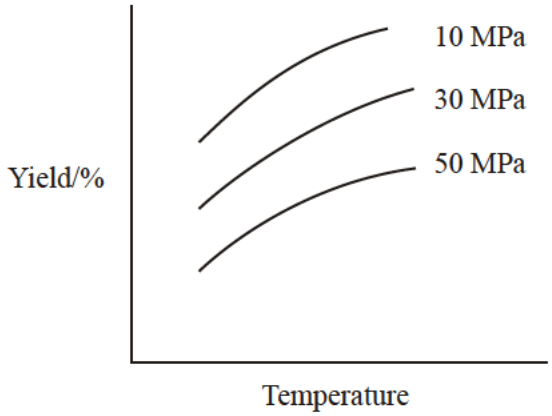
AQA A2 CHEMISTRY

TOPIC 4.2

EQUILIBRIA

1. (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 .....

.....

.....

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

The forward reaction is .....

Explanation .....

.....

.....

(6)

(b) When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm^3, the following equilibrium was established at 700 K.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

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.....

.....

(ii) Write an expression for K_c for the equilibrium.

.....

.....

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

.....

.....

(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

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

.....

.....

(7)
(Total 13 marks)

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

$$\begin{array}{l}CH_2COOH\\ |\\ CH_2COOH\end{array} + 2\,CH_3OH \rightleftharpoons \begin{array}{l}CH_2COOCH_3\\ |\\ CH_2COOCH_3\end{array} + 2H_2O \qquad \Delta H^{\ominus} = -15\ kJ\,mol^{-1}$$

acid **X** ester **Y**

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 dm^3.

(a) 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)

(b) 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)

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

.....

.....

(1)

(d) Calculate the value of K_c for this reaction and deduce its units.

Calculation .....

.....

.....

.....

Units of K_c .....

.....

(3)

(e) State the effect, if any, of increasing the temperature on the value of K_c

.....

(1)

(Total 9 marks)

3. As a first step in the manufacture of nitric acid it has been suggested that nitrogen monoxide, NO, can be formed from nitrogen and oxygen in a reversible reaction.

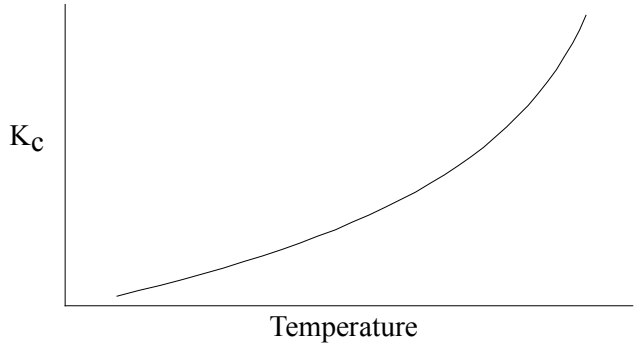
(a) Write an equation for this reaction and deduce an expression for the equilibrium constant, K_c

Equation.....

K_c .....

(2)

(b) The sketch graph below shows how the value of K_c for this reaction changes with temperature.



Use this graph to deduce whether the reaction is exothermic or endothermic.

Explain your answer.

.....

.....

(2)

(c) The value of K_c for this reaction is 1×10^{-5} at 1500 K.

Explain the significance of this value for an industrial chemist interested in manufacturing nitrogen monoxide by the direct combination of the elements.

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.....

(2)

(d) When cooled, nitrogen monoxide reacts with oxygen to form gaseous nitrogen dioxide, NO_2, in a reversible reaction.

(i) Write an equation for this reaction.

.....

(ii) State how an increase in pressure would change the position of the equilibrium and the value of the equilibrium constant for this reaction.

Change in equilibrium position.....

Change in equilibrium constant.....

(3)

(Total 9 marks)

4. The manufacture of methanol can be achieved in two stages.

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

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus} = +210 \text{ kJ mol}^{-1}$$

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)
(Total 6 marks)

5. The reaction between hydrogen and iodine can be represented by the following equation:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = +52 \text{ kJ mol}^{-1}$$

(a) Write a K_C expression for the decomposition of hydrogen iodide. At a given temperature, the value of K_C for this reaction is 20. What will be the value of K_C for the reaction between hydrogen and iodine at this temperature?

(2)

(b) The pressure of an equilibrium mixture of hydrogen iodide, hydrogen and iodine was increased. State what, if anything, would happen to:

(i) the rates of both forward and reverse reactions;

(2)

(ii) the position of equilibrium;

(1)

(iii) the value of the equilibrium constant.

(1)
(Total 6 marks)

6. (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.

$$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$$

The ethanoic acid present at equilibrium required 72.5 cm^3 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)
(Total 9 marks)

7. When ammonia gas is heated, a homogeneous, dynamic equilibrium is established between ammonia and its constituent elements. This decomposition is endothermic.

(a) Explain the terms *homogeneous, dynamic* and *equilibrium*.
Write an equation for this decomposition and derive an expression for the equilibrium constant, K_c

(5)

(b) State and explain the conditions under which a high equilibrium concentration of hydrogen would be obtained.

(4)

(c) The decomposition of ammonia might in the future be used as an industrial method for the manufacture of hydrogen.
Explain why an industrial chemist might decide to use conditions different from those you have given in part (b) if large quantities of hydrogen were to be produced by this decomposition. Discuss the effect that using a catalyst would have on the equilibrium yield and on the amount of hydrogen which could be produced in a given time.

(6)
(Total 15 marks)

3. A fixed mass of marble is reacted with dilute hydrochloric acid at a constant temperature. Explain why the rate of the reaction is increased if the lumps of marble are reduced in size.

.....

.....

.....

(2)

(Total 2 marks)

(c) Hydrogen peroxide decomposes more rapidly in the presence of aqueous hydrogen bromide. The decomposition proceeds as shown by the following equations.

$$H_2O_2 + HBr \rightarrow HBrO + H_2O$$

$$HBrO + H_2O_2 \rightarrow H_2O + O_2 + HBr$$

(i) Write an equation for the overall reaction.

.....

(ii) Define the term *catalyst*.

.....

.....

(iii) Give **two** reasons, other than an increase in the reaction rate, why these equations suggest that hydrogen bromide is behaving as a catalyst.

Reason 1 .....

Reason 2 .....

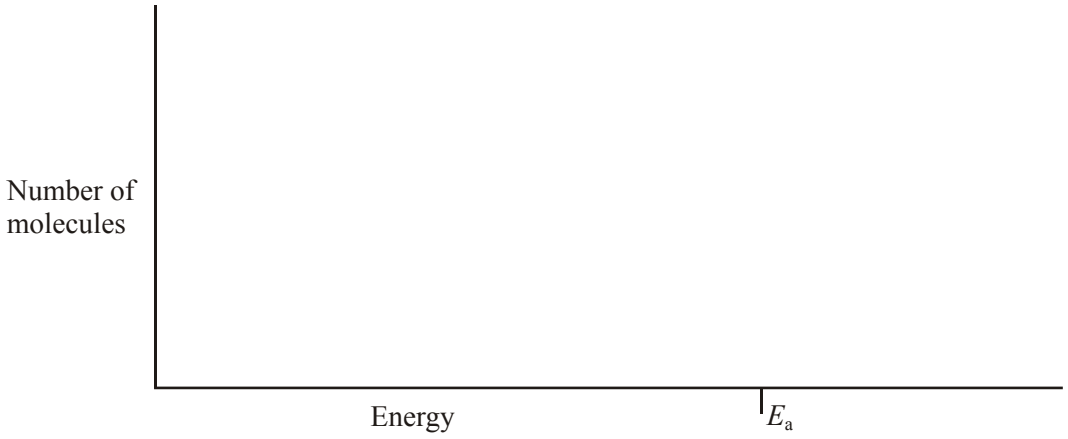
(5)

(Total 10 marks)

5. Gas **G** decomposes as shown in the equation below.

$$G(g) \rightarrow X(g) + Y(g)$$

(a) Draw, on the axes below, a Maxwell–Boltzmann distribution curve for a sample of **G** in which only a small proportion of molecules has energy greater than the activation energy, E_a.



(3)

(b) Define the term *activation energy*.

.....

.....

(2)

(c) At any time, most of the molecules of **G** have energy less than the activation energy. Suggest why, at a constant temperature, most of **G** eventually decomposes.

.....

.....

(2)

(d) State the effect, if any, of adding a catalyst on the time required for **G** to decompose, compared with a similar sample without a catalyst. Explain in general terms how the catalyst has this effect.

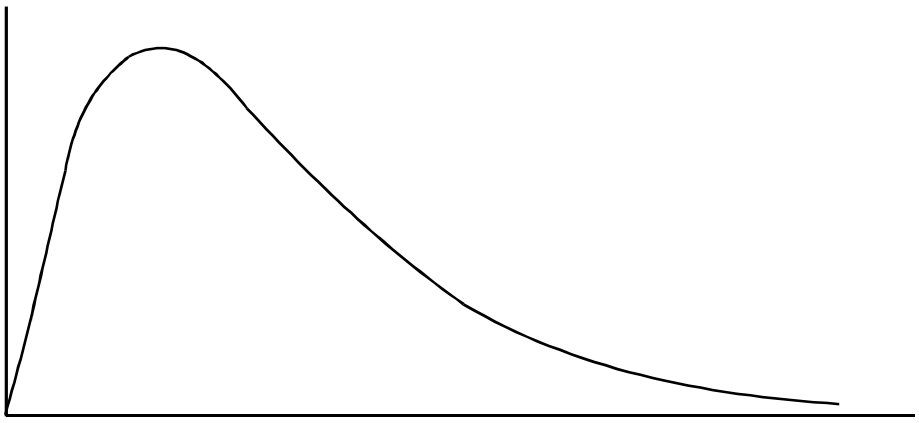
Time for decomposition …….....

Explanation …….

.....…….

(3)
(Total 10 marks)

7. (a) Below is a Maxwell–Boltzmann curve showing the distribution of molecular energies for a sample of gas at a temperature *T*.



(i) Label the axes on the diagram above.

(ii) What does the area under the curve represent?

.....

(iii) State why this curve starts at the origin.

.....

(4)

(b) (i) State what is meant by the term *activation energy*.

.....

.....

(ii) The rate of a chemical reaction may be increased by an increase in reactant concentration, by an increase in temperature and by the addition of a catalyst.

State which, if any, of these changes involves a different activation energy. Explain your answer.

Change(s) .....

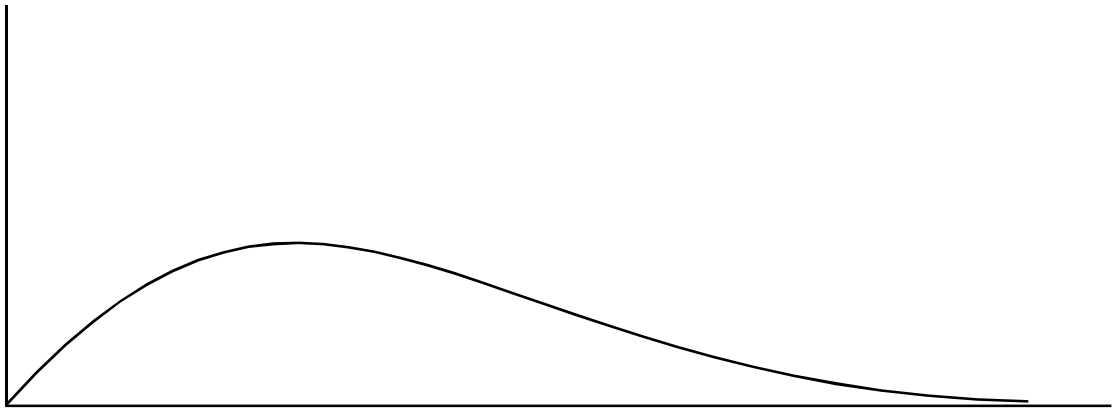
Explanation .....

.....

(5)
(Total 9 marks)

(Total 8 marks)

10. The diagram below represents a Maxwell–Boltzmann distribution curve for the particles in a sample of a gas at a given temperature. The questions below refer to this sample of particles.



(a) Label the axes on the diagram.

(2)

(b) On the diagram draw a curve to show the distribution for this sample at a **lower** temperature.

(2)

(c) In order for two particles to react they must collide. Explain why most collisions do not result in a reaction.

.....

(1)

(d) State one way in which the collision frequency between particles in a gas can be increased without changing the temperature.

.....

(1)

(e) Suggest why a small increase in temperature can lead to a large increase in the reaction rate between colliding particles.

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(2)

(f) Explain in general terms how a catalyst works.

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(2)
(Total 10 marks)

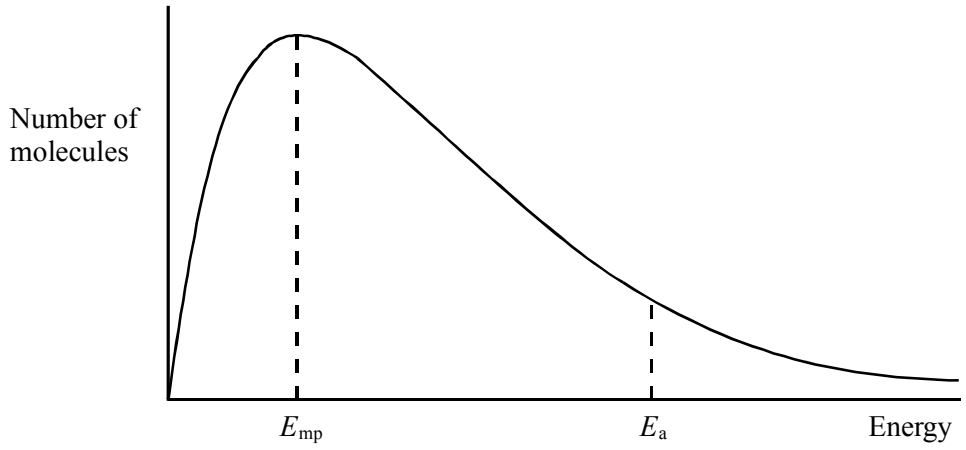
12. (a) State what is meant by the term *activation energy* of a reaction.

(1)

(b) State in general terms how a catalyst increases the rate of a chemical reaction.

(2)

(c) The curve below shows the Maxwell–Boltzmann distribution of molecular energies, at a constant temperature, in a gas at the start of a reaction. On this diagram the most probable molecular energy at this temperature is indicated by the symbol E_{mp} and the activation energy by the symbol E_a.



Consider the following changes.

(i) The number of molecules is increased at constant temperature.

(ii) The temperature is decreased without changing the number of molecules.

(iii) A catalyst is introduced without changing the temperature or the number of molecules.

For **each** of these changes state how, if at all, the following would vary:

- the value of the most probable energy, E_{mp}
- the number of molecules with the most probable energy, E_{mp}
- the area under the molecular energy distribution curve
- the number of molecules with energy greater than the activation energy, E_a

(12)
(Total 15 marks)

13. (a) Define the term *activation energy* for a chemical reaction.

(2)

(b) Draw, with labelled axes, a curve to represent the Maxwell–Boltzmann distribution of molecular energies in a gas. Label this curve $\mathbf{T}_1$. On the same axes, draw a second curve to represent the same sample of gas at a lower temperature. Label this curve $\mathbf{T}_2$.

Use these curves to explain why a small decrease in temperature can lead to a large decrease in the rate of a reaction.

(8)

(c) Give **one** reason why most collisions between gas-phase reactants do not lead to a reaction. State and explain **two** ways of speeding up a gas-phase reaction other than by changing the temperature.

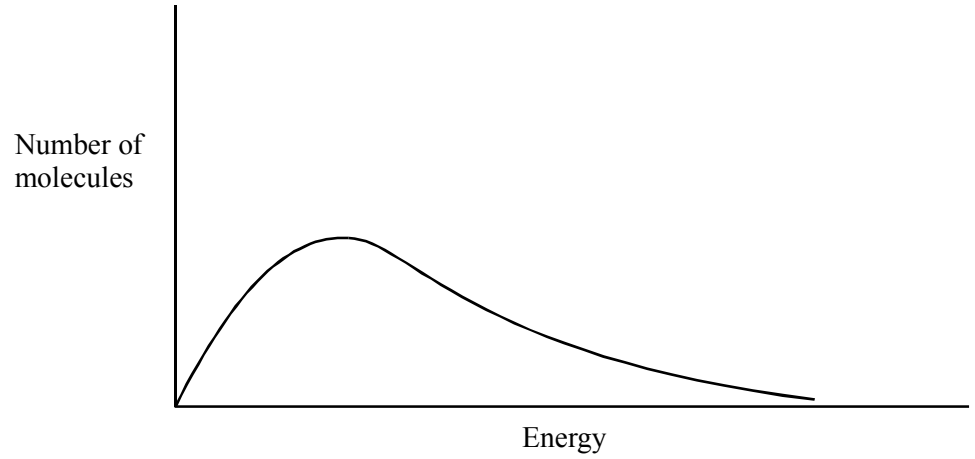
(5)
(Total 15 marks)

14. Draw a Maxwell-Boltzman curve for a sample of gas at a temperature, T_1. On the same axes draw a second curve for the same sample of gas at a higher temperature, T_2. Label the curves and the axes clearly. Explain, using these curves, why an increase in temperature increases the rate of a gas phase reaction.

Suggest how and why the first curve would change if a larger mass of gas were used at temperature T_1.

(Total 10 marks)

15. (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.

$$A(g) \rightleftharpoons B(g) + C(g) \qquad \Delta H \text{ is positive}$$

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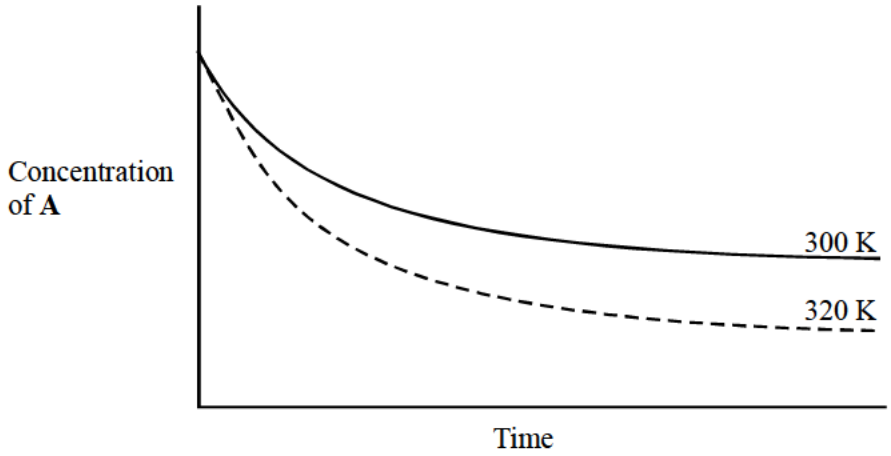
(ii) Explain why the decomposition of **A** is faster at higher temperatures.

.....

.....

(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.

.....

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

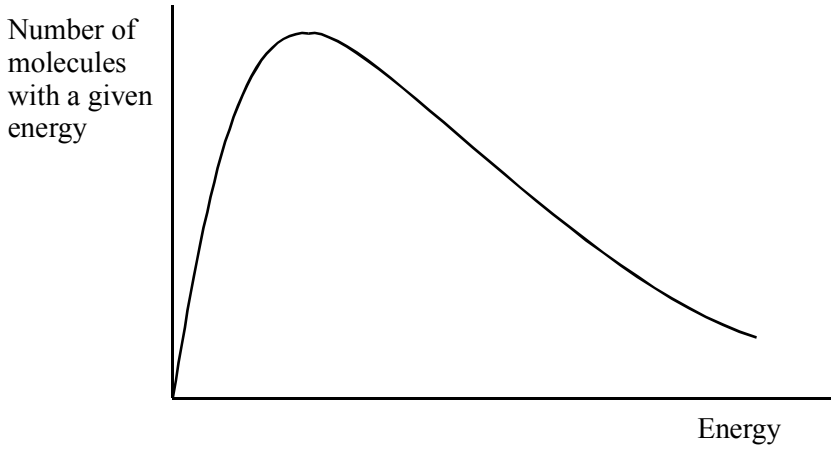
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(3)
(Total 11 marks)

20. (a) The diagram below shows the distribution curve for the energies of molecules in a given mass of methane.



(i) If the graph were extended to higher energies, at what point would the curve meet the horizontal axis? Explain your answer.

Point.....

Explanation.....

.....

.....

(ii) Sketch on the diagram a curve for a larger mass of methane at the same temperature.

(iii) A sample of ethane containing the same number of moles as the sample of methane above is at the same temperature and pressure. Describe how the distribution curve for ethane differs, if at all, from that above.

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.....

(5)

(b) Give two requirements for a reaction to occur between two gaseous molecules.

Requirement 1.....

Requirement 2.....

(2)
(Total 7 marks)

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

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

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?

.....

(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)

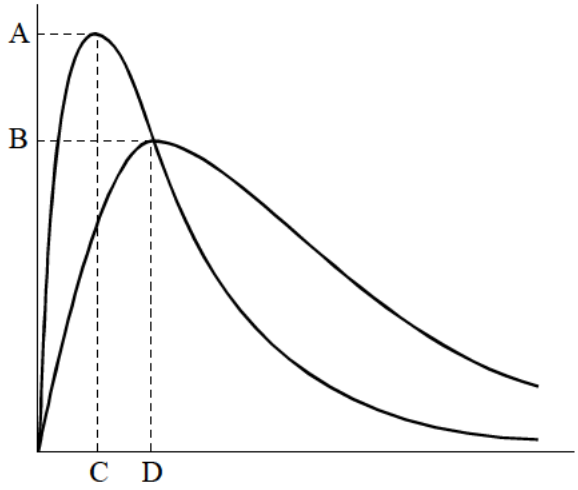
(e) In the processes above, the equilibrium yield of methanol is low. Suggest what is done with the unreacted carbon dioxide and hydrogen.

.....

(1)

(Total 12 marks)

22. (a) The diagram below shows the Maxwell-Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.



(i) Label both axes.

(ii) Choose one of the letters on the axes above which represents the most probable energy of the molecules at the lower temperature.

.....

(3)

(b) Give two requirements for a reaction to occur between molecules in the gas phase.

Requirement 1 .....

Requirement 2 .....

(2)

(c) Which has the greater effect on the initial rate of a first-order reaction:

either increasing the temperature of the reaction mixture from 300 K to 309 K (a 3% increase)

or increasing the concentration of the reagent from 1.00 M to 1.03 M (also a 3% increase)?

Briefly explain your answer.

Greater effect .....

Explanation .....

.....

.....

(3)

(Total 8 marks)

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

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H^{\ominus} = +180 \text{ kJ mol}^{-1}$$

(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 .....

.....

.....

.....

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

Explanation .....

.....

.....

(6)

(Total 6 marks)

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

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

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

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

Effect on yield of SO_3 .....

Effect on K_p .....

(2)

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

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus} = +205 \text{ kJ mol}^{-1}$$

(a) State Le Chatelier's principle.

.....

.....

(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 .....

.....

.....

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

Effect on yield of hydrogen .....

Explanation .....

.....

.....

(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 .....

(2)
(Total 9 marks)

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

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

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.*

.....

.....

(2)

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

.....

.....

(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.....

(2)

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

Effect.....

Explanation.....

.....

.....

(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.

.....

(1)

(Total 10 marks)

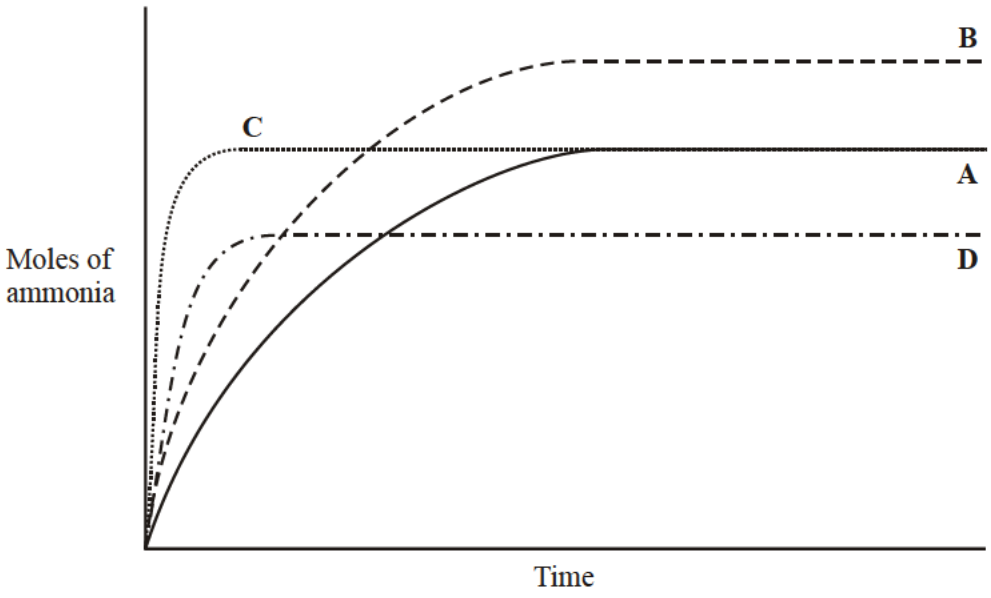
28. The equation for the formation of ammonia is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

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.

.....

.....

(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 .....

.....

.....

.....

(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 .....

.....

.....

(3)
(Total 9 marks)

29. When carbon monoxide reacts with steam at 670 K, the following homogeneous dynamic equilibrium is established.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H^{\ominus} = -42 \text{ kJ mol}^{-1}$$

(a) (i) Explain why this reaction is described as a *homogeneous* reaction.

.....

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

.....

.....

.....

(3)

(b) State the effect, if any, of the following changes on the concentration of hydrogen in the equilibrium mixture. In each case, explain your answer.

(i) An increase in the concentration of steam

Effect.....

Explanation.....

.....

(ii) A decrease in the temperature

Effect.....

Explanation.....

.....

(6)

(c) State and explain the effect, if any, of a catalyst on the position of this equilibrium.

Effect.....

Explanation.....

(3)
(Total 12 marks)

30. The industrial process for converting ammonia into nitric acid is carried out in three stages.

Stage 1 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^{\ominus} = -950 \text{ kJ mol}^{-1}$

Stage 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^{\ominus} = -114 \text{ kJ mol}^{-1}$

Stage 3 $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^{\ominus} = -117 \text{ kJ mol}^{-1}$

(a) Consider the reaction in **Stage 1** above.

(i) State how the temperature should be changed in order to increase the yield at equilibrium in this reaction. Explain your answer.

Temperature change.....

Explanation.....

.....

(ii) State how the pressure should be changed in order to increase the yield at equilibrium in this reaction. Explain your answer.

Pressure change.....

Explanation.....

.....

(4)

(b) The **Stage 1** reaction is carried out by passing ammonia and air over a platinum gauze at a temperature of 900°C and a pressure of 700kPa.

(i) What are the advantages of using this temperature and this pressure?

Temperature.....

Explanation.....

(ii) Give two reasons why the catalyst is used in the form of a gauze.

Reason 1.....

Reason 2.....

(4)

(c) The reaction by which NO is formed directly from nitrogen and oxygen is shown below.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H^{\ominus} = +180 \text{ kJ mol}^{-1}$$

(i) Give the name for the enthalpy change for this reaction.

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(ii) Explain fully the meaning of the symbol $^{\ominus}$

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(iii) Suggest why reactions between nitrogen and oxygen are often considered to be environmentally unfriendly.

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.....

(iv) Explain why the decomposition of NO into its elements is favoured by a low temperature.

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(7)

(d) By considering the reactions in **Stage 2** and **Stage 3,** suggest how the overall yield of nitric acid could be increased without altering either the temperature or the pressure chosen for each of the three stages.

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(2)
(Total 17 marks)

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

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

(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?

.....

(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.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H_f^{\ominus} = -92 \text{ kJ mol}^{-1}$$

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)

33. Methanol, CH_3OH, 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 $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ is $\Delta H^{\ominus} = +206 \text{ kJ mol}^{-1}$

Stage 2 $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$

(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)

34. When ammonia gas is heated, a homogeneous, dynamic equilibrium is established between ammonia and its constituent elements. This decomposition is endothermic.

(a) Explain the terms *homogeneous, dynamic* and *equilibrium*.
Write an equation for this decomposition and derive an expression for the equilibrium constant, K_c

(5)

(b) State and explain the conditions under which a high equilibrium concentration of hydrogen would be obtained.

(4)

(c) The decomposition of ammonia might in the future be used as an industrial method for the manufacture of hydrogen.
Explain why an industrial chemist might decide to use conditions different from those you have given in part (b) if large quantities of hydrogen were to be produced by this decomposition. Discuss the effect that using a catalyst would have on the equilibrium yield and on the amount of hydrogen which could be produced in a given time.

(6)
(Total 15 marks)

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

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

(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)

36. (a) Define the term *activation energy* for a reaction.

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(2)

(b) Give the meaning of the term *catalyst.*

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(2)

(c) Explain in general terms how a catalyst works.

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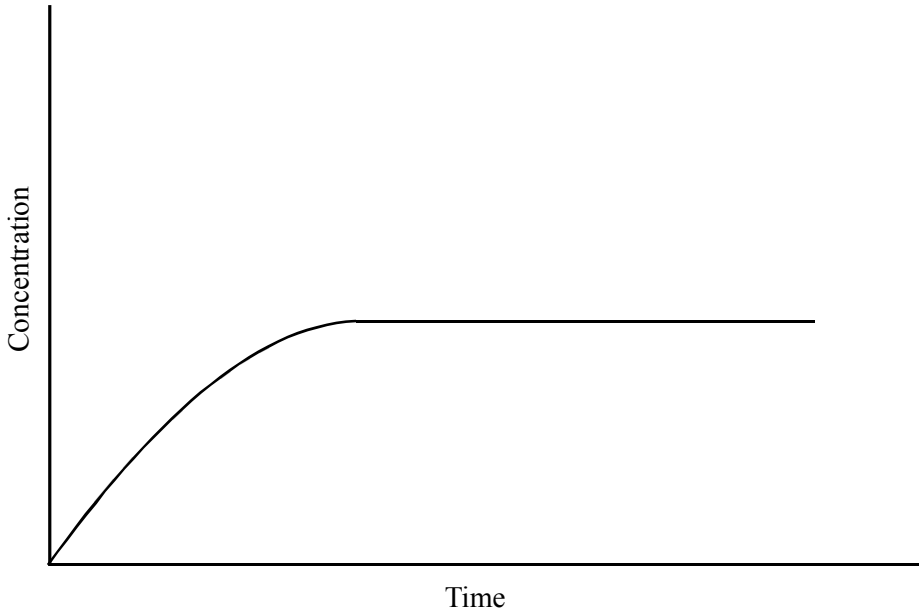
(2)

(d) In an experiment, two moles of gas **W** reacted completely with solid **Y** to form one mole of gas **Z** as shown in the equation below.

$$2W(g) + Y(s) \rightarrow Z(g)$$

The graph below shows how the concentration of **Z** varied with time at constant

temperature.



(i) On the axes above, sketch a curve to show how the concentration of **W** would change with time in the same experiment. Label this curve **W**.

(ii) On the axes above, sketch a curve to show how the concentration of **Z** would change with time if the reaction were to be repeated under the same conditions but in the presence of a catalyst. Label this curve **Z.**

(iii) In terms of the behaviour of particles, explain why the rate of this reaction decreases with time.

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(6)
(Total 12 marks)

AQA A2 CHEMISTRY

TOPIC 5.3

REDOX EQUILIBRIA

BOOKLET OF PAST EXAMINATION QUESTIONS

1. (a) Define the term *oxidising agent* in terms of electrons.

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(1)
(Total 1 mark)

2. Use the data in the table below, where appropriate, to answer the questions which follow.

Standard electrode potentials	$E^{\ominus}$/V
$Fe^{3+}(aq) + e^- \rightarrow F2^{2+}(aq)$	+0.77
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$2BrO_3^-(aq) + 12H^+(aq) + 10e^- \rightarrow Br_2(aq) + 6H_2O(l)$	+1.52
$O_3(g) + 2H^+(aq) + 2e^- \rightarrow O_2(g) + H_2O(l)$	+2.08
$F_2O(g) + 2H^+(aq) + 4e^- \rightarrow 2F^-(aq) + H_2O(l)$	+2.15

Each of the above can be reversed under suitable conditions.

(a) (i) Identify the most powerful reducing agent in the table.

.....

(ii) Identify the most powerful oxidising agent in the table.

.....

(iii) Identify **all** the species in the table which can be oxidised in acidic solution by $BrO_3^-(aq)$.

.....

(4)

(b) The cell represented below was set up.

$Pt|Fe^{2+}(aq), Fe^{3+}(aq) \parallel BrO_3^-(aq), Br_2(aq)|Pt$

(i) Deduce the e.m.f. of this cell.

.....

(ii) Write a half-equation for the reaction occurring at the negative electrode when current is taken from this cell.

.....

(iii) Deduce what change in the concentration of $Fe^{3+}(aq)$ would cause an increase in the e.m.f. of the cell. Explain your answer.

Change in concentration .....

Explanation .....

.....

.....

(6)
(Total 10 marks)

3. Use the data below, where appropriate, to answer the following questions.

Standard electrode potentials	$E^{\ominus}$/V
$S_2O_8^{2-}(aq) + 2e^- \rightarrow 2SO_4^{2-}(aq)$	+2.01
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$NO_3^-(aq) + 3H^+(aq) + 2e^- \rightarrow HNO_2(aq) + H_2O(l)$	+0.94
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77

(a) From the table above, select the species which is the most powerful reducing agent.

.....

(1)

(b) Deduce the oxidation state of

(i) chromium in $Cr_2O_7^{2-}$ .....

(ii) nitrogen in HNO_2 .....

(2)

(c) (i) Calculate the e.m.f. of the cell represented by

$Pt \mid Mn^{2+}(aq), MnO_4^-(aq) \parallel S_2O_8^{2-}(aq), SO_4^{2-}(aq) \mid Pt$

.....

(ii) Deduce an equation for the reaction which occurs when an excess of $S_2O_8^{2-}(aq)$ is added to an aqueous solution of $Mn^{2+}(aq)$ ions.

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(3)

(Total 13 marks)

4. Use the standard electrode potential data given in the table below, where appropriate, to answer the questions which follow.

	$E^{\ominus}$/V
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow H_2SO_3(aq) + H_2O$	+0.17
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l)$	+0.34
$O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O_2(aq)$	+0.68
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$2IO_3^-(aq) + 12H^+(aq) + 10e^- \rightarrow I_2(aq) + 6H_2O(l)$	+1.19
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$	+1.52

Each of the above can be reversed under suitable conditions.

(a) The cell represented below was set up under standard conditions.

$Pt \mid H_2SO_3(aq), SO_4^{2-}(aq), \| Fe^{3+}(aq), Fe^{2+}(aq) \mid Pt$

(i) Calculate the e.m.f. of this cell.

.....

(ii) Write a half-equation for the oxidation process occurring at the negative electrode of this cell.

.....

(2)

(b) The cell represented below was set up under standard conditions.

$Pt \mid H_2O_2(aq), O_2(g) \parallel IO_3^-(aq), I_2(aq) \mid Pt$

(i) Write an equation for the spontaneous cell reaction.

.....

.....

.....

(ii) Give **one** reason why the e.m.f. of this cell changes when the electrodes are connected and a current flows.

.....

(iii) State how, if at all, the e.m.f. of this standard cell will change if the surface area of each platinum electrode is doubled.

.....

(iv) State how, if at all, the e.m.f. of this cell will change if the concentration of IO_3^- ions is increased. Explain your answer.

Change, if any, in e.m.f. of cell .....

Explanation .....

.....

(7)

(c) An excess of acidified potassium manganate(VII) was added to a solution containing $V^{2+}(aq)$ ions. Use the data given in the table to determine the vanadium species present in the solution at the end of this reaction. State the oxidation state of vanadium in this species and write a half-equation for its formation from $V^{2+}(aq)$.

Vanadium species present at end of reaction .....

Oxidation state of vanadium in final species .....

Half-equation .....

(3)

(Total 12 marks)

5. Use the table of standard electrode potentials given below to answer the following questions.

	$E^{\ominus}$/V
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+ 1.36
$Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$	+1.07
$NO_3^-(aq) + 3H^+(aq) + 2e^- \rightarrow HNO_2(aq) + H_2O(1)$	+0.94
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$I_2(aq) + 2e^- \rightarrow 2I^-(aq)$	+0.54
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(1)$	+0.34
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	–0.44

(a) In terms of electron transfer, define the term *oxidising agent.*

.....

(1)

(b) (i) Give the conditions under which the electrode potential for $Cl_2(g)/2Cl^-(aq)$ is +1.36 V.

.....

.....

.....

(ii) Give a change in one of these conditions which would result in the electrode potential becoming more positive. Explain your answer.

Change in conditions .....

Explanation .....

.....

(5)

(c) (i) Which of the reducing agents in the table is the weakest?

.....

(ii) Identify all the species in the table which could convert $I^-aq)$ into $I_2(aq)$ but which could not convert $Br^-(aq)$ into $Br_2(l)$.

.....

(iii) Identify the metal ions which would be left in solution if an excess of powdered iron metal was added to an acidified solution containing $VO^{2+}(aq)$ ions.

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(5)

(Total 11 marks)

6. Use the standard electrode potential data in the table below to answer the questions which follow.

			$E^{\ominus}/V$
$Ce^{4+}(aq) + e^-$	$\rightleftharpoons$	$Ce^{3+}(aq)$	+1.70
$MnO^-(aq) + 8H^+(aq) + 5e^-$	$\rightleftharpoons$	$Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$Cl_2(g) + 2e^-$	$\rightleftharpoons$	$2Cl^-(aq)$	+1.36
$VO_2^+(aq) + 2H^+(aq) + e^-$	$\rightleftharpoons$	$VO^{2+}(aq) + H_2O(l)$	+1.00
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	+0.77
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$	$\rightleftharpoons$	$H_2SO_3(aq) + H_2O(l)$	+0.17

(a) Name the standard reference electrode against which all other electrode potentials are measured.

.....

(1)

(b) When the standard electrode potential for $Fe^{3+}(aq) / Fe^{2+}(aq)$ is measured, a platinum electrode is required.

(i) What is the function of the platinum electrode?

.....

(ii) What are the standard conditions which apply to $Fe^{3+}(aq)/Fe^{2+}(aq)$ when measuring this potential?

.....

.....

.....

(3)

(c) The cell represented below was set up under standard conditions.

$$Pt|H_2SO_3(aq), SO_4^{2-}(aq)||MnO_4^-(aq), Mn^{2+}(aq)|Pt$$

Calculate the e.m.f. of this cell and write an equation for the spontaneous cell reaction.

Cell e.m.f. .....

Equation.....

.....

(3)

(d) (i) Which one of the species given in the table is the strongest oxidising agent?

.....

(ii) Which of the species in the table could convert $Fe^{2+}(aq)$ into $Fe^{3+}(aq)$ but could not convert $Mn^{2+}(aq)$ into $MnO_4^-(aq)$?

.....

(3)

(e) Use data from the table of standard electrode potentials to deduce the cell which would have a standard e.m.f. of 0.93 V. Represent this cell using the convention shown in part (c).

.....

(2)

(Total 12 marks)

7. Large blocks of magnesium are bolted onto the hulls of iron ships in an attempt to prevent the iron being converted into iron(II), one of the steps in the rusting process.

Use the data below, where appropriate, to answer the questions which follow.

			$E^{\ominus}$ / V
$Mg^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.37
$Fe^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44
$O_2(g) + 2H_2O(l) + 4e^-$	$\rightleftharpoons$	$4OH^-(aq)$	+0.40

(a) Calculate the e.m.f. of the cell represented by $Mg(s)|Mg^{2+}(aq)||Fe^{2+}(aq)|Fe(s)$ under standard conditions. Write a half-equation for the reaction occurring at the negative electrode of this cell when a current is drawn.

Cell e.m.f. .....

Half-equation .....

.....

(2)

(b) Deduce how the e.m.f. of the cell $Mg(s)|Mg^{2+}(aq)||Fe^{2+}(aq)|Fe(s)$ changes when the concentration of Mg^{2+} is decreased. Explain your answer.

Change in e.m.f. .....

Explanation .....

.....

(3)

(c) Calculate a value for the e.m.f. of the cell represented by $Pt(s)|OH^-(aq)|O_2(g)||Fe^{2+}(aq)|Fe(s)$ and use it to explain why iron corrodes when in contact with water which contains dissolved oxygen.

Cell e.m.f. .....

Explanation .....

.....

(2)
(Total 7 marks)

8. The table below shows some values for standard electrode potentials.

Electrode	Electrode reaction	$E^{\ominus}$ / V
A	$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	– 1.18
B	$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	– 0.44
C	$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	– 0.25
D	$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	– 0.14
E	$2H^+(g) + 2e^- \rightleftharpoons H_2(g)$	?

(a) (i) Give the name of electrode **E** and indicate its role in the determination of standard electrode potentials.

.....

.....

(2)

(ii) What is the value of the standard electrode potential for electrode **E**?

.....

(1)

(b) The electrochemical cell set up between electrodes **C** and **D** can be represented by the cell diagram:

$$Ni(s) \left| Ni^{2+}(aq) \right|\!\!\left| Sn^{2+}(aq) \right| Sn(s)$$

(i) Calculate the e.m.f. of this cell.

.....

(1)

(ii) State which would be the positive electrode.

.....

(1)

(iii) Write an equation to show the overall reaction in the cell.

.....

(1)

(c) Use the standard electrode potential data given in the table above:

(i) to explain whether or not you would expect a reaction to occur if a piece of tin were to be added to a test tube containing aqueous iron(II) sulphate;

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.....

.....

(2)

(ii) to predict and explain two observations you would expect to make if a small piece of manganese were to be added to a test tube containing hydrochloric acid of concentration 1 mol dm^{-3}.

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(4)

(Total 12 marks)

9. Use the data below to answer the questions that follow

Reaction at 298 K			$E^{\ominus}/V$
$Ag^+(aq) + e^-$	$\rightarrow$	Ag(s)+	+0.08
$AgF(s) + e^-$	$\rightarrow$	$Ag(s) + F^-(aq)$	+0.78
$AgCl(s) + e^-$	$\rightarrow$	$Ag(s) + Cl^-(aq)$	+0.22
$AgBr(s) + e^-$	$\rightarrow$	$Ag(s) + Br^-(aq)$	+0.07
$H^+(aq) + e^-$	$\rightarrow$	$\frac{1}{2} H_2(g)$	0.00
$D^+(aq) + e^-$	$\rightarrow$	$\frac{1}{2} D_2(g)$	–0.004
$AgI(s) + e^-$	$\rightarrow$	$Ag(s) + I^-(aq)$	–0.15

The symbol D denotes deuterium, which is heavy hydrogen, ^2_1H.

(a) By considering electron transfer, state what is meant by the term *oxidising agent*.

.....

(1)

(b) State which of the two ions, $H^+(aq)$ or $D^+(aq)$, is the more powerful oxidising agent. Write an equation for the spontaneous reaction which occurs when a mixture of aqueous H^+ ions and D^+ ions are in contact with a mixture of hydrogen and deuterium gas. Deduce the e.m.f. of the cell in which this reaction would occur spontaneously.

Stronger oxidising agent......

Equation......

.....

.....

e.m.f......

.....

(3)

(c) Write an equation for the spontaneous reaction which occurs when aqueous F^- ions and Cl^- ions are in contact with a mixture of solid AgF and solid AgCl. Deduce the e.m.f. of the cell in which this reaction would occur spontaneously.

Equation.....

.....

e.m.f......

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(2)

(d) Silver does not usually react with dilute solutions of strong acids to liberate hydrogen.

(i) State why this is so.

.....

(ii) Suggest a hydrogen halide which might react with silver to liberate hydrogen in aqueous solution. Write an equation for the reaction and deduce the e.m.f. of the cell in which this reaction would occur spontaneously.

Hydrogen halide.....

Equation.....

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.....

e.m.f......

.....

(4)
(Total 10 marks)

10. (a) The following reaction occurs in aqueous solution.

$$5S_2O_8^{2-} + Br_2 + 6H_2O \rightarrow 2BrO_3^- + 12H^+ + 10SO_4^{2-}$$

Identify the reducing agent in this reaction and write a half-equation for its action.

Reducing agent .....

Half-equation .....

(2)

(b) The electrode potential for the half-equation

$$Co^{2+}(aq) + 2e \rightarrow Co(s)$$

is measured by reference to a standard hydrogen electrode.

(i) State the temperature at which the standard electrode potential $E^{\ominus}$ is measured, and give the concentration of $Co^{2+}(aq)$ that must be used.

Temperature .....

Concentration .....

(ii) Electrode potentials are usually measured by reference to a secondary standard electrode. Identify a secondary standard electrode and give a reason why it is used rather than a standard hydrogen electrode.

Secondary standard electrode .....

Reason .....

(4)

(c) Cobalt in oxidation states +2 and +3 forms complex ions with water, ammonia and cyanide ligands. Use, where appropriate, the data given below to answer the questions which follow.

$[Co(H_2O)_6]^{3+}(aq) + e^-$	$\rightarrow$	$[Co(H_2O)_6]^{2+}(aq)$	$E^{\ominus} = +1.81$ V
$\frac{1}{2} O_2(g) + 2H^+(aq) + 2e^-$	$\rightarrow$	$H_2O(l)$	$E^{\ominus} = +1.23$ V
$[Co(NH_3)_6]^{3+}(aq) + e^-$	$\rightarrow$	$[Co(NH_3)_6]^{2+}(aq)$	$E^{\ominus} = +0.10$ V
$2H^+(aq) + 2e^-$	$\rightarrow$	$H_2(g)$	$E^{\ominus} = 0.00$ V
$[Co(CN)_6]^{3-}(aq) + e^-$	$\rightarrow$	$[Co(CN)_6]^{4-}(aq)$	$E^{\ominus} = -0.80$ V

(i) Which of the six cobalt species shown above is the most powerful oxidising agent?

.....

(ii) Identify a cobalt(II) species which cannot be oxidised by gaseous oxygen.

.....

(iii) Hydrogen is evolved when a salt containing the cobalt species $[Co(CN)_6]^{4-}(aq)$ is reacted with a dilute acid. Use the electrode potentials given above to explain the formation of the hydrogen gas.

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(4)

(Total 10 marks)

11. The table below shows some values for standard electrode potentials. These data should be used, where appropriate, to answer the questions that follow concerning the chemistry of copper and iron.

Electrode reaction	$E^{\ominus}$/V
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	– 0.44
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+ 0.34
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+ 0.40
$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightleftharpoons NO(g) + 2H_2O(l)$	+ 0.96

(a) Write an equation to show the reaction that occurs when iron is added to a solution of a copper(II) salt.

.....

(1)

(b) A similar overall reaction to that shown in (a) would occur if an electrochemical cell was set up between copper and iron electrodes.

(i) Write down the cell diagram to represent the overall reaction in the cell.

.....

(2)

(ii) Calculate the e.m.f. of the cell.

(1)

(c) (i) Use the standard electrode potential data given to explain why copper reacts with dilute nitric acid but has no reaction with dilute hydrochloric acid.

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(3)

(ii) Write an equation for the reaction between copper and dilute nitric acid.

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(2)

(d) Although iron is a widely used metal, it has a major disadvantage in that it readily corrodes in the presence of oxygen and water. The corrosion is an electrochemical process which occurs on the surface of the iron.

(i) Use the standard electrode potential data given to write an equation for the overall reaction that occurs in the electrochemical cell set up between iron, oxygen and water.

.....

(1)

(ii) State, with a reason, whether the iron acts as the anode or cathode of the cell.

.....

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(2)

(iii) Predict and explain whether or not you would expect a similar corrosion reaction to occur with copper in the presence of oxygen and water.

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(2)

(Total 14 marks)

12. (a) Name the standard reference electrode against which electrode potentials are measured and, for this electrode, state the conditions to which the term *standard* refers.

Name .....

Conditions .....

.....

.....

(4)

(b) The standard electrode potentials for two electrode reactions are given below.

$S_2O_8^{2-}(aq) + 2e^- \rightarrow 2SO_4^{2-}(aq)$ $\quad E^{\ominus} = +2.01$ V

$Ag^+(aq) + e^- \rightarrow Ag(s)$ $\quad E^{\ominus} = +0.80$ V

(i) A cell is produced when these two half-cells are connected.
Deduce the cell potential, $E^{\ominus}$, for this cell and write an equation for the spontaneous reaction.

$E^{\ominus}$ value .....

Equation .....

.....

(ii) State how, if at all, the electrode potential of the $S_2O_8^{2-}/SO_4^{2-}$ equilibrium would change if the concentration of SO_4^{2-} ions was increased.
Explain your answer.

Change, if any, in electrode potential .....

Explanation .....

.....

(6)
(Total 10 marks)

13. For **each** of the reactions listed below

(i) identify which species, if any, are acting as oxidising agents;

(ii) determine the oxidation states before and after reaction of any species that are oxidised;

(iii) write half-equations, including state symbols, for all redox reactions that occur.

$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$

$5H_2O_2(aq) + 2Mn^{2+}(aq) \rightarrow 2MnO_4^-(aq) + 6H^+(aq) + 2H_2O(l)$

$Cr_2O_7^{2-}(aq) + H_2O(l) \rightarrow 2CrO_4^{2-}(aq) + 2H^+(aq)$

$Cl_2(aq) + 2OH^-(aq) \rightarrow Cl^-(aq) + ClO^-(aq) + H_2O(l)$

(11)
(Total 11 marks)