

**Q28.**

- (a) State what is meant by the term *activation energy* of a reaction.

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**(1)**

- (b) State in general terms how a catalyst increases the rate of a chemical reaction.

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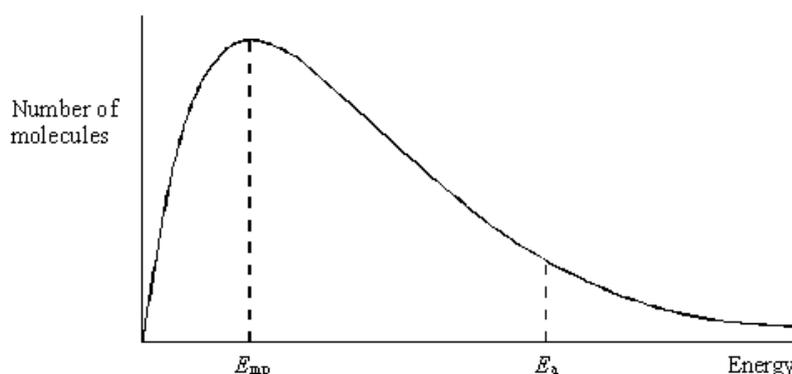
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**(2)**

- (c) The curve 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 indicated by the symbol  $E_{mp}$  and the activation energy by the symbol  $E_a$ .



Consider the following changes.

- (i) The number of molecules is increased at constant temperature.
- (ii) The temperature is decreased without changing the number of molecules.
- (iii) A catalyst is introduced without changing the temperature or the number of molecules.

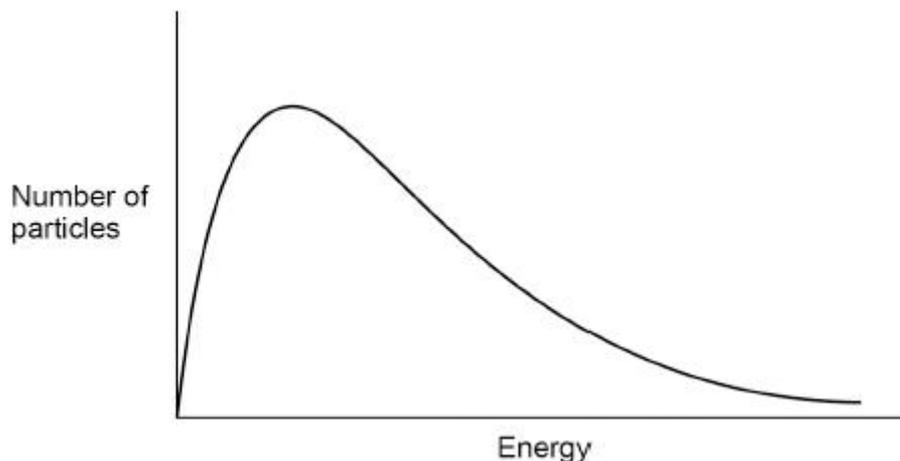
For **each** of these changes state how, if at all, the following would vary:

- the value of the most probable energy,  $E_{mp}$
- the number of molecules with the most probable energy,  $E_{mp}$
- the area under the molecular energy distribution curve
- the number of molecules with energy greater than the activation energy,  $E_a$



**Q30.**

This is a Maxwell–Boltzmann distribution for a gaseous reactant.



What is represented by the total area under the curve?

- A** total energy of the particles
- B** activation energy for the reaction
- C** total number of reacting particles
- D** total number of particles present

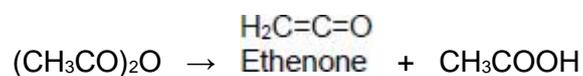
(Total 1 mark)

**Q31.**

This question is about ethanoic anhydride.

In the gas phase, ethanoic anhydride  $(\text{CH}_3\text{CO})_2\text{O}$  decomposes to form ethenone.

The equation is



- (a) Ethenone is the simplest member of the ketene homologous series. Ketenes all contain one C=C double bond and one C=O double bond.

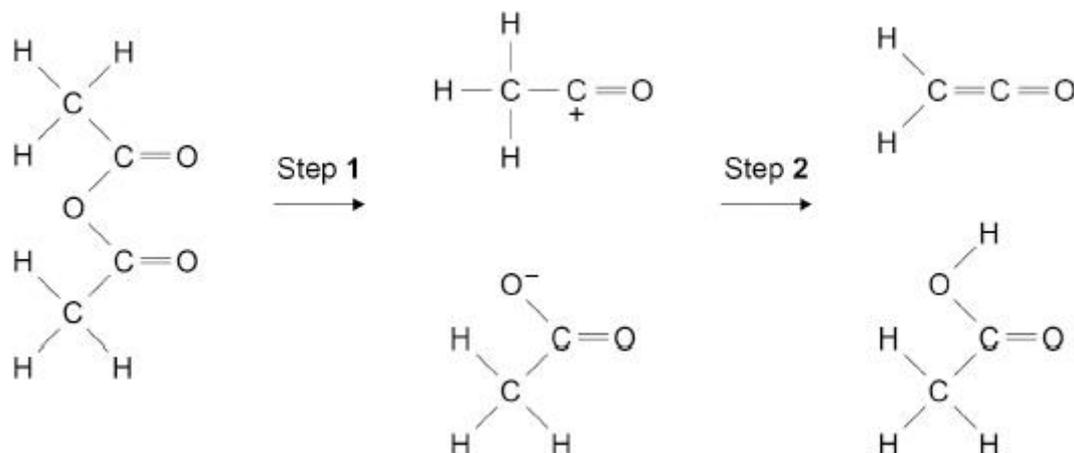
Deduce the general formula for the ketene homologous series.

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(1)



- (b) The figure below shows an incomplete suggested mechanism for the decomposition of ethanoic anhydride.



Complete the mechanism in the figure above by adding three curly arrows and any relevant lone pairs of electrons.

(3)

- (c) For a chemical reaction the relationship between the rate constant,  $k$ , and the temperature,  $T$ , is shown by the Arrhenius equation.

$$k = Ae^{\frac{-E_a}{RT}}$$

For the decomposition of gaseous ethanoic anhydride

the activation energy,  $E_a = 34.5 \text{ kJ mol}^{-1}$

the Arrhenius constant,  $A = 1.00 \times 10^{12} \text{ s}^{-1}$

At temperature  $T_1$  the rate constant,  $k = 2.48 \times 10^8 \text{ s}^{-1}$

Calculate  $T_1$

The gas constant,  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

$T_1$  \_\_\_\_\_ K

(3)



- (d) Sketch the Maxwell–Boltzmann distribution of molecular energies for gaseous ethanoic anhydride at temperature  $T_1$  and at a higher temperature  $T_2$

Include a label for each axis, and mark on the appropriate axis a typical position for the activation energy.

Explain why the rate of reaction is faster at  $T_2$



Explanation

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(5)

(Total 12 marks)

**Q32.**

Draw the Maxwell–Boltzmann distribution curves for a fixed mass of a gas at two different temperatures.

This gas decomposes when heated.

By reference to these distribution curves, explain why the rate of decomposition of this gas increases at higher temperatures.

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**(Total 6 marks)**

**Q28.**

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

1

- (b) Catalyst effect:-  
Alternative route (or more molecules have  $E_a$ ) **(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]****Q29.**

D

**[1]****Q30.**

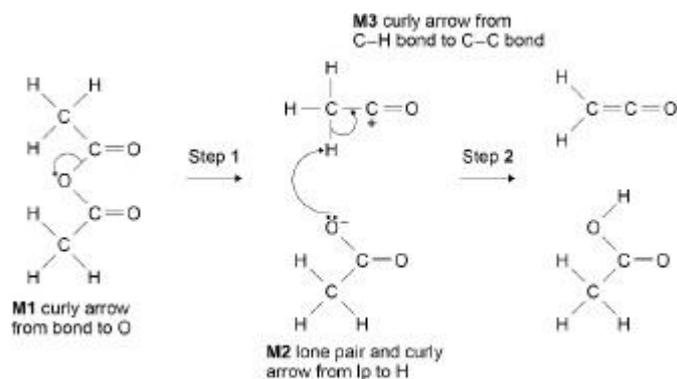
D

*total number of particles present***[1]****Q31.**

- (a)  $C_nH_{2n-2}O$   
*Allow  $C_nH_{2n}CO$  or  $(CH_2)_nCO$  or  $C_nH_{2(n-1)}O$*

1

- (b)



Allow other C-O bond breaking for M1

3

(c) M1  $\frac{k}{A} = e^{-E_a/RT}$

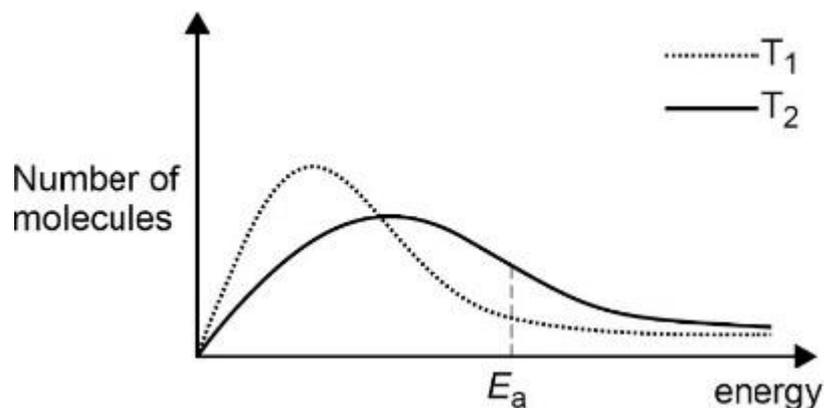
M2  $8.302 = \frac{34500}{8.31 \times T}$

M3  $T = 500 \text{ K}$

OR via  $\ln k = \ln A - \frac{E_a}{RT}$  or shown with numbers

3

(d)



M5 At  $T_2$  (many) more particles have  $E \geq E_a$

M1 x axis labelled correctly (kinetic not required)

AND y axis labelled correctly allow particles

M2  $E_a$  labelled on x axis

M3 Distribution correct shape for  $T_1$

M4 Peak at  $T_2$  lower with max shifted right and only crosses once

5

[12]

Q32.

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



<b>Level 3</b> <b>5-6</b> <b>marks</b>	<b>All stages are covered and each stage is generally correct and virtually complete.</b> (6 v 5) Answer is well structured, with no repetition or irrelevant points, and covers all aspects of the question. Accurate and clear expression of ideas with no errors in use of technical terms.
<b>Level 2</b> <b>3-4</b> <b>marks</b>	<b>All stages are covered but stage(s) may be incomplete or may contain inaccuracies OR two stages are covered and are generally correct and virtually complete.</b> (4 v 3) Answer has some structure and covers most aspects of the question. Ideas are expressed with reasonable clarity with, perhaps, some repetition or some irrelevant points. If any, only minor errors in use of technical terms.
<b>Level 1</b> <b>1-2</b> <b>marks</b>	<b>Two stages are covered but stage(s) may be incomplete or may contain inaccuracies OR only one stage is covered but is generally correct and virtually complete.</b> (2 v 1) Answer includes statements which are presented in a logical order and / or linked.
<b>Level 0</b>	Insufficient correct chemistry to gain a mark.

### Stage 1 - Single distribution curve

1a suitable axis labels:

vertical: number/proportion/fraction of molecules/particles;

horizontal: (kinetic) energy

1b suitable shape (including on LHS must start reasonably close to 0,0 and RHS must not meet x-axis or rise upwards (on each curve drawn))

### Stage 2 - Distribution curve at higher temperature

2a peak moves to the right and down

2b area under the curve (roughly) the same

2c lines cross once only

### Stage 3 - Why a gas reacts faster at higher temperature

3a molecules have more energy

3b more molecules have the activation energy

3c higher proportion of collisions are successful / increases frequency of successful collisions