higher temperature which creates a reduced yield but in a shorter space of time ignore reference to increase pressure leading to safety / cost issues

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Time plotted along x-axis AND sensible scale that uses most of graph paper AND both axes labelled (1) Points plotted accurately (1) Correct curve of best fit (1)	3	
		ii	Evidence of tangent drawn correctly on the graph from the origin (1) $(0.023/25) = 9.2 \times 10^{-4} \text{ (mol dm}^{-3} \text{ s}^{-1})$ (1)	2	allow answer between 8×10^{-4} and 1×10^{-3} allow answer from line drawn through origin and data point at 50 s: $0.024/50 = 4.8 \times 10^{-4}$
		iii	(Differ) initial gradient steeper AND (Same) curve reaches same height	1	look on graph paper for this answer
	c	i	The catalyst / vanadium(V) oxide / V_2O_5 is solid while the reactants are gases, so the catalyst is in a different state from the reactants.	1	
		ii	Catalysts lower the energy demand for a reaction OR Less combustion of fossil fuels and therefore lower carbon dioxide emissions OR Allows different reactions to take place with greater atom economy / less waste OR Allows less toxic chemicals to be used	1	

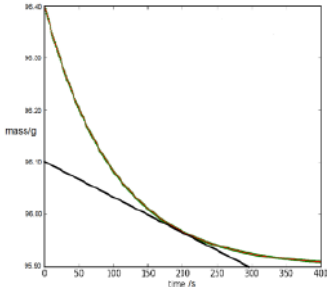
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	<i>Boltzmann distribution (2 marks)</i>  Correct drawing of a Boltzmann distribution i.e. curve must start within the first small square nearest to the origin AND must not touch the x-axis at high energy (1) Axes labelled (number of) molecules and (kinetic) energy (1) <i>Explanation (2 marks)</i> Catalyst (provides an alternative route) AND with a lower activation energy (1) (With a catalyst) more molecules have energy above activation energy OR greater area under curve above the activation energy	4	candidates do not need E_a on graph ignore a slight inflexion on the curve do not allow two curves allow particles instead of molecules on y-axis do not allow enthalpy for x-axis label do not allow atoms instead of particles or molecules allow ecf for the subsequent use of atoms (instead of molecules or particles) allow annotations on Boltzmann distribution diagram ignore more molecules have enough energy to react (as not linked to E_a) ORA if states the effect with no catalyst ignore (more) successful collisions
			Total	18	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
8	a	i	carbon dioxide lost/evolved/given off/or produced as a gas ✓	1	DO NOT ALLOW water or steam or CO₂ evaporates Examiner's Comments Candidates who failed to state that the gas being lost was CO₂ could not access the mark for this question. Vague answers relating to water being produced, products being gases, products being lost or a gas evolved were often given by Candidates.
		ii	FIRST CHECK ANSWER ON THE ANSWER LINE IF answer = 1.85 OR 1.845 g award 3 marks ----- $n(\text{HNO}_3)$ $= 1.25 \times \frac{20.0}{1000} = 0.0250 \text{ mol } \checkmark$ $n(\text{SrCO}_3)$ $= \frac{0.0250}{2} = 0.0125 \text{ mol } \checkmark$ $m(\text{SrCO}_3)$ $= 0.0125 \times 147.6 = 1.845 \text{ g OR } 1.85 \text{ g } \checkmark$	3	If there is an alternative answer, check to see if there is any ECF credit possible ALLOW ECF from incorrect $n(\text{HNO}_3)$ molar mass of SrCO₃ = 147.6 (g mol⁻¹) ALLOW ECF from incorrect $n(\text{SrCO}_3)$ Examiner's Comments The vast majority of candidates were able to complete this calculation arriving at the correct answer to score all three available marks. The most common error was in calculating the amount, in moles, of the SrCO₃ from the stoichiometry given in the equation. This resulted in an answer which was twice that expected however two marks could still be obtained by applying error carried forward. Answer = 1.845 g or 1.85 g
	b	i	rate of reaction decreases AND concentration decreases / reactants are used up ✓	1	ALLOW reaction slows down ALLOW concentration of reactants decreases.

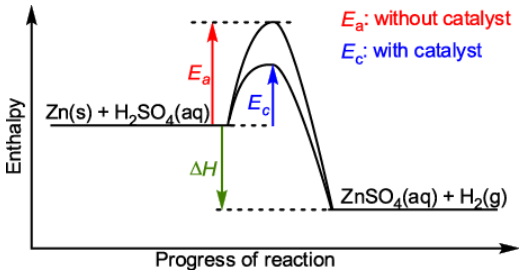
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	less frequent collisions ✓	1	ALLOW fewer collisions per unit time OR collisions less often OR decreased rate of collision IGNORE less successful collisions / less collisions less chance of collisions Examiner's Comments Very few candidates were able to explain the change in the rate of the reaction during the first 200 seconds of the experiment. This relatively straightforward question required a statement that the rate decreases as the concentration of the reactants decreases due to there being less frequent collisions. Although a large number of candidates were able to state that the rate decreases few were able to explain why. This was possibly due to candidates having to apply their understanding in an unfamiliar context rather than from a lack of knowledge
		ii	Attempted tangent on graph drawn to line at approximately $t = 200$ s ✓	1	ALLOW 1 SF up to calculator value, in range 5×10^{-4} to 8×10^{-4} IGNORE units IGNORE sign Examiner's Comments This was the first time AS level candidates have been required to calculate a rate of reaction from a graph and many found this quite testing. Although many knew that a tangent was required only the most able candidates were able to arrive at a value for the gradient that was within the expected range. Candidates sometimes took as their values the point at which their tangent cut the axes rather than calculating the change in mass or change in time. Acceptable range 5×10^{-4} to 8×10^{-4}
		ii	Gradient (y/x) e.g. $\frac{0.20}{290} = 6.9 \times 10^{-4}$ ✓ 	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Flask OR beaker AND balance AND stopwatch OR stop clock OR other timing device ✓	1	DO NOT ALLOW round-bottomed flask. IGNORE weighing scales
			Records mass at time intervals ✓	1	ALLOW 'weigh at time intervals'
			Time interval quoted between 10-50s ✓	1	Examiner's Comments This was the second question that required candidates to describe an experiment that they could have carried out as part of their course. Even if this experiment had not been completed in class, candidates should be able to recognise that mass needs to be measured over a period of time. As the reaction was between an acid and a carbonate a suitable named reaction vessel such as a beaker or flask was required. A balance was needed for mass measurement and a timing device to monitor time. A simple statement that mass should be recorded at a given time interval scored two marks with one mark being allocated to suitable apparatus. At this level it is expected that candidates will be familiar with the correct names for the apparatus required to carry out an investigation.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9	a	i	 Zn and H₂SO₄ on LHS AND ZnSO₄ + H₂ on RHS ✓ ΔH labelled with product below reactant AND arrow downwards ✓ E_a AND E_c correctly labelled with E_c below E_a ✓	3	ANNOTATE ANSWER WITH TICKS AND CROSSES IGNORE state symbols. ΔH: DO NOT ALLOW -ΔH ALLOW this arrow even if it has a small gap at the top and bottom i.e. does not quite reach reactant or product line E_a: ALLOW no arrowhead or arrowheads at both ends of activation energy line The E_a line must point to maximum (or near to the maximum) on the curve OR span approximately 80% of the distance between reactants and maximum regardless of position ALLOW AE or A_E for E_a Examiner's Comments Many candidates are well-prepared for this type of question however there are still some issues regarding the use of double headed arrows to indicate an enthalpy change. Whilst allowed by the examiners for showing activation energies, a correct single headed arrow was required to illustrate ΔH. A small proportion of candidates omitted hydrogen as a product, despite it being stated in the question.
		ii		4	ANNOTATE ANSWER WITH TICKS AND CROSSES Curve must start at origin. The limit of acceptability is that the curve must start within the first small square nearest the

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	Correct drawing of a Boltzmann distribution curve ✓ Axes labelled y axis: (number of) molecules AND x axis: (kinetic) energy ✓ Catalyst lowers the activation energy (by providing an alternative route) ✓ QWC - (With a catalyst a) greater proportion of molecules with energy greater than activation energy OR (With a catalyst a) greater proportion of molecules with energy equal to the activation energy OR (With a catalyst there is a) greater area under curve above the activation energy ✓		origin. Curve must not touch the x-axis at higher energy IGNORE a slight inflexion on the curve DO NOT ALLOW two curves DO NOT ALLOW a curve that bends up at the end by more than one small square ALLOW particles instead of molecules on y axis DO NOT ALLOW enthalpy for x-axis label DO NOT ALLOW atoms instead of particles or molecules ALLOW ECF for the subsequent use of atoms (instead of molecules or particles) ALLOW annotations on Boltzmann distribution diagram QWC requires more molecules have / exceed activation energy / E_a. IGNORE more molecules have enough energy to react for the QWC mark (as not linked to E_a) ORA if states the effect with no catalyst IGNORE (more) successful collisions Examiner's Comments Candidates are very familiar with the Boltzmann distribution curve and there were many examples of excellent diagrams. The majority of candidates scored maximum marks in this part. Failure to identify that more molecules have an energy greater than the activation energy when a catalyst is used, was a common reason why only three marks were scored.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Catalyst (name or correct formula) AND balanced equation for the reaction catalysed ✓	1	Many possible responses but in practice it is likely that examples will be few, e.g. Fe AND $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$ $\text{V}_2\text{O}_5/\text{Pt}$ AND $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$ $\text{H}_2\text{SO}_4/\text{H}_3\text{PO}_4$ AND $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH}$ Hydrogenation of an alkene: e.g. Ni AND $\text{C}_2\text{H}_4 + \text{H}_2 \rightarrow \text{C}_2\text{H}_6$ Esterification: e.g. H_2SO_4 AND $\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightarrow \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$ ALLOW multiples for equation Note: the reaction chosen must be a feasible industrial reaction. If you see an alternative from the list above please contact your TL Examiner's Comments Most candidates were able to provide an equation for an industrial process with a suitable catalyst. The most frequent correct response was the use of Fe in the Haber process. Other common responses included the use of an acid catalyst for the preparation ethanol from ethene and Ni for the hydrogenation of an alkene.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Any two from: lower temperatures / lower pressures (can be used) ✓ lower energy demand OR uses less fuel OR reduces CO₂ emissions ✓ (different reactions can be used with) greater atom economy OR less waste OR can reduce use of toxic solvents OR can reduce use of toxic reactants ✓ (catalysts are often enzymes) generating specific products ✓	2	IGNORE catalyst not used up in reaction IGNORE catalyst can be re-used IGNORE lower activation energy IGNORE cheaper IGNORE less greenhouse gases OR reduces global warming ALLOW increases atom economy ALLOW reduce use of hazardous / toxic / harmful / poisonous chemicals Examiner's Comments The majority of candidates were able to provide two suitable examples of how catalysts increase the sustainability of chemical processes. The mark scheme allowed a variety of different responses that reflected the specification statements being assessed. The strongest responses focussed on the use of lower temperatures and reduced CO₂ emissions. Reference to alternative processes with a better atom economy was also frequently seen.
			Total	10	

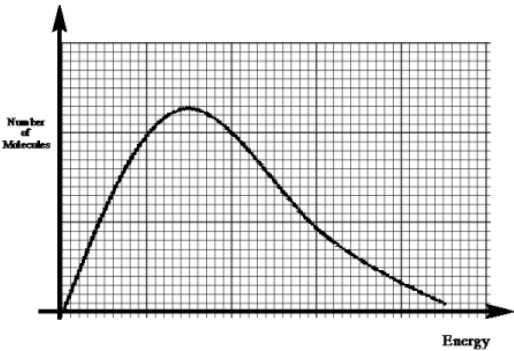
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
10	<i>Please refer to marking instructions on page 5 of mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) All three scientific points are covered in detail and explained thoroughly. <i>The method is logically structured and clear calculations are shown for an appropriate mass of metal and suitable volume of acid. The drawing of a tangent and determination of the gradient is communicated well.</i> Level 2 (3–4 marks) Candidates cover all three scientific points but explanations may be incomplete. OR Two of the scientific points are described thoroughly with no omissions. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence. e.g. there are clear calculations to justify mass and acid volume supported by some working and units; a simple description for determining initial rate related to tangent but no detail of how to measure gradient..</i> Level 1 (1–2 marks) There is a description based on at least two of the main scientific points OR The candidate explains one scientific point thoroughly with few omissions. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. e.g. 'add zinc and acid and measure volume (no mass, volume or time intervals); calculations that have little structure, absent units and little working.</i>	6	Indicative scientific points 1. Method • measure mass of (excess) zinc (using 2 decimal place balance) • measure volume of hydrochloric acid (using measuring cylinder) • mix zinc and acid in flask • measure gas volume at time intervals 2. Calculations • moles of hydrogen $72/24000 = 0.00300 \text{ mol}$ • minimum mass of zinc $0.003 \times 65.4 = 0.20 \text{ g}$ • moles of hydrochloric acid $\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$ $0.00300 \times 2 = 0.00600 \text{ mol}$ • volume / concentration of acid If $[\text{HCl}(\text{aq})] = 0.1 \text{ mol dm}^{-3}$ appropriate volume of acid = $0.006 \times 1000/0.1 = 60 \text{ cm}^3$ If $[\text{HCl}(\text{aq})] \geq 0.3 \text{ mol dm}^{-3}$, too low ($\leq 20 \text{ cm}^3$) If $[\text{HCl}(\text{aq})] \leq 0.03 \text{ mol dm}^{-3}$ too high ($\geq 200 \text{ cm}^3$) 3. Processing results • Plot a graph of volume against time • Draw a tangent at $t = 0$ • Gradient of tangent = initial rate • Gradient = volume / time

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			0 marks <i>No response or no response worthy of credit.</i>		Examiner's Comment: This question was marked using a level of response mark scheme and relatively few candidates were able to achieve Level 3. Many vague and rambling responses failed to mention the basic requirement to measure the volume of gas at regular time intervals. Some preferred to record the change in mass and ignored the diagram with a labelled gas syringe, while some carried out the experiment in a measuring cylinder. The question advises candidates to show working in their calculations but many omitted calculations from their answer. The question asked for an explanation of how the results could be processed graphically but this section was often lacking detail. Level 1 responses usually included the measurement and mixing of reactants and an attempt at processing the results by plotting a graph but further detail was missing. Candidates achieving Level 2 usually included a calculation of the moles of reactants and a more detailed description of how to process the results. Some excellent Level 3 responses included a full calculation of the mass of zinc and volume of hydrochloric acid required for the experiment.
			Total	6	

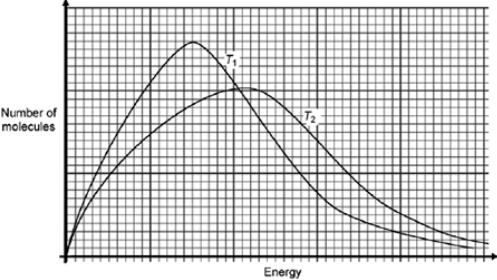
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
11	a	 Correct drawing of Boltzmann distribution Curve starts within two small squares of origin AND not touching the x axis at high energy ✓ <i>axes labels:</i> y: (number of) molecules/particles AND x: (kinetic) energy ✓ Catalyst and activation energy Catalyst provides a lower activation energy OR E_c shown below E_a on Boltzmann distribution ✓ More molecules/particles/collisions have energy above activation energy (with catalyst) OR greater area under curve above activation energy ✓	4	FULL ANNOTATIONS WITH TICKS, CROSSES, CON, etc MUST BE USED IGNORE a slight inflexion on the curve DO NOT ALLOW two curves <i>Confusion with effect of temperature</i> DO NOT ALLOW 'atoms' as y-axis label DO NOT ALLOW 'enthalpy' for x-axis label ALLOW 'more molecules have enough energy to react' IF y axis labelled as 'atoms' ALLOW ECF for atoms (instead of molecules/particles) IGNORE (more) successful collisions IGNORE response implying 'more collisions' <i>(confusion with effect of greater temperature)</i> Examiner's Comments This was a well answered question showing that the majority of candidates were well-acquainted with the Boltzmann distribution. Labelling of the axes was a common cause of error. Some candidates

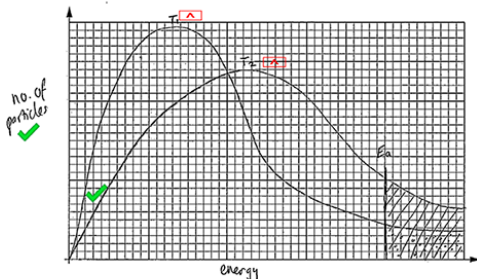
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					showed two curves, confusing the effect of a catalyst with temperature. Most candidates knew that the activation energy was lower with a catalyst than without. A significant number of candidates limited their explanations to 'successful collisions' without referring to more molecules exceeding the lower activation energy in the presence of catalyst. The best responses secured all four marks from a well-drawn and annotated graph.
	b		<i>Two max ✓✓ from:</i> • Lower temperatures / less heat / less thermal energy • Less fossil fuels / oil / coal / gas / non-renewable fuels • Reduces CO₂ emissions	2	IGNORE lower pressures OR less energy (<i>in question</i>) IGNORE just 'less fuel' IGNORE less global warming IGNORE less greenhouse gases, less CO, less NO <i>CO₂ required</i> Examiner's Comments There were many excellent responses in terms of lower temperature, use of less fossil fuels and a reduction in emission of carbon dioxide as a contributor to global warming. Weaker responses lacked precision and often repeated information supplied in the question about less energy demand.
			Total	6	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
12	Boltzmann distribution 3 marks  Curve Curve starts within one small square of origin AND curve does not touch x axis at high energy AND curve does not increase by more than one small square at higher energy ✓ Labels Axes labels correct: • Number of molecules AND Energy ✓ Curves for two temperatures Drawing of two curves with higher and lower temperature clearly identified in diagram or text AND higher T maximum to right AND at least one small square lower than lower T max ✓ Explanation 1 mark More molecules have energy greater than E_a OR Greater area under curve above E_a ✓ <i>Could be in diagram</i>	4	FULL ANNOTATIONS MUST BE USED THROUGHOUT NOTE: Look for marking criteria within annotations on Boltzmann distribution diagram IGNORE slight inflexion on the curve For labels, ALLOW number of particles ALLOW amount of molecules/particles IGNORE number of atoms ALLOW kinetic energy IGNORE enthalpy for energy IGNORE curves meeting at higher energy BUT DO NOT ALLOW crossing over by more than one small square ALLOW more molecules have the energy to react IGNORE more successful collisions OR collide more frequently DO NOT ALLOW explanation is in terms of two activation energies (i.e. 'catalyst explanation') Examiner's Comments Overall, this question was answered well. Most candidates showed two Boltzmann distribution curves at different temperatures. Labelling of the axes was usually correct, although the labels were sometimes seen the wrong way around. Most candidates were aware that more

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					molecules possessed the required activation energy at a higher temperature, although lower ability candidates discussed frequency of collisions instead. Strangely, many good responses were spoilt by not labelling which of the two curves was at higher temperature. This is shown in the otherwise excellent response in the exemplar. Exemplar 5 (b) Using the Boltzmann distribution model, explain how the rate of a reaction is affected by temperature. You are provided with the axes below, which should be labelled.  The increase in temperature shifts the curve to the right allowing more particles to have the energy above the activation energy shown by greater area over E_a under curve T_2 than under curve T_1.
			Total	4	
13			C	1 (AO1.1)	Examiner's Comments The role of activation energy in the rate of a reaction with increasing temperature was well-known and most candidates chose the correct option C. From the annotations on candidate scripts, many had ruled out options A and B entirely. D was anticipated as being the main distractor and this proved to be the case. Activation energy has a much greater effect than increasing collision frequency.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14	a	i	Use of graph paper linear numerical scale chosen for x axis AND Time / s added as label AND ALL points plotted correctly ✓	1(AO2.4×1)	ALLOW Time (s) OR Time in s ALLOW seconds OR sec OR secs Tolerance ± 1 small square Point at 0,0 NOT required ALLOW up to 3 plotting errors <u>Examiner's Comments</u> Most candidates obtained this mark, some lost the mark because they did not use a linear scale or provide units.
		ii	Anomaly point at 80 s circled ✓	1(AO2.4×1)	ALLOW one more anomalous point NOT on the curve drawn in (iii) <u>Examiner's Comments</u> Nearly all the candidates obtained this mark
		iii	Line smooth curve using all points EXCEPT point at 80 s ✓	1(AO3.1)	<u>Examiner's Comments</u> Nearly all the candidates obtained this mark
	b		Initial slope is steeper AND curve levels off at an earlier time ✓ Same volume of gas produced (58 cm ³) ✓	2(AO2.8×2)	Tolerance ± 1 small square <u>Examiner's Comments</u> Many students did not sketch this curve or sketched a curved that was less steep and did not finish at 58cm ³ .

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Rate (Acid) concentration decreases. ✓ Collisions Fewer collisions per second OR less frequent collisions ✓	2(AO 1.1×2)	IGNORE amount of acid decreases, response must imply a volume and NOT area, e.g. fewer particles/molecules/ions in same space /volume 'fewer collisions' alone is not sufficient (no rate) <u>Examiner's Comments</u> Many responses detailed why the graph was steep at the beginning, rather than answering the question. Those that did explain the decrease often omitted the words concentration and frequency so the majority did not gain 2 marks. A large number of candidates discussed particles "losing energy" and "less successful collisions" so were not given any marks.
	d	i	Catalyst lowers the activation energy (by providing an alternative route) ✓ A greater proportion of molecules have more energy greater than/equal to activation energy ✓	2(AO1.2×2)	ALLOW 'more' for 'greater proportion' ALLOW more molecules have sufficient energy to react IGNORE (more) successful collisions <u>Examiner's Comments</u> Most candidates scored the first marking point but many did not achieve the second marking point as their explanations were too vague.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Reactants have different physical states ✓	1(AO2.1)	ALLOW idea that copper(II) sulfate solution is homogeneous in relation to the acid, but heterogeneous in relation to the zinc <u>Examiner's Comments</u> Almost half of the candidates answered this question correctly, the remainder did not realise that the question gave them the answer to the state that the copper sulphate solution was in. Many answers stated that it could be solid or aqueous, so difficult to classify.
			Total	10	