**Q1.**          Hydrogen and carbon monoxide were mixed in a 2:1 mole ratio. The mixture was allowed to reach equilibrium according to the following equation at a fixed temperature and a total pressure of 1.75 × 104 kPa.

2H2(g)   +   CO(g)      CH3OH(g)

(a)     The equilibrium mixture contained 0.430 mol of carbon monoxide and 0.0850 mol of methanol.

(i)      Calculate the number of moles of hydrogen present in the equilibrium mixture.

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(ii)     Hence calculate the mole fraction of hydrogen in the equilibrium mixture.

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(iii)     Calculate the partial pressure of hydrogen in the equilibrium mixture.

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**(5)**

(b)     In a different mixture of the three gases at equilibrium, the partial pressure of carbon monoxide was 7550 kPa, the partial pressure of hydrogen was 12300 kPa and the partial pressure of methanol was 2710 kPa.

(i)      Write an expression for the equilibrium constant, *K*p, for this reaction.

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(ii)     Calculate the value of the equilibrium constant, *K*p, for the reaction under these conditions and state its units.

*K*p ........................................................................................................

.............................................................................................................

*Units* ....................................................................................................

**(3)**

(c)     Two isomeric esters **E** and **F** formed from methanol have the molecular formula C6H12O2

Isomer **E** has only 2 singlet peaks in its proton n.m.r. spectrum.

Isomer **F** is optically active.

Draw the structures of these two isomers.

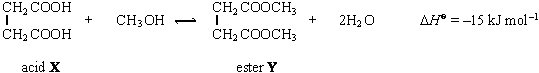
*Isomer* ***E***

*Isomer* ***F***

**(2)**

**(Total 10 marks)**

**Q2.**          Acid **X** reacts with methanol to form ester **Y** according to the following equation.



A mixture of 0.25 mol of **X** and 0.34 mol of methanol was left to reach equilibrium in the presence of a small amount of concentrated sulphuric acid. The equilibrium mixture thus formed contained 0.13 mol of **Y** in a total volume of *V* dm3.

(a)     Name **X**.

......................................................................................................................

**(1)**

(b)     Using **X** to represent the acid and **Y** to represent the ester, write an expression for the equilibrium constant, *K*c, for this reaction.

**(1)**

(c)     Calculate the number of moles of **X**, the number of moles of methanol and the number of moles of water in the equilibrium mixture.

*Moles of* **X .**..................................................................................................

*Moles of methanol* .......................................................................................

*Moles of water …*..........................................................................................

**(3)**

(d)     State why the volume *V* need not be known in calculating the value of *K*c for the reaction.

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**(1)**

(e)     Calculate the value of *K*c for this reaction and deduce its units.

*Calculation* ...................................................................................................

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*Units of K*c .....................................................................................................

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**(3)**

(f)      State the effect, if any, of increasing the temperature on the value of *K*c

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**(1)**

**(Total 10 marks)**

**Q3.**          Nitrogen dioxide dissociates according to the following equation.

2NO2(g)    2NO(g)  +  O2(g)

When 21.3 g of nitrogen dioxide were heated to a constant temperature, *T*, in a flask of volume 11.5 dm3, an equilibrium mixture was formed which contained 7.04 g of oxygen.

(a)     (i)      Calculate the number of moles of oxygen present in this equilibrium mixture and deduce the number of moles of nitrogen monoxide also present in this equilibrium mixture.

*Number of moles Of O2 at equilibrium* .................................................

.............................................................................................................

*Number of moles of NO at equilibrium* .................................................

(ii)     Calculate the number of moles in the original 21.3 g of nitrogen dioxide and hence calculate the number of moles of nitrogen dioxide present in this equilibrium mixture.

*Original number of moles of NO2* ................................................................

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*Number of moles of NO2 at equilibrium* ...............................................

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**(4)**

(b)     Write an expression for the equilibrium constant, *K*c, for this reaction. Calculate the value of this constant at temperature T and give its units.

*Expression for Kc* ..........................................................................................

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*Calculation* ....................................................................................................

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**(4)**

(c)     The total number of moles of gas in the flask is 0.683. Use the ideal gas equation to determine the temperature *T* at which the total pressure in the flask is 3.30 × 105 Pa.   
(The gas constant *R* = 8.31 J K–1mol–1)

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**(3)**

(d)     State the effect on the equilibrium yield of oxygen and on the value of Kc when the same mass of nitrogen dioxide is heated to the same temperature *T*, but in a different flask of greater volume.

*Yield of oxygen* .............................................................................................

*Value of Kc* ....................................................................................................

**(2)**

**(Total 13 marks)**

**Q4.**          (a)     A flask containing a mixture of 0.200 mol of ethanoic acid and 0.110 mol of ethanol was maintained at 25 °C until the following equilibrium had been established.

CH3COOH(l) + C2H5OH(l)    CH3COOC2H5(l) + H2O(l)

The ethanoic acid present at equilibrium required 72.5 cm3 of a 1.50 mol dm–3 solution of sodium hydroxide for complete reaction.

(i)      Calculate the value of the equilibrium constant, *K*c, for this reaction at 25 °C.

(ii)     The enthalpy change for this reaction is quite small. By reference to the number and type of bonds broken and made, explain how this might have been predicted.

**(9)**

(b)     Aspirin can be prepared by acylation using either ethanoyl chloride or ethanoic anhydride, as represented by the equations shown below.

CH3COCl + HOC6H4COOH → CH3COOC6H4COOH + HCl

(CH3CO)2O + HOC6H4COOH → CH3COOC6H4COOH + CH3COOH

(i)      By a consideration of the intermolecular forces involved, explain why the product HCl is a gas but the product CH3COOH is a liquid at room temperature.

(ii)     Give **two** industrial advantages of using ethanoic anhydride rather than ethanoyl chloride in the manufacture of aspirin.

**(4)**

**(Total 13 marks)**

**Q5.**          When a mixture of 0.345 mol of PCl3 and 0.268 mol of Cl2 was heated in a vessel of fixed volume to a constant temperature, the following reaction reached equilibrium.

PCl3(g)   +   Cl2(g)      PCl5(g)           *H* = –93 kJ mol–1

At equilibrium, 0.166 mol of PCl5 had been formed and the total pressure was 225 kPa.

(a)     (i)      Calculate the number of moles of PCl3 and of Cl2 in the equilibrium mixture.

*Moles of PCl3* ......................................................................................

*Moles of Cl2 ..*.......................................................................................

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

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**(3)**

(b)     Calculate the mole fraction and the partial pressure of PCl3 in the equilibrium mixture.

*Mole fraction of PCl3* .....................................................................................

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*Partial pressure of PCl3* ................................................................................

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**(3)**

(c)     (i)      Write an expression for the equilibrium constant, *K*p, for this equilibrium.

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(ii)     The partial pressures of Cl2 and PCl5 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.

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**(4)**

(d)     State the effect on the mole fraction of PCl3 in the equilibrium mixture if

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

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

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**(2)**

**(Total 12 marks)**

**Q6.**          At high temperatures, SO2Cl2 dissociates according to the following equation.

SO2Cl2(g)    SO2(g)  +  Cl2(g)               Δ*H* = +93 kJ mol–1

When 1.00 mol of SO2Cl2 dissociates, the equilibrium mixture contains 0.75 mol of Cl2 at 673 K and a total pressure of 125 kPa.

(a)     Write an expression for the equilibrium constant, *K*p, for this reaction.

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**(1)**

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

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**(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.

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(ii)     Calculate the partial pressure of SO2Cl2 and the partial pressure of Cl2 in the equilibrium mixture.

*Partial pressure of SO2Cl2* ...................................................................

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*Partial pressure of Cl2 .*.........................................................................

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**(5)**

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

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**(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 Kp* ..................................................................................................

*Explanation* ..................................................................................................

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**(2)**

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

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**(1)**

**(Total 14 marks)**

**Q7.**          (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)    3Y(g)  +  2Z(g)        Δ*H* = –200 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**CH3COOH(l) + C2H5OH(l)    CH3COOC2H5(l) + H2O(l)      ∆*H* = –2.0 kJ mol–1

**Reaction 2**CH3COCl(l) + C2H5OH(l) → CH3COOC2H5(l) + HCl(g)            ∆*H* = –21.6 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, ∆*S*, and the standard free-energy change, ∆*G*, for **Reaction 2** at 298 K.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | CH3COCl(l) | C2H5OH(l) | CH3COOC2H5(l) | HCl(g) |
| *S*/JK1mol1 | 201 | 161 | 259 | 187 |

**(8)**

**(Total 15 marks)**

**Q8.**          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

2SO2(g) + O2(g)    2SO3(g)              Δ*H* =  –196 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* ................................................................................

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**(3)**

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

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**(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 .........................................................................….............

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*Calculation* .................................................................................…...............

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*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 SO3* ...................................................…............................

*Effect on K*p ...................................................................................................

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**(2)**

**(Total 13 marks)**

**Q9.**          Tetrafluoroethene, C2F4, is obtained from chlorodifluoromethane, CHClF2, according to the equation:

2CHClF2(g)  C2F4(g) + 2HCl(g)             Δ*H*~~ο~~ = +128kJ mol–1

(a)     A 1.0 mol sample of CHClF2 is placed in a container of volume 18.5 dm3 and heated.

When equilibrium is reached, the mixture contains 0.20 mol of CHClF2

(i)      Calculate the number of moles of C2F4 and the number of moles of HCl present at equilibrium.

*Number of moles of C2F4* ...................................................................

*Number of moles of HCl* .....................................................................

(ii)     Write an expression for *K*c for the equilibrium.

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(iii)     Calculate a value for *K*c and give its units.

*Calculation* ..........................................................................................

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*Units* ....................................................................................................

**(6)**

(b)     (i)      State how the temperature should be changed at constant pressure to increase the equilibrium yield of C2F4

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(ii)     State how the total pressure should be changed at constant temperature to increase the equilibrium yield of C2F4

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**(2)**

(c)     C2F4 is used to manufacture the polymer polytetrafluoroethene, PTFE. Name the type of polymerisation involved in the formation of PTFE.

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**(1)**

**(Total 9 marks)**

**Q10.**         (a)     State and explain the effect of a catalyst on the rate and on the equilibrium yield in a reversible reaction.

**(5)**

(b)     Explain the terms *heterogeneous* and *active sites* as applied to a catalyst. Give **two** reasons why a ceramic support is used for the catalyst in catalytic converters in cars. Explain how lead poisons this catalyst.

**(7)**

(c)     In aqueous solution, Fe2+ ions act as a homogeneous catalyst in the reaction between   
I– and ions. Give **one** reason why the reaction is slow in the absence of a catalyst. Write equations to show how Fe2+ ions act as a catalyst for this reaction.

**(5)**

**(Total 17 marks)**

**Q11.**          The manufacture of methanol can be achieved in two stages.

(a)     In the first stage, methane and steam react according to the following equation.

CH4(g) + H2O(g)  CO(g) + 3H2(g)                           ∆*H*~~ο~~= +210 kJ mol–1

Discuss, with reasons, the effects of increasing separately the temperature and the pressure on the yield of the products and on the rate of this reaction.

**(6)**

(b)     In the second stage, carbon monoxide and hydrogen react according to the following equation.

CO(g) + 2H2(g)  CH3OH(g)

A 62.8 mol sample of carbon monoxide was added to 146 mol of hydrogen. When equilibrium was reached at a given temperature, the mixture contained 26.2 mol of methanol at a total pressure of 9.50 MPa.

Write an expression for the equilibrium constant, *K*p, for this reaction. Calculate a value for *K*p at this temperature and give its units.

**(8)**

**(Total 14 marks)**

**Q12.**         (a)     The expression for an equilibrium constant, *K*c, for a homogeneous equilibrium reaction is given below.



(i)      Write an equation for the forward reaction.

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(ii)     Deduce the units of *K*c

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(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.

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**(3)**

(b)     A 36.8 g sample of N2O4 was heated in a closed flask of volume 16.0 dm3. An equilibrium was established at a constant temperature according to the following equation.

N2O4(g)  2NO2(g)

The equilibrium mixture was found to contain 0.180 mol of N2O4

(i)      Calculate the number of moles of N2O4 in the 36.8 g sample.

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(ii)     Calculate the number of moles of NO2 in the equilibrium mixture.

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(iii)     Write an expression for *K*c and calculate its value under these conditions.

*Expression for Kc* .................................................................................

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*Calculation* ..........................................................................................

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(iv)    Another 36.8 g sample of N2O4 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)**

**Q13.**          A sealed flask containing gases **X** and **Y** in the mole ratio 1:3 was maintained at 600 K until the following equilibrium was established.

X(g) + 3Y(g)  2Z(g)

The partial pressure of **Z** in the equilibrium mixture was 6.0 MPa when the total pressure was 22.0 MPa.

(a)     (i)      Write an expression for the equilibrium constant, *K*p, for this reaction.

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(ii)     Calculate the partial pressure of **X** and the partial pressure of **Y** in the equilibrium mixture.

*Partial pressure of* ***X*** ...........................................................................

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*Partial pressure of* ***Y*** ............................................................................

(iii)     Calculate the value of *K*p for this reaction under these conditions and state its units.

*Value of K*p ..........................................................................................

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*Units of K*p ...........................................................................................

**(6)**

(b)     When this reaction is carried out at 300 K and a high pressure of 100 MPa, rather than at 600 K and 22.0 MPa, a higher equilibrium yield of gas **Z** is obtained.

Give two reasons why an industrialist is unlikely to choose these reaction conditions.

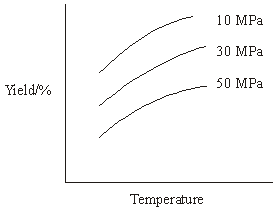
*Reason 1* .....................................................................................................

*Reason 2* .....................................................................................................

**(2)**

**(Total 8 marks)**

**Q14.**          (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* .........................................................................................

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

*The forward reaction is* .......................................................................

*Explanation* .........................................................................................

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**(6)**

(b)     When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm3, the following equilibrium was established at 700 K.

2HI(g)   H2(g) + I2(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*…................................................

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(ii)     Write an expression for *K*c for the equilibrium.

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

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(iv)    Calculate the value of *K*c at 700 K.

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

H2(g) + I2(g)  2HI(g)

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**(7)**

**(Total 13 marks)**

**Q15.**          Carbon monoxide and hydrogen are used in the manufacture of methanol. An equilibrium is established according to the following equation.

                                    Cu catalyst  
CO(g)   +   2H2(g)            CH3OH(g)                      ∆*H* = –9l kJ mol–1

(a)     Give **two** features of a reaction at equilibrium.

Feature 1 .....................................................................................................

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Feature 2 ......................................................................................................

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**(2)**

(b)     Explain why an increase in temperature causes a decrease in the equilibrium yield of methanol.

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**(2)**

(c)     (i)      State what is meant by the term *catalyst*.

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**(1)**

(ii)     State the effect, if any, of the copper catalyst on the position of this equilibrium at a fixed temperature.

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**(1)**

(d)     Two methods are used to produce carbon monoxide from natural gas. Equations for these two methods are shown below.

Method 1         CH4 + H2O → 2CO + 3H2

Method 2         CH4 + CO2 → 2CO + 2H2

The manufacture of methanol from these sources of carbon monoxide has been described as carbon neutral.

(i)      ......................................................................................................................

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**(1)**

(ii)     Show how combining the equations from these two methods can lead to the 1:2 mol ratio of carbon monoxide to hydrogen required for this synthesis of methanol.

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**(1)**

**(Total 8 marks)**

**Q16.**          A mixture was prepared using 1.00 mol of propanoic acid, 2.00 mol of ethanol and 5.00 mol of water. At a given temperature, the mixture was left to reach equilibrium according to the following equation.

CH3CH2COOH + CH3CH2OH  CH3CH2COOCH2CH3 + H2O       ∆*H*~~ο~~= –22 kJ mol–1

The equilibrium mixture contained 0.54 mol of the ester ethyl propanoate.

(a)     (i)      Calculate the amounts, in moles, of propanoic acid, of ethanol and of water in this equilibrium mixture.

Moles of propanoic acid ......................................................................

Moles of ethanol .................................................................................

Moles of water ....................................................................................

**(3)**

(ii)     Write an expression for the equilibrium constant, *K*c, for this equilibrium.

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**(1)**

(iii)     Calculate a value for *K*c for this equilibrium at this temperature. Explain why this *K*c value has no units.

Calculation ..........................................................................................

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Explanation .........................................................................................

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**(3)**

(b)     For this equilibrium, predict the effect of an increase in temperature on each of the following.

(i)      the amount, in moles, of ester at equilibrium

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**(1)**

(ii)     the time taken to reach equilibrium

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**(1)**

(iii)     the value of *K*c

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**(1)**

**(Total 10 marks)**

**Q17.**          The reaction of methane with steam produces hydrogen for use in many industrial processes. Under certain conditions the following reaction occurs.

CH4(g) + 2H2O(g)  CO2(g) + 4H2(g)             ∆*H*~~ο~~= +165 kJ mol–1

(a)     Initially, 1.0 mol of methane and 2.0 mol of steam were placed in a flask and heated with a catalyst until equilibrium was established. The equilibrium mixture contained 0.25 mol of carbon dioxide.

(i)      Calculate the amounts, in moles, of methane, steam and hydrogen in the equilibrium mixture.

Moles of methane ...............................................................................

Moles of steam …................................................................................

Moles of hydrogen ..............................................................................

**(3)**

(ii)     The volume of the flask was 5.0 dm3. Calculate the concentration, in mol dm–3, of methane in the equilibrium mixture.

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**(1)**

(b)     The table below shows the equilibrium concentration of each gas in a different equilibrium mixture in the same flask and at temperature *T*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| gas | CH4(g) | H2O(g) | CO2(g) | H2(g) |
| concentration / mol dm–3 | 0.10 | 0.48 | 0.15 | 0.25 |

(i)      Write an expression for the equilibrium constant, *K*c, for this reaction.

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**(1)**

(ii)     Calculate a value for *K*c at temperature *T* and give its units.

Calculation ..........................................................................................

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Units of *K*c ............................................................................................

**(3)**

(c)The mixture in part (b) was placed in a flask of volume greater than 5.0 dm3 and allowed to reach equilibrium at temperature *T*.  
State and explain the effect on the amount of hydrogen.

Effect on amount of hydrogen .....................................................................

Explanation ..................................................................................................

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**(3)**

(d)Explain why the amount of hydrogen decreases when the mixture in part (b)reaches equilibrium at a lower temperature.

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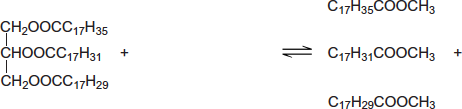
**(2)**

**(Total 13 marks)**

**Q18.**Esters are produced by the reaction of alcohols with other esters and by the reaction of alcohols with carboxylic acids.

(a)     The esters which make up biodiesel are produced industrially from the esters in vegetable oils.

(i)      Complete the equation for this formation of biodiesel.



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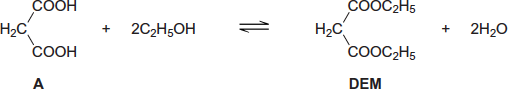
**(2)**

(ii)     Write an equation for the complete combustion of C17H35COOCH3.

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**(2)**

(b)     The ester commonly known as diethyl malonate (**DEM**) occurs in strawberries and grapes. It can be prepared from acid **A** according to the following equilibrium.



(i)      A mixture of 2.50 mol of **A** and 10.0 mol of ethanol was left to reach equilibrium in an inert solvent in the presence of a small amount of concentrated sulfuric acid.  
The equilibrium mixture formed contained 1.80 mol of **DEM** in a total volume, *V* dm3, of solution.

Calculate the amount (in moles) of **A**, of ethanol and of water in this equilibrium mixture.

Moles of **A** .............................................................................................

Moles of ethanol ....................................................................................

Moles of water........................................................................................

**(3)**

(ii)     The total volume of the mixture in part (b)(i) was doubled by the addition of more of the inert solvent.

State and explain the effect of this addition on the equilibrium yield of **DEM**.

Effect ....................................................................................................

Explanation ...........................................................................................

...............................................................................................................

**(2)**

(iii)    Using **A** to represent the acid and **DEM** to represent the ester, write an expression for the equilibrium constant *K*c for the reaction.

...............................................................................................................

...............................................................................................................

**(1)**

(iv)    In a second experiment, the equilibrium mixture was found to contain 0.85 mol of **A**, 7.2 mol of ethanol, 2.1 mol of **DEM** and 3.4 mol of water.

Calculate a value of *K*c for the reaction and deduce its units.

Calculation.............................................................................................

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...............................................................................................................

Units.......................................................................................................

...............................................................................................................

**(3)**

**(Total 13 marks)**

**Q19.**When heated above 100 °C, nitrosyl chloride (NOCl) partly decomposes to form nitrogen monoxide and chlorine as shown in the equation.

2NOCl(g)   2NO(g) + Cl2(g)

(a)      A 2.50 mol sample of NOCl was heated in a sealed container and equilibrium was established at a given temperature. The equilibrium mixture formed contained 0.80 mol of NO.

Calculate the amount, in moles, of Cl2 and of NOCl in this equilibrium mixture.

Moles of Cl2 ...................................................................................................

Moles of NOCl ................................................................................................

**(2)**

(b)     A different mixture of NOCl, NO and Cl2 reached equilibrium in a sealed container of volume 15.0 dm3. The equilibrium mixture formed contained 1.90 mol of NOCl and 0.86 mol of NO at temperature *T*.

The value of *K*c for the equilibrium at temperature *T* was 7.4 × 10−3 mol dm−3.

(i)      Write an expression for the equilibrium constant *K*c

...............................................................................................................

...............................................................................................................

**(1)**

(ii)     Calculate the amount, in moles, of Cl2 in this equilibrium mixture.

...............................................................................................................

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*(Extra space)* .......................................................................................

...............................................................................................................

...............................................................................................................

**(4)**

(iii)    Consider this alternative equation for the equilibrium at temperature *T*.

NOCl(g)   NO(g) + Cl2(g)

Calculate a value for the different equilibrium constant *K*c for the equilibrium as shown in this alternative equation. Deduce the units of this *K*c

Calculation ............................................................................................

...............................................................................................................

...............................................................................................................

...............................................................................................................

Units .....................................................................................................

...............................................................................................................

**(2)**

**(Total 9 marks)**

**M1.**          (a)     (i)      0.86 **(1)**

(ii)     total moles = 0.86 + 0.43 +0.085 = 1.375 **(1)  
** mole fraction of H2 =  = 0.625 **(1)**

(0.62 ‑ 0.63)

*Conseq on (i)*

(iii)     pp = mole fractn × total P **(1)**     = 0.625 × 1.75 × 104     = 1.09 × 104 (kPa) **(1)**

*or 1.1(0)  
Ignore units  
Conseq on (ii)*

**5**

(b)     (i)      Kp =  **(1)**

*Penalise [  ]*

(ii)     *K*p =  = 2.37 (2.4) × 10–9  **(1)**

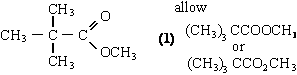
*OR 2.37 × 10–15*

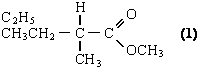
*Units*: kPa–2 **(1)**

*or Pa–2*

*not conseq to wrong Kp expression*

**3**

(c)     *Isomer* ***E****:* 

*Isomer* ***F****: *

**2**

**[10]**

**M2.**          (a)     (1, 4-) buta(ne)dioic acid **(1)**

*NOT dibutanoic acid, butane dicarboxylic acid, or ethane  
dicarboxylic acid Penalise wrong numbers*

**1**

(b)     Kc =  **(1)**

*if Kc expression wrong lose units mark in (e) also must be [  ]*

**1**

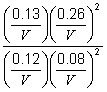
(c)     *Moles of* ***X***: 0.25 - 0.13 = 0.12 **(1)***Moles of methanol*: 0.34 - 0.26 = 0.08 **(1)***Moles of water*: 0.26 **(1)**

**3**

(d)     Equal no. of moles on each side of equation **(1)**

*OR V cancels out (provided not incorrectly qualified)*

**1**

(e)     *Calculation*: Kc =  **(1)**

 = 11(.4) **(1)**

*Can score all 3 conseq on (b) and (c)  
If different values from (c) used allow units only  
(conseq on correct Kc)*

*Units of K*c: none **(1)**

*but lose this mark if Kc is wrong even if none given*

**3**

(f)      decrease **(1)**

**1**

**[10]**

**M3.**          (a)     (i)      *Number of moles of O2 at equilibrium: * = 0.22 **(1)**

*Number of moles of NO at equilibrium:* 0.44 **(1)**

*OR 2 × mol of oxygen*

**3**

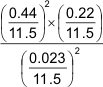
(ii)     *Original number of moles of NO2: * = 0.46(3) **(1)**

*Number of moles of NO2 at equilibrium:*0.46(3) – 0.44 = 0.02(3) **(1)**

*OR conseq on mol NO above*

**1**

(b)     *Expression for KC*: KC =  **(1)**

*Calculation:* KC =  = 7.0(0) mol dm–3**(1) (1) (1)**

*If mol NO2 = 0.02; KC = 9.26 (9.3)  
or conseq on values from (a)  
If vol missed, score only KC and units  
If KC wrong: max 2 for correct use of vol and conseq units  
If KC wrong and no vol: max 1 for conseq units*

**3**

(c)     pV = nRT **(1)**

T =  =

**(1)** for using 11.5 × 10–3 as V

          T = 669 K **(1)**

**4**

(d)     *Yield of oxygen:* increased **(1)***Value of K*c*:* no effect **(1)**

**2**

**[13]**

**M4.**          (a)     (i)      Moles NaOH = mv/1000 = 1.50 × 72.5/1000 = 0.108 to 0.11 **(1)**Moles of ethanoic acid at equilibrium = moles sodium hydroxide **(1)**Moles ester = moles water (=moles acid reacted) **(1)** = 0.200 – 0.108 = 0.090 to 0.092 **(1)**Moles ethanol = 0.110 – 0.091 = 0.018 to 0.020 **(1)***K*C      = [Ester] [Water]/[Acid] [Alcohol] **(1)**

*Allow if used correctly*

          = (0.091)2/0.109 × 0.019 = 3.7 to 4.9 **(1)**

*Ignore units*

*NB     Allow the answer 4 one mark as correct knowledge*

**7**

(ii)     Similar (types) of bond broken and made **(1)**Same number of the bonds broken and made **(1)**

*any number if equal*

*NB  If a list given then the total number of each type of bond broken and made must be the same*

**2**

(b)     (i)      (Weak) dipole-dipole attraction between HCl molecules **(1)**(Strong) **hydrogen bonds** between CH3COOH molecules **(1)**

*NB     Ignore van der Waals forces*

**2**

(ii)     Ethanoic anhydride is

cheap compared to ethanoyl chloride **(1)**

less corrosive than ethanoyl chloride or HCl evolved **(1)**

reaction less violent or vigorous or exothermic or dangerous  
or safer to use **(1)**

less vulnerable to hydrolysis **(1)**

reaction more easily controlled **(1)**

**Max 2**

**[13]**

**M5.**          (a)     (i)      *Moles of PCl3*: 0.345 – 0.166 = 0.179 **(1)**

*Moles of Cl2*: 0.268 – 0.166 = 0.102 **(1)**

*3 sig figs*

(ii)     0.447 **(1)**

*allow 2 sig figs  
conseq on (i)*

**3**

(b)     *Mole fraction of PCl3*: 0.179/0.447 **(1)** = 0.4(00)

*Partial pressure of PCl3*: pp = mol fn × total P **(1)**                                 = 0.400 × 225 = 90 **(1)** kPa **(1)**

**3**

(c)     (i)      Kp =  **(1)**

*ignore brackets except [ ]*

*must show P*

(ii)     Kp =  **(1)** = 1.8**(1)** × 10–2 **(1)** Kpa–1 **(1)** (or 1.81 × 10–5 Pa–1)

*If 83.6 and 51.3 wrong way round, AE – 1,  
answer = 6.81 × 10–3*

*If Kp × in (i) allow max 2 for substitution of numbers and conseq units*

**4**

(d)     (i)      increased **(1)**

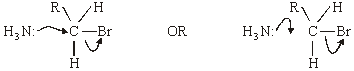
(ii)     increased **(1)**

**2**

**[12]**

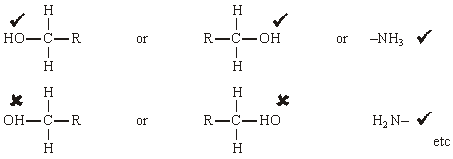
          Organic points

(1)     Curly arrows: must show movement of a pair of electrons,  
i.e. from bond to atom or from lp to atom / space  
e.g.



(2)     Structures

penalise sticks (i.e. ) once per paper



Penalise once per paper

          allow CH3– or –CH3 or  or CH3    or   H3C–

**M6.**          (a)     Kp =  **(1)**

**1**

(b)     0.25 + 0.75 + 0.75 = 1.75 **(1) (1)**

**2**

(c)     (i)      *p* = Total pressure × mol fraction **(1)**

(ii)     *Partial of SO2Cl2*: 125 ×  = 17.9 kPa **(1)**

*Partial pressure of Cl2*: 125 ×  = 53.6 kPa **(1) (1)**

**5**

(d)     Kp =  **(1)** = 161 **(1)** kPa **(1)**

**3**

(e)     *Effect on Kp*: increase **(1)***Explanation*: increase T sends equilibrium in endothermic direction **(1)**

**2**

(f)      no effect **(1)**

**1**

**Notes**

(a)     If Kp has [ ] lose mark in (a) but allow full marks in (d)

          If Kp wrong/upside down etc, allow max 2 in (d) for substitution of numbers **(1)**   
and consequential units **(1)**

(b)     Mark for moles of SO2Cl2 can be scored in part (c) (ii) if not gained in (b)

          1.75 get **(2)**

          If moles of SO2Cl2 = 1, this is a Chemical Error, hence a 2 mark penalty

•    If total moles given in (b) = 1.75, this scores [2] in (b); but if the no moles of   
SO2Cl2 = 1 in (c)(ii), lose both marks in (c)(ii) for pp of SO2Cl2 = (1/1.75) × 125,   
i.e. the 2 mark penalty is in (c)(ii).

•    If total moles given in (b) = 2.5, score zero in (b), but can gain full marks in (c)(ii) consequentially, i.e. the 2 mark penalty is in (b).

•    If moles of SO2Cl2 = 1 and total in (b) does not equal 2.5, still lose both in (b)   
but can get all 4 conseq in (c)(ii) for 1/x etc and 0.75/x etc

(c)     (i)      Allow “Total pressure = sum of partial pressures” for **(1)** or pA = xA × ptot

(ii)     First mark is for mole fraction.  
If either number in either mole fraction is not consequential on (b),   
then lose both marks for that partial p.

(d)     If pCl2 is not equal to pSO2 or any number used in Kp is not conseq on (c)(ii),   
allow units only

          SIG FIGS; must be 3 sig figs in (b) but then allow 2 sig figs in (c) and (d);   
(ignore extra figs) but penalise incorrect rounding

(e)     If effect wrong, no marks for explanation.  
If effect missing, e.g. answer states “equm shifts to right”, mark on.  
In the explanation, the word “endothermic” (or its equivalent) is essential.

**[14]**

**M7.**          (a)     *M1*    Kp = (PY)3. (PZ)2/ (PW)2.( PX)      *NB [ ] wrong*

**1**

*M2*    temperature

**1**

*M3*    increase

**1**

*M4*    particles have more energy or greater velocity/speed

**1**

*M5*    more collisions with E > Ea or more successful collisions

**1**

*M6*    Reaction exothermic or converse

**1**

*M7*    Equilibrium moves in the left

**1**

          Marks for other answers  
*Increase in pressure or concentration*   *allow M1, M5, M6*         *Max 3  
Addition of a catalyst;*                             *allow M1, M5, M6*         *Max 3  
Decrease in temperature;*                      *allow M1, M2, M6*         *Max 3  
Two or more changes made;*                 *allow M1, M6*                *Max 2*

(b)     (i)      Advantage; reaction goes to completion, not reversible  
or faster

**1**

         Disadvantage; reaction vigorous/dangerous

*(exothermic must be qualified)*

          or HCl(g) evolved/toxic  
or CH3COCl expensive

*NB     Allow converse answers  
     Do not allow reactions with other reagents e.g. water  
     or ease of separation*

**1**

(ii)     Δ*S* = ΣS products – ΣS reactants

**1**

Δ*S* = (259 + 187) – (201 + 161)

**1**

Δ*S* = 84 (JK–1 mol–1)     *(Ignore units)*

*Allow – 84 to score* ***(1)*** *mark*

**1**

Δ*G* = Δ*H* – *T*Δ*S*

**1**

      = – 21.6 – 298 × 84/1000  
 = – 46.6 kJ mol–1 or – 46 600 J mol–1

**1**

*Allow* ***(2)*** *for – 46.6 without units*

*(Mark ΔG consequentially to incorrect ΔS)*

*(e.g. ΔS = –84 gives ΔG = +3.4 kJ mol–1)*

**1**

**[15]**

**M8.**          (a)     12 (kPa)

**1**

          pp = mole fraction × total pressure **or** mole fraction = 12/104

**1**

          = 0.115

*(allow 0.12)*

**1**

(b)     68 (kPa)

**1**

(c)     Kp = 

*(If Kp wrong, allow consequential units only)*

*(penalise square brackets in expression but then mark on)*

**1**

               = 

**1**

      = 0.669

*(Allow 0.67)*

*(Allow full marks in calculation consequential on their   
values in (a) and (b))*

**1**

          kPa–1

**1**

(d)     T2

*(Must be correct to score any marks in this section)*

**1**

          Exothermic

**1**

Reduce T to shift equilibrium to the right  
or forward reaction favoured by low T  
or Kp increases for low T  
or low T favours exothermic reaction

**1**

(e)     Increase

**1**

          None

**1**

**[13]**

**M9.**          (a)     (i)      moles of C2F2 = 0.40   mark independently from HC1

**1**

moles of HC1 = 0.80   **not** consequential

**1**

(ii)     

wrong Kc means they can only

         score for units in (iii) consequ

         on their Kc

**1**

(iii)     

**1**

         = 0.35

**1**

mol dm–3

**1**

(b)     (i)      increase

**1**

(ii)     decrease

**1**

(c)     addition or radical

**1**

**[9]**

**M10.**          (a)     effect on reaction rate:     catalyst provides an alternative reaction route.;

**1**

with a lower *E*a*;*

**1**

more molecules able to react or rate increased;

**1**

equilibrium:               forward and backward rates changes by  
                                 the same amount;

**1**

                                 hence concentration of reactants and  
                                 products constant or yield unchanged;

**1**

(b)     heterogeneous: catalyst in a different phase or state to that of  
the reactants;

**1**

          active site:    place where reactants adsorbed or attached or bond etc.;

**1**

          reaction occurs or an explanation of what happens;

*(allow absorbed)*

**1**

          reasons:              large surface area;  
                            reduce cost or amount of catalyst;

**2**

          catalyst poison:   lead adsorbed;  
                            lead not desorbed or site blocked;

*(lead adsorbed irreversibly scores both of these marks)*

**2**

(c)     reaction slow as: both ions negatively charged or ions repel;

**1**

2Fe2+ + S2O82– → 2Fe3+ + 2SO42–Species;  
                                                         Balanced;

**2**

2Fe3+ +2I–    →   2Fe2+ + I2                         Species ;  
                                                         Balanced;

**2**

**[17]**

**M11.**          (a)     *(must state correct effect on yield or rate to score the reason mark)*

T       effect:  higher temp:    yield greater or shifts equilibrium to right;

**1**

effect:   higher temp:   rate increased;

**1**

reason:  endothermic

OR

more particles have E>Ea

**1**

OR

more successful/productive collisions;

**1**

P       effect:   higher pressure: yield less or shifts equilibrium to left;

**1**

         effect:   higher pressure: rate increased;

reason: increase in gas moles L to R

OR

greater collision frequency;

*(Q of L mark)*

**1**

(b)     M1     equilibrium moles of CO = 62.8 - 26.2 = 36.6

**1**

M2     equilibrium moles of H2 = 146 – 2(26.2) = 93.6

**1**

M3     total no moles = 36.6 + 93.3 + 26.2 = 156.4

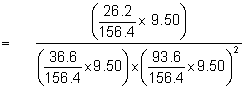
**1**

M4     partial pressure = mole fraction x total pressure

**1**

M5            

**1**

M6    





**1**

M7     0.022(1)        2.2(l)×10–8 2.2(l)×10–14

**1**

M8        MPa–2 kPa–2 Pa–2

**1**

*If no subtraction lose M1, M2 and M3)  
(If ×2 missed in M2, lose both M2 and M3)  
(If M1 gained but moles of H2 = 73.2 (i.e. double CO), M2 and M3 lost)  
(If M1 gained but mol H2 = 2(146 – 26.2), M2 and M3 lost)  
(If M1 and M2 correct but M3 lost for CE, penalise M6 also)  
(M4 can be gained from the numbers in the expression for M6 even if these numbers are wrong)  
(If Kp contains [ ] lose M5 but then mark on)  
(If chemically wrong expression for Kp, lose M5, M6 and M7 (allow M8 conseq on their Kp))  
(If divided by 9.5, or not used 9.5 at all, lose M6 and M7 (and M4))  
(If tried to convert to kPa and is factor(s) of 10 out, penalise in M6 and allow M8 for kPa–2)*

**[14]**

**M12.**          (a)     (i)      C + 3D 2A + B

**1**

(ii)     mol dm–3

**1**

(iii)     (forward reaction is) exothermic or more products formed

**1**

(b)     (i)      for N2O4 Mr = 92.0

**1**

Mol = 

**1**

(ii)     mol N2O4 reacted = 0.400 – 0.180 = 0.220

**1**

mol NO2 formed = 0.440

**1**

(iii)     Kc  =  (NO2)2

**1**

          (N2O4)

=       (0.44/16)2

**1**

          (0.18/16)

=       0.067

**1**

(iv)    move to NO2/ to right / forwards

**1**

none

**1**

**[12]**

**M13.**          (a)     (i)      (*K*p) = (pz)2/(px)(py)3

*(penalise use of square brackets, allow ())*

**1**

(ii)     **X** (22–6)/4 = 4 (MPa)

*(mark is for value 4 only, ignore units)*

**1**

**Y** obtained by multiplying value for **X** by 3

*(allow conseq on wrong value for* ***X****)*

**1**

**Y** 4.0 × 3 = 12 (MPa)

*(mark is for value 12 only)*

**1**

(iii)     *K*p = 6.02/4.0 × 12.03 = 5.21 × 10–3

*(allow conseq on wrong values for* ***X*** *and****Y*** *e.g.62/3 × 93 = 0.165)*

(if *K*p wrong in (a)(i) CE)

**1**

MPa–2

*(allow any unit of P–2 provided ties to P used for Kp value)*

**1**

(b)     high pressure expensive (due to energy or plant costs)

**1**

(Rate is) slow (at lower temperatures)

**1**

**[8]**

**M14.**          (a)     (i)      Increase (if wrong no further marks in part (i)

**1**

higher *P* gives lower yield or moves to left

**1**

Eqm shifts to reduce *P* or eqm favours side with fewer moles

**1**

(ii)     Endothermic if wrong no further marks in part (ii)

**1**

increase *T* increases yield or moves to right

**1**

Eqm shifts to reduce *T* or eqm favours endothermic direction

**1**

(b)     (i)      Moles of iodine  =  0.023

*If wrong no marks in (i)*

**1**

Moles of HI        = 0.172

**1**

*If × 2 missed, max 1 in part (iv)*

(ii)     *K*c = 

*must be square brackets (penalise once in paper)  
 – if round, penalise but mark on in (iv)*

*if Kc wrong, no marks in (iv) either but mark on from a minor slip in formula*

**1**

(iii)     V cancels in *K*c expression

*or no moles same on top and bottom of expression*

*or total moles reactants = moles products,  
i.e. total no of moles does not change*

**1**

(iv)    *K*c  = 

*Conseq on (i)*

**1**

= 0.0179 or 1.79 × 10–2

*Allow 0.018 or 1.8 × 10–2*

**1**

(v)     *K*c = 55.9or 56

*Conseq i.e. (answer to (iv))–1*

**1**

**[13]**

**M15.**          (a)     **M1**    Concentrations of reactants and products remain constant

*For M1  
NOT “equal concentrations”  
NOT “amount”*

**1**

**M2**    Forward rate = Reverse / backward rate

*Credit the use of [ ] for concentration  
Ignore dynamic, ignore closed system*

**1**

(b)     **M1**    The (forward) reaction / to the right is exothermic or  
releases heat OR converse for reverse reaction.

**1**

**M2**    The equilibrium responds by absorbing heat / lowering temperature  
***OR***Promotes the endothermic reaction by absorbing heat /  
lowering temperature  
***OR***Temperature increase is opposed (by shift to the left)  
***OR***Change is opposed by absorbing heat / lowering temperature.

**1**

(c)     (i)      A substance that speeds up / alters the rate  
but is unchanged at the end / not used up.

*Both ideas needed  
Ignore references to activation energy and alternative route.*

**1**

(ii)     None OR no change OR no effect OR nothing OR Does not  
affect it / the position (of equilibrium) OR (The position is) the  
same or unchanged.

**1**

(d)     (i)      An activity which has no net / overall (annual) carbon emissions  
to the atmosphere  
***OR***An activity which has no net / overall (annual) greenhouse gas  
emissions to the atmosphere.  
***OR***There is no change in the total amount of carbon dioxide /  
carbon /greenhouse gas present in the atmosphere.

*The idea that the carbon / CO2 given out equals the carbon / CO2 that was taken in*

*Ignore carbon monoxide*

**1**

(ii)     A method which shows (see below) OR states in words that two  
times the first equation + the second equation gives the correct ratio.

2 (CH4 + H2O             →             CO + 3H2)  
    CH4 + CO2             →             2CO + 2H23CH4 + 2H2O + CO2  →             4CO + 8H2

         Ratio = 1 : 2

**1**

**[8]**

**M16.**          (a)     (i)      acid            0.46

**1**

alcohol        1.46

**1**

water          5.54

**1**

(ii)     Kc = 

*penalise ( )  
allow molecular formulae or minor slip in formulae*

**1**

(iii)     

*Allow without V*

*Conseq on values in (a)(i)  
If values used wrongly  
or wrong values inserted  
or wrong Kc              no marks for calc*

**1**

4.45 or 4.5

*Part (a)(iii) for info 0.46 × 1.46 = 0.6716*

**1**

cancel (as equal no of moles on each side of equation)

**1**

*Possible wrong answers*

|  |  |  |
| --- | --- | --- |
| *acid          0.46* |  | *gives* |
| *alcohol      1.46* |  | *Kc = 3.59* |
| *water         4.46* |  |  |

|  |  |  |
| --- | --- | --- |
| *acid           0.46* |  | *gives* |
| *alcohol      1.46* |  | *Kc = 0.434* |
| *water         0.54* |  |  |

(b)     (i)      decrease or be reduced or fewer

**1**

(ii)     decrease or be reduced or less time or faster or quicker

**1**

(iii)     decrease or be reduced

**1**

**[10]**

**M17.**          (a)     (i)      mol CH4 = 0.75

**1**

mol H2O = 1.5

**1**

mol H2 = 1(.0)

**1**

(ii)     0.15 (mol dm–3)

*conseq = (mol CH4)/5*

**1**

(b)     (i)      

not just numbers

*do not penalise ( )  
If wrong Kc no marks for calc but allow units conseq to their Kc*

**1**

(ii)     

*No marks for calc if concs used wrongly or wrong values inserted*

**1**

0.025(4)

**1**

mol2 dm–6

*allow 1 here for correct units from wrong Kc*

**1**

(c)     increase

*if wrong, no further marks in (c)*

**1**

**M1** lower P

**1**

**M2** eqm shifts to side with more moles (Le Chatelier)

*not “greater volume” for M1 but allow “moves to form a greater volume” for M2*

**1**

(d)     (forward reaction is) endothermic or backward reaction is exothermic

**1**

eqm shifts in exothermic direction or to oppose reduction  
of or change in temp

*This mark must have reference to temp change or exothermic reaction*

**1**

**[13]**

**M18.**(a)     (i)      3CH3OH

*Not molecular formula*

**1**

HOCH2CH(OH)CH2OH

**1**

(ii)     →   19CO2   +   19H2O

*Or doubled*

**1**

C17H35COOCH3 + 27½ or 55/2 O2

*Consequential on correct right-hand side*

**1**

(b)    (i)       A0.7

**1**

Ethanol6.4

**1**

Water3.6

**1**

(ii)     No effect

*If wrong, CE= 0*

**1**

Equal moles on each side of equation ***OR*** V cancels

*Ignore moles of gas*

**1**

(iii)    M1 

*Must have all brackets but allow ( )*

**1**

(iv)    M2 

*If Kc wrong can only score M4 for units consequential to their Kc working in (b)(iv)*

**1**

M3 0.55 (min 2dp)

**1**

M4 No units

**1**

**[13]**

**M19.**(a)    Cl2 0.4

**1**

NOCl 1.7

**1**

(b)    (i)      *K*c= 

*Penalise expression containing V  
Allow ( ) here, but must have all brackets.  
If Kc expression wrong, max 2 in (b)(ii) for  
M1 for correct rearrangement of their Kc and  
M4 for multiplying by 15*

**1**

(ii)     M1  

*Mark is for rearrangement of correct Kc expression.  
If Kc rearrangement wrong, can only score max 2 for:  
M3 and M4*

**1**

M2



*Rounding 1.90 / 15 wrongly to 0.126 is AE*

**1**

M3  [Cl2] = 0.0361 to 0.0365 (min 2 sfs)

*Mark for correct calculation of [Cl2]*

**1**

M4  mol Cl2 = 0.54 to 0.55

***Correct answer scores 4 ignore working***

*Mark is for answer of (M3 × 15)*

**1**

(iii)    ((7.4 × 10−3) = ) 0.086

Allow 0.085 to 0.086)

*Mark for answer* ***OR*** *conseq on their Cl2*

**

*Or     *

**1**

mol ½ dm−3/2 ***OR*** mol 0.5 dm −1.5

*NOT *

**1**

**[9]**