Q1. Sulphur dioxide and oxygen were mixed in a 2:1 mol ratio and sealed in a flask with a catalyst.
The following equilibrium was established at temperature T_1

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

The partial pressure of sulphur dioxide in the equilibrium mixture was 24 kPa and the total pressure in the flask was 104 kPa.

(a) Deduce the partial pressure of oxygen and hence calculate the mole fraction of oxygen in the equilibrium mixture.

Partial pressure of oxygen .....

Mole fraction of oxygen .....

.....

.....

(3)

(b) Calculate the partial pressure of sulphur trioxide in the equilibrium mixture.

.....

(1)

(c) Write an expression for the equilibrium constant, K_p, for this reaction. Use this expression to calculate the value of K_p at temperature T_1 and state its units.

Expression for K_p .....

.....

Calculation .....

.....

.....

Units .....

(4)

(d) When equilibrium was established at a different temperature, T_2, the value of K_p was found to have increased. State which of T_1 and T_2 is the lower temperature and explain your answer.

Lower temperature.....

Explanation .....

.....

(3)

(e) In a further experiment, the amounts of sulphur dioxide and oxygen used, the catalyst and the temperature, T_1, were all unchanged, but a flask of smaller volume was used.

Deduce the effect of this change on the yield of sulphur trioxide and on the value of K_p.

Effect on yield of SO_3 .....

Effect on K_p .....

.....

(2)
(Total 13 marks)

Q2. The following information concerns the equilibrium gas-phase synthesis of methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

At equilibrium, when the temperature is 68 °C, the total pressure is 1.70 MPa. The number of moles of CO, H_2 and CH_3OH present are 0.160, 0.320 and 0.180, respectively.

Thermodynamic data are given below.

Substance	$\Delta H_f^\ominus$ / kJ mol^{-1}	$S^\ominus$ / J K^{-1} mol^{-1}
CO(g)	−110	198
H_2(g)	0	131
CH_3OH(g)	−201	240

The mole fraction of hydrogen in the equilibrium mixture is

A 0.242

B 0.485

C 0.653

D 0.970

(Total 1 mark)

Q3. This question relates to the equilibrium gas-phase synthesis of sulphur trioxide:

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

Thermodynamic data for the components of this equilibrium are:

Substance	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$SO_3(g)$	−396	+257
$SO_2(g)$	–297	+248
$O_2(g)$	0	+204

This equilibrium, at a temperature of 585 K and a total pressure of 540 kPa, occurs in a vessel of volume 1.80 dm^3. At equilibrium, the vessel contains 0.0500 mol of $SO_2(g)$, 0.0800 mol of $O_2(g)$ and 0.0700 mol of $SO_3(g)$.

At equilibrium in the same vessel of volume 1.80 dm^3 under altered conditions, the reaction mixture contains 0.0700 mol of $SO_3(g)$, 0.0500 mol of $SO_2(g)$ and 0.0900 mol of $O_2(g)$ at a total pressure of 623 kPa. The temperature in the equilibrium vessel is

A 307 °C

B 596 K

C 337 °C

D 642 K

(Total 1 mark)

Q4. This question relates to the equilibrium gas-phase synthesis of sulphur trioxide:

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

Thermodynamic data for the components of this equilibrium are:

Substance	$\Delta H_f^\ominus$ / kJ mol^{-1}	$S^\ominus$ / J K^{-1} mol^{-1}
$SO_3(g)$	−396	+257
$SO_2(g)$	–297	+248
$O_2(g)$	0	+204

This equilibrium, at a temperature of 585 K and a total pressure of 540 kPa, occurs in a vessel of volume 1.80 dm^3. At equilibrium, the vessel contains 0.0500 mol of $SO_2(g)$, 0.0800 mol of $O_2(g)$ and 0.0700 mol of $SO_3(g)$.

Possible units for the equilibrium constant K_p include

A no units

B kPa

C Mpa^{-1}

D kPa^{-2}

(Total 1 mark)

Q5. The following information concerns the equilibrium gas-phase synthesis of methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

At equilibrium, when the temperature is 68 °C, the total pressure is 1.70 MPa. The number of moles of CO, H_2 and CH_3OH present are 0.160, 0.320 and 0.180, respectively.

Thermodynamic data are given below.

Substance	$\Delta H_f^\ominus$ / kJ mol^{-1}	$S^\ominus$ / J K^{-1} mol^{-1}
CO(g)	−110	198
$H_2(g)$	0	131
$CH_3OH(g)$	−201	240

Possible units for the equilibrium constant, K_p, for this reaction are

A no units

B kPa

C MPa^{-1}

D kPa^{-2}

(Total 1 mark)

Q6. This question relates to the equilibrium gas-phase synthesis of sulphur trioxide:

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

Thermodynamic data for the components of this equilibrium are:

Substance	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$SO_3(g)$	−396	+257
$SO_2(g)$	–297	+248
$O_2(g)$	0	+204

This equilibrium, at a temperature of 585 K and a total pressure of 540 kPa, occurs in a vessel of volume 1.80 dm^3. At equilibrium, the vessel contains 0.0500 mol of $SO_2(g)$, 0.0800 mol of $O_2(g)$ and 0.0700 mol of $SO_3(g)$.

The mole fraction of SO_3 in the equilibrium mixture is

A 0.250

B 0.350

C 0.440

D 0.700

(Total 1 mark)

Q7. This question relates to the equilibrium gas-phase synthesis of sulphur trioxide:

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

Thermodynamic data for the components of this equilibrium are:

Substance	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$SO_3(g)$	−396	+257
$SO_2(g)$	–297	+248
$O_2(g)$	0	+204

This equilibrium, at a temperature of 585 K and a total pressure of 540 kPa, occurs in a vessel of volume 1.80 dm^3. At equilibrium, the vessel contains 0.0500 mol of $SO_2(g)$, 0.0800 mol of $O_2(g)$ and 0.0700 mol of $SO_3(g)$.

With pressures expressed in MPa units, the value of the equilibrium constant, K_p, is

A 4.90

B 6.48

C 9.07

D 16.8

(Total 1 mark)

Q8. (a) The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.

$2W(g) + X(g) \rightleftharpoons 3Y(g) + 2Z(g) \qquad \Delta H = -200 \text{ kJ mol}^{-1}$

Write an expression for the equilibrium constant, K_p, for this reaction.
State one change in the conditions which would both increase the rate of reaction and decrease the value of K_p. Explain your answers.

(7)

(b) Ethyl ethanoate can be prepared by the reactions shown below.

Reaction 1

$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l) \qquad \Delta H^{\ominus} = -2.0 \text{ kJ mol}^{-1}$

Reaction 2

$CH_3COCl(l) + C_2H_5OH(l) \rightarrow CH_3COOC_2H_5(l) + HCl(g) \qquad \Delta H^{\ominus} = -21.6 \text{ kJ mol}^{-1}$

(i) Give one advantage and one disadvantage of preparing ethyl ethanoate by **Reaction 1** rather than by **Reaction 2**.

(ii) Use the information given above and the data below to calculate values for the standard entropy change, $\Delta S^{\ominus}$, and the standard free-energy change, $\Delta G^{\ominus}$, for **Reaction 2** at 298 K.

	$CH_3COCl(l)$	$C_2H_5OH(l)$	$CH_3COOC_2H_5(l)$	$HCl(g)$
$S^{\ominus}$/JK^{1}mol^{1}	201	161	259	187

(8)
(Total 15 marks)

Q9. When a mixture of 0.345 mol of PCl_3 and 0.268 mol of Cl_2 was heated in a vessel of fixed volume to a constant temperature, the following reaction reached equilibrium.

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g) \qquad \Delta H^{\ominus} = -93 \text{ kJ mol}^{-1}$$

At equilibrium, 0.166 mol of PCl_5 had been formed and the total pressure was 225 kPa.

(a) (i) Calculate the number of moles of PCl_3 and of Cl_2 in the equilibrium mixture.

Moles of PCl_3 .....

Moles of Cl_2 .....

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

.....

(3)

(b) Calculate the mole fraction and the partial pressure of PCl_3 in the equilibrium mixture.

Mole fraction of PCl_3 .....

.....

Partial pressure of PCl_3 .....

.....

(3)

(c) (i) Write an expression for the equilibrium constant, K_p, for this equilibrium.

.....

.....

(ii) The partial pressures of Cl_2 and PCl_5 in the equilibrium mixture were 51.3 kPa and 83.6 kPa, respectively, and the total pressure remained at 225 kPa. Calculate the value of K_p at this temperature and state its units.

.....

.....

.....

(4)

(d) State the effect on the mole fraction of PCl_3 in the equilibrium mixture if

(i) the volume of the vessel were to be increased at a constant temperature,

.....

(ii) the temperature were to be increased at constant volume.

.....

(2)
(Total 12 marks)

Q10. At high temperatures, SO_2Cl_2 dissociates according to the following equation.

$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$ $\Delta H^{\ominus} = +93 \text{ kJ mol}^{-1}$

When 1.00 mol of SO_2Cl_2 dissociates, the equilibrium mixture contains 0.75 mol of Cl_2 at 673 K and a total pressure of 125 kPa.

(a) Write an expression for the equilibrium constant, K_p, for this reaction.

.....

.....

(1)

(b) Calculate the total number of moles of gas present in the equilibrium mixture.

.....

(2)

(c) (i) Write a general expression for the partial pressure of a gas in a mixture of gases in terms of the total pressure.

.....

.....

(ii) Calculate the partial pressure of SO_2Cl_2 and the partial pressure of Cl_2 in the equilibrium mixture.

Partial pressure of SO_2Cl_2 .....

.....

Partial pressure of Cl_2 .....

.....

(5)

(d) Calculate a value for the equilibrium constant, K_p, for this reaction and give its units.

.....

.....

.....

(3)

(e) State the effect, if any, of an increase in temperature on the value of K_p for this reaction.
Explain your answer.

Effect on K_p .....

Explanation .....

.....

(2)

(f) State the effect, if any, of an increase in the total pressure on the value of K_p for this reaction.

.....

(1)
(Total 14 marks)