**Q1.**          (a)     Hydrogen used in the Haber Process is produced in the following dynamic equilibrium reaction.

CH4(g)   +   H2O(g)      CO(g)   +   3H2(g)

(i)      In terms of rates and of concentrations, what does the term *dynamic equilibrium* mean?

*Rates* ..................................................................................................

*Concentrations* …................................................................................

(ii)     State how an increase in pressure will affect the equilibrium yield of hydrogen. Explain your answer.

*Equilibrium yield* .................................................................................

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

(iii)     The equilibrium yield of hydrogen is reduced when the reaction is carried out at a lower temperature. What can be deduced about the enthalpy change in this reaction?

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(iv)    Explain why the equilibrium yield is unchanged when a catalyst is introduced.

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**(8)**

(b)     Ammonia is produced in the Haber Process according to the following equation.

N2(g)   +   3H2(g)    2NH3(g)                           Δ*H*f = –92 kJ mol–1

Typical operating conditions are 450 °C and 20 MPa (200 bar).

(i)      Explain why 450 °C is a compromise temperature.

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(ii)     Explain why 20 MPa is a compromise pressure.

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**(6)**

**(Total 14 marks)**

**Q2.**          Hydrogen is produced by the reaction between steam and methane when the following dynamic equilibrium is established.

CH4(g)   +   H2O(g)      CO(g)   +   3H2(g)        Δ*H* = +206 kJ mol–1

(a)     Use Le Chatelier’s principle to predict the separate effects of an increase in temperature and of an increase in pressure on the yield of hydrogen obtained in the above reaction. In each case, explain your answer.

**(6)**

(b)     State how, and explain why, the use of a catalyst might or might not change the equilibrium yield of hydrogen, and also the amount of hydrogen produced, in a given time.

**(4)**

**(Total 10 marks)**

**Q3.**          Methanol can be synthesised from carbon monoxide by the reversible reaction shown below.

CO(g)  +  2H2(g)    CH3OH(g)              Δ*H* = –91 kJ mol–1

The process operates at a pressure of 5 MPa and a temperature of 700 K in the presence of a copper-containing catalyst. This reaction can reach dynamic equilibrium.

(a)     By reference to rates and concentrations, explain the meaning of the term *dynamic equilibrium.*

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**(2)**

(b)     Explain why a high yield of methanol is favoured by high pressure.

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**(2)**

(c)     Suggest **two** reasons why the operation of this process at a pressure much higher than 5 MPa would be very expensive.

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

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

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**(2)**

(d)     State the effect of an increase in temperature on the equilibrium yield of methanol and explain your answer.

*Effect*.............................................................................................................

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

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**(3)**

(e)     If a catalyst were not used in this process, the operating temperature would have to be greater than 700 K. Suggest why an increased temperature would be required.

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**(1)**

**(Total 10 marks)**

**Q4.**          (a)     A sample of a gas was sealed into a flask at temperature *T* and pressure *P*. The Maxwell–Boltzmann distribution of energies for the molecules in this sample is shown below.



(i)      Using the axes above, sketch the curve that you would expect if this sample of gas at pressure *P* had been cooled. Label this curve **X**.

(ii)     Using the axes above, sketch the curve that you would expect if another sample of the same gas was sealed in the same flask at the original temperature, *T*, but at a higher pressure. Label this curve **Y**.

**(4)**

(b)     Gas **A** decomposes slowly to form gases **B** and **C**. An equilibrium is established as shown by the following equation.

          A(g)  B(g) + C(g)              Δ*H* is positive

(i)      In terms of the behaviour of molecules, state what must happen before molecules of **A** can react to form **B** and **C**.

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(ii)     Explain why the decomposition of **A** is faster at higher temperatures.

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**(4)**

(c)     The graphs below show how, starting from **A** alone, the concentration of **A** varies with time at temperatures of 300 K and 320 K for the reversible reaction given in part (b).



(i)      Suggest why, as shown on the graphs, the concentration of **A** remains constant after a time.

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(ii)     Explain why, at 320 K, the concentration of **A** falls to a lower value compared with the reaction at 300 K.

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**(3)**

**(Total 11 marks)**

**Q5.**          Hydrogen is produced on an industrial scale from methane as shown by the equation below.

CH4(g) + H2O(g)  CO(g) + 3H2(g)             Δ*H* = +205 kJ mol–1

(a)     State Le Chatelier’s principle.

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**(1)**

(b)     The following changes are made to this reaction at equilibrium. In each case, predict what would happen to the yield of hydrogen from a given amount of methane. Use Le Chatelier’s principle to explain your answer.

(i)      The overall pressure is increased.

*Effect on yield of hydrogen* .................................................................

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

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(ii)     The concentration of steam in the reaction mixture is increased.

*Effect on yield of hydrogen* .................................................................

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

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**(6)**

(c)     At equilibrium, a high yield of hydrogen is favoured by high temperature. In a typical industrial process, the operating temperature is usually less than 1200 K. Suggest two reasons why temperatures higher than this are not used.

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

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

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**(2)**

**(Total 9 marks)**

**Q6.**          Methanol can be formed on an industrial scale from carbon dioxide and hydrogen by a reversible reaction as shown below.

CO2(g)   +   3H2(g)      CH3OH(g)   +   H2O(g)

The reaction can be carried out in the presence of a chromium-based catalyst at a temperature of 700 K and a pressure of 30 MPa. Under these conditions, equilibrium is reached when 2% of the carbon dioxide has been converted.

(a)     How does the rate of the forward reaction compare with that of the backward reaction when 2% of the carbon dioxide has been converted?

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**(1)**

(b)     (i)      If the pressure was reduced but the temperature was kept the same, deduce what would happen to the equilibrium yield of methanol. Explain your answer.

*Yield* ...................................................................................................

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

(ii)     Give two reasons why, in general, industry prefers to operate processes at pressures lower than 30 MPa.

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

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

**(5)**

(c)     If the chromium-based catalyst was replaced with a more efficient catalyst but other conditions were kept the same, deduce what would happen to the equilibrium yield of methanol. Explain your answer.

*Yield* .............................................................................................................

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

**(2)**

(d)     In the presence of a very efficient copper-based catalyst, this industrial process can be operated at a lower temperature of 500 K and a pressure of 30 MPa. Under these conditions, at equilibrium, more of the carbon dioxide is converted into methanol.

Use this information to deduce the sign of the enthalpy change for the reaction.
Explain your deduction.

*Sign of enthalpy change* ..............................................................................

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

**(3)**

(e)     In the processes above, the equilibrium yield of methanol is low. Suggest what is done with the unreacted carbon dioxide and hydrogen.

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**(1)**

**(Total 12 marks)**

**Q7.**         Methanol, CH3OH, is a convenient liquid fuel.

(a)     An experiment was conducted to determine the enthalpy of combustion of liquid methanol. The energy obtained from burning 2.12 g of methanol was used to heat 150 g of water. The temperature of the water rose from 298 K to 362 K. (The specific heat capacity of water is 4.18 J K–1 g–1)

(i)      Define the term *standard enthalpy of combustion*.

(ii)     Use the data above to calculate a value for the enthalpy of combustion of one mole of liquid methanol.

**(7)**

(b)     Methanol can be synthesised from methane and steam by a process that occurs in two stages.

*Stage 1* CH4(g) + H2O(g)  3H2(g) + CO(g)    Δ*H*~~ο~~ = +206 kJ mol–1

*Stage 2* CO(g) + 2H2(g)  CH3OH(g)                 Δ*H*~~ο~~ = –91 kJ mol–1

(i)      Explain why, in *Stage 1*, a higher yield of hydrogen and carbon monoxide is **not** obtained if the pressure is increased.

(ii)     *Stage 2* is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for *Stage 2*.

**(5)**

(c)     The standard enthalpies of combustion of carbon monoxide and of hydrogen are
–283 kJ mol–1 and –286 kJ mol–1, respectively. Use these data and the enthalpy change for *Stage 2* to calculate a value for the standard enthalpy of combustion of gaseous methanol.

**(3)**

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**(Total 15 marks)**

**Q8.**          The equation for the formation of ammonia is shown below.

N2(g) + 3H2(g)  2NH3(g)

Experiment **A** was carried out starting with 1 mol of nitrogen and 3 mol of hydrogen at a constant temperature and a pressure of 20 MPa.

Curve **A** shows how the number of moles of ammonia present changed with time.

Curves **B**, **C** and **D** refer to similar experiments, starting with 1 mol of nitrogen and 3 mol of hydrogen. In each experiment different conditions were used.



(a)     On curve **A**, mark the point that represents the time at which equilibrium is first reached. Label this point **X**.

**(1)**

(b)     State Le Chatelier’s principle.

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**(1)**

(c)     Use Le Chatelier’s principle to identify which one of the curves **B**, **C** or **D** represents an experiment carried out at the same temperature as experiment **A** but at a higher pressure. Explain why this curve is different from curve **A**.

*Curve* ...........................................................................................................

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

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**(4)**

(d)     Identify which one of the curves **B**, **C** or **D** represents an experiment in which the conditions are the same as in experiment **A** except that a catalyst is added to the reaction mixture. Explain your choice of curve.

*Curve* ...........................................................................................................

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

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**(3)**

**(Total 9 marks)**

**Q9.**          At high temperatures, nitrogen is oxidised by oxygen to form nitrogen monoxide in a reversible reaction as shown in the equation below.

N2(g)  + O2(g)  2NO(g)        ∆*H*~~ο~~   =   +180 kJ mol–1

(a)     In terms of electrons, give the meaning of the term *oxidation*.

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**(1)**

(b)     State and explain the effect of an increase in pressure, and the effect of an increase in temperature, on the yield of nitrogen monoxide in the above equilibrium.

*Effect of an increase in pressure on the yield* .............................................

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

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*Effect of an increase in temperature on the yield* ........................................

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

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**(6)**

(c)     Nitrogen monoxide, NO, is formed when silver metal reduces nitrate ions, NO in acid solution.

(i)      Deduce the oxidation state of nitrogen in NO and in NO

NO.......................................................................................................

NO....................................................................................................

(ii)     Write a half-equation for the reduction of NOions in acid solution to form nitrogen monoxide and water.

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(iii)     Write a half-equation for the oxidation of silver metal to Ag+(aq) ions.

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(iv)    Hence, deduce an overall equation for the reaction between silver metal and nitrate ions in acid solution.

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**(5)**

**(Total 12 marks)**

**Q10.**          In the Haber Process for the manufacture of ammonia, nitrogen and hydrogen react as shown in the equation.

N2(g) + 3H2(g)  2NH3(g)            ∆*H*~~ο~~= –92 kJ mol–1

The table shows the percentage yield of ammonia, under different conditions of pressure and temperature, when the reaction has reached dynamic equilibrium.

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature / K | 600 | 800 | 1000 |
| % yield of ammonia at 10 MPa | 50 | 10 | 2 |
| % yield of ammonia at 20 MPa | 60 | 16 | 4 |
| % yield of ammonia at 50 MPa | 75 | 25 | 7 |

(a)     Explain the meaning of the term *dynamic equilibrium*.

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**(2)**

(b)     Use Le Chatelier’s principle to explain why, at a given temperature, the percentage yield of ammonia increases with an increase in overall pressure.

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**(3)**

(c)     Give a reason why a high pressure of 50 MPa is not normally used in the Haber Process.

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**(1)**

(d)     Many industrial ammonia plants operate at a compromise temperature of about 800 K.

(i)      State and explain, by using Le Chatelier’s principle, one advantage, other than cost, of using a temperature lower than 800 K.

*Advantage* ..........................................................................................

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

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(ii)     State the major advantage of using a temperature higher than 800 K.

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(iii)     Hence explain why 800 K is referred to as a *compromise temperature*.

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**(5)**

**(Total 11 marks)**

**Q11.**          The study of equilibrium constants enables chemists to calculate the composition of equilibrium mixtures.

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

*K*c = 

(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)     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 10 marks)**

**Q12.**          Methanol is a useful liquid fuel that can be produced by direct combination of carbon monoxide and hydrogen.

                            CO(g) + 2H2(g)  CH3OH(g)                  Δ*H*~~ο~~= –91 kJ mol–1

(a)     Explain why a low temperature and a high pressure favour a high yield of methanol in this reaction.

*Low temperature* ..........................................................................................

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*High pressure* ..............................................................................................

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**(4)**

(b)     The industrial manufacture of methanol using this reaction is carried out at a compromise temperature of 400 °C under a pressure of 20 MPa in the presence of a Cr2O3/ZnO catalyst.

(i)      Justify the use of a compromise temperature.

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(ii)     What effect, other than on the yield, does the use of high pressure have on the reaction?

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**(3)**

**(Total 7 marks)**

**Q13.**          Nitric acid is manufactured from ammonia in a process that involves several stages.

(a)     In the first stage, ammonia is converted into nitrogen monoxide and the following equilibrium is established.

4NH3(g) + 5O2(g)  4NO(g) + 6H2O(g)              ∆*H* = –905 kJ mol–1

The catalyst for this equilibrium reaction is a platinum–rhodium alloy in the form of a gauze. This catalyst gauze is heated initially but then remains hot during the reaction.

(i)      In terms of redox, state what happens to the ammonia in the forward reaction.

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**(1)**

(ii)     Suggest a reason why the catalyst must be hot.

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**(1)**

(iii)     Suggest a reason why the catalyst remains hot during the reaction.

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**(1)**

(iv)    State how a catalyst increases the rate of a reaction.

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**(2)**

(b)     In the second stage, nitrogen monoxide is converted into nitrogen dioxide. The equation for the equilibrium that is established is shown below.

2NO(g) + O2(g)  2NO2(g)                  ∆*H* = –113 kJ mol–1

Explain why the equilibrium mixture is cooled during this stage of the process.

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**(2)**

(c)     In the final stage, nitrogen dioxide reacts with water as shown by the following equation.

2NO2(g) + H2O(l) → H+(aq) + NO3–(aq) + HNO2(aq)

Give the oxidation state of nitrogen in each of the following.

NO2 ...............................................................................................................

NO3– …...........................................................................................................

HNO2 .............................................................................................................

**(3)**

**(Total 10 marks)**

**Q14.**          Hess’s Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

(a)     State the meaning of the term *enthalpy change*.

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**(1)**

(b)     State Hess’s Law.

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**(1)**

(c)     Consider the following table of data and the scheme of reactions.

|  |  |
| --- | --- |
| Reaction | Enthalpy change / kJ mol–1 |
|             HCl(g)  →        H+(aq)  +          Cl–(aq) | –75 |
|             H(g)     +          Cl(g)    →        HCl(g) | –432 |
|     H(g)   +     Cl(g)    →    H+(g)    + Cl–(g) | +963 |



Use the data in the table, the scheme of reactions and Hess’s Law to calculate a value for ∆*H*r

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**(3)**

**(Total 5 marks)**

**Q15.**          Hydrogen gas is used in the chemical industry.

(a)     Tungsten is extracted by passing hydrogen over heated tungsten oxide (WO3).

(i)      State the role of the hydrogen in this reaction.

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**(1)**

(ii)     Write an equation for this reaction.

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**(1)**

(iii)     State **one** risk of using hydrogen gas in metal extractions.

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**(1)**

(b)     Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.

 + H2  CH3(CH2)16COOH
                     oleic acid                                                               stearic acid

(i)      Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

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**(1)**

(ii)     State the type of stereoisomerism shown by oleic acid.

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**(1)**

(c)     Hydrogen reacts with nitrogen in the Haber Process. The equation for the equilibrium that is established is shown below.

N2(g) + 3H2(g)  2NH3(g)

(i)      State Le Chatelier’s principle.

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**(1)**

(ii)     Use Le Chatelier’s principle to explain why an increase in the total pressure of this equilibrium results in an increase in the equilibrium yield of ammonia.

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**(2)**

(d)     Hydrogen reacts with oxygen in an exothermic reaction as shown by the following equation.

H2(g) + O2(g) → H2O(g)                ∆*H* = –242 kJ mol–1

Use the information in the equation and the data in the following table to calculate a value for the bond enthalpy of the H–H bond.

|  |  |  |
| --- | --- | --- |
|   | O–H | O=O |
| Mean bond enthalpy / kJ mol–1 | + 463 | + 496 |
|  |  |  |

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**(3)**

**(Total 11 marks)**

**Q16.**          Glucose, produced during photosynthesis in green plants, is a renewable source from which ethanol can be made. Ethanol is a liquid fuel used as a substitute for petrol.
The processes involved can be summarised as follows.

Process **1**                          Photosynthesis in green plants
6CO2 + 6H2O → C6H12O6 + 6O2

Process **2**                          Fermentation of glucose to form ethanol

Process **3**                          Complete combustion of ethanol
CH3CH2OH + 3O2 → 2CO2 + 3H2O

(a)     State **three** essential conditions for the fermentation of aqueous glucose in Process **2**.

Write an equation for the reaction that takes place during this fermentation.

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**(4)**

(b)     It has been claimed that there is no net carbon (greenhouse gas) emission to the atmosphere when ethanol made by Process **2** is used as a fuel.

State the term that is used to describe fuels of this type.

Use the equations for Processes **1, 2** and **3** to show why it can be claimed that there is no net emission of carbon-containing greenhouse gases.

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**(3)**

(c)     Use the information from the equation for Process **3** above and the mean bond enthalpies from the table below to calculate a value for the enthalpy change for this process.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   | C–H | C–C | C–O | O–H | C=O | O=O |
| Mean bondenthalpy / kJ mol–1 | +412 | +348 | +360 | +463 | +743 | +496 |
|  |  |  |  |  |  |  |

Give **one** reason why the value calculated from mean bond enthalpies is different from the value given in a data book.

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**(4)**

(d)     A student carried out a simple laboratory experiment to measure the enthalpy change for Process **3**. The student showed that the temperature of 200 g of water increased by 8.0 °C when 0.46 g of pure ethanol was burned in air and the heat produced was used to warm the water.

Use these results to calculate the value, in kJ mol–1, obtained by the student for this enthalpy change. (The specific heat capacity of water is 4.18 J K–1 g–1)

Give **one** reason, other than heat loss, why the value obtained from the student’s results is less exothermic than a data book value.

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**(4)**

**(Total 15 marks)**

**Q17.**          A scientist used mass spectrometry to analyse a sample of the air near a fertiliser factory. The sample of air included traces of a gas which was shown by its molecular ion to have a precise *M*r = 44.00105

(a)     State the meaning of the term *molecular ion*.

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**(1)**

(b)     (i)      Use the following data to show that the trace gas was dinitrogen oxide (N2O).

Show your working.

|  |  |
| --- | --- |
| **Atom** | **Precise relative atomic mass** |
| 12C | 12.00000 |
| 14N | 14.00307 |
| 16O | 15.99491 |

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**(1)**

(ii)     Propane is used as a fuel in the fertiliser factory. State why both propane and its combustion product, carbon dioxide, might have been identified as the trace gas if the scientist had used relative molecular masses calculated to one decimal place.

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**(1)**

(iii)     State why the precise relative atomic mass for the 12C isotope is exactly 12.00000

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**(1)**

(c)     Dinitrogen oxide is formed when ammonia is oxidised according to the following equation.

2NH3(g) + 2O2(g) → N2O(g) + 3H2O(l)

(i)      Use the standard enthalpies of formation in the table below to calculate a value for the standard enthalpy change of this reaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | NH3(g) | O2(g) | N2O(g) | H2O(l) |
| ΔHf~~ο~~/ kJ mol–1 | –46 | 0 | +82 | –286 |
|  |  |  |  |  |

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**(3)**

(ii)     State **one** condition necessary for enthalpies of formation to be quoted as standard values at a specified temperature of 298 K.

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**(1)**

**(Total 8 marks)**

**Q18.**          Sulfuric acid is made from SO3 which can be manufactured in a series of stages from iron(II) disulfide (FeS2), found in the mineral iron pyrites.

(a)     In the first stage, FeS2 is roasted in air to form iron(III) oxide and sulfur dioxide.

(i)      Balance the following equation for this reaction.

..........FeS2 + ..........O2 → ..........Fe2O3 + ..........SO2

**(1)**

(ii)     Deduce the oxidation state of sulfur in each of the following compounds.

SO2 .....................................................................................................

FeS2.....................................................................................................

**(2)**

(b)     In the second stage of the manufacture of sulfuric acid, sulfur dioxide reacts with oxygen. The equation for the equilibrium that is established is shown below.

SO2(g)  +  O2(g)    SO3(g)        *ΔH* = –98 kJ mol–1

State and explain the effect of an increase in temperature on the equilibrium yield of SO3

Effect of increase in temperature on yield ..................................................

Explanation …..............................................................................................

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**(3)**

(c)     In the extraction of iron, carbon monoxide reacts with iron(III) oxide. Write an equation for this reaction and state the role of the carbon monoxide.

Equation ......................................................................................................

Role of the carbon monoxide .......................................................................

**(2)**

**(Total 8 marks)**

**Q19.**          The diagram below shows a Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.
*E*a is the activation energy for the decomposition of this gas.



(a)     (i)      On this diagram, sketch the distribution for the same sample of gas at a higher temperature.

**(2)**

(ii)     With reference to the Maxwell–Boltzmann distribution, explain why an increase in temperature increases the rate of a chemical reaction.

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**(2)**

(b)     Dinitrogen oxide (N2O) is used as a rocket fuel. The data in the table below show how the activation energy for the decomposition of dinitrogen oxide differs with different catalysts.

2N2O(g)  2N2(g) + O2(g)

|  |  |
| --- | --- |
|   | Ea / kJ mol–1 |
| Without a catalyst | 245 |
| With a gold catalyst | 121 |
| With an iron catalyst | 116 |
| With a platinum catalyst | 136 |

(i)      Use the data in the table to deduce which is the most effective catalyst for this decomposition.

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**(1)**

(ii)     Explain how a catalyst increases the rate of a reaction.

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**(2)**

**(Total 7 marks)**

**Q20.**          Oxygen and ozone (O3) both occur as gases in the upper atmosphere.
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF3Cl

(a)     (i)      Give the IUPAC name of CF3Cl

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**(1)**

(ii)     Complete the following equation that shows the formation of a chlorine atom from a molecule of CF3Cl



**(1)**

(iii)     State what the • represents in Cl•

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**(1)**

(b)     Write two equations that show how chlorine atoms catalyse the decomposition of ozone into oxygen.

Equation 1 ....................................................................................................

Equation 2 ....................................................................................................

**(2)**

(c)     An equilibrium is established between oxygen and ozone molecules as shown below.

3O2(g) 2O3(g)                Δ*H* = +284 kJ mol–1

(i)      State Le Chatelier’s principle.

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**(1)**

(ii)     Use Le Chatelier’s principle to explain how an increase in temperature causes an increase in the equilibrium yield of ozone.

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**(2)**

(d)     Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants.
With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

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**(1)**

**(Total 9 marks)**

**Q21.**          The following dynamic equilibrium was established at temperature T in a closed container.

P(g) + 2Q(g) 2R(g)                        Δ*H*~~ο~~ = –50 kJ mol–1

The value of Kc for the reaction was 68.0 mol–1 dm3 when the equilibrium mixture contained
3.82 mol of **P** and 5.24 mol of **R**.

(a)     Give the meaning of the term *dynamic equilibrium*.

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

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**(2)**

(b)     Write an expression for Kc for this reaction.

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**(1)**

(c)     The volume of the container was 10.0 dm3.

Calculate the concentration, in mol dm–3, of **Q** in the equilibrium mixture.

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

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**(4)**

(d)     State the effect, if any, on the equilibrium amount of **P** of increasing the temperature.
All other factors are unchanged.

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**(1)**

(e)     State the effect, if any, on the equilibrium amount of **P** of using a container of larger volume. All other factors are unchanged.

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**(1)**

(f)      State the effect, if any, on the value of Kc of increasing the temperature.
All other factors are unchanged.

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**(1)**

(g)     State the effect, if any, on the value of Kc of using a container of larger volume.
All other factors are unchanged.

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**(1)**

(h)     Deduce the value of the equilibrium constant, at temperature *T*, for the reaction

2R(g) P(g) + 2Q(g)

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**(1)**

**(Total 12 marks)**

**Q22.**          A sample of nitrogen dioxide gas (NO2) was prepared by the reaction of copper with concentrated nitric acid.

(a)     (i)      Balance the equation for the reaction of copper with concentrated nitric acid.

Cu + ........ HNO3 → Cu(NO3)2 + ........ NO2 + ........ H2O

**(1)**

(ii)     Give the oxidation state of nitrogen in each of the following compounds.

HNO3 ........................................................

NO2 ..........................................................

**(2)**

(iii)     Deduce the half-equation for the conversion of HNO3 into NO2 in this reaction.

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**(1)**

(b)     The following equilibrium is established between colourless dinitrogen tetraoxide gas (N2O4) and dark brown nitrogen dioxide gas.

N2O4(g)  2NO2(g)               Δ*H* = 58 kJ mol–1

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

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

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

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**(2)**

(ii)     Use Le Chatelier’s principle to explain why the mixture of gases becomes darker in colour when the mixture is heated at constant pressure.

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**(2)**

(iii)     Use Le Chatelier’s principle to explain why the amount of NO2 decreases when the pressure is increased at constant temperature.

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**(2)**

**(Total 10 marks)**

**Q23.**Ammonia is manufactured by the Haber process in which the following equilibrium is established.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| N2(g) | + | 3H2(g) |  | 2NH3(g) |

(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 a catalyst has no effect on the position of an equilibrium.

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

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**(2)**

(c)     The diagram shows how the equilibrium yield of ammonia varies with changes in pressure and temperature.



(i)      Use the diagram to state the effect of an **increase** in pressure at constant temperature on the yield of ammonia. Use Le Chatelier’s principle to explain this effect.

Effect on yield ........................................................................................

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

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

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**(3)**

(ii)     Use the diagram to state the effect of an **increase** in temperature at constant pressure on the yield of ammonia. Use Le Chatelier’s principle to explain this effect.

Effect on yield ........................................................................................

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

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

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**(3)**

(d)     At equilibrium, with a pressure of 35 MPa and a temperature of 600 K, the yield of ammonia is 65%.

(i)      State why industry uses a temperature higher than 600 K.

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**(1)**

(ii)     State why industry uses a pressure lower than 35 MPa.
Do **not** include references to safety.

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**(1)**

**(Total 12 marks)**

**Q24.**(a)     A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume V dm3. The mixture was left to reach equilibrium as shown by the following equation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| H2(g) | + | l2(g) |  | 2Hl(g) |

At a given temperature, the equilibrium mixture contained 2.06 mol of hydrogen iodide.

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

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

Moles of iodine ......................................................................................

**(2)**

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

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**(1)**

(iii)    *K*c for this equilibrium has no units.
State why the units cancel in the expression for *K*c

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**(1)**

(iv)     A different mixture of hydrogen, iodine and hydrogen iodide was left to reach equilibrium at the same temperature in a container of the same volume.
This second equilibrium mixture contained 0.38 mol of hydrogen, 0.19 mol of iodine and 1.94 mol of hydrogen iodide.

Calculate a value for *K*c for this equilibrium at this temperature.

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

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**(2)**

(b)     This question concerns changes made to the four equilibria shown in parts (b)(i) to (b)(iv).
In each case, use the information in the table to help you choose from the letters **A** to **E** the best description of what happens as a result of the change described. Write your answer in the box.

Each letter may be used once, more than once or not at all.

|  |  |  |
| --- | --- | --- |
|   | **Position of equilibrium** | **Value of equilibrium constant, *K*c** |
| **A** | remains the same | same |
| **B** | moves to the right | same |
| **C** | moves to the left | same |
| **D** | moves to the right | different |
| **E** | moves to the left | different |

(i)      Change: increase the temperature of the equilibrium mixture at constant pressure.

H2(g)     +     I2(g)          2Hl(g)∆*H*ϴ = +52 kJ mol–1   

**(1)**

(ii)     Change: increase the total pressure of the equilibrium mixture at constant temperature.

3H2(g)     +     N2(g)          2NH3(g)∆*H*ϴ = -92 kJ mol–1   

**(1)**

(iii)    Change: add a catalyst to the equilibrium mixture at constant temperature.

CO(g)   +   H2O(g)      CO2(g)   +   H2(g)∆*H*ϴ = -41 kJ mol–1   

**(1)**

(iv)    Change: add chlorine to the equilibrium mixture at constant temperature.

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

**(1)**

**(Total 10 marks)**

**Q25.**A study of equilibrium is important for understanding chemical reactions.

(a)     State le Chatelier’s principle.

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

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**(1)**

(b)     Catalysts play an important role in many reactions.

(i)      State the meaning of the term *catalyst*.
Explain, in general terms, how catalysts work.

Meaning of the term *catalyst* .................................................................

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How catalysts work ..............................................................................

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**(3)**

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

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(ii)     State the effect, if any, of a catalyst on the time taken to reach equilibrium.

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**(1)**

(iii)    State the effect, if any, of a catalyst on the position of an equilibrium.

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**(1)**

(c)     Consider the following equilibrium reactions.

*ΔH*ᶿ / kJ mol−1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **P** | H2(g) + l2(g)  |  | 2Hl(g) |   | −10 |
| **Q** | CO2(g) + 3H2(g) |  | CH3OH(g) + H2O(g) |   | −49 |
| **R** | N2O4(g) |  | 2NO2(g) |   | +58 |
| **S** | N2(g) + 3H2(g) |  | 2NH3(g) |   | −92 |
| **T** | C2H4(g) + H2O(g) |  | CH3CH2OH(g) |   | −42 |

In each of parts (c)(i) to (c)(v), you should record in the box one of the letters, **P, Q, R, S** or **T**, that corresponds to the equilibrium that best fits the information provided.
You may use each letter once, more than once or not at all.

(i)      A decrease in temperature at constant pressure shifts the position of this equilibrium from right to left.
 

**(1)**

(ii)     This equilibrium uses concentrated phosphoric acid as a catalyst in a hydration reaction.
 

**(1)**

(iii)    A decrease in pressure at constant temperature shifts the position of this equilibrium from left to right.
 

**(1)**

(iv)    There is no change in the position of this equilibrium when the pressure is increased at constant temperature.
 

**(1)**

(v)     An increase in the concentration of steam at constant temperature and constant pressure shifts the position of this equilibrium from right to left.
 

**(1)**

**(Total 11 marks)**

**Q26.**Ethanol is an important industrial compound.

(a)     Ethanol can be produced by the hydration of ethene.
The equation for the equilibrium that is established is

H2C=CH2(g)   +   H2O(g)       CH3CH2OH(g) Δ*H* = −42 kJ mol−1

The operating conditions for the process are a temperature of 300 oC and a pressure of 7 MPa.
Under these conditions, the conversion of ethene into ethanol is 5%.

(i)      Identify the catalyst used in this process.
Deduce how an overall yield of 95% is achieved in this process without changing the operating conditions.

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**(2)**

(ii)     Use your knowledge of equilibrium reactions to explain why a manufacturer might consider using an excess of steam in this process, under the same operating conditions.

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**(3)**

(iii)    At pressures higher than 7 MPa, some of the ethene reacts to form a solid with a relative molecular mass greater than 5000.

Deduce the identity of this solid.

Give **one** other reason for **not** operating this process at pressures higher than 7 MPa.
Do **not** include safety reasons.

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**(2)**

(b)     Write an equation for the reaction that has an enthalpy change that is the standard enthalpy of formation of ethanol.

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**(2)**

(c)     When ethanol is used as a fuel, it undergoes combustion.

(i)      Define the term *standard enthalpy of combustion*.

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**(3)**

(ii)     Consider these bond enthalpy data.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   |  | C–H | C–C | C–O | O=O | C=O | O–H |
|   | **Bond enthalpy / kJ mol−1** | 412 | 348 | 360 | 496 | 805 | 463 |

Use these data and the equation to calculate a value for the enthalpy of combustion of gaseous ethanol.

CH3CH2OH(g)   +   3O2(g)        2CO2(g)   +   3H2O(g)

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**(3)**

(d)     Gaseous ethanol can be used to convert hot copper(II) oxide into copper.

(i)      Deduce the role of ethanol in this reaction.

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**(1)**

(ii)     Draw the structure of the organic compound with *M*r = 60 that is produced in this reaction.

**(1)**

**(Total 17 marks)**

**Q27.**Sulfuric acid is manufactured by the Contact Process.

(a)     In this process, sulfur dioxide reacts with oxygen.
The equation for the equilibrium that is established is

SO2(g) + O2(g)       SO3(g) *ΔH* = −98 kJ mol−1

(i)      State and explain the effect of a **decrease** in temperature on the equilibrium yield of SO3.

Effect of a decrease in temperature on yield .......................................

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

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

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**(3)**

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

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

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

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**(2)**

(b)     Write an equation for the reaction of concentrated sulfuric acid with potassium bromide to form potassium hydrogensulfate and hydrogen bromide.

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**(1)**

(c)     Bromine is one of the products formed when concentrated sulfuric acid reacts with hydrogen bromide.

Write an equation for this reaction.
State the role of sulfuric acid in this reaction.

Equation

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

Role of sulfuric acid .......................................................................................

**(3)**

(d)     Concentrated sulfuric acid is used in a two-stage process to convert 2-methylpropene into 2-methylpropan-2-ol.

Stage **1** (CH3)2C=CH2 + H2SO4         (CH3)2C(OSO2OH)CH3

Stage **2**  (CH3)2C(OSO2OH)CH3 + H2O        (CH3)2C(OH)CH3 + H2SO4

(i)      Name and outline a mechanism for Stage **1** of this conversion.

Name of mechanism .........................................................................

Mechanism

**(5)**

(ii)     Deduce the type of reaction in Stage **2** of this conversion.

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**(1)**

(iii)    State the overall role of sulfuric acid in this conversion.

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**(1)**

**(Total 16 marks)**

**M1.**          (a)     (i)      *Rates:* Rates are equal, forward and backward **(1)***Concentrations:* Concentrations are constant **(1)**

*Q of L mark*

(ii)     *Equilibrium yield:* Decreases **(1)**

*if wrong allow max 1 for a correct moles statement*

         *Explanation:* More moles / moleculesof product (or 2 → 4) **(1)**Reaction / equilibrium moves to left / reduce constraint **(1)**

*NOT “volume” answers*

*Allow one for “Reaction favours fewer molecules”*

(iii)     Enthalpy of reaction is positive / endothermic **(1)**

(iv)    Both forward and backward rates changed / increased **(1)**by equal amount (same proportion) **(1)**

*allow one for “Ea of forward and backward reactions reduced by an equal amount”*

**8**

(b)     (i)      The reaction is exothermic **(1)**High temperature gives a low equilibrium yield **(1)**Rate of reaction higher at higher temperature **(1)**

*An “equilibrium statement” needed e.g. low temp favours
the reaction
Do not allow answers based on cost of higher
temperature etc*

(ii)     Higher pressure gives a higher yield **(1)**4 moles of gaseous reactant form 2 moles of gaseous
product **(1)**Higher pressure generation or equipment is expensive
to produce **(1)**

*Equilibrium statement required
Cost factor
N.B. NOT a safety answer*

**6**

**[14]**

**M2.**          (a)     **Increase in temperature:**

          Yield is increased **(Allow if for H2 (g) or products) (1)**Reaction endothermic **(1)**Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to
oppose change **OR** to absorb heat **(1)**

*If “Yield statement” incorrect allow max one if reaction stated to be endothermic*

**Increase in pressure:**

Yield is decreased **(Allow if for H2 (g) or products) (1)**Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles
on right **(1)**Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to
oppose change **OR** to reduce pressure **(1)**

*If “Yield statement” incorrect allow max one if number of moles change is correct.*

**6**

(b)     **Equilibrium yield:**Unaffected **or** equilibrium unchanged **(1)**Rate or speed increased **(1)**Forward and backwards reactions equally or by the same amount **(1)**

**Amount of hydrogen produced:**More hydrogen produced (1)

**4**

**[10]**

**M3.**          (a)     rate forward reaction = rate backward reaction **(1)**concentration remains constant **(1)**

*NOT ‘Equal’,
Allow  ‘The same’ if clear that means constant*

**2**

(b)     fewer moles (of gas) on R.H.S **(1) (or converse)**(methanol favoured) by reducing applied pressure **(1)**

*Or removing constraint*

**2**

(c)     Power / energy required to provide high pressure / pumping **(1)**Strong pressure vessel / or equipment **(1)**

*High maintenance costs* ***(1)****High insurance costs* ***(1)****Any two*

**2**

(d)     Effect: decreases **(1)**Explanation: reaction exothermic (or reverse reaction endothermic) **(1)**                   system tries to lower T or remove constraint or
                   oppose the change
                   or endothermic reaction favoured

**3**

(e)     to speed up reaction **(1)**

*or otherwise to slow
or takes too long
or to give more molecules E > EA*

**1**

**[10]**

**M4.**          (a)     (i) (ii)

**4**

****

(b)     (i)      collide **(1)**with sufficient energy (or E  Ea) **(1)** (*or with correct orientation*)

(ii)     molecules (or particles) have more energy (or move faster) **(1)**more molecules (or collisions) have E ≥ Ea (or sufficient energy) **(1)**

**4**

(c)     (i)      equilibrium reached **(1)**(or rate forward reaction = rate backward)

(ii)     Reaction is endothermic **(1)**or ΔH +ve
or reverse reaction is exothermic

endothermic reaction favoured **(1)**(or reaction shifts to R
or moves forward
or more products formed)

**3**

**[11]**

**M5.**          (a)     An equilibrium opposes change **(1)**

**1**

(b)     (i)      *Effect on yield of hydrogen:* decreases **(1)**

*Note C.E. if not decrease, but mark on if no answer*

*Explanation:* pressure lowered (or increase opposed) **(1)**by favouring fewer moles (of gas) **(1)**

(ii)     *Effect on yield of hydrogen*: increase **(1)**

*CE if wrong as above*

*Explanation*: pressure / concentration / reactants / steam reduced **(1)** by shifting to right **(1)**

*or steam removed or forward reaction favoured*

**6**

(c)     *Reason 1*: cost of high temperature / energy **(1)**

*Reason 2*: cost of plant (to resist high T) too high **(1)**OR plant could not contain high T

**2**

**[9]**

**M6.**          (a)     Same

**1**

(b)     (i)      Decreases

**1**

         More moles on left hand side

**1**

         Equilibrium moves to increase the pressure

*(Or to oppose the change or to compensate for low pressure)*

**1**

(ii)     Cost of producing high pressure **(1)**Cost of plant to resist high pressure **(1)**Correct safety factor with reason **(1)**

**max 2**

(c)     No change

**1**

          Catalyst has no effect on equilibrium position

*(Or catalyst affects rate of forward and backwards reactions equally)*

**1**

(d)     Negative

**1**

Reaction *(or equilibrium)* moves in the exothermic
direction *(or to the right)*

**1**

          In order to oppose the change *(or to raise the temperature)*

**1**

(e)     Recycled (*or re-used or ‘put back in’*)

**1**

**[12]**

**M7.**          (a)     (i)      enthalpy change when 1 mol of a substance
(or compound) (QL mark)

**1**

is (completely) burned in oxygen (or reacted in excess oxygen)

**1**

at 298 K and 100 kPa (or under standard conditions)

**1**

(ii)     heat produced = mass of water × Sp heat capacity
*xΔT* (or *mcΔT)*

**1**

= 150 × 4.18 × 64 (note if mass = 2.12 lose first 2 marks
then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2
must have correct units)

**1**

moles methanol = mass/Mr = 2.12/32 (1)
= 0.0663

**1**

         Δ*H* = – 40.1/0.0663 = – 605 kJ (mol–1)

**1**

*(allow –602 to –608 or answer in J)*

*(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks*

(b)     (i)      equilibrium shifts to left at high pressure

**1**

because position of equilibrium moves to favour
fewer moles (of gas)

**1**

(ii)     at high temperature reaction yield is low (or at low *T* yield is high)

**1**

at low temperature reaction is slow (or at high *T* reaction is fast)

**1**

therefore use a balance (or compromise) between rate and yield

**1**

(c)     Δ*H* = ΣΔ*H*c~~ο~~(reactants) – *ΣΔH*c~~ο~~ (products) (or correct cycle)

**1**

*ΔH*c~~ο~~ (CH3OH) = *ΔHc~~ο~~*(CO) + 2 × *ΔHc~~ο~~*(H2) – Δ*H*

**1**

= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ mol–1) ( *units not essential but lose mark if units wrong)
(note + 764 scores 1/3)*

**1**

**[15]**

**M8.**          (a)     mark labelled **X** on curve **A** where curve **C** joins **A**;

**1**

(b)     equilibrium opposes a change;

*(Q of L mark)*

**1**

(c)     **B**

**1**

          more ammonia is produced (or yield increases);

**1**

fewer moles (of gas) on right ( or 4 mol goes to 2 mol);

**1**

equilibrium moves to oppose increase in pressure (or oppose change);

**1**

(d)     **C**

**1**

          amount of ammonia (or yield or equilibrium) unchanged;

**1**

reaction is faster;

**1**

**[9]**

**M9.**          (a)     removal/loss of electrons

**1**

(b)     no change

**1**

equal number of gaseous moles on either side

**1**

both sides affected equally

**1**

increases

**1**

equilibrium moves to lower the temperature/oppose the change

**1**

endothermic reaction favoured /forward reaction is endothermic

**1**

(c)     (i)      +2

**1**

+5

**1**

(ii)     NO3– + 4H+ + 3e– → NO +2H2O

**1**

(iii)     Ag → Ag+ + e–

**1**

(iv)    NO3– + 4H+ + 3Ag → NO + 2H2O + 3Ag+

**1**

**[12]**

**M10.**          (a)     Rate forward reaction = rate backward reaction (1)

Concentrations of reactants and products are constant (1)

**2**

(b)     System opposes change (1)

Moves to the side with fewer moles (1)

In this case NH3 (2 moles) on right side < N2 + H2 together
(4 moles) on left side of equation (1)

**3**

(c)     Too expensive to generate etc (1)

**1**

(d)     (i)      Yield of ammonia increases (1)

Exothermic reaction favoured (1)

System moves to raise temp / or oppose decrease in temp (1)

**3**

(ii)     Faster reaction (1)

**1**

(iii)     Balance between rate and yield (1)

**1**

**[11]**

**M11.**          (a)     (i)      C + 3D → 2A + B

**1**

(ii)     mol dm–3

**1**

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

**1**

(b)     (i)      Moles of iodine = 0.023

**1**

Moles of HI = 0.172

**1**

(ii)     *K*c = 

**1**

(iii)     V cancels in *K*c expression

**1**

(iv)    *K*c = 

**1**

= 0.0179 or 1.79 × 10–2

**1**

(v)     *K*c = 55.9 or 56

*Conseq i.e. (answer to (iv))–1*

**1**

**[10]**

**M12.**          (a)     Low temperature

Reaction is exothermic

**1**

Low T reduces effect of heat evolved
or heat evolved opposes the change in temperature

**1**

High pressure

3 mol gas → 1 mol gas

**1**

High p favours fewer moles by lowering p
or forward reaction reduces volume and lowers p

**1**

(b)     High T gives a low yield

**1**

but    Low T gives a low rate  compromise

**1**

increases reaction rate/catalyst surface contact

**1**

**[7]**

**M13.**          (a)     (i)      Oxidation

***OR***

Oxidised ONLY

**1**

(ii)     Any one from

•        to provide/overcome activation energy

•        to provide the minimum energy to make the reaction go/start

*NOT simply to increase the (initial) reaction rate.*

**1**

(iii)     The reaction is exothermic OR releases heat (energy)

**1**

(iv)    M1
Catalysts provide an alternative route/pathway OR an alternative
mechanism

***OR***

(in this case) surface adsorption occurs (or a description
of adsorption)

*Ignore reference to "surface" alone*

M2
Lowers the activation energy

***OR***

of lower activation energy

**2**

(b)     M1
The (forward) reaction is exothermic OR the (forward) reaction
releases heat

***OR***

The reverse reaction is endothermic or absorbs heat

M2 – Direction of change N.B. M2 depends on correct M1
At lower temperatures,

•        the equilibrium yield of NO2 is greater

•        more NO2 is formed

•        equilibrium shifts (left) to right

•        (equilibrium) favours the forward reaction

(***OR*** converse for higher temperatures)

**2**

(c)     NO2           (+) 4

NO3-        (+) 5

HNO2         (+) 3

**3**

**[10]**

**M14.**          (a)     Heat (energy) change at constant pressure

*Ignore references to standard conditions, but credit specified pressure.*

**1**

(b)     The enthalpy change/heat (energy) change (at constant pressure) in a
reaction is independent of the route/path taken (and depends only
on the initial and final states)

**1**

(c)     Δ*H* + 963 = –75 – 432 OR Δ*H* + 963 = – 507 (**M1**)

Δ*H* = –75 – 432 – 963 (**M1** and **M2**)

Δ*H* = **–1470** (kJ mol–1)

Award 1 mark for + 1470

*Award full marks for correct answer*

*Ignore units.*

*Ignore numbers on the cycle*

***M1*** *and* ***M2*** *can score for an arithmetic error*

**3**

**[5]**

**M15.**          (a)     (i)      Reducing agent

***OR***

Reduce(s) (WO3/tungsten oxide)

OR

electron donor

OR

to remove oxygen (from WO3/tungsten oxide or to form water);

**1**

(ii)     WO3 + **3**H2 → W + **3**H2O

*Or multiples*

**1**

(iii)     *One from*

H2 is

•    explosive

•    flammable or inflammable

•    easily ignited

*Ignore reference to pressure or temperature*

**1**

(b)     (i)      Addition

*Ignore “electrophilic”*

*Penalise “nucleophilic addition”*

***OR***

(catalytic) hydrogenation

OR

Reduction

**1**

(ii)     Geometric(al)

***OR***

cis/trans OR E Z OR E/Z

**1**

(c)     (i)      (If any factor is changed which affects an equilibrium), the
position of equilibrium will shift/move/change/respond/act
so as to oppose the change.

***OR***

(When a system/reaction in equilibrium is disturbed), the
equilibrium shifts/moves in a direction which tends to
reduce the disturbance

*A variety of wording will be seen here and the key part is the last phrase and must refer to movement of the equilibrium.*

***QoL***

**1**

(ii)     **M1 – Statement of number of moles/molecules**There are more moles/molecules (of gas) on the left/of reactants

***OR***

fewer moles/molecules (of gas) on the right./products

***OR***

there are 4 moles/molecules (of gas) on the left and 2 moles/
molecules on the right.

*Ignore “volumes” for M1*

*Mark independently*

**M2 – Explanation of response/movement in terms of pressure**Increase in pressure is opposed (or words to that effect)

***OR***

pressure is lowered by a shift in the equilibrium (from left) to
right/favours forward reaction.

**2**

(d)     ΣB(reactants) – ΣB(products) = Δ*H* (**M1**)

***OR***

Sum of bonds broken – Sum of bonds formed = ΔH (**M1**)

B(H–H) + ½B(O=O) – 2B(O–H) = – 242 (**M1**)

B(H–H) = – 242 – ½(+496) + 2(+463) (this scores **M1** and **M2**)

B(H–H) = (+)436 (kJ mol–1) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

*M1 could stand alone*

*Award full marks for correct answer.*

*Ignore units.*

*Two marks can score with an arithmetic error in the working.*

**3**

**[11]**

**M16.**          (a)     **Three conditions in any order for M1 to M3**

**M1**    yeast or zymase

**M2**    30 °C ≥ T ≤ 42 °C

**M3**    anaerobic/no oxygen/no air OR neutral pH

**M4**    C6H12O6  **2**C2H5OH + **2**CO2OR
**2**C6H12O6  **4**C2H5OH + **4**CO2

*Mark independently*

*Penalise “bacteria” and “phosphoric acid” using the list principle*

*Ignore reference to “aqueous” or “water” (i.e. not part of the list principle)*

*Or other multiples*

**4**

(b)     **M**1    Carbon-neutral

*Ignore “biofuel”*

**1**

**M2**    6 (mol/molecules) CO2/carbon dioxide taken in/used/used
up (to form glucose or in photosynthesis)

**1**

**M3**    6 (mol/molecules) CO2/carbon dioxide given out due to
**2** (mol/molecules) CO2/carbon dioxide from fermentation/
Process 2 and **4** (mol/molecules) CO2/carbon dioxide from
combustion/Process 3

*It is NOT sufficient in M2 and M3 for equations alone without commentary or annotation or calculation*

**1**

(c)     **M1**    **(could be scored by a correct mathematical expression)**

(Sum of) bonds broken – (Sum of) bonds made/formed = Δ*H*

***OR***

(Σ) Breactants – (Σ) Bproducts = Δ*H*

                                          (where B = bond enthalpy/bond energy)

*For M1 there must be a correct mathematical expression using ΔH or “enthalpy change”*

**M2**    Reactants = (+) 4719
***OR***Products = (–) 5750

**M3**    Overall + 4719 – 5750 = **–1031** (kJ mol–1) **(This is worth 3 marks)**

*Award full marks for correct answer.*

*Ignore units.*

*M2 is for either value underlined*

*M3 is NOT consequential on M2*

**3**

**Award 1 mark ONLY for +1031**

Candidates may use a cycle and gain full marks.

M4     Mean bond enthalpies are not specific for this reaction
*OR* they are average values from many different
compounds/molecules

***Do not forget to award this mark***

**1**

(d)     **M1**    q = m c ΔT (this mark for correct mathematical formula)

**M2**    = 6688 (J) OR 6.688 (kJ) OR 6.69 (kJ) OR 6.7 (kJ)

**M3**    0.46g is 0.01 mol
therefore ΔH = **– 669** kJ mol–1 OR – **670** kJmol–1OR **–668.8** kJ mol–1

*Award M1, M2 and M3 for correct answer to the calculation*

*Penalise M3 ONLY if correct answer but sign is incorrect*

*In M1, do not penalise incorrect cases in the formula*

*If m = 0.46 or m = 200.46 OR if ΔT = 281, CE and penalise M2 and M3*

*If c = 4.81 (leads to 7696) penalise M2 ONLY and mark on for M3 = –769.6 OR –770*

*Ignore incorrect units in M2*

**M4**    Incomplete combustion

***Do not forget to award this mark. Mark independently***

**4**

**[15]**

**M17.**          (a)     The molecular ion is

•        The molecule with one/an electron knocked off/lost

*Ignore the highest or biggest m/z peak*

***OR***

•        The molecule with a (single) positive charge

***OR***

•        the ion with/it has the largest/highest/biggest m/z (value/ratio)

*Ignore “the peak to the right”*

***OR***

•        the ion with/it has an m/z equal to the *M*r

*Ignore “compound”*

**1**

(b)     (i)      2(14.00307) + 15.99491 = 44.00105

*A sum is needed to show this*

**1**

(ii)     Propane/C3H8 and carbon dioxide/CO2 (and N2O) or
they or both the gases/molecules or all three gases/molecules
have an (imprecise) *M*r of 44.0 (OR 44)

***OR***

they have the same ***M*r** or molecular mass (to one d.p)

*This could be shown in a calculation of relative masses for propane and carbon dioxide*

**1**

(iii)     By definition

***OR***

The standard/reference (value/isotope)

*Ignore “element”*

*Ignore “atom”*

**1**

(c)     (i)      **M1 (could be scored by a correct mathematical expression)**

ΔH = ΣΔHproducts – ΣΔHreactants

OR a correct cycle of balanced equations

**M1 and M2 can be scored with correct moles as follows**Δ*H* + 2(– 46) = +82 + 3(– 286)

Δ*H* – 92 = – 776

Δ*H* = 92 – 776 OR 92 + 82 – 858

**M3**Δ*H* = – 684 (kJ mol–1) (This is worth 3 marks)

**Award 1 mark ONLY for + 684**

*Full marks for correct answer.*

*Ignore units.*

*Deduct one mark for an arithmetic error.*

**3**

(ii)     The value is quoted at a pressure of 100 kPa OR 1 bar or 105 Pa

***OR***

All reactants and products are in their standard states/their normal
states at 100 kPa or 1 bar

*Ignore 1 atmosphere/101 kPa*

*Ignore “constant pressure”*

**1**

**[8]**

**M18.**          (a)     (i)      **4**FeS2 + **11**O2  **2**Fe2O3 + **8**SO2

**2**             **5**½                      **(1)**              **4**

*Or multiples of this equation*

**1**

(ii)     **M1**    **(+) 4**

**M2    – 1**

*Ignore working*

*M1, credit (+) IV*

*M2, credit – I*

**2**

(b)     **M1** Lower/smaller/decreases/reduced yield
***OR*** equilibrium shifts (right) to left

**M2** (Forward) reaction is exothermic OR reverse reaction is endothermic

**M3** (By Le Chatelier’s principle) equilibrium responds/shifts/moves
(R to L)
to lower the temperature
***OR*** to absorb the heat
***OR*** to cool the reaction

*If M1 is blank, mark on and credit M1 in the text.*

*If M1 is incorrect, only credit correct M2*

*Mark M2 independently – it may be above the arrow in the equation*

*For M3, not simply “to oppose the change/temperature”*

**3**

(c)     **M1** Fe2O3 + 3CO  **2**Fe + **3**CO2

*Or multiples*

*Ignore state symbols*

**M2** Reducing agent
***OR*** Reduce(s) (Fe2O3/iron(III) oxide)
***OR*** Electron donor
***OR*** to remove the oxygen (from iron(III) oxide to form CO2)
***OR*** reductant

*For M2, credit “reduction”*

**2**

**[8]**

**M19.**          (a)     (i)      **M1**    The peak of the new curve is displaced to the right.

**M2** All of the following are required

•        The new curve starts at the origin

•        The peak of the new curve is lower than the original

•        and the new curve only crosses the original curve once

•        and an attempt has been made to draw the new curve
correctly towards the energy axis but not to touch the
original curve

•        the new curve must not start to diverge from the original curve

*M1 is low demand*

*M2 is higher demand.*

**2**

(ii)     **M1**    Increase in the number/proportion of molecules with *E ≥ E*a

OR    more molecules have *E ≥ E*a

OR    more molecules have sufficient energy to react

**M2**    More effective/productive/successful collisions

*Ignore “molecules have more energy”*

*Ignore “more energetic collisions”*

*Ignore “molecules gain activation energy”*

*Ignore “more collisions”*

*Accept “particles” for “molecules” but NOT “atoms”*

*Ignore “chance of collision”; this alone does not gain M2*

**2**

(b)     (i)      Iron ***OR*** Fe

**1**

(ii)     **M1** Catalysts provide an alternative route/pathway/mechanism

***OR***

(in this case) surface adsorption/surface reaction occurs.

*For M1, not simply “provides a surface” alone*

**M2** that has a lower activation energy

***OR***

lowers the activation energy

*For M2, the candidate may use a definition of activation energy without referring to the term*

**2**

**[7]**

**M20.**          (a)     (i)      chlorotrifluoromethane

*Spelling must be correct but do not penalise “flouro”*

*Ignore use of 1–*

**1**

(ii)     CF3•

*May be drawn out with dot on C*

*OR if as shown dot may be anywhere*

**1**

(iii)     An unpaired/non-bonded/unbonded/free/a single/one/lone
electron

*NOT “bonded electron” and NOT “paired electron”*

*NOT “pair of electrons”*

*NOT “electrons”*

*Ignore “(free) radical”*

**1**

(b)     **M1**   Cl• + O3 → ClO• + O2

**M2**    ClO• + O3 → **2**O2 + Cl•

*Mark independently*

*Equations could gain credit in either position*

*The dot can be anywhere on either radical*

*Penalise the absence of a dot on the first occasion that it is seen and then mark on. Do not make the same penalty in the next equation, but penalise the absence of a dot on the other radical.*

*Apply the list principle for additional equations*

**2**

(c)     (i)      (If any factor is changed which affects an equilibrium),
the (position of) equilibrium will shift/move so as to oppose
the change.

***OR***

(When a system/reaction in equilibrium is disturbed),
the equilibrium shifts/moves in a direction which tends to
reduce the disturbance

*Must refer to equilibrium*

*Ignore reference to “system” alone*

*A variety of wording will be seen here and the key part is the last phrase.*

*An alternative to shift/move would be the idea of changing/altering the position of equilibrium*

**1**

(ii)     **M1** The (forward) reaction/to the right is endothermic or
takes in heat

***OR*** The reverse reaction/to the left is exothermic or gives out heat

**M2** The equilibrium moves/shifts to oppose the increase in
temperature

*M2 depends on a correct statement for M1*

*For M2 accept*

*The equilibrium moves/shifts*

*•    to take in heat/lower the temperature*

*•    to promote the endothermic reaction and take in heat/   lower the temperature*

*•    to oppose the change and take in heat/lower the             temperature*

*(leading to the formation of more ozone)*

**2**

(d)     Any one of

•        Pentane does not contain chlorine OR C–Cl (bond)

•        Pentane is chlorine-free

•        Pentane does not release chlorine (atoms/radicals)

*Ignore reference to F OR C–F OR halogen*

*Ignore “Pentane is not a CFC”*

*Ignore “Pentane is a hydrocarbon”*

*Ignore “Pentane only contains C and H”*

*Ignore “Pentane is C5H12”*

**1**

**[9]**

**M21.**         (a)     Forward and backward reactions proceeding at equal rate

**1**

Amount (Conc or moles or proportion) of reactants and
products remain constant

*Not “reactants and products have equal conc”*

**1**

(b)     **M1** 

*Allow ( ) but must have all brackets*

*If Kc wrong can only score* ***M3*** *(process mark)*

*for dividing both R and P by volume)*

**1**

(c)     **M2** [Q]2 = 

*Rearrangement of correct Kc expression*

*If wrong Kc used can only score* ***M3*** *for correct use of vol*

*If wrong rearrangement can only score max 2 for* ***M3*** *and* ***M5*** *for correct √*

**1**

**M3** [Q]2 = 

*Process mark for dividing both R and P by volume even in incorrect expression*

*If vol missed can only score max 2 for* ***M2*** *and M5 for correct √*

*If vol used but then wrong maths can score* ***M2 M3*** *and* ***M5*** *for correct √*

*If moles used wrongly, eg (2 × 5.24) or (5.24 × 10/103)*

*can only score* ***M2*** *and* ***M5***

**1**

**M4** [Q]2 = 0.0106

*Correct calculation of Q2*

**1**

**M5** [Q] = 0.10(3)

*Correct taking of √*

**1**

(c)     cont.

Wrong rearrangement and no use of volume

**0**

Wrong rearrangement

*For Correct use of volume* ***M3*** *and Correct taking of square root* ***M5***

**2 max**

No use of volume

*2 max*

***answer = 0.325***

*Ignore subsequent multiplying or dividing by 10.*

***0.0325 or 3.25*** *still score max 2*

*For Correct rearrangement* ***M2*** *and*

*Correct taking of square root* ***M5***

**2 max**

Use of volume but maths error e.g. using (5.24)2/10
when should be (5.24/10)2

*Scores 3*

***also giving answer 0.325***

*for* ***M2****,* ***M3*** *and* ***M5***

**3**

Use of volume but Q/10 also used
or Q multiplied by 10 at end
(i.e.muddling moles with concentration)

***Gives answer 1.03***

*For Correct rearrangement* ***M2*** *and*

*Correct taking of square root* ***M5***

**2 max**

Wrong use of moles, e.g (5.24 × 2) or (5.24 × 10/103)

*For Correct rearrangement* ***M2*** *and*

*Correct taking of square root* ***M5***

**2 max**

Wrong Kc used, e.g. missing powers

*For Correct use of volume* ***M3***

**1 max**

(d)     Increase or more or larger

*Allow moves to left*

**1**

(e)     Increase or more or larger

*Allow moves to left*

**1**

(f)      Decrease or less or smaller

*NOT allow moves left*

**1**

(g)     No effect or unchanged or none

**1**

(h)     0.0147 or 0.0148 or 1.47 × 10-2 or 1.48 × 10-2

Allow 0.015 or 1.5 × 10-2

If not 0.0147, look at (c) for conseq correct use
of their [Q] in new Kc = 1.39 × [Q]2

*Not allow just 1/68.0*

*ignore units*

**1**

**[24]**

**M22.**          (a)     (i)      Cu + **4**HNO3 → Cu(NO3)2 + **2**NO2 + **2**H2O

*Or multiples*

*Ignore state symbols*

**1**

(ii)     **M1**     HNO3 (+) **5**

**M2**     NO2 (+) **4**

*Ignore working out*

*M1 Credit (V)*

*M2 Credit (IV)*

**2**

(iii)     HNO3 + H+ + e– → NO2 + H2O

OR

NO3– + 2H+ + e– → NO2 + H2O

*Or multiples*

*Ignore state symbols*

*Ignore charge on the electron unless incorrect and accept loss of electron on the RHS*

**1**

(b)     (i)      **In either order**

**M1** Concentration(s) (of reactants and products)
remain(s) constant / stay(s) the same / remain(s)
the same / do(es) not change

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

*For M1 accept [ ] for concentration*

*NOT “equal concentrations” and NOT “concentration(s) is/are the same”*

*NOT “amount”*

*Ignore “dynamic” and ignore “speed”*

*Ignore “closed system”*

*It is possible to score both marks under the heading of a single feature*

**2**

(ii)     **M1**

The (forward) reaction / to the right is endothermic
or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives
out / releases heat

**M2 depends on correct M1 and must refer to temperature/heat**

The equilibrium shifts / moves left to right to oppose the increase in temperature

*M2 depends on a correct statement for M1*

*For M2, the equilibrium shifts/moves*

*to absorb the heat OR*

*to lower the temperature OR*

*to cool the reaction*

**2**

(iii)     **M1 refers to number of moles**

There are fewer moles (of gas) on the left OR more
moles (of gas) on the right.
OR there is one mole (of gas) on the left and 2 moles
on the right.

**M2 depends on correct M1 and must refer to pressure**The equilibrium shifts / moves right to left to oppose the
increase in pressure

*M2 depends on a correct statement for M1*

*For M2, the equilibrium shifts/moves to lower the pressure.*

**2**

**[10]**

**M23.**(a)     **In either order**

*For M1 accept [ ] for concentration*

**M1** Concentrations (of reactants and products) remain or stay constant / the same

*NOT “equal concentrations” and NOT “concentration(s) is / are the same”*

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

*NOT “amount”*

*Ignore “dynamic” and ignore “speed”*

*Ignore “closed system”*

*It is possible to score both marks under the heading of a single feature*

**2**

(b)     **M1** Catalysts increase rate of / speed up both forward and reverse / backward
reactions

*If M1 is given as “no effect” / “no change” then CE= 0 for clip*

**M2** increase in rate / affect on rate / speed is equal / the same

*Ignore references to “decrease in rate”*

**2**

(c)     (i)     **M1** (The yield) increases / goes up / gets more

*If M1 is given as “decreases” / “no effect” / “no change” then CE= 0 for clip, but mark on from a blank.*

**M2**    There are more moles / molecules (of gas) on the left / of reactants

*Ignore “volumes”, “articles” “atoms” and “species” for M2*

         ***OR*** fewer moles / molecules (of gas) on the right / products

         ***OR*** there are 4 moles / molecules (of gas) on the left and 2 moles /      molecules on the right.

         ***OR*** (equilibrium) shifts / moves to the side with less moles / molecules

**M3 Can only score M3 if M2 is correct**

         The equilibrium shifts / moves (from left to right) to oppose the increase
in pressure

*For M3, not simply “to oppose the change”*

*For M3 credit the equilibrium shifts / moves to lower / decrease the pressure*

*(There must be a specific reference to the change that is opposed)*

**3**

(ii)     **M1**     The yield decreases / goes down / gets less

*If M1 is given as “increase” / “no effect” / “no change” then CE= 0 for clip, but mark on from a blank.*

**M2**     (Forward) reaction is exothermic ***OR*** gives out / releases heat

         ***OR***

         reverse reaction is endothermic ***OR*** takes in / absorbs heat

**Can only score M3 if M2 is correct**

The equilibrium shifts / moves (from right to left) to oppose the increase in temperature

*For M3, not simply “to oppose the change”*

*For M3 credit the equilibrium shifts / moves*

*to absorb the heat OR*

*to cool the reaction OR*

*to lower the temperature*

*(There must be a specific reference to the change that is opposed)*

**3**

(d)     (i)     Must be comparative

*Credit correct reference to rate being too (s)low / (s)lower at temperatures less than 600 K*

Higher rate of reaction

***OR*** increase / speed up the rate (of reaction)

*Ignore statements about the “yield of ammonia”*

***OR*** Gets to equilibrium faster/ quicker

***OR*** faster or quicker rate / speed of attainment of equilibrium

**1**

(ii)     Less electrical pumping cost

*Not just “less expensive” alone*

***OR***

*Not just “less energy or saves energy” alone*

Use lower pressure equipment / valves / gaskets / piping etc.

*Credit correct qualified references to higher pressures*

***OR***

Uses less expensive equipment

*Ignore references to safety*

**1**

**[12]**

**M24.**(a)      (i)     mol H2 = 0.47

**1**

mol I2 = 0.17

*If answers reversed, ie*

*mol H2 = 0.17*

*mol I2 = 0.47*

*then allow one mark (for second answer).*

**1**

(ii)     

Penalise expression containing V
But mark on in (a)(iv)

***Penalise missing square brackets*** *in this part(and not elsewhere in paper) but mark on in (a)(iv)*

**1**

(iii)    equal number of moles (on each side of equation)

***OR***

equal moles (top and bottom of *K*c expression)

**1**

(iv)     

Ignore V

*If Kc wrong in (a)(ii) (wrong powers or upside down etc) no marks here*

**1**

= 52(.1)

**1**

(b)     (i)      **D**

**1**

(ii)     **B**

**1**

(iii)    **A**

**1**

(iv)    **C**

**1**

**[10]**

**M25.**(a)    (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

*Must refer to equilibrium*

*Ignore reference to “system” alone*

*A variety of wording will be seen here and the key part is the last phrase*

***OR***

(When a system / reaction in equilibrium is disturbed), the (position of) equilibrium shifts / moves in a direction which tends to reduce the disturbance

*An alternative to shift / move would be the idea of changing / altering the position of equilibrium*

**1**

(b)    (i)      M1
A substance that speeds up the reaction / alters the rate but is chemically unchanged at the end / not used up

*Both ideas needed for* ***M1***

*Credit can score for* ***M1****,* ***M2***  *and* ***M3*** *from anywhere within the answer*

M2
Catalysts provide an alternative route / alternative pathway / different mechanism

M3
that has a lower activation energy / *Ea*

***OR***lowers the activation energy / *Ea*

**3**

(ii)     (Time is) less / shorter / decreases / reduces

*Credit “faster”, “speeds up”, “quicker” or words to this effect*

**1**

(iii)    None

**1**

(c)     (i)      R

**1**

(ii)     T

**1**

(iii)    R

**1**

(iv)    P

**1**

(v)     Q

**1**

**[11]**

**M26.**(a)     (i)      M1 c(oncentrated) phosphoric acid / c(onc.) H3PO4***OR*** c(oncentrated) sulfuric acid / c(onc.) H2SO4

*In* ***M1****, the acid must be concentrated.
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.*

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
***OR*** pass the gases over the catalyst several / many times

*In* ***M2****, ignore “remove the ethanol”.
Credit “re-use”.*

**2**

(ii)     M1
(By Le Chatelier’s principle) the equilibrium is driven / shifts / moves to the right / L to R / forwards / in the forward direction

**M2 depends on a correct statement of M1**The equilibrium moves / shifts to

•        oppose the addition of / increased concentration of / increased moles / increased amount of water / steam

•        to decrease the amount of steam / water

**Mark M3 independently**M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

**3**

(iii)    M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

**M2 At higher pressures**More / higher cost of electrical energy to pump / pumping cost
***OR***Cost of higher pressure equipment / valves / gaskets / piping etc.
***OR*** expensive equipment

*Credit all converse arguments for* ***M2***

**2**

(b)     M1 for balanced equation

M2 for state symbols in a correctly balanced equation

2C(s / graphite) + 3H2(g) + ½O2(g)   CH3CH2OH(l)
(C2H5OH)

*Not multiples but credit correct state symbols in a correctly balanced equation.*

*Penalise C2H6O but credit correct state symbols in a correctly balanced equation.*

**2**

(c)    (i)      M1 The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

*If standard enthalpy of formation* ***CE=0***

M2 is burned / combusts / reacts completely in oxygen
***OR*** burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states
***OR*** (all) reactants and products / (all) substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K

*For* ***M3****Ignore reference to 1 atmosphere*

**3**

(ii)     M1

*Correct answer gains full marks*

ΣB(**reactants**) − ΣB(**products**) = *ΔH*

*Credit 1 mark for (+) 1279 (kJ mol−1)*

OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = *ΔH*

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
                         (2060)   (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*(3220)     (2778)
OR using only bonds broken and formed (**4256 − 5535**)

*For other incorrect or incomplete answers, proceed as follows*

*•        check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (****M1*** *and* ***M2****)*

*•        If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of* ***M1*** *which could be in words and scores* ***only M1***

M3
ΔH= **− 1279** (kJ mol−1)

*Allow a maximum of one mark if the only scoring point is LHS = 4719* ***OR*** *RHS = 5998*

Award 1 mark for +1279

**Candidates may use a cycle and gain full marks**

**3**

(d)    (i)      Reducing agent ***OR*** reductant ***OR*** electron donor
***OR*** to reduce the copper oxide

*Not “reduction”.*

*Not “oxidation”.*

*Not “electron pair donor”.*

**1**

(ii)     CH3COOH

**1**

**[17]**

**M27.**(a)     (i)      M1 (Yield) increases / goes up / gets more

*If* ***M1*** *is blank, mark on and seek to* ***credit the correct information in the explanation.****If* ***M1*** *is incorrect CE=0 for the clip.*

M2
The (forward) reaction / to the right is exothermic or gives out / releases heat
***OR*** The reverse reaction / to the left is endothermic or takes in / absorbs heat

***M3*** *depends on a correct statement for* ***M2***

**M3 depends on correct M2 and must refer to temperature / heat**The (position of ) equilibrium shifts / moves left to right to oppose the
decrease in temperature

*For* ***M3****, the equilibrium shifts / moves
to release heat* ***OR****to raise the temperature* ***OR****to heat up the reaction.*

**3**

(ii)     M1    *Concentration(s)* (of reactants and products) remain or stay constant /
         the same

*For* ***M1*** *credit [ ] for concentration.*

M2    Forward rate = reverse / backward rate

*Not “equal concentrations”.
Not “concentrations is / are the same”.
Not “amount”.*

*Ignore “dynamic” and ignore “speed”.*

*Ignore “closed system”.*

*It is possible to score both marks under the heading of a single feature.*

**2**

(b)     KBr + H2SO4   KHSO4 + HBr

*Credit this equation in its ionic form.*

*Ignore state symbols.*

*Credit multiples.*

**1**

(c)     M1 SO2 identified

**M2 correctly balanced equation (would also gain M1)**

*Credit* ***M2*** *equation in its ionic form.*

*Ignore state symbols.*

**2**HBr + H2SO4   Br2 + SO2 + **2**H2O

*Credit multiples.*

*Not H2SO3 on the right-hand side.*

**Mark M3 independently**M3 Oxidising agent ***OR*** electron acceptor ***OR*** oxidant
***OR*** to oxidise the bromide (ion) / HBr

***M3*** *Not “electron pair acceptor”.*

**3**

(d)    (i)      **M1 Electrophilic addition**

 

***M1*** *both words required.*

***For the mechanism
M3*** *Penalise incorrect partial charges on O − H bond and penalise formal charges
Ignore partial negative charge on the double bond.*

***M5*** *Not HSO4 –*

*For* ***M5****, credit as shown or −:OSO3H ONLY with the negative charge anywhere on this ion****OR*** *correctly drawn out with the negative charge placed correctly on oxygen.*

M2 must show an arrow from the double bond towards the H atom of the H − O bond / HO on a compound with molecular formula for H2SO4M2 could be to an H+ ion and M3 an independent O − H bond break on a compound with molecular formula for H2SO4

*Max any 3 of 4 marks* ***for a correct mechanism*** *using the wrong organic reactant or wrong organic product (if shown) or a primary carbocation.*

M3 must show the breaking of the O − H bond on H2SO4

*Penalise once only in any part of the mechanism for a line and two dots to show a bond.*

M5 must show an arrow from the lone pair of electrons on the correct oxygen of the negatively charged ion towards the positively charged carbon atom on their carbocation

*Credit the correct use of “sticks”.*

*For* ***M5****, credit attack on a partially positively charged carbocation structure, but penalise* ***M4***

**NB The arrows here are double-headed**

**5**

(ii)     Hydrolysis

*Credit “(nucleophilic) substitution” but do not accept any other prefix.*

*Credit phonetic spelling.*

**1**

(iii)    Catalyst

**1**

**[16]**