IB · DP · Chemistry

2 hours 12 questions

Structured Questions: Paper 2

17.1 The Equilibrium Law

Easy (4 questions)	/22
Medium (5 questions)	/40
Hard (3 questions)	/40
Total Marks	**/102**

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Easy Questions

1 (a) State Le Chatelier's principle.

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(2 marks)

(b) Sulfur trioxide, SO_3, decomposes to establish an equilibrium producing sulfur dioxide, SO_2, and oxygen as shown in the reaction.

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

State the effect on the yield of sulfur dioxide if the concentration of sulfur trioxide is increased.

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(1 mark)

(c) Give the expression for K_c for the reaction outlined in part (b).

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(1 mark)

(d) For the reaction outline in part (a), at dynamic equilibrium, the concentrations of each compound are given in the table below when the temperature is 600°C.

	SO_3	**SO_2**	**O_2**
Concentration at equilibrium ($mol\ dm^{-3}$)	0.093	0.100	0.200

Calculate the value of K_c to 3 significant figures.

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(2 marks)

2 (a) The reaction below shows the decomposition of dinitrogen tetroxide, N_2O_4, into two molecules of nitrogen dioxide, NO_2.

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

A dynamic equilibrium is reached at a temperature of 298K. The concentrations of each of the compounds at equilibrium are shown in the table below.

	N_2O_4	**NO_2**
Concentration at equilibrium (mol dm^{-3})	0.0647	0.0206

Give the expression for K_c for this reaction.

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(1 mark)

(b) Calculate a value for K_c to three significant figures.

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(2 marks)

(c) State the units for K_c for the reaction outlined in part (a).

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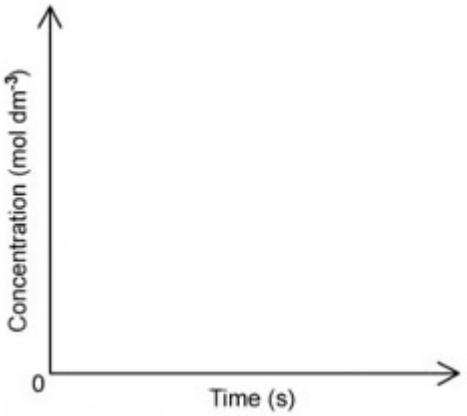
(1 mark)

(d) At the start of the reaction outlined in part (a) dinitrogen tetroxide, N_2O_4, is the only compound present.

Sketch two lines on the graph shown below to show the change in concentration for both dinitrogen tetroxide, N_2O_4, and nitrogen dioxide, NO_2 as the reaction reaches dynamic equilibrium.

You should make reference to the information given in the table in part (a).



(3 marks)

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

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

State the equilibrium constant expression, K_c , for this reaction.

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(1 mark)

(b) The following equilibrium concentrations, in mol dm^{-3} , were obtained at 761 K.

$[H_2(g)]$	$[I_2(g)]$	$[HI(g)]$
8.72×10^{-4}	2.72×10^{-3}	1.04×10^{-2}

Calculate the value of the equilibrium constant at 761 K.

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(1 mark)

(c) Determine the value of ΔG^{θ}, in kJ, for the above reaction at 761 K using section 1 of the data booklet.

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(1 mark)

(d) Comment on whether this reaction is feasible.

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(1 mark)

4 (a) Methanoic acid and methanol react to form the ester methyl methanoate and water as follows:

$$H_2COOH\ (l) + CH_3OH\ (l) \rightleftharpoons HCOOCH_3\ (l) + H_2O\ (l)$$

At 35 ^{o}C, the free energy change, ΔG, for the reaction is -3.79 kJ mol^{-1}.

Using sections 1 and 2 of the data booklet, calculate the value of K_c for this reaction to 2 decimal places.

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(2 marks)

(b) Using your answer to part (a), predict and explain the position of the equilibrium.

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(2 marks)

(c) The value for ΔG = -4.21 kJ mol^{-1} as the temperature is increased to 50°C.

State what happens to the value of the equilibrium constant.

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(1 mark)

Medium Questions

1 (a) Nitrogen(II) oxide is an atmospheric pollutant linked to acid rain. It can be formed by the combustion of fossil fuels or from the following dissociation of nitrosyl chloride.

$$2NOCl\,(g) \rightleftharpoons 2NO\,(g) + Cl_2\,(g)$$

Predict, giving your reason, the sign of the standard entropy change for the forward reaction.

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(1 mark)

(b) At 230 ^{O}C, the value of K_C for the dissociation of nitrosyl chloride is 4.5 x 10^{-3}. Describe the significance of the value of K_C.

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(1 mark)

(c) Using Sections 1 and 2 of the Data Booklet, calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction at 230 ^{O}C.

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(2 marks)

(d) At 465 ^{O}C, the value of K_C for the dissociation of nitrosyl chloride is 9.2 x 10^{-2}.

In terms of the equilibrium position, suggest how this K_C value supports the fact that the forward reaction is endothermic.

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(1 mark)

2 (a) The following reaction is used to manufacture sulfuric acid.

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

A mixture of 2.00 mol SO_2 (g) and 1.40 mol O_2 (g) is placed inside a 1.00 dm^3 flask and allowed to reach equilibrium at a temperature, T_1. At equilibrium, 0.30 mol of SO_3 (g) was present. Determine the equilibrium concentration of SO_2 (g) and O_2 (g), and hence calculate the value of K_C, including units, at this temperature.

(5 marks)

(b) Using Sections 1 and 2 of the Data Booklet and your answer to (a), calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction at a temperature of 700K.

(2 marks)

(c) Experimental data can be used to calculate the reaction quotient, Q, and the equilibrium constant, K_C.
Distinguish between these two terms.

(1 mark)

(d) 1.20 mol SO_2 (g), 1.60 mol O_2 (g) and 0.85 mol SO_3 (g) were mixed in a 1.00 dm^3 container at temperature, T_2.

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

Use your answer to (a) to deduce the direction of this reaction, showing your working.

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(2 marks)

3 (a) Carbon monoxide and chlorine react to form phosgene, $COCl_2$, according to the following equation.

$$CO\ (g) + Cl_2\ (g) \rightleftharpoons COCl_2\ (g)$$

Deduce the equilibrium constant expression, K_C, including units for this reaction.

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(2 marks)

(b) 0.50 mol CO (g) and 0.30 mol Cl_2 (g) were mixed in a 10.0 dm^3 container. At equilibrium, 0.10 mol of $COCl_2$ (g) was present. Determine the equilibrium concentration of CO (g) and Cl_2 (g), and hence calculate the value of K_C.

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(4 marks)

(c) Use Sections 1 and 2 of the Data Booklet with your answer to (b) to deduce, showing your working, the temperature of the reaction at which the standard Gibbs free energy change, $\Delta G^{\ominus}$, is -8.40 kJ.

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(3 marks)

(d) At 873 K, the standard Gibbs free energy change, $\Delta G^{\ominus}$, was found to be +11.7 kJ.

Deduce, giving your reasons, whether the forward reaction is endothermic or exothermic. Use your answer to (c).

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(2 marks)

4 (a) The following thermochemical data is for the oxidation of iron to produce iron(III) oxide at 300 K.

$$\Delta H^{\ominus} = -824.2 \text{ kJ mol}^{-1}$$

$$2Fe\ (s) + \frac{3}{2} O_2\ (g) \rightleftharpoons Fe_2O_3\ (s)$$

$$\Delta S^{\ominus} = -270.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

Explain why the enthalpy value given is the enthalpy of formation, $\Delta H^{\ominus}_f$, of iron(III) oxide.

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(1 mark)

(b) Using Section 1 of the Data Booklet, calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for the oxidation of iron to iron(III) oxide at 300 K.

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(2 marks)

(c) Use you answer to (b) and Sections 1 and 2 of the Data Booklet to calculate a value, in terms of *e*, for K_C for this reaction at 300 K.

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(3 marks)

(d) Use your answer to (c) to explain why the following oxidation of iron to iron(III) oxide at 300 K can be considered to be irreversible.

$$2Fe\ (s) + \frac{3}{2} O_2\ (g) \rightleftharpoons Fe_2O_3\ (s)$$

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(1 mark)

5 (a) Ethanol and ethanoic acid react to form ethyl ethanoate according to the following equation.

$$C_2H_5OH + CH_3COOH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

0.47 mol of ethanol and 0.25 mol of ethanoic acid were mixed in a 5.0 dm^3 container and left to reach equilibrium. At equilibrium, there was found to be 0.28 mol of ethanol. Calculate the number of moles of the remaining chemicals at equilibrium.

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(2 marks)

(b) The reaction is performed in a 5.0 dm^3 container.

Deduce the equilibrium constant expression, K_C, for the reaction of ethanol and ethanoic acid and explain why the number of moles can be used directly in your expression.

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(2 marks)

(c) Using your answer to part (b), calculate, showing your working, a value for the equilibrium constant expression, K_C, for the reaction of ethanol and ethanoic acid.

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(1 mark)

(d) A second experiment reacting ethanol and ethanoic acid was performed. Analysis showed the equilibrium mixture to contain 0.16 mol ethanoic acid, 0.11 mol ethyl ethanoate and 0.12 mol water. Calculate the number of moles of ethanol in the equilibrium mixture.

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(2 marks)

Hard Questions

1 (a) A 0.680 mol sample of SO_3 is introduced into a 3.04 dm^3 reaction container and allowed to reach equilibrium at temperature *T*.
32% of the SO_3 had decomposed.

Calculate the value for K_c in this reaction, giving your answer to 2 significant figures.

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

(6 marks)

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

(4 marks)

(c) 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.

(3 marks)

(d) Comment on whether the reaction in part (a) is likely to take place spontaneously at temperature *T*.

(2 marks)

2 (a) A mixture of 1.32 moles of *E*, 1.49 moles of *F* and 0.752 moles of *G* were placed into a 5.0 dm^3 container at temperature, *T*, and allowed to reach equilibrium. At equilibrium, the number of moles of *E* was 1.86.

Calculate the value of the equilibrium constant, K_c , to 3 significant figures.

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

(5 marks)

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

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

A beaker contained 35 cm^3 of 0.18 mol dm^{-3} of an aqueous solution of *G*.

8.41 x 10^{-3} moles of *H* and 3.1 x 10^{-3} moles of *J* were also added to the beaker. The equilibrium mixture contained 4.1 x 10^{-3} moles of *G*.

Calculate the number of moles of *H*, *J* and *K* at equilibrium.

(5 marks)

(c) Using sections 1 and 2 of the data booklet, calculate the equilibrium constant at 300 K for the oxidation of iron:

$$2Fe(s) + \frac{3}{2} O_2(g) \rightarrow Fe_2O_3(s)$$

$$\Delta H^{\ominus} = -824.2 \text{ kJ mol}^{-1}$$

$$\Delta S^{\ominus} = -270.5 \text{ J mol}^{-1}$$

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(3 marks)

(d) Suggest what the value for K_c calculated in part (c) suggests about the equilibrium position for the oxidation of iron.

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(1 mark)

3 (a) 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.

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

At equilibrium, the reaction mixture contained 3.25 moles of CH_3CH_2COOH, 1.15 moles of $HOCH_2CH_2CH_2OH$, and 1.18 moles of $C_9H_{16}O_4$.

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

Calculate the concentration of water in the reaction mixture at equilibrium. Give your answer to 3 significant figures.

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(3 marks)

(b) A student deduced that in order to calculate the value of K_c for the reaction in part (a) you must work out the concentrations using the overall volume.

Is the student correct? Justify your answer.

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(2 marks)

(c) Using sections 1 and 2 of the data booklet, determine the value for ΔG for the reverse reaction in part(a) given that temperature T= 30°C. Give your answer, in kJ, to 2 significant figures.

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(2 marks)

(d) The reverse reaction in part (a) is slightly endothermic. At a different temperature, T_2, the value for ΔG decreases to -0.52 kJ mol^{-1}.

State whether the new temperature, T_2, is higher or lower than the original temperature. Justify your answer.

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(4 marks)