**Q17.**

(a) Define the term *activation energy* for a chemical reaction.

**(2)**

(b) Draw, with labelled axes, a curve to represent the Maxwell–Boltzmann distribution of molecular energies in a gas. Label this curve **$T_1$**. On the same axes, draw a second curve to represent the same sample of gas at a lower temperature. Label this curve **$T_2$**.

Use these curves to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction.

**(8)**

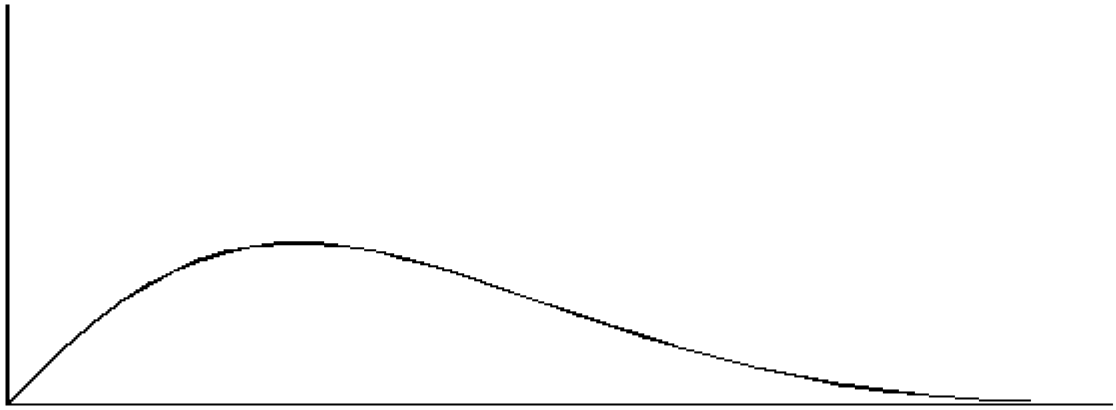
(c) Give **one** reason why most collisions between gas-phase reactants do not lead to a reaction. State and explain **two** ways of speeding up a gas-phase reaction other than by changing the temperature.

**(5)**

**(Total 15 marks)**

## Q18.

The diagram below represents a Maxwell–Boltzmann distribution curve for the particles in a sample of a gas at a given temperature. The questions below refer to this sample of particles.



(a) Label the axes on the diagram.

**(2)**

(b) On the diagram draw a curve to show the distribution for this sample at a **lower** temperature.

**(2)**

(c) In order for two particles to react they must collide. Explain why most collisions do not result in a reaction.

**(1)**

(d) State one way in which the collision frequency between particles in a gas can be increased without changing the temperature.

___

**(1)**

(e) Suggest why a small increase in temperature can lead to a large increase in the reaction rate between colliding particles.

___

___

___

**(2)**

(f) Explain in general terms how a catalyst works.

___

___

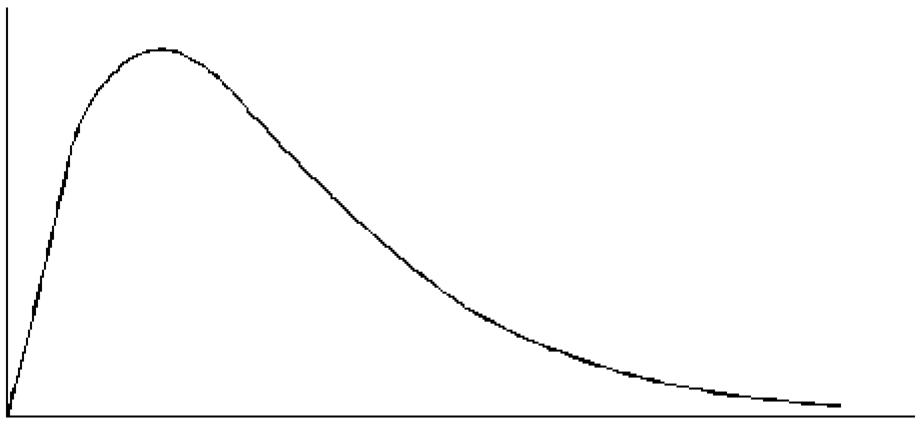
___

**(2)**

**(Total 10 marks)**

**Q19.**

(a) Below is a Maxwell–Boltzmann curve showing the distribution of molecular energies for a sample of gas at a temperature *T*.



(i) Label the axes on the diagram above.

(ii) What does the area under the curve represent?

___

(iii) State why this curve starts at the origin.

___

**(4)**

(b) (i) State what is meant by the term *activation energy*.

___

___

(ii) The rate of a chemical reaction may be increased by an increase in reactant concentration, by an increase in temperature and by the addition of a catalyst.

State which, if any, of these changes involves a different activation energy. Explain your answer.

*Change(s)* ___

*Explanation* ___

___

**(5)**

**(Total 9 marks)**

## Q20.

This question is about ethanoic anhydride.

In the gas phase, ethanoic anhydride $(CH_3CO)_2O$ decomposes to form ethenone.

The equation is

$$(CH_3CO)_2O \rightarrow \underset{\text{Ethenone}}{H_2C{=}C{=}O} + CH_3COOH$$

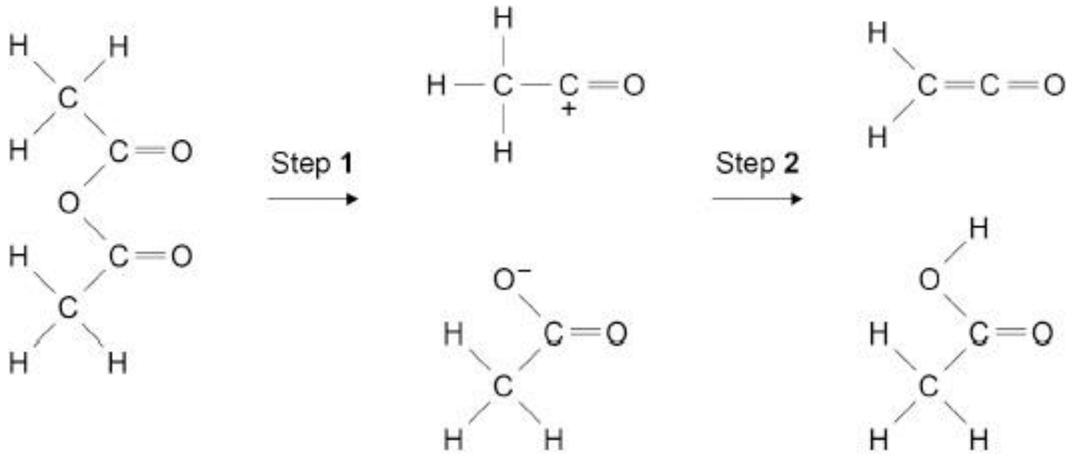
(a) Ethenone is the simplest member of the ketene homologous series. Ketenes all contain one C=C double bond and one C=O double bond.

Deduce the general formula for the ketene homologous series.

___

**(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 kJ $mol^{-1}$
the Arrhenius constant, A = $1.00 \times 10^{12}$ $s^{-1}$

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

Calculate $T_1$

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

$T_1$ ______________________ 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

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

**(5)**

**(Total 12 marks)**

**Q21.**

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.

**(Total 6 marks)**

**Mark Scheme**

## Q17.

(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) increases the collision frequency;

*(or more collisions)*
*(do not allow if stated to be due to increase in energy implied by temperature increase)* 1

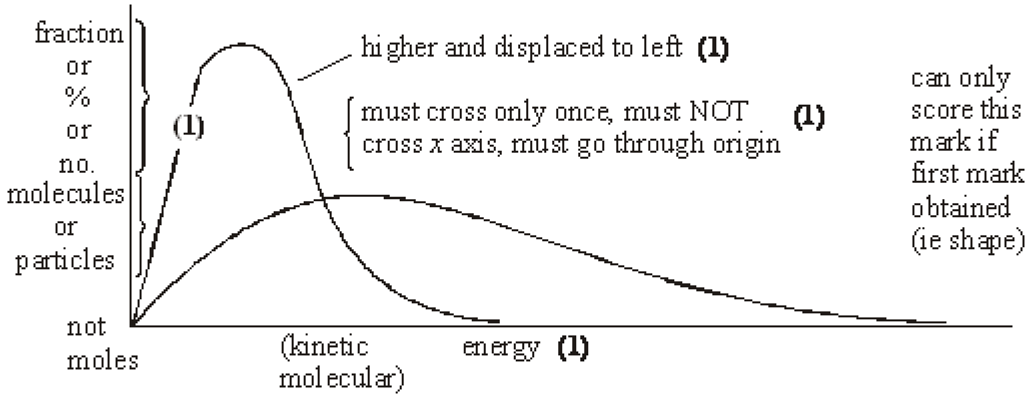
add a catalyst; 1

lowers <u>activation energy</u> (or $E_a$) *(Q of L mark);* 1

**[15]**

## Q18.

(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)**

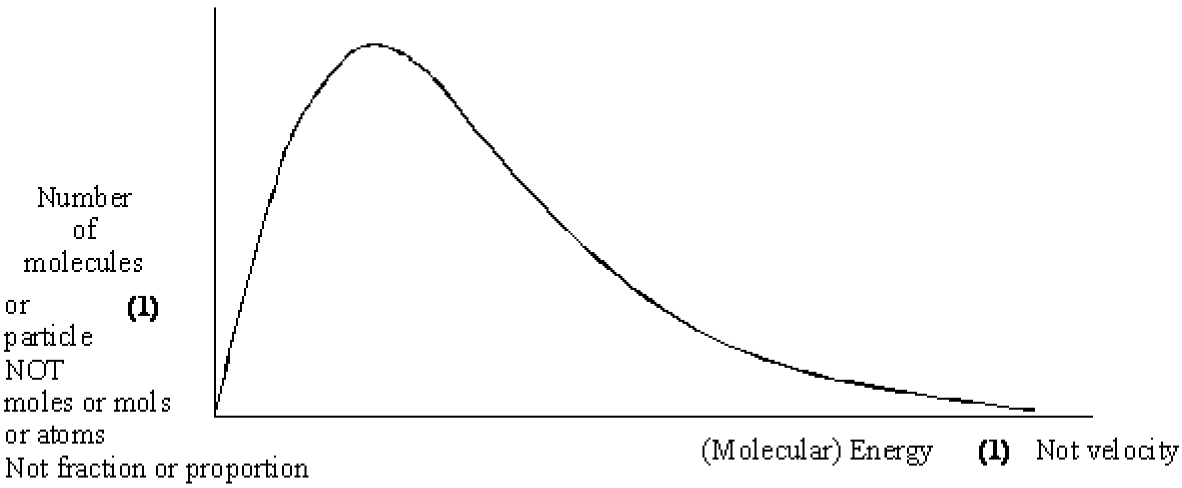
*NOT KE increases with T* 2

(f) Lowers $E_a$ **(1)**
alternative route **(1)** 2

**[10]**

## Q19.

(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**

(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]**

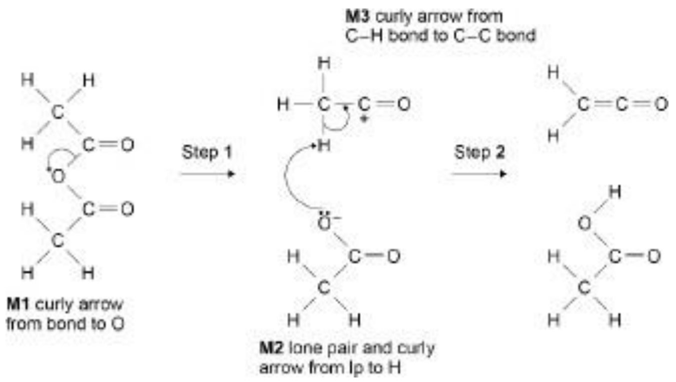
## Q20.

(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 $\frac{k}{A} = e^{-Ea/RT}$

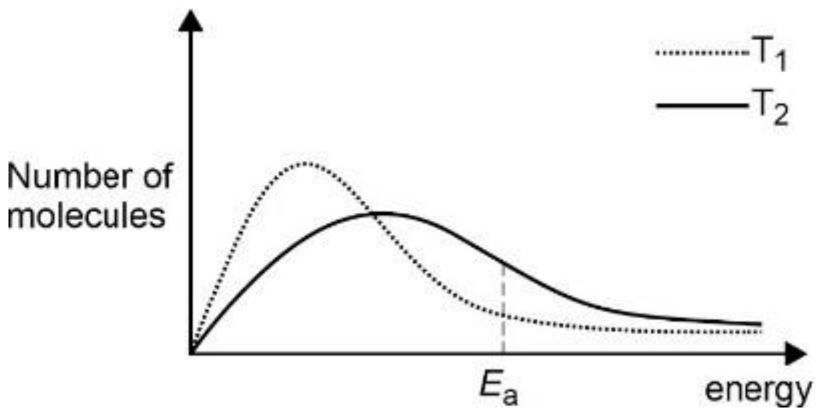
M2 $8.302 = \frac{34500}{8.31 \times T}$

M3 T = 500 K

*OR via ln k = ln A - $\frac{Ea}{RT}$ 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 Ea 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]**

## Q21.

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**<br>**5-6 marks** | **All stages are covered and each stage is generally correct and virtually complete.**<br>(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. |
| **Level 2**<br>**3-4 marks** | **All stages are covered but stage(s) may be incomplete or may contain inaccuracies OR**<br>**two stages are covered and are generally correct and virtually complete.**<br>(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. |
| **Level 1**<br>**1-2 marks** | **Two stages are covered but stage(s) may be incomplete or may contain inaccuracies OR**<br>**only one stage is covered but is generally correct and virtually complete.**<br>(2 v 1) Answer includes statements which are presented in a logical order and / or linked. |
| **Level 0**<br>**0 marks** | 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

**[6]**