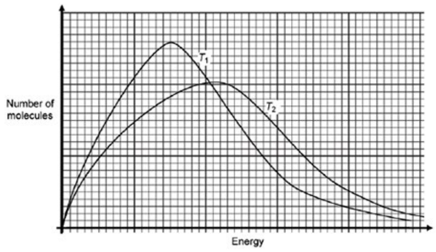
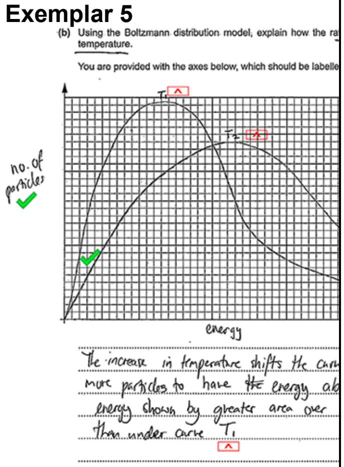
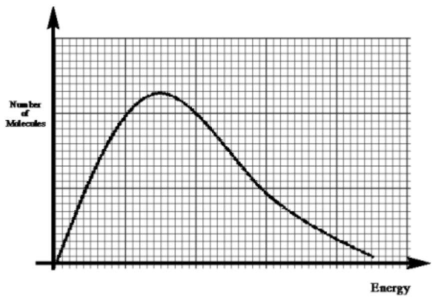
Mark scheme – Reaction Rates

Question			Answer/Indicative content	Marks	Guidance
1	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 **Examiner's Comments** 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(AO2.4x1)	**ALLOW** one more anomalous point **NOT** on the curve drawn in (iii) **Examiner's Comments** Nearly all the candidates obtained this mark
		iii	**Line** smooth curve using all points **EXCEPT** point at 80 s ✓	1(AO3.1)	**Examiner's Comments** 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 **Examiner's Comments** Many students did not sketch this curve or sketched a curved that was less steep and did not finish at $58cm^3$.
	c		**Rate** (Acid) **concentration** decreases. ✓ **Collisions**	2(AO1.1×2)	**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 per second **OR** less frequent collisions ✓		'fewer collisions' alone is not sufficient (no rate) **Examiner's Comments** 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 **Examiner's Comments** Most candidates scored the first marking point but many did not achieve the second marking point as their explanations were too vague.
		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 **Examiner's Comments** 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**	
2			***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 ✓ *Could be in diagram*	**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)

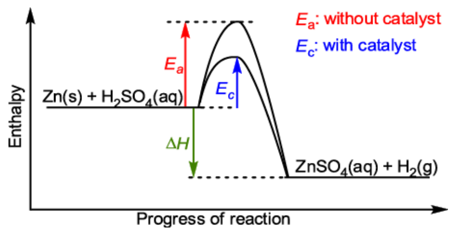
					Examiner's Comments Overall, this question was answered well. Most candidates showed two Boltzmann distribution curves at different temperatures. Labelling of the axes was usually correct, although the labels were sometimes seen the wrong way around. Most candidates were aware that more molecules possessed 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** 
			Total	**4**	
3			(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**	

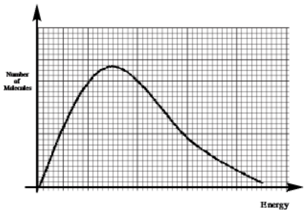
4	a		 ***Correct drawing of Boltzmann distribution*** Curve starts within **two** small squares of origin **AND** **not** touching the × axis at high energy ✓ *axes labels:* y: (number of) molecules/particles **AND** x: (kinetic) energy ✓ ***Catalyst and activation energy*** Catalyst provides a lower 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 *Confusion with effect of temperature* **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' *(confusion with effect of greater temperature)* **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 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		***Two max ✓✓from:*** • Lower temperatures / less heat / less **thermal** energy • Less fossil fuels / oil / coal / gas / non-renewable fuels • Reduces CO_2 emissions	**2**	**IGNORE** lower pressures **OR** less energy *(in question)* **IGNORE** just 'less fuel' **IGNORE** less global warming **IGNORE** less greenhouse gases, less CO, less NO *CO_2 required* **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**	
5			*Please refer to marking instructions on page 5 of mark scheme for guidance on how to mark this question.*	**6**	**Indicative scientific points** **<u>1. Method</u>**

			Level 3 (5–6 marks) All three scientific points are covered in detail and explained thoroughly. *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.* **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. *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..* **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. *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.* **0 marks** *No response or no response worthy of credit.*		• 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 **<u>2. Calculations</u>** • moles of hydrogen 72/24000 = 0.00300 mol • minimum mass of zinc 0.003 × 65.4 = 0.20 g • moles of hydrochloric acid $Zn + 2HCl \rightarrow ZnCl_2 + H_2$ 0.00300 × 2 = 0.00600 mol • volume / concentration of acid If [HCl(aq)] = 0.1 mol dm^{-3} appropriate volume of acid = 0.006 × 1000/0.1 = 60 cm^3 If [HCl(aq)] ≥ 0.3 mol dm^{-3}, too low (≤ 20 cm^3) If [HCl(aq)] ≤ 0.03 mol dm^{-3} too high (≥ 200 cm^3) **<u>3. Processing results</u>** • Plot a graph of volume against time • Draw a tangent at t = 0 • Gradient of tangent = initial rate • Gradient = volume / time

					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

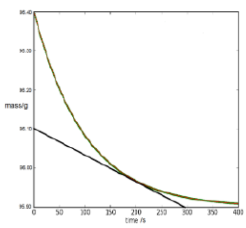
					acid required for the experiment.
			Total	**6**	
6	a	i	 Zn and H_2SO_4 on LHS **AND** $ZnSO_4$ + H_2 on RHS ✓ Δ*H* labelled with product below reactant **AND** arrow downwards ✓ E_a **AND** E_c correctly labelled with E_c below E_a ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **IGNORE** state symbols. Δ***H***: **DO NOT ALLOW** −Δ*H* **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 Δ*H*. A small proportion of candidates omitted hydrogen as a product, despite it being stated in the question.

		ii	 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 ✓	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 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 activaction energy when a catalyst is used, was a common reason why only three marks were scored.
	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** $N_2 + 3H_2 \rightarrow 2NH_3$ V_2O_5/Pt **AND** $2SO_2 + O_2 \rightarrow 2SO_3$ H_2SO_4/H_3PO_4 **AND** $C_2H_4 + H_2O \rightarrow C_2H_5OH$ Hydrogenation of an alkene: e.g. Ni **AND** $C_2H_4 + H_2 \rightarrow C_2H_6$ Esterification: e.g. H_2SO_4 **AND** $CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$ **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.

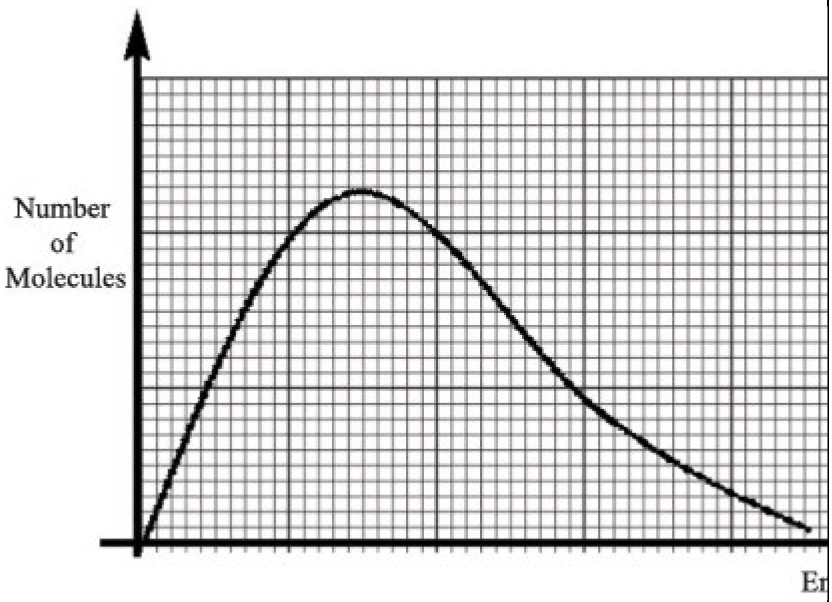
		ii	**Any two from:** lower temperatures / lower pressures (can be used) ✓ lower energy demand **OR** uses less fuel **OR** reduces CO_2 emissions ✓ (different reactions can be used with) greater atom economy **OR** less waste **OR** can reduce use of toxic solvents **OR** can reduce use of toxic reactants ✓ (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 CO_2 emissions. Reference to alternative processes with a better atom economy was also frequently seen.
			Total	**10**	
7	a	i	carbon dioxide lost/evolved/given off/or produced as a gas ✓	1	**DO NOT ALLOW** water or steam or CO_2 evaporates **Examiner's Comments** Candidates who failed to state that the gas being lost was CO_2 could not access the

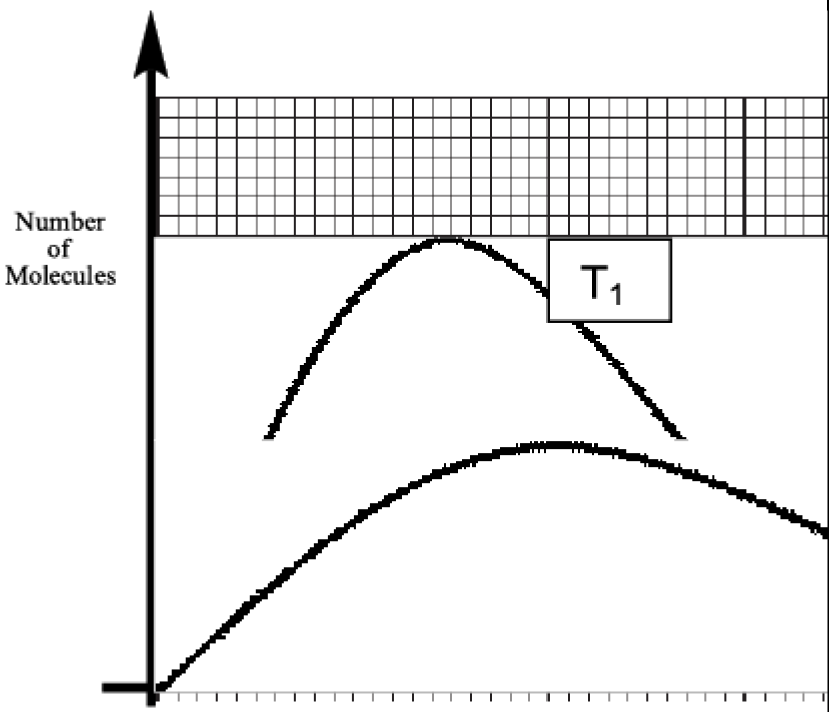
					mark for this question. Vague answers relating to water being produced, products being gases, products being lost or a gas evolved were often given by Candidates.
		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **IF answer = 1.85 OR 1.845 g award 3 marks** .... $n(HNO_3)$ $= 1.25 \times \frac{20.0}{1000} = 0.0250$ mol ✓ $n(SrCO_3)$ $= \frac{0.0250}{2} = 0.0125$ mol ✓ $m(SrCO_3)$ = 0.0125 × 147.6 = 1.845 g **OR** 1.85 g ✓	3	**If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW ECF** from incorrect $n(HNO_3)$ molar mass of $SrCO_3$ = 147.6 (g mol^{-1}) **ALLOW ECF** from incorrect $n(SrCO_3)$ **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 $SrCO_3$ 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.
		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	
		ii	Gradient (y/x) e.g. $\frac{0.20}{290} = 6.9 \times 10^{-4}$ ✓ 	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}
	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**	
8	a		Increased rate **AND**	2	**ALLOW** particles for molecules **IGNORE** atoms **Response must imply a volume and not area**

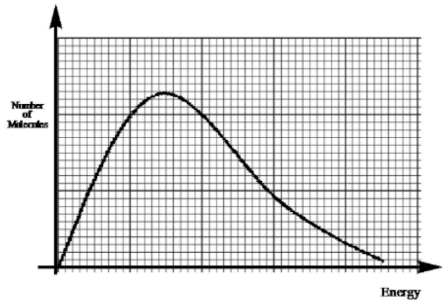
			greater concentration of molecules / more molecules per (unit) volume ✓ More collisions per second / more frequent collisions ✓		**ALLOW** more molecules in the **same space** **OR** more molecules in the **same volume** **OR** same number of molecules in a **smaller volume** **IGNORE** molecules are closer together (*no idea of volume*) **ALLOW** collisions more often **OR** increased rate of collision **IGNORE** more chance of collisions 'more collisions' alone is **not** sufficient (*no rate*) **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.

	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.
	c		Allows reactions to take place at lower temperatures ✓	1	**ALLOW** less heat (required) **IGNORE** references to pressure **IGNORE** references to less energy (*in question*) 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**	
9		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	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Candidates do not need Ea 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

			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✓		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. 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**	
10	a	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) = 9.2×10^{-4} (mol dm^{-3} 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 = 4.8×10^{-4}
		iii	(Differ) initial gradient steeper **AND** (Same) curve reaches same height	1	look on graph paper for this answer
	b	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	

		iii	*Boltzmann distribution (2 marks)*  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) *Explanation (2 marks)* 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	**12**	
11		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	*Tangent* tangent drawn to curve at *t* = 50 s (1)	2	Annotate tangent on graph **Note**: This mark can only be

			Calculation of rate from the gradient of tangent drawn e.g. rate = $\frac{64}{94}$ = 0.68 ($cm^3\ s^{-1}$) (1)		awarded from a tangent **allow ecf** for tangent drawn at different time from 50 s **allow** ±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**	