IB · DP · Chemistry

2 hours 13 questions

Structured Questions: Paper 2

7.1 Equilibrium

7.1.1 The State of Equilibrium / 7.1.2 The Equilibrium Law / 7.1.3 Equilibrium Constant Relationships / 7.1.4 The Reaction Quotient / 7.1.5 Le Chatelier's Principle / 7.1.6 Catalysts & Equilibrium

Easy (4 questions)	/17
Medium (5 questions)	/47
Hard (4 questions)	/29
Total Marks	**/93**

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Easy Questions

1 (a) Distinguish between the terms reaction quotient, *Q*, and equilibrium constant, K_c.

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(1 mark)

(b) Write an expression for the reaction quotient, Q, for this reaction.

$$2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3\,(g)$$

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(1 mark)

(c) The equilibrium constant, K_c, for the reaction is 0.282 at temperature T whilst the reaction quotient is calculated to be 0.5.

Deduce the direction of the initial reaction.

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(1 mark)

2 (a) Urea can be made by the direct combination of ammonia and carbon dioxide gases.

$$2NH_3\,(g) + CO_2\,(g) \rightleftharpoons CO(NH_2)_2\,(g) + H_2O\,(g)$$

Write the equilibrium constant expression, K_c.

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(1 mark)

(b) $\Delta H < 0$ for the forward reaction.

Predict the effect on the equilibrium constant, K_c, when the temperature is increased.

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(1 mark)

(c) Predict what will happen to the equilibrium position if there is a decrease in pressure.

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(1 mark)

(d) The K_c value for the reaction is determined to be 2×10^{-9} mol dm^{-3} at 298 K.

Determine the magnitude of K_c if the reaction is reversed.

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(1 mark)

3 (a) The following reaction was allowed to reach equilibrium at 761 K.

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2HI\,(g) \qquad \Delta H^{\theta} < 0$$

Determine the K_c expression for this reaction.

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(1 mark)

(b) The K_c value for the reaction in part a) is found to be 48.52.

Deduce the K_c value for the following reaction.

$$\frac{1}{2}H_2\,(g) + \frac{1}{2}I_2\,(g) \rightleftharpoons HI\,(g)$$

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(1 mark)

(c) The temperature of the reaction is increased to 703K and the new K_c value is found to be 54.30.

Explain why the value of K_c has changed.

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(1 mark)

(d) A catalyst is added in an attempt to speed up the rate of reaction.

State what will happen to the value of K_c.

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(1 mark)

4 (a) State what is meant by the term *dynamic equilibrium*.

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(1 mark)

(b) Describe **two** characteristics of a reaction at equilibrium.

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(2 marks)

(c) State and explain the effect of a catalyst on the position of equilibrium.

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(2 marks)

(d) Methanoic acid reacts with methanol to form the ester methyl methanoate.

$$HCOOH\ (l) + CH_3OH\ (l) \rightleftharpoons HCOOCH_3\ (l) + H_2O\ (l)$$

The esterification reaction is exothermic. State the effect of increasing temperature on the value of the equilibrium constant (K_c) for this reaction.

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(1 mark)

Medium Questions

1 (a) Ammonia gas can be synthesized by the direct combination of nitrogen gas and hydrogen gas. When the two gases are reacted together in a sealed container the following equilibrium reaction takes place:

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g) \qquad \Delta H = -92.6\ kJ$$

Describe two characteristics of a reaction in a state of *dynamic equilibrium*.

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(2 marks)

(b) Write the equilibrium constant expression, K_c, for the reaction in part (a).

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(1 mark)

(c) Explain, with a reason, how each of the following changes can affect the position of equilibrium in part (a).

i) The volume of the container is increased.

ii) Ammonia is removed from the container.

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(4 marks)

(d) Ammonia is manufactured industrially by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the position of equilibrium and the value of K_c.

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(1 mark)

2 (a) Sulfuric acid is produced on an industrial scale in the Contact Process. The middle step of the process involves the following equilibrium reaction:

$$2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3\,(g) \qquad \Delta H = -198\ kJ$$

$K_c >> 1$ at 200 °C and 100 kPa

Outline what the information given about K_c tells you about the extent of the reaction at the conditions specified.

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(1 mark)

(b) The actual operating conditions of the Contact Process are 450 °C and 200 kPa. Explain the choice of using these operating conditions in terms of temperature and pressure.

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(4 marks)

(c) Suggest, with a reason, whether using pure oxygen instead of air would be an improvement to the Contact Process.

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(1 mark)

(d) Write the equilibrium constant expression for the **reverse** reaction of the Contact Process.

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(1 mark)

3 (a) A sample of chlorine gas is reacted with sulfur dioxide at 375 ^{o}C in a 1dm^3 container. The equilibrium reaction produces colourless sulfuryl chloride, SO_2Cl_2, and the enthalpy change for the reaction is -84 kJ mol^{-1}.

Write the equation for the reaction and deduce the equilibrium constant expression.

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(2 marks)

(b) If the reaction in part (a) is carried out at 300 ^{o}C, predict what will happen to the equilibrium concentration of SO_2Cl_2 and the value of K_c. Explain your answer.

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(3 marks)

(c) If the reaction in (a) is now carried out in a 2.00 dm^3 container, predict, with a reason what will happen to the equilibrium concentration of SO_2Cl_2 and the value of K_c.

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(3 marks)

(d) If the same reaction is carried out in part (a) with a catalyst, explain how this will affect the equilibrium concentration of SO_2Cl_2.

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(2 marks)

4 (a) A reaction mixture was set up in a syringe containing dinitrogen tetraoxide gas and nitrogen dioxide gas as shown in the equation below:

$$N_2O_4\,(g) \rightleftharpoons 2NO_2\,(g) \qquad ?H = +58\ kJ\ mol^{-1}$$

The appearance of the gases is quite different; dinitrogen tetraoxide is a pale-yellow gas, whereas nitrogen dioxide is dark brown in colour.

State why this equilibrium reaction is considered homogeneous and deduce the equilibrium constant expression for the reaction.

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(2 marks)

(b) Explain why the reaction mixture turns darker in colour when it is heated.

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(3 marks)

(c) The reaction which takes place in part (a) has a K_c value of 3.21. A student claims that increasing the temperature of this reaction will increase the value of K_c.

Is the student correct? Justify your answer.

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(3 marks)

(d) Using Le Chatelier's principle, explain what would be seen if the plunger of the syringe was pressed and the gases within the syringe were compressed.

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(3 marks)

5 (a) During an esterification reaction, methanol and ethanoic acid react together to form the ester, methyl ethanoate, and water as shown below:

$$CH_3OH\,(l) + CH_3COOH\,(l) \rightleftharpoons CH_3COOCH_3\,(l) + H_2O\,(l) \quad K_c = 7.21 \text{ at } 298K$$

A chemist sets up the reaction and allows it to reach *dynamic equilibrium* at a constant temperature.

i) State the meaning of the term *dynamic equilibrium*.

ii) Give one key condition which must be satisfied for a reversible reaction to reach dynamic equilibrium.

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(3 marks)

(b) Once the reaction in part (a) is set up, the chemist leaves it for 24 hours to make sure that it has reached equilibrium.

State how the chemist could check to make sure that the reaction mixture had reached equilibrium.

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(2 marks)

(c) When the chemist sampled the concentrations of the substances in the reaction mixture and calculated a value for the reaction quotient, she determined the value of Q to be 5.34.

i) State the meaning of the term *reaction quotient*.

ii) Deduce, with a reason, whether the reaction had reached equilibrium and what conclusion can be drawn from the value of Q.

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(3 marks)

(d) Adding more ethanoic acid to the reaction mixture will increase the yield of the ester produced.

Use Le Chatelier's principle to explain the above statement.

(3 marks)

Hard Questions

1 (a) The following dynamic equilibrium was reached at temperature, *T,* in a closed container.

$$2X\,(g) + Y\,(g) \rightleftharpoons 2Z\,(g) \qquad \Delta H = -65\ kJ\ mol^{-1}$$

The value of K_c for the reaction was 75.0 $mol^{-1}\ dm^3$ when the equilibrium mixture contained 2.97 mol of *Y* and 5.38 mol of *Z*.

i) Define dynamic equilibrium.

[2]

ii) Write an expression for K_c for the reaction.

[1]

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(3 marks)

(b) If the conditions for a closed container are changed, it can affect the concentrations of the reactants, products and K_c.

State the effect, if any, on the concentration of *Y* at equilibrium if temperature, *T,* is decreased and give a reason for your answer.

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(2 marks)

(c) Calculate the equilibrium constant for the following reaction at temperature, *T*.

$$2Z\,(g) \rightleftharpoons 2X\,(g) + Y\,(g)$$

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(1 mark)

2 (a) A 0.680 mol sample of SO_3 is introduced into a reaction container and allowed to reach equilibrium at temperature *T*.

$$2SO_3\,(g) \rightleftharpoons 2SO_2\,(g) + O_2\,(g) \qquad \Delta H = +196\ kJ\ mol^{-1}$$

The value of K_c for the reaction was 7.9×10^{-3} mol dm^{-3}.

The size of the container for the reaction is increased. State the effect if any on the equilibrium constant, K_c, and the position of equilibrium. Justify your answer.

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(4 marks)

(b) The temperature of the reaction in part (a) is increased. State the effect, if any, on the equilibrium constant, K_c, and the position of equilibrium. Justify your answer.

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(3 marks)

(c) If the value of the equilibrium constant, K_c, is 2.7×10^{-2} at temperature ***T1*** for the reaction:

$$2SO_3\,(g) \rightleftharpoons 2SO_2\,(g) + O_2\,(g)$$

Calculate the equilibrium constant, K_c, for the reaction:

$$4SO_2\,(g) + 2O_2\,(g) \rightleftharpoons 4SO_3\,(g)$$

Give your answer to 2 decimal places.

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(1 mark)

3 (a) A mixture in a container at temperature, *T*, is allowed to reach equilibrium.

$$2E\,(g) \rightleftharpoons 2F\,(g) + G\,(g) \quad \Delta H = -143\ kJ\ mol^{-1}$$

The value of K_c for the reaction at *T* is 2.98 mol dm^{-3}. Comment on the relationship between the concentration of the reactant *E* and products *F* and *G* with regards to K_c.

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(2 marks)

(b) Reactants *G* and *H* react together to form products *J* and *K* according to the equation

$$3G + H \rightleftharpoons 4J + K$$

Write the expression for the equilibrium constant, K_c.

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(1 mark)

(c) Diesters are compounds often used as synthetic lubricants for machinery such as compressors. The reaction below shows the formation of a diester from propanoic acid and propane-1,3-diol.

$$2CH_3CH_2COOH + HOCH_2CH_2CH_2OH \rightleftharpoons C_9H_{16}O_4 + 2H_2O$$

The value for K_c at temperature, *T*, is 1.29.

The forward reaction is slightly exothermic. At a different temperature, *T1*, the value for K_c increases to 22.78.

State whether the new temperature, *T1*, is higher or lower than the original temperature. Justify your answer.

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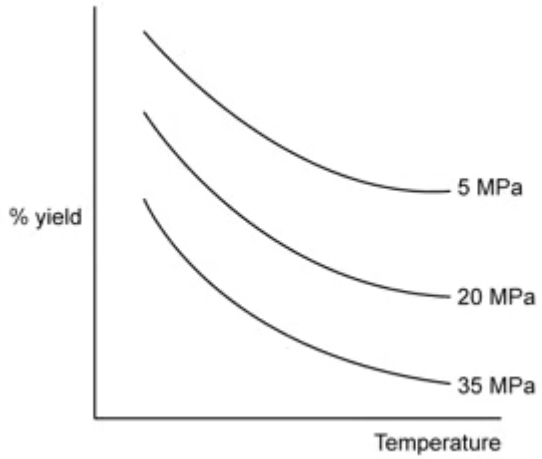
(3 marks)

4 (a) The graph below shows the effect of pressure and temperature on the equilibrium yield of gaseous molecules.



Using the graph, explain whether the forward reaction is exothermic or endothermic.

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(3 marks)

(b) Use the graph to explain whether the forward reaction will involve either an increase or decrease in the number of moles of a gas.

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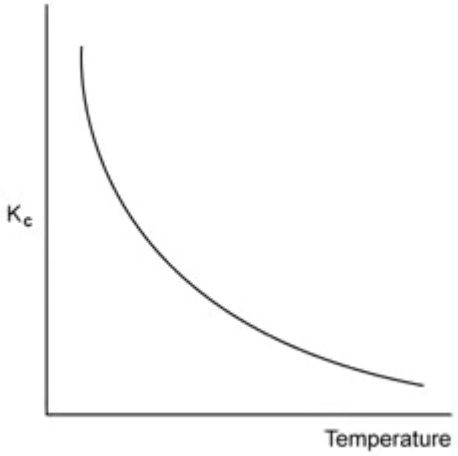
(3 marks)

(c) The graph to show the relationship between temperature and K_c for a **different** dynamic equilibrium to produce a gaseous product is shown below.



Use the information shown in the graph to establish whether the **forward reaction** is exothermic or endothermic. Justify your answer.

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(3 marks)