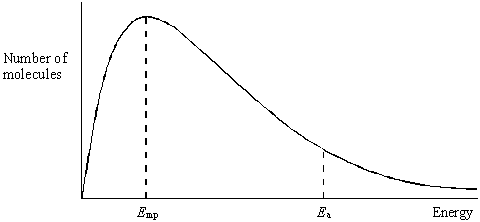
**Q1.**         (a)     State what is meant by the term *activation energy* of a reaction.

**(1)**

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

**(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

**(12)**

**(Total 15 marks)**

**Q2.**          (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?

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

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**(4)**

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

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(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* .........................................................................................

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**(5)**

**(Total 9 marks)**

**Q3.**          (a)     Define the term *activation energy* for a reaction.

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**(2)**

(b)     Give the meaning of the term *catalyst.*

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**(2)**

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

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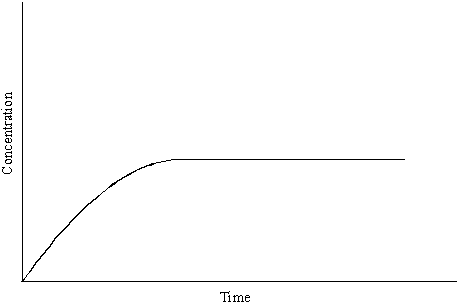
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**(2)**

(d)     In an experiment, two moles of gas **W** reacted completely with solid **Y** to form one mole of gas **Z** as shown in the equation below.

2W(g)  +  Y(s)  →  Z(g)

The graph below shows how the concentration of **Z** varied with time at constant temperature.



(i)      On the axes above, sketch a curve to show how the concentration of **W** would change with time in the same experiment. Label this curve **W**.

(ii)     On the axes above, sketch a curve to show how the concentration of **Z** would change with time if the reaction were to be repeated under the same conditions but in the presence of a catalyst. Label this curve **Z.**

(iii)     In terms of the behaviour of particles, explain why the rate of this reaction decreases with time.

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**(6)**

**(Total 12 marks)**

**Q4.**          The table below contains some standard enthalpy of formation data.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Substance | C(s) | N2(g) | H2O(g) | CO2(g) | NH4NO3(s) |
| Δ*H*f/ kJ mol–1 | 0 | 0 | –242 | –394 | –365 |

(a)     Why are the values of the standard enthalpy of formation for carbon and nitrogen zero?

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**(1)**

(b)     State Hess’s Law.

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**(2)**

(c)     Use *H*f data from the table to calculate a value for the enthalpy change for the following reaction.

NH4NO3(s)  +  C(s)  →  N2(g)  +  2H2O(g)  +  CO2(g)

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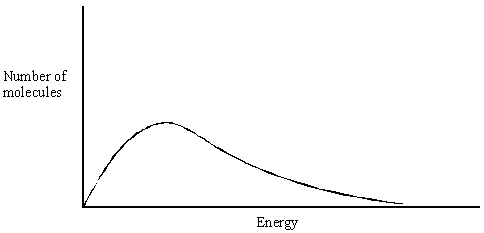
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**(3)**

**(Total 6 marks)**

**Q5.**          (a)     A sample of a gas was sealed into a flask at temperature *T* and pressure *P*. The Maxwell–Boltzmann distribution of energies for the molecules in this sample is shown below.



(i)      Using the axes above, sketch the curve that you would expect if this sample of gas at pressure *P* had been cooled. Label this curve **X**.

(ii)     Using the axes above, sketch the curve that you would expect if another sample of the same gas was sealed in the same flask at the original temperature, *T*, but at a higher pressure. Label this curve **Y**.

**(4)**

(b)     Gas **A** decomposes slowly to form gases **B** and **C**. An equilibrium is established as shown by the following equation.

          A(g)  B(g) + C(g)              Δ*H* is positive

(i)      In terms of the behaviour of molecules, state what must happen before molecules of **A** can react to form **B** and **C**.

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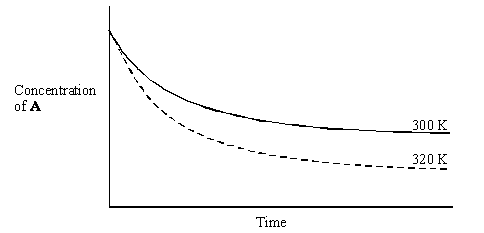
(ii)     Explain why the decomposition of **A** is faster at higher temperatures.

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**(4)**

(c)     The graphs below show how, starting from **A** alone, the concentration of **A** varies with time at temperatures of 300 K and 320 K for the reversible reaction given in part (b).



(i)      Suggest why, as shown on the graphs, the concentration of **A** remains constant after a time.

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(ii)     Explain why, at 320 K, the concentration of **A** falls to a lower value compared with the reaction at 300 K.

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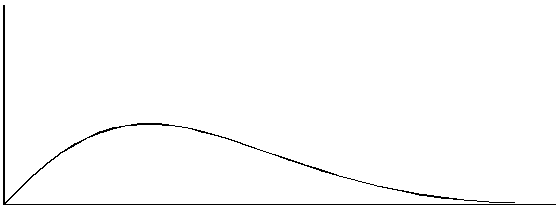
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**(3)**

**(Total 11 marks)**

**Q6.**          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.

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**(1)**

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

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**(1)**

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

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**(2)**

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

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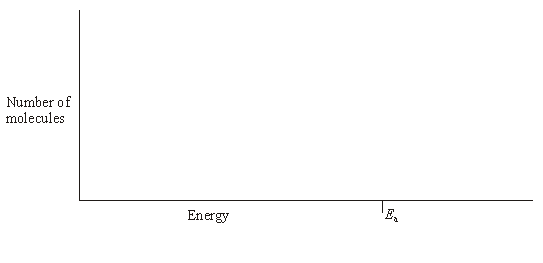
**(2)**

**(Total 10 marks)**

**Q7.**          Gas **G** decomposes as shown in the equation below.

G(g) → X(g) + Y(g)

(a)     Draw, on the axes below, a Maxwell–Boltzmann distribution curve for a sample of **G** in which only a small proportion of molecules has energy greater than the activation energy, *E*a.



**(3)**

(b)     Define the term *activation energy*.

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**(2)**

(c)     At any time, most of the molecules of **G** have energy less than the activation energy.  
Suggest why, at a constant temperature, most of **G** eventually decomposes.

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**(2)**

(d)     State the effect, if any, of adding a catalyst on the time required for **G** to decompose, compared with a similar sample without a catalyst. Explain in general terms how the catalyst has this effect.

*Time for decomposition* ...............................................................................

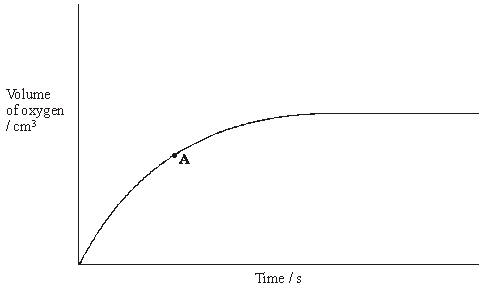
*Explanation* ..................................................................................................

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**(3)**

**(Total 10 marks)**

**Q8.**          The curve below shows how the volume of oxygen evolved varies with time when 50 cm3 of a 2.0 mol dm–3 solution of hydrogen peroxide, H2O2, decomposes at 298 K.



(a)     State how you could use the curve to find the rate of reaction at point **A**.

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**(1)**

(b)     Sketch curves, on the above axes, to illustrate how the volume of oxygen evolved would change with time if the experiment was repeated at 298 K using the following.

(i)      100 cm3 of a 1.0 mol dm–3 solution of H2O2. Label this curve **X**.

(ii)     25 cm3 of a 2.0 mol dm–3 solution of H2O2 in the presence of a catalyst.   
Label this curve **Y**.

**(4)**

(c)     Hydrogen peroxide decomposes more rapidly in the presence of aqueous hydrogen bromide. The decomposition proceeds as shown by the following equations.

          H2O2 + HBr  →  HBrO + H2O

          HBrO + H2O2 →  H2O + O2 + HBr

(i)      Write an equation for the overall reaction.

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(ii)     Define the term *catalyst*.

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(iii)     Give **two** reasons, other than an increase in the reaction rate, why these equations suggest that hydrogen bromide is behaving as a catalyst.

*Reason 1* ............................................................................................

*Reason 2* ............................................................................................

**(5)**

**(Total 10 marks)**

**Q9.**          (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)**

**Q10.**          The gas-phase reaction between hydrogen and chlorine is very slow at room temperature.

H2(g) + Cl2(g) → 2HCl(g)

(a)     Define the term *activation energy*.

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**(2)**

(b)     Give **one** reason why the reaction between hydrogen and chlorine is very slow at room temperature.

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**(1)**

(c)     Explain why an increase in pressure, at constant temperature, increases the rate of reaction between hydrogen and chlorine.

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**(2)**

(d)     Explain why a small increase in temperature can lead to a large increase in the rate of reaction between hydrogen and chlorine.

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**(2)**

(e)     Give the meaning of the term *catalyst*.

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**(1)**

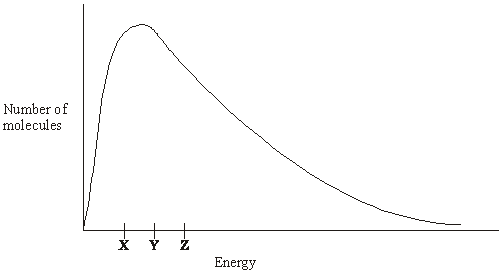
(f)      Suggest **one** reason why a solid catalyst for a gas-phase reaction is often in the form of a powder.

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**(1)**

**(Total 9 marks)**

**Q11.**          The diagram below shows the Maxwell–Boltzmann distribution of molecular energies in a sample of a gas.



(a)     (i)      State which one of **X**, **Y** or **Z** best represents the mean energy of the molecules.

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(ii)     Explain the process that causes some molecules in this sample to have very low energies.

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**(3)**

(b)     On the diagram above, sketch a curve to show the distribution of molecular energies in the same sample of gas at a higher temperature.

**(2)**

(c)     (i)      Explain why, even in a fast reaction, a very small percentage of collisions leads to a reaction.

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(ii)     Other than by changing the temperature, state how the proportion of successful collisions between molecules can be increased. Explain why this method causes an increase in the proportion of successful collisions.

*Method for increasing the proportion of successful collisions* ............

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*Explanation …*.....................................................................................

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**(4)**

**(Total 9 marks)**

**Q12.**          Kinetic studies enable chemists to suggest mechanisms for reactions.

(a)     The following data were obtained in a series of experiments on the rate of the reaction between compounds **A** and **B** at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentration of **A**/mol dm–3 | Initial concentration of **B**/mol dm–3 | Initial rate/ mol dm–3 s–1 |
| **1** | 0.12 | 0.15 | 0.32 × 10–3 |
| **2** | 0.36 | 0.15 | 2.88 × 10–3 |
| **3** | 0.72 | 0.30 | 11.52 × 10–3 |

(i)      Deduce the order of reaction with respect to **A**.

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(ii)     Deduce the order of reaction with respect to **B**.

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**(2)**

(b)     The following data were obtained in a series of experiments on the rate of the reaction between NO and O2 at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentration of NO/mol dm–3 | Initial concentration of O2/mol dm–3 | Initial rate/ mol dm–3 s–1 |
| **4** | 5.0 × 10–2 | 2.0 × 10–2 | 6.5 × 10–4 |
| **5** | 6.5 × 10–2 | 3.4 × 10–2 | To be calculated |

The rate equation for this reaction is

rate = *k*[NO]2[O2]

(i)      Use the data from Experiment **4** to calculate a value for the rate constant, *k*, at this temperature, and state its units.

*Value of k* ............................................................................................

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*Units of k .*............................................................................................

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(ii)     Calculate a value for the initial rate in Experiment **5**.

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(iii)     Using the rate equation, a scientist suggested a mechanism for the reaction which consisted of the two steps shown below.

          Step 1    NO + NO → N2O2

          Step 2    N2O2 + O2 → 2NO2

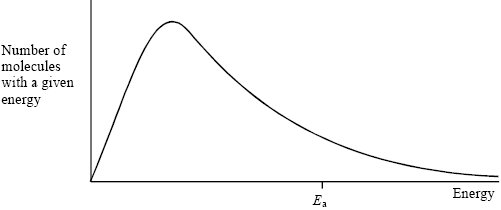
Which did the scientist suggest was the rate–determining step?

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**(5)**

**(Total 7 marks)**

**Q13.**          The diagram below shows the Maxwell–Boltzmann energy distribution curve for a sample of gas at a fixed temperature. *Ea* is the activation energy for the decomposition of this gas.



(a)     On this diagram sketch the distribution curve for the same sample of gas at a higher temperature.

**(3)**

(b)     (i)      What is the effect of an increase in temperature on the rate of a chemical reaction?  
Explain your answer with reference to the Maxwell–Boltzmann distribution.

*Effect* ..................................................................................................

*Explanation .*........................................................................................

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(ii)     What is the effect of the addition of a catalyst on the rate of a chemical reaction?  
Explain your answer with reference to the Maxwell–Boltzmann distribution.

*Effect* .................................................................................................

*Explanation* ........................................................................................

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**(6)**

**(Total 9 marks)**

**Q14.**          Sodium thiosulfate solution (Na2S2O3) reacts slowly with dilute hydrochloric acid to form a precipitate. The rate of this reaction can be studied by measuring the time (*t*) that it takes for a small fixed amount of precipitate to form under different conditions. The fixed amount of precipitate is taken as the amount needed to obscure a cross on paper.

The equation for this reaction is shown below.

Na2S2O3 + 2HCl →2NaCl + S + SO2 + H2O

(a)     Identify the insoluble product of this reaction which forms the precipitate.

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**(1)**

(b)     When this reaction takes place, the collision between the reacting particles requires an activation energy. State what is meant by the term *activation energy*.

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**(2)**

(c)     In terms of particles, explain why, at a fixed temperature, you might expect the rate of this reaction to double when the concentration of sodium thiosulfate is doubled and the concentration of hydrochloric acid remains the same.

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**(2)**

(d)     (i)      State what is meant by the term *rate of reaction*.

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**(1)**

(ii)     Consider the description of the way in which this experiment is carried out.  
Use your understanding of the term *rate of reaction* to explain why it is

possible to use a simplified formula  as a measure of the rate of **this** reaction.

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**(1)**

**(Total 7 marks)**

**Q15.**          The method of extraction of zinc has changed as different ores containing the element have been discovered and as technology has improved.

**Extraction process 1**In the earliest process, calamine (impure zinc carbonate) was heated with charcoal in earthenware pots. This two-stage process gave a low yield of zinc.

        ZnCO3(s) → ZnO(s) + CO2(g)

ZnO(s) + C(s) → Zn(s)    + CO(g)

**Extraction process 2**Deposits of calamine were being used up and a new two-stage process was developed using zinc sulfide ores. All of the waste gases from this process were released into the atmosphere.

2ZnS(s) + 3O2(g) → 2ZnO(s) + 2SO2(g)

ZnO(s) +    C(s) →      Zn(s) + CO(g)

**Extraction process 3**The modern process uses the electrolysis of aqueous solutions of very pure zinc sulfate. The first step in this process is the same as the first step in Extraction process **2**. The second step uses sulfuric acid made from the SO2 collected in the first step. The third step involves the electrolysis of zinc sulfate solution to form pure zinc.

2ZnS(s) +      3O2(g) → 2ZnO(s)      + 2SO2(g)

ZnO(s) + H2SO4(aq) →   ZnSO4(aq) +  H2O(l)

ZnSO4(aq)  Zn(s)

(a)     In the first stage of Extraction process **1** the following equilibrium is established when zinc carbonate is heated in a closed container.

ZnCO3(s)  ZnO(s) + CO2(g)

Use Le Chatelier’s principle to suggest and explain the effect on the yield of zinc oxide of allowing the carbon dioxide to escape from the container.

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**(3)**

(b)     State and explain **one** environmental reason why Extraction process **3** is an improvement over Extraction process **2**.

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**(3)**

(c)     Give **one** reason why Extraction process **3** is an expensive method of making zinc but one which is justified in terms of the product formed.

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**(2)**

(d)     Deduce the half-equation for the formation of zinc from zinc ions during the electrolysis of zinc sulfate solution and identify the electrode at which this reaction occurs.

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**(2)**

(e)     Identify **one** reaction from the three extraction processes that is **not** a redox reaction and state the type of reaction that it is. In terms of redox, state what happens to the carbon in Extraction process **2**.

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**(3)**

(f)      Zinc and magnesium both react with steam in a similar way. Write an equation for the reaction of zinc with steam and name the products of this reaction.

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**(2)**

**(Total 15 marks)**

**Q16.**          A scientist used mass spectrometry to analyse a sample of the air near a fertiliser factory. The sample of air included traces of a gas which was shown by its molecular ion to have a precise *M*r = 44.00105

(a)     State the meaning of the term *molecular ion*.

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**(1)**

(b)     (i)      Use the following data to show that the trace gas was dinitrogen oxide (N2O).

Show your working.

|  |  |
| --- | --- |
| **Atom** | **Precise relative atomic mass** |
| 12C | 12.00000 |
| 14N | 14.00307 |
| 16O | 15.99491 |

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**(1)**

(ii)     Propane is used as a fuel in the fertiliser factory. State why both propane and its combustion product, carbon dioxide, might have been identified as the trace gas if the scientist had used relative molecular masses calculated to one decimal place.

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**(1)**

(iii)     State why the precise relative atomic mass for the 12C isotope is exactly 12.00000

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**(1)**

(c)     Dinitrogen oxide is formed when ammonia is oxidised according to the following equation.

2NH3(g) + 2O2(g) → N2O(g) + 3H2O(l)

(i)      Use the standard enthalpies of formation in the table below to calculate a value for the standard enthalpy change of this reaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | NH3(g) | O2(g) | N2O(g) | H2O(l) |
| ΔHf~~ο~~/ kJ mol–1 | –46 | 0 | +82 | –286 |
|  |  |  |  |  |

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**(3)**

(ii)     State **one** condition necessary for enthalpies of formation to be quoted as standard values at a specified temperature of 298 K.

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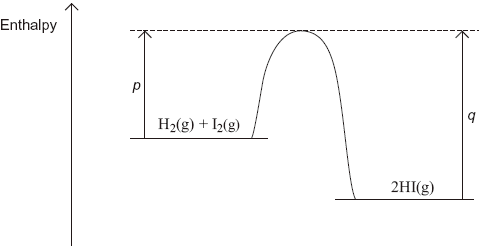
**(1)**

**(Total 8 marks)**

**Q17.**          An equation for the equilibrium reaction between hydrogen, iodine and hydrogen iodide is shown below.

H2(g) + I2(g)  2HI(g)

(a)     The curve in the diagram below illustrates the reaction profile for this equilibrium reaction without a catalyst.



(i)      Draw on the diagram a curve to illustrate the reaction profile for this equilibrium reaction **with** a catalyst.

**(2)**

(ii)     Use the diagram to deduce whether the formation of hydrogen iodide from hydrogen and iodine is exothermic or endothermic.

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**(1)**

(iii)     State what the diagram suggests about the sum of the bond enthalpies for the reactant molecules compared with the product molecules.

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**(1)**

(iv)    In terms of *p* and *q*, identify the following for this equilibrium without a catalyst.

A value for the activation energy for the forward reaction ..................

A value for the overall enthalpy change for the forward reaction

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**(2)**

(b)     A mixture of H2(g) and I2(g) was allowed to reach equilibrium.

(i)      State the effect of a catalyst on the rate of attainment of this equilibrium.

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**(1)**

(ii)     State and explain the effect of an increase in total pressure on the rate of attainment of this equilibrium.

Effect of an increase in pressure on rate ..........................................

Explanation ........................................................................................

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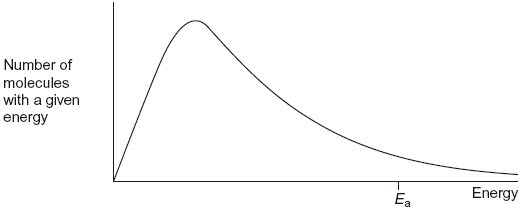
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**(3)**

**(Total 10 marks)**

**Q18.**          The diagram below shows a Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.  
*E*a is the activation energy for the decomposition of this gas.



(a)     (i)      On this diagram, sketch the distribution for the same sample of gas at a higher temperature.

**(2)**

(ii)     With reference to the Maxwell–Boltzmann distribution, explain why an increase in temperature increases the rate of a chemical reaction.

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**(2)**

(b)     Dinitrogen oxide (N2O) is used as a rocket fuel. The data in the table below show how the activation energy for the decomposition of dinitrogen oxide differs with different catalysts.

2N2O(g)  2N2(g) + O2(g)

|  |  |
| --- | --- |
|  | Ea / kJ mol–1 |
| Without a catalyst | 245 |
| With a gold catalyst | 121 |
| With an iron catalyst | 116 |
| With a platinum catalyst | 136 |

(i)      Use the data in the table to deduce which is the most effective catalyst for this decomposition.

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**(1)**

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

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**(2)**

**(Total 7 marks)**

**Q19.**          (a)     In the presence of the catalyst rhodium, the reaction between NO and H2 occurs according to the following equation.

2NO(g) + 2H2(g)  N2(g) + 2H2O(g)

The kinetics of the reaction were investigated and the rate equation was found to be

rate = *k*[NO]2[H2]

The initial rate of reaction was 6.2 × 10–6 mol dm–3 s–1 when the initial concentration of NO was 2.9 × 10–2 mol dm–3 and the initial concentration of H2 was 2.3× 10–2 mol dm–3.

(i)      Calculate the value of the rate constant under these conditions and give its units.

Calculation ..........................................................................................

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Units ....................................................................................................

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**(3)**

(ii)     Calculate the initial rate of reaction if the experiment is repeated under the same conditions but with the concentrations of NO and of H2 both doubled from their original values.

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**(1)**

(b)     Using the rate equation and the overall equation, the following three-step mechanism for the reaction was suggested. X and Y are intermediate species.

Step **1**           NO  +  NO       X

Step **2**              X  +  H2         Y

Step **3**              Y  +  H2         N2 + 2H2O

Suggest which **one** of the three steps is the rate-determining step.

Explain your answer.

Rate-determining step..................................................................................

Explanation ..................................................................................................

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*(Extra space)* ...............................................................................................

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**(2)**

**(Total 6 marks)**

**Q20.**          This question is about the extraction of titanium from titanium(IV) oxide by a two-stage  
process.  
The first stage in the process produces titanium(IV) chloride. In the second stage,  
titanium(IV) chloride is converted into titanium.  
The enthalpy change for the second stage can be determined using Hess’s Law.

(a)     Give **one** reason why titanium is **not** extracted directly from titanium(IV) oxide using carbon.

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**(1)**

(b)     Give the meaning of the term *enthalpy change*.

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**(1)**

(c)     State Hess’s Law.

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**(1)**

(d)     Define the term *standard enthalpy of formation*.

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**(3)**

(e)     The following standard enthalpy of formation data refer to the second stage in the extraction of titanium.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | TiCl4(g) | Na(I) | NaCl(s) | Ti(s) |
| Δ*H*f~~ο~~/ kJ mol–1 | –720 | +3 | –411 | 0 |
|  |  |  |  |  |

(i)      State why the value for the standard enthalpy of formation of Na(I) is **not** zero.

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**(1)**

(ii)     Use data from the table to calculate a value for the standard enthalpy change of the following reaction.

TiCl4(g) + 4Na(I)  4NaCl(s) + Ti(s)

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**(3)**

(iii)     State the role of sodium in this reaction.

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**(1)**

**(Total 11 marks)**

**Q21.**          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*.

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**(2)**

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

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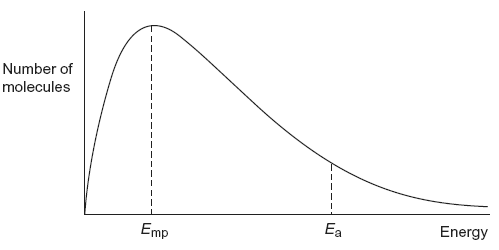
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**(2)**

(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*mpThe 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.

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**(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.

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**(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.

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**(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.

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**(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 ....................................................................

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**(2)**

(ii)     The hydration of but-2-ene.

Catalyst ..............................................................................................

Name of organic product ....................................................................

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**(2)**

**(Total 12 marks)**

**Q22.**At high temperatures and in the presence of a catalyst, sulfur trioxide decomposes according to the following equation.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2SO3(g) |  | 2SO2(g) | + | O2(g) | ∆*H*ϴ = +196 kJ mol–1 |

(a)     In an experiment, 8.0mol of sulfur trioxide were placed in a container of volume 12.0 dm3 and allowed to come to equilibrium.  
At temperature *T*1 there were 1.4 mol of oxygen in the equilibrium mixture.

(i)      Calculate the amount, in moles, of sulfur trioxide and of sulfur dioxide in the equilibrium mixture.

Amount of sulfur trioxide .......................................................................

Amount of sulfur dioxide ........................................................................

**(2)**

(ii)     Write an expression for the equilibrium constant, *K*c, for this equilibrium.

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**(1)**

(iii)    Deduce the units of *K*c for this equilibrium.

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**(1)**

(iv)     Calculate a value of *K*c for this equilibrium at temperature *T*1

(If you were unable to complete the calculations in part (a)(i) you should assume that the amount of sulfur trioxide in the equilibrium mixture was 5.8 mol and the amount of sulfur dioxide was 2.1 mol. These are **not** the correct values.)

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*(Extra space)* ........................................................................................

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**(3)**

(b)     The experiment was repeated at the same temperature using the same amount of sulfur trioxide but in a larger container.  
State the effect, if any, of this change on:

(i)      the amount, in moles, of oxygen in the new equilibrium mixture

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**(1)**

(ii)     the value of *K*c

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**(1)**

(c)     The experiment was repeated in the original container but at temperature *T*2The value of *K*c was smaller than the value at temperature *T*1State which is the higher temperature, *T*1 or *T*2Explain your answer.

Higher temperature ........................................................................................

Explanation ....................................................................................................

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*(Extra space)* .................................................................................................

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**(3)**

**(Total 12 marks)**

**Q23.**The initial rate of the reaction between two gases **P** and **Q** was measured in a series of experiments at a constant temperature. The following rate equation was determined.

rate = *k***[P]**2**[Q]**

(a)     Complete the table of data below for the reaction between **P** and **Q**.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial [**P**] /mol dm–3 | Initial [**Q**] /mol dm–3 | Initial rate /mol dm–3 s–1 |
| **1** | 0.20 | 0.30 | 1.8 = 10–3 |
| **2** | 0.40 | 0.60 |  |
| **3** | 0.60 |  | 5.4 = 10–3 |
| **4** |  | 0.90 | 12.2 = 10–3 |

*(Space for working)* .......................................................................................

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**(3)**

(b)     Use the data from Experiment **1** to calculate a value for the rate constant *k* and deduce its units.

Calculation .....................................................................................................

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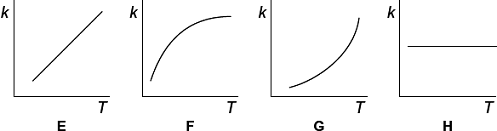
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Units ...............................................................................................................

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**(3)**

(c)     Consider the graphs **E**, **F**, **G** and **H** below.



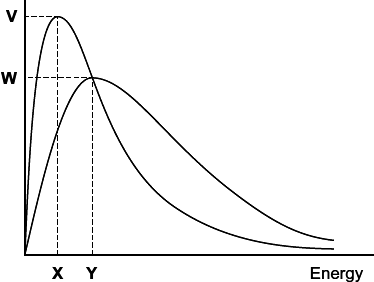
Write in the box below the letter of the graph that shows how the rate constant *k* varies with temperature.



**(1)**

**(Total 7 marks)**

**Q24.**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.

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**(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.

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**(2)**

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

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**(1)**

**(Total 6 marks)**

**Q25.**Gases **P** and **Q** react as shown in the following equation.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 2P(g) | + | 2Q(g) |  | R(g) | + | S(g) |

The initial rate of the reaction was measured in a series of experiments at a constant temperature. The following rate equation was determined.

rate = *k*[**P**]2[**Q**]

(a)     Complete the table of data for the reaction between **P** and **Q**.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial [**P**] / mol dm–3 | Initial [**Q**] / mol dm–3 | Initial rate / mol dm–3 s–1 |
| 1 | 2.5 × 10–2 | 1.8 × 10–2 | 5.0 × 10–5 |
| 2 | 7.5 × 10–2 | 1.8 × 10–2 |  |
| 3 | 5.0 × 10–2 |  | 5.0 × 10–5 |
| 4 |  | 5.4 × 10–2 | 4.5 × 10–4 |

*(Space for working)* .......................................................................................

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**(3)**

(b)     Use the data from Experiment **1** to calculate a value for the rate constant (*k*) at this temperature. Deduce the units of *k*.

Calculation .....................................................................................................

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Units ...............................................................................................................

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**(3)**

**(Total 6 marks)**

**Q26.**The manufacture of food grade phosphoric acid for use in cola drinks begins with the production of pure white phosphorus from the mineral fluoroapatite, Ca5F(PO4)3

(a)     Complete the following equation for the manufacture of phosphorus.

....Ca5F(PO4)3   +   9SiO2   +   ....C      9CaSiO3   +   CaF2   +   ....CO   +   ....P

**(1)**

(b)     As the phosphorus cools, it forms white phosphorus, P4

Give the oxidation state of phosphorus in each of the following.

P4 .............................................................

H3PO4 ......................................................

**(2)**

(c)     Fertiliser grade phosphoric acid is manufactured from sulfuric acid and calcium phosphate.  
Use the following precise relative atomic mass data to show how mass spectrometry can be used to distinguish between pure sulfuric acid (H2SO4) and pure phosphoric acid (H3PO4) which both have *M*r = 98 to two significant figures.

|  |  |
| --- | --- |
| **Atom** | **Precise relative atomic mass** |
| 1H | 1.00794 |
| 16O | 15.99491 |
| 31P | 30.97376 |
| 32S | 32.06550 |

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**(1)**

(d)     Concentrated phosphoric acid is used as a catalyst in the hydration of propene to form the alcohol CH3CH(OH)CH3 as the main organic product.  
The industrial name for this alcohol is isopropyl alcohol.

(i)      State the meaning of the term *catalyst*.

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*(Extra space)* ........................................................................................

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**(1)**

(ii)     State the meaning of the term *hydration*.

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*(Extra space)* ........................................................................................

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**(1)**

(iii)     Write an equation for the hydration of propene to form isopropyl alcohol.  
Give the IUPAC name for isopropyl alcohol.

Equation ................................................................................................

IUPAC name ..........................................................................................

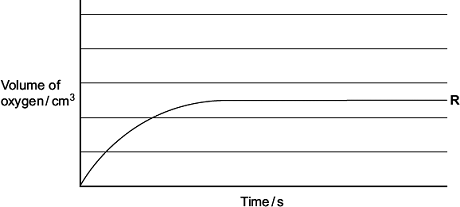
**(2)**

**(Total 8 marks)**

**Q27.**A student carried out an experiment to determine the rate of decomposition of hydrogen peroxide into water and oxygen gas.  
The student used 100 cm3 of a 1.0 mol dm–3 solution of hydrogen peroxide at 298K and measured the volume of oxygen collected.  
Curve **R**, in each of **Figures 1**, **2** and **3**, shows how the total volume of oxygen collected changed with time under these conditions.

(a)     Draw a curve on **Figure 1** to show how the total volume of oxygen collected will change with time if the experiment is repeated at 298 K using 100 cm3 of a 2.0 mol dm–3 solution of hydrogen peroxide.

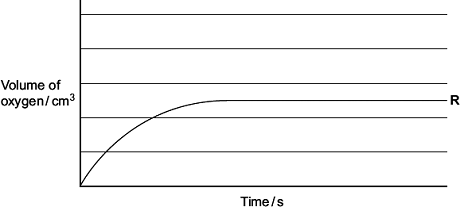
**Figure 1**



**(2)**

(b)     Draw a curve on **Figure 2** to show how the total volume of oxygen collected will change with time if the experiment is repeated at 298 K using 100 cm3 of a 0.4 mol dm–3 solution of hydrogen peroxide.

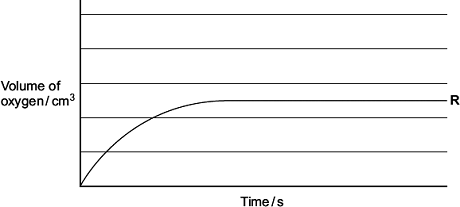
**Figure 2**



**(2)**

(c)     Draw a curve on **Figure 3** to show how the total volume of oxygen collected will change with time if the **original** experiment is repeated at a temperature higher than 298 K.  
You should assume that the gas is collected at a temperature of 298 K.

**Figure 3**



**(2)**

(d)     Explain why the slope (gradient) of curve **R** decreases as time increases.

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*(Extra space)* .................................................................................................

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**(2)**

(e)     The student discovered that hydrogen peroxide decomposes at a faster rate when a few drops of aqueous hydrogen bromide are added to the solution.  
The student found on the Internet that this decomposition is thought to proceed in two steps as shown by the following equations.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Step **1** | H2O2 | + | HBr |  | HBrO | + | H2O |  |  |
| Step **2** | HBrO | + | H2O2 |  | H2O | + | O2 | + | HBr |

(i)      Write an equation for the overall reaction.

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**(1)**

(ii)     Give **one** reason, other than the increase in rate of reaction, why the student was able to deduce that hydrogen bromide behaves as a catalyst in this two-step reaction.

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**(1)**

**(Total 10 marks)**

**Q28.**A study of equilibrium is important for understanding chemical reactions.

(a)     State le Chatelier’s principle.

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*(Extra space)* .................................................................................................

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**(1)**

(b)     Catalysts play an important role in many reactions.

(i)      State the meaning of the term *catalyst*.  
Explain, in general terms, how catalysts work.

Meaning of the term *catalyst* .................................................................

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How catalysts work ..............................................................................

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**(3)**

*(Extra space)* ........................................................................................

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(ii)     State the effect, if any, of a catalyst on the time taken to reach equilibrium.

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**(1)**

(iii)    State the effect, if any, of a catalyst on the position of an equilibrium.

...............................................................................................................

**(1)**

(c)     Consider the following equilibrium reactions.

*ΔH*ᶿ / kJ mol−1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **P** | H2(g) + l2(g) |  | 2Hl(g) |  | −10 |
| **Q** | CO2(g) + 3H2(g) |  | CH3OH(g) + H2O(g) |  | −49 |
| **R** | N2O4(g) |  | 2NO2(g) |  | +58 |
| **S** | N2(g) + 3H2(g) |  | 2NH3(g) |  | −92 |
| **T** | C2H4(g) + H2O(g) |  | CH3CH2OH(g) |  | −42 |

In each of parts (c)(i) to (c)(v), you should record in the box one of the letters, **P, Q, R, S** or **T**, that corresponds to the equilibrium that best fits the information provided.  
You may use each letter once, more than once or not at all.

(i)      A decrease in temperature at constant pressure shifts the position of this equilibrium from right to left.  
 

**(1)**

(ii)     This equilibrium uses concentrated phosphoric acid as a catalyst in a hydration reaction.  
 

**(1)**

(iii)    A decrease in pressure at constant temperature shifts the position of this equilibrium from left to right.  
 

**(1)**

(iv)    There is no change in the position of this equilibrium when the pressure is increased at constant temperature.  
 

**(1)**

(v)     An increase in the concentration of steam at constant temperature and constant pressure shifts the position of this equilibrium from right to left.  
 

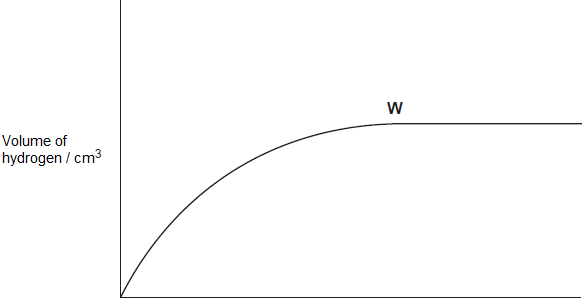
**(1)**

**(Total 11 marks)**

**Q29.**(a)     **Figure 1** shows the volume of hydrogen gas collected when a sample of magnesium reacted with an excess of dilute hydrochloric acid.

The rate of this reaction can be studied by measuring the time it takes for a given volume of hydrogen to be collected.

**Figure 1**

****

Time / s

(i)      State the meaning of the term *rate of reaction*.

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**(1)**

(ii)     State and explain what has happened to the rate of this reaction at point **W** in **Figure 1**.

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**(2)**

(iii)     In terms of collision theory explain why, at a fixed temperature, the rate of this reaction doubles when the concentration of the hydrochloric acid doubles.

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**(2)**

(b)     In a study of the reaction in part (a), a student referred to activation energy.

(i)      State the meaning of the term *activation energy*.

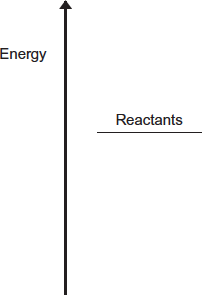
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**(1)**

(ii)     Complete **Figure 2** by drawing the shape of the reaction profile from reactants to products for an exothermic reaction.  
Show the position of the products. Show and label the activation energy.

**Figure 2**

****

**(2)**

(c)     Barium metal reacts very quickly with dilute hydrochloric acid, but it reacts more slowly with water.

(i)      Write an equation for the reaction of barium with water.

...............................................................................................................

**(1)**

(ii)     A solution containing barium ions can be used to show the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction that occurs and state what is observed.

Simplest ionic equation

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Observation

...............................................................................................................

**(2)**

(iii)     State **one** use of barium sulfate in medicine.  
Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use .......................................................................................................

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Explanation ............................................................................................

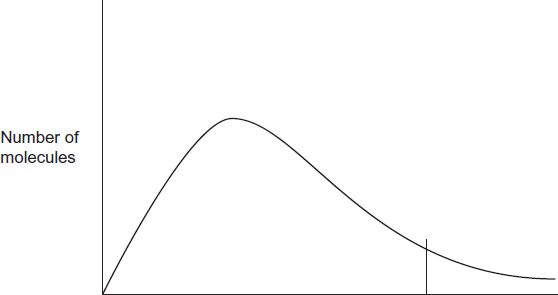
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**(2)**

**(Total 13 marks)**

**Q30.**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.



Energy Ea

*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.

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**(2)**

**(Total 5 marks)**

**M1.**          (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)**

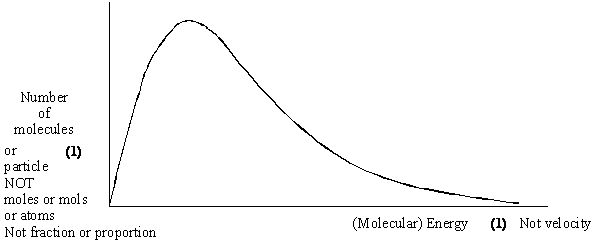
**2**

(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*  *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*  Ea decreased **(1)**Catalyst introduced:-  
                 Position of *E*mp unchanged **(1)**                 Molecules with *E*mp unchanged **(1)** Area under curve unchanged **(1)**                 Molecules with *E*  *E*a increased **(1)**

**12**

**[15]**

**M2.**          (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]**

**M3.**          (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**

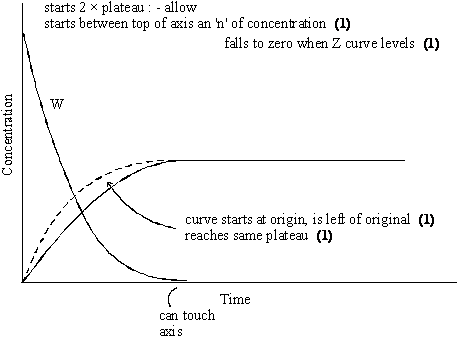
(c)     provides alternative reaction route **(1)**with a lower activation energy **(1)**

*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]**

**M4.**          (a)     They are elements **(1)**

*Ignore irrelevant comments*

**1**

(b)     Enthalpy change **(1)**

*or heat energy change or heat change or ΔH or any named enthalpy change C.E. if change not mentioned*

          Independent of route **(1)**

*OR depends on initial and final states  
Only give second mark if first mark awarded except allow if energy used instead of enthalpy*

**2**

(c)     ΔH = ΣΔHf(products) ‑ ΣΔHf(reactants) **(1) (Or a cycle)**      = 2 × –242 + ½ × –394 – (–365) **(1)** **(also implies first mark)**      = -316 kJ mol–1 **(1)**

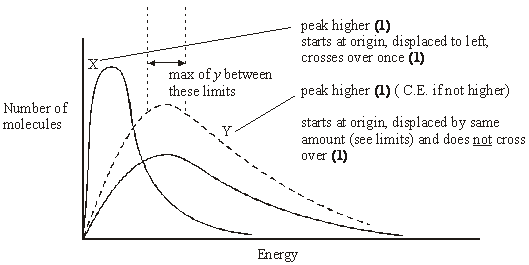
**3**

*Ignore no units penalise wrong units  
+316 scores 1/3*

**[6]**

**M5.**          (a)     (i) (ii)

**4**

****

(b)     (i)      collide **(1)**with sufficient energy (or E  Ea) **(1)** (*or with correct orientation*)

(ii)     molecules (or particles) have more energy (or move faster) **(1)**more molecules (or collisions) have E ≥ Ea (or sufficient energy) **(1)**

**4**

(c)     (i)      equilibrium reached **(1)**(or rate forward reaction = rate backward)

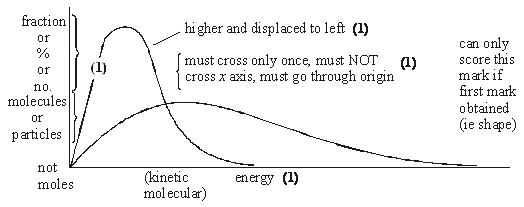
(ii)     Reaction is endothermic **(1)**or ΔH +ve  
or reverse reaction is exothermic

endothermic reaction favoured **(1)**(or reaction shifts to R  
or moves forward  
or more products formed)

**3**

**[11]**

**M6.**          (a)



**2**

(b)     See above

**2**

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

**1**

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

**1**

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

*NOT KE increases with T*

**2**

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

**2**

**[10]**

**M7.**          (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 > Ea*)

**1**

          Due to collisions

**1**

(d)     Decreases

**1**

*E*a lowered **(1)**By alternative route **(1)**So more molecules have energy > Ea **(1)**

**max 2**

**[10]**

**M8.**          (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)      2H2O2 → 2H2O + O2

**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]**

**M9.**          (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 T1 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 Ea) *(Q of L mark);*

**1**

**[15]**

**M10.**          (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]**

**M11.**          (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* >*Ea* (1)

**1**

(ii)     Add a catalyst (1)

Lowers *Ea* (1)

More collisions/molecules have energy> *Ea* (1)

**3**

**[9]**

**M12.**          (a)     (i)      2

**1**

(ii)     0

**1**

(b)     (i)      rate/[NO2]2[O2]

**1**

13

**1**

mol dm–3

**1**

(ii)     1.9 × 10–3

**1**

(iii)     Step 2

**1**

**[7]**

**M13.**          (a)     Peak lower

**1**

and moved to right

**1**

start at the origin and curve crosses once only

**1**

(b)     (i)      (Rate of reaction) increases

**1**

(At a higher temperature) more molecules/particles

**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) increases                                                                  1

         lowers activation energy                                                                         1

         so that more molecules are able to react                                              1

*Mark CE if incorrect effect given*

**[9]**

**M14.**          (a)     Sulfur OR S OR S8

*Sulphur*

**1**

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

*Mark these independently*

**1**

**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]**

**M15.**          (a)     **M1**    The yield of zinc oxide increases/greater

*If M1 is given as “decrease” OR “no effect” then CE= 0*

**M2**    Removal of the carbon dioxide results in the **equilibrium  
Either** Shifting/moving/goes to the right  
         shifting/moving/goes L to R  
         favours the forward reaction/towards the products

**M3**    (By Le Chatelier’s principle) the reaction/equilibrium will  
respond so as to replace the CO2/lost product  
OR to make more CO2OR to increase concentration of CO2

*For M3, not simply “to oppose the change/to oppose the loss of CO2/to oppose the removal of carbon dioxide.”*

**3**

(b)     **M1**    Process 2 produces/releases SO2***OR*** Process 2 produces/releases CO

**M2**    It/Process 3 avoids the release of SO2 OR CO  
***OR*** It/Process 3 (captures and) converts SO2 to H2SO4

**M3**    SO2 causes acid rain OR is toxic/poisonous  
***OR*** CO is toxic/poisonous

**3**

*Ignore “global warming” and “greenhouse gases” and “the ozone layer”*

*If both CO and SO2 claimed to form acid rain, treat as contradiction*

(c)     **M1**    Process 3 (is expensive because it) uses electrolysis  
OR due to high electricity/electrical consumption

**M2**    this is justified because the product/zinc is pure

*Ignore “energy”*

*Penalise “purer”*

**2**

(d)     **M1**    Zn2+ + 2e–  Zn

*Ignore state symbols*

**M2**    the negative electrode OR the cathode

*Ignore absence of negative charge on electron*

*Accept electrons subtracted from RHS*

**2**

(e)     **M1**    The reaction of ZnO with sulfuric acid  
OR the second reaction in Extraction process 3

**M2**    neutralisation or acid-base

OR alternatively

**M1**    The reaction of zinc carbonate in Extraction process 1

*M1 could be the equation written out in both cases*

**M2**    (thermal) decomposition

*M2 depends on correct M1*

**M3**    It/carbon is oxidised/gains oxygen/changes oxidation state/number  
from 0 to +2/increase in oxidation state/number in Process 2

***Do not forget to award this mark****Ignore reference to electron loss but penalise electron gain*

*Ignore “carbon is a reducing agent”*

**3**

(f)      **M1**    Zn + H2O  ZnO + H2

**M2**    Zinc oxide and hydrogen

OR as an alternative

**M1**    Zn + 2H2O  Zn(OH)2 + H2

**M2**    Zinc hydroxide and hydrogen

*Mark independently*

*If ZnO2 is given for zinc oxide in the equation, penalise M1 and mark on*

*If ZnOH is given for zinc hydroxide in the equation, penalise M1 and mark on*

*Ignore state symbols*

*Credit multiples of the equation*

*If M1 is blank, either of the M2 answers could score*

*To gain both marks, the names must match the correct equation given.*

**2**

**[15]**

**M16.**          (a)     The molecular ion is

•        The molecule with one/an electron knocked off/lost

*Ignore the highest or biggest m/z peak*

***OR***

•        The molecule with a (single) positive charge

***OR***

•        the ion with/it has the largest/highest/biggest m/z (value/ratio)

*Ignore “the peak to the right”*

***OR***

•        the ion with/it has an m/z equal to the *M*r

*Ignore “compound”*

**1**

(b)     (i)      2(14.00307) + 15.99491 = 44.00105

*A sum is needed to show this*

**1**

(ii)     Propane/C3H8 and carbon dioxide/CO2 (and N2O) or  
they or both the gases/molecules or all three gases/molecules  
have an (imprecise) *M*r of 44.0 (OR 44)

***OR***

they have the same ***M*r** or molecular mass (to one d.p)

*This could be shown in a calculation of relative masses for propane and carbon dioxide*

**1**

(iii)     By definition

***OR***

The standard/reference (value/isotope)

*Ignore “element”*

*Ignore “atom”*

**1**

(c)     (i)      **M1 (could be scored by a correct mathematical expression)**

ΔH = ΣΔHproducts – ΣΔHreactants

OR a correct cycle of balanced equations

**M1 and M2 can be scored with correct moles as follows**Δ*H* + 2(– 46) = +82 + 3(– 286)

Δ*H* – 92 = – 776

Δ*H* = 92 – 776 OR 92 + 82 – 858

**M3**Δ*H* = – 684 (kJ mol–1) (This is worth 3 marks)

**Award 1 mark ONLY for + 684**

*Full marks for correct answer.*

*Ignore units.*

*Deduct one mark for an arithmetic error.*

**3**

(ii)     The value is quoted at a pressure of 100 kPa OR 1 bar or 105 Pa

***OR***

All reactants and products are in their standard states/their normal  
states at 100 kPa or 1 bar

*Ignore 1 atmosphere/101 kPa*

*Ignore “constant pressure”*

**1**

**[8]**

**M17.**          (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 H2 and I2/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 H2 and I2/reactants

*Accept “It OR the sum will be smaller or less”*

**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)

***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>EAct

*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 EAct/energy of particles is stated.*

*Max 1 for M2 and M3 if reference to “atoms”*

**3**

**[10]**

**M18.**          (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 ≥ E*a

OR    more molecules have *E ≥ 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*

**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]**

**M19.**          (a)     (i)      

*mark is for insertion of numbers into a correctly*

*rearranged rate equ, k = etc*

*AE (-1) for copying numbers wrongly or swapping two numbers*

**1**

= 0.32 (min 2sfs)

**1**

mol–2 dm6 s–1 Units must be conseq to their *k*

*Any order*

*If k calculation wrong, allow units conseq to their k*

**1**

(ii)     4.95 × 10–5 to 4.97 × 10–5 or 5.0 × 10–5 (min 2 sfs)

(ignore units)

*rate = their k × 1.547 × 10–4*

**1**

(b)     Step 2

*If wrong no further mark*

**1**

One H2 (and two NO) (appear in rate equation)  
or species (in step 2) in ratio/proportion as in the rate equation

**1**

**[6]**

**M20.**          (a)     One from

•        Ti is not produced

•        TiC / carbide is produced OR titanium reacts with carbon

•        Product is brittle

•        Product is a poor engineering material

*Penalise “titanium carbonate”*

*Ignore “impure titanium”*

*Credit “titanium is brittle”*

**1**

(b)     Heat (energy) change at constant pressure

***QoL***

**1**

(c)     The enthalpy change in a reaction is independent of  
the route taken (and depends only on the initial and final states)

*Credit “heat change at constant pressure” as an alternative to “enthalpy change”*

**1**

(d)     **M1** The enthalpy change / heat change at constant pressure  
when 1 mol of a compound / substance / product

*For M1, credit correct reference to molecule/s or atom/s*

**M2** is formed from its (constituent) elements

**M3** with all reactants and products / all substances in  
standard states

OR all reactants and products / all substances in normal  
states under standard conditions / 100 kPa / 1 bar and any  
specified T (usually 298 K)

*Ignore reference to 1 atmosphere*

**3**

(e)     (i)      Na / it is not in its standard state / normal state under  
standard conditions

OR

Standard state / normal state under standard conditions  
for Na is solid / (s)

***QoL***

*Ignore “sodium is a liquid or sodium is not a solid”*

**1**

(ii)     **M1 ∆Hr = ∑∆Hf (products) - ∑∆Hf (reactants)**

**M2 ∆Hr** = 4(−411) − (−720) − 4(+3)             = −1644 + 720 − 12             (This also scores M1)

**M3**        = **−936** (kJ mol−1)

*Correct answer gains full marks*

***Credit 1 mark for + 936*** *(kJ mol−1)*

***Credit 1 mark for – 924*** *(kJ mol−1)i.e. assuming value for Na(l) = 0*

*For other incorrect or incomplete answers, proceed as follows*

*•        check for an arithmetic error (AE), which is either a         transposition error or an incorrect multiplication; this would         score 2 marks (M1 and M2)*

*•        If no AE, check for a correct method; this requires* ***either****a correct cycle with 2Cl2 and 4Na OR a* ***clear complete         statement*** *of M1 which could be in words and scores         only M1*

**3**

(iii)    Reducing agent

*Ignore “reduces titanium”*

OR reductant OR reduces TiCl4

OR electron donor

**1**

**[7]**

**M21.**          (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) H3PO4 OR (Concentrated) H2SO4

**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]**

**M22.**(a)      (i)     Mol SO3 = 5.2

**1**

Mol SO2 = 2.8

**1**

(ii)     

Penalise expression containing numbers or V

*Allow ( ) but must have all brackets. If brackets missing but otherwise correct, penalise here but mark on*

Ignore subsequent correct working

*If Kc wrong (wrong powers or upside down etc) can only score M1 in (a)(iv)*

**1**

(iii)    mol dm–3

*Allow conseq to their wrong Kc*

**1**

(iv)*If Kc wrong in (a)(iv) (wrong powers or upside down etc) can only score M1*

*Values from (a)(i)*

**   or   

*Alternative values*

**

**1**

**M1**    *For dividing all three by volume – if volume missed or used wrongly,         lose M1 & M2 but can score M3 conseq*

**M2**    *insertion of values (allow conseq use of their wrong values from (a)(i))*

*AE (–1) for copying numbers wrongly or swapping two numbers*

**1**

*Values from (a)(i)***M3**    = 0.0338 or 0.034  
         (allow 0.03376 to 0.035)  
         Min 2 sfs  
         Ignore units in (a)(iv)

*If vol missed score only M3*

*Values from (a)(i)*

*0.406 - allow values between 0.40 (if correctly rounded) and 0.41*

*Alternative values***M3**    0.0153 or 0.015  
         (allow 0.015 to 0.017)  
         Min 2 sfs  
         Ignore units in (a)(iv)

*from alternative values allow 0.18 to 0.184*

**1**

(b)     (i)     Increase or more moles (of oxygen) or higher

**1**

(ii)     No change or no effect or none or (remains) same

**1**

(c)     **M1**    T1

*If T2 CE = 0*

**1**

**M2**    (At Temp,T2, when Kc is lower) Equm/reaction moves to left or  
         towards reagent or towards SO3 OR moles SO3 increases

**1**

**M3**    This reverse reaction is exothermic,

***OR***

**M3**    (forward) reaction is endothermic

**M2**    if Temp is increased Equm/reaction moves to right or towards product  
         or towards SO2   OR moles SO2 increases

***OR***

**M3**    (forward) reaction is endothermic

**M2**    if Temp is decreased Equm/reaction moves to left or towards reagent  
         or towards SO3   OR moles SO3 increases

**1**

**[12]**

**M23.**(a)    Exp 2   14.(4) ×10–3   ***OR***   1.4(4) ×10–2   or 0.014

*Allow 2sf*

**1**

Exp 3   0.1(0)

**1**

Exp 4   0.3(0)

*If three wrong answers, check their value of k in 1(b).*

*They can score all 3 if they have used their (incorrect) value of k. see below.*

*Exp 2   rate = 0.096 × k*

*Exp 3   [****Q****] = 0.015/k*

*Exp 4   [****P****] = 0.116/√k*

**1**

(b)      

*mark is for insertion of numbers into a correctly rearranged rate equ , k = etc*

**1**

= 0.15 (min 2sfs)                   (allow )

*if upside down, score only units mark*

*AE (–1) for copying numbers wrongly or swapping two numbers*

**1**

mol–2 dm+6 s–1

*Any order*

*If k calculation wrong, allow units conseq to their k*

**1**

(c)     G

**1**

**[7]**

**M24.**(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 > Eact

***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 ≥ Eact / 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 ≥ Eact”*

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

*Accept reference to “atoms”, “molecules”, “particles”*

*Ignore “species”*

**1**

**[6]**

**M25.**(a)     Exp 2  4.5 ×10–4

*Min 2sf*

**1**

Exp 3  4.5 ×10–3

*If three wrong answers, check their value of k in (b).*

**1**

Exp 4  0.043 OR 4.3 ×10–2        OR 0.044 OR 4.4 ×10–2

*They can score all 3 if they have used their (incorrect) value of k. see below.*

*Exp 2 rate = k × (1.0125 × 10–4)*

*Exp 3 [****Q****] = 0.02/k*

*Exp 4 [****P****] = 0.0913/√k*

**1**

(b)     

*Mark is for insertion of numbers into a correctly rearranged rate equ , k = etc*

*If upside down, score only units mark from their k*

*AE (-1) for copying numbers wrongly or swapping two numbers*

**1**

= 4.4(4) (allow 40/9)

**1**

mol–2dm+6s–1

*Any order*

*If k calculation wrong, allow units conseq to their k expression*

**1**

**[6]**

**M26.**          (a)     **2**Ca5F(PO4)3+ 9SiO2 +**15**C9CaSiO3 + CaF2 +**15**CO + **6**P

**1**

(b)     **M1** (P4 =) **0**

**M2** (H3PO4 =) **(+) 5**

*Accept Roman numeral V for* ***M2***

**2**

(c)     H2SO4

***Both numbers*** *required*

*Mr*      = 2(1.00794) + 32.06550 + 4(15.99491)  
= **98.06102 or 98.0610 or 98.061 or 98.06 or 98.1**

*Calculations not required*

**and**

H3PO4

*Mr*      = 3(1.00794) + 30.97376 + 4(15.99491)  
= **97.97722 or 97.9772 or 97.977 or 97.98 or 98.0**

**1**

(d)     (i)      A substance that speeds up a reaction OR alters / increases the rate of a  
reaction **AND** is chemically unchanged at the end / not used up.

***Both ideas*** *needed*

*Ignore reference to activation energy or alternative route.*

**1**

(ii)     The addition of water (**QoL** ) to a molecule / compound

***QoL- for the underlined words***

**1**

(iii)     **M1** CH3CH=CH2 + H2O  CH3CH(OH)CH3

            (C3H6)

*For* ***M1*** *insist on correct structure for the alcohol but credit correct equations using either C3H6 or double bond not given.*

**M2** propan-2-ol

**2**

**[8]**

**M27.**          (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 O2

**2**

(d)     **M1**    The (concentration / amount of) H2O2 or reactant falls / decreases / used up

*Mark independently*

***OR***

The number of H2O2 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)      **2**H2O2 → **2**H2O + O2

*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]**

**M28.**(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 / *Ea*

***OR***lowers the activation energy / *Ea*

**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]**

**M29.**(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 ≥ Ea

***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 + **2**H2O   Ba(OH)2 + H2

*Ba + 2H2O Ba2+ + 2OH− + H2*

*Allow multiples*

*Ignore state symbols*

**1**

(ii)     M1    Ba2+ + SO42−  BaSO4

*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      BaSO4 / 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]**

**M30.**(a)    M1 On the energy axis *E*mp at the maximum of the original peak

***M1*** *The limits for the horizontal position of Emp 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* ≥ *E*a***OR*** fewer molecules have *E* ≥ *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]**