AQA A-LEVEL CHEMISTRY · 7405

CHEMISTRY



MARK SCHEME

3.1.5 KINETICS

SCORE	PERCENTAGE
/753	%

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Q1.

(a) Amount / number / proportion / percentage / fraction / moles of molecules / particles

Penalise an incorrect qualification of the number eg NOT number of molecules with E greater than Ea.

Not 'atoms'.

1

(b) There are no molecules / particles with zero energy

OR

All of the molecules / particles are moving / have some energy

Not 'atoms'.

The answer should relate the energy to the molecules.

1

(c) **C** (The most probable energy)

1

(d) **M1** The peak of the new curve is displaced to the right and lower than the original

M2 All of the following needed

- The new curve starts at the origin and should begin to separate from the original almost immediately
- and the new curve only crosses the original curve once
- and the total area under the new curve is approximately the same as the original
- and an attempt has been made to draw the new curve correctly towards the axis above the original curve but not to touch the original curve

2

(e) None / no effect / stays the same

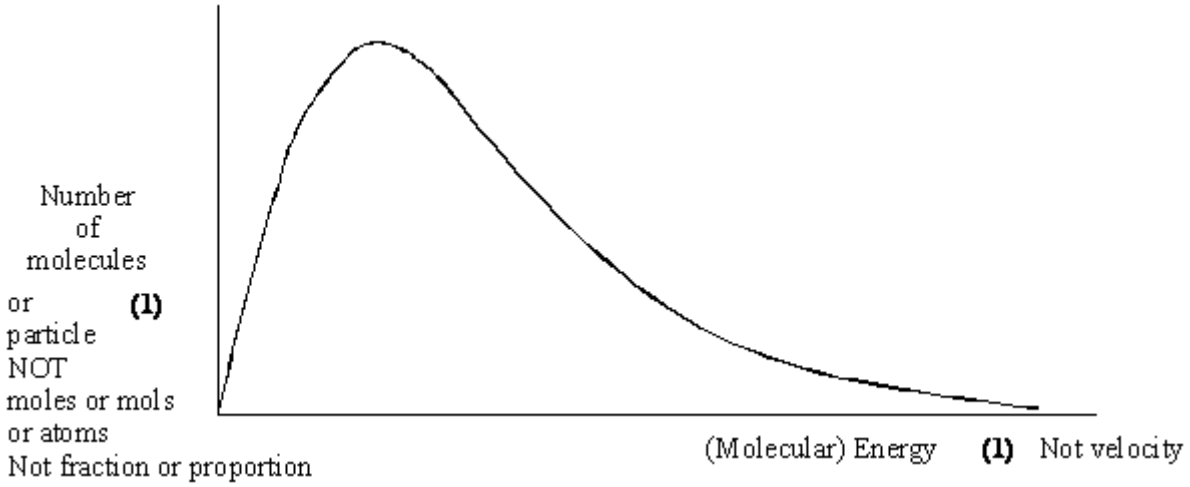
1

[6]

Q2.

(a) (i)

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(ii) The total number of particles (or molecules) in the sample

OR the number of molecules present

(iii) No molecules have no energy

OR all molecules have some energy

Do not allow "if there are no molecules there is no energy"

4

(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**

OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

Explanation: Alternative route **(1),** with a lower activation energy **(1)**

OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii)

5

[9]

Q3.

D

[1]

Q4.

(a) Activation energy;-
The minimum energy needed for a reaction to occur / start **(1)**

1

(b) Catalyst effect:-
Alternative route (or more molecules have Ea) **(1)**
Lower activation energy **(1)**

2

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(c) Increase in moles of gas:-
Position of E_{mp} unchanged **(1)**
More molecules with E_{mp} **(1)**
Area under curve increases **(1)**
Molecules with $E \geq E_a$ increased **(1)**
Temperature decreased:-
Position of E_{mp} moves to the left **(1)**
More molecules with E_{mp} **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ decreased **(1)**
Catalyst introduced:-
Position of E_{mp} unchanged **(1)**
Molecules with E_{mp} unchanged **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ increased **(1)**

12

[15]

Q5.

(a) Graph starts at origin

1

Graph skewed to left and has decreasing gradient to maximum

1

Graph after maximum decreases in steepness, never touches *x* axis, levels out less than 5 mm from *x* axis.

1

(b) Minimum energy

1

To start a reaction (*or for a reaction to occur*)

1

(c) Molecules gain energy (*or always some molecules have* $E > E_a$)

1

Due to collisions

1

(d) Decreases

1

E_a lowered **(1)**
By alternative route **(1)**
So more molecules have energy > E_a **(1)**

max 2

[10]

Q6.

D

[1]

Q7.

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(a) energy

Ignore reference to

- *any units (e.g. J, kJ, $J\,mol^{-1}$, $kJ\,mol^{-1}$)*
- *particles*
- *molecules*
- *kinetic*

***NOT** mean energy or average energy*

***NOT** E*

1

(b) **M1** maximum peak height is lower and displaced to the right of the original

1

M2 all of the following

- starts at the origin but does not follow the original line
- shows separation as soon as possible from the original line
- crosses the original curve once only
- similar area to original curve
- an attempt has been made to draw the new curve correctly towards the energy axis above the original curve but not to touch the original curve (or axis)

1

(c) **M1** an increase in the number/amount/proportion/fraction of molecules with

$E \geq E_a$ / with activation energy

or more molecules have $E \geq E_a$ / with activation energy

or more molecules have enough / sufficient energy (to react)

M1

Ignore

- *Molecules have more energy*
- *More energetic collisions*
- *More collisions*

Allow $E > E_a$ in place of $E \geq E_a$

Credit particles for molecules (but not atoms)

*Penalise for **M1** reference to increased activation energy*

1

M2 more successful / effective / productive collisions in a given time / period

or higher rate of successful / effective / productive collisions

or higher frequency of successful / effective / productive collisions

M2

Must refer to <u>both</u> idea of successful / effective / productive collisions and the rate / frequency of collisions

Ignore 'chance of collision'

1

[5]

Q8.

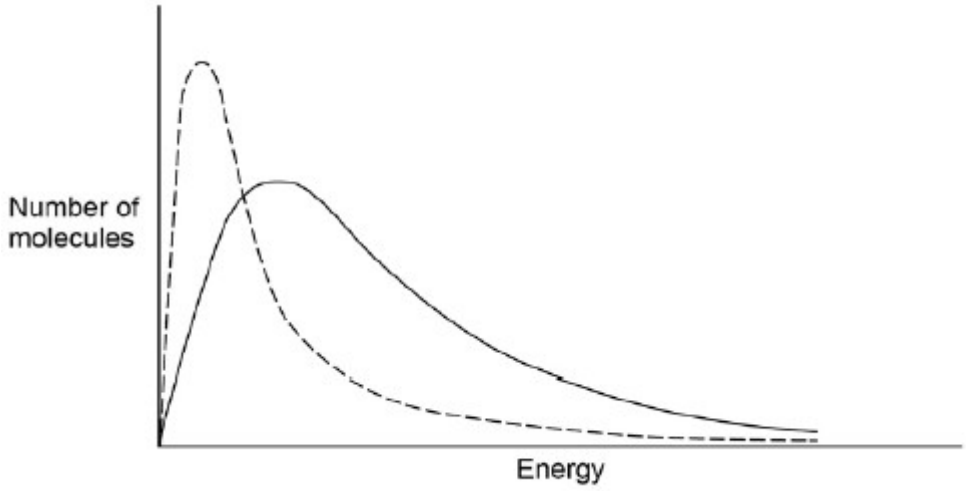
D

[1]

Q9.

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(a)



M1 Curve is higher and displaced to the left
M2 Only crosses the original curve <u>once</u>

2

(b) Rate of reaction decreases (no mark)

Fewer particles will have energy greater than or equal to the activation energy

1

Fewer <u>successful</u> collisions in a given time
Less frequent <u>successful</u> collisions

1

(c) The amount of gas present (or number of molecules) has been reduced / or the pressure has been reduced

1

Rate of reaction decreases (no mark)

Particles are spread further apart

1

Fewer collisions between gas particles so fewer <u>successful</u> collisions

1

[7]

Q10.

D

[1]

Q11.

A

[1]

Q12.

C

[1]

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Q13.

B

[1]

Q14.

(a) (i) Curve drawn from origin with peak clearly lower and to right.

*New curve crosses original once only, finishes above original and does **not** clearly curve up*

***IGNORE** relative areas*

1

(ii) (Relative areas under curves indicate) <u>many</u> (owtte)
more molecules with E greater than or equal to Ea (at higher T)
or reverse argument

***ALLOW** 'particles'*

***IGNORE** 'atoms'*

1

(Large) increase in (number of) <u>successful</u> (owtte) <u>collisions per unit</u> time

OR '<u>frequency</u> of successful <u>collisions</u>'

1

(b) (i) Yield increases

Yield decreases/stays the same CE = 0

If not answered mark on

1

More moles/molecules (of gas) on left/fewer on right/3 on left 1 on right

1

<u>Equilibrium shifts/moves</u> (to right) to reduce pressure/oppose higher pressure

No M3 if 'more moles on right' in M2

***IGNORE** 'favours'*

***NOT** just 'oppose the change'*

QoL means that M3 is only awarded if these ideas are clearly linked in one statement

1

(ii) Higher T would increase rate but decrease yield/make less methanol
OR
Lower T decreases rate but increases yield;

*If no mention of both rate **AND** (idea of) yield max 1*

1

Chosen T is a compromise/balance (between rate and yield) owtte

1

[8]

Q15.

C

[1]

Q16.

(a) M1 On the <u>energy axis</u> E_{mp} at the maximum of <u>the original peak</u>

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M1 *The limits for the horizontal position of E_{mp} are defined as above the word "the" in the sentence below the graph.*

M2 The peak of their new curve is displaced to the left and higher than the original.

M3 All of the following are required

- The new curve starts at the origin and should begin to separate from the original almost immediately
- and the new curve crosses the original curve once
- and an attempt has been made to draw the new curve correctly towards the energy axis below the original curve but not to touch the original curve or the axis

3

(b) **The rate of reaction decreases as the temperature decreases because**

M1 A decrease in the number / proportion of molecules with $E \geq E_a$
OR fewer molecules have $E \geq E_a$
OR fewer molecules have sufficient / enough energy to react / decompose

In M1
Ignore "molecules have less energy".
Ignore "less energetic collisions".
Ignore "molecules do not gain activation energy".
Ignore "fewer collisions".
Credit "particles" for "molecules" but NOT "atoms".

M2 Fewer effective / productive / successful collisions in a given time / given period
OR fewer frequent effective / productive / successful collisions
OR lower rate of effective / productive / successful collisions

*Ignore "chance of collision"; this alone does not gain **M2***

2

[5]

Q17.

(a) Number / proportion / percentage / fraction of molecules

Ignore "particles"

1

(b) None ***OR*** no effect ***OR*** no change

1

(c) **X**

1

(d) **Answers in either order**

M1 collision ***OR*** collide

Mark independently

M2 collision / molecules / particles

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Ignore "correct" amount of energy

with the activation energy

OR with $E \geq E_{act}$

OR with sufficient /enough energy

OR with the minimum energy

OR with the correct orientation

2

(e) A small increase in temperature results in many more / much higher proportion of / a lot more / significantly more molecules / particles / collisions with $E \geq E_{act}$/ energy greater than the activation energy / sufficient energy / enough energy / minimum energy to react
(compared with a small increase in concentration)

Not just "more molecules with $E \geq E_{act}$"
*The answer must convey that the increase is **significant***
Accept reference to "atoms", "molecules", "particles"
Ignore "species"

1

[6]

Q18.

(a) **M1** The activation energy is the minimum / least / lowest energy

Mark independently
Ignore ''heat'' and ignore ''enthalpy''

M2 (energy) for a reaction to occur / to go / to start

OR (energy) for a successful / effective collision

Ignore "breaking the bonds''

2

(b) **M1** Catalysts provide an alternative route OR an alternative mechanism OR alternative / different path(way)

M2 Lowers the activation energy

Mark independently
Ignore reference to ''surface''

2

(c) (i) Stay(s) the same

1

(ii) Increases

Credit ''increase" or ''increased''

1

(iii) Increases

Credit ''increase'' or ''increased''

1

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(iv) Stay(s) the same

1

(d) (i) **M1** yeast or zymase

M2 ethanol

Ignore ''enzyme''

In M2, ignore ''alcohol'' and ignore any formula

2

(ii) **M1** (Concentrated) H_3PO_4 OR (Concentrated) H_2SO_4

M2 butan-2-ol

Credit correct names

Ignore ''hydrogenphosphate or hydrogensulfate''

Ignore ''dilute'' or ''aq''

Do not penalise absence of hyphens in name.

In M2, ignore any formula

2

[12]

Q19.

(a) (i) **M1** The peak of the new curve is displaced to the right.

M2 All of the following are required

- The new curve starts at the origin
- The peak of the new curve is lower than the original
- and the new curve only crosses the original curve once
- and an attempt has been made to draw the new curve correctly towards the energy axis but not to touch the original curve
- the new curve must not start to diverge from the original curve

M1 is low demand

M2 is higher demand.

2

(ii) **M1** Increase in the number/proportion of molecules with $E \geq E_a$

OR more molecules have $E \geq E_a$

OR more molecules have sufficient energy to react

M2 More effective/productive/successful collisions

Ignore "molecules have more energy"

Ignore "more energetic collisions"

Ignore "molecules gain activation energy"

Ignore "more collisions"

Accept "particles" for "molecules" but NOT "atoms"

Ignore "chance of collision"; this alone does not gain M2

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2

(b) (i) Iron ***OR*** Fe

1

(ii) **M1** Catalysts provide an alternative route/pathway/mechanism

OR

(in this case) surface adsorption/surface reaction occurs.

For M1, not simply "provides a surface" alone

M2 that has a lower activation energy

OR

<u>lowers the activation energy</u>

For M2, the candidate may use a definition of activation energy without referring to the term

2

[7]

Q20.

(a) Peak lower

1

and moved to right

1

start at the origin and curve crosses once only

1

(b) (i) (Rate of reaction) <u>increases</u>

1

(At a higher temperature) <u>more molecules/particles</u>

1

have the minimum energy needed to react/have activation energy/have successful collisions

Mark CE if incorrect effect given

1

(ii) (Rate of reaction) <u>increases</u> 1

lowers activation energy 1

so that more molecules are able to react 1

Mark CE if incorrect effect given

[9]

Q21.

(a) (i) Z (1)

1

(ii) Collisions (1)

Cause some molecules to slow down or lose energy (1)

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2

(b) Curve starts at origin and is displaced to the right (1)

Curve lower and does not touch energy axis (1)

2

(c) (i) Only a small percentage/very few collisions have $E > E_a$ (1)

1

(ii) Add a catalyst (1)

Lowers E_a (1)

More collisions/molecules have energy > E_a (1)

3

[9]

Q22.

(a) the minimum energy;

1

Energy required for a reaction to occur;
(or to start a reaction or for successful collisions)

1

(b) axes labelled:- y: number *(or fraction or %)* of molecules *(or particles)*
x: energy *(or KE);*

1

curve starts at origin;

1

skewed to right;

1

approaches x axis as an asymptote;
(penalise a curve that levels off > 10% of max peak height or a curve that crosses the energy axis)

1

second curve displaced to the left (and does not cross T_1 curve for a second time)

1

and peak higher;

1

many fewer molecules;

1

fewer molecules have $E > E_a$;
(can score this mark from suitably marked curves)

1

(c) molecules *(or particles or collisions)* do not have enough energy;
(or orientation may be wrong)

1

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increase the pressure;

1

(or increase the concentration or reduce the volume)
increases the collision frequency;

(or more collisions)
(do not allow if stated to be due to increase in energy implied by temperature increase)

1

add a catalyst;

1

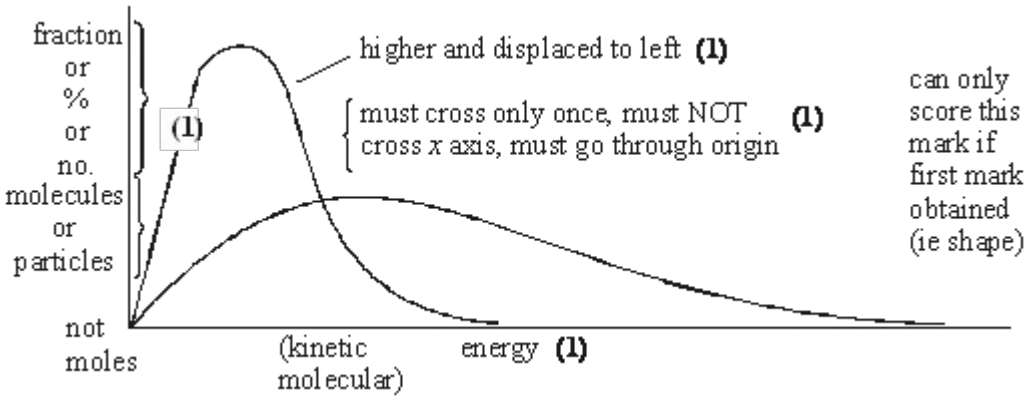
lowers <u>activation energy</u> (or E_a) *(Q of L mark);*

1

[15]

Q23.

(a)



2

(b) See above

2

(c) Energy < E_a or must have enough energy (to react) **(1)**

1

(d) Increase concentration (or pressure) **(1)**

1

(e) Many **(1)** more molecules have E > E_a / enough energy **(1)**

NOT KE increases with T

2

(f) Lowers E_a **(1)**
alternative route **(1)**

2

[10]

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Q1.

Overall this was a relatively high-scoring question. The demanding part (b) highlighted some significant misconceptions about the Maxwell–Boltzmann distribution. It was evident that many students had little idea why the curve started at the origin. Common misconceptions were that the origin referred to zero rate or that the reaction had not started or even that the origin is absolute zero.

Q2.

This question was well answered by most candidates. Candidates who lost marks usually made errors in part (a). These errors included incorrect labelling of the axes of the Maxwell-Boltzmann curve with temperature being the most common incorrect answer. The reason why this curve starts at the origin also proved difficult and there were some incorrect answer to section (iii). Many candidates scored full marks in part (b).

Q4.

This question was well answered. The term activation energy was well understood and most candidates knew how, in general terms, a catalyst increases the rate of a chemical reaction. Part (c) was also well answered. Most candidates were able to deduce how the distribution of molecular energies would change if the number of molecules was increased at constant temperature or the temperature was reduced without a change in the number of molecules. The only common error was to state that, when the temperature was reduced, the number of molecules with the most probable energy, E_{mp} would fall. The effect of a catalyst was well known and most candidates gained full marks for their answer to (c)(iii).

Q5.

Most candidates were able to gain some marks for this question which, nevertheless, discriminated well between strong and weak candidates. The curves drawn in answer to part (a) were seldom good enough to gain full marks. They were not always skewed obviously to the left and many curves did not approach the energy axis as an asymptote. Most answers to part (b) were correct but weaker candidates lost one of the two marks by failing to mention some idea of a ‘minimum’ energy. Part (c) proved to be a hard question; only the best candidates recognised that the energy of the molecules would be redistributed by collision. Part (d) was an easier question though candidates often referred to a rate of reaction rather than answering the question by mentioning how the time taken for decomposition would be changed.

Q6.

Many students (58.9%) got this question correct but many confused the most probable energy with the mean energy of the particles.

Q7.

(a) This was a straightforward mark which most students scored.

(b) Most students knew that the distribution shifted to the right and the peak lowered, but many failed to draw their distribution so that the area under the curve remained the same to show that the number of molecules was unchanged.

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(c) Many students could explain that more particles had the required activation energy at higher temperatures, but only the best students explained that this increased the frequency of successful collisions, with many simply referring to the chance or number of successful collisions rather than the frequency.

Q14.

In part (a) most students were able to sketch an appropriate curve, although some made the mistake of joining the end of their curve to the original curve or to the horizontal axis. The explanation depended on it being clear that many more molecules would have $E > E_a$ and that therefore the frequency of successful collisions would greatly increase. Too many answers simply referred to an increase in energy leading to an increase in collisions.

The first part of (b) was generally well answered although, when applying le Chatelier's principle to a specific situation, students must be clear that the shift in position of an equilibrium is in order to oppose a specific change. In this case the shift is to oppose the increase in pressure. In part (b)(ii) quite a lot of answers were expressed in a confused manner. Students are advised to tailor their answer to the actual question rather than repeat generic responses related to the idea. In this case the phrase in the question 'rather than at a higher temperature' was key, with the expectation being that students would suggest that, although a higher temperature would increase the rate, it would decrease the yield so the chosen value was a compromise. Students who introduced the idea of lower temperatures could still earn credit but a mention of compromise or optimum conditions was required in order to score the second mark.

Q16.

Over two-thirds of students gained at least 2 of the 3 marks in part (a). The commonest error was a failure to mark E_{mp} **on the appropriate axis** as required in the question. In part (b), it was important to specify that at a lower temperature there would be fewer successful collisions **in a given time**. This requirement meant that fewer than 10% of students achieved full marks for this part of the question.

Q17.

There was a requirement in parts of this question to refer specifically to molecules since the distribution was for molecular energies. Part (e) proved to be the most challenging because students were required to state that many more molecules gained energy greater than the activation energy when there was a small increase in temperature.

Q18.

After a relatively easy start in parts (a) and (b), candidates were challenged by their understanding of the Maxwell-Boltzmann distribution in part (c), with part (c)(ii) proving the most demanding. A small proportion of candidates failed to follow the instruction to use the specified words (increases, decreases or stays the same) but the marking catered for this, awarding marks for correct chemistry. Part (d) was lower scoring than anticipated with the identity of the catalyst in part (d)(ii) least well known.

Q19.

The curve in part (a)(i) had an easy mark and a more demanding one and only 53% scored full marks. In part (a)(ii), many candidates did not appreciate that an increased likelihood of particle collision is not the same as an increase in the number of successful collisions. The explanation of how a catalyst increases the rate of a reaction was well known.

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Q21.

This question was not answered well. Only a few candidates scored high marks. The most common wrong answer in (a) (i) was Y. In part (a) (ii) many candidates did not mention collisions or the fact that during collision some particles gained energy whilst others lost energy and slowed down. Part (b) was the most well done section in this question with candidates being able to draw a Maxwell - Boltzmann distribution curve at a higher temperature. In part (c) (i) many candidates made no reference to few collisions having the necessary activation energy. Part(c) (ii) was not answered well by many candidates since they did not read the question and relate their answer to the proportion of successful collisions. Many candidates referred to increasing the concentration or pressure which would simply increase the number of successful collisions. Even those who gave the correct answer of catalyst did not fully explain how this increased the proportion of successful collisions.

Q22.

It was pleasing to note that many candidates were able to score reasonably high marks for this question. Answers to part (a) were usually correct. The curves in part (b) were mostly drawn well. The most common error was to show a curve levelling off horizontally too far above the energy axis. However, only the best candidates were able to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction. Many good answers to part (c) were seen. The most common error was to suggest that an increase in pressure raised the rate of a gas phase reaction by increasing the energy of the molecules. Some weaker candidates lost marks because they gave pressure and concentration as the two ways of speeding up the reaction. They did not realise that, for a gas, increasing the concentration is the same effect as increasing the pressure.

Q23.

This question was answered well by most candidates except for part (e). Weaker candidates did not usually label the axes correctly in part (a). The most common error was to label the vertical axis ‘Energy’ and the horizontal axis ‘Time’. The curve in part (b) was drawn correctly by the great majority of candidates. Answers to parts (c) and (d) were usually succinct and correct. In part (e) few candidates, even amongst the most able, were able to explain why a small increase in temperature leads to a large increase in the rate of a reaction. Answers were restricted to a simple explanation of why any increase in temperature increases reaction rate. Many weaker candidates attempted incorrectly to attribute the large increase in the reaction rate to an increase in collision frequency. Part (f) was not answered well by many of the weaker candidates who gave a definition of a catalyst rather than an explanation of how it works.

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Effect of temp on reaction rate Physical chemistry

Name: _____

Class: _____

Date: _____

Time: **130 minutes**

Marks: **126 marks**

Comments:

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Q1.

(a) energy

Ignore reference to

- *any units (e.g. J, kJ, J mol^{-1}, kJ mol^{-1})*
- *particles*
- *molecules*
- *kinetic*

***NOT** mean energy or average energy*

***NOT** E*

1

(b) **M1** maximum peak height is lower and displaced to the right of the original

1

M2 all of the following

- starts at the origin but does not follow the original line
- shows separation as soon as possible from the original line
- crosses the original curve once only
- similar area to original curve
- an attempt has been made to draw the new curve correctly towards the energy axis above the original curve but not to touch the original curve (or axis)

1

(c) **M1** an increase in the number/amount/proportion/fraction of molecules with

$E \geq E_a$ / with activation energy

or more molecules have $E \geq E_a$ / with activation energy

or more molecules have enough / sufficient energy (to react)

M1

Ignore

- *Molecules have more energy*
- *More energetic collisions*
- *More collisions*

Allow $E > E_a$ in place of $E \geq E_a$

Credit particles for molecules (but not atoms)

*Penalise for **M1** reference to increased activation energy*

1

M2 more successful / effective / productive collisions in a given time / period

or higher rate of successful / effective / productive collisions

or higher frequency of successful / effective / productive collisions

M2

Must refer to <u>both</u> idea of successful / effective / productive collisions and the rate / frequency of collisions

Ignore 'chance of collision'

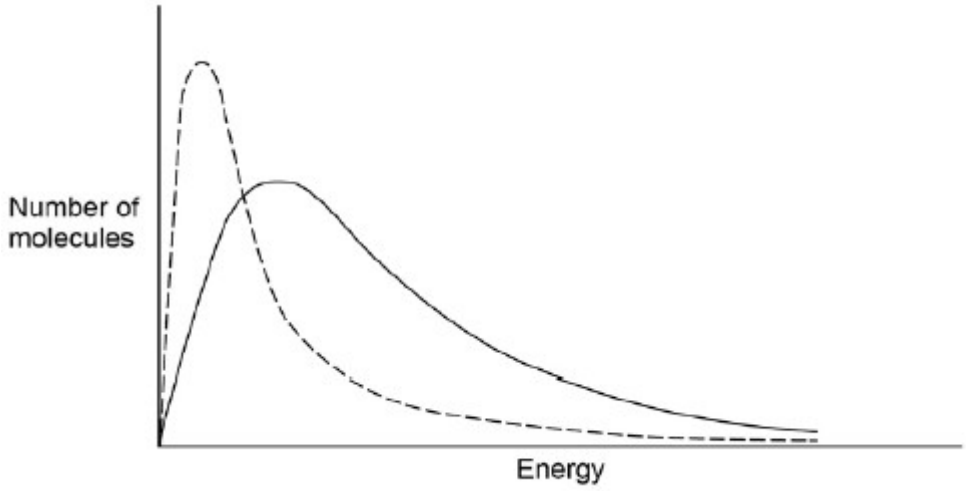
1

[5]

Q2.

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(a)



M1 Curve is higher and displaced to the left
M2 Only crosses the original curve <u>once</u>

2

(b) Rate of reaction decreases (no mark)

Fewer particles will have energy greater than or equal to the activation energy

1

Fewer <u>successful</u> collisions in a given time
Less frequent <u>successful</u> collisions

1

(c) The amount of gas present (or number of molecules) has been reduced / or the pressure has been reduced

1

Rate of reaction decreases (no mark)

Particles are spread further apart

1

Fewer collisions between gas particles so fewer <u>successful</u> collisions

1

[7]

Q3.

A

[1]

Q4.

(a) Consider experiments 1 and 2: [B constant]

[A] increases × 3: rate increases by 3^2 therefore 2nd order with respect to A

1

Consider experiments 2 and 3:

[A] increases × 2: rate should increase × 2^2 but only increases × 2

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Therefore, halving [B] halves rate and so 1st order with respect to B

1

Rate equation: rate = $k[A]^2[B]$

1

(b) rate = $k\,[C]^2[D]$ therefore k = rate / $[C]^2[D]$

1

$$k = \frac{7.2\times10^{-4}}{\left(1.9\times10^{-2}\right)^2 \times \left(3.5\times10^{-2}\right)} = 57.0$$

Allow consequential marking on incorrect transcription

1

$mol^{-2}\ dm^{+6}\ s^{-1}$

Any order

1

(c) rate = $57.0 \times (3.6 \times 10^{-2})^2 \times 5.4 \times 10^{-2} = 3.99 \times 10^{-3}$ (mol dm^{-3} s^{-1})

OR

Their $k \times (3.6 \times 10^{-2})^2 \times 5.4 \times 10^{-2}$

1

(d) Reaction occurs when molecules have $E \geq E_a$

1

Doubling T by 10 °C causes <u>many</u> more molecules to have this E

1

Whereas doubling [**E**] only doubles the number with this E

1

(e) $E_a = RT(\ln A - \ln k) / 1000$

Mark is for rearrangement of equation and factor of 1000 used correctly to convert J into kJ

1

$E_a = 8.31 \times 300\ (23.97 - (-5.03)) / 1000 = 72.3$ (kJ mol^{-1})

1

[12]

Q5.

(a) (i) Curve drawn from origin with peak clearly lower and to right.

*New curve crosses original once only, finishes above original and does **not** clearly curve up*

***IGNORE** relative areas*

1

(ii) (Relative areas under curves indicate) <u>many</u> (owtte) more molecules with E greater than or equal to Ea (at higher T)

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or reverse argument

ALLOW *'particles'*

IGNORE *'atoms'*

1

(Large) increase in (number of) <u>successful</u> (owtte) <u>collisions per unit</u> time

OR <u>'frequency</u> of successful <u>collisions'</u>

1

(b) (i) Yield increases

Yield decreases/stays the same CE = 0

If not answered mark on

1

More moles/molecules (of gas) on left/fewer on right/3 on left 1 on right

1

<u>Equilibrium shifts/moves</u> (to right) to reduce pressure/oppose higher pressure

No M3 if 'more moles on right' in M2

IGNORE *'favours'*

NOT *just 'oppose the change'*

QoL means that M3 is only awarded if these ideas are clearly linked in one statement

1

(ii) Higher T would increase rate but decrease yield/make less methanol

OR

Lower T decreases rate but increases yield;

*If no mention of both rate **AND** (idea of) yield max 1*

1

Chosen T is a compromise/balance (between rate and yield) owtte

1

[8]

Q6.

(a) <u>Amount / number / proportion / percentage / fraction / moles</u> of <u>molecules / particles</u>

Penalise an incorrect qualification of the number eg NOT number of molecules with E greater than Ea.

Not 'atoms'.

1

(b) There are no molecules / particles with zero energy

OR

All of the molecules / particles are moving / have some energy

Not 'atoms'.

The answer should relate the energy to the molecules.

1

(c) **C** (The most probable energy)

1

(d) **M1** The peak of the new curve is <u>displaced to the right</u> and <u>lower</u> than the original

M2 All of the following needed

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- The new curve starts at the origin and should begin to separate from the original almost immediately
- and the new curve only crosses the original curve once
- and the total area under the new curve is approximately the same as the original
- and an attempt has been made to draw the new curve correctly towards the axis above the original curve but not to touch the original curve

2

(e) None / no effect / stays the same

1

[6]

Q7.

(a) As concentration increases the amount of heat given out increases / temperature increases **(M1)**

Any order.

Ignore references to an exothermic reaction.

1

More successful collisions or reactions in a given time **OR** more particles have the activation energy **(M2)**

Allow could be a second / n^{th} order reaction.

1

(An increase in temperature or more heat given out) increases the rate of a reaction **(M3)**

1

(b) The magnesium is coated with an oxide / MgO **(M1)**

Allow magnesium hydroxide.

1

MgO / the coating / the corrosion product has to be removed before Mg will react
OR Mg and MgO / the coating / the corrosion product react at different rates
OR Initially MgO / the coating / the corrosion product reacts not Mg **(M2)**

Ignore inert coating.

1

(c) Any **two** from:

Any order.

Slower with hot water or faster with steam

The hot water produces $Mg(OH)_2$ / the hydroxide **OR** steam produces MgO / the oxide

(Slow) bubbling with hot water **OR** bright white light / flame / white solid with steam

2 max

(d) Magnesium sulfate is soluble and calcium sulfate is insoluble / slightly

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soluble / magnesium sulfate is more soluble / calcium sulfate is less soluble / correct trend in solubility **(M1)**

Any order.

***M1** requires a comparison of the two solubilities.*

Calcium sulfate coats the surface of the calcium **(M2)**

Coating prevents further contact with / reaction by the acid **(M3)**

*'Calcium sulfate forms a protective coating' scores **M2** only.*

3

[10]

Q8.

(a) **Award in either order for curve**

"Steeper" requires line to be on the left of the original line, starting from the origin

M1 curve is steeper than original and starts at the origin

M2 curve levels at the top line on the graph

2

(b) **Award in either order for curve**

"Shallower" requires line to be on the right of the original line, starting from the origin

M1 curve is shallower than original and starts at the origin

M2 curve levels at the first line on the graph

2

(c) **M1** curve would be steeper than original

"Steeper" requires line to be on the left of the original line, starting from the origin

M2 curve levels at the same original volume of O_2

2

(d) **M1** The (concentration / amount of) H_2O_2 or reactant falls / decreases / used up

Mark independently

OR

The number of H_2O_2 or reactant molecules/ particles falls / decreases

M2

The rate of reaction / rate of decomposition / rate of formation of oxygen / frequency of collisions / (effective) collisions in a given time decreases / is slower

2

(e) (i) $\mathbf{2}H_2O_2 \rightarrow \mathbf{2}H_2O + O_2$

Ignore state symbols

Accept only this equation or its multiples

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Extra species must be crossed through

1

(ii) hydrogen bromide / it does not appear in the overall equation

OR

hydrogen bromide / it is not <u>used up</u> in the reaction / <u>unchanged at the end</u> of the reaction

OR

hydrogen bromide / it is regenerated / re-formed (in Step 2)

1

[10]

Q9.

(a) <u>Number / proportion / percentage / fraction</u> of <u>molecules</u>

Ignore "particles"

1

(b) None ***OR*** no effect ***OR*** no change

1

(c) **X**

1

(d) **Answers in either order**

M1 collision ***OR*** collide

Mark independently

M2 collision / molecules / particles

Ignore "correct" amount of energy

with the <u>activation</u> energy

OR with $E \geq E_{act}$

OR with <u>sufficient /enough</u> energy

OR with the <u>minimum</u> energy

OR with the correct orientation

2

(e) A small increase in temperature results in <u>many more / much higher proportion of / a lot more / significantly more molecules / particles / collisions</u> with <u>$E \geq E_{act}$/ energy greater than the activation energy / sufficient energy / enough energy / minimum energy to react</u>
(compared with a small increase in concentration)

Not just "more molecules with $E \geq E_{act}$"

*The answer must convey that the increase is **significant***

Accept reference to "atoms", "molecules", "particles"

Ignore "species"

1

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[6]

Q10.

(a) Antacid

OR

to neutralise acidity

OR

eases indigestion

Credit suitable reference to indigestion or to laxative or to relief of constipation

1

(b) **M1** Decrease in T decreases the energy of the particles/ions/H^+/molecules

M2 (also scores M1) Decrease in the number of/less particles/ions/ H^+/molecules with $E \geq E_{Act}$ or $E \geq$ minimum energy to react

*In **M1** and **M2,** credit "atoms" but ignore "calcium carbonate", ignore "calcium", ignore any ion formula except H^+*

M3 Few(er)/Less effective/productive/successful collisions

QoL

3

(c) (i) Strontium has a higher melting point than barium, because

Correct reference to size of cations/proximity of electrons
M1 (For Sr) delocalised electrons closer to cations/positive ions/atoms/nucleus

OR

cations/positive ions/atoms are smaller

OR

cation/positive ion/atom or it has fewer (electron) shells/levels

Ignore general Group 2 statements

Penalise M1 if Sr or Ba is said to have more or less delocalised electrons

Ignore reference to shielding

***CE = 0** for reference to molecules or intermolecular forces or covalent bonds*

Relative strength of metallic bonding
M2 (Sr) has stronger attraction between the cations/positive ions/ atoms/nucleus and the delocalised electrons

OR

stronger metallic bonding
(assume argument refers to Sr but accept converse argument for Ba) 2

Ignore "Van der Waals forces (between atoms)" but penalise

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if "between molecules"

(ii) $Sr + \mathbf{2}H_2O \rightarrow Sr(OH)_2 + H_2$

Or multiples

1

(d) $\mathbf{2}Mg + TiCl_4 \rightarrow \mathbf{2}MgCl_2 + Ti$

Or multiples

1

[9]

Q11.

(a) Peak lower

1

and moved to right

1

start at the origin and curve crosses once only

1

(b) (i) (Rate of reaction) <u>increases</u>

1

(At a higher temperature) <u>more molecules/particles</u>

1

have the minimum energy needed to react/have activation energy/have successful collisions

Mark CE if incorrect effect given

1

(ii) (Rate of reaction) <u>increases</u> 1

lowers activation energy 1

so that more molecules are able to react 1

Mark CE if incorrect effect given

[9]

Q12.

(a) minimum energy

1

to start a reaction/ for a reaction to occur/ for a successful collision

1

(b) activation energy is high / few molecules/particles have sufficient energy to react/few molecules/particles have the required activation energy

(or breaking bonds needs much energy)

1

(c) molecules are closer together/ more particles in a given volume

1

therefore collide more often

1

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(d) many

1

more molecules have energy greater than activation energy (QoL)

1

(e) speeds up a reaction but is chemically unchanged at the end

1

(f) increases the surface area

1

[9]

Q13.

(a) the minimum energy;

1

Energy required for a reaction to occur;
(or to start a reaction or for successful collisions)

1

(b) axes labelled:- y: number *(or fraction or %)* of molecules *(or particles)*
x: energy *(or KE);*

1

curve starts at origin;

1

skewed to right;

1

approaches x axis as an asymptote;
(penalise a curve that levels off > 10% of max peak height or a curve that crosses the energy axis)

1

second curve displaced to the left (and does not cross T_1 curve for a second time)

1

and peak higher;

1

many fewer molecules;

1

fewer molecules have $E > E_a$;
(can score this mark from suitably marked curves)

1

(c) molecules *(or particles or collisions)* do not have enough energy;
(or orientation may be wrong)

1

increase the pressure;

1

(or increase the concentration or reduce the volume)

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increases the collision frequency;

(or more collisions)
(do not allow if stated to be due to increase in energy implied by temperature increase)

1

add a catalyst;

1

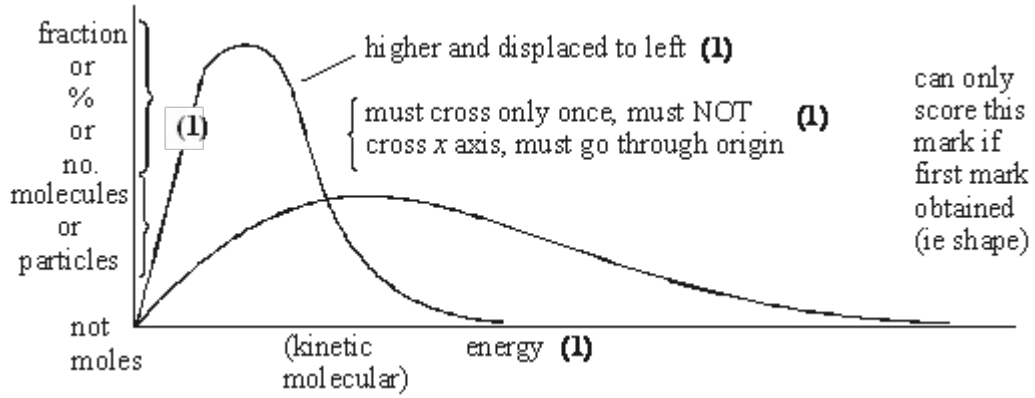
lowers activation energy (or E_a) *(Q of L mark);*

1

[15]

Q14.

(a)



2

(b) See above

2

(c) Energy < E_a or must have enough energy (to react) **(1)**

1

(d) Increase concentration (or pressure) **(1)**

1

(e) Many **(1)** more molecules have E > E_a / enough energy **(1)**
NOT KE increases with T

2

(f) Lowers E_a **(1)**
alternative route **(1)**

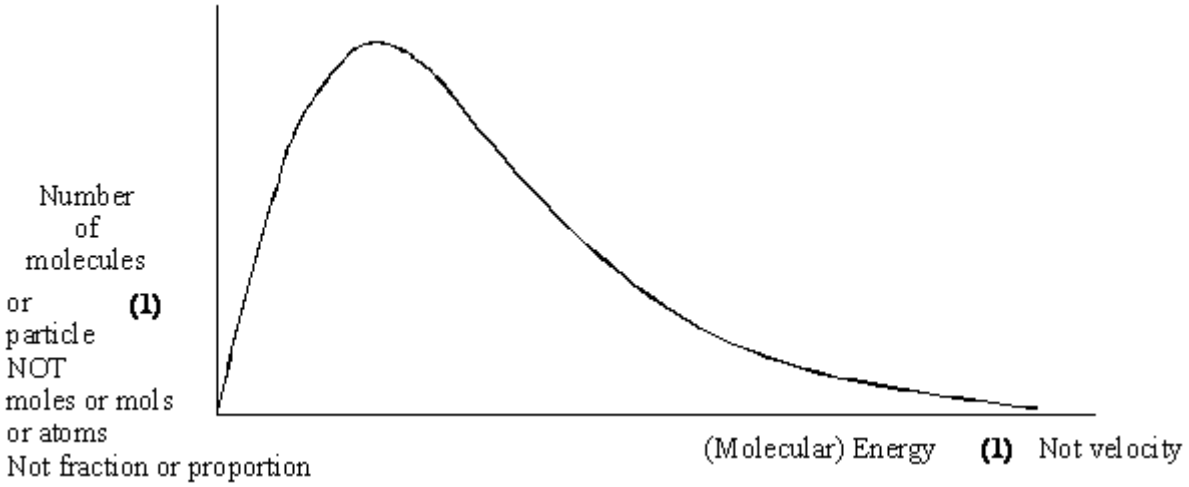
2

[10]

Q15.

(a) (i)

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(ii) The total number of particles (or molecules) in the sample

OR the number of molecules present

(iii) No molecules have no energy

OR all molecules have some energy

Do not allow "if there are no molecules there is no energy"

4

(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**

OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

Explanation: Alternative route **(1),** with a lower activation energy **(1)**

OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii)

5

[9]

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Q1.

(a) This was a straightforward mark which most students scored.

(b) Most students knew that the distribution shifted to the right and the peak lowered, but many failed to draw their distribution so that the area under the curve remained the same to show that the number of molecules was unchanged.

(c) Many students could explain that more particles had the required activation energy at higher temperatures, but only the best students explained that this increased the frequency of successful collisions, with many simply referring to the chance or number of successful collisions rather than the frequency.

Q5.

In part (a) most students were able to sketch an appropriate curve, although some made the mistake of joining the end of their curve to the original curve or to the horizontal axis. The explanation depended on it being clear that many more molecules would have $E > E_a$ and that therefore the frequency of successful collisions would greatly increase. Too many answers simply referred to an increase in energy leading to an increase in collisions.

The first part of (b) was generally well answered although, when applying le Chatelier's principle to a specific situation, students must be clear that the shift in position of an equilibrium is in order to oppose a specific change. In this case the shift is to oppose the increase in pressure. In part (b)(ii) quite a lot of answers were expressed in a confused manner. Students are advised to tailor their answer to the actual question rather than repeat generic responses related to the idea. In this case the phrase in the question 'rather than at a higher temperature' was key, with the expectation being that students would suggest that, although a higher temperature would increase the rate, it would decrease the yield so the chosen value was a compromise. Students who introduced the idea of lower temperatures could still earn credit but a mention of compromise or optimum conditions was required in order to score the second mark.

Q6.

Overall this was a relatively high-scoring question. The demanding part (b) highlighted some significant misconceptions about the Maxwell–Boltzmann distribution. It was evident that many students had little idea why the curve started at the origin. Common misconceptions were that the origin referred to zero rate or that the reaction had not started or even that the origin is absolute zero.

Q7.

(a) This part was found demanding. Few students were able to relate correctly an increase in concentration to an increase in temperature. Many answers contained no reference to temperature at all. In addition, some teachers tended to mark this question generously. Many students should have not been awarded the second mark as they did not state that there would be more successful collisions in a given time. Some students were incorrectly given full credit without making any reference to the extra heat generated by the reaction affecting the rate of this reaction.

(b) In this part, a surprising number of students did not realise that the surface coating was magnesium oxide, and an even larger number thought that magnesium oxide

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would not react with hydrochloric acid. This chemical error often went unpunished.

(c) This part was answered well, although many students gave only one difference, spreading the explanation across all four answer lines.

(b) In this part, a large number of students referred to solubility of the metals themselves rather than the sulfates. A solubility comparison was often lacking and few students appreciated that the insoluble calcium sulfate would prevent further contact between the acid and the metal.

Given the increasing pressure on schools and colleges to deliver the teaching programme, this was, overall, a very positive session. Teachers are once again thanked for the trouble taken with the coursework. Their efforts continue to be much appreciated by the moderator team.

Q8.

In this question it was necessary to have an appreciation not only of amount of substance but also how changes in conditions altered the rate of a reaction. In part (e), the only acceptable answer for the overall equation was one in which the various intermediates were cancelled.

Q9.

There was a requirement in parts of this question to refer specifically to molecules since the distribution was for molecular energies. Part (e) proved to be the most challenging because students were required to state that <u>many</u> more molecules gained energy greater than the activation energy when there was a small increase in temperature.

Q10.

All parts of this question discriminated well. It is a matter of concern that more than half the candidates were unable to write a correct equation for the reaction of magnesium with titanium(IV) chloride.

Q12.

Although the more able candidates found this question relatively straightforward, the weaker candidates found the task of explaining concisely rather difficult.

The majority of candidates answered (a) correctly although many failed to realise that the reaction in (b) would be slow because few molecules had the minimum activation energy needed to react.

In part (c) several incorrect answers included the assumption that increasing pressure increases energy! Answers to part (d) were generally done well. In (e) many candidates failed to score since they did not state that a catalyst is a substance that speeds up a reaction whilst remaining chemically unchanged. Instead candidates described how a catalyst worked in a reaction. Generally however candidates knew that powdered catalysts increase the surface area and hence scored the mark in (f).

Q13.

It was pleasing to note that many candidates were able to score reasonably high marks for this question. Answers to part (a) were usually correct. The curves in part (b) were mostly drawn well. The most common error was to show a curve levelling off horizontally

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too far above the energy axis. However, only the best candidates were able to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction. Many good answers to part (c) were seen. The most common error was to suggest that an increase in pressure raised the rate of a gas phase reaction by increasing the energy of the molecules. Some weaker candidates lost marks because they gave pressure and concentration as the two ways of speeding up the reaction. They did not realise that, for a gas, increasing the concentration is the same effect as increasing the pressure.

Q14.

This question was answered well by most candidates except for part (e). Weaker candidates did not usually label the axes correctly in part (a). The most common error was to label the vertical axis ‘Energy’ and the horizontal axis ‘Time’. The curve in part (b) was drawn correctly by the great majority of candidates. Answers to parts (c) and (d) were usually succinct and correct. In part (e) few candidates, even amongst the most able, were able to explain why a small increase in temperature leads to a large increase in the rate of a reaction. Answers were restricted to a simple explanation of why any increase in temperature increases reaction rate. Many weaker candidates attempted incorrectly to attribute the large increase in the reaction rate to an increase in collision frequency. Part (f) was not answered well by many of the weaker candidates who gave a definition of a catalyst rather than an explanation of how it works.

Q15.

This question was well answered by most candidates. Candidates who lost marks usually made errors in part (a). These errors included incorrect labelling of the axes of the Maxwell-Boltzmann curve with temperature being the most common incorrect answer. The reason why this curve starts at the origin also proved difficult and there were some incorrect answer to section (iii). Many candidates scored full marks in part (b).

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Q1.

(a) **M1** provides a different route / mechanism / pathway

Ignore reference to (frequency of) collisions, surface area or active sites

1

M2 with lower activation energy

Penalise reference to increasing energy of particles (CE = 0)

*Allow E_a / E_{act} or definition of activation energy in **M2***

1

(b) **M1** line 2 = steeper than original and finishes at same height

1

M2 line 3 = less steep than original and finishes at half the height

If two correct lines are drawn but neither labelled, then allow 1 mark.

If two correct lines are drawn and only one is labelled, then allow 2 marks.

If only one correct line is drawn and neither are labelled, then 0 marks.

If two correct lines are drawn but line 2 is labelled 1 and line 3 is labelled 2, then allow 1 mark

Allow some unevenness in drawing of lines in terms of height it levels off at, with up to a quarter of a box of unevenness

At the start, lines must separate from the original before the first vertical line.

In terms of the origin, lines must start within one half of a square of the origin.

For each line ignore the time at which the line becomes horizontal – it is the fact it is more or less steep than the original line that matters (along with the height at which it finishes)

1

(c) **M1** more particles/molecules/reactants/H_2O_2/moles in given/same volume/space
OR
particles/molecules/reactants/H_2O_2/moles closer together

Penalise reference to changing the activation energy (CE = 0)

*For **M1** do not allow area*

1

M2 successful collisions are more frequent

*For **M2***

successful collisions – allow reference to collisions with sufficient energy or collisions with the activation energy or effective collisions

more frequent – allow reference to per unit time, per second (but ignore reference to rate of collisions, ignore chance of

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collisions, ignore likelihood of collisions)

1

[6]

Q2.

(a) H_2O_2 and/or I^- <u>concentration</u> change is negligible /
H_2O_2 and/or I^- <u>concentration</u> (effectively) constant

<u>Only</u> the <u>concentration</u> of H^+ changes.

so have a constant/no effect on the rate / so is zero order (w.r.t. H_2O_2 and I^-) / a and b are zero

Ignore references to H^+ is limiting reagent / rds / H_2O_2/I^- not in rate equation

Do not allow reference to catalyst.

2

(b) Stop the reaction / quench

By dilution / cooling / adding a reagent to react with H_2O_2/I^-

Allow valid suggestions about how to stop the reaction.

Do not allow reaction with acid/alkali / neutralisation for M2

Do not penalise other named reagents.

Ignore references to measuring volume and adding indicator

2

(c) M1: constant gradient

OR

change/decrease in concentration is proportional to time

Allow constant rate / rate = k

Ignore reference to straight line

Not increase in concentration / concentration is inversely proportional / concentration (on its own) is proportional

M2: as $[H^+]$ changes/decreases

M2 dependent on correct M1

Allow rate v concentration graph would give horizontal straight line owtte

Allow so $[H^+]$ has no effect on the rate

2

(d) evidence of attempt at calculation of gradient via $\Delta y/\Delta x$

allow construction lines on graph

$k_1 = 0.0012 / 1.2 \times 10^{-3}$

At least 2 sf (0.00118 – 0.00122)

Correct answer scores 2/2

No ecf from incorrect or inverted numbers in M1

k_1 = – 0.0012 scores 1/2

Additional processing of data such as including $[H^+]$ loses M2

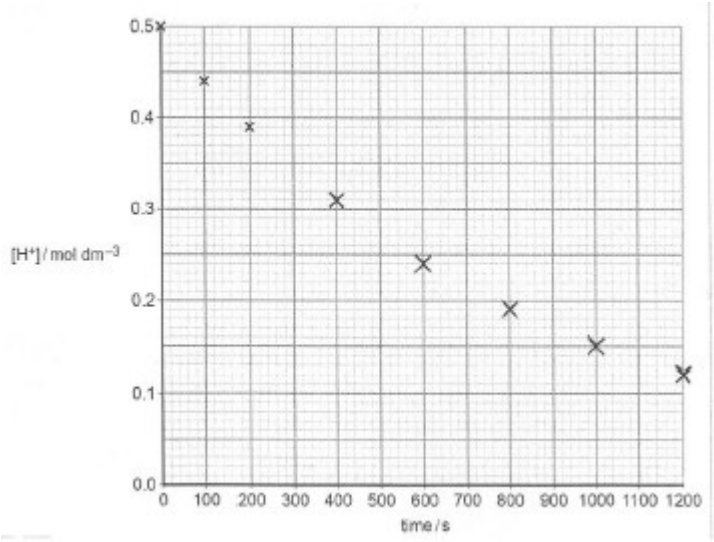
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units = <u>mol dm^{-3} s^{-1}</u>

M3 mark independently

3

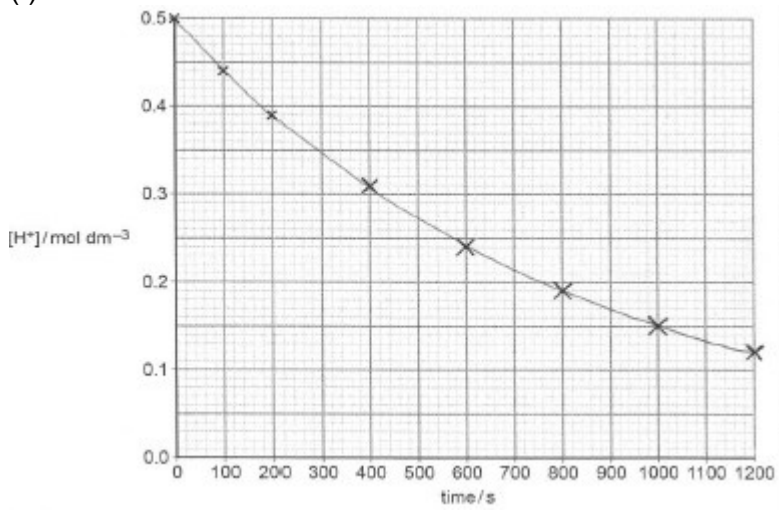
(e) 5 points correctly plotted



Allow ±half a small square for each point

1

(f)



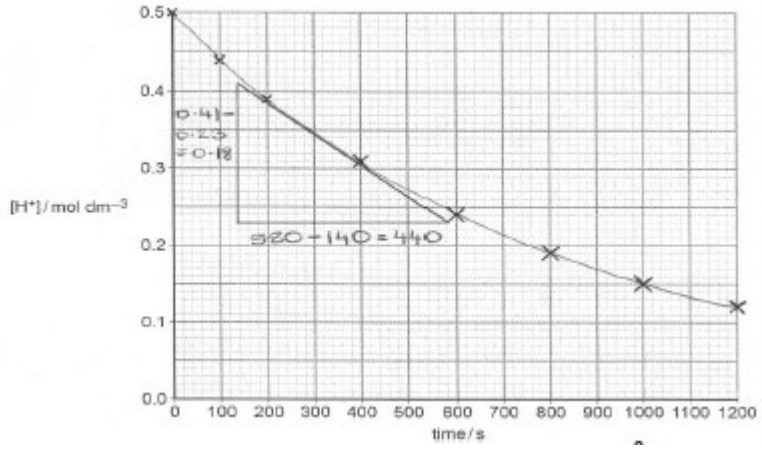
Smooth curve only within one small square of all points (ecf on part (e))

Not a series of straight lines between points

1

(g)

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M1: Tangent to curve drawn at $[H_3O^+] = 0.35$ mol dm^{-3}

e.g. 0.18/440

M1 for a tangent / triangle / other suitable working

Allow ECF for both M1 and M2 following on from straight line drawn in 01.6, but must show suitable construction on graph for M1

M2: Rate = 4.09×10^{-4} (mol dm^{-3} s^{-1})

Ignore negative signs

Allow value in range 3.70×10^{-4} - 4.50×10^{-4}

At least 2sf

ecf from any straight line for correctly calculated gradient

2

(h) This question is marked using levels of response. Refer to the Mark Scheme Instructions for examiners for guidance on how to mark this question

Level 3 5-6 marks	All stages are covered and the explanation of each stage is correct and virtually complete. Answer is coherent and shows progression through all three stages. A clear explanation of how the order is determined from the results is needed to show coherence.
Level 2 3-4 marks	All stages are covered (NB 'covered' means min 2 from stage 2) but the explanation of each stage may be incomplete or may contain inaccuracies **OR** two stages covered and the explanations are generally correct and virtually complete Answer is coherent and shows some progression through all three stages. Some steps in each stage may be out of order and incomplete
Level 1 1-2 marks	Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies **OR** only one stage is covered but the explanation is

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	generally correct and virtually complete Answer shows some progression between two stages
Level 0 0 marks	Insufficient correct Chemistry to warrant a mark

Indicative Chemistry content Method 1

Stage 1 Preparation

1a Measure (suitable/known volumes of) some reagents (ignore quoted values for volume)
1b Measure (known amount of) **X** / use a colorimeter
1c into separate container(s) – (allow up to two reagents and **X** measured together into one container); reference to **A**, **B** or **C** added last. NOT if **X** added last.

Stage 2 Procedure

2a Start clock/timer at the point of mixing (don't allow if only 2 reagents mixed) (allow even if **X** not added or added last)
2b Time recorded for appearance of blue colour/specific reading on colorimeter/disappearing cross
2c Use of same concentration of **B** and **C** / same total volume / same volume/amount of **X**
2d Same temperature/use water bath
2e Repeat with different concentrations of A (can be implied through different volumes of A and same total volume)

Stage 3 Use of Results

3a 1/time taken is a measure of the rate
3b plot of 1/time against volumes/concentrations of **A** or plot log(1/time) vs log(volume or concentration of **A**)
3c description of interpreting order from shape of 1/time vs volume or concentration graph / gradient of log plot gives order / allow interpretation of time vs concentration graph / ratio between change in concentration and change in rate (e.g, $2x[A] = 2 \times$ rate so 1st order)

Indicative Chemistry content – Alternative Method Using Colorimetry and repeated Continuous Monitoring

Stage 1 Preparation

1a Measure (suitable/known volumes of) **A**, **B** and **C** (ignore quoted values for volume)
1b Use of colorimeter
1c into separate container(s) – (allow up to two reagents measured together into one container) – ignore use of **X**

Stage 2 Procedure

2a Start clock/timer at the point of mixing
2b Take series of colorimeter readings at regular time intervals

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2c Use of same concentration of **B** and **C** / same total volume / (same volume/amount of **X**)
2d Same temperature
2e Repeat with different concentrations of **A** (can be implied through different volumes of **A** and same total volume)

Stage 3 Use of Results

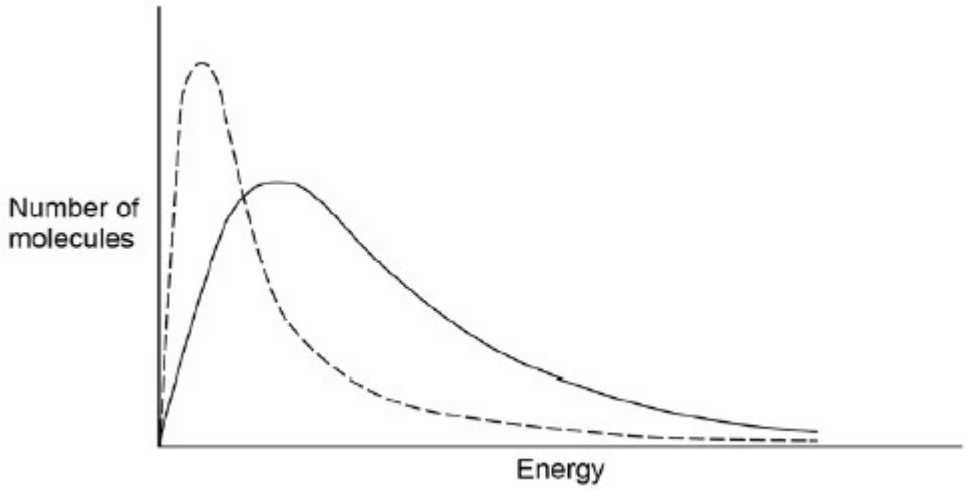
3a Plot absorbance vs time and measure/calculate gradient at time=0
3b plot of gradient against volumes/concentrations of **A** or plot log(1/time) vs log(volume or concentration of A)
3c description of interpreting order from shape of 1/time vs volume or concentration graph / gradient of log plot gives order

6

[19]

Q3.

(a)



M1 Curve is higher and displaced to the left
M2 Only crosses the original curve <u>once</u>

2

(b) Rate of reaction decreases (no mark)

Fewer particles will have energy greater than or equal to the activation energy

1

Fewer <u>successful</u> collisions in a given time
Less frequent <u>successful</u> collisions

1

(c) The amount of gas present (or number of molecules) has been reduced / or the pressure has been reduced

1

Rate of reaction decreases (no mark)

Particles are spread further apart

1

Fewer collisions between gas particles so fewer <u>successful</u> collisions

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1

[7]

Q4.

A

[1]

Q5.

C

[1]

Q6.

(a) (i) **M1**

High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2

The (forward) reaction / to the right is endothermic or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M3 depends on correct M2 and must refer to temperature / heat

M3** depends on a correct statement for **M2

At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

to absorb heat OR

to lower the temperature OR

to cool down the reaction

3

(ii) **M1**

The reaction gets to equilibrium faster / in less time

OR

Produces a small yield faster / in less time

OR

Increases the rate (of reaction / of attainment of equilibrium)

Mark independently

M2

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

AND

- more collisions in a given time / increased collision frequency

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*Penalise **M2** for reference to <u>increased</u> energy of the particles*

2

(iii) **M1** <u>Increase in / more / large(r) / big(ger) surface area / surface sites</u>

Mark independently

*For **M1** accept Éan increase in surface"*

M2 <u>increase in / more</u> <u>successful</u> / <u>productive</u> / <u>effective</u> <u>collisions</u> (in a given time) (on the surface of the catalyst / with the nickel)

*For **M2** not simply "more collisions"*

Ignore "the chance or likelihood" of collisions

2

(b) **M1**

No effect / None

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2 requires a correct M1

<u>Equal / same</u> <u>number / amount</u> of <u>moles / molecules / particles</u> on either side of the equation

OR

2 <u>moles / molecules / particles</u> on the left and 2 <u>moles / molecules / particles</u> on the right

M2** depends on a correct statement for **M1

*In **M2 not** "atoms"*

2

[9]

Q7.

(a) (i) Uses sensible scales.

*Lose this mark if the **plotted points** do not cover half of the paper.*

Lose this mark if the graph plot goes off the squared paper

Lose this mark if volume is plotted on the <u>x</u>-axis

1

All points plotted correctly

Allow ± one small square.

1

Smooth curve from 0 seconds to at least 135 seconds − the line must pass through or close to all points (± one small square).

Make some allowance for the difficulties of drawing a curve but do not allow very thick or doubled lines.

1

(ii) Any value in the range 91 to 105 s

Allow a range of times within this but not if 90 quoted.

1

(b) (i) Using pV = nRT

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This mark can be gained in a correctly substituted equation.

1

$100\,000 \times 570 \times 10^{-6} = n \times 8.31 \times 293$

Correct answer with no working scores one mark only.

1

n = 0.0234 mol

Do not penalise precision of answer but must have a minimum of 2 significant figures.

1

(ii) Mol of $ZnCO_3$ = 0.0234

Mark consequentially on Q6

M1
1

Mass of $ZnCO_3$ = M1 × 125.4 = 2.9(3) or 2.9(4) g

If 0.0225 used then mass = 2.8(2) g

M2
1

(iii) Difference = (15.00 / 5) − Ans to b

If 2.87 g used then percentage is 4.3

M1
1

Percentage = (M1 / 3.00) × 100

Ignore precision beyond 2 significant figures in the final answer

If 2.82 g used from (ii) then percentage = 6.0

M2
1

(c) A reaction vessel which is clearly airtight round the bung

1

Gas collection over water or in a syringe

Collection vessel must be graduated by label or markings

Ignore any numbered volume markings.

1

[13]

Q8.

(a) (i) Award mark for **X on the time axis** at the point where the lines just become **horizontal**

*Allow this mark if **X** is above the letters "sh" in the word "show" in part(ii) - in the range of lines 31 to 33.*

1

(ii) They are equal / the same

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OR

Forward (rate) = Reverse / backward (rate)

Allow the word 'speed' in this context.

Ignore reference to concentration.

1

(b) Both **OR** forward and reverse reactions occur at the same time

OR both are occurring at once

OR both occur all of the time

OR both are ongoing

OR both never stop

Ignore 'at equal rates'.

Ignore reference to concentration or equilibrium.

The idea that both reactions occur simultaneously is essential.

The simple idea of 'both reactions occurring' is insufficient for the mark.

1

(c) (i) **M1** No effect / no change / none / stays the same

M2 requires correct **M1**

*In **M2**, ignore reference to particles or atoms.*

M2 Equal (number of) moles / molecules on both sides

2

(ii) **M1** Less time or it decreases or (equilibrium) reached faster (ie **M1** is a reference to time taken)

*If **M1** is 'more time / it increases' or 'no effect', then **CE=0** for the clip.*

*Reference to faster / increased rate / increased speed alone penalises **M1**, but mark on **M2** and **M3**.*

M2 More particles / molecules in a given volume / space

OR the particles / molecules are closer together

*If **M1** is blank, then look for all three marks in the text.*

M3 More successful / productive collisions in a given time

OR more collisions with $E>E_{Act}$ in a given time

OR more frequent successful / productive collisions

OR increased / greater successful / productive collision frequency / rate

Ignore reference to reactants / products.

*Penalise **M3** if an increase / decrease in the value of E_{Act} is stated.*

3

[8]

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Q9.

(a) Amount / number / proportion / percentage / fraction / moles of molecules / particles

Penalise an incorrect qualification of the number eg NOT number of molecules with E greater than Ea.

Not 'atoms'.

1

(b) There are no molecules / particles with zero energy

OR

All of the molecules / particles are moving / have some energy

Not 'atoms'.

The answer should relate the energy to the molecules.

1

(c) **C** (The most probable energy)

1

(d) **M1** The peak of the new curve is displaced to the right and lower than the original

M2 All of the following needed

- The new curve starts at the origin and should begin to separate from the original almost immediately
- and the new curve only crosses the original curve once
- and the total area under the new curve is approximately the same as the original
- and an attempt has been made to draw the new curve correctly towards the axis above the original curve but not to touch the original curve

2

(e) None / no effect / stays the same

1

[6]

Q10.

(a) (Measure the) volume of gas / mass of the container + contents

1

Suitable named piece of equipment

Gas syringe (or inverted burette or measuring cylinder, as long as student has referred to the cylinder being filled with water) / balance.

Equipment must be correct for the measurement stated.

1

(b) Any **one** of:

- Mass of magnesium

Allow amount of magnesium.

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- Surface area of magnesium

1

(c) (i) Gravity: Conical flask or beaker and funnel /

Vacuum: Sealed container with a side arm and Buchner or Hirsch funnel

Must be either gravity filtration (with a V-shaped funnel) or vacuum filtration (with a side-arm conical flask) appropriately drawn.

1

Filter paper

Must show filter paper as at least two sides of a triangle (V-shaped) for gravity filtration or horizontal filter paper for vacuum filtration.

1

(ii) Wash with / add (a small amount of cold) water

Ignore filtering.

1

[6]

Q11.

(a) Sensible scales

Plotted points (including 0,0) must cover more than half the graph paper.

If axis wrong way round lose this mark but mark on consequentially.

Do not allow broken axis.

1

Plots points correctly

1

(b) Ring around the origin

1

(c) Line through points is smooth

Line must pass within ± 1 small square of each plotted point except the anomaly (allow one plot ± 2 small square – at 40 or 60s).

1

Line through points is best fit and ignores anomaly (allow one plot ± 2 small square)

Lose this mark if student's line is doubled.

Kinked line loses this mark.

Lose this mark if the line does not pass through the origin + / – 1 small square.

Lose this mark if the line deviates to anomaly.

1

(d) Draws suitable tangent

Must touch the curve at 30s and must not cross the curve.

Lose this mark if the tangent is unsuitable but mark on.

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1

Chooses appropriate x and y values from their graph

Mark consequentially if axes plotted the wrong way around.

Allow information clearly shown on graph.

1

Correctly calculates y / x

Difference in x values and y values must be at least 10 small squares in either direction.

1

Gives answer with correct units (mol dm^{-3} s^{-1}) or correct variant

Lose this mark if answer not to minimum of 2 significant figures and no units or incorrect units are given.

If student has used axis the wrong way round, the unit mark can be awarded for either the correct unit based on their graph or for the correct unit for rate.

1

[9]

Q12.

(a) As <u>concentration increases</u> the amount of heat given out increases / temperature increases **(M1)**

Any order.

Ignore references to an exothermic reaction.

1

More <u>successful</u> collisions or reactions <u>in a given time</u> **OR** more particles have the activation energy **(M2)**

Allow could be a second / n^{th} order reaction.

1

(An increase in temperature or more heat given out) increases the rate of a reaction **(M3)**

1

(b) The magnesium is coated with an <u>oxide / MgO</u> **(M1)**

Allow magnesium hydroxide.

1

MgO / the coating / the corrosion product has to be removed before Mg will react
OR Mg and MgO / the coating / the corrosion product react at different rates
OR Initially MgO / the coating / the corrosion product reacts not Mg **(M2)**

Ignore inert coating.

1

(c) Any **two** from:

Any order.

Slower with hot water or faster with steam

The hot water produces $Mg(OH)_2$ / the hydroxide **OR** steam produces MgO / the oxide

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(Slow) bubbling with hot water **OR** bright white light / flame / white solid with steam

2 max

(d) Magnesium sulfate is soluble and calcium sulfate is insoluble / slightly soluble / magnesium sulfate is more soluble / calcium sulfate is less soluble / correct trend in solubility **(M1)**

Any order.

***M1** requires a comparison of the two solubilities.*

Calcium sulfate coats the surface of the calcium **(M2)**

Coating prevents further contact with / reaction by the acid **(M3)**

*'Calcium sulfate forms a protective coating' scores **M2** only.*

3

[10]

Q13.

(a) (i) Change in concentration (of a substance / reactant / product) in unit time / given time / per (specified) unit of time

*This may be written mathematically **OR** may refer to the gradient of a graph of concentration / volume against time*

OR

Amount of substance formed / used up in unit time / given time / per (specified) unit of time

Ignore additional information including reference to collisions

1

(ii) At **W**

M1 (QoL)

The rate / it is zero

M2

The magnesium has all reacted / has been used up

Ignore reference to the acid being used up

OR

No more collisions possible between acid and Mg

OR

Reaction is complete / it has stopped

OR

No more hydrogen / product is produced

2

(iii) M1

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Twice / double as many particles / hydrogen ions (in a given volume)

*Penalise reference to (hydrochloric acid) molecules in **M1***

*Penalise reference to "HCl particles" in **M1***

OR

Twice / double as much hydrochloric acid

M2

Twice / double as many effective / successful collisions (in a given time)

OR

Twice / double as many collisions with either sufficient energy to react ***OR*** with $E \geq E_a$

OR

double the successful / effective collision frequency

2

(b) (i) The activation energy is the minimum energy for a reaction to go / start

OR

Minimum energy for a successful/ effective collision

1

(ii) M1 Products lower than reactants on the profile

Mark independently

M2 Activation energy (E_a) shown and labelled correctly from reactants to peak of curve

Mark independently

2

(c) (i) $Ba + \mathbf{2}H_2O \longrightarrow Ba(OH)_2 + H_2$

$Ba + 2H_2O \longrightarrow Ba^{2+} + 2OH^- + H_2$

Allow multiples

Ignore state symbols

1

(ii) M1 $Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4$

*Ignore state symbols in **M1***

*Not multiples in **M1***

M2 White precipitate / solid

Extra ions must be cancelled

*Penalise contradictory observations in **M2***

2

(iii) M1 Barium meal / barium swallow / barium enema

*Accept a correct reference to **M1** written in the explanation in **M2**, unless contradictory*

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OR used in X-rays ***OR*** to block X-rays ***OR*** X-ray contrast medium ***OR*** CT scans

M2 $\underline{BaSO_4 \text{ / barium sulfate is insoluble}}$ (and therefore not toxic)

*For **M2** NOT barium ions*

NOT barium

NOT barium meal and NOT "It"

Ignore radio-tracing

2

[13]

Q14.

(a) **Award in either order for curve**

"Steeper" requires line to be on the left of the original line, starting from the origin

M1 curve is steeper than original and starts at the origin

M2 curve levels at the top line on the graph

2

(b) **Award in either order for curve**

"Shallower" requires line to be on the right of the original line, starting from the origin

M1 curve is shallower than original and starts at the origin

M2 curve levels at the first line on the graph

2

(c) **M1** curve would be steeper than original

"Steeper" requires line to be on the left of the original line, starting from the origin

M2 curve levels at the $\underline{\text{same original volume}}$ of O_2

2

(d) **M1** The (concentration / amount of) $\underline{H_2O_2 \text{ or reactant}}$ falls / decreases / used up

Mark independently

OR

The number of $\underline{H_2O_2 \text{ or reactant}}$ molecules/ particles falls / decreases

M2

The $\underline{\text{rate}}$ of reaction / $\underline{\text{rate}}$ of decomposition / $\underline{\text{rate}}$ of formation of oxygen / $\underline{\text{frequency of collisions}}$ / (effective) $\underline{\text{collisions in a given time}}$ decreases / is slower

2

(e) (i) $\mathbf{2}H_2O_2 \rightarrow \mathbf{2}H_2O + O_2$

Ignore state symbols

Accept only this equation or its multiples

Extra species must be crossed through

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1

(ii) hydrogen bromide / it does not appear in the overall equation

OR

hydrogen bromide / it is not <u>used up</u> in the reaction / <u>unchanged at the end</u> of the reaction

OR

hydrogen bromide / it is regenerated / re-formed (in Step 2)

1

[10]

Q15.

(a) (i) **M1** drawn curve <u>starts at reactants</u> and <u>ends at products</u>

Tapered lines into the original curve gain credit for M1

M2 curve peak is <u>below</u> the one drawn in the question (and may show one/two humps)

Mark M1 and M2 independently

2

(ii) Exothermic (reaction)

Ignore "ΔH is negative"

1

(iii) Σ bond (enthalpy) <u>reactants</u> < Σ bond (enthalpy) <u>products</u>

The sum for H_2 and I_2/reactants is <u>less than/lower than/smaller than</u> the sum for 2HI/products
OR
The sum for 2HI/products is <u>more than/larger than/bigger than</u> the sum for H_2 and $I_{2/reactants}$

Accept "It OR the sum will be <u>smaller</u> or <u>less</u>"

1

(iv) **M1** p

2

M2 $-(q - p)$

OR

$p - q$

OR

$-q + p$

M2 demands that the sign for an exothermic reaction is part of the outcome mathematically.
Ignore case

(b) (i) Increase/speed up/faster (rate of attainment of equilibrium)

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OR

Increase/speed up/faster rate of <u>both</u> forward <u>and</u> reverse reaction

OR

Increase/speed up/faster rate of reaction

Credit "It took less time"

1

(ii) **M1** Increase/speed up/faster (rate of attainment of equilibrium)

M2 <u>More particles/molecules</u> in a <u>given volume/space</u>
OR the <u>particles</u>/<u>molecules</u> are clos<u>er</u> together
OR an increase in concentration.

M3 More/higher chance of successful/effective/productive collisions (between particles)
OR <u>more collisions/higher chance of collisions (of particles) with $E>E_{Act}$</u>

If M1 is blank, mark on and credit M1 in the text

If M1 is given as "decrease"/"no effect"/"no change" then CE = 0 for clip

In M1, if increase <u>both</u> the forward and reverse reaction, but no mention of rate, penalise M1 but mark on.

In M1, if increase <u>either</u> forward rate <u>or</u> reverse rate <u>only</u>, then penalise M1 but mark on.

Penalise M3 if an increase in the value of E_{Act}/energy of particles is stated.

Max 1 for M2 and M3 if reference to "atoms"

3

[10]

Q16.

Measure <u>volume</u> of gas / <u>mass loss</u>

If 'measure concentration' must explain how to score mark

1

At (regular) time intervals

Ignore references to temperature
Accept 'against time'
Do not accept 'with time' or 'over time' on its own

1

[2]

Q17.

(a) Sulfur OR S OR S_8

Sulphur

1

(b) **M1** The activation energy is the <u>minimum</u> / <u>least</u> / <u>lowest</u>

Mark these independently

1

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M2 Energy for a reaction to occur / to go / to start
OR
Energy for a successful / effective collision

1

(c) Explanation:

M1 Twice as many / double number of particles

M1 NOT molecules

1

M2 More / twice / double (effective) collisions (in a given time)
OR
Double / greater / increased collision frequency

1

(d) (i) (Measured) change in concentration (of a substance) in unit time / given time

May be written mathematically
OR the gradient of the concentration (against) time

1

(ii) The measured change / amount (of precipitate) / cloudiness is fixed or constant or unchanged

1

[7]

Q18.

(a) minimum energy

1

to start a reaction/ for a reaction to occur/ for a successful collision

1

(b) activation energy is high / few molecules/particles have sufficient energy to react/few molecules/particles have the required activation energy

(or breaking bonds needs much energy)

1

(c) molecules are closer together/ more particles in a given volume

1

therefore collide more often

1

(d) many

1

more molecules have energy greater than activation energy (QoL)

1

(e) speeds up a reaction but is chemically unchanged at the end

1

(f) increases the surface area

1

[9]

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Q19.

(a) Gradient (or slope) (or draw a tangent)

1

(b) (i) Curve **X** is lower and starts at origin

1

And levels out at same volume as original curve

1

(ii) Curve **Y** is steeper than original and starts at origin

1

Then levels out at half the volume of the original

1

(c) (i) $2H_2O_2 \rightarrow 2H_2O + O_2$

1

(ii) Speeds up (alters the rate of) a chemical reaction

1

Remains unchanged (or not used up)

1

(iii) Remains unchanged (or not used up or not in the overall reaction equation)

1

Offers alternative reaction route (or acts as an intermediate)

1

[10]

Q20.

(a) <u>minimum</u> energy **(1)**
required before a reaction can occur or go or start **(1)**

2

(b) speeds up (changes) reaction rate **(1)**
without being (chemically) changed **(used up) (1)**

2

(c) provides alternative reaction route **(1)**
with a lower activation energy **(1)**

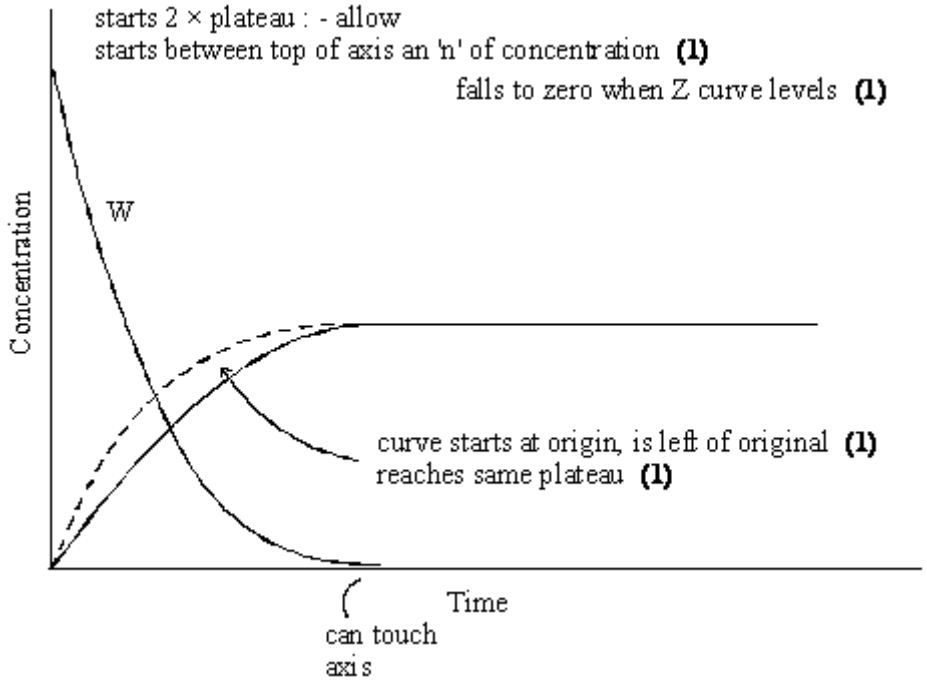
in (b) and (c) reward 4 marks for 4 points wherever found

2

(d) (i)

(ii)

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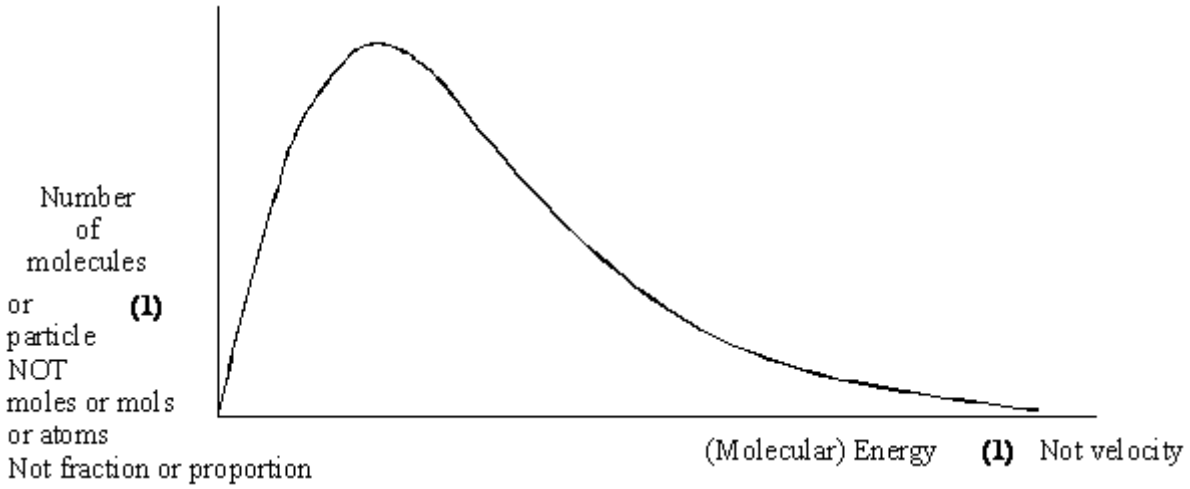
(iii) fewer collisions **(1)**
W used up **(1)**
or reactants
or reagents
or fewer particles

6

[12]

Q21.

(a) (i)



(ii) The total number of particles (or molecules) in the sample
OR the number of molecules present

(iii) No molecules have no energy
OR all molecules have some energy
Do not allow "if there are no molecules there is no energy"

4

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(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**

OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

Explanation: Alternative route **(1),** with a lower activation energy **(1)**

OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii)

5

[9]

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Q1.

(a) Most students could explain how a catalyst works in general terms (73.3% gained both marks), but some gave specific details of how heterogeneous catalysts work rather than referring to catalysts in general.

(b) Many students struggled to work out how the amount of H_2O_2 in similar reactions affects the relative amount of oxygen formed.

(c) Many students referred to the number of successful collisions rather than the frequency of successful collisions when explaining why the concentration of hydrogen peroxide affects the rate of reaction.

Q2.

(a) This proved to be a tougher starter question than anticipated (63.4% of students failed to score). In many cases, the question was repeated as an attempt at the answer with students suggesting that "the rate only depends on $[H^+]$". Since this information had been given in the question, answers such as this could not be credited. The expected answer, that 'a large excess makes the concentrations effectively constant so that they do not affect the rate', was seldom seen.

(b) As with part (a), not many students were able to achieve both marks (only 9.7%), with few suggesting 'quenching'. Given how frequently quenching was, unnecessarily, suggested in answers to (h), this was surprising. In many cases, students described the process of titration itself rather than what should be done to the sample *before* titration. 74% of students failed to score here.

(c) This question proved easier, with just over a third of students achieving both marks for appreciating that the line indicated a constant rate, showing that the falling concentration of hydrogen ions was having no effect.

(d) A common error here was for students to start by (correctly) calculating the gradient of the line but then to divide it by a value for the $[H^+]$ (usually 0.5) or even by $[H^+]^2$ – despite having been told in part (c) that the order with respect to $H^+(aq)$ is zero. 36% of students, however, did gain all three marks.

(e) 97.3% of students were able to plot the points correctly onto the given grid.

(f) A significant number of students assumed that the instruction to 'draw a line of best fit' meant that the line must be straight. Students must learn that a best-fit line must be the best-fit to the points as plotted, so may be either straight or curved depending on the relationship between the plotted points; at A-level, students are expected to make this decision for themselves. Just under 40% of students did not gain this mark.

(g) The idea of drawing a tangent (or, for award of 'error carried forward', simply constructing a 'triangle' on a straight line) proved tricky, with a significant minority of students simply dividing 0.35 by the corresponding time value from their line.

(h) Fewer students than expected recognised the clue in the information given in the question that this was best done as a 'clock' reaction. Many students suggested answers that did not include 'X' in the initial mixture, as suggested, while many others used a variety of convoluted procedures involving what were essentially

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'continuous monitoring' methods to generate concentration versus time graphs. In some cases, this was followed by a description of finding the gradient at $t = 0$, which addressed the requirement of the question to calculate an initial rate for each experiment. However, a direct measurement would have been much easier, both to do and to describe.

Credit was given for a wide variety of suggestions because, although a particular approach was hoped for, there are indeed several alternative approaches that would work. However, many students seemed to think that actual measurements of concentration (of what substance was often unclear from the descriptions) are needed, which led to suggestions that samples should be removed at timed intervals and titrated against X or placed into a colorimeter (the need to quench these samples was often over-looked). If a colorimeter was used, then the best approach for continuous monitoring is simply to allow the reaction to proceed in the colorimeter and take a series of readings at timed intervals – much easier than sampling. The mean mark on this question was only 1.8 out of 6.

The extra answer space available this year meant that fewer students needed additional pages for this question, but many confused, badly ordered and muddled answers were seen that took up far more space than necessary through repetition and unnecessary elaboration.

Reading the question is always key, but here many students could have saved a lot of time and space by noticing that the question asked only about a method to determine the order of this reaction with respect to A. This would have avoided the need for them to repeat most of the procedure, looking at successively changing the concentrations of A, then B, then C, while keeping each of the other two constant. Levels-of-response questions are marked using 'levels' and the key to success is for students to concentrate first on the inclusion of as much correct Chemistry as possible to ensure access to Level 3 (worth 5 or 6 marks). This is probably best achieved using a 'bullet point' approach to structuring the answer. Within a level, the mark awarded depends on the clarity and coherence of an answer, together with there being a clear, logical progression through the description.

Appropriate apparatus and quantities should be mentioned as necessary. For example, rather than stating "add A, B and C to a container", a good start to the answer would be to write, "A measuring cylinder was used to measure known volumes, of known concentrations, of A, B and C into separate beakers". Unless specifically asked to suggest suitable volumes/concentrations, then it is sufficient for students to indicate that they would make a measurement without needing to state a value.

Q6.

Students have begun to demonstrate considerable ability in using Le Chatelier's principle to explain the effect of changing reaction conditions on equilibrium yield, but are less effective in their explanations concerning rates of reaction. The low demand first mark in part (a)ii proved elusive for some and the higher demand mark was marred by incomplete answers missing important ideas such as more collisions *in a given time* and more particles *in a given volume* or words to that effect in each case. In part (a)iii the idea that there is an increase in the available surface area when a catalyst is spread onto an inert honeycomb was understood by many, but the necessity to state that this would lead to an increase in *successful* collisions was often missed. Overall only about one fifth of students scored both marks in part (a)ii and part (a)iii.

Q7.

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Part (a)(i) produced the usual crop of poor scales and poor lines of best fit that were curiously accepted by some centres. Additionally, a failure to plot the point at 0,0 should be penalised. Part (a)(ii) was a very easy question and there were many good answers to parts (b)(i) and (ii). Weaker students still have problems with correct substitution and rearrangement of the equation. Part (b)(iii) was a more challenging question and many Centres failed to give credit for a (correct) alternative method. Part (c) again highlighted the need for students to get better training in the drawing of diagrams. This is a communication skill and correct chemical apparatus should be seen – poor bungs and cross-sections were very common and centres were often too lenient in their marking.

Q8.

Part (a) was straightforward but only a small number of students scored the mark in part (a)(i) whereas most scored the mark in part (a)(ii). Explanation of the term “dynamic” in part (b) proved demanding. Only the higher-scoring students conveyed the idea that both reactions are occurring all of the time and the common misconception was that this term meant only that the rates were equal. Part (c)(i) was straightforward and the majority of students scored both marks. However, part (c)(ii) proved more demanding with considerable confusion between time and rate. Fewer than half of all students scored 2 marks and only a very small number were able to state clearly why an increase in the total pressure would lead to a decrease in the time taken to reach equilibrium and score all 3 marks.

Q9.

Overall this was a relatively high-scoring question. The demanding part (b) highlighted some significant misconceptions about the Maxwell–Boltzmann distribution. It was evident that many students had little idea why the curve started at the origin. Common misconceptions were that the origin referred to zero rate or that the reaction had not started or even that the origin is absolute zero.

Q10.

(a) In this part, ’amount’ was not sufficient. Many students simply referred to measuring the mass of the reagents but, since this is not practically possible without including the container too, it was not credited. Surprisingly, many students incorrectly wanted to measure the temperature.

(b) In this part, ’reagents’ was insufficient since it is the magnesium that is critical. Although the quality of the diagram was not part of the assessment, poor diagrams often failed to show a clear filter funnel and a visible filter paper; this was penalised. For some reason, a large number of students decided incorrectly that distillation was the required process. The final question simply needed ’wash with water’ and yet attracted some very complicated answers.

Q11.

In part (a) and (b) were answered well. About half of the students were able to draw a correct line of best fit in part (c) or a suitable tangent with the necessary calculations for in part (d). Lines and curves of best fit should not be doubled or kinked and should not deviate towards anomalous values. Whilst the majority of students could draw a tangent to their curve, marks were most commonly lost by incorrect reading of the axis for two values on this tangent.

Q12.

(a) This part was found demanding. Few students were able to relate correctly an increase in concentration to an increase in temperature. Many answers contained no reference to temperature at all. In addition, some teachers tended to mark this question generously. Many students should have not been awarded the second mark as they did not state that there would be more successful collisions in a given time. Some students were incorrectly given full credit without making any reference to the extra heat generated by the reaction affecting the rate of this reaction.

(b) In this part, a surprising number of students did not realise that the surface coating was magnesium oxide, and an even larger number thought that magnesium oxide would not react with hydrochloric acid. This chemical error often went unpunished.

(c) This part was answered well, although many students gave only one difference, spreading the explanation across all four answer lines.

(b) In this part, a large number of students referred to solubility of the metals themselves rather than the sulfates. A solubility comparison was often lacking and few students appreciated that the insoluble calcium sulfate would prevent further contact between the acid and the metal.

Given the increasing pressure on schools and colleges to deliver the teaching programme, this was, overall, a very positive session. Teachers are once again thanked for the trouble taken with the coursework. Their efforts continue to be much appreciated by the moderator team.

Q13.

In part (a)(i), many students were unable to state that the rate is zero at point W. There were many qualitative answers to part (a)(iii) even though the word “double” is used twice in the question. In part (b), students often failed to label their reaction profile with sufficient clarity and only 45% scored both marks.

Q14.

In this question it was necessary to have an appreciation not only of amount of substance but also how changes in conditions altered the rate of a reaction. In part (e), the only acceptable answer for the overall equation was one in which the various intermediates were cancelled.

Q15.

Intended to be a relatively straightforward introduction to the paper, parts of this question proved challenging to many candidates. In part (a)(iii), only 30% of the candidates were able to explain that the diagram showed that the sum of the bond enthalpies of the reactants was less than that of the products. In part (b)(ii) confusion arose between the effect of pressure on the rate of a reaction involving gases and how pressure changes might affect the position of an equilibrium.

Q16.

Many candidates seemingly forgot the details of an experiment they will surely have met several times before. Concise answers scoring both points were surprisingly rare. A significant number of candidates measured the time taken for a given volume of gas to be produced. Candidates should not use the term ’amount’ when they mean ’volume’. Many candidates adopted a scattergun approach, listing every variable they could think of.

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Q17.

This question took as its context an experiment similar to that considered in PSA6 and while parts (a) and (b) proved relatively accessible for most candidates, the question posed in (c) proved very demanding. Only the better candidates were able to express adequately the meaning of the term *rate of reaction* and only those who read the whole question with care could access the relatively straightforward idea behind part (d)(ii).

Q18.

Although the more able candidates found this question relatively straightforward, the weaker candidates found the task of explaining concisely rather difficult.

The majority of candidates answered (a) correctly although many failed to realise that the reaction in (b) would be slow because few molecules had the minimum activation energy needed to react.

In part (c) several incorrect answers included the assumption that increasing pressure increases energy! Answers to part (d) were generally done well. In (e) many candidates failed to score since they did not state that a catalyst is a substance that speeds up a reaction whilst remaining chemically unchanged. Instead candidates described how a catalyst worked in a reaction. Generally however candidates knew that powdered catalysts increase the surface area and hence scored the mark in (f).

Q19.

This question was answered quite well and most candidates gained a reasonable number of marks. Answers to part (a) were usually correct though weak candidates sometimes suggested, incorrectly, that the rate could be obtained simply by dividing the volume by the time. In part (b) candidates were able to show curves with the correct initial gradients but curves showing the correct final volumes of oxygen were much less common. In part (c) (i) many candidates lost a mark because HBr was included incorrectly in the overall equation. Answers to parts (c) (ii) and (c) (iii) were often awarded full marks. In part (c) (ii), some candidates attempted to answer the question by describing how a catalyst works rather than answering the question by explaining that a catalyst is a substance that alters the rate of a chemical reaction whilst being chemically unchanged.

Q20.

Parts (a), (b) and (c) were answered well by most candidates. Part (d), however, discriminated very effectively between good and weak candidates. Only the best candidates sketched a curve for **W** correctly. In particular, it was not recognised that the initial concentration of **W** was twice the final concentration of **Z**. More candidates sketched a correct curve for **Z** in the presence of a catalyst though weak candidates usually showed the concentration of **Z** finishing too high. In part (d) (iii) weak candidates did not recognise that the collision frequency of reacting particles would decrease. Answers often contained irrelevant reference to some change in activation energy.

Q21.

This question was well answered by most candidates. Candidates who lost marks usually made errors in part (a). These errors included incorrect labelling of the axes of the Maxwell-Boltzmann curve with temperature being the most common incorrect answer. The reason why this curve starts at the origin also proved difficult and there were some incorrect answer to section (iii). Many candidates scored full marks in part (b).

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Q1.

(a) As concentration increases the amount of heat given out increases / temperature increases **(M1)**

Any order.

Ignore references to an exothermic reaction.

1

More successful collisions or reactions in a given time **OR** more particles have the activation energy **(M2)**

Allow could be a second / n^{th} order reaction.

1

(An increase in temperature or more heat given out) increases the rate of a reaction **(M3)**

1

(b) The magnesium is coated with an oxide / MgO **(M1)**

Allow magnesium hydroxide.

1

MgO / the coating / the corrosion product has to be removed before Mg will react
OR Mg and MgO / the coating / the corrosion product react at different rates
OR Initially MgO / the coating / the corrosion product reacts not Mg **(M2)**

Ignore inert coating.

1

(c) Any **two** from:

Any order.

Slower with hot water or faster with steam

The hot water produces $Mg(OH)_2$ / the hydroxide **OR** steam produces MgO / the oxide

(Slow) bubbling with hot water **OR** bright white light / flame / white solid with steam

2 max

(d) Magnesium sulfate is soluble and calcium sulfate is insoluble / slightly soluble / magnesium sulfate is more soluble / calcium sulfate is less soluble / correct trend in solubility **(M1)**

Any order.

***M1** requires a comparison of the two solubilities.*

Calcium sulfate coats the surface of the calcium **(M2)**

Coating prevents further contact with / reaction by the acid **(M3)**

*'Calcium sulfate forms a protective coating' scores **M2** only.*

3

[10]

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Q2.

(a) (i) Change in concentration (of a substance / reactant / product) in unit time / given time / per (specified) unit of time

*This may be written mathematically **OR** may refer to the gradient of a graph of concentration / volume against time*

OR

Amount of substance formed / used up in unit time / given time / per (specified) unit of time

Ignore additional information including reference to collisions

1

(ii) At **W**

M1 (QoL)

The rate / it is zero

M2

The magnesium has all reacted / has been used up

Ignore reference to the acid being used up

OR

No more collisions possible between acid and Mg

OR

Reaction is complete / it has stopped

OR

No more hydrogen / product is produced

2

(iii) M1

Twice / double as many particles / hydrogen ions (in a given volume)

*Penalise reference to (hydrochloric acid) molecules in **M1***

*Penalise reference to "HCl particles" in **M1***

OR

Twice / double as much hydrochloric acid

M2

Twice / double as many effective / successful collisions (in a given time)

OR

Twice / double as many collisions with either sufficient energy to react ***OR*** with $E \geq E_a$

OR

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double the successful / effective collision frequency

2

(b) (i) The activation energy is the minimum energy for a reaction to go / start

OR

Minimum energy for a successful/ effective collision

1

(ii) M1 Products lower than reactants on the profile

Mark independently

M2 Activation energy (E_a) shown and labelled correctly from reactants to peak of curve

Mark independently

2

(c) (i) $Ba + \mathbf{2}H_2O \longrightarrow Ba(OH)_2 + H_2$

$Ba + 2H_2O \longrightarrow Ba^{2+} + 2OH^- + H_2$

Allow multiples

Ignore state symbols

1

(ii) M1 $Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4$

*Ignore state symbols in **M1***

*Not multiples in **M1***

M2 White precipitate / solid

Extra ions must be cancelled

*Penalise contradictory observations in **M2***

2

(iii) M1 Barium meal / barium swallow / barium enema

*Accept a correct reference to **M1** written in the explanation in **M2**, unless contradictory*

OR used in X-rays ***OR*** to block X-rays ***OR*** X-ray contrast medium ***OR*** CT scans

M2 $BaSO_4$ / barium sulfate is insoluble (and therefore not toxic)

*For **M2** NOT barium ions*

NOT barium

NOT barium meal and NOT "It"

Ignore radio-tracing

2

[13]

Q3.

(a) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

Must refer to equilibrium

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Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase

OR

(When a system / reaction in <u>equilibrium</u> is disturbed), the (position of) <u>equilibrium</u> shifts / moves in a direction which tends to <u>reduce the disturbance</u>

An alternative to shift / move would be the idea of <u>changing / altering the position</u> of equilibrium

1

(b) (i) M1

A substance that <u>speeds up the reaction / alters the rate</u> but is <u>chemically unchanged at the end / not used up</u>

*Both ideas needed for **M1***

*Credit can score for **M1**, **M2** and **M3** from anywhere within the answer*

M2

Catalysts provide an alternative route / alternative pathway / different mechanism

M3

that has a <u>lower activation energy / E_a</u>

OR

<u>lowers the activation energy / E_a</u>

3

(ii) (Time is) less / shorter / decreases / reduces

Credit "faster", "speeds up", "quicker" or words to this effect

1

(iii) None

1

(c) (i) R

1

(ii) T

1

(iii) R

1

(iv) P

1

(v) Q

1

[11]

Q4.

(a) q = 500 × 4.18 × 40

Do not penalise precision.

1

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= 83600 J

Accept this answer only.
Ignore conversion to 83.6 kJ if 83600 J shown.
Unit not required but penalise if wrong unit given.
Ignore the sign of the heat change.
An answer of 83.6 with no working scores one mark only.
An answer of 83600 with no working scores both marks.

1

(b) Moles (= 83.6 / 51.2) = 1.63

Using 77400 alternative gives 1.51 mol
Allow (a) in kJ / 51.2
Do not penalise precision.

1

Mass = 1.63 × 40(.0) = 65.2 (g)

Allow 65.3 (g)
Using 77400 alternative gives 60.4 to 60.5
Allow consequential answer on M1.
1 mark for M_r (shown, not implied) and 1 for calculation.
Do not penalise precision.

2

(c) Molarity = 1.63 / 0.500 = 3.26 mol dm–3

Allow (b) M1 × 2
Using 1.51 gives 3.02

1

(d) Container splitting and releasing irritant / corrosive chemicals

*Must have reference to both aspects; splitting or leaking (can be implied such as contact with body / hands) **and** hazardous chemicals.*
Allow 'burns skin / hands' as covering both points
Ignore any reference to 'harmful'.
Do not allow 'toxic'.

1

(e) (i) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Allow fractions / multiples in equation.
Ignore state symbols.

1

(ii) Iron powder particle size could be increased / surface area lessened

Decrease in particle size, chemical error = 0 / 3
Change in oxygen, chemical error = 0 / 3

1

Not all the iron reacts / less reaction / not all energy released / slower release of energy / lower rate of reaction

Mark points M2 and M3 independently.

1

Correct consequence of M2

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An appropriate consequence, for example

- *too slow to warm the pouch effectively*
- *lower temperature reached*
- *waste of materials*

1

(f) (i) Conserves resources / fewer disposal problems / less use of landfill / fewer waste products

Must give a specific point.

Do not allow 'does not need to be thrown away' without qualification.

Do not accept 'no waste'.

1

(ii) Heat to / or above 80 °C (to allow thiosulfate to redissolve)

Accept 'heat in boiling water'.

If steps are transposed, max 1 mark.

1

Allow to cool before using again

Reference to crystallisation here loses this mark.

1

[14]

Q5.

(a) Number / proportion / percentage / fraction of molecules

Ignore "particles"

1

(b) None ***OR*** no effect ***OR*** no change

1

(c) **X**

1

(d) **Answers in either order**

M1 collision ***OR*** collide

Mark independently

M2 collision / molecules / particles

Ignore "correct" amount of energy

with the activation energy

OR with $E \geq E_{act}$

OR with sufficient /enough energy

OR with the minimum energy

OR with the correct orientation

2

(e) A small increase in temperature results in many more / much higher proportion of

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/ a lot more / significantly more molecules / particles / collisions with $E \geq E_{act}$/ energy greater than the activation energy / sufficient energy / enough energy / minimum energy to react
(compared with a small increase in concentration)

Not just "more molecules with $E \geq E_{act}$"
*The answer must convey that the increase is **significant***
Accept reference to "atoms", "molecules", "particles"
Ignore "species"

1

[6]

Q6.

(a) **M1** The activation energy is the minimum / least / lowest energy

Mark independently
Ignore ''heat'' and ignore ''enthalpy''

M2 (energy) for a reaction to occur / to go / to start

OR (energy) for a successful / effective collision

Ignore "breaking the bonds''

2

(b) **M1** Catalysts provide an alternative route OR an alternative mechanism OR alternative / different path(way)

M2 Lowers the activation energy

Mark independently
Ignore reference to ''surface''

2

(c) (i) Stay(s) the same

1

(ii) Increases

Credit ''increase" or ''increased''

1

(iii) Increases

Credit ''increase'' or ''increased''

1

(iv) Stay(s) the same

1

(d) (i) **M1** yeast or zymase

M2 ethanol

Ignore ''enzyme''
In M2, ignore ''alcohol'' and ignore any formula

2

(ii) **M1** (Concentrated) H_3PO_4 OR (Concentrated) H_2SO_4

M2 butan-2-ol

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Credit correct names
Ignore ''hydrogenphosphate or hydrogensulfate''
Ignore ''dilute'' or ''aq''
Do not penalise absence of hyphens in name.
In M2, ignore any formula

2

[12]

Q7.

(a) Sulfur OR S OR S_8

Sulphur

1

(b) **M1** The activation energy is the <u>minimum</u> / <u>least</u> / <u>lowest</u>

Mark these independently

1

M2 Energy for a reaction to occur / to go / to start
OR
Energy for a <u>successful / effective</u> collision

1

(c) Explanation:

M1 <u>Twice</u> as many / <u>double</u> number of <u>particles</u>

M1 NOT molecules

1

M2 <u>More / twice / double</u> (effective) <u>collisions</u> (in a given time)
OR
<u>Double / greater / increased collision frequency</u>

1

(d) (i) (Measured) <u>change</u> in <u>concentration</u> (of a substance) in unit <u>time</u> / given <u>time</u>

May be written mathematically
OR the gradient of the <u>concentration</u> (against) <u>time</u>

1

(ii) The measured change / amount (of precipitate) / cloudiness is <u>fixed</u> or <u>constant</u> or <u>unchanged</u>

1

[7]

Q8.

(a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$

1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] – (391 \times 3)$

1

$= –46.5 \text{ kJ mol}^{-1}$

1

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Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
2-3	– claims partially supported by evidence – good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC **1**

but, since the reaction is exothermic **1**

the equilibrium yield is lower QWC **1**

The higher the pressure the greater the equilibrium yield QWC **1**

because there is a reduction in the number of moles of gas in the reaction **1**

but higher pressure is expensive to produce or plant is more expensive to build QWC

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1

A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

Q9.

(a) (i) Z (1)

1

(ii) Collisions (1)

Cause some molecules to slow down or lose energy (1)

2

(b) Curve starts at origin and is displaced to the right (1)

Curve lower and does not touch energy axis (1)

2

(c) (i) Only a small percentage/very few collisions have $E > E_a$ (1)

1

(ii) Add a catalyst (1)

Lowers E_a (1)

More collisions/molecules have energy > E_a (1)

3

[9]

Q10.

(a) the minimum energy;

1

Energy required for a reaction to occur;

(or to start a reaction or for successful collisions)

1

(b) axes labelled:- y: number *(or fraction or %)* of molecules *(or particles)*
x: energy *(or KE);*

1

curve starts at origin;

1

skewed to right;

1

approaches x axis as an asymptote;

(penalise a curve that levels off > 10% of max peak height or a curve that crosses the energy axis)

1

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second curve displaced to the left (and does not cross T_1 curve for a second time)

1

and peak higher;

1

many fewer molecules;

1

fewer molecules have $E > E_a$;
(can score this mark from suitably marked curves)

1

(c) molecules *(or particles or collisions)* do not have enough energy;
(or orientation may be wrong)

1

increase the pressure;

1

(or increase the concentration or reduce the volume)
increases the collision frequency;
(or more collisions)
(do not allow if stated to be due to increase in energy implied by temperature increase)

1

add a catalyst;

1

lowers activation energy (or E_a) *(Q of L mark);*

1

[15]

Q11.

(a) Graph starts at origin

1

Graph skewed to left and has decreasing gradient to maximum

1

Graph after maximum decreases in steepness, never touches *x* axis, levels out less than 5 mm from *x* axis.

1

(b) Minimum energy

1

To start a reaction (*or for a reaction to occur*)

1

(c) Molecules gain energy (*or always some molecules have* $E > E_a$)

1

Due to collisions

1

(d) Decreases

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1

E_a lowered **(1)**
By alternative route **(1)**
So more molecules have energy > E_a **(1)**

max 2

[10]

Q12.

(a) **Award in either order for curve**

"Steeper" requires line to be on the left of the original line, starting from the origin

M1 curve is steeper than original and starts at the origin

M2 curve levels at the top line on the graph

2

(b) **Award in either order for curve**

"Shallower" requires line to be on the right of the original line, starting from the origin

M1 curve is shallower than original and starts at the origin

M2 curve levels at the first line on the graph

2

(c) **M1** curve would be steeper than original

"Steeper" requires line to be on the left of the original line, starting from the origin

M2 curve levels at the same original volume of O_2

2

(d) **M1** The (concentration / amount of) H_2O_2 or reactant falls / decreases / used up

Mark independently

OR

The number of H_2O_2 or reactant molecules/ particles falls / decreases

M2

The rate of reaction / rate of decomposition / rate of formation of oxygen / frequency of collisions / (effective) collisions in a given time decreases / is slower

2

(e) (i) $\mathbf{2}H_2O_2 \rightarrow \mathbf{2}H_2O + O_2$

Ignore state symbols

Accept only this equation or its multiples

Extra species must be crossed through

1

(ii) hydrogen bromide / it does not appear in the overall equation

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OR

hydrogen bromide / it is not <u>used up</u> in the reaction / <u>unchanged at the end</u> of the reaction

OR

hydrogen bromide / it is regenerated / re-formed (in Step 2)

1

[10]

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Q1.

(a) This part was found demanding. Few students were able to relate correctly an increase in concentration to an increase in temperature. Many answers contained no reference to temperature at all. In addition, some teachers tended to mark this question generously. Many students should have not been awarded the second mark as they did not state that there would be more successful collisions in a given time. Some students were incorrectly given full credit without making any reference to the extra heat generated by the reaction affecting the rate of this reaction.

(b) In this part, a surprising number of students did not realise that the surface coating was magnesium oxide, and an even larger number thought that magnesium oxide would not react with hydrochloric acid. This chemical error often went unpunished.

(c) This part was answered well, although many students gave only one difference, spreading the explanation across all four answer lines.

(b) In this part, a large number of students referred to solubility of the metals themselves rather than the sulfates. A solubility comparison was often lacking and few students appreciated that the insoluble calcium sulfate would prevent further contact between the acid and the metal.

Given the increasing pressure on schools and colleges to deliver the teaching programme, this was, overall, a very positive session. Teachers are once again thanked for the trouble taken with the coursework. Their efforts continue to be much appreciated by the moderator team.

Q2.

In part (a)(i), many students were unable to state that the rate is zero at point W. There were many qualitative answers to part (a)(iii) even though the word “double” is used twice in the question. In part (b), students often failed to label their reaction profile with sufficient clarity and only 45% scored both marks.

Q3.

This question was high scoring. In part (b)(i), almost 48% scored full marks and for those who did not, it was the idea that catalysts alter the rate of a reaction and are chemically unchanged at the end of the reaction that was missed most often.

Q4.

Section B proved more demanding. In part (a), the calculation had similar faults to Question 5 but some students failed to read that the answer was to be in Joules - an answer in kJ was penalized unless there was a clear correct answer in the working. Part (b) and part (c) were well done though the alternative answer to part (a) was frequently used in these. In part (d), only a few students failed to highlight the need for the bag to split or the chemicals to come into contact with skin / hands. Part (e)(i) indicated that a considerable number of students found difficulties with the equation; common errors were the wrong formula for iron (III) oxide, the inclusion of ions on the reagent side of the equation and using Fe2 for the metal. Part (e)(ii) contained many good partial answers but there was a significant failure to focus finally on why longer times might not be an advantage. In part (f)(i), the main errors were to re-state the question about being

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reusable or to indicate that there would be no waste following use of these handwarmers. There were some vague answers to part (f)(ii) which referred to 'heating' the bag or 'keeping it in a warm place' and, for some, the contents were removed before further treatment. Nevertheless, sensible answers were frequently seen.

Q5.

There was a requirement in parts of this question to refer specifically to molecules since the distribution was for molecular energies. Part (e) proved to be the most challenging because students were required to state that many more molecules gained energy greater than the activation energy when there was a small increase in temperature.

Q6.

After a relatively easy start in parts (a) and (b), candidates were challenged by their understanding of the Maxwell-Boltzmann distribution in part (c), with part (c)(ii) proving the most demanding. A small proportion of candidates failed to follow the instruction to use the specified words (increases, decreases or stays the same) but the marking catered for this, awarding marks for correct chemistry. Part (d) was lower scoring than anticipated with the identity of the catalyst in part (d)(ii) least well known.

Q7.

This question took as its context an experiment similar to that considered in PSA6 and while parts (a) and (b) proved relatively accessible for most candidates, the question posed in (c) proved very demanding. Only the better candidates were able to express adequately the meaning of the term *rate of reaction* and only those who read the whole question with care could access the relatively straightforward idea behind part (d)(ii).

Q9.

This question was not answered well. Only a few candidates scored high marks. The most common wrong answer in (a) (i) was Y. In part (a) (ii) many candidates did not mention collisions or the fact that during collision some particles gained energy whilst others lost energy and slowed down. Part (b) was the most well done section in this question with candidates being able to draw a Maxwell - Boltzmann distribution curve at a higher temperature. In part (c) (i) many candidates made no reference to few collisions having the necessary activation energy. Part(c) (ii) was not answered well by many candidates since they did not read the question and relate their answer to the proportion of successful collisions. Many candidates referred to increasing the concentration or pressure which would simply increase the number of successful collisions. Even those who gave the correct answer of catalyst did not fully explain how this increased the proportion of successful collisions.

Q10.

It was pleasing to note that many candidates were able to score reasonably high marks for this question. Answers to part (a) were usually correct. The curves in part (b) were mostly drawn well. The most common error was to show a curve levelling off horizontally too far above the energy axis. However, only the best candidates were able to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction. Many good answers to part (c) were seen. The most common error was to suggest that an increase in pressure raised the rate of a gas phase reaction by increasing the energy of the molecules. Some weaker candidates lost marks because they gave pressure and concentration as the two ways of speeding up the reaction. They did not realise that, for a gas, increasing the concentration is the same effect as increasing the pressure.

Q11.

Most candidates were able to gain some marks for this question which, nevertheless, discriminated well between strong and weak candidates. The curves drawn in answer to part (a) were seldom good enough to gain full marks. They were not always skewed obviously to the left and many curves did not approach the energy axis as an asymptote. Most answers to part (b) were correct but weaker candidates lost one of the two marks by failing to mention some idea of a 'minimum' energy. Part (c) proved to be a hard question; only the best candidates recognised that the energy of the molecules would be redistributed by collision. Part (d) was an easier question though candidates often referred to a rate of reaction rather than answering the question by mentioning how the time taken for decomposition would be changed.

Q12.

In this question it was necessary to have an appreciation not only of amount of substance but also how changes in conditions altered the rate of a reaction. In part (e), the only acceptable answer for the overall equation was one in which the various intermediates were cancelled.

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Q1.

(a) **M1** provides a different route / mechanism / pathway

Ignore reference to (frequency of) collisions, surface area or active sites

1

M2 with lower activation energy

Penalise reference to increasing energy of particles (CE = 0)

*Allow E_a / E_{act} or definition of activation energy in **M2***

1

(b) **M1** line 2 = steeper than original and finishes at same height

1

M2 line 3 = less steep than original and finishes at half the height

If two correct lines are drawn but neither labelled, then allow 1 mark.

If two correct lines are drawn and only one is labelled, then allow 2 marks.

If only one correct line is drawn and neither are labelled, then 0 marks.

If two correct lines are drawn but line 2 is labelled 1 and line 3 is labelled 2, then allow 1 mark

Allow some unevenness in drawing of lines in terms of height it levels off at, with up to a quarter of a box of unevenness

At the start, lines must separate from the original before the first vertical line.

In terms of the origin, lines must start within one half of a square of the origin.

For each line ignore the time at which the line becomes horizontal – it is the fact it is more or less steep than the original line that matters (along with the height at which it finishes)

1

(c) **M1** more particles/molecules/reactants/H_2O_2/moles in given/same volume/space
OR
particles/molecules/reactants/H_2O_2/moles closer together

Penalise reference to changing the activation energy (CE = 0)

*For **M1** do not allow area*

1

M2 successful collisions are more frequent

*For **M2***

successful collisions – allow reference to collisions with sufficient energy or collisions with the activation energy or effective collisions

more frequent – allow reference to per unit time, per second (but ignore reference to rate of collisions, ignore chance of

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collisions, ignore likelihood of collisions)

1

[6]

Q2.

(a) (i) **M1**

High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2

The (forward) reaction / to the right is endothermic or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M3 depends on correct M2 and must refer to temperature / heat

M3** depends on a correct statement for **M2

At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

to absorb heat OR

to lower the temperature OR

to cool down the reaction

3

(ii) **M1**

The reaction gets to equilibrium faster / in less time

OR

Produces a small yield faster / in less time

OR

Increases the rate (of reaction / of attainment of equilibrium)

Mark independently

M2

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

AND

- more collisions in a given time / increased collision frequency

*Penalise **M2** for reference to increased energy of the particles*

2

(iii) **M1** Increase in / more / large(r) / big(ger) surface area / surface sites

Mark independently

*For **M1** accept Éan increase in surface"*

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M2 increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)

*For **M2** not simply "more collisions"*

Ignore "the chance or likelihood" of collisions

2

(b) **M1**
No effect / None

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2 requires a correct M1
Equal / same number / amount of moles / molecules / particles on either side of the equation
OR
2 moles / molecules / particles on the left and 2 moles / molecules / particles on the right

M2** depends on a correct statement for **M1

*In **M2 not** "atoms"*

2

[9]

Q3.

(a) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase

OR

(When a system / reaction in equilibrium is disturbed), the (position of) equilibrium shifts / moves in a direction which tends to reduce the disturbance

An alternative to shift / move would be the idea of changing / altering the position of equilibrium

1

(b) (i) M1
A substance that speeds up the reaction / alters the rate but is chemically unchanged at the end / not used up

*Both ideas needed for **M1***

*Credit can score for **M1**, **M2** and **M3** from anywhere within the answer*

M2
Catalysts provide an alternative route / alternative pathway / different mechanism

M3
that has a lower activation energy / E_a

OR

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lowers the activation energy / E_a

3

(ii) (Time is) less / shorter / decreases / reduces

Credit "faster", "speeds up", "quicker" or words to this effect

1

(iii) None

1

(c) (i) R

1

(ii) T

1

(iii) R

1

(iv) P

1

(v) Q

1

[11]

Q4.

(a) **Award in either order for curve**

"Steeper" requires line to be on the left of the original line, starting from the origin

M1 curve is steeper than original and starts at the origin

M2 curve levels at the top line on the graph

2

(b) **Award in either order for curve**

"Shallower" requires line to be on the right of the original line, starting from the origin

M1 curve is shallower than original and starts at the origin

M2 curve levels at the first line on the graph

2

(c) **M1** curve would be steeper than original

"Steeper" requires line to be on the left of the original line, starting from the origin

M2 curve levels at the same original volume of O_2

2

(d) **M1** The (concentration / amount of) H_2O_2 or reactant falls / decreases / used up

Mark independently

OR

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The number of $\underline{H_2O_2}$ or reactant molecules/ particles falls / decreases

M2

The rate of reaction / rate of decomposition / rate of formation of oxygen / frequency of collisions / (effective) collisions in a given time decreases / is slower

2

(e) (i) $\mathbf{2}H_2O_2 \rightarrow \mathbf{2}H_2O + O_2$

Ignore state symbols

Accept only this equation or its multiples

Extra species must be crossed through

1

(ii) hydrogen bromide / it does not appear in the overall equation

OR

hydrogen bromide / it is not used up in the reaction / unchanged at the end of the reaction

OR

hydrogen bromide / it is regenerated / re-formed (in Step 2)

1

[10]

Q5.

(a) **M1** The activation energy is the minimum / least / lowest energy

Mark independently

Ignore "heat" and ignore "enthalpy"

M2 (energy) for a reaction to occur / to go / to start

OR (energy) for a successful / effective collision

Ignore "breaking the bonds"

2

(b) **M1** Catalysts provide an alternative route OR an alternative mechanism OR alternative / different path(way)

M2 Lowers the activation energy

Mark independently

Ignore reference to "surface"

2

(c) (i) Stay(s) the same

1

(ii) Increases

Credit "increase" or "increased"

1

(iii) Increases

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Credit "increase" or "increased"

1

(iv) Stay(s) the same

1

(d) (i) **M1** yeast or zymase

M2 ethanol

Ignore "enzyme"
In M2, ignore "alcohol" and ignore any formula

2

(ii) **M1** (Concentrated) H_3PO_4 OR (Concentrated) H_2SO_4

M2 butan-2-ol

Credit correct names
Ignore "hydrogenphosphate or hydrogensulfate"
Ignore "dilute" or "aq"
Do not penalise absence of hyphens in name.
In M2, ignore any formula

2

[12]

Q6.

(a) (i) **M1** The peak of the new curve is displaced to the right.

M2 All of the following are required

- The new curve starts at the origin
- The peak of the new curve is lower than the original
- and the new curve only crosses the original curve once
- and an attempt has been made to draw the new curve correctly towards the energy axis but not to touch the original curve
- the new curve must not start to diverge from the original curve

M1 is low demand
M2 is higher demand.

2

(ii) **M1** Increase in the number/proportion of molecules with $E \geq E_a$

OR more molecules have $E \geq E_a$

OR more molecules have sufficient energy to react

M2 More effective/productive/successful collisions

Ignore "molecules have more energy"
Ignore "more energetic collisions"
Ignore "molecules gain activation energy"

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Ignore "more collisions"
Accept "particles" for "molecules" but NOT "atoms"
Ignore "chance of collision"; this alone does not gain M2

2

(b) (i) Iron ***OR*** Fe

1

(ii) **M1** Catalysts provide an alternative route/pathway/mechanism

OR

(in this case) surface adsorption/surface reaction occurs.
For M1, not simply "provides a surface" alone

M2 that has a lower activation energy

OR

lowers the activation energy
For M2, the candidate may use a definition of activation energy without referring to the term

2

[7]

Q7.

(a) (i) **M1** drawn curve starts at reactants and ends at products
Tapered lines into the original curve gain credit for M1

M2 curve peak is below the one drawn in the question
(and may show one/two humps)
Mark M1 and M2 independently

2

(ii) Exothermic (reaction)
Ignore "ΔH is negative"

1

(iii) Σ bond (enthalpy) reactants < Σ bond (enthalpy) products

The sum for H_2 and I_2/reactants is less than/lower than/smaller than the sum for 2HI/products
OR
The sum for 2HI/products is more than/larger than/bigger than the sum for H_2 and $I_{2/reactants}$
Accept "It OR the sum will be smaller or less"

1

(iv) **M1** p

2

M2 $-(q - p)$

OR

$p - q$

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OR

$-q + p$

M2 demands that the sign for an exothermic reaction is part of the outcome mathematically.
Ignore case

(b) (i) Increase/speed up/faster (rate of attainment of equilibrium)

OR

Increase/speed up/faster rate of both forward and reverse reaction

OR

Increase/speed up/faster rate of reaction

Credit "It took less time"

1

(ii) **M1** Increase/speed up/faster (rate of attainment of equilibrium)

M2 More particles/molecules in a given volume/space
OR the particles/molecules are closer together
OR an increase in concentration.

M3 More/higher chance of successful/effective/productive collisions (between particles)
OR more collisions/higher chance of collisions (of particles) with $E > E_{Act}$

If M1 is blank, mark on and credit M1 in the text

If M1 is given as "decrease"/"no effect"/"no change" then CE = 0 for clip

In M1, if increase both the forward and reverse reaction, but no mention of rate, penalise M1 but mark on.

In M1, if increase either forward rate or reverse rate only, then penalise M1 but mark on.

Penalise M3 if an increase in the value of E_{Act}/energy of particles is stated.

Max 1 for M2 and M3 if reference to "atoms"

3

[10]

Q8.

(a) (i) Oxidation

OR

Oxidised ONLY

1

(ii) Any one from

- to provide/overcome activation energy
- to provide the minimum energy to make the reaction go/start

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NOT simply to increase the (initial) reaction rate.

1

(iii) The reaction is exothermic OR releases heat (energy)

1

(iv) M1
Catalysts provide an alternative route/pathway OR an alternative mechanism

OR

(in this case) surface adsorption occurs (or a description of adsorption)

Ignore reference to "surface" alone

M2
Lowers the activation energy

OR

of lower activation energy

2

(b) M1
The (forward) reaction is exothermic OR the (forward) reaction releases heat

OR

The reverse reaction is endothermic or absorbs heat

M2 – Direction of change N.B. M2 depends on correct M1
At lower temperatures,

- the equilibrium yield of NO_2 is greater
- more NO_2 is formed
- equilibrium shifts (left) to right
- (equilibrium) favours the forward reaction

(***OR*** converse for higher temperatures)

2

(c) NO_2 (+) 4

NO_3^- (+) 5

HNO_2 (+) 3

3

[10]

Q9.

(a) Peak lower

1

and moved to right

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start at the origin and curve crosses once only 1

1

(b) (i) (Rate of reaction) <u>increases</u> 1

(At a higher temperature) <u>more molecules/particles</u> 1

have the minimum energy needed to react/have activation energy/have successful collisions 1

Mark CE if incorrect effect given

(ii) (Rate of reaction) <u>increases</u> 1

lowers activation energy 1

so that more molecules are able to react 1

Mark CE if incorrect effect given

[9]

Q10.

(a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$ 1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] – (391 \times 3)$ 1

$= –46.5 \text{ kJ mol}^{-1}$ 1

Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
2-3	– claims partially supported by evidence

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	– good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC

1

but, since the reaction is exothermic

1

the equilibrium yield is lower QWC

1

The higher the pressure the greater the equilibrium yield QWC

1

because there is a reduction in the number of moles of gas in the reaction

1

but higher pressure is expensive to produce or plant is more expensive to build QWC

1

A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

Q11.

(a) minimum energy

1

to start a reaction/ for a reaction to occur/ for a successful collision

1

(b) activation energy is high / few molecules/particles have sufficient energy to react/few molecules/particles have the required activation energy

(or breaking bonds needs much energy)

1

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(c) molecules are closer together/ more particles in a given volume

1

therefore collide more often

1

(d) many

1

more molecules have energy greater than activation energy (QoL)

1

(e) speeds up a reaction but is chemically unchanged at the end

1

(f) increases the surface area

1

[9]

Q12.

(a) Gradient (or slope) (or draw a tangent)

1

(b) (i) Curve **X** is lower and starts at origin

1

And levels out at same volume as original curve

1

(ii) Curve **Y** is steeper than original and starts at origin

1

Then levels out at half the volume of the original

1

(c) (i) $2H_2O_2 \rightarrow 2H_2O + O_2$

1

(ii) Speeds up (alters the rate of) a chemical reaction

1

Remains unchanged (or not used up)

1

(iii) Remains unchanged (or not used up or not in the overall reaction equation)

1

Offers alternative reaction route (or acts as an intermediate)

1

[10]

Q13.

(a) Graph starts at origin

1

Graph skewed to left and has decreasing gradient to maximum

1

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Graph after maximum decreases in steepness, never touches *x* axis, levels out less than 5 mm from *x* axis.

1

(b) Minimum energy

1

To start a reaction (*or for a reaction to occur*)

1

(c) Molecules gain energy (*or always some molecules have* $E > E_a$)

1

Due to collisions

1

(d) Decreases

1

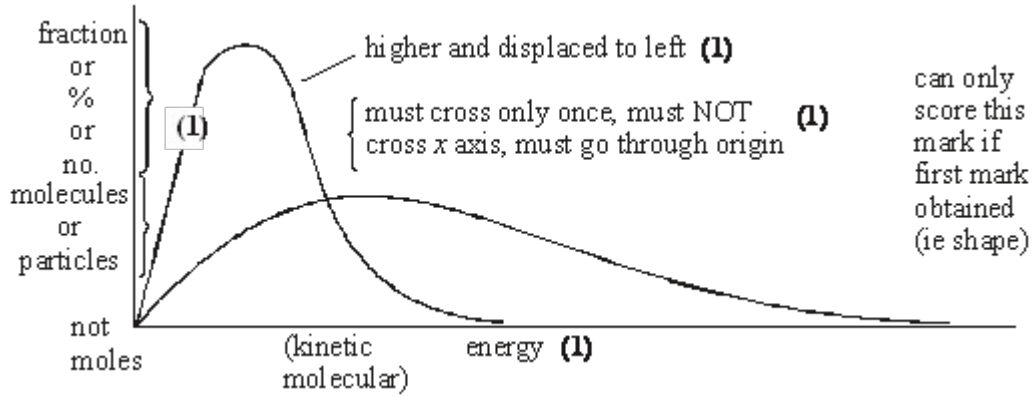
E_a lowered **(1)**
By alternative route **(1)**
So more molecules have energy > E_a **(1)**

max 2

[10]

Q14.

(a)



2

(b) See above

2

(c) Energy < E_a or must have enough energy (to react) **(1)**

1

(d) Increase concentration (or pressure) **(1)**

1

(e) Many **(1)** more molecules have E > E_a / enough energy **(1)**
NOT KE increases with T

2

(f) Lowers E_a **(1)**
alternative route **(1)**

2

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[10]

Q15.

(a) minimum energy **(1)**
required before a reaction can occur or go or start **(1)**

2

(b) speeds up (changes) reaction rate **(1)**
without being (chemically) changed **(used up) (1)**

2

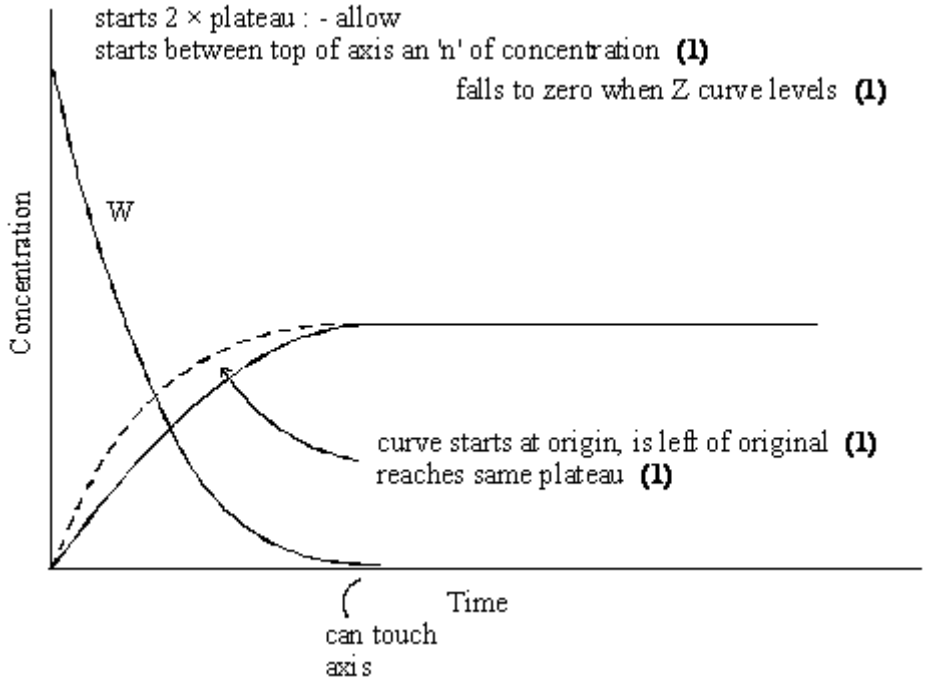
(c) provides alternative reaction route **(1)**
with a lower activation energy **(1)**

in (b) and (c) reward 4 marks for 4 points wherever found

2

(d) (i)

(ii)



(iii) fewer collisions **(1)**
W used up **(1)**

or reactants
or reagents
or fewer particles

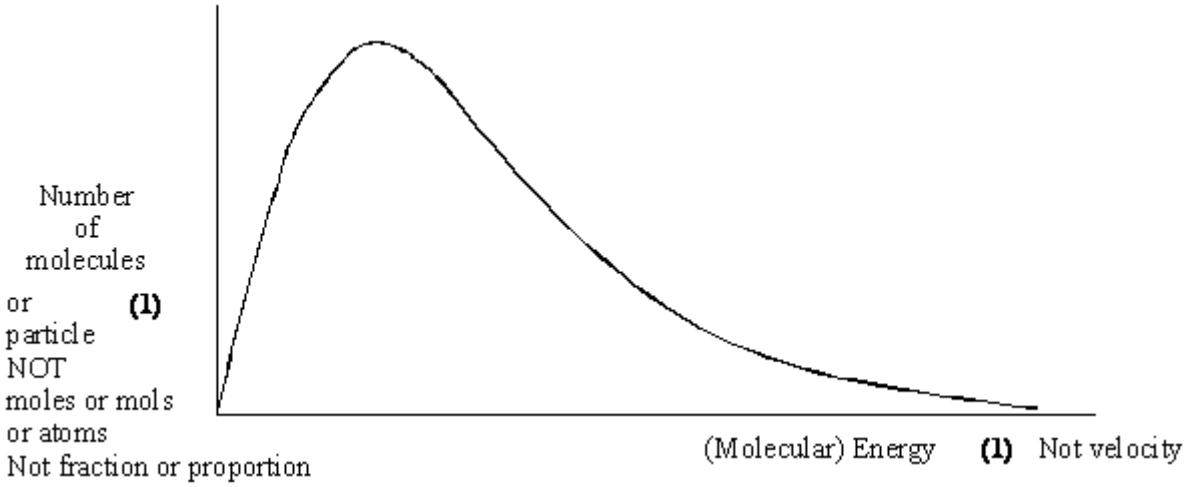
6

[12]

Q16.

(a) (i)

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(ii) The total number of particles (or molecules) in the sample

OR the number of molecules present

(iii) No molecules have no energy

OR all molecules have some energy

Do not allow "if there are no molecules there is no energy"

4

(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**

OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

Explanation: Alternative route **(1),** with a lower activation energy **(1)**

OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii)

5

[9]

Q17.

(a) **Increase in temperature:**

Yield is increased **(Allow if for H_2 (g) or products) (1)**
Reaction endothermic **(1)**
Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to oppose change **OR** to absorb heat **(1)**

If "Yield statement" incorrect allow max one if reaction stated to be endothermic

Increase in pressure:

Yield is decreased **(Allow if for H_2 (g) or products) (1)**
Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles on right **(1)**

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Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to oppose change **OR** to reduce pressure **(1)**

If "Yield statement" incorrect allow max one if number of moles change is correct.

6

(b) **Equilibrium yield:**
Unaffected **or** equilibrium unchanged **(1)**
Rate or speed increased **(1)**
Forward and backwards reactions equally or by the same amount **(1)**

Amount of hydrogen produced:
More hydrogen produced (1)

4

[10]

Q18.

(a) Activation energy;-
The minimum energy needed for a reaction to occur / start **(1)**

1

(b) Catalyst effect:-
Alternative route (or more molecules have Ea) **(1)**
Lower activation energy **(1)**

2

(c) Increase in moles of gas:-
Position of E_{mp} unchanged **(1)**
More molecules with E_{mp} **(1)**
Area under curve increases **(1)**
Molecules with $E \geq E_a$ increased **(1)**
Temperature decreased:-
Position of E_{mp} moves to the left **(1)**
More molecules with E_{mp} **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ decreased **(1)**
Catalyst introduced:-
Position of E_{mp} unchanged **(1)**
Molecules with E_{mp} unchanged **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ increased **(1)**

12

[15]

Q19.

D

[1]

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Q1.

(a) Most students could explain how a catalyst works in general terms (73.3% gained both marks), but some gave specific details of how heterogeneous catalysts work rather than referring to catalysts in general.

(b) Many students struggled to work out how the amount of H_2O_2 in similar reactions affects the relative amount of oxygen formed.

(c) Many students referred to the number of successful collisions rather than the frequency of successful collisions when explaining why the concentration of hydrogen peroxide affects the rate of reaction.

Q2.

Students have begun to demonstrate considerable ability in using Le Chatelier's principle to explain the effect of changing reaction conditions on equilibrium yield, but are less effective in their explanations concerning rates of reaction. The low demand first mark in part (a)ii proved elusive for some and the higher demand mark was marred by incomplete answers missing important ideas such as more collisions *in a given time* and more particles *in a given volume* or words to that effect in each case. In part (a)iii the idea that there is an increase in the available surface area when a catalyst is spread onto an inert honeycomb was understood by many, but the necessity to state that this would lead to an increase in *successful* collisions was often missed. Overall only about one fifth of students scored both marks in part (a)ii and part (a)iii.

Q3.

This question was high scoring. In part (b)(i), almost 48% scored full marks and for those who did not, it was the idea that catalysts alter the rate of a reaction and are chemically unchanged at the end of the reaction that was missed most often.

Q4.

In this question it was necessary to have an appreciation not only of amount of substance but also how changes in conditions altered the rate of a reaction. In part (e), the only acceptable answer for the overall equation was one in which the various intermediates were cancelled.

Q5.

After a relatively easy start in parts (a) and (b), candidates were challenged by their understanding of the Maxwell-Boltzmann distribution in part (c), with part (c)(ii) proving the most demanding. A small proportion of candidates failed to follow the instruction to use the specified words (increases, decreases or stays the same) but the marking catered for this, awarding marks for correct chemistry. Part (d) was lower scoring than anticipated with the identity of the catalyst in part (d)(ii) least well known.

Q6.

The curve in part (a)(i) had an easy mark and a more demanding one and only 53% scored full marks. In part (a)(ii), many candidates did not appreciate that an increased likelihood of particle collision is not the same as an increase in the number of successful

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collisions. The explanation of how a catalyst increases the rate of a reaction was well known.

Q7.

Intended to be a relatively straightforward introduction to the paper, parts of this question proved challenging to many candidates. In part (a)(iii), only 30% of the candidates were able to explain that the diagram showed that the sum of the bond enthalpies of the reactants was less than that of the products. In part (b)(ii) confusion arose between the effect of pressure on the rate of a reaction involving gases and how pressure changes might affect the position of an equilibrium.

Q8.

This question discriminated well, although the oxidation states in part (c) proved very straightforward for a high proportion of the candidates.

Q11.

Although the more able candidates found this question relatively straightforward, the weaker candidates found the task of explaining concisely rather difficult.

The majority of candidates answered (a) correctly although many failed to realise that the reaction in (b) would be slow because few molecules had the minimum activation energy needed to react.

In part (c) several incorrect answers included the assumption that increasing pressure increases energy! Answers to part (d) were generally done well. In (e) many candidates failed to score since they did not state that a catalyst is a substance that speeds up a reaction whilst remaining chemically unchanged. Instead candidates described how a catalyst worked in a reaction. Generally however candidates knew that powdered catalysts increase the surface area and hence scored the mark in (f).

Q12.

This question was answered quite well and most candidates gained a reasonable number of marks. Answers to part (a) were usually correct though weak candidates sometimes suggested, incorrectly, that the rate could be obtained simply by dividing the volume by the time. In part (b) candidates were able to show curves with the correct initial gradients but curves showing the correct final volumes of oxygen were much less common. In part (c) (i) many candidates lost a mark because HBr was included incorrectly in the overall equation. Answers to parts (c) (ii) and (c) (iii) were often awarded full marks. In part (c) (ii), some candidates attempted to answer the question by describing how a catalyst works rather than answering the question by explaining that a catalyst is a substance that alters the rate of a chemical reaction whilst being chemically unchanged.

Q13.

Most candidates were able to gain some marks for this question which, nevertheless, discriminated well between strong and weak candidates. The curves drawn in answer to part (a) were seldom good enough to gain full marks. They were not always skewed obviously to the left and many curves did not approach the energy axis as an asymptote. Most answers to part (b) were correct but weaker candidates lost one of the two marks by failing to mention some idea of a ‘minimum’ energy. Part (c) proved to be a hard question; only the best candidates recognised that the energy of the molecules would be redistributed by collision. Part (d) was an easier question though candidates often referred

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to a rate of reaction rather than answering the question by mentioning how the time taken for decomposition would be changed.

Q14.

This question was answered well by most candidates except for part (e). Weaker candidates did not usually label the axes correctly in part (a). The most common error was to label the vertical axis 'Energy' and the horizontal axis 'Time'. The curve in part (b) was drawn correctly by the great majority of candidates. Answers to parts (c) and (d) were usually succinct and correct. In part (e) few candidates, even amongst the most able, were able to explain why a small increase in temperature leads to a large increase in the rate of a reaction. Answers were restricted to a simple explanation of why any increase in temperature increases reaction rate. Many weaker candidates attempted incorrectly to attribute the large increase in the reaction rate to an increase in collision frequency. Part (f) was not answered well by many of the weaker candidates who gave a definition of a catalyst rather than an explanation of how it works.

Q15.

Parts (a), (b) and (c) were answered well by most candidates. Part (d), however, discriminated very effectively between good and weak candidates. Only the best candidates sketched a curve for **W** correctly. In particular, it was not recognised that the initial concentration of **W** was twice the final concentration of **Z**. More candidates sketched a correct curve for **Z** in the presence of a catalyst though weak candidates usually showed the concentration of **Z** finishing too high. In part (d) (iii) weak candidates did not recognise that the collision frequency of reacting particles would decrease. Answers often contained irrelevant reference to some change in activation energy.

Q16.

This question was well answered by most candidates. Candidates who lost marks usually made errors in part (a). These errors included incorrect labelling of the axes of the Maxwell-Boltzmann curve with temperature being the most common incorrect answer. The reason why this curve starts at the origin also proved difficult and there were some incorrect answer to section (iii). Many candidates scored full marks in part (b).

Q17.

This question was well answered. Many candidates in part (a) used Le Chatelier's principle to predict correctly the effect of increasing temperature and increasing pressure on the yield of hydrogen in the given equilibrium reaction. Candidates who made the wrong prediction were able to score one mark for each change if they stated correctly that the reaction was endothermic and that there was a reduction in the number of moles of gas in the reaction as written. Part (b) was also well answered but some candidates did not differentiate clearly between the equilibrium yield of hydrogen and the amount of hydrogen produced in a given time.

Q18.

This question was well answered. The term activation energy was well understood and most candidates knew how, in general terms, a catalyst increases the rate of a chemical reaction. Part (c) was also well answered. Most candidates were able to deduce how the distribution of molecular energies would change if the number of molecules was increased at constant temperature or the temperature was reduced without a change in the number of molecules. The only common error was to state that, when the temperature was reduced, the number of molecules with the most probable energy, E_{mp} would fall. The

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effect of a catalyst was well known and most candidates gained full marks for their answer to (c)(iii).

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