Rates and Equilibria

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

....

....
(1)

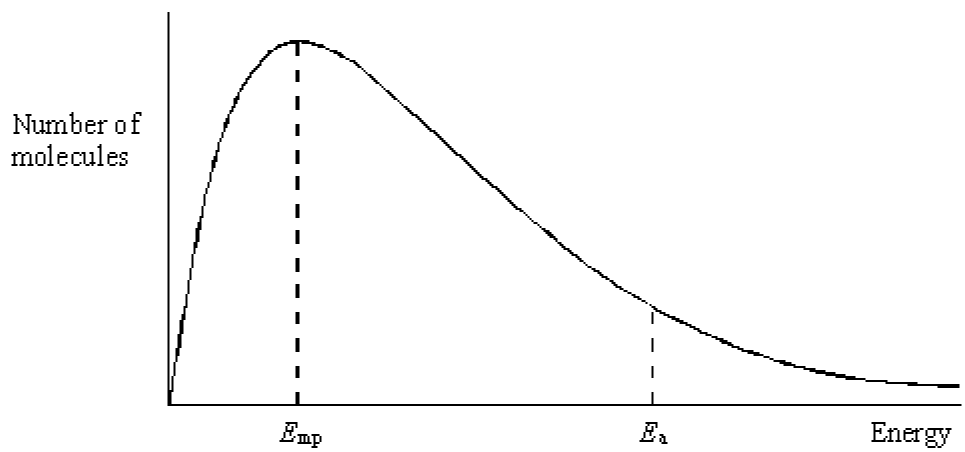
(b) State in general terms how a catalyst increases the rate of a chemical reaction.

....

....

....
(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}

(i) ....

(ii) ....

(iii) ....

- the number of molecules with the most probable energy, E_{mp}

(i) ....

(ii) ....

(iii) ....

- the area under the molecular energy distribution curve

(i) ....

(ii) ....

(iii) ....

- the number of molecules with energy greater than the activation energy, E_a

(i) ....

(ii) ....

(iii) ....

(12)
(Total 15 marks)

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

....

....

(2)

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

....

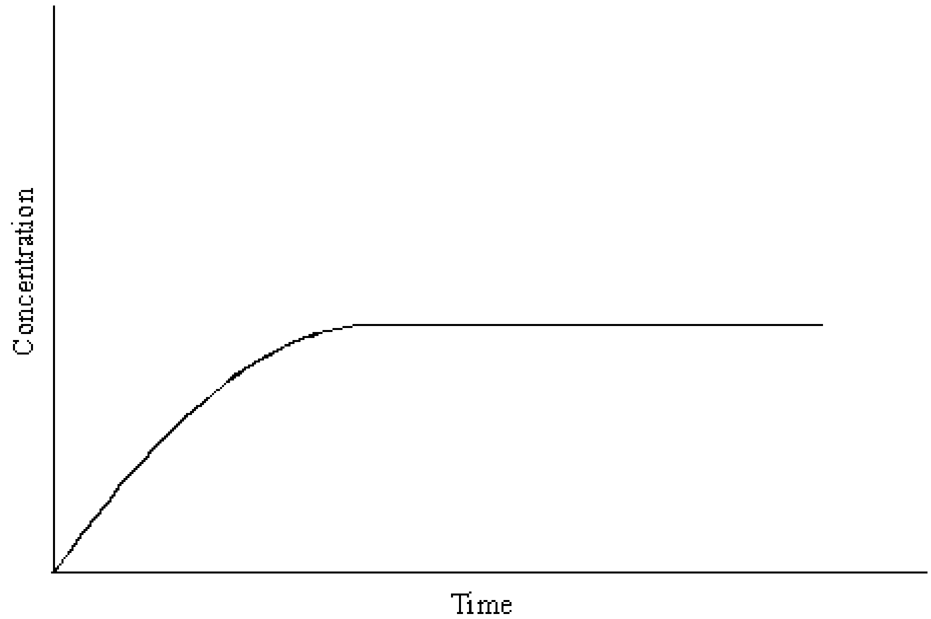
....

(2)

(c) 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.

$2W(g) + Y(s) \rightarrow Z(g)$

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.**

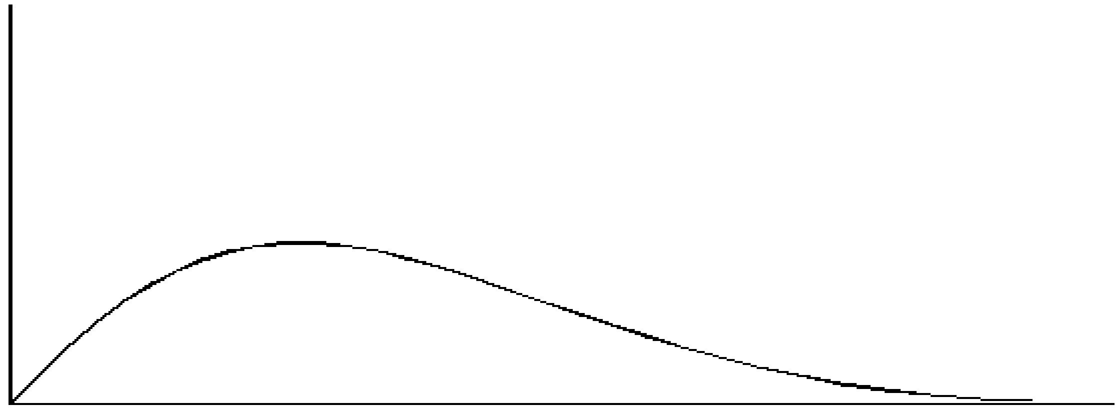
(iii) In terms of the behaviour of particles, explain why the rate of this reaction decreases with time.

....

....

(6)
(Total 10 marks)

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



(a) Label the axes on the diagram.

(2)

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

(2)

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

....

(1)

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

....

(1)

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

....

....

....

(2)
(Total 8 marks)

4. An equation for the decomposition of hydrogen peroxide is

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

(a) The rate of reaction can be determined by collecting the oxygen formed and measuring its volume at regular intervals.

Draw a diagram to show the apparatus that you would use to collect and measure the volume of the oxygen formed.

(2)

(b) Explain how you could use your results from the experiment in part (a) to determine the initial rate of this reaction.

....

....

....

....

....

(2)

(c) The rate of decomposition of hydrogen peroxide is increased by the addition of cobalt(II) ions.

Outline the essential features of an additional experiment to show that the rate of decomposition is increased by the addition of cobalt(II) chloride. Use the same method and the same apparatus as in part (a).

....

....

....

....

....

(2)
(Total 6 marks)

5. (a) The expression for an equilibrium constant, K_c, for a homogeneous equilibrium reaction is given below.

$$K_c = \frac{[A]^2[B]}{[C][D]^3}$$

(i) Write an equation for the forward reaction.

....

(ii) Deduce the units of K_c

....

(iii) State what can be deduced from the fact that the value of K_c is larger when the equilibrium is established at a lower temperature.

....

(3)

(b) A 36.8 g sample of N_2O_4 was heated in a closed flask of volume 16.0 dm^3. An equilibrium was established at a constant temperature according to the following equation.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

The equilibrium mixture was found to contain 0.180 mol of N_2O_4

(i) Calculate the number of moles of N_2O_4 in the 36.8 g sample.

....

....

(ii) Calculate the number of moles of NO_2 in the equilibrium mixture.

....

....

(iii) Write an expression for K_c and calculate its value under these conditions.

Expression for K_c ....

....

Calculation ....

....

....

....

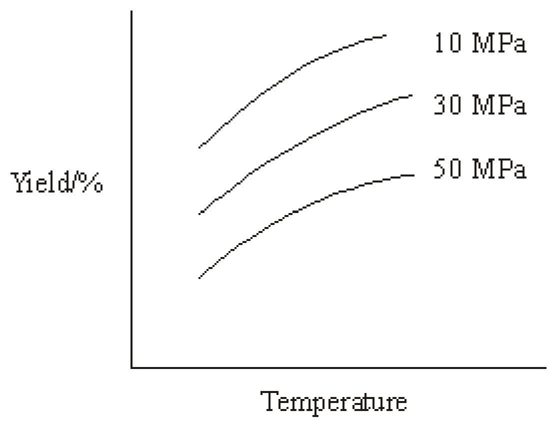
(iv) Another 36.8 g sample of N_2O_4 was heated to the same temperature as in the original experiment, but in a larger flask. State the effect, if any, of this change on the position of equilibrium and on the value of K_c compared with the original experiment.

Effect on the position of equilibrium ....

Effect on the value of K_c ....

(9)
(Total 12 marks)

6. (a) The diagram below shows the effect of temperature and pressure on the equilibrium yield of the product in a gaseous equilibrium.



(i) Use the diagram to deduce whether the forward reaction involves an increase or a decrease in the number of moles of gas. Explain your answer.

Change in number of moles ....

Explanation ....

....

....

(ii) Use the diagram to deduce whether the forward reaction is exothermic or endothermic. Explain your answer.

The forward reaction is ....

Explanation ....

....

....

(6)

(b) When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm^3, the following equilibrium was established at 700 K.

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

The equilibrium mixture was found to contain 0.023 mol of hydrogen.

(i) Calculate the number of moles of iodine and the number of moles of hydrogen iodide in the equilibrium mixture.

Number of moles of iodine..

Number of moles of hydrogen iodide…..

....

(ii) Write an expression for K_c for the equilibrium.

....

....

(iii) State why the volume of the flask need not be known when calculating a value for K_c.

....

....

(iv) Calculate the value of K_c at 700 K.

....

....

....

(v) Calculate the value of K_c at 700 K for the equilibrium

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

....

....

(7)
(Total 13 marks)

7. In the Haber Process for the manufacture of ammonia, nitrogen and hydrogen react as shown in the equation.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^\ominus = -92 \text{ kJ mol}^{-1}$$

The table shows the percentage yield of ammonia, under different conditions of pressure and temperature, when the reaction has reached dynamic equilibrium.

Temperature / K	600	800	1000
% yield of ammonia at 10 MPa	50	10	2
% yield of ammonia at 20 MPa	60	16	4
% yield of ammonia at 50 MPa	75	25	7

(a) Explain the meaning of the term *dynamic equilibrium*.

....

....

(2)

(b) Use Le Chatelier's principle to explain why, at a given temperature, the percentage yield of ammonia increases with an increase in overall pressure.

....

....

....

(3)

(c) Give a reason why a high pressure of 50 MPa is not normally used in the Haber Process.

....

(1)

(d) Many industrial ammonia plants operate at a compromise temperature of about 800 K.

(i) State and explain, by using Le Chatelier's principle, one advantage, other than cost, of using a temperature lower than 800 K.

Advantage ....

Explanation ....

....

(ii) State the major advantage of using a temperature higher than 800 K.

....

(iii) Hence explain why 800 K is referred to as a *compromise temperature*.

....

(5)
(Total 11 marks)

8. Use the information about the following solutions to answer the question below.

Solution F: This is a mixture of 1 mol of propanoic acid, 1 mol of methanol and 2 mol of water.

Solution G: This was originally the same mixture as solution **F** but it has been left to reach equilibrium.

Solution **G** was found to contain 0.5 mol of propanoic acid. Which one of the following is the value of the equilibrium constant (K_c) for the following equilibrium?

$$\text{propanoic acid + methanol} \rightleftharpoons \text{methyl propanoate + water}$$

A 0.2

B 1

C 5

D 10

(Total 1 mark)

9. Ethanoic acid reacts with ethanol in a reversible reaction represented by the equation below. In an experiment 3.0 mol of ethanoic acid were mixed with 1.0 mol of ethanol and when the reaction had reached equilibrium 0.9 mol of water had been formed.

$$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$$

The percentage of ethanoic acid converted into the ester $CH_3COOC_2H_5$ in this reaction is

A 22.5%

B 30%

C 43%

C 90%

(Total 1 mark)

10. The data below refer to the industrial production of nitric acid from ammonia.

Reaction 1 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^\ominus = -909 \text{ kJ mol}^{-1}$

Reaction 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^\ominus = -115 \text{ kJ mol}^{-1}$

Reaction 3 $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^\ominus = -117 \text{ kJ mol}^{-1}$

Possible units for the equilibrium constant, K_c, for *reaction 2* are

A $\text{mol}^{-2} \text{ m}^6$

B $\text{mol}^{-1} \text{ dm}^3$

C no units

D mol dm^{-3}

(Total 1 mark)

11. The equilibrium yield in **all three** reactions is increased when

A the pressure is increased.

B the pressure is decreased.

C the temperature is increased.

D the temperature is decreased.

(Total 1 mark)

12. When one mole of ammonia is heated to a given temperature, 50 per cent of the compound dissociates and the following equilibrium is established.

$$NH_3(g) \rightleftharpoons \tfrac{1}{2} N_2(g) + \tfrac{3}{2} H_2(g)$$

What is the total number of moles of gas present in this mixture?

A 1.5

B 2.0

C 2.5

D 3.0

(Total 1 mark)