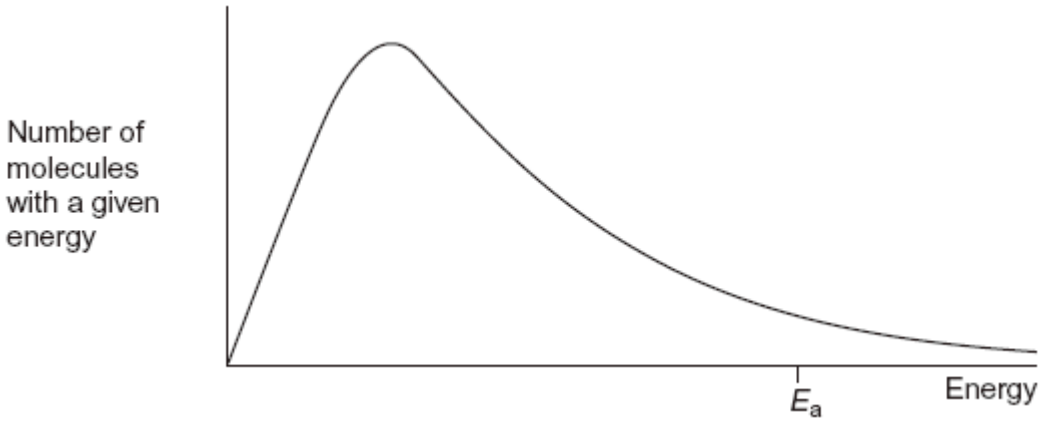
Q1. The diagram below shows a Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.
E_a is the activation energy for the decomposition of this gas.



(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.

.....

.....

.....

.....

.....

(2)

(b) Dinitrogen oxide (N_2O) 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.

$$2N_2O(g) \longrightarrow 2N_2(g) + O_2(g)$$

	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.

.....

(1)

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

.....

.....

.....

.....

(2)
(Total 7 marks)

Q2. The gas-phase reaction between hydrogen and chlorine is very slow at room temperature.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

(a) Define the term *activation energy*.

.....

.....

(2)

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

.....

.....

(1)

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

.....

.....

(2)

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

.....

.....

(2)

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

.....

.....

(1)

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

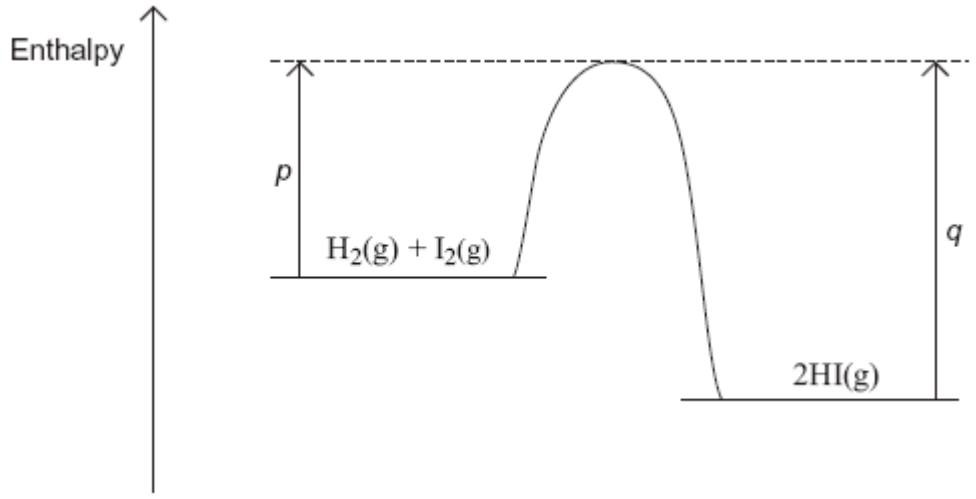
.....

(1)
(Total 9 marks)

Q3. An equation for the equilibrium reaction between hydrogen, iodine and hydrogen iodide is shown below.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(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.

.....

(1)

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

.....

.....

(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

.....

(2)

(b) A mixture of $H_2(g)$ and $I_2(g)$ was allowed to reach equilibrium.

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

.....

(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 .....

.....

.....

.....

.....

(3)
(Total 10 marks)

Q4. A method of synthesising ammonia directly from nitrogen and hydrogen was developed by Fritz Haber. On an industrial scale, this synthesis requires a high temperature, a high pressure and a catalyst and is very expensive to operate.

(a) Use the data given below to calculate a value for the enthalpy of formation of ammonia

Bond	N ≡N	H – H	N – H
Mean bond enthalpy/kJ mol^{-1}	945	436	391

(3)

(b) A manager in charge of ammonia production wished to increase the daily production of ammonia and reduce the production costs. How would a chemist explain the factors that would influence the commercial efficiency of this production process?

(8)
(Total 11 marks)

Q5. Nitric acid is manufactured from ammonia in a process that involves several stages.

(a) In the first stage, ammonia is converted into nitrogen monoxide and the following equilibrium is established.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$

The catalyst for this equilibrium reaction is a platinum–rhodium alloy in the form of a gauze. This catalyst gauze is heated initially but then remains hot during the reaction.

(i) In terms of redox, state what happens to the ammonia in the forward reaction.

.....

(1)

(ii) Suggest a reason why the catalyst must be hot.

.....

(1)

(iii) Suggest a reason why the catalyst remains hot during the reaction.

.....

(1)

(iv) State how a catalyst increases the rate of a reaction.

.....

.....

.....

.....

(2)

(b) In the second stage, nitrogen monoxide is converted into nitrogen dioxide. The equation for the equilibrium that is established is shown below.

$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -113$ kJ mol^{-1}

Explain why the equilibrium mixture is cooled during this stage of the process.

.....

.....

.....

.....

(2)

(c) In the final stage, nitrogen dioxide reacts with water as shown by the following equation.

$$2NO_2(g) + H_2O(l) \rightarrow H^+(aq) + NO_3^-(aq) + HNO_2(aq)$$

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

NO_2 .....

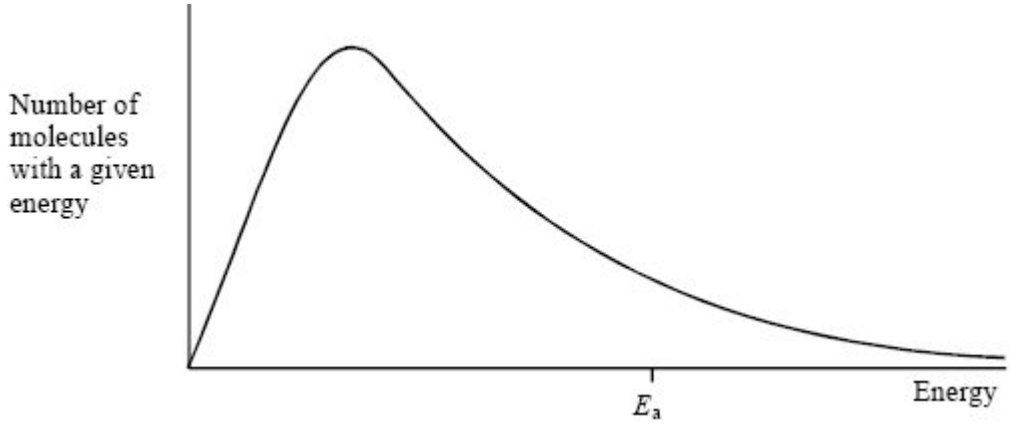
NO_3^- .....

HNO_2 .....

(3)

(Total 10 marks)

Q6. The diagram below shows the Maxwell–Boltzmann energy distribution curve for a sample of gas at a fixed temperature. E_a 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 .....

.....

.....

(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 .....

.....

.....

(6)
(Total 9 marks)