IB · DP · Chemistry

3 hours 25 questions

Structured Questions

How Far? The Extent of Chemical Change

The Characteristics of Dynamic Equilibrium / The Equilibrium Law / The Equilibrium Constant / Le Chatelier's Principle / The Reaction Quotient (HL) / Equilibrium Law Problem Solving (HL) / The Equilibrium Constant & Gibbs Energy (HL)

Easy (8 questions)	/39
Medium (10 questions)	/87
Hard (7 questions)	/69
Total Marks	**/195**

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Easy Questions

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

.....

(1 mark)

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

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

.....

(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.

.....

(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.

.....

(1 mark)

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

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

.....

(1 mark)

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

.....

(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.

.....

(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.

.....

(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.

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

.....

(1 mark)

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

Explain why the value of K_c has changed.

.....

(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.

.....

(1 mark)

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

.....

(1 mark)

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

.....

.....

(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)

5 (a) State Le Chatelier's principle.

.....

.....

(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.

.....

(1 mark)

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

.....

(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.

.....

.....

(2 marks)

6 (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.

.....

(1 mark)

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

.....

.....

(2 marks)

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

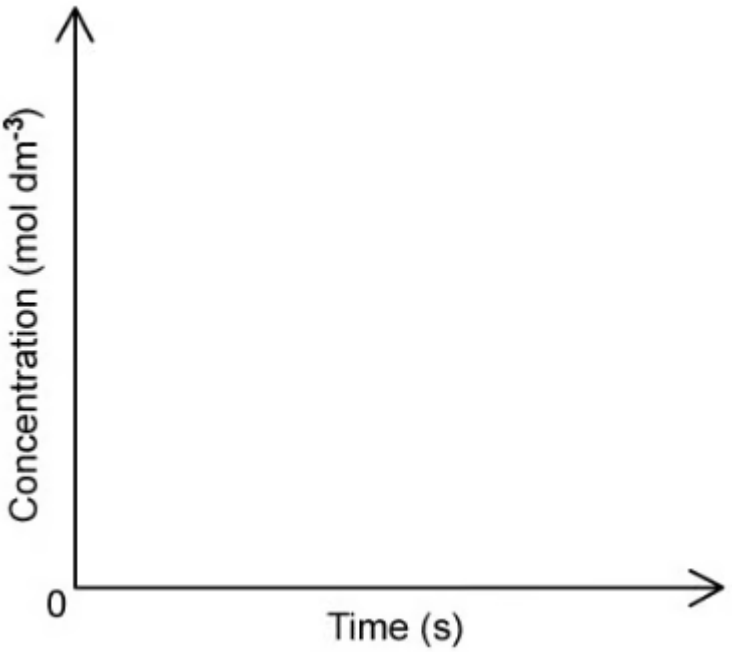
.....

(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)

7 (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.

.....

(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.

.....

(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.

.....

(1 mark)

(d) Comment on whether this reaction is feasible.

.....

(1 mark)

8 (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.

.....

(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. [2]

ii) Ammonia is removed from the container.

[2]

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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:

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

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*.

[2]

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

[1]

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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*.

[1]

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

[2]

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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.

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(3 marks)

6 (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)

7 (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)

8 (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.

(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.

(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.

(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)

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

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

- $\Delta H^{\ominus}$ = -824.2 kJ mol^{-1}
- $\Delta S^{\ominus}$ = -270.5 J K^{-1} mol^{-1}

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

(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.

(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.

(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.

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

(1 mark)

10 (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.

(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.

(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.

(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.

(2 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*.

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

.....

(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.

(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.

(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.

(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.

.....

(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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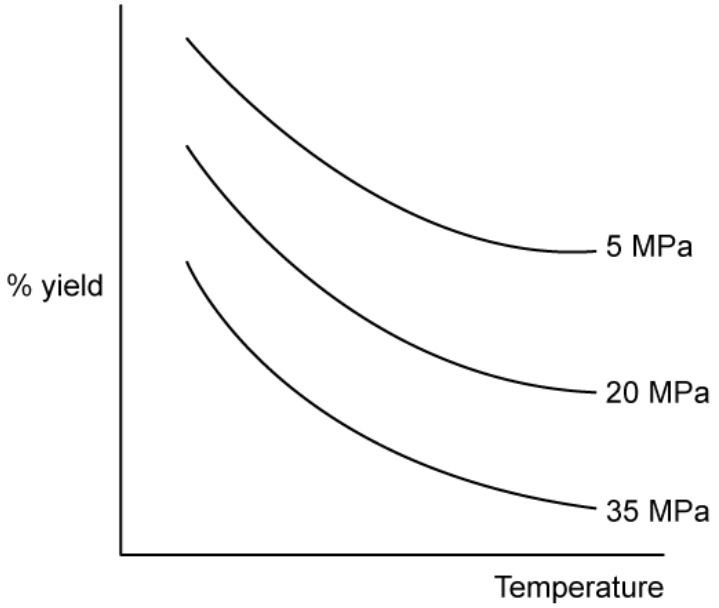
(3 marks)

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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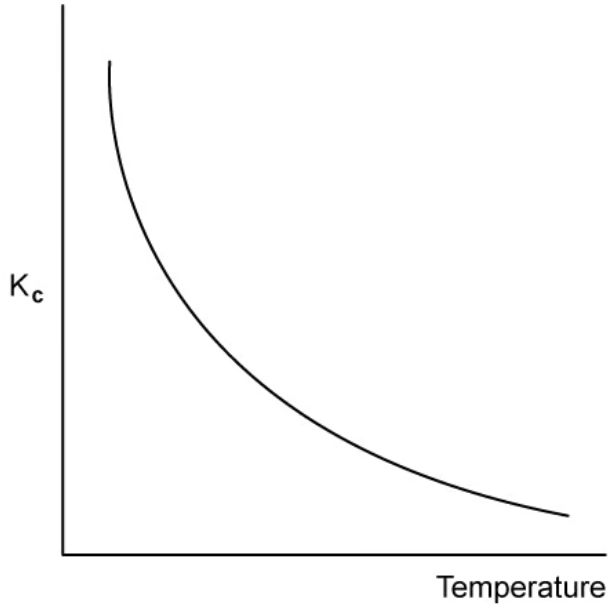
(3 marks)

(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)

5 (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 decreased. 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*.

.....

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(2 marks)

6 (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:

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

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

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

(3 marks)

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

(1 mark)

7 (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.

(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.

(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.

(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.

(4 marks)