Q1.

Which statement about molecules in a gas is correct?

A At a fixed temperature they all move at the same speed. ⬭

B At a fixed temperature their average kinetic energy is constant. ⬭

C As temperature increases, there are more molecules with the most probable energy. ⬭

D As temperature decreases, there are fewer molecules with the mean energy. ⬭

(Total 1 mark)

Q2.

Consider the change that occurs in the shape of the curve for the distribution of molecular energies in a gas when the temperature of the gas is increased.

Which is a correct statement about the gas molecules at a higher temperature?

A There are more molecules with any given energy. ⬭

B There are more molecules with the mean energy. ⬭

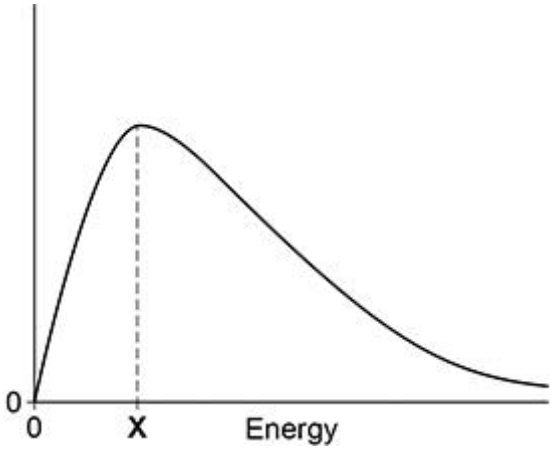
C There are more molecules with the most probable energy. ⬭

D There is an increase in the most probable energy of the molecules. ⬭

(Total 1 mark)

Q3.

The figure below shows the Maxwell–Boltzmann distribution of molecular energies in a sample of gas.



(a) Label the *y*-axis on the figure above.

(1)

(b) State why the curve starts at the origin.

_____

_____

(1)

(c) State what **X** indicates on the figure above.

X indicates _____

_____

(1)

(d) Half of the gas molecules in the sample are removed.
The remaining gas molecules are kept at the same temperature.

Draw the new distribution of molecular energies for the remaining gas on the figure above.

(2)

(Total 5 marks)

Q4.

Which statement about the distribution curve of molecular energies in an ideal gas at a given temperature is correct?

A There are no molecules with zero energy. ⬭

B The curve is symmetrical about the maximum. ⬭

C Changing the temperature has no effect on the position of the maximum. ⬭

D Most molecules have the mean energy. ⬭

(Total 1 mark)

Q5.

Which statement about the molecules in a sample of a gas is correct?

A At a given temperature they all move at the same speed. ⬭

B At a given temperature their average kinetic energy is constant. ⬭

C As temperature increases, there are more molecules with the most probable energy. ⬭

D As temperature decreases, there are fewer molecules with the mean energy. ⬭

(Total 1 mark)

Q6.

Which statement is correct for the distribution curve of molecular energies in a gas?

A The curve is symmetrical about the maximum. ⬭

B There are always some molecules with zero energy. ⬭

C The position of the maximum of the curve is not dependent on the temperature. ⬭

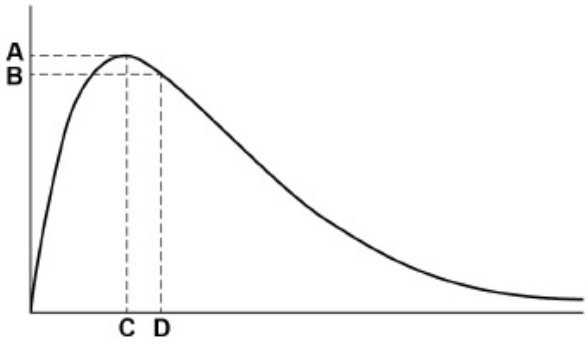
D The mean energy of the molecules is greater than the most probable energy of the molecules. ⬭

(Total 1 mark)

Q7.

The Maxwell–Boltzmann distribution of molecular energies in a sample of gas at a fixed temperature is shown.

Which letter represents the mean energy of the molecules?



A ⬭

B ⬭

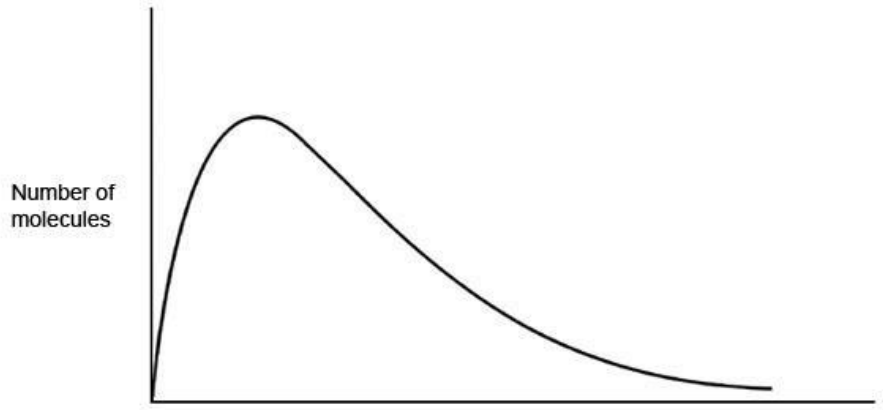
C ⬭

D ⬭

(Total 1 mark)

Q8.

The graph shows the Maxwell−Boltzmann distribution of molecular energies in a sample of gas at a fixed temperature.



.....

(a) Label the horizontal axis on the graph.

(1)

(b) On the graph, sketch a distribution of molecular energies for this sample of gas at a higher temperature.

(2)

(c) This gas decomposes on heating.

Explain why an increase in temperature increases the rate at which this gas decomposes.

_____

_____

_____

_____

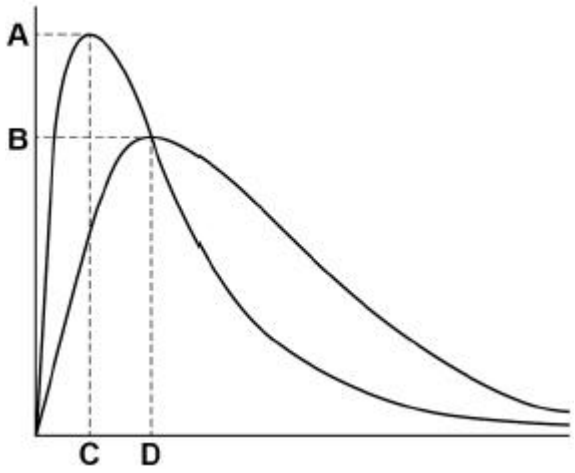
_____

(2)

(Total 5 marks)

Q9.

The diagram shows the Maxwell−Boltzmann distribution of molecular energies in a gas at two different temperatures.



Which letter represents the most probable energy of the molecules at the higher temperature?

A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

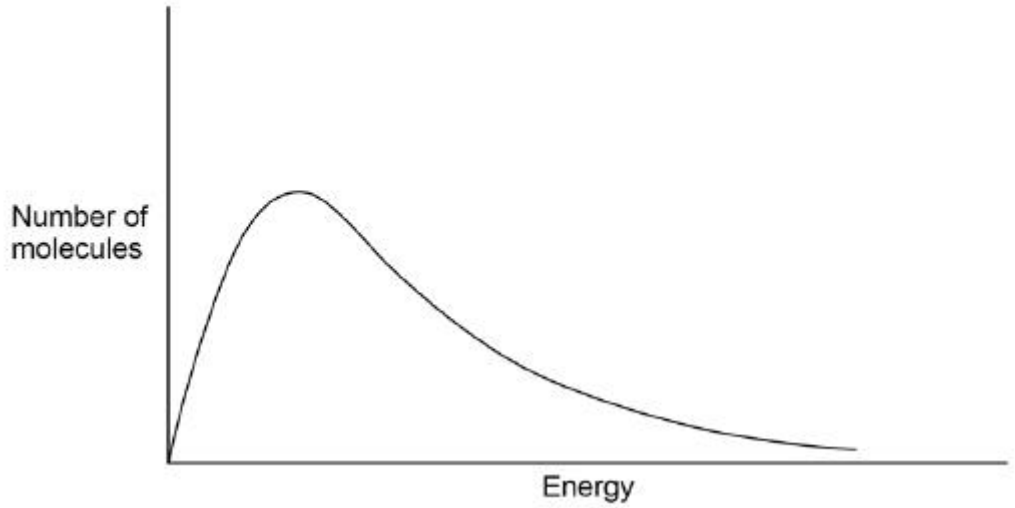
Q10.

Nitryl chloride reacts with nitrogen monoxide according to the equation:

$$ClNO_2(g) + NO\ (g) \longrightarrow NO_2(g) + ClNO(g)$$

The Maxwell–Boltzmann distribution curve in **Figure 1** shows the distribution of molecular energies in 1 mol of this gaseous reaction mixture (sample **1**) at 320 K.

Figure 1



(a) On the same axes, draw a curve for sample **1** at a lower temperature.

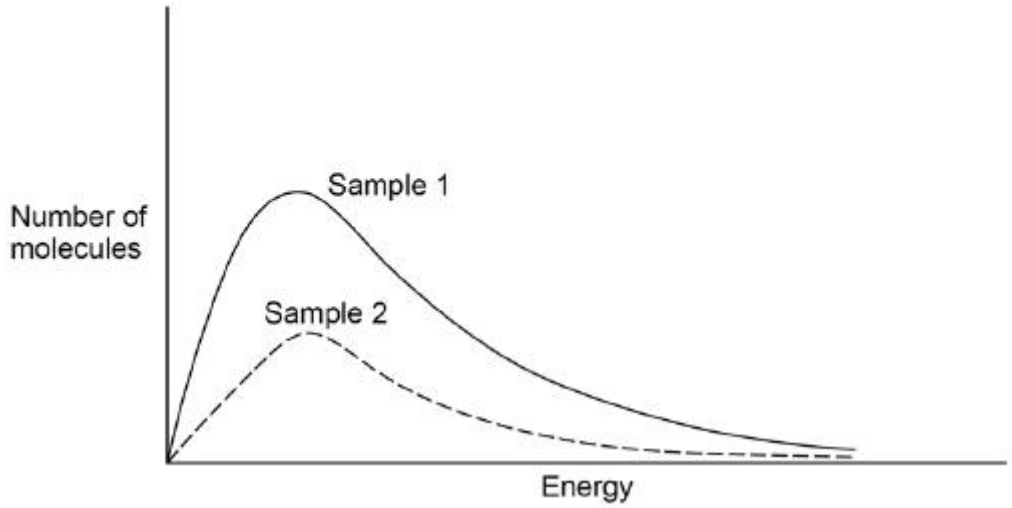
(2)

(b) Explain the effect that lowering the temperature would have on the rate of reaction.

(2)

(c) A Maxwell–Boltzmann distribution curve was drawn for a second sample of the reaction mixture in the same reaction vessel. **Figure 2** shows the results.

Figure 2



Deduce the change that was made to the reaction conditions.

Explain the effect that this change has on the rate of reaction.

Change _____

_____

Explanation _____

_____

_____

_____

_____

_____

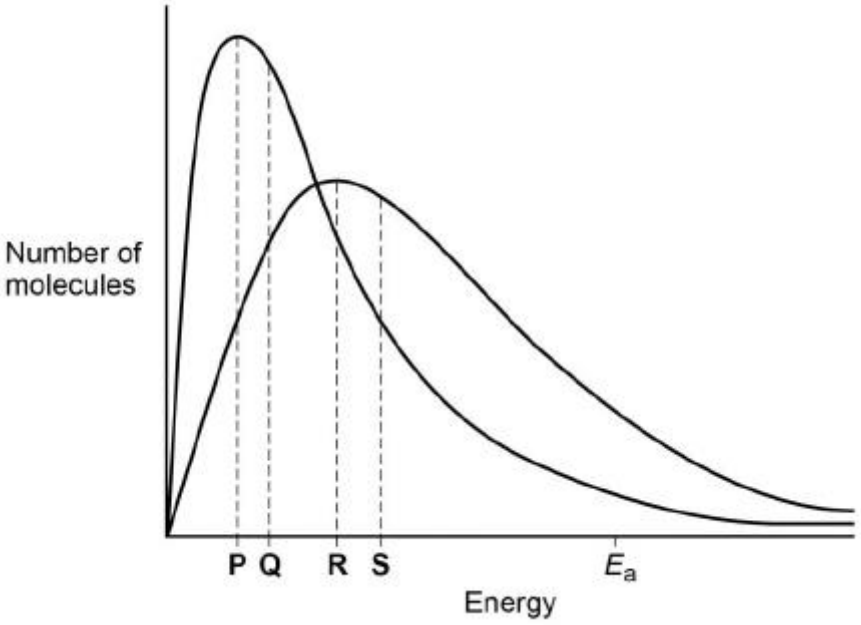
_____

(3)

(Total 7 marks)

Q11.

The question below is about the Maxwell–Boltzmann distribution shown for a sample of a gas, X, at two different temperatures.



Which letter shows the mean energy of the molecules at the higher temperature?

A P ⬭

B Q ⬭

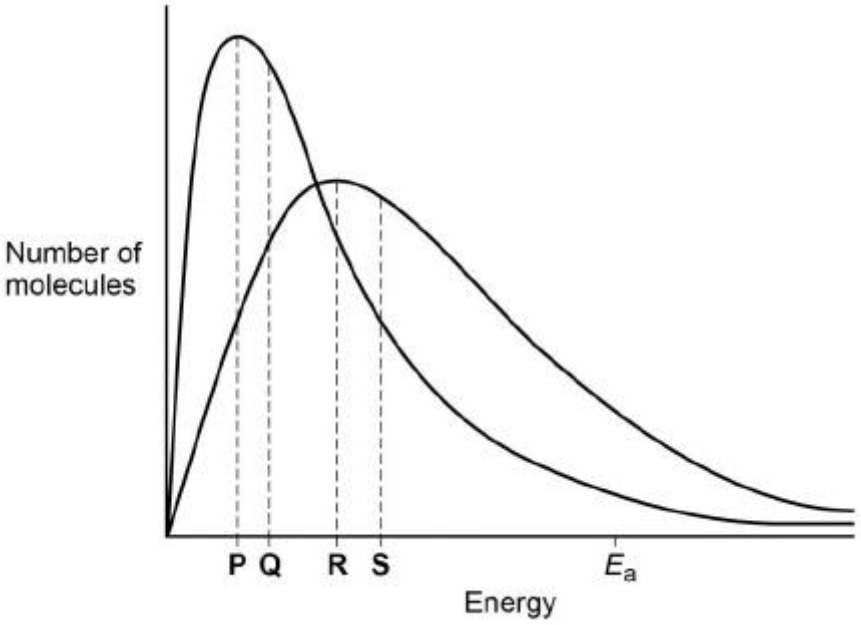
C R ⬭

D S ⬭

(Total 1 mark)

Q12.

The question below is about the Maxwell–Boltzmann distribution shown for a sample of a gas, X, at two different temperatures.



Which statement is correct for the higher temperature?

A The area under the curve to the left of E_a decreases. ⬭

B The total area under the curve increases. ⬭

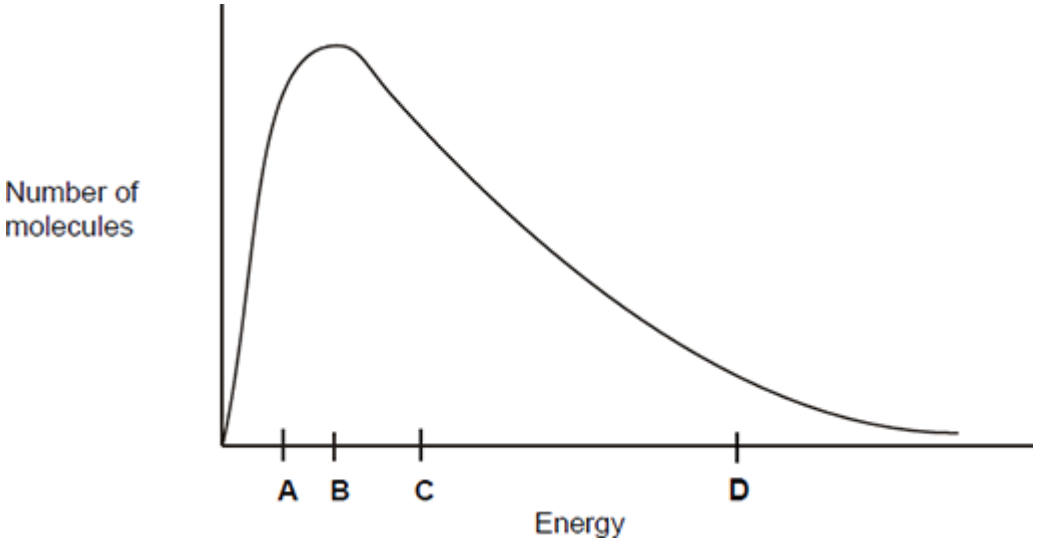
C The activation energy decreases. ⬭

D More molecules have the mean energy. ⬭

(Total 1 mark)

Q13.

This question is about the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas shown in the figure below.



Which letter best represents the mean energy of the molecules?

A ⬭

B ⬭

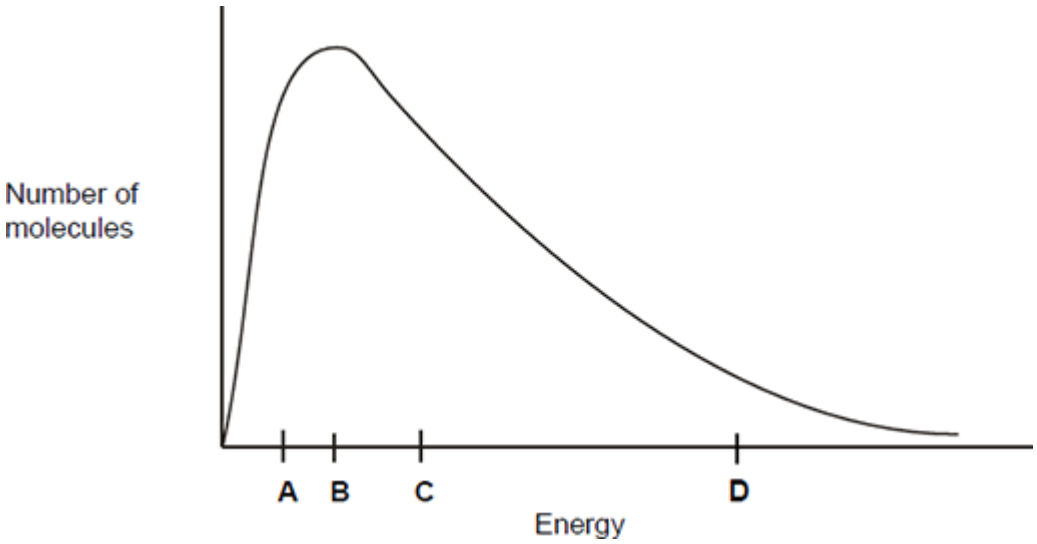
C ⬭

D ⬭

(Total 1 mark)

Q14.

This question is about the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas shown in the following figure.



What does the area under the curve represent?

A The total energy of the particles. ⬭

B The total number of particles. ⬭

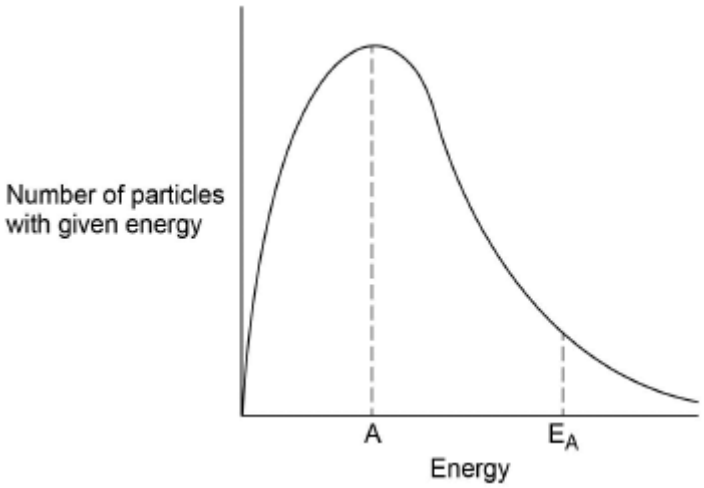
C The number of particles that can react with each other. ⬭

D The total number of particles that have activation energy. ⬭

(Total 1 mark)

Q15.

The graph below shows a typical energy distribution for particles of an ideal gas in a sealed container at a fixed temperature.



Which of the following statements is true?

A Position A represents the mean energy of a molecule in the container. ⬭

B Addition of a catalyst moves the position of E_A to the right. ⬭

C The area under the curve to the right of E_A represents the number of molecules with enough energy to react. ⬭

D The position of the peak of the curve at a higher temperature is further away from both axes. ⬭

(Total 1 mark)

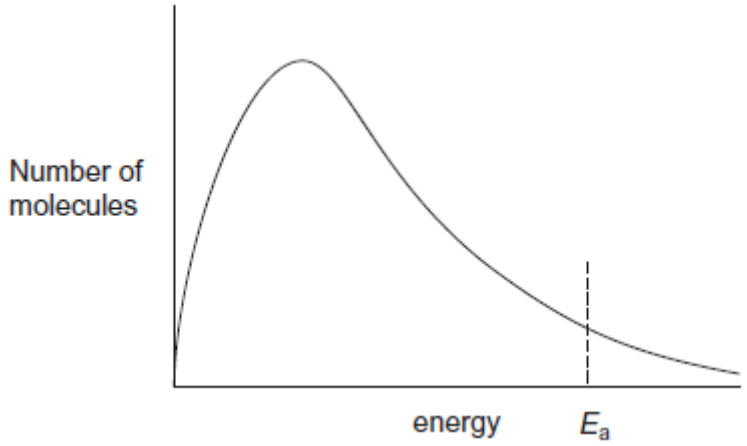
Q16.

Methanol, for use as a fuel, can be produced by the reaction of carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90 \text{ kJ mol}^{-1}$$

The reaction is typically carried out at 300 °C and 3×10^7 Pa, in the presence of a catalyst.

(a) The graph shows the Maxwell–Boltzmann distribution for a mixture of carbon monoxide and hydrogen at 300 °C.



(i) Sketch a second curve on the graph to show the distribution of molecular energies in this mixture at a higher temperature.

(1)

(ii) Explain with reference to both curves on the graph how a small change in temperature leads to a large change in the rate of reaction.

_____

_____

_____

_____

(2)

(b) Both the rate of production and equilibrium yield of methanol are considered when choosing the most appropriate conditions for the operation of this process on an industrial scale.

(i) State and explain the effect of a higher pressure on the equilibrium yield of methanol.

(3)

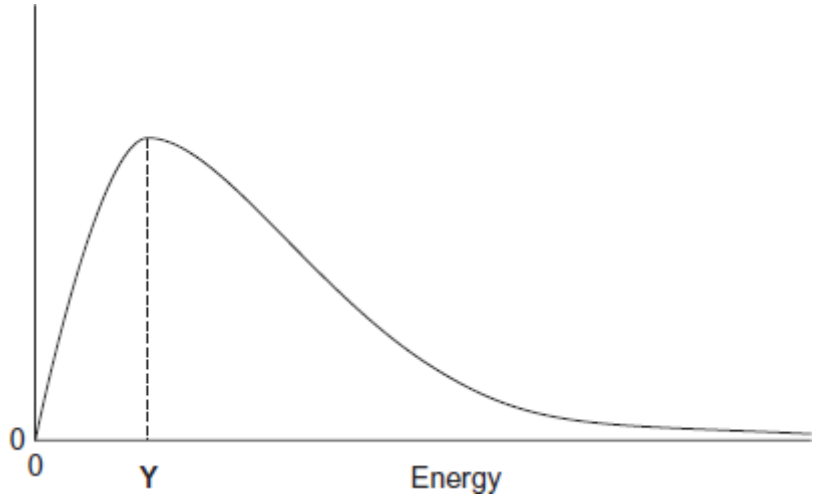
(ii) By considering both rate and yield, state why the reaction is carried out at a temperature of 300 °C rather than at a higher temperature.

(2)

(Total 8 marks)

Q17.

The following figure shows the Maxwell.Boltzmann distribution of molecular energies in a sample of gas at temperature *T*.



(a) One of the axes is labelled.
Label the other axis.

(1)

(b) State why the curve starts at the origin.

_____

_____

_____

(1)

(c) Which of the following, **A**, **B** or **C**, describes what the value of **Y** represents in the figure?
Write the correct letter, **A**, **B** or **C**, in the box.

A The energy needed for a successful collision
B The minimum energy needed for a reaction to occur
C The most probable energy

☐

(1)

(d) On the figure above, draw a distribution of molecular energies in this sample of gas at a **higher** temperature.

(2)

(e) The pressure of the original sample of gas is doubled at temperature *T*.

State the effect, if any, of this change on the value of **Y**.

_____

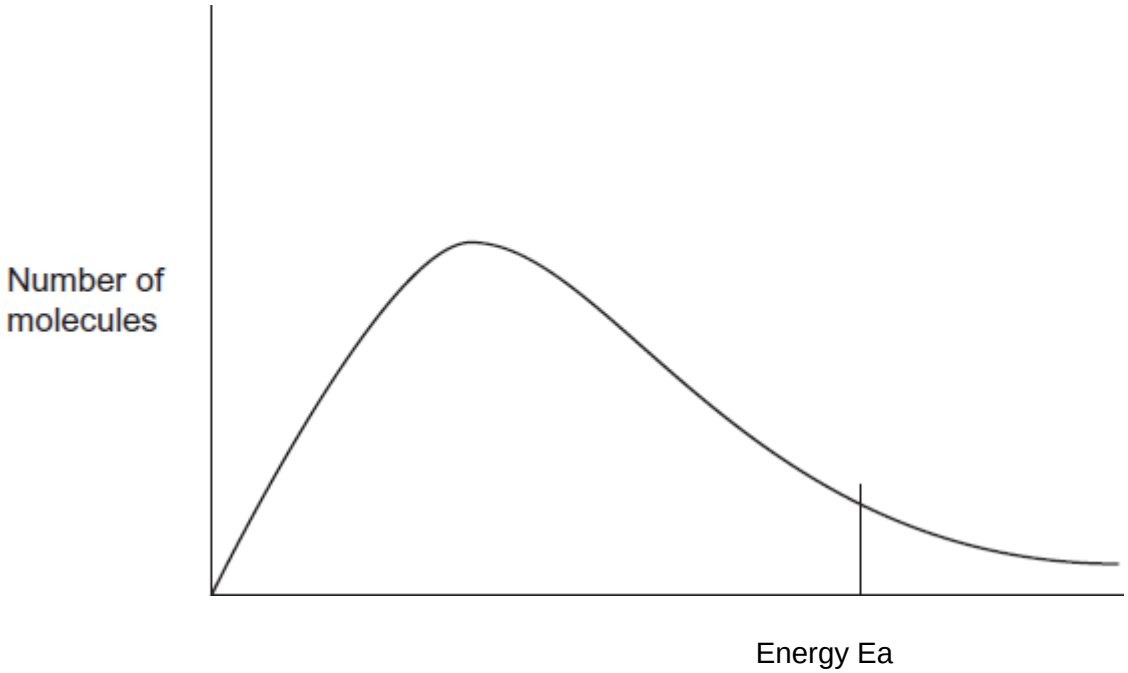
_____

(1)

(Total 6 marks)

Q18.

The diagram shows the Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.
E_a is the activation energy for the decomposition of this gas.



E_{mp} is the most probable value for the energy of the molecules.

(a) On the appropriate axis of this diagram, mark the value of E_{mp} for **this** distribution.

On this diagram, sketch a new distribution for the same sample of gas at a **lower** temperature.

(3)

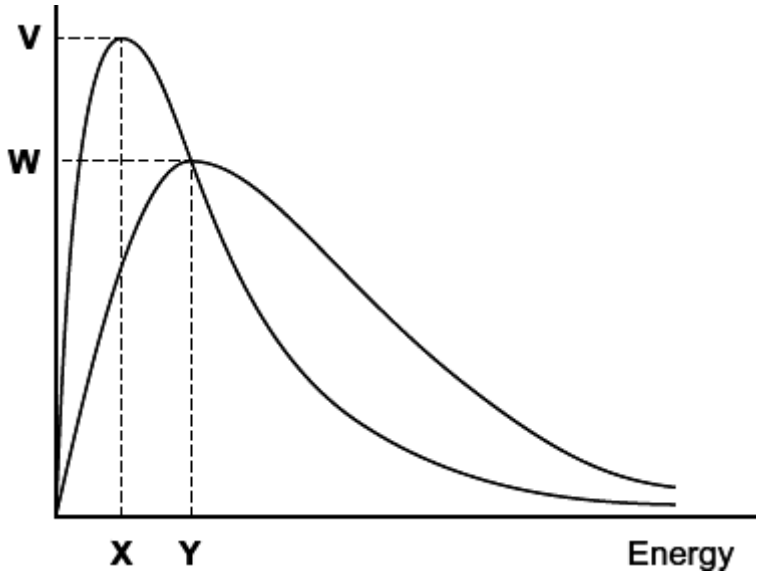
(b) With reference to the Maxwell–Boltzmann distribution, explain why a decrease in temperature decreases the rate of decomposition of this gas.

(2)

(Total 5 marks)

Q19.

The diagram shows the Maxwell-Boltzmann distribution of molecular energies in a gas at two different temperatures.



(a) One of the axes is labelled. Complete the diagram by labelling the other axis.

(1)

(b) State the effect, if any, of a solid catalyst on the shape of either of these distributions.

(1)

(c) In the box, write the letter, **V**, **W**, **X** or **Y**, that represents the most probable energy of the molecules at the lower temperature.

(1)

(d) Explain what must happen for a reaction to occur between molecules of two different gases.

(2)

(e) Explain why a small increase in temperature has a large effect on the initial rate of a reaction.

(1)

(Total 6 marks)

Q20.

The rate of a chemical reaction is influenced by the size of the activation energy. Catalysts are used to increase the rates of chemical reactions but are not used up in the reactions.

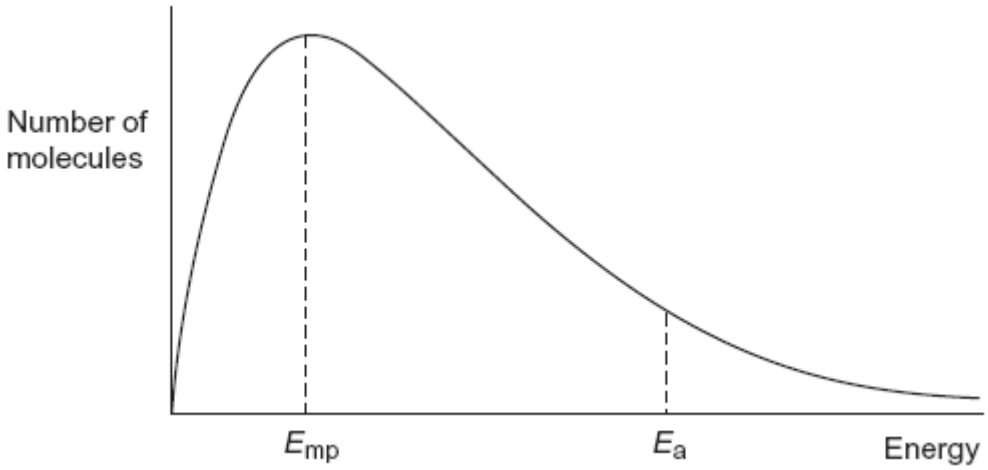
(a) Give the meaning of the term *activation energy*.

(2)

(b) Explain how a catalyst increases the rate of a reaction.

(2)

(c) The diagram below shows the Maxwell–Boltzmann distribution of molecular energies, at a constant temperature, in a gas at the start of a reaction.
On this diagram the most probable molecular energy at this temperature is shown by the symbol E_{mp}
The activation energy is shown by the symbol E_a



To answer the questions (c)(i) to (c)(iv), you should use the words **increases**, **decreases** or **stays the same**. You may use each of these answers once, more than once or not at all.

(i) State how, if at all, the value of the most probable energy (E_{mp}) changes as the total number of molecules is increased at constant temperature.

_____

(1)

(ii) State how, if at all, the number of molecules with the most probable energy (E_{mp}) changes as the temperature is decreased without changing the total number of molecules.

_____

(1)

(iii) State how, if at all, the number of molecules with energy greater than the activation energy (E_a) changes as the temperature is increased without c hanging the total number of molecules.

_____

(1)

(iv) State how, if at all, the area under the molecular energy distribution curve changes as a catalyst is introduced without changing the temperature or the total number of molecules.

_____

(1)

(d) For each of the following reactions, identify a catalyst and name the organic product of the reaction.

(i) The fermentation of an aqueous solution of glucose.

Catalyst _____

Name of organic product _____

_____

(2)

(ii) The hydration of but-2-ene.

Catalyst _____

Name of organic product _____

_____

(2)

(Total 12 marks)

Mark schemes

Q1.

B

At a fixed temperature their average kinetic energy is constant

[1]

Q2.

D

There is an increase in the most probable energy of the molecules.

[1]

Q3.

(a) Number of molecules (with a particular energy)

Ignore particles / atoms

Allow amount or fraction or proportion for number

1

(b) There are no molecules with no energy

All molecules / particles have some energy

Allow particles / atoms

1

(c) Most probable / common / modal energy

1

(d) **M1** Peak should be at same energy (i.e. in line with X)

***M1** and **M2** marked independently*

1

M2 Overall area should be half the original area; after diverging from the origin, the second line should not touch the first line

***M2** area should be about half of the original*

1

[5]

Q4.

A

There are no molecules with zero energy.

[1]

Q5.

B

At a given temperature their average kinetic energy is constant

[1]

Q6.

D

The mean energy of the molecules is greater than the most probable energy of the molecules

[1]

Q7.

D

[1]

Q8.

(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]

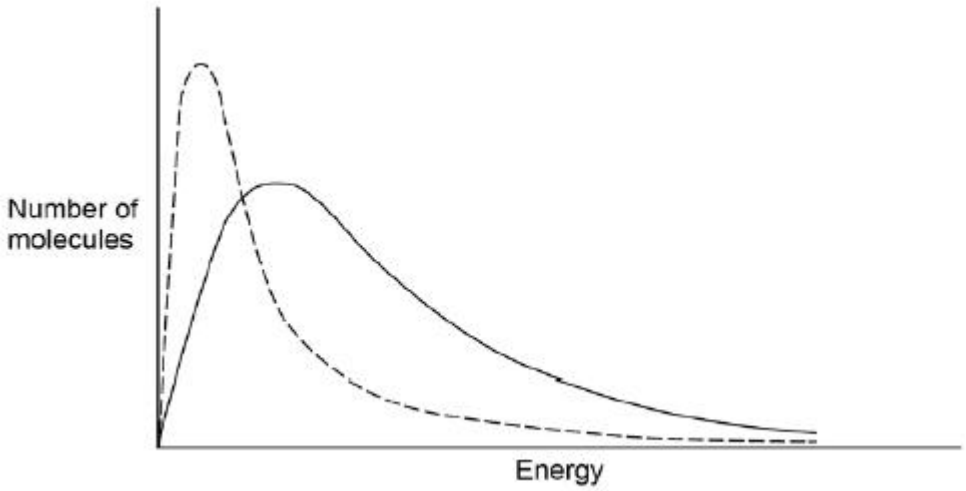
Q9.

D

[1]

Q10.

(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]

Q11.

D

[1]

Q12.

A

[1]

Q13.

C

[1]

Q14.

B

[1]

Q15.

C

[1]

Q16.

(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]

Q17.

(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]

Q18.

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

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]

Q19.

(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 / 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]

Q20.

(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 <u>ethanol</u>

Ignore "enzyme"

In M2, ignore "alcohol" and ignore any formula

2

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

M2 <u>butan-2-ol</u>

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]